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Invited Review

Astrophysics in 1998

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ABSTRACT. From Alpha (Orionis and the parameter in mixing-length theory) to Omega (Centauri and the density of the universe), the Greeks had a letter for it. In between, we look at the Sun and planets, some very distant galaxies and nearby stars, neutrinos, gamma rays, and some of the anomalies that arise in a very large universe being studied by roughly one astronomer per 10^7 Galactic stars.

1. INTRODUCTION

Astrophysics in 1998 welcomes a new co-author, Markus Aschwanden, formerly of the University of Maryland astronomy department, and as a direct result, gives some attention to solar physics, which has been relatively neglected in recent years. Lucy-Ann McFadden, meanwhile, is up to her very capable shoulders in the Near Earth Asteroid Rendezvous (NEAR) project, a Maryland honors program, a science museum for families, and heaven knows what else. Astrophysics in 1991 to 1997 appeared in PASP on page 1 of volumes 104–107, page 8 of volume 108, page 78 of 109, and page 223 of 110, respectively. They are cited below as Ap91, Ap92, etc.

The journals scanned were the issues that reached library shelves between 1997 October 1 and 1998 September 30 of *Nature*, *Physical Review Letters*, *Science*, *The Astrophysical Journal* (plus *Letters* and *Supplements*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Supplements* and *Reviews*), *Solar Physics*, *Acta Astronomica*, *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*, *Astrophysical Letters and Communications*, *New Astronomy*, *IAU Circulars*, and (of course) *Publications of the Astronomical Society of the Pacific*. Several of these have become quite difficult to locate, as more and more subscriptions are dropped, and coverage of *Astrofizica*, *Astronomische Nachrichten*, and *Astrophysical Letters and Communications* is not complete. This is part of a trend in astronomical publication that can be traced back at least to the late 19th century, for major papers to be more and more concentrated in a few highly regarded journals, and, of course, for power to be concentrated in fewer and fewer editorial hands.

1.1. Up, Up, and Away

A great many things got started during the year. *Cassini* was launched safely toward Saturn on 1997 October 15. The Planet B mission to Mars took off in July, 1998 and so was renamed *Nozomi* (Hope), following an excellent custom that has saved the Japanese space program from having had a named mission blow up on the launch pad or enter a geostationary orbit on the ocean floor for a very long time.

The first data came back from *HALCA*, the space-based radio interferometer (Hirabayashi et al. 1998). With a baseline to earth-bound radio dishes exceeding 25,000 km, it has tightened the limits on the sizes of some components in quasar jets and driven their apparent brightness temperatures above 10^{12} K (the limit for incoherent synchrotron emission).

Early data were also reported from the recommissioned Hooker 100″ telescope on Mount Wilson (Hartkopf et al. 1997); from the second OGLE survey for gravitational lensing events due to MACHOS—and for variable stars—(Udalski et al. 1997a; it uses a dedicated 1.3 m telescope at Las Campanas); from the first of the four 8 meter mirrors that will make up the Very Large Telescope (Kaper 1998); from the Sloan Digital Sky Survey (Turner 1998); from the second flight of the *ORFEUS* extreme-ultraviolet telescope (Hurwitz et al. 1998a and about seven following papers; it saw a lot of O VI); and from a very large number of adaptive optics systems, including one on the Russian 6 meter telescope (Weigelt et al. 1998), though they are not the solution to all the astronomical problems you ever thought of (Esslinger & Edmunds 1998).

Alpha Orionis (Betelgeuse) has been resolved at the 0″.2 level with a nulling interferometer, which greatly suppresses the flux from the central star, allowing one to see the sur-

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rounding disk, and, someday, perhaps, planets (Hinz et al. 1998).

Rugate is a filter to suppress the near-infrared OH lines produced by the earth's atmosphere (Offer & Bland-Hawthorn 1998). It is a Latin word, not a relative of the Rugrats. Oya et al. (1998) report data from a device with similar function (and a design with some resemblance to a radial-velocity spectrometer), but without a Latin name.

COME-ON-PLUS is a coronagraph to be used with adaptive optics (Beuzit et al. 1997), and we suspect that the name was selected by someone who was not a native speaker of American English.

A replica of the telescope with which Karl Jansky did his pioneering work in radio astronomy has been erected close to the original site in New Jersey (Tyson & Wilson 1998). It is not intended as a working model.

Finally, as drivers of relatively sedate vehicles ("my other car is a Volvo"), we wish to record with awe a disk wind that goes from 0 to 3000 km s^{-1} in 6–8 minutes. It belongs to the cataclysmic variable BZ Cam (Ringwald & Naylor 1998).

1.2. L'Envoi

Some things also came to an end. After a long (in both time and wavelength) and, we hope, happy life, the *Infrared Space Observatory* (*ISO*) was turned off (Bonnet 1998). *ROSAT* made the mistake of an inexperienced eclipse observer and looked too closely at the Sun (with the declared termination of the guest observer program coming just after our year ended). *SOHO*, in contrast, sort of forgot to look at the Sun until its batteries had run down badly, but seems to have made a remarkable recovery.

It was not quite so devastating a year as 1997 for the American astronomical community, but deaths reported to the AAS and/or ASP during the reference year included Richard Herr, Barry Rappaport, Victor Szebehely, Andrew Michalitsianos, Walter McAfee, Charles Worley, Anthony Jenzano, Georgeanne Caughlan, David Schramm, John Baer, Frank Bradshaw Wood, Gabriel Kojoian, Emil Herzog, Robert L. Wildey, John Wang, Charles Franklin Prosser, Jr., Karl Kamper, Alexander Rodgers, Robert Light, James B. Willett, Guenter Brueckner, William Titteman, and Olin J. Eggen. Many of them were in the midst of active astronomical careers, and their papers are cited elsewhere in these pages.

2. SOLAR PHYSICS

The Sun has never been watched so closely in all wavelengths and with such high spatial resolution as this year. The solar literature received a substantial boost from the *Solar and Heliospheric Observatory* (*SOHO*), which probed almost everything from the interior of the Sun (via helioseismology) out to 30 solar radii in the heliosphere, accompanied by an armada of other space-borne instruments: *Yohkoh*, the *Compton Gamma Ray Observatory* (*CGRO*), the *Transition Region and Coronal Explorer* (*TRACE*), *Wind*, *Ulysses*, and so forth. Short dives into space yielding unique solar glimpses have also been accomplish by rocket flight such as NRL HRTS, NRL ETI, and GSFC SERTS, and the shuttle payload SPARTAN 201.

What's the scientific harvest? Despite the overwhelming multicolor vision in invisible wavelengths, the complex intricacies of solar plasma physics could not yet be sufficiently disentangled to yield solutions to the problems posed by coronal heating, acceleration of the solar wind, or particle acceleration in solar flares. However, encouraging new findings were presented.

Coronal heating by dissipative Alfvén waves in multiple resonance layers that drift throughout coronal loops is predicted by recent theories (Ofman et al. 1998). Observationally, quasi-periodic wave trains have been detected in solar plumes; they carry an energy flux that is almost enough to heat coronal holes (DeForest & Gurman 1998). Falconer et al. (1998) localize the sources of coronal heating concentrations in the magnetic network. Krucker & Benz (1998) inquire into the faintest extreme-ultraviolet (EUV) brightness fluctuations in the quiet Sun and find that a surprisingly high percentage, at least 85% of all pixels in the EUV images they investigated, vary significantly all the time. Such small EUV brightenings have been interpreted in terms of "miniflares" or "network flares" that heat the plasma of tiny, low-lying loops to EUV ($\lesssim 1$ MK) temperatures but do not show up in ($\gtrsim 2$ MK) soft X-rays (Berghmans et al. 1998). The energy for these tiny EUV brightenings is believed to come from magnetic reconnection events of low-lying quiet-Sun loops, which reconnect preferentially near the chromospheric network and require a magnetic flux replacement within 48 hr on average (Schrijver et al. 1998). The finest structures of the magnetic field detected with *SOHO*/MDI down to a resolution of 1″ are now described as "magnetic carpet" textures.

Exciting progress was also reported from helioseismology. Global *p*-mode oscillations of the solar interior are now so accurately measured that even slight disturbances from active regions can be registered and dubbed "seismic holography of solar activity" (Braun et al. 1998; Chen et al. 1998b). Even more dramatic is the first detection of a "Sun quake" caused by a solar flare (Kosovichev & Zharkova 1998). It was compared with the "energy that would be released if the earth's continents were covered with a yard of dynamite and detonated all at once!" Said Sun quake was also rated on the Richter scale in one of the spaceweather-prone web-page advertisements. It rated an 11.3!

Talking about the most energetic energy releases in the daily life of our Sun, the solar flares, the understanding of the underlying plasma physics did not become easier. Masuda's discovery of "above-the-loop-top" hard X-ray sources (Masuda et al. 1994) was celebrated as the revelation of the primary particle acceleration site (Tsuneta & Naito 1998). This was localized in the plasma outflow in the cusp of X-type magnetic reconnection processes in the recent literature and glamorously enhanced in hard X-ray images reconstructed with pixon methods (Alexander & Metcalf 1997). But the big picture became clouded again with the demonstration of secondary flare loops, seen in soft X-rays and radio, that interact with the primary flare loop, seen in hard X-rays (Nishio et al. 1997), because the magnetic topology in a "three-legged flare loop configuration" is not easily understood. Models with three-dimensional magnetic reconnection seem to be inescapable (Longcope & Silva 1997; Somov et al. 1998). X-type reconnection processes were observationally traced by ejected plasma blobs (Ohyama & Shibata 1998), by bidirectional plasma jets in EUV (Innes et al. 1997), and by microwave signatures in soft X-ray jets (Kundu et al. 1997). Some flares were observed in gamma rays to produce nuclear lines for as long as 2 hr (Murphy et al. 1997). Taking a break from exploring the violent flare action per se, patient researchers started to study the "waiting time" distribution between flares (Wheatland et al. 1998). Others started to play with cellular automata models (MacKinnon et al. 1996; MacKinnon & MacPherson 1997). However, serious work was resumed by transforming these numerical toys into discretized magnetohydrodynamic (MHD) equations (Isliker et al. 1998).

Acceleration of the solar wind is another hot topic that was stimulated by recent *SOHO*, *Ulysses*, and *Wind* data. *SOHO*/UVCS measurements discovered temperature anisotropies of order $T_{\rm perp}/T_{\rm parallel} \approx 100$, which were interpreted as dissipation of high-frequency, ion-cyclotron, resonance Alfvén waves (Kohl et al. 1998). Habbal et al. (1997) presented the first evidence that the slow solar wind originates in streamer stalks, while the fast wind is ubiquitous in the inner corona. The geoeffective impact of the Sun was demonstrated with coronal mass ejections launched during flares (Dere et al. 1997; Chen et al. 1997a), dramatically recorded with wide-angle cinematic views from the *SOHO*/LASCO coronagraph, leading to alerts in press releases.

Miscellaneous: Also perhaps of astronomical interest is the degree of roundness of the Sun. The latest meridian transit measurements, combined with the solar limb darkening, yield a radius of $R_\odot = 695{,}508 \pm 0.026$ Mm (Brown & Christensen-Dalsgaard 1998). Careful measurements of the EUV limb with *SOHO*/EIT revealed that the polar radius was larger than the equatorial radius, an oddity that was attributed to spicules giving the chromosphere a bumpy surface (Zhang et al. 1998a).

3. XI, KAPPA, ALPHA, AND OTHER DEVILISH DETAILS OF STELLAR STRUCTURE

Stellar structure and evolution are generally put forward as the best example of solved problems in astrophysics. What is meant is that we can write down four differential equations (for dM/dr, dP/dr, dL/dr, and dT/dr), which make use of three auxiliary quantities (κ, the opacity to radiation; ϵ, the rate of energy generation; and an equation of state, each as a function of temperature, density, and composition). Next we solve the equations numerically and evolve them forward through small time steps. The result is sets of stellar models and evolutionary tracks or isochrones that really do look a lot like real stars. It seems unlikely that any fundamental problems remain, except in the realm of star formation, for which, notoriously, we have no theory. This section is, therefore, mostly about details—why is there structure on the red giant and horizontal branches of globular clusters, what happens when stars become fully convective, is there still missing opacity, and so forth?

3.1. Xi, Kappa, and Sigma

Microturbulence, ξ, is the parameter in which we hide our remaining ignorance about the mechanisms that broaden absorption lines in stellar atmospheres (and it may or may not mean anything that you almost never find yourself wanting to use a negative one to fit your curve of growth). It is supposed to represent gas motions on scales smaller than the mean free path of photons. But the models of stellar atmospheres don't actually give the values of ξ that you use in curves of growth for the same stars (Gillet et al. 1998).

The atomic parameters needed for detailed analysis of stellar spectra continue to be assembled from combinations of laboratory data and calculations. They include cross sections for collisional excitation and deexcitation, recombination and ionization, atomic energy levels and even wavelengths (Biemont et al. 1998), and (standing for them all here) *f*-values and opacities that measure the difficulty a photon in a line or a continuum experiences in getting out of the star and on his way to our telescopes. (Bosons are masculine, fermions are feminine, as you will know from large committees, spectator sports, and fraternal lodges.)

That we still need better opacity information, especially for cool stars, is not in doubt (Tripicchio et al. 1997). And "better" nearly always means "more," partly because it is easier to have forgotten something than to have invented it out of whole cloth, and partly because there is still opacity missing in various wavelength regimes, assuming, of course, that you want your model atmospheres to look like the stars they are modeling (Golimowski et al. 1998). The problem becomes acute close to the dividing line between M dwarfs that fuse hydrogen and brown dwarfs that do not, especially when you need to convert to observers' units and decide where real stars fall relative to the line (Luhman et al. 1997; Brocato et al. 1998).

In the brown dwarf regime, dust may (Schultz et al. 1998) or may not (Oppenheimer et al. 1998) be confusing the issue. It is certainly confusing the astronomers, since the two groups are looking at the same star, G1 229B. Artifacts you can achieve with sufficiently odd absorption conditions include apparent metallicities 10 times the correct value (in BAL [broad absorption line] quasars; Hamann 1998) and main sequences depressed 2 mag at a given color (Harris et al. 1998b on dwarf carbon stars). Just as improving his handwriting forced the apocryphal student to learn to spell, better opacities will sometimes force you to do other parts of the physics better as well (Starrfield et al. 1998 on nova explosions).

But the winner of the oddity of the year award in the opacity class is the contribution of H_2 at low temperatures and high densities. The H_2 molecule acquires a modest pressure-induced dipole (can't you just see it clutching a dressing gown around its suddenly separated charge clouds) and thereby adds a blue tinge, in infrared colors, to the coolest white dwarfs (Hansen 1998) and to the coolest main-sequence stars (Chabrier & Baraffe 1997). Both have consequences for designing searches for these elusive stars and for interpreting the numbers you find.

Cross sections for nuclear reactions are one of the (many) things symbolized by σ. 1998 is the first year in many not to have to cope with a paper (or more often a preprint) purporting to revolutionize stellar theory by changing the rate of some key nuclear reaction by an enormous factor. But Brown (1998) notes that beryllium is destroyed in low-mass stars by a subthreshold reaction, whose poorly known spin and parity leave a stray factor of 10 in the reaction rate near 4×10^6 K.

3.2. White Dwarf Anomalies

Normal discussions of stellar evolution begin with the main sequence or star formation and lumber on through to end points. We will lumber backward (and note that there are some other aspects of stellar astronomy in § 8).

The temperature scale for DA (hydrogen atmosphere) white dwarfs suffered a major recalibration in the direction of lower temperatures at a given color over the range 50,000–70,000 K (Barstow et al. 1998). The revision comes from including the effects of previously neglected atmospheric metals. Other temperature ranges are likely to be affected as well; they just haven't done the work yet. Heavy elements are apparently also the reason that half the stars in the GW Vir or PG 1159 instability strip don't pulse. The ones that do have nitrogen-rich surfaces, rather than carbon or oxygen (Dreizler & Heber 1998), and we are not far from being able to use their period change to study white dwarf cooling (O'Brien et al. 1998).

The obvious way to make very low mass (helium-core) white dwarfs is in close binary systems, with mass transfer setting in after the core forms but before it gets hot enough to start helium burning (Jeffery & Pollacco 1998). But a planet or brown dwarf companion that spirals in and merges with the core can also do the job (Nelemans & Tauris 1998), and this is a good thing, because at least a few single, slowly rotating white dwarfs of low mass seem to be out there (Maxted & Marsh 1998). Even the hottest white dwarfs do not quite cool fast enough to see in real time, but the PG 1159 star PG 0122+200 is getting close: a few more years should either establish changes in its oscillation periods or set tight limits.

3.3. Planetary Nebulae

Planetaries, like mayflies, have to do their thing quickly, and somewhere in the Milky Way there is surely a year-old toddler, though we might not recognize it, since turn-on is a rather complex balance between stellar winds and photoionization (Chevalier 1997). He 3-1357, whose emission lines turned on only about 5 yr ago, comes very close. A *Hubble Space Telescope* (*HST*) image shows collimated flow feeding it (Bobrowski et al. 1998). The basic shape of the outflow may already be set before you can even recognize the nebula (Haniff & Buscher 1998).

Marching logarithmically away in time, we hit IC 4997, whose radio morphology has changed since 1995 (Miranda & Torrelles 1998); Vy 2-2, whose expansion age is 213 ± 26 yr (Christianto & Seaquist 1998); and two nebulae with mixtures of carbon-rich and oxygen-rich characteristics, indicating a thermal pulse in the progenitor star in the last 1000 yr (Waters et al. 1998).

3.4. Thermal Pulses, Last Helium Flashes, and Galloping Giants

Multi-shelled circumstellar material (Schroeder et al. 1998; Steffen et al. 1998), chemical anomalies (Frost et al. 1998b), and very rapid changes in stellar colors and visible-light output are all signs that the end is at hand. The example that caught everyone's eye was FG Sge, which has displayed all of these traits over the past century, but is now settling down as a sort of R CrB variable and looks rather dull (Gonzalez et al. 1998; Tatarnikov et al. 1998).

V605 Aql apparently experienced a last helium flash early in this century. The star has been recovered (Clayton & De Marco 1997). It is the nucleus of a previously known planetary nebula, Abell 58, and is now quite faint because of dust obscuration. But it is probably at least as bright as $M_B = -4.7$ and as hot as 50,000 K. The 1921 spectrogram, exposed by Knut Lundmark on the Lick Crossley telescope, has also been recovered, in Sweden, with a little help from Bidelman (1974). Taking one's plates home with one is an old astronomical custom that observatory directors struggled for decades to discourage. You might think that the advent of digital electronic everything would have solved the problem; but the modern equivalent is not archiving your data, and it is also very popular. Incidentally, V605 Aql near maximum light looked like an undimmed R CrB, with an effective temperature near 5000 K.

Most recent is Sakurai's object, which during the year has acquired a planetary nebula (seen as a radio source; Eyres et al. 1998), a variable star designation, V 4334 Sgr, and an expanding literature (Duerbeck et al. 1997, who note that CK Vul in 1671 was probably a similar sort of beast, though no spectrograms have been recovered). V 4334 Sgr has been cooling even faster than FG Sge in its heyday (Arkhipova et al. 1998). Still other objects that may be related are Abell 30 and 78 and the planetary nebula in M22 (Jacoby et al. 1998).

3.5. The Twilight of a Massive Star

Massive stars do everything faster, the most conspicuous recent example having been the post–red-supergiant IRC +10 420, which has gone from F8If in the 1970s to A5 in the 1990s and is probably en route to landing among the Wolf-Rayet stars (Klochkova et al. 1997; Oudmaijer 1998). The process is arguably part of the total phenomenon called "blue loops," meaning that massive stars sashay back and forth across the HR diagram when burning zones cross compositional discontinuities (de Jager 1998; Dohm-Palmer et al. 1997).

Just which stars become Wolf-Rayets is still being sorted out, but a couple of papers agree that it is easier if you are metal rich (Massey 1998; Smith & Maeder 1998). We are not surprised, having concluded that most things are easier if you are rich—not, unfortunately, on the basis of personal experience.

All in all, a massive star is very busy in its last 10^4 yr, establishing asymmetries that may later appear in the supernova explosion (Kastner & Weintraub 1998), storing its angular momentum (Heger & Langer 1998), shedding its outer layers and then turning off its wind (Benetti et al. 1998, on SN 1994aj), and generally readjusting its structure to make a better supernova (Heger et al. 1997; Bazan & Arnett 1998, a 3D calculation with plumes and ribbons).

We all agree, of course, that the last thing a presupernova does to get ready is to build up an iron (etc.) core to the point of collapse. Just where is that point? Well, two modern codes, applied to a 25 $M_\odot$ star of solar composition, find 1.51 and 1.78 $M_\odot$ (Chieffi et al. 1998). There are also differences in the extent of the convective zones and other details.

3.6. The Asymptotic Giant Branch

The eye-catcher here was the report of an OB association in the Large Magellanic Cloud, where most of the bright stars are asymptotic giant branch (AGB) members, including the long-period variables (Kodaira et al. 1998). Somehow, we thought only stars of somewhat lower masses did this. The rest of the members are very bright blue stars. Apparently, to make details on the HR diagram come out right, it is essential to include the effects of radiation pressure (Steffen et al. 1997), a range of initial metallicities (Frogel & Whitelock 1998; van Loon et al. 1998), and mass loss (Frost et al. 1998a). As a side benefit, you also get carbon stars as numerous and almost as bright as we see them, depending on whether $M_{\rm bol} = -6.8$ (Frost et al. observations) and $M_{\rm bol} = -6.5$ (Marigo et al. 1998 calculations) are different numbers.

A last helium flash automatically gives you a second AGB phase (as if one weren't enough). Koesterke et al. (1998) suggest that this may be relevant to the origin of PG 1159 stars with large current rates of mass loss. In this context, $10^{-7}\, M_\odot\, {\rm yr}^{-1}$ is "large."

3.7. The Horizontal Branch

The HR diagram for the globular cluster in your elementary astronomy textbook almost certainly shows a gap somewhere in the middle of the horizontal branch. That is where the RR Lyrae stars live, and this is not what Kravtsov et al. (1997) mean when they ask whether there are gaps in the distribution of HB stars in M79. The study with the biggest sample (Catelan et al. 1998) concludes that many purported gaps simply reflect statistics of small numbers, but that there are some real ones, including NGC 6229, and that they should provide clues to the nature of the second parameter. Ferraro et al. (1998) and Grundahl et al. (1998) agree about the reality and suggest different amounts of mass loss or mixing on the red giant branch as the cause.

The "extended horizontal branch" is extended toward the blue and is a source of excess ultraviolet emission in globular clusters and other old populations (e.g., O'Connell et al. 1997). Eggen (1998a) reported that NGC 6791 is unique among the open clusters of the Galactic disk in having such stars. "Super horizontal branch stars" are fairly common, at least in NGC 6522 (Shara et al. 1998). Their evolutionary status is uncertain, but supposing that they are descended from blue stragglers is attractive because there are such a lot of ways of making those (Ouellette & Pritchet 1998; Preston & Landolt 1998, on mergers and mass transfer, respectively).

A few blue stragglers are also Am stars, which must surely have something to do with the price of beans, but we are not quite sure what, and neither was Andrievsky (1998). Bidelman (1998), on the other hand, has provided a unified hypothesis for the Am, Ap, and blue straggler stars, using processes in close binaries for all of them. He also notes that blue stragglers first show up in an HR diagram from Ebbighausen (1940).

3.8. Pulsating Stars

Cepheid pulsating variables still present a discrepancy between the surface gravities (masses) determined from spectroscopic or pulsational properties and those determined from evolutionary tracks (Luck et al. 1998). There is also considerable scatter in the radii determined from different methods, including the Baade-Wesselink (Bono et al. 1998). The observed relationships among mass, period, and luminosity are not very well fitted by models for some populations (Baraffe et al. 1998), but at least there is no gap in the $N(P)$ distribution (Buchler et al. 1997a). One would expect *HIPPARCOS* parallaxes and proper motions for Cepheids to have had something to say about these issues, but the primary focus has been on getting the best possible zero-point to the P-L relation (rather than on tidying up its internal structure), so as to move on to the Large Magellanic Cloud and the Hubble constant (Feast et al. 1998; Madore & Freedman 1998; Bergeat et al. 1998).

The existence of non-pulsating stars within the Cepheid strip remains puzzling. A good many display small velocity wiggles (0.05–3.0 km s^{-1}) with periods of 60–80 days, as if embarrassment at their non-compliance had caused a bit of nonradial oscillation (Butler 1998). And some good news about Polaris: its fading away as a pulsational variable seems to have stopped in about 1996 (Cox 1998; Kamper & Fernie 1998).

RR Lyrae stars resemble Cepheids in several ways, of which the least inspiring is that the pulsation calculations are an only moderately good match to observed light and radial-velocity curves (Kovacs & Kanbur 1998; Jurcsik 1998). The instability strip for horizontal-branch stars narrows as metallicity increases, but the stars cross slower (Bono et al. 1997). They are the BL Her stars, in case it might have slipped your mind. *HIPPARCOS* data may or may not have clarified any of these issues. Again, analysis has focused on the calibration of extra-galactic distance scales, and the focus has not resulted in a “best-bet” distance to anything (McNamara 1997; Fernley et al. 1998).

The single most important advance in 9 Aurigae variables was the recognition that they should really be called γ Dor stars. This means that we will no longer have to struggle to persuade copy editors that 9 must not be spelled out as nine. In addition, evidence continues to mount that nonradial pulsation is the best fit to their multiple, day-long modes (Zerbi et al. 1997a, 1997b; Ushomirsky & Bildsten 1998). The numbers continue to increase (Poretti et al. 1997; Kaye & Strassmeier 1998; Hatzes 1998a), and the first one in a cluster has been found (Zerbi et al. 1998).

3.9. Red Giants

Why did the star cross the Herzsprung gas? has at least as many answers as Why did the chicken cross the road? Answers to the latter can be found on web sites associated with the name of Paul Erdos (no, we're not going to explain, but see Bar-Ilan 1998 for the details). It is not clear that the right answer to the former question is entirely in hand yet, but Eggleton et al. (1998) point out that having a helium core that grows to the limiting Chandrasekhar-Schoenberg mass (about 10% of the star) is not enough unless you also have a very peculiar equation of state. The discontinuity in mean molecular weight at the edge of the core is also part of the crossing motivation.

The luminosity function for red giants in globular clusters has a bump, which Cassisi et al. (1997) attributed to diffusion. Diffusion is, we suppose, mixing in a modest mood, and so a reasonable lead-in to the ancient topic of composition anomalies among red giants (and other evolved stars) in globular clusters. Many of the patterns are associated with products of nuclear reactions that might reasonably occur in elderly, low-mass stars, especially for the isotopes of CNO, but also sometimes Na, Ne, Al, and products of the *s*-process. Here, extra mixing does seem to be most of the answer (Charbonnel & do Nascimento 1998; Denissenkov et al. 1998; Cavallo et al. 1998; King et al. 1998b). The last group notes that reactions in a somewhat more massive companion, which dumps its wretched refuse and then hides its degenerate head, is also a possible scenario.

But nothing you can do in a low-mass star will account for the correlations in the giants of M92, where europium (a classic *r*-process product) is involved. Langer et al. (1998) hence conclude that the stars must have begun with different heavy element abundances, contributed by supernovae before they formed. Do not, however, try to hold your stock in the metal factory for too long—the diffusion boys may try to sell it short when they get tired of Ap stars.

3.10. Mixing It Up on the Main Sequence

The more mixed-up author caught more than a dozen papers during the year in which a major thrust was that main-sequence stars show evidence of more mixing and earlier mixing than standard models produce. Some things are reduced at the surface, especially lithium, beryllium, and boron (Boesgaard et al. 1998), and the process must start even before hydrogen fusion is fully established (Jeffries 1997). Other things are built up, especially helium (Lyubimkov et al. 1997), and the Sun was not exempt from the process, whatever it is (Basu 1997).

The main competition to extra mixing as an explanation for oddities in stellar surface composition is mass loss (Morel et al. 1997), and it was outvoted, at least on the lower main sequence during 1998. Very massive stars and helium stars are, of course, a different story (Langer 1998; Leushin et al. 1998)

Some other unexpected aspects of main-sequence structure concern convection. Our Sun apparently began its life with a convective core (Venturi et al. 1998). The core formed because abundant carbon was initially converted to nitrogen in a beginning of a CNO cycle, with the usual strong temperature dependence of the reaction rate producing a gradient of energy generation steep enough to drive convection. As soon as all the carbon gets hung up as ^{14}N, the core disappears.

Stars with masses of less than about 0.25–0.30 $M_\odot$ are convective throughout, but nothing much happens to stellar activity (that is, dynamo-generated magnetic fields, angular momentum loss, etc.) there, at least in the Pleiades (Krishnamurthi et al. 1998). There is, however, a glitch in the mass-radius relation for stars in the solar neighborhood that occurs at about this mass, which the authors (Clemens et al. 1998a) do not attribute to this cause.

Nothing much is also what happens at the color, $B-V=0.2$–0.3, where convective envelopes begin to appear (Newberg & Yanny 1998). A sizeable number of other papers during the index year dealt with convection, especially overshoot and alternatives to mixing-length theory (Deupree 1998; Canuto & Dubovikov 1998), who need no fewer than five serious equations to replace one alpha, the parameter of MLT. Bernkopf (1998) actually requires two different values of alpha at different places in his stars. But we must hurry on to earlier evolutionary phases, or we will never come back the previous night.

3.11. Before the Beginning

Young stellar objects are not as bright as they used to be. The maximum achieved by a 0.5 $M_\odot$ star any time from class 0 to the main sequence is 0.4 $L_\odot$, down from 3 $L_\odot$ in earlier calculations (Myers et al. 1998). Among T Tauri stars, the difference between the classical ones and the weak-lined ones is not (or not always) an evolutionary sequence. In the 1–3 Myr old cluster IC 348, Herbig (1998) finds that the two classes are, on average, the same age. The WWTTs are, however, more concentrated to the cluster core, which might suggest a loss of outdoor clothing in tidal encounters.

T Tauri stars are often spotted, so that one can say something about their rotation. It is differential, with what Johns-Krull & Hatzes (1997) call "anti-solar differential rotation." This means that whether the poles or the equator is faster is backwards from the Sun. You have half a sentence to remember which way it goes for the Sun, before we hop on to Hatzes (1998b) and Ruediger et al. (1998), who explain, or at least describe, which sort occurs at which rotation periods, and other correlations with stellar properties.

Among more massive pre–main-sequence stars, many Herbig Ae/Be stars have disks, as pre-MS stars should (Mannings & Sargent 1997), but it is not entirely clear that they have the right surface gravities for their expected position on an HR diagram (Kovalchuk & Pugach 1997). For once, the *HIPPARCOS* data help. Van den Ancker et al. (1998) report absolute magnitudes for 44 examples and find that not only are the stars perched properly above the MS, but also the most variable ones are farthest from the zero-age main sequence.

3.12. Star Formation

When you describe star formation to a class of undergraduate science majors, you always begin by deriving an expression for the Jeans mass. It was, therefore, a surprise to read that the clumps in seven giant molecular clouds have a power-law mass distribution from 10^{-4} to 10^{+4} $M_\odot$, with no sign of any glitch or discontinuity at the Jeans mass (Kramer et al. 1998b). The importance of magnetic fields in the substructure of star-forming clouds was, however, affirmed during the year (Schleuning 1998). A mild rumble of dispute continues about the extent to which ambipolar diffusion is responsible for removing excess field from cores that are trying to contract. Important (Li 1998; Ciolek & Mouschovias 1998); unimportant (Nakano 1998), said the king, trying to figure out which sounded better. Zweibel (1998) meanwhile said that the process is important because it drives a new instability that in turn leads to turbulence and accelerated fragmentation in molecular clouds.

Other words that go with star formation (usually as adjectives), and for which observations provide some evidence of importance include:

- turbulence (Goodman et al. 1998; Lis et al. 1998)
- hierarchical (Efremov & Elmegreen 1998)
- dynamical (and non-hierarchical) fragmentation (Whitworth et al. 1998; Klessen et al. 1998, who predict that fragmentation will make a power-law distribution of stellar masses, while processes dominated by the Jeans mass will make a log-normal one)
- triggered; to which one can only say, some of them are (de Boer et al. 1998) and some of them aren't (Braun et al. 1997); both, as it happens, in the LMC
- episodic; undoubtedly, but it shows only in dwarf galaxies (Hurley-Keller et al. 1998; Gallagher et al. 1998)
- bar driven, no (Perea et al. 1997) or yes (Boeker et al. 1997), and
- cooling flows, yes; Lemonon et al. (1998) present a reasonably clean case for Abell 2390, based on infrared fluxes seen by ISOCAM; some indirect evidence in color gradients and line strengths, suggesting that only the relatively small fraction of the gas that gets into emission-line regions (cool and dense) forms stars, is shown by Cardiel et

al. (1998). And we still don't know what becomes of the rest (Ap94, § 10).

Sober truth is that star formation remains a heavily empirical subject, though the observational empire (no, the words are not cognate) can sometimes be remarkably informative. Consider how many theorists have labored hard to produce relaxation (odd, that) in star clusters, so that the biggest stars would find their way to the center. Apparently, the massive stars simply started out there in many cases (Hillenbrand & Hartmann 1998 and Bonnell & Davies 1998 on Orion; Fischer et al. 1998 on NGC 2157; Su et al. 1998 on M 11; Chen et al. 1998a on NGC 4815; Raboud & Mermilliod 1998 on NGC 6231). Bonnell et al. (1998) have put forward a mechanism for the formation of stars above 10 $M_\odot$ from collisions and mergers of intermediate ones. The model accounts both for central concentrations and for the most massive stars being formed only in big, dense clouds.

The Bonnell et al. (1998) picture also predicts lots of close (tidal capture) binaries. Fragmentation, on the other hand, makes lots of wide binaries (Nelson 1998; Sigalotti 1998), with the distribution of mass ratios that is seen, at least, in the Hyades for binaries with $a = 5$–50 AU (Patience et al. 1998). And we recorded a dozen other papers under a heading "one, two, many," addressing the formation of binaries, singletons, and small groups, selecting out here, perversely, a couple that deal specifically with triple systems. These indicate that a good deal of post-formation dynamical evolution goes into determining the populations we actually see (Valtonen 1998; Tokovinin 1997).

Is this the place to put our anthropologist and native stories? "One, two, many" is, of course, the way very primitive peoples are supposed to have counted; hence the Neanderthal chemist who studied the series "methane, ethane, paraffin." Two other favorites end "ask him the word for index finger" (on the use of native informants in language learning) and "did you know they are serving free beer in the village?" (on how to deal with the tribes of liars and truth tellers).

3.13. Some Really Bright Stars

Alpha CrB is the only "alpha" with total eclipses. It also displays apsidal motion (Schmitt 1998). Alpha Ari and Alpha Cas have revealed their limb darkening directly to a three-element optical interferometer with closure phase (Hajian et al. 1998, and we hope keeping it closed prevented some of the embarrassment the stars might otherwise have felt). Alpha Cyg variables may all be periodic, though the data Sterken et al. (1997) present are for a mere Zeta (Sco); and all evolved massive stars are Alpha Cyg variables (van Genderen et al. 1998; and therefore Socrates is mortal?).

Alpha Orionis has convective *hot* spots in an interferometer image (Wilson et al. 1997a) and large convective cells in a VLA radio image (Lim et al. 1998). Alpha Cen has distinctly nonsolar composition, with $[\mathrm{CNO/Fe}] = +0.24$ (Neuforge-Verheecke & Magain 1997).

Beta Ceti is one of a small handful of single X-ray stars in its class (M III), according to Maggio et al. (1998) and Huensch et al. (1998). Beta Lyrae has bipolar outflow (Hoffman et al. 1998). Well, to quote the chap who threw up after breakfast every morning, doesn't everybody? Beta Orionis is experiencing both infall and outflow (Israelian et al. 1997). Beta Cephei is the prototype of the Beta Cepheid variables, and there are at least a few in Cyg OB2 (Pigulski & Kolaczkowski 1998). Beta Crucis is a Beta Cepheid, and a fairly complicated, binary one at that (Aerts et al. 1998). Delta Ceti is also a Beta Cepheid, and if the pulsation is driven by opacity, its mass is 10.6 $M_\odot$ (Cugier & Nowak 1997).

Beta Pictoris, as you may have heard, has a dust disk. If you hadn't heard, at least 14 papers during the year were anxious to tell you about it. We note only a model for warping the disk late in life, which might permit the formation of non-coplanar planets (Armitage & Pringle 1997). Not in our backyard solar system, if you don't mind.

Gamma Cas is the secondary of a bright X-ray source, and whether the primary is a white dwarf or a neutron star is still being disputed (Kubo et al. 1998; Smith et al. 1998b). Gamma Cygni experienced a major outburst in the 1600s and currently has a spectrum more complex than it was 60 yr ago. In other words, it acts a good deal like Eta Carinae (Markova & de Groot 1997; Najarro et al. 1997).

This has the happy effect of allowing us to skip Delta Scuti stars (oh, all right; they show a period-luminosity relation in *HIPPARCOS* data; Petersen & Høg 1998; Antonello & Pasinetti Fracassini 1998) and a few other intermediate letters and go straight on to Eta Carinae, or at least a subset of the dozen or so papers that discussed it. It had a second outburst in 1890, almost as powerful in kinetic energy as the 1843 one (Smith et al. 1998c; Smith & Gehrz 1998). Since then, it has been quite active in the bands we call radio (Duncan et al. 1997), X-ray (Corcoran et al. 1997), and theory (Dwarkadas & Balick 1998a; Pittard et al. 1998, on the X-rays as colliding winds). The star may actually be a binary (Davidson 1997) or even a triple (Livio & Pringle 1998), though it is not clear that having company made much contribution to the main events of 1843 (incidentally, it takes a large history book to find anything that happened in 1843 more exciting than the eruption of Eta Carinae).

3.14. Binary Evolution

The common-envelope binary phase, responsible for casting out both mass and angular momentum to make short-period evolved systems, is itself a remarkably short period, only a few years to lose 40% of the eventual total mass excretion (Sandquist et al. 1998). Two X-ray binaries have probably been caught close to the time when they will reappear as binary pulsars: Aquila X-1 has begun its propeller phrase to shut off accretion and turn on rotation powering (Campana et al. 1998), while SAX J1808.4−3658 (XTE J1808−369) is the first low-mass X-ray binary to reveal a well-defined, unique rotation period. It is only 2.3 ms, so the end of mass accretion will signal the appearance of a binary millisecond pulsar (Wijnands & van der Klis 1998; Chakrabarty & Morgan 1998; White 1998).

Every year we intend to write a comprehensive section entitled "all periods change faster than you expect them to." And every year we fail. But an explanation in terms of magnetic cycles may even apply to the eclipsing binary millisecond pulsar J2051−0827 (Stappers et al. 1998).

4. NU IS FOR NEUTRINO

At least in Yiddish, "Nu?" is a question. Perhaps also in physics. In recent years, the dominant question has been, What are the rest masses of the three known species of neutrino? Closely related questions concern the possible role of stable or decaying neutrinos as dark matter and as promoters of the formation of large-scale structure in the universe, neutrino contributions to the ejection of the envelopes of massive stars in Type II supernovae, and the long-standing shortage of observed neutrinos coming from the Sun compared to predictions using the standard model.

Ap95, § 5, touched on neutrino contributions to supernovae (for which their mass is not a major factor). At that moment, it seemed as if the worrisome problem of how to eject the stellar envelope had been solved by three-dimensional, neutrino-driven convection. This may still be so, but the latest word is negative. Mezzacappa et al. (1998) report that their neutrino-driven convection is vigorous, but dynamically unimportant, even for Newtonian gravity (a favorable prevarication) and a 15 $M_\odot$ star. It just doesn't blow up.

Neutrinos as dark matter appear very briefly in § 11.4 in among the other candidates, but we note here that using them to make supermassive objects at the centers of galaxies, in lieu of black holes, would require rest masses of at least 12–14 keV, which is not what the laboratory experiments have been saying this year (Tsiklauri & Viollier 1998). A decaying neutrino with a rest mass near 25 eV (cf. Ap91, § 11.6) also does not exactly jump out at you from the 1998 literature, but the emission line it will leave at 915 ± 7 Å might when the EURD instrument finishes its mission on *Minisat-01* (Sciama 1998). EURD is clearly "extreme ultraviolet something or other," and Bharadwaj & Sethi (1998) would say that this sort of decaying neutrino can already be excluded as a contributor either to intergalactic ionization or to the formation of large-scale structure.

Three separate lines of evidence nevertheless strongly suggest non-zero rest masses, probably for all three neutrino species (or more!). All three are of the sort that require us to express the findings in the form of two slightly odd parameters: (1) the square of the difference in masses between two species, and (2) $\sin^2 2\theta$, where θ is generally called the Weinberg angle. The first new result concerns muon neutrinos made at Los Alamos National Laboratory and requires that they be able to oscillate (change) into electron neutrinos at a rate that could be explained by a fairly wide range of mass differences and Weinberg angles, though $\Delta m^2 = 0.1$ eV^2 looks good and 10^{-3} eV^2 is really off the scale (Athanassoula et al. 1998).

Second, and accompanied by the pressiest releases, was an announcement from the owners and operators of the Superkamiokande detector in Japan that they had confirmed the disappearance of muon neutrinos made in the upper atmosphere when they must travel a long way to get to the detector (which means going through the earth, but it is transparent for this purpose). The missing ones are not becoming electron neutrinos, which Superkamiokande also sees, and must be rotating into τ neutrinos or some previously unknown species separated by Δm^2 in the range 0.5–6 × 10^{-3} eV^2 and a largish Weinberg angle (Fukuda et al. 1998a, a *Physical Review Letter* that stretched to six pages because the names of the 120 authors occupied more than one!).

This brings us, thirdly, back to the Sun. Data continue to accumulate, with 26 yr of Homestake mine results (the ^{37}Cl detector, or Davis experiment) summarized by Cleveland et al. (1998), and the first year of Superkamiokande results, pertaining only to the B^8 (highest energy) neutrinos summarized by Fukuda et al. (1998b). There is no doubt that each detected flux is less than the standard model prediction (e.g., Bahcall et al. 1995), by factors of at least 3 and at least 2, respectively. There is no evidence, so far, for time variability in what Superkamiokande sees, and that in the Homestake data is in some dispute (Walther 1997; Sturrock et al. 1997). No new numbers for average detected flux or variability in the gallium experiments appeared during the index year. These are the only detectors that can see the neutrinos from the commonest form of hydrogen fusion in the Sun, the ppI chain. Gallium, unfortunately, is a good deal more expensive than cleaning fluid and presents temptations to nonscientific uses.

The solar data can, in any case, also be explained by a range of combinations of Δm^2 and $\sin^2 2\theta$. The only problem is that, putting together the Los Alamos, Superkamiokande, and solar neutrino data sets, we have more equations than unknowns if only three sorts of neutrino participate, and no consistent set of numbers can be found. Thus, either the physics of neutrino oscillation must be rather different from what is generally assumed, or there must be (at least) a fourth sort of neutrino into which one or more of the known ones can disappear, but which does not show up either as a contributor to energy density in the early universe or as a channel into which the Z boson can decay (Suzuki 1998). Some of the possible values of Δm^2 will affect the amount of large-scale structure that should be seen by the Sloan Digital Sky Survey, giving us the potential for either partial resolution of the current confusion, or a fourth value inconsistent with any of the others (Hu et al. 1998b).

5. PHI IS FOR PHASE: THE INTERGALACTIC AND INTERSTELLAR MEDIA

5.1. Intergalactic Gas

Once it was thought to close the universe and produce the X-ray background. Then, for a while, there wasn't any, because intergalactic neutral hydrogen would have absorbed the radiation from QSOs emitted shortward of 1216 Å (the Gunn-Peterson limit), and ionized hydrogen would Compton-distort the spectrum of the cosmic background radiation by more than the *COBE* data allow. Then there was some, but it was in little clouds, producing absorption lines in the spectra of QSOs and with dubious relationships to galaxies. And then there was the "helium Gunn-Peterson effect."

Where are we in 1998? Well, the general absorption due to ionized helium (Ap94, § 5.9) continues to look like diffuse gas and not just the sum of clouds (Zheng et al. 1998). And diffuse absorption by hydrogen has probably been seen, depressing the continuum about 11% in QSOs studied by Khersonsky et al. (1997) and by Fang et al. (1998). Analysis indicates that though there is indeed a diffuse medium in at least some directions and some redshifts, this is not where most of the baryons are.

Modelers have reached the same conclusion (Zhang et al. 1998d). The gas is filamentary early on and then more like lumpy (Ostriker & Evrard 1998; Quilis et al. 1998). And, observations and calculations concur, it is mostly at 10^5–10^6 K (Kirkman & Tytler 1997; Perna & Loeb 1998; Mittaz et al. 1998). That is, it nestles just between the temperatures at which it would either absorb too much Lyα or radiate too many X-rays. EUV and X-ray absorption by ions like O VIII may be the best tracer. The gas, when first reionized at $z = 5$–10 by something with a spectrum like a QSO, would have been at about 2×10^4 K (Haehnelt & Steinmetz 1998), and further heating occurs at the same time structure develops.

5.2. Intergalactic Everything Else

What else is between the galaxies? Dust, at least in clusters, according to Arnaud & Mushotzky (1998) and Stickel et al. (1998), reporting on two different clusters (and it strikes one as remarkable that dust survives amid such hot gas!). But there is remarkably little neutral hydrogen, even in clusters, and even in "cooling-flow" clusters, as has been seen (or rather, not seen) most recently by O'Dea et al. (1998). And not much either in superclusters, where the density is not much more than the cosmic average (Molnar & Birkinshaw 1998).

Magnetic fields are also pretty puny. Within clusters, not much more than the 0.3 μG needed to make the radio synchrotron features we see (Henriksen 1998; Ensslin & Biermann 1998). Limits are still tighter between the clusters, at least for coherent fields and if there are electrons out there to produce Faraday rotation, nanogauss or less, says Kolatt (1998).

There are, of course, photons. In the infrared, the limits that come from seeing Markarian galaxies 421 and 501 at TeV energies are, at very most, what we would expect to be coming from galaxies and QSOs, and perhaps rather less (Biller et al. 1998; Stanev & Franceschini 1998; Haarsma & Partridge 1998; see also § 6.1). As for ultraviolet photons, star-forming galaxies make a great many, but very few get out (Deharveng et al. 1998; Devriendt et al. 1998). Thus the clouds that make QSO absorption lines see essentially what is radiated by the sum of the QSOs themselves (Songaila 1998; Theuns et al. 1998; Das & Khare 1998).

Just about every previous Ap9x has asked whether one can add up known sources of X-rays and gamma rays to account for the backgrounds seen; and if so, which sources. The answer is still indeterminate, with at least 13 papers on the X-ray background and a handful on the gamma rays, not all reaching the same conclusions.

5.3. Interstellar Materials

We now detect diffuse material at distances from a few pc to $z = 4$, and at temperatures from less than 3 K to 10^8 K or more. It became clear a number of years ago that interstellar material tends to accumulate in several discrete phases, because of the way cooling processes depend on temperature and density and because gases in contact generally establish pressure equilibrium. Thus, one has molecular, cold neutral, warm neutral, ionized, and coronal gas in many places, and there is at least a strong family resemblance among the phases seen in different galaxies (Kim et al. 1998a, 1998b and Wakker et al. 1998 on the LMC; Wiklind & Combes 1997 on a galaxy at $z = 0.25$; Dahlem 1997; Spaans & Carollo 1998; Illarionov & Igumenshchev 1998, giving models).

5.3.1. A Word or Two about Dust

It's fluffy. That is, the volume occupied and the surface area presented to photons are larger than you could get from normal, known abundances of heavy elements (especially carbon), unless there is a good deal of empty space distributed through the grains (Fogel & Leung 1998;

Kimura et al. 1997 on circumstellar production; Vaidya & Gupta 1997 on fitting extinction curves). There are also implications for the effects of radiation pressure from stars on their surroundings (Wolff et al. 1998) and for X-ray scattering (the Slysh mechanism, so called because it was discovered by Overbeck; Smith & Dwek 1998).

A given galaxy, or even a given molecular cloud, can have dust at a range of temperatures—in fact, *must* have to account for the full range of infrared emission (Kramer et al. 1998a). But the average grain seems to spend half its life being transiently heated above the equilibrium temperature by stray UV photons and collisions and the other half transiently cooling (Manske & Henning 1998; Duley & Poole 1998). We suspect the same guy is in charge who controls the temperature in our seminar room.

The coldest dust is particularly important because it is easy to miss in emission studies, and yet, of course, it does its full fair share of absorbing. Opinions on how much is around seem to range from little (Lagache et al. 1998, who find nothing below 18 K in DIRBE and FIRAS data for the Milky Way) to lots (Alton et al. 1998; Kruegel et al. 1998 with *ISO* data; Odenwald et al. 1998, who note that you need a submillimeter survey to get a complete inventory).

A proper inventory of cold dust is essential to answering the elderly question of how opaque are the disks of spiral galaxies when seen face-on. The final answer to this is clearly not in, and there may be no final answer, in the sense that A_v, or whatever wavelength appeals to you, versus radius in a spiral disk varies a great deal from one galaxy to another, and, probably, between arms and interarms in each galaxy. Meanwhile, everybody who reported this year seems to have found A_v between 0.1 and 0.5 mag for locations like ours, even if in other galaxies (Buat & Burgarella 1998; Trewhella 1998; Xilouris et al. 1998; and undoubtedly we have missed some).

A related question is the extent to which we are failing to find high-redshift QSOs because they are obscured by dust, either their own or in galaxies and gas clouds along the way. Most of the 1998 answers to how much dust gets in the way of high-z QSOs seem to be in the range "oodles." Sometimes it is internal (De Brueck et al. 1998, using colors and optical polarization in one QSO; Ivison et al. 1998 from submillimeter emission in a high-redshift radio galaxy). And sometimes it is intervening (McLeod et al. 1998 on colors of lensed quasars; Boisse et al. 1998 on the effects of damped Lyα; Carilli et al. 1998a, noting that red quasars are more likely to show 21 cm absorption). Benn et al. (1998) conclude, alternatively, that redness is a result of emitting red light, and dust is not a major factor. The issue was first raised in recent years by Webster et al. (1995).

Dust made in odd places is likely to be odd in composition (Evans et al. 1997 on novae; Gordon & Clayton 1998 on the SMC, and many others). But even everyday dust changes in composition as the cloud or disk it belongs to ages (Gail 1998 on protoplanetary disks; Cecchi-Pestellini & Williams 1998 on carbon-rich materials; Chiar et al. 1998 on ice mantles).

5.3.2. *Probably Dust*

Absorption, scattering, and emission by interstellar material produces enough puzzles, even of identification, to keep the proverbial seven spectroscopists with seven brooms busy for at least seven years. Three that have been with us for a long time without complete resolution are the 2175 Å feature, "extended red emission," and "unidentified" diffuse (infrared) bands.

The 2175 Å feature (called 2200 Å at slightly poorer resolution) is ubiquitous in the Milky Way, though not always of the same amplitude (Megier et al. 1997), but is largely missing from the Small Magellanic Cloud (Gordon & Clayton 1998), while it does show up in the sum for QSO intergalactic absorption systems (Malhotra 1997). Lab data suggest that grain size and shape are at least as important as composition in determining the central wavelength (Schnaiter et al. 1998). But other authors are equally certain they know what is responsible, including naphthalene (Beegle et al. 1997) and carbon onions (Henrard et al. 1997).

"Extended red emission," originally found in a few dense regions like the Red Rectangle, now means "extended," perhaps even ubiquitous, in space (Gordon et al. 1998 using data from *Pioneer 10* and *11* to avoid confusion from zodiacal dust) as well as in wavelength. Among the substances credited are hydrogenated amorphous carbon (Darbon et al. 1998; Szomoru & Guhathakurta 1998) and silicon nanocrystals (Ledoux et al. 1998b; Witt et al. 1998).

The diffuse interstellar infrared absorption bands were discovered by Gillett (1973) and have been identified ever since. Unfortunately, they have been identified as many different things by many different observers, theorists, and hangers-on. Cami et al. (1997) suggest that there are actually two families of bands, somewhat anti-correlated and therefore with different carriers. Thus at least two models can be right. This does not guarantee that they are the most popular two, or even in the current pool, unless your two choices are PAHs (polycyclic aromatic hydrocarbons) and not PAHs. The pro-camp includes Cook & Saykally (1998, lab data), Lemke et al. (1998, detection in local cirrus), and Manske & Henning (1998, detection in the starburst infrared emission from NGC 6090). The con-camp find that PAHs are quickly changed into other things, at least under laboratory conditions, by the addition (Snow et al. 1998) and subtraction (Ekern et al. 1997) of hydrogen atoms.

Schutte et al. (1998) recommend PAHs plus solid CO_2, water ice, and much other stuff (based on *ISO* data). Lacy et al. (1998a) recommend similar multiplicity for the 10 μm "silicate" feature, including ammonia ice. The responsible stuff is formed as part of normal dust assemblage, since the features are seen in AGB stars by *ISO* (Justtanont et al. 1998). And they are found in spectra of large galaxies in the Virgo cluster, but not the dwarfs (Boselli et al. 1998).

Optical astronomy has had unidentified interstellar absorption bands for much longer (permitting much more creative explanations, including viruses and still more complex molecules). Whatever they are, the strength of the absorption is only moderately well correlated with A_v, the official signature of dust (Galazutdinov et al. 1998). And, moving on out to the far-infrared and submillimeter regime, we find more absorption structures that can be at least roughly matched by laboratory spectra for an assortment of substances, provided that you allow for two-photon processes (Mennella et al. 1998).

5.3.3. Molecules at High Density

The newsiest release item here was the discovery of -5% to $+17\%$ circular polarization in the infrared radiation from the Orion Molecular Cloud 1 (Bailey et al. 1998). Laboratory data indicate that exposure to circularly polarized ultraviolet radiation can turn a racemic mix of organic molecules into one with an excess of one enantiomer over the other, by selective destruction. Thus, If you can extrapolate from IR to UV, and If the solar system formed in a region with such circular polarization of the light (coming from outside), then one has a possible way of accounting for a predominance of, for instance, left-handed amino acids and right-handed sugars (the ones we use)—or, of course, the contrary—and also for the apparent excess of left-handed amino acids in the Murchison meteorite (Ap97 § 7.1). The necessary assemblage of Ifs is large and complex, and, while this is not exactly evidence, Stanley Miller, a pioneer student of organic molecular formation in the primitive earth, says he doesn't believe it.

Other things that may or may not be going on in the dense molecular clouds include (a) CO swallowing more than its fair share of ^{13}C (yes, according to Lucas & Liszt 1998; no, at least in Orion, according to Keene et al. 1998), (b) pressure support from Alfvén waves (Martin et al. 1997 say yes, and we have no reason to disagree), (c) significant contributions to dark matter (De Paolis et al. 1998; Combes & Pfenniger 1997) and, while you are likely to have the same reservations we do, it is ultimately an observational issue, probably best resolved at submillimeter wavelengths, (d) enormous numbers of still unidentified absorption lines, 337 of 1730 between 0.8 and 1.0 mm according to Nummelin et al. (1998), (e) some, but not all, molecules dividing themselves between gas and dust phases (Dartois et al. 1998; Boudin et al. 1998—*ISO* data again), and, of course (f) photodissociation, though only at the edges and responsible for allowing us to go on to other phases with dozens of GMC papers still uncited (Petitpas & Wilson 1998; Gomez et al. 1998; both addressing coexistence of molecular, neutral, and ionized phases).

5.3.4. Less Dense Molecular Gas

Diffuse and translucent clouds differ only slightly in their balance of gas and dust (Sofia et al. 1998). This became an "annoyance highlight" as the denser author tried to figure out which was which. It turns out that the translucent ones are denser. High-latitude clouds tend to be of these transitory types (Sahu et al. 1998b), and they are not much given to star formation, at least in the Milky Way (Palla et al. 1997). BUT not all high-latitude clouds are puny things in NGC 891, a frequently advertised Milky Way twin, which has dust and gas structures of $10^6\ M_\odot$ extending 1.5 kpc from its plane (Howk & Savage 1997).

5.3.5. Neutral Hydrogen

Here is a phase that can have three subphases, at least in the reflection nebula NGC 7023. They are marked by carbon in the form of CO, C I, and C II (Gerin et al. 1998). H I is the most abundant phase, winning out over H_2 by about 5 to 1 in the root mean square average spiral (Casoli et al. 1998). This is true even in spiral arms, where the H I is busily condensing into H_2 clouds (Heyer & Terebey 1998). The warm H I (4000–7000 K) occupies more space (filling factor 0.4) than the cool H I ($T \lesssim 150$ K), but, being less dense, does not contribute most of the mass (Carilli et al. 1998c).

H I extends to even larger distances from the Galactic plane than molecular gas, again in NGC 891, with a halo up to $|z| = 5$ kpc (Swaters et al. 1997). Ours gets almost as high, in a diffuse sort of way (Kalberla et al. 1998, reporting a survey from Dwingeloo).

The question of whether the ratio of deuterium to hydrogen varies in our Galaxy is addressed via the H I (and Lyα absorption from the two isotopes). The answer remains a good, firm, positive maybe (Dring et al. 1997).

5.3.6. Ionized Hydrogen: H II

This is the traditional sort of 10^4 K stuff found in Stromgren spheres, though a great many of the brightest ones are density bounded (which is not what Stromgren had in mind; Rozas et al. 1998). The gas can also be shock ionized rather than photoionized, but then the sphere is turned inside out (Pynzar & Shishov 1997).

H II regions turn on first as emitters of infrared from hot dust (Testi et al. 1998); then the radio peeks out (Faison et al. 1998; Johnson et al. 1998; Molinari et al. 1998), and they are entitled to be called ultracompact H II regions, some of which can be very big (Turner et al. 1998, on those in the starburst galaxy NGC 5253). Finally, visible light finds it way out, and the region gets its picture taken for elementary astronomy books and has its elemental abundances measured (Perez 1997).

Because hot stars normally form in sizable groups, their zones of ionization can merge to make giant H II regions. Crowther & Dessart (1998) have examined NGC 3603 and 30 Doradus and conclude that about 100 OB and Wolf-Rayet stars in each are contributing more ionization and kinetic energy than is likely to be added by the stars' eventually becoming Type II supernovae.

5.3.7. Ionized Hydrogen: Coronal Gas

This is the stuff at $T = 10^5$–10^6 K that one knew had to be inside supernova remnants, but which eventually also turned up in the form of O VI absorption lines in ultraviolet spectra of stars in the halo of our Galaxy. The continuum around 1000 Å has also been seen (Korpela et al. 1998), and this gas is the primary contributor to the local soft X-ray background (Snowden et al. 1998). At various times in the past, observers and theorists have concluded that this hottest phase should have expanded, so that overlapping old supernova remnants eventually filled the largest fraction of interstellar space. This no longer seems probable. The local filling factor is less than 20% (Ferriere 1998). And most of the highly ionized gas at high latitude is also in discrete, isolated SNRs (Shelton 1998).

Our own particular corner (or spheroid) of interstellar space is, nevertheless, a region of tenuous hot gas, generally called the local superbubble. The edges are quite irregular (Park et al. 1997), and we see its contributions to the X-ray background at 0.25 keV (Snowden et al. 1998), to the scintillation of pulsars (Bhat et al. 1998), and to the structure of the H I, infrared, and radio-continuum emission from around its edges. Shocks there could perhaps have triggered star formation in the Orion and Monocerus regions (Heiles 1998). Papers in previous years have suggested that the local superbubble might be the remnant of some particular supernova, responsible, e.g., for a particular pulsar or H II structure (like the Gum Nebula). This year's geewhizzery is that at least some such structures could be the result of gamma-ray bursts (§ 6.3).

6. GAMMA RAYS AND THEIR SOURCES

Any photon is entitled to call itself a gamma ray, but what is meant here are ones from PeV or TeV down to 100 keV or thereabouts (that is, photons captured by devices funded by gamma-ray programs rather than X-ray programs).

6.1. The TeV Sources

Ap97, § 11.4 left us with five of these, three pulsar-powered nebulae (surrounding the Crab, Vela, and PSR B1706−44) and two very nearby blazars, Mrk 421 and 501. All are still with us, and the inventory has increased slightly. The spectrum of the Crab source indicates that the magnetic field near the center of the nebula is only about 1.6×10^{-4} G, half to a third of the equipartition and minimum-energy values (Hillas et al. 1998). A couple of modelers (Aharonian et al. 1997; Finley et al. 1998) agree that the best bet for getting photons up to these energies is inverse Compton scattering by relativistic electrons that one already knew had to be there to radiate synchrotron X-rays. Remember that even the X-rays from the Crab Nebula are polarized. Whether the photons start out as part of the nebular supply or as infrared background remains to be sorted out.

On second thought, perhaps these three sources should have been described simply as supernova remnants rather than as pulsar-driven nebulae, because the fourth example is SNR 1006 (Tanimori et al. 1998, reporting CANGAROO data). No one has ever seen a pulsar therein, and SNR 1006 is generally blamed on a Type Ia supernova. The discoverers credit the photons to inverse Compton scattering of microwave background photons by electrons up to 10^{14} eV. Buckley et al. (1998c) report only upper limits from the Whipple observatory for TeV photons from six other nearby remnants, including IC 443 and W44. They believe that this casts doubts on the ability of SNRs to accelerate cosmic rays. Notice that IC 443 is the prototype of SNRs interacting with nearby molecular gas, a possible cosmic ray accelerator site (§ 9).

The high-mass X-ray binary Cen X-3 (whose EGRET flux is unusually variable) just missed the cut, being detected up to 0.4 TeV by the Durham Mark 6 Cerenkov telescope at Narrabri (Chadwick et al. 1998). You could regard this either as a failing on the part of Cen X-3 or as a triumph on the part of the instrument builders, who have managed to push Cerenkov techniques down to these lower energies.

Among the blazar sources, both Mrk 421 and Mrk 501 are prone to flaring (Zweerink et al. 1997; Catanese et al. 1997), with some correlations across a wide range of wavelengths and marginal evidence for a 12.7 day quasi-periodic oscillation in the flux from Mrk 501 (Hayashida et al. 1998, using the Dugway prototype Cerenkov telescope). Both spectra sag gently below a pure power law at the highest energies seen (Samuelson et al. 1998; Stecker & de Jager 1998); this is probably a sign that photon-photon interactions with intergalactic infrared radiation are close to killing off the sources and would keep us from seeing either higher energy gamma rays or more distant active galaxies. The implied infrared background is, in fact, already rather less than what one had thought was out there (Biller et al.

1998). The TeV sources do not absolutely have to have narrower beaming or more highly relativistic jets than other (EGRET) active galactic nuclei (AGNs), but it doesn't hurt (Celotti et al. 1998; Salvati et al. 1998).

A third (almost) TeV blazar is 1ES 2344+514 (Catanese et al. 1998). It is the next closest, at $z = 0.044$, after the two Markarian galaxies, and has actually been seen only to 0.35 TeV and only when flaring. Neither it nor Mrk 501 are EGRET sources, though Mrk 421 is. The spectral differences reflect, on the one hand, more serious damage to the most distant source inflicted by intergalactic infrared photons and, on the other hand, some difference in the emission processes, affecting the ratio of TeV (Cerenkov) to GeV (EGRET) flux. 3C 66A has been reported as the first addition to the inventory from the Cerenkov detector in the Crimea (Neshpor et al. 1998).

The natural source for the AGN gamma rays (as for the SNR ones) is Compton upscattering of lower frequency photons by the electrons you know have to be there to produce X-ray synchrotron (Xie 1998). Mrk 501, whose synchrotron emission extends up to 200 keV, would seem to be a very clean case (Pain et al. 1998), but Mannheim (1998) nevertheless prefers radiation by relativistic protons. Astronomers have been (sporadically) looking for proton synchrotron radiation at least since the grayer author was a graduate student.

Come to think of it, however, the search for radiation that could be definitely blamed on inverse Compton scattering has gone on just about as long. X-rays from rich clusters of galaxies (which turned out to be mostly Bremsstrahlung) were an early false alarm. In fact, a C^{-1} component has only just been seen from a few clusters, associated with a central radio source (Limaneto et al. 1997 on NGC 685) or in the ultraviolet (Hwang 1997; Sarazin & Lieu 1998). They note that the responsible photons belong to the cosmic microwave background (CMB), as was originally postulated for cluster X-rays (Felten & Morrison 1966).

The year also saw several claims for "the first clear case of inverse Compton radiation in extragalactic contexts" associated with individual radio galaxies (Kuncic et al. 1998 on gigahertz-peaked sources; Bagchi et al. 1998 on steep-spectrum sources; Tashiro et al. 1998 on the large radio doubles Cen B and Fornax A). Hardcastle et al. (1998), making no priority claims, remind us that not seeing X-rays from optical hot spots in radio lobes means that C^{-1} is not occurring, and that this sets a lower limit to the local magnetic field, sometimes rather stronger than the equipartition value. Their examples are 3C 33, 3C 111, and Cygnus A.

6.2. The MeV to GeV Sources

This is the regime that has been greatly enriched by photons gathered in the four instruments of the *CGRO*. These are EGRET (highest energy), OSSE, COMPTEL, and BATSE (the one that sees bursters).

At last count, there were six pulsars (or closely associated stuff) seen by EGRET above 100 MeV and one picked up only by OSSE at somewhat lower energies. There were also at least eight theoretical papers during the year, modeling the emission in various ways. Dyks (1998) is not necessarily the best of the lot, but it has a very nice summary of the observed properties of the sources, in case you want to test your own model.

The current catalog of blazars seen by EGRET includes 51 sources (Mukherjee et al. 1997). Because most of them have not been under observation for very long, record-setting events occur fairly often, like the fastest flare of a BL Lac (less than 8 hr in gamma rays, 2 hr in visible light; Bloom et al. 1997) and a similarly brisk outburst in 3C 279 (Wehrle et al. 1998). The most obvious model, with a shock in a relativistic jet, is not actually a very good fit to the flares (Bednarek 1998), but the real news on the theoretical front is that the sources are now sufficiently plentiful that the models no longer outnumber them.

Unidentified gamma-ray sources were, in the days of *COS B*, the single largest class. They are still fairly abundant, with 30 in the EGRET catalog (Lamb & Macomb 1997). This is, of course, more than enough to be divided into two (or more) classes. Lamb & Macomb find that the sources with larger apparent brightnesses are more concentrated toward the Galactic plane, indicating, naturally, a Galactic population as one contributor. Sturner et al. (1997) propose otherwise unrecognized 10^4–10^5 yr old supernova remnants as a candidate. Tavani et al. (1998), having found a second variable source with no obvious active galaxy in its error box, suggest a previously unrecognized sort of galactic transient. Strickman et al. (1998) ask, rhetorically, whether LSI $+61°303$ (a radio-emitting, Be X-ray binary) could be the prototype. And, moving up the ladder of strangeness, we find isolated Kerr-Newman black holes (the kind with net electric charge), with the radiation coming from electron-positron pairs in their magnetospheres, sort of like pulsars (Punsly 1998).

Geminga used to count as an unidentified gamma-ray source, but has now been seen at so many other wavelengths that we can only say "enough already" and stick it back into the previous section as one of the seven gamma-ray pulsars. A radio counterpart was the last to be added (Malofeev & Malov 1997; Shitov & Pugachev 1997, as well as a couple of papers cited in Ap97), but the word has been slow to get out (Caraveo et al. 1998). The weakness and wide profile of the pulsed radio emission indicate that the magnetic and rotation axes of the pulsar are nearly aligned (Gil et al. 1998; Malov 1998). The optical emission from Geminga is probably also weakly pulsed at 0.237 s (Shearer et al. 1998), and a spectral feature at 6000 Å implies a magnetic field of 3–5 $\times 10^{11}$ gauss if it is a cyclotron resonance

(Mignani et al. 1998). This last is, not surprisingly, a Faint Object Spectrograph (FOS) result, given that, if you are stuck on earth, Geminga contributes only 0.5% of the sky background, even from the site of the Keck telescopes (Martin et al. 1998).

Gamma rays are unquestionably emitted from the general vicinity of the Galactic center (at least in two dimensions!), but we have read and had to unread so many preprints and papers on the details in the past year that they are all blurred into " it is complicated " (Markoff et al. 1997; Mayer-Hasselwander et al. 1998), whether you are concerned about variability, angular distribution, or positron annihilation and other spectral features.

Gamma-ray lines in general, and their sources, remain few and far between. Diehl & Timmes (1998) review the sort expected from supernovae and their remnants and leave us with roughly one example of each: aluminum-26 from the general interstellar medium, titanium-44 from the SNR Cas A, and iron-56 and iron-57 from supernova 1987A and possibly 1991T, which was a Type Ia event and expected to make lots of iron (cf. Bowers et al. 1997). Diehl & Timmes do not address the more problematic ^{12}C and ^{16}O lines from the Orion Nebula, recognizable in COMPTEL data but not in OSSE (which is not necessarily a contradiction; Harris et al. 1998c).

6.3. Gamma-Ray Bursters

GRBs have been all over the place—in the literature (78 papers entered in our notebooks in the index year, excluding IAU Circulars) and in space, with associated redshifts ranging from 0.0084 for the event 980425 (Woosley & Paczynski 1998; IAU Circulars 6884 to 6918) to 3.42 for GRB 971214 (Kulkarni et al. 1998 and three following papers). A VERY crude summary is that, up to about 1998 October 1, 18 X-ray afterglows had been caught. Half of these had yielded optical identifications. When the optical transient faded, there was always some sort of host galaxy around, with the GRB having been fairly near the center and the hosts not giant Es or Ss, but rather feeble things, like the galaxies littered over the Hubble Deep Field images. Two or three also had rapidly varying radio counterparts, with much of the early variability being due to interstellar scintillation, which decreased when the sources expanded to about 10^{17} cm in size. And, finally, it is nigh on to impossible to extract this minimal data set from anything in the archival literature, and we have cheated rampantly, making use of an excellent review talk given by Neil Gehrels at a conference early in October.

Truth (whether godly or satanic in nature) is widely held to be in the details. This subject is, however, very far from being ready for review at either a detailed or divine level. It is safe to say that the bursts are not all precisely the same sort of thing. GRB 970111 was, for instance, very bright as a gamma source, but there was no hint of an X-ray afterglow (Feroci et al. 1998). The two with the longest light curves did not fade in the same way (Diercks et al. 1998). One had a radio counterpart, but not much in visible light, which could just have been swallowed by dust (Taylor et al. 1998; IAU Circulars 6864, 6868, 6860, 6874, 6864, all on GRB 980329). And so forth.

Of those events with modest amounts of data already in print, the two most interesting are the ones with the extreme redshifts just mentioned. For GRB 971214, the enormous distance means that the total energy radiated was truly spectacular if isotropic (Kulkarni et al. 1998), and fairly impressive even with beaming (Wijers 1998): 3×10^{53} and 3×10^{51} ergs, for instance.

In contrast, 980425 was practically next door, in a small galaxy called ESO 184-G82. An X-ray transient, an optical transient, and a radio transient were all within the GRB error box (which is, of course, large). But the X-ray position is inconsistent with the optical and radio ones. Evidently, either the gamma ray = X-ray, but the radio + optical are unrelated, or the optical + radio = gamma ray, but the X-ray is unrelated. Both have probabilities of about one per cubic universe, but one or the other must be true. (Note added in proof: All locations now agree.) And, while we are at it, the optical event was also supernova 1998bw, a somewhat anomalous Type Ic event (IAU Circular 6918). The radio source had an initial brightness temperature of 3×10^{14} K (IAU Circular 6903), sufficiently above the limit set by inverse Compton destruction of radio photons that it must have been expanding relativistically.

GRB 970508 already starred in Ap97. Perhaps the most important development was the appearance of a host galaxy when the transient faded (Sokolov et al. 1998). A couple of just-for-fun observations: the X-ray afterglow of GRB 780506 (no, that's not a misprint) was probably caught by *HEAO 1* detectors (Connors & Hueter 1998). And the High-Energy Gamma-Ray Array (HEGRA) may have recorded 20 TeV emission from one event in the GRANT/WATCH data base that happened when BATSE was on the wrong side of the earth to see it (Padilla et al. 1998b).

Another 50+ GRB papers during the year reported either statistical data or models. There are no overwhelming correlations on the sky with Abell clusters, supernovae, or anything else (Kippen et al. 1998; Wang & Wheeler 1998). The by now enormous number of BATSE events can be binned in a great many different ways by duration, spectrum, substructure, peak flux, and so forth. Dyson & Schaefer (1998) try 49 different properties and, predictably, find a couple of 2-3 σ relationships. Burenin et al. (1998) report a correlation on the sky with AGNs and QSOs having $z = 0.1$ to 0.32. This perhaps supports a model in which the events come from neutron star collisions and mergers in dense clusters at galactic centers, permitting repeat events, until everything is gathered into a central black hole (Dokuchaev et al. 1998).

The theories, models, and scenarios can be divided crudely into relatively detailed simulations of jets and fireballs, intended to reproduce light curves and spectra of the afterglows, and novel sources for the basic energy supply. Panaitescu & Meszaros (1998, who model the spectrum you expect when a shock hits surrounding material) can represent the first class (many of which are not very easy to read), and Luchkov & Polyashova (1998, who associate GRBs with processes in flare stars) can represent the second (most of which are not very likely to be right). In between, we found Qin et al. (1998), who derive the energy from accretion-induced collapse of a neutron star to a black hole, but then go on to describe the emission from a dirty fireball with moderate beaming. Another 30+ papers are wrongfully neglected, but we predict that most of the authors will be back in the GRB pool again next year.

If indeed the events occur within the disks of star-forming galaxies, they will deposit at least 10^{53} ergs into the surrounding interstellar medium. This could be the cause of H I supershells, produced at a rate of about one per 10^7 yr per galaxy (Loeb & Perna 1998).

6.4. Soft Gamma Repeaters

These were one of the highlights of Ap94 (§ 5.3), because of the evidence that they were associated with supernova remnants and so with young neutron stars, probably with very strong magnetic fields. The inventory at that time was precisely three, the one in SNR N49 in the Large Magellanic Cloud (aka 1979 March 5), SGR 1806-20 in a filled-center SNR in the Milky Way, and B1900+14 with at least a possible SNR counterpart.

Reference year 1998 saw (a) the much-awaited discovery of a fourth SGR, (b) recognition of assorted periodicities, (c) increased evidence for strong magnetic fields, including rapid spin-down of rotation periods, and (d) truly spectacular activity on the part of SGR 1900+14.

The new one is called SGR 1627-41 (meaning, as usual, a rather approximate position in equatorial coordinates). It was reported first in BATSE data (IAU Circular 6946) and soon after from *BeppoSAX* (IAU Circular 6945), *Ulysses* (IAU Circular 6948), *RXTE* (IAU Circular 6950), and Konus (IAU Circular 6966). The two satellites that are not in near-earth orbit permitted triangulation to a reasonably good position, which probably falls within supernova remnant G337.0-0.1 (IAU Circulars 6948, 6966). Power spectrum analysis of the RXTE data stream reveals a 6.7 s quasi-periodic oscillation, which could, however, be associated with a nearby black hole X-ray binary (IAU Circular 6962).

A period of about 8 s as the bursts gradually decreased in amplitude is part of the folklore of the 1979 March 5 event. This year, SGR 1806−20 revealed a period of 7.47 s, with a characteristic $dP/dL = 2.6 \times 10^{-3}$ s yr^{-1}, corresponding to an age of 1500 yr. The assumption that the period change is due to spin-down accompanying the usual magnetic dipole radiation of a pulsar leads to a magnetic field of 8×10^{14} G (Kouveliotou et al. 1998).

SGR 1900+14 came back with the robins in spring 1998. It also came back (IAU Circular 7001) with a coherent pulsation period of 5.16 s, a period derivative of $dP/dt = -6 \times 10^{-11}$ s s^{-1}, and, therefore, a likely magnetic field of 5×10^{14} G and an age close to 1500 yr. The robin turned into a lion on 27 August, with a strong gamma-ray burst seen by Konus, *RXTE*, *BATSE*, *Ulysses*, and *BeppoSAX*. There was clearly energy above 100 keV, casting doubts on the name "soft" gamma repeater (IAU Circulars 7001-7005). The total power reaching earth is a bit uncertain, since many of the detectors saturated, but the flux was enough to produce ionization in the earth's nighttime atmosphere of the sort generally seen only when the Sun is up, suggesting "day for night" as the name for the event or the source. Your non-astronomical friends may well have asked, as ours did, whether the burst was in any sense dangerous. "Only for theorists," is the short answer. The longer one is, no more so than being outdoors in the daytime, and with less chance of sunburn. (You know the story: at the recital debut of Isaac Stern, an older, noted violinist sat next to Vladimir Horowitz and remarked, "My, but it's hot in here." "Not for pianists" was the answer.)

7. COFFEE BREAK: PSI IS FOR PSHAW, PSILOCIN, AND PSO FORTH

This is intended partly as a do-it-yourself section. It records a variety of items that left us (VERY briefly) speechless, and you are encouraged to add your own favorite examples.

7.1. Queen Anne Is Dead and Related Non-Surprises

In the great cosmic scheme of things, 3C 273 is located behind the Virgo Cluster (Hurwitz et al. 1998b). That they are in the same direction in the sky has been known for some time. Redshifts of quasi-stellar objects are proportional to their distances from us in the usual Hubblean way (Qin et al. 1997). And a static Euclidean universe fits data on the angular diameters of radio sources less well than an expanding, Friedmann-Robertson-Walker universe (Buchalter et al. 1998). The test for cosmic density is indeterminate.

Among active galaxies, there are real pairs of QSOs and quasars that are close to each other on the sky and in redshift, as well as lensed mock pairs (Munoz et al. 1998; Jackson et al. 1998; Hewett et al. 1998, with Margaret Harding a very welcome surprise among the authors). The separations of real pairs extend down to 4″ or less, overlapping the range of lensed pseudo-pairs (Michalitsianos et al.

1997). Signatures include seeing radio emission from only one of the pair and differences in the narrow absorption lines that cannot be time delays or microlensing.

Unification (meaning, particularly, the importance of the direction of your sight line to an AGN relative to its disk and jets) is part of the story of what makes the richness of phenomenology and correlations among quasars, Seyferts, and all the rest, but not the whole story. We caught 48 relevant papers during the year, surely missed some others, and note only that older quasars have more massive black holes, suggesting that accretion is important in their lives (Srianand & Gopal-Krishna 1998).

Moving closer to home, we thought briefly that stimulated absorption in the interstellar medium was a brand-new process, but on second thought, it sounds a lot like masing, upside down (Frayer et al. 1998). Hg/Mn stars are unusually rich in mercury and manganese (Pintado et al. 1998), including the first example found as a binary companion to a Cepheid (Wahlgren & Evans 1998). Among MACHO events, binary lenses are much commoner than binary lenses (Dominik 1998a, 1998b). This is a rediscovery of the mass-luminosity relation by a very difficult method. But the first lensee in the Small Magellanic Cloud seems to be an ellipsoidally distorted contact binary (which guarantees that the two stars are about the same brightness; Udalski et al. 1997b). And the general-relativistic corrections to the definition and location of the galactic plane are negligible (Tao & Huang 1998).

7.2. *HIPPARCOS*

The *HIPPARCOS* data base is finally making an impression on the astronomical community, with 93 papers using its results in our notebooks this year (and at least seven surely missed, so call it a round 100). Most are still coming from European authors. Many of the investigations confirm and improve numbers and relationships one knew something about before. Some of these appear in other sections. But, in a very different vein, it is disconcerting to discover just how poorly the traditional luminosity classification of stellar spectra (types I, II, III, IV, V) actually picks out stars of different absolute brightnesses on an HR diagram (Jaschek & Gomez 1998; Newberg & Yanny 1998).

Spectroscopic values of log g are similarly rather poor indicators of luminosity, especially for stars of low metallicity (Fuhrmann 1998) and nuclei of planetary nebulae (Pottasch & Acker 1998). The same can be said for (or against?) other broadband indicators (McNamara 1997). Nor, apparently, is the Wilson-Bappu effect as good a guide to stellar brightnesses as one used to think. Using better parallaxes from *HIPPARCOS* and improved line data from *IUE* does not reduce the scatter in the correlation between intensity of the line reversal and stellar luminosity (Scovill & Mena-Werth 1998; Wilson & Bappu 1958).

One has, with reluctance, to conclude that it is probably the traditional tools that are at fault. Use of an artificial neutral network and principle-component analysis to classify stellar spectra reveals that you can produce nice, clean groups, but they are not closely related to MKK types (Singh et al. 1998)

HIPPARCOS is, however, apparently at fault in the discrepancy between its numbers and ground-based estimates of the distances to X-ray binaries (Chevalier & Ilovaisky 1998; Steele et al. 1998). Proper motions for them, measured from the satellite and fed into the expressions for secular and statistical parallax, result in distances that are only about 10% of those found in other ways (including considerations of the X-ray luminosities and numbers of systems in the Milky Way, interstellar absorption, and so forth). This may be understood, but not by us.

On the plus side, if you have really good parallaxes, you can check on whether traditional Lutz-Kelker corrections to less good ones have been done correctly. Oudmaijer et al. (1998) find that observations confirm the theory (first presented in Trumpler & Weaver 1953). For instance, if the average error in parallax is 17.5%, then you calculate a mean luminosity that is too small by 30%. Applying this to the Cepheid calibration of the distance to the Large Magellanic Cloud puts it at 51.5 kpc, neither the largest nor the smallest value reported in the last two years. Incidentally, there is a corresponding "photometric Lutz-Kelker" effect, which arises because faint objects are commoner than bright ones. Thus, non-zero, symmetric errors will push data points in the direction of too bright more often than too faint (Hogg & Turner 1998).

A few other anomalies into which *HIPPARCOS* data have fed are (a) Sirius B seems to fall on the mass-radius relation for a carbon interior, while one would expect ONeMg from its mass of 1.17 $M_\odot$ (Holberg et al. 1998); (b) traditional signatures for youth in stars (lithium, activity, T Tauri type disks...) fail if the gold standard is not yet having reached the main sequence (Favata et al. 1998); (c) errors in distances to open clusters are very large (whether the errors are in the *HIPPARCOS* data or in the moving cluster method and its derivatives; Pinsonneault et al. 1998); and (d) the LMC could be almost anywhere (Fernley et al. 1998).

7.3. Back to the Drawing Board

A smattering of topics where the obvious answer may not be the right one. The Sackett halo (Ap94, § 5.8, on "a faint luminous halo that may trace the dark matter distribution of spiral galaxy NGC 5907"), has had its existence and red color confirmed again (Lequeux et al. 1998), but it may just be a small, captured elliptical galaxy, not necessarily tracing the dark halo.

The Blandford-Znajek mechanism (Blandford & Znajek 1977) is a way of extracting energy from rotating black holes (a follow-up paper on extracting blood from rotating turnips was apparently never published). It requires enough charged particles in the vicinity of the horizon to sustain sizable currents and magnetic fields. Hirotani & Okamoto (1998) assure us that pair production makes enough plasma to take care of things, but then Daniel & Tajima (1998) turn around and use up the pairs in a different way.

Evidence for jets collimated by the accretion disks in cataclysmic variables was reported by Shahbaz et al. (1997). It took the form of weaker, satellite lines on either side of Hα. Actually, they had rediscovered the pair of [N II] lines that indeed flank Hα (O'Brien & Cohen 1998; Margon & Deutsch 1998).

Stars on the extended horizontal branch are not the cause of the ultraviolet excess in the LMC star cluster NGC 1978, because it hasn't got any (Cole et al. 1997). These stars and their descendents remain, however, the best bet for the UV from old stellar populations in M31 and M33 (Brown et al. 1998a) and for giant elliptical galaxies (Yi et al. 1998). The advantage of looking close by is, of course, that you can count the individual blue stragglers, sdOB stars, hot horizontal branch members, and so forth that can be identified only collectively in more distant populations. Landsman et al. (1998) report plenty of all of them in the oldish clusters M67, NGC 188, and NGC 6791.

Pulsar radio emission is not a result of coherent curvature radiation, according to Lesch et al. (1998), who say that it leads to the wrong correlations of emitted frequency and location of the emission region.

Qiao & Lin (1998) propose as an alternative inverse Compton scattering of still lower frequency photons. The only appropriate response that comes to mind is, "How about them 'Skins?!"

7.4. Stellar Anomalies

There are no red giants in the Hyades supercluster, which includes Praesepe (Eggen 1998b). This becomes less surprising if there is no Hyades supercluster, in the way that there is apparently no Pleiades supercluster (Griffin 1998a).

AE Lyncis = 54 Cam, and one might suppose it had been singled out as a star of very large proper motion. In fact, it is an example of pseudosynchronous rotation in a close binary system, but the phenomenon does not seem to be defined anywhere in the paper (Fekel 1998), and so it could be either more or less interesting than the change of constellation.

Are the effects of general relativity (or some other theory of gravity) detectable in the apsidal motion of binaries with non-compact components? The answer "yes" or at least "maybe" goes back a fur piece (Guinan & Maloney 1985). In a handful of systems, $d\omega/dt$ is different from what should be produced by stellar evolution plus general relativity (Claret 1998; Lacy 1998). Confusingly, Lacy includes DI Her among the systems where the observed value is smaller than expected, while Claret puts it among the systems where observed apsidal rotation exceeds theoretical expectation. And not to be cited here because out of the review period is a recent preprint that reduces $d\omega/dt$ by putting a cosmic string along the rotation axis of one of the stars.

It was a surprise also to be told (a) that only 30% of 1 $M_\odot$ stars make planetary nebulae en route to becoming white dwarfs (Allen et al. 1998, modeling the chemical evolution of the galaxy rather than statistics of numbers of main sequence stars, planetary nebulae, and white dwarfs), (b) that there are stars outside the RR Lyrae instability strip with low-amplitude pulsation, but apparently only when they are observed from China (Xiong et al. 1998b), and (c) that M31 had a nova unlike anything ever seen in the Milky Way, rising from B fainter than 22 mag in the POSS, to 20.5 between 1969 and 1990, to $B = 12.25$, and now fading (Sharov et al. 1998). This is a very slow nova indeed. The first slow nova caught in the LMC was, on the other hand, much like Galactic ones (de Laverny et al. 1998).

We had generally supposed that Wolf Rayet stars got that way by shedding lots of hydrogen envelope (onto another star, if it is available) and so were slightly surprised to read that the WR is essentially the same mass as the OB companion in CQ Cep (Demircan et al. 1997) and noticeably the more massive star in the same system as studied by Harries & Hilditch (1997). The system is probably in the Ceph OB1 association. Given the extent to which astronomers are accused of not analyzing and publishing their observations promptly, it would be nice to be able to say that ongoing mass transfer had changed M_2/M_1 between the two data sets, but this is probably not the right answer. γ^2 Velorum, which also gets analyzed more than once in a typical year, has the mass ratio you would expect, with O + WR = 29 + 9 $M_\odot$ (Schmutz et al. 1997).

Even the Sun is a bit odd sometimes. Its size as determined from seismological data is 0.04% smaller than the observed photosphere (Schou et al. 1997). It is even odder if the 11 yr activity cycle is driven by solar motion around the barycenter of the solar system (Zaqarashvili 1997, which seems to imply 11 = 12). The dipole moment of the Sun does not change detectably during the cycle, but the hexadecupole does (Kuhn et al. 1998). The dipole part has been looked for and alternately seen and not seen through most of the century, back at least to Schur & Ambronn (1905). The reason for the fractionation of hydrogen and helium as you go from photosphere to corona to wind remains poorly understood (Peter & Marsch 1998), though the absence of similar separation by first ionization potential in Procyon has been explained (curiously, by the same chap, Peter 1998).

The rotation of white dwarfs is a result of asymmetric mass ejection while they were asymptotic giant branch stars rather than of conservation of angular momentum over the ages (Spruit 1998). Analogously, the magnetic fields are not due to flux conservation either but are the result of dynamos in action (Schmidt & Grauer 1997, building on a model by Thomas et al. 1995).

7.5. Strangeness on Larger Scales

Only 8 pages from where Lesgourgues et al. (1998) explain that you get a better fit between a standard cold dark matter model of the universe and observations of large-scale structure if you include extra power on small scales (relative to a Harrison-Zeldovich spectrum), Canavezes et al. (1998) explain that you get a better fit by including extra power on large scales.

Poor old Antlia (meaning the dwarf spheroidal galaxy). First it wasn't a new member of the Local Group (Ap97, § 10.3), and now it probably isn't a member at all, having been shoved out to 1.3 Mpc (Aparicio et al. 1997).

The spiral arms of the Milky Way are driven by a density wave (Efremov 1997). This is not quite the same as saying that we live in a grand design spiral, but one is nevertheless surprised at the messy result of what is supposed to be a tidy cause. Zhang (1998) proposed that spirals arise from phase transitions and then last a Hubble time. The refereeing process for the paper took almost that long.

The universe could still have non-boring topology lurking just outside the range of present data (Cornish et al. 1998), along the lines suggested by Friedmann (1929). It could even have escaped having an initial singularity—but only by being empty (Raychaudhuri 1998), in which case there is no use renewing your subscription to *PASP*. We could also be at the center of an inhomogeneous but isotropic universe (Dabrowski & Hendry 1998), in which case you don't need to subscribe to anything; it will all come to you.

That well-known number SBS 1543+593 is a mock Seyfert—that is, a $z = 0.8$ QSO superimposed on a $z = 0.009$ galaxy (Reimers & Hagen 1998). And, as it were, conversely, the "Galactic center" X-ray source 1734−292 is really a background Seyfert (Marti et al. 1998), and a couple of seeming QSO hosts are really intervening Seyfert galaxies between us and $z = 2.5$ (Lehnert & Becker 1998).

All cosmic rays, even low-energy ones, come from outside the Galaxy (Plaga 1998). Or, alternatively, all cosmic rays, even very high energy ones, come from inside the Galaxy (Zirakashvili et al. 1998).

Binary stars have been part of the inventory since William Herschel confirmed what John Michell had realized on statistical grounds, and binary clusters of stars since the early telescopes resolved Misan (no, we hadn't heard of it before either) into h and χ Persei. Now come binary clusters of galaxies, at least in the X-ray regime (Hughes & Birkinsaw 1998). Or perhaps one should just think of them as mergers observed prematurely.

Classifying galaxies is evidently no more reliable than classifying stars (§ 7.1), in the sense that bulge-to-disk ratios, measured objectively, are not strongly correlated with the types given in standard catalogues like RC3 (Scorza et al. 1998).

7.6. We Never Thought They Were

Baryonic acoustic oscillations are probably not the cause of cosmic structure on the scale of 100 h^{-1} Mpc (Eisenstein et al. 1998). The comet-like structures in the planetary nebula NGC 7293 (the Helix Nebula) are not caused by its two-phase nature (O'Dell 1998) or by anything else that Burkert & O'Dell (1998) were able to think of. The shapes of bipolar planetary nebulae are not due to their being squeezed around the waist (Sahai & Trauger 1998, who have obviously remembered that a gentleman grasps a bottle around its neck and a girl around her waist). Magnetic fields could, however be relevant (Garcia-Segura 1997).

The universe is not chiral (Carroll & Field 1997), though Ralston et al. (1998) do agree. And there is not much antimatter, at least in our Hubble radius (Cohen et al. 1998).

7.7. They Did It Their Way

A brief compendium of (a) examples of hard work that paid off and (b) the contrary. Clearly under (a) come the investigations in which radio astronomers have recovered information about small-scale structure from data intended for geodetic purposes, like monitoring the rotation and wobble of the earth (Fey et al. 1997 on superluminal motion in 4C 39.25; Tateyama et al. 1998 on new components in the jet of BL Lac). Egan et al. (1998), who have learned something about dense cores in giant molecular clouds from infrared data gathered by the *MSX*, a Ballistic Missile Defense satellite, clearly deserve the "swords into plowshares" award for 1998.

The International Astronomical Union has worked quite hard in recent years to define and explain how to measure a time coordinate that takes into account all relevant physics (including, for instance, changes in gravitational redshift as we move in and out of the solar potential). But, according to Standish (1998), they have merely recreated the system that the Jet Propulsion Laboratory and other trackers of satellites had been using all along. The more kitchen-friendly author is slightly reminded of a very elaborate recipe, involving ground ham and pork and many spices, the outcome of which was home-made Spam. Meanwhile, the official spatial coordinate system is rapidly being transformed from one based on the positions of visible stars (FK5) to one based on radio and optical positions of extragalactic radio sources (Ma et al. 1998; Feissel & Mignard

1998). This is clearly different from the past and, at least in the sense of being more nearly inertial, better.

The Lense-Thirring effect is the eponymous equivalent of the dragging of inertial frames by (for instance) a rapidly rotating, massive, compact body (Lense & Thirring 1918). There is no easy way to extract it from a myriad of nonrelativistic reasons for small changes around rotating objects. You can, however, work very hard on politics and fund-raising (and, thereby, eventually launch Gravity Probe B, which will explore distortions of spacetime around the earth). Alternatively, you can look hard at X-ray binary systems, where neutron stars and perhaps black holes are guaranteed to be more compact and more rapidly rotating than the earth. Candidate systems include the black hole transients GRO J1655−44 and GRS 1915+105 (Cui et al. 1998), the low-mass X-ray binary GX 340+0 (Jonker et al. 1998), and perhaps a few others (Stella & Vietri 1998). In no case is the "best fit" a perfect fit to the various frequency patterns seen in the X-ray fluxes, but there is some indication that the two black hole systems just mentioned (which are also the Galactic "superluminal" or mini-quasar sources) may have black holes rotating close to the maximum value, $a/m = 1$, permitted by general relativity, while others, like Cygnus X-1, have slowly rotating BHs. Finally, luck may intervene and reveal something that looks like inertial-frame dragging in timing data from satellites that were launched for very different purposes (Ciufolini et al. 1998, using *LAGEOS* and *LAGEOS II*, and attracting a certain amount of scepticism).

But for shear chutzpah, we'll take the GBRT ("Grand Balloon Radio Telescope") a design with so long a focal length that the secondary has to be hung from a sky hook (Legg 1998), and the universe of Murante et al. (1997), in which the large-scale distribution of galaxies is no more significant than that of the constellations.

Long work, as well as hard: Giorgio Abetti, who published a book review at the age of 98, must be another contender for the longest publication record, but, like Abbott, rather difficult to chase down. The record for the longest series of publications very probably belongs to Griffin (1998b), whose papers reporting orbits of spectroscopic binaries now number more than 140. These by now probably constitute a data base large enough to justify statistical analysis.

8. BEEN THERE; DONE THAT (SOME OLD ISSUES RECONSIDERED)

We look here at 1998 developments in areas that have been considered at some length in earlier editions of Ap9x. About many of them you will already have made up your mind, so feel free not to read those sections. In fact, feel free not to read any of them, since *PASP* does not operate (at least not yet) a "pay per view" system. The earlier discussions are not generally cited, because the conclusions are similar enough that you might be tempted to quote Emerson at us.

8.1. Stellar Mass Distributions

Is there a universal initial mass function [meaning $N(M)$ for stars at formation]? Of the 20 or so pertinent papers in the reference year, about 1/3 said "yes", 1/3 said "no", and 1/3 suggested that this was not going to be the right question to ask for much longer. For instance, the main sequence of the Pleiades shows more structure than you would expect from statistical fluctuations alone (Belikov et al. 1998); elliptical galaxies may have their stellar mass functions correlated with total mass (Tantalo et al. 1998); and, while lots of globular clusters turn over from power laws to flat or decreasing distributions at low mass, it isn't always the same low mass (Chabrier & Mera 1997; King et al. 1998a; Pulone et al. 1998).

The size of the "universe" you choose to average over also matters. Individual H II regions, OB associations, and so forth in the Large and Small Magellanic Clouds yield slopes all the way from −1.0 to −2.0 (in units where the Salpeter 1955, function is −1.35) according to Parker et al. (1998), while Bresolin et al. (1998), considering whole galaxies, find the same slope for the massive stars in spirals with a range of types.

Thus we come to advanced questions in the field. What functions more complex than power laws (Salpeter 1955) or log-normal distributions (Miller & Scalo 1979) are a better description of reality? What correlations do you find when you use log-log paper to compare IMFs with all the other properties one might measure for stellar populations? And (favorite of the more duplicitous author), what does the contribution of binary systems do to your statistics?

Initial binary populations definitely cannot be the same everywhere. The oldish open cluster NGC 2506 has something like 20% of its main sequence in binaries where the two stars are of nearly equal luminosity (and, therefore, even more nearly equal mass, Marconi et al. 1997), a class of system generally regarded as rare in the solar neighborhood, though not necessarily in star formation regions (Kohler & Leinert 1998). And the binaries do matter. Van Bever & Vanbeveren (1998) remark that starbursts will generally be interpreted as younger than they really are, because blue stragglers partly repopulate the upper main sequence.

8.2. The Distribution of Galaxy Masses

In one sense, the galaxian $N(M)$ is like the stellar function—there are lots of little ones and rather few big ones (Phillipps et al. 1998a; Cote et al. 1997), with sharpish limits on both ends. In another sense, it is very different, and should be much less well defined, since there is no doubt that galaxies come in a number of morphological types (not all of them known to Hubble), made in different ways, and not always made with an "initial" mass that is relevant to what they look like now. Under the circumstances, one should perhaps be surprised that even so general a shape as a Schechter (1976) luminosity function, with two fairly free parameters, actually fits the observations in many different contexts (Trentham 1998; Secker & Harris 1997; De Propris & Pritchet 1998; Andreon 1998). No surprise at all is due the observation that the actual parameter values cover a considerable range (Small et al. 1997; Molinari & Smareglia 1998), or that sometimes not even the general functional form is very satisfactory (Ratcliffe et al. 1998).

The next steps are more or less the same as for stellar mass distributions: look for correlations with something that might be causal, like local density (Phillipps et al. 1998b), and don't forget to allow for evolutionary effects (Adami et al. 1998a). Both these papers call attention to dwarf galaxies being less common in dense environments, which could, of course, be either "causal" or "evolutionary."

8.3. Cast of Supporting Stars

White dwarfs with both hydrogen and helium are better described by stratification than by mixing (Barstow & Hubeny 1998).

RV Tauri stars may be simply a long-period extension of type II Cepheids, in which case the longer (double) period is probably the real fundamental, based on many examples found in the LMC by the MACHO project (Alcock et al. 1998a). The period-luminosity relation is $M_v = +1.34 - 3.07 \log P$ (days).

Blue straggler production mechanisms are many and varied. The best bet for the core of 47 Tucanae is the coalescence of W UMa binaries, which would explain both the masses ($1.7 \pm 0.4\ M_\odot$) and the rapid rotation (Shara et al. 1997).

The low-luminosity X-ray sources in globular clusters are also probably of two or more types. That is, some are cataclysmic variables, but some are probably neutron star binaries having the decade off for one reason or another (Verbunt et al. 1997; Ferraro et al. 1997). The latter suggest that, together with T Sco in M80, they constitute a new class of cataclysmic variable. And some are perhaps X-ray binaries with very strong magnetic fields and low rates of mass transfer (Gotthelf & Kulkarni 1997). Curiously, M3 probably has one CV and one radio source, but they are not the same object, and neither is an X-ray source (Laget et al. 1998). All or nearly all strong X-ray sources in globular clusters display type I (nuclear flash) bursts. This means that none of them have black hole primaries (in't Zand et al. 1998)

The Cepheid instability strip continues to have the location of its edges (especially the red one) depend very much on how you treat convection and its coupling to the pulsation (Xiong et al. 1998a; Yecko et al. 1998).

Where are the MACHO lenses? If the MAssive Compact Objects that lens stars in the LMC are not actually in our Halo, then the lessons to be learned about Galactic dark matter are greatly modified. Possibilities suggested and anti-suggested during the year include (a) red clump stars only 30–35 kpc from us (proposed by Zaritsky & Lin 1997, and denied by Beaulieu & Sackett 1998), (b) faint stars in tidal debris trailed from the Clouds and the Magellanic Stream (favored by Zhao 1998 and Johnston 1998, but declared impossible by Gould et al. 1998, on the basis of surface brightness maps of the region made by de Vaucouleurs 1957), (c) stars in the Small Magellanic Cloud (Palanque-Delabrouille et al. 1998, only for events in the SMC, of course, and endorsed by Afonso et al. 1998 for the event of 1998 June 14), (d) stars in the already known disk and spheroid of our own Milky Way (Gates et al. 1998), and (e) the warped disk of the Milky Way (Evans et al. 1998). The fall-back position, if the lenses are in our halo, remains old white dwarfs. Shoving the average mass into the range of brown dwarfs is not in the realm of practical politics, even with a rather convoluted model halo (Gyuk 1998). But you just don't expect there to be that many halo white dwarfs (von Hippel 1998)!

What drives stellar mass loss? Many things, we admitted in Ap93 (§ 4). The inventory has not decreased in the interim, though of course every mechanism has been declared inoperative somewhere by somebody who wants to operate a different one. Augmentation includes (a) twisted magnetic fields (Seemann & Biermann 1997; Kaper et al. 1997), (b) contraction of AGB cores (Lewis 1997), (c) radiation pressure on molecules (Groenewegen et al. 1998), (d) non-spherical grains (which increase the efficacy of radiation pressure; Il'in & Voshchinnikov 1998), (e) dust formed when shocks dissipate (Le Betre & Winters 1998), (f) this coupon good for one free beer at AAS meeting (if you have read this far), (g) a wind used twice over (Raga et al. 1998), and (h) all previous mechanisms plus a few new ones, plus some additional refinements for cases of winds from disks and novae (Vlahakis & Tsinganos 1998, and with five you get egg roll and possibly jets). In galactic winds, the ionized gas leads and drags molecular gas along with it (Ohyama & Taniguchi 1998).

The precessors: HZ Her was the first X-ray binary advertised as having a precessing disk (responsible for a 35 day period in its very complex light curve). It is still a good bet, along with a good many other X-ray binaries (Larwood 1998; Konig et al. 1997; Cowley et al. 1998; Goranskii et al. 1998; Fukue et al. 1998) and pulsars (D'Alessandro & McCulloch 1997; Wex et al. 1998). The behavior of Cygnus X-2 is not well fitted by precession. Comets may also show precession periods of 5–10 yr, which affect their orbits detectably in three cases, according to Krolikowska et al. (1998).

Heating of stellar coronae: Among many questions still lying about, one that continues to intrigue us is whether the "basal" minimum rate is attributable to acoustic processes (with higher rates coming from magnetic processes)—or do you always need the magnetic stuff? Acoustic, say Buchholz et al. (1998). Magnetic, say Judge & Carpenter (1998). And just as we were getting used to contributions from microflares (Montes et al. 1997 and several other papers), along came nanoflares (Judge et al. 1998).

8.4. Some Old Questions about Neutron Stars

"Kick Velocities": Do neutron stars receive a firm nudge at their birth? And if so, is it just what you would expect from sometimes unbinding close binaries during a first or second supernova explosion in the system, or is there an extra piece from asymmetric explosions? As it happens, of the 20+ papers during the year, both the first and last said "yes" to part 1 and "probably extra" to part 2 (Hansen & Phinney 1997, 1998; Kalogera et al. 1998), though "yes" and "probably not" were almost as common. We think we have detected a curious gradient in the process—the younger the author, the harder he wants to kick (Iben & Tutukov 1998). The answer "no" to both parts seems to have gone out of fashion, though we found a few "yes and no," that is, bimodal, answers from Fryer et al. (1998), Lyne et al. (1998, giving smaller kicks to future millisecond pulsars), and Pskovkii & Dorofeev (1998, actually trimodal). An adequate kick could have been produced just by asymmetric neutrino emission, according to Lai & Qian (1998).

Perhaps the truest word comes from Tauris & Takens (1998), who conclude that deciding what sort of kick you need in order to account for various observations of pulsars and X-ray binaries is harder than you think it is going to be.

Rotation rate and magnetic field evolution: Another sizable subliterature addressed observations or explanations of changes in neutron star angular momenta and magnetism with time. The place to start, clearly, is with the idea that kick velocities are themselves the cause of the rapid rotation of young pulsars (Spruit & Phinney 1998, building on a suggestion from Burrows et al. 1995). The rotation gradually slows down for reasons we think we understand, leading to the expected matches between pulsar ages and remnant ages. Understanding breaks down at the level of the second derivative, which should yield $n = -PP''/P'^2 = 3$ for pure dipole radiation. The fourth or fifth case where $n < 3$ has just turned up (Eikenberry et al. 1998a). It was preceded by one explanation (Allen & Horvath 1997), and followed shortly by two others, in the form of gradual alignment of the angular momentum and magnetic field axes (Casini & Montemayor 1998) or coupling to the superfluid interior (Sedrakian & Cordes 1998).

Rotation of the millisecond (old, low-field) pulsars is attributed to accretion from a binary companion and is a whole separate can of theorists (Goussard et al. 1998; Li et al. 1998b).

Cooling of neutron stars has always provided a temptation to insert your favorite new process, including pion condensation, transition to strange quark matter, pairing in superfluids, and so forth. The problem remains that we have very few decently measured surface temperatures for neutron stars (which persist in radiating by mechanisms other than blackbody cooling), and the issue remains fairly indeterminate (Schaab et al. 1998). Even glitches get into the act (Hirano et al. 1997). For a thorough review of the subject, see Tsuruta (1998). The issue of cooling cannot, in fact, be entirely decoupled from the evolution of B and J (Urpin & Konenkov 1997). In particular, the 10^{14} G fields of soft gamma repeaters first retard and then accelerate cooling (Heyl & Hernquist 1997).

Supernovae, neutron stars, and supernova remnants are associated at least some of the time, but the correlation is by no means complete. Sometimes we lose a few, like the 6.9 ms source that falls on top of SNR RCW 103 (proposed by Gotthelf et al. 1997 as the fifth X-ray–loud, radio-quiet, rotation-powered pulsar in an SNR), but it is probably not related to the SNR (Kaspi et al. 1998). The superposed PSR 1853+01 is not the central X-ray brightpoint in W44 and is again probably unrelated (Harrus et al. 1997). But the inventory stays about constant, for Heyl & Hernquist (1998) found another neutron star for RCW 103 almost immediately. It is 1E 161348-5055, one of the sort that lives mostly on stored thermal energy or secret accretion from its surroundings. Such accreting neutron stars are a good deal rarer in the *ROSAT* catalog than you might expect (Copli et al. 1998). Allakhverdiev et al. (1997) suggest, not for the first time, that most pulsars are born faint, so that you should not expect to find one in every SN II remnant.

The SNR/PSR combination G55.0+0.3 = J1933+202, with both about 10^6 yr old, is plausibly the oldest such pairing (Matthews et al. 1998), and the custom of labeling one partner in Galactic coordinates and the other in equatorial coordinates requires us all to take their word for the association. The youngest pair is, of course, SN 1987A, *if* there is a neutron star there. Wu et al. (1998) think it has been seen as a source of accretion luminosity in the light curve. They are probably not in the majority. The second-youngest is SN 1979C in M100, recovered by *ROSAT* (Immler et. al. 1998a).

Assuming that supernova remnants come from supernovae leads to reasonable agreement with other indicators of what the SN rate must be in various sorts of galaxies (Filipovic et al. 1998). And, with regret, we let a dozen other papers on this classic topic sink slowly in the west.

X-ray–driven mass loss? The more brash author was once laughed at by colleagues for suggesting that mass loss from a particular secondary star might be driven by irradiation from the primary. "No, no, Virginia. We're talking about X-ray system, not a radio pulsar like 1957+20." Well, they do too, so say Li & Wang (1998), Nelson et al. (1997), and Chakrabarty (1998), though not in all conceivable systems.

Cyclotron resonance features were once a major argument in favor of the "local" models for GRBs. That *CGRO* sees such features in some X-ray binaries but not in GRBs was a highlight several years ago. The same can now be said about *BeppoSAX*, which has recovered the previously known spectral structure in Her X-1 (Dal Fiume et al. 1998) and in Vela X-1 (Orlandini et al. 1998). Both imply magnetic fields of several times 10^{12} G.

The Crab Nebula neutron star has lost its title as fastest young pulsar (§ 9), but still generated more papers than any other single NS/SNR combination. Some things that have gone away (meaning that they probably never existed) include gamma-ray lines in the 1–10 MeV range (van der Meulen et al. 1998), the main argument against Poynting flux as the way energy is transported away from the pulsar (Begelman 1998), and the "best bet" model for glitches, which involves pinning and unpinning vortex lines to the crust, the pinning being far too weak (Pizzochero et al. 1997; Jones 1998). In response, Ruderman et al. (1998) have provided a more complex, improved glitch factory. On the other hand, we welcome back evidence for a slow-moving halo outside the visible nebula (Sankrit & Hester 1997), which is, however, not necessarily the old Murdin & Clark (1981) halo.

8.5. Star Clusters and Interstellar Material

Destruction of globular clusters continues (Murali & Weinberg 1997; Capuzzo-Dolcetta & Vignola 1997). Both intrinsic (evaporative) and extrinsic (tidal) processes contribute, and we are not sure whether there is supposed to be a bit left behind or not. For open clusters, evaporative processes dominate, and there should be some sort of compact binary or stellar remnant (Spitzer 1940; Ambartsumian 1938). De la Fuentes Marcos (1998) estimates that there should be 300,000,000 of the remnants strewn through the Milky Way, each of about 30 $M_{\odot}$. The dissolution process gets under way even before star formation is complete (Nakajima et al. 1998).

Formation of globular clusters is long since over, at least in our Galaxy. Whether it continues elsewhere remains in dispute. Popular potential sites for young globular clusters include the Large Magellanic Cloud (Seleznev 1997), other small, gassy galaxies (Hilker et al. 1997), blue compact dwarf galaxies (Oestlin et al. 1998), mergers, where one might thereby be able to account for the large ratio of numbers of globular clusters to total luminosity seen in giant elliptical galaxies (Miller et al. 1997; Carlson et al. 1998), tidal tails (Fritze-von Alvensleben 1998; Tyson et al. 1998), or cooling flows (Brodie et al. 1998).

The problem with nearly all of these is that, for star populations outside the Milky Way, the young, luminous stars make it almost impossible to learn much about the low-mass, faint stars, which are the ones that must be present in large numbers if a cluster is to end up looking like our globulars. In a clever about-face, Harris et al. (1998d) suggest that ellipticals have a large ratio of clusters to other stars because they have lost the gas that would have made the other stars, rather than because they have gained extra globulars!

Central black holes in globular clusters went pretty much out of fashion when the X-ray sources turned out to be evolved binary stars, but they cannot be ruled out simply from the structures of the clusters (Sosin 1997).

Distances to planetary nebulae have had a "long scale" and a "short scale" for almost as long as the Hubble constant has. Both were originally due to Michael Seaton, who should not, however, be blamed for later developments. If you require that the dynamical age of the nebula be the same as the evolutionary age of the central star, you get the long scale (Mal'kov 1997). Strangely, this is not necessarily the right thing to do. Structure formation in the nebula can make the dynamical age look smaller than the real one (Dwarkadas & Balick 1998b). We have thought this through three times and concluded twice that correcting for this actually increases the distances you find, and once that it decreases them. Tajitsu & Tamua (1998) have recreated something like the old Shklovsky method of getting PN distances (which assumed that all had the same mass of ionized gas). They assume that all have the same mass of dust, detectable in *IRAS* data.

Corradi et al. (1998) conclude that non-spherical PNe have random orientations in the Milky Way. There have been claims to the contrary, one of which was an item eventually dropped from last year's "terminally weird" section (Phillips 1997).

Temperature of the Orion Nebula: This was a burning issue back when General Motors was a Boy Scout, and we thought it had been long since resolved. Two determinations this year have, however, error bars that do not quite overlap each others' central values of 8300 K (Wilson et al. 1997b) and 9500 K (Rubin et al. 1998).

The chemical composition probably has been established; it's just that not everybody likes the answer. Even including the dust, metallicity is less than solar, both for the H II region and for the stars forming in it (Esteban et al. 1998). The oxygen is virtually all tied up in CO and H_2O (Harwit et al. 1998). Should we then conclude that the Sun is metal rich for its station in life? No, say Twarog et al. (1997). Yes, say Wielen & Wilson (1997).

Spallation (knocking apart heavy nuclei with proton bullets to make lighter ones) is how most of the world's lithium, beryllium, and boron were probably made. Garcia Lopez et al. (1998) deduce that, at least early in the history of the Galaxy, it was done mostly by relativistic CNO smashing into stationary hydrogen in the interstellar medium. This sounds a little like trying to use a nail to hit a hammer, though, come to think of it, that is exactly what happens in the rest frame of the hammer. Duncan et al. (1998) point out that near supernovae is a good place to have it all happen.

8.6. Extragalactic Repetitoria

What and where is the warm absorber? The X-ray spectra of many active galaxies show absorption features whose precise energies indicate that the atoms responsible are partly ionized ("warm"). Where, then, is the responsible gas, and is it doing anything else we can measure? The answers, for a long time, were "somewhere along the line of sight," and "not so's you'd notice." George et al. (1998) now report, however, that emission from the "warm absorber" gas has been seen in *ASCA* continuum spectra of 18 type I Seyfert galaxies. Reynolds et al. (1997) have perhaps seen its emission lines of Fe X, XI, and XII. Very broad Ne VII emission in QSOs could be their warm absorbers at work (Hamann et al. 1998), and absorption lines of highly ionized oxygen are reported by Brandt et al. (1997b), again for one object. Mathur et al. (1998) have seen what is probably the same stuff, blueshifted as well as very broad, in one radio-quiet QSO.

The gas is probably dusty (Komossa & Fink 1997a, 1997b; Leighly et al. 1997, a very finely structured paper, as you will see if you look at the references). In summary, then, we can now say that the warm absorber gas is quite close to the active nucleus (to provide the large velocity dispersion) and that it is also warm enough to emit this and that. There are, naturally, also cold absorbers (Malizia et al. 1997), but one doesn't expect them to be doing anything else you should see.

Double galactic nuclei started turning up in sharp *HST* images, beginning with M31 and reviving interest in questions of whether both have black holes, whether they represent merger remnants, and so forth. They have continued to proliferate (Nonino et al. 1998). Raising the ante, Taniguchi & Shioya (1998) report that Arp 220 is really a quadruple.

Do we exist? (1) Dwarf spirals: yes (Drinkwater & Gregg 1998), not really (Ho et al. 1997a, 1997b, 1997c), well maybe (Xia et al. 1998, who report a close companion to Mrk 273 with $M_B = -16$ and $L_X = 6 \times 10^{41}$ ergs s^{-1}); (2) Type 2 quasars (meaning toroidally obscured, like Seyfert 2 galaxies): yes, at least one (Brandt et al. 1997a), but not many others (Halpern & Moran 1998; Halpern et al. 1998); (3) Type 2 other sorts of AGNs: maybe (Barth et al. 1997), yes, and they contribute to the X-ray background (Boyle et al. 1998).

Newborn AGNs? Old and dying ones? Ones that turn on and off? These, of course, all bear on the ancient issue of whether 1% of all galaxies are active for most of their lives, or nearly 100% of them are active for about 1% of their lives. For instance, compact, steep-spectrum radio sources could be young (Morganti et al. 1997) and short-lived (Reynolds & Begelman 1997), or physically distinct from large doubles (Artyukh et al. 1998). We think this particular issue is largely settled by the properties of a compact double that is all of 87 h^{-1} pc across and expanding at 0.25 h^{-1} c. That is, it has a dynamical age of less than 10^4 yr and no excuse not to grow into a large double (Owsianik & Conway 1998). Owsianik et al. (1998) report another, still younger one.

Then there are the gigahertz-peaked sources, which are firmly confined but old (Carvalho 1998) or young and short lived (Snellen et al. 1998). Or, perhaps some but not all of the compact and gigahertz sources will evolve into big, old ones (O'Dea 1998).

At the other end of the scale, one can debate whether the really big double radio sources are old and dying (Venturi et al. 1998; Iyomoto et al. 1998; Slee & Roy 1998), or merely poorly disciplined and unconfined (Mack et al. 1998). Owen & Eilek (1998) present evidence for sources turning both on and off, but, of course, no simple evolutionary model fits (DeYoung 1997).

Radio halos are fed from galactic disks. There aren't really a lot of other candidates, but Duric et al. (1998) have seen the process in action, in the form of tentacles of material with flat spectral index (meaning newly accelerated electrons) extending from the disk to the halo of NGC 5775. The senior author remembers when the question of whether the Milky Way had such a halo was a burning one, but no longer remembers why (or what the answer was).

"*Alignments*": The core idea here is that many radio galaxies at large redshift show strong correlations between radio morphology and visible light, especially emission lines and typically in elongated structures. Possible explanations have included jet-ionized gas, jet-triggered star formation, scattering of central light by jet material, and some others we don't remember. Similar things also happen at modest redshifts like 0.24 (Clark et al. 1998, who blame jet-induced shocks in surrounding stuff), but are not universal at high z (Best et al. 1997)

Evidence for all mechanisms has appeared somewhere during the year (not all in the same paper!). In particular, in some (often nearby) cases, you can see that the jets are running into something. The something can be companion galaxies (Lacy et al. 1998b; Harris et al. 1998a), perhaps companion galaxies in the process of being accreted (Pentericci et al. 1998; Windhorst et al. 1998), or gas in extended emission line regions (Fosbury et al. 1998, with 10 examples, including Cen A; Graham 1998).

Within the jets themselves, the same alignment persists from VLBI to VLA to single-dish scales in some sources, often the brightest (Rantakyro et al. 1998). In others it does not (Ulvestad et al. 1998). Centaurus A rejoices in its own sort of misalignment. Its 40 pc central disk, resolved with *HST*, is not perpendicular to the jets (Schreier et al. 1998).

Other things that might or might not be aligned are large-scale structures and the galaxies in them. Some, but not much, appears to cover all the 1998 error bars (Hu et al. 1998a; Cabanela & Aldering 1998; Jaaniste et al. 1998). And, of course, the one you have been waiting for: quasars along the minor axes of spiral galaxies, where they will eventually evolve into small companion galaxies, their redshifts decreasing with age until they reproduce the Holmberg effect of a deficiency of companion galaxies in galactic planes (Arp 1998). Poor old 3C 212 apparently misunderstood its instructions for this complex process and has a lower redshift galaxy off the end of the radio jet of a higher z quasar (Stockton & Ridgway 1998).

8.7. The Redshift History of Star Formation

Once upon a time, there were no stars. Now there are a great many, mostly not very young. Necessarily, then, the star formation rate has been fairly large at some point in the past. Theorists tend to think of star formation as a function of time, since they calculate the progress of mergers, bursts, and other dynamical, star-driving processes in years. Observers, on the other hand, tend to report things in redshift units, since that is what is directly measured. They are in charge of this section.

It should be kept in mind that all tracers of star formation are primarily sensitive to the rare, massive bright ones that emit most of the light, but add up to very little of the total mass. Thus, any number for absolute or relative star formation has had folded into it some assumption about the stellar mass distributions. The standard units are (a) multiples of the current value (1–10 typically; e.g., Madau et al. 1998) and (b) $M_\odot$ yr^{-1} Mpc^{-3}, with a peak value perhaps approaching unity (e.g., Hogg et al. 1998; Lilly et al. 1998).

Open a new window and you will see a new scene. This is just what has happened in the first submillimeter (850 μm) survey of galaxies in the Hubble Deep Field (HDF). SCUBA (presumably not self-contained, underwater breathing apparatus?), mounted on the J.C. Maxwell telescope, found only seven of the HDF galaxies, but their colors and brightnesses imply that (1) star formation peaked near $z = 3$, and (2) the rate is about five times what you would have deduced from optical and UV data. If other galaxies are similar, their far-infrared contribution will add up to about half the background seen by *COBE*, and the rest presumably comes from galaxies too faint for SCUBA (Hughes et al. 1998; Barger et al. 1998; Scott 1998).

The secret word is, of course, dust. Other papers during the index year that emphasized how much we are likely to be losing to dust absorption included Soifer et al. (1998 on a very dusty $z = 4.92$ galaxy in the infrared), Kunth et al. (1998, on the unsuitability of Lyα as a tracer of star formation, since it is attacked by both gas and dust), Driver et al. (1998, on star formation rates in HDF galaxies of different types, leading to the conclusions that mergers make spirals!), Tresse & Maddox (1998, comparing optical and ultraviolet indicators), and Wiebe et al. (1998, on the evolution of the Milky Way).

The lesson of dust has not yet been fully incorporated into our textbooks (though we hope for something speedier than the 20+ yr it took for Trumpler's 1930 discovery to reach the extragalactic distance scale). But, at least qualitatively, it seems safe to say that galaxy formation started early, certainly well before $z = 5$ (Peacock et al. 1998; Swain 1998; Larionov 1998). There are, however, still interesting things going on at quite small redshift (Oke et al. 1998; Postman et al. 1998; Lubin et al. 1998a, 1998b). That is, as several groups state explicitly, SFR(z) is a very broad function, and we cannot point to any single short epoch during which most of the stars now in spheroids were formed (Giallongo et al. 1998; Peacock et al. 1998; Guiderdoni et al. 1997; Zepf et al. 1997). Finally, and very much as you would expect, the histories are different for galaxies that we now see as different morphological types and for galaxies in high- and low-density environments (Gavazzi et al. 1998; Brainerd & Smail 1998; Madau et al. 1998; Driver et al. 1998; van Dokkum et al. 1998; Balogh et al. 1997).

The majority view is that ellipticals and galaxies in rich clusters made their stars early; spirals, irregulars, and field galaxies later (though at least one paper contradicts each of these); and that galaxies didn't necessarily look much like their present forms when they were working hardest to make stars (Cowie & Hu 1998; Sawaicki & Yee 1998; Fasano et al. 1998; Kauffmann & Charlot 1998). Quasi-stellars do the same thing as galaxies (whatever that is), only there are not so many of them. Boyle & Terlevich (1998) find that 1/40th of the luminosity density at rest wavelength 2800 Å comes from QSOs over a wide range of redshifts.

The redshift history of star formation is very intimately tangled up with what are generally called galaxy formation, the evolution of clustering, the effects of mergers and interactions, and so forth. We took notes on well over 100 papers on these related topics this year. Many of the issues have also been around for a long time: What makes cD galaxies? (Krivitsky & Kontorovich 1997; Garijo et al. 1997; Dubinski 1998). Are topological defects good (Durrer et al. 1997) or bad (Chiu et al. 1998) as seeds for galaxy formation? Can cold dark matter form Zeldovich-style pancakes? (yes, Doroshkevich et at. 1998; no, Lee & Shandarin

1998). Are there dark or invisible galaxies and clusters? (maybe, Bartlett 1998; Kneissl et al. 1998). Both are studies of apparent clusters revealed by Sunyaev-Zeldovich absorption of the 3 K background radiation and not by the presence of lots of galaxies). Are there any truly young galaxies, making their first stars right now? (No, just temporarily blinding starbursts, Schulte-Ladbeck et al. 1998). And so on, babbling into the night that must have pervaded the universe before the first stars formed.

9. $\aleph_1$: THINGS OF WHICH THERE ARE SEVERAL

The mathematicians, having long ago exhausted the Greek alphabet, turned to the Hebrew and dubbed the various sorts of infinities $\aleph_1$ (like the rational numbers), $\aleph_2$ (the real numbers), and so forth. An even better symbol might have been the ancient Egyptian hieroglyph for one million, which depicts a man with his arms thrown up in amazement. Perhaps the relative paucity of publishers prepared to provide a variety of hieroglyphic typefaces came into it. In any case, this section includes, first, an assortment of kinds of things of which we now have seen enough examples (roughly umpteen) to start asking deeper questions about origins, evolution, meaning, and so forth; and, second the usual countdown from many to two, leading up to examples in the next section of firsts and other extrema.

Since there is occasional debate on the extent to which zero is entitled to be called a number, we note here the zero examples found so far of (a) CO emission in blue compact dwarf galaxies (Gondhalekar et al. 1998, who looked at 18), (b) H_20 masers in radio galaxies of Fanaroff-Riley type I (Henkel et al. 1998, who looked at 50), and (c) potential progenitors for Type Ia supernovae, if you think they, or at least the bright ones, come from mergers of white dwarf pairs with total mass larger than the Chandrasekhar limit and orbit periods short enough for merger to occur in a Hubble time (Schmidt et al. 1998; Saffer et al. 1998; Han 1998).

9.1. Umpteen

Black holes at the centers of galaxies counted as a discovery in Ap94 (§ 8) and as rather routine by Ap97 (§ 10.1). The expanded sample now permits the traditional astrophysical activity of plotting them on log-log paper. The strongest (or anyhow most published) correlation is a fairly constant ratio near 0.005 between black hole mass and the mass of the stellar spheroid of the galaxy (e.g., a sample of 32 with reasonably homogeneous *HST* data in Magorrian et al. 1998). Three forms of causality have been suggested: (1) the galaxy comes first and does something to determine the mass of the black hole (Merritt & Quinlan 1998), (2) black holes collapse before the peak of galaxy and star formation and help determine what the galaxy does (Silk & Rees 1998; Chokshi 1997; Stiavelli 1998), or (3) a starburst and a black hole compete for gas at the same time, and the interactions and feedback lead to mass ratios like those seen (Wang & Biermann 1998). These can be regarded as the chicken, egg, and potato salad models.

Given the elegance of the probing of the black hole in NGC 4258 from the H_2O maser sources in a Keplerian disk around it, we are sorry to report that NGC 3076 has a superficially similar disk, but the velocities are dominated by supersonic turbulence (Trotter et al. 1998b). In NGC 1052, the masers aren't even in a disk, but arranged roughly parallel to the radio jet (Claussen et al. 1998).

Galactic hosts of active nuclei have also advanced from being a discovery, even a debated discovery (Ap95, § 10), to a commonplace. They are not perhaps quite ready for log-log paper, but at the Linnean level of putting things in boxes, it has become clear that the traditional pairing of radio loud = elliptical hosts and radio quiet = disks does not entirely hold up (Boyce et al. 1998; Aretxaga et al. 1998; Hooper 1998). The belief arose partly by analogy with nearby, faint sources (Seyfert galaxies really are spirals and not strong radio sources; radio galaxies are nearly always Es) and partly from the expectation that too much gas in a galaxy would keep jets from getting out of the vicinity of the black hole to make large radio lobes. That blazars and optically violently variable QSOs should be gas free comes from a similar combination of observation and expectation and is similarly not completely true (Wright et al. 1998a, 1998b). The excess of fainter companion galaxies around QSO hosts noted some years ago does seem to have held up (Hall 1998).

Galaxies with kinematically discordant cores, rotating perpendicular to, anti-parallel to, much faster than, or otherwise at odds with the main galaxy are a third set that has gone from rare (Ap93, § 10.8) to numerous. Capture of a small companion from a retrograde orbit is such an obvious explanation (especially when you note that the cores are often also chemically decoupled; Sil'chenko et al. 1997) that it seems almost churlish to suggest alternatives. Harsoula & Voglis (1998) have, nevertheless, devised a scenario for doing it all at once from early collapse. A barred stage intervenes. Since both spiral and elliptical galaxies are concerned and the decouplings can be of several types, we obviously have a situation ripe for subclassification and multiple models. One oddity, NGC 6503, has a normal enough looking rotation curve for its gas, but the central core of stars has the remarkably small velocity dispersion of 21 km s^{-1} (Bottema & Gerritsen 1997).

Stars less than 20–25 pc *from us* continue to proliferate (Fleming 1998, an X-ray–selected sample; Decourant et al. 1998, a proper-motion sample). One would expect *HIP*-

PARCOS parallaxes to have revealed many more of these, but none of the 89 or so *HIPPARCOS* papers we recorded during the year seems to address the issue.

Anomalous pulsars: Official classes of pulsars are (1) rotation powered, most often seen as radio sources, and (2) accretion powered, most often seen as X-ray sources. There are probably now enough examples to constitute a separate class of objects that have periods of 5–10 s, X-ray emission, no recognizable optical identification or evidence for orbital motion, often no associated supernova remnant, and spin-downs so rapid that the implied magnetic field is about 10^{14} G. *ASCA* sources J1845−0258 (Gotthelf & Vasisht 1998) and AX J1845.0−0300 (Torii et al. 1998) were presented as the fifth and eighth examples. Because of the strong fields and rapid spin-down, energy extraction by the standard rotating dipole mechanism provides as much energy as we see coming from them, despite the slow rotation.

This is all very well, but the burgeoning population does absolutely nothing to help with understanding what had seemed to be the prototype object, 1E 2239+586. It has a period of about 7 s and no evidence for an optical companion or orbital motion. There is a supernova remnant in the vicinity (CTB 190, with an expansion age of 3000 yr, which would be about right for the spin-down age of one of the other 5–10 s pulsars). Unfortunately, 1E 2239 is slowing its period at a rate that has been constant for 19 yr and is much too small to provide the observed luminosity from a rotating neutron star (Parmar et al. 1998; Baykal et al. 1998). The fact that two of the class members are also soft gamma repeaters is just there to make it all more difficult (Kulkarni & Thompson 1998) and does nothing for the prototypical problem.

Other stellar entities that have become common include (1) X-ray pulsars (Kommers et al. 1998, on J1105−6107, which like many of the others is unpulsed and really a pulsar-fed nebula), (2) X-ray binaries where the primary is a black hole with mass quite close to 7 $M_\odot$ (van der Hooft et al. 1998; Bailyn et al. 1998, who note that V404 Cyg is more massive and its companion more evolved), (3) third dredge-up, which arguably occurs in all AGB stars, but you don't notice the effects until the planetary nebula stage (Vassiliadis et al. 1998a), and (4) pulsating sdB stars (O'Donoghue et al. 1998, and the next few papers, including the first binary members of the class). This last has naturally led to the prediction of yet another, related, new class of variable star, pulsating members of the extending horizontal branch, and data on some candidate examples (Charpinet et al. 1997—the same group that predicted the sdB pulsators).

9.2. Countdown

The starting point is the 4,661,836 stars in an updating of the Astrograph Catalogue (Urban et al. 1998), normalized to the *HIPPARCOS* coordinate system, but with mean epoch 1907. So far, 990,182 of them have yielded proper motions (Høg et al. 1998).

Roughly 2 million radio sources have been found in a VLA survey of most of the northern sky (Condon et al. 1998). It covers a larger sky area, but with poorer angular resolution and sensitivity, than the FIRST survey mentioned in previous years.

Both dwarf the mere 78,000 systems in the new *Washington Double Star Catalog* (Worley & Douglass 1997), which, like the two previous compilations, does not appear in full in the paper version.

ROSAT has imaged 372 *IRAS* galaxies (Boller et al. 1998, who do put the data on paper). Lists of galaxies that are just *ROSAT* or just *IRAS* sources would, of course, come back to an enormous number.

One doesn't normally think of Ap and Bp stars as being terribly common, but 342 have recognizable periods in brightness, spectrum, or magnetic field strength (Catalano & Renson 1998), out of a total inventory of 6000.

Omega Centauri is one of the most populous globular clusters, and the OGLE gravitational microlensing search has found light curves for 140 RR Lyrae stars and Population II Cepheids in it (Kaluzny et al. 1997b).

The 133 supernovae reported between 1 January and 30 September 1998 (IAU Circular 7022, SN 1998ec) are almost certainly on the road to an all-time record.

Models of the formation and evolution of X-ray binaries predict large numbers of systems with helium star or Wolf-Rayet secondaries. Whether there are 100 missing (Mitra 1998) or only 99 (Ergma & Yungelson 1998) depends on whether you think Cyg X-3 actually belongs to the class.

Our notes record Ferland et al. (1998) as the 90th review of the algorithm CLOUDY, but this is conceivably an exaggeration.

The 47 parameter model for fitting DIRBE data for the Milky Way (Freudenreich 1998) is, however, sober truth, and one nods in gratitude at Gunn et al. (1998) for pointing out that there are occasions when more parameters are not useful. Their context is interpreting the considerable scatter seen in correlations of stellar activity with rotation period or Rossby number.

The 28 ZZ Ceti (pulsating DA white dwarf) stars found so far (Giovannini et al. 1998, with the new one having the second-longest period of 18 minutes) just barely outnumber the 26 brown dwarf candidates in the Pleiades (Bouvier et al. 1998). The eight or so with good spectra apparently have masses of 0.04 to 0.08 $M_\odot$ (Festin 1998; Zapatero Osorio et al. 1997). The latter actually reports a somewhat larger group of candidates, and even you, young as you are, probably remember when there were zero.

One of the ZZ Ceti stars has at least 19 recognizable modes, or an average of 2.21 modes per author (Kleinman et al. 1998).

At least 15 barred spirals actually have double bars, with the inner one rotating faster (Jungwiert et al. 1997).

About a dozen assorted active galaxies have been seen at extreme ultraviolet wavelengths (Craig & Fruscione 1997), but this is a statement about the number of windows in the Milky Way, not about the AGNs, which surely all radiate in this band.

The equivalent of a 10 page *Astrophysical Journal Letter* has been achieved by the authors of ApJ 501, L127 and L131 by separating the observations from the theory and re-ordering the authors.

Moving into single digits brings us to the ninth-brightest QSO at $V = 14.42$ and $z = 0.1$, found because it is a *ROSAT* source (Read et al. 1998). One wonders how many more may be lurking within the range of even rather small telescopes. The ninth radio galaxy with optical jets, 3C 15, is non-thermal in both wavebands, and the nucleus is obscured (Martel et al. 1998). The ninth eclipsing polar is also the third with an orbit period longer than the gap in the $N(P)$ distribution for cataclysmic variables in general (Buckley et al. 1998a).

Six are the cool Algols (Torres et al. 1998), the very late M subdwarfs (Gizis et al. 1997, an APM discovery), the polars (cataclysmic binaries with strong magnetic fields anchored to the white dwarf components) with orbit periods very close to 80 minutes (Burwitz et al. 1998), and, to within ± 1, the DB (helium atmosphere) white dwarfs with strong magnetic fields (Reimers et al. 1998, though the second had been reported only issues before, in Jordan et al. 1998). Ritter & Kolb (1998) have published only an advertisement for the sixth catalogue of CVs and low-mass X-ray binaries.

Five are the plausible optical identifications of X-ray binaries in globular clusters (Deutsch et al. 1998, on NGC 6441) and the supernova remnants interacting with adjacent molecular clouds (Wilner et al. 1998, on 3C 391). IC 443 was first; the others are W28, W44, CTB 109, and G84.2−0.8.

Four are the millisecond X-ray pulsars (Kuiper et al. 1998). The most recent is a binary with an optical identification and only about half the flux pulsed, suggesting that the magnetic and rotation axes may be nearly aligned. There are four different periods seen in WZ Sge (the prototype dwarf nova with long intervals between outbursts). The one near 28 s is also seen in the X-ray flux and is probably the rotation period of the white dwarf (Patterson et al. 1998). MG 0248+0641 is the fourth radio galaxy whose lobes have rings, joining 3C 219, 3C 310, and Hercules A. The magnetic field goes around the ring, and some sort of bubble instability in the jets is probably responsible (Conner et al. 1998).

Four is a most unlikely number for the images in strong gravitational lensing (which are usually 3 or 5, though often with one very faint or perched atop the lens image), but a sufficiently strong cusp in the lens potential can yield an even number (2 or 4) of images (Evans & Wilkinson 1998).

Three brings us to the "well-known classes of astrophysical objects" that are just in the process of being recognized, sometimes because they involve the intersection of two fairly rare classes. Examples include open clusters with X-ray–emitting blue stragglers, with IC 4651 added to M67 and NGC 752 by Belloni & Tagliaferri (1998). The stars are rapid rotators, and so presumably the products of mass transfer or merger in close binaries. We also find the second and third cataclysmic variables in open clusters, Kaluzny et al. (1997a) reporting two in NGC 6791, where M67 had formerly stood alone. Jacoby et al. (1997) have found the third and fourth planetary nebulae in globular clusters (Pal 6 and NGC 6441). The first two were M15 and M22. All also host X-ray binaries, vaguely suggesting binary progenitors for the PNe.

Third classes inevitably appear where you have had two before. Ap97 noted a potential third class of supernova remnant, associated with OH masing. Further work suggests that these may be the ones that accelerate cosmic rays, because of the strong magnetic fields just behind their shocks (Claussen et al. 1997). Green et al. (1997) note that many of the OH maser SNRs are also interacting with nearby molecular gas (a "five" just above). If you don't like this set of correlations, you can have a different third class in addition to shell and filled-center (plerion) types, characterized by a shell plus a central X-ray enhancement that is probably not due to a pulsar (Craig et al. 1997; Rho & Petre 1998). But many of Green et al.'s objects also belong to this class.

Threes and twos are of at least two or three kinds, about which one can say (1) oh, goody, here is another, so I wasn't wrong the first time, (2) there is more than one way to skin a cat, and (3) there is more than one cat, if you have found a successful skinning method. The use of the disk instability invented to explain dwarf novae for X-ray binaries, active galaxies, and so forth is a case (3) mentioned in earlier years. A new one (to us anyhow) is magnetic reconnection, long proposed as a way of heating the solar corona and setting off flares. It may also operate in active galactic nuclei (Di Matteo 1998) and in the general interstellar medium (Kaneda et al. 1997; Birk et al. 1998).

Other examples are disk coronae, which account for some of the observed characteristics of X-ray binaries and AGNs and are probably also to be found around T Tauri stars (Kwan 1997), and Lindblad resonances, long known to affect motions in the disks of spiral galaxies. They probably also occur in the disks of cataclysmic variables and assorted young stellar objects, where horizontal forces due to the second star or a planet replace epicycles (Lubow & Olgilvie 1998).

9.3. Second Examples

Most of these are quite straightforward, and they are simply listed, more or less from near to far. Supply the words " the second " before each ASP-style bullet (the words were originally " NASA bullet " but we aren't sure they look the same).

◦ Really cool white dwarf, at $T = 3900$ K (Hambly et al. 1997)

◦ White dwarf with both strong magnetic field and large mass (Ferrario et al. 1998, and see Cropper et al. 1998a on the masses of white dwarfs in magnetic CVs)

◦ Visual binary orbit found with the fine guidance sensor on *HST*; also the first (Franz et al. 1998; Hershey & Taff 1998)

◦ Intermediate polar with a period smaller than the 2–3 hr gap (Buckley et al. 1998b)

◦ Magnetic CV with X-ray outbursts (Hellier et al. 1997)

◦ Triple-mode RR Lyrae star (Antipin 1997)

◦ Binary RR Lyrae (Chicherov 1997 removes one; Fernley & Barnes 1997 add seven)

◦ Rapid X-ray burster, meaning the sort where the bursts are caused by accretion instabilities rather than nuclear explosions (IAU Circulars 6813 and 6992)

◦ Supersoft X-ray binary with optical jets (Tomov et al. 1998)

◦ Kind of intergalactic star, red giants in Virgo (Ferguson et al. 1998). Intergalactic planetary nebulae appeared in the Virgo and Fornax clusters in time for Ap97. Such stars could add up to about 10% of the stellar mass in the clusters, assuming a particular initial mass function and so forth. The idea that there should be such stars as a result of galaxy interactions in clusters came from Zwicky (1951), and the first search was attempted by de Vaucouleurs (1960), who thought he had found some, but probably had not. His photometry remains useful down to the present as a constraint on dwarf galaxies.

◦ Detection of Lyα emission from a damped Lyα system that has absorption redshift somewhat larger than the emission-line redshift of the QSO (Møller et al. 1998)

◦ Detection of CO at redshift exceeding 4 (Guilloteau et al. 1997).

9.4. Second Types and Methods

Starting near home with the Sun, we learn that it has two kinds of wind, fast and slow (Habbal et al. 1997; Bravo & Stewart 1997), arising from different parts of the polar coronal holes. Curiously, AGB stars can also have double molecular winds, as revealed by CO data, when the star changes its pulsation mode or surface composition (Knapp et al. 1998).

The second star with its coronal loops resolved (UV Ceti B, with VLBI, Benz et al. 1998) might seem to belong in the preceding section, and near the beginning at that, since the first one was the Sun. But, digging a little shallower, we find that evidence is accumulating for there also being two *kinds* of coronal loops, both in RS CVn stars (Griffiths & Jordan 1998) and in G stars, where they are at different temperatures (Ventura et al. 1998). That there are two coronae in Capella (the first X-ray star) is not terribly surprising when you remember that it is a binary (Linsky et al. 1998). The two can be separated in ultraviolet data, and the one attached to the F stars shows evidence for a 6 yr activity cycle (Katsova & Scherbakov 1998). Closely related are the two radio sources, thermal and nonthermal, in some WR + OB binaries (Niemela et al. 1998). The thermal part is the WR wind, the nonthermal part the two winds colliding.

Stellar evolution and nucleosynthesis are a rich source of duplicitous ways of doing things. Sometimes these are understood. For instance, there are two subclasses of spectral class S stars, one with Tc and one without. It is fairly clear that the Tc-free ones are all mass-transfer binaries, the star we see having been polluted by a companion that is now a white dwarf (Jorissen & Knapp 1998; Jorissen et al. 1998). Those with Tc have, on the other hand, done it to themselves, and we are seeing recently synthesized *s*-process material that has been mixed to the surface less than 10^6 yr ago.

Indeed, there are also two sorts of *s*-process, deriving the neutrons to be captured by iron-peak seeds from α captures by ^{13}C and ^{22}Ne, respectively, as has been known for decades. The ^{13}C mechanism dominates in lower mass stars (Gallino et al. 1998) and is recognizable in the composition of SiC grains in meteorites, so this was probably the dominant contribution to solar system material. But other stars show abundance patterns suggestive of the ^{22}Ne mechanism, which releases neutrons at a higher rate, but over a shorter time (Abia & Wallerstein 1998). Naturally, one gets still better fits to detailed elemental and isotopic abundance patterns by allowing for a whole range of neutron exposure times, densities, and ambient temperatures (Goriely 1997). Or, as George Gamow used to say, with five parameters you can fit an elephant. If the elephant is seen in profile and the parameters are sine waves of various amplitudes and wavelengths, this is more or less true.

Not to be outdone, the *r*-process (rapid neutron capture) also claims two subspecies, responsible primarily for making nuclides above and below $A = 140$. Both had already been at work when the metal-poor stars of our halo formed (Sneden et al. 1998), and they have contributed recognizably different products to two sorts of grains found in meteorites (Richter et al. 1998). Multiplicity persists as to just where the two sorts of *r*-process occur. Richter et al. suggest that low-A products come from accretion-induced Type II supernovae, and high-A ones from core-collapse events (cf. Cameron 1998). Wheeler et al. (1998) situate the high-A production in low-mass cores that collapse as a result of electron capture, and Qian et al. (1998) propose collapse to a neutron star for the low-A peak and collapse to a black hole for the high-A one. In fact, there are a few isotopes like ^{129}In and ^{115}Sn whose assignment among the *s*-, *r*-, or *p*-processes is still not sorted out (Theis et al. 1998).

The quintessential two-or-more issue in stellar evolution is the "second parameter" in globular clusters, which permits clusters with the same metal abundance (the first parameter) to have different sorts of HR diagrams, especially different distributions of the horizontal-branch stars from red to blue. The traditional answers were the ratio of CNO to Fe and age. Within the index year, Wachter et al. (1998) said it's not the CNO/Fe abundance ratio, and Sweigert & Catelan (1998) said it's not age, and not mass loss on the red giant branch, either. Our favorite comes from Smith et al. (1997, 1998a), who say neither they nor we know what the second parameter is, but it's not the same in all cases. They compare the globular clusters belonging to the Fornax dwarf spheroidal galaxy with those belong to the Milky Way.

There is, perhaps, a new bandwagon gathering speed and riders (hardly anybody wants to be the horse out in front pulling) in favor of variable amounts of mixing of core helium into stellar envelopes (Kraft et al. 1998). The senior author has appeared in these pages before as an advocate of age and CNO. Incidentally, old open clusters can also have "second-parameter" horizontal-branch structures, as in the case of NGC 6791, which has $[\mathrm{Fe/H}] = +0.4$, and blue HB stars that are not blue stragglers, though they may be binary products (Peterson & Green 1998).

Also noted in the 1998 literature is the second easiest way to write nonsense: just visit the website http://www.cs.monash.edu.au/cgi-bin/ and it will produce some postmodern prose for you. The easiest way? Clearly it has been discovered by the present authors.

10. PRIMUS, CITIUS, ALTIUS, FORTIUS

Items like these must be approached with the eye of faith (hence the use of a Latin rather than Greek heading). Many of the statements are model dependent; some will have ignored obscure (or even not so obscure) earlier results; and some will have been misunderstood by the present authors. But they are such fun to collect, whether of physical importance, like large-scale structure and very high energy cosmic rays, or not (the longest paper series and fastest refereeing).

10.1. Cosmic Extrema

The largest scale structure. Virtually all approaches to this issue by observers, using surveys of galaxies, clusters, and such, come up with numbers between 100 and 150 h^{-1} Mpc, where h is the Hubble constant in units of 100 km s^{-1} Mpc^{-1}. In inverse alphabetical order, we found, Zucca et al. (1997), Vettolani et al. (1997), Teerikorpi et al. (1998), Plionis & Kolokotronis (1998), Martinez (1998, using a new statistic which we do not claim to have mastered), Kerscher et al. (1998, at the upper end of the range, the missing of which they attribute to sparse sampling in some other surveys), Kalinkov et al. (1998), and Geller et al. (1997). A couple of these describe the distribution of galaxies as a fractal of dimension 2 or thereabouts, but indicate that the turnover to homogeneity occurs on the same large scales mentioned in the other papers.

The strongest disagreement comes from Ryabinkov et al. (1998), who conclude that the distribution of QSO emission line redshifts has peaks at eight values between 1.2 and 3.2. These are not equally spaced, so this is not a new claim of periodicity.

The highest energy cosmic rays are counted as "cosmic" because charged particles more energetic than about 10^{15} eV cannot be confined to the Galaxy even if they could be made here. And the spectrum extends to 10^{20} eV with no clear break (Takeda et al. 1998). But they don't necessarily belong to the whole universe either. From the point of view of a particle with that sort of energy, a photon from the cosmic microwave background looks like a big, fierce gamma ray and stops it in its tracks. Thus, at very best, whether the primary particles are supposed to be protons or iron nuclei (each dominates in some lower energy range), they cannot be reaching us from more than about 100 Mpc away (Stecker 1998, refining a much earlier calculation). The arrival directions of the six most energetic events so far recorded are scattered over the part of sky available to the detectors and do not obviously point at a nearby radio galaxy, EGRET source, or what have you (Medina Tanco 1998). In desperation, one turns to particles and processes for which the physics is less certain.

This was already happening a couple of years ago (Ap96, § 11.5), but the latest round includes (1) protons made (nearby) by the annihilation of monopoles in closed loops of "cosmic necklace," meaning monopoles joined together by strings (Berezinsky & Vilenkin 1997; and you should not ask your jeweler to try to restring these), (2) topological defects making Higgs and gauge bosons that, in turn, make more familiar particles (Bhattacharjee et al. 1998a, 1998b, in which case the same physics in the early universe was responsible for the excess of baryons over anti-baryons to which we owe our existence), or (3) generic decaying dark matter particles (Hillas 1998; Berezinsky et al. 1997). You win with this strategy because the parent particles are part of the dark matter of our own Galactic halo, and so the decay products don't have far to travel.

10.2. Remarkable Active Galaxies

The largest quasar is not PKS 0241+011, which is really three separate radio sources (Nilsson & Lehto 1997). It would have stretched across 2.4 h^{-1} Mpc if a single object, but HE 1127−1304 ($z = 0.6$) is just about the same size, for $H = 50$ km s^{-1} Mpc^{-1} and $q = 1/2$ (Bhatnagar et al. 1998).

The brightest QSO or anything else in the universe might be the $z = 3.87$ source APM 08276, at 5×10^{45} ergs s^{-1} (for some H and q), except that it may well be lensed and so bright mostly in our direction (Irwin et al. 1998). The brightest nearby AGN, outshining even 3C 273, is PDS 452 at $z = 0.184$ (Torres et al. 1997).

The highest redshift radio-loud quasar, at $z = 4.72$, was also the brightest X-ray QSO at z greater than 4 (Fabian et al. 1997; Hook & McMahon 1998). It is perhaps beamed at us in one or both wavelength regimes. Later papers brought forward additional contenders for brightest radio quasar at $z > 4$ and highest redshift X-ray–selected QSO (Fabian et al. 1998; Schneider et al. 1998). The highest redshift source in 3C, on the other hand, is at a mere $z = 2.47$ (van Breugel et al. 1998).

The first BAL radio quasar has also the highest optical polarization of the objects with broad absorption lines, up to 13% in the continuum and emission lines, but zero in the broad absorption lines (Brotherton et al. 1997).

QSO absorption lines should not be blamed on the background light sources that enable us to see them, but the record low metallicity in a damped Lyα system is less than [Fe/H] $= -3.2$ (Ledoux et al. 1998a). The most distant cloud seen as a 21 cm absorber is at $z = 3.388$ (Kanekar & Chengalur 1997, reporting data from Ooty). There is also damped Lyα at the same redshift.

The largest superluminal velocity arguably belongs to a $z = 3.1$ quasar for which the apparent projected speed along the jet is $(27 \pm 17)h^{-1}c$ (Fendt et al. 1998). It seems to belong to a moving component between two stationary ones.

Mildly active galaxies include the Markarian-selected (ultraviolet-excess) ones, in which Schlegel & Kirshner (1998) have recorded the first Type II supernova, and the radio galaxies in which Athreya et al. (1998) report what could be the largest scale coherent magnetic fields, stretching over 5–10 kpc, based on rotation measures. Markarian 501 sports the highest frequency synchrotron radiation, but only when it is flaring (Lamer & Wagner 1998). The radio galaxy 3C 84 (Perseus A) has what is apparently the first radio "millihalo," only 60 pc across in VLBA data that also revealed a counterjet (Silver et al. 1998).

10.3. Outstanding Galaxies and Clusters

The largest redshift once again belongs to a galaxy selected by optical methods, the Lyman-dropout technique (Ap96, § 12.1). The magic number is 5.34 (Dey et al. 1998), with larger ones already on our side of the event horizon. Assuming $q = 1/2$, no absorption by dust, and a few other things, they find a star formation rate of about 6 $M_\odot$ yr^{-1} h_{50}^2 and general resemblance to "lower" redshift (meaning $z = 3$!) galaxies of less than L^*, the bend in the Schechter luminosity function. Thommes et al. (1998) report seven candidate Lyα emission-line galaxies near $z = 5.7$, but "more work is needed." It is likely that 1–5 images in the Hubble Deep Fields will reveal redshifts of 6 to 7, when/if it becomes possible to get spectra (Lanzetta et al. 1998).

The bluest galaxy, at least at $U-I$, is still almost half gas, even if you count only the H I (O'Neil et al. 1998). It is of quite low metallicity, so adding up the molecular gas using CO as a tracer may be difficult.

The most distant X-ray cluster has perhaps been found at $z = 2.156$ (Carilli et al. 1998b), though the argument is a bit indirect.

The highest M/L cluster, at 1200 $M_\odot/L_\odot$, was originally found as an *ASCA* source (Hattori et al. 1997). The poor thing really has only one galaxy (Sahu et al. 1998a), and if it were typical of the universe, recollapse would be in our travel plans. Since most clusters of galaxies are pervaded by X-ray gas at 10^7 K or thereabouts, one doesn't really expect to find much dust in them, but dust is the most likely explanation of the far-infrared emission from Coma as seen by *ISO* (Stickel et al. 1998).

Supernovae in starburst (*etc.*) *galaxies*: The more explosive author used to worry that none had ever been seen (though many very young remnants have been announced over the years). Richmond et al. (1998) have done a systematic search of 142 nearby starbursts. Yes, there are supernovae, but the rates are much the same, per unit luminosity, as in normal galaxies. And there is no detectable brightening of the nucleus by hordes of SNe. Every galaxy is entitled to have a bit of everything, so it may be only statistics of small numbers that has delayed until this year the discovery of the first supernova in a blue compact dwarf galaxy (Popescu et al. 1997 on SN 1995ab) and the first giant molecular cloud in a galaxy as early as Sab (Taylor & Wilson 1998 on M81).

10.4. Neutron Stars, Supernovae, White Dwarfs, and Other Evolved Extrema

The fastest young pulsar. NP 0532 in the Crab Nebula, with rotation $P = 0.033$ s, held this title for 30 years, only at last to be bested by one in the supernova remnant N157B in the Large Magellanic Cloud, discovered in a fairly dead heat by users of *BeppoSAX* (Cusumano et al. 1998) and *RXTE* (Marshall et al. 1998). So far, there are only X-ray data, but they establish a clear period of 0.016 s and a measurable slowing-down time of about 5000 yr. This is close to the estimated age of the supernova remnant. The implications are (a) that the neutron star was rotating much faster at birth (unlike the Crab pulsar) and (b) that the magnetic field is about 9×10^{11} G (weaker than the Crab). It has had one glitch in 3.5 yr of timing data. The fastest neutron star spin-down, at 3.9 ms yr^{-1}, belongs to the X-ray binary GX $1+4$, and lasted only three months (IAU Circular 6749).

The most massive neutron star is perhaps that in 4U $1820-30$, at 2.2 $M_\odot$. This follows if the observed quasi-periodic oscillation at 1060 Hz is the marginally stable orbit around the star (Zhang et al. 1998c).

According to the models calculated by Datta et al. (1998), a neutron star must be rotating rapidly to be stable at that large a mass, with a cutoff at 2 $M_\odot$ for non-rotating ones. If all the numbers are correct, the system won't be with us for long.

The brightest X-ray source in the Local Group, at 10^{39} erg s^{-1}, is X-8 in M33 (Dubus et al. 1997). It is probably a black hole X-ray binary with an orbit period of about 10 days, though the data stream is dominated by a period of 106 days. The shortest recurrence period among the transient X-ray binaries thought to harbor black holes is 600–700 days for 4U $1630-47$ (Kuulkers et al. 1997). It should have gone off again in 1998 January, but we forgot to watch. The mean recurrence time is about 6 yr (based on 17 systems; Chen et al. 1997b), and has inevitably been blamed on some sort of disk instability like the ones responsible for dwarf novae. The most warped disk in an X-ray binary is surely the 90° or more suggested by van Kerkwijk et al. (1998) to explain rapid switches between spin-up and spin-down of accreting neutron stars.

The largest bulk gamma? The more relativistic author had recorded the galactic "superluminal source," or mini-quasar, GRS $1915+105$ as displaying the largest ever relativity parameter near 10^3, but on second reading is not at all sure that this is what Mirabel et al. (1998) and Eikenberry et al. (1998b) are really saying.

The first X-ray SN I was 1994I in M51 (Immler et al. 1998b, with a *ROSAT* detection about 90 days after the explosion). It is, however, a Type Ic, and they are supposed to be surrounded by shed envelop stuff, just waiting to be shock heated by ejecta.

The longest continuous record of a supernova spectrum naturally belongs to SN 1987A. This has permitted accurate estimates of the amounts of material ejected (Kozma & Fransson 1998), including 7.7 $M_\odot$ of H, 5.8 $M_\odot$ of He, 1.9 $M_\odot$ of O, smaller amounts of Mg, Ne, and N, plus 0.006 $M_\odot$ of Fe, with carbon, sulphur, and calcium indeterminate. This is particularly unfortunate for carbon, since the C/O ratio would be interesting. Emission-line components signal that the ejecta are beginning to hit the inner, pre-supernova ring (Sonneborn et al. 1998; Michael et al. 1998), and the X-ray and other fireworks that were predicted variously for 1990 to 2001 should truly break out soon. "Observations are encouraged at all wavelengths," as the IAU circulars always say. IAU Circular 6761 in this case.

The weakest neutron star magnetic field could perfectly well be zero, but Aql X-1 at 10^8 G may be the weakest we can measure, and even it is based on an assumption about what causes the transient bursting (Zhang et al. 1998b).

The slowest rotating neutron stars remain the ones in Be X-ray binaries at 1412 and 837 s (Haberl et al. 1998). To maximize your astonishment, divide these by the limiting break-up period of about 0.0015 s.

The largest mass cut between stars that become white dwarfs and stars that make core-collapse supernovae is surely the 60 $M_\odot$ found by Mowlavi et al. (1998). But they were evolving stars with initial composition $X = 0.42$, $Y = 0.48$, and $Z = 0.19$, so that the potential for radiation pressure on both metallic lines and dust is truly enormous. The stars also have very short lifetimes. For solar composition, we expect the mass cut to come close to the 7.6 $M_\odot$ found by Elson et al. (1998a) from a white dwarf in NGC 1818 in the LMC.

The most massive white dwarf is, by definition, just a smidge less than the Chandrasekhar limit. A good candidate is the *Extreme Ultraviolet Explorer* source $\mathrm{J}0317-855$, with $\log g = 9.5$, meaning a mass of about 1.35 $M_\odot$. It also has a rotation period of 725 s, a magnetic field near 450 MG, and a cooling age less than that of a nearby DA companion, LB 9802 (Ferrario et al. 1997). All this sounds a lot like what you would expect from the recent merger of two lower mass white dwarfs, and perhaps we should call the product the first failed SN Ia?

The most massive DO, PG $0109+112$, is only 0.74 $M_\odot$. It is also probably the first one to be caught still wearing its planetary nebula (Werner et al. 1997). The combination may be merely an effect of statistics of small numbers. DOs, massive white dwarfs, and planetary nebulae are all relatively rare. The youngest white dwarf may or may not be MCT $0501-2856$ with a cooling time less than 10^5 yr, but it is surely in the running (Vennes et al. 1998). It is a helium white dwarf of only 0.4 $M_\odot$ and so cools very rapidly, having already reached 68.6 kK and may be a post–PG 1159 star. Incidentally, since our galaxy forms white dwarfs at a rate of about one per year, there is bound to be a one-year-old toddler out there somewhere. It just isn't very likely to be within sighting distance of us.

The weakest white dwarf magnetic field, like the weakest neutron star one, is derived from an assumption about propeller effects on accretion. It is 100 kG for V471 Tau, which accretes at only 10^{-5} of the Bondi-Hoyle rate (Sion et al. 1998). Zeeman broadening of its lines might be detectable with GHRS to confirm the field strength.

The hottest, youngest, and most massive white dwarf binary found so far is a visual system. This is very good from the point of view of learning about the individual stars, but very bad from the point of view of potential progenitors of Type Ia supernovae. The current masses are 1.1 and 0.8 $M_\odot$, and the progenitors (allowing for the different cooling ages and simultaneous birth) must have been about 6.5 and 3.8 $M_\odot$ (Finley & Koester 1997). The first white dwarf in attendance upon a BV secondary is HR 2875 (= η Puppis). It took data from both *EUVE* and *ROSAT* to recognize the unusual combination (Vennes et al. 1997).

The fastest expansion of a planetary nebula probably isn't in this year's data base. The 200 km s^{-1} logged for Kj PN8 by Meaburn (1997) is respectable, but easily outdone by the [N II] knots in MyCn18 reported by Bryce et al. (1997) at 500 km s^{-1}. The main body of that nebula expands at less than 50 km s^{-1}.

10.5. Way-out Stars

The most massive stars might be those in a cluster of O, B, and WR stars in 30 Doradus. They extend to O3 If in spectral type and to at least 120 $M_{\odot}$ in mass, a limit because the evolutionary tracks go no farther, and there are a few stars brighter than the 120 $M_{\odot}$ track (Massey & Hunter 1998; Walborn & Blades 1997). One never, however, quite stops worrying about "the" brightest star being an unresolved binary or tight cluster, as has happened many times before.

The fastest star is perhaps HD 220127, at 1000 km s^{-1} (Eggen 1998a). If you plan to observe it, apply for time now, since it will leave the Galaxy in only a billion years.

The smallest star masses, directly determined from an eclipsing spectroscopic binary, remain 0.23 and 0.21 $M_{\odot}$ for CM Dra (Viti et al. 1997). This is well above the M dwarf/brown dwarf cut, and all reports of smaller masses are necessarily based on extrapolations using atmospheric models of some sort.

The coolest star seems to be the non-degenerate component of WZ Sge at less than 1700 K (Ciardi et al. 1998, relying on infrared data). It may itself be somewhat degenerate. The coolest giants are positive furnaces by comparison, at 2800 K for M8 III (Perrin et al. 1998).

The latest spectral type has been more or less officially dubbed L (Kirkpatrick 1998). We had wanted P (if only so as eventually to be able to refer to Pp peculiar stars). But Philip Keenan is quoted as approving of the new designation, and, in the absence of an opinion from Annie J. Cannon, that probably settles it.[3] The examples will mostly be brown dwarfs.

The youngest intermediate mass star is a 6 $M_{\odot}$ analog of the Class O sources at lower mass (Eiroa et al. 1998). It lives in NGC 7129 and will become a Herbig Ae star in the future (and we trust that George will write about it with his crow-quill pen).

The most distant dwarf Cepheids so far have been resolved in the Carina dwarf spheroidal galaxy. Remember that these stars are 2 mag fainter than the RR Lyraes (being, in effect, variable blue stragglers), and admire the diligence of Matteo et al. 1998).

The first direct detection of changes in radius of a Mira variable through its pulsation period have been recorded for R Leo by the Cambridge Optical Aperture Synthesis Telescope (COAST; Burns et al. 1998). The amplitude is about 35% in the very near infrared, and the phase relative to radial velocity variations and light curve is not quite what you expect. This is perhaps to be blamed on titanium oxide (which should be back home keeping the paint white anyhow).

The first half dozen circular polarization detections of stellar magnetic fields pertain to a curious range of stellar types (Donati et al. 1997). One is not surprised at fields up to kilogauss in stars known to be active anyway, like RS CVn binaries, AB Doradus, and YY Men (an FK Comae star). V410, a naked T Tauri star, is a surprise. It ought to be fully convective, and dynamo models generally work at the base of a convective envelope. Apparently real dynamos are less fussy. The technique, Zeeman Doppler imaging, was proposed by Semel (1989). The high-field parts of the stars' surfaces are generally cooler than their surroundings, as for the Sun.

The hottest T Tauri flare, on V773 Tau, reached 10^8 K, according to *ASCA* data and Tsuboi et al. (1998).

The shortest activity cycle period is said to be 25,5 days for the KO IV part of the binary UX Ari (KO IV + G5 V; Massi et al. 1998). The orbit period is 6.4 days, and the authors also describe a 158 day period as being analogous to the 110 yr period in solar activity. The star is supposed to have both unusually large differential rotation and an unusually deep convective envelope, permitting toroidal flux to be generated and destroyed very quickly. But it is all just a bit improbable none the less. Cycles of stellar activity found elsewhere are in the range 3–30 yr, and are not strongly correlated with rotation period. This is more or less understood (Brandenberg et al. 1998).

10.6. Blatant Binaries

Orbit periods: The fastest BY Dra (spotted flare) pair is a new *ROSAT* source with $P = 0.465$ days (Chevalier & Ilovaisky 1997). White dwarfs can nestle much closer together, and if the 569 s period seen in the X-ray sources RX J1914.4+2456 is actually the orbit, it is the fastest binary anywhere, and the system must consist of two white dwarfs (Cropper et al. 1998b) If not, then another low-mass, double white dwarf at $P = 1028$ s counts as the fastest cataclysmic

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[3] James Liebert has generously provided the following explanation for the choice of spectral type L for stars cooler than M9.5. The Harvard system of spectral classification originally used almost the entire alphabet, in standard order. L was, however, one of the letters declared unnecessary as long ago as the time of Annie J. Cannon herself, while type P continued to be used for planetary nebulae much more recently. Thus L was ripe for recycling, while P was not. Given the current functions of M, N, R, and S, the next available type is probably T, to be used perhaps for stars cooler than about 1000 K, and the more Native American author looks forward eventually to being able to report on Teepees, when peculiar ones are discovered.

variable (Harvey et al. 1998, whose senior author lists his affiliation as the Center for Backyard Astronomy). In the latter case, an 11 minute X-ray binary remains the shortest period orbiting pair.

More orbits: The longest period W Ursae Majoris (contact) binaries extend only to 1.3–1.5 days (Rucinski 1998). Dumm et al. (1998) report a period of 1401 days for the eclipsing binary BX Mon. This is very far from being a world record, but it is a cataclysmic variable, and a white dwarf is not as easy to pass directly in front of as a larger star. Passing completely behind is nigh onto impossible. Among O-type stars, the triple HD 57061 harbors both the longest period 0 × 2 spectroscopic system at 155 days and the shortest period 0 × 2 eclipsing system at 1.3 days (van Leeuwen & van Genderen 1997). V3903 Sgr is perhaps the youngest 0 × 2 binary (Vaz et al. 1997).

The first Be star for which we can say with some confidence that it was spun up by mass transfer from a companion is ϕ Per (Gies et al. 1998). The companion is an sdO, and the phenomenon is roughly the inverse of what happens in the sort of X-ray binary where M_1 is a neutron star and M_2 a Be.

HD 84948 and HD 171948 are the first two binaries where both members are λ Boo stars (the sort that seem to have misplaced a large fraction of their atmospheric heavy elements; Paunzen et al. 1998). The rotation speeds are less than $v \sin i = 20$ km s^{-1}, a record low for these early-type stars. And we are not quite sure whether having them in pairs makes it half as hard or twice as hard to explain the abundance anomalies. The authors in any case conclude that mass loss is not the answer.

The lowest amplitude outbursts in what seem to be dwarf novae are about 0.6 mag. Honeycutt et al. (1998) have found six examples. The systems also have shortish recurrence times for the species, near 10 days, and the traditional disk instability may not be the responsible mechanism.

10.7. Clusters and the Interstellar Medium

The most stars in a multiplet? HD 193322, with 5–7 stars randomly distributed among spectroscopic, visual, and speckle binary systems is probably not the extremum (McKibbin et al. 1998). But the "Arches" cluster at the Galactic center has taken the record for most O stars, at least in the Milky Way, with about 100 (Serabyn et al. 1998); NGC 3603 is next, with 50. A_v to that region is about 28 mag, so you won't be surprised to hear that the images were taken at J, H, and K.

The coldest CO will have to beat that in the "Boomerang Nebula," which is seen in absorption against the 2.7 K cosmic background (Sahai & Nyman 1997). H_2CO is also sometimes "anti-mased" in similar fashion.

Masers, on the other hand, must somehow be pumped up, and the first detection of the infrared line needed for OH masing comes from *ISO* data for IRC +10420 (Sylvester et al. 1997). The basic line is a 34.6 μm doublet, and there is a cascade to 98.7 μm and longer wavelengths.

New molecules found in interstellar gas this year include C-C_2H_4O (ethylene oxide; Dickens et al. 1997) and C_5N (cyanobutadiynyl; Guelin et al. 1998). And no, we don't know to pronounce it either. Nor can we claim to understand the details of how McCarthy et al. (1998) managed to produce $HC_{15}N$ and $HC_{17}N$ to study their spectra. Neither has (yet) been seen in the ISM, but, at a molecular weight of 219, $HC_{17}N$ sets a record even for laboratory spectroscopy.

The largest halo of radio scattering, 3″ at 20 cm, belongs to NGC 6334B (Trotter et al. 1998a). The H_2O masers, which the authors presumably started out to study, are not scattered, and so must be in front of the nuclear source. This also tells you that the scattering occurs in NGC 6334B, not in the Milky Way.

10.8. Names and Dates, People and Places

Here we are truly asking for trouble, reporting what seems to have been the fastest refereeing, a paper in *MNRAS* (293, L68), which was submitted on 1997 December 23 and accepted on 1997 November 12, and also the first 11 page *Astrophysical Journal* Letter (Kimble et al. 1998, reporting on STIS).

The weirdest words: It is not so difficult to get used to tachocline (Elliott 1997 and many later papers during the year) once you know what it means. It is the level at which solar rotation changes from being differential in the envelope to solid-body inside, near the base of the convective envelope. The more Americanized author is inclined to think that isotach would convey the meaning better. But the location is found by analysis of solar seismology data, and having tangled once over astro/asteroseismology with Gough (1996) disinclines her to try the experiment again. The implication of Allain (1998) seems to be that this sort of decoupling does not happen for all solar-type stars.

Discoseismology (Solheim et al. 1998) is a wonderful word that means just what it says, though of cross-cultural parentage. The paper is actually about millihertz modes in AM CVn (a low-mass, short-period, double white dwarf) and important in its own right.

On the other hand, it will take some time to get used to roundchromes (Gurzadyan 1997), RATTS (Sterzik et al. 1997, formerly runaway T Tauri stars, and we have written about them ourselves this year), synchronic bands in the tale of Comet Hale-Bopp (Watanabe et al. 1997), and HINERS (Murayama et al. 1998). These last are the opposite of LINERS.

Annealing is a fine word, just unexpected in the context of data processing (Bratsolis & Sigelle 1998; Pourbaix 1998). It is tempting to imagine the crew, driven to distraction by their hardware, dipping it into boiling water, in the hopes that the flaws will smooth out. Actually, the image is not infinitely wrong. Annealing is a method for fitting a many-parameter model to noisy data when the first guesses at the parameter values could be way off. Early work on it was done by Metropolis et al. (1953, where "al." consists of two Rosenbluths and two Tellers!).

Cyclotron vortex waves were not known to Maxwell, and so Mendell (1998a) is undoubtedly entitled to call them whatever he wants. They are sort of like Alfvén waves, but the restoring tension comes from vortex energy density rather than from $B^2/8\pi$. Come to think of it, Alfvén waves were not known to Maxwell either, and this was supposedly used as an argument against the publication of his early papers on the subject.

Clemens et al. (1998b) have discovered what may be the first CEGs (common-envelope galaxies), but nobly refrained from applying the acronym to NGC 4490+4485. "Harassment" comes from an Old French word meaning "to set the dog on," and if you happen to meet an Old French dog, you might try yelling "hare!" at it and see what happens. In the galactic case (Moore et al. 1998 and several other papers), you can try hollering "hare" at your N-body simulation, but it probably won't do much good, since very few N-body simulations speak Old French. The Old English equivalent is "sic'em, boy."

Credit where she is due: We still haven't found out who Strehl was, but for more about Hanle and his effect, see Moruzzi & Strumia (1991). Einstein really did write down Einstein's equations first (Corry et al. 1997). But Hilbert gets to keep his transform, even though the reference cited is Gabor (1946); and, yes, he is generally advertised as having been related to Zsa Zsa, Magda, and all.

No astronomical year can pass without ideas being borrowed and reborrowed from Chandrasekhar. We note the Chandrasekhar-Milne expansion (Lee 1998); and Thompson beats Chandrasekhar, at least in amount of scattering of visible light from AGNs (Beloborodov 1998), but the names of the radio components in NGC 1068 (Roy et al. 1998) must surely have been borrowed from S. Candlestickmaker's "The Imperturbability of Elevator Operators."

The Schroedinger equation and Fermi-Dirac statistics often turn up in quantum mechanical contexts, but it is a surprise to see them used to describe modes of pulsating stars (Buchler et al. 1997b) and the collapse of star clusters (Chavanis & Sommeria 1998), respectively. Along the same lines, the Bohr atom provides at least as good a fit to solar system orbits as does the Bode-Titius "law" (Reinisch 1998), a point previously noted by Casell (1929) and Barnothy (1946), in the days when *Nature* and *Science* were less solemn publications than they have become in recent years.

Many things have been around for a long time without the community agreeing about how useful or relevant they really are. Examples include Bernoulli's equation for studies of contact binary stars (Hazlehurst 1997 versus Kaehler 1997), Kolmogoroff spectra for interstellar turbulence (Sobolev et al. 1998), and the Jeans mass versus the Jeans length for the formation of binary systems (Boss 1998a).

The earliest astrophysical maser/laser paper? Menzel (1937), remarking that negative absorption was possible but unlikely to be important, pushes this history still further back (with thanks to Vladimir Strelnitski for the information).

11. LAMBDA, OMEGA, *H*, AND *K*: THE STATE OF THE UNIVERSE

We prognosticated last year (with a little help from our friends' preprint shelves) that the people measuring cosmological parameters using Type Ia supernovae as their candles would shortly join the small-Omega (and perhaps non-zero Lambda) camp. This has indeed happened. But first, a look at minor progress on the more ancient parameters.

11.1. Distance Scales and Hubble Constants

From the time of Hubble's first paper (Hubble 1929) to about 1960, the "received" value of the parameter H (whose units are km s^{-1} Mpc^{-1}) dropped more or less monotonically, from more than 500 to about 100, and enthusiastic extrapolators began to suspect that it might soon pass through zero and the universe begin to contract. This did not happen. Instead, H went into oscillation or even fibrillation between values near 100 and values near 50 km s^{-1} Mpc^{-1}, stoutly maintained by separate small groups of workers.

Recent years have seen such a spectacular proliferation of published numbers that it has become tempting to report just the median. It was 75 for 1992 (Ap92, § 8.4), 71 in 1994 (Ap94, § 11), and 65 in 1997 (Ap97, § 12.3.1). Within the present reference year, we found 23 specific values published, with a median of 60 km s^{-1} Mpc^{-1}. At least three papers hit it right on the nose (Tripp 1997, 1998; Salaris & Cassisi 1998). Two other results were of the general form "if you do this analysis naively, you will get value X, but with careful thought you get Y." In one case Y is smaller than X (Shanks 1997, concerning Malmquist bias); in the other, Y is larger than X (Kochanek 1997, on metallicity corrections to the period-luminosity relation for Cepheids).

Potential differences between the local and global values of H have now been reduced to, at most, a 10% effect (Zehavi et al. 1998; Shi & Turner 1998; Wang et al. 1998) Rashly extrapolating again, you might conclude that even the median value will pass through zero shortly before the centenary of Hubble's paper.

As you have known since early second childhood, redshifts are easy to measure if there are recognizable emission or absorption features. The hard part is distances. We all have our favorite meter sticks, and just about every one of them has been declared unreliable during the year:

- Surface brightness fluctuations: There are large differences between the values found from the ground and with *HST* (Morris & Shanks 1998).
- Tully-Fisher relation between line widths and luminosity for spirals: the line widths are very different for different gas phases (Tutui & Sofue 1997).
- Cepheids: There are still uncertainties in the correction to be made for varying metal abundances in the stars, though the Key Project team believes that these are small (Kennicutt et al. 1998; Kochanek 1997 disagrees).
- Luminosity function of planetary nebulae: the nebulae are not the same sorts of beasts, and their nuclei do not put out the same amount of ionizing radiation as a function of evolutionary age in different galaxies (Vassiliadis et al. 1998b; Stasinska et al. 1998).
- Time delays in gravitationally lensed quasars: the polite word is "model dependent." "Messy" is perhaps clearer (Wiklind & Combes 1998).
- Radio-emitting supernovae at 6 cm: these are rare, and we have data on only a few (Weiler et al. 1998).
- Luminosity function of globular clusters: although said luminosity function may have been universal when the galaxies and clusters were born (Ostriker & Gnedin 1997), it is thereafter subject to major variations among galaxies that result from dynamical evolution (Gnedin 1997). On the purely observational front, many big galaxies have two populations of clusters, with different metallicities, locations, kinematics, and luminosity distributions. These get mixed together in studies of more distant galaxies, so that the peak is not a standard candle. About a dozen papers during the year flagged this as a general problem, from van den Bergh (1998) to Sharples et al. (1998), including the best-studied case, M31, where the "globular cluster distance modulus" and the "*HIPPARCOS*-calibrated distance modulus" differ by 0.3 mag (Holland 1998). The small galaxy NGC 1379 is unusual in having unimodal distributions of cluster properties and, apparently, only one population (Elson et al. 1998b).
- Sunyaev-Zeldovich effect: it can be confounded by real fluctuations in the microwave background (Cen 1998), by radio sources in the cluster or in the background or foreground (Cooray et al. 1998), or by inappropriate modeling of the cluster (Yoshikawa et al. 1998).

M87 is a good illustration of the magnitude of the problems. Its distance from surface brightness fluctuations is 14.4 Mpc (Ciardullo et al. 1998), while a properly calibrated Tully-Fisher relation puts it at 19 Mpc (Shanks 1997).

New methods arise to challenge the old ones just about as fast as the latter are criticized. Rauzy et al. (1998) suggest that the 15th brightest galaxy in a cluster is a better standard candle than the first or third, with a dispersion of only 0.2 in absolute magnitude. Their first result is that peculiar velocities of more than 1200 km s^{-1} in their sample are automatically ruled out. Collins & Mann (1998) conclude that the brightest galaxies in luminous X-ray clusters also have a very narrow range of absolute magnitudes. They have used the results to join the "fairly small Ω, maybe moderate Λ" team of the next section.

The most complicated new approach looks at rich clusters of galaxies that emit X-rays, lens their backgrounds, and have dynamically important magnetic fields. The combination of rotation measure, lensing, and X-ray data will lead to a distance, because the three depend on different powers of electron density and distance (Makino 1997). The simplest new approach is the determination of accurate orbit parameters for detached, eclipsing binaries. Step one, finding some in M31, is underway (Kaluzny et al. 1998).

Until the new methods, the clouded old ones, and still others not explicitly mentioned here all agree, one can say only that the problems start very close to us, putting the Galactic center somewhere between 7.1 kpc (Olling & Merrifield 1998, from a rotation curve) and 8.4 kpc (Paczynski & Stanek 1998, using red clump stars found by OGLE and calibrated by *HIPPARCOS*) away from us. The current IAU standard distance is 8.5 kpc, reduced from the 10 kpc taken as standard from 1965 to 1985.

Things get worse by the time you reach the Large Magellanic Cloud, which you do at 41 (Stanek et al. 1998), 42 (Udalski et al. 1998), 50 (Gieren et al. 1998), or maybe even 55 (Ap97, § 5.3) kpc.

11.2. The Age of the Universe

The customary assumption is that this age has to be at least as large as the ages of the oldest things in it (apparently the globular clusters) plus however long it took those to form. We have no desire to quarrel with this assumption and, indeed, decreasing need. The effect of improved treatments of equation of state, opacities, diffusion, neutrino losses, and nuclear reaction rates has been largely in the direction of decreasing age estimates based on the main sequence, horizontal branch, or other stars in globular clusters (Cassisi et al. 1998). Thus, 12 Gyr for the oldest clusters (and as little as 7–8 Gyr for the youngest) now falls within everybody's error bars (Bergbusch & Vandenberg 1997; Gratton et al. 1997; Salaris & Weiss 1997; Chaboyer et al. 1998; Jimenez & Padoan 1998; Sarajedini et al. 1997; Rosenberg et al. 1998). And you should probably add in a Gyr or so for the clusters to get started making low-mass stars after the big bang.

Numbers for other galaxies or clusters in them remain consistent but necessarily less precise. Ages for Milky Way stars other than in globular clusters cover a wider range. Hansen & Phinney (1998) report that the oldest binary millisecond pulsar systems reach 15 Gyr, based on the cooling ages of their white dwarf secondaries, while the oldest (single) white dwarfs in the Galactic disk clock in at 8–10 Gyr (Leggett et al. 1998; Winget 1997), and are generally supposed to be younger than the cluster stars.

One very encouraging development is that the two independent methods of main-sequence turnoff and white dwarf cooling lead to the same age (4–4.5 Gyr) for the old open cluster M67 (Richer et al. 1998). They have taken the precaution of using isochrones that incorporate the same physics for both. To look for similar consistency in the globular clusters requires seeing to the bottom of the white dwarf cooling curves, which will inevitably be fainter than the $M_v = +14.6$ found for M67. And the globulars are farther away.

11.3. Advanced Cosmological Parameters

Most of us feel we understand, at least in principle, what is meant by the age of the universe and the numerical value of the Hubble constant, and what one has to do to measure each. In contrast, Ω (the ratio of total matter density to that required to stop the expansion of a $\Lambda = 0$ universe), Λ (the cosmological constant, which in its "useful" guise partly counteracts gravity at large distances and can lead to exponential expansion), k (the spatial curvature), and q (the deceleration parameter, $= \Omega/2$ if and only if $\Lambda = 0$) are both more difficult to understand and more difficult to measure, partly because they are more likely to require data from long ago and far away.

In addition, the quantities that come most directly from observations, including luminosity distance and angular diameter distance, are functions of more than one of the basic quantities. Of course, you could measure q directly just by watching a very large number of redshifts with very high precision for a very long time. The last two "verys" come from the smallness of the effect (parts in 10^{10} yr^{-1}), and the first "very" from the need to average out all changes in redshift due to physical acceleration and deceleration of gas or galaxies. Loeb (1998) has reconsidered this approach, last popularized when very narrow 21 cm absorption lines turned up in quasar spectra.

Sticking as long as possible to the comprehensible, we can safely say that Ω has to be at least as big as the amount of stuff that we see directly in luminous stars and gas and indirectly as gravitating material in rich clusters of galaxies. We note about 20 papers that used this sort of approach to concur with last year's majority view that Ω in all forms of matter, light or dark, breast or thigh, is a good deal less than unity, with 0.3 ± 0.1 overlapping nearly all the central values. Please scan the following list of papers along these lines only if you want to be sure your name is spelled correctly (if it isn't, see § 13): Watkins (1997), Evrard (1997), White et al. (1997), Croft et al. (1997), Henry (1997), Davis et al. (1997), Kitayama & Suto (1997), Fan et al. (1997), Gorski et al. (1998), Ferguson & Babul (1998), Barmby & Huchra (1998), Kitayama et al. (1998), da Costa et al. (1998), Bahcall & Fan (1998), Padilla et al. (1998a), Eke et al. (1998, a very well written paper!), Adami et al. (1998b), Valdarnini et al. (1998), Markevich et al. (1998), and Cavaliere et al. (1998).

Two small sets of dissidents have been allowed to survive for at least another year. One set concludes that one or more of the methods used by somebody else is actually very insensitive and doesn't tell us much about Ω per se (Mathiesen & Evrard 1998; Gheller et al. 1998 on X-ray clusters; Jenkins et al. 1998 on galaxy velocities). Members of the other set maintain that Ω close to 1 (or $q \geq 1/2$) is a possible fit to some assemblage of data, perhaps even the best fit (Blanchard & Bartlett 1998 on X-ray clusters; Sigad et al. 1998; Small et al. 1998; Pen 1997 on angular diameters of moderate-redshift clusters).

A few observational tests are actually sensitive primarily to Λ (because the coasting phase puts lots of space and so lots of galaxies at the coasting redshift). All involve some sort of gravitational lensing; that is, you are sampling simultaneously from two different redshift bins. There are so far no specific numbers found from weak gravitational lensing (the kind that makes faint arcs; Kaiser 1998) or from distortions of QSO clustering versus redshift (Popowski et al. 1998). But positive values or upper limits have been deduced from yet other forms of lensing or their absence. The numbers of lensed QSOs found in the Hubble Snapshot Survey suggest to Chiba & Yoshii (1997) that Λ is about 0.8, but to Park & Gott (1997) that no standard model is a good fit.

Falco et al. (1998) deduce an upper limit of 0.62 from lensed radio quasars. A similar limit of 0.7 comes from the observation of strong correlations between fluctuations seen in the microwave background by *COBE* and fluctuations in the X-ray background. The point is that the foreground stuff is affecting the background stuff, via an integrated Sachs-Wolfe effect (Boughn et al. 1998). Kardashev (1997) deduces some support for a dominant cosmological constant from the angular diameters of radio sources (an old and hopeless test for any cosmological parameter, because it is controlled primarily by evolution of the sources).

It is time to bite the analytical bullet and look at combinations of Ω and Λ. First, put them into consistent dimensionless units by calling what used to be plain Ω, Ω_m (meaning matter) and dividing Λ in physical units by $3H^2$ to get Ω_Λ. Then, if you peek in the back of the book at Einstein's equations in their most general form, you will discover that $\Omega_m + \Omega_\Lambda = 1$ corresponds to $k = 0$ or flat space, which is, arguably, what is predicted by inflation.

Now, luminosity distance (the distance proxy that keeps flux received $= L/4\pi d^2{}_1$ for all d) is a function of Ω_m minus Ω_Λ, while things involving angular diameters are sensitive to Ω_m *plus* Ω_Λ. This latter class includes the first acoustic or

Doppler peak in the CMB fluctuations (meaning that the fluctuation amplitudes that have been dropping in size from dipole to quadrupole to higher order multipoles perk up again around $l = 160$ to 350. See Zaldarriaga et al. (1997), Hancock et al. (1998), or any good modern cosmology book (meaning one that does not start by assuming $\Lambda = 0$) for how and why these sensitivities arise. The first acoustic peak has probably been seen, but is not very restrictive (Hancock et al. 1998, on data from Saskatoon).

This brings us, at long last, to luminosity distances for Type Ia supernovae. They are the kind that get their energy from the explosive burning of about 1 $M_\odot$ of degenerate carbon and oxygen to iron-peak elements. And when you compare the peak luminosities, ejection velocities, and rates of evolution of light curves and spectra, the systematics all makes sense as depending on the mass of ^{56}Fe (etc.) produced, so that it is rational to treat them not as standard candles, but as standardizable candles (Mazzali et al. 1998; Cappellaro et al. 1997). Such supernovae have now been studied over a sufficiently wide range of redshifts that you can trace out d_1 versus z and have the Hubble constant drop out as a normalization that doesn't matter to $\Omega_m - \Omega_\Lambda$ (though it crashes back in if you want to separate the two Ω's).

The two groups slogging away on this problem, with independent data sets and analyses, though some overlap of personnel, have now both reported results from largish samples (Reiss et al. 1998; Perlmutter et al. 1998; Garnavich et al. 1998). The numbers do not agree perfectly, but in a diagram of Ω_Λ versus Ω_m, the narrow ellipse of allowed parameter space excludes both $\Omega_m = 1$ and $q = 1/2$ by several standard deviations. The locus of maximum probability crosses the $\Omega_m = 0.2$–0.3 regime implied by clustering studies very close to the $k = 0$ (flat space) line.

This is surely not the last word on the subject. Whether it is even a satisfactory word for the time being depends very much on how you felt about the cosmological constant before these papers appeared. The more rapidly expanding author has always been perfectly happy with it, as was G. H. de Vaucouleurs through the decades when he defended a large value for H. Anyhow, the time is now ripe for the jackals of review papers to move in and choose consistent sets of all the constants (Coles 1998; Baum 1998) and to be mildly grateful that the resulting universe is one in which we can exist (Tegmark & Rees 1998). The present authors are spared having to do this by having done it last year (Ap97, § 12.3).

11.4. Oh Dear, What Can the Matter Be?

You are allowed to choose one, two, or three from among cold dark matter, hot dark matter, and strings or other topological defects. Having some baryons is compulsory. Of the couple dozen papers addressing just how many (based on abundances of deuterium, lithium, and helium, or observed gas in X-ray clusters, quasar absorption lines, and so forth), we note only the review by Schramm & Turner (1998), promising that if you vote with them, you will not often be on the losing side, at least in the short run. H once again rears its unkempt head, but "a few percent of the closure density" would satisfy most contributors to the discussion.

That there are baryons today happens because they very slightly outnumbered the antibaryons long ago. Another answer to "why" comes from Ma & Sarkar (1998) in the form of adding two heavy Higgs triplets to get leptogenesis, which then leads to a baryon excess at the electroweak phase transition. (It doesn't help much to define the words; the order also matters).

The other forms of matter also had their fans during the year. Cheng et al. (1997) conclude that cold dark matter is useful for fitting the spectrum of CMB fluctuations. Gawiser & Silk (1998) favor hot dark matter, amounting to about 20% of closure density. And Spergel & Pen (1998) include a large component of strings, enabling the universe to be flat and still act in some ways as if q were quite small. Dvali et al. (1998) propose a scheme that can only be called "my defect can beat your defect," in which domain walls sweep away magnetic monopoles and then themselves decay away.

11.5. Not Even Matter

We still cannot decide whether quintessence as an alternative to a cosmological constant counts as matter or not, so it has to live out here all by itself. It has an equation of state different from those of matter, radiation, or Λ, and is capable of clumping to help form large-scale structures (Caldwell et al. 1998).

12. EPSILON: OUR SOLAR SYSTEM AND OTHERS

Epsilon is the traditional small quantity ("for every ϵ there is a δ," say the proofs of elementary calculus), and planets (etc.) indeed make up a vary small part of the mass of any star-based system, though a much larger fraction of the literature.

12.1. Extra–Solar System Planets

Both numbers and confidence continue to increase. The most recent tables include a dozen or more stars with things orbiting them whose masses are comparable to that of Jupiter, most recognized because the measured radial velocities of hosts oscillate in small-amplitude reflection of the planets' motions (R. P. Butler 1998, private communication and preprints). Vanished is the threat to the very existence of these planets posed by supposedly variable line profiles that would have signaled nonradial oscillations of the stars rather than planets (Willems et al. 1997; Gray 1998; Hatzes et al. 1998; Brown et al. 1998b, and undoubtedly others). An assortment of other planet mimics, including star spots and inhomogeneous convection, can also be ruled out by comparing the data for the advertised host stars with the level of velocity fluctuations found for other stars (typically 20–48 m s^{-1}, and largely instrumental; Saar et al. 1998).

Thus we can turn with confidence to the host stars, knowing they are special, and learn that they are systematically somewhat metal rich (Fuhrmann et al. 1997) but not otherwise unusual in surface composition (Tomkin et al. 1997). They range in age from 1–20 Gyr and in mass from 0.97 to 1.27 $M_\odot$ (Fuhrmann et al. 1998, not for the complete sample).

The naive reviewer has naturally been assuming that these stars have planets because they are metal rich, making it easier for solids to condense. Gonzalez (1998), however, asserts the converse, that the stars are metal rich (at least on their surfaces) because they have planets, and some left over planetary stuff has fallen in. The same was argued for the Sun long ago, and we still haven't found the reference.

Less direct evidence has been advanced for planets or comets orbiting Aldebaran (Hatzes & Cochran 1998), Geminga (Mattox et al. 1998), and various white dwarfs (Parriott & Alcock 1998), including the unique emission line star GD 356 (Li et al. 1998a) and the white dwarf in the Red Rectangle (Jura & Turner 1998). The largest class of indirect detections consists of stars, single or binary, that still harbor dust disks, gaps or holes which can be attributed to resonances with something in orbit or where peculiarities of the dust indicate that it might be derived from cometary breakup (Malfait 1998). Many of the gaps are undoubtedly real and significant (Jayawardhana et al. 1998; Koerner et al. 1998), but some are probably artifacts of improper allowance for the different paths taken by the optical and infrared radiation that reaches us (Close et al. 1997, on R Mon).

The prototype remains β Pictoris, which appeared in at least 15 papers during the review year. With complete arbitrariness, we mention only the first (Pantin et al. 1997, analyzing pre-*ISO* infrared observations) and Liseau & Artymowicz (1998), reporting a gas-to-dust ratio of less than 0.1 in the disk, derived from upper limits on CO and other molecular emission.

That even binary protostars can support disks (Ghez et al. 1997) has been confirmed by a second system with resolved images of stars and disk. The resolution was achieved almost simultaneously with interferometry (Duvert et al. 1998) and with adaptive optics (Close et al. 1998).

On the theoretical front, puzzlement continues that some eccentricities are high for such short-period orbits. De la Fuentes Marcos & de la Fuentes Marcos (1997) explain the ellipticities as the result of interactions with other stars in a young cluster, while Black (1997) prefers to suspect that many of the putative planets are really brown dwarfs, with masses exceeding 10–30 M_J and entitled to their eccentricities (see also Mazeh et al. 1998).

The short-period orbits themselves were not initially expected, and the envelope-back explanations of 1997 have given way to more complete calculations of how residual planetesimals can move Jupiters around, some plunging suicidally into the parent stars, some surviving in small orbits, and some moving on out to resemble our own solar system (Murray et al. 1998; Trilling et al. 1998). Boss (1998b) perceives the whole thing as an unexpected opportunity to probe whether planets in general form by accretion over 10^7 yr or by gravitational disk instabilities in 10^5. Just, he says, look for planets around stars with ages in between.

We feel vaguely that the presence in giant molecular clouds of CO clumps with masses as small as that of Jupiter (Heithausen et al. 1998) ought to have something to do with the problem, but apparently it doesn't. Perhaps the secret is that the little bits are photoevaporated away before they can do anything interesting, as seems to be the case in Orion (Johnstone et al. 1998). And when substellar things do succeed in forming, their structure is unexpectedly complex (Burrows et al. 1997). Metals begin dropping out of the photosphere, the interior develops a radiative zone, and this is still before any account has been taken of the effects of irradiation by the nearby big, bright star.

Finally, there are places where planets are rare. They make up at most 10%–20% of the dark halo of the Milky Way (Renault et al. 1998; Alcock et al. 1998b), since we do not see any of the very short duration gravitational lensing events they could cause. And the inventory of planets orbiting pulsars has not increased since Ap92, § 3. In fact, it may have decreased, doubts having been cast on the reality of the one with a 25.54 day orbit around B1257+12, because the same period shows up in *Pioneer 10* tracking data. Thus it may be the rotation of the Sun changing the amount of plasma along our sight lines, and therefore the radio-wave travel time from the pulsar to us (Scherer et al. 1997).

12.2. Moon, Mercury, Mars, and Meteorites

The main news from the Moon was transmitted by the Lunar Prospector package (Binder 1998 and six following papers). Highlights include additional evidence for hydrogen at the poles, presumably water (but Mendell 1998b isn't so sure); an iron core about 300 km across; localized spots of magnetic field, leading to a magnetosphere of only about 100 km extent; a number of gravity anomalies (some of which used to be called mascons); and many details about rock types and surface composition and their correlations with altitude and other properties. Very crudely, these resemble the ones on earth, with basalts and other mafic rocks lying low, feldspars and other sials lying higher, and anomalies associated with specific (impact?) craters, like Mare Imbrium. A possible alternative to impacts as the source of melting of the mare and such is tidal heating, if the lunar orbit had an eccentricity close to 0.5 when the moon was only 4.6 Earth radii away (Touma & Wisdom 1998). Io works that way.

Mercury seems to have been useful mostly for setting upper limits on theories of gravity. General relativity is still perfectly OK (Pijpers 1998), and there is no evidence in the evolution of its orbit for any effect of a cosmological constant (Cardona & Tejeiro 1998). Neither is unexpected; the surprise is that useful limits on Λ could come from another few years of data on Mercury.

Mars has had two instrument packages reporting back to us during the year. The official *Pathfinder* papers (Golombek et al. 1997 and six following papers) just missed Ap97 (§ 3). In addition to evidence for liquid water and interesting petrology in the past, *Pathfinder* has seen precession of the Martian rotation axis at a rate that implies a dense core. The *Global Surveyor* mission also reported in (Albee et al. 1998). It finds that the northern hemisphere is very flat and low lying, as if exposed to a major impact, extensive oceans, or even plate tectonics. Only an upper limit could be set to the global magnetic field ($< 2 \times 10^{21}$ G cm^3). Spohn et al. (1998) reviewed our knowledge of Mars just before the new mission results arrived.

Meanwhile, the evidence for native life, or even native organic material in a meteorite from Mars has come to seem still less persuasive. Some of the material must actually be terrestrial contamination, because its ^{14}C age is less than the time the meteorite has been on earth (Bada et al. 1998; Jull et al. 1998). On the plus side of the ledger is the first detection of deuterated water on Mars, present in a proportion $D/H = 1.5 \pm 0.6 \times 10^{-4}$ (Krasnopolsky et al. 1998). This is higher than the terrestrial ratio, but lower than the Venusian (cf. Ap94, § 9.1), and whether it implies that Mars had more water in the past remains to be sorted out.

Meteoritic evidence is always difficult to interpret, perhaps because there is so much of it. During the year, we heard about diamond dust (Andersen et al. 1998), polycyclic aromatic hydrocarbons in graphite grains (Messenger et al. 1998), pure Type II supernova products (Nittler et al. 1998), grains rich in *s*-process products (Nicolussi et al. 1998), nova dust (Gehrz et al. 1998; Jose & Hernanz 1998), and all sorts of fossil radioactivities. These are nuclides that were something else when the meteorites solidified, like ^{26}Al, now seen as ^{26}Mg. Disagreement remains, after 30 yr or so of discussion, on whether the primary contributor was an AGB star (Sahijpal et al. 1998) or a supernova (Boss & Foster 1998), and whether, in the latter case, the last supernova to contribute material to the solar system might have triggered its formation (Wasserberg et al. 1998; Foster & Boss 1997).

In what is perhaps a step backward, doubts have been cast on the presence in the Murchison meteorite of amino acids with an intrinsic excess of the left-handed form, based on possibly inadequate mass resolution of the chromatography used (Pizzarello & Cronin 1998).

And, for those who like to plan their observing runs well ahead, Williams (1997) predicts that the off-year Leonids will become more detectable after 2160.

12.3. Big Planets, Small Moons

Our favorite in this category is a firm case for global warming, not on earth, but on Triton (Elliot et al. 1998). The evidence comes from a comparison of the atmospheric scale height seen by *Voyager 2* in 1985 with that seen by *HST* (via a stellar occultation) in 1997. The temperature increase is about 2.4 K, from 37.5 to 39.9 K, and must be part of a cyclic process. A likely cause is the moon's odd orientation, so that the subsolar point has moved from latitude 47°.8 to 51° during the same period. In any case, you will still need a sweater.

Uranus has acquired two new moons, probably in fact quite recently, since they are of the high-eccentricity, retrograde-orbit, asteroid-capture variety (Gladman et al. 1998). And Miranda, which had presumably been there all along, supposedly broke apart and reassembled at some time (Marzari et al. 1998). Neptune has soldiered on with its familiar complement of moons, but Galatea has got rather ahead of herself in orbit (5° or 8.6 minutes, according to Roddier et al. 1998).

Galileo continues to explore the moons of Jupiter in greater detail, with McKinnon (1997) providing a mid-course overview. Io, tidally heated, had at least 12 volcanic vents hotter than any on earth in 1997 (McEwen et al. 1998). Callisto has a cratered surface, only very slight chemical differentiation (Anderson et al. 1998), and a detectable magnetic field, perhaps related to its subsurface ocean (Kivelson 1998). And Europa joins the bucket brigade, with evidence for subsurface water. There are also crustal ice, convection and cracking, differential rotation, evaporites, and so forth (Carr et al. 1998 and three following papers; McCord et al. 1998 and following papers).

Jupiter may be guarding us from frequent bombardment by comets (Lovell 1998), though we have heard the opposite claimed in connection with sources of terrestrial volatiles, but he is himself at risk of being zapped by one Shoemaker-Levy type event every 500–1000 yr (Nakamura & Kurahashi 1998). We had no takers on last year's offer of comet insurance, and are thinking of tailoring the new prospectus to a Jovian audience. Jupiter radiates more energy than the Sun delivers there. The usual explanation is continued slow contraction and/or differentiation. Ouyed et al. (1998) favor deuterium fusion. If true, this erases one of the traditional distinctions between brown dwarfs and planets.

12.4. Asteroids, Comets, and Beyond

Ceres was first, and still makes up roughly half of the entire mass of the main asteroid belt, despite having shrunk about 5% from the standard IAU mass value to $4.76 \times 10^{-10} M_{\odot}$ (Viateau & Rapaport 1998). It is a fairly rapid rotator, as, apparently, are all asteroids of type M (the ones with metal-rich surfaces and albedos near 0.15, Lagerkvist et al. 1998). But Ceres itself is type C, for carbonaceous.

Enough objects have now been found in the Kuiper belt (Luu & Jewitt 1998) to demonstrate that they come in two types, fairly white and very red ($B-V = 1.1$ to 1.3), with not much in between (Tegler & Romanishin 1998). The total mass in the Kuiper belt, extending outward to 75 AU, could be much larger than that in the "main" asteroid belt, up to an earth mass, in which case the belt could be blamed for the small eccentricity of Neptune's orbit (Ward & Hahn 1998). It is possible that the Kuiper asteroids, Neptune, and Pluto all formed on the same timescale (Kenyon & Luu 1998).

The distinction between comets and asteroids ceased to be clear-cut in 1979, when what had been comet 1949g turned up as asteroid 1979 VA (later 4015 Wilson-Harrington, for the discoverers of the comet), having lost a tail. The distinction in orbit parameters is also fuzzy, because Jupiter can kick former asteroids into comet-type orbits, as well as capturing parabolic comets into short-period asteroid-like orbits (Di Martino et al. 1998). X-ray comets have also been with us for a few years (Ap97, § 2.2), but with the addition of data from the *EUVE* for four, it has become more probable that the emission mechanism is charge exchange with the solar wind (Mumma et al. 1997)

The number of cometary nuclei resolved by fly-bys, *HST*, and so forth has reached the level of "many," now including 46P/Wirtanen, the target of the upcoming European Rosetta mission. At 0.6 km, it is one of the smaller ones (Larny et al. 1998). It differs from Halley (the standard comet!) in having most of its surface active, in having a fairly low dust-to-gas ratio, and in various other ways (Stern et al. 1998; Farnham & Schleicher 1998).

Work on Halley continues more than a decade past perihelion passage and has led to a fairly precise determination of its composition as 26% Si, Mg, and Fe oxides, 23% complex organic material, 9% of things like PAHs, and 30% water with minor contamination by CO, CO_2, CH_3OH, and other simple molecules (Greenberg 1998). Most of the simple molecules seen in the coma and tail boiled off the dust component, not the gas of more complicated molecules (Greenberg & Li 1998). Expect to read the last paper on the 1986 apparition of Halley in 2061, just before the next perihelion passage.

But our absolute favorites in the "things comets do" list for 1998 both come from Hale-Bopp, whose tail OH apparently mased a background *IRAS* source in April of 1997 (Galt 1998), and whose tail sang along with the 2–5 minute oscillations (no *p*-modes) in the solar wind (Steffens & Nuernberger 1998).

The finest stuff (in degree of particulation, if not moral principles) in the solar system is the interplanetary dust. It is made of little bits broken off bigger things, leading again to a less than clear distinction between classes. Thus Vokrouhlicky (1998) describes something he calls the Yarkovsky effect (no, Yarkovsky isn't cited), in which smaller asteroids recoil from absorbing and reemitting solar radiation. We thought it happened to interplanetary grains and was called the Poynting-Robertson effect.

You might get interplanetary grains near the Earth in two ways. First, you can make them in the lab, along with Rotundi et al. (1998), who used soot. Second, you can let them leak in periodically with the changing eccentricity of the Earth's orbit, along with Kortenkamp & Dermott (1998), who used a computer. Neither sort is likely to trigger ice ages.

12.5. Back to Earth

We come past Venus, so as to be able to update points made in Ap91 (§ 2). Most of the current Venusian crust structures are the result of the action of mantle plumes and are 0.5–1.0 Gyr old. That is, there is definitely mantle convection, but no evidence for any subduction, and the character of the convection must have changed rather abruptly when the lithosphere thickened about 1 Gyr ago (Phillip & Hansen 1998). And it is always Venus that makes us regret most that the more euphonious adjective associated with the name of each planet has been preempted for non-astronomical purposes (think jovial, martial, mercurial,.... "nothing connected with any of the planets, I trust" said punnacious colleague upon hearing we had been unwell.)

Entering the terrestrial atmosphere from above, we look back to note an outstanding summary of the brightness of the night sky, from UV to far infrared, separated into contributions from pollution, zodiacal light, stars, the Milky Way, and all the rest (Leinert et al. 1998). The authors have graciously provided the actual data in graphs and tables, and not just a web address whence the information might be extractable. Wolfendale (1998) has described a mechanism that might permit the earth's climate to respond to solar cycles. It involves ionization of the upper atmosphere by cosmic rays (which in turn influences cloud cover), and so belongs here.

Touching your feet at last to the ground, you find that the earth has a number of normal modes with periods of minutes, and, as Suda et al. (1998) have found, those in the 2–7 mHz band are ringing constantly, even when not driven by earthquakes.

What drives what isn't always clear. Sidorenkov (1997) suggests that El Nino and the Southern Oscillation (ENSO) keep Chandler wobble going, but also conversely, leading to an assortment of periods in common. El Nino, at least, has been around for some time, and Grove (1998) reports that its effects were particularly grim in Andhra Pradash (India) in 1789–1791, when the monsoon failed for several consecutive years. Other bad periods, there and elsewhere, fell in 1396, 1685–1699, and 1877–1878. He does not mention any concurrent damage done by Chandler wobble. The effects of El Nino can also be traced in the records of infrared extinction at the Cerro Tololo Interamerican Observatory (CTIO) (Frogel 1998, a topic originally recorded under "doing things the hard way").

Firmly confined to the surface of the earth are (1) the extreme fluctuations of sea level in and out of ice ages at Bab El Mandeb (160 m according to Rohling et al. 1998; mostly we just like the name, which means Gate of Tears), (2) an alternative hypothesis for the origin of eukaryotic (nucleated, complex) cells from prokaryotic ones, in which H_2 is a waste product of a eubacterium but useful to an archaeobacterium, and so they decide to live together (Martin & Mueller 1998, who do not mention POSSLQs), (3) the enormous power of press releases in determining which scientific advances and publications are featured in the popular press, at least in medicine (Lewis 1998), and (4) the curious fact that kohanim (like white four-o'clocks, but unlike apples and oranges) breed true (Thomas et al. 1998). Calendric good fortune shields the late Mr. Jefferson and his potential descendents from our callous remarks. All of which have led so far from astrophysics that all we can do is hasten on to the still greater crimes of § 13.

13. BUT I DON'T KNOW WHERE OR WHEN (OR HOW, OR WHY, OR WHO)

Under the current Gregorian calendar, Friday the 13th happens slightly more often than Friday the 12th. This may or may not account for the constant supply of strange errors, our own and others', now traditionally recorded in this section.

13.1. Cui Bono?

It is well known that a couple of monkeys banging away on typewriters long enough would eventually produce one of these reviews. Several colleagues have, of late, suggested that this is how they are actually done. In any case, the monkey who first wrote, in imperfect parallel to Shakespeare, "to be or not to be; that is the gzornplats" was presumably responsible for the following near approximations to the names of real people.

I. Pherari—Ivanio Puerari is at INAOE in Puebla, Mexico.

F.K. Lik—Liu Fukun is at SISSA in Treiste, Italy.

Lutz-Kelcker—D.H. Kelker is no longer to be found in any of the standard directories.

R. Ignale—Rico Ignace is at University of Glasgow, Scotland (and is an expert on the effect of Hanle, who completed a Ph.D. at Göttingen under James Franck).

D. Mehringen, who appears in Ap96 as Mehriger—we're going to ask Dr. Mehringer if we can call him David in the future.

M. White and Witten—Martin White and Wayne Hu are both at University of British Columbia in Vancouver, and you wouldn't believe how this one happened.

R. Barbainis—Richard Barvainis is at Haystack Observatory, Massachusetts Institute of Technology, and no, they observe radio waves. But let us tell you about the Blue Seal Laundry someday.

13.2. More or Less

Here, in order of section number, are a few corrections to numerical values.

Section 4.4: The Campbell reference actually appears in Oppenheimer et al. (1997), not in the paper cited, which is the immediately following one, but what does it mean that we were told by the people accidentally cited, not by those accidentally ignored?

Section 4.5: The paper by A. W. Harris & A. W. Harris (Alan for both, not Allan!) is not quite a record. The existence of a paper by Harris, Harris, & Harris (Bill, Gretchen, and Hugh) was brought to our attention by Sidney van den Bergh, of whom there is only one, but who ended his collection of Flak by pointing out that the F was Flugzeug, not Flieger, on his side of the Atlantic. Our memory of the period is just a little hazy.

Section 8.3: AU Peg is a binary Cepheid with an orbit period of 53 days (Harris et al. 1984, though George Wallerstein, who called this to our attention, gave the year of publication as 1884), which beats Z Lac at 1 yr by a whole bunch.

Section 10.1: The black hole in NGC 49459454. The 10^6 $M_\odot$ one belongs in NGC 4945 and the 19^9 $M_\odot$ one in NGC 4594. They were portmanteaued into NGC 4954 (but a discrepancy for the measured mass in Arp 102B remains).

Section 12.3.2 We are happy to report that Saul Perlmutter is actually to be found at a redshift considerably less than 0.5. The inequality should have said $0.5 < z < 1.0$.

Section 10.6: The first spiral lens. The one responsible for the Einstein cross is apparently a disk galaxy (Huchra et al. 1985), but the potential that bends the light is spheroidal.

13.3. Unclassifiable

This very heterogeneous collection begins and ends with items from advertisements received during the year. In between are some favorites from the archival literature. No authors are cited, because it is generally not possible to decide whether they are in any way responsible for what was printed.

" If you are interested in submitting your paper and unprintable items to Astroparticle Physics, please contact us at http://www..... ".
" Method for extracting gravitational radiation from a three-dimensional numerical relativity simulation " (PRL 80, 1812, abstract). Long ago, the Here and There section of *Observatory* noted a similar title, " Scattering of light by a system of simultaneous linear differential equations, " and remarked that " this is a source of opacity that most astronomers seem to have overlooked. " And if equations can be opaque enough to scatter starlight, there is no reason that simulations cannot be dense enough to radiate gravitational waves.
" Apocalypse soon...I would not be prepared to take further action " (MNRAS 296, 619, text). Braver are the authors who wrote " We thought that before we retire... " (A&AS, 131, 319, abstract).

Block that hyphen. You have yourself probably had to defend your papers from gems like " open-star cluster " on the basis that you cannot remember ever having seen a cluster of open stars. Sympathize, therefore, with the victims of " the literature-distance modulus " (ApJ, 504, 725, abstract) and " the detection of a broad-line at all suggests...... " (MNRAS, 299, 710, abstract).

Some favorite figures: On AJ, 114, page 2093, spot the radio continuum (and congratulate your ophthalmologist if you succeed). Figure 7 on page 1113 of ApJ, 504 could well have been captioned, " The eyes of Alabama are upon you. " But formulating a caption for ApJ, 500, 966 suitable for mixed company defeats us (it resembles a stomach and lower intestines).

The misplaced modifier walks at midnight: " The discovery of the first real pulsating sdB stars in South Africa " (ApJ, 489, L199, introduction). " Upon receipt, flawed issues 8, 9, and 10 of Volume 81 should be discarded " (editorial in PRL 81, 2619), but it was too late. They had already come.

A bouquet of innovative methods: " Radiative bluntbody problem " (MNRAS, 293, 383, title); " fuzzy divisive hierarchical clustering " (Ap&SS, 252, 205); " radiative non–top hat jets " (A&A, 332, 714, title); " trees in fields " (MNRAS, 295, 475, title of paper not about landscaping); and " the forth and back approximation " (ApJ, 487, 735, title). This last must be a close relative of the hero of the limerick " A lion who lived in the zoo....He reversed it, and walked fro and to. "

" If theory is just a way of relating observational facts to each other " (ApJ, 495, 669, summary), then the grinding noise you hear is Eddington turning over in his grave.

A few projects for King Alfonso XII of Spain, who is supposed to have said that he " could have given some advice for its simplification. " " The class II maser transitions...show enhanced absorption toward class I sources " (Ap&SS, 253, 305, but then Type II supernovae generally occur among Population I stars). " Desorption [is] suppressed, i.e., from ≈ 50 K for neat CH_4 to ≈ 150 K for CH_4 in the H_2O matrix. " (ApJ, 490, 710, abstract, and once you remember " neat, as in whiskey " this is actually rather clever). " The profile of both lines cannot be simultaneously fit for all but one of our stars " (A&A, 336, 613, abstract. The author is admittedly from Athens, but it is Athens, Georgia). And " data...which have been used the save derive its radial velocity map. " (A&A, 335, 1029, which might have defeated even Alfonso the Wise).

From a US Naval Observatory press release looking forward to the millennium: " The ball was dropped every day at noon...until 1885. " Since then, Washington generally drops the ball during working hours.

The new math at work, in an advertisement for the volume *Critical Dialogues in Cosmology* sent out by World Scientific Press, which lists one of the articles as " Dynamical Measurements Favor a Value of 1/2 Close to Unity." Applications to record redshifts, telescope diameters, and budgets are clearly countless (to within a factor of 2).

The following colleagues generously provided various forms of input for this review. Not all of them will be pleased with what was done with their suggestions, but we are nevertheless alphabetically grateful to Sidney van den Bergh, William P. Bidelman (we are still trying to get up the nerve to call him Billy), Heino Falcke, Roger Griffin, George Herbig, Luis Ho, Roberta Humphreys, Richard (Rico) Ignace, Ivan King, Robert Kraft, James Liebert, Fukun Liu, Lucy-Ann McFadden, Dmitrij Nadyozhin, Leos Ondra, Bohdan Paczynski, Ivanio Puerari, Blair Savage, Eric Schulman, Douglas Scott, Vladimir Strelnitzki, Yervant Terzian, and George Wallerstein.

Maggie Berry, who alphabetized the Ap9x references for a number of years, has left the Maryland astronomy department for greener pastures (including, happily, a greener paycheck). The task this year was done in the Tempe PASP office, and we are enormously grateful to Anne Cowley and her staff assistant for bravery above and beyond the call of duty.

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