Publications of the Astronomical Society of the Pacific, **113**:1025–1114, 2001 September

Invited Review

Astrophysics in 2000

Virginia Trimble

Department of Astronomy, University of Maryland, College Park, MD 20742; and Department of Physics and Astronomy,
University of California, Irvine, CA 92697

and

Markus J. Aschwanden

Lockheed Martin Advanced Technology Center, Solar and Astrophysics Laboratory, Department L9-41, Building 252,
3251 Hanover Street, Palo Alto, CA 94304; aschwanden@lmsal.com

Received 2001 April 13; accepted 2001 April 13

ABSTRACT. It was a year in which some topics selected themselves as important through the sheer numbers of papers published. These include the connection(s) between galaxies with active central engines and galaxies with starbursts, the transition from asymptotic giant branch stars to white dwarfs, gamma-ray bursters, solar data from three major satellite missions, and the cosmological parameters, including dark matter and very large scale structure. Several sections are oriented around processes—accretion, collimation, mergers, and disruptions—shared by a number of kinds of stars and galaxies. And, of course, there are the usual frivolities of errors, omissions, exceptions, and inventories.

1. INTRODUCTION

Astrophysics in 2000 is the tenth, and probably last, of its ilk. The predecessors, Astrophysics in 1991, 1992, etc., appear somewhere near the beginnings of volumes 104 to 112 of *PASP* and are cited below as Ap91, Ap92, and so forth. In the intervening decade, the number of astronomical words published per year has increased by something like 50%, a growth that is not reflected for some reason in the numbers of papers indexed in *Astronomy and Astrophysics Abstracts* (22,848 in 1989 and 24,406 in 1999), many of them abstracts and conference presentations. But the time required to read the 5000 or so papers per year appearing in major journals has increased proportionally and now exceeds what can be extracted from the authors' other responsibilities. Or, from another point of view, at its current rate of expansion of 5% per year, a paper copy of the *Astrophysical Journal* would close the universe by 4450.

The journals scanned were the issues that reached the library shelves between 1 October 1999 and 30 September 2000 of *Nature*, *Physical Review Letters*, *Science*, *The Astrophysical Journal* (plus *Letters* and *Supplement Series*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Supplements* and *Reviews*), *Astronomical Journal* (always part of the data base, but unaccountably missing from the printed list in Ap99), *Acta Astronomica*, *Revista Mexicana Astronomia y Astrofisica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica*, *Astronomische Nachrichten*, *Journal of Astrophysics and Astronomy*, *Publications of the Astronomical Society of Japan*, *Bulletin of the Astronomical Society of India*, *Baltic Astronomy*, *New Astronomy*, *IAU Circulars*, and, of course, *Publications of the Astronomical Society of the Pacific*. On the grounds that even review writers are entitled to an occasional afternoon off, we have reserved the right to look at *Observatory*, *Journal of the Royal Astronomical Society of Canada*, *Monthly Notices of the Astronomical Society of South Africa*, *Journal of the American Association of Variable Star Observers*, and a few others just for fun, without systematic recording of their contents.

1.1. Ave

Among the entities to be welcomed this year were the remaining three mirrors, at 8 meters each, of the Very Large Telescope, the dedications of the Green Bank Telescope and LIGO (no published data from either yet), the opening of the new Rose Center and Hayden Planetarium at the American Museum of Natural History (which also seems to have begun a new custom of reviewing such exhibits as if they were books), the Gruber Prize in Cosmology (first two winners, P. James E. Peebles and Allan R. Sandage), and the (apparently successful) launches of *Newton-XMM* (10 December), *Cluster II* (in two lots, 12 July and 9 August), *HETE II* (a second try at the *High Energy Transient Explorer*, the second adjective referring, we hope, to the events to be monitored, not to the mission itself), the *Shenzhou* "unoccupied orbiter" (21 hours in orbit on 26 November), the part of the *International Space Station* called Zvezda (on 12 July), and *ACRIMSat* (20 December). About 150 Ph.D.'s in astronomy and related subjects were awarded in the USA during the year.

1.2. Atque

During the year, there were some things that came and went, or went and came, so quickly or so often that it was hard to decide whether to say "hello" or "goodbye." Among these were the radio interferometry satellite *HALCA* (with about three near-failures and rescues), *NEAR* (which came much *NEAR*er to the asteroid Eros in February 2000 than in the previous year), the *Pluto-Kuiper Express* (which was cancelled, but followed quickly by a new Plutonic announcement of opportunity), *MIR*, *New Astronomy Reviews* (a reincarnation of the old *Vistas in Astronomy*), and the *Iridium* set of communications satellites (which really does deserve to be called *Dysprosium*). A special award goes to *Voyager 1*, which has reached 76 AU from the Sun (the furthmost the mind of man has ever set foot, as it were) and still hasn't reached the heliopause.

1.3. Vale

Among the things we lost during the year were the *Mars Polar Lander* and its associated penetrators (declared dead in December), the *Compton Gamma Ray Observatory* (put into a geostationary orbit on the ocean floor on 4 June), the NRAO 12-meter dish (though closing a ground-based telescope is generally less irreversible than the space-based case), *Astro E* (an unsuccessful launch on 10 February, continuing the Japanese tradition of never losing a named spacecraft), Comet *LINEAR* (whose brief appearance in July as six smaller comets showed that there is intermediate-level structure between dust grains and the nucleus, to be called cometesimals, if you must), and the *Irish Astronomical Journal*, which ceased publication in mid-volume after 50 years. It was a somewhat informal, chatty publication (long edited by Ernst Opik), and its loss is yet another in a sequence of relatively informal publications that have disappeared in recent years, including *Quarterly Journal of the Royal Astronomical Society*, *Astrophysical Letters*, and another journal edited for some years by the more blue-pencilled author and not named here for fear of legal action. *ROSAT* collected a small amount of posthumous data between late October and late December 1998, spotting a $z = 4.22$ blazar and the highest redshift X-ray absorption to date (Boller et al. 2000). And *ASCA* succumbed to atmospheric drag on 12 July.

Our human losses included five staff members of IRAM killed in an accident (to whom Cox et al. 2000 is dedicated), Dennis Sciama ("doktorgrossvater" and even gross gross vater to a number of US-based astronomers), Colin Ronan (one of the great writers of popular astronomy), Abraham Taub (one of the last direct links to Einstein), and the following members of the American astronomical community, in roughly the order that the news reached us: Walter Wild, Billy McCormac, David Beard, John DeWitt, Sidney Kastner, Valentin Boriakoff, Charlene Heisler, Jan van Paradijs, Freeman Miller, John Evans, Gareth Jones, William Calder, Carol Rieke, Clinton Constant, Douglas Duke, Patricia Rogers Campbell, William Kaula, Gijsbert van Herk, John Wolbach, Philip Keenan, James Cuffey, Harrison Mendenhall, Samuel Goldstein, Jeffrey Willick, Jerome Korman, Frederick Hollander, Jean Heidemann, K. Narahari Rao, James W.-K. Mark, Edward Dyer, Robert Hjellming, Henk van de Hulst, John Simpson, Bill Fastie, Donald Billing, John O'Keefe, Herbert Friedman, Frank Kerr, Raymond Grenchik, and Joseph Weber (on the 30th of September, last day of the index year and first day of year 5761).

2. SOLAR PHYSICS

Additional journals scanned for this section were *Solar Physics* and the relevant parts of *Journal of Geophysical Research*, *Geophysical Research Letters*, *Advances in Space Research*, *Astroparticle Physics*, and *Space Science Reviews*. The cut-off date was set, in some cases, by arrival at the electronically mirrored website of NASA's Astrophysics Data System rather than at library shelves. The usual guidelines pertain to this and the following eleven sections. Focus is on papers published during the reference year. Papers on which the present authors' names appear are cited only if they have been shown to be wrong. And the historical background is cited only occasionally and erratically. In this context, it is worth remembering another of the classic sayings of Raymond Arthur Lyttleton. When it was pointed out to him that his stationery, unlike the rest of what was used at the Institute of Theoretical Astronomy in Cambridge, did not mention that Fred Hoyle was the director, his response was, "Well, it doesn't say he isn't." And so, if we have failed to say that you were the first to sweep dysprosium under the carpet, there was no intention to say that you weren't.

The following six sections explore the Sun from interior to heliosphere, inside out. Most of the new observations come from the currently operating space missions, *Yohkoh*, the *Solar and Heliospheric Observatory* (*SoHO*), and the *Transition Region and Coronal Explorer* (*TRACE*).

2.1. Solar Interior

2.1.1. Neutrinos—Do They Care about the Solar Magnetic Field?

Our knowledge about the solar neutrino problem did not make a critical giant leap with century turn (see the Bahcall & Davis 2000 Millennium Essay). Although we still are detecting a solar neutrino every other day with the Homestake chlorine detector, the detected capture rate is still a factor of three below theoretical predictions. The claim that the neutrino has a magnetic moment, based on an apparent anti-correlation of the neutrino flux (measured at Homestake) with the solar cycle, has been further refuted as a statistical fluke caused by overestimating the significance of smoothed data (Boger, Hahn, & Cumming 2000). This further slashes hopes that the resonance spin flavor precession of neutrinos can be used to probe the interior solar magnetic field, although theoretical scenarios furnish plausible fits to the gallium, chlorine, and Super-

Kamiokande experiments (Guzzo & Nunokawa 1999; Pulido & Akhmedov 2000). Nevertheless, power spectra of the Homestake and GALLEX data show a prominent peak near 13 cycles per year, compatible with the rotation frequency of the solar radiative zone, and thus suggest a nonzero magnetic moment (Sturrock et al. 1999a).

Whether internal gravity waves at the bottom of the convection zone disturb the chemical mixing in the solar core and in this way reduce the produced neutrino flux was also studied (Montalban & Schatzman 1999). Alternatively, the source of solar neutrinos was thought to come from cosmic-ray impingement in the solar atmosphere, where cascades of secondary particles from high energy *pp*-interactions decay into both electronic and muonic neutrinos (Hettlage et al. 2000). Thus, it is not even clear whether the solar neutrinos originate inside or outside the Sun!

2.1.2. The Third Era of Helioseismology

The end of the millennium marks the beginning of the third era of helioseismology, according to a review by Gough (2000). The first era was the establishment of initial results on the depth of the solar convection zone and the protosolar helium abundance, using instruments that had *not* been designed for this purpose. The second era was the determination of the spherically symmetric component of the hydrostatic stratification in the solar interior and the angular velocity using inversion methods of normal modes, using instruments that had actually been designed for this purpose. The new third era, starting now, calls for refined methods that push the precision to unprecedented limits by systematically exploiting deviations from normal modes (such as rotational splitting, asymmetric line profiles, etc.), so that more sophisticated questions can be asked about the solar dynamo, equation of state, chemical composition, properties of convection, and seat of solar activity. Many also anticipate the long-awaited discovery of gravitational mode (*g*-mode) oscillations.

2.1.3. The Search for Gravity Waves (g-Mode)

Gravity waves supposedly exist only below the solar convection zone, since gravity cannot act as a restoring force because of the value of the buoyancy frequency in the convection zone. The search for solar gravity (*g*-mode) oscillations intensified (Mateos & Palle 1999; Provost, Berthomieu, & Morel 2000; Appourchaux et al. 2000). Although concerted efforts using multiple instruments (MDI/*SoHO* and GONG) were undertaken, no positive detection was achieved, but firm upper limits of ≤10 mm/sec at 200 μHz in velocity and 0.5×10^{-6} in amplitude were established (Appourchaux et al. 2000).

2.1.4. Solar Internal Rotation—A Matter of Anchor Depth

The differential solar rotation can be measured with at least four techniques (Beck 2000): Doppler shift, Doppler feature tracking, magnetic feature tracking, and *p*-mode splittings. Of course, every method yields a different rotation rate, depending on the anchor depth of the tracing phenomenon used. An interesting new result is that "supergranulation rotates at a rate greater than the maximum rotation rate within the convection zone, suggesting that they are not simple convection cells anchored at a particular depth" (Beck 2000). The persistence of Hale's polarity law on the east-west orientation of emerging active regions requires a stable (not mixed up by convection) source below the convection zone, which probably coincides with the tachocline (Abbett, Fisher, & Fan 2000).

The latest helioseismic inversions yield an equatorial radius of 0.693 ± 0.002 and an equatorial thickness of 0.039 ± 0.013 for the tachocline (Charbonneau et al. 1999), the rotational shear layer at the base of the convection zone.

2.1.5. Getting in Touch with the Solar Core

The rotation rate in the solar core can only be probed with low degree oscillations. Evidence for the detection of low radial order ($n < 10$) acoustic modes of low angular degree ($l = 0, 1, 2$) has been reported by Bertello et al. (2000b). While it is now well established that the differential rotation persists in the convection zone and becomes mainly solid below the tachocline, it is still controversial whether the core is rotating slower, faster, or at the same rate as the radiative zone. Current investigations model the sound speed in the solar core with asymmetric line profiles in low frequency mode ($l = 1, 2, 3$) power spectra (Thiery et al. 2000; Basu & Antia 1999, 2000; Basu et al. 2000; Bertello et al. 2000a), finding a dip in the sound speed difference at 0.18 solar radii (Basu et al. 2000). The rotation rate of the core was found to be consistent with a solid rotator at a rate of about 435 nHz (Bertello et al. 2000a).

2.1.6. Solar Internal Structure Inversion (p-Mode)

The inversion of the internal structure of the Sun relies on a reference model which provides the physical quantities as function of the solar radius. Although the standard model reproduces the internal sound speeds measured by helioseismology impressively well, there is still some tweaking necessary at the edge of the tachocline, or to match the photospheric lithium abundance (Brun, Turck-Chieze, & Zahn 1999). Recent improvements on the inversion of *p*-mode oscillations focus on numerical simulations of the asymmetry of *p*-mode line profiles (Rabello-Soares et al. 1999; Georgobiani et al. 2000), the influence of turbulence (Rosenthal et al. 1999; Bi & Xu 2000; Brüggen 2000), random flows in the convection zone (Murawski & Pelinovsky 2000), radiative effects of convective overshooting (Kiefer et al. 2000), inversion techniques with special high resolution at the base of the convection zone (Marchenkov, Roxburgh, & Vorontsov2000), the influence of surface magnetic flux on low degree *p*-modes (Moreno-Insertis & Solanki 2000), the interaction of the large-scale poloidal velocity field (Roth & Stix 1999), and variability during the solar cycle (Chaplin et al. 2000; Howe, Komm, & Hill 1999; Komm, Howe, & Hill 2000).

2.1.7. Fundamental Global Oscillations (f-Mode)

A number of new studies dealt with the fundamental mode (*f*-mode, $n = 0$, while $n > 0$ correspond to *p*-modes), also known as the surface gravity wave. The observed frequencies (with *SoHO*/MDI) of the solar *f*-mode show deviations from the classical dispersion relation $\omega_0^2 = gk$ (Murawski 2000c; Murawski & Diethelm 2000), where g is the gravity of the Sun. Improved modeling of the *f*-mode and the turbulent velocity field has been performed by Medrek & Murawski (2000). Deviations of the *f*-mode at high wavenumbers k were modeled in terms of coherent and random flows associated with supergranules and granules (Murawski 2000a), or with the convection zone (Murawski 2000b), and *f*-mode frequency splittings were explained by migration of zonal flows (Schou 1999).

2.1.8. Ocean Waves on the Sun? (r-Mode)

It was suggested that the solar differential rotation could be explained by "*r*-mode oscillations, waves analogous to terrestrial Rossby waves, which are seen on the ocean as large-scale (hundreds of kilometers) variations of sea-surface hills (5-cm-high waves), which propagate slowly either east or west (they could take tens of years to cross the Pacific Ocean)." Calculations predict that the analogous photospheric hills produced by solar *r*-waves would have altitudes of 100 m and surface spacings of 87,000 ± 6000 km, producing a corrugated surface of the photosphere (Kuhn et al. 2000). Rossby-type waves were even proposed to account for the periodicity of flaring on time periods of 51 to 154 days (Lou 2000).

2.1.9. Local Helioseismology

The refinement and increasing complexity of new analysis methods become most apparent in the distressed terminology. How do you manage to use the same word three times in the same title with a different meaning each time? Here is an example: "Phase Time and Envelope Time in Time-Distance Analysis and Acoustic Imaging" (Chou & Duvall 2000). "Time is of essence," obviously (like in realty sales contracts).

Local helioseismology demonstrates crisper than ever that they can produce a tomographic rendering of the subsurface structure of sunspots (nicely illustrated on the popular *SoHO*/MDI coffee mugs). Recent studies with local seismology, however, dealt not only with sunspots (Chou, Sun, & Chang 2000), in and away from sunspots (Kumar et al. 2000; Barnes & Cally 2000; Rosenthal & Julien 2000), but also with subphotospheric rotation and velocity flows (Hernandez & Patron 2000; Hernandez et al. 2000), emerging flux (Chang, Chou, & Sun 1999), rapidly-growing active regions (Thomas & Stanchfield 2000), and solar flares (Zharkova & Kosovichev 2000).

The excitation of solar oscillations has been studied from the traveling wave characteristics of a few thousand seismic events, which were found to be generated just below the solar surface and capable of sustaining the *p*-mode spectrum, consistent with a model of monopole sources but not consistent with a model of stochastic excitation by turbulent convection (Strous, Goode, & Rimmele 2000).

2.1.10. Solar Dynamo

Do we finally understand the heartbeat of the Sun? It was reported that a mean field model of the solar dynamo can be made consistent with the solar rotation law, the alpha-effect can be adjusted to mimic a plausible butterfly diagram, and chaotic, intermittent behavior such as the Maunder minimum can be reproduced with small Prandtl numbers (Moss & Brooke 2000). Observational tests of dynamo models check also on active latitudes and the hemispheric helicity sign rule (Kuzanyan, Bao, & Zhang 2000). Several studies focus on the driver of the dynamo: the generation of magnetic fields by turbulent convection (Thelen & Cattaneo 2000), magnetic coupling between a fluid shell and an inner electrically conducting core (Schubert & Zhang 2000), emergence of embedded magnetic flux (Chiueh 2000), or a buoyancy-driven alpha effect (Ossendrijver 2000b). Numerical simulations of buoyant flux tubes became a separate industry (Abbett et al. 2000; Wissink et al. 2000). The toroidal magnetic flux in a rotating star alone cannot drive a dynamo, unless there exist additional transverse helical waves that propagate along the flux tubes (Ossendrijver 2000a). Realistic models of the internal (radial and toroidal) rotation are critical prerequisites for a successful dynamo model (Markiel & Thomas 1999).

2.2. The Solar Photosphere

2.2.1. Dermatology of Granules, Mesogranules, and Supergranules

When you look at your inner hand, you notice the life lines (so all-important for handreaders), then the wrinkles when you make a fist, and then the fine meandering lines that make up your unique fingerprints. The same dermatology is now investigated on the solar skin (called photosphere). The first problem is to hierarchize the fractal patterns, and the second is to scrutinize their physical role.

While granules (with typical horizontal sizes of 1000-2000 km) have long been established as smallest observable convection cells on the solar surface, the question arose whether the observed clustering on larger scales, called mesogranules (5000-10,000 km) or supergranules (20,000-30,000 km), detected with correlation tracking techniques (Shine, Simon, & Hurlburt 2000; Hoekzema & Brandt 2000), tessellation tiling (Hagenaar 1999; Srikanth, Singh, & Raju 2000), rotational Dopplergrams (Beck & Schou 2000), or Fourier spectra (Hathaway et al. 2000), are also formed by cellular convection (e.g., driven by superadiabaticity in deeper layers where neutral helium ionizes). However, numeric 2-D simulations demonstrate that the mesogranule formation is driven close beneath the surface (Ploner, Solanki, & Gadun 2000; Gadun et al. 1999), and thus excludes the existence of meso-giant convection cells. In addition, supergranules are believed not to be formed by convection cells, but rather as a result of a large-scale instability of the granular flow (Rieutord et al. 2000). So there are no supergiant convection cells either. The evolution of granules was numerically simulated with the finding of two different kinds of deaths: fragmentation by buoyancy braking and dissolving by shrinking through external gas pressure (Ploner, Solanki, & Gadun 1999). The phenomenon of *explosive granules* has also been simulated numerically and was thought to be driven by spontaneously developing downflows due to Rayleigh-Taylor instabilities in the convective flows (Hirzberger et al. 1999). In case you are confused about the jargon and terminology of multi-granularity we are using here, you may consult an excellent, brand-new textbook on solar and stellar magnetic activity (Schrijver & Zwaan 2000).

2.2.2. Dermatology of Intergranular Paths: The Network

While granules buffet each other like molecules in Brownian motion, there has to be buffer zone in between that may play an important role in the photospheric dynamics too. The intergranular paths have been identified as sinks of granular downflows, since we can measure granular Doppler shifts or flow patterns from kork models of computer-generated velocity fields. Recent studies focus on details in these intergranular gaps. Every bright point of the photospheric network was found to coincide with a magnetic element of a small size within $0''.5$ (Müller et al. 2000; O'Shea et al. 2000). The spatial and temporal relations require a dynamic model, in which a magnetic element in the network becomes bright when it is compressed by the surrounding granules as they converge (Müller et al. 2000). It was confirmed that the Na D_2 line can be used as a proxy for magnetic structures equally well as the Ca II K line. Power spectra in network bright points show differences in internetwork areas, implying that the oscillations at these chromospheric levels are not directly coupled with those in lower layers (Cauzzi et al. 2000). Unexplained narrow polarization peaks in the Doppler cores of Na I D_1 and D_2 lines have been explored by Stenflo, Gandorfer, & Keller (2000a), which cannot be understood with the current quantum-mechanical theory (Stenflo, Keller, & Gandorfer 2000b). Spectral lines with core formation heights between 250 and 500 km also show velocities that are different from the lower-lying convection zone (Hanslmeier et al. 2000). Some studies go into incredible detail. For instance, Sanchez-Almeida & Lites (2000) infer information on microscale variability (about kilometer-sized irregularities) in the photospheric magnetic field based on asymmetric Stokes profiles. Modeling of such unresolved microscales seems to indicate that a significant fraction of the photospheric magnetic flux remains undetected (Sanchez-Almeida & Lites 2000).

2.2.3. Flux-Tube Dynamics or Spaghetti Cooking

To study the subject of flux-tube dynamics must be the same fun for a solar physicist as it is for a cook to watch boiling spaghetti. What a challenge is it to measure the velocities, viscosities, and collision angles of computer-generated whirling spaghetti to learn something about the convective motion of the steamy water vapor that comes out of the pot. Now you will easily understand the following.

The dynamics of photospheric and subphotospheric flux tubes becomes increasingly more important in understanding their effect on coronal heating. Observations from *SoHO*/MDI reveal that small-scale magnetic flux tubes collide in the internetwork driven by the converging granular flows. Depending on the geometric angle between colliding flux tubes, noncollinear and X-type collisions occur, which have been simulated in detail and show that shock waves result (Furusawa & Sakai 2000), which could be an important energy source for coronal heating. The dynamics of photospheric flux tubes may turn oscillatory. The excitation of oscillations in the magnetic network through the footpoint motion of photospheric magnetic flux tubes located in intergranular lanes has been modeled successfully, with the finding that turbulent convective upflows fit the (G-band) data better than intermittent short-duration pulses (Hasan, Kalkofen, & van Ballegooijen 2000). Facular contrast measured across the solar disk was found to provide support for a *hot-wall model* of facular flux tubes (Ahern & Chapman 2000). The dynamics in plage flux tubes was also studied from the inversion of Stokes spectra, providing information on internal downflows or convective collapses of magnetic fluxes (Bellot Rubio, Ruiz Cobo, & Collados 2000b, 2000c). Inversion of spectra from unresolved granules (i.e., all we get from stellar observations) has been demonstrated to require at least two atmospheric components, one corresponding to granular upflows and the other to downflows. This exercise at least demonstrated that we are capable of probing convection in late-type stars (Frutiger et al. 2000). The importance of photospheric flux-tube motion was further stressed by a chromospheric reconnection model, where the inflow speed of the Sweet-Parker magnetic reconnection model was found to be compatible with the photospheric speed of magnetic cancellation features (Litvinenko 1999; Litvinenko & Martin 1999). Furthermore, a clear correlation between dynamic changes in the photospheric magnetic field and energetic events in the chromosphere and transition region (the so-called explosive events) have strengthened the picture of an electromechanical coupling between the photosphere and the transition region (Tarbell, Ryutova, & Shine 2000).

2.2.4. Sunspot Oscillations and Dynamics

How does a sunspot feel the solar global oscillations? The existence of magnetic field oscillations in the photosphere of a sunspot umbra is still controversial. Bellot Rubio et al. (2000a) report a significant detection in three Fe I lines, a result that is believed to be more robust against instrumental and seeing problems, and they suggest that the magnetic field oscillations are caused by upward and downward moving opacity fluctuations across the altitudes to which the Fe spectral band is tuned. At the umbral/penumbral boundary, oscillations were also detected, believed to be caused by magnetic field lines swaying in response to a *p*-mode driver (Kupke, LaBonte, & Mickey 2000). Waves have then been observed to propagate from inside the umbra into the penumbra, which suggests that the running penumbral waves are excited by the same resonator (Tsiropoula, Alissandrakis, & Mein 2000; Christopoulou, Gerogakilas, & Koutchmy 2000). The locations of multi-mode oscillations, of which some modes have been compared with the *whispering gallery mode* in acoustics, were studied by Zhugzhda, Balthasar, & Staude (2000), who find that the power is concentrated in isolated pores outside of larger umbrae and at the boundary between umbra and penumbra.

Numerical simulations of fluid motions in a sunspot reveal a *collar* of hidden inflow beneath the penumbrae of large spots, besides the well-known outflow to the moat, a configuration that is thought to be responsible for the longevity of the sunspot (Hurlburt & Rucklidge 2000). Doppler observations show upflows near the inner boundary and downflows at the outer boundary of the penumbra, with nearly horizontal outflows in between (Schlichenmaier & Schmidt 2000).

2.2.5. Photospheric Abundances

The solar photospheric Fe abundances has been determined from 3-D, time-dependent, hydrodynamical models to $\log \epsilon_{\rm Fe\,I} = 7.44 \pm 0.05$ and $\log \epsilon_{\rm Fe\,II} = 7.45 \pm 0.10$ (Asplund et al. 2000a). The modeling of Fe line shapes, shifts, asymmetries seems to imply that the micro- and macroturbulence concepts are obsolete in these 3-D analyses (Asplund et al. 2000b). The photospheric Si abundance has been determined to $\log \epsilon_{\rm Si} = 7.51 \pm 0.04$ (Asplund 2000). The first determination of elemental composition in the photospheric layers of magnetic flux tubes (opposed to values averaged over the quiet photosphere) revealed hints of a weak *First Ionization Potential* (*FIP*) effect inside the magnetic flux tubes, but the upper limit is well below the large enhancements seen in the corona (Sheminova & Solanki 1999).

Measurements of the abundance of Fe relative to H have been performed in the corona by comparing EUV line data from *SoHO*/CDS with thermal bremsstrahlung radio data from the VLA (White et al. 2000), finding an enhancement by a factor of four compared with the photospheric values. This result implies that low FIP elements such as Fe are enhanced in the solar corona relative to photospheric values (White et al. 2000).

2.2.6. Solar Rotation and Oblateness

The solar rotation rate was more accurately modeled by including meridional flows in feature-tracking methods (Snodgrass & Smith 2000). Meridional motions and rotation rates were found to be very different during quiet and active periods (Meunier 1999). It is no surprise that the corona rotates differently from the solar surface, because some slipping is possible as the result of continuous magnetic reconnection and disconnection at coronal hole boundaries. Differential rotation rates of soft X-ray features in the solar corona have been measured by a method of harmonic filtering using the Lomb-Scargle periodogram (Weber et al. 1999).

Accurate measurements of the solar oblateness with *SoHO*/MDI show that quadrupole and hexadecpole shape terms are marginally inconsistent with solar rotation data (Armstrong & Kuhn 1999).

2.3. Chromosphere

2.3.1. Time-averaged Structure

There is less and less that can be said about the structure of the chromosphere in the sense of a static sphere, but more and more is said about the dynamical processes that make up its transient nature. One author went as far as to ask “Does the Sun have a *full-time chromosphere*?” (Kalkofen, Ulmschneider, & Avrett 1999), criticizing that a particular dynamic model (Carlsson & Stein 1995) did not reproduce the correct time average of chromospheric EUV emission, and thus mimicked only a *“part-time chromosphere.”* There is a growing insight that inversion of chromospheric observational data is not unique and does not lead to any valid model of its structure, while only forward-fitting of dynamic (time-dependent) models represents a sensible approach (Judge & MacIntosh 1999). It is even doubtful whether forward-modeling reveals the correct structure of the chromosphere at this point, because understanding of the underlying physics is too incomplete, given the dynamics of the highly variable vertical spicules and the moderately variable horizontal Hα fibrils (Schrijver & Zwaan 2000, p. 218). New *TRACE* observations show that the so-called *moss* structure (Berger et al. 1999; Martens, Kankelborg, & Berger 2000), the interface between hot (3-5 MK) coronal loops and cooler (<1 MK) chromospheric plasma over plage areas, shows time variability of order of 10 s (Berger et al. 1999). Dark point features observed in He I 1083 nm show short-term variations below 30 s, probably associated with microflares (MacQueen et al. 2000). Thus, we need dynamic models, by all means.

2.3.2. Convection-driven Dynamics

Chromospheric dynamics has been studied with improved 3-D numerical simulations. One such simulation studies the excitation of acoustic waves that are excited at the top of the convective zone and immediately above the convective overshoot zone by small granules that undergo a rapid collapse, in the sense that upflow reverses to downflow, on a time scale shorter than the atmospheric acoustic cutoff (3-minute) period (Skartlien, Stein, & Nordlund 2000). The observed acoustic events, internetwork bright grains (in Ca II H and K line), and associated shock waves are thought to be linked to such wave transients. High cadence observations (16 s) in C II and O VI lines, which cover the temperature range from 20,000 K in the upper chromosphere to 300,000 K in the transition region, reveal large-scale coherent oscillations on spatial scales of 3–7 Mm with periods between 120 and 200 s, which show phase differences that are consistent with upward-propagating waves and drive oscillations in the transition region plasma (Wikstol et al. 2000). On the other side, the frequently occurring *bright cell grains*, chromospheric features that overlay magnetic intranetwork, were found to show no correlation with the magnetic field (Worden, Harvey, & Shine 1999), and thus do not manifest the acoustic shocks proposed by Carlsson & Stein (1995) and Skartlien et al. (2000).

The detection of MHD waves in the photosphere has been attempted, using multiple spectral lines that probe the phase shift and amplitude difference in various photospheric heights (Norton & Ulrich 2000).

2.3.3. Reconnection-driven Dynamics

The shuffling of the chromospheric footpoints of coronal magnetic field lines, either by convective motion or horizontal flows, tangles up the magnetic field into complex nested bundles that can only be relaxed by magnetic reconnection processes. After such network-field reconnection events, the relaxed field lines are thought to spring quickly upward and acquire kinetic energy, which is dumped into the corona via acoustic waves (Sturrock et al. 1999b; Roald, Sturrock, & Wolfson 2000). A similar mechanism was suggested by Wilhelm (2000) for spicules and macrospicules, where chromospheric plasma is carried up by the relaxing magnetic field following a field line reconnection. The colliding and reconnecting flux tubes can produce cascades of shock waves, which propagate in different upward directions until they collide and cause explosive instabilities with plasma jets (Ryutova & Tarbell 2000; Tarbell et al. 2000). This scenario was tested by comparing Doppler shifts measured from *SoHO* /SUMER (also observed by Brekke et al. 2000) with the predicted shock speeds (Ryutova & Tarbell 2000). Numerical MHD simulations also show that shock waves of colliding chromospheric flux tubes excite surface and body Alfvén waves, possibly contributing to coronal heating (Furusawa & Sakai 2000; Sakai et al. 2000). Chae et al. (2000) observed that chromospheric reconnection injects cool material into an active filament. Sarro et al. (1999) model the thermal upflows in such explosive events and simulate the C IV response, assessing for the first time departures from the ionization equilibrium under such conditions. Harra, Gallagher, & Phillips (2000) did statistics on EUV brightenings (i.e., microflares with energies in the range of 10^{25}–10^{27} erg) and found an interesting difference in the power-law distributions between those occurring in the network and those inside network cells: network brightenings are found to have energies an order of magnitude higher than cell brightenings, possibly supporting two different heating mechanisms, acoustic waves that form shocks in the cell interior, versus magnetic reconnection-driven nanoflares in the network.

2.3.4. Magnetic Mapping

The magnetic mapping from the photospheric surface through the chromosphere to the transition region is thought to be defined by the catacomb-like geometry of flux-tube canopies, rooted in strong-field regions, while the intervening volume covers weak-field regions where acoustic processes dominate (Schrijver & Zwaan 2000). The mapping from the photospheric to the chromospheric magnetic field was studied (Zhang & Zhang 2000a), but even the definition of canopy heights is not unique (Zhang & Zhang 2000b). The finite width of photospheric sources needs also to be considered to generate more accurate coronal potential field configurations (Oliver et al. 1999). The cross-sectional variation is decisive for coronal heating models (Lothian & Browning 2000). Fourier-based autocorrelation measurements with *SoHO*/CDS show that network boundaries have an almost constant width up to a temperature of about $T \approx 10^{5.4}$ K and then fan out rapidly at coronal temperatures (Patsourakos et al. 1999), in agreement with earlier canopy models by Gabriel.

2.4. Corona

2.4.1. The Coronal Magnetic Field

The problem of reconstructing the coronal magnetic field from well-posed boundaries (i.e., from a photospheric magnetogram) is still not fully solved but is significantly improved for regular solutions (without current sheets), compared with ill-posed boundaries that cause an exponentially growing error with height (Amari, Boulmezaoud, & Mikic 1999). The topologies of potential and force-free models are in general not even qualitatively equivalent, except near localized sources (Brown & Priest 2000), and also depend sensitively on the finite width of photospheric sources (Oliver et al. 1999). The detailed geometry of the three-dimensional magnetic field has been scrutinized for polar crowns (Zhao, Hoekzema, & Scherrer 2000a), active region loops (Mandrini, Démoulin, & Klimchuk 2000), or for magnetic reconnection in kinked loops (Baty et al. 2000a, 2000b).

A fairly recent discovery is that the chirality of the solar magnetic field is hemisphere dependent—the magnetic field in the northern/southern hemisphere has negative/positive helicity. Now, the first studies of current helicity of the large-scale magnetic field have been undertaken, showing a significant asymmetry in latitude, likely to be attributed to the Coriolis force (Pevtsov & Latushko 2000).

More sensitive techniques using infrared spectropolarimeters have been developed to enable more precise measurements of the weak coronal magnetic field (Lin, Penn, & Tomczyk 2000; Lin & Casini 2000).

2.4.2. The Quiet Sun

Although nobody believes that there is such a thing as a *"Quiet Sun,"* you still can find a number of new publications with this term in the title. It should rather be called the *Statistical Sun*, because one attempts to extract some physical parameters by averaging over space and time, at least in slowly-varying parts of the solar corona. Statistical quantities are still a prerequisite for three-dimensional stereoscopic (Vedenov et al. 2000) and tomographic reconstruction methods (Frazin 2000) or for opacity calculations in a spherical corona (Fischbacher et al. 2000). Analysis of statistical EUV emission revealed an excess of the hydrostatic stratification that was interpreted in terms of resonant scattering, in EUV lines with high oscillator strengths (Schrijver & McMullen 2000; Wood & Raymond 2000), as well as in single-ionized helium (Delaboudinière 1999). Also the line widths of EUV spectral lines were found to be broadened over a height range of 1.03–1.45 solar radii, indicating nonthermal motion or turbulence (Doschek & Feldman 2000). Radial density profiles of the corona can also used to test solar wind models (Gallagher et al. 1999) or to test coronal abundance models, i.e., to determine the enrichment factor for low first-ionization-potential (low FIP) elements (Warren 1999). However, the spatial averaging of the multi-temperature corona (for instance, see high resolution images of the corona in green and red lines; Takeda et al. 2000), which involves not only the correct differential emission measure distribution $d\mathrm{EM}(T)/dT$, but also its proper translation into line-of-sight averaged densities expressed with the corresponding multi-scale height $\lambda(T)$ distribution, is not trivial, and still causes discrepancies in EUV and SXR temperature comparisons that are not understood (Wolfson et al. 2000a). Attempts to determine the differential emission measure distribution of the global corona have been conducted with at two-temperature approach (Zhang, White, & Kundu 1999). *TRACE* and *Yohkoh* observations, however, reveal an ubiquitous multi-temperature inhomogeneity, which can only be characterized with a continuous differential emission measure distribution $d\mathrm{EM}(T)/dT$.

2.4.3. Coronal Loops

While the complexity of stellar coronae is concealed by distance, the solar corona clearly shows myriads of loops in EUV and soft X-rays, each one of which represents a thermally insulated mini-atmosphere that has to be modeled separately. Although these building blocks of the solar corona have been known for three decades after *Skylab*, progress in physical modeling of loops only now is showing a breakthrough, with the latest high resolution observations of *TRACE*. Coronal loops are now detected from tiny dipoles, which barely stick out of the chromosphere, to huge trans-equatorial connectors (Pevtsov 2000; Khan & Hudson 2000; Benevolenskaya et al. 1999). The geometry of loops has been investigated in more detail by measuring their cross-sectional variation along their length, which was found to be remarkably constant, much more than expected from dipolar magnetic field models or from some twist-driven coronal heating models (Klimchuk 2000; Klimchuk, Antiochos, & Norton 2000; Watko & Klimchuk 2000). Scaling laws between the mean coronal magnetic field and the loop length were tested, indicating a slight preference for stress-driven coronal heating models over wave heating models (Mandrini et al. 2000). By modeling the temperature and density profile of individual loops, it was found that a steady state solution with a uniform heating function is not consistent with the data (Lenz et al. 1999; Oluseyi et al. 1999), a hypothesis that was taken for granted since the pioneering work of Rosner, Tucker, & Vaiana (1978), and was frequently applied to loops in solar and stellar coronae. In fact, recent modeling of coronal loops from *SoHO*/EIT and *TRACE* observations revealed that only a nonuniform heating function can account for their basal *overpressure* and near-isothermal structure in EUV, with the heating concentrated in the lowest 10 Mm of the solar corona. Uniformly heated multi-thread models with a range of temperatures can account for their near-isothermal structure (Reale & Peres 2000) but fail to reproduce their density structure. Many loops are also found not to be in steady state (e.g., Nightingale, Aschwanden, & Hurlburt 1999), but rather in a transient heating or catastrophic cooling phase. Such dynamic loops are much harder to model, but some initial attempts have been made with hydrodynamic codes (Reale et al. 2000a, 2000b, Peres 2000). To make things even more complicated, Lenz (2000) found also that elemental abundance variations and the dependence of the ion heating rate on abundance variations play a role in the determination of the coronal heating function.

2.4.4. Loop Oscillations

A special dynamic manifestation of some coronal loops are oscillations in the fundamental kink mode, a discovery made by *TRACE* a year ago. This new diagnostic capability opens a new field of *coronal seismology* (Roberts 2000). The strong damping of these oscillations that has been observed, however, remains a major puzzle (Roberts 2000). While initially an interpretation in terms of viscous and ohmic damping of resonant Alfvén waves has been proposed, predicting a stunningly low Reynolds number, nine orders of magnitude below the classical value (Nakariakov et al. 1999), alternative interpretations in terms of photospheric drivers that control the amplitude and decay of transverse oscillations of coronal field lines have been proposed (Schrijver & Brown 2000). Besides standing oscillation modes, also propagating wave modes (probably slow magnetoacoustic waves) have also been detected in coronal loops with *TRACE* (DeMoortel, Ireland, & Walsh 2000).

2.4.5. The Coronal Heating Problem

No, we have not yet solved *the coronal heating problem*. But the prospects are better than ever because we finally managed to localize the coronal heating source. The latest *SoHO*/EIT and *TRACE* observations point consistently in the direction that all the heating occurs in the lowest 10 Mm of the corona, a strong constraint for theoretical heating models. Priest et al. (2000) arrived at the opposite conclusion, favoring uniform heating or looptop heating, based on a temperature analysis of loops observed with *Yohkoh*, but that result is hampered by statistical uncertainties (MacKay et al. 2000), and is probably subject to a hydrostatic weighting bias of the multi-temperature corona inflicted by the broadband temperature response of *Yohkoh*.

Wave heating models employ dissipation of resonant Alfvén waves (e.g., Bélien, Martens, & Keppens 1999; DeGroof & Goossens 2000, Voitenko & Goossens 2000a, 2000b) which generally have relatively large dissipation lengths (and are not gravitationally damped; McKenzie & Axford 2000a, 2000b), and thus tend to heat the corona over large altitude ranges. “For long-wavelength Alfvén waves, phase mixing or resonant absorption tends to produce a heating that is more intense near the summit for the fundamental mode since the wave amplitude is highest there” (Priest et al. 2000). This class of heating models seems not to be consistent with the footpoint heating revealed by *TRACE*, even if random footpoint motion produces enough resonances to make this mechanism globally efficient (DeGroof & Goossens 2000). Wave heating models are also less consistent with data regarding their scaling of the magnetic field strength with loop length (Mandrini et al. 2000).

Another class of coronal heating models deals with wave turbulence (for recent work see Dmitruk & Gómez 1999; Matthaeus et al. 1999), caused by stochastic or turbulent reconnection in many small current sheets, e.g., nanoflaring driven by footpoint braiding as suggested by Parker (1972). The slow footpoint motions braid the coronal field through a series of equilibria that become turbulent, either because of the braiding-induced current sheets or because of small-scale MHD tearing-mode instabilities. Since the loop cross sections appear to be relatively uniform (Klimchuk 2000), braiding and turbulence are expected to spread uniformly along the loop, as demonstrated by recent 3-D resistive MHD numerical simulations (Galsgaard et al. 1999), which is not consistent with the footpoint-concentrated heating indicated by the *TRACE* data.

Obviously the new *TRACE* observations favor heating models that have the highest energy input in the lower corona or even in the chromosphere. Good candidates are models involving chromospheric reconnection (e.g., Sturrock et al. 1999b; Roald et al. 2000; Wilhelm 2000; Ryutova & Tarbell 2000; Tarbell et al. 2000; Furusawa & Sakai 2000; Sakai et al. 2000; Chae et al. 2000; Sarro et al. 1999; Goodman 2000a; Longcope & Kankelborg 1999). Strong heating was observed mainly for loops that embrace an island of insulated magnetic polarity and a magnetic nullpoint above (Falconer et al. 2000), indicating magnetic reconnection close to the footpoints of large coronal loops. Correlations between the soft X-ray brightness and photospheric magnetic field strength was interpreted as indicator of coronal heating by reconnection of magnetic elements in the chromospheric network (Wolfson et al. 2000b). Many of these chromospheric heating processes convey massive upflows, which indeed have been detected in active region loops from Doppler shifts, simultaneously with downflows of cooler material (Brosius et al. 1999, 2000). Near-chromospheric heating can also be accomplished by upflow of suprathermal particles, which might even work as heating process of Galactic halo outflows (Hirth & Krüger 2000).

2.4.6. Microflaring, Nanoflaring, Picoflaring, …?

The high (arcsecond) resolution of EUV images from *TRACE* have clearly shown us the existence of numerous small-scale flare-like phenomena, which are termed by the prefix (micro, nano, …) that corresponds to the energetic fraction of the largest solar flares observed in human history. New studies of such tiny EUV brightenings relate them to photospheric magnetic cancellation events (Longcope & Kankelborg 1999; Kankelborg & Longcope 1999), reconnecting small-scale loops (Ireland, Wills-Davey, & Walsh 1999), network-associated variability (Harra et al. 2000; Brkovic et al. 2000), explosions of sheared magnetic fields in the cores of initially closed bipoles (Moore et al. 1999b), and flare-like chromospheric evaporation upflows (Brown et al. 2000c; Krucker & Benz 2000). If we look at the size distribution of the small-scale loops (Parnell & Jupp 2000) involved in these phenomena, it tails off quickly with height, with the majority confined to altitudes less than 10 Mm, similar to the height extent of the heating function of large-scale loops measured by *TRACE*. Therefore, we should call them *transition region nanoflares*, in contrast to the theoretical anticipation of *coronal nanoflares* (Vekstein & Katsukawa 2000) postulated by Parker (1988). So we have a dual meaning of the nanoflare concept: the theoretical framework predicts them high up and throughout the corona, while the observations nail them all down to the chromosphere and transition-region zone. Ironically, this discrepancy has not been discussed in the literature at all. Another problem is that nanoflares probably do not extend down to the pico or fempto regime, just because any scaling with spatial size, temperature, or energy content would place them on such a tiny scale that they would be completely engulfed in the chromosphere, without having any chance to contribute to coronal heating. No Olbers’s paradox!

2.5. Flares and CMEs

This section is mainly about eruptive phenomena in the solar corona, which includes eruptive filaments, prominences, flares, and coronal mass ejections. In large eruptive events one sees all of these phenomena performing in concert, but the conductor (always a magnetic destabilization process) may sometimes give any type of instrument a solo part, or may pick out any subset of instrument combinations. The only kind of performance we have not seen yet is whether the orchestra can perform without conductor (e.g., a flare without a magnetic driver).

2.5.1. *Filaments*

Let us first consider *quiescent filaments*, which are not eruptive. Filament channels are regions in which the coronal magnetic field is strongly aligned with the underlying polarity inversion line in the photosphere. There are currently two schools of thought on how filaments form. One model is that the weak axial field from the surrounding corona is transported toward the polarity inversion line where it is concentrated into narrow filament channels. The alternative scenario is that axial fields are generated in the convection zone and emerge into the corona through the photosphere. A recent mean-field model demonstrates how filament channels are formed by random footpoint motions that cause small-scale twisting and braiding of field lines, where magnetic flux cancellation plays an important role (Van Ballegooijen, Priest, & MacKay 2000). Modeling of observations shows that photospheric reconnection driven by canceling magnetic features leads to a significant upward mass flux and the formation of a filament (Litvinenko & Martin 1999), upward motion on one side and downward motion on the other side (Magara & Kitai 1999). Magnetic reconnection resulting from flux emergence and cancellation can also break a quiescent filament into multiple segments (Jiang & Wang 2000). However, the observed hemisphere pattern of dextral and sinistral channels cannot be reproduced with the mean-field model (Van Ballegooijen et al. 2000), while new observing techniques have been developed to determine the chirality of filaments, yielding the preliminary result that the hemispheric pattern of filament chirality is the same as for active-region helicity (Chae 2000).

Complex magnetic processes, such as shearing, twisting, kinking, or tether-cutting can destabilize the mass suspended in a filament and give rise to an eruptive phenomenon, which may turn into a flare or a coronal mass ejection, or both. This poorly understood magnetic destabilization process is still subject of numerous theoretical (e.g., DeVore & Antiochos 2000; Uchida et al. 1999) and observational investigations (Wang et al. 2000c; Schmieder et al. 2000). An interesting property is that filaments produced by a single, sheared dipole arcade tend to be stable and not prone to erupt (DeVore & Antiochos 2000), while filaments located in quadrupolar arcades can easily be triggered to erupt (*"magnetic break-out model"* of Antiochos, DeVore, & Klimchuk 1999; Su & Su 2000; Uchida et al. 1999). The key feature of the Antiochos model is the multi-polar topology, where magnetic reconnection between a sheared arcade and a neighboring flux system triggers the eruption. Aulanier et al. (2000) develop a 3-D magnetic reconnection model with a magnetic nullpoint above the sheared arcade and generalized Antiochos's theorem to *"A magnetic breakout is the opening of initially low lying sheared fields, triggered by reconnection at a null point that is located high in the corona and that defines a separatrix enclosing the sheared fields."*

2.5.2. *Prominences*

Filaments and prominences became a unified phenomenon, having a dissimilar appearance only because of their different background: filaments are cool material appearing in dark absorption in front of the bright solar disk, while prominences appear as bright emission in front of the dark sky above the limb. The morphological differences are thus mainly of an observational nature, while theoretical models are based on common physics. Theoretical models simulated the thermal nonequilibrium of a stretched-out, dipped flux tube (Antiochos, MacNeice, & Spicer 2000), the inflow of enthalpy and ionization energy (Anzer & Heinzel 2000), the dynamic formation and stability of helical prominences (DeVore & Antiochos 2000), the levitation of prominence threads by incompressible MHD waves (Pecseli & Engvold 2000), and the distribution and asymmetry of prominences (Verma 2000).

Observations revealed two types of prominences: active and eruptive types. Eruptive prominences were found to be more strongly associated with CMEs; the associated CMEs have cores, and separation of escaping material occurs in a height range of 1.20-1.35 solar radii, where the formation of an X-type neutral line was inferred (Gilbert et al. 2000). A number of accompanying phenomena are observed in eruptive prominences: coronal dimming, twisted cores, X-ray arcade formation, X-ray brightenings, EUV eruption, and white-light CMEs (Gopalswamy et al. 2000; Plunkett et al. 2000; Srivastava et al. 2000). Eruptions are observed with twisted cores, rotating about their axis during outward motion, and the helical structure of the CME is found to be consistent with the ejection of a magnetic flux rope (Plunkett et al. 2000). Eruptive prominences and CMEs seem to have common drivers, caused by a large-scale restructuring of the coronal magnetic field (Srivastava et al. 2000).

2.5.3. *Flares*

We count over one hundred refereed papers about solar flares published during the reported year, which happens to coincide with the peak of the current solar cycle, when the flare frequency is highest. To summarize them in a sentence: one finds more complex topologies of magnetic reconnection scenarios, more detailed evidence for magnetic reconnection, higher-resolution images in more wavelengths, more extreme limits for the smallest detectable flares, and more "missing links" between flares and coronal mass ejections.

Magnetic reconnection.—The origin of flares can only be understood in terms of magnetic reconnection. While previous models mainly dealt with steady reconnection in current sheets (2-dimensional case), recent work concentrates on new generations of fast regimes in steady reconnection, unsteady reconnection (X-type collapse), and reconnection in 3 dimensions, along separatrix surfaces, spines, fans, 3-D null points, and *bald patches* (Priest & Forbes 2000; Forbes 2000a, 2000b; Lin & Forbes 2000; Schrijver & Brown 2000; Titov & Demoulin 1999; Galsgaard et al. 2000; Birn et al. 2000). The theoretical spearheading stimulated immediate modeling of observations. Aulanier et al. (2000) model the second *Bastille day flare* (14 July 2000) with a coronal nullpoint, with its associated *"spine"* field line, and its *"fan"* surface surrounding the parasitic polarity and find evidence for the *"magnetic breakout model"* (Antiochos et al. 1999) as trigger of the eruptive flare. Hudson (2000) conjectures that a volume implosion should precede the magnetic energy release in flares. Evidence for magnetic reconnection in flares (Shibata 1999) was further corroborated with magnetic modeling of soft X-ray data (Zhang 2000; Zhang et al. 2000; Yurchyshyn et al. 2000a), by the discovery of supra-arcade downflows (McKenzie 2000) that have actually been predicted by reconnection flare models, by the finding of collimated plasma jets observed in EUV (Alexander & Fletcher 1999), and by multi-wavelength analysis of magnetically driven eruptions (Gallagher et al. 2000; Hori et al. 2000; Qiu et al. 2000b). The top of flare loops seen in soft X-rays indicate spotty patterns of highly inhomogeneous temperatures (Doschek 1999), possibly related to the newly discovered high temperature outflows from reconnection sites (McKenzie & Hudson 1999; McKenzie 2000). Very few studies care about the 3-D geometry of flare loops (e.g., Nitta et al. 1999), which could possibly constrain the magnetic reconnection topology. Alternative flare drivers involve flux pile-up reconnection (Craig & Watson 2000) or magnetic shearing and flux emergence (Li et al. 2000a, 2000b; Ranns et al. 2000; Ishii et al. 2000). Observational measurements of photospheric magnetic field changes during flares that could serve as tests of these models are still difficult (Cameron & Sammis 1999; Kosovichev & Zharkova 1999; Lozitsky et al. 2000; Wang et al. 2000b; Yurchyshyn et al. 2000b). However, the change of current helicity (Bao et al. 1999) and sigmoidicity in flaring regions (Canfield, Hudson, & McKenzie 1999; Aurass et al. 1999; Sterling et al. 2000) were found to act as significant flare indicators.

Particle acceleration site.—Magnetic reconnection is thought to operate in an unsteady mode, controlled by repeated formation and subsequent coalescence of magnetic islands (known as *"secondary tearing"* or *"impulsive bursty"* regime of reconnection). Two-dimensional MHD simulations of this dynamic regime successfully reproduced the quasi-periodic time pattern of particle acceleration episodes as it is observed in decimetric radio pulsations (Kliem et al. 2000). Subsequent magnetic island formation of shear-driven arcades can also lead to a sequence of homologous flares (Choe & Cheng 2000). Simulations of the particle orbits in the DC electric fields associated with the dynamic multiple X-points demonstrate acceleration in bursty pulses (Kliem et al. 2000; Litvinenko 2000), similar to what stochastic acceleration models would produce (Miller, LaRosa, & Moore 1996). Alternatively, MHD turbulence cascading was also considered to provide efficient acceleration of quasi-thermal electrons (Tsap 2000). The observed pulsed mode of particle acceleration was also explained by modulating the penetration depth of partially ionized plasma into current-carrying flare loops (Zaitsev, Urpo, & Stepanov 2000). The temporal fluctuations of the hard X-rays of precipitating electrons is highly correlated with the gyrosynchrotron emission of the accelerated electrons in the coronal trap (Lee & Wang 2000), although the kinematic modeling still represents a challenge (Petrosian & Donaghy 1999). In particular, the *above-the-loop-top* hard X-ray sources discovered by Masuda et al. (1994), from which also high temperature plasma is detected (Warren et al. 1999; Warren 2000), can be modeled by magnetic trapping in convergent cusps, as well as by plasma turbulence at the acceleration site (Petrosian & Donaghy 1999). The electron kinematics is most easily measured with time-of-flight delays to remote footpoints in double-loop flares (Hanaoka 1999).

Chromospheric flare response.—The nonthermal electrons accelerated at the coronal reconnection site precipitate and heat up the chromospheric plasma. They probably account entirely for the resulting hard X-ray emission at energies above 20 keV because alternative models with neutralized ion beams (Karlicky et al. 2000) produced comparable hard X-rays only in two cases out of 19 (Brown et al. 2000d), although the ion energy was found to be comparable with that of electrons (Ramaty & Mandzhavidze 1999). Numerical simulations of the electron impact predict Hα line polarization (Zharkova & Syniavskii 2000) and nonthermal line broadening (Fang, Henoux, & Ding 2000; Gan et al. 2000). Some white-light flares show unusually high Ca II K-line intensities that cannot be explained by standard electron precipitation models, so that particle acceleration mechanisms have been invoked even in the (highly collisional) lower chromosphere (Ding 1999). White-light flares were found to exhibit a surprising lack of correlation with soft and hard X-ray images (Sylwester & Sylwester 2000). Instead, Hα time structures show much closer relations to hard X-rays (Trottet et al. 2000; Wang et al. 2000d) or radio emission (Vrsnak et al. 2000).

Postflare phase.—Postflare loops just represent the "smoke" of the chromosphere, after it has been bombarded during the impulsive flare phase. Although this "postflare smoke" clouds the scene of action completely, its filling factor was determined to be as low as 1% to 20%, using Fe XIV line intensities (Varady, Fludra, & Heinzel 2000). Such small filling factors would modify emission measure–inferred electron densities in postflare loops up to an order of magnitude, questioning the accuracy of scaling law studies (e.g., Garcia et al. 2000; Shibata & Yokoyama 1999) based on filling factors of unity. With this grain of salt, night-time astronomers, nevertheless, might be pleased to hear that a universal scaling law was found between flare temperatures and soft X-ray emission measures that extends from solar to stellar flares (Shibata & Yokoyama 1999).

Radio emission.—When soft X-ray emission is considered as "the smoke of the gun" of a violent flare event, radio emission provides the "audio sound." That clarifies how hard it is to reconstruct the crime scene just from the sounds of the shooting. Nevertheless, radio images, spectra, and frequency-time drift rates are used to reconstruct the particle kinematics on solar flare scenes. Here are some examples of such sophisticated modeling work. Frequency-dependent modeling of the gyrosynchrotron emission in a trapping flare loop using VLA images and OVRO spectra revealed a photospheric field strength of 870 G, electron densities of $\lesssim 10^8$ cm^{-3}, and electron energies of 8–210 keV (Nindos et al. 2000). Calculations of plasma radiation driven by the loss-cone instability of magnetically trapped energetic electrons in (hotter) stellar coronae suggest much higher radiation levels than in the solar corona (Stepanov et al. 1999). The asymmetry of the magnetic field in double-footpoint flares was included in models of electron-cyclotron maser emission, but was not found to be sufficiently constraining to discriminate between different emission mechanisms (Conway & Willes 2000). Multi-resolution analysis of decimetric millisecond spikes revealed bandwidths as small as 0.1% of the center frequency (Messmer & Benz 2000), which suggests spatial fragmentation of the energy release region down to ≈50 km. A spatial fragmentation of the energy release region was also reported from millimeter observations (Raulin et al. 2000). Nonlinear analysis of frequency distributions of such decimetric spike bursts in terms of attractor dimensions and Lyapunov exponents was employed to corroborate or disprove their coherent emission mechanism (Meszarosova et al. 2000). Anisotropic particle distributions generated by the electron firehose instability were considered to be suitable for electron acceleration (Paesold & Benz 1999). A new scenario for radio type III emission was proposed by Wu, Yoon, & Li (2000), based on X-mode Bernstein waves instead of Langmuir waves.

Flare statistics.—The size distribution of flare energies, following a power law like most of the nonlinear energy dissipation processes in the universe governed by self-organized criticality, is still controversial at the lower end of the energy scale, where a diverging distribution could explain the all-important problem of coronal heating. The flare size distribution has been modeled in terms of Alfvénic dissipation processes (Wheatland & Uchida 1999), as well as in terms of cellular automata by conserving magnetic helicity (Chou 1999). No relationship was found between flare time intervals and flare energies (Wheatland 2000a), nor was a difference discovered in flare frequency distributions among different active regions (Wheatland 2000b). Although a positive relation was found between magnetic structures and flare occurrence, not every large magnetic region produces large flares (Sammis, Tang, & Zirin 2000). The so-called waiting time (or flare time interval) distribution was found to be consistent with a Poisson process (Wheatland 2000c), a fact that stands in contrast to the expected power-law distribution of self-organized systems.

2.5.4. Coronal Mass Ejections

Coronal mass ejections (*CMEs*) manifest the aftermath of major coronal magnetic instability or disequilibrium, similar to the fallout after a nuclear bomb explosion. It is also equally difficult to reconstruct the initial trigger mechanism from the dynamics of the mass ejecta, which is all we can observe. However, recent statistics show that S-shaped filaments have a high probability to trigger an eruption (Canfield et al. 1999; Sterling et al. 2000). The standard picture predicts that the origin of a flare or a CME is caused by the eruption of a filament-like feature, where the stretching of field lines produces cusps overlaying the sigmoid feature, which is confirmed by *Yohkoh* observations (Sterling et al. 2000), although ejecta are not always seen in soft X-rays (Nitta & Akiyama 1999). Theoretical simulations reproduce the finding that such S-shaped structures can be created by twisted flux tubes in highly nonlinear 3-D force-free magnetic configurations, which cannot stay in equilibrium and release substantial amounts of magnetic energy, comparable to the energy of the open field configuration (Amari et al. 2000; Wolfson & Dlamini 1999). The stability of magnetic arcades was also found to depend on the convergence of chromospheric footpoint motion and the divergence of fanning coronal field lines (Birn et al. 2000).

The phenomena of flares, CMEs, and prominence eruptions were unified in the sense that they all involve a disruption of the coronal magnetic field. If the disruption occurs in an active region, we generally see flare ribbons in the chromosphere and call it a "flare." If the disruption occurs outside an active region, surface emission may be too weak to be considered as a standard flare and the disruption goes unnoticed, unless it leads to a CME (Forbes 2000a). Large flares almost always produce a CME, but small flares rarely do (Forbes 2000a). More than half of all CMEs are associated with the eruption of large *quiescent prominences*, horizontal magnetic fields that become unstable by disruption of the currents that support the filaments (Forbes 2000a; Gilbert et al. 2000), or by injection of poloidal flux (Krall, Chen, & Santoro 2000). The unstable, erupting filament can have a helical structure, but the associated shock front might assume a bubble-like shell structure.

Observationally, we are still not sure which CMEs have the geometric topology of 3-D bubbles (Delannée et al. 2000) or helical flux ropes (Chen et al. 2000b) because both can have similar projections if viewed edge-on, but they imply quite different physical drivers. A comprehensive observation, by tracking over 32 solar radii, convincingly indicated the topology of a magnetic flux rope with its legs connected to the Sun (Chen et al. 2000b). Others report the morphological structure of a helix, consisting of several strands with a moderate pitch angle, rotating (Plunkett et al. 2000) or untwisting (at a rate of about $\approx 10^{-3}$ radians/sec; Ciaravella et al. 2000). The latitudinal topology of CMEs is very asymmetric; close to 70% of the mass is ejected from within a single hemisphere (Lewis & Simnett 2000). Some CMEs cannot be detected in emission, but show up only as dimming on the solar surface (Delannée et al. 1999, 2000; Harrison & Lyons 2000), or depletion of the radio brightness temperature (Ramesh & Sasty 2000).

A chromospheric manifestation of CMEs are EIT waves (Thompson et al. 2000a; 2000b), which propagate spherically or asymmetrically from an eruption site. The association of such EIT waves with radio type II bursts, which represent the manifestation of shock waves through the corona, clearly links chromospheric versus coronal signatures of CMEs in many events (Klassen et al. 2000; Maia et al. 2000; Reiner et al. 2000). A unified model of CMEs and piston-driven fast-mode MHD shocks, producing type II bursts, has been modeled by Magara et al. (2000). However, numerical simulations of EIT waves in terms of fast-mode MHD waves reproduce surface speeds of order ≈200 km/sec but are unable to account for velocities in excess of 600 km/sec associated with Moreton waves and type II radio bursts, unless the initial disturbance is assumed to have the form of a strong, super-Alfvénic shock (Wang 2000).

The kinematics of CMEs has been studied. It was found that the potential and kinetic energies increase at the expense of the magnetic energy as the CME moves out, keeping the total energy roughly constant (Vourlidas et al. 2000). This demonstrates that flux-rope CMEs are magnetically driven. The mass carried by CMEs could account for up to 8% of the total solar mass loss through the solar wind (Lewis & Simnett 2000). CMEs were found to originate non-uniformly during solar minimum, but almost uniformly in longitude during solar maximum (Watari & Watanabe 2000). The propagation of CMEs in interplanetary space shows a deceleration of the speed according to scintillation data (Manoharan et al. 2000). A CME and eruptive prominence was observed to accelerate up to ≈20 solar radii and then to decelerate to the velocity of the ambient solar wind (Srivastava et al. 2000).

The geoeffectiveness of CMEs is rather complex. One would expect that directivity is a main factor, but Cane, Richardson, & Cyr (2000) found that only about half of the frontside halo CMEs encounter Earth. It was found that the geoeffectiveness of ejecta depends strongly on the southward magnetic field component B_z, irrespective of whether or not the ejecta has a magnetic cloud structure (Cane et al. 2000). Also, the transit speeds of ejecta to Earth are found to be only loosely correlated with CME speeds (Cane et al. 2000).

2.6. Solar Wind and Heliosphere

2.6.1. Coronal Holes and Solar Wind Sources

Coronal holes demarcate those parts of the solar surface with open magnetic fields, which supposedly reveal most clearly the energy input that accelerates and heats the fast solar wind (with speeds up to ≈800 km/sec). Hassler et al. (1999) made the important discovery that outflow velocities (measured from Ne VII velocity maps) originate predominantly along chromospheric network boundaries, with the strongest outflows occurring at the intersections of network boundaries. These Ne VII observations constitute the first two-dimensional velocity maps of coronal holes and clearly reveal the source region of the fast solar wind. However, there are still a number of puzzling questions: Why are outflows only seen in Ne VII, at a temperature of $T_e \approx 0.8$ MK (Hassler et al. 1999; Wilhelm et al. 2000)? Why are the observed hydrogen temperature gradients much smaller than expected from transition region models (Marsch, Tu, & Wilhelm 2000)? Are the polar radio brightenings observed at millimeter wavelengths related to solar wind outflows (Pohjolainen, Portier-Fozzani, & Ragaigne 2000; Pohjolainen 2000)?

2.6.2. Plumes, Rays, and Jets

Polar plumes are cool, dense, linear, magnetically open structures that arise from predominantly unipolar magnetic footpoints in the solar polar coronal holes. The hydrostatic nature of plumes seems to be puzzling. The density profile of an off-limb section of a plume was found to exhibit a constant pressure over a height range of 70,000 km (Young, Klimchuk, & Mason 1999), instead of an exponential dropoff with a scale height of 50,000 km, as expected for an electron temperature of $T_e \approx$ 1.0 MK. The authors suggest that an accelerating force in the plume is responsible for this oddity. Another observation of a plume during a solar eclipse revealed an embedded jet that propagated outward with a speed of $v \approx 200$ km s^{-1}(Lites et al. 1999).

The dynamic nature of plumes is not less challenging. The detection of propagating compressional waves in polar plumes with *SoHO*/EIT (DeForest & Gurman 1998), *SoHO*/CDS (Banerjee et al. 2000a), and *SoHO*/UVCS (Ofman et al. 2000a) has been interpreted as propagating slow magnetoacoustic waves (Ofman, Nakariakov, & DeForest 1999; Ofman et al. 2000b; Banerjee et al. 2000a) and has been modeled in terms of nonlinear dissipative spherical Alfvén waves (Nakariakov, Ofman, & Arber 2000), which possibly could play a role in the acceleration of the fast solar wind. *SoHO*/UVCS measurements show that fast solar wind is preferentially accelerated in interplume lanes, reaching speeds of 105–150 km/sec there, while the outflow velocity inside plumes is lower, i.e., 0–65 km/sec (Giordano et al. 2000). The velocity shear in the mass flow in the plume/interplume boundary is thought to trap MHD waves and to lead to resonant flow instabilities (Andries, Tirry, & Goossens 2000). Localized cooling processes and related downflows inside plumes are suspected to excite global oscillations at the solar surface (Rast 1999).

Other radial features that manifest open magnetic field lines and look similar to *plumes* are called *rays*, also domiciled near solar polar regions. Differences between the two phenomena have been investigated by Li, Jewitt, & LaBonte (2000d), who find that rays are hot plasma structures formed in active regions, but not parts of polar coronal holes, some with lifetimes over five solar rotations.

Collimated plasma outflows, called *jets*, previously observed in soft X-rays, are now increasingly observed also in EUV, and thus at cooler temperatures, with *SoHO*/UVCS (Dobrzycka, Raymond, & Cranmer 2000), with *SoHO*/LASCO (Wood et al. 1999), in EUV, and in radio (Ramesh 1999). Tracking of jets beyond 3 solar radii shows that the kinematics can be fitted by near-ballistic motion, but gravity seems not to be the only regulating force, while the jets become incorporated into the solar wind further out (Wood et al. 1999).

2.6.3. Solar Wind Observations

Coronal holes have high ion temperatures, which increase even further with distance from the Sun, and comparatively low electron temperatures, below ≈1.3 solar radii. Measurements of the solar wind include flow velocities (Bavassano & Bruno 2000; Reginald & Davila 2000; Tappin, Simnett, & Lyons 1999), electron temperatures (Reginald & Davila 2000), static and dynamic pressures (Kawano, Russell, & Newbury 2000), magnetic field fluctuations (Bavassano & Bruno 2000; Chashei et al. 1999), and magnetic field depressions (Franz, Burgess, & Horbury 2000). Synoptic velocity maps of the solar wind have been obtained by Balachandran (2000). The solar wind was found to originate at preferred longitudes (Neugebauer et al. 2000). Periodicities were identified in solar wind velocity, temperature, and density (Das & Gosh 1999). Temporal correlations were reported between solar interior, coronal, and heliospheric solar wind signatures (Woo, Armstrong, & Habbal 2000). The topology of the solar wind has been characterized by three surfaces, corresponding to Alfvénic, slow, and fast magnetosonic speeds (Exarhos & Moussas 2000). Density, temperature, and velocity measurements in the height range of 20,000–200,000 km made with *SoHO*/SUMER (Wilhelm et al. 2000) could be reproduced with theoretical two-fluid models that include radiative losses, thermal conduction, electron-proton heat exchange, proton heating by cyclotron-damped Alfvén waves and Alfvén wave pressure in funnels (Hackenberg, Mann, & Marsch 2000).

2.6.4. Solar Wind Modeling

Because collisions are unimportant in the low density extended corona and interplanetary medium, electrons and ions can have quite different velocity distributions and anisotropies, which gives rise to an extreme and fascinating diversity of anisotropic temperatures and outflow velocities. A key effort in modeling the solar wind comprises dissipation of ion cyclotron resonant Alfvén waves (Cranmer 2000; Isenberg, Martin, & Hollweg 2000; Hollweg 2000a, 2000b, 2000c). Analytical treatments exist for two-fluid, three-fluid, or four-fluid turbulence-driven models for preferential acceleration and heating of heavy ions (Hollweg 2000a, 2000b, 2000c; Qiu 2000a). In a mammoth project, the wave damping arising from more than 2000 low abundance ion species has been included in such a model (Cranmer 2000). The results require high frequency (10–10,000 Hz) waves generated throughout the corona, which resonate with ions of charge-to-mass ratios of about 0.1, and this way heat and accelerate the high speed solar wind (Cranmer 2000). The amplitude of the alleged high frequency waves cannot directly be detected by Faraday rotation (Mancuso & Spangler 2000), but perhaps by Faraday screen depolarization (Spangler & Mancuso 2000). Alpha-particles were found to effect the dispersion relation of ion cyclotron waves and its heating of the solar wind plasma (Li & Habbal 1999, 2000). The pickup of interstellar ions in the supersonic solar wind is thought to generate significant levels of magnetic field fluctuations (Zank et al. 2000).

Various forms of waves have been considered that play a role in the solar wind. Alfvén waves can transform into other MHD waves as the result of inhomogeneous (velocity shear-induced) flows (Kaghashvili & Esser 2000). MHD waves may drive a nonlinear cascade, preferentially exciting high perpendicular wavenumber fluctuations (Leamon et al. 2000; Hu, Habbal, & Li 1999). Flows and shock compressions at corotating interaction regions were reproduced by analytical models (Lee 2000). The evolution of the solar wind has been numerically simulated by Wang et al. (2000a) and Tam & Chang (1999). Acceleration of the fast solar wind was also modeled in terms of emerging new magnetic flux (Fisk et al. 1999).

Two-dimensional MHD models of the magnetic field of the corona and interplanetary medium have been developed by Sittler & Guhathakurta (1999). The topology of magnetic clouds was modeled by Hidalgo et al. (2000). The sector structures of the interplanetary magnetic field associated with fast plasma streams were modeled by Mavromichalaki, Vassilaki, & Tsagouri (1999). The shock compression at corotating interaction regions was simulated by Lee (2000).

2.6.5. Solar Wind Composition

Elemental fractionation is a process controlled by electromagnetic fields that separates individual elements and fixes their relative abundance in the solar wind. The influence of Coulomb collisions on isotopic and elemental fractionation in the solar wind acceleration process was studied by Bodmer & Bochsler (2000). A non-Maxwellian distribution has to develop rapidly as function of height to explain the composition observed in interplanetary space (Esser & Edgar 2000). The instruments from *SoHO*/CELIAS and MTOF were used to determine the aluminum abundance (Bochsler et al. 2000) and the Fe/O abundance in the solar wind (Aellig et al. 1999). Li^6 was detected in the solar wind, which is likely to be produced by wave-resonant particle acceleration processes in flares (Ramaty et al. 2000). The main contribution to ^{4}He spectrum was found to be of anomalous origin, while proton and ^{3}He spectra were interpreted to be of solar origin at low energies, and of galactic cosmic-ray origin at high energies (Gomez-Herrero et al. 2000).

2.6.6. Solar Energetic Particle Events

Solar Energetic Particle (*SEP*) *events* are produced at solar flare sites or in shock fronts of CMEs (Vainio, Kocharov, & Laitinen 2000), but the localization of their origin is often controversial (e.g., Dryer et al. 1999). Both impulsive flare acceleration and CME-driven shocks were invoked in the interpretation of enriched ^{3}He events detected during solar quiet periods and during large flares (Clayton, Guzik, & Wefel 2000). 30 MeV n^{-1} ions were found to be accelerated mainly near the Sun, at heliocentric distances <2 solar radii (Kocharov et al. 2000). A search for SEP events during postflare phases with arcades following CMEs turned up only few events (5), while most (30) of the arcade events had no SEP increases, nullifying evidence for postflare arcade acceleration of SEP events (Kahler, McAllister, & Cane 2000). Some studies find that neither impulsive flare acceleration nor interplanetary CMEs accounts for the correct timing, so that a third acceleration process is needed (Laitinen et al. 2000) or two-source injections (Miroshnichenko, De Koning, & Perez-Enriquez 2000; Lockwood, Debrunner, & Ryan1999). A major uncertainty in the reconstruction of the timing or particle release is the pitch angle scattering during interplanetary particle transport (Buttighoffer et al. 1999), as well as possible cross-field transport (Giacalone, Jokipii, & Mazur 2000), but some information was obtained from the rigidity dependence of the particle scattering mean free path (Droege 2000). Mazur et al. (2000) infer from the random walk (over 3.2 hr) of SEP particles interplanetary magnetic field line mixing corresponding to a length of 0.03 AU. Krucker & Lin (2000) find two classes of solar proton events, one that travels almost scatter-free but is released 0.5–2 hr after the electrons, while the other shows a significantly longer path ($\approx$2 AU) but is released simultaneously with the electrons. Trans-iron abundances of SEP events were reported by Reames (2000), showing distinctly different properties for impulsive and gradual SEP events.

3. THESE DISTRACTED GLOBES

We tour the planets and planet left-overs that orbit other stars and the Sun.

3.1. Beyond the 3 LY Limit—Observations

Preliminary, nay even premature, reports of a transit of HD 209458 by its planet (radial velocity companion) just made the time cut for Ap99. Detections of its subsequent transits have become commonplace, with ground-based photometry reported by Henry et al. (2000), Charbonneau et al. (2000), and Jha et al. (2000) and multiple events extracted from the *Hipparcos* data base by Castellano et al. (2000) and Robichon & Arenou (2000). Indeed, slightly out of period, amateur astronomers have begun monitoring the transits. Analysis by the observers and by Mazeh et al. (2000) reveals that the mass of the planet is about 2/3 that of Jupiter and the radius rather larger, so that the density is only 0.3 g cm^{-3} (even more of a floater than Saturn, if you could find a big enough ocean). A harbinger of things to come is that the transit made a detectable change in the profiles of absorption lines in the spectrum of the parent star as recorded by ELODIE (Queloz et al. 2000b). This means that we can look forward some day to information on the composition of the planetary atmosphere, although separating the reflected planet light with a space-based interferometer would yield a cleaner planetary spectrogram than subtraction techniques.

Transits also happen in the solar system, as watched from Earth, with the next Mercurial one due in May 2003 (these are not rare) and the next Cytherean pair in 2004 and 2012. These are rare, and even we have only vague memories of the previous pair in 1874 and 1882.

Radial velocity monitoring continues to yield more (Queloz et al. 2000a), and more (Udry et al. 2000), and more (Vogt et al. 2000) of the class loosely described as hot Jupiters, including two with masses a bit less than that of Saturn (Marcy et al. 2000) and one for which the best-fit mass is about 10 times that of Jupiter (Korzenik et al. 2000, with at least one still heftier one in the press release stage. Overviews of the Lick survey (Cumming et al. 1999) and others (Marcy & Butler 2000) reveal that about 10% of solar-type stars have at least one companion of planetary mass, that the mass distribution is something like $dN/dM \propto M^{-1}$, and that masses larger than 3 M_J in orbits with semi-major axes of 4–6 AU are genuinely rare.

Full details of the three-planet family belonging to Upsilon And have appeared (Butler et al. 1999), and you have all heard hints of additional planet pairs and multiples, besides, of course, the companions of PSR 1257+12, which number at least three (Wolszczan et al. 2000b) and perhaps four (Wolszczan et al. 2000a). Pulsars in general do not display infrared-emitting protoplanetary disks. Thus either they already have planets (one example) or they never will (the other 900 and 99; Greaves & Holland 2000).

Other ways in which planets might reveal themselves include (*a*) distortion of the times of eclipses in close binaries (a gravitational effect, not an occultation one), with a tentative case made for CM Dra (Deeg et al. 2000), (*b*) a bit of reflected light appearing as a bit of Doppler-shifted spectrum superimposed on the main, stellar one (Cameron et al. 1999, with an "interesting if true" example of Tau Boo), (*c*) a little twitch in the light curve of a microlensing (MACHO) event, with two tentative candidates, 97-BLG-41 (Bennett et al. 1999, where the lens was already a close binary system) and 98-BLG-35 (Rhie et al. 2000, an otherwise-single star lens).

And, dropping rapidly down the probability curve, we find (*d*) a CH_3OH maser which Slysh et al. (1999) interpret as belonging to a planet in orbit around an O-type star, (*e*) a bunch of stars surrounded by disks whose structures include central holes or gaps that might be due to the tidal effects of planets (Jourdain et Muizon et al. 1999; Weinberger et al. 1999; Dent et al. 2000), and (*f*) dust enough to make a throng of Kuiper Belt Objects like ours around 55 Cnc, Rho CrB, and HD 210277, though not around 51 Peg, Ups And, or Gl 876 (Trilling et al. 2000; Jayawardhana et al. 2000). Note, however, that these stars are all already known to have radial-velocity companions of planetary mass, so we are either (*a*) cheating or (*b*) moving on to properties of host stars.

All or nearly all planet-blessed stars, including the Sun, are (as you have heard before) somewhat metal-rich by the standards of their locations and ages (Gimenez 2000). There are also probably mild anomalies in the amounts of carbon and sodium (Gonzalez & Laws 2000) but not in lithium (Ryan 2000). Gimenez (2000) also reports that the hosts of the planets with the smallest masses may be the most metal-rich. Yes, he, and you, and we can all think of physical reasons that this might be so but also of selection effects that would produce the same impression. Apparently other host stars do not share the Sun's relatively low speed relative to the local standard of rest (Gonzalez 1999).

Stellar activity, because it can be expected to jiggle line profiles around, is a traditional confounding variable in planet searches. This is not a falsifiable hypothesis as it stands, but Henry et al. (2000b) report that four of a sample of nine known hosts also display activity-related variability in the H and K features of Ca II (most for the youngest hosts; Kuerster et al. 2000).

The conclusion that a bunch of faint, red things in the direction of the Trapezium (Lucas & Roche 2000) are truly orphan planets is dependent on being sure that you have allowed correctly for field stars, conversion of colors into temperatures, and conversion of luminosity and temperature in turn into masses (Hillenbrand & Carpenter 2000).

3.2. Theory

Twenty or so papers dealt with planet formation, orbit evolution, and so forth. But, as a 19th century cookbook is supposed to have said, "first catch your rabbit." According to Heacox (1999) and to Stepinski & Black (2000) this has still to be done. The radial velocity companions, whether their masses are those traditionally called brown dwarfs or called planets, are, so these authors say, part of a single population, statistically like close binary star companions and formed in the same way, not real planets at all. They define real planets by formation mechanism (out of protoplanetary disks) and chemical differentiation. Both are difficult to observe. Coplanarity of several planets might also count and could be observable.

Assuming, however, that "extrasolarsystem planets" is not an empty set, we can pick up and carry on from last year's slogan, "Make and then migrate." Data continue to support presence of an excess of large dust grains in disks of protostars, relative to the general interstellar medium (Bouwman et al. 2000) and the ability of grains to aggregate and grow rapidly (Blum et al. 2000, reporting results from a microgravity experiment on the Space Shuttle).

Should one worry that some sets of models and initial conditions, including close binaries, make no gas giants at all (Papalòizou & Larwood 2000: Nelson 2000) or make them only with considerable difficulty (Ikoma 2000)? Not necessarily, since 90% or so of stars so far surveyed have no gas giants, at least up close. Indeed one feels that only one paper in 10 on theory of planet formation should report success. Studies of the medical literature show, however, that negative results of trials are less likely to be reported than positive ones (but see the beginning of § 9).

Instead, successes outnumber failures. Sasselov & Lecar (2000) have moved the "snow line" in and can make Jupiters at 1 AU. Well, all right, only one per star, we suppose, but Armitage & Hansen (1999) write that the first big planet will actually trigger formation of more, so that the natural outcome is several Jupiter-plus masses in highly eccentric orbits. Will the product last long enough to be seen? More details are needed, but the specific circumstances of the three planets of Ups And give it permission to stick around for a gigayear (Rivera & Lissauer 2000) or more (Laughlin & Adams 1999), whether or not the orbits can be described by Bode's Law (Laskar 2000).

Lubow et al. (1999) offer an explanation for an upper mass limit to real planets of 6–10 M_J. It arises from the increased difficulty gas finds in flowing tidily across the gap tidally created by the planet as the planet and the gap both grow. They assume that the planet remains a fixed distance from its star. If it does not, then the migration process should throw out little bits of sublimed planetesimals, which might show up as transient absorption lines (Quillen & Holman 2000). And, of course, you must stop the migration (by having the planetesimal disk all used up) before all the planets hit their stars, or we will not be here to talk about it (Kley 2000).

A theorist's work is, however, never done. If planets form and persist, then we want to be able to account for their properties. Burrows et al. (2000b) match the low density implied for the transiting planet of HD 209586 with a body that is both hydrogen-rich and heated by its star. Sudarsky et al. (2000) propose a five-stage cooling (or heating) sequence, from cold ammonia (like Jupiter) through water clouds, neutral alkali metals, and methane, to silicate grains as the dominant source of atmospheric opacity. Those with water clouds and silicate grains high in their atmospheres will have the largest optical albedos. A given planet might pass through two or three of the stages as its parent star evolves. Planets at different distances from their hosts will fill the full sequence.

Ford et al. (2000) predict that planets should be common even among old stars, based on their model for PSR 1620−26 in the globular cluster M4. Just possibly, this prediction has already been falsified by tight upper limits to numbers of planets in small orbits around the stars of 47 Tucanae set by absence of evidence for transits by them (Brown et al. 2000).

Also still in the realm of the theorist are the chemical and physical consequences to a star of swallowing one or more planets (Siess & Livio 1999 and a number of other papers). Somewhere between imaginative and convoluted are the thoughts (*a*) that a diet of planets increases lithium abundance, not because there was lithium in the planets, but because the capture triggers the nuclear reaction $\mathrm{He}^3(\alpha, \gamma)\mathrm{Be}^7(e^-, \nu_e)\mathrm{Li}^7$ in the star (Denissenkov & Weiss 2000) and (*b*) that a planet belonging to AA Dor tried to swallow its star during common envelope binary evolution, rather than the converse (Rauch 2000).

3.3. Inside the 3 LY Limit: Major Planets

Pluto (notice that the combination of this name and section heading is already a political statement) has ethane as well as methane on its surface (Nakamura et al. 2000). It also has a moon, whose surface composition is more uniform than Pluto's own. Pluto is in a stable, 3:2 orbital resonance with Neptune (Varadi 1999, on the stability, not the resonance, which may well have been known to Tombaugh).

Neptune probably migrated outward to its present location, given the large number of small objects in various resonances with it (Ida et al. 2000b).

Uranus is not an X-ray source (Ness & Schmidt 2000). Neither for that matter is Neptune. Saturn was seen for the first time in the observations reported by Ness & Schmidt, but is nowhere near so bright as Jupiter.

Saturn has seasons, revealed by infrared spectra of molecules in its stratosphere. (Ollivier et al. 2000). They are unpleasant even by Minnesota standards ("July and winter"). Saturn also, above all, has moons (30 in the latest out-of-period rumor), but even the old, familiar ones do not have densities known well enough to look for a correlation between density and distance from the planet (Dourneau & Baratchart 1999) of the sort found for Jovian inner satellites.

Jupiter has a Great Red Spot, which is some sort of Rossby wave (Li et al. 2000c). Encrenaz (1999), in a review of the GRS and other Jovian surface features, says that it was discovered by Robert Hooke in 1664. The story is, of course, enormously more complicated, and we won't spoil it by condensation from the tale as told by Hockey (1999), and quote only one line, from p. 142, "No one questioned Virtue" (meaning the Rev. James Virtue). Other Jovian traits include absolutely oodles of weather, driven by moist convection, like Earth's, but with an internal rather than solar heat source (Gierasch et al. 2000) and abundances of argon, krypton, and xenon relative to iron which equal the cosmic values. This means that the planet must have formed from cold planetesimals, able to retain even these extremely volatile elements (Owen et al. 1999). It would seem that the disk-instability model for the formation of Jupiter and other massive planets (Boss 2000b) would equally well, perhaps better, account for the presence of noble gases in cosmic proportions.

Jupiter also has at least its fair share of moons. Most discussed were Europa, with evidence for transient subsurface brine, the evidence coming from an induced magnetic field (Kivelson et al. 2000) and the heating from tidal dissipation along faults (Gaidos & Nimmo 2000), and Io. The latter was imaged and otherwise autopsied by Galileo in October 1999, with results reported in six papers beginning with McEwan et al. (2000). Highlights of the results include all sorts of lava fountains and flows, mostly mafic (low viscosity), some rather hellish colors attributed to sulfur compounds, and sporadic melting of snowfields (not H_2O snow, of course; Kieffer et al. 2000). Io sheds so vigorously that it can support a variable exosphere (Russell & Kivelson 2000) and aurorae (Trafton 2000) and still keep up the Jovian dust supply (Graps et al. 2000).

Mars has rocks, both andesite (like the Andes) and basalt (like the bas of the ocean), but the relationships among rock type, age, and elevation are different from the terrestrial ones (Blandfield et al. 2000) for reasons that are perhaps understood (Zuber et al. 2000). Mars is also very widely credited with enough water in the past to flow, erode, gully, and all (Malin & Edgett 2000; Head et al. 2000) though the flat northern plain may well be tectonic rather than plutonic (Stevenson 1999). But the Martian heresy of the year is undoubtedly the suggestion (Hoffman 2000) that all the sinuous channels, gullies, and other features now generally blamed on ancient water flows are really the result of cold, dry eruptions of gas, dust, and rock, fueled by exploding liquid carbon dioxide. Thus the Mars of the past would always have been cold and dry, like Mars today. The liquid is necessarily stored underground, at 35 atm or more pressure, and liberated by crustal collapse and, perhaps, impacts. The terrestrial analogues are pyroclastic flows, like those triggered by volcanic eruptions in Montserrat in the 1990's and at Mt. St. Helens in May 1980.

Earth turned up in so many contests, most of them only very remotely astrophysical, that it gets its own section, and we note here only that it has been impact-cratered at a rate of about 10^{-14} km^2 yr^{-1} over the past 125 million years (Hughes 2000) and has had fish for some 600 million years (Shu et al. 1999; Janvier 1999). Putting these together, we calculate that fish collectively could have seen the formation of a total cratered area of 6 m^2 and deduce that we have not properly interpreted at least one of the results.

Venus is skimmed by the crescent moon every synodic period of the pair (a moonth or so), but only rather rarely close enough and high enough in the sky to conduce to astrology, and even then you must be in the right time zone, weather conditions, and so forth. December 29, 2000 was roughly the third best the more Cytherean author has seen and reinforced the impression that such a conjunction is at least as likely a source of star-and-crescent images as supernova 1054.

Mercury was never completely mapped by *Mariner 10.*

Ground-based observers are now filling in the gaps with *I*-band images taken at the Mt. Wilson 60″ (Dantowitz et al. 2000; Baumgardner et al. 2000). The data are analyzed using "selective image reconstruction," which seems to mean using only the sharpest of many very short exposures. The features being found correspond reasonably well with those implied by radar mapping. The authors provide the additional information that the phases of Mercury were discovered in 1639 by Zupux and again in 1644 by Hevelius, while Mercury itself was discovered in 265 BCE by Timocharis. Having always credited Og Troglodyteson, we are tempted to quote a cousin (Farmer 2000) who says that the ancient Greeks often claimed to be the first to have done something, when really they were just the first to write about it.

Another Planet X (this one must be about XVIII) has been deduced from comet orbits by Murray (1999). It has a retrograde orbit with a period of 5.8 Myr and must have been captured relatively recently (though presumably not since the last announcement of a 10th planet).

3.4. Sweating the Small Stuff

A whew of relief was heard all the way to Eros and back on 15 February 2000, when NEARShoemaker, back for second try (Ap99, § 3.3.3), swooped in close enough to learn that the asteroid is 34 × 11 × 11 km in size, essentially saturated with 1-km craters (but no fish), non-precessing, chondritic on its surface, not quite homogeneous but also not globally differentiated despite some melting, internally porous (10%–13% empty space, leading to an average density of 2.67 g cm^{-3}), and easy to get away from with escape velocities of 3–17 m s^{-1}. The set of encounter papers appears in the 21 September issue of *Science*, beginning with Yoemans et al. (2000).

Other near-earth asteroids are only about half as common as previously advertised, with 500–1000 larger than 1 km in diameter versus 1000–2000 (Rabinowitz et al. 2000). Most should be found by 2020, and, by way of calibration, the object that hit Tunguska in 1908 (a very near earth asteroid) was about 0.07 km across. Bottke et al. (2000) point out that the asteroids so far uninventoried are likely to have orbits of large eccentricity, large inclination, or both, and will be hard to detect, but also somewhat less likely to hit Earth.

Trojan asteroids and quasi-satellites are in quasi-stable orbits. The former are known to exist, leading or trailing Jupiter around the Sun for a few million years and then departing to be replaced by others (Tsiganis et al. 2000; Christou et al. 2000). The latter librate around the longitudes of their associated planets in liver-shaped orbits for thousands (near Jupiter) to hundreds of millions (near Neptune) of years (Wiegert et al. 2000). None are known, but we aren't all that fond of liver anyhow. In case it should ever come up, Thersites (1868) was the ugliest Trojan. It probably came from eating too much liver.

"Trans-Neptunian Objects" tells you where they are. "Kuiper Belt Objects" tells you who thought about them (and perhaps the sort of axial ratio to expect, if you are old enough to remember Gerard P.). "Plutinos" tells you that some of them are in 3:2 orbital resonance with Neptune, as is Pluto (Yu & Tremaine 1999). "Centaurs" are another orbit family, not concentrated in the direction of the constellation Centaurus (or even Equuleus), but lying between Saturn and Neptune. KBOs are supposed to be the reservoir from which low inclination, short-period comets arise (which in turn tells you that they are icy more than stony or metallic, like proper asteroids). Though the first one was found as recently as 1992, numbers have grown to permit statistical studies of both orbits and surfaces.

Orbit studies logically start with formation, and there is apparently no difficulty in making the (highly extrapolated) known numbers and sizes if you start with a protoplanetary disk mass a few times the minimum needed to make just the major planets (Kenyon & Luu 1999) The (again highly extrapolated) total mass of KBOs is comparable with that in the main asteroid belt (Trujillo et al. 2000, who also define some orbital subtypes without mythological names). The best estimate for the distribution of KBO sizes may come from craters on the surface of Triton. As you might expect, little ones are commoner than big ones, with $dN/dr \propto r^{-3}$ (Stern & McKinnon 2000). Pluto continues to affect the orbits of the other Plutinos, introducing gaps in the distributions of orbital eccentricity and inclination at its own values (Nesvorný et al. 2000), from which you may deduce that Pluto itself is not just another Plutino.

KBO surfaces, as well as those of the smaller moons of the outer planets, Charon, and Chiron are frequently icy, but with a wide range of colors (visible to infrared) indicating a range of surface compositions and weathering patterns. There is no obvious bimodality or other discrete subset structure (Brown 2000; Luu et al. 2000; Brown & Calvin 1999; Barucci et al. 2000: Noll et al. 2000).

Ordinary main-belt asteroids are the rocky and metallic ones (as their meteoritic fragments have been telling us for as long as it has been respectable to believe in "stones from the sky"—Jefferson did not). Surface studies and densities largely confirm what had been supposed. The bigger ones (Ceres, Pallas, Juno, and Vesta) have the infrared signatures of surface silicates (Dotto 2000). Of these, Ceres is the least dense, at 2.24 ± 0.04 g cm^{-3} (Michalek 2000). Vesta and Pallas are both probably denser than 3 g cm^{-3}, but the masses are poorly determined because none of the largest asteroids has had a really close encounter. Hermione and Psyche did, and both claim to have densities near 1.8 g cm^{-3} (Viateau 2000), reasonable for the rocky Hermione, less so for the supposedly metallic Psyche. A second asteroid with a moon, 45 Eugenia, revealed a density near 1.2 g cm^{-3}, close to the value found for the first case, Mathilde (Merline et al. 1999). The buzz word was "rubble pile", also mentioned by Ostro et al. (2000) for 216 Kleopatra (radar reflection data) and by Leinhardt et al. (2000), who note that such structure makes it easier to understand both how asteroids and planets were assembled in the first place and the characteristic "dog bone" shape, like that suspected for Kleopatra. The proper phrase might be soggy rubble pile, according to Zolensky et al. (2000), describing one meteorite that seems to be briny. Analysis of the dissipation of wobbles, on the contrary, shows asteroids to be drier than the Earth (Efroimsky & Lazarian 2000).

Asteroid orbits are subjected to a great many random perturbations. Vozikis et al. (2000) have applied a chaos detector to some of them but have not actually detected any chaos in their "power spectrum of geodesic divergence". In case you might have forgotten, Piazzi was the first to spot an asteroid, Ceres, on 1 January 1801 (sounds of centennial trumpets and krummhorns), and Gauss is generally said to have invented the method of least squares in order to extrapolate its orbit from inconsistent observations.

The asteroid-comet distinction is not a clean one. Comet 107P Wilson-Harrington is also minor planet 4015, and comet 95P Chiron is also minor planet 2060. Chiron was initially an asteroid (Centaur) that later displayed cometary activity, while Wilson-Harrington, a catalogued comet, was later independently discovered temporarily embarassed by loss of its coma. Other examples exist (Toth 2000). The topic merited a brief, cogent review (Yoemans 2000), whose discussion of objects with the orbit of one type and the morphology of the other is a grave temptation to citing of James (1611).

Comet inventories are not so complete as we have been accustomed to suppose. *SoHO* found one by chance, post perihelion, that probably peaked near $m = +11$ (just a tad faint for amateur discovery), wasting its photons on the desert air. Discoverer (Makinen et al. 2000) and commentator (A'Hearn 2000) suggest that similar comets may be about as common as near-earth asteroids, but that search strategies are much less advanced, and many are being missed, especially those with out-of-ecliptic orbits.

A number of dynamical issues remain of interest, including non-gravitational effects on comet orbits (Festou & Barade 2000) and families of short-lived orbits tied to planets (Drobyshevski 2000b) in somewhat the same way that the Trojan asteroids are tied to Jupiter. But if you had a comet in your lab, what you would really want to ask it is, "How far has your chemistry gone towards complex molecules?" A recently-selected NASA mission, DeepImpact, won't quite bring the samples home, but it is scheduled to plunge into a comet and kick stuff out of the interior on Fourth of July some years downstream. Meanwhile, both Hale-Bopp (Ziurys 1999) and several others (Wyckoff et al. 2000) have revealed carbon and nitrogen with isotopic ratios very close to the solar system average, implying that comets can provide information about the very early initial conditions for prebiological chemical evolution.

Hale-Bopp, by the way, really had a double nucleus (Marchis et al. 1999), Hale and Bopp we presume, but are not sure which is which. Mini-comets, made mostly of ice, have a long and bumpy history (of which Frank et al. 1986 is an intermediate protruberance). Bronshten (2000) has in mind a different, less volatile class of mini-comets, whose members disrupt lower in the atmosphere (50–120 km up) and are the cause of fireballs. Tunguska, at 80 tons, was, in his view, one of the larger ones. This is, you will note, a good deal less massive than you would expect for the 70 m diameter mentioned above for Tunguska as an asteroid shard.

Many comets have dust tails wagging years behind them in their orbits, even poor old comet 15P/Finley, which has been turning into an asteroid for the past 300 years (Beech et al. 1999). These make meteor showers if we happen to cross through them (Jenniskens & Betlem 2000 on 55P/Tempel-Tuttle and 109P/Swift-Tuttle) and lead us inevitably to the next topic (Hughes & Williams 2000 on comet and meteoroid stream orbits).

The Leonids of November 17–18 were not only a better show in 1999 than in 1998 (Watanabe et al. 2000 vs. Ap99, § 3.3.2), they were better than can be entirely understood, with light trails up to 2 km wide (LeBlanc et al. 2000). Also more and better than expected were the flashes when some hit the Moon (Ortiz et al. 2000, who also use the absence of such flashes at other times to say that there are not a lot of mini-comets wandering around our neck of the solar system). Some commentators have expressed reservations about the nature of these flashes (e.g., Weissman 1999, who suggested space debris or satellites reflecting sunlight). With data in hand from 1998, 1999, and by now 2000, predictions for the new few passages through the Leonid stream have naturally improved. One change is an increase in the best value for density of the fragments from 1 to 4 g cm^{-3}, and it will hardly be worth going outdoors in November 2001, at least for the meteors (Goeckel & Jehn 2000).

Some other meteors and, especially, meteorites constitute samples of which we can again ask, "How far has your chemistry gone?" Far enough that you need both grain-surface and aqueous reactions to make everything you see in Murchison and Orgueil etc., say Sephton & Gilmour (2000).

3.5. Global Issues

We live, it seems, only 0.05 pc from the edge of a typical ($T \approx 7000$ K, $n_{\mathrm{H}} \approx n_e \approx 0.1\ \mathrm{cm}^{-3}$), small (93 pc^3), warm interstellar cloud, and will depart from it in about 3000 years (Redfield & Linsky 2000). The authors also raise the question of whether such mean cloudlets are permanent entities or transient shock features or turbulent eddies (Linsky et al. 2000). The next cloud we enter will be the one now inhabited by Alpha Cen A and B.

Not much closer to home is the heliopause, toward which *Voyager 1* and *2* struggle ever onward (most recent ETA 2020; Ferlet 1999). This is, we keep telling ourselves, no further ahead than the Patras IAU (which was just yesterday) is behind. What is more, models of the interface between solar wind and local interstellar medium are rapidly acquiring the status of testable predictions, at least relative to the first one (Munch & Unsold 1962, according to Linsky et al.). In a recent model, Fahr et al. (2000) find they need to include effects of five fluids, solar wind, local ISM, pick-up ions, Galactic cosmic rays, and anomalous cosmic rays. Data on the interface seen as Lyman alpha absorption lines in stars yield a temperature for the neutral hydrogen wall of 38,000 K (Wood et al. 2000), which is a funny temperature for neutral H!

Cosmogony for many decades meant specifically the effort to understand formation of the solar system. This task has, in recent years, been largely subsumed as part of the study of star and planet formation in general. Thus we find "make and then migrate" scenarios for our system as well as others (Thommes et al. 1999).

Unique, however, to the solar system is the evidence provided by fossil or extinct radioactivities. These are the decay products of finite-lifetime nuclides that are found in chemical contexts indicating that they must have been live when a dust grain or larger entity solidified. Chemically-distinct inclusions in meteorites, especially carbonaceous chondrites, are the prototype sites, and Al^{26} (now Mg^{26}) and I^{129} (now Xe^{129}) are two of a dozen or more examples. Because some of the half-lives are quite short, the implication is either that stuff that was gaseous when the solar system acquired its identity solidified in a hurry (e.g., less than a million years) or that many "pre-solar" grains survived to be incorporated whole and unmelted into the meteorites, or, of course, both. The present interplanetary dust includes (still, or again, if knocked off asteroids and all) grains with isotopic anomalies in hydrogen and nitrogen, suggesting pre-solar origin (Messenger 2000). Because these are not decay products, no particular time scale is implied.

The author whose father was a chemist has been predicting for several years that eventually this whole topic will be understood well enough that you could remember what all the various radioactivities and anomalies and their meanings are just by looking at a periodic table. This has not so far happened (see Arnould & Prantzos 1999 for an overview). What index year 2000 did see was (1) evidence for short-lived radioactivities and grain heating being quite inhomogeneous through the solar nebula (Meibon et al. 2000 on heating; Guan et al. 2000 on chemical inhomogeneities; Lugaro et al. 1999), and (2) evidence suggesting that the various fossil radioactivities originated in more than one sort of site and process. Contributors include (*a*) Type II supernovae, the only place you are likely to get the *p*-process nuclide Nb^{92} (Yin et al. 2000) and two other *p*-process chronometers, all of which suggest 10 Myr of decay between synthesis and solidification, and $Mo^{97,98}$ incorporated into grains immediately after their synthesis in the *r*-process (Meyer et al. 2000a), (*b*) asymptotic giant branch stars with a range of masses so as to make SiC grains with a range of ratios of Si^{28}:Si^{29}:Si^{30} (Lugaro et al. 1999), (*c*) irradiation of the solar nebula itself, since Be^{10} can be made only by spallation (McKeegan et al. 2000) and it was live when Allende formed; this irradiation must have come from the Sun itself, as opposed, for instance to a nearby supernova (Hua et al. 2000), and (*d*) dust melting provided by a nearby gamma-ray burst close to the time of solar system formation (McBreen & Hanlon 1999).

Was there a particular AGB star, supernova, or even gamma-ray burst whose impact triggered the collapse of the cloud that became our solar system? Stock in this hypothesis has risen and fallen many times since Opik (1953) first said yes. Vanhala & Boss (2000) conclude that such a scheme remains possible, with the newly-made atoms carried in on the wing of a Rayleigh-Taylor instability, but the triggering event must have happened closer to us than 0.1 pc (for an AGN star) or a few parsecs (for a supernova).

3.6. Terra and Terratoriality

Most distracted of all are our own globe and its inhabitants. This section contains some items published during the year about the Earth as a terrestrial a planet and as an (the?) abode of life and some otherwise unclassifiable papers that transcended even the elastic limits of § 13.

3.6.1. Earth, Water, and Fire

An explorer starting at the center of the Earth will find an iron core. Introductory textbooks generally show two phases, solid iron (etc.) at the very center and fluid around it. But the experts are up to five phases (Anderson & Isaak 2000). Next comes the rocky mantle, where live the convective currents that drive plate tectonics, continental drift, and all, reviewed in a historical context by Stevenson (2000) and in the context of other earth dynamical systems by Rowan & Smith (2000). Atop that floats the crust and has for a very long time. The oldest continental rock dated so far has been solid for 4.0055 Gyr (Bleeker & Stern 1999). The basaltic ocean crust, by the way, is recycled regularly and never more than a few $\times 10^8$ yr old, in case your copy of Holmes (1978) is up in the attic.

Formation of crust (again meaning the granitic stuff that stays out of water so we can study it) has not happened at a constant rate in the intervening 4 Gyr (DeSmet et al. 2000), with peak rates perhaps occurring at epochs when oscillations in the fluid core are in resonance with the luni-solar tides (Greff-Lefftz & Legros 1999). Such resonances will come and go as the Moon moves away and into an ever-longer-period orbit.

Since the Moon has to go somewhere, and we have just mentioned tides, this is perhaps the place to note that recent data on ocean currents and depths suggest that the shallow seas usually blamed (Yellow, Bering, Hudson's Bay, etc.) in fact dissipate only about half of the rotational energy of the Earth that must be got rid of to account for the observed lengthening of the day and month. The rest happens in deep oceans (Egbert & Ray 2000).

That the initial lunar orbit was smaller than the present one is not in question. Ward & Canud (2000) believe that it was also inclined about 10° to the Earth's equator and Eriksson & Simpson (2000) that it was quite circular. Both are described as signatures of formation from a disk of debris made by an impact. The Moon has not hit us since (except in the eye, like a big pizza pie), but the rate at which other things hit it went through a relative minimum 500–600 Myr ago (Culler 2000). If the author said that this had something to do with the Cambrian explosion of new body parts, we missed it. If he did not, somebody else surely will. A fairly sudden shift in the orientation, by about 20°, of the Earth's rotation axis relative to the mantle occurred at about the time of the K-T (Cretaceous-Tertiary) boundary (Sauers & Koppers 2000) and may or may not have been a contributing cause to the extinction of the last of the featherless dinosaurs. Goldreich & Toomre (1969) discussed the physics of such a shift some time ago (well, not by brontosauran standards).

Some of the above, solid-earth items may be disputed, but it is only when you get to the atmosphere, climate, and environmental issues that things become truly inflammatory. Ice Ages have been part of the accepted wisdom for a couple of centuries. The idea that the entire Earth has been ice-locked at several times in the past (most recently in the immediate pre-Cambrian, 560 Myr ago) is more recent and has received additional observational support this year (Hydei 2000). And, of course, that also may or may not have had anything to do with the Cambrian explosion, which now seems to have included all the phyla, even the vertebrates (Shu et al. 1999). Ice ages of the one-hemisphere-at-a-time variety have long been blamed on details of the Earth's orbit, precession, etc., so that insolation drives the atmospheric CO_2 content which in turn drives the ice sheets (Shackleton 2000). Warming of the land, sea, and air, in other words, has not been monotonic since the Cambrian, but it does seem to be going on now with at least some help from the inhabitants (Levitos et al. 2000; Crowley 2000).

Somewhere between climate and weather are multi-year oscillations. Somehow calling it ENSO (for El Nino and Southern Oscillation, not Enso Grimaldi) gives one more feeling of control than grandmother Farmer[1] saying, "well, we've always had wet years and dry years." That these atmospheric oscillations seem to drive or be driven by Chandler wobble (Clark 2000; Sidorenko 2000) continues (Ap98, § 12.5) to surprise. After all, Gram didn't even know Chandler (Seth Carl, 1846–1913) though, born in 1886, she could have.

Inhabitants of one sort or another have been around on Earth for a long time, beginning to raise the atmospheric oxygen content about 2.5 Gyr ago (Canfield et al. 2000). That spontaneous generation was not an ongoing process on Earth was known to Homer (Mazzarello 1999). Indeed Hoyle & Wickramasinghe (1999) opine that it has never occurred at all, life forms drifting from place to place in an infinitely old universe. If, however, life arose here ("well, a little on Saturday night, but not much the rest of the time"), then some part of the process must have made it chiral, that is, able to use only one of the two mirror forms of various complex molecules. Ap98 (§ 5.3.3) mentioned the possibility that the cause is polarized irradiation of interstellar molecules. Compton & Pagni (1999) have again suggested that the ultimate origin is parity nonconservation in weak interaction processes.

Evolution since then has proceeded by some combination of extinctions of established species (episodic in time, but not periodic, say Jetsu & Pelt 2000) and radiation of new ones. When and where radiation outpaces extinction, you get biodiversity. We have a sneaking suspicion that the extreme concentration of such diversity on Earth at present has not been a long-term pattern. Twenty-five "hot spots," covering 1.5% of the land area, house 45% of vascular plant species and 35% of four vertebrate groups (Myers et al. 2000). Many are where you would expect (Madagascar and other islands, Amazon rain forest, patches of south and southeast Asia and Africa), but coastal California, from Baja to the Oregon border, is also on the list. Unfortunately, these limited land areas also have faster than average growth of their human populations at present (Cincutta et al. 2000).

While extinction is forever, environmental damage need not be. At Tunguska yet again, a favorite slide (without which we wouldn't believe this) shows that, 80 years after the impact, the trees that have grown back are about the same size as those that were knocked over. They are, admittedly, not the same species, and you may wish to intone learnedly, "boreal succession" just to show you know how to pronounce it. Even around Mt. St. Helens, only 20 years post-blowout, things are beginning to creep back (Franklin et al. 2000), including conifers, pocket gophers, salamanders (well, they were supposed to live in fire), and human rock hounds seeking minerals melted into near gem-quality stones. These brave pioneers may well have metabolisms differing from the averages of their species, but the human average is exactly what you would expect for the body mass of the species, according to Kleiber's Law (Smil 2000). And, in case the next dominant species should want to know how we did it, the human genome project will eventually enable them to find out (Venter & Collins 2000), although its present state is roughly that of "Having all the letters of the Bible; now: divide them into words, figure out what the individual words mean; decide if they make sense in that order; and correct the mistakes" (Box 2000).

You might think that the price of chicken could not offend anyone. But Navia (2000) points out that it has declined by a factor of five in real terms since 1934 and suggests that gradually increasing use of the antibiotic sulfanilimid may be responsible

3.6.2. Air

"Don't hold your breath," the Farmer's daughter used to say, when she meant that something anticipated was not likely to happen any time soon. Here are about one-third of the results originally indexed under that heading, or "Queen Anne is

---

[1] Yes, the less cultivated author really did have a Grandmother Farmer, Gram for short, though a Danish Paulsen by birth, and yes, there is a considerable family repertoire of "Farmer's Daughter" stories.

dead," or "we never thought they were," or "neither of the above."

- X-ray binaries in the *Hipparcos* sample all have zero parallax to within the uncertainties (Clark & Dolan 1999).
- Comptonized thermal synchrotron radiation (i.e., *really* hot electrons) is not often the dominant process anywhere (Wardzinski & Zdziarski 2000).
- Orbits of visual binaries are not systematically parallel to the Galactic plane (Glebocki 2000).
- Dwarf galaxies are smaller than others when imaged in H I (Thuan et al. 1999).
- J-type carbon stars (defined as having unusually strong C^{13} molecular features) have lots of C^{13} (as well as N and Li; Abia & Isern 2000).
- The quasar pair Q1634+267A,B is not easily interpreted either as two separate objects or as a lensed image (Peng et al. 1999).
- For some intermediate polars (a species of cataclysmic variable with moderate magnetic field) disk overflow and stream feeding are both inconsistent with the observations (Ferrario & Wickramasinghe 1999).
- Two (more) former CVs are really QSOs (Rossa et al. 1999).
- A feature in the X-ray spectrum of PKS 2149−306 is blueshifted by $\Delta\lambda/\lambda = -2.7$ to -2.8 (Yaqoob et al. 1999), but it is seen at 17 keV, and you will remember what happened to the 17 keV neutrino (Ap93, § 2.1).
- The absolute positions of radio quasars and BL Lac objects wiggle around at the 0.5 milliarcsec level (Feissel et al. 2000) in data obtained for geodetic purposes (i.e., in the hope that they would not wiggle around, though for us studying quasar astrophysics it is very interesting that they do).
- ET And is too a variable star, with a period of about 2.4 hours (Lehmann et al. 1999).
- Most "featureless" optical spectra will reveal lines, or at least classifiable shapes if you beat on them hard enough—all but 2 of the 14 attacked by Sefako et al. (1999).
- BUT if you see only a single, broad emission feature, it could be [O II] rather than Lyman alpha and you will go badly astray in guessing the redshift (Stern et al. 2000c).
- Suitable amounts of physical rotation of a source can turn unpolarized light into linearly polarized (Harries 2000 on hot stars) and linearly polarized into circularly polarized (Lyubarski & Petrova 1998 on pulsars).
- Spectral and scintillation data for a large number of radio galaxies and quasars at 102 MHz are best fit with a density of relativistic electrons and magnetic field strength proportional to source size, r, to the powers r^{-5} and $r^{+3.6}$ respectively (Tyul'bashev & Chernikov 2000). The latter, at least, puzzles.
- Rosenbush (1999a) has predicted that the old novae LS And and V592 Her and maybe V1330 Cyg should be the next additions to the inventory of recurrent novae (always small and fluctuating). We aren't quite sure how old he is, but hope that he lives to see the prediction falsified or, even better, verified.
- The average of weak gravitational lensing over the entire sky is demagnification (that is, more sources are dimmed than brightened; Barber et al. 1999), though not by much. Contrary to popular superstition, more than half of our children are below average.
- But, by way of compensation, all slowly-rotating B9 to A3 stars are slightly peculiar (Adelman 1999).

Well, there it is. Average and normal are not the same.

4. STELLAR ESCHATOLOGY

Neutron stars (§ 4.3) and black holes (§ 4.5) have been hot topics for such a long time that the laws of thermodynamics would seem to require them to have internal energy sources. Mass-market attention to the transition from asymptotic giant branch stars to planetary nebulae and white dwarfs seems, in contrast, to be a relatively modern phenomenon. Perhaps it is correlated with the recent proliferation of books like *How We* (ordinary people) *Die*, in contrast with more Shakespearean "sad stories of the death of kings."

4.1. From AGB to PN

Asymptotic giant branch stars are to horizontal branch (or clump) stars as ordinary red giants are to main sequence members. That is, (*a*) they come after, (*b*) they last about 10% as long, and (*c*) they are fueled largely by fusion in a shell of the same stuff that fused in the core before (helium or hydrogen). In addition, their luminosity and other properties are mostly a function of the mass of the core inside the fusion shell (Paczynski 1970; Refsdal & Weigert 1970; Uus 1970). Unique to the AGB is the extreme thinness of the burning shells, which causes them to flash on and off, driving convection zones that chase each other back and forth across the star and eventually pollute the surface with production of the interior reactions (Iben & Renzini 1983), including nitrogen, carbon, *s*-process products (Lebzelter & Hron 1999 on Tc), and lithium, to the Galactic supply of which they make a significant contribution according to Abia et al. (1999), Ventura et al. (1999), and Polosukhina et al. (1999).

Within living memory, the rest was simple. You blinked briefly while the extended, cool envelope lifted off (its total energy is positive anyhow, allowing for ionization), and soon you had a spherical or ringlike shell of planetary nebula expanding at 10–30 km/sec around, and ionized by, a pre-WD core. And the core cooled down toward the white dwarf regime on about the same 10^4 yr time scale as the nebula dissipated.

When the curtain rises on the new, more complex Y2K scenario, AGB stars already have winds blowing, as indeed do stars all their lives. The AGB ones are cool ($\lesssim$100–200 K) and slow, as you would expect from atmospheric conditions (Crawford & Barlow 2000), and carry off material at rates that are largest for the most massive stars at the latest phases, up to $10^{-3}\ M_\odot\ \mathrm{yr}^{-1}$ (van Loon et al. 1999). Since there is something like a solar mass to be got rid of, we are not surprised to hear that statistics imply an average duration for this superwind phase of 3700 years, about half of which is spent as an OH/IR star (that is, with OH maser emission; the IR part the poor star cannot help; Lewis 2000).

But mass loss is by no means steady. First, these stars are all pulsators (Miras, semi-regulars, RV Tauri stars and all). The pulsation is a wind-driver (Schroeder et al. 1999) with the superwind turning on (for LMC composition and masses) as the period lengthens to about 500 days (Nishida et al. 2000), though of course the period shortens again (and mass loss continues) as we see down to hotter photospheres (Barthes et al. 2000 on HD 56126). The pulsation (dynamical) times are too short to show directly in later nebular structure.

Remember, however, those shell flashes. They too contribute to mass ejection, and the times between them are long enough to yield discrete shells visible later on in the PNe. U Cas probably had its first flash about 800 years ago (Lindqvist et al. 1999). The post-AGB star IRC +10216 has lots of shells, implying mass loss modulated at 200–800 yr intervals (Mauron & Huggins 1999). TT Ari is somewhere in between, still visible in the visible (you can tell from the name) but with multiple CO (cold) shells around. One implication is that there should already be lots of gas and dust outside those shells, left from an earlier slow wind (Steffen & Schoenberner 2000).

Multiple-shelled PN NGC 6891 is a fairly typical end-product, having kinematic ages consistent with interpulse times (Guerrero et al. 2000a; Phillips 2000b on other late He-flash double shells and halos). Soker (2000) has advanced a competing hypothesis, that multi-shelled PNe and proto-planetaries are evidence for solar-type cycles with periods of 200–1000 years.

Early shell flashes will change the outer star only slightly, for instance the recent period decrease in the Mira S Sex (Merchan Benitez & Jurado Vargas 2000). But a very late, last thermal pulse can return a blue star to the AGB, drastically modify its surface composition, and set the stage for R CrB-type fadings caused by carbon dust (Herwig et al. 1999). The prototype is FG Sge (Ap99, § 5.4) and the most recent example is V4334 Sgr (Sakurai's object). V4334 is extreme by any standard—its evolution more rapid than that of FG Sge and its first fading (11 magnitudes in *V*) large even by R CrB standards, though naturally the energy eventually sneaks out as infrared (Kerber et al. 1999; Duerbeck et al. 2000; Tyne et al. 2000; Kipper 1999; Pavlenko & Yakovina 2000). Before looking again at the ejecta we can follow at least a subset of the stars evolving through a series of phases defined by their prototypes, FG Sge, RY Sgr, R CrB, UV Cam (which has stopped drastic fadings since the early 20th century) to XX Cam, which no longer even sports an IR excess (Doroshenko et al. 2000).

Now about those nebulae. A proper PN is, of course, an emission line source, meaning that the gas has to be ionized. Since the ejected shells contain CO, the gas must first be dissociated. That process can be tracked in the C I/CO ratio (Knapp et al. 2000). By the time H_2 molecules are hot enough to be seen in emission, non-spherical shapes have already been established (Hrivnack et al. 1999; Garcia-Lario et al. 1999). Ionization, of course, comes afterwards, but so quickly that H_2 remains just outside the ionized region, tracking the twisted and bipolar morphology of the ionized part (Guerrero et al. 2000b).

Bipolar or the opposite is as simple as PN shapes get. Ueta et al. (2000) report that zero of 21 proto-PNe imaged with *HST* are spherical. They deduce a correlation with progenitor mass, in the sense that low mass cores have slow enough mass loss that we can see the central star and elongated emission from an equatorially-concentrated superwind, while higher mass ones cloak their central stars in ejecta of sufficient mass that the fast stuff can get out only along the polar directions and we see bipolar morphology (an astrophysical shape common enough that it desperately needs a less pompous name; there will be a small prize for the best suggestion). This mass correlation has a nice, logical sound to it, and Stanghellini et al. (2000) concur for an LMC sample that bipolar shape is a signature of a massive progenitor as deduced from the N/C ratio and closeness to the Galactic plane. Phillips (2000a) disagrees, saying that the axial ratios of PNe do not much depend on initial mass, or, indeed, on interactions with interstellar material.

Wind composition also matters, because carbon dust increases the efficiency with which radiation pressure pushes on the ejecta, leading to larger outflow velocities for carbon-rich Miras than for oxygen-rich ones (Groenewegen et al. 1999). Remember, however, that it is easier to make a carbon star if total metallicity is small to start with (because there is not so much oxygen to swamp with carbon made from the triple-alpha reaction). Indeed, it is possible to reach the proto-planetary stage with O/C still >1 only for initial metallicities larger than those characteristic of the solar neighborhood (Leahy et al. 2000). Not surprisingly, larger initial metallicity eventually results in a larger dust/gas ratio in AGB winds, whatever the dust is made of (van Loon 2000). The assortment of *s*-process products seen at the post-AGB stage also depends on initial metallicity, but this is part of a different story (van Winckel & Reyniers 2000).

As you would expect, when hotter layers with larger escape velocities are uncovered, wind speed increases, leading, inevitably to two-speed models and colliding winds. BD +30°1639 is the best case so far for X-rays coming from slow wind material shocked by the fast wind, as opposed to a coronal or jet source or a very hot star (other reasons for PNe to be X-ray sources; Leahy et al. 2000).

The prize for maximum complexity during the transition from AGB to PN goes, uncontested, to V Hya, still near the beginning of the process at $T_e = 2650$ K. It is a binary ($P = 17$ yr) with both fast and slow winds, and the cool star is also a carbon-rich Mira ($P = 530$ days; Knapp et al. 1999).

Even it will have to work hard to match up to the multiplicity of structures seen in more highly evolved objects, including M2-9, which is a rotating corkscrew with a period of 20 yr, according to a data stream begun by Minkowski (1947) and completed by Doyle et al. (2000). K4-47, which appears to consist entirely of core and jets and blobs, perhaps arising from a binary plus precession (Corradi et al. 2000) and He 2-47 and M1-37, each of which has seven or eight dramatically young blobs or multiple jets (Sahai 2000), add to a picture in which an AGB star can become any of a wide variety of shapes and sizes of nebula as it dies.

4.2. White Dwarfs

If there is a white dwarf angel when we get wherever we are going, she is going to have to answer a hand's worth of questions. (1) What is the maximum main sequence mass that leaves a white dwarf, and how does this depend on initial composition, rotation, and whatever else? (2) How do mass loss, gravitational settling, dredge-up, accretion, and residual nuclear reactions combine to yield the full range of surface compositions found, and how many trajectories are there through "surface composition space?" (3) Are present calculations of cooling rates good enough that the sparcity of very faint disk WDs tells about the onset of star formation in the Galactic disk, and can this be extended to globular cluster and field halo stars to set limits to the age of the universe? (4) Do all white dwarfs rotate as slowly as the subset for which we have rotation periods from narrow line profiles or shifting magnetic patterns (e.g., more than 100 years for GD 209 and G840-23, Berdyugin & Piirola 1999; 18 yr for R Aqr, Hollis & Koupelis 2000)? and (5) What is the physics responsible for the very wide range of WD magnetic fields (measured at 3×10^4–10^9 G for 25% of single stars, with the rest smaller), and why is the range smaller, only 10^7–3×10^8 G in close (cataclysmic) binaries?

None of the more than 50 indexed white dwarf papers entirely answered any of these questions, so here are some partial answers, followed by sometimes more complete answers to questions we hadn't actually asked.

Starting, back to front, with magnetic fields and rotation, Wickramasinghe & Ferrario (2000) conclude (*a*) that the distribution of rotation periods is bimodal, with merger products responsible for the fast ones, and (*b*) that strong fields in single stars descend from both Ap/Bp stars and mergers. Incidentally, the stars with large fields are more likely than others to have atmospheres with hydrogen and helium mixed and to have larger masses than the weak-field stars. The commonest topology is an off-center dipole.

Cooling calculations cannot yet be subjected to the test of whether they predict the correct changes for pulsation periods, and though they will be, only the hot, young end of the track will be thus checked (Kepler et al. 2000). Meanwhile, isochrones are getting better. Richer et al. (2000) include the effects of non-gray atmospheres, and some extra ultraviolet opacity in hot DA atmospheres comes from iron (Chayer et al. 2000). Where the iron comes from is left as an exercise for the reader. Down inside the WD, a traditional uncertainty is how much energy is released (and, therefore, how much the life is extended) by separation of carbon and oxygen during core crystallization. Cyrstallization itself locks up energy in zero-point fluctuations and so shortens cooling times. The answer seems to be that phase separation is a 10%–20% effect (Isern et al. 2000) delaying coolth by not much more than a Gyr at most (Montgomery et al. 1999). Small amounts of residual fusion will, of course, also extend cooling times, and are not as easy to rule out as you might think (Napiwotzki 1999; Sarna et al. 2000).

White dwarfs with iron cores cool much faster than the CO ones that are the baseline models, but unless they are a good deal more numerous than the three found among *Hipparcos* targets, the total effect on luminosity distributions and age estimates will be modest (Panei et al. 2000). The author who has done more ironing remains surprised that there are any of these at all. The three are GC 140, EG 50, and Procyon B, with a mass of $0.65 \pm 0.15\ M_\odot$ determined independently from its orbit (Girard et al. 2000) and from its spectroscopic surface gravity.

The ultimate test of white dwarf cooling theory will, of course, be the faintest stars in the globular clusters. But, until a larger, spacier telescope than *HST* comes along, M67 remains the best check on whether white dwarf cooling ages equal main sequence turnoff ages. "More or less" say Richer et al. (2000), 3–4 Gyr from the WDs versus 4 Gyr from the MS.

The answer to the questions about surface composition seems to be that both the stars and the theorists have to work fairly hard. A quick recap: DO's are very hot and display He II features. DA's are pure hydrogen (at least until you look very carefully). DB's display neutral helium. And anybody with a Z in his name also has heavy elements in the atmosphere. DC means continuum only (not carbon) and is thought to imply a cool helium atmosphere. OK.

Gravitational settling begins and He/H starts to fall when the star fades below about 3000 $L_\odot$, while a planetary nebula is likely still to be visible (Driebe et al. 1999). Complete elimination of helium from the photosphere (assuming there is hydrogen to float) is inhibited by wind as weak as $10^{-12}\ M_\odot$/yr and is completed near $\log g = 7$ (Unglaub & Bues 2000, who also conclude that there must be at least two separate trajectories through the white dwarf composition space from the beginning). That is, DAO and DA stars must come from precursors that have hydrogen in their photospheres at all stages, while the very hot PG 1159 stars (with $\log g$ already $= 7.5$–8.0) feed into the DO and DB territories. The separation is, it seems, normally complete before the star is compact enough to count as a real white dwarf, in the sense that 5 DBAs have recently been reclassified as various sorts of subdwarfs (Bergeron et al. 2000).

Accretion of interstellar material is now part of the received doctrine for elements heavier than carbon and oxygen in white dwarf atmospheres (Friedrich et al. 1999 on three DBAZs where all but a millionth of the hydrogen has already settled out of the atmosphere, despite the accretion being recent and rapid, and Koester & Wolff 2000 on a couple of DZAs for which log H/He is still as large as -3). The metals, however, still do not look quite like what one would have expected from accretion. The spotty distribution (in both angle and height) of silicon in the hot DAZ GD 394 (Dupuis et al. 2000) naturally prompts one to say "magnetic fields of complex topology," while the excess of nickel over iron in the DO REJ 0503$-$289 (Barstow et al. 2000) brings an equally immediate "ummm?"

Coming at last back to the issues of mass and statistics, we recall that previous editions of Ap9x have caught assorted calibrations of the WD/NS mass cut and apparent statistical discrepancies among the death rates of AGB stars, the birth rates of WD, and the throughput of PNe. This year we noted only (*a*) that there are a lot of white dwarfs, 121 within 20 pc, which is still incomplete beyond 15 or 16 pc (Tat & Terzian 1999), (*b*) that the average (commonest, mode) mass is 0.58 $M_\odot$, but quite a few reach to 1.1 $M_\odot$ and beyond (Vennes 1999), (*c*) that the average mass of the nuclei of planetary nebulae in the bulge is, at 0.61 $M_\odot$, a tad larger than you would expect for the population (Gesicke & Zijlstra 2000, and no, you cannot yet see the white dwarfs there), and (*d*) that Lambda Sco, the most massive star (B1.5 IV) with a white dwarf companion, must be pushing upward on the WD/NS dividing line as it goes around every 5.96 days (Berghoefer et al. 2000b). Three less extreme BV+WD systems are currently known (Burleigh & Barstow 2000).

Now a few questions that we didn't think to ask. Are white dwarfs the accretors in anomalous X-ray pulsar binaries? Maybe (Geroyannis & Papasotiriou 2000). Are they the accretors in supersoft X-ray binaries? Yes (Reinsch et al. 2000), if you don't insist on a perfect fit to the spectrum (Shimura 2000), and provided that you define the class to exclude X-ray sources with spectra that you might call supersoft but that are known to be other things (Greiner 2000, a catalog).

And finally, how many white dwarfs does it take ~~to change a light bulb~~ to make up a triple? Three, and they are called 1704+481, Sanduleak B, and GR 577 (Maxted et al. 2000).

4.3. Neutron Stars

Not being sure what the important questions were, we sorted through the 100 or so indexed neutron star papers looking for what colleagues had said were interesting answers, and came up with the following.

Magnetic fields. Well, we aren't any of us getting any younger, and there was general agreement that neutron star fields do eventually die away, get expelled, or whatever, though it may take 10^8 yr (Konar & Bhattacharya 1999; Makishima et al. 1999; Konenkov & Geppert 2000; Jahan-Miri 2000). It took only 10^6–10^7 yr when we too were younger. The process apparently starts with the field re-orienting to become more nearly perpendicular to the rotation axis or with non-perpendicular moments dying off first, as the period slows to 0.1 sec (Malov 1999). And, as you drivers of previously-owned pulsars are aware, recycled ones are just not the same (Possenti et al. 1999).

In mild dispute, however, is the prevalence of fields in excess of something $\times 10^{14}$ G among the soft gamma repeaters and anomalous X-ray pulsars (Ap99, § 7). To continue the discussion, Harding et al. (1999) find that a strong field model of SGR 1806–20 is not self-consistent unless the emission and spin-down are both episodic, and Chatterjee et al. (2000) have again presented a fossil accretion disk model as an alternative for the X-ray pulsars with $P = 6$–12 sec . On the strong magnetic field side of the court we find Gogus et al. (1999 concerning SGRs) and Kaspi et al. (1999 on the timing of anomalous X-ray pulsars). Association of both sorts of neutron stars with young massive stars (Vrba et al. 2000) and supernova remnants (Gaensler et al. 1999; Corbel et al. 1999) are, we think, just evidence that, whatever they are doing, they haven't been doing it for very long.

Radio-quiet, unpulsed, and other oxymoronic pulsars. No, we can't claim that these make up a well-defined set or that, even if they did, we could put them into an evolutionary sequence. The game plan, however, is Cas A first, with a few other young supernova remnants, a few strange non-pulsars which arguably are neutron stars, and finally what are called pulsar wind nebulae (the words are equally informative in any order, with nouns and adjective appropriately adjusted to nebular pulsar winds, windy nebular pulsars, and so forth).

Non-pulsar of the year was the compact X-ray source imaged by *Chandra* near the center of supernova remnant Cas A, whose discovery just made the cut for Ap99 (§ 5.2). The initial theoretical gloss was that the emission was difficult to understand as that of a neutron star dating from 1650–90. Not surprisingly, ingenuity has triumphed, and emission either from a cooling neutron star or from a residual accretion disk around a black hole now seems possible (Pavlov et al. 2000; Umeda et al. 2000).

Hughes et al. (2000) show the *Chandra* image and point out that, not only are there iron-rich knots of stuff from the silicon burning shell of the progenitor star, but they are outside the silicon-rich material, overturned by the action of neutrino-driven plumes of material rich in (then) Ni^{56}, as must also have been the case in SN 1987A for the gamma rays to get out as quickly as they did. (See Lawrence et al. 2000 for an update on the ejecta of 1987A and Middleditch et al. 2000 for a report, not the first, that its remnant is no longer a radio-silent pulsar.) Returning to Cas A, data from the *Infrared Space Observatory* also show that the mixing of the layers of the parent star occurred on a macroscopic scale, leaving knots of O-burning stuff, C-burning stuff, and so forth (Douvion et al. 1999). Hwang et al. (2000b) show maps in the X-ray lines of Si, S, Ar, Co, and Fe. All but the iron one look a lot like the optical image you are used to. Other relatively young supernova remnants with evidence for element segregation include Vela (Tsunemi et al. 1999), the Cygnus Loop (Miyata & Tsunemi 1999), and SN 1006 (Vink et al. 2000).

A last-Cas update on the progenitor: Sad to say, the copy of Flamsteed's *Atlas Coelestis* in the Zinner collection at San Diego State University does not show his rogue star labeled, "This otherwise unknown star may have been the supernova progenitor of radio source Cas A." Indeed it doesn't even show Tycho's star, B Cas, progenitor of Tycho's SNR, though other atlases do, including Tycho's own posthumous *Astronomiae Instauratae Orogymnasmata*. Incidentally, Tycho numbered the stars neither from bright to faint, east to west, nor north to south, but from important to unimportant body parts. Thus 1 and 2 are head and heart, 4 the private parts, 6–10 hands and feet, 21 the belly button, and 23–26 the Arundinis in her hand. (It means reed, but we had to look it up, so why shouldn't you?)

The X-ray compact core of SNR G347.4−6.5 is unpulsed (Slane et al. 1999) and so presents the same choices as the core of Cas A, though at less good angular resolution. The core of radio SNR PKS 1209−51/52 appears compact in the *Chandra* image. It is radio-silent, but X-ray pulsed at $P = 0.424$ sec (Zavlin et al. 2000). Whatever the energy source for these (residual heat, left-over accretion disks, or rotational kinetic energy), when they fade, they fade very thoroughly. That is, even deep surveys reveal very few old, isolated neutron stars as X-ray sources (Treves et al. 2000). One might have expected at least a bit of accretion luminosity when they pass through denser bits of interstellar medium, but apparently they are rolling too fast to gather much moss (Popov et al. 2000).

Two more classes that are not pulsars: (1) any of the first 92 FIRST sources with linear polarization in excess of 5% (Crawford et al. 2000) and (2) a bunch of unidentified EGRET sources, although the argument is largely statistical, since EGRET error boxes are large (Oka et al. 1999; Zhang et al. 2000a). The unidentified gamma-ray sources with variability on time scales near one day are probably not pulsars either (Wallace et al. 2000).

This brings us to "pulsar wind nebulae," meaning filled-center sources of synchrotron radio and/or X-rays resulting from the confinement of a relativistic pulsar wind by external pressure (Gaensler et al. 2000). These do not require the pulsar to be aimed at you and so, if you look really hard and see no nebula, then there is no pulsar or no confining material. A surprising absence is that of the X-ray core of SNR Pup A, which is an X-ray pulsator at 75 msec (Zavlin et al. 1999), and has plenty of stuff around, but no radio synchrotron (Gaensler et al. 2000).

Older pulsar wind nebulae are also rarer than expected. Stappers et al. (1999) looked at five pulsars with $P = 0.06$–0.2 sec, rediscovered one PWN, did not confirm a second, and set three tight upper limits. Becker et al. (1999) similarly report that several *ASCA* candidates (including Geminga) for PWNe were false alarms.

Masses. The smallest you are likely to be able to form in a Type II supernova is 0.9 $M_\odot$ (Strobel et al. 1999). The largest we spotted was 2 $M_\odot$ for the accretor in a low mass X-ray binary, derived from the assumption that its quasi-periodic oscillations mark the period of the innermost stable orbit (Schaab & Weigel 1999). The polite way of expressing any reservations you might have about this is "model dependent" (Semerak 1999a, 1999b). If 2 $M_\odot$ isn't enough, strange quark stars will take you to somewhat higher masses (2.6 $M_\odot$ according to Zdunik 2000—a truly random sample of a dozen papers mentioning these hypothetical entities). And on beyond, one finds perhaps still more compact stable families of stars with still more generic equations of state (Glendenning & Kettner 2000). Only recently have we suspected that, when Fritz Zwicky called these more compact structures Object Hades, he was really saying, "Oh, H- - -!".

Pulsation and precession. The former remains unseen after 32 years, and at least the *r*-modes are perhaps damped away by magnetic field (Rezzolla et al. 2000). The sparcity of astronomical and planetary objects known to exhibit free precession relative to the number of lectures devoted to the phenomenon in upper division mechanics courses was noted several years ago. Stairs et al. (2000) have added to the inventory the 250 second and 1000 day oscillations in pulse shape and derivative of PSR B1828−11, while Melatos (2000) notes that such things are not free anyhow (pause for suitable feeble joke about the costs of computing and observing time) but are coupled to radiative torques, leading to a time scale of a few years for, e.g., the Crab Nebula pulsar, where precession (free or coupled) is not seen anyhow.

Pulsars. Having reported last year that an observed pulsar, J2144−3933 with $P = 8.5$ sec, ought to have died when the most productive astronomers were pterodactyles, we are happy to note a reprieve, in the form of a (take a deep breath) space-charge-limited-flow-polar-cap-acceleration model (Zhang, Harding, & Muslimov 2000).

Binaries and multiples. It is possible for a pulsar to be younger than (that is, to have collapsed to a neutron star since the death of) its white dwarf companion say Tauris & Sennels (2000), mentioning two examples by their ZIP+4 codes. Their model began with $7 + 5$ $M_\odot$ main sequence stars and a period of 10 days. Merging pairs of neutron stars can produce all of the heavy ($A > 130$) *r*-process abundance peak (Freiberghaus et al. 1999). And the binary millisecond pulsar 1620−26 in the globular cluster M4 has, according to timing measurements reported by Thorsett et al. (1999), a third star of only 0.012 $M_\odot$ in a 100 yr (25 AU) orbit.

Kick velocities. The speed at which a pulsar begins its life is completely dominated by asymmetry of the supernova explosion for both binary and single stars said Donder & Vanbeveren (1999). With so firm a statement in hand, we almost gave up reading about the subject and so nearly missed the largest asymmetry to date, which imparted a velocity of 740 km/sec (with large error bars) to the X-ray binary Cir X-1

(Tauris et al. 1999). No kick at all was needed for the low mass XRBs with black holes (Nelemans et al. 1999), and space velocities are in general a good deal smaller for systems that remain together long enough to recycle their pulsars (Gothoskar & Gupta 2000).

Pulsars. They radiate, a few over a very wide range of wavelengths (Malov 1999). This is not a new discovery. The radiation is polarized, perhaps always 100%, but with gremlins adding up modes to conceal this (McKinnon & Stinebring 2000). Still under discussion are (*a*) the area from which the photons come (Gwinn et al. 2000), (*b*) the emission process that sends them on their way (Xu et al. 2000), and (*c*) how the charged particles that do the radiating are accelerated and transported to get where they need to be to do their job (Beskin & Rafikov 2000), and we are neither repudiating nor endorsing the specific suggestions made in the cited papers. Under the circumstances, the now-long-established thought that millisecond pulsars do something different from the others (Kuzmin & Losovski 2000) is not as informative as it might be.

Pulsars also glitch, being glitchiest when they rotate fastest (Lyne et al. 2000b, who specifically vote against a decrease in moment of inertia, and hence for an increase in magnetic moment, as part of the process). Bastrukov et al. (1999), however, ask to have starquakes taken back into consideration after many years of neglect, at least for binary pulsars in eccentric orbits. What Sedrakyan & Shahabasyan (1999) are asking to have taken into consideration is less clear.[2]

Et Cetera. Here live all sorts of interesting papers concerning X-ray binaries, quasi-periodic-oscillations, and such that are this year's data drop. A few appear in § 5.5.

4.4. Crab'd and Confined

The spectacular *Chandra* image of the Crab Nebula just missed the temporal cut for Ap99 and is now to be found many places (Weisskopf & Hester 1999; Weisskopf et al. 2000). It shows jets roughly parallel to the long axis of the nebula and a torus and inner ring that presumably tell the jets which way to go. The data also reveal where energy is being deposited by the pulsar wind, since the brighter bits also have harder spectra. In a bit of tidying up, Wallace et al. (1999) conclude that the nebula resides inside an H I bubble, that is, in a low density region, and does not sport an outer emission line coat. The extended H-beta emission reported by Murdin (1994) apparently belongs to a background source. Thus about half the mass of the progenitor star remains unaccounted for. The fastest moving gas reaches -2500 km/sec in C IV emission (a STIS result; Sollerman et al. 2000b). The previous record was -2200 km/sec in ground-based, photographic spectra of Hα and [N II] exposed long ago by Rudolph Minkowski.

The less-euphoniously named SNR 0540$-$69, in the Large Magellanic Cloud, once called more Crab-like than the Crab (not by us), shows hints of a similar torus-jet structure in its *Chandra* image (Gotthelf & Wang 2000). The Tycho remnant, unlike the Crab, apparently does have a faint, outer halo of optical emission, possibly nitrogen-rich (Ghavamian et al. 2000). This presumably consists of gas shed by the parent star before 1572 (well, long before 1572, allowing for light travel, but you know what we mean).

The Tycho and Kepler remnants (but not the Crab) have in common with Cas A the curious trait of X-ray nebulae expanding faster than radio nebulae, although they are currently the same size in the two wavelength regimes (Hughes 1999 on Kepler). Could this just be a phase that every (non-pulsar) SNR goes through at age 400 or thereabouts? In order to get bright X-rays from the region around a pulsar, its electron-positron wind must cool directly by synchrotron radiation and not waste its energy making shocks and such (Chevalier 2000). This happens for the Crab and 0540$-$69, but not for Vela and CTB 80.

Supernova remnants come and go. 3C 397, for instance, is only about 1000 years old (Dyer & Reynolds 1999) and far enough north ($\delta \approx +7°$) and close enough that someone might well have seen it from China or Europe. SN 1988Z was undoubtedly seen, and it has just been promoted from elderly SN to young SNR in the last year or two (Aretxaga et al. 1999). The Gum Nebula, on the other hand, should probably be removed from your SNR handbook, not that it has faded away, but because a study of its radio recombination lines suggests that it is a purely thermal source (Woermann et al. 2000a).

Finally, last year we mentioned a bunch of SNRs that are at present colliding with molecular clouds or other bits of densish interstellar matter, so this year we will note only that Pup A is not doing so (Woermann et al. 2000b).

4.5. Black Holes

Horizon-enshrouded objects of planetary and globular cluster mass may belong in the basket of dark matter candidates (§ 12). The sort found in Galactic centers appear as part of the discussion of starburst versus active galaxies (§ 11). And here are a few other topics that have not yet disappeared behind $R = 2GM/Rc^2$ ($R = 2M$ in relativists' units), though some may deserve it.

The proceedings of a December, 1997 conference on black holes appeared belatedly as Nos. 3 and 4 of *Journal of Astrophysics and Astronomy*. X-ray binaries, cosmic censorship, and other traditional topics are addressed, but the favorite of the more redshifted author is the conclusion of Frolov & Forsaev (1999) that the entropy of a black hole is derivable from work published by Sakharov in 1968. This is not only pre-Hawking but pre-Bekenstein. The name Hawking radiation nevertheless stands in accordance with well-established principles of eponymy (Stigler 1999). The radiation has not yet been seen, but if it were, it should not have a blackbody spectrum, owing

---

[2] The old English custom under which a convicted criminal could ask to have other offences "taken into consideration," so that one sentence would cover the whole lot, may or may not be relevant.

to von Zeipel's theorem (de Vries & Schmidt-Kaler 2000). It should be mostly on branes if there are extra dimensions (meaning more than four, not just more than you feel you need; Emparan et al. 2000). And (take a deep breath) the "coincidence" that we live at a time when a primordial black hole now boiling away (10^{15} g) has classical and quantum entropies roughly equal incorporates the same physics as the "coincidence" that we live when the Hubble time is roughly the lifetime of main sequence stars (Barrow 1999).

We think that the intersection of the papers of Fabbri et al. (2000) and Anderson et al. (2000) is that Reissner-Nordstrom black holes take longer to evaporate than Kerr or Schwarzschild BHs, but not, literally, forever. The Kerr ones, however, require an infinite number of oscillations (which Zeno, at least, thinks means forever) to reach an infinite value of the curvature scalar at their centers (Ori 1999).

A double handful of other papers dealt with spectral and energetic signatures that might allow us to distinguish (nearly) maximally rotating Kerr black holes from Schwarzschild or near-Schwarzschild ones. A quick and biased overview suggests that the most readily observable should be spectral (Kurpiewski & Jaroszynski 2000; Martocchia et al. 2000) and the least observable the particles that achieve negative energy before falling back in (Li 2000). This, however, allows energy extraction to be as efficient as that from merging BH pairs (Li & Paczynski 2000), thereby matching the fluxes for the brightest X-ray sources in other spiral galaxies (Makishima et al. 2000).

And the rest is binaries, which undoubtedly make it more difficult to produce a black hole than if you start with a single star of the same mass (Wellstein & Langer 1999). Nevertheless, X-ray binaries with black holes (meaning things with sizes like Schwarzschild horizons and masses too large for neutron stars, whether or not they turn your watch into a ruler) have become so numerous that we decided unilaterally last year to call them just plain old BHXRBs, and not "black hole candidates." This year we note a suggestion of fractal magnetic structure in their accretion disks (Kawaguchi et al. 2000) and some new orbital data for an old friend, Nova 1938 = Ginga X-ray nova 1989 (Herczeg & Maloney 1999). Yes, it is still way over the Oppenheimer-Volkoff limit for any orientation you might choose ($M_2 \sin^2 i = 6.7\ M_\odot$). A special adverbial award goes to Uemura et al. (2000) writing on XTE J1118+480, "possibly the first firmly identified black hole candidate X-ray transient in the halo."

Intermediate mass black holes of 10–100 $M_\odot$ have decorated several press releases during the year and are just creeping into the archival literature. The "what has changed" here is improved angular resolution of the current crop of X-ray satellites, which allows resolving what used to be multiple, confused sources in external galaxies into individual sources whose luminosities and spectra can be determined (Ward 2000). Being older than the satellites, we feel free, however, to sound a warning (you can imitate the sound by tearing this page out of PASP, but only if it is not a library copy) derived from the history of "the most massive single star," whether R136 in the LMC or some other. The point is that successive generations of improved angular resolution have persisted in separating off more and more components, until the brightest was probably not much more massive than 100 $M_\odot$. One can imagine the same thing happening for the X-ray sources, until individual masses are about what you would expect from the core of a 100 $M_\odot$ star, the canonical 6–10 $M_\odot$ of the known XRBs.

5. FRITZ KREISLER, PART I

Here you will meet a great many old friends, in the way you meet your classmates at the 25th reunion. Just long enough to say, "Hello," "I remember you from Miss Munro's social studies class" (this need not be true),"How are you doing?" and "Hope to see you soon again." (This need not be true either.) Most were originally indexed under "The Old Refrain," (music by Kreisler), though you may conceivably also be reminded of a description of a vocal recital, "She sang the whole thing. Even the part clearly labeled 'refrain' ".

5.1. Fundamental Constants and Particles

The Higgs particle has (probably) been seen (Janot 2000). This was the last missing particle in the standard model of particle physics (following the production and recognition of the tau neutrino earlier in the year) and is the one that allows all the others to have non-zero masses. Without it, there would be no demand for Weightwatchers, Metracal, or diagonally seamed garments. The discovery follows a traditional pattern whereby bosons (the Higgs) are found at CERN and fermions (the tau neutrino) at Fermilab. Since the Higgs completes the standard model, it is appropriate that its rumor should have been followed soon (though out of period) by one for a measurement of the dipole moment of the muon which disagrees with the standard model prediction and perhaps foreshadows the coming of supersymmetry, technicolor, or other new physics (as opposed to systematic errors). See Wilczek (1999, on CP violation) for what it means for something to be evidence of "Beyond the standard model."

A quark-gluon plasma has, perhaps, been made at CERN (Antinori et al. 2000). Whether this is the first since the big bang depends on the level of technology achieved on other planets.

Holmlid (2000) says that he has seen the de-excitation of Rydberg matter in unidentified infrared bands from the interstellar medium. Notice that the "IR" part of this rules out one's first guess that Rydberg matter does something at 13.6 eV.

Somebody (besides us) once said that the only absolutely conserved quantities in the universe are those (charge, angular momentum, and mass-energy) for which the cosmic total is zero. Lepton number is not conserved "beyond the standard model" and McDonald (2000) has revived the idea that there might be an excess of neutrinos over anti-neutrinos that is very large (10^8–10^9) compared to the baryon excess over antibaryons, though still small (1% or thereabouts) compared to the number density of photons. This sort of imbalance is too small to affect the products of nuclear reactions in the early universe by more than the error bars due to other factors.

Antimatter that persists as the universe cools down below a few MeV ($z = 10^{10}$, $T \approx 3 \times 10^{10}$ K) is another idea that has been in and out of fashion with the regularity of wide lapels. Kurki-Suonio & Sihvola (2000) have again explored the use of persistent antimatter to increase the amount of deuterium and decrease the amount of helium coming out of the big bang, thus giving better agreement with the observations, even if the baryon content of the universe is larger than last year's best-buy value.

The chirality (handedness) of life could be a reflection of fundamental physics (§ 3.6.1), a result of ultraviolet irradiation of interstellar molecules (Chrysostomou et al. 2000, showing that the dust in OMC-1 does indeed see the ultraviolet from the central source), or merely a small error in coordinate systems (Mignard & Froeschle 2000). Actually, this last merely points out that the fundamental coordinate system FK5 has global rotation, which is unlikely to be responsible for either cosmic or local handedness. But if some bit of fundamental physics begins to sound a little too bottom heavy, you can always close the discussion by saying, 'Well, if it weren't like that, we wouldn't be here to talk about it.' This may well be true for the ratio of carbon to oxygen made in stars and its dependence on the balance between coulomb (electromagnetic) and strong (nuclear) forces (Oberhummer et al. 2000). If you take this sort of argument seriously, you generally call it the anthropic principle.

Newton's constant of gravity, G, has been the least precise of the important constants for decades. It may still be, but $G = 6.674215 \pm 0.00092 \times 10^{-x}$ ($x = 8$ or 11 in some popular unit systems) is a very considerable improvement, and probably a change in the 4th digit from what you learned in school. The new value comes from a new sort of torsional balance, owned and operated by Gundlach & Merkowicz (2000). Our knowledge of the masses of the Sun and Earth were thereby also much improved to 1.988425 and 5.972245 (± errors of similar small fractions and in suitable units). The expected lifetime of the Sun is thereby decreased by about 0.07% or 6 million years. Oh dear. We were counting on that time to finish this review.[3]

5.2. Better Mousetraps

Notoriously, if you build a better mousetrap, then (*a*) nature will build a better mouse and (*b*) you will lose your shirt trying to market it, but some venture capitalist will make a fortune selling mousetrap pads. We hope that neither of these will be the fate of the imaginative new devices and observatories pandected here.

Images and spectra from the X-ray satellites *Chandra* and *XMM-Newton* appeared in many colleagues' lists of highlights for the year. *Chandra* images are mentioned in § 4.4 on supernova remnants and elsewhere. In addition, there are some very interesting early results on clusters of galaxies, for instance the X-ray hole coinciding with the location of the radio lobes in Hydra A, and a point source at the radio core (McNamara et al. 2000). Most of the three dozen or so X-ray cluster papers we caught during the year, however, still were reporting data from *ASCA*, *BeppoSAX*, or even older missions. And *XMM-Newton* made the archival literature only through its successful launch (§ 1.2).

Optical interferometry and adaptive optics were the second-most-mentioned technology during the year. Saha (1999) provided a very comprehensive review of interferometric techniques and their application. The nulling interferometer (Wallace et al. 2000a) can suppress a central point source by a factor up to 10^4 to facilitate examination of the surrounding sky. Planet searches are, of course, the driver for this. Keck I has been used as a Michelson interferometer by masking part of the aperture to yield a dynamic range of 200 (Tuthill et al. 2000b). The range sounds larger when you say it in magnitudes (5.75), and the ESO New-Technology Telescope has been pushed to a dynamic range of 9 mag in the *K* band (Neuhauser et al. 2000).

Adaptive optics is for when you have only one telescope, though if it happens to be Keck II, images of $0''.02$ are achievable first time out (Wizinowich et al. 2000). Even the comparatively petite SOR reaches $0''.05$ resolution, though its users have had lots of practice (Angel & Fugate 2000, a minireview). Given how hard it is to find even a single guide star for A0, to the point where people make them with lasers, you might suppose that asking for multiple guide stars would render the whole thing impossible. In fact, multiple guide star adaptive optics can apparently be made to work over the entire sky (Ragazzoni et al. 2000, who note that the scheme was first proposed by Beckers 1989). Several other papers in this territory noted that some of their intellectual infrastructure had come from other papers by the same author. Under the circumstances, we think it ominous that he has moved to Chicago, where there are hardly enough guide stars to find your way around the Loop. Some additional papers reporting results achieved with adaptive optics and interferometry appear with their astronomical subjects, as someday clearly all such papers will.

More than 40 other named (or more often acronymed) devices, algorithms, and sites appeared in the year 2000 literature. It is not necessarily undesirable to have been omitted from this list of favorites.

- The Very Small Array is being built to look for Galactic

---

[3] Yes, we know that the lifetime of the Sun actually depends on the product *GM*, which is not affected, rather than on either separately, but it makes a good story.

foreground noise that impedes our view of the cosmic microwave background (Giardini et al. 2000). The name and acronym were, however, already used some years ago for a pair of small radio telescopes operated at Sonoma State College by Lynn Cominski and her students, and we have the T-shirt to prove it (but are not quite sure how to cite a T-shirt in *PASP* house style—the style of the T-shirt is large, sloppy, and magenta).

- GRAPE4, which was used to show that warps in disks of spiral galaxies are more stable if the halo is prolate instead of oblate (Ideta et al. 2000) has been succeeded by GRAPE5 (Kawai et al. 2000), whose purpose in life is to calculate gravitational forces in *N*-body problems, while a regular computer takes care of the orbits of the particles.

- NBODY1 to NBODY6 was a series of (strangely enough 6) algorithms used to study multi-object systems in which gravity is the dominant force, from planetesimals to cosmology. Aarseth (1999) is the text of the Brouwer Prize Lecture by the developer, who once ran out of his office on a Saturday morning when very few people were around, asking, “Virginia, how many planets are there?” “Nine,” said she (this being in the days before nasturtiums had been cast upon Pluto). “I’ve made eight,” said Sverre, about 10 years into this 40 year effort.

- Last year we asked what immersed gratings were immersed in, doubting that it was either water or wine. That of Lee & Allington-Smith (2000) swims in glycerol, of which there seem to be several dozens kinds, with indices of refraction between 1.403 and 1.478. It’s amazing what you can find in the *Handbook of Chemistry and Physics* (though a speaker at a recent AAS meeting, unable to locate the coefficient of thermal expansion of an AAS president, was forced to use that of rock salt).

- AGAPEROS (Melchior et al. 2000b) is a new automated search for gravitational lensing by stars (etc.) whose first yield is 632 variable stars in the Large Magellanic Cloud, noise to some observers, signal to others.

- Diabolo is a high throughput, dual-channel, millimeter photometer (Benoit et al. 2000). If the first is an acroynm for the second, it is not in any of the languages we know.

- PHEBUS was a gamma-ray detector (Barat et al. 2000), while Phoebus is a collaboration to study solar oscillations (Appourchaux et al. 2000).

- Mt. Graham is the home of (at least) three telescopes and a much larger number of Mt. Graham red squirrels. The latter apparently don’t mind the company of the former as much as had been feared (Young & Smith 2000). They eat very different sorts of nuts.

- Biosphere 2 wasn’t really home to anybody, but some of its temporary residents managed to collect observations of V803 Cen, a dwarf nova with a helium star donor (Patterson et al. 2000).

- Milagrito is a prototype of the Milagro array to detect very high energy gamma rays by counting muons and such, so that you don’t have to wait for dark clear nights to see flashes of Cerenkov radiation. Atkins et al. (1999) reported its first scientific results in a paper whose 44 authors may have outnumbered the photons they counted. The flux found for Mrk 501 was consistent with earlier Cerenkov measurements.

- Queue observing is the idea that projects accepted for a particular (ground-based) telescope are carried out with the proposer not present, in an order intended to make most efficient use of changing sky and weather conditions. Tried at WIYN for several years, it was less productive of “scientific papers per observing night” than standard PI observing by a factor about 1.4 (Massey et al. 2000). The sample of papers is small, and no citation data were compiled so that the 9 “queue” papers could conceivably be much more valuable than the 19 “non-queue” papers (though we doubt it). Space-based observatories nearly all operate in a queue-like mode, owing to the difficulty of getting observers there and back in a timely fashion.

- X-ray focusing optics push ever onward to harder photons. Pieces of an LP record work at 23 keV (Cederstroem et al. 2000), providing a focal length of 22 cm when the pieces are 180 μm apart. This innovative use for what is now nearly a waste product gives renewed hope to those of us who have saved our hula hoops, frisbees, nerf balls, and pet rocks.

- X-ray grazing incidence interferometry appears to require something more than four LP records, but Cash et al. (2000) are thinking about it as a way to resolve the microarcsecond structure of shadows cast by black holes, death inspirals, and other cheerful topics.

- Fast Intermediate-band Lightgathering Medium is still being used, along with what seems to be the world’s largest interference filter (35.6 × 35.6 cm, centered at Hα) to look for Herbig-Haro objects (Mader et al. 1999) and to survey the Milky Way (Georgelin et al. 2000). Though it has been only a little more than a century since there was real disagreement among variable star astronomers about whether visual or photographic methods were best (Saladyga 1999), the acronym film has been in use for so long that the full name has nearly been forgotten. This topic was originally indexed under “making a virtue out of necessity,” along with the use of a transit circle in Washington, DC (Rafferty & Holdenried 2000), the measurement of radio pulsar polarization using a single feed (Ramkumar & Deshpande 1999), and the biomechanical servo of Kraan-Korteweg (2000, a catalogue of 3279 galaxies in a small portion of the zone of avoidance covered by the ESO/SRC Schmidt survey plates, found by eye examination).

- WISP has recorded the first wide-field UV polarimetric image of anything. Cole et al. (1999b) chose the LMC and concluded that many of the UV photons that eventually make their way out have been scattered.

- CDS and ADS are the two giant astronomical data bases located (in so far as anything largely electronic can be said to be located) at Strasbourg and NASA. Genova et al. (2000) and the following three papers and Kurtz et al. (2000) and the three papers after that explain what is in them.

Laboratory measurements continue to be crucial for many parts of astrophysics. Familiar cases include nuclear reaction rates (Rayet & Hashimoto 2000 on what is needed for better calculation of yields from the *s*-process), properties of dust (Wurm & Blum 2000 on grain shapes), atomic data (Nahar et al. 2000, paper XLIII from the Iron Project), and molecular properties (Arnoult et al. 2000 on PAHs, which, we have just learned, are to be regarded as dangerous pollutants on Earth, although a good thing to have in interstellar space). Other, less usual examples of laboratory astrophysics include:

- A dynamo made of rotating liquid sodium (Gailitis et al. 2000), which is another thing you might not want in your backyard, though very useful at the center of the Earth (Jackson 2000).
- A radiative shock (Shigemori et al. 2000) with the velocity of the blast wave less than the Sedov-Taylor value (but in agreement with better calculations).
- Masing HCN, the only molecule known to be excited by the same mechanisms in laboratory and ISM (chemical pumping; Schilke et al. 2000).
- A laser-driven blast wave of eventual relevance to supernovae and gamma-ray bursts (Keilty et al. 2000).
- The proceedings of an entire (Spring 1999) conference devoted to laboratory astrophysics with intense lasers (Remington et al. 2000).

There are, of course, many other astrophysical processes for which observations and the best available theory disagree, and one only wishes one could make laboratory measurements, for instance the broadening of hydrogen lines arising from levels with $n = 200$ and higher in H II regions (Bell et al. 2000).

5.3. Processes and Phenomena

Light echoes began with Nova Persei 1901 (Kapteyn 1907) and continued with Nova Sgr 1936 (Swope 1940). The case of SN 1987A has been discussed many places, but SN 1991T (Sparks et al. 1999) is a recent addition to the club. Light echoes from dust could contribute to the late optical glows from gamma-ray bursters (Esin & Blandford 2000). And it is just barely possible that we might still see that of Tycho's 1572 supernova (Maslov 2000). Highly polarized, near infrared in a ring about 5″ across is the best bet. This comes so close to time travel ("see what Tycho saw") that it feels a bit spooky. Except, of course, that Tycho did very little near infrared observing.

Detonation (supersonic) versus deflagration (subsonic) has been an issue in models of Type Ia supernovae for years. Half a dozen or more papers discussed it, making a further distinction between delayed and convective deflagration (Dupke & White 2000) and noting a pathological case (Sharpe 1999), chosen from among self-sustaining, supported, cellular, and double detonation (this last means helium ignites first, then carbon and oxygen). Timmes & Niemeyer (2000) discuss the somewhat similar dichotomy for helium explosions in X-ray bursters, invoking a process triply eponymed to Zeldovich, von Neumann, and Döring. Richard Armour described a triumvirate as an arrangement in which, when one of them left the room, the other two made uncomplimentary remarks about him. One suspects it would have been Döring in this case.

What pumps OH masers? Different processes at high density (star formation regions) and low (supernova remnants) says Caswell (1999).

You have to add energy to ionize or excite atoms and to dissociate molecules (indeed sometimes to make them if there is a barrier to get over). Is this done by photon absorption or particle impacts (shocks)? Yet another example of "both please" as you might expect, illustrated by Quillen et al. (1999 on excitation of H_2 molecules in Seyfert galaxies), Sugai & Malkan (2000 on ionization in LINERs), Muthu et al. (2000 on shock ionization in some planetary nebulae, where we have known that there is photoionization since the time of Zanstra or thereabouts), and, among a number of others, Palumbo et al. (2000 on the chemistry to make the carriers of the 4.62 μm band, which can be promoted by ion bombardment as an alternative to ultraviolet photolysis).

Inverse Compton scattering was, in its day, a mechanism looking for a source to operate in. This year there were at least 15 places, or anyhow papers, where it happened (from Giommi et al. 1999 on the blazar SJ 0716+714 to Sazonov & Sunyaev 2000 on the preferential backscattering of soft photons) and at least six where it did not (from Blasi 2000 on making the hard X-ray tail in clusters of galaxies by distorting the Maxwell-Boltzmann distribution to Berghoefer et al. 2000a on the soft X-ray and extreme UV excesses of M87 and the Virgo cluster as synchrotron), where we mention only the first and last papers from each point of view that appeared during the year. Notice that "both please" is not a possible answer for the C^{-1} or not C^{-1} case, unless you are willing to accept synchrotron-self-Compton as an example (Tagliaferri et al. 2000).

Where is the return current? In the outer collar of the jets from young stellar objects, where the current goes out in the core, say Lery & Frank (2000).

Is the Jeans mass good for anything? Certainly not for earning citations for Jeans (not even from us). But does it have anything to do with star formation? More than you might think in recent, magnetically dominated years (Indebetouw & Zweibel 2000) according to Coppin et al. (2000 reporting SCUBA data on OMC-1 and emphasizing fragmentation processes) and Curry & McKee (2000 on models of Jeans mass cores inside much larger, stable clouds).

Turbulence and star formation are two things we have been describing for years as "not very well understood" (compared, say, to hydrostatic equilibrium and the structure of main sequence stars). It is, therefore, altogether fitting and proper that a connection between the two should be coming into play. First, it seems that turbulent flow in H I speeds up the formation of molecular clouds and their first stars (Ballesteros-Paredos et al.

1999). The associated magnetic field should also be turbulent or stochastic (Parker & Jokipii 2000). Second, the turbulent structures within the resulting molecular clouds may translate directly into the initial mass function, $N(M)$, of the stars formed (Myers 2000; Muench et al. 2000). Simplifying nearly beyond recognition, stars form in the small, still pools, close to the Jeans mass, in between turbulent vorticies (Elmegreen 1999; Kornreich & Scalo 2000). Such turbulence in molecular clouds dissipates in much less than the free fall time and must be continuously driven (Mac Low 1999). Shocks from many sources (Kornreich & Scalo 2000) and thermal instabilities (Burkert & Lin 2000) are among the drivers.

Not quite everyone regards turbulence as a good description of star formation regions. Gosachinskii & Morozova (1999) find that the internal velocity dispersions of H I clouds as a function of their size are not described by a turbulent spectrum, while Lazarian & Pogosyan (2000) say that the description is OK, but that a Kolmogorov turbulent cascade is not the cause.

Convection and turbulence remain important after stars form, and the year witnessed many papers concerning convective overshoot, semi-convection, and their observable consequences for stellar evolution and surface abundances (e.g., Herwig et al. 1999; Bruntt et al. 1999). There also appeared paper M in a series of N ($N \geq M$) by Canuto (1999) in which the author, sometimes with colleagues, struggles onward toward a unified theory of stellar turbulence, including rotation and so forth. This one introduces a post-Schwarzschild, post-Ledoux criterion for convective instability, turbulent kinetic energy >0.

Stars and the ISM are not the only places where convection happens. On Earth we call it weather. They also increasingly do so on Jupiter, though "they" is, unfortunately, not the Jovians, but only terrestrials interested in Jovian surface phenomena (Gierasch et al. 2000; Ingersoll et al. 2000; Seiff 2000). The correlations of storms and lightning imply moist convection (like on Earth), but driven by heat from inside rather than from the Sun. Gu et al. (2000) applied mixing length theory to the convective transport of energy in accretion disks (for cataclysmic variables, active galactic nuclei, and X-ray binaries), but did not mention weather, let alone trying to do anything about it.

5.4. Stellar Structure and Evolution

What drives stellar winds? All the things you've ever heard of (Ap93, § 4) from MHD waves (Airapetian et al. 2000) to radiation pressure in the absorption lines. And if the momentum in the outgoing radiation isn't as large as the momentum in the wind, then all the photons just have to work twice as hard (Herald et al. 2000) or even six times as hard (Nugis & Lamers 2000). The proper name for this is "multiple scattering." Much the same can be said for winds from disks in various contexts (Pereyra et al. 2000 on cataclysmic variables).

Missing opacity, meaning that to make your model stellar atmospheres match the colors (etc.) of real ones, you must use optical (etc.) opacities larger than the sum of all the causes you know about, continues to be missed (Cassisi et al. 1999 on globular cluster stars).

High latitude (halo) B stars are puzzling if they are massive young objects rather than evolved (post-AGB) low mass ones. Lehner et al. (2000) draw attention to a particularly anomalous one, with Population I composition and surface gravity, but very small rotation velocity ($v \sin i < 5$ km/sec) and microturbulence less than 2 km/sec, compared to the OB norm of 15 km/sec (Villamariz & Herrero 2000). Well, there are also some people who seem to have been born middle-aged.

Dwarf carbon stars supposedly got that way by being dumped on by an asymptotic giant branch companion (now a white dwarf), and they ought to exist if you want to blame binary mass transfer for composition anomalies in more evolved stars. They do (Ap93, § 5.3), but one wonders whether 0 out of 48 in a high latitute sample of carbon stars with upper limits to their proper motions is really enough (Totten et al. 2000). It is easier to make a carbon star if metallicity is small to begin with, but Zacs et al. (2000) say that BD +75°348 is the old disk analog of the halo CH (giant) stars.

Supermetalrich stars continue to exist, an analysis of Mu Leo (K2 III) yielding [Fe/H], [Ca/H], and [Mg/H] $= 0.3 \pm 0.04$ according to Smith & Ruck (2000), who find the expected, lower metallicities for other K giants in the solar neighborhood and and in the Hyades using the same techniques.

Dynamical screening is, um, er … . Well, ordinary screening is that two protons (etc.) attempting to get over their mutual coulomb barrier so as to embrace each other's nuclear potentials will, on average, find some portion of an electron between them, which lowers the barrier a bit (remember electrons are bigger than protons in a quantum mechanical sense). Dynamical screening is a further lowering of the barrier when you remember that the particles are all running around madly. Round one in whether this is an important effect was fought several years ago. We missed citing the TKO arguments of Gruzinov (1998), but Opher & Opher (2000) now say that those arguments are invalid (without voting on whether or not dynamical screening is important). Shaviv & Shaviv (2000) say again that it is important. (The family aspect of the discussion reminds one a bit of the Hatfields and the McCoys.) And, just in case you think that, at least, the sign of the effect was agreed upon, if not the amplitude, Tsytovich (2000) has weighed in with a calculation of screening that has static effects cancelling out, so that only dynamical screening remains and, he says, raises rather than lowering the coulomb barrier. This would reduce the rate of proton captures by Be^7 in the Sun by about a factor of two, reducing the expected flux of the highest energy neutrinos by a comparable amount.

The first ionization potential (FIP)? Well, every element has one. The question is whether stellar coronae and winds are enriched in those that are relatively easy to ionize. Yes for the Sun; apparently not for some other stars (Ap98, § 7.4); and maybe for Capella (Brickhouse et al. 2000), with deficient coronal neon the only representative of high FIP elements.

Are there other stars like the Sun? Well, sort of. But Glushneva et al. (2000) are not the first to note that stars with the same spectral type generally have different colors, and conversely. Sekiguchi & Fukugita (2000) conclude that the standard solar $B-V = 0.62$ is either wrong or anomalous or both.

OB runaway stars, liberated by supernova explosions of their binary companions, were firmly expected before the concept of mass transfer early in the evolution of close binaries was established. Now we prefer to expect runaway binaries, with a neutron star left from the first explosions still bound to the OB secondary. Examples remain rare, and just as Israelian et al. (2000) were getting our hopes up for HD 188209, with what seemed to be a 6.4 day period, they let us down with the phrase quasi-period and the conclusion that it is not a binary.

Models of stellar atmospheres have been around long enough that even we are not quite old enough to remember when the reversing layer approximation (Schuster 1905; Schwarzschild 1914) was the best availalble. These days they generally have to be non-LTE (Przybilla 2000, and no way of writing this out with any number of hyphens will convey the idea that it is the equilibrium that is being negated not the local), non-spherical (Allende Prieto et al. 2000), stratified in velocity (Luttermoser 2000), extended (Hauschildt et al. 1999), expanding (Fitzpatrick & Massa 1999), and probably other things in the dozen papers we indexed but haven’t cited. And even then, you cannot always get so simple a thing as the temperature of a star consistently from the whole spectrum (Kotnik-Karuza & Jurdana-Sepic 2000). By the way, Karl Schwarzschild also invented LTE.

L and T dwarfs, unknown, or at least unnamed, a couple of years ago, are now so numerous that even a centipede has to take off his shoes to count them (Fan et al. 2000b; Kirkpatrick et al. 2000; Burgasser et al. 2000a), the largest yield currently coming from the 2MASS and SDSS surveys. Increasingly, it is possible to make both statistical and extremal statements. Lithium line strength peaks at L6.5. The temperature gap between type L8 and the hottest T V is less than 350 K, which is why we don’t catch many transition objects with methane just phasing in (Leggett et al. 2000). Activity indicators are slightly discordant, but the latest X-ray source is vB10, and it may appear only in flares with no quiescent material hotter than 10^6 K (Fleming et al. 2000) No stars later than L4.5 show Hα emission; and Beuermann et al. (2000) suggest that the brown dwarf secondary of the polar EF Eri has no magnetic field, which may be characteristic of the class.

A real and significant gap is that in the numbers of companions with masses between big planets ($10\ M_{\rm J} = 0.01\ M_\odot$) and small stars ($0.1\ M_\odot$; Halbwachs et al. 2000), though there are now about 10 companions with measured masses $\lesssim 0.1\ M_\odot$ (Delfosse et al. 1999).

Among the L and T extrema we find the first double brown dwarf with a spectroscopic orbit, PP 15 (Basri & Martin 1999) and three probable visual binary BDs (Koerner et al. 1999; Reid & Mahoney 2000), and the coolest and faintest, Gl 570D, at $T = 750 \pm 50$ K and $L = 2.8 \pm 0.3 \times 10^{-6}\ L_\odot$ (Burgasser et al. 2000b).

A dozen or more papers address *L* and *T* spectra. Some of the interesting conclusions are (*a*) you need dust opacity to fit the observations (Pavlenko et al. 2000), (*b*) BDs have their very own unidentified spectra features (McLean et al. 2000), (*c*) there are modest differencies in the spectral subtypes assigned by different groups (Martin et al. 1999), and (*d*) the absorption in the Na I D doublet takes out so much yellow light that the net visible color might well be purple (Liebert et al. 2000; Burrows et al. 2000a). Draft poems beginning “I never saw a purple star” should be submitted to the more purple author in plain brown envelopes.

Lithium, despite its fragility at high temperatures, is to be found in at least a few stars at every major evolutionary phase (pre-white-dwarf), not to mention in 20-some papers. Some stars still have it (Stout-Batalha et al. 2000) and some have it again, either because they have produced it themselves (de la Reza et al. 2000) or because they have not yet fully digested a dinner of lithium-rich brown dwarf or planet (Pilachowski et al. 2000) or both (Denissenkov & Weiss 2000).

Other surface anomalies can be fairly firmly assigned to upward mixing of nuclear reaction products. Technetium remains the classic example, making it to the top as semi-regular variables evolve into Miras (Lebzelter & Hron 1999). Other anomalies are surely due to radiative levitation and other surface processes. The spotty surfaces of the Ap and Bp stars are classic examples (Leone et al. 2000; Khokhlova et al. 2000). Still other anomalies are still being debated between the nuclear and surface camps, although Roby et al. (1999) had to wait almost 3.5 years between submission and publication to be allowed to do so.

Many authors asked for more or earlier mixing than you naively expect for both main sequence (Gonzalez & Wallerstein 2000) and red giant (Boyarchuk et al. 2000) stars, but Takeda & Takada-Hidai (2000) were unusual in asking for anti-mixing so that the surface ratio of H to He goes down in their stars as N/C goes up.

And, though we have collected several dozen other papers addressing a comparable number of other issues in stellar structure and evolution, it is time to say goodnight, Dick (Good night, Dick) and admit that, not only do evolutionary tracks calculated by different groups using equally plausible (though different) physics and methods disagree by up to 20% on important issues like main sequence lifetime (Dominguez et al. 1999), but sometimes no one set of tracks will fit both members of a close binary system (Lastennet et al. 2000), which brings us naturally to binary stars.

5.5. Binary Stars

Cowling (1941) thought that having a close companion might drive stellar pulsation (next section), though he didn’t consider damping. In fact, the two characteristics seem for the most part to be randomly assorted. There are a few anti-correlations. None of the rapidly-oscillating Ap stars is a spectroscopic binary (Hubrig et al. 2000), and only one of the pulsating white dwarfs, GW Lib, is known to have a companion (D. Koester, private communication to Hubrig et al.). Thus one can arrange the traditional questions about binary stars into the same sort of evolutionary sequence found for single stars, multiplied by itself. In a few cases, we begin with the answers.

There are no Population III binaries (and no Population III single stars). The incidence in Population II is much more like that in Population I than was thought a generation ago, when there were supposed to be almost no Pop II binaries. There may still be a modest relative deficit at the separations characteristic of visual binaries and common proper motion pairs (Allen et al. 2000a). Occasional disruptions of wide pairs over the past 15 Gyr are at least as likely as some initial difference.

When do binaries form? Early, in the sense that the incidence among T Tauri stars is, if anything, rather larger than for main sequence pairs at the separation probed by speckle interferometry (Koehler et al. 2000, who also note that the fraction of speckle binaries varies from one star formation region to another). Apparently either some pre-MS binaries fall apart or their orbits shrink. A pair with separation of 8900 AU contains the youngest stars in Orion (Chini et al. 2000).

How and where do binary stars form? Boss (2000a), in a report from an April 2000 meeting in Potsdam says, “fragmentation is the only game in town” (because separate formation and capture cannot account for the shared circumstellar disks often seen). Tsuribe & Inutsuka (1999) partially demure, suggesting that only the cooler clouds can fragment to binaries. Boss et al. (2000) favor the non-isothermal clouds, which is perhaps not quite the same set. Bate (2000) reaffirms that fragmentation plus accretion favors the production of pairs with mass ratios near one among short period system, and that mass ratios less than 0.1 are quite difficult to produce. Soederhjelm (2000) provides data from the *Hipparcos* catalog supporting the association between large mass ratios and short periods.

When and how does companionship affect evolution of stars? From the very beginning imply Looney et al. (2000) on shared versus separate disks and envelopes in pre-MS binaries of various separations. The intermediate case of a shared envelop happens at $a = 150$–3000 AU. Early interaction is sufficient to synchronize what otherwise might be separate events, since visual double T Tauris are, as a rule, either both classic type or both weak lined, meaning that the partners lose their disks together (Duchene et al. 1999)

Some classes of stars are always binaries, whether by definition or hard-won observations, including (*a*) W UMa’s by definition, and more work is still needed to understand how the components maintain different effective temperatures despite sharing an envelope (Wang 1999), (*b*) RS CVn stars, whose spots hover around preferred longitudes; Holzwarth & Schuessler (2000) blame symmetry breaking due to the companion, but we think single active stars can also have preferred spot longitudes, (*c*) Ba II giants, a product of hard work, continuing with the deduction that some must have been polluted by mass transfer from their companions while they were still on the main sequence, because the white dwarfs have cooling times longer than the giant lifetimes (Böhm-Vitense et al. 2000), (*d*) Beta Lyrae, with (for lack of other explanations) a circumbinary ring which must have formed out of material lost during the evolution of the system (Umana et al. 2000), and (*e*) the cleanest set of binaries we know, those with orbit parameters determined by Daniel M. Popper, of which HS Aqr is the last, at least in this world (Popper 2000).

All the cataclysmic variables are, of course, also binaries by definition, and frequently also by observation. New subtypes are declared from time to time, including smooth versus featured light curves (Rosenbush 1999b), TOADs that also have normal dwarf nova outbursts (Wheatley et al. 2000), a continuum between SU UMa and WZ Sge types (Baba et al. 2000, the latter are, roughly, the TOADs), and (*d*) a class of dwarf novae with periods smaller than the underinhabited $P = 2$–3 hour gap and with magnetic fields between those of the AM Her stars and those of the intermediate polars (King & Wynn 1999). “Supermediate” polars is the name that comes to mind. The prototype is EX Hya. Schmid et al. (2000) have gone the other direction, proposing a unified model for some previously separate classes, based on our orientation relative to the orbit plane, rather like “unified” models of active galaxies.

But the burning front before us is, “Do novae hibernate?” That is, after an outburst, do they eventually fade (reduce their mass transfer rates) far below the levels seen a few years to decades pre- and post-explosion. A canonical nova outburst brightens the system by at least 10 magnitudes. Do we have evidence for CVs much fainter than +5? Yes, undoubtedly. Gaensicke et al. (2000a) and Reimers & Hagen (2000) provide specific examples, where mass transfer is $10^{-12}\ M_{\odot}$/yr or less and doesn’t even keep the white dwarf warm. But we have no guarantee that these systems ever have had or will have classical nova explosions. The alternative approach is, therefore, to try to recover known old novae, the strategy that originally led to the hibernation scenario. Most recently, Robertson et al. (2000) have probably found Nova 1678 (V529 Ori) and a number of 20th century events, but not Nova 1612 and several others. A look at the numbers suggests the increasingly familiar answer, some of them do and some of them don’t.

The largest class of binary papers during the year dealt with X-ray binaries (a dozen on quasi-periodic oscillations alone). The middle two papers (in temporal sequence, that is, all of them are, of course, of above average quality) reported (*a*) the third case of ≈1 Hz QPOs in a low mass XRB which persist during the low intensity state (Jonker et al. 2000 and Miller 2000), and, conversely (*b*) QPOs that disappear at high mass transfer rates (the high state) (Cui 2000; Campana 2000).

From among the other dozens of XRB papers, we pluck at random another probable example of mass transfer that is sustained by X-ray heating of the donor star (Greiner et al. 2000b). Some pulsar binaries like 1957+20 have been advertised as doing this for years, however much it may sound like pulling yourself up by your own bootstraps (no, we don’t remember bootstraps, having always used button hooks).

And, in case you are interested in black holes and their formation, Israelian et al. (1999, with a commentary from Cowan 1999) have provided evidence that the donor star in BHXRB GRO 1655–40 (one of the galactic superluminals or microquasars) has on its surface 6–10 times the solar abundance of C, Mg, Si, and S, but normal iron, identifiable with the ejecta of a typical Type II supernova. This rated a News and Views commentary because it implies that supernovae can leave black holes as their direct core product, there not having been enough time in the life of the system for mass transfer to drive a neutron star above the Oppenheimer-Volkoff limit (the NS equivalent of the Chandrasekhar limit for white dwarfs) and feed it up to the present mass. Having an F–G III donor, this system also adds one to the very small group of XRBs (prototype Her X-1) with intermediate mass donors, although the data are out of period (Shahbaz et al. 1999).

The final large class of binary star papers dealt with assorted examples of changing orbital periods and reasons these might happen. An exception is 64 Peg, whose period is probably not changing after all (Boden et al. 1999, reporting resolution of the pair with the Palomar Testbed Interferometer). Such resolution can only become more common and increase our supply of accurately measured stellar masses, e.g., Pourbaix (2000) reporting on 40 systems and Griffin & Griffin (2000) on one that would surely benefit from that sort of attention.

Of the papers reporting period changes, the middle one (again temporally) was Liu & Yang (2000), who found $\Delta P/P = -5 \times 10^{-11}$ for W UMa between 1949 and 1998. This may seem like an awfully small ΔP to be able to detect, but 40 years is an awful lot of periods of W UMa. The amplitude is very much what you would expect from the thermal oscillation model of how W UMa stars earn their livings (Lucy 1968).

Orbital inclinations can also change if a third star exerts suitable torques. We thought briefly that there had been two new examples during the year, but in fact Milone et al. (2000) and Torres & Stefanik (2000) were both talking about SS Lac, which started eclipsing in about 1885, had central eclipses around 1912, and hasn't blinked since 1937. It should start eclipsing again in about 1150 or 2300 years. The two previously known quitters are AY Mus and V107 Sco.

5.6. Variable Stars

At some level, all stars vary (probably on every time scale from that of atmospheric waves to the main sequence lifetime). Out of the range of possibilities, about 30 types, dozens of individual stars, and many theoretical considerations appeared in something like 100 indexed papers. Unfairly short shrift to all except the few to which we responded, "I didn't know you did that" (as the bishop said to the actress).

- A few dozen M giants with periods less than 10 days (Koen & Laney 2000). Spots and ellipsoidal shapes can be ruled out, and very high overtone pulsation (often more than one mode per star) seems to be all that is left.
- Contrarily, there are B stars with unexpectedly long periods of 1–5 days (De Cat et al. 2000a). The authors suggest radial modes of high order. About half the stars are in binaries, which may or may not have anything to do with the price of modes (half of all stars are in binaries, after all).
- In the spectrum of α^2 CVn, lines coming from ions with different distributions on the surface show different radial velocity curves (Gerth et al. 1999). The oddness of this star was known to Struve & Swings (1943) and to Belopolsky (1914) before them.
- Epsilon Per is a multi-mode, pulsating close binary system (De Cat et al. 2000b). Despite the 13 pages of the paper, the authors do not seem to find space to mention the spectral types, but since the analysis uses Si III lines, we conclude that at least one of the stars is hot. Gies et al. (1999) kindly clarify that the primary is a B III star, and the largest-amplitude example of giant variability. De Cat et al. (2000b) note that there is a probable third, visual, component.
- Procyon A is bright enough to be monitored by *WIRE*, and comparison of data with models should eventually yield very precise values of its mass, radius, and luminosity (Chaboyer et al. 1999; Barban et al. 1999).
- Some Herbig Ae stars are also Delta Scuti non-radial pulsators (Marconi et al. 2000b). It is not quite clear why this needed the urgent publication of a Letter, since the first example was reported in 1927. But then it has also been known for many years that some snarks are boojums.
- In the O9 III+B1 III system ι Ori, the variability is actually due to modest tidal distortion, reminding us, that as Cowling (1941) said at the beginning of the previous section, one can imagine cases where, given some sort of resonance between an orbit period and a natural frequency, binary companions could drive pulsation.

5.7. People and Places; Words and Music

Lowell (Percival) would surely be pleased that the telescopes at his observatory continue to be upgraded (Wilkinson 1999) and even more pleased at the ever-increasing abundance of water on Mars, or at least of papers discussing it (Malin & Edgett 2000).

See Naples and then die? Well, not immediately, but radar interferometry, using the *ERS 1* and *2* satellites shows that there has been subsidence in the region of subway construction (Lanari 1999).

Kolmogorov-Sinai entropy is properly credited by Heinamaki et al. (1999), and if you get it wrong you have to wander for 40 years.

A "bad-fish zone" occurs in a plot of profile shapes for elliptical galaxies, derived from various kinds of stellar orbits by Zhao (1999). There are also some bananas and pretzels, and your fate, should you try to swallow them all, is foretold in the multi-versed song that begins, "Found a peanut …"

Most of the early women astronomers worked closely with male relatives. Add Sophie Brahe (1536–1643, sister of Tycho) to the more familiar Elisabeth Kropmann Hevelius (1647–1693, a wife), Caroline Herschel (1750–1848, a sister), and Margaret Huggins (1848–1915, a wife, who could conceivably have met Caroline H. but probably did not).

The farming of fishivores can use up more pounds of fish protein than it produces (Naylor et al. 2000).

Descartes lives, or at least something rather similar to his vortex model for the formation of planets (Godon & Livio 2000).

The forest method is, of course, an offshoot of tree codes (Yahagi et al. 1999).

MOCS is a way of apportioning credit for citations to multi-authored papers among the authors (Jones 1999). Given the high level of wit manifest in this (once again) weekly column, it is ominous that the author has left for us the obvious remark about not judging a colleague until one has walked a day in his MOCS.

TLAs: The best set of the year appeared as section heading in Blandford's (1998) concluding remarks at a conference whose proceedings appear in *Astrophysics and Space Science* Vol. 261. The worst are the ones that duplicate a set already in use, for instance RGB for *ROSAT*-Green Bank survey rather than red giant branch (Laurent-Muehleisen et al. 1999). The paper is about the ratio of radio to X-ray luminosity from BL Lac sources. What is a TLA? Oh, a three-letter acronym, of which there are only 17,576 possible. We would like to claim dibs on our own initials, but they are already in use.

Giordano Bruno is not, it seems, to be pardoned (Sodana 2000).

Asperger's syndrome is over-represented among people in mathematics, science, and engineering (Baron-Cohen et al. 2000). Normally, we would make you look it up, but it spoils the joke not to realize that the syndrome is a borderline version of autism, often associated with great intellectual gifts but very limited "people" skills.

CP and PN are among the newly detected molecules in IRC +10216 (Cernicharo et al. 2000), and it is not in any way the fault of the molecules or the authors if we thought initially that they should be (*a*) violated and (*b*) centered on a PNN.

L6 is a class of semi-regular variables as well as a spectral type of brown dwarf (Kerschbaum 1999), and so much for the reason that type P was rejected (Ap98, § 10.5).

Dendrograms are a way of showing hierarchical clustering (Durret et al. 2000) and work like clad diagrams for illustrating evolutional relationships. Dendrochronology is tree-ring dating. The root is the Greek word for tree, and if the derivatives make you think of dandruff, it is probably because they are deciduous trees.

MyCn 18, He 111, KjPn 9, and Mz 3 are all planetary nebulae with supersonic outflows (Redman et al. 2000). The first two are short for Mayall (Margaret, not Nicholas) and Cannon and Henize. As for the others … .

Oosterhoff III globular clusters have larger average periods for the RR Lyrae stars than Oosterhoff II's (I's are the shortest), but the two known examples also have the largest metallicities, among the clusters, reversing the trend from high Fe/H in type I's to lower Fe/H in type II's (Pritzl et al. 2000).

Whether the Casimir force really takes place between actual, rather than gedanken, metal plates is still being debated, we were surprised to hear, at the two or three!?! level (Bordag et al. 2000). Sadly, it is no longer possible to ask Casimir.

Epagomenal, embolismic, and bissextile all appear in a book review (Yallop 2000) without definitions, but we suspect they have nothing to do with digestion, failure of the circulatory system, or, um, er … .

Aging observers: Stanton (1999) finds no correlation between observers' ages and the errors they make estimating magnitudes, up anyhow to age 65. The author of *Observatory*, 120, 188, who is approaching that limit, however, concluded that it would not be possible for him to delay publication until the orbit of HD 146117, whose period is just 7 days longer than 4 years, moved its phase = 0° around to the time of year when it is up.

Very remote observing: It has been called to our attention that the Wyoming 2.3 meter telescope has been operated from Saratov State University.

Cenek (Vicenz) Strouhal, about whom we enquired last year (§ 11.1) was a pupil of Ernst Mach and worked on singing wires (e.g., Strouhal 1878).

NOIDS are non-optical identification objects (PASP, 112, 304, results). Iogenic means "made by Io" (AJ, 120, 488, abstract). FREDs are part of the title of ApJ, 534, L35, and we didn't catch the definition. CaTs are interpreted in A&A, 359, 18. Radix-4Butterfly is part of a title (PASJ, 52, 447) and leaves one wondering whether it is an astronomical object, a data processing technique, or something else.

Milankovich cycles as the cause of ice ages were proposed about 50 years earlier by Croll (1875). Given the customs of eponymity, this proves we have the right name for them.

Herbig-Haro object numbers: If you would like to keep count, along with the numbers of McDonalds hamburgers sold, the website is http://casa.colorado.edu/hhcat/.

Maryland is the best-funded state in the Union, measured by federal R&D dollars per resident, and, before you try to descend, locust-like, on one of our institutions, remember that NIH is in Bethesda. The level is $1513 per resident (*Science* 288, 2111). New Mexico is number two, but remember LLNL and Sandia before you try to cart off the VLA!

"Subdwarf," about which we earlier enquired, was coined by Kuiper (1939). Not surprisingly, his invention quickly won out over the earlier "intermediate white dwarf."

Dionysius Exiguus (of the missing year zero) was born in what is now Romania, and James Kaler claimed to be the only native Albanian astronomy (i.e., native of Albany, NY).

And Alan Cousins (2000) holds the record for astronomer who published over the longest period of time. We would gladly have sung a suitable paean of praise if we had known him a bit better.

6. ON GROWTH AND FORM: ACCRETION AND COLLIMATION

The beginning of § 9.2 notes that the distinction between tearing things apart and putting them back together again is, in astrophysics, not a very clear one, nearly everything having been recycled a good deal. Nevertheless, this section focuses on processes that occur over a wide range of length and mass scales and contribute to making things look the way they do, at least for a while. It won't hurt also to be reminded of D'Arcy Thompson and the fact that making something much bigger (or smaller) generally requires other changes as well.

6.1. Accretion

The dictionary meaning is "growth or increase by external additions," implying that something is already there. Thus accretion is, at most, the last part of a formation process (e.g., from disks around young stellar objects or accretion of dwarf companions by larger galaxies; §§ 9.2 and 9.3), and may be completely distinct from it, as in the case of accretion onto evolved stars or black holes. We take a look at some of these, from inside in the case of the Milky Way, from outside for the others (especially the black holes).

6.1.1. High Velocity Clouds (*HVCs*)

The outstanding question here is whether these represent fresh material being added to the Milky Way (etc.) or merely subsequent appearances of incompletely ejected gas. Pretend you have never heard of these entities (which like many other astronomical discoveries were first reported in a paper with Oort as second or third author: Muller, Oort, & Raimond 1963) and are learning for the first time that there are clouds of neutral hydrogen with velocities centered around -100 km/sec, in many directions in the sky, including well outside the plane, where galactic differential rotation does not predict large negative velocities. The first thing you will surely ask is how far away are they? Next, perhaps, what else is in them? Are they gravitationally bound? What happens when they hit? And so forth.

All of these have been answered many times, but the answers are discordant and cannot be crammed into a single picture frame, even if the Milky Way is not a typical spiral galaxy, and still less so if it is. Oort himself believed them to be primordial or nearly primordial material being added to the galaxy from well outside the Milky Way. The subsequent discussion has been complicated by the tendency of later authors also to speak for the whole class of HVCs, which is almost certainly not appropriate. Oort's view is still part of the story. Braun & Burton (1999, an important out-of-period paper that we indexed last year under two categories and neglected to cite under either) list 66 clouds, each about 1° across and approaching at about -100 km/sec, and conclude that they are compact, isolated, H I clouds of about $10^7\ M_\odot$ falling in from as far away as 1 Mpc. Thus the total set (Braun & Burton 2000) could be the missing dwarf galaxies expected from many models of the formation of the Local Group (Moore et al. 1999a; cf. Ap99, § 8.3).

But infalling primordial gas cannot be the whole story, and a trusting look at the year's literature requires the conclusion that the HVCs are not all the same sort of beast, either in current contents or in origin, distance, and eventual fate.

For instance:

(*a*) Some have very hot O VI gas but no H_2 (Sembach et al. 2000; Murphy et al. 2000, both reporting data from *FUSE*), while others have H_2 and metals at low ionization and nearly solar abundance (Richter et al. 1999), with the very next paper (Wakker et al. 1999) reporting a cloud of lower, but not zero, metallicity, whose accretion would suggest a solution for the G-dwarf problem (§ 7.2).

(*b*) 20% or more of a list of 215 show head-tail structure indicative of interaction with halo gas and so of location very close to the Milky Way (Bruens et al. 2000) but the list partly overlaps the Braun & Burton (1999) set of supposedly distant clouds.

(*c*) Lubowicz et al. (2000) conclude that the galactic enter must have accreted quite a lot of primordial gas in recent gigayears to keep the D/H ratio as high as the $1.7 \pm 0.3 \times 10^{-6}$ they observed there.

(*d*) Unless the accretion deduced by Lubowicz et al. (2000) ended the day before yesterday, there must still be many clouds at large distances, while Combes & Charmandaris (2000) deduce a typical distance of 20 kpc from the absence of HCO^+ in 27 that are already known to contain heavy elements and happen to be in the directions of bright millimeter sources (quasars).

(*e*) HVCs with a tenth or more of solar metallicity are not rare (Bowen et al. 2000, reporting the first ones with manganese; Brosch et al. 1999 on a possible association of dust with infalling H I; Lehner et al. 1999 on several with multiple absorption components of Ca II and Na I only a few km/sec apart; Zwaan 2000, a mini-review).

(*f*) If the HVCs are virialized, then the ratio of dark to baryonic mass is 10–50, like that in (some) dwarf galaxies (Braun & Burton 2000; Zwaan 2000; Briggs et al. 2000).

The alternative to primordial, newly-arriving gas to describe the place of the HVCs in the great scheme of things is as the "return current" of a fountain structure, in which gas is driven at high speed out of the galactic plane, in chimneys and diffusely (Collins et al. 2000), by supernovae and falls back down most of the time (Shapiro & Field 1976 said it first).

Can observations of other galaxies help us, if the Milky Way is not unique? To a certain extent, yes. Chimneys and fountains (the hot, outgoing part) are fairly common (Pietsch et al. 2000; Alton et al. 2000; Sembach et al. 1999; Rossa & Dettmar 2000; Wills et al. 1999), and the outgoing stuff in NGC 5668 (Jimenez-Vicente & Battaner 2000) would look like high velocity clouds if we were down inside it (cf. Schulman et al. 1994).

On the other (fifth or sixth) hand, a hard look for H I with large relative velocities around 1 Mpc from 300 galaxies and 14 groups found none around either (Zwaan & Briggs 2000), where about 250 around the galaxies and 70 around the groups were expected if the HVCs we see from the Milky Way fill the Local Group and we are a typical galaxy and group. This need not be the final answer—perhaps we are not living in a typical galaxy. But the result is certainly suggestive. It is also a paper that is easy to like. The authors have consulted and thank a number of colleagues who have been strong supporters of the "far out" picture.

6.1.2. Cooling Flows

"Cooling flow" is shorthand for a cluster of galaxies in which X-ray data reveal that the central gas really is cooler than gas further out or, at least, that the cooling time is much smaller than the age of the universe, so that gas will inevitably lose pressure support and flow inwards. Data from the *Einstein* observatory, though the years have rolled over their heads, still require this to be happening in many clusters (Arabadjis & Bregman 2000), with continued reinforcements from all the relevant satellites since. Many of the implied flows are as large as 10^3 $M_\odot$ yr^{-1} (Allen 2000), though some clusters, especially ones of small total mass, appear to be immune (Nakazawa et al. 2000).

Where the gas cools or goes to remains something of a puzzle. The "soft" *ROSAT* band follows it down to 10^5–10^6 K in a few clusters (Buote 2000). There is sometimes a bit of nebular (meaning 10^4 K) gas (Hutchings & Balogh 2000). And there we lose it. The year saw no reports of significant neutral gas or ongoing star formation to modify the situation described in Ap94, § 10, and only an upper limit on CO (Fujita et al. 2000). And, while some of the gas can and should slip into a central black hole of the dominant cluster galaxy (Quataert & Narayan 2000), it cannot all go there, or central black holes would be much brighter than they actually are (Brighenti & Mathews 2000).

One might suppose that the cooling flow process was systematically interrupted by the next merger, so that not much gas ever actually gets to the center or gets very cool. Imanishi & Ueno (1999) report that there is nedeed some suppression by mergers of the central X-ray emission of ultraluminous infrared galaxies, but a cluster-sized cooling flow soldiers on, at least in Abell 644 (Bauer & Sarazin 2000). Hanlan & Bregman (2000) point out that the standard scenario cannot really apply to giant elliptical galaxies, because it predicts a central component that isn't actually seen, implying that "more work is needed," but again this does not seem to help much with the global problem.

6.1.3. Accretion Disk Instabilities

A truly unstable disk would be one that disappears completely, perhaps to reform in due course, as in the BeXRB A0535+26 (Haigh et al. 1999). All the cataclysmic binaries we see (Fedorova et al. 2000) and at least one AGN accretion disk (Jones et al. 2000a) are stable in this sense, though they may sometimes get stuck between accretion and excretion (Ikhsanov 2000 on AE Aqr).

What is meant here (and usually by the phrase) is the sort of instability that turns smooth, laminar, differentially-rotating flows into distorted shapes, waves, turbulence, and other general untidiness. Instabilities in this sense are generally regarded as a Good Thing in theoretical astrophysics, because they permit efficient transport of angular momentum outward and mass inward to fuel accretion-powered sources. We will discuss disk distortions first, then sudden changes in disk vicosity as a driver of dwarf novae (etc.), and finally the various classes of instability modes that provide angular momentum transport and other sorts of couplings.

Easiest to describe of the distortions are two-armed spirals and warps. An $m = 2$ spiral was reported in the cataclysmic binary IP Peg some years ago (Ap97, § 7.3). Similar ones are now to be found in a good many other CVs (Joergens et al. 2000), in low mass X-ray binaries (Tagger & Pellat 1999, on their role in producing low frequency quasi-periodic oscillations in LMXRBs), and other kinds of close binary systems (Lanzafame et al. 2000). Additional theoretical work on IP Peg etc. has been done by Makita et al. (2000) and Blondin (2000). Goodman & Evans (1999) report the result of what is said to be the first analytically solved stability analysis of a differentially rotating, Mestel (1965) disk. Whether or not an S forms depends on how waves reflect back from the central cusp, which is a black hole for Goodman & Evans, but was not for Mestel, farsighted though he has always been.

Spiral arms also occur in spiral galaxies, where the driver can be either internal instabilities or an external perturber, or, sometimes, both in a single galaxy (Shu et al. 2000), so we guess they belong here. Particularly challenging are data showing that galaxies traditionally supposed to be flocculent actually have an underlying $m = 2$ grand design (Elmegreen et al. 1999) and that leading arms are not so rare as you might have been taught (Puerari et al. 2000). And a quick reminder of the package insert, neither we nor the authors are claiming these as the first reports of these phenomena, just as reports during the fiscal year. Incidentally, like diamonds heated above 4827°C, a spiral is not forever (Patsis & Kaufmann 1999; Griv et al. 2000).

Next easiest to describe are warped disks (remember the fate of phonograph records left on the curved back seat of a car parked in summer sunshine?). Warps must be common on galactic scales since they are shared by the H I in the Milky Way (Weaver & Williams 1974) and the stars of M31 (Innanen et al. 1982), and, this year, some Seyfert galaxies (Schinnerer et al. 2000) and merger products like NGC 6240 (Tecza et al. 2000). And, on the scale of the sorts of accretion disks we thought we had started out to talk about in this section, warps are to be found around some black hole X-ray binaries (Esin et al. 2000a in A0620−00), the X-ray binaries that display quasi-periodic oscillations, and even around T Tauri stars (Lai et al. 1999).

Next (and coming gradually closer to the sorts of instabilities you thought the section title implied) are the sort responsible for the outbursts of dwarf novae. For decades, there has been a gentle controversy between a sudden change in the disk itself and a sudden change in outflow from the donor star (or, rather, between advocates of these two pictures). The disk sort is a result of viscosity increasing suddenly when density in the disk rises above a critical value, the star sort a result of pulsation, activity cycles, or any of the other ills to which stars are heir. The more viscous author has been a long-sitting advocate of the disk instability as the primary one, but several papers published during academic year 2000 cast strong votes for "both please." These include Hellier et al. (2000) on intermediate polars, Rosenzweig et al. (2000) on SU UMa, and Baptista et al. (2000) and Baptista & Catalan (2000) both on EX Dra.

It is, however, true that when authors from other territories invoke a "dwarf-nova type instability," for instance to model black hole binary sources like GRO 1655−40 and A0620−00, what they have in mind is the viscosity-driven disk picture (Esin et al. 2000b; Menou et al. 2000; Gu & Lu 2000).

Finally, we come to the phenomena normally described as "disk instabilities." Two analyses during the year focused on particular modes. Pietrini & Krolik (2000) on convection, which they conclude will happen in all reasonable Shakura-Sunyaev disks (the ones that hide all the uncertainties about viscosity in a single parameter called α) and Li et al. (2000c) on an analog to the Rossby waves in planetary atmospheres. Upping the ante, two other projects identified and classified large numbers of modes of instability. For a system with cylindrical symmetry, shear, rotation, stratified density, and magnetic field, Kim & Ostriker (2000) find nine, five with toroidal fields and four with poloidal fields; two overstable and seven unstable. The most frustrating thing about this paper is that the main table listing properties of the modes identifies them only by acronyms (FM, ATB, BIB, etc.) and the key is not nearby. Only uncertainty about what the letters actually means protects you from having us tell you that the BIB instability protects black holes from sloppy disks. But the record goes to Balbus (2000), who reports 11 different instabilities, in an analysis that relies on an analogy between angular momentum and entropy that was first pointed out by Lord Rayleigh. Neither paper considered a Shakespearean classification in which some disks are born unstable, some achieve instability, and others have instability thrust upon them.

6.1.4. Advection-Dominated Accretion Flow

When quasars and such were young and beautiful, about 35 years ago, it was customary to be astounded by how bright they are, especially when it was recognized that spherical accretion would take most of the available gravitational potential energy down the tubes into the black hole with it. In recent years, it has become customary to be astounded at how faint many sources powered by black holes are (including the one at the center of the Milky Way) and to try to figure out a way to make inflowing gas take most of the available energy down with it, even when the accretion is not spherical. One solution is called ADAF, advection-dominated accretion flow. The dictionary meaning of advection is heat transport by horizontal air flow—close enough—and the etymology is ad (to) + vehere (to carry, think "vehicle"). You might feel that roots meaning "carry with" rather than "carry to" would be more appropriate, but "convection" is already in use for other purposes. The verb "advect" is, by the way, a back formation, like "to buttle" from butler.

In common with many new ideas, ADAF a few years ago (Ap95, § 2.3) explained just about everything. It remains true that an assortment of active galaxies and X-ray binaries have spectra that are nicely fit by a (geometrically) thin accretion disk having a hole in the middle where stuff breaks loose and falls in without radiating much more (Quateart et al. 1999; Lu & Yu 1999; Liu et al. 1999; Meyer et al. 2000b; Chary et al. 2000; Mineshige et al. 2000; Watarai et al. 2000), and you can set up (calculated!) physical conditions where this combination should occur (Kaburaki 2000). The larger the accretion rate, the more complex the calculations become (Park & Ostriker 1999, with a "complexity" threshold near 5% of the Eddington accretion rate) and the more carefully they need to be done (Manmoto et al. 2000).

Predictably, you can also set up initial conditions where ADAF won't occur (Bisnovatyi-Kogan & Lovelace 2000; Janiuk et al. 2000).

Now, suppose that you know (from stellar dynamics, phase lags, or whatever) that there is a Big Bad Wolf, sorry, big black hole inside something, and it still isn't very bright. What are the alternatives to ADAF? Well, perhaps there wasn't much gas around in the first place to be accreted. But, if you know from observations that gas is not in short supply, perhaps most of it gets blown back out from some intermediate radius before it has a chance to radiate much (Blandford & Begelman 1999).

Consider Sgr A* as a case study. Manmoto (2000a) fits the spectrum with ADAF around Kerr black hole. Coker et al. (1999), on the other hand, conclude that there is no steady accretion disk, just occasional stray clouds falling in. And, go on other modelers, an outgoing relativistic jet is the most promising source for the photons reaching us (Coker et al. 1999; Agol 2000). Garcia et al. (2000) are really talking about a jet as the best fit to the *Chandra* data on the core source of M31 but mention that the same probably applies to Sgr A*. Garcia et al. make the additional very important point that the radio emission from Sgr A* shows very little Faraday rotation, which means that there is indeed not much (ionized, magnetized) gas around. Belloni et al. (2000b) present a rather similar picture for the microquasar (black hole X-ray binary with apparent superluminal motion) GRS 1915+105, in which the gas shoved out by the jet has never reached very close to the black hole.

Theorists, of course, get the last word. Stone et al. (1999) set out to model non-radiative accretion onto a black hole and found that most of the gas goes back out again in roughly isotropic, convective flow. Abramowicz et al. (2000) have responded that indeed outflow is inevitable, but that this does not negate the occurrence of ADAF. They mention consultation with Blandford & Begelman, but not Stone.

The bottom ("you pays your money and you takes your choice") line appears to be that this is yet another case of "both, please," with the amount of advection varying from little to lots as a function of the local inner disk (if any!) vicosity and on how observers originally classified the sources.

6.1.5. Young Stellar Objects

Most of us are persuaded that stars form out of more diffuse material which must, therefore, condense, contract, accrete etc. Nevertheless, nearly all observations of pre-main-sequence and proto-stars are dominated by outflowing stuff (next section, on collimation). The same can, of course, be said for active galactic nuclei (indeed has been said many times at conferences by G. R. Burbidge and others). V. A. Ambartsumyan was perhaps unique in also drawing the "obvious" conclusion from the stellar data and saying that star formation occurs by expansion out of very dense, pre-stellar matter (putting planetary nebulae, for instance, near the beginning of the story, not the end).

Starting, in spite of these distinguished hold-outs, with the conventional wisdom, we are happy to report that some dense cores in molecular clouds are indeed contracting rather faster than they are rotating (Lai & Crutcher 2000) and that the outflow really matters only at relatively late stages, if you are interested mostly in the final mass of the star (Padoan et al. 1999). Sylvester & Mannings (2000) report that at least one Beta Pic style disk is still self-luminous from ongoing accretion. Contraction does not, however, happen as fast as you would expect from free fall in dense cores, implying some magnetic or other support (Lee et al. 1999a). In addition some Class I sources (the sort that have just finished their major epoch of contraction) are rotating at break-up (Greene & Lada 2000).

Thus, in an overwhelming rediscovery of the obvious and well-known, we conclude that, to form stars, you (or the gas cloud) must shed both angular momentum and magnetic flux, and that one of the two primary jobs of disks around young stellar objects is to take care of this. Their other task is, of course, to form planets (§ 3.2). Before going on to list the various proposals for just how YSO disks do their job (which leads on to collimation in the next section), a brief pause is in order to note (*a*) the first circumtertiary (circumtrinary?) disk (Monin & Bouvier 2000) and (*b*) the first results from NANDEN, the 4-meter Japanese millimeter telescope at Las Campanas, a set of papers beginning with Fukui et al. (1999), most of which report observations of star formation regions.

Now, moving on out (from the point of view of the angular momentum, so that some of the matter can move on in), two groups cast votes in favor of tidally induced gravitational torques (Yorke & Bodenheimer 1999; Nomura & Mineshige 2000) as being more important than turbulent viscosity. Pickett et al. (2000) found that an S-shaped pattern is likely to form in massive YSO disks (§ 6.1.3 above) and that this can produce the desired transport. Vasconcelos et al. (2000) conclude that the Balbus-Hawley instability may occur (the requisite magnetic field being there anyhow and the necessary level of ionization coming from Alfvénic heating). Like any increase in disk viscosity, this will enhance mass and angular momentum transport.

Finally, Ferreira et al. (2000) focus on the interaction between the magnetosphere of a protostar and the field of its accretion disk and find that this can reduce the rotation of the central object to 10%–20% of break-up while the protostar is still largely hidden from view. Outgoing material comes from both magnetosphere and disk and is somewhat bipolar, carrying us simultaneously forward and backward (for bipolar outflow observed along its axis) to the next section.

6.2. Collimation

"Consider a spherical cow" is a standard joke at the expense of physicists or engineers (depending on who is telling it) and is probably not a bad approximation for calculating heat loss, evaporation, and food and water requirements. The next step is, of course, the oblate or bipolar cow. ("One end is moo the other milk" said Ogden Nash[4]), and a remarkably wide range of subjects of astronomical investigation are, to second order, bipolar, collimated, or jet-like in their excreta. The classes we found were young or youngish stellar objects (including Herbig-Haros and Eta Car), planetary nebulae, cataclysmic variables, supernovae, X-ray binaries, gamma-ray bursters, active galactic nuclei (where one of the truly ancient questions is whether typical jet are one or two sided), and undoubtedly we forgot to look for some others. The Sun is apparently not an example, with oblate corona and a wind of more complex topology (§ 2.6).

6.2.1. Young Stellar Objects

Collimated, magnetic, rotating outflows play a vital role in star formation. Without them, gravity might never win out over magnetic, turbulent, rotational, and other support, and we

---

[4] Consider how few anthologies could have reprinted this gem if he had begun by saying, "The cow is of the bovine herd …."

would all spend our entire lives as cold gas clouds. (Pause, while you consider colleagues who seem to spend their entire lives as hot gas clouds.)

Once upon a time, the less collimated author was firmly of the opinion that, if infall and outflow were going to co-exist, then the outflow should occur at the equator of a rotating protostar, with co-rotation enforced by a strongish, poloidal magnetic field, so that when gas at last broke loose, it carried away more than its fair share of angular momentum. The infall would happen at the poles, where rotation was well below breakup. Modern truth is just the opposite, both observations (Tamura et al. 1999 on polarization in T Tauri stars) and calculations (Tomisaka 2000) say that you have a toroidal field in the disk with bipolar outflow perpendicular to it. Even Eta Car has a torus around its waist (Morris et al. 1999).

If you are coming fresh to this topic, the place to start is undoubtedly with Shu, Adams, & Lizano (1987), who rank as the top two major advances of the previous decade or so the recognition of (*a*) the relative inefficiency of star formation and (*b*) the ubiquity of outflows.

Flowing furthest out are the Herbig-Haro objects, on which we have pontificated previously (Ap96, § 4.1). Originally, these were mysteriously isolated optical emission nebulae far from any obvious exciting star. One now thinks of them as the whole path from YSO out to the "beam dump" two or more parsecs away (Cabritt & Raga 2000; Canto et al. 2000; Eisloeffel 2000). If a Herbig-Haro object, like a short story, has a beginning, a middle, and an end, the beginning is near a YSO, with disk and, often, some blobby, bipolar stuff nearby, even if the jet is one sided (Molinari et al. 2000a on HH 7, 8, 9, and 10). Some of the substructure is already established there (Rodriguez et al. 2000a on HH 1 and 2). The middle contains knots, which can be either due primarily to shocks resulting from variable ejection speed (Hartigan et al. 2000 on L1551) or not due primarily to shocks resulting from variable ejection speed (Lee & Burton 2000). At the end, they die either because they run into something (Cabritt & Raga 2000 on observations of HH 34, de Gouveia dal Pino 1999, a calculation) or because ambipolar diffusion robs them of their collimation and they become mere bipolar outflow (Frank et al. 1999), or, occasionally, because they get completely ionized (Rosado et al. 1999). There is still an official numbered roster of HHs, but the other, uncounted, structures in the Serpens cloud shown by Davis et al. (1999) look a good deal like HH 455–460.

What can be said about the details of how a rotating, magnetised disk feeds outgoing polar flows or jets that carry field and angular momentum with them? We caught seven papers addressing this issue during the year, which, like lists of seven causes of the Civil War, suggests that no one of them can be the whole story. Here they are, in the order in which they appeared, which happens to put the field-free one at the end:

- In at the equator and out at the poles, say Lery et al. (1999), with the outflow driven by Poynting flux and radiative heating.
- Jets are easy to make, say Turner et al. (1999), contradicting some things we were told last year (Ap99, § 4.3).
- The interaction between stellar magnetosphere and accretion disk is critical, say Goodson et al. (1999).
- Some jets precess, say Rodriguez-Franco et al. (1999), and this helps them to drive larger molecular outflows. Some AGN jets probably also precess (Sudou & Taniguchi 2000), but it is not so clear what this is good for.
- Oranges and lemons, say the bells of St. Clements. Oops, wrong song.
- Poloidal magnetic fields are not totally useless tending to stabilize, say Gardiner et al. (2000) and with lots of pretty pictures to show it.
- Weaker winds will be more collimated, say Delamarter et al. (2000).
- Line profile data actually require simultaneous infall and outflow, say Rawlings et al. (2000), who examined HCO^+.
- There will always be a place in battle for the well-bred horse, said a distinguished general in the lead-up to World War II.
- The far infrared giveth (traces the toroidal disk) and the near infrared taketh away (traces the bipolar outflow) in AFGL 2136, say Harvey et al. (2000).
- Evaporating proplyd disks can explain both monopolar and bipolar outflows, say Richling & Yorke (2000).

Theory and observation again concur on an extra refinement of YSO jets: the best collimated, most focused stuff is a dense, fast moving core, surrounded by a lower density sheath (Bacciotti et al. 2000, a STIS image of DG Tau; Frank et al. 2000; Stone & Hardee 2000, who find that a magnetic field as weak as 10^{-4} G provides confinement of the gas along the jet axis).

And, of course, some day it is all over. The disk, once as massive as the central core (Shepherd & Kurtz 1999), fades to a mere shadow of its former self (Duvert et al. 2000 on the transition from classical to weak-lined T Tauri stars), and, with loss of collimation, you may even eventually get equatorial winds (Beskin & Okamoto 2000), of the sort once envisaged by the more equatorial author. The moral of this is that you should never throw away an old hypothesis. Like wide lapels and shoes with pointed toes, it will come back into fashion.

Though disks thus vanish, some fairly old stars still show infrared emission attributable to a flat distribution of dust (Song et al. 2000). Well, so would our Sun, seen from far, but not too far, away. Up close it is called the zodiacal light. Both it and the dust seen around other old stars are probably secondary, flaked off asteroids, moons, comets, and all, which formed long ago, the first time the star had a disk. Forming planets is, of course, the other thing that accretion disks around YSOs are good for.

6.2.2. Planetary Nebulae

That none of these are spherical and many are quite complicated in form was noted in § 4.1 (Ueta et al. 2000; Bachiller et al. 2000; Solf 2000; Doyle et al. 2000; Vasquez et al. 2000; Sahai 2000). In contrast to virtually all other sorts of astronomical structures in this section, no one writing about planetary nebulae seems to think that magnetic fields are of much importance. If the theorem due to Woltjer ("The larger our ignorance, the stronger the magnetic field.") still obtains, then PNe must be the best-understood of bipolar structures. This may conceivably be true.

Many planetaries have binary nuclei (Phillips 2000a), which helps because material lost from binaries, especially during a common envelope phase, is likely to be concentrated in the equatorial plane, leaving the polar directions for faster, lower-density gas to stream out later. Josselin et al. (2000) have observed a bunch in CO and remind us that the molecular gas forms a ring around the bipolar outflow exactly as you might have guessed. More complex, and producing bipoles of narrower waists, is the scenario of Soker & Rappaport (2000) in which the hot star (main sequence or white dwarf) has an accretion disk provided by an AGB companion, forcing the wind to come out at the poles (and, of course, providing some diffuse gas to make it out of, if you feel the need). Another oddity, probably of binary provenance, is K4-47, whose optical line emission comes only from core, jet, and moving blobs, conceivably (Corradi et al. 2000) with the binary contributing precession as well as collimation. Some PNe are, however, not bipolar at all, looking (like the one in Lyrae) like plain old rings.

6.2.3. Cataclysmic Variables

A self-respecting CV is a close binary with an extended star feeding an accretion disk around a white dwarf. Subsets are the classical novae and recurrent novae (which have nuclear explosions), the dwarf novae and nova-like variables (with changes in brightness due to some instability in rate of mass accretion on to the white dwarf), and all of the above with magnetic fields of various strengths attached to the white dwarf.

Famous novae look fairly round (think of the standard Astronomy 100 image of GK Per = Nova Persei 1901). Those like Nova Herculis 1934 with axial ratios of 3:2 or thereabouts are, says Scott (2000), prolate. He also finds that the composition of the ejecta varies with latitude and attributes both to rapid rotation of the exploding white dwarf, rather than to binary star effects of the sort advertised for planetary nebulae.

The symbiotic stars are, roughly, CVs with giant donors and much longer orbit periods. R Acquarii was one of the few targets for which a pre-fix *HST* image already had one saying, "oh, wow," now I see what is going on. What you probably see there is a very extended envelope of the giant, material in the orbit plane, and collimated jets flowing outward from the white dwarf. Tuthill et al. (2000a) show an image in the near infrared from Keck used as an interferometer that has many of the same structures.

Year 2000 added bipolar outflow associated with two more symbiotics, Hen 3-1341 (Tomov et al. 2000), which has bipolar jets during its outbursts but not otherwise, and Hen 2-90, which has always been bipolar, but just got promoted from planetary nebula to symbiotic with a B [e] component (Sahai & Nyman 2000). In addition to the usual "magnetic field plus rotation" modelers can draw also on binary processes.

CVs do not shed much when they are not undergoing nuclear explosions. Indeed a traditional test to distinguish a dwarf nova with very long time between outbursts (like WZ Sge) from a real nova or recurrent nova is the absence of spectroscopic or morphological evidence for expelled material. There is, however, characteristically a wind off the accretion disk, driven by radiation pressure, and it is not spherically symmetric (Feldmeier & Shlosman 1999).

6.2.4. Supernovae

Most of the middle-aged supernova remnants are only moderately non-spherical, at least if you allow for differential extinction (think of Cas A and the Cygnus Loop) and/or look at X-ray or radio maps, though we know that many neutron stars begin their lives with significant recoil velocities that must be mirrored by the diffuse ejecta (§ 4.3). In the case of the Crab Nebula, the inner structure shows considerably more collimation than the 3:2 axial ratio of the outer nebula (Weisskopf et al. 2000) and it is a safe prediction (given that falsification will take 1000 years) that the same will be true for SN 1987A when it is the same age (Lawrence et al. 2000).

One's first reaction is that, if neutron stars are to be sent flying at several hundred km/sec, nebular countermotion should be more conspicuous. But remember that the remnant mass typically exceeds the neutron star mass and the expansion velocity typically exceeds the kick velocity, both by factors of 3–10. An asymmetry of 10% will do, and if we think it is in the wrong direction (as in the Crab, where both the pulsar velocity and the brightest emission are north west of the pulsar) it just shows that we don't understand the situation. The Crab does, anyhow, seem to have sort of a belt around the waist of its elongated main remnant (cf. papers cited in Ap95, § 6.8).

6.2.5. X-Ray Binaries and "Microquasars"

X-ray binaries have even less right than cataclysmic binaries to expel material, since the energy per gram available from fusion is considerably less than the gravitational binding energy on a neutron star (It is larger on a white dwarf). Apart from SS 433 (whose surrounding nebulosity, seen at many wavelengths, has perhaps been continuously fed from the central binary, rather than representing one-shot supernova ejection), the main evidence for collimated outflow, indeed outflow of any kind, is the radio jets found in about 20% of persistent X-ray binaries "Persistent" in this context does not mean that they are tiresome about wanting to be cited, but just that they are generally at home and turned on when you come to visit. Interestingly, the ones with neutron stars and the ones with black holes are not very different at radio wavelengths, saying that the mechanism must work at either a surface or a horizon (Fender & Hendry 2000). Some fast jets belong to black hole XRBs (Cyg X–3 as well as SS 433), and Watarai & Fukue (1999) say that a radiation-pressure-driven wind off an accretion disk can provide the necessary kinetic energy and collimation.

But the fastest jets in the west belong to a couple (so far) of transient sources which, in the radio, show a one-sided, core-jet structure with (as for many AGNs) motion so rapid that you would think it faster than the speed of light across the sky (Ap94, § 5.4). In fact, GRS 1955+105 and GRO J1655–40 both have jet speeds close to 90% of *c*, but aimed more or less directly at us. GRS 1915 also has a counterjet headed away from us, but it is less well collimated than the approaching one (Garcia-Miro et al. 1999) and GRO J1655 has a magnetic field perpendicular to its jet over most of its length (Hannikainen et al. 2000). Both subdued counterjets and perpendicular fields are often found in various AGNs, further justifying the name microquasar for the local ones. It is anyhow easier to write and abbreviate than "galactic superluminal source."

6.2.6. Gamma-Ray Bursters

The highly relativistic beaming and its observational consequences in models of gamma-ray bursters appear in § 8, which reports no more of the theory than "really rapid rotation" (probably of a black hole) and "very strong magnetic fields." The next level of sophistication seems to be detailed numerical modeling, at which point we gave up. This large step from waving of hands to waiving of comprehensibility is shared by many of the discussions of collimation in young stellar objects, active galaxies, and so forth. The situation is reminiscent of the hoary old question, "what makes red giants?" People will tell you several different things (Ap95, § 12.3; Ap98, § 3.8), none of which sounds very convincing, and then be reduced to telling you, "Well, it comes out of the equations when you evolve a star." Indeed it does, and in this sense, what makes red giants is a solved problem. Perhaps the jet collimation one is too.

6.2.7. Active Galactic Nuclei

Here, at the other end of the length scale away from young stellar objects, we come to the second context where, without significant collimation, life would be very different. Indeed active galactic nuclei might never have been declared to be a class, since the strong extragalactic radio sources of the sort catalogued in 3C, for which optical astronomers set out in the early 1950's to find counterparts, produce their synchrotron radio photons from some combination of an inner core-jet structure (often unresolved without VLBI) and outer lobe structures of sizes up to a megaparsec, fed from the center by those jets and their extensions. The jets set out at an appreciable fraction of the speed of light, signified by rapid changes in central structure and front/back asymmetries. They may slow down as they go (Bondi et al. 2000), but even typical extended lobes are expanding at about 10% of *c* (Arshakian & Longair 2000).

What is in the jets? Franco Pacini is supposed to have said that relativistic tomatoes would do. In practice, one knows that there is magnetic field (or very low frequency, coherent electromagnetic waves), organized enough to yield net polarization (e.g., Ros et al. 2000 on the change in field direction along the jet of 3C 345, and Aloy et al. 2000a on a helical field in blazar 1055+018). There must also be particles, relativistic enough to radiate. Electrons are essential (there being no other negative charges in our particle box). And, of course, there must also be positrons or protons for charge neutrality on large scales. Arguments have been made over the years for, on the one hand, mostly positrons, to avoid net Faraday rotation, and, on the other hand, mostly protons, to transport kinetic energy efficiently. Sikora & Madejski (2000) advocate the increasingly familiar "both, please" for the jets of blazars on the basis of their ratios of synchrotron X-rays to radio emission. The jets start out as electron-proton fluids with electron-positron pair production along the way, when the particles meet up with X- and gamma-ray photons in the hot, inner accretion disk. The jets are sturdy (compared to ripe tomatoes) but not indomitable (compared to Franco Pacini), and occasional bends, when they encounter other salad ingredients, are both seen (Lara et al. 1999) and modeled (Higgins et al. 1999).

Some of the nearer (and, unfortunately, less powerful) AGNs allow us to take a fairly close look at what is happening. In Cen A, for instance, the axis of the radio jet is more or less parallel to the axis of a 240×75 pc torus of infrared-emitting material (Bryant & Hunstead 1999). This provides a close connection between accretion and collimation and also indicates that angular momentum on large scales is important. Similar things can be said about the alignment of jet, disk, and extended radio components of NGC 4258 (Cecil et al. 2000).

On the theoretical side, Natarajan & Armitage (1999) note that even a warped disk will align the jet of an AGN in 10^6 yr, less than 10% of its lifetime. Somehow this reminds one of the truism that even paranoids have real enemies.

We note in § 11.2 (on black holes in AGNs) that rapid rotation of the BH itself encourages more energetic, collimated jets and may indeed be needed to make a serious quasar. Koide et al. (2000) echo this (with $a/m = 0.95$ being a good place to start) and go on to say that energy extraction and collimation are most efficient when the surrounding disk and the black hole are counter-rotating. Perhaps the evolutionary pattern is then not toward misalignment but a slow-down of the BH rotation to $a = 0$, at which time further accretion can spin it up the other way, to quase again another day.

Two sorts of acceleration are required to make AGNs happen—individual electrons must be pushed up to $\gamma \approx 10^3$ or more, and the relativistic fluid as a whole must be shoved along at a bulk $\Gamma = 3$–10 or more. The $\Gamma = 25$ found by Qian et al. (2000) for the blazar A0 0235+164 pushes the bounds of credibility, and the brightness temperature of 3C 279, $T_b \gtrsim 5 \times 10^{12}$ K (Piner et al. 2000) is the same sort of demanding beast. The alternative is some sort of coherent emission process, as must definitely occur in pulsars, which you may find either more or less credible.

In any case, when Heinz & Begelman (1999) say that acceleration occurs in a region of tangled magnetic field, they mean acceleration of the bulk plasma, while when Birk & Lesch (2000) say that acceleration must occur all along the jet of M87 (at the expense of magnetic energy) they mean acceleration of the individual electrons. Moving along with the jet, Heinz & Begelman (2000) attribute most of the collimation to the effect of pushing through a medium of decreasing density (not rotation and field effects). Unexpected observational support comes in the form of evidence for recollimation outside of 20 kpc (where you more or less run out of interstellar material in most galaxies). The evidence is rather indirect—the disappearance at that size scale of a correlation of the size of the hot spot (where the jet dumps its energy) with source size as a whole (Jeyakumar & Saikia 2000). And, just as a rose is a rose is a rose, the jet is the jet is the jet, or, at least, Hardcastle & Worrall (2000) say that the optical radio, and X-ray nuclei of 3C galaxies coincide and lie at the base of the radio jet. Truly, we would have worried if they had found the contrary.

Are AGN jets characteristically one-sided or two-sided? This is an “old refrain” question to which, by now, you will be expecting the answer, “yes,” or “both.” We can distinguish four levels of lopsidedness. First, there are sources where the total luminosity and spectrum are about the same on both sides. Cen A is one (Alvarez et al. 2000), and its arcsecond-scale counterjet has probably just been spotted by *Chandra* (Kraft et al. 2000). The 10 compact, symmetric radio galaxies found by Peck & Taylor (2000) are face-on examples of the evolutionary phase preceding Cen A.

Second, there are sources with jets going in both directions, but the emission from one is noticeably absorbed by material in something like an accretion disk (Walker et al. 2000b on 3C 84 = NGC 1275; van Langevelde et al. 2000 and Jones et al. 2000a on NGC 4261; and Kameno et al. 2000 on OQ 208). Third, there are sources in which the real difference between jets that look unequal is comparable with the differences introduced by absorption, Doppler boosting, and light travel time asymmetries (Aloy et al. 2000b; Jeyakumar & Saikia 2000; Bondi et al. 2000; Arshakian & Longair 2000). Fourth, there are sources in which, no matter how hard you look, you just don’t find a counterjet. Cygnus A, the first and prototypical radio galaxy, and Pictor A are in this class (Tingay et al. 2000).

In these sources that are very asymmetric on small scales, the extended radio lobe on the jetless side is generally a good deal fainter than its jet-fed mate. Explanations, including both permanent asymmetry and flip-flopping, have competed over the years, and there was not a definitive winner in 2000. Igumenschchev (2000) reported, however, that some combinations of initial conditions in his model of black hole plus accretion disk led to unipolar outflows.

7. FOR DESTRUCTION, ICE: COLLISIONS, DISRUPTIONS, AND TIDAL TAILS

You might (or might not) want to assign this section the subtext, “When bad things happen to good stars and galaxies.”

7.1. SCAM

This acronym, which stands for stellar collisions and mergers, was the title (innocently adopted, the organizers said) of a three-day workshop, which the less innocent author attended, coming away with the expectation that there would be lots of papers on the topic during the year. She was wrong, hence the relative compactness of the section.

The SX Phe stars and other blue stragglers (stars seemingly too hot, massive, and young to belong to the neighborhood) continue to be the class for which collisions and mergers in binary systems are most often invoked (Ap91, § 5). Some are binaries and some are not (Preston & Landolt 1999). Analysis of their pulsation modes remains the best mass indicator for the single ones (Zhou et al. 1999), and the name “dwarf Cepheid” does not add any information and should probably be discontinued.

Blue stragglers are commonest (or at least easiest to recognize) in globular clusters (Rood et al. 1999 on M3), and the distribution of their ages in 47 Tuc may be telling us that the cluster went through core collapse a couple of billion years ago (Sills et al. 2000). In the halo field there are many blue, metal-poor, intermediate age, binaries with small mass functions (Preston & Sneden 2000). These must have arisen out of the mass transfer process proposed by McCrea (1964) rather than from complete mergers. In any case, multiple origins are required. On the one hand, mergers appear unlikely in the four open clusters studied by Andrievsky et al. (2000) where the stragglers rotate more slowly than the other stars. And, on the other hand, collisions of stars not previously in binary pairs is unlikely for NGC 6791 which has a small central density (Yong et al. 2000). Stellar encounters, collisions, envelope-stripping, and mergers may or may not have anything to do with making some globulars bluest at their centers (Howell et al. 2000).

Other sorts of stars for which SCAM may be part of the story include (*a*) luminous blue variables (Pasquali et al. 2000), (*b*) helium stars with large surface gravity (Saio & Jeffery 2000), (*c*) the disk of Beta Pic (Kalas et al. 2000), and (*d*) the most massive stars, which are both rather difficult to form through a single accretion process and preferentially found in large, dense star clusters (Massi et al. 2000; Figer et al. 2000). Ballantyne et al. (2000) showcase an isolated O8.5 V star, asking whether a merger origin is possible and coming down firmly on the fence, while Norberg & Maeder (2000) definitely favor accretion. In any case, stars formed in dense environments like the galactic center, will inevitably be vulnerable to collision damage (Alexander 1999), though the collision damage waiver is almost never a good investment.

Stars near the centers of active galactic nuclei also find themselves well within the madding crowd, and stellar collisions probably contribute to AGN variability (Torricelli-Ciamponi et al. 2000), an idea that can be traced all the way back to the first, 1963, Texas Symposium (Gold et al. 1965).

7.2. E Pluribus Galactibus Unum Galacticum

Galaxies and clusters thereof are forever tearing each other apart and putting the pieces back together again. Indeed the processes are really a continuum, since loss of identity (especially for the smaller partner) is a prerequisite to becoming incorporated in the larger whole (almost enough to make a dwarf galaxy feel religious).

Thus, "What is a galaxy?" and "Is it a group or a galaxy?" are not such silly questions as they sound to astronomers who remember when galaxies were "the basic building blocks of the universe." Even with so casual a definition as "something that feels its own self-gravity more strongly than the effects of its neighbors" you may have to look hard to see the difference. On the one hand, for instance, HCG 18 is really a single galaxy with star-forming clumps (Plana et al. 2000) on the grounds that the velocity field is continuous across it. HCG 31 and 54 may be similar (and the only other cases in the Hickson catalog of 100 or so compact groups). But, on the other hand, something like 20% of what are usually described as ultra-luminous infrared galaxies are really small groups with mergers in their immediate past or future (Borne et al. 2000). Evans et al. (2000a) show some of the details for IRAS 14348−144, where, so far, only the less luminous galaxies have been robbed of their individual gas components. Jones et al. (2000c) and Romer et al. (2000) identify additional group mergers in progress from X-ray images. If compact groups resist this process for longer than you would have expected, it may be because they actually contain many more faint galaxies than are usually included in the dynamical calculations (Tovmassian & Chavushyan 2000; Murayama et al. 2000, reporting a seventh member of the Seyfert Sextet; it plays piccolo).

Even our own beloved Local Group will someday be a giant elliptical, with specific frequency of globular clusters = 3 (Forbes et al. 2000). Not having figured out any better place to put it, we will here mention that the Milky Way has, of late, come to seem a much more equal, or even dominant, partner with M31 than it used to be (Wilkinson & Evans 1999; Loinard et al. 1999; García Cole et al. 1999; Côte et al. 2000a; Evans & Wilkinson 2000; Anguita et al. 2000; Evans et al. 2000b; Dehnen 1999). For more on the Local Group (whose zero-velocity surface has moved out a bit to 1.18 Mpc) see the reviews by van den Bergh (1999, 2000c).

Also in small groups of galaxies you find (or rather Holmberg did) the Holmberg (1969) effect. It is the relative deficiency of satellite galaxies with projected positions close to the equatorial plane of the dominant galaxy, combined with a greater extent of the satellite systems along the polar axis. The mechanism could be either destruction or inhibition of formation (Zaritsky & Gonzalez 1999). Hartwick (2000), looking at the Milky Way and M31, concludes that the main contributor is preferential accretion of companion galaxies from along filamentary large scale structures.

The alternative fate for a group of galaxies that doesn't settle down into a single potential well is to gather with other groups to become a cluster, which itself may find other clusters to commune with, and so forth. Iwasawa et al. (2000), for instance, suggest that the X-ray morphology and high temperature for its luminosity of the Zwicky cluster 1718.1−0108 mean that it is actually three or more groups caught in flagrante delicto. That such crimes are common follows from the evidence for guilt (substructure) displayed by both of our favorite, nearby clusters, Virgo (Lee et al. 2000a; Kikuchi et al. 2000) and Coma (Watanabe et al. 1999; Bravo-Alfaro et al. 2000). Common even in recent gigayears (Patton et al. 2000), and even commoner in the past say Reshetnikov (2000a, 2000b) and Le Fevre et al. (2000), reporting evidence for redshift dependences of $(1+z)^{4\pm 1}$ and $(1+z)^{3.2\pm 0.6}$, respectively.

Evidence for mergers can include both substructure in whole clusters and damage to individual galaxies. X-ray images and temperature distributions are particularly good indicators of ongoing and past processes (Molendi et al. 1999; Kikuchi et al. 2000; Takizawa 2000; and Molendi et al. 2000 on Abell 2256, where the crim. con. has also disrupted a former cooling flow relationship). Other sources of complimentary information include weak gravitational lensing (Umetsu & Futamase 2000) and old fashioned optical photometry (Metevier et al. 2000 on the Butcher-Oemler effect in two clusters).

Both Metevier et al. and Maurogordato et al. (2000, on Abell 521) are trying hard to push us on to the next subtopic, because they point out that individual galaxies as well as the overall cluster structure show collision damage. Before following them, we pause only to note (*a*) that Abell 222 and 223 will surely merge in the future (Proust et al. 2000) to form Abell $222\frac{1}{2}$, or maybe Abell 445, and (*b*) that Chiueh & Wu (2000) have provided an alibi in the form of a mechanism to assemble clusters with two cores even without any merger intervening. This may or may not be part of the explanation for close pairs of galaxies that seem to show no evidence for interactions (Zasova et al. 2000).

"Il faut souffrir pour être belle," the Farmer's daughter used to say. For galaxies, it is a bit the opposite—the most elegant, gas rich, grand design spirals are generally found only where nobody is around to bruise their arms. Indeed, the gas is the first to go, yielding first to tidal removal and then to ram pressure stripping (Lee et al. 2000a) and leaving anemic spirals (Vollmer et al. 1999 on NGC 4548 in Virgo) and trails of gas and radio-emitting plasma behind them through the intracluster medium (Henriksen et al. 2000; Stevens et al. 1999a; Drake et al. 2000; Clemens et al. 1999). The stars, too, get pulled out and about, as you have known since Toomre & Toomre (1972) told you so. Curiously, gas and stars can leave on quite different trajectories (Hibbard et al. 2000, on three Arp galaxies). And, in due course, off also comes part or all of the extended, dark matter halo, to join a communal pool (Sensui et al. 1999), leaving the rest of the galaxy even more vulnerable (Dubinski et al. 1999).

Grenacher et al. (1999) suggest that our own galactic halo may have been flattened by interactions with the Magellanic Clouds, leading inexorably to

7.3. Destruction In and Around the Milky Way

The relatively new, big question here is whether the halo stars are largely or even all rubble from tidally disrupted dwarf spheroidal galaxies, whose relic cores are the globular clusters, or a subset of them. Notice that this makes at least numerological sense. If a (proto) globular cluster is the $10^5\ M_\odot$ core of a $10^7\ M_\odot$ dSph, then the total stellar mass of the halo should be roughly 100 times the $10^7\ M_\odot$ found in the 200 globular clusters. This is at least approximately right. A more detailed argument in favor is that about 10% of the low metallicity stars in the outer halo have kinematic properties suggesting that they came from a single disruption (Helmi et al. 1999). A project is now under way to acquire enough kinematic data to look for similar residual structure through most of the halo (Morrison et al. 2000).

Destruction is certainly a present phenomenon. The Large and Small Magellanic Clouds both show damage (including loss of gas in a stream) and will not be with us for many more orbit periods (Weinberg 2000; Kunkel et al. 2000). Most of our favorite dwarf spheroidals are also losing some of their marbles, er, stars (Majewski et al. 2000 on Carina, Johnston et al. 1999 on IGI, Colpi et al. 1999 on Fornax and IGI). If IGI (the dwarf spheroidal in Sagitarrius) has no Magellanic-style gas stream (Burton & Lockman 1999), it is only because it has no gas to speak of. Fornax has managed to hang on to an elderly globular cluster of its own (Oh et al. 2000), but van den Bergh (2000b) believes that Fornax is not a representative of the class conceivably ancestral to the outer globular clusters, while IGI (which also has one of its own) is.

Do the globulars themselves vote in favor of this scenario? Well, ω Cen (our most massive) has stars of several ages as well as of several metallicities (Lee et al. 1999b), with stellar ages and abundances correlated in the same way they are in dSph's (Hughes & Wallerstein 2000; Smith et al. 2000a; Pancino et al. 2000). A prediction is that ω Cen should have its own dark matter halo (Carraro & Lia 2000), which one might find by measuring velocities of stars more than 20 pc from its center. That it, like nearly all other galactic globular clusters, has a tidal tail of stars being lost (Leon et al. 2000) is perhaps an argument against significant dark matter in the cluster. On the other hand, it does have just about the smallest of these tails. "Stars being left behind" is, by the way, not the right way to describe these fugitives, since the "tails" are expected to extend along the cluster orbits in front of them as well as behind (Combes et al. 1999). These are, we suppose, by analogy with elephants, tidal trunks (or moos, in the case of the bipolar cow).

Another long-standing issue in galactic kinematics is the relationship among star formation processes in the disk, open clusters, moving groups, star streams or other relics of open clusters and associations, and the general field population of the disk. Open clusters anything like as old as we think the disk must be are, as you know, rare (Carraro et al. 1999 on NGC 6793 and Berkeley 17; Sarajedini et al. 1999). Many young clusters are, as first highlighted by Adriaan Blaauw and V. A. Ambartsumian more than 40 years ago (separately!), expanding (Mirzoyan et al. 1999), while the cluster within which our Sun formed is long gone (Ida et al. 2000a, on what the other stars did to Kuiper Belt Objects). In between come the star streams, like the one allied with the Tucana association (Zuckerman & Webb 2000). The stars concerned are all quite young, but they make up part of what Eggen (1992) called the Pleiades group, which includes much older stars.

Clearly lack of coevality is a fatal objection to regarding a bunch of stars as having formed in a single open cluster, but we think that Dehnen (2000) is proposing that our location, just outside the outer Lindblad resonance of the Milky Way bar, makes it possible for stars with similar location (in the rotating coordinate system) and kinematics to form over a considerable fraction of a galactic rotation period. Maturity provides no absolute protection to clusters. HR1614 and its associated moving group are something like 2 Gyr old and were gravitationally bound until a rotation period or two ago (Feltzing & Homberg 2000).

We had intended to close this section with words of wisdom about Gould's Belt, but are slightly put off by the probability that its stars (including the low mass ones now recognized, Makarov & Urban 2000, and gas—Lindblad's ring) were assembled by a local explosion, rather than a star formation event (Poeppel & Marronetti 2000). It is not clear that this explains the observation that the whole systems seems to be rotating (Comeron 1999), but then neither do the competing hypotheses of giant star formation event or impact of a high velocity cloud. The kinematic time scale of the rotation is 3–6 × 10^7 yr, like the ages of the brightest member stars (Torra et al. 2000), and this is also at least a plausible age for a population of intrinsically weak gamma-ray sources that are found in the same part of the sky (Gehrels et al. 2000), if they are fading pulsars (Grenier 2000).

Gould's Belt is stored in our mental file drawer very close to the radio emission feature called the North Polar Spur (probably because they appeared in the same graduate course on galactic structure), and somehow this seemed to imply that both should also be fairly close to Earth by astronomical standards.

True for Gould's Belt, but perhaps not for the spur (despite its enormous angular size). Sofue (2000) has attributed it to a starburst at the galactic center.

7.4. Rubble Around the Construction Site

Serious archeologists do wonders with kitchen middens, so perhaps you can draw conclusions that we have not from the possible-to-probable existence of (*a*) star streams in the giant ellipticals of the Virgo and Coma Clusters (Pierce & Berrington 2000), (*b*) disrupted galaxies in the Coma and Centaurus Clusters (Calcaneo-Roldan et al. 2000), (*c*) remains or even ghosts of the globular clusters originally owned by galaxies that participated in mergers near the centers of most rich clusters (Blakeslee 1999; Gebhardt & Kissler-Patig 1999; Capuzzo-Dolcetta & Tesseri 1999), (*d*) pairs of star clusters in the process of merging (De Oliveira et al. 2000), and (*e*) at least one runaway star cluster, moving at 50 km/sec perpendicular to the disk of the Large Magellanic Cloud (Graff & Gould 2000). It is the cluster in which the progenitor of SN 1987A seems to have originated and is apparently escaping from the scene of the crime.

8. KREISLERIANA, PART II

The appetizer tray stocked with year-2000 answers to hoary questions and the converse continues onward beyond stars to the insterstellar, material, galaxies, and the universe.

8.1. Dust and the Interstellar Medium

Dust is remarkably ubiquitous in the universe, with even an intergalactic component occasionally invoked to explain the apparent faintness of distant supernovae (Aguirre & Haiman 2000). We logged in roughly 40 dusty sites, nine components, and seven processes. Here appear a small subset of the most and least familiar.

A very broad absorption feature near 2200 or 2175 Å was an early discovery of ultraviolet astronomy. Common in the Milky Way (though strangely not in nebulae where the exciting star can be identified; Zagury 2000), it is by no means spread over all other galaxies, and no QSO is known to display the feature (Pitman et al. 2000, pointing out that an earlier report was a false alarm). The least exotic carrier mentioned during the year was graphite with a range of grain sizes (Will & Aannestad 1999).

The most exotic constituents we picked out were magnesium protosilicates (blamed for a 2 μm feature in Cas A and elsewhere; Chan & Onaka 2000) and nanodiamonds (credited with some 3–15 μm bands; Jones & d'Hendecourt 2000). The former is a new dust candidate; the latter is, of course, a nanogirl's best friend. And there are lots of ices, H_2O outweighing all the rest put together by a factor near three (Gibb et al. 2000). The rest, in order of declining abundance toward the protostar W33A are CH_3OH, CO_2, CH_3, HCO, NH_3, CO, HCOOH, H_2CO, XCN, CH_4, $HCOO^-$, HDO, $C^{13}O_2$, and OCS, at one-fivehundredth of H_2O.

Places where dust is found (in addition to back of our refrigerator) include:

- The B[e] X-ray binary CI Cam (Clark et al. 2000a).
- The cooling-flow clusters of galaxies Sersic 159-03 (Hansen et al. 2000) and Abell 2670 (Hansen et al. 1999).
- The winds coming off hot stars, including luminous blue variables (Parthasarathy et al. 2000; Voors et al. 2000), some but not all Wolf-Rayet stars (Williams & van der Hucht 2000; Cherchneff et al. 2000), and post-AGN stars (Arkhipova et al. 2000).
- Novae, both before (Kawabata et al. 2000 on V4444 Sgr, 1999) and after the explosion (Taranova & Shenavrim 2000 on V1016 Cyg).
- Symbiotic stars, where the polarization caused by dust scattering varies in days to months (Brandi et al. 2000).
- Some but not all ultracompact H II regions, if defined by their radio emission (Molinari et al. 2000b).
- Planetary nebulae (too many papers to cite, from Stasinska & Szczerba 1999 to O'Dell 2000, on the Helix nebula).
- Not-so-compact H II regions (Orsatti et al. 2000),
- The same E/SO galaxies and AGNs that have gas (Tomita et al. 2000).
- The Moon, some of whose dust ought to reach Earth's upper atmosphere, though apparently none has ever been seen (Yamamoto & Nakamura 2000).
- Comets, whose dust has been variously described as just interstellar stuff glued into various-sized grit (Evlanov et al. 2000) or as the product of post-condensation processing (Rietmeijer et al. 1999). The break-up of Comet LINEAR into six chunks suggests a size scale between dust and nuclei, to be called cometesimals.

Formation and destruction of grains must be the dominant processes, in the way that birth and death are for humans, that is to say, not necessarily the most interesting ones. In between, analogous to getting your first job, comes alignment (Smith et al. 2000, the first demonstration that it happens to carbon-rich as well as oxygen-rich grains, so that both can produce dichroic polarization). Magnetic fields are part of the deal (Straizys et al. 1999) in a tradition that goes back to Davis & Greenstein (1951). Pick your own analogy for the observation that dust is frequently also flaky or fluffy (Vaidya et al. 2000; Blum et al. 2000) and dizzy or spinning (de Oliveira-Costa et al. 1999; Finkbeiner et al. 1999).

And if you fear that nanodiamonds might be too expensive, there is also spinel, $MgAl_2O_4$ to be had at the interstellar jewelry store (Posch et al. 1999).

The other 99% of the interstellar medium is gas, with all the usual elements in the usual proportions, minus "depletion," meaning whatever is condensed out on the grains (Welty et al. 1999, chosen from among many papers on the topic because it is, probably, the last on which Lyman Spitzer will appear as an author). Four fairly old questions and some partially-new answers follow.

What is the ratio of H_2 to CO, and is it constant, so that the latter can be used as a proxy for the former? Really big in starbursts, and so no, say Bergvall et al. (2000). Apparently small in Seyfert galaxies, and so no, again, say Papadopoulos & Allen (2000), but much the same in the bulge of M31 as in the solar neighborhood (Melchior et al. 2000a). For explanation of the units in which the average value is $H_2/\mathrm{CO} = 2 \times 10^{20}\ H_2\ \mathrm{cm}^{-2}\ (\mathrm{K\ km\ s}^{-1})^{-1}$; see Ap95, § 7.2.

Just how much deuterium enrichment is possible in molecules? Spectacularly, up to $N_2D^+/N_2H^+ = 0.35$ in a couple of cloud cores, report Tine et al. (2000).

Where is most of the oxygen in molecular gas, since it is neither O_2 nor H_2O, according to Goldsmith et al. (2000) and Bergin et al. (2000), both part of the set of first results from SWAS. No answer was provided, but our candidate is sodium bithusilate.

Where is the warm absorber? Well, all right, first, what is the warm absorber? What it absorbs is X-rays, coming from the nuclei of Seyfert galaxies, and the "warm" part is dictated by the presence of absorption features due to ions like O VI. Things said about it during the year include:

- It's an MHD wind from the black hole accretion disk (Bottorff et al. 2000).
- The UV and X-ray absorbing gas are not mostly the same stuff, even when they are at about the same temperature (Kriss et al. 2000a, 2000b).
- The outflow velocity is about 440 ± 220 km/sec for the Fe XVIII–XXI (X-ray absorbing) stuff in NGC 3783 (Kaspi et al. 2000a). And, though the outflow velocity and line width are comparable in X-ray and UV gas, relative strengths require two components. In other galaxies, the gas warm enough to emit and absorb O VIII X-rays is flowing out somewhat faster than the gas which absorbs the UV lines (Kaastra et al. 2000). These two slightly contradictory results both derive from *Chandra* data.
- You need not just two but three absorbing zones, or a continuum, to fit all the observations of MCG −6-30-15 (Morales et al. 2000), a somewhat better-known AGN than you might think from its name.
- And a mini-campaign on NGC 1068 reveals that gas near 10^6 K both emits and absorbs over a wide range of wavelengths (Lutz et al. 2000; Nicastro et al. 2000; Alexander et al. 2000).

8.2. Chemical Evolution of Galaxies and Stellar Populations

"Do you guys have a G dwarf problem?" remains the question we would most like to ask when intergalactic communication has been established. Our G dwarf problem is that there are fewer ones of very small metallicity in the solar neighborhood than you would expect from a simple model of gradual enrichment in a homogeneous, closed box, where the same proportion of high and low mass stars form in each generation. The local sparcity of stars with $[\mathrm{Fe/H}] - \leq 4$ (Arghast et al. 2000) and even < -3 (Anthony-Twarog et al. 2000) persists. The standard solutions, as you might expect, do away with one or more of the simple assumptions (Martinelli & Matteucci 2000), and, if your first extragalactic contact is with someone in the Large Magellanic Cloud (not totally unreasonable!) the answer will apparently be, "yes" (Dirsch et al. 2000).

"Stars of Negligible Content" (Reiz 1954), as the *Astrophysical Journal*[5] running head of long ago charmingly called them, continue to elude us, and it is not, at least for smallest masses, just that they have managed to make or acquire enough CNO in the interim to affect their evolution or hide their negligibility (Weiss et al. 2000), though Preston (2000) notes that it is not clear just how many you would expect to find, even for the simple, closed box (etc.) model.

Creeping cautiously away from $Z = 0$, we find the age-metallicity relationship. Two recent samples (Garnett & Kobulnicky 2000 and Rocha-Pinto et al. 2000) show much tighter correlations (real scatter ≤0.15 dex) than earlier work (Edvardsson et al. 1993). We are told that the new results are better and that the Swedish sample may have had some odd bias, but the Swedish samplers do not appear to have been consulted.

It is not news, nor even your father's Olds, that the local average metallicity for even the youngest stars is less than solar (Rocha-Pinto et al. 2000; Garnett & Kobulnicky 2000; Korotin et al. 1999; Andrievsky et al. 1999).

Uncertainties multiply as we look outward to other galaxies and their stellar populations, which must generally be studied from integrated spectra and colors. The core problem, which the more adjustable author continues to think of as "the curse of the adjustable parameter," is that, even for a single, isochronal population, the effects of total metallicity, variations from solar element ratios, population age, duration of starburst, and initial mass function can be very difficult to distinguish. The difficulties grow when you are examining the sum of many generations of stars, in which all of the above may have changed, and gas with more or less than its fair share of heavy elements flowed in or out as well.

Overviews of the star population problem are given by Nakata et al. (1999) and Vazdekis & Arimoto (1999). Kennicutt et al. (2000) discuss H II regions, for which gas temperature is an additional confounding variable. We caught something like three dozen papers focused primarily on some particular

---

[5] Reiz (1954), in case you wondered, was calculating models for what he called "Miss Roman's high velocity subdwarfs." That male scientists were given unadorned surnames, while female ones were invariably Miss Roman or Mrs. Burbidge in those days, is one of customs that most of us now find less than charming. According to early IAU directories, the first successful rebel was Prof. Wilhelmina Iwanowska of Torun.

indicator for some particular parameter and (rather arbitrarily) note here (*a*) Yi et al. (2000) on convective overshoot and metallicity as uncertainties in determining ages of galaxies near $z = 1.5$ (the range is 1.5–3.5 Gyr), (*b*) Tamura & Ohta (2000) on age versus metallicity as the dominant factor for color gradients in elliptical galaxies at moderate redshift, (*c*) Pilyugin & Ferrini (2000) on the combination of star formation rate versus time with loss of metals in winds for S and Irr galaxies, (*d*) Molla & Garcia-Vargas (2000) on fitting indices of line strengths in elliptical galaxies with a range of a gas and metallicities, and (*e*) Ferreras & Silk (2000) on the degeneracy between the efficiency of star formation and gas outflows. This topic was initially indexed under "don't hold your breath," and the cited papers are generally very frank about the continuing large uncertainties in deconvolving the major contributing factors.

The possibility of variations in the interstellar ratio D/H is a part of galactic chemical evolution with cosmological implications. Last year, we emphasized evidence for real variability, so fairness requires citing this year Bluhm et al. (1999), who say that all the measured ratios are consistent with 1.5×10^{-5} at the 1–2 σ level. At one time, the interstellar value, augmented by however much deuterium you thought had been destroyed in stars, was the best available estimate for the cosmic value. See Dolgov & Pagel (1999) and Lemoine et al. (1999) for interesting takes on the possibility that both the processed interstellar deuterium abundance and the unprocessed, intergalactic D/H may vary.

8.3. Meet the Milky Way

The distance to the galactic center was roughly 0 kpc to William Herschel and Heber D. Curtis (and many in between), 20 kpc to Shapley, and has cycled several times between 10 and 8.5 kpc since Oort (1927, 1928) entered the fray. A double handful of values published during the index year (many with three "significant" figures) had a mean of 8.1 kpc. Only one set of error bars took in everybody else's numbers, $R_0 = 7.2$ to 8.6 kpc from Beaulieu et al. (2000). Mishurov (2000) noted, not for the first time, that we are quite close to the corotation radius, and Salim & Gould (1999) predicted that, within 30 years, we will know R_0 to better than 1% from the analysis of orbits of stars around the central black hole.

For the local rotation speed, 220 km/sec remains a popular value (Nakashima et al. 2000, who also find that the circular speed declines to 175 km/sec 5 kpc outside the solar circle). But we caught somewhat smaller numbers (about 215 km/sec in Beaulieu et al.) and considerably larger ones (270 km/sec, according to Mendez et al. 1999). The local escape speed exceeds 420 km/sec (García Cole et al. 1999). And the combination of Oort constants, A–B, which should be the circular velocity divided by R_0, is 23–27 km/sec, says Mignard (2000), who looked at *Hipparcos* distances and proper motions for 20,000 stars.

Do other galaxies (sosies, de Vaucouleurs used to call them) resemble the Milky Way? Undoubtedly, though which and how is harder to say. NGC 4527 has the most similar rotation curve (and you have just seen how well ours is known) according to Sofue et al. (1999). And NGC 891 has a similarly complex, multi-phase interstellar medium (Howk & Savage 2000). The Milky Way also has (and analogies to all can be found in other galaxies):

(*a*) a bar, which can be traced out to the solar circle (Feast & Whitelock 2000),

(*b*) spiral arms, four grand design ones says Sevenster (1999), two on our side and two on the other (roughly analogous to how you get six elephants into a Volkswagen), and a large contrast in gas density between the arms and interarm regions (Ungerechts et al. 2000),

(*c*) a bulge containing $3–4 \times 10^{10}$ stars (Lopez-Corredoira et al. 2000), which is just what it should have to go with its $2.6 \times 10^6\ M_\odot$ black hole (§ 11),

(*d*) a disk with a warp, which is either short-lived (Drimmel et al. 2000) or evidence in favor of Modified Newtonian Dynamics (MOND; Brada & Milgrom 2000) or both, or, we trust, neither,

(*e*) three local stellar populations, defined from both kinematics and composition (Caloi et al. 1999).

(*f*) an usually small, or badly misdetermined ratio of radius at which the optical disk cuts off to scale length (Pohlen et al. 2000), and

(*g*) H II regions with helium abundance as large as $Y = 0.28$ (Deharveng et al. 2000). This says that the sum total of chemical evolution over galactic history has produced $\Delta Y/\Delta Z$ close to 3 (larger than many modelers of stellar nucleosynthesis would have expected). Deharveng et al. also note that even O6.5 stars produce helium Stromgren ameboids smaller than their hydrogen Stromgren ameboids. This is, of course, the sort of factoid that casts doubts upon values of the primordial helium abundance determined from H II regions in metal-poor galaxies. In any case, the "observed" value of $\Delta Y/\Delta Z$ remains poorly known. Ribas et al. (2000a) report 2.2 ± 0.8, found by forcing both members of each of 50 double-lined, spectroscopic, eclipsing binary systems to have the same X, Y, Z, and age, while Guenther & Demarque (2000) deduce $\Delta Y/\Delta Z \lesssim 1$ from a similar-analysis of Alpha Cen A and B.

And if there is anything else you would like to know about the Milky Way, consult the set of review articles introduced by Irion (1999).

8.4. Some Other Galaxies and Groups

The Local Group has a new member (Whiting et al. 1999), which can be found by looking through Cetus. (Have you ever looked through a whale? Did you see Giapetto? Jonah? Partly digested krill?) It is a dwarf spheroidal or elliptical and brings total LG membership to 36 (van den Bergh 2000c), extending to 1.18 Mpc (van den Bergh 1999), with some dynamical distortion caused by the much more massive Cen A group (van den Bergh 2000a). Andromeda IV remains excluded from the canonical LG, but it is perhaps a background galaxy to, rather than a star formation region in (Ap93, § 2.7), M31 (Ferguson et al. 2000).

The Large Magellanic Cloud has its center somewhere between 45.1 and 62.5 kpc from the center of the Milky Way (Groenewegen & Oudmaijer 2000). The first nine million LMC stars plotted on an HR or Hess diagram reveal a different history of star formation from that in the Milky Way, but with about the same start time (Alcock et al. 2000). These stars, along with the horizontal branch ones in the dwarf irregular WLM (Rejkuba et al. 2000) are at least part of the answer to the very old question of whether seemingly-young galaxies actually have underlying old stars (yes, as a rule). A Hess diagram, like an HR diagram, is a plot of luminosity versus some indicator of effective temperature, but showing density of stars at each point rather than a separate dot for each star (Hess 1924). Who was Kienle (assuming you have just looked at the reference)? Martin Schwarzschild's thesis advisor, among other achievements. Who was Seeliger (Hugo von, 1849–1924)? He was one of the people who suggested that nova explosions happened when swarms of meteoritic material hit stars (with thanks to Cole et al. 1999a for getting us started on this path).

The spiral galaxies form a two-parameter family (two papers), a three-parameter family (four papers), or a four-parameter family (only one paper, Bershady et al. 2000, contrary to what you were expecting). It is probably not true that each one of the 60+ papers on spiral galaxy structure during the year answered a different question (though they may each have given a different answer), but there were surely more than the five mentioned here.

1. Do spirals have maximal disks, meaning the sort that puts as much mass into the central disk, bulge, and bar as the luminosity profile allows, eliminating the need for a core concentration of dark matter? Yes, it would seem, for some (Blais-Ouellette et al. 1999) and no for others (Maller et al. 2000).
2. Do spirals have non-thermal halos, which was once primarily the question Does the radio emission from the Milky Way have a spheroidal component? Yes, for relativistic electrons in the Milky Way (Moskalenko & Strong 2000). Yes, but they are made of discrete loops and filaments (Irwin et al. 2000). And, not much, for NGC 5907 (Dumke et al. 2000).
3. How much of the UV gets out? Less than 2% locally say Tumlinson et al. (1999), thus nearly all the local intergalactic background is due to active galaxies. Quite a lot from large star formation regions and starburst galaxies, say Witt & Gordon (2000) and Beckman et al. (2000). The Milky Way comes in between, with 3%–30% escaping, say Dove et al. (2000).
4. Are there disks without bulges? Yes, UGC 7321 (Matthews et al. 1999), for example.
5. Does NGC 5907 have an unusual halo? Yes (Zepf et al. 2000), though it probably has little to do with a population of faint stars tracing a dark matter potential (Ap94, § 5.8).

Elliptical galaxies featured in a comparable number of papers (but with the ratio of theory to observations running at 2:1, vs. 1:2 for spirals). Questions to which you might or might not have been wanting the answer include:

1. Do they rotate? Some hardly at all, less than 30 km/sec at the radius where the circular velocity would be 400 km/sec in the cD NGC 1399 (Fornax A, Saglia et al. 2000). Some quite a lot, but they are at most, very faint X-ray sources (Pellegrini 1999), to which M87, with $V_c/\sigma_v = 300/450$ at $r = 32$ kpc, would seem to be an exception (Cohen 2000).
2. Are they segregated, meaning at systematically different places from spirals, especially in rich clusters? Yes, of course (as was probably known to Herschel, though not in those words), not even concentric with the S's in Abell 426, the Perseus cluster (Bruzendorf & Meusinger 1999). And the types don't all have the same distribution of luminosities either (Saracco et al. 1999, and a large handful of other papers during the year).
3. Did they form from monolithic collapses of large, nonspinning blobs or by repeated, hierarchical mergers of smaller units? Blobs, say Kawata (1999) and Hozumi et al. (2000). Hierarchically, say Papadopoulos et al. (2000, and many others, who unfairly, go uncited). And, of course, some of each, say Côte et al. (2000) and Gratton et al. (2000), both as it happens talking about the Milky Way, rather than ellipticals.

SO (*lenticular*) *galaxies* raise the traditional question, why? That is, why no young stars, conspicuous arms, or gas? Some combination of ram pressure, tidal stripping, and a last starburst, conclude Quilis et al. (2000) and Sadler et al. (2000). And you may wish to meditate on the profound question of why the starburst associated with the departure of the gas is always the last one (Quilis et al.) and why your missing car keys are always found in the last place you look. Yeah, we tried buying one of those devices that makes the keys chirp at you when you ask them where they are, but we misplaced the device. Still, they say you don't really have to start worrying until you can't remember what keys are for (this is not the same as being unclear on whether B744 is the department office and R602 the Xerox room, or conversely).

Dwarf galaxies must be loved by the Prime Mover, because she has made so many of them (like beetles and attorneys), indeed is apparently still making them, at least in galaxy mergers (Braine et al. 2000; Weilbacher et al. 2000; Alonso-Herrero et al. 2000b; Johnson & Conti 2000). You might want to ask whether they have their own dark matter halos. And by now you know that we are going to tell you that some very probably do (Côte et al. 1999 on And II) and others may well not (Tamura & Hirashita 1999). Have we found all the dwarfs? No, not even those within 1000 km/sec and within the local super-cluster (Schneider & Schombert 2000; Karachentsev et al. 2000a), especially the ones with low optical surface brightness and/or small H I mass. The missing ones are probably about as numerous as those already catalogued.

Are there dwarf galaxies in voids? Indeed there are only dwarf galaxies in voids, insist Popescu et al. (1999). Other examiners are not so severe though they agree that dwarfs are over-represented (Vennik et al. 2000) and probably formed late in the history of the universe (Grogin & Geller 2000). But, as Grogin & Geller (1999) very properly remind us, the statistics aren't very good, because there are not very many galaxies in voids!

Galaxies live (mostly) in clusters, and, it seems, have always done so at some level. The $z = 2.4$ agglomeration of Lyman alpha emitters reported by Keel et al. (1999) is not a record (a $z = 3.09$ cluster from Steidel et al. 2000 and an out-of-period press release on the group around 3C 294 with $z \approx 4$ may be), but it comes with the additional information that the sky coverage by $z = 2.4$ clusters is less than 0.4%, which is to say that there are not very many of them compared with $z = 0$ clusters, Abell's census of which was only one-half complete (Holden et al. 1999). As for when clusters stopped forming, the answer is, "Not yet." Massive ones are still contracting and adding outliers from their surroundings (Clowe et al. 2000; Balogh et al. 2000).

Galaxy formation, or study thereof, remains a major industry, yielding 30-some papers during the reference year. Kay et al. (2000) explore the consequences of varying 13 input parameters to the models, one at a time, to see which really matter. Unfortunately, the ones that do include both poorly-known physics (like gas cooling rates) and aspects of the calculations themselves (like spatial resolution). And, as we have remarked ad nauseum, the formation of galaxies and larger scale structure remains TMIUPIMA (This is actually an acronym for "the most important unsolved problem in modern astrophysics," not the Telugu word for ingrown toenail).

8.5. Some Cosmic Questions

Here are some aspects of the universe as a whole that did not seem to fit into § 12, including background radiation, source evolution, and re-ionization.

8.5.1. Backgrounds

Starting with the longest wavelengths, we encounter new measurements at four frequencies near 1 MHz from the *WIND* mission, made about 1 Gm from Earth during solar minimum. These reveal much less anisotropy than was recorded earlier by *IMP-6*. It is about 10% and due to emission and absorption by the Milky Way (Tokarev et al. 2000). The larger *IMP-6* anisotropies were a result of terrestrial and solar interference.

We skip blithly across the cosmic microwave background, noting only (*a*) that more and more people are thinking of more and more subtle effects that will produce fluctuations in the brightness or polarization smaller than we can yet look for (Cooray et al. 2000; van Waerbeke et al. 2000a; Scannapieco 2000), (*b*) a continuing low level rumble over whether the second acoustic peak in the fluctuation spectrum, near wave number $l = 600$, has been seen and whether the implied baryon density in the universe is awkwardly large (Peterson et al. 2000, data from the South Pole; de Bernardis et al. 2000, the Boomerang balloon data; Peebles et al. 2000 on suppression of the second peak by delayed recombination; Tegmark & Zaldarriaga 2000), (*c*) that the spectrum of the first peak is the one expected from conventional wisdom and $T = 2.7$ K for the basic background (Miller et al. 1999).

The submillimeter background comes from the sum of star formation at still larger redshifts than are probed in the infrared (Gisbert et al. 2000, interpreting data from *COBE*).

Of the far infrared background recorded by *COBE*, 10% is attributable to sources resolved at 120 μm by the *Infrared Space Observatory* (Scott et al. 2000). Another important aspect of the IR background tentatively detected by *DIRBE* is that it is very close to the maximum amount that will still let us see the TeV gamma rays from Mkn 510 (Guy et al. 2000). Aharonian et al. (1999) make the same point, introducing the acronym DEBRA for diffuse extragalactic background radiation, which is not obviously helpful unless your observatory is on Mount Ephraim (theirs, HEGRA, is actually in the Canary Islands).

The visible background light of the night sky has contributions from Earth, solar system, galaxy, and beyond, and is more often thought of as noise than as signal. There is an International Dark Sky Association devoted to its reduction. They focus on the terrestrial contribution.

The (relatively) local intergalactic background of ultraviolet amounts to about 3400 photons/cm^2-sec or 1.3×10^{-13} erg/(sec cm^2 Hz ster), if it is simply the sum of radiation from local active galaxies (Shull et al. 1999). This background at large redshift is part of the "reionization" issue addressed below.

The X-ray background appeared in more than 20 papers. At the soft ($\leq$1 keV) end, it is rather more spotty than previously advertised (Soltan et al. 1999), and something like 1/4 of the harder (2–10 keV) part can be attributed to resolved sources (Della Ceca et al. 1999). But the nagging issue remains, that across both energy bands, the background is rather harder (flatter spectrumed) than most of the sources, QSOs, Seyfert galaxies, clusters, and so forth (Blair et al. 2000). The result is a continued search and discovery operation aimed at finding additional, harder sources that can contribute to the total. The papers we caught and, very briefly what they say, include: (*a*) Ueda et al. (1999) on the fainter *ROSAT* sources, (*b*) Wilman & Fabian (1999) and Madejski et al. (2000) on absorbed or obscured Seyfert 2 galaxies, (*c*) di Matteo & Allen (1999) and Allen et al. (2000b) sources in elliptical galaxies, (*d*) Moran et al. (1999) starbursts at $z = 1$–2, (*e*) Maiolino et al. (2000) on faint sources observed with *BeppoSAX*, which turn out to consist of $\frac{1}{3}$ blue, high redshift QSO, $\frac{1}{3}$ galaxies at modest redshift with modest reddening, and $\frac{1}{3}$ empty fields, (*f*) Akiyama et al. (2000) on faint sources observed with ASCA and Lehmann et al. (2000) pointing out that most of these are not a previously-advertised new class of galaxies with narrow emission lines, and (*g*) three papers reporting *Chandra* data (Mushotsky et al. 2000; Brandt et al. 2000; Fiore et al. 2000), of which the general thrust is that these are fairly evenly divided among QSOs, normal and starbursting galaxies, and empty fields, and that a large fraction of the 2–10 keV sources are also seen at $\lesssim 2$ keV, so that even fairly faint *Chandra* sources are not really revealing the much-desired population things with harder spectra.

The gamma-ray background, more recently recognized, has also generally been ascribed to a sum of many sources, possibly quite distant, and this would seem still to be the majority view (Muecke & Pohl 2000; Strong et al. 2000). Loeb & Waxman (2000) have, however, proposed that what we are really seeing is 3 K (cosmic microwave backgroud) photons, boosted to 100 MeV to TeV by inverse Compton scattering on electrons accelerated by shock waves as large scale structures of sheets and filaments form in the universe. In this picture, the photons we collect, though isotropic to better than 5% on angular scales $\gtrsim 1°$, were produced quite locally. The slightly bedraggled electrons are then later responsible for producing radio synchrotron emission when they pass through the magnetized halos of galaxies (§ 8.4).

8.5.2. Long Ago and Far Away

Ap99 devoted a whole section (§ $8\frac{1}{2}$) to the concept that, moderately long ago (meaning $z = 0.3$–3 or thereabouts) many things were not even moderately different from here and now. Given the amount of time we spend in other contexts trying to persuade various recalcitrant colleagues that all of us really do live in an evolutionary universe and that there really was a hot-dense phase (big bang) 10–20 Gyr ago, looking at things again this way may seem contrary minded. Nevertheless, that is where the surprises lay, for the following classes of astronomical sources, sinks, etc.

Field elliptical galaxies. Little or no change in their number density since $z = 1.5$ (Scodeggio & Silva 2000).

Quasars' choice of environments. The increasing preference for dense environments as you look back over $z = 0.5$–0.8 is not strong as has been previously advertised (Wold et al. 2000).

Absorption lines in QSO spectra. They are generally produced in galaxies these days. The same was true for the lines of the Lyman alpha forest, in that the extended gas envelopes of known galaxies suffice to produce one half to all of them (Chen et al. 2000, who looked at the Hubble Deep Field, presently so crowded with astronomers that it is a miracle there is room for any galaxies). The thermal widths of the gas producing the Lyman beta forest are also much the same now as at $z = 2.0$–2.5 ($b = 31 \pm 7$ km/sec, corresponding to $T =$ 50,000 K; Shull et al. 2000, reporting early *FUSE* results).

The damped Lyman alpha absorbers, compared to the forest clouds, contain more gas and cooler gas, and (in case you had forgotten), the damping really is the quantum mechanical, $\Delta E \times \Delta t = \hbar$, sort from an upper level with a very short lifetime. The average metallicity of the absorbing gas changed much less from $z = 4.5$ to 1.7 than you might expect (Prochaska &Wolfe 2000), and indeed bears a family resemblance to gas now in galaxies (Haehnelt et al. 2000). Comparing optical and radio observations of this gas leads to the conclusion that interstellar media then had the same sorts of warm and cool phases as interstellar media now (Lane et al. 2000). The (similarly-constituted) disks were, however, either bigger or more common in the past (Bunker et al. 1999).

The fraction of quasi-stellar et ceteras that were radio loud remained steady as the population turned on from $z = 4$ down to $z = 2$ (Stern et al. 2000a). Much the same can be said about the fraction that are X-ray bright over the same redshift range (Miyaji et al. 2000; Kaspi et al. 2000b). Other QSO nonevolvers are the degree of variability at fixed luminosity (Hawkins 2000) and the emission line properties of radio-loud ones (Wilman et al. 2000). Keep, however, firmly in mind that the comoving number density of active galaxies in general was enormously larger at $z = 2$–3 than now, and indeed may still be rising as we look back before $z = 3$ (Wisotzki 2000).

Clusters of galaxies that emit X-rays collected the largest number of "not much evolution" papers during the year, and we cite only the first (Schindler 1999, with no significant change in mass, gas mass, X-ray luminosity, metallicity, or their correlations back to $z = 1$) and the last (Fairley et al. 2000, with similar remarks on the correlation of X-ray luminosity and temperature).

Even the distribution of galaxy luminosities in clusters has not changed much since $z = 0.3$ (Naslund et al. 2000). Inevitably, however, as you look back far enough, you come to an epoch when galaxies were busily getting brighter through merger-induced starbursts and fading back again. Which of these dominates a large collection of galaxies is described as "active" versus "passive" evolution, and is a topic of prolonged discussion, not resolved in 2000. "Neither of the above," is, however, excluded (Serjeant et al. 2000a; Oliver et al. 2000).

8.5.3. Reionization and the Early History of Star Formation

In the standard model, the baryons were completely ionized before about $z = 2000$, recombined and were neutral for a while after that, and are now again largely ionized in so far as they are not hidden in very compact entities. Remember that even the Lyman alpha forest clouds, though we detect them via absorption from the ground state of hydrogen, are at 50,000 K or so. Just when the reionization occurred and where the necessary ultraviolet photons came from are an important part of the complex story of early star formation, galaxy evolution, and the origins of active galactic nuclei. You mustn't pump in too many photons before about $z = 35$ or the spectrum of the CMB will be distorted into shapes we do not see (Hu 2000, Griffiths et al. 1999), and you mustn't wait until too late, or intergalactic neutral hydrogen will absorb both Gunn and Peterson. Songaila et al. (1999) say that $z = 4.7$ is already too late, while Miralda-Escudé et al. (2000) pick $z = 6$ and predict an absorption trough there.

The intergalactic supply of ionizing photons at $z = 0$ has contributions from star-forming galaxies and from AGNs (Sanantaray & Khare 2000). What can be said about what happened in between? The first objects to collapse had masses of 10^6–10^7 $M_\odot$ (Nishi & Susa 1999; Bromm et al. 1999; Susa & Kitayama 2000) in baryons. The authors of all three papers have in mind fragmentation of those first units, starting perhaps at $z \approx 30$, into very massive and (because of the very tiny opacity of nearly pure hydrogen and helium gas) very blue Population III stars. Monolithic collapse into a first generation of black holes and proto-AGNs might also be possible. The formation of Pop III stars must have ceased by $z = 3$ or we would know about them from their H II regions (Tumlinson & Shull 2000).

Meanwhile, UV photons are pouring out. The molecules get wiped out first, by $z = 25$ (Ciardi et al. 2000). Next to bite the dust is neutral hydrogen, somewhere in the range $z = 5$–15 or more (Valageas & Silk 1999; Chiu & Ostriker 2000; Ciardi et al. 2000; Gnedin 2000, and there is probably some disagreement, although few error bars are given). And, finally, some He II lingers down to $z \approx 3$ (Miralda-Escudé 2000; Heap et al. 2000; Bryan & Machacek 2000). The error bars should probably be quite large on all numbers mentioned, since the actual rate of formation of pop III stars vs redshift, the fraction of UV that escapes, and the ratio of AGNs to star formation all enter (Cojazzi et al. 2000).

Notice that, while all this involves early star formation (also Dietrich & Welhelm-Erkens 2000; Sato et al. 2000) the main epoch of star formation still lies ahead at $z = 2$–3 (Smail et al. 2000; Kobayashi et al. 2000). And, from among a dozen papers that emphasized the differences in SFR(z) found by various techniques, we managed to lose the one that said agreement was actually pretty good. Clearly the last word (nay, the last 10^5 words) has not been said on this, if only because, when you choose to look at a particular tracer of star formation (ultraviolet, blue light, radio synchrotron emission, H_2 or CO, H II, far infrared from dust …) you automatically pick sources in which lots of that tracer gets out (Conselice et al. 2000). This is true for fine structure within galaxies, as well as for galaxies as a whole (Hunter et al. 2000).

As for the physical process(es) of star formation per se, most of the more than 70 papers read and indexed will go uncited, except for the most extreme, whose authors conclude that mergers of bits and pieces to make galaxies is really the only trigger that matters globally (van Kampen et al. 1999; Blain et al. 1999). Recent examples of merger-induced star formation, where we can look at the details, seem to have turned on and off again very quickly—in 10^6 yr in NGC 4038/39, say Neff & Ulvestad (2000).

8.6. Non-Photon Astronomy

Most of the things in the world—shoes, ships, sealing wax, cabbages, kings—are non-photons. From the point of view of the astronomy, however, the inventory is pretty much limited to meteorites and Moon samples (mentioned in § 3), cosmic rays, neutrinos and other dark matter particles, and gravitational radiation. On the subject of other dark matter particles, the literature offered us only an upper limit to some product of the number density and cross-sections of WIMPs (Abusardi et al. 2000). The only actual gravitational radiation data published during the year (Weber 2001) reported a statistically significant correlation between pulses recorded by a pair of bar antennas and events from the bursting pulsar.

8.6.1. Cosmic Rays

Cosmic rays, and even the recognition that they come from outside the Earth's atmosphere, predate all bands of photon astronomy except the optical (meaning visible light and its near neighbors that also penetrate the atmosphere and can be detected by similar methods). A quick and dirty summary of the conventional wisdom is that, at least up to the maximum energy that can be confined by the galactic magnetic field, CRs are close to the cosmic mix of stuff (with extra heavies perhaps associated with acceleration near supernovae and extra odd-Z elements, odd-A nuclides, and Li, Be, and B from spallation as they travel). The particles have been shock accelerated, in or near supernovae or their remnants with, perhaps, some pre-acceleration in stellar flares or elsewhere. CRs stick around for about 10 Myr, passing through 3–6 g/cm^2 of disk material in that time, before being degraded, or, more likely, escaping the galactic disk. The generic question is, of course, how true is all this? And the big puzzle of the 1990's has been, how do CRs with energies in excess of 10^{19}–10^{20} eV get to us through the photons of the microwave and infrared backgrounds?

On the "all is well" side, we have the continued comfort of knowing that all the positrons (Boezio et al. 2000) and antiprotons (Bergstroem et al. 2000) are secondaries, made en route. A number of authors reaffirmed the adequacy of various sorts of shock acceleration processes to reach 10^{15} eV or thereabouts (e.g., Lucek & Bell 2000, with specific reference to Alfvén waves). The mean time CRs spend in the disk has perhaps dropped a bit from what we are used to, to 6 Myr, and the grammage traversed gone up a bit to 12 g/cm^2 (Brunetti & Codino 2000; Ahlen et al. 2000). The two are closely coupled, because both are measured from secondary abundances like LiBeB/CNO, with stable secondaries telling you the grammage and unstable ones the dwell time. We *think* this is still true (but are not dead sure) if some of the lithium comes from fusion between cosmic ray alpha particles and ISM alpha particles rather than from spallation (Casuso & Beckman 2000).

At 10^{15} eV comes "the knee," meaning a change in slope of the power-law spectrum of CR numbers as a function of energy, from $E^{-2.6}$ to $E^{-3.2}$. Here also the ratio of protons and alphas to heavier nuclei drops steeply (Arqueros et al. 2000), and the combination is generally taken as a signature that we are running out of *galactic* cosmic rays (because local sources cannot accelerate to higher energies, they leak out really fast, or both) and seeing an extragalactic population, coming from AGNs, gamma-ray bursters, or your other favorite blast.

But the excitement is not over. At 10^{17}–10^{18} eV, the mean particle mass is going down again (Abu-Zayyad et al. 2000), until, above 10^{19} eV, fewer than half the particles are iron, other heavy nuclides, or, indeed, photons (Ave et al. 2000). Gamma rays at least as a contaminant are expected either if 10^{20} eV anythings are coming to us through more than 10–20 Mpc of the CMB or if 10^{20} eV anythings are the decay products of WIMPS, defects, or whatever.

Well then, what is responsible for the air showers whose initiating energies are comparable with well-hit golf balls? Protons and such accelerated around the black holes of nearby dead AGNs say Farrar & Piran (2000) and Boldt & Loewenstein (2000). Either iron nuclei (Blasi et al. 2000a) or protons (de Gouveia dal Pino & Lazarian 2000) accelerated around very young, rapidly rotating, strong field neutron stars in the Milky Way? A cluster-wide acceleration process that we don't understand very well, according to Siemieniec-Ozieblo & Ostrowski (2000). Or, surely the most fun, annihilation of neutrino-anti-neutrino pairs, where one is a 1.9 K neutrino from the cosmic background and the other a really high energy one from decay of superheavy ($\geq 10^{22}$ eV) relict particles (Gelmini & Kusenko 2000).

What are cosmic rays good for? Well, in addition to making Li, Be, and B and causing human mutations, they can also ionize the interiors of molecular clouds (van der Tak & van Dishoeck 2000) and charge exchange with iron near the galactic center (Tanaka et al. 2000). Oh yes, they can also discharge gold leaf electroscopes, which is more or less where we came in on this section.

8.6.2. Neutrinos

Neutrinos from the Sun live in § 2.2.1, and the detector cup is about half full or half empty, relative to the standard solar model (Abdurashitov et al. 1999, reporting on seven years of SAGE data).

Photons travel at very close to the speed of light, and neutrinos travel at very close to the speed of neutrinos, except for the highest energy ones, which can be slowed down by about one part in 10^{14} by quantum gravity effects (Alfaro et al. 2000), and yes, this would leave the ones from cosmological gamma-ray bursters lagging an hour or so behind the photons (Gambini & Pullin 1999).

When they are feeling generous, expansive, and outgoing, neutrinos can help to explode supernovae, drive winds off neutron stars, and encourage the *r*-process (Sumiyoshi et al. 2000). When they are feeling selfish, exclusive, and paranoid they may gather together in neutrino balls and imitate black holes (Munyaneza et al. 1999).

You might reasonably conclude that sterile neutrinos should not be allowed to reproduce. Indeed they are only just barely able to live, in the sense that no one is simultaneously a viable solution to the problem posed by reconciling solar neutrino data, the SuperKamiokande numbers for atmospheric neutrino oscillation, and Los Alamos laboratory data favoring finite neutrino masses and to constraints imposed by Big Bang nucleosynthesis (Shi & Fuller 1999).

9. GAMMA-RAY BURSTERS

This was the year, we had promised, that we were going to try to make sense of the whole set of ways that GRBs produce photons and send them on their way, put the processes into sensible order, and explain them in one, glorious clarifying paragraph. We failed. It had also seemed probable that this would be the year in which the connection between GRBs and various kinds of supernovae was clarified. That didn't happen either. There was, however, modest progress on several topics that have been around for a while.

9.1. The Hype-, Hyper-, Hypest-nova Connection

The GRB year began with a compact review of the association with supernovae by Jan van Paradijs (1999) written very shortly before his death and triggered by the pair SN 1998bw and GRB 980425. Through the year, it became increasingly clear that this event(s) was/were neither a typical GRB, having a denser than average circumstellar environment (Li & Chevalier 1999) and being faint even for its duration (Norris et al. 2000) nor a typical supernova, having made rather a lot of Ni^{56} for a core-collapse event (Sollerman et al. 2000a) and displaying an assortment of spectral anomalies (Stathakis et al. 2000). If, however, you are going to use the peculiarities as evidence for this being a single event, then it is unfair to count among them that 1998bw was the first Type Ib/c (indeed any sort of Type I) supernova to be seen at photon energies exceeding 2 keV (Pian et al. 2000). The small inventory of possible additional associations was augmented by SN 1997cy$\overset{?}{=}$GRB 970514 (Germany et al. 2000; Turatto et al. 2000), another supemova that seems to have been profligate in Ni^{56} production. Some of its other nucleosynthetic products may have been swallowed by a black hole.

Most supernovae, even failed supernovae or collapsars, do not make GRBs, perhaps because they do not form black holes sufficiently rapidly or leave them spinning fast enough (Macfadyen & Woosley 1999). Black holes remain the energy source of choice (e.g., Brown et al. 2000a, who also propose the galactic superluminal source (microquasar) GRO J1655−40 as a post-GRB). But no model goes unsung. Kaiser et al. (2000) alternatively describe microquasar radio behavior as the time-resolved version of processes that Rees & Meszaros (1994) put into GRBs themselves (shocks along a relativistic jet). Wheeler et al. (2000) propose a magnetar for intrinsically weak GRBs like 980425. And Wang et al. (2000e) and Bombaci & Datta (2000) prefer a second collapse from neutron star to strange quark star to do the GRB part.

9.2. Where Two or Three Are Gathered

Ap99 (§ 7) left as an open question whether the Gamma-Ray Bursters are all at heart the same sort of beast. The answer is now pretty clearly, “no”. Majority opinion finds two classes, long duration events (a subset of which have X-ray, optical, and/or radio tails, host galaxies, and redshifts) and short duration events, lasting at most a second, with somewhat harder spectra and, to date, no counterparts at other wavelengths, though *HETE II* may be changing this even as we write (or you read).

The long (etc.) ones are quite likely to come from collapse of a single, massive star core to a rapidly rotating black hole, so that the event location will still be near a star formation region; and the short ones are the product of mergers of pairs of neutron stars or neutron star plus black hole (Fryer et al. 1999; Hakkila et al. 2000). Closely associated is the conclusion that, while some of the perceived correlations among peak fluence, duration, spectrum, and total flux are the result of redshift and time dilation, there are also intrinsic correlations (Mitrofanov et al. 1999; Atteia 2000; Lloyd et al. 2000).

Within this picture, only the long-duration events would be expected to share the redshift history of cosmic star formation (cf. Boettcher & Dermer 2000), and the “no host” problem largely vanishes. Some of the apparently bright events, located accurately with the Interplanetary Network or from afterglows are truly bright, far away, and in dwarf starforming galaxies below the detection limit (e.g., GRB 990519, Beuermann et al. 1999), while merger products have had time to move some distance away from the star-formation regions where they were born.

The host galaxies observed so far seem to have roughly a Schechter distribution of luminosities (Schaefer 2000; Hjorth et al. 2000 on GRB 990712 in a galaxy with $L = 0.2L^*$). Are you surprised that optical tails can be seen from within star formation regions? Waxman & Draine (2000) were, and so sat down to calculate how much dust the gamma event itself would vaporize in the first 10 seconds. The answer is, along the axis of beamed gamma rays (the direction we are looking), a whole giant molecular cloud’s worth.

Third classes or subclasses of several sorts have also been proposed, based on progenitors, environments, or burst properties. An NS/BH pair is less likely to be expelled from its host galaxy than a double neutron star (Belczynski et al. 2000) and, we suppose, will develop somewhat differently (Janka et al. 1999). Just what happens when jets slow down and dump their contents into their surroundings (the late afterglow phase) is bound to depend on whether the environment is a relatively dense circumstellar shell shed by a single massive progenitor, the average interstellar medium, or something still more tenuous. The set of real afterglows seems to include some of each (Chevalier & Li 2000; Frail et al. 2000a; Thompson & Madau 2000; Livio & Waxman 2000), the authors being divided on whether this should cast doubts on all such events coming directly from core collapses.

Alternative third classes whose distribution on the sky or in space is different from the main two (isotropic!) sets were proposed by Cline et al. (1999a, durations less than 0.1 sec and V/V_m and $\log N$–$\log S$ Euclidean), by Belousova et al. (1999), and by Meszaros et al. (2000, intermediate duration and dim). No specific progenitors were suggested.

Statistical studies rest heavily on completeness of samples. Have we been getting enough GRBs? The raw BATSE data can be mined for events just below the threshold at which you get an automatic shout of “burst here” from the software. Kommers et al. (2000) have looked in this twilight zone, finding mostly long-duration bursts with $V/V_m = 0.177$ (meaning that half the events are in the closest 17.7% of the volume surveyed, whatever it is). They conclude that more sensitive detectors would not have increased the yield much above the one event per day seen. Stern et al. (2000b) on the other hand, find about as many events below the trigger flux as above, and conclude that number versus flux received flattens but does not turn over. Neither paper seriously disagrees with the conclusion that events we have not seen are a lot like the ones we have.

9.3. Beam Me Down, Scotty

A quick summary of the energy situation for GRBs is that, with a reasonable degree of beaming, any of the suggested prime movers can provide enough (Meszaros et al. 1999), while without it, none can (e.g., 10^{54} ergs from GRB 990123; Briggs et al. 1999).

All estimates of the amount of energy you “save” this way are, in some sense, theoretical, since NASA has so far failed to provide a mission that can observe a single burst from more than one direction. But the radio and optical afterglows do probe an interval when relativistic ejecta are slowing down and coming to emit more or less isotropically (Rhoads 1999; Hurley et al. 2000; Huang et al. 2000; Dal Fiume et al. 2000). The early X-ray emission is also beamed (Greiner et al. 2000a; Kuulkers et al. 2000), the later X-ray emission perhaps isotropic and even a flickering standard candle (Kumar 2000). As usual the X-ray cone has an opening angle roughly equal to Γ^{-1}, where Γ is the bulk relativity parameter of the outgoing stuff.

One should not expect the correction factor from apparent total energy for an isotropic emitter to the real world to be the same for all events, since it will depend both on just what the ejecta are doing (Levinson & Eichler 2000) and on just where we are relative to the axis of the emission cone. Frail et al. (2000a) offer us only a factor of 10 for GBB 970508, while Harrison et al. (1999) are more generous, proffering a factor 300 from the optical and radio declines of GBB 990510. Kumar & Piran (2000b) and Beloborodov et al. (2000) suggest that one could get an independent estimate of the beaming angle from early, rapid fluctuations of gamma-ray flux. Seeing this will require the collecting area and time resolution of *HETE II*.

Why are the ejecta and the emission collimated, relativistic, and beamed? Well, apparently just about all cosmic ejecta are at least collimated (§ 6.2). The GRBs, however, get a head start, if, as is now widely advocated, the central engine is (at least for the ones with measured redshifts) a rapidly rotating, highly magnetized black hole (Macfadyen & Woosley 1999; Ruffini et al. 1999; Aloy et al. 2000; van Putten 2000; Lee et al. 2000b), even if you get there by a fairly complex path (Vietri & Stella 1999).

9.4. What Photons Through Yonder Windows Break?

Well, mostly they are gamma rays, and mostly they are made by charged particles wiggling. Now all we have to figure out is (*a*) how do they keep from being degraded into lower forms of existence? (*b*) what are the charged particles, and (*c*) why are they wiggling so fast for such a short time? The phrases "baryon-poor" (confusingly transmogrified into "baryon-pure" in Phys. Rev. Lett., 85, 2669), "relativistic electrons," and "compact" have been part of the response to a, b, and c for some time. A new phrase that has risen to prominence this year is "internal shocks," meaning bits of jets that are collectively moving out with sizable bulk Γ's also catching up to each other at large relative velocities.

Keeping baryons away from the emitting jets (lest they turn the gamma ray prince into X-ray frogs) remains important. Lee & Kluzniak (1999) and Janka et al. (1999) tackled the neutron star plus black hole case, and Rosswog et al. (2000) the binary NS case. Fuller et al. (2000) note that a ratio of neutrons to protons $\gtrsim 10^3$ greatly reduces the baryon loading problem, at least for the first 11 minutes. Meszaros & Rees (2000) go on to associate various degrees of baryon loading with the sorts of photons that will get to you, from photospheric (least loading) to mostly synchrotron to subrelativisticallly Comptonized (most loading).

As for what you wiggle, relativistic electrons got most of the votes, though Tokuhisa & Kajino (1999) preferred meson synchrotron emission in a field of 10^{16}–10^{17} G. As for how the wiggling is done, Smolsky & Usov (2000) revived what is called synchrocompton radiation (Rees 1971). This is what electrons do when they find themselves in such very low frequency electromagnetic radiation that the electric and magnetic vectors look to them like static fields (the former to accelerate, the latter to make circular orbits). With wind gammas of 100 or more driving the waves, you get first-round photons up to 10 MeV and a second round of inverse Compton scattering up to 10^{13} eV.

The words synchrotron and Compton were mentioned in various permutations, mostly and favorably by Granot et al. (2000), Dermer et al. (2000), and Brainerd (2000), with, however, a firm negative vote from Ghisellini (2000) who concludes that the spectrum comes out wrong and proposes that Comptonization by quasi-thermal electrons might work better. A very high therm would seem to be required.

Many of the events show millisecond pulse substructure, and this rapid variability implies compact emission regions, and perhaps multiple ones. Several variants appeared, including a shotgun (Heinz & Begelman 1999), multiple subjets (Nakamura 2000), multiple shocks and shells (Kumar & Piran 2000a), and very compact emission regions each with a small range of particle γ's (Walker et al. 2000a).

There was a handful (five papers, literally) of discussion of internal shocks in jets and what you should see as a result (GRBs of course, or this paragraph would be in a different section). In order of appearance, they were Meszaros & Rees (2000), Spada et al. (2000), Daigne & Mochkovitch (2000), Beloborodov (2000), and Ramirez Ruiz & Fenimore (2000).

Lower-energy photons are the province of the tails or afterglows now associated with a number (but still a small fraction) of burst events. Such tails were actually predicted from a fireball model (meaning lots and lots of electron-positron pairs and photons in a small but expanding volume, Meszaros & Rees 1997). This remains the model to beat, according to Frail et al. (2000b), who endeavored to fit the radio as well as optical and X-ray fading of GRB 991216. The scenario called PEM (Pair ElectroMagnetic Pulse) is apparently different enough that the authors (Ruffini et al. 2000) did not find it necessary to cite much of the fireball literature.

Only the brightest events yield gamma-ray spectra with many wavelength resolution elements. Preece et al. (2000) show a set from BATSE. Pre-BATSE evidence for cyclotron resonances in GRB spectra remains one of the piles of dirt under the rug, because the required magnetic field of 10^{12} G or so would imply emission near the surface of neutron stars, the sort of model generally accepted before it became clear just how isotropic on the sky the GRBs are (Ap97, § 11.2; Ap92, § 6.5). Barat et al. (2000) have gathered all available photons from the very bright GRB 910406 and suggest that it had an umpteen-component spectrum, so that drawing an envelope over them all might give the impression of 10–50 keV features. This would be a happy resolution, in which everybody gets prizes, either for accurate reporting of observed spectra or for rethinking what they must mean.

And, as the Sun pulls away from shore and our boat sinks slowly in the west, you are left with another 40-some interesting GRB papers unmentioned, but a review article (Piran 1999) that catches many important issues omitted here.

10. MOURNFUL NUMBERS

These are all astronomical, though some are very small (second and third examples of previously unique phenomena, firsts, and extrema). Others are very large and evidence of the imaginations and hard work of the community. The numbers also illustrate a fairly well known theorem, that first digits of real numbers are distributed somewhat logarithmically. That is, they are more likely to begin with 1, 2, or 3 than with 7, 8, or 9. Telephone numbers are different. They are most likely to begin with a new area code.

10.1. Countdown

$10^{50–100}$, the potential, finite, future of life in the universe, according to Krauss & Starkman (2000). The units probably don't matter.

8×10^{10} photometric measurements made by the MACHO project (Alcock et al. 1999).

5×10^{10}, the galactic millennium in years. Some interesting things will happen in the meantime (Hodge 2000).

5.25×10^{8} lines of TiO and H_2O included in a model atmosphere for pre-main-sequence stars (Allard et al. 2000).

17,000,000 infrared point sources in the first release of data from DENIS (Epchtein et al. 1999).

105,924 sources in the *ROSAT* All-Sky Survey (Voges et al. 2000). Each is represented by at least six photons, and the catalog will not be issued in print form.

83,992 visual binary systems in the *Washington Double Star Catalogue*. All are exactly where they should be, but we misplaced the reference.

60,000 OB stars in the Milky Way (Reed 2000), for which we have reasonable data on about 3000. The implied formation rate is about 1/40 years, not enormously different from estimated rates of core-collapse supernovae.

22,168 regular orbits included in a dynamical model of the bulge of the Milky Way (Haefner et al. 2000).

18,811 sources from the *ROSAT* All-Sky Survey in the archival literature (Voges et al. 1999). This is less than 20% of the total, as per the old high energy astrophysics conference protest slogan, "free the *ROSAT* 100,000."

13,875 X-ray stars from the cross correlation of the Tycho (*Hipparcos*) and *ROSAT* catalogues (Guillout et al. 1999).

11,310 candidate galaxies from a visual search of 560 square degrees in the galactic zone of avoidance. Only 152 of them were previously catalogued (Roman et al. 2000).

9286 stars with polarization data (Heiles 2000, who prints only sample tables).

3000 languages that have become extinct since 1900 (Krauss 1992). About 3000 remain.

2355 galaxies in Abell 496, for which Moretti et al. (1999) report luminosities.

2049 Cepheids in the Small Magellanic Cloud, with light curves from the OGLE project (Udalski et al. 1999, who show all the light curves!).

1952, the Carrington rotation number in September 1999, which was Space Weather Month (Kozyra & Webb 1999). Carrington must have started counting before 1875 (because that is when he died). In fact he and Hodgson were the first to report seeing a white-light solar flare, in September 1859.

1781 periodic variables found so far by the Robotic Optical Transient Search Experiment (Akerlof et al. 2000). One of the less burning question is whether the acronym ROTSE is pronounced like ROTC. A more significant point is that, since their primary goal is to find non-periodic variables (transients), these are in a sense all noise.

1302 young stellar objects with *IRAS* colors (Iwata et al. 1999).

1049 sources (plus one CLEAN artefact) in a survey down to 0.1 Jy at 408 MHz (Vigotti et al. 1999). We remember when 3C went all the way down to about 9 Jy (but it looked at a larger fraction of the sky).

758 *ROSAT* sources in the Large Magellanic Cloud (Haberl & Pietsch 1999).

719 star clusters in the Small Magellanic Cloud, with 46 added by the OGLE project (Bica & Dutra 2000) and perhaps 40 more to be found, compared to 900 predicted by Hodge (1986).

745 star clusters in the LMC, with 126 added by OGLE (Pietrzynski et al. 1999).

674 X-ray sources in a statistically complete subsample (yeah, the *ROSAT* ASS again). They include 274 stars, 26 galaxies, 284 AGNs, 78 clusters of galaxies, and 12 empty fields at visible wavelength (Krautter et al. 1999).

636 Delta Scuti stars, about half newly-recognized since 1994 (Rodriguez et al. 2000).

476 catalogued LINERs seen by *FIRST* (Carrillo et al. 1999). Most are bright, early-type galaxies.

475 Herbig-Haro objects, including 15 new ones near compact reflection nebulae (Aspin & Reipurth 2000).

463 flare stars with ultraviolet data (Gershberg et al. 1999).

380 variable-star light curves obtained with a 13.5 cm telescope, by a single observer, looking at a small part of the sky (Pojmanski 2000).

280 Cepheids with light curves from *Hipparcos* (Groenewegen 1999). About 10% are W Vir (Pop II) stars, and 216 are Population I, pulsating in the fundamental mode.

271 diffuse absorption bands produced by the interstellar medium, with wavelengths between 4460 and 8800 Å (Galazutkinov et al. 2000). Most of the central wavelengths are said to be accurate to 0.1 Å, leaving us in doubt about just how diffuse they can actually be (not anyhow more than 16 Å on average!).

226 confirmed diffuse interstellar bands over a somewhat different wavelength band (Tuairisg et al. 2000), or 213 (Weselak et al. 2000). All three papers make the point that the inventories are open-ended, with new bands being seen and previously reported ones not always confirmed. The first lists

came from Hegen (1922) and Merrill (1934), who showed that the origins were truly interstellar.

212 extragalactic radio sources imaged in total and linearly polarized intensity (Reid et al. 1999).

156 nearby eclipsing binaries, whose light and radial velocity curves may be clean enough for direct distant determinations (Kruszewski & Semeniuk 1999). The method goes back at least to Joel Stebbins' work with a selenium photometer on Delta Orionis in 1915, and the eventual goal is to reach extragalactic systems.

134 candidate planetary nebulae in M33 (Magrini et al. 2000).

118 supernovae discovered in 2000, up to the witching data of 30 September (2000dn in IAU Circ. 7494, dated 29 September). The rest of the calendar year will clearly use up the 2000e's and probably the 2000f's. 1999 nearly ran off the g's (SN 1999gu in IAU Circ. 7346), and one can see dimly ahead to a time when the IAU may need to reconstitute its Supernova Working Group to decide upon a method of naming events beyond, say, 2008zz. The first SNWG was Zwicky's creation and died with him. The most useful product of the second, which declared itself supernumerary after SN 1987A made the word supernova conscious, was probably the resolution declaring that Zwicky's use of double lower case letters after the first 26 events in a year should be official. Our favorite was 2000cp, since the composition (unknown to us) was surely at least chemically pure.

106 giant molecular clouds in a more or less complete census of the LMC (Fukui et al. 1999). The paper is part of a "first results" package from NANDEN, the Japanese millimeter (the wavelength of operation, not the size) telescope at Las Campanas. The H_2 mass adds up to about 10% of the H I mass of the LMC.

70 authors on a paper reporting optical detection of a gamma-ray burst (990328; Schaefer et al. 1999). The telescope is in Venezuela, which may or may not have anything to do with it. Anyone who is puzzled by the ordering of the authors' names has probably never met the first author.

70 sinusoidal light curves for variable stars in the Tycho Catalogue (Koen & Schumann 1999). The telescope probably passed over Venezuela.

39 primeval galaxies, meaning ones with infrared luminosity in excess of $10^{13}\ L_\odot$ and star formation rates in excess of $10^3\ M_\odot$/yr. Most are, however, at redshifts of only 0.3–1.0 (Rowan-Robinson 2000).

34 modes seen in a single Delta Scuti star, U CVn (Breger et al. 1999). Most have frequencies in the range 52–112 μHz, and about half are linear combinations of the other half.

30 pulsars known to have glitched (Urama & Okeke 1999). Glitch activity is approximately logarithmic in dP/dt, the time derivative of the period.

26 broad photometric bands? Well, perhaps not, but Steele & Howells (2000) have reached Z without revealing the secret of its wavelength. I–Z is, anyhow, not a good temperature indicator for stars of type L.

23 carbon atoms in the longest chain molecule expected in IRC +10216 according to Millar et al. (2000), whose reaction network used 3851 reactions among 407 species.

20 pulsars in the globular cluster 47 Tuc, reported in the Newsletter of the Australia Telescope.

$20 \leftarrow 19 = n$, the highest Rydberg line seen in the Sun (Clark et al. 2000b). It has a wave number of 29.6 cm^{-1} and is limb brightened.

19 X-ray emitting supernova remnants in the SMC (Haberl et al. 2000).

17 moons belonging to Jupiter. This is merely a progress report, with additional satellites being reported for all the giant planets on a near-weekly schedule. For instance, IAU Circ. contains the names for the 18th, 19th, and 20th Uranian moons. None of them is much good for spooning under, and Uranus isn't real strong on June either.

13 Gamma Dor stars (Kaye et al. 1999). We knew the first (Ap97, § 8.3; Ap98, § 3.8) back when it was still called 9 Aurigae.

12 different codes from which the development of very large scale structure in the universe can be computed. They are compared by Frenk et al. (1999) and found to be in reasonable agreement.

11 CH_3OH masers (Val'tts et al. 1999).

11 classes of stars with evidence for magnetic activity (Jetsu et al. 1999).

10 or 11 X-ray dippers (Smale & Wachter 1999). These are low mass systems in which a flared accretion disk occults its own hot center once per orbit period, of importance in confirming that these sources really are binaries.

10 supernovae seen as X-ray sources (Schlegel 1999).

Nine sites from which TeV gamma-ray astronomy is being done (Catanese and Weekes 1999). Actually there is a 10th, at Yangajing, Tibet (Amenomori et al. 1999), but the paper still fits here because it has a total of nine authors who are either Tibetan, surnamed Zhang, or both. We won't tell you how to recognize a Tibetan author, but it once caused the editor of another journal to ask a lead author whether he was absolutely certain about the names of his colleagues. In either case, the installations outnumber the confirmed sources: three or four supernova remnants and a comparable number of low redshift blazars.

Eight — *ROSAT* candidates for Be-star X-ray binaries in the LMC (Stevens et al. 1999).

— low mass X-ray binary systems in which the frequencies of the quasi-periodic oscillations trace out a Z-shape in suitable coordinates that involve X-ray "color" or hardness ratio (Smale & Kuulkers 2000).

Seven — the number of mathematics problems for the solutions of which the Clay Mathematics Institute has offered $1,000,000 each (Jaffe 2000).

— pulsars probably detected by EGRET as gamma-ray sources (Kuiper et al. 2000). The most recent is J0218+4237 with a period of about 2.5 msec.

Six — AM CVn stars. These are the odd cataclysmic variables whose prototype is HZ 29 and which apparently consist of two low mass, helium white dwarfs in very tight orbits. Skillman et al. (1999) and El-Khoury & Wickramasinghe (2000) report that AM CVn itself has both an orbit and a superhump period near 1000 sec.

— stars of spectral type WO, presumably the last evolutionary stage in the life of a massive star en route from the main sequence via other forms of Wolf-Rayet star to a bare CO core (Afanasev et al. 2000).

— low mass X-ray binaries that show X-ray eclipses (Wachter et al. 2000).

Five — medal winners on the US team at the International Physics Olympiad held in Leicester UK (Hargreaves 2000). All were silver or bronze medals, only the Chinese team receiving five golds. Other high scorers were Russia, Hungary, India, and Iran (including the woman with the highest score). The US team members were all men, including two from Southern California and two from the Washington suburban area (for which the author who sporadically occupies both these sites can take absolutely no credit).

— roAp stars (meaning "rapidly oscillating") which also have Ap companions (Gelbmann et al. 2000).

— measured orbit periods for low mass X-ray binaries in globular clusters (in't Zand et al. 2000).

— types of H I shells in the interstellar medium of the LMC (Kim et al. 1999). Shells and supershells occupy most of the ISM there.

— lower limit to the number of sorts of instabilities in stars with both magnetic field and differential rotation (Spruit 1999).

— blue-shifted, iron-rich absorption line systems in the spectrum of a single QSO (Dobrzycki et al. 1999). The clouds presumably all result from a single explosive event.

Among the notable fours are:

Binary pulsar J1811−1536, at $P = 0.104$ sec and 18.8 days, probably the fourth with a second neutron star as its companion (Lyne et al. 2000a).

The heart chambers of a small ornithiscean dinosaur, whose name we do not remember. They don't answer anyhow (Fisher et al. 2000).

The dwarf novae with deep eclipses and period longer than the gap in $N(P)$ (Gaensicke et al. 2000b).

P4M, where the fourth P means "parabolic" (Brieu & Evrard 2000). What about the other three P's? They are all particles; the acronymial method of studying evolution of complex dynamical systems, P3M, means particle-particle/particle-mesh.

A bunch of quadruple star systems, including LHX 1070, all of whose members are M and L dwarfs, less than 20 pc from us (Leinert et al. 2000); HR 266, all of whose members are B9-A1 dwarfs, in a hierarchical pattern with periods of 83 yr, 4.8 yr, and 4 days (Balenga et al. 1999); and HD 98800, in which two spectroscopic binaries make up a visual binary 38 AU apart, and only one of the pairs is surrounded by a dust disk (Koerner et al. 2000). Anything that isn't forbidden is compulsory as Gell-Mann is supposed to have said.

There is also, perhaps, a 4-armed spiral to be found in the distribution of OH stars in our own galaxy (Sevenster 1999), though Drimmel (2000) avers that the real distribution of mass has only two arms (even if the gas shows four). He is also looking at infrared data and the main body of the disk, suggesting a real contradiction. The average would, of course, be an $m = 3$ spiral, which is at least approximately what the galactic nuclear disk looks like. Vollmer & Duschl (2000) find that most of the motions therein are Keplerian and turbulent, not outflowing. We cannot, in any case, complete with NGC 1228 whose two arms split into three each outside the bar, according to Fuchs & Moellenhoff (1999).

3.5 are the post-Newtonian equations of Rezzolla et al. (1999). We are in no position to object to other people doing things by halves, but are still struggling over the adjective. Is it the 3-and-one-halfth, the three-point fifth, the third-and-one-half approximation or what?

The source J005734.78−272822.4 (Page et al. 2000) presents similar problems of pronunciation, but equally worrying is the rapidity with which reality has caught up with what was meant to be a parody (Trimble & Sciatti III 2000).

The threes, some of which clarify astrophysical classes and some of which confuse include:

The third sdOB star in a visual binary (Makarov & Fabricus 1999). The orbit periods are all of order 100 years, so it will take a while for measured masses to settle the old issue of just where these stars live in the evolutionary scheme of things.

The third optical burst from an X-ray transient binary (Gneiding et al. 1999, not all from the same source).

Three meanings for the acronym AIC. Accretion-induced collapse came first (Ap91, § 6.1). And then there was the Akaike'i Information Center (Ap&SS, 271, 213) and Achromatic Interfero-Coronagraph (A&AS 145,, 141).

The third case of transient interstellar absorption (Price et al. 2000). This one is caused by H I in the Orion-Eridanus supershell. Some others are due to other parts of Orion and to the Vela SNR, which was the first reported (Hobbs et al. 1982).

Three components in the emission lines of Seyfert 2 NGC 1069 (Crenshaw & Kraemer 2000).

Ni^{48}, the third doubly-magic nucleus of nickel (Blank et al. 2000). The others are 56 (which you know about from supernovae) and 78. Only nickel can make this claim.

The third detection of Mkn 501 at TeV energies (Andreeva et al. 2000), apparently a delayed report, given the nine installations mentioned above.

The third-largest Kuiper Belt Object, $1996TO_{66}$ at about 326 km (Hainaut et al. 2000). Bigger are Pluto (oh, you knew that?)

and Charon. The rotation period is 6.25 hours and other variability may be due to comet-like activity.

Three basic X-ray states of the microquasar GRS 1915+105 (Belloni et al. 2000a).

And the three protons of the stable if not very familiar ion H_3^+ (Encrenaz et al. 2000; van der Tak & van Dishoeck 2000).

Two brings us to:

The second medal awarded to Visnjan Observatory for discovery of a comet by amateur astronomers.

The second binary Cepheid (meaning that both stars belong to the class). It is EV Sct (Kovtyukh & Andrievsky 1999). The first was CE Cas. Both are in open clusters, NGC 6664 and 7790, which given the rarity of Cepheids in clusters strikes us as odd.

The second $m = 1$ spiral in a disk around a binary Wolf-Rayet star, WR 98a (Monnier et al. 1999).

The second detection of polarization in a non-mased radio emission line, CO in an *IRAS* source (Girart et al. 1999). The first was reported nearly 20 years ago (Goldreich & Kylafis 1981).

The second compact blue dwarf galaxy (Tol 65) with a companion of low surface brightness (Papaderos et al. 1999). The first was I Zw 18 (famous for its minimal metallicity). More examples, the authors note, are needed, in order to test their suggestion that the pairs in each case formed from a single H I concentration.

The second closest star of the future will be less than 0.5 pc away within 20 Myr, according to extrapolations of *Hipparcos* measurements (Garcia-Sanchez 2000). The closest will still be at 1 AU.

The second interstellar molecule to be found in double deuterated form is ND_2H in L134N (Roueff 2000). The first was D_2CO.

Two acceleration mechanisms for the gas stream in QQ Vul, a magnetic cataclysmic variable or AM Her star (Schwope et al. 2000).

The Second Tycho Catalogue (Høg et al. 2000). It includes positions, proper motions, and two-color photometry for the 2.5 million brightest stars in the sky (and so could have been listed as 2.5×10^6 above).

Second example of gravitational lensing by a small group of galaxies near $z = 1$ (Rusin et al. 2000). The first was reported in 1999 and in both cases the group members are all low mass galaxies. Additional examples could reveal whether the dark to luminous mass ratio is the same in these groups as in richer clusters nearer the present epoch.

The second basaltic asteroid, 1459 Magnya (Lazzaro et al. 2000). The first was 4 Vesta and they are thought to be fragments of the same parent body.

The second faintest white dwarf at $M_V = +16.8$ (Hambly et al. 1999). The authors suggest that it may be a halo star (i.e., MACHO candidate). There are, of course, probably very many still fainter white dwarfs but, like the trans-Lehrerian elements, they haven't been discarvard (rhymes with Harvard).

10.2. War, Peace, and Hearts of His or Her Countrypersons

This section of extrema is appropriately named for George Washington, with politically correct improvements, because so many of the discoveries were financed by federal grants. We caught about 25 firsts and three or four times as many other extrema and lay out for you a subset chosen for potential astrophysical significance. This lot is ordered from near to far. Mentally supply "the first" before each item.

Drawing of a sunspot dates from 1128. The artist, John of Worcester, presumably a firm believer in the immutability of the heavens, is said to have thought he was seeing opaque objects passing by (Stephenson & Willis 1999). In case you wondered, transits of Mercury are not naked eye events, and there were none of Venus that decade.

Stable compound incorporating argon (Kriachichev et al. 2000). It is HArF, made in Finland. Only helium and neon still resist chemical bonding, but similar methods may work for them (and presumably also the low temperature).

Spectroscopic orbit for a pair of brown dwarfs. Both show lithium, and the mass ratio is 0.85 (Basri & Martin 1999).

Triple white dwarf (Maxted et al. 2000). The close pair is a spectroscopic binary, with one helium and one carbon-oxygen component, also a first; other known WD pairs have mass ratios close to one and the same core composition for both stars.

Binary white dwarf consisting of two polars, TX J1914+24 (Ramsay et al. 2000).

Balmer lines due to deuterium (Hebrard et al. 2000). Seen in Orion, they are fluoresced by Lyman alpha, which is good for detection but very bad for measuring the D/H ratio.

Planetary nebula distance measured using optical proper motions (Plus radial velocities, Reed et al. 1999). The radio proper motion technique was pioneered by Masson (1989), and the first optical proper motions measured by William Liller, who was not cited, in the late 1960's.

Planetary nebula made by both stars of a binary dying in close succession, KjPn8 (Lopez et al. 2000).

X-ray lines of Cr and Mn from a source outside the solar system (Hwang et al. 2000a) in the supernova remnant W49B.

Luminous blue variable displaying a coherent period, 8.26 days for B416 in M33 (Shemmer et al. 2000). No cause was suggested.

Chimney that has blown out of the plane of the Milky Way on both sides of the plane (McClure-Griffiths 2000). Our notes said "to north and south," but perpendicular to the galactic plane is north and south only in the sense that the San Diego Freeway can be said to run north and south through Orange County.

EGRET detection of a microquasar (LS 5039, this is not actually one of the superluminal ones; Parades et al. 2000).

Star of type Onfp(Ocf). No, we aren't quite sure what it is, but it must be quite bright, since it is in the SMC (Walborn et al. 2000).

Star cluster in IC 1613 (Wyder et al. 2000). Baade (1963) had looked for, but did not find, clusters in this dwarf irregular galaxy.

Superluminal Seyfert, III Zw 2 (Brunthaler et al. 2000).

10.3. The Wisest, Brightest, Meanest of Mankind

These are, on the whole, ordered from far to near, and the ’est words are supplied, since it is not always self-evident just what is extreme. The quote is from Alexander Pope, who also said of governments, “What e’er is best administer’d is best.” We are not sure what fraction of his proposals were funded, but it’s clear he understood astronomers, to wit, “To observations which ourselves we make, We grow more partial for th’observer’s sake.”

Record redshifts. $z = 5.5$ for the QSO RD 300 (Stern et al. 2000b), based, however, only on R-band drop out. At $M_B = -22.7$ ($H = 100$) it would be the faintest high redshift QSO. $z = 5.03$ for a QSO in the Sloan Digital Sky Survey (Fan et al. 2000a), also reporting $z = 4.92$ as a probable record for a QSO with broad absorption lines. The most distant BL Lac object (Fan et al. 1999, again from SDSS) has a damped Lyman alpha system which puts the source at $z \geq 4.62$. And the most distant BAL QSO with detected X-ray emission is also the optically brightest (Brandt et al. 1999).

Some other QSO and AGN items. The largest QSO nebula (meaning ionized from the nucleus) extends to 200 pc (Shopbell et al. 1999). The gas is in smooth rotation and must belong largely to a host galaxy, not a merger or cooling flow. The closest pair of QSOs (meaning to each other, the redshift is 2.24) is CTQ 839, with a projected separation of $2''.1$ or 8 h^{-1} kpc, and a velocity difference of less than 100 km/sec (Morgan et al. 2000). They are not a good candidate for lensing, however, since the spectra are very different. They must have rather small host galaxies and be at risk of collision or merger, if they haven’t already begun to interact and share a host.

The brightest narrow-lined Seyfert 1 galaxy is Ark 564 (Vaughan et al. 1999, who leave us wondering who was Ark?). M81 is the closest LINER (Pellegrini et al. 2000).

The *HST* Key Project on the cosmic distance scale has truly reported their last galaxy and finally got I before K in the alphabetized part of the author list (Sakai et al. 1999).

Some other galaxy extrema. The most metal poor remains I Zw 18, though the search for competitors continues (Kniazev et al. 2000). The limit occurs close to [Fe/H] $= -2$ because star formation is very inefficient at smaller metallicities and one O V star can ionize a whole cloud of 10^2–10^4 $M_\odot$ (Nishi & Tashiro 2000). The most massive spiral galaxies top off at 2×10^{12} $M_\odot$ according to Salucci & Burkert (2000), who say it is related to a breakdown of scaling of core density with core radius at the largest disk masses. The closest weak lensing occurs in Abell 3667 ($z = 0.055$; Joffre et al. 2000). One gets, of course, a measurement of the cluster mass. It is not unusual.

The reddest galaxies. These are conceivably important because they might be displaying unusually large amounts of dust, star formation that ended a really long time ago, very high metallicity, or, of course, measurement errors. The answer appears to be “all of the above,” although not all authors have in mind quite the same definition of very red. Cimatti et al. (1999) present a sample where some are dusty and some are old. A SCUBA sample with $I-K \geq 6$–7 in the Hubble Deep Field includes galaxies not actually seen by Hubble, a major impediment to assigning types (Smail et al. 1999b), but others with a bit more information include both AGNs and star formers, both, of course, with lots of dust (Cooray 1999). Soifer et al.’s (1999) sample is defined by $R-K > 5$, and the underlying galaxies are not all the same sort of beast, even after corrections for reddening. Finally, Margoniner & de Carvalho (2000) report that a previously-advertised population of very red galaxies in rich clusters at moderate redshift belongs to the “oops” category.

Star clusters. The puniest NGC one is 6994 with three bright members at its core (Bassino et al. 2000). Actually a few NGC numbers correspond to asterisms with no physical members at all, or, as a colleague once said, “Either your phone number hasn’t changed, or NGC 6948 is an interesting object.” It is, in fact, one of those asterisms.

Neutron stars. The largest mass this year, 7.944 $M_\odot$ (Negi & Durgapal 2000) is, not surprisingly, a calculation not an observation. It requires the star to have a speed of sound equal to the speed of light in its core, a polytropic envelope (carrying the new, higher postage rate), and a radius of 33 km. The shortest rotation period for a neutron star, as opposed to a strange quark star, is also a calculation (Glendenning 2000). The most interesting bit is that the Keplerian period is not unique for rotating neutron stars because frame dragging depends on latitude.

X-ray binaries. The longest orbit period for a low mass one is 304 days for GX 1+4 (Pereira et al. 1999), besting the previous record by a factor 10. The shortest orbit period for a LMXRB is 80 minutes (King 2000). This reflects a turn-around in the evolution of the period analogous to the one in cataclysmic variables. The fastest quasi-periodic oscillations are at 1200 and 1800 Hz in Cen X-3, a high mass XRB (Jernigan et al. 2000). The longest X-ray binary burst fueled by nuclear reactions was 86 minutes for 4U 1735−44, seen by *BeppoSAX* (Cornelisse et al. 2000). There were no other bursts for several days before or after, in accordance with the long-honored models with characteristics of a relaxation oscillator (the sort of toilet you have to fill up completely before you can flush it again, even if it wasn’t totally emptied the first time).

White dwarfs and cataclysmic variables. The shortest rotation period for a white dwarf is 33 sec in the CV AE Aqr (Choi et al. 1999). VY Scl is a CV and part of a triple system with $P = 5.8$ days, probably the shortest “long” period known in a triple (Martinez-Pais et al. 2000). The oldest recovered nova is 1678 (Robertson et al. 2000). Non-recoveries of others like 1612 means that they must be even fainter. The most stable stellar optical clock is the pulsating WD G117-1515A, with $P = 215$ s and $dP/dt < 3 \times 10^{-15}$ sec/sec. Once its proper motion and such are sorted out, this should turn into a measured value of periodic change, to be compared with what is expected as WDs cool (Kepler et al. 2000). Some radio pulsars have even greater period stability.

Other close binary stars. The shortest period Algol is W Crv at $P = 0.388$ days. It must have started with a mass ratio close to one and never have had a rapid mass transfer phase (Rucinski & Lu 2000). The W UMa whose mass ratio comes closest to 1, at 0.970 ± 0.003 is V753 Mon (Rucinski et al. 2000). The total mass of the system is also fairly large, and it must be trying to tell us something about what is needed to maintain contact systems in contact.

Star formation and young stellar objects. The closest molecular cloud with recent star formation is MBM 12 at 65 ± 35 pc (Hearty et al. 2000a) or 60–90 pc (Hearty et al. 2000b). At least the authors agree with themselves about the name of the region (which tells you that it is a high latitude molecular cloud if you happen to have your Long Ranger code ring handy). The cluster is the second closest after that centered on TW Hya. The smallest measured velocity is 4–10 m/sec for the infall of CS gas in a dense core in a star formation region (Heithausen 1999). To put this in context, 7 m/sec is the still slightly superhuman 25 km/hr, that is, you could not keep it up for long, but a cheetah could. The fastest Herbig-Haro object is in a region called 66D37 (even by its closest friends; Raines et al. 2000) and displays a proper motion equivalent to 850 ± 200 km/sec in infrared images.

The most massive stars. It remains puzzling that the largest numbers found directly in binary systems, e.g., $45 + 20\ M_\odot$ for the 03 V + 08 V pair HD 93205 (Antokhina et al. 2000) remain considerably smaller than the numbers extending above $100\ M_\odot$ found by matching observations of luminosity and temperature to evolutionary tracks. It is presumably somehow relevant that measured values of surface gravity give something in between, e.g., 37–64 $M_\odot$ for stars with evolutionary masses of 30–140 $M_\odot$ (Herrero et al. 2000), and the cause must be rather early mass loss, though the *IRAS* source discussed by Shepherd et al. (2000), which has already dumped 50–60 $M_\odot$ in 10^4–10^5 yr, seems excessive. Or perhaps not, if you look at the largest mass loss rates, up to $10^{-3}\ M_\odot$/yr for a few asymptotic giant stars (van Loon et al. 1999) and $10^{-2}\ M_\odot$/yr for a protostar in Orion (Nakano et al. 2000). Both must be rather short-lived phases.

The fastest planetary nebula gas clocks in at 2500 km/sec (*IUE* spectra reported by Feibelman 2000), beating the 600 km/sec for knots in MyCn18 reported by O'Connor et al. (2000). But both are cheating. The latter is probably ejecta from a nova-type explosion of the central binary, and the former is probably a hot stellar wind from the central pre-white-dwarf, not the material from an atmosphere of a red giant that we normally mean by the phrase "planetary nebula."

The longest comet tail, streaming 3.8 AU out of the nucleus of Hyakutake, was caught by *Ulysses* in 1996 (Jones et al. 2000b). The previous record of 2 AU was set in March 1843 by, we presume, the Great Comet of 1843. Hyakutake's tail also displayed conspicuous pick-up ionization from the solar wind at about the same time (Gloeckler et al. 2000).

The largest number of references in a single parentheses is 103 (Li & Wilson 1999), beginning with Pringle & Rees (1972). The paper concerns the structure of accretion disks with magnetic fields.

The largest numerical error of the year probably came from Wilman & Fabian (1999) who attribute some part of the X-ray background to Seyfert 2 galaxies absorbed by $10^{-24} \le N_{\rm H} \le 10^{+25}$ atoms/cm^2. We think 10^{+24} may have been intended, owing to the difficulty of detecting X-ray absorption by very small column densities.

The highest observatory is Cerro Toco, a Chilean site from which anisotropies in the cosmic microwave background are being measured (Miller et al. 1999). It is at 5200 meters, and ALMA will go nearby.

The smallest limit on the charge of the photon may be $10^{-29}\ e$ set by Sivaram (1999) from observations of GRB 990123. Their limit on the photon mass is 10^{-44} g and is not a record.

The smallest observer is the one required to verify that the uncertainty principle still applies to energy, angular momentum, and so forth measured from inside the system (Aharonov & Reznik 2000).

If you dislike getting up in the dark as much as we do, you may always have been too bleary eyed to wonder whether the latest sunrise occurs close to the winter solstice or immediately after the onset of daylight savings time. This turns out to depend a little on just which day DST starts, a good deal on the equation of time, and most on your latitude. Post DST is later (by a few to 29 min) at northern latitudes south of 44°. The solstice period is later, by a few to 40-some minutes at latitude 44° to 60°, beyond which you get tangled up with sunrises and sets that happen once a year rather than once a day. The calculation was generously done for us by Brian Marsden, whose 35 years as director of the IAU central telegram bureau also set a record.

The largest geoid, 8 × 17 meters, was found in Spain (Garcia-Guinea 2000). If you think of geoids primarily as ornaments for coffee tables, then this one was clearly meant for the Immensosaurus family (and a collection of the "Astrophysics in …" reviews for their coffee table book).

11. MENAGE À TROIS: RELATIONSHIPS AMONG QSOs, STARBURSTS, AND BLACK HOLES

First, some definitions, which apply throughout this paper, although other writers might choose slightly different ones. Active Galactic Nuclei (AGNs) are ones that emit half or more of the galaxy's total luminosity from a region unresolved by ground-based optical techniques of the pre-adaptive-optics era. The brightest sort (100 times or so the power of an L* galaxy coming from the core) are quasars (if they are strong radio sources), QSOs (if they are not), and BL Lac objects or Blazars if they are more like BL Lacertae used to be (it now has emission lines) than BL Lac was like a variable star. Rapidly varying polarization is typical. Statistics require that the brighter AGN conditions cannot persist for more than about 1% of the age of the universe, so QSOs (etc.) can be thought of as events as well as objects.

Starbursts are usually thought of as events, during which a galaxy (or potential galaxy part) is forming stars at many times (10× or 100×) the rate that it could keep up for the age of the universe. Astrophysical black holes (whether of stellar or galactic mass) are entities with effective sizes not enormously larger than the Schwarzschild radius for their masses, and are not to be confused with theorists black holes, inside which your wrist watch turns into a ruler and conversely. We are not sure about pocket watches.

11.1. Black Holes versus Bulge or Elliptical Galaxy

You have had a few years to get used to the idea that data for (many) galaxies reveal a strong linear correlation between the mass of the central black hole and the mass of stars in the spheroidal components (Ap98, § 9.1), with the mass of the black hole $\approx 1\text{–}2 \times 10^{-4}$ times the mass of the spheroid. The time has come to ask (1) is the relation generally true? (2) if true, how much real scatter is there around it? and (3) how many different ways has the correlation been explained?

First, is it true? Not apparently for the later spirals (Salucci et al. 2000). And this may be because their bulges are not the same sort of beast as larger ones. They show different correlations of stellar population, size, and surface brightness (Khosroshahi et al. 2000; Molla et al. 2000), and there has been a modest ground swell (ground bulge?) of opinion for making them from repeated dissipation of central bars rather than from collapse or mergers (Carollo 1999; Zhang & Wyse 2000). Should we keep the Milky Way on the graph? It is neither a very early nor a very late spiral (de Vaucouleurs et al. 1990), and it does quite unambiguously have a central black hole of $2.6\text{–}3.3 \times 10^6\ M_\odot$ (Genzel et al. 2000; Ghez et al. 2000).

A good indicator of reality for the correlation for the larger bulges is that it gets tighter with better data. Earlier papers focused on bulge luminosity as a mass indicator. Both Ferrarese & Merritt (2000) and Gebhardt et al. (2000) look instead at the velocity dispersion of the bulge stars (which should probe mass with less sensitivty to details of stellar population than does luminosity) and find that the scatter is reduced. Unfortunately, the two groups find two different functional forms, with $M(\mathrm{BH}) \propto \sigma_v^x$ and $x = 4.8 \pm 0.5$ and 3.75 ± 0.3 respectively.

Despite these disagreeing by more than their probable errors, both papers conclude that the answer to question (2) is that the scatter is largely observational. There are exceptions. Shields et al. (2000) point to the LINER NGC 4203 as a real ratio-disturber, having an upper limit to the black hole mass of $6 \times 10^6\ M_\odot$, at most one-fifth of what you expect.

Third, we found something like six or seven explanations for the correlation during the index year. Most are not readily classifiable into our earlier types of chicken (bulge came first), egg (black hole came first), and potato salad (co-evolution). Whatever order they are presented in will offend some author (above and beyond the offense of being mentioned in these pages at all). The one adopted is simply the order in which the papers appeared on library shelves.

Fabian (1999), building on an idea from Silk & Rees (1998), watches both the spheroid and black hole grow until, at the observed ratio, wind ejects cold gas from the galaxy and stops the growth of both. One expects the wind energy to heat the intergalactic medium to as much as 10^7 K; the ejecta may be what we see as broad absorption lines in QSO spectra (arguably all QSOs have such clouds, just not always along our line of sight, Ogle et al. 1999); and the scenario predicts that a new population of black-hole powered, hard X-ray sources should appear at $z > 1$. (Cf. § 8.5.1.)

Franceschini et al. (1999) say that accretion onto a central black hole should track the rate of star formation, so that everything is big and bright together, and systems of large mass and luminosity evolve faster than others.

Monaco, Salucci, & Danese (2000) start with the spin of the dark matter halo as setting the efficiency of both black hole growth and star formation. Slow spin yields big bulges and holes, and the ones in the biggest halos turn on first (which more or less agrees with observations).

Kauffmann & Haehnelt (2000) propound a second class of egg salad model, in which the co-evolution of black hole mass, AGN activity, and galaxy growth is driven by mergers. As time goes on from $z \approx 2$ to the present, there are fewer mergers, less gas available, and a longer cooling time for the gas (the cold component being seen as the damped Lyman alpha absorption features in QSO spectra).

Merrifield et al. (2000) propose another merger-driven scenario, with the key quantity being the length of time since the last major merger in hierarchical galaxy formation. This then determines the age of the dominant stellar population and the final mass of the black hole via the amount of material still in gaseous form and available to be accreted by it.

Ostriker (2000) invokes self-interacting dark matter (the hot new cold candidate mentioned in § 12.4.2). It leads to both the black hole mass and the luminosity of the galaxy scaling with circular velocity as $V_c^{9/2}$, consistent, at least, with what Ferrarese & Merritt (2000) report a couple of paragraphs above and, of course, setting BH mass in a fixed ratio to galaxy luminosity. An initial central seed BH of about 25 $M_\odot$ is needed and comes presumably from a massive Population III star.

Seven being a lucky number, we feel compelled also to note the work of Liszka et al. (2000) on X-ray variability of NGC 5538, which seems to require the central engine to be a dense cluster of stellar mass black holes. If these are indeed stellar remnants and you adopt a constant initial mass function, we suppose this will imply a fixed ratio of "engine" mass to mass in old stars, but do not know quite what else to do with it, except wait patiently until all the black holes merge into a single big one (Rees 1978), while singing, "Hi ho, hi ho, it's off to Kerr we go."

11.2. Binary Black Holes

We tuck these in here both because of the probable connection with mergers of galaxies (§ 7.2) and because black holes brought together by merging galaxies must themselves eventually come together into a product that can get closer to the extreme Kerr limit on angular momentum, $a/m = 1$ in suitable units, than can be achieved by accretion spinup (Agol & Krolik 2000). And, in turn, a rapidly rotating black hole is probably a Good Thing for some of the processes by which they may power AGNs. It is the angular-momentum related part of the mass-energy of a BH that you can extract. Thus the sequence from binary black hole to rapid spin allows the theorist to tap some of the orbital energy of the merging galaxy pair for a later QSO. Indeed Zhang & Chu (2000) suggest that the only way to turn on a really bright quasar is through merger of a pair of galaxies, each with its own black hole. The rapid rotation is probably useful for jet collimation as well as energy extraction.

Do binary black holes actually turn up in present, past, or future active galaxies? The best known example is the blazar OJ 287 with its 12 year periodic light curve (Valtaoja et al. 2000; Abraham 2000; Katajainen et al. 2000), though doubts have been cast even on it (Kidger 2000). Other, less well known, candidates are AO 0235+164 which is also perhaps periodic (Chen et al. 2000a); 3C 273, where a second BH perhaps drives precession of the jet of the first (Romero et al. 2000); PKS 0429−014, another precessor (Britzen et al. 2000); and NGC 3597, particularly interesting because it also has some young globular clusters, whose presence could be another merger signature (Forbes & Hau 2000). OX 169 has, meanwhile, withdrawn itself from the candidate list. What had seemed to be a double-peaked emission profile of the H-alpha line was really a single H-alpha feature plus the stronger of the two lines of [N II] which flank it (Halpern & Eracleous 2000).

Clearly most galaxies do not have binary black holes now, though even for the Milky Way this is not as easy to rule out as you think it is going to be (Jaroszynski 2000), but Quillen et al. (2000) suggest that most E and SO galaxies have a black hole binary and merger in their past, based on their shapes and the scattering of star orbits required to match them.

11.3. Black Holes and AGNs

Yes, we are pretty sure it takes one from column A to get one from column B, even if that is not part of your a priori definition of an active nucleus.

The most important thing in a black hole's life (like a jockey's) is its mass. This, according to Magorrian & Tremaine (1999) cannot be less than $10^6\ M_\odot$ in any galaxy here and now, because that many stars will have been swallowed in a Hubble time, no matter what the initial BH and star populations were like. The limit will not be easy to test. If the observations tell you, for instance, that a small galaxy in the Local Group does not have a black hole of more than $10^6\ M_\odot$, then the most probable value is zero, while actually seeing evidence for smaller ones presents observational challenges.

If you, the black hole, support a serious, accretion-powered active galaxy for 10^8 yr, you will inevitably swallow at least $10^8\ M_\odot$ of stars, over-ripe tomatoes, or whatever is available. Thus, points out Mathur (2000), small masses necessarily go with the youth of AGNs, whether they are QSOs at $z \approx 2$ or Seyferts now. The paper is unusual in containing no equations.

What we measure most often is not the BH mass per se but the luminosity for which it is responsible. How closely are they related? Many astronomers have reported correlations over the years, but not always the same ones. Early prejudice that most AGNs would sit at their Eddington luminosities, proportional to mass, has largely gone out of fashion. This time around, we find $L \propto M^2$ (Sergeev et al. 1999) and $M \propto L^{0.8}$ (Wandel et al. 1999). Unfortunately, the two papers make use of rather similar, reverberation time arguments, in which the time delay by which changes in H-beta flux lag the continuum implies a length and so a mass scale.

11.4. Monsters, Starbursts, and Monster Starbursts

Why should the relationship between quasars (etc.) and star formation even be an issue? In so far as QSOs have galaxies around them, and all evidence says that they do (Ap95, § 10), stars must have formed and must be contributing to the luminosity we see. Hughes et al. (2000a) confirm that, when you move the slit of your spectrograph off the center of a quasar or radio galaxy, the photons that get through are mostly starlight, not scattered AGN waves.

Nevertheless, very considerable discussion persist on, first, whether specific sources and classes of sources are sending us mostly photons that began around black holes or mostly photons that began in photospheres and, second, on whether these sources or classes of sources can be placed in some evolutionary order, probably involving mergers. Two barriers get in the way of deciding which sorts of photons are arriving. First is that they may have been reprocessed by dust (etc.) blurring or erasing spectral and polarization signatures of their origins. The second is insufficient angular resolution (especially in the submillimeter band, but sometimes also infrared, X-ray, and even optical for more distant sources). Thus we cannot always separate nuclear from cytoplasmic contributions, let alone decide whether "nuclear" means the inner few AU (near the Schwarzschild radius) or the inner few parsecs.

Notice that disagreement about the dominant energy source for particular classes of sources (LINERs, ultra-luminous infrared galaxies, *IRAS* sources, etc.) need not mean that no evolutionary relationships exist. Perhaps the adopted categories are just not the right ones for the purpose.[6] A few individual sources (especially the bright sort that tend to become unrepresentative prototypes) with lots of light (etc.) of both kinds are also not a real objection to an average, monotonic evolution sequence. The discovery that most really bright, distant astronomical objects have comparable contributions from AGNs and from massive stars would be a strong argument against models in which one systematically evolves to the other. Naturally, several different evolutionary sequences, and none, have been advocated.

Under the circumstances, it is not surprising that of the 230-plus papers we indexed under AGNs for the year, more than 50 dealt with some aspect of the black hole/starburst connection. The second largest category dealt with "unification"—the primacy of orientation for relationships among subtypes. It included 48 papers, 28 voting yes (including an extensive review by Veron-Cetty &Veron 2000), 13 voting no, and 7 voting for both or neither.

The place to begin looking for which engine is under the hood is the proceedings of a conference on the subject, for which Joseph & Sanders (1999) provided a closing debate. Since then, surveys of parts of the sky by the *Chandra* X-ray satellite and the Submillimeter Common-User (not meant as the insult it sounds like) Bolometric Array (SCUBA) have added significantly to the inventories. A minimalist summary is that SCUBA finds starbursts and *Chandra* finds AGNs (Fabian et al. 2000), though a subset of SCUBA-selected galaxies looks optically as if there are both weak active nuclei and mergers or interactions (Ivison et al. 2000). Indeed the AGN contribution to distant SCUBA sources could be large enough to affect estimates of star formation rates as a function of redshift (McMahon et al. 1999).

The next step beyond this minimalist summary is to look at individual objects and subclasses and what has been said about them by observers. You might choose (*a*) to watch for cases where the division between black hole and star-powered luminosity is just what you were expecting from the source name or classes, (*b*) to watch for cases where it is the opposite, or (*c*) to skip down 1500 words or so to the theory paragraphs.

LINERs (to start with the faintest) consist either of some sources of each sort (Ji et al. 2000; Barth & Shields 2000) or of sources that do both but both sporadically (Sakamoto et al. 2000). Pogge et al. (2000) collected a large number of *HST* images of LINERs specifically to resolve the AGN/starburst dichotomy and conclude by admitting that they have worked very hard without answering the original question. Alonso-Herrero et al. (2000a) may well have worked just as hard to conclude that all of their 10 LINERs have both H II regions and SNRs from a starburst and also an AGN, but do not seem to regard this as a failure.

3C 18, the brightest FIR source in the 3C catalog ($>10^{13}\ L_\odot$), shows no evidence that anything except the AGN is heating the dust (Willott et al. 2000). Indeed a bit more dust would have left it an unidentified 3C source.

Blazar PKD 2155−304 emits optically thin synchrotron all the way from the far infrared recorded by *ISO* to X-rays (Bertone et al. 2000), which counts as pure AGN.

Per A = NGC 1275 = 3C 84 has the fraction of its nuclear infrared luminosity that is due to the AGN at least 10 times that due to stars (Krabbe et al. 2000). We claim therefore that two of the three names are misleading!

In Centaurus A, both near and far infrared are due to stars (Alexander et al. 1999; Unger et al. 2000), the extended synchrotron radio source is fueled by the AGN, and the X-rays have some of each. *Chandra* caught it with an off-center source flaring up brighter than the nucleus (Steinle et al. 2000), and whether the transient is some sort of X-ray binary or, conceivably, a young SN/SNR, it is star-powered.

In contrast to Cen A, most of a sample of 79 radio galaxies show at most modest evidence for extra star formation above the norm for their giant elliptical and SO types (Govoni et al. 2000). Smail et al. (1999a) note, however, that many radio galaxies in clusters at $z \sim 0.4$ have (contrary to earlier impressions) enough dust to hide current star formation from optical eyes. This is, however, what infrared is for.

NGC 4945 emits near and mid-infrared that is half to entirely produced by stars, while the X-rays are all (Comptonized) AGN emission (Spoon et al. 2000; Marconi et al. 2000a).

NGC 6240 is an *IRAS* galaxy, meaning that you think of stars first, but the X-ray luminosity measured by *BeppoSAX* puts it in the AGN box as well (Vignati et al. 1999).

Conversely, Mkn 273 ($z = 0.04$ ULIRG), which looks like a Seyfert 2, is really driven by a nuclear starburst (Colina et al. 1999). The central region has a number of radio sources that are young SNRs and such, though the brightest central one could be an AGN (Carilli & Taylor 2000).

The host of 3C 48 is undergoing a merger and is close to the peak rate of triggered star formation (Canalizo & Stockton 2000). The less felicitously named UN J1025–0040 finds itself in similar circumstances of being vigorously powered by both sorts of engines (Canalizo et al. 2000).

In principle, there is a distinction between *IRAS* galaxies (extending up "only" to $10^{12}\ L_\odot$, an example of the Scott effect) and ULIRGs, even brighter and so rare that none was close enough to be caught by *IRAS*. Murphy et al. (1999) found no evidence for an obscured AGN in the vast majority of the *IRAS* galaxies they examined (broad H-alpha emission would

---

[6] A possibly illuminating analogy is with H. N. Russell's "giant and dwarf" theory of stellar evolution. He was, in fact, right that stars are red and distended before they reach the main sequence, though the trajectory between is more like a vertical Hayashi track than his horizontal one, and gravitational potential energy is, in effect, his "giant stuff." But the few stars we see above the main sequence which are of this type (T Taurids, Herbig Ae/Be stars, assorted *IRAS* classes, etc.) are greatly outnumbered by post-MS red giants. Excessively Bright Galaxy Centers could also pass through nearly the same box in observation space more than once or while doing more than one kind of thing.

have counted as evidence). Heisler & De Robertis (1999) presented another *IRAS* sample that includes starbursts, obscured active nuclei, some unobscured Seyferts, and a few with lots of stars and an AGN. IRAS 12397+3820 is a "both please" Guainazzi et al. (2000).

The very most luminous galaxies also yield a range of deductions from the data sets. (1) ULIRGs with warm 20–60 μm colors are mid-merger and have both starbursts and fueled AGNs (Surace et al. 2000). (2) Even the 8–25 μm mid-infrared is largely unresolved (at Keck) and comes from an AGN (Soifer et al. 2000), (3) Optical luminosities of more than and less than 10^{11} $L_\odot$ are associated respectively with frequent (87%) and infrequent (27%) presence of compact radio cores (Kewley et al. 2000), but if you take this cut as a definition of an AGN, then many of them still have more starlight than monster light, and (4) two examiners of hard X-ray sources settle on "obscured nucleus" (Pappa et al. 2000) and "mix of photons from stars and heavily absorbed AGN" (Risaliti et al. 2000).

OK. In the preceding dozen sources and classes are to be found (1) some that are all AGN, (2) some that are all stars, (3) both, with IR and X-ray apportioned as you would expect, (4) both, but even a good deal of the X-ray emission is stellar, and (5) both, but even some of the far, mid, or near infrared is black-hole powered. Under the circumstances, feel free to go fly a kite or engage in some other activity you enjoy while we try to sort out the possibilities from about 10 theory groups and 12 scenarios. In fact we ourselves were a little tempted not to return from a break necessitated by having to explain to a Kindly Old Gentleman on the telephone why our astronomy department could not sell him a star name for the 12th birthday of his great grandson, who is interested in astronomy.[7]

Choice A is that there is no close connection between galaxies in which we have seen starbursts and galaxies that are AGN hosts, on the grounds that the underlying morphology is different (Serjeant et al. 2000b). In this case, we can all fly kites until tea time.

Choice B is that fueling of a black hole and of nuclear star formation is a symbiotic (Williams et al. 1999) or competitive (Oliva et al. 1999) arrangement, with the same gas supply for both at the same time, presumably provided from a merger of gas-rich galaxy parts, though a monolithic collapse might also work. This entitles you to play Frisbee until the Sun is over the yardarm, and since it really does sound most like the data, be sure your yardarm is in the right direction.

Choice C, that a merger leads to a starburst leads to an AGN is several years old and appears again in Wilman et al. (1999) along with some serious botany of four *IRAS* galaxies. Roughly concurring are Binette et al. (2000), who describe a radio galaxy with A Past (starburst) and Zheng et al. (1999) whose *IRAS* galaxies span a sequence from mergers of disk galaxies, to stars, to AGNs, to placid giant elliptical galaxies in their *HST* photometry. Boisson et al. (2000) suggest some details, based on population synthesis for a central starburst, which ages to a Seyfert 2, on to a clone of NGC 1275 (a radio galaxy, but with gas and all), to a Seyfert 1, to a normal galaxy. Other choices of initiating event would perhaps yield intermediate states resembling the more violent AGNs. Tennis anyone?

Choice D is the converse, that is mergers that do not advance from starburst to AGN, even for very bright galaxies (Rigopoulou et al. 1999) and may even go the other direction, according to Roche & Eales (2000) who find that Fanaroff-Riley I radio galaxies (a sort of AGN) become ULIRGs. The evidence is that the latter have, on average, closer companions and assumes that mergers are the initiating events.

Finally, you cannot doubt that, if quasars are the consequences of mergers, and mergers were commoner in the past, then quasars should have been commoner in the past. This is undoubtedly true, by $(1 + z)^6$ or thereabouts (Percival & Miller 1999). And, having committed the fallacy of affirming the consequent, we can but echo a much more distinguished author who said, "Seyfert galaxies are industrial accidents." We would gladly have committed the fallacy of the undistributed middle, but find that our middles have become a good deal more distributed over the 10 years of this series of reviews. Post hoc, ergo propter hoc.

12. THE UNIVERSE IN SIX (OR MORE) NUMBERS

Just how many you need is authority-dependent, ranging upward from the frugal six of Rees (2000) to a few dozen, to take in the standards models of both particle physics (ending perhaps with the mass of the Higgs particle; § 5.4) and of cosmology (ending with something slightly before the Big Bang; § −1). Here are some traditional favorites, a few numbers we hadn't heard of before, and a selection of the peaks and valleys in between.

12.1. For the H of It

The 19 values of Hubble's constant published during the year (giving only one vote to a package of five papers from the *HST* Key Project Team; Mould et al. 2000) had a median of 64 km/sec/Mpc, hit on the nose by Jha et al. (1999), who used 43 supernovae and a calibration that includes metal-dependence of the period-luminosity relation for Cepheid variables. The median continued the gentle rise with time noted in Ap99 (§ 12.1, where it was 62). Only Phillips et al. (1999) gave a three-figure answer (63.3), we and they both hesitating to describe these as "significant" figures. They too are supernova buffs and used color curves corrected for extinction in the host galaxies. The widest error bars were admitted by Lahav et al. (2000b) and covered both 50 and 70 km/sec/Mpc, but then it is really a paper on Bayesian methods, which are ex-

---

[7] Actually there are several reasons, beginning with not having an astronomy department at UC Irvine. The recommended alternative was a pair of 7 × 50 binoculars (the old navy standard) and a family trip to the country on a clear night.

cellent for changing one's mind gradually, but less good on the road to Damascus. The data are measurements of fluctuations of the cosmic microwave background radiation, and a cosmological constant that contributed 0.7 toward a critical density of 1.0 was assumed.

Cepheid variables and Type Ia supernovae were, inevitably, the most discussed of the 20 or so distance indicators we read about. At least two Cepheid problems remain. The first is that absolute luminosity at a given period undoubtedly varies with metallicity, via the mass, radius, and temperature corresponding to a given period. There are real differences (e.g., Paczynski & Pindor 2000); the models do not entirely reproduce available data (Antonello et al. 2000); and (where have you heard this before?) "more data are needed" (Caputo et al. 2000b). The model-based corrections slightly increase the H found by the methods of the Key Project, because (Caputo et al. 2000c) most galaxies that host Type Ia supernovae are more metal-rich than the Large Magellanic Cloud. Use of infrared as well as optical colors can improve the chances of being able to standardize SNIa's in different sorts of environments (Krisciunas et al. 2000).

The second residual error source is Cepheids whose images are contaminated by real or optical companions. If no correction is made for this, you will give the star a brighter apparent magnitude and a smaller amplitude than it deserves, and think that it is closer to you than it really is. If RW Car, with a close binary companion nearly as bright as itself (Fernie 2000) were typical, this would be a disastrous source of systematic error. On average, it is perhaps 0.1 m in measured magnitudes (Gibson et al. 2000; Saha et al. 2000) or 10% in H (Mochejska et al. 2000). This last comes from a project called DIRECT but, according to the authors, uses indirect methods!

Type Ia supernovae are also afflicted by two problems of rather similar type, one concerning the physics of the events and one observational in nature. First is potential dependence on the stars involved that might vary systematically with redshift (and which also is a worry if you are trying to get Ω and Λ from SN observations). By way of reminder, Type Ia's are nuclear explosions in degenerate carbon-oxygen cores or white dwarfs. Thus their peak luminosity can be affected by total metallicity of the initial star (via the C/O ratio in the degenerate core), core mass, whether the progenitor is a single or binary star, and whether the burning front moves super- or subsonically (detonation vs. deflagration). That is, SNa Ia are not standard candles. Some of the properties, including burn speed, apparently also affect the correlation of peak luminosity with rate of fading that is normally used to standardize them (Sorokina et al. 2000). All these would matter relatively little if nearby and distant events included the same mix of progenitors and explosion processes. We found during the year one vote for "same" (Aldering et al. 2000) and one for "different" (Riess et al. 1999a, 1999b). In the latter data set, the more distant events are fainter on average. This (as remarked upon by Sidney van den Bergh at a 1996 conference) would be mostly unlikely as an observational selection effect. The dominant physics is that progenitors of smaller initial metallicity end up with cores having smaller C/O ratio and so less energy to release in the flash up to iron.

The second supernova snake-in-the-grass is the possibility of gray, uniformly distributed dust dimming apparent magnitudes of distant events without reddening them (Croft et al. 2000), so as to mimic the relation between redshift and apparent magnitude in a universe with $q < 0$ or positive cosmological constant, Λ. The discussion by Aguirre & Haiman (2000) comes quite close to a recantation from one of the stronger proponents of the dust alternative. A definitive test is, however, at hand. Intergalactic dust sufficient to spoil our Ia candles will scatter the images of X-ray emitting QSOs enough for detection by the current generation of satellites. If we see the scattering the dust is there. If we don't it isn't.

Given some ultimate X-ray mission, one could even measure directly the distances to Type II (X-ray emitting) supernovae, using the time delay of radiation scattered by intervening dust. Predehl et al. (2000) have just made this work for Cyg X-3 (9 kpc from us), though it failed for Sco X-1 (Bradshaw et al. 1997). And the author who remembers 1965 best will always thing of this as the Slysh mechanism, because it was first proposed by Overbeck (1965).

Only 18 distance indicators remain to be addressed. Keep in mind, however, that when you can apply two or more, they often do not agree. For instance, Aparicio et al. (2000) find smaller distances to some dwarf galaxies from red giants than from Cepheids. They think that the RG distances are right, or at least that the Cepheid ones are wrong. We will, therefore, not attempt to adjudicate among the indicators, but just list them, in approximate increasing order of the distances at which they are useful, with one reference each, in case you need an entry point to learn more about them.

(1) Parallaxes and main sequence fitting for open star clusters (Gatewood et al. 2000), (2) double-lined, spectroscopic eclipsing binaries (Ribas et al. 2000), (3) a period-luminosity relation for Delta Scuti stars (Peterson & Christensen-Dalsgaard 1999), (4) clump stars, which have in spades the problem of age and composition dependence (Sarajedini 1999), and put the LMC claustrophobically close to us at 44.5 kpc (Udalski 2000), compared to (5) RR Lyrae stars (Caputo et al. 2000a), though both disagree with (6) field horizontal branch stars (Carretta et al. 2000) and (7) stars at the tip of the red giant branch (which put the LMC at 51 kpc, Cioni et al. 2000), (8) planetary nebulae (Cazetta & Maciel 2000), (9) long period variables, which also have a "parent population" problem (Barthes et al. 1999), and (10) closely related red supergiants (Jurcevic et al. 2000), (11) globular clusters, with continuing uncertainty from the bimodal distribution of luminosities in many galaxies (Lee & Kim 2000) and from how you tie them to local subdwarfs (Salaris et al. 2000), (12) novae, another multi-population species, since the accreting white dwarf is likely to be of larger mass and different composition among the youngest stars (Shara et al. 1999), (13)

fluctuations of the surface brightness of galaxies (Jerjen et al. 2000, who looked at dwarf ellipticals), (14) the $I-K$ colors of spirals, which the authors de Grijs & Peletier (1999) say is not as good as (15) the Tully-Fisher relation between the maximum rotation speed in a spiral and its physical diameter (Koda et al. 2000, on the physical cause of the correlation—galaxy mass—and the scatter—galaxy angular momentum), (16) the Faber-Jackson relation between velocity dispersion and physical size in elliptical galaxies, whose scatter arises from younger galaxies having formed when the cosmic density was smaller (Forbes & Ponman 1999), and (17) the Sunyaev-Zeldovich effect, in which the electrons in X-ray emitting clusters of galaxies upscatter photons passing through from the CMB, with X-ray luminosity and CMB decrement depending on different powers of distance. Blasi et al. (2000b) point out that a non-thermal tail of high energy electrons (responsible perhaps for hard X-ray excesses in the spectra of some clusters) can mess up the whole thing royally. And, in case you think you have been deprived of the 18th method, notice that there are actually two in number (1).

12.2. Very Large Scale Structure and Streaming

We voted against fractals (hierarchical structure persisting on scales larger than about 150 h^{-1} Mpc) last year and see no reason to ask for a hand recount this year (Bharadwaj et al. 1999; Hatton 1999). Indeed the observations can almost be said to have reached a steady state on several points, with $\xi(r)$ proportional to $r^{-1.7}$–$r^{-1.8}$, intrinsically bright galaxies more clustered than faint ones, ellipticals more clustered than spirals (Seaborne 1999 on Stromlo APM vs. *IRAS* galaxies), and much of the structure on sheets and filaments (Lahav et al. 2000a; Schmalzing et al. 1999; Bharadwaj et al. 2000; Guzzo et al. 2000; Fynbo et al. 2000, each with a different sample, but rather concordant results).

What you see is redshift dependent in the expected sense—that is, at $z \gtrsim 4$ you pick out only the galaxies in rare, massive haloes which are going to be more clustered than commoner halo types by the time you reach $z = 0$, and this shows up as a large bias parameter, $b = 5$ at $z = 4$ (Arnoutz et al. 1999; Magliocchetti et al. 2000). In between, there is actually a good deal of what we would just the other day have called high redshift clustering, but might now call intermediate redshift clustering (Steidel et al. 2000; Williger et al. 2000; Sanchez & Gonzalez-Serrano 1999; Kurk et al. 2000).

That radio data alone will not reveal this large scale structure apparently has held from the time of the 3C (Third Cambridge) survey in the 1960's down to the present, according to Artyukh (2000) and Venturi et al. (2000), who are unable to find even the Shapley concentration. They suggest that merging of clusters of galaxies might switch off existing radio sources, so that they do not trace the largest scales.

What remains to be sorted out? First are continuing discrepancies among several redshift surveys on how much power persists out beyond 80 h^{-1} Mpc (Hoyle et al. 1999) and ditto for how much deviation there is from pure Hubble flow on these larger scales (Giovanelli et al. 1999). Next, is there really a Great Attractor? Yes, say Woudt et al. (1999), but it is mostly the Norma or ACO 3627 cluster.

Third, should we believe various, previously-advertised, quasi-periodicities in the redshift distributions for galaxies or clusters? No, say some observers (Drinkwater et al. 2000). Yes, say several theorists, perhaps because their theories can explain it (Kaminker et al. 2000; Krilova & Chizhov 2000), and if the period is 130 h^{-1} Mpc at all redshifts, then you can use it as a standard meter stick to measure the cosmological constant (Roukema & Mamon 2000), which, of course, turns out to be about 0.7.

Fourth, where does the dipole converge? This is the local version of "how big is the largest structure?" and answers range from 60 h^{-1} Mpc (that is 6000 km/sec, da Costa et al. 2000) to 200 h^{-1} Mpc (Rowan-Robinson et al. 2000) and more than 18,000 km/sec, over which peculiar velocities do not trace the presence of the obvious observed clusters and voids, and the bulk flows do not decrease with distance Karachentsev et al. 2000b). Tomita (2000a, 2000b) finds that we live in an underdense region of about this size. New massive data sets like SDSS should clarify most of these issues in a few years, so we feel no compulsion to brush off the hanging chads and vote this year.

On the theoretical front, simulation, and perhaps dissimulation continues. A real highlight was the comparison of 12 codes applied to the same problem (predicting what typical clusters should look like, given standard cold dark matter and non-radiative gas) Frenk et al. (1999) report that most results agree to 50%–10%, apart from the predicted X-ray luminosities, which are very sensitive to small fluctuations in the gas density. Incidentally, "al." includes all 12 coders.

12.3. Some of the Other Numbers, Ω_m, Ω_b, Λ, k, and t

The 24th General Assembly of the International Astronomical Union in August 2000 had in common with the 23rd GA in Kyoto in 1997 a symposium devoted in large measure to the cosmological parameters. And at least the author who attended both was surprised not by new values being reported but by the near-constancy of the bandwagon numbers over the intervening three years. That is, most of the speakers and poster presenters either supported or thought it necessary to oppose a set of numbers:

- Ω (matter) = 0.30–0.35, of which
- a few % = baryons,
- $\lesssim$1% = neutrinos (but probably not zero), and the rest is cold dark matter,
- $k = 0$ (flat space),
- Ω (Λ) = 0.65–0.7 (cosmological constant, quintessence, or dark energy),
- age = 13–14 Gyr (for $H = 65$),

- $n = 1$ (Harrison-Zeldovich spectrum of primordial fluctuations),
- $\sigma_8 \approx 1$ (normalization of that spectrum),
- $q < 0$ (that is expansion currently accelerating).

This seems to be 10 numbers, but they are not all independent. For instance, if you claim to know Ω_m and Λ but not to know k (the spatial curvature), then you are fighting Einstein and perhaps even Euclid. It is, however, possible to carry out measurements of these three things by different methods and arrive at results that are not mutually consistent.

It would be dishonest to claim that the literature of the index year was equally coherent. But, of the roughly 100 indexed papers, only 10 or 15 disagreed significantly (and observationally) with the consensus. Most unfairly, we note only the following: (1) consistent, fairly standard sets of numbers along these lines published by Mauskofp et al. (2000), Melchiorri et al. (2000, including new CMB data), Novosyadlyj et al. (2000, emphasizing large scale structure), Henry (2000, emphasizing X-ray clusters), and Bridle et al. (1999 discussing the normalization σ_8); (2) a new, independent estimator of matter density from weak gravitational lensing by structure larger than clusters (Wittman et al. 2000), which also favors an open or Λ-dominated universe, but be warned that van Waerbeke et al. (2000) believe that they have seen lensing by cosmic shear, which is not part of the consensus model, (3) an improvement of the age estimate, 14 ± 3 Gyr, from the ratio of thorium to europium in the globular cluster M15 (Sneden et al. 2000); (4) evidence for both a cosmological constant and some neutrinos from counts of quasars (Lin & Chu 1998); (5) non-confirmation for non-Gaussianness of the CMB (Contaldi et al. 2000); yes the word sounds awful, but non-Gaussianhood or non-Gaussianity aren't much better; and (5) a few candidates for "where are most of the baryons?" including low surface brightness galaxies (O'Neil & Bothun 2000), ordinary X-ray emitting clusters (Wu & Xue 2000), hot supercluster gas (Boughn 1999), and gas at 10^5–10^7 K that emits various sorts of EUV continuum (Lieu et al. 1999; Tripp et al. 2000) and soft X-rays (Scharf et al. 2000). All of these loci are concentrated around galaxies, clusters, sheets, and filaments, not spread in a uniform intergalactic medium.

12.4. Between the Dark and the Daylight

Our minds are, pretty much, made up (though see § 12.5) on this: 90% or more of the stuff that contributes to gravitational potentials in the universe does not emit or absorb its fair share of light (that is, dark matter exists), and we haven't a clue what it is. One each from columns (A) baryonic, (B) hot (neutrino-like), (C) cold (neutralino-like), and (D) pressure (lambda-like) must, you might suppose, surely include at least portions of the truth, though some of the authors cited below would perhaps not endorse even this most general sort of description. The ordering of the candidates is, roughly, this A to D, followed by (E) "other," and we apologize to anyone whose favorite we have misunderstood so badly as to include it in the wrong category.

Just in case you might have forgotten, dark matter can be both warm (Sellwood 2000, unfortunately no better than hot or cold for making large scale structure) and fuzzy (Hu et al. 2000). The latter consists of 10^{-22} eV scalar particles, cold because they have come from a Bose-Einstein condensate rather than from a heat bath (like axions in this respect) and good for avoiding excess structure formation on small linear scales.

12.4.1. The Baryons

All our friends are made of these, and, including galaxies, clusters, and all as friends, may or may not add up to the baryon inventory implied by big bang nucleosynthesis (Vangioni-Flam et al. 2000). Indeed some analyses of X-ray clusters find rather more baryons than one wants ($\Omega_b = 0.14$ for $H = 50$ km/sec/Mpc according to Wu & Xue 2000). The same stuff was in Lyman alpha forest clouds at large redshift according to Salucci & Persic (1999b). In addition, at some level, there must also exist brown dwarfs; old cold white dwarfs; gas in cold clouds, high velocity clouds, and interstellar clouds; and various sort of black holes that formed late enough that their matter still counted as baryons during BBN. This is true for stellar-mass black holes, like the two possible MACHO lenses near 6 $M_\odot$ mentioned by Bennett et al. (2000) and 10^6 $M_\odot$ black holes formed by Baumgarte & Shapiro (1999) and earlier, in the literature if not in cosmic time, by Bond, Carr, & Arnett (1983). In contrast, mini or primordial black holes take material out of the inventory before nucleosynthesis and do not count as baryons.

Thus during the year, baryonic cases were made for (*a*) high velocity clouds as half the dark matter in the Local Group and perhaps with their own supplies of non-baryonic DM (Lopez-Corredoira et al. 1999), (*b*) dense, planet-mass clouds of molecular gas in the halo, yielding the galactic gamma-ray halo when cosmic ray protons hit their atoms, and capable of collision, dissipation, and dynamical evolution to produce the Tully-Fisher relation (Walker 1999; Kalberla et al. 1999); they would also contribute to the infrared background according to Sciama (2000) who identified them as the descendents of the Lyman alpha forest clouds in his last published paper, (*c*) old halo white dwarfs as most of the MACHO lenses and half of the halo dark matter (Ibata et al. 1999, 2000; Hodgkin et al. 2000; Hambly et al. 1999; Mendez & Minniti 2000), based on very small numbers found so far in *HST* and ground-based searches.

There are, of course, also arguments against each of these, taking them in the same order, (*a*) the HVCs can have nearly-solar metallicity, which associates them with the Milky Way, not the Local Group as a whole (Richeter et al. 1999; Wakker et al. 1999, and many other papers during the index year), (*b*) small molecular clouds are unlikely to be stable at moderate redshift (Wardle & Walker 1999), and (*c*) the stars that would become such white dwarfs will produce more heavy elements, especially carbon, than actually exist in the Milky Way (Fields et al. 2000).

These baryonic and galaxy-based candidates get naturally tangled up with two related issues: (1) Is there a separate, disk component of dark matter? Yes, say Salucci & Persic (1999a) and Giraud (2000), and no, say Holmberg & Flynn (2000) and van Zee & Bryant (1999), and (2) Where and what are the Massive Compact Halo Objects responsible for gravitational lensing of stars in the Large and Small Magellanic Clouds? This latter topic defied compression into dependent clauses, but, if the lenses are mostly in the L and SMCs themselves (Salati et al. 1999; Evans & Kerins 2000; Afonso et al. 2000; Zhao et al. 2000) or stars lost from the LMC (Weinberg 2000; Graff et al. 2000), then they are not really DM candidates anyhow. In any case, the final inventory from the MACHO and EROS sensing surveys would require only about 20% of the dynamical halo mass to be in the form of lenses (earlier numbers were 50% or more), even if all the lenses are halo objects (Lasserre et al. 2000). Other galaxies, at least quasar hosts, may have their own MACHO supplies with masses also in the old white dwarf range (Refsdal et al. 2000; Koopmans & de Bruyn 2000; Wyithe et al. 2000).

The galaxy NGC 5907 was once suspected of having much of its halo dark matter in the form of faint, red stars (Ap94, § 5.8). The most recent word is that it has very little halo material, whether you look for individual stars (Zepf et al. 2000), diffuse light (Yost et al. 2000), or dynamical evidence (Reshetnikov & Sotnikova 2000).

The acid test for significant diffuse intergalactic gas has always been the (absence of a) Gunn-Peterson effect—Lyman alpha absorption shortward of 1216 Å in QSOs at redshifts larger than about 1.9—and while we aren't precisely tired of this topic, there is now the possibility of an independent check from presence or absence of Thompson scattering halos around radio sources at larger redshift (Geller et al. 2000). The current limit is $\Omega(\mathrm{IGM}) < 0.65$. The idea appears in Sholomitskii & Yaskovitch (1990).

12.4.2. Hot or Cold

Neutrinos, the prototypical hot dark matter particles, continue to exist. Indeed the long-expected third sort, the tau neutrino has finally been seen by the DONUT (Direct Observation of ND Tau) experiment at Fermilab (Kane 2000; Lundberg 2000). Data, or at least papers analyzing the data, in support of small but non-zero rest mass for neutrinos continue to proliferate (e.g., Ma 1999; Shi & Fuller 1999; Abdurashitov et al. 1999). Though the contribution to total cosmic density seems to be at most a few percent, HDM remains of interest in connection with the formation of large scale structure (Fukugita et al. 2000).

A decaying neutrino with mass just large enough that the photons from its decay will ionize hydrogen (Sciama 1991) does not fit the ionization data very well (Sanchez & Anez 2000), and, more serious, the expected UV photons are just not there (Bowyer et al. 1999).

Not actually new this year, but a surprise princess candidate, is self-interacting dark matter. The particles have some significant cross section for scattering each other (e.g., $\sigma/m_x = 4 \times 10^{-25}$ cm^2/GeV, Firmani et al. 2000), but small or zero ones for annihilation or dissipation and interaction with baryons. The most important virtue of self-interacting DM is that it softens the cores of galaxies from the sharp cusps made by normal CDM so that they look more like real galaxies. It can also seed central black holes with masses properly scaled to other properties of the host galaxies and put satellite galaxies where they belong (Ostriker 2000; Moore et al. 2000; Burkert 2000; Peebles 2000; Spergel & Steinhardt 2000).

Meanwhile, new limits continue to be set to nuclearites and other neutral DM candidates capable of strong or other interactions with protons (Bernabei et al. 1999; Yoshida et al. 2000). Other limits pertain to assorted decaying or annihilating DM particles whose products would include anti-protons in the primary cosmic rays (Bergstroem et al. 1999) or interference with big bang nucleosynthesis (Jedamzik 2000).

Black holes are probably cold (in the sense of being nonrelativistic at decoupling) and are included here so they won't feel forgotten. A significant, if not dominant, contribution in either substellar mass, primordial BHs (Jacobson 1999) or supermassive ones (Murali et al. 2000) remains harder to rule out than you might expect. We are not quite sure what to say to the primordial black holes of Rabinowitz (1998), which are also responsible for ball lightning (because the presence of the Earth catalyzes radiation emitted by gravitational tunneling), but will try "Good morning," if we meet any of them.

12.4.3. Topological Defects

Here live the monopoles (non-minimally coupled global ones according to Nucamendi et al. 2000), textures as seeds for early galaxy formation (Ribeiro & Letelier 1999), and topological defects of other dimensionalities which Digal et al. (2000) think can perhaps be produced without phase transitions.

12.4.4. None of the Above

Experienced readers will take this section heading to mean candidates that the authors regard as very strange, do not understand, or both. They will be right with "both" for DAEMONS (DArk Electric Matter Objects; Drobyshevski 2000a) and the particles for which thermodynamic time runs backward, preventing electromagnetic interactions (Shulman 1999). These seem to be new stocks on the market.

Scalar fields and scalar (bosonic) particles, presumably capable only of self and gravitational interactions have, in contrast, a long history (Ford 1987; Kaup 1968). Things that have been said about them as dark matter candidates during the year include: (*a*) If this stuff dominates structure formation, additional data on fluctuations of the cosmic microwave background will tell us so (Hu & Peebles 2000). (*b*) "Stars" made of them can have masses ranging from the Chandrasekhar limit up to $10^{10}\ M_{\odot}$ and they can produce gravitational lensing like other stars (Dabrowki & Schunck 2000). (*c*) The interaction potential may be repulsive, so as to suppress structure on scales smaller than galaxies (Goodman 2000). (*d*) And naturally soft bosons could be responsible for cosmic acceleration (Cormier & Holman 2000), which leads naturally to … .

Quintessence, that stuff that exerts negative pressure in proportion to its density, with a proportionality constant between 0 and -1 (the unique value for a cosmological constant). Said proportionality "constant" could, in fact be a function of time or redshift (Saini et al. 2000) and, if so, the current epoch of cosmic acceleration could be transient, with deceleration to follow (Barrow et al. 2000). A version of this, motivated by string theory (Albrechet & Skordia 2000) may indeed produce acceleration starting "about now," despite the parameters in the quintessence potential being of order unity in Planck units (which for an ordinary cosmological constant would mean a value larger than the observed one by a factor 10^{120} or thereabouts).

An alternative, but also string-motivated scalar field, tuned to fit numbers and masses of galaxies and clusters (i.e., contributing 10% of the closure density) gives back cosmic expansion proportional $t^{2/3}$, like that of a universe closed with matter, which would seem to disagree with observations (Amendola 2000).

12.4.5. Double Dark

Whatever your favorite candidate(s) may be, one has to end by asking whether there are any galaxy or cluster-sized halos made of them that are not at all illuminated by galaxies. Not many, seems to be the answer, though several of the limits come from looking for things that gas does, so that halos not even filled with gas are not so strongly ruled out. There are no galaxy-free X-ray clusters in the *ROSAT* catalog (Romer et al. 2000), no Sunyaev-Zeldovich decrements of the CMB in optically empty fields (Subrahmanyan et al. 2000), and perhaps one empty halo in a weak lensing map of Abell cluster 1947 (Erben et al. 2000).

12.5. Their Universe, and Welcome to It

If you are casting only one vote, save it for the standard general relativistic, expanding, hot big bang with one to a few kinds of fairly conventional dark matter (§§ 12.1–12.4.3). Here, however, are some of the other candidates for Universe of the 21st Century. The first set includes ideas that are "in addition to" the standard model and which may help to explain, clarify, or justify it. Next come the "instead of" models, beginning with old friends like MOND and quasi-steady-state. And we trickle off into mists of incomprehension. Lines between the sets and between model universes and DM candidates are not sharp, for instance in the case of the transiently accelerating universe of Barrow et al. (2000).

12.5.1. Branes, Brains, and Extra Dimensions

These go together both because, if the street where you live is a 3-brane (we think it might be short for membrane), then there must be lurking somewhere higher-dimensional space for those three to be embedded in, and because some very smart people seem to be working in the area. The place to begin is the mini-review (Gibbons 2000), which we indexed as "cosmology as 3-brane, 11-dimension, superstrings, compactification, and all, with consequences for new particles and big bang nucleosynthesis." Other things that were said about the scheme range from the almost obvious to the obscure.

For instance, other (compactified) dimensions will tend to slow down cosmic expansion, so that you need to add cosmological constants (yes, probably more than one) to get back the $R(t)$ that we see (Cline et al. 1999b). Extra dimensions also affect the microwave background (Melchiorri et al. 1999). The stuff on either side of "our" 3-brane could be anti-de Sitter 5-space (Chamblin & Gibbons 2000). Gravity in a brane-world is linearized Brans-Dicke (scalar-tensor) gravity. Shadow matter is what lies on the other brane, and, for a given Newtonian mass, it produces 25% less deflection of light (Garriga & Tanaka 2000). Gravity could be five-dimensional on very large and very small scales and 4-D in between, where we live (Gregory et al. 2000; Csaki et al. 2000). The Gregory et al. case has three 3-branes, and we don't know what lives on the third one. Finally, what you see is what you get only in your own set of dimensions, and our 4-D big bang is perhaps a shock wave in 5-D (Wesson et al. 2000).

This section also logically contains inflation, symmetry breaking, phase transitions, and other parts of physics that may be part of the universe before big bang nucleosynthesis, decoupling, and the other events from which we can receive photons and other direct signals. Undoubtedly progress is being made in these territories, but it was not reported in the particular set of journals scanned this year.

12.5.2. "I Never Forget a Face …"

Oldest of friends, the quasi-steady-state universe, has been developing some wrinkles (well, the original steady state is only five years younger than the elder author), with filaments, clusters, and voids being produced by discrete, random creation centers (Nayeri et al. 1999). In this model, distant Type Ia supernovae look faint both because of accelerating cosmic expansion and because of significant intergalactic dust (Banerjee et al. 2000b). Can the dust be checked in the way it can for a conventional model? Possibly not. QSOs in such a universe are not at the distances implied by their redshifts, and so the sight lines may be too short for X-ray scattering to be detectable.

Arp (1998) continues to compile observations that he concludes provide evidence for such non-cosmological redshifts. It is not clear whether he would regard the Wolf effect (Wolf 1986) as an appropriate mechanism or not. Roy et al. (2000) believe that this dynamical multiple scattering and screening can account for large redshift difference between galaxies and quasars in the same (three-dimensional) part of space, but they do not cite any Arp papers. Some earlier work in this area had suggested that there were X-ray filaments connecting QSOs to galaxies and clusters (with similar sky location but very different redshift) in *ROSAT* maps. It turns out that these are an artefact of smoothed photon-limited data (Hardcastle 2000).

The universe of Alcaniz & Lima (1999) has continuous creation but a Friedmann-Robertson-Walker metric and a finite past age, larger, however, than the age of a standard universe with the same Hubble constant.

MOND (MOdified Newtonian Dynamics) incorporates a minimum possible acceleration due to gravity, which serves some of the same purposes as dark matter, for instance in explaining why the rotation speeds of spiral galaxies do not drop off as $r^{-1/2}$ in optically-faint outskirts. But MOND is different from dark matter in a good many other ways, for instance its prediction for the second acoustic peak in the fluctuation spectrum of the microwave background radiation (McGaugh 1999) and for gravitational deflection of light (Edery 1999, who conclude that one might be forced to give up the equivalence of gravitational and inertial mass), the expected shape for the fundamental plane of giant elliptical galaxies (in the space of galaxy size, surface brightness, and velocity dispersion, Sanders 2000), the slope of the Tully-Fisher relationship for spirals (McGaugh et al. 2000), and the correlation of other properties of spirals with central surface brightness (van den Bosch & Dalcanton 2000). A good deal of fine tuning of most of these is required to bring agreement with observations. The same can, however, to a certain extent be said of dark matter(s), and has been firmly said by the supporters of MOND. A truth-in-reviewing statement is probably in order here. We still think it's probably wrong, but are not unaware that the number of astronomers prepared to devote some time to it has increased in recent years.

The idea of a cold big bang also has a 40-year history. Aguirre (2000) gives it a very luke warm shoulder, pointing out that, if you make helium and the microwave photons in stars and galaxies, you get no acoustic peak and no deuterium to speak of, not to mention requiring a closure density in baryons.

The main difficulty with these three or four alternatives seems to be that one has to work quite hard to make them look indistinguishable in most ways from the standard hot big bang. Roughly the same can be said about additional acquaintances past age 30, including (1) baryon-symmetric cosmology (Kirilova & Chizhov 2000), (2) two-metric theories of gravity with topological defects (Avelino & Martins 2000) or without (Reddy & Rao 2000), and (3) universes with complex topology (Roukema 2000, which includes a nice tutorial on the subject; Inoue et al. 2000). That primordial black holes in a scalar-tensor universe grow in mass rather than evaporating could eventually prove to be an advantage (Jacobson 1999).

12.5.3. "… But in Your Case, I'm Willing to Make an Exception"

Most of the following eight or so other alternative cosmologies are not brand new either, but they still retain their power to make one respond, "You don't say!" "How does this model work?" "He didn't say," in the Spike Jones version.

Universes in which something you thought was constant varies—a variable fine structure constant as an alternative to a cosmological constant (Barrow & Magueijo 2000), the masses of baryons (Massa 2000), or G and c, but not Ω_m or h^2H/Gcm^3, where m is a baryon mass (Tomaschitz 2000).

A universe in which some of the things you thought varied must be constant, because it includes a set of six significant numbers (very different from the Rees, 2000, six numbers!) that are quantized in powers of Gm_p^2/hc, but include the mass of a black hole that is just evaporating now and the mass of the observable universe (Andreev & Kombert 2000); the last two increase with time.

A soft bang that expands from an infinite, non-singular past (Rebhan 2000).

A potentially cyclic universe that does not require "much" deviation from general relativity (Fakir 2000).

Universes with cylindrical symmetry and/or expansion in only two dimensions for magnetic or other reasons (Bali & Meena 1999; Kilin & Yavus 2000; Das & Banerjee 2000).

The scale-expanding cosmos, in which both space and time expand and redshifts are caused by tired light. There are a variety of consequences for pulsars, planets, and Earth as well (Masreliez 2000).

PUFT, which has no big bang, but definite values for $H = 75.7$ km/sec, age $= 17.35$ Gyr, and the total mass of the universe $= 3.13 \times 10^{58}$ g. Rigid bodies moving through space (including the interior of Earth) are heated (Schmutzer 2000).

And, all we can do is quote, a universe with "simultaneous creation of matter and geometry from the vacuum of a flat, empty spacetime without structure" (Vertogradova & Grishkan 2000). As this seems to be the ultimate free lunch, we hurry on to § 13, for which you would also be ill advised to pay anything.

13. ONLY TEE MARTOONIS

The complete text of this phrase (often quoted by the Farmer's daughter) is "I'm not as drunk as some thinkle peep. I've only had tee martoonis." The misplaced modifier is only part of why we were reminded of this phrase in contemplating our own errors and those of others during the year.

13.1. The Lederhosen Prize

A generous senior colleague offered recently to nominate one of us for this. The actual name turned out to be slightly different. But we do think that there should be a prize given to the astronomer who did the most during the year to encourage a general pulling up of socks in the field. The colleagues who pointed out to us the following mistakes in Ap99 are all candidates.

Sect. 10.7. HDE 31685 should have been HDE 316285.

The first mentions of Hg^{204} in Ap stars (§ 6.4) and stellar rings (§ 8.6) were probably Bidelman (1956) and Hodge (1986). Well, we didn't say they weren't, but the Bidelman paper was improperly omitted from a much earlier review (Trimble 1975).

Sect. 6.7. The RV Tauri stars in globular clusters are too RV Tauri stars from very early times (Arp & Wallerstein 1956). In addition, C. H. Payne Gaposchkin and H. S. Hogg so categorized them in well-known catalogues, and, as the chap who called it to our attention pointed out, "If General Motors calls it a Chevrolet, it's a Chevrolet."

Sect. 10.8. The blueshift should, of course, have been described as $\Delta\lambda/\lambda = -0.1$ to -0.3, not pluses, which are redshifts!

Sect. 10.8. The oldest archived plates greatly predate 1879. Harvard has one of the Pleiades from 9/10 October 1857. It shows three stars.

Sect. 5.4. A colleague attempted to clarify for us the phrasing of onset of declines in R CrB stars relative to pulsation phrase, citing Duerberk et al. (2000), who apparently got it wrong. The real story is that minimum brightness within a main fading event is also minimum brightness in the pulsation cycle, but, the explanation continued, "Unfortunately I am also 'allows' me similar mistakes. And every time I am afraid to devise a bicycle." Well, some of ours have square wheels too.

Sect. 9.2. Several readers (including an undergraduate) recognized the terminology from jacks and offered to beat either author.

Sect. 9.3. The "issue of an archival journal with a cD attached to its cover." We could have sworn that the manuscript said CD, but the commentator's reaction was that the MACHO people should be searching closer to home. Indeed a whole cD galaxy would make a spectacular "microlens" and hasten the moment at which the paper versions of major journals will grow to close the universe.

13.2. The James Challis Prize

A recently-postdoctoraled astronomer explained his possibly premature publication last year on a hot topic by saying he had not wished to be a candidate for this prize. Challis, in case you might have forgotten, actually observed and charted Neptune from Cambridge on the 12th of August, in a bit of sky he had already examined on the 30th of July, but had not bothered to compare his notebook pages until after Galle and d'Arrest had announced their discovery. It was back in 1846, so you can be excused for not remembering the details, but many of the items which follow seem to have their origins in a rush to print (or, occasionally, astro/ph).

"Goods are totally free from bark and apparently free from live plant pest." So said the document that came with a volume we recently ordered. It was, unfortunately, the best review that book received.

"Enclosed is a brief survey to help ensure that our records pertaining to legacy gifts of the type set forth in the attached survey." We didn't fill out the survey (which was part of a fund-raising letter from the SETI Institute).

"Since the N/H ratio plays an important role in the formation scenarios of Jupiter, we wanted to confirm or infirm the Galileo result." (BAAS, 32, 1014).

"See Author (1992) for a pedestrian derivation of … " (ApJ, 529, 433, footnote). We are pretty sure "Author" did not see this before it was published.

"Many groups … specifically wave … the proprietary period in their proposals." (STScI Newsletter, 16, No. 4, p. 2). As in, wave bye-bye.

"Typical poor Abel clusters" (AJ, 119, 611). They can't even afford that second 1.

"Origin of the *X-Y* Relation" is part of the title of ApJ 534, L89. The abstract explains, "There is no *X-Y* relation."

"Baade (1993) cited in PASP, 111, 1150. They were tough in those days. But a number of papers seem to have had trouble keeping track of who their own authors were, for instance: A, B, C, and D are the first-page authors of ApJ, 525, 10, but the running head is A, B, and D, with C in the acknowledgements. "This work was performed as part of the author's PhD thesis" say the acknowledgements of ApJ, 524, 372, but the paper has two authors. A, B, and C, are the first-page authors of ApJ 528, 436, but the running head mentions only A and B. The paper A&A, 351, 358, by authors X and Y, mentions a private communication from Y. Can you whisper in your own ear?

"The distance has been revised from 65 ± 5 pc to 65 ± 35 pc" (A&A, 353, 1044, abstract) is perhaps just great (and meritorious!) honesty, but the following incorporate numerical errors of factors of two or larger, or geometry in which pi is different from the familiar value.

"19,636 km (one and a half times the earth's circumference)" (Science, 287, 53).

"Thankful to G. J. M. and Y. H. C. for allowing us to use his … mosaics" (AJ, 118, 1408, acknowledgements). It happens also that Y. H. C. is a "she."

"We find 7 X's, including 4 Y's and 4 Z's" (PASP, 111, 1398, abstract). Well, maybe one of the Y's is also a Z, but the context makes it unlikely.

"…thermal transport of the eleven orders of magnitude of the Rayleigh number ($10^6 \leq R_a \leq 10^7$)" (Nature, 404, 837, abstract).

"Application of the results to the intracluster medium is being reduced to 5–7 orders of magnitude less than the mean free path due to Coulomb collisions" (ApJ, 533, 84, abstract and text). Can you reduce an application? Maybe. Can you reduce it to be less than a mean free path? Really hard.

Picture this! AJ, 199, 2338 shows a Hertzsprung-Russell diagram with hot stars to the right. Deliberate clearly, but it takes a bit of getting used to. "The added grey-scale solid symbols” of ApJ, 536, 274 are actually red. But to make up for it, MNRAS, 310, 983 Fig. 1 attempts to color-code using red and magenta, while ApJ, 523, 555 and 557 have rediscovered quarter-tones, the sepia variant on the sort of picture that used to be called a half-tone.

“Le mot bust.” In most of these, we think we know what the author meant, indeed some of them were probably deliberate. Feel free to add your own commentaries of the sort provided in *Observatory* magazine’s “Here and There” section. “Future space missions … will be able to shade new light on our knowledge” (A&AS, 145, 323, abstract). “… kinematics of a large deal of the local ISM” (A&A, 358, 299, abstract). “… and then…adding proscribed amounts of heat per particle …” (ApJ, 532, 17). “The start solid lines represent…” (A&A, 349, 832, fig. caption). “Hereto we use” (New Astron., 4, 167). “The overall flow properties of derived by …” (MNRAS, 319, 954, conclusions). “SOB” (PASP, 112, 662, text; it mean superoutbursts, but smile when you call me that). “If the absorptions is responsible for the ISM…” (ApJ, 534, L184). “A reddening map to control the patchiness of the dust” (ApJ, 527, 167, abstract. If only we could!). Section title “Appendix A: Appendix” (A&A, 356, 1001; luckily there is no Appendix B). “But there is a prize to pay: the initial advantage of genetic algorithms usually not to end in side-extrema is reduced” (A&A, 357, 1180, footnote). “Endly, we have compared …” (A&A, 352, 382, conclusion). “… suddenly shifts inward vvvv from about a few hundred …” (A&A, 354, L67). And, undoubtedly written with heartfelt intent, “… thank C. G. for insightful harassment” (ApJS, 125, 361).

We end with a few items that could be catalogued under, “With friends like these…”

“Human skeleton dating from 11,500 to 11,500 million years ago” (Science, 287, 874, a letter to the editor). “Contributions which will appear in the PASP through the year 200 to mark the upcoming millennium” (PASP, 112, 869, a very old footnote). And, “A few years ago, astronomers determined that distant supernovae were receding from the center of the universe much faster than before” (Science, 289, 1109). But, if you are left feeling unappreciated, just remember with Robert May (writing in Nature, for 4 May 2000) that, “There are no societies to express public support for nematodes.”

Author Aschwanden made use of the Astrophysics Data System (ADS) and his work was partially supported by NASA contract NAS8-00119. Author Trimble made use of the libraries of the University of California and the University of Maryland and, increasingly (and regretfully, as library collections become less and less accessible), of private journal subscriptions. Her page charges were partially supported by fees received for writing and editing for *Sky and Telescope* and the American Physical Society. A special thank you to the Boise Cascade Office Products company whose “recycled steno notebook” provided space for this year’s indices and some of the inspiration for § 13.

Colleagues to whom we are grateful for providing input, output, throughput, and up-with-it-put for Ap2000 include Lawrence H. Aller, William P. Bidelman, Tereasa Brainerd, Kris Davidson, Luke Dones, Yuri Efremov, Martin Elvis, Michael Feast, Luigi Foschini, Martin Gaskell, Roger Griffin, Carl Hansen, Chris Impey, Rosina Iping, James Kaler, Korado Korlevich, Kevin Krisciunas, Kam-ching Leung, Brian Marsden, Ray Martin, Adrian Melott, Leon Mestel, Eugene Milone, Michael Molnar, Leos Ondra, Bohdan Paczynski, Alexander Potekhin, Saul Rappaport, Alexander Rosenbush, Larry Rudnick, Sebastian Sanchez, Steve Shore, Zhen-ru Wang, George Wallerstein, Doug Welch, and Lodewijk Woltjer. Prof. Christian Klixbull Jørgensen (of the chemistry department of the University of Geneva), who had provided input for a number of years, died during the index year.

Once again, co-editor Anne P. (what does it stand for?) Cowley helped with the references at a level deserving of coauthorship or sainthood.

REFERENCES

Aarseth, S. J. 1999, PASP, 111, 1333
Abbett, W. P., Fisher, G. H., & Fan, Y. 2000, ApJ, 540, 548
Abdurashitov, J. N., et al. 1999, Phys. Rev. Lett., 83, 4686
Abia, C., & Isern, J. 2000, ApJ, 536, 438
Abia, C., et al. 1999, A&A, 351, 273
Abraham, Z. 2000, A&A, 355, 915
Abramowicz, M. A., et al. 2000, MNRAS, 314, 775
Abusaidi, R., et al. 2000, Phys. Rev. Lett., 84, 5699
Abu-Zayyad, T., et al. 2000, Phys. Rev. Lett., 84, 4276
Adelman, S. J. 1999, MNRAS, 310, 146
Aellig, M. R., et al. 1999, J. Geophys. Res., 104, 224769
Afanas’ev, V. L., et al. 2000, Astron. Lett., 26, 153
Afonso, C., et al. 2000, ApJ, 532, 340
Agol, E. 2000, ApJ, 538, L121
Agol, E., & Krolik, J. H. 2000, ApJ, 528, 161
Aguirre, A. N. 2000, ApJ, 533, 1
Aguirre, A., & Haiman, Z. 2000, ApJ, 532, 28
Aharonian, F. A., et al. 1999, A&A, 350, 757
Aharonov, Y., & Reznik, B. 2000, Phys. Rev. Lett., 84, 1368
A’Hearn, M. F. 2000, Nature, 405, 285
Ahern, S., & Chapman, G. A. 2000, Sol. Phys. 191, 71
Ahlen, S. P., et al. 2000, ApJ, 534, 757
Airapetian, V. S., et al. 2000, ApJ, 528, 965
Akerlof, C., et al. 2000, AJ, 119, 1901
Akiyama, M., et al. 2000, ApJ, 532, 700
Albrecht, A., & Skordis, C. 2000, Phys. Rev. Lett., 84, 2076
Alcaniz, J. S., & Lima, J. A. S. 1999, A&A, 349, 729
Alcock, C., et al. 1999, PASP, 111, 1539
———. 2000, AJ, 119, 2194
Aldering, G., et al. 2000, AJ, 119, 2110
Alexander, D., & Fletcher, L. 1999, Sol. Phys., 190, 167
Alexander, D. M., et al. 1999, MNRAS, 310, 78
Alexander, T. 1999, ApJ, 527, 835
Alexander, T., et al. 2000, ApJ, 536, 710
Alfaro, J., et al. 2000, Phys. Rev. Lett., 84, 2318
Allard, F., et al. 2000, ApJ, 539, 366

Allen, C., et al. 2000a, A&A, 356, 529
Allen, S. W. 2000, MNRAS, 315, 269
Allen, S. W., et al. 2000b, MNRAS, 311, 493
Allende Prieto, C., et al. 2000, ApJ, 528, 885
Alonso-Herrero, A., et al. 2000a, ApJ, 530, 688
———. 2000b, ApJ, 532, 845
Aloy, M. A., et al. 2000a, ApJ, 528, L85
———. 2000b, ApJ, 531, L119
Alton, P. B., et al. 2000, A&AS, 145, 83
Alvarez, H., et al. 2000, A&A, 355, 863
Amari, T., Boulmezaoud, T. Z., & Mikic, Z. 1999, A&A, 350, 1051
Amari, T., Luciani, J. F., Mikic, Z., & Linker, J. 2000, ApJ, 529, L49
Amendola, L. 2000, MNRAS, 312, 521
Amenomori, M., et al. 1999, ApJ, 525, L93
Anderson, O. L., & Isaak, D. G. 2000, Am. Minerologist, 85, 376
Anderson, P. R., et al. 2000, Phys. Rev. Lett., 85, 2438
Andreev, A. Y., & Komberg, B. V. 2000, Astron. Rep., 44, 139
Andreeva, N. A., et al. 2000, Astron. Lett., 26, 199
Andries, J., Tirry, W. J., & Goossens, M. 2000, ApJ, 531, 561
Andrievsky, S. M., et al. 1999, A&A, 350, 598
———. 2000, A&A, 356, 517
Angel, R., & Fugate, B. 2000, Science, 288, 455
Anguita, C., et al. 2000, AJ, 120, 845
Anthony-Twarog, B. J., et al. 2000, AJ, 119, 2882
Antinori, F., et al. 2000, Nature, 403, 561 (quoted)
Antiochos, S. K., DeVore, C. R., & Klimchuk, J. A. 1999, ApJ, 510, 485
Antiochos, S. K., MacNeice, P. J., & Spicer, D. S. 2000, ApJ, 536, 494
Antokhina, E. A., et al. 2000, ApJ, 529, 463
Antonello, E., et al. 2000, A&A, 356, L37
Anzer, U., & Heinzel, P. 2000, A&A, 358, L75
Aparicio, A., et al. 2000, AJ, 119, 177
Appourchaux, T., et al. 2000, ApJ, 538, 401
Arabadjis, J. S., & Bregman, J. N. 2000, ApJ, 536, 144
Aretxaga, I., et al. 1999, MNRAS, 309, 343
Arghast, D., et al. 2000, A&A, 356, 873
Arkhipova, V. P., et al. 2000, Astron. Lett., 26, 609
Armitage, P. J., & Hansen, B. M. S. 1999, Nature, 402, 633
Armstrong, J., & Kuhn, J. R. 1999, ApJ, 525, 533
Arnould, M., & Prantzos, N. 1999, NewA, 4, 283
Arnoult, K. M., et al. 2000, ApJ, 535, 815
Arnouts, S., et al. 1999, MNRAS, 310, 540
Arp, H. 1998, Ap&SS, 262, 337
Arp, H., & Wallerstein, G. 1956, AJ, 61, 272
Arqueros, F., et al. 2000, 359, 682
Arshakian, T. G., & Longair, M. S. 2000, MNRAS, 311, 846
Artyukh, V. S. 2000, Astron. Rep., 44, 349
Aspin, C., & Reipurth, B. 2000, MNRAS, 311, 522
Asplund, M. 2000, A&A, 359, 755
Asplund, M., et al. 2000a, A&A, 359, 743
———. 2000b, A&A, 359, 729
Atkins, R., et al. 1999, ApJ, 525, L25
Atteia, J.-L. 2000, A&A, 353, L18
Aulanier, G., et al. 2000, ApJ, 540, 1126
Aurass, H., et al. 1999, Sol. Phys., 190, 267
Ave, M., et al. 2000, Phys. Rev. Lett., 85, 2244
Avelino, P. P., & Martins, C. J. A. P. 2000, Phys. Rev. Lett., 85, 1370
Baade, W. 1963, Evolution of Stars and Galaxies (Cambridge: Harvard Univ. Press)
Baba, H., et al. 2000, PASJ, 52, 429
Bacciotti, F., et al. 2000, ApJ, 537, L49
Bachiller, R., et al. 2000, A&A, 353, L5
Bahcall, J. N., & Davis, R. J. 2000, PASP, 112, 429
Balachandran, B. 2000, Sol. Phys., 195, 195
Balbus, S. A. 2000, ApJ, 534, 420
Balenga, I. I., et al. 1999, Astron. Lett., 25, 797
Bali, R., & Meena, B. L. 1998, Ap&SS, 262, 89
Ballantyne, D. R., et al. 2000, ApJ, 539, 283
Ballesteros-Paredes, J., et al. 1999, ApJ, 527, 285
Balogh, M. L., et al. 2000, ApJ, 540, 113
Banerjee, D., O'Shea, E., & Doyle, J. G. 2000a, Sol. Phys., 196, 63
Banerjee, S. K., et al. 2000b, AJ, 119, 2583
Bao, S. D., et al. 1999, A&AS, 139, 311
Baptista, R., & Catalan, M. S. 2000, ApJ, 539, L55
Baptista, R., et al. 2000, MNRAS, 316, 529
Barat, C., et al. 2000, ApJ, 538, 152
Barban, C., et al. 1999, A&A, 350, 617
Barber, A. J., et al. 1999, MNRAS, 310, 453
Barnes, G., & Cally, P. S. 2000, Sol. Phys., 193, 373
Baron-Cohen, S., et al. 2000, Science, 287, 1395
Barrow, J. D. 1999, NewA, 4, 333
Barrow, J. D., & Magueijo, J. 2000, ApJ, 532, L87
Barrow, J. D., et al. 2000, MNRAS, 316, L41
Barstow, M. A., et al. 2000, MNRAS, 314, 109
Barth, A. J., & Shields, J. C. 2000, PASP, 112, 753
Barthes, D., et al. 1999, A&AS, 140, 55
———. 2000, A&A, 359, 168
Barucci, M. A., et al. 2000, AJ, 120, 496
Basri, G., & Martin, E. L. 1999, AJ, 118, 2460
Bassino, L. P., et al. 2000, A&A, 355, 138
Bastrukov, S. I., et al. 1999, Astrofiz., 42, 177
Basu, S., & Antia, H. M. 1999, ApJ, 525, 517
———. 2000, ApJ, 531, 1088
Basu, S., et al. 2000, ApJ, 535, 1078
Bate, M. R. 2000, MNRAS, 314, 33
Baty, H. 2000a, A&A, 353, 1074
———. 2000b, A&A, 360, 345
Bauer, F., & Sarazin, C. L. 2000, ApJ, 530, 22
Baumgardner, J., et al. 2000, AJ, 119, 2458
Baumgarte, T. W., & Shapiro, S. L. 1999, ApJ, 526, 941
Bavassano, B., & Bruno, R. 2000, J. Geophys. Res., 105, 5113
Beaulieu, S. F., et al. 2000, AJ, 120, 855
Beck, J. G. 2000, Sol. Phys., 191, 47
Beck, J. G., & Schou, J. 2000, Sol. Phys., 193, 333
Becker, W., et al. 1999, A&A, 352, 532
Beckers, J. M. 1989, Proc. SPIE, 1114, 215
Beckman, J. E., et al. 2000, AJ, 119, 2728
Beech, M., et al. 1999, MNRAS, 310, 168
Belopolsky, A. 1914, Astron. Nachr., 196, 1
Belczynski, K., et al. 2000, A&A, 355, 479
Bélien, A. J. C., Martens, P. C. H., & Keppens, R. 1999, ApJ, 526, 478
Bell, M. B., et al. 2000, PASP, 112, 1236
Belloni, T., et al. 2000a, A&A, 355, 271
———. 2000b, A&A, 358, L29
Bellot Rubio, L. R., et al. 2000a, ApJ, 534, 989
Bellot Rubio, L. R., Ruiz Cobo, B., & Collados, M. 2000b, ApJ, 535, 475
———. 2000c, ApJ, 535, 489
Beloborodov, A. M. 2000, ApJ, 539, L25
Beloborodov, A. M., et al. 2000, ApJ, 535, 158
Belousova, I. V., et al. 1999, Astron. Rep., 43, 734
Benevolenskaya, E. E., Kosovichev, A. G., & Scherrer, P. H. 1999, Sol. Phys., 190, 145
Bennett, D. P., et al. 1999, Nature, 402, 57
Bennett, D., et al. 2000, Science, 287, 411 (quoted)

Benoit, A., et al. 2000, A&AS, 141, 523
Berdyugin, A. V., & Piirola, V. 1999, A&A, 352, 619
Berger, T. E., et al. 1999, Sol. Phys., 190, 409
Bergeron, P., et al. 2000, PASP, 112, 837
Berghoefer, T. W., et al. 2000a, ApJ, 535, 615
———. 2000b, ApJ, 538, 854
Bergin, E. A., et al. 2000, ApJ, 539, L129
Bergstroem, D., et al. 2000, ApJ, 534, L177
Bergstroem, L., et al. 1999, ApJ, 526, 215
Bergvall, N., et al. 2000, A&A, 359, 41
Bernabei, R., et al. 1999, Phys. Rev. Lett., 83, 4918
Bershady, M. A., et al. 2000, AJ, 119, 2645
Bertello, L., et al. 2000a, ApJ, 535, 1066
———. 2000b, ApJ, 537, L143
Bertone, E., et al. 2000, A&A, 356, 1
Beskin, V. S., & Okamoto, I. 2000, MNRAS, 313, 445
Beskin, V. S., & Rafikov, R. R. 2000, MNRAS, 313, 433
Beuermann, K., et al. 1999, A&A, 352, L26
Beuermann, K., et al. 2000, A&A, 354, L49
Bharadwaj, S., et al. 1999, A&A, 351, 405
———. 2000, ApJ, 528, 21
Bi, S., & Xu, H. 2000, A&A, 357, 300
Bica, E., & Dutra, C. M. 2000, AJ, 119, 1214
Bidelman, W. P. 1956, S&T, March
Binette, L., et al. 2000, A&A, 356, 23
Birk, G. T., & Lesch, H. 2000, ApJ, 530, L77
Birn, J., et al. 2000, ApJ, 541, 1078
Bisnovatyi-Kogan, G. S., & Lovelace, R. V. E. 2000, ApJ, 529, 978
Blain, A. W., et al. 1999, MNRAS, 309, 715
Blair, A. J., et al. 2000, MNRAS, 314, 138
Blais-Ouellette, S., et al. 1999, AJ, 118, 2123
Blakeslee, J. P. 1999, AJ, 118, 1506
Blandfield, J. E., et al. 2000, Science, 287, 1626
Blandford, R. D. 1998, Ap&SS, 261, 345
Blandford, R. D., & Begelman, M. C. 1999, MNRAS, 303, L1
Blank, B., et al. 2000, Phys. Rev. Lett., 84, 116
Blasi, P. 2000, ApJ, 532, L9
Blasi, P., et al. 2000a, ApJ, 533, L123
———. 2000b, ApJ, 535, L71
Bleeker, W., & Stern, R. 1999, Science, 286, 2254
Blondin, J. M. 2000, NewA, 5, 53
Bluhm, H., et al. 1999, A&A, 352, 287
Blum, J., et al. 2000, Phys. Rev. Lett., 85, 2426
Bochsler, P., et al. 2000, J. Geophys. Res., 105, 112659
Boden, A. F., et al. 1999, ApJ, 527, 360
Bodmer, R., & Bochsler, P. 2000, J. Geophys. Res., 105, 47
Boettcher, M., & Dermer, C. D. 2000, ApJ, 529, 635
Boezio, M., et al. 2000, ApJ, 532, 653
Boger, J., Hahn, R. L., & Cumming, J. B. 2000, ApJ, 537, 1080
Böhm-Vitense, E., et al. 2000, ApJ, 533, 969
Boisson, C., et al. 2000, A&A, 357, 850
Boldt, E., & Loewenstein, M. 2000, MNRAS, 316, L29
Boller, T., et al. 2000, MNRAS, 315, L23
Bombaci, I., & Datta, B. 2000, ApJ, 530, L69
Bond, J. R., Carr, B. J., & Arnett, W. D. 1983, Nature, 304, 514
Bondi, M., et al. 2000, MNRAS, 314, 11
Bordag, M., et al. 2000, Phys. Rev. Lett., 85, 503
Borne, K. D., et al. 2000, ApJ, 529, L77
Boss, A. P. 2000a, Nature, 405, 405
———. 2000b, ApJ, 536, L101
Boss, A. P., et al. 2000, ApJ, 528, 325
Bottorff, M. C., et al. 2000, ApJ, 537, 134
Bottke, W. F., et al. 2000, Science, 288, 2190
Boughn, S. P. 1999, ApJ, 526, 14
Bouwman, J., et al. 2000, A&A, 360, 213
Bowen, D. V., et al. 2000, ApJ, 536, 225
Bowyer, S., et al. 1999, ApJ, 526, 10
Boyarchuk, A. A., et al. 2000, Astron. Rep., 44, 76
Box, A. 2000, Science, 288, 238
Brada, R., & Milgrom, M. 2000, ApJ, 531, L21
Bradshaw, C. F., et al. 1997, ApJ, 484, L55
Braine, J., et al. 2000, Nature, 403, 867
Brainerd, J. J. 2000, ApJ, 538, 628
Brandi, E., et al. 2000, A&AS, 145, 197
Brandt, W. N., et al. 1999, ApJ, 525, L69
———. 2000, AJ, 119, 2349
Braun, R., & Burton, W. B. 1999, A&A, 341, 437
———. 2000, A&A, 354, 853
Bravo-Alfaro, H., et al. 2000, AJ, 119, 580
Breger, M., et al. 1999, A&A, 349, 225
Brekke, P., et al. 2000, Adv. Space Res., 26, 457
Brickhouse, N. S., et al. 2000, ApJ, 530, 387
Bridle, S. L., et al. 1999, MNRAS, 310, 565
Brieu, P. P., & Evrard, A. E. 2000, NewA, 5, 163
Briggs, M. S., et al. 1999, ApJ, 524, 82
Brighenti, F., & Mathews, W. G. 2000, ApJ, 535, 650
Britzen, S., et al. 2000, A&A, 360, 65
Brkovic, A., et al. 2000, A&A, 353, 1083
Bromm, V., et al. 1999, ApJ, 527, L5
Bronshten, V. A. 2000, Astron. Lett., 26, 328
Brosch, N., et al. 1999, MNRAS, 308, 651
Brosius, J. W., Thomas, R. J., & Davila, J. M. 1999, ApJ, 526, 494
Brosius, J. W., et al. 2000, Sol. Phys., 193, 117
Brown, D. S., & Priest, E. R. 2000, Sol. Phys., 194, 197
Brown, G. E., et al. 2000a, NewA, 5, 191
Brown, J. C., et al. 2000c, A&A, 359, 1185
Brown, J. C., et al. 2000d, ApJ, 541, 1104
Brown, M. E. 2000, AJ, 119, 977
Brown, M. E., & Calvin, W. M. 1999, Science, 287, 107
Brown, T. M., et al. 2000, BAAS, 32, 676
Bruens, C., et al. 2000, A&A, 357, 120
Brüggen, M. 2000, MNRAS, 312, 887
Brun, A. S., Turck-Chieze, S., & Zahn, J. P. 1999, ApJ, 525, 1032
Brunetti, M. T., & Codino, A. 2000, ApJ, 528, 789
Brunthaler, A., et al. 2000, A&A, 357, L45
Bruntt, H., et al. 1999, A&AS, 140, 135
Bruzendorf, J., & Meusinger, H. 1999, A&AS, 139, 141
Bryan, G. L., & Machacek, M. E. 2000, ApJ, 534, 57
Bryant, J. J., & Hunstead, R. W. 1999, MNRAS, 308, 431
Bunker, A. J., et al. 1999, MNRAS, 309, 875
Buote, D. A. 2000, ApJ, 532, L113
Burgasser, A. J., et al. 2000a, AJ, 120, 1100
———. 2000b, ApJ, 531, L57
Burkert, A. 2000, ApJ, 534, L143
Burkert, A., & Lin, D. N. C. 2000, ApJ, 537, 270
Burleigh, M. R., & Barstow, M. A. 2000, A&A, 359, 977
Burrows, A., et al. 2000a, ApJ, 531, 438
Burrows, A., et al. 2000b, ApJ, 534, L97
Burton, W. B., & Lockman, F. J. 1999, A&A, 349, 7
Butler, R. P., et al. 1999, ApJ, 526, 916
Buttighoffer, A., et al. 1999, A&A, 351, 385
Cabrit, S., & Raga, A. 2000, A&A, 354, 667
Calcaneo-Roldan, C., et al. 2000, MNRAS, 314, 324
Caloi, V., et al. 1999, A&A, 351, 925
Cameron, A. C., et al. 1999, Nature, 402, 751
Cameron, R., & Sammis, I. 1999, ApJ, 525, L61
Campana, S. 2000, ApJ, 534, L79
Canalizo, G., & Stockton, A. 2000, ApJ, 528, 210
Canalizo, G., et al. 2000, AJ, 119, 59
Cane, H. V., Richardson, I. G., & St. Cyr, O. C. 2000, Geophys. Res. Lett., 27/21, 3591
Canfield, D. E., et al. 2000, Science, 288, 658

Canfield, R. C., Hudson, H. S., & McKenzie, D. E. 1999, Geophys. Res. Lett., 26, 627
Canto, J., et al. 2000, MNRAS, 313, 656
Canuto, V. M. 1999, ApJ, 524, 311
Caputo, F., et al. 2000a, MNRAS, 316, 819
———. 2000b, A&A, 354, 610
———. 2000c, A&A, 359, 1059
Capuzzo-Dolcetta, R., & Tesseri, A. 1999, MNRAS, 308, 961
Carilli, C. L., & Taylor, G. B. 2000, ApJ, 532, L95
Carlsson, M., & Stein, R. F. 1995, ApJ, 440, L29
Carollo, C. M. 1999, ApJ, 523, 566
Carraro, G., & Lia, C. 2000, A&A, 357, 977
Carraro, G., et al. 1999, MNRAS, 309, 430
Carretta, E., et al. 2000, MNRAS, 316, 721
Carrillo, R., et al. 1999, Rev. Mex. Astron. Astrophys., 35, 187
Cash, W., et al. 2000, Nature, 407, 160
Cassisi, S., et al. 2000, MNRAS, 315, 679
Castellano, T., et al. 2000, ApJ, 532, L51
Casuso, E., & Beckman, J. E. 2000, PASP, 112, 942
Caswell, J. L. 1999, MNRAS, 308, 683
Catanese, M., & Weekes, T. C. 1999, PASP, 111, 1193
Cauzzi, G., Falchi, A., & Falciani, R. 2000, A&A, 357, 1093
Cazetta, J., & Maciel, W. J. 2000, Rev. Mex. A&A, 36, 3
Cecil, G., et al. 2000, ApJ, 536, 675
Cederstroem, B., et al. 2000, Nature, 404, 951
Cernicharo, J., et al. 2000, A&AS, 142, 181
Chaboyer, B., et al. 1999, ApJ, 525, L41
Chae, J. 2000, ApJ, 540, L115
Chae, J., et al. 2000, Sol. Phys., 195, 333
Chamblin, A., & Gibbons, G. W. 2000, Phys. Rev. Lett., 84, 1090
Chan, K.-W., & Onaka, T. 2000, ApJ, 533, L33
Chang, H., Chou, D., & Sun, M. 1999, ApJ, 526, L53
Chary, R., et al. 2000, ApJ, 531, 756
Chaplin, W. J., et al. 2000, MNRAS, 313, 32
Charbonneau, D., et al. 2000, ApJ, 529, L45
Charbonneau, P., et al. 1999, ApJ, 527, 445
Chashei, I. V., et al. 1999, Sol. Phys., 189, 399
Chatterjee, P., et al. 2000, ApJ, 534, 373
Chayer, P., et al. 2000, ApJ, 538, L91
Chen, H.-W., et al. 2000, ApJ, 533, 120
Chen, J., et al. 2000b, ApJ, 533, 481
Chen, Y. J., et al. 2000a, Ap&SS, 266, 495
Cherchneff, I., et al. 2000, A&A, 357, 572
Chevalier, R. A. 2000, ApJ, 539, L45
Chevalier, R. A., & Li, Z.-Y. 2000, ApJ, 536, 195
Chini, R., et al. 2000, A&A, 357, L37
Chiu, W. A., & Ostriker, J. P. 2000, ApJ, 534, 507
Chiueh, T. 2000, ApJ, 539, 933
Chiueh, T., & Wu, X.-P. 2000, A&A, 353, 823
Choe, G. S., & Cheng, C. Z. 2000, ApJ, 541, 449
Choi, C.-S., et al. 1999, ApJ, 525, 399
Chou, D., & Duvall, T. L. 2000, ApJ, 533, 568
Chou, D., Sun, M., & Chang, H. 2000, ApJ, 532, 622
Chou, Y. P. 1999, ApJ, 527, 958
Christopoulou, E. B., Georgakilas, A. A., & Koutchmy, S. 2000, A&A, 354, 305
Christou, A. A., et al. 2000, A&A, 356, L71
Chrysostomou, A., et al. 2000, MNRAS, 312, 103
Ciaravella, A., et al. 2000, ApJ, 529, 575
Ciardi, B., et al. 2000, MNRAS, 314, 611
Cimatti, A., et al. 1999, A&A, 352, L45
Cincutta, R. P., et al. 2000, Nature, 404, 990
Cioni, M.-R. L., et al. 2000, A&A, 359, 601
Clark, G. 2000, Science, 289, 710 (quoted)
Clark, J. S., et al. 2000a, A&A, 356, 50
Clark, L. L., & Dolan, J. F. 1999, A&A, 350, 1085
Clark, T. A., et al. 2000b, A&A, 357, 757
Clayton, E. G., Guzik, T. G., & Wefel, J. P. 2000, Sol. Phys., 195, 175
Clemens, M. S., et al. 1999, MNRAS, 308, 364
Cline, D. B., et al. 1999a, ApJ, 527, 827
Cline, J. M., et al. 1999b, Phys. Rev. Lett., 83, 4245
Clowe, D., et al. 2000, ApJ, 539, 540
Cohen, J. G. 2000, AJ, 119, 162
Cojazzi, P., et al. 2000, MNRAS, 315, L51
Coker, R., et al. 1999, ApJ, 531, 642
Cole, A. A., et al. 1999a, AJ, 118, 1657
Cole, A. A., et al. 1999b, AJ, 118, 2280 & 2292
Colina, L., et al. 1999, ApJ, 527, L13
Collins, J. A., et al. 2000, ApJ, 536, 645
Colpi, M., et al. 1999, ApJ, 525, 720
Combes, F., & Charmandaris, V. 2000, A&A, 357, 75
Combes, F., et al. 1999, A&A, 352, 149
Comeron, F. 1999, A&A, 351, 506
Compton, R., & Pagni, R. 1999, Science, 296, 1282
Conselice, C. J., et al. 2000, AJ, 119, 79
Contaldi, C. R., et al. 2000, ApJ, 534, 25
Conway, A. J., & Willes, A. J. 2000, A&A, 355, 751
Cooray, A. R. 1999, NewA, 4, 377
Cooray, A., et al. 2000, ApJ, 540, 1
Coppin, K. E. K., et al. 2000, A&A, 356, 1031
Corbel, S., et al. 1999, ApJ, 526, L29
Cormier, D., & Holman, R. 2000, Phys. Rev. Lett., 84, 5936
Cornelisse, R., et al. 2000, A&A, 357, L21
Corradi, R. L. M., et al. 2000, ApJ, 535, 823
Côte, P., et al. 1999, ApJ, 526, 147
———. 2000, ApJ, 533, 869
———. 2000a, ApJ, 537, L91
Cousins, A. 2000, MNASSA, 59, 12
Cowan, J. 1999, Nature, 401, 124
Cowling, T. G. 1941, MNRAS, 101, 367
Cox, P., et al. 2000, A&A, 353, L25
Craig, I. J. D., & Watson, P. G. 2000, Sol. Phys., 191, 359
Cranmer, S. R. 2000, ApJ, 532, 1197
Crawford, F., et al. 2000, AJ, 119, 2376
Crawford, I. A., & Barlow, M. J. 2000, MNRAS, 311, 370
Crenshaw, D. M., & Kraemer, S. B. 2000, ApJ, 532, 247
Croft, R. A. C., et al. 2000, ApJ, 534, L123
Croll, J. 1875, Climate and Time (New York: Appleton)
Crowley, T. J. 2000, Science, 289, 230
Csaki, C., et al. 2000, Phys. Rev. Lett., 84, 5932
Cui, W. 2000, ApJ, 534, L31
Culler, T. S. 2000, Science, 287, 1788
Cumming, A., et al. 1999, ApJ, 526, 890
Curry, C. L., & McKee, C. F. 2000, ApJ, 528, 734
Dabrowski, M. P., & Schunck, F. E. 2000, ApJ, 535, 316
da Costa, L. N., et al. 2000, ApJ, 537, L81
Daigne, F., & Mochkovitch, R. 2000, A&A, 358, 1157
Dal Fiume, D., et al. 2000, A&A, 355, 454
Dantowitz, R. F., et al. 2000, AJ, 119, 2455
Das, A., & Banerjee, A. 1999, Ap&SS, 268, 425
Das, T. K., & Gosh, M. K. 1999, MNRAS, 310, 414
Davis, C. J., et al. 1999, MNRAS, 309, 141
Davis, L., & Greenstein, J. L. 1951, ApJ, 114, 206
de Bernardis, P., et al. 2000, Nature, 404, 955
De Cat, P., et al. 2000a, A&A, 355, 1015
———. 2000b, A&A, 359, 539
De Donder, E., & Vanbeveren, D. 1999, NewA, 4, 167
Deeg, H. J., et al. 2000, A&A, 358, L5
DeForest, C. E., & Gurman, J. B. 1998, ApJ, 501, L217
de Gouveia dal Pino, E. M. 1999, ApJ, 526, 862
de Gouveia dal Pino, E. M., & Lazarian, A. 2000, ApJ, 536, L31

de Grijs, R., & Peletier, R. F. 1999, MNRAS, 310, 157
DeGroof, A., & Goossens, M. 2000, A&A, 356, 724
Deharveng, L., et al. 2000, MNRAS, 311, 329
Dehnen, W. 1999, ApJ, 524, L35
———. 2000, AJ, 119, 800
Delaboudinière, J. P. 1999, Sol. Phys., 188, 259
Delamarter, G., et al. 2000, ApJ, 530, 923
Delannée, C., & Aulanier, G. 1999, Sol. Phys., 190, 107
Delannée, C., Delaboudinière, J. P., & Lamy, P. 2000, A&A, 355, 725
de la Reza, R., et al. 2000, ApJ, 535, L115
Delfosse, X., et al. 1999, A&A, 350, L39
Della Ceca, R., et al. 1999, ApJ, 524, 674
DeMoortel, I., Ireland, J., & Walsh, R. W. 2000, A&A, 355, L23
Denissenkov, P. A., & Weiss, A. 2000, A&A, 358, L49
Dent, W. R. F., et al. 2000, MNRAS, 314, 702
de Oliveira, M. R., et al. 2000, MNRAS, 311, 589
de Oliveira-Costa, A., et al. 1999, ApJ, 527, L9
Dermer, C. D., et al. 2000, ApJ, 537, 785
DeSmet, J., et al. 2000, Tectonophys., 322, 19
de Vaucouleurs, G., et al. 1990, Third Reference Catalogue of Bright Galaxies (Berlin: Springer)
DeVore, C. R., & Antiochos, S. K. 2000, ApJ, 539, 954
de Vries, A., & Schmidt-Kaler, T. 2000, Ap&SS, 266, 371
Dietrich, M., & Wilhelm-Erkens, U. 2000, A&A, 354, 17
Digal, S., et al. 2000, Phys. Rev. Lett., 84, 826
di Matteo, T., & Allen, S. W. 1999, ApJ, 527, L21
Ding, M. D. 1999, A&A, 351, 368
Dirsch, B., et al. 2000, A&A, 360, 133
Dmitruk, P., & Gómez, D. O. 1999, 527, L63
Dobrzycka, D., Raymond, J. C., & Cranmer, S. R. 2000, ApJ, 538, 922
Dobrzycki, A., et al. 1999, A&A, 349, L29
Dolgov, A. D., & Pagel, B. E. J. 1999, NewA, 4, 231
Dominguez, I., et al. 1999, ApJ, 524, 226
Doroshenko, V. T., et al. 2000, Astron. Lett., 26, 460
Doschek, G. A. 1999, ApJ, 527, 426
Doschek, G. A., & Feldman, U. 2000, ApJ, 529, 599
Dotto, E. 2000, A&A, 358, 1133
Dourneau, G., & Baratchart, S. 1999, A&A, 350, 680
Douvion, T., et al. 1999, A&A, 352, L111
Dove, J. B., et al. 2000, ApJ, 531, 846
Doyle, S., et al. 2000, AJ, 119, 1339
Drake, N., et al. 2000, MNRAS, 314, 768
Driebe, T., et al. 1999, A&A, 350, 89
Drimmel, R. 2000, A&A, 358, L13
Drimmel, R., et al. 2000, A&A, 354, 67
Drinkwater, M. J., et al. 2000, A&A, 355, 900
Drobyshevski, E. M. 2000a, MNRAS, 311, L1
———. 2000b, MNRAS, 315, 517
Droege, W. 2000, ApJ, 537, 1073
Dryer, M., Wu, C. C., & Smith, Z. K. 1999, J. Geophys. Res., 104, 22407
Duchene, G., et al. 1999, A&A, 351, 954
Dubinski, J., et al. 1999, ApJ, 526, 607
Duerbeck, H. W., et al. 2000, AJ, 119, 2360
Dumke, M., et al. 2000, A&A, 355, 512
Dupke, R. A., & White III, R. E. 2000, ApJ, 528, 139
Dupuis, J., et al. 2000, ApJ, 537, 977
Durret, F., et al. 2000, A&A, 356, 815
Duvert, G., et al. 2000, A&A, 355, 165
Dyer, K. K., & Reynolds, S. P. 1999, ApJ, 526, 365
Edery, A. 1999, Phys. Rev. Lett., 83, 3990
Edvardsson, B., et al. 1993, A&A, 275, 101
Efroimsky, M., & Lazarian, A. 2000, MNRAS, 311, 269
Egbert, G. D., & Ray, R. D. 2000, Nature, 405, 775
Eggen, O. J. 1992, AJ, 103, 1302
Eisloeffel, J. 2000, A&A, 354, 236
El-Khoury, W., & Wickramasinghe, D. 2000, A&A, 358, 154
Elmegreen, B. G. 1999, ApJ, 530, 277
Elmegreen, D. M., et al. 1999, AJ, 118, 2618
Emparan, R., et al. 2000, Phys. Rev. Lett., 85, 499
Encrenaz, T. 1999, A&A Rev., 9, 17
Encrenaz, T., et al. 2000, A&A, 358, L83
Epchtein, N., et al. 1999, A&A, 349, 236
Erben, T., et al. 2000, A&A, 355, 23
Eriksson, K. A., & Simpson, E. L. 2000, Geology, 28, 831
Esin, A. A., & Blandford, R. D. 2000, ApJ, 534, L151
Esin, A. A., et al. 2000a, ApJ, 532, 1069
Esin, A. A., et al. 2000b, A&A, 354, 987
Esser, R., & Edgar, R. J. 2000, ApJ, 532, L71
Evans, A. S., et al. 2000a, ApJ, 529, L85
Evans, N. W., & Kerins, E. 2000, ApJ, 529, 917
Evans, N. W., & Wilkinson, M. I. 2000, MNRAS, 316, 929
Evans, N. W., et al. 2000b, ApJ, 540, L9
Evlanov, E. N., et al. 2000, Astron. Lett., 26, 473
Exarhos, G., & Moussas, X. 2000, A&A, 356, 315
Fabbri, A., et al. 2000, Phys. Rev. Lett., 85, 2434
Fabian, A. C. 1999, MNRAS, 308, L39
Fabian, A. C., et al. 2000, MNRAS, 315, L8
Fahr, H. J., et al. 2000, A&A, 357, 268
Fairley, B. W., et al. 2000, MNRAS, 315, 669
Fakir, R. 2000, ApJ, 537, 533
Falconer, D. A., et al. 2000, ApJ, 528, 1004
Fan, X., et al. 1999, ApJ, 526, L57
———. 2000a, AJ, 119, 1
———. 2000b, AJ, 119, 928
Fang, C., Henoux, J., & Ding, M. D. 2000, A&A, 360, 702
Farmer, J. 2000, private communication
Farrar, G. R & Piran, T. 2000, Phys. Rev. Lett., 84, 3527
Feast, M. W., & Whitelock, P. A. 2000, MNRAS, 317, 460
Fedorova, A. V., et al. 2000, Astron. Rep., 44, 309
Feibelman, W. A. 2000, PASP, 112, 861
Feissel, M., et al. 2000, A&A, 359, 1201
Feldmeier, A., & Shlosman, I. 1999, ApJ, 526, 344
Feltzing, S., & Holmberg, J. 2000, A&A, 357, 153
Fender, R. P., & Hendry, M. A. 2000, MNRAS, 317, 1
Ferguson, A. M. N., et al. 2000, AJ, 120, 821
Ferlet, R. 1999, A&A Rev., 9, 153
Fernie, J. D. 2000, AJ, 120, 978
Ferrarese, L., & Merritt, D. 2000, ApJ, 539, L9
Ferrario, L., & Wickramasinghe, D. T. 1999, MNRAS, 309, 517
Ferreira, J., et al. 2000, MNRAS, 312, 387
Ferreras, I., & Silk, J. 2000, MNRAS, 316, 786
Festou, M. C., & Barale, O. 2000, AJ, 119, 3119
Fields, B. D., et al. 2000, ApJ, 534, 265
Figer, D. F., et al. 1999, ApJ, 525, 759
Finkbeiner, D. P., et al. 1999, ApJ, 524, 867
Fiore, F., et al. 2000, NewA, 5, 143
Firmani, C., et al. 2000, MNRAS, 315, L29
Fischbacher, G. A., Loch, S. D., & Summers, H. P. 2000, A&A, 357, 767
Fisher, P. E., et al. 2000, Science, 288, 503
Fisk, L. A., Schwadron, N. A., & Zurbuchen, T. H. 1999, J. Geophys. Res., 104, 19765
Fitzpatrick, E. L., & Massa, D. 1999, ApJ, 525, 1011
Fleming, T. A., et al. 2000, ApJ, 533, 327
Forbes, D. A., & Hau, G. K. T. 2000, MNRAS, 312, 703
Forbes, D. A., & Ponman, T. J. 1999, MNRAS, 309, 623
Forbes, D. A., et al. 2000, A&A, 358, 471
Forbes, T. G. 2000a, Phil. Trans. R. Soc. A, 358, 711
———. 2000b, Adv. Space Res., 26, 549

Ford, E. B., et al. 2000, A&A, 528, 336
Ford, L. H. 1987, Phys. Rev. D, 35, 2339
Frail, D. A., et al. 2000a, ApJ, 537, 191
———. 2000b, ApJ, 538, L129
Franceschini, A., et al. 1999, MNRAS, 310, L5
Frank, A., et al. 1999, ApJ, 524, 947
———. 2000, ApJ, 540, 342
Frank, L., et al. 1986, Geophys. Res. Lett., 13, 303
Franklin, J., et al. 2000, Science, 288, 1578 (quoted)
Franz, M., Burgess, D., & Horbury, T. S. 2000, J. Geophys. Res., 105, 112725
Frazin, R. A. 2000, ApJ, 530, 1026
Freiburghaus, C., et al. 1999, ApJ, 525, L121
Frenk, C. S., et al. 1999, ApJ, 525, 554
Friedrich, S., et al. 1999, A&A, 350, 865
Frolov, V. P., & Fursaev, D. V. 1999, A&A, 20, 121
Frutiger, C., et al. 2000, A&A, 358, 1109
Fryer, C. L., et al. 1999, ApJ, 526, 152
Fuchs, B., & Moellenhoff, C. 1999, A&A, 352, L36
Fujita, Y., et al. 2000, PASJ, 52, 235
Fukui, Y., et al. 1999, PASJ, 51, 745
Fukugita, M., et al. 2000, Phys. Rev. Lett., 84, 1082
Fuller, G. M., et al. 2000, Phys. Rev. Lett., 85, 2673
Furusawa, K., & Sakai, J. I. 2000, ApJ, 540, 1156
Fynbo, J. U., et al. 2000, A&A, 355, 37
Gadun, A. S., Solanki, S. K., & Johannesson, A. 1999, A&A, 350, 1018
Gaensicke, B. T., et al. 2000a, A&A, 354, 605
———. 2000b, A&A, 356, L79
Gaensler, B. M., et al. 1999, ApJ, 526, L37
———. 2000, ApJ, 537, L35
Gaidos, E. J., & Nimmo, F. 2000, Nature, 405, 637
Gailitis, A., et al. 2000, Phys. Rev. Lett., 84, 4365
Galazutdinov, G. A., et al. 2000, PASP, 112, 648
Gallagher, P. T., et al. 1999, ApJ, 524, L133
———. 2000, Sol. Phys., 195, 367
Galsgaard, K., MacKay, D. H., Priest, E. R., & Nordlund, A. 1999, Sol. Phys., 189, 95
Galsgaard, K., et al. 2000, Sol. Phys., 193, 1
Gambini, R., & Pullin, J. 1999, Phys. Rev. D, 59, 124021
Gan, W. Q., Henoux, J. C., & Fang, C. 2000, A&A, 354, 691
Garcia, M. R., et al. 2000, ApJ, 537, L23
García Cole, A., et al. 1999, Rev. Mexicana Astron. Astrofis., 35, 111
Garcia-Guinea, J. 2000, Science, 288, 2127 (quoted)
Garcia-Lario, P., et al. 1999, ApJ, 526, 854
Garcia-Miro, C., et al. 1999, A&A, 351, 147
Garcia-Sanchez, J. 2000, PASP, 112, 422
Gardiner, T. A., et al. 2000, ApJ, 530, 834
Garnett, D. R., & Kobulnicky, H. A. 2000, ApJ, 532, 1192
Garriga, J., & Tanaka, T. 2000, Phys. Rev. Lett., 84, 2778
Gatewood, G., et al. 2000, ApJ, 533, 938
Gebhardt, K., & Kissler-Patig, M. 1999, AJ, 118, 1526
Gebhardt, K., et al. 2000, ApJ, 539, L13
Gehrels, N., et al. 2000, Nature, 404, 363
Gelbmann, M., et al. 2000, A&A, 356, 200
Geller, R. M., et al. 2000, ApJ, 539, 73
Gelmini, G., & Kusenko, A. 2000, Phys. Rev. Lett., 84, 1378
Genova, F., et al. 2000, A&AS, 143, 1
Genzel, R., et al. 2000, MNRAS, 317, 348
Georgelin, Y. M., et al. 2000, A&A, 357, 308
Georgobiani, D., et al. 2000, ApJ, 530, L139
Germany, L. M., et al. 2000, ApJ, 533, 320
Geroyannis, V. S., & Papasotiriou, P. J. 2000, ApJ, 534, 359
Gershberg, R. E., et al. 1999, A&AS, 139, 555
Gerth, E., et al. 1999, A&A, 351, 133
Gesicki, K., & Zijlstra, A. A. 2000, A&A, 358, 1058
Ghavamian, P., et al. 2000, ApJ, 535, 266
Ghez, A. M., et al. 2000, Nature, 407, 349
Ghisellini, G. 2000, MNRAS, 312, L1
Giacalone, J., Jokipii, J. R., & Mazur, J. E. 2000, ApJ, 532, L75
Giardino, G., et al. 2000, MNRAS, 313, 689
Gibb, E. L., et al. 2000, ApJ, 536, 347
Gibbons, G. 2000, Science, 287, 49
Gibson, B. K., et al. 2000, ApJ, 530, L5
Gierasch, P. J., et al. 2000, Nature, 403, 628
Gies, D. R., et al. 1999, ApJ, 525, 420
Gilbert, H. R., Holzer, T. E., Burkpile, J. T., & Hundhausen, A. J. 2000, ApJ, 537, 503
Gimenez, A. 2000, A&A, 356, 213
Giommi, P., et al. 1999, A&A, 351, 59
Giordano, S., et al. 2000, ApJ, 531, L79
Giovanelli, R., et al. 1999, ApJ, 525, 25
Girard, T. M., et al. 2000, AJ, 119, 2428
Girart, J. M., et al. 1999, ApJ, 525, L109
Giraud, E. 2000, ApJ, 531, 701
Gispert, R., et al. 2000, A&A, 360, 1
Glebocki, R. 2000, Acta Astron., 50, 211
Glendenning, N. K. 2000, Phys. Rev. Lett., 85, 1150
Glendenning, N. K., & Kettner, C. 2000, A&A, 353, L9
Gloeckler, G., et al. 2000, Nature, 404, 576
Glushneva, I. N., et al. 2000, Astron. Rep., 44, 246
Gnedin, N. Y. 2000, ApJ, 535, 530
Gneiding, C. D., et al. 1999, A&A, 352, 543
Godon, P., & Livio, M. 2000, ApJ, 537, 396
Goeckel, C., & Jehn, R. 2000, MNRAS, 317, L1
Gogus, E., et al. 1999, ApJ, 526, L93
Gold, T., Axford, I., & Roy, E. C. 1965, in Quasi-Stellar Sources and Gravitational Collapse, ed. I. Robinson et al. (Chicago: Univ. Chicago Press), 93
Goldreich, P., & Kylafis, N. D. 1981, ApJ, 243, L75
Goldreich, P., & Toomre, A. 1969, J. Geophys. Res., 74, 1558
Goldsmith, P. F., et al. 2000, ApJ, 539, L123
Gomez-Herrero, R., et al. 2000, Sol. Phys., 194, 405
Gonzalez, G. 1999, MNRAS, 308, 447
Gonzalez, G., & Laws, C. 2000, AJ, 119, 390
Gonzalez, G., & Wallerstein, G. 2000, PASP, 112, 1081
Goodman, J. 2000, NewA, 5, 103
Goodman, J., & Evans, N. W. 1999, MNRAS, 309, 599
Goodman, M. L. 2000a, ApJ, 533, 501
Goodson, A. P., et al. 1999, ApJ, 524, 142
Gopalswamy, N., Hanaoka, Y., & Hudson, H. S. 2000, Adv. Space Res., 25, 1851
Gosachinskii, I. V., & Morozova, V. V. 1999, Astron. Rep., 43, 777
Gothoskar, P., & Gupta, Y. 2000, ApJ, 531, 345
Gotthelf, E. V., & Wang, Q. D. 2000, ApJ, 532, L117
Gough, D. O. 2000, in IAU Symp. 203, Recent Insights into the Physics of the Sun and Heliosphere: Highlights from *SoHO* and Other Space Missions (San Francisco: ASP), 1
Govoni, F., et al. 2000, A&A, 353, 507
Graff, D. S., & Gould, A. P. 2000, ApJ, 534, L51
Graff, D. S., et al. 2000, ApJ, 540, 211
Granot, J., et al. 2000, ApJ, 534, L163
Graps, A. L., et al. 2000, Nature, 405, 48
Gratton, R. G., et al. 2000, A&A, 358, 671
Greaves, J. S., & Holland, W. S. 2000, MNRAS, 316, L21
Greene, T. P., & Lada, C. J. 2000, AJ, 120, 430
Greff-Lefftz, M., & Legros, H. 1999, Science, 286, 1707
Gregory, R., et al. 2000, Phys. Rev. Lett., 84, 5928
Greiner, J. 2000, NewA, 5, 137
Greiner, J., et al. 2000a, A&A, 353, 998
———. 2000b, A&A, 355, 1041
Grenacher, L., et al. 1999, A&A, 351, 775

Grenier, I. A. 2000, Nature, 404, 304
Griffin, R. E. M., & Griffin, R. F. 2000, MNRAS, 312, 225
Griffiths, L. M., et al. 1999, MNRAS, 308, 854
Griv, E., et al. 2000, Phys. Rev. Lett., 84, 4280
Groenewegen, M. A. T. 1999, A&AS, 139, 245
Groenewegen, M. A. T., et al. 1999, A&AS, 140, 197
Groenewegen, M. A. T., & Oudmaijer, R. D. 2000, A&A, 356, 849
Grogin, N. A., & Geller, M. J. 1999, AJ, 118, 2561
———. 2000, AJ, 119, 32
Gruzinov, A. V. 1998, ApJ, 496, 503
Gu, P.-G., et al. 2000, ApJ, 534, 380
Gu, W.-M., & Lu, J.-F. 2000, ApJ, 540, L33
Guainazzi, M., et al. 2000, A&A, 355, 113
Guan, Y, et al. 2000, Science, 289, 1330
Guenther, D. B., & Demarque, P. 2000, ApJ, 531, 503
Guerrero, M. A., et al. 2000a, MNRAS, 313, 1
———. 2000b, ApJS, 127, 125
Guillout, P., et al. 1999, A&A, 351, 1003
Gundlach, J. H., & Merkowitz, S. M. 2000, Phys. Rev. Lett., 85, 2869
Guy, J., et al. 2000, A&A, 359, 419
Guzzo, L., et al. 2000, A&A, 355, 1
Guzzo, M. M., & Nunokawa, H. 1999, Astropart. Phys., 12, 87
Gwinn, C. R., et al. 2000, ApJ, 531, 902
Haberl, F., & Pietsch, W. 1999, A&AS, 139, 277
Haberl, F., et al. 2000, A&AS, 142, 41
Hackenberg, P., Mann, G., & Marsch, E. 2000, A&A, 360, 1139
Haefner, R., et al. 2000, MNRAS, 314, 433
Haehnelt, M. G., et al. 2000, ApJ, 534, 594
Hagenaar, H. J. 1999, Ph.D. thesis, Univ. Utrecht
Haigh, N. J., et al. 1999, MNRAS, 310, L21
Hainaut, O. R., et al. 2000, A&A, 356, 1076
Hakkila, J., et al. 2000, ApJ, 538, 165
Halbwachs, J. L., et al. 2000, A&A, 355, 581
Halpern, J. P., & Eracleous, M. 2000, ApJ, 531, 647
Hambly, N. C., et al. 1999, MNRAS, 309, L33
Hanaoka, Y. 1999, PASJ, 51, 483
Hanlan, P. C., & Bregman, J. N. 2000, ApJ, 530, 213
Hannikainen, D. C., et al. 2000, ApJ, 540, 521
Hansen, L., et al. 1999, A&A, 349, 406
———. 2000, A&A, 356, 83
Hanslmeier, A., et al. 2000, A&A, 356, 308
Hardcastle, M. J. 2000, A&A, 357, 884
Hardcastle, M. J., & Worrall, D. M. 2000, MNRAS, 314, 359
Harding, A. K., et al. 1999, ApJ, 525, L125
Hargreaves, L. 2000, Phys. Today, 53(9), 58
Harra, L. K., Gallagher, P. T., & Phillips, K. J. H. 2000, A&A, 362, 371
Harries, T. J. 2000, MNRAS, 315, 722
Harrison, F. A., et al. 1999, ApJ, 523, L121
Harrison, R. A., & Lyons, M. 2000, A&A, 358, 1097
Hartigan, P., et al. 2000, AJ, 119, 1872
Hartwick, F. D. A. 2000, AJ, 119, 2248
Harvey, P. M., et al. 2000, ApJ, 534, 846
Hasan, S. S., Kalkofen, W., & Van Ballegooijen, A. A. 2000, ApJ, 535, L67
Hassler, D. M., et al. 1999, Science, 283, 810
Hathaway, D. H., et al. 2000, Sol. Phys., 193, 299
Hatton, S. 1999, MNRAS, 310, 1128
Hauschildt, P. H., et al. 1999, ApJ, 525, 871
Hawkins, M. R. S. 2000, A&AS, 143, 465
Heacox, W. D. 1999, ApJ, 526, 928
Head, J. W., et al. 1999, Science, 286, 2034
Heap, S. R., et al. 2000, ApJ, 534, 69
Hearty, T., et al. 2000a, A&A, 353, 1044
———. 2000b, A&A, 357, 681
Hebrard, G., et al. 2000, A&A, 354, L79
Hegen, M. L. 1922, LOB, 10, 146
Heiles, C. 2000, AJ, 119, 923
Heinamaki, P., et al. 1999, MNRAS, 310, 811
Heinz, S., & Begelman, M. C. 1999, ApJ, 527, L35
———. 2000, ApJ, 535, 104
Heisler, C. A., & De Robertis, M. M. 1999, AJ, 118, 2038
Heithausen, A. 1999, A&A, 349, L53
Hellier, C., et al. 2000, MNRAS, 313, 703
Helmi, A., et al. 1999, Nature, 402, 53
Henriksen, M., et al. 2000, ApJ, 529, 692
Henry, G. W., Baliunas, S. L., Donahue, R. A., Fekel, F. C.. & Soon, W. 2000b, ApJ, 531, 415
Henry, G. W., Marcy, G. W., Butler, R. P, Vogt, S. S. 2000a, ApJ, 529, L41
Henry, J. P. 2000, ApJ, 534, 565
Herald, J. E., Schulte-Ladbeck, R. E., Eenens, P. R. J., & Morris, P. 2000, ApJS, 126, 469
Herczeg, T. J., & Maloney, M. T. 1999, J. AAVSO, 27, 22
Hernandez, I. G., & Patron, J. 2000, Sol. Phys., 191, 37
Hernandez, I. G., et al. 2000, ApJ, 535, 454
Herrero, A., et al. 2000, A&A, 354, 193
Herwig, F., et al. 1999, A&A, 349, L5
Hess, R. 1924, in Seeliger Festschrift, ed. H. Kienle (Berlin: Springer), 262
Hettlage, C., Mannheim, K., & Learned, J. G. 2000, Astropart. Phys., 13, 45
Hibbard, J. E., et al. 2000, AJ, 119, 1130
Hidalgo, M. A., et al. 2000, Sol. Phys., 194, 165
Higgins, S. W., et al. 1999, MNRAS, 309, 273
Hillenbrand, L. A., & Carpenter, J. M. 2000, ApJ, 540, 236
Hirth, W., & Krüger, A. 2000, A&A, 354, 365
Hirzberger, J., et al. 1999, ApJ, 527, 405
Hjorth, J., et al. 2000, ApJ, 534, L147
Hobbs, L. M., et al. 1982, ApJ, 252, L17
Hockey, T. 1999, Galileo’s Planet, Inst. of Physics Publishing
Hodge, P. 1986, PASP, 98, 1113
———. 2000, PASP, 112, 1005
Hodgkin, S. T., et al. 2000, Nature, 403, 57
Hoekzema, N. M., & Brandt, P. N. 2000, A&A, 353, 389
Hoffman, N. 2000, Icarus, 146, 326
Høg, E., et al. 2000, A&A, 355, L27
Holden, B. P., et al. 1999, AJ, 118, 2002
Hollis, J. M., & Koupelis, T. 2000, ApJ, 528, 418
Hollweg, J. V. 2000a, J. Geophys. Res., 104, 24781
———. 2000b, J. Geophys. Res., 104, 24793
———. 2000c, J. Geophys. Res., 105, 15699
Holmberg, E. 1969, Ark. Astron., 5, 305
Holmberg, J., & Flynn, C. 2000, MNRAS, 313, 209
Holmes, A. 1978, Principles of Physical Geology (3d ed.: New York: Wiley)
Holmlid, L. 2000, A&A, 358, 276
Holzwarth, V., & Schuessler, M. 2000, Astron. Nachr., 321, 175
Hori, K., et al. 2000, ApJ, 533, 557
Howe, R., Komm, R., & Hill, F. 1999, ApJ, 524, 1084
Howell, J. H., et al. 2000, AJ, 119, 1259
Howk, J. C., & Savage, B. D. 2000, AJ, 119, 644
Hoyle, F., & Wickramasinghe, D. T., eds. 1999, Ap&SS, 268, Nos. 1/3
Hoyle, F., et al. 1999, MNRAS, 309, 659
Hozumi, S., et al. 2000, MNRAS, 311, 377
Hrivnak, B. J., et al. 1999, ApJ, 524, 849
Hu, W. 2000, ApJ, 529, 12
Hu, W., & Peebles, P. J. E. 2000, ApJ, 528, L61
Hu, W., et al. 2000, Phys. Rev. Lett., 85, 1158
Hu, Y. Q., Habbal, S. R., & Li, X. 1999, J. Geophys. Res., 104, 24819
Hua, X.-M., et al. 2000, ApJ, 531, 1081

Huang, Y. F., et al. 2000, A&A, 355, L43
Hubrig, S., et al. 2000, A&A, 355, 1031
Hudson, H. S. 2000, ApJ, 531, L75
Hughes, D. H., et al. 2000a, MNRAS, 316, 204
Hughes, D. W. 2000, MNRAS, 317, 429
Hughes, D. W., & Williams, I. P. 2000, MNRAS, 315, 629
Hughes, J., & Wallerstein, G. 2000, AJ, 119, 1225
Hughes, J. P. 1999, ApJ, 527, 298
Hughes, J. P., et al. 2000, ApJ, 528, L109
Hunter, D. A., et al. 2000, AJ, 119, 668
Hurlburt, N. E., & Rucklidge, A. M. 2000, MNRAS, 314, 793
Hurley, K., et al. 2000, ApJ, 534, L23
Hutchings, J. B., & Balogh, M. L. 2000, AJ, 119, 1123
Hwang, U., et al. 2000a, ApJ, 532, 970
———. 2000b, ApJ, 537, L119
Hydei, W. J. 2000, Nature, 405, 425
Ibata, R. A., et al. 1999, ApJ, 524, L95
Ibata, R., et al. 2000, ApJ, 532, L41
Iben, I., & Renzini, A. 1983, ARA&A, 21, 271
Ida, S., et al. 2000a, ApJ, 528, 351
———. 2000b, ApJ, 534, 428
Ideta, M., et al. 2000, MNRAS, 311, 733
Igumenschchev, I. V. 2000, MNRAS, 314, 54
Ikhsanov, N. R. 2000, A&A, 358, 201
Ikoma, M. 2000, ApJ, 537, 1013
Imanishi, M., & Ueno, S. 1999, ApJ, 527, 709
Indebetouw, R., & Zweibel, E. G. 2000, ApJ, 532, 361
Ingersoll, A. P., et al. 2000, Nature, 403, 630
Innanen, K. A., et al. 1982, ApJ, 254, 515
Inoue, K. T., et al. 2000, MNRAS, 314, L21
In't Zand, J. J. M. 2000, A&A, 355, 145
Ireland, J. Wills-Davey, M., & Walsh, R. W. 1999, Sol. Phys., 190, 207
Irion, R. 1999, Science, 287, 62
Irwin, J. A., et al. 2000, AJ, 119, 1592
Isenberg, P. A., Martin, L. M., & Hollweg, J. V. 2000, Sol. Phys., 193, 247
Isern, J., et al. 2000, ApJ, 528, 397
Ishii, T., et al. 2000, PASJ, 52, 337
Israelian, G., et al. 1999, Nature, 401, 142
———. 2000, MNRAS, 316, 407
Ivison, R. J., et al. 2000, MNRAS, 315, 209
Iwasawa, K., et al. 2000, MNRAS, 313, 515
Iwata, I., et al. 1999, PASJ, 51, 653
Jackson, A. 2000, Nature, 405, 1003
Jacobson, T. 1999, Phys. Rev. Lett., 83, 2699
Jahan-Miri, M. 2000, ApJ, 532, 514
Jaffe, A. 2000, Nature, 405, 319 & 383 (quoted)
James, K. 1611, Genesis XXVII, 22
Janiuk, A., et al. 2000, MNRAS, 314, 364
Janka, H.-T., et al. 1999, ApJ, 527, L39
Janot, P. 2000, Nature, 407, 118 (quoted)
Janvier, P. 1999, Nature, 402, 21
Jaroszynski, M. 2000, Acta Astron., 50, 67
Jayawardhana, R., et al. 2000, ApJ, 536, 425
Jedamzik, K. 2000, Phys. Rev. Lett., 84, 3248
Jenniskens, P., & Betlem, H. 2000, ApJ, 531, 1161
Jerjen, H., et al. 2000, AJ, 119, 166
Jernigan, J. G., et al. 2000, ApJ, 530, 875
Jetsu, L., & Pelt, J. 2000, A&A, 353, 409
Jetsu, L., et al. 1999, A&A, 351, 212
Jeyakumar, S., & Saikia, D. J. 2000, MNRAS, 311, 397
Jha, S., et al. 1999, ApJS, 125, 73
———. 2000, ApJ, 540, L45
Ji, L., et al. 2000, A&A, 355, 922
Jiang, Y., & Wang, J. 2000, A&A, 356, 1055
Jimenez-Vincente, J., & Battaner, E. 2000, A&A, 358, 812
Joergens, V., et al. 2000, A&A, 356, L33
Joffre, M., et al. 2000, ApJ, 534, L131
Johnson, K. E., & Conti, P. S. 2000, AJ, 119, 2146
Johnston, K. V., et al. 1999, AJ, 118, 1719
Jones, A. P., & d'Hendecourt, L. 2000, A&A, 355, 1191
Jones, D. 1999, Nature, 402, 600
Jones, D. L., et al. 2000a, ApJ, 534, 165
Jones, G. H., et al. 2000b, Nature, 404, 574
Jones, L. R., et al. 2000c, MNRAS, 312, 139
Jonker, P. G., et al. 2000, ApJ, 531, 453
Joseph, R. D., & Sanders, D. B. (eds.) 1999, Ap&SS, 261, Nos. 1 and 2
Josselin, E., et al. 2000, A&A, 353, 363
Jourdain de Muizon, M., et al. 1999, A&A, 350, 875
Judge, P. G., & McIntosh, S. W. 1999, Sol. Phys., 190, 331
Jurcevic, J. S., et al. 2000, MNRAS, 313, 868
Kaastra, J. S., et al. 2000, A&A, 354, L83
Kaburaki, O. 2000, ApJ, 531, 210
Kaghashvili, E. K., & Esser, R. 2000, ApJ, 539, 463
Kahler, S. W., McAllister, A. H., & Cane, H. V. 2000, ApJ, 533, 1063
Kaiser, C. R., et al. 2000, A&A, 356, 975
Kalas, P., et al. 2000, ApJ, 530, L133
Kalberla, P. M. W., et al. 1999, A&A, 350, L9
Kalkofen, W., Ulmschneider, P., & Avrett, E. H. 1999, ApJ, 521, L141
Kameno, S., et al. 2000, PASJ, 52, 209
Kaminker, A. D., et al. 2000, A&A, 358, 1
Kane, G. 2000, Science, 289, 527 (quoted)
Kankelborg, C. C., & Longcope, D. 1999, Sol. Phys., 190, 59
Kapteyn, J. 1907, Astron. Nachr, 157, 207
Karachentsev, I. D., et al. 2000a, A&AS, 145, 415
———. 2000b, Astron. Rep., 44, 150
Karlicky, M., et al. 2000, A&A, 353, 729
Kaspi, S., et al. 2000a, ApJ, 535, L17
———. 2000b, AJ, 119, 2031
Kaspi, V. M., et al. 1999, ApJ, 525, L33
Katajainen, S., et al. 2000, A&AS, 143, 357
Kauffmann, G., & Haehnelt, M. 2000, MNRAS, 311, 576
Kaup, D. J. 1968, Phys. Rev., 172, 1331
Kawabata, K. S., et al. 2000, ApJ, 540, 429
Kawaguchi, T., et al. 2000, PASJ, 52, L1
Kawai, A., et al. 2000, PASJ, 52, 659
Kawano, H., Russell, C. T., & Newbury, J. A. 2000, J. Geophys. Res., 105, 7583
Kawata, D. 1999, PASJ, 51, 931
Kay, S. T., et al. 2000, MNRAS, 316, 374
Kaye, A. B., et al. 1999, MNRAS, 308, 1081
Keel, W. C., et al. 1999, AJ, 118, 2547
Keilty, K. A., et al. 2000, ApJ, 538, 645
Kennicutt, R., et al. 2000, ApJ, 537, 589
Kenyon, S. J., & Luu, J. X. 1999, ApJ, 526, 465
Kepler, S. O., et al. 2000, ApJ, 534, L185
Kerber, F., et al. 1999, A&A, 350, L27
Kerschbaum, F. 1999, A&A, 351, 627
Kewley, L. J., et al. 2000, ApJ, 530, 704
Khan, J. I., & Hudson, H. S. 2000, Geophys. Res. Lett., 27, 1083
Khokhlova, V. L., et al. 2000, Astron. Lett., 26, 177
Khosroshahi, H. G., et al. 2000, ApJ, 531, L103
Kidger, M. R. 2000, AJ, 119, 2053
Kiefer, M., Grabowski, U., Mattig, W., & Stix, M. 2000, A&A, 355, 381
Kieffer, S. W., et al. 2000, Science, 288, 1204
Kikuchi, K., et al. 2000, ApJ, 531, L95
Kilin, C.-D., & Yavuz, I. 2000, Ap&SS, 271, 11
Kim, S., et al. 1999, AJ, 118, 2797
Kim, W.-T., & Ostriker, E. C. 2000, ApJ, 540, 372

King, A. R. 2000, MNRAS, 315, L33
King, A. R., & Wynn, G. A. 1999, MNRAS, 310, 203
Kipper, T. 1999, Baltic Astron., 8, 483
Kirilova, D. P., & Chizhov, M. V. 2000, MNRAS, 314, 256
Kirkpatrick, J. D., et al. 2000, AJ, 120, 447
Kivelson, M. G., et al. 2000, Science, 289, 1340
Klassen, A., et al. 2000, A&AS, 141, 357
Kley, W. 2000, MNRAS, 313, L47
Kliem, B., et al. 2000, A&A, 360, 715
Klimchuk, J. A. 2000, Sol. Phys., 193, 53
Klimchuk, J. A., Antiochos, S. K., & Norton, D. 2000, ApJ, 542, 504
Knapp, G. R., et al. 1999, A&A, 351, 97
Knapp, G. R., et al. 2000, ApJ, 534, 324
Kniazev, A. Yu., et al. 2000, Astron. Lett., 26, 129
Kobayaski, C., et al. 2000, ApJ, 539, 26
Kocharov, L., et al. 2000, A&A, 357, 716
Koda, J., et al. 2000, ApJ, 532, 214
Koehler, E., et al. 2000, A&A, 356, 541
Koen, C., & Laney, D. 2000, MNRAS, 311, 636
Koen, C., & Schumann, R. 1999, MNRAS, 310, 618
Koerner, D. W., et al. 2000, ApJ, 533, L37
Koerner, R. W., et al. 1999, ApJ, 526, L25
Koester, D., & Wolff, B. 2000, A&A, 357, 587
Koide, S., et al. 2000, ApJ, 536, 668
Komm, R. W., Howe, R., & Hill, F. 2000, ApJ, 531, 1094
Kommers, J. M., et al. 2000, ApJ, 533, 696
Konar, S., & Bhattacharya, D. 1999, MNRAS, 308, 795
Konenkov, D., & Geppert, U. 2000, MNRAS, 313, 66
Koopmans, L. V. E., & de Bruyn, A. G. 2000, A&A, 358, 793
Kornreich, P., & Scalo, J. 2000, ApJ, 531, 366
Korotin, S. A., et al. 1999, A&A, 351, 168
Korzennik, S. G., et al. 2000, ApJ, 533, L147
Kosovichev, A. G., & Zharkova, V. V. 1999, Sol. Phys., 190, 459
Kotnik-Karuza, D., & Jurdana-Sepic R. 2000, A&A, 355, 595
Kovtyukh, V. V., & Andrievsky, S. M. 1999, A&A, 350, L55
Kozyra, J., & Webb, D. 1999, SCOSTEP Newsletter 3(1), 1
Kraan-Korteweg, R. C. 2000, A&AS, 141, 123
Krabbe, A., et al. 2000, A&A, 354, 439
Kraft, R. P., et al. 2000, ApJ, 531, L9
Krall, J., Chen, J., & Santoro, R. 2000, ApJ, 539, 964
Krauss, L. M., & Starkman, G. D. 2000, ApJ, 531, 22
Krauss, M. 1992, Language, 68, 1
Krautter, J., et al. 1999, A&A, 350, 743
Kriachichev, L., et al. 2000, Nature, 406, 874
Krisciunas, K., et al. 2000, ApJ, 539, 658
Kriss, G. A., et al. 2000a, ApJ, 535, 58
———. 2000b, ApJ, 538, L17
Krucker, S., & Benz, A. O. 2000, Sol. Phys., 191, 341
Krucker, S., & Lin, R. P. 2000, ApJ, 542, L61
Kruszewski, A., & Semeniuk, I. 1999, Acta Astron., 49, 561
Kuerster, M., et al. 2000, A&A, 353, L33
Kuhn, J. R., et al. 2000, Nature, 405, 544
Kuiper, G. P. 1939, ApJ, 89, 548
Kuiper, L., et al. 2000, A&A, 359, 615
Kumar, B., et al. 2000, Sol. Phys., 191, 293
Kumar, P. 2000, ApJ, 538, L125
Kumar, P., & Piran, T. 2000a, ApJ, 532, 286
———. 2000b, ApJ, 535, 152
Kunkel, W. E., et al. 2000, AJ, 119, 2789
Kupke, R., LaBonte, B. J., & Mickey, D. L. 2000, Sol. Phys., 191, 97
Kurk, J. D., et al. 2000, A&A, 358, L1
Kurki-Suonio, H., & Sihvola, E. 2000, Phys. Rev. Lett., 84, 3756
Kurpiewski, A., & Jaroszynski, M. 2000, Acta Astron., 50, 79
Kurtz, M. J., Eichhorn, G., Accomazzi, A., Grant, C. S., Murray, S. S., & Watson, J. M. 2000, A&AS, 143, 41
Kuulkers, E., et al. 2000, ApJ, 538, 638
Kuzanyan, K., Bao, S., & Zhang, H. 2000, Sol. Phys., 191, 231
Kuzmin, A. D., & Losovsky, B. Ya. 2000, Astron. Lett., 26, 500
Lahav, O., et al. 2000a, MNRAS, 312, 166
———. 2000b, MNRAS, 315, L45
Lai, D., et al. 1999, ApJ, 524, 1030
Lai, S.-P., & Crutcher, R. M. 2000, ApJS, 128, 271
Laitinen, T., et al. 2000, A&A, 360, 729
Lanari, R. 1999, Science, 287, 37 (quoted)
Lane, W. M., et al. 2000, ApJ, 532, 146
Lanzafame, G., et al. 2000, PASJ, 52, 515
Lara, L., et al. 1999, A&A, 352, 443
Laskar, J. 2000, Phys. Rev. Lett., 84, 3240
Lasserre, T., et al. 2000, A&A, 355, L39
Lastennet, E., et al. 1999, A&A, 349, 485
Laughlin, G., & Adams, F. C. 1999, ApJ, 526, 881
Laurent-Muehleisen, S. A., et al. 1999, ApJ, 525, 127
Lawrence, S. S., et al. 2000, ApJ, 537, L123
Lazarian, A., & Pogosyan, D. 2000, ApJ, 537, 720
Lazzaro, D., et al. 2000, Science, 288, 2037
Leahy, D. A., et al. 2000, ApJ, 540, 442
Leamon, R. J., et al. 2000, ApJ, 537, 1054
LeBlanc, A. G., et al. 2000, MNRAS, 313, L9
Lebzelter, T., & Hron, J. 1999, A&A, 351, 533
Lee, C. W., et al. 1999a, ApJ, 526, 788
Lee, C. Y., & Wang, H. 2000, Sol. Phys., 195, 149
Lee, D., & Allington-Smith, J. R. 2000, MNRAS, 312, 57
Lee, H., et al. 2000a, ApJ, 530, L17
Lee, H. K., et al. 2000b, ApJ, 536, 416
Lee, J.-K., & Burton, M. G. 2000, MNRAS, 315, 11
Lee, M. A. 2000, J. Geophys. Res., 105, A5, 10491
Lee, M. G., & Kim, E. 2000, AJ, 120, 260
Lee, W. H., & Kluzniak, W. L. 1999, MNRAS, 308, 780
Lee, Y.-W., et al. 1999b, Nature, 402, 55
Le Fevre, O., et al. 2000, MNRAS, 311, 565
Leggett, S., et al. 2000, ApJ, 536, L35
Lehmann, H., et al. 1999, A&A, 351, 267
Lehmann, I., et al. 2000, A&A, 354, 35
Lehner, N., et al. 1999, A&A, 352, 257
———. 2000, MNRAS, 314, 199
Leinert, C., et al. 2000, A&A, 353, 691
Leinhardt, Z. M., et al. 2000, Icarus, 146, 133
Lemoine, M., et al. 1999, NewA, 4, 231
Lenz, D. D., et al. 1999, Sol. Phys., 190, 131
Lenz, D. D. 2000, Sol. Phys., 193, 131
Leon, S., et al. 2000, A&A, 359, 907
Leone, F., et al. 2000, A&A, 355, 315
Lery, T., & Frank, A. 2000, ApJ, 533, 897
Lery, T., et al. 1999, A&A, 350, 254
Levinson, A., & Eichler, D. 2000, Phys. Rev. Lett., 85, 236
Levitos, S., et al. 2000, Science, 28, 2225
Lewis, B. M. 2000, ApJ, 533, 959
Lewis, D. J., & Simnett, G. M. 2000, Sol. Phys., 191, 185
Li, H., et al. 2000a, PASJ, 52, 465
Li, H., et al. 2000b, PASJ, 52, 483
Li, H., et al. 2000c, ApJ, 533, 1023
Li, J., Jewitt, D., & LaBonte, B. 2000d, ApJ, 539, L67
Li, J., & Wilson, G. 1999, ApJ, 527, 910
Li, L.-X. 2000, ApJ, 540, L17
Li, L.-X., & Paczynski, B. 2000, ApJ, 534, L197
Li, X., & Habbal, S. 1999, Sol. Phys., 190, 485
———. 2000, J. Geophys. Res., 105, 7483L

Li, Z.-Y., & Chevalier, R. A. 1999, ApJ, 526, 716
Liebert, J., et al. 2000, ApJ, 533, L155
Lieu, R., et al. 1999, ApJ, 527, L77
Lin, H., & Casini, R. 2000, ApJ, 542, 528
Lin, H., Penn, M. J., & Tomczyk, S. 2000, ApJ, 541, L83
Lin, J., & Forbes, T. G. 2000, J. Geophys. Res., 105, A2, 2375
Lin, W.-B., & Chu, Y.-Q. 1998, Ap&SS, 262, 15
Lindqvist, M., et al. 1999, A&A, 351, L1
Linsky, J. L., et al. 2000, ApJ, 528, 756
Liszka, L., et al. 2000, ApJ, 540, 122
Lites, B. W., et al. 1999, Sol. Phys., 190, 185
Litvinenko, Y. E. 1999, ApJ, 515, 435
———. 2000, Sol. Phys., 194, 327
Litvinenko, Y. E., & Martin, S. F. 1999, Sol. Phys., 190, 45
Liu, B. F., et al. 1999, ApJ, 527, L17
Liu, Q., & Yang, Y. 2000, A&AS, 142, 31
Livio, M., & Waxman, E. 2000, ApJ, 538, 187
Lloyd, N. M., et al. 2000, ApJ, 534, 227
Lockwood, J. A., Debrunner, H., & Ryan, J. M. 1999, Astropart. Phys,, 12, 97
Loeb, A., & Waxman, E. 2000, Nature, 405, 156
Loinard, L., et al. 1999, A&A, 351, 1087
Longcope, D. W., & Kankelborg, C. C. 1999, ApJ, 524, 483
Looney, L. W., et al. 2000, ApJ, 529, 477
Lopez, J. A., et al. 2000, ApJ, 538, 233
Lopez-Corredoira, M., et al. 1999, A&A, 351, 920
———. 2000, MNRAS, 313, 392
Lothian, R. M., & Browning, P. K. 2000, Sol. Phys., 194, 205
Lou, Y. 2000, ApJ, 540, 1102
Lozitsky, V. G., et al. 2000, Sol. Phys., 191, 171
Lu, Y., & Yu, Q. 1999, ApJ, 526, L5
Lubow, S. H., et al. 1999, ApJ, 526, 1001
Lubowicz, D. A., et al. 2000, Nature, 405, 1025
Lucas, P. W., & Roche, P. F. 2000, MNRAS, 314, 858
Lucek, S. G., & Bell, A. R. 2000, MNRAS, 314, 65
Lucy, L. B. 1968, ApJ, 151, 1123
Lugaro, M., et al. 1999, ApJ, 527, 369
Lundberg, B. 2000, Nature, 406, 334 (quoted)
Luttermoser, D. G. 2000, ApJ, 536, 923
Lutz, D., et al. 2000, ApJ, 536, 697
Luu, J. X., et al. 2000, ApJ, 531, L151
Lyne, A. G., et al. 2000a, MNRAS, 312, 698
———. 2000b, MNRAS, 315, 534
Lyubarskii, Y. E., & Petrova, S. A. 1998, Ap&SS, 262, 379
Ma, E. 1999, Phys. Rev. Lett., 83, 2514
Macfadyen, A. I., & Woosley, S. E. 1999, ApJ, 524, 262
MacKay, D. H., et al. 2000, Sol. Phys., 193, 93
Mac Low, M.-M. 1999, ApJ, 524, 169
MacQueen, R. M., et al. 2000, Sol. Phys., 191, 85
Mader, S. L., et al. 1999, MNRAS, 310, 331
Madejski, G., et al. 2000, ApJ, 535, L87
Magara, T., & Kitai, R. 1999, ApJ, 524, 469
Magara, T., et al. 2000, ApJ, 538, L175
Magliocchetti, M., et al. 2000, MNRAS, 314, 546
Magorrian, J., & Tremaine, S. 1999, MNRAS, 309, 447
Magrini, L., et al. 2000, A&A, 355, 713
Maia, D., et al. 2000, ApJ, 528, L49
Maiolino, R., et al. 2000, A&A, 355, L47
Majewski, S. R., et al. 2000, AJ, 119, 760
Makarov, V. V., & Fabricius, C. 1999, A&A, 349, L34
Makarov, V. V., & Urban, S. 2000, MNRAS, 317, 289
Makinen, J. T. T., et al. 2000, Nature, 405, 321
Makishima, K., et al. 1999, ApJ, 525, 978
———. 2000, ApJ, 535, 632
Makita, M., et al. 2000, MNRAS, 316, 906
Malin, M. C., & Edgett, K. S. 2000, Science, 288, 2230
Maller, A. H., et al. 2000, ApJ, 533, 194
Malov, I. F. 1999, Astron. Rep., 43, 727
Mancuso, S., & Spangler, S. R. 2000, ApJ, 539, 480
Mandrini, C. H., Démoulin, P., & Klimchuk, J. A. 2000, ApJ, 530, 999
Manmoto, T. 2000a, ApJ, 534, 734
Manmoto, T., et al. 2000, ApJ, 529, 127
Manoharan, P. K., et al. 2000, ApJ, 530, 1061
Marchenkov, K., Roxburgh, I., & Vorontsov, S. 2000, MNRAS, 312, 39
Marchis, F., et al. 1999, A&A, 349, 985
Marconi, A., et al. 2000a, A&A, 357, 24
Marconi, M., et al. 2000b, A&A, 355, L35
Marcy, G. W., & Butler, R. P. 2000, PASP, 112, 137
Marcy, G. W., et al. 2000, ApJ, 536, L43
Margoniner, V. E., & de Carvallho, R. R. 2000, AJ, 119, 1562
Markiel, J. A., & Thomas, J. H. 1999, ApJ, 523, 827
Marsch, E., Tu, C. Y., & Wilhelm,.K. 2000, A&A, 359, 381
Martens, P. H. C., Kankelborg, C. C., & Berger, T. E. 2000, ApJ, 537, 471
Martin, E. L., et al. 1999, AJ, 118, 2466
Martinelli, A., & Matteucci, F. 2000, A&A, 353, 269
Martinez-Pais, I. G., et al. 2000, ApJ, 538, 315
Martocchia, A., et al. 2000, MNRAS, 312, 817
Maslov, A. I. 2000, Astron. Lett., 26, 428
Masreliez, C. J. 2000, Ap&SS, 266, 399
Massa, C. 2000, Ap&SS, 271, 83
Massey, P., et al. 2000, NewA, 5, 25
Massi, F., et al. 2000, A&A, 353, 598
Masson, C. R. 1989, ApJ, 336, 294
Masuda, S., Kosugi, T., Hara, H., Tsuneta, S., & Ogawara, Y. 1994, Nature, 371, 495
Mateos, I. M., & Palle, P. L. 1999, Sol. Phys., 189, 241
Mathur, S. 2000, MNRAS, 314, L17
Matthaeus, W. M., et al. 1999, ApJ, 523, L93
Matthews, L. D., et al. 1999, AJ, 118, 2751
Maurogordato, S., et al. 2000, A&A, 355, 848
Mauron, N., & Huggins, P. J. 1999, A&A, 349, 203
Mauskofp, P. D., et al. 2000, ApJ, 536, L59
Mavromichalaki, H., Vassilaki, A., & Tsagouri, I. 1999, Sol. Phys., 189, 199
Maxted, P. F. L. et al. 2000, MNRAS, 314, 334
Mazeh, T., et al. 2000, ApJ, 532, L55
Mazur, J. E., et al. 2000, ApJ, 532, L79
Mazzarello, P. 1999, Nature, 402, 237
McBreen, B., & Hanlon, L. 1999, A&A, 351, 759
McClure-Griffiths, N. M. 2000, AJ, 119, 2828
McCrea, W. H. 1964, MNRAS, 128, 147
McDonald, J. 2000, Phys. Rev. Lett., 84, 4798
McEwen, A. S., et al. 2000, Science, 288, 1193
McGaugh, S. S. 1999, ApJ, 523, L99
McGaugh, S. S., et al. 2000, ApJ, 533, L99
McKeegan, K. D., et al. 2000, Science, 289, 1334
McKenzie, D. E. 2000, Sol. Phys., 195, 381
McKenzie, D. E., & Hudson, H. S. 1999, ApJ, 519, L93
McKenzie, J. F., & Axford, W. I. 2000a, Sol. Phys., 193, 153
———. 2000b, ApJ, 537, 516
McKinnon, M. M., & Stinebring, D. R. 2000, ApJ, 529, 435
McLean, I. S., et al. 2000, ApJ, 533, L45
McMahon, R. G., et al. 1999, MNRAS, 309, L1
McNamara, B. R., et al. 2000, ApJ, 534, L135
Medrek, M., & Murawski, K. 2000, ApJ, 529, 548

Meibon, A., et al. 2000, Science, 288, 839
Melatos, A. 2000, MNRAS, 313, 217
Melchior, A.-L., et al. 2000a, MNRAS, 312, L29
———. 2000b, A&AS, 145, 11
Melchiorri, A., et al. 1999, Phys. Rev. Lett., 83, 4464
———. 2000, ApJ, 536, L63
Mendez, R. A., & Minniti, D. 2000, ApJ, 529, 911
Mendez, R. A., et al. 1999, ApJ, 524, L39
Menou, K., et al. 2000, MNRAS, 314, 498
Merchan Benitez, P., & Jurado Vargas, M. 2000, A&A, 353, 264
Merline, W. J., et al. 1999, Nature, 401, 565
Merrifield, M. R., et al. 2000, MNRAS, 313, L29
Merrill, P. W. 1934, PASP, 46, 206
Messenger, S. 2000, Nature, 404, 968
Messmer, P., & Benz, A. O. 2000, A&A, 354, 287
Mestel, L. 1963, MNRAS, 126, 553
Meszaros, A., et al. 2000, ApJ, 539, 98
Meszaros, P., & Rees, M. J. 1997, ApJ, 476, 232
———. 2000, ApJ, 530, 292
Meszaros, P., et al. 1999, NewA, 4, 303
Meszarosova, H., et al. 2000, A&A, 360, 1126
Metevier, A. J., et al. 2000, AJ, 119, 1090
Meunier, N. 1999, ApJ, 527, 967
Meyer, B. S., et al. 2000a, ApJ, 540, L49
Meyer, F., et al. 2000b, A&A, 354, L67
Michalak, G. 2000, A&A, 360, 366
Middleditch, J., et al. 2000, NewA, 5, 243
Mignard, F. 2000, A&A, 354, 522
Mignard, F., & Froeschle, M. 2000, A&A, 354, 732
Millar, T. J., et al. 2000, MNRAS, 316, 195
Miller, A. D., et al. 1999, ApJ, 524, L1
Miller, J. A., LaRosa, T. N., & Moore, R. L. 1996, ApJ, 461, 445
Miller, M. C. 2000, ApJ, 531, 458
Milone, E. F., et al. 2000, AJ, 119, 1405
Mineshige, S., et al. 2000, PASJ, 52, 499
Minkowski, R. 1947, PASP, 59, 257
Miralda-Escudé, J. 2000a, ApJ, 528, L1
Miralda-Escudé, J., et al. 2000, ApJ, 530, 1
Miroshnichenko, L. I., De Koning, C. A., & Perez-Enriquez, R. 2000, Space Sci. Rev., 91, 615
Mirzoyan, L. V., et al. 1999, Astrofiz., 42, 247
Mishurov, Yu. N. 2000, Astron. Rep., 44, 6
Mitrofanov, I. G., et al. 1999, ApJ, 523, 610
Miyaji, T., et al. 2000, A&A, 353, 25
Miyata, E., & Tsunemi, H. 1999, ApJ, 525, 305
Mochejska, B. J., et al. 2000, AJ, 120, 810
Molendi, S., et al. 1999, ApJ, 525, L73
———. 2000, ApJ, 534, L43
Molinari, S., et al. 2000a, ApJ, 538, 698
———. 2000b, A&A, 355, 617
Molla, M., & Garcia-Vargas, M. L. 2000, A&A, 359, 18
Molla, M., et al. 2000, MNRAS, 316, 345
Monaco, P., Salucci, P., & Danese, L. 2000, MNRAS, 311, 279
Monin, J.-L., & Bouvier, J. 2000, A&A, 356, L75
Monnier, J. D., et al. 1999, ApJ, 525, L97
Montalban, J., & Schatzman, E. 1999, A&A, 351, 347
Montgomery, M. H., et al. 1999, ApJ, 525, 482
Moore, B., et al. 1999a, ApJ, 524, L19
———. 2000, ApJ, 535, L21
Moore, R. L., et al. 1999b, ApJ, 526, 505
Morales, R., et al. 2000, MNRAS, 315, 149
Moran, E. C., et al. 1999, ApJ, 526, 649
Morenis-Insertis, F., & Solanki, S. K. 2000, MNRAS, 313, 411
Moretti, A., et al. 1999, A&AS, 140, 155
Morgan, N. D., et al. 2000, AJ, 119, 1083
Morris, P. W. et al. 1999, Nature, 402, 502
Morrison, H. L., et al. 2000, AJ, 119, 2254
Moskalenko, I., & Strong, A. W. 2000, ApJ, 528, 357
Moss, D., & Brooke, J. 2000, MNRAS, 315, 521
Mould, J. R., et al. 2000, ApJ, 529, 786
Muecke, A., & Pohl, M. 2000, MNRAS, 312, 177
Muench, A. A., et al. 2000, ApJ, 533, 358
Muller, C. A., Oort, J. H., & Raimond, E. 1963, CR Acad. Sci. Paris, 257, 1661
Müller, R., et al. 2000, A&A, 359, 373
Munch, G., & Unsold, A. 1962, ApJ, 135, 711
Munyaneza, F., et al. 1999, ApJ, 526, 744
Murali, C., et al. 2000, MNRAS, 313, 87
Murawski, K. 2000a, ApJ, 537, 495
———. 2000b, A&A, 358, 343
———. 2000c, A&A, 360, 707
Murawski, K., & Diethelm, K. 2000, A&A, 358, 753
Murawski, K., & Pelinovsky, E. N. 2000, A&A, 359, 759
Murayama, T., et al. 2000, AJ, 119, 1691
Murdin, P. M. 1994, MNRAS, 269, 89
Murphy, E. M., et al. 2000, ApJ, 538, L35
Murphy, T. W., et al. 1999, ApJ, 525, L85
Murray, J. B. 1999, MNRAS, 309, 31
Mushotzky, R. F., et al. 2000, Nature, 404, 459
Muthu, C., et al. 2000, A&A, 355, 1098
Myers, N., et al. 2000, Nature, 403, 853
Myers, P. C. 2000, ApJ, 530, L119
Nahar, S. N., et al. 2000, A&AS, 144, 141
Nakamura, R., et al. 2000, PASJ, 52, 551
Nakamura, T. 2000, ApJ, 534, L159
Nakano, T., et al. 2000, ApJ, 534, 976
Nakariakov, V. M., Ofman, L., & Arber, T. D. 2000, A&A, 353, 741
Nakariakov, V. M., et al. 1999, Science, 285, 862
Nakashima, J., et al. 2000, PASJ, 52, 275
Nakata, F., et al. 1999, MNRAS, 309, L25
Nakazawa, A., et al. 2000, PASJ, 52, 623
Napiwotzki, R. 1999, A&A, 350, 101
Naslund, M., et al. 2000, A&A, 356, 435
Natarajan, P., & Armitage, P. J. 1999, MNRAS, 309, 961
Navia, A. A. 2000, Science, 288, 2133
Nayeri, A., et al. 1999, ApJ, 525, 10
Naylor, R. J., et al. 2000, Nature, 405, 1017
Neff, S. G., & Ulvestad, J. S. 2000, AJ, 120, 670
Negi, P. S., & Durgapal, M. C. 2000, A&A, 353, 641
Nelemans, G., et al. 1999, A&A, 352, L87
Nelson, A. F. 2000, ApJ, 537, L65
Ness, J.-U., & Schmitt, J. H. M. M. 2000, A&A, 355, 394
Nesvorný, D., et al. 2000, AJ, 119, 953
Neugebauer, M., et al. 2000, J. Geophys. Res., 105, 2315
Neuhauser, R., et al. 2000, A&A, 354, L9
Nicastro, F., et al. 2000, ApJ, 536, 718
Nightingale, R. W., Aschwanden, M., J., & Hurlburt, N. E. 1999, Sol. Phys., 190, 249
Nindos, A., et al. 2000, ApJ, 533, 1053
Nishi, R., & Susa, H. 1999, ApJ, 523, L103
Nishi, R., & Tashiro, M. 2000, ApJ, 537, 50
Nishida, S., et al. 2000, MNRAS, 313, 136
Nitta, N., & Akiyama, S. 1999, ApJ, 525, L57
Nitta, N., et al. 1999, Sol. Phys., 189, 181
Noll, K. S., et al. 2000, AJ, 119, 970
Nomura, H., & Mineshige, S. 2000, ApJ, 536, 429
Norberg, P., & Maeder, A. 2000, A&A, 359, 1025
Norris, J. P., et al. 2000, ApJ, 534, 248
Norton, A. A., & Ulrich, R. K. 2000, Sol. Phys., 192, 403
Novosyadlyj, B., et al. 2000, A&A, 356, 418
Nucamendi, U., et al. 2000, Phys. Rev. Lett., 84, 3037
Nugis, T., & Lamers, H. J. G. L. M. 2000, A&A, 360, 227

Oberhummer, H., et al. 2000, Science, 289, 88
O'Connor, J. A., et al. 2000, ApJ, 531, 336
O'Dell, C. R. 2000, AJ, 119, 2311
Ofman, L., Nakariakov, V. M., & DeForest, C. E. 1999, ApJ, 514, 441
Ofman, L., et al. 2000a, ApJ, 529, 529
———. 2000b, ApJ, 533, 1071
Ogle, P. M., et al. 1999, ApJS, 125, 1
Oh, K. S., et al. 2000, ApJ, 531, 727
Oka, T., et al. 1999, ApJ, 526, 764
Oliva, E., et al. 1999, A&A, 350, 9
Oliver, R., et al. 1999, A&A, 351, 733
Oliver, S., et al. 2000, MNRAS, 316, 749
Ollivier, J. L., et al. 2000, A&A, 356, 347
Oluseyi, et al. H. M. 1999, ApJ, 527, 992
O'Neil, K., & Bothun, G. 2000, ApJ, 529, 811
Oort, J. H. 1927, Bull. Astron. Netherlands, 3, 275
———. 1928, Bull. Astron. Netherlands, 4, 269
Opher, M., & Opher, R. 2000, ApJ, 535, 473
Opik, E. J. 1953, Irish Astron. J., 2, 219
Ori, A. 1999, Phys. Rev. Lett., 83, 5423
Orsatti, A. M., et al. 2000, A&AS, 144, 195
Ortiz, J. L., et al. 2000, Nature, 405, 921
O'Shea, E., et al. 2000, A&A, 358, 741
Ossendrijver, M. A. 2000a, A&A, 359, 1205
Ossendrijver, M. A. 2000b, A&A, 359, 364
Ostriker, J. P. 2000, Phys. Rev. Lett., 84, 5258
Ostro, S. J., et al. 2000, Science, 288, 836
Overbeck, J. W. 1965, ApJ, 141, 864
Owen, T., et al. 1999, Nature, 402, 269
Paczynski, B. 1970, Acta Astron., 20, 47
Paczynski, B., & Pindor, B. 2000, ApJ, 533, L103
Padoan, P., et al. 1999, ApJ, 525, 318
Paesold, G., & Benz, A. O. 1999, A&A, 351, 741
Page, M. J., et al. 2000, MNRAS, 312, 207
Palumbo, M. E., et al. 2000, ApJ, 534, 801
Pancino, E., et al. 2000, ApJ, 534, L83
Panei, J. A., et al. 2000, MNRAS, 312, 531
Papaderos, P., et al. 1999, A&A, 352, L57
Papadopoulos, P. P., & Allen, M. L. 2000, ApJ, 537, 631
Papadopoulos, P. P., et al. 2000, ApJ, 528, 626
Papaloizou, J. C. B., & Larwood, J. D. 2000, MNRAS, 315, 823
Pappa, A., et al. 2000, MNRAS, 314, 589
Parades, J. M., et al. Science, 288, 2340
Park, M.-G., & Ostriker, J. P. 1999, ApJ, 527, 247
Parker, E. N. 1972, ApJ, 174, 499
———. 1988, ApJ, 330, 474
Parker, E. N., & Jokipii, J. R. 2000, ApJ, 536, 331
Parnell, C. E., & Jupp, P. E. 2000, ApJ, 529, 554
Parthasarathy, M., et al. 2000, A&A, 355, 221
Pasquali, A., et al. 2000, AJ, 119, 1352
Patsis, P. A., & Kaufmann, D. E. 1999, A&A, 352, 469
Patsourakos, S., et al. 1999, ApJ, 522, 540
Patterson, J., et al. 2000, PASP, 112, 625
Patton, D. R., et al. 2000, ApJ, 536, 153
Pavlenko, Y. V., & Yakovina, L. A. 2000, Astron. Rep., 44, 209
Pavlenko, Y., et al. 2000, A&A, 355, 245
Pavlov, G. G., et al. 2000, ApJ, 531, L53
Peck, A. B., & Taylor, G. B. 2000, ApJ, 534, 90
Pecseli, H., & Engvold, O. 2000, Sol. Phys., 194, 73
Peebles, P. J. E. 2000, ApJ, 534, L127
Peebles, P. J. E., et al. 2000, ApJ, 539, L1
Pellegrini, S. 1999, A&A, 351, 487
Pellegrini, S., et al. 2000, A&A, 353, 447
Peng, C. Y., et al. 1999, ApJ, 524, 572
Percival, W., & Miller, L. 1999, MNRAS, 309, 823
Pereira, M. G., et al. 1999, ApJ, 526, L105
Peres, G. 2000, Sol. Phys., 193, 33
Pereyra, N. A., et al. 2000, ApJ, 532, 563
Petersen, J. O., & Christensen-Dalsgaard, J. 1999, A&A, 352, 547
Peterson, J. B., et al. 2000, ApJ, 532, L83
Petrosian, V., & Donaghy, T. Q. 1999, ApJ, 527, 945
Pevtsov, A. A. 2000, ApJ, 531, 553
Pevtsov, A. A., & Latushko, S. M. 2000, ApJ, 528, 999
Phillips, J. P. 2000a, A&A, 358, 1049
Phillips, J. P. 2000b, AJ, 119, 2332
Phillips, M. M., et al. 1999, AJ, 118, 1766
Pian, E., et al. 2000, ApJ, 536, 778
Pickett, B. K., et al. 2000, ApJ, 529, 1034
Pierce, M. J., & Berrington, R. C. 2000, ApJ, 531, L99
Pietrini, P., & Krolik, J. H. 2000, ApJ, 539, 216
Pietrzynski, G., et al. 1999, Acta Astron., 49, 521
Pietsch, W., et al. 2000, A&A, 360, 24
Pilachowski, C. A., et al. 2000, AJ, 119, 2895
Pilyugin, L. S., & Ferrini, F. 2000, A&A, 358, 72
Piner, B. G., et al. 2000, ApJ, 537, 91
Piran, T. 1999, Phys. Rep., 314, 575
Pitman, K. M., et al. 2000, PASP, 112, 537
Plana, H., et al. 2000, AJ, 120, 621
Ploner, S. R. O., Solanki, S. K., & Gadun, A. S. 1999, A&A, 352, 679
Ploner, S. R. O., Solanki, S. K., & Gadun, A. S. 2000, A&A, 356, 1050
Plunkett, S. P., et al. 2000, Sol. Phys., 194, 371
Poeppel, W. G. L., & Marronetti, P. 2000, A&A, 358, 299
Pogge, R. W., et al. 2000, ApJ, 532, 323
Pohjolainen, S. 2000, A&A, 361, 349
Pohjolainen, S., Portier-Fozzani, F., & Ragaigne, D. 2000, A&AS, 143, 227
Pohlen, M., et al. 2000, A&A, 357, L1
Pojmanski, G. 2000, Acta Astron., 50, 177
Polosukhina, N., et al. 1999, A&A, 351, 283
Popescu, C. C., et al. 1999, A&A, 350, 414
Popov, S. B., et al. 2000, ApJ, 530, 896
Popper, D. M. 2000, AJ, 119, 2391
Posch, T., et al. 1999, A&A, 352, 609
Possenti, A., et al. 1999, ApJS, 125, 463
Pourbaix, D., et al. 2000, A&AS, 145, 215
Predehl, P., et al. 2000, A&A, 357, L25
Preece, R. D., Briggs, M. S., Mallozzi, R. S., Pendleton, G. N., Paciesas, W. S., & Band, D. L. 2000, ApJS, 126, 19
Preston, G. 2000, PASP, 112, 141
Preston, G. W., & Landolt, A. U. 1999, AJ, 118, 3006
Preston, G. W., & Sneden, C. 2000, AJ, 120, 1014
Price, R. J., et al. 2000, MNRAS, 312, L43
Priest, E. R., & Forbes, T. 2000, Magnetic Reconnection (Cambridge: Cambridge Univ. Press)
Priest, E. R., et al. 2000, ApJ, 539, 1002
Pringle, J. E., & Rees, M. J. 1972, A&A, 21, 1
Pritzl, B., et al. 2000, ApJ, 530, L41
Prochaska, J. X., & Wolfe, A. M. 2000, ApJ, 533, L5
Proust, D., et al. 2000, A&A, 355, 443
Provost, J., Berthomieu, G., & Morel, P. 2000, A&A, 353, 775
Przybilla, N., et al. 2000, A&A, 359, 1085
Puerari, I., et al. 2000, A&A, 359, 932
Pulido, J., & Akhmedov, E. Kh. 2000, Astropart. Phys., 13, 227
Qian, S. J., et al. 2000, A&A, 357, 84
Qiu, H. Y., Esser, R., & Habbal, S. R. 2000a, J. Geophys. Res., 105, 5093
Qiu, J., et al. 2000b, Sol. Phys., 194, 269
Quataert, E., & Narayan, R. 2000, ApJ, 528, 236
Quateart, E., et al. 1999, ApJ, 525, L89

Queloz, D., et al. 2000a, A&A, 354, 99
———. 2000b, A&A, 359, L13
Quilis, V., et al. 2000, Science, 288, 1617
Quillen, A. C., & Holman, M. 2000, AJ, 119, 397
Quillen, A. C., et al. 1999, ApJ, 527, 696
———. 2000, ApJS, 128, 85
Rabello-Soares, M. C., et al. 1999, A&A, 350, 672
Rabinowitz, D., et al. 2000, Nature, 403, 165
Rabinowitz, M. 1998, Ap&SS, 262, 391
Rafferty, T. J., & Holdenried, E. R. 2000, A&AS, 141, 423
Ragazzoni, R., et al. 2000, Nature, 403, 54
Raines, S. N., et al. 2000, ApJ, 528, L115
Ramaty, R., & Mandzhavidze, N. 2000, in IAU Symp. 195, Highly Energetic Physical Processes and Mechanisms for Emission from Astrophysical Plasmas (San Francisco: ASP), 123
Ramaty, R., Tatischeff, V., Thibaud, J. P., Kozlovsky, B., & Mandzhavidze, N. 2000, ApJ, 534, L207
Ramesh, R. 1999, Sol. Phys., 189, 85
Ramesh, R., & Sastry, C. V. 2000, A&A, 358, 749
Ramirez Ruiz, E., & Fenimore, E. E. 2000, ApJ, 539, 712
Ramkumar, P. S., & Deshpande, A. A. 1999, J. Astrophys. Astron., 20, 37
Ramsay, G., et al. 2000, MNRAS, 311, 75
Ranns, N. D. R., et al. 2000, A&A, 360, 1163
Rast, M. P. 1999, ApJ, 524, 462
Rauch, T. 2000, A&A, 356, 665
Raulin, J. P., et al. 2000, A&A, 355, 355
Rawlings, J. M. C., et al. 2000, MNRAS, 313, 461
Rayet, M., & Hashimoto, M. 2000, A&A, 354, 740
Reale, F., & Peres, G. 2000, ApJ, 528, L45
Reale, F., et al. 2000a, ApJ, 535, 412
Reale, F., et al. 2000b, ApJ, 535, 423
Reames, D. V. 2000, ApJ, 540, L111
Rebhan, E. 2000, A&A, 353, 1
Reddy, D. R. K., & Rao, N. V. 2000, Ap&SS, 271, 165
Redfield, S., & Linsky, J. L. 2000, ApJ, 534, 825
Redman, M. P., et al. 2000, MNRAS, 312, L23
Reed, B. C. 2000, AJ, 120, 314
Reed, D. S., et al. 1999, AJ, 118, 2430
Rees, M. J. 1971, Nature, 229, 312
———. 1978, Observatory, 98, 210
———. 2000, Just Six Numbers (New York: Basic)
Rees, M. J., & Meszaros, P. 1994, ApJ, 430, L93
Refsdal, S., & Weigert, A. 1970, A&A, 6, 426
Refsdal, S., et al. 2000, A&A, 360, 10
Reginald, N. L., & Davila, J. M. 2000, Sol. Phys., 195, 111
Reid, I. N., & Mahoney, S. 2000, MNRAS, 316, 827
Reid, R. I., et al. 1999, ApJS, 124, 285
Reimers, D., & Hagen, H.-J. 2000, A&A, 358, L45
Reiner, M. J., et al. 2000, ApJ, 529, L53
Reinsch, K., et al. 2000, A&A, 354, L37
Reiz, A. 1954, ApJ, 120, 342
Rejkuba, M., et al. 2000, AJ, 120, 801
Remington, B. A., et al., eds. 2000, ApJS, 127, 211
Reshetnikov, V. P. 2000a, A&A, 353, 92
———. 2000b, Astron. Lett., 26, 61
Reshetnikov, V. P., & Sotnikova, N. Ya. 2000, Astron. Lett., 26, 277
Rezzolla, L., et al. 1999, ApJ, 525, 935
Rezzolla, L., et al. 2000, ApJ, 531, L139
Rhie, S. H., et al. 2000, ApJ, 533, 378
Rhoads, J. E. 1999, ApJ, 525, 737
Ribas, I., et al. 2000, ApJ, 528, 692
Ribas, I., et al. 2000a, MNRAS, 313, 99
Ribeiro, A. L., & Letelier, P. S. 1999, MNRAS, 309, 817
Richer, H. B., et al. 2000, ApJ, 529, 318
Richeter, P., et al. 1999, Nature, 402, 386
Richling, S., & Yorke, H. W. 2000, ApJ, 539, 258
Richter, P., et al. 1999, Nature, 402, 386
Riess, A. G., et al. 1999a, AJ, 118, 2668
———. 1999b, AJ, 118, 2675
Rietmeijer, F. J. M., et al. 1999, ApJ, 527, 395
Rieutord, M., et al. 2000, A&A, 357, 1063
Rigopoulou, D., et al. 1999, AJ, 118, 2625
Risaliti, G., et al. 2000, A&A, 357, 13
Rivera, E. J., & Lissauer, J. J. 2000, ApJ, 530, 454
Roald, C. B., Sturrock, P. A., & Wolfson, R. 2000, ApJ, 538, 960
Roberts, B. 2000, Sol. Phys., 193, 139
Robertson, J. W., et al. 2000, AJ, 119, 1365
Robichon, N., & Arenou, F. 2000, A&A, 355, 295
Roby, S. W., et al. 1999, ApJ, 524, 974
Rocha-Pinto, H. J., et al. 2000, A&A, 358, 850
Roche, N., & Eales, S. A. 2000, MNRAS, 317, 120
Rodriguez, E., et al. 2000, A&AS, 144, 469
Rodriguez, L. F., et al. 2000a, AJ, 119, 882
Rodriguez-Franco, A., et al. 1999, A&A, 351, 1103
Roman, A. T., et al. 2000, ApJS, 127, 27
Romer, A. K., et al. 2000, ApJS, 126, 209
Romero, G. E., et al. 2000, A&A, 360, 57
Rood, R. T., et al. 1999, ApJ, 523, 752 (on M3)
Ros, E., et al. 2000, A&A, 354, 55
Rosado, M., et al. 1999, AJ, 118, 2962
Rosenbush, A. E. 1999a, Astrofiz., 42, 140
———. 1999b, Astrofiz., 42, 270
Rosenthal, C. S., & Julien, K. A. 2000, ApJ, 532, 1230
Rosenthal, C. S., et al. 1999, A&A, 351, 689
Rosenzweig, P., et al. 2000, PASP, 112, 632
Rosner, R., Tucker, W. H., & Vaiana, G. S. 1978, ApJ, 220, 643
Rossa, J., & Dettmar, R.-J. 2000, A&A, 359, 433
Rossa, J., et al. 1999, A&A, 350, 379
Rosswog, S., et al. 2000, A&A, 360, 171
Roth, M., & Stix, M. 1999, A&A, 351, 1133
Roueff, E. 2000, A&A, 354, L63
Roukema, B. F. 2000, MNRAS, 312, 712
Roukema, B. F., & Mamon, G. A. 2000, A&A, 358, 395
Rowan, L., & Smith, H. J. 2000, Science, 288, 1983
Rowan-Robinson, M. 2000, MNRAS, 316, 885
Rowan-Robinson, M., et al. 2000, MNRAS, 314, 375
Roy, S. et al. 2000, A&A, 353, 1134
Rucinski, S. M., & Lu, W. 2000, MNRAS, 315, 587
Rucinski, S. M., et al. 2000, AJ, 120, 1133
Ruffini, R., et al. 1999, A&A, 350, 334
———. 2000, A&A, 359, 855
Rusin, D., et al. 2000, ApJ, 533, L89
Russell, D. T., & Kivelson, M. G. 2000, Science, 287, 199
Ryan, S. G. 2000, MNRAS, 316, L35
Ryutova, M., & Tarbell, T. D. 2000, ApJ, 541, L29
Sadler, E. M., et al. 2000, AJ, 119, 1180
Saglia, R. P., et al. 2000, AJ, 119, 153
Saha, A., et al. 2000, PASP, 112, 163
Saha, S. K. 1999, Bull. Astron. Soc. India, 27, 443
Sahai, R. 2000, ApJ, 537, L43
Sahai, R., & Nyman, L. A. 2000, ApJ, 538, L145
Saini, T. D., et al. 2000, Phys. Rev. Lett., 85, 1162
Saio, H., & Jeffery, C. S. 2000, MNRAS, 313, 671
Sakai, J. K., Kawata, T., Yoshida, K., Furusawa, K., & Cramer, N. F. 2000, ApJ, 537, 1063
Sakai, S., et al. 1999, ApJ, 523, 540
Sakamoto, K., et al. 2000, ApJ, 533, 149
Sakharov, A. D. 1968, Doklady, 12, 1040
Saladyga, M. 1999, J. AAVSO, 27, 154
Salaris, M., et al. 2000, A&A, 355, 299
Salati, P., et al. 1999, A&A, 350, L57

Salim, S., & Gould, A. 1999, ApJ, 523, 633
Salucci, P., & Burkert, A. 2000, ApJ, 537, L9
Salucci, P., & Persic, M. 1999a, A&A, 351, 442
———. 1999b, MNRAS, 309, 923
Salucci, P., et al. 2000, MNRAS, 317, 488
Sammis, I., Tang, F., & Zirin, H. 2000, ApJ, 540, 583
Sanantaray, A., & Khare, P. 2000, J. Astrophys. Astron., 21, 19
Sanchez, N. M., & Anez, N. Y. 2000, A&A, 354, 1123
Sanchez, S. F., & Gonzalez-Serrano, J. I. 1999, A&A, 352, 383
Sanchez-Almeida, J., & Lites, B. W. 2000, ApJ, 532, 1215
Sanders, R. H. 2000, MNRAS, 313, 767
Saracco, P., et al. 1999, A&A, 349, 751
Sarajedini, A. 1999, AJ, 118, 2321
Sarajedini, A., et al. 1999, AJ, 118, 2894
Sarna, M. J., et al. 2000, MNRAS, 316, 84
Sarro, L. M., et al. 1999, A&A, 351, 721
Sasselov, D. D., & Lecar, M. 2000, ApJ, 528, 995
Sato, S., et al. 2000, ApJ, 537, L73
Sauers, W. W., & Koppers, A. A. P. 2000, Science, 287, 455
Sazonov, S. Y., & Sunyaev, R. A. 2000, Astron. Lett., 26, 494
Scannapieco, E. 2000, ApJ, 540, 20
Schaab, C., & Weigel, M. K. 1999, MNRAS, 308, 718
Schaefer, B. E. 2000, ApJ, 533, L21
Schaefer, B. E., et al. 1999, ApJ, 524, L103
Scharf, C., et al. 2000, ApJ, 528, L73
Schilke, P., et al. 2000, ApJ, 528, L37
Schindler, S. 1999, A&A, 349, 435
Schinnerer, E., et al. 2000, ApJ, 533, 850
Schlegel, E. M. 1999, ApJ, 527, L85
Schlichenmaier, R., & Schmidt, W. 2000, A&A, 358, 1122
Schmalzing, J., et al. 1999, ApJ, 526, 568
Schmid, H. M., et al. 2000, A&A, 355, 261
Schmieder, B., et al. 2000, A&A, 358, 728
Schmutzer, E. 2000, Astron. Nachr., 321, 137
Schneider, S. E., & Schombert, J. M. 2000, ApJ, 530, 286
Schou, J. 1999, ApJ, 523, L181
Schrijver, C. J., & Brown, D. S. 2000, ApJ, 537, L69
Schrijver, C. J., & McMullen, R. A. 2000, ApJ, 531, 1121
Schrijver, C. J., & Zwaan, C. 2000, Solar and Stellar Activity (Cambridge: Cambridge Univ. Press)
Schroeder, K.-P., et al. 1999, A&A, 349, 898
Schubert, G., & Zhang, K. 2000, ApJ, 532, L149
Schulman, E., et al. 1994, ApJ, 423, 180
Schuster, A. 1905, ApJ, 21, 1
Schwarzschild, K. 1914, Sitzungsber. Preussichen Akad. Wiss., 1183
Schwope, A. D., et al. 2000, MNRAS, 313, 533
Sciama, D. W. 1991, Comments Astrophys., 15, 71
———. 2000, MNRAS, 312, 33
Scodeggio, M., & Silva, D. R. 2000, A&A, 359, 953
Scott, A. D. 2000, MNRAS, 313, 775
Scott, D., et al. 2000, A&A, 357, L5
Seaborne, M. D. 1999, MNRAS, 309, 89
Sedrakyan, D. M., & Shahabasyan, K. M. 1999, Astrofizika, 42, 169
Sefako, R. R., et al. 1999, MNRAS, 309, 1043
Seiff, A. 2000, Nature, 403, 603
Sekiguchi, M., & Fukugita, M. 2000, AJ, 120, 1072
Sellwood, J. A. 2000, ApJ, 540, L1
Sembach, K. R., et al. 1999, ApJ, 524, 98
———. 2000, ApJ, 538, L31
Semerak, O., et al. 1999a, MNRAS, 308, 691
Semerak, O., et al. 1999b, MNRAS, 308, 705
Sensui, T., et al. 1999, PASJ, 51, 943
Sephton, M. A., & Gilmour, I. 2000, ApJ, 540, 588
Sergeev, S. G., et al. 1999, AJ, 118, 2658
Serjeant, S., et al. 2000a, MNRAS, 316, 768
———. 2000b, MNRAS, 317, L29
Sevenster, M. N. 1999, MNRAS, 310, 629
Shackleton, N. J. 2000, Science, 289, 1897
Shahbaz, T., et al. 1999, MNRAS, 306, 89
Shapiro, P. R., & Field, G. B. 1976, ApJ, 205, 762
Shara, M. M., et al. 1999, PASP, 111, 1367
Sharpe, G. J. 1999, MNRAS, 310, 1039
Shaviv, G., & Shaviv, N. J. 2000, ApJ, 529, 1054
Sheminova, V. A., & Solanki, S. K. 1999, A&A, 351, 701
Shemmer, O., et al. 2000, MNRAS, 311, 698
Shepherd, D. S., & Kurtz, S. E. 1999, ApJ, 527, 690
Shepherd, D. S., et al. 2000, ApJ, 535, 833
Shi, X., & Fuller, G. M. 1999, Phys. Rev. Lett., 83, 3120
Shibata, K. 1999, Astrophys. Space Sci., 264, 129
Shibata, K., & Yokoyama, T. 1999, ApJ, 526, L49
Shields, J. C., et al. 2000, ApJ, 534, L27
Shigemori, K., et al. 2000, ApJ, 533, L159
Shimura, T. 2000, MNRAS, 315, 345
Shine, R. A., Simon, G. W., & Hurlburt, N. E. 2000, Sol. Phys., 193, 3
Sholomitskii, G. B., & Yaskovitch, A. L. 1990, Astron. Lett., 16, 387
Shopbell, P. L., et al. 1999, ApJ, 524, L83
Shu, D.-G., et al. 1999, Nature, 402, 42
Shu, F. H., Adams, F. C., & Lizano, S. 1987, ARA&A, 25, 23
Shu, F. H., et al. 2000, ApJ, 535, 190
Shull, J. M., et al. 1999, AJ, 118, 1450
———. 2000, ApJ, 538, L13
Shulman, L. S. 1999, Phys. Rev. Lett., 83, 5419
Sidorenko, N. S. 2000, Astron. Rep., 44, 414
Siemieniec-Ozieblo, G., & Ostrowski, M. 2000, A&A, 355, 51
Siess, L., & Livio, M. 1999, MNRAS, 308, 1133
Sikora, M., & Madjeski, G. 2000, ApJ, 534, 109
Silk, J., & Rees, M. J. 1998, A&A, 331, L1
Sills, A., et al. 2000, ApJ, 535, 298
Sittler, E. C. Jr., & Guhathakurta, M. 1999, ApJ, 523, 812
Sivaram, C. 1999, Bull. Astron. Soc. India, 27, 627
Skartlien, R., Stein, R. F., & Nordlund, A. 2000, ApJ, 541, 468
Skillman, D. R., et al. 1999, PASP, 111, 1281
Slane, P., et al. 1999, ApJ, 525, 357
Slysh, V. I., et al. 1999, Astron. Rep., 43, 657
Smail, I., et al. 1999a, ApJ, 525, 609
———. 1999b, MNRAS, 308, 1061
———. 2000, ApJ, 528, 612
Smale, A. P., & Kuulkers, E. 2000, ApJ, 528, 702
Smale, A. P., & Wachter, S. 1999, ApJ, 527, 341
Smil, V. 2000, Nature, 403, 597
Smith, C. H., et al. 2000, MNRAS, 312, 327
Smith, G., & Ruck, M. J. 2000, A&A, 356, 570
Smith, V. V., et al. 2000a, AJ, 119, 1239
Smolsky, M. V., & Usov, V. V. 2000, ApJ, 531, 764
Sneden, C., et al. 2000, ApJ, 536, L85
Snodgrass, H. B., & Smith, A. A. 2000, Sol. Phys., 191, 21
Sodana, A. 2000, Nature, 403, 822 (quoted)
Soederhjelm, S. 2000, Astron. Nachr., 321, 165
Sofue, Y. 2000, ApJ, 540, 224
Sofue, Y., et al. 1999, PASJ, 51, 737
Soifer, B. T., et al. 1999, AJ, 118, 2065
———. 2000, AJ, 119, 509
Soker, N. 2000, ApJ, 540, 436
Soker, N., & Rappaport, S. 2000, ApJ, 538, 241
Solf, J. 2000, A&A, 354, 674
Sollerman, J., et al. 2000a, ApJ, 537, L127
Sollerman, J., et al. 2000b, ApJ, 537, 861
Soltan, A. M., et al. 1999, A&A, 349, 354
Song, I., et al. 2000, ApJ, 533, L41
Songaila, A., et al. 1999, ApJ, 525, L5
Sorokina, E. I., et al. 2000, Astron. Lett., 26, 67

Spada, M., et al. 2000, ApJ, 537, 824
Spangler, S. R., & Mancuso, S. 2000, ApJ, 530, 491
Sparks, W. B., et al. 1999, ApJ, 523, 585
Spergel, D. N., & Steinhardt, P. J. 2000, Phys. Rev. Lett., 84, 3760
Spoon, H. W. W., et al. 2000, A&A, 357, 898
Spruit, H. C. 1999, A&A, 349, 189
Srikanth, R., Singh, J., & Raju, K. P. 2000, ApJ, 534, 1008
Srivastava, N., Schwenn, R., Inhester, B., Martin, S. F., & Hanaoka, Y. 2000, ApJ, 534, 468
Stairs, I. H., et al. 2000, Nature, 406, 484
Stanghellini, L., et al. 2000, ApJ, 534, L167
Stanton, R. H. 1999, J. AAVSO, 27, 97
Stappers, B. W., et al. 1999, MNRAS, 308, 609
Stasinska, G., & Szczerba, R. 1999, A&A, 352, 297
Stathakis, R. A., et al. 2000, MNRAS, 314, 807
Steele, M., & Howells, L. 2000, MNRAS, 313, L43
Steffen, M., & Schoenberner, D. 2000, A&A, 357, 180
Steidel, C. C., et al. 2000, ApJ, 532, 170
Steinle, H., et al. 2000, A&A, 357, L57
Stenflo, J. O., Gandorfer, A., & Keller, C. U. 2000a, A&A, 355, 781
Stenflo, J. O., Keller, C. U., & Gandorfer, A. 2000b, A&A, 355, 789
Stepanov, A. V., et al. 1999, ApJ, 524, 961
Stephenson, F. R., & Willis, D. M. 1999, Astron. & Geophys., 40(6), 21
Stepinski, T. F., & Black, D. C. 2000, A&A, 356, 903
Sterling, A. C., et al. 2000, ApJ, 532, 628
Stern, B. E., et al. 2000b, ApJ, 540, L21
Stern, D., et al. 2000a, AJ, 119, 1526
———. 2000b, ApJ, 533, L75
———. 2000c, ApJ, 537, 73
Stern, S. A., & McKinnon, W. B. 2000, AJ, 119, 945
Stevens, I. R., et al. 1999a, MNRAS, 310, 663
Stevens, J. B., et al. 1999, MNRAS, 309, 421
Stevenson, D. J. 1999, Science, 287, 135 (quoted)
Stevenson, D. J. 2000, Science, 267, 997
Stigler, S. 1999, Statistics on the Table (Cambridge: Harvard Univ. Press), chap. 14
Stone, J. M., & Hardee, P. E. 2000, ApJ, 540, 192
Stone, J. M., et al. 1999, MNRAS, 310, 1002
Stout-Batalha, N. M., et al. 2000, ApJ, 532, 474
Straizys, V., et al. 1999, Baltic Astron., 8, 355
Strobel, K., et al. 1999, A&A, 350, 497
Strong, A. W., et al. 2000, ApJ, 537, 763
Strouhal, C. 1878, Widemann's Annalen der Physik und Chemie, 5, 216
Strous, L. H., Goode, P. R., & Rimmele, T. R. 2000, ApJ, 535, 1000
Struve, O., & Swings, P. 1943, ApJ, 98, 361
Sturrock, P. A., et al. 1999a, ApJ, 523, L177
Sturrock, P. A., et al. 1999b, ApJ, 524, L75
Su, Q. R., & Su, M. 2000, Sol. Phys., 194, 121
Subrahmanyan, R., et al. 2000, MNRAS, 315, 808
Sudarsky, D., et al. 2000, ApJ, 538, 885
Sudou, H., & Taniguchi, Y. 2000, AJ, 120, 697
Sugai, H., & Malkan, M. A. 2000, ApJ, 529, 219
Sumiyoshi, K., et al. 2000, PASJ, 52, 601
Surace, J. A., et al. 2000, ApJ, 529, 170
Susa, H., & Kitayama, T. 2000, MNRAS, 317, 175
Swope, H. 1940, Harvard Bulletin, 913, 11
Sylvester, R. J., & Mannings, V. 2000, MNRAS, 313, 73
Sylwester, B., & Sylwester, J. 2000, Sol. Phys., 194, 305
Tagger, M., & Pellat, R. 1999, A&A, 349, 1003
Tagliaferri, G., et al. 2000, A&A, 354, 431
Tanaka, Y., et al. 2000, PASJ, 52, L25
Takeda, A., et al. 2000, PASJ, 52, 375
Takeda, Y., & Takada-Hidai, M. 2000, PASJ, 52, 113
Takizawa, M. 2000, ApJ, 532, 183
Tam, S. W. Y., & Chang, T. 1999, Geophys. Res. Lett., 26, 3189
Tamura, M., et al. 1999, ApJ, 525, 832
Tamura, N., & Hirashita, H. 1999, ApJ, 525, L17
Tamura, N., & Ohta, K. 2000, AJ, 120, 533
Tappin, S. J., Simnett, G. M., & Lyons, M. A. 1999, A&A, 350, 302
Taranova, O. G., & Shenavrim, V. I. 2000, Astron. Lett. 26, 600
Tarbell, T. D., Ryutova, M., & Shine, R. 2000, Sol. Phys., 193, 195
Tat, H. H., & Terzian, Y. 1999, PASP, 111, 1258
Tauris, T. M., & Sennels, T. 2000, A&A, 355, 236
Tauris, T. M., et al. 1999, MNRAS, 310, 1165
Tecza, M., et al. 2000, ApJ, 537, 178
Tegmark, M., & Zaldarriaga, M. 2000, Phys. Rev. Lett., 85, 2240
Thelen, J., & Cattaneo, F. 2000, MNRAS, 315, L13
Thiery, S., et al. 2000, A&A, 355, 743
Thomas, J. H., & Stanchfield, D. C. H., II. 2000, ApJ, 537, 1086
Thommes, E. W., et al. 1999, Nature, 402, 635
Thompson, B. J., et al. 2000a, Geophys. Res. Lett., 27, 1431
———. 2000b, Sol. Phys., 193, 161
Thompson, C., & Madau, P. 2000, ApJ, 538, 105
Thorsett, S. E., et al. 1999, ApJ, 523, 763
Thuan, T. X., et al. 1999, A&AS, 139, 1
Timmes, F. X., & Niemeyer, J. C. 2000, ApJ, 537, 993
Tine, S., et al. 2000, A&A, 356, 1039
Tingay, S. J., et al. 2000, AJ, 119, 1695
Titov, V. A., & Demoulin, P. 1999, A&A, 351, 707
Tokarev, Yu. V., et al. 2000, Astron. Lett., 26, 553
Tokuhisa, A., & Kajino, T. 1999, ApJ, 525, L117
Tomaschitz, R. 2000, Ap&SS, 271, 181
Tomisaka, K. 2000, ApJ, 528, L41
Tomita, A., et al. 2000, AJ, 120, 123
Tomita, K. 2000a, ApJ, 529, 26
———. 2000b, ApJ, 529, 38
Tomov, T., et al. 2000, A&A, 354, L25
Toomre, A., & Toomre, J. 1972, ApJ, 178, 623
Torra, J., et al. 2000, A&A, 359, 82
Torres, G., & Stefanik, R. P. 2000, AJ, 119, 1914
Torricelli-Ciamponi, G., et al. 2000, A&A, 358, 57
Toth, I. 2000, A&A, 360, 375
Totten, E. J., et al. 2000, MNRAS, 314, 630
Tovmassian, H. M., & Chavushyan, V. H. 2000, AJ, 119, 1687
Trafton, L. M. 2000, AJ, 120, 488
Treves, A., et al. 2000, PASP, 112, 297
Trilling, D. E., et al. 2000, ApJ, 529, 499
Trimble, V. 1975, Rev. Mod. Phys., 47, 877
Trimble, V., & Sciatti, H. J., III. 2000, Observatory, 120, 7p
Tripp, T. M., et al. 2000, ApJ, 534, L1
Trottet, G., et al. 2000, A&A, 356, 1067
Trujillo, C. A., et al. 2000, ApJ, 529, L103
Tsap, Y. T. 2000, Sol. Phys., 194, 131
Tsiganis, K., et al. 2000, A&A, 354, 1091
Tsiropoula, G., Alissandrakis, C. E., & Mein, P. 2000, A&A, 355, 375
Tsunemi, H., et al. 1999, PASJ, 51, 711
Tsuribe, T., & Inutsuka, S.-I. 1999, ApJ, 523, L155
Tsytovich, V. N. 2000, A&A, 356, L57
Tuairisg, S. O., et al. 2000, A&AS, 142, 225
Tumlinson, J., & Shull, J. M. 2000, ApJ, 528, L65
Tumlinson, J., et al. 1999, AJ, 118, 2148
Turatto, M., et al. 2000, ApJ, 534, L57
Turner, N. J., et al. 1999, ApJ, 524, 129
Tuthill, P. G., et al. 2000a, ApJ, 534, 907
———. 2000b, PASP, 112, 555
Tyne, V. H., et al. 2000, MNRAS, 315, 595
Tyul'bashev, S. A., & Chernikov, P. A. 2000, Astron. Rep., 44, 286
Uchida, Y., et al. 1999, PASJ, 51, 553
Udalski, A. 2000, ApJ, 531, L25

Udalski, A., et al. 1999, Acta Astron., 49, 437
Udry, S., et al. 2000, A&A, 356, 590
Ueda, Y., et al. 1999, ApJ, 524, L11
Umana, G., et al. 2000, A&A, 358, 229
Uemura, M., et al. 2000, PASJ, 52, L15
Ueta, T., et al. 2000, ApJ, 528, 861
Umeda, H., et al. 2000, ApJ, 534, L193
Umetsu, K., & Futamase, T. 2000, ApJ, 539, L5
Unger, S. J., et al. 2000, A&A, 355, 885
Ungerechts, H., et al. 2000, ApJ, 537, 221
Unglaub, K., & Bues, I. 2000, A&A, 359, 1042
Urama, J. O., & Okeke, P. N. 1999, MNRAS, 310, 313
Uus, U. 1970, Naut. Informatskii, 17, 32
Vaidya, D. B., et al. 2000, J. Astrophys. Astron., 21, 91
Vainio, R., Kocharov, L., & Laitinen, T. 2000, ApJ, 528, 1015
Valageas, P., & Silk, J. 1999, A&A, 350, 725
Valtaoja, E., et al. 2000, ApJ, 531, 744
Val'tts, I. E., et al. 1999, MNRAS, 310, 1077
VanBallegooijen, A. A., Priest, E. R., & MacKay, D. H. 2000, ApJ, 539, 983
van den Bergh, S. 1999, A&A Rev., 9, 273
van den Bergh, S. 2000a, AJ, 119, 609
———. 2000b, ApJ, 530, 777
———. 2000c, PASP, 112, 529
van den Bosch, F. C., & Dalcanton, J. J. 2000, ApJ, 534, 146
van der Tak, F. F. S., & van Dishoeck, E. F. 2000, A&A, 358, L79
Vangioni-Flam, E., et al. 2000, A&A, 360, 15
Vanhala, H. A. T., & Boss, A. P. 2000, ApJ, 538, 911
van Kampen, E., et al. 1999, MNRAS, 310, 43
van Langevelde, H. J., et al. 2000, A&A, 354, L45
van Loon, J. T. 2000, A&A, 354, 125
van Loon, J. T., et al. 1999, A&A, 351, 559
van Paradijs, J. 1999, Science, 286, 691
van Putten, M. H. P. M. 2000, Phys. Rev. Lett., 84, 3752
van Waerbeke, L., et al. 2000, A&A, 358, 30
van Waerbeke, L. et al. 2000a, ApJ, 540, 14
van Winckel, H., & Reyniers, M. 2000, A&A, 354, 135
van Zee, L., & Bryant, J. 1999, AJ, 118, 2172
Varadi, F. 1999, AJ, 118, 2526
Varady, M., Fludra, A., & Heinzel, P. 2000, A&A, 355, 769
Vasconcelos, M. J., et al. 2000, ApJ, 534, 967
Vaughan, S., et al. 1999, MNRAS, 308, L34
Vazdekis, A., & Arimoto, N. 1999, ApJ, 525, 144
Vazquez, R., et al. 2000, A&A, 357, 1031
Vedenov, A. A., et al. 2000, Astron. Rep., 44, 112
Vekstein, G. E., & Katsukawa, Y. 2000, ApJ, 541, 1096
Vennes, S. 1999, ApJ, 525, 995
Vennik, J., et al. 2000, A&AS, 142, 399
Venter, C., & Collins, F. 2000, Nature, 405, 983 (quoted)
Ventura, P., et al. 1999, ApJ, 524, L111
Venturi, T., et al, 2000, MNRAS, 314, 594
Verma, V. K. 2000, Sol. Phys., 194, 87
Veron-Cetty, M.-P., & Veron, P. 2000, A&A Rev., 10, 81
Vertogradova, E. G., & Grishkan, Yu. S. 2000, Astron. Rep., 44, 142
Viateau, B. 2000, A&A, 354, 725
Vietri, M., & Stella, L. 1999, ApJ, 527, L43
Vignati, P., et al. 1999, A&A, 349, L57
Vigotti, M., et al. 1999, A&AS, 139, 359
Villamariz, M. R., & Herrero, A. 2000, A&A, 357, 597
Vink, J., et al. 2000, A&A, 354, 931
Voges, W., et al. 1999, A&A, 349, 389
Voges, W., et al. 2000, IAU Circ., 7432, 3
Vogt, S. S., et al. 2000, ApJ, 536, 902
Voitenko, Y. M., & Goossens, M. 2000a, A&A, 357, 1073
———. 2000b, A&A, 357, 1086
Vollmer, B., & Duschl, W. J. 2000, NewA, 4, 581
Vollmer, B., et al. 1999, A&A, 349, 411
Voors, R. H. M., et al. 2000, A&A, 356, 501
Vourlidas, A., et al. 2000, ApJ, 534, 456
Vozikis, C. L., et al. 2000, A&A, 359, 386
Vrba, F. J., et al. 2000, ApJ, 533, L17
Vrsnak, B. 2000, Sol. Phys., 194, 285
Wachter, S., et al. 2000, ApJ, 534, 380
Wakker, B. P., et al. 1999, Nature, 402, 388
Walborn, N. R., et al. 2000, PASP, 112, 1243
Walker, K. C., et al. 2000a, ApJ, 537, 264
Walker, M. A. 1999, MNRAS, 308, 551
Walker, R. C., et al. 2000b, ApJ, 530, 233
Wallace, B. J., et al. 1999, ApJS, 124, 181
Wallace, K., et al. 2000a, Nature, 406, 700
Wallace, P. M., et al. 2000, ApJ, 540, 184
Wandel, A., et al. 1999, ApJ, 526, 579
Wang, C., et al. 2000a, J. Geophys. Res., 105, 2337
Wang, H., et al. 2000b, ApJ, 536, 971
Wang, H., et al. 2000c, ApJ, 542, 1080
Wang, J.-M. 1999, AJ, 118, 1845
Wang, J. X., et al. 2000d, ApJ, 530, 1071
Wang, X. Y., et al. 2000e, A&A, 357, 543
Wang, Y. M. 2000, ApJ, 543, L89
Ward, M. J. 2000, BAAS, 32, 1561
Ward, W. R., & Canud, R. M. 2000, Nature, 403, 741
Wardle, M., & Walker, M. 1999, ApJ, 527, L109
Wardzinski, G., & Zdziarski, A. A. 2000, MNRAS, 314, 183
Warren, H. P. 1999, Sol. Phys., 190, 363
———. 2000, ApJ, 536, L105
Warren, H. P., et al. 1999, ApJ, 527, L121
Watanabe, J., et al. 2000, PASJ, 52, L21
Watanabe, M., et al. 1999, ApJ, 527, 80
Watarai, K., & Fukue, J. 1999, PASJ, 51, 725
Watarai, K., et al. 2000, PASJ, 52, 133
Watari, S., & Watanabe, T. 2000, Sol. Phys., 194, 393
Watko, J. A., & Klimchuk, J. A. 2000, Sol. Phys., 193, 77
Waxman, E., & Draine, B. T. 2000, ApJ, 537, 796
Weaver, H., & Williams, D. R. 1974, A&AS, 17, 251
Weber, J. 2001, Phys. Essays, in press
Weber, M. A., et al. 1999, Sol. Phys., 189, 271
Weilbacher, P. M., et al. 2000, A&A, 358, 819
Weinberg, M. D. 2000, ApJ, 532, 922
Weinberger, A. J., et al. 1999, ApJ, 525, L53
Weiss, A., et al. 2000, ApJ, 533, 413
Weisskopf, M., & Hester, J. 1999, Science, 286, 211 (quoted)
Weisskopf, M. C., et al. 2000, ApJ, 536, L81
Weissman, P. R. 1999, Science News, 156, 356 (quoted)
Wellstein, S., & Langer, N. 1999, A&A, 350, 148
Welty, D. E., et al. 1999, ApJS, 124, 465
Weselak, T., et al. 2000, A&AS, 142, 239
Wesson, P. S., et al. 2000, A&A, 358, 425
Wheatland, M. S. 2000a, Sol. Phys., 191, 381
———. 2000b, ApJ, 532, 1209
———. 2000c, ApJ, 536, L109
Wheatland, M. S., & Uchida, Y. 1999, Sol. Phys., 189, 163
Wheatley, P. J., et al. 2000, MNRAS, 317, 343
Wheeler, J. C., et al. 2000, ApJ, 537, 810
White, S. M., et al. 2000, ApJ, 534, L203
Whiting, A. B., et al. 1999, AJ, 118, 2767
Wickramasinghe, D. T., & Ferrario, L. 2000, PASP, 112, 873
Wiegert, P., et al. 2000, AJ, 119, 1978
Wikstol, O., Hansteen, V. H., Carlsson, M., & Judge, P. G. 2000, ApJ, 531, 1150
Wilczek, F. 1999, Nature, 402, 22
Wilhelm, K. 2000, A&A, 360, 351
Wilhelm, K., et al. 2000, A&A, 353, 749

Wilkinson, M. I., & Evans, N. W. 1999, MNRAS, 310, 645
Wilkinson, P. 1999, Science, 287, 37 (quoted)
Will, L. M., & Aannestad, P. A. 1999, ApJ, 526, 242
Williams, P. M., & van der Hucht, K. A. 2000, MNRAS, 314, 23
Williams, R. J. R., et al. 1999, MNRAS, 310, 913
Williger, G. M., et al. 2000, ApJ, 532, 77
Willott, C. J., et al. 2000, MNRAS, 313, 237
Wills, K. A., et al. 1999, MNRAS, 309, 395
Wilman, R. J., & Fabian, A. C. 1999, MNRAS, 309, 862
Wilman, R. J., et al. 1999, MNRAS, 309, 299
———. 2000, MNRAS, 317, 9
Wisotzki, L. 2000, A&A, 353, 853
Wissink, J. G., et al. 2000, ApJ, 536, 982
Witt, A. N., & Gordon, K. D. 2000, ApJ, 528, 799
Wittman, D. M., et al. 2000, Nature, 405, 143
Wizinowich, P., et al. 2000, PASP, 112, 315
Woermann, B., et al. 2000a, MNRAS, 315, 241
———. 2000b, MNRAS, 317, 421
Wold, M., et al. 2000, MNRAS, 316, 267
Wolf, E. 1986, Phys. Rev. Lett., 54, 1370
Wolfson, R., & Dlamini, B. 1999, ApJ, 526, 1046
Wolfson, R., et al. 2000a, ApJ, 529, 570
———. 2000b, ApJ, 539, 995
Wolszczan, A., et al. 2000a, ApJ, 528, 907
———. 2000b, ApJ, 540, L41
Woo, R., Armstrong, J. W., & Habbal, S. R. 2000, ApJ, 538, L171
Wood, B. E., Karovska, M., Cook, J. W., Howard, R. A., & Brueckner, G. E. 1999, ApJ, 523, 444
Wood, B. E., et al. 2000, ApJ, 537, 304
Wood, K., & Raymond, J. 2000, ApJ, 540, 563
Worden, J., Harvey, J., & Shine, R. 1999, ApJ, 523, 450
Woudt, P. A., et al. 1999, A&A, 352, 39
Wu, C. S., Yoon, P. H., & Li, Y. 2000, ApJ, 540, 572
Wu, X.-P., & Xue, Y.-J. 2000, MNRAS, 311, 825
Wurm, G., & Blum, J. 2000, ApJ, 529, L57
Wyckoff, S., et al. 2000, ApJ, 535, 991
Wyder, T. K., et al. 2000, PASP, 112, 594
Wyithe, J. S. B., et al. 2000, MNRAS, 315, 62
Xu, R. X., et al. 2000, ApJ, 535, 354
Yahagi, H., et al. 1999, ApJS, 124, 1
Yallop, B. 2000, Observatory, 120, 212
Yamamoto, S., & Nakamura, A. M. 2000, A&A, 356, 1112
Yaqoob, T., et al. 1999, ApJ, 525, L9
Yi, S., et al. 2000, ApJ, 533, 670
Yin, Q. Z., et al. 2000, ApJ, 536, L49
Yoemans, D. 2000, Nature, 404, 829
Yoemans, D. K., et al. 2000, Science, 289, 2085
Yong, H., et al. 2000, ApJ, 539, 928
Yorke, H. W., & Bodenheimer, P. 1999, ApJ, 525, 330
Yoshida, N., et al. 2000, ApJ, 535, L103
Yost, S. A., et al. 2000, ApJ, 535, 644
Young, P. R., Klimchuk, J. A., & Mason, H. E. 1999, A&A, 350, 286
Young, P., & Smith, C. 2000, Science, 289, 228
Yu, Q., & Tremaine, S. 1999, AJ, 118, 1872
Yurchyshyn, V. B., et al. 2000a, ApJ, 540, 1143
———, ApJ, 538, 968
Zacs, L., et al. 2000, A&A, 358, 1022
Zagury, F. 2000, NewA, 5, 211
Zaitsev, V. V., Urpo, S., & Stepanov, A. V. 2000, A&A, 357, 1105
Zank, G. P., Rice, W. K. M., & Wu, C. C. 2000, J. Geophys. Res., 105, 25079
Zaritsky, D., & Gonzalez, A. H. 1999, PASP, 111, 1508
Zasova, A. V., et al. 2000, A&AS, 144, 429
Zavlin, V. E., et al. 1999, ApJ, 525, 959
———. 2000, ApJ, 540, L25
Zdunik, J. L. 2000, A&A, 359, 143
Zepf, S. E., et al. 2000, AJ, 119, 1701
Zhang, B., Harding, A. K., & Muslimov, A. G. 2000, ApJ, 531, L135
Zhang, B., & Wyse, R. F. G. 2000, MNRAS, 313, 310
Zhang, H. 2000, A&A, 359, L19
Zhang, H., et al. 2000, A&A, 357, 725
Zhang, J., White, S. M., & Kundu, M. R. 1999, ApJ, 527, 977
Zhang, L., et al. 2000a, A&A, 357, 957
Zhang, M., & Zhang, H. 2000a, Sol. Phys., 194, 19
———. 2000b, Sol. Phys., 194, 29
Zhang, Y., & Chu, Y. 1999, ApJ, 526, 555
Zhao, H. 1999, MNRAS, 309, 636
Zhao, H. S., et al. 2000, ApJ, 532, L37
Zhao, X. P., Hoekzema, J. T., & Scherrer, P. H. 2000a, ApJ, 538, 932
Zharkova, V. V., & Kosovichev, A. G. 2000, in ASP Conf. Ser. 206, High Energy Solar Physics Workshop—Anticipating HESSI, ed. R. Ramaty & N. Mandzhavidze (San Francisco: ASP), 77
Zharkova, V. V., & Syniavskii, D. V. 2000, A&A, 354, 714
Zheng, Z., et al. 1999, A&A, 349, 735
Zhou, A.-Y., et al. 1999, MNRAS, 308, 631
Zhugzhda, Y. D., Balthasar, H., & Staude, J. 2000, A&A, 355, 347
Ziurys, L. M. 1999, ApJ, 527, L67
Zolensky, M. E., et al. 2000, Science, 285, 1377
Zuber, M. T., et al. 2000, Science, 287, 1788
Zuckerman, B., & Webb, R. A. 2000, ApJ, 535, 959
Zwaan, M. A. 2000, Science, 28, 822
Zwaan, M. A., & Briggs, F. H. 2000, ApJ, 530, L61

Note added in proof.—On June 18, 2001, just two months after this manuscript had been accepted, a press release announced the discovery of transformations of the electron-neutrino into other active flavors, i.e., into the muon-neutrino and tau-neutrino, measured since 1999 with the new Sudbury Neutrino Observatory (Q. R. Ahmad et al., Phys. Rev. Lett., submitted [2001]). This discovery solves the 30 year old mystery of the missing solar ^{8}B neutrinos and confirms that the total number of electron-neutrinos produced in the Sun is just as predicted by detailed solar models.