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Invited Review

Astrophysics in 2004

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ABSTRACT. In this 14th edition of ApXX,[1] we bring you the Sun (§ 2) and Stars (§ 4), the Moon and Planets (§ 3), a truly binary pulsar (§ 5), a kinematic apology (§ 6), the whole universe (§§ 7 and 8), reconsideration of old settled (§ 9) and unsettled (§ 10) issues, and some things that happen only on Earth, some indeed only in these reviews (§§ 10 and 11).

1. INTRODUCTION

The sequence of events leading up to Ap04 is very much the same as in previous years. We read some papers, take some notes, make some selections, and write. Somewhere along the way, with luck, we also think.

Section 2 was assembled using papers found on the Astrophysics Data System (ADS), maintained with support from NASA. These include *Solar Physics*, *Geophysics Research Letters*, *Journal of Geophysical Research*, *Astroparticle Physics*, *Acta Astronomica Sinica*, *Chinese Journal of Astronomy and Astrophysics*, *Advances in Space Science*, and *Space Science Reviews*, as well as those used for the other sections.

Used in compiling sections 3–13 were the issues that reached library shelves (or, increasingly, V. T.'s mailbox) between 1 October 2003 and 30 September 2004 of *Nature*, *Science*, *Physical Review Letters*, the *Astrophysical Journal* (plus *Letters* and *Supplement Series*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Reviews*), *Astronomical Journal*, *Acta Astronomica*, *Revista Mexicana de Astronomía y Astrofí sica*, *Astrophysics and Space Sciences*, *Astronomy Reports*, *Astronomy Letters*, *Astrofizica*, *Astronomische Nachrichten*, *Publications of the Astronomical Society of Japan*, *Journal of Astrophysics and Astronomy*, *Bulletin of the Astronomical Society of India*, *Contributions of the Astronomical Observatory Skalnate Pleso*, *New Astronomy* (plus *Reviews*), *IAU Circulars*, and, of course, *Publications of the Astronomical Society of the Pacific*. Journals read less systematically and irregularly cited include *Observatory*, *Journal of the American Association of Variable Star Observers*, *ESO Messenger*, *Astronomy and Geophysics*, *Mercury*, *New Scientist*, *Sky & Telescope*, *Monthly Notes of the Astronomical Society of South Africa*, and *Journal of the Royal Astronomical Society of Canada*.

1.1. Up

Our assumption is that the more astronomers and the more facilities they have, the better. Thus the following successful launches, inaugurations, and such all count as good news: (1) *Messenger* to Mercury on 3 August, (2) two Chinese magnetospheric satellites in January and July, (3) a new Kavli Institute for Cosmological Physics at the University of Chicago, (4) the April decision of Russia to join ESA, (5) the beginning of actual data collection by *Gravity Probe B* on 27 August, 4 months into the 13-month mission (and we can't wait to hear what its catchy new name will be when it is declared a success), in the way that *Muses C* became *Hayabusa* after its May 2003 launch, (6) the launch of *Rosetta* on 2 March, (7) the increase to 30% (in 2001) of US high school students taking physics, (8) the capture of comet dust by *Stardust* on 2 January (it is due back in 2006 with its bits of Comet Wild 2), (9) the 60 antennas of LOFAR in place in fall 2004, (10) *Shenzhou 5*, which put a third country into manned space programs on 15 October 2003, (11) the expanded Sudbury facility planned by the Canadian Foundation for Innovation, (12) Mars arrivals by *Nozumi* (13 December), *Beagle 2* (25 December), *Spirit* (4 June), and *Opportunity* (24–25 June), (13) an upturn in numbers of graduate students enrolled in engineering, science, etc., nicely, as usual, mirror imaging the state of the economy, and (14) the participants in IAU Colloquium 196, who, contrary to forecasts by a peer review group, had clear weather to see the 2004 transit of Venus from the same location where Jeremiah Horrocks had been the first to record seeing such an event in 1639.

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[1] Astrophysics in 1991 to 2003 appeared in volumes 104–116 of *PASP*. They are cited here as Ap91, etc.

1.2. Down

Conversely, losses of things, at any stage from preliminary budgets, to launches, to planned and unplanned mission terminations count as bad news, Sadly, a few entities appear in both the previous subsection and this one, including (1) *Nozumi*, which flew on past Mars in October, unable to stop, (2) *Beagle 2*, which never phoned home after leaving its Conestoga wagon-equivalent (but leaving much ill feeling on all sides, e.g., *Nature*, 430, 954), and (3) *Contour* (a briefly "up" in August 2002) has now been understood to have died in three separate pieces after overheating by exhaust gases and melting.

And some other losses: (1) SWAS collected its last (submillimeter) data on 23 July, (2) *Midori II*, an Earth-observation probe began to observe Earth from very close up on 31 October, (3) STIS, the Space Telescope Imaging Spectrograph on (curiously) the *Space Telescope* closed up shop during the summer, to be followed most of us very much fear by the entire *HST* within the next couple of years, (4) *SNOE*, the *Student Nitro-Oxide Explorer*, ceased Exploring (atmospheric composition, we think, rather than students) on 13 December 2003 after a mission of 5 years and 290 days. It was allowed to burn up on re-entry and so is presumably now part of the atmosphere is so assiduously explored. (5) *Eddington*, a high-precision photometric mission designed to looked for planetary transits and quivering stars has been removed from the ESA queue; various NASA plans for investigations of "deep space" have also been delayed or worse, (6) *Genesis*, after collecting solar wind particles for months on end, returned to Earth on 8 September unfortunately at about 193 miles per hour (an upside-down accelerometer having failed to initiate parachute deployment), and they were picking bits of it out of the desert floor for weeks, (7) Los Alamos National Lab, closed for security concerns, and so unable to assemble the required quantity of Pu^{238} pellets to power an upcoming Pluto mission (carrying Plutonium to Pluto may or may not make you think of carrying coals to Newcastle, which is, however, now a net importer), (8) *Biosphere II*, closing for lack of funding, fresh air, enthusiasm, and so forth, (9) the Cambridge primate center, with planning suspended at the beginning of calendar 2004 (the primates were probably not asked), (9) the New York WE-6 numbers, from which one had for one's entire life been able to learn upcoming weather and "At the tone, the time will be…" (*New Yorker*, 12 April, p. 29), ceased to operate on 24 March (the California equivalent disappeared long ago), and (10) one less Ph.D.-level physicist, because the University of Constance (Germany) took back that of J. H. Schoen for "undignified behavior" (they should see us after a few beers). A small prize will be given for a better revision of the institution's name than our feeble "University of Inconstance."

1.3. In, Out

And here are a few more complicated scenarios. (1) *WIRE* never deployed for its primary purpose, but was back up as a stellar photometer in mid December, (2) the American *Terrestrial Planet Finder* and European *Darwin* (devices for direct imaging) remain on the books at year's end for deployment somewhere around 2020, and *Eddington* had slipped back into the queue at midyear (though with its goal peculiarly described as "measuring the frequency of omitted light" *Nature* 429, 698), (3) *RHESSI* and *INTEGRAL* received special issues of appropriate journals (*ApJ Letters* 595, No. 2, and *A&A* 411, No. 1, respectively), (3) Operations at the Gran Sasso Lab are slowly being restored to normal, but, in mid-May, Borexino was still on hold, and the Gallium Neutrino Observatory gone for good; imagine all those wasted neutrinos who devoted their lives to reaching terrestrial experiments, only to find no one waiting for them. How many neutrinos? Well, just about all the solar B^8 ones we had been expecting, according to S. N. Ahmed et al. (*Physical Review Letters* 92, 1813), and for the Be^7, proton-proton, CNO, and other neutrino fluxes, we will just have to possess our souls in patience. A next-generation neutrino experiment is back in the plans in Japan after personal intervention by Nobel Prize winner Masatoshi Koshiba (*Nature* 429, 746). Well, isn't that what Nobel Prizes are for?

1.4. Astronomers' Ups and Downs

There were undoubtedly several hundred new ones, worldwide, receiving Ph.D.'s, including the first mainstream astronomy Ph.D. from the University of California, Irvine, to Dr. Tammy Bosler for work on the use of the infrared calcium infrared triplet feature as an abundance indicator for stellar population studies.

The losses were perhaps not quite so many, because there were not so many Ph.D.'s given in 1950 or thereabouts, and again we note only one: Dr. Janet Mattei, long-time director of the American Association of Variable Star Observers and an irreplaceable bridge between the amateur and professional communities.

Two new concepts appear in Ap04, somewhere between up and down: The Garrison Keillor paper, proposal, or whatever, meaning (like his joke book), pretty good, and the green dot, a symbol of surprise placed next to a few dozen papers during the elder author's initial note-taking. All green dot papers have been cited somewhere in the following pages.

2. THE SUN

2.1. The Solar Interior

2.1.1. Neutrino Flavors

The Sun and stars shine by nuclear burning of hydrogen into helium, where the main nuclear process $4p \rightarrow {}^4\mathrm{He} + 2e^+ + 2\nu_e$ produces electronic neutrinos (ν_e). Pontecorvo and Gribov predicted already in 1969 that low-energy solar neutrinos undergo a "personality disorder" on their travel to Earth and oscillate into other flavors of muonic (ν_μ) and tauonic (ν_τ) neutrinos, which turned out to be the solution of the "missing neutrino problem" for detectors that are sensitive only to the highest-energy (electronic) neutrinos, such as the chlorine tank of Raymond Davis Jr. in the Homestake Gold Mine in South Dakota or the gallium detectors GALLEX in Italy and SAGE in Russia. Only the Kamiokande and Super-Kamiokande I pure-water experiments and the Sudbury Neutrino Observatory (SNO; Ontario, Canada) heavy-water experiments are somewhat sensitive to the muonic and tauonic neutrinos. It was the SNO that measured for the first time all three lepton flavors (Ahmad et al. 2002; see Ap02) and in this way brilliantly confirmed the theory of "neutrino (flavor) oscillations."

In the meantime, follow-up experiments with Super-Kamiokande I have been performed, and an upper limit of the neutrino magnetic moment has been found, about 10 orders of magnitude weaker than the Bohr magneton, i.e., $\mu_\nu \leq 1.1 \times 10^{-10}\mu_B$ (Liu et al. 2004c; Miranda et al. 2004). Other neutrino parameters such as the mass differences and mixing angles between the three neutrino flavors have also been gradually improved, using SNO and KamLAND nuclear data (Balantekin & Yuksel 2003a, 2003b; DeHolanda & Smirnov 2004a, 2004b; Aliani et al. 2004), CHOOZ reactor data, KEK-to-Kamioka accelerator data, and Super-Kamiokande I atmospheric data (Fogli et al. 2004).

The solar neutrino flux measured with Super-Kamiokande I was also found to oscillate with a period of 2.5 yr (Shiray 2004), as well as with periods corresponding to harmonics of the solar rotation rate and to an *r*-mode oscillation with spherical harmonic indices $l = 2$, $m = 2$ (Sturrock 2004), besides day-night and seasonal variations (Smy et al. 2004; Blennow et al. 2004), while others found no significant periodicity (Yoo et al. 2003).

The helioseismic measurements with GOLF and MDI onboard the *SOHO* spacecraft have achieved a major breakthrough in the knowledge of the solar core, providing an improved accuracy of the sound speed profile from the detection of low-degree low-order *p*-modes, which allow more accurate ^{8}B neutrino flux predictions (Coudivat et al. 2003a; Bahcall & Pinsonneault 2004).

2.1.2. Perfecting Solar p-Mode Oscillations

What can you do else after you have beaten down measurements of helioseismic frequencies to an accuracy of $<10^{-5}$? Comparisons of GONG and MDI data focus on *p*-mode-correlated and uncorrelated noise properties to understand the different sense of asymmetry as function of the *p*-mode velocity and intensity power spectra (Barban & Hill 2004; Rajaguru et al. 2004; Jefferies et al. 2003). Alternatively, it was proposed that the *p*-mode asymmetry reversal is produced by radiative transfer effects in different temperature layers (Georgobiani et al. 2003). Other deviations or disturbances of *p*-mode oscillations are caused by the ringing of large flares (Ambastha et al. 2003), by thermal perturbations in active regions (Basu et al. 2004), by subsurface fluid dynamics (Komm et al. 2004; Zhao & Kosovichev 2004; Haber et al. 2004), by convection rolls (Stix & Zhugzda 2004), by rapid variations in the second helium ionization zone and at the base of the convective envelope (Verner et al. 2004), by Alfvén wave resonances of density fluctuations deep within the Sun (Burgess et al. 2004), by solar cycle effects (Chaplin et al. 2004a; Dziembowski & Goode 2004; Kholikov et al. 2004; Salabert et al. 2004), and by observational duty cycles (Chaplin et al. 2004b; Jiménez-Reyes et al. 2004a) and they also manifest themselves differently in full-disk and resolved-Sun analysis techniques (Jiménez-Reyes et al. 2004b; Chaplin et al. 2004a, 2004c).

A new method to model solar oscillations $l - \nu$ power spectra was demonstrated by Jefferies & Vorontsov (2004), who forward-fitted the entire power spectrum in a wide range of frequencies (ν) and degrees (l) in a single shot, instead of dividing up the spectrum into thousands of small regions and fitting the peaks individually, as it is traditionally done. Talking about methods, note that helioseismologists fill partial gaps in a time series with the so-called repetitive music method (Salabert et al. 2004).

2.1.3. Probing Stellar p-Mode Oscillations

Dramatic progress in asteroseismology has been achieved from the unambiguous detection of stochastically excited oscillations in stars other than the Sun, e.g., in η Bootis (DiMauro et al. 2004; Lochard et al. 2004) or ξ Hydrae (Frandsen et al. 2002; Stello et al. 2004), which allows us to probe stellar structure and evolution (Kurtz 2004; Christensen-Dalsgaard 2004; Stein et al. 2004; New 2004; Thompson 2004) and to measure stellar differential rotation (Gizon & Solanki 2004; García et al. 2004).

2.1.4. Solar Interior Models

Also physical models of the solar interior have been perfected to an unprecedented accuracy level from the helioseismic constraints over the last two decades. Significant differences between the helioseismic and theoretical standard models are mostly confined to the regions below the convective zone, where issues of opacity changes or turbulent mixing are somewhat uncertain. New updated solar models with the Toulouse-Geneva Evolutionary Code take into account the most recent nuclear reaction rates, equation of state, opacities, microscopic diffusion, and rotation-induced mixing (with feedback effects of the μ-gradient due to helium settling) and can explain why lithium is depleted in the present Sun while beryllium is not and why ^{3}He has not increased at the solar surface for at least 3 Gyr (Richard et al. 2004).

2.1.5. Solar Rotation

The rotation profile has been derived deeper than ever, with the finding of a flat rotation profile down to 0.2 solar radii (Coudivat et al. 2003b), and for the first time a full set of individual *m*-component rotational splittings has been computed for modes $l \leq 4$ and $1 < \nu < 2$ mHz (García et al. 2004). Fluctuations in the rotational speed of the tachocline have been found at a period of 1.3 yr from helioseismic measurements, which seem to correlate with 1.3 yr variations in the solar wind speed measured at 1 AU distance out in the heliosphere (Mursula & Vilppola 2004).

2.1.6. Nonaxisymmetric Solar Dynamo

"Becoming ever more tightly constrained by observations and theory, the *solar dynamo model* that we have now bears little resemblance to the model studied just 30 years ago and, furthermore, it is likely to be modified in the near future" (Bushby & Mason 2004). Two spectral regimes of magnetic field amplification in MHD flows are envisioned: a "small-scale dynamo"and a "large-scale dynamo," depending on the scale on which fields are amplified relative to the primary forcing scale of the turbulence (Blackman 2003). Magnetic helicity conservation arguments play an important role in solar dynamo models, such as in the Parker migratory dynamo model with nonlinear saturation mechanism (Kleeorin et al. 2003), although magnetic helicity is not gauge-invariant and therefore cannot be used for models in practice (Brandenburg & Matthaeus 2004).

Coronal holes (Bilenko 2004) and active regions occur in preferred longitudes—they are not randomly distributed—which motivated for the first time the modeling of the solar mean field dynamo in terms of nonaxisymmetric α-effects (Bigazzi & Ruzmaikin 2004; Chan et al. 2004). The nonaxisymmetry is a key ingredient in models of tachocline dynamics (Miesch & Gilman 2004; Rempel 2004; Zhang et al. 2003b; Brun 2004; Forgacs-Dajka 2004) that lead to the emergence of rising flux tubes as a consequence of these (shear-driven) nonaxisymmetric (kink-type) instabilities. This was extensively studied with numerical MHD simulations (Abbett et al. 2004; Dikpati et al. 2003, 2004a; Fan 2004; Fan & Gibson 2004; Manchester et al. 2004; Tobias & Hughes 2004; Cline et al. 2003; Magara 2004) and surface observables such as active-region tilt angles (Toth & Gerlei 2004; Holder et al. 2004). Numerical MHD simulations and analytical models of the solar cycle focused also on the depth of meridional flows (Gilman & Miesch 2004; Guerrero & Munoz 2004; Petrovay & Kerekes 2004; Durney 2003) and polar field reversals (Dikpati et al. 2004b; Durrant et al. 2004).

2.1.7. Beyond Einstein

The unification of quantum field theory and general relativity has been attempted using constraints from solar spectropolarimetric observations (Solanki et al. 2004). The authors considered an example of a metric-affine gauge theory of gravity in which torsion couples nonminimally to the electromagnetic field. This coupling causes a phase difference to accumulate between different polarization states of light as they propagate through the metric-affine gravitational field, where solar spectroscopy is thought to provide a constraint on the coupling constant.

2.2. The Photosphere

2.2.1. High-Resolution Imaging at 0″.1

Unprecedented high-resolution images became available from the new Swedish 1-m Solar Telescope (SST) on La Palma, Canary Islands, which is believed to produce images with a resolution approaching the diffraction limit of ≈0″.12 (≈80 km on the solar surface!) at 488 nm (Lites et al. 2004). One of the most striking effects of such high-resolution imagery is the visualization of the three-dimensionality of photospheric structures, such as the Wilson depression of the dark floors of pores, or the raised level of light bridges over sunspot umbrae, typically elevated by 200–450 km above the umbra (Lites et al. 2004). Although elementary magnetic elements with kilogauss field strengths have been postulated earlier, dubbed as "hidden magnetism" (Stenflo 2004), the smallest magnetic features detected with 0″.1 resolution were found to be unresolved and to consist of complex "filigree" ribbons, inconsistent with the model of ensembles of subresolution, kilogauss fluxtubes (Berger et al. 2004). The amount of undetected magnetic flux due to insufficient resolution is estimated to be about 50% in Kitt Peak synoptic charts (Krivova & Solanki 2004). On the other side, the Advanced Stokes Polarimeter measures the so far weakest polarization signals, with flux densities in the range of 1.5–50 Mx cm^{-2} (in internet work regions), although it sacrifices spatial resolution (Socas-Navarro et al. 2004).

The shapes of small-scale magnetic features has found to be fractal ($D \approx 1.4$), in agreement with numerical simulations of magneto-convection (Janssen et al. 2003). The authors conclude that complexity and geometric similarity of magnetic structures continues when zooming into smaller and smaller scales. On one side, this scale-free behavior allows predictions for new high-resolution telescopes, but the authors find an unexpected break of self-similarity (and thus a change in the fractal dimension) at a scale of $l \approx 0''.5$ (Janssen et al. 2003).

2.2.2. New Evidence for Mesogranulation

While the granulation and supergranulation structures represent widely-accepted borderlines of subphotospheric convection cells (Berrilli et al. 2004; DelMoro et al. 2003; Rast 2003; Rast et al. 2004), the existence of an intermediate pattern, called mesogranulation, has been more controversial. However, new evidence for mesogranulation has been put forward from correlation-tracking of horizontal flows, establishing size scales of 5″–10″ (3600–7200 km) for mesogranules (Dominguez Cerdena 2003; Roudier et al. 2003; Roudier & Muller 2004). Interestingly, detailed studies of pores, i.e., isolated fluxtubes carrying upflows and surrounded by a ring of downflows, have been found to have about the same radial extent (Sankarasubramanian & Rimmele 2003). It was also noted that granulation behaves as a random distribution of elastic features with a very broad distribution in size, while supergranulation behaves as a random distribution of close-packed, coherent stiff features with a well-defined mean size (Berrilli et al. 2004). Furthermore, supergranulation cells were found to be aligned in the north-south direction (Lisle et al. 2004) or to undergo longitudinal wave motion (Schou 2003).

2.2.3. Photospheric Wave Phenomena

"Observations of the seismic waves generated by the sunquake of 9 July 1996 are remarkably similar to the pattern of ripples generated by a stone dropped into a pond" (Podesta 2003). The author modeled then the sunquake with an inviscid, incompressible fluid model in analogy to water waves but found that the distances between successive wave crests were larger than observed and concluded that the sunquake is composed primarily of acoustic (*p*-mode) waves rather than *f*-modes. Indications of shock waves in the photospheric granulation have also been identified in the quiet Sun, caused by abrupt braking of the fast (supersonic) horizontal flow of the granular plasma toward the intergranular lane, whose temporal evolution was observed for the first time in Fe II (Rybak et al. 2004). Photospheric granular flows are now tracked with a "ball-tracking" method, after granulation images have been turned into a hill-and-valley surface (Potts et al. 2004). Wavelike motions of supergranulation cells have been observed mostly in the longitudinal (north-south) direction (Schou 2003).

2.2.4. Sunspot Dynamics, Waves, and Oscillations

High-resolution imaging of fine structure in sunspots (e.g., Rouppe van der Voort et al. 2004; Rimmele 2004) has at least answered a very old question: what causes the filamentary structure of the penumbra, with magnetic fields forming an interlocking comblike configuration, that surrounds the dark central umbra of a sunspot? The interaction between magnetic fields and small-scale turbulent convection outside the spot leads to the downward transport of magnetic flux, submerging magnetic flux tubes (downward pumping) below the solar surface and resulting in a strongly fluted structure, as evidenced by numerical MHD simulations (Thomas & Weiss 2004; Tobias & Weiss 2004; Weiss et al. 2004) and statistical analysis of superpenumbral whorls around sunspots (Balasubramaniam et al. 2004) and outward-moving penumbral grains (Bonet et al. 2004). The magnetic field in penumbral fluxtubes is found to drop more slowly with radial distance than the background field and thus possibly drives the Evershed flow (Borrero et al. 2004). In the transition region above sunspots, "dual flows" are observed in half of the cases (Brynildsen et al. 2004a).

Running umbral waves were measured in the chromosphere, with a period of 2.8 minutes and a phase speed of 45–60 km/sec (Kobanov & Makarchik 2004). Three-minute oscillations detected above sunspot umbras in the transition region and coronal temperatures clearly established the existence of upward-propagating acoustic waves (Brynildsen et al. 2004b), although alternative explanations in terms of non-Maxwellian distribution functions in sunspot plumes were also proposed (Doyle et al. 2003). Sunspot plumes were found to exhibit 5-minute oscillations in the chromosphere but 2–3-minute oscillations in the transition region, while no oscillations were detected in the overlying corona, suggesting a strong damping or a downward reflection of waves (Rendtel et al. 2003). Theoretical simulations confirmed that the observed 3-minute and 5-minute oscillations are both compatible with the predictions of magnetoacoustic oscillations, but that most of the observed power in the magnetogram signal oscillations is actually due to cross-talk from the temperature and density oscillations associated with the magnetoacoustic wave (Ruedi & Cally 2003).

2.3. Chromosphere and Transition Region

2.3.1. Sorry, There Are No Wineglasses

The magnetic connection between the solar surface (i.e., photosphere) and the corona, through the mysterious chromosphere and transition region, has always been a puzzle. However, the most popular concept, i.e., that the magnetic field is concentrated in small tubelike concentrations in the photospheric network and then expands rapidly in height, resulting in a vaultlike canopy, has been criticized recently (Schrijver & Title 2003). On the basis of magnetic potential field extrapolations in realistic renderings of photospheric network concentrations, the authors conclude that "the commonly held notion of a wineglass-shaped canopy of network flux that fully encloses weakly magnetic regions below is fundamentally wrong." Instead they find that as much as half of the coronal field in quiet-Sun regions may be rooted in a mixed-polarity internetwork field throughout supergranules rather than in the network flux concentrations (Schrijver & Title 2003). Needless to say, this result has far-reaching consequences for the identification of sources for coronal heating and acceleration of the solar wind. For instance, the relative motions of myriads of magnetic fragments impose "binary reconnections" that drive coronal heating (Priest et al. 2003). Regarding acceleration of the solar wind, velocity measurements in the 10830 Å He I line suggest that only 4% of the chromospheric mass outflow is sufficient to produce the fast solar wind (Kulagin & Kouprianov 2003).

2.3.2. Chromoseismology

Waves have been found everywhere on the Sun, so we have helioseismic, photoseismic, chromoseismic, as well as coronaseismic phenomena. While chromospheric waves have historically been observed in Hα, the so-called Moreton waves, they have now also been detected in 10830 Å He I images, apparently slow-mode waves that propagate downward from the corona into the upper chromosphere (Gilbert & Holzer 2004; Gilbert et al. 2004a). The complicated interplay, coupling, and mixing of fast and slow magnetoacoustic-gravity waves between low-β and high-β regions has been simulated with MHD codes in great detail, leading to oscillations in some confined regions (Bogdan et al. 2003). The subphotospheric convective motion launches upward-propagating acoustic waves also, which steepen into shocks (Wedemeyer et al. 2004). Chromospheric oscillations have been detected in 1700, 1600, 1216, and 1550 Å wavelengths, with most frequent periods of 283 s in the network, which was also found to have a greater oscillatory power than the internetwork (McAteer et al. 2004; McIntosh & Smillie 2004). They were also seen in coronal holes (Kobanov et al. 2003; McIntosh et al. 2004). Oscillations with periods between 100 and 500 s have also been discovered in dark mottles and dark grains, which were interpreted as the same structures, the only difference being their respective inclinations to the line of sight (Tziotziou et al. 2003, 2004). The driving mechanism for mottles (as well as for spicules) is believed to be magnetic flux cancellation caused by magnetic reconnection (Tsiropoula & Tziotziou 2004).

2.3.3. The Solution of the Spicule Problem

Spicules were discovered back in 1877, but their intrinsic physical mechanism has been revealed only now, using a combination of high-resolution imaging and MHD simulations. Spicules are believed to be produced by the previously ignored subphotospheric *p*-modes, which apparently leak sufficient energy from the global resonant cavity into the chromosphere to power shocks that drive upward flows and form spicules (DePontieu et al. 2004).

2.4. Corona

2.4.1. Fingerprinting the Coronal Magnetic Field

The crispy and fine-chiseled coronal loops exhibited in *TRACE* EUV images have a seducing appeal to theoreticians to match up their models; they design quantitative methods to optimize the fitting of theoretical magnetic field lines to observed coronal loops (Carcedo et al. 2003; Wiegelmann 2004). Some design more efficient codes to calculate nonlinear force-free fields (Wheatland 2004; Li et al. 2004b), determine both the photospheric and coronal alpha-parameter of force-free loops, and conclude from their agreement that the electric currents are of subphotospheric origin (Burnette et al. 2004), while comparisons of the helicity in active regions with associated interplanetary magnetic clouds reveal that the total twist differs by an order of magnitude (Leamon et al. 2004). The magnetic twist was also measured in Hα surges, and it was found that the direction of observed spin of these surges is consistent with the relaxation of the stored twist in the magnetic field (Jibben & Canfield 2004). It became a commonplace that the solar corona is far more dynamic than previously thought, but a new result that quantifies the restlessness of the quiet-Sun corona is that the timescale for magnetic flux to be remapped is only 1.4 hr, about 10 times shorter than the photospheric flux recycling time (Close et al. 2004), which can be considered as a percolation process (Fragos et al. 2004). Note that also the coronal hole boundaries are not steady; evidence for magnetic reconnection has been spotted in the form of bidirectional jets right at the boundaries (Madjarska et al. 2004) or in the form of footpoint switching between open and closed field lines (Wang & Sheeley 2004).

2.4.2. Tickling Coronal Loops at Their Feet

If you are a ticklish person, you know very well that it does not take much energy input at the feet to make the whole body jump. In analogy, all the action that drives coronal heating seems to come from upward-propagating waves at the footpoint of coronal loops or open field lines (Erdélyi 2004). The tickling stimulation can be arranged by a small-scale magnetic reconnection process or by magnetic flux emergence (Schmieder et al. 2004a), while the signal propagates upward in the form of turbulence-driven Alfvén waves (Li & Habbal 2003; Dmitruk & Matthaeus 2003), ion-cyclotron waves (Markovskii & Hollweg 2004; Peter & Vocks 2003; Vocks & Mann 2004; Zhang 2003), or fast- and slow-mode MHD shock waves (Orta et al. 2003; Ryutova & Shine 2004; Cuntz 2004) generated by nonlinear Alfvén waves (Moriyasu et al. 2004).

Everybody understands that the tickled and jumping body warms up with time, which applies also to the coronal heating problem, since the upward-propagating waves get dissipated by various mechanisms, such as by resonant absorption (Luo et al. 2004), wave-particle interactions (Wu & Fang 2003), phase mixing, or other wave-damping mechanisms. One study attempts to determine the heating function from the cooling process, using EUV *TRACE* observations (Winebarger & Warren 2004). The physical connection between the loop footpoints and coronal loop body, however, is very difficult to trace, even with multitemperature observations (Landi & Feldman 2004), and even more difficult to model (Landi & Landini 2004; McIntosh & Poland 2004). In addition, the hydrodynamic structure of the coronal loop part itself turned out to be difficult to model. The pressure of most loops was found to be high above the values expected for a hydrostatic equilibrium, possibly explainable by nonlinear MHD waves (Terradas & Ofman 2004), and the flat temperature profiles cannot be modeled even with steady-flow models (Patsourakos et al. 2004; Petrie et al. 2003). Modest bulk flows in the order of tens of km/sec, however, seem to be required to enable the mixed gravitational settling of ions and electrons (Lenz 2004). Only time-dependent heating models can account for the observed density and temperature profiles (Warren & Winebarger 2003).

After the heating of coronal loops stops, they cool first quasi-stationarily by thermal conduction and radiative loss. But at some point, a radiative instability sets in owing to an unstable temperature gradient which leads to a cyclic sequence of condensation and catastrophic cooling, observable by signs of high-speed downflows (Mueller et al. 2003, 2004) and moving blobs (Costa & Stenborg 2004).

2.4.3. *Coronal Waves and Oscillations*

Theoretical plausibility and observational evidence are two different things. Among the upward-propagating waves into the solar corona, we can detect only those with density modulations (such as acoustic or shock waves) or amplitude modulations (kink-mode MHD oscillations), while those with magnetic field modulations (such as Alfvén waves) are invisible and virtually undetectable, unless one consults line widths (Moran 2003). Magnetoacoustic waves are an intermediate branch and thus could possibly be detectable, although it would be more difficult than for acoustic waves. So, let's see what the observers find.

Upward-propagating acoustic waves have indeed been detected from the space-time modulation of the EUV flux in fan-shaped diverging coronal loops, from which the damping due to thermal conduction was studied (DeMoortel & Hood 2004; Klimchuk et al. 2004) and the usefulness of wavelet analysis was tested (DeMoortel et al. 2004). Significant oscillations with periods of 7–8 minutes were also reported in Lyα 1216 Å as far out as 1.5–2.2 solar radii (Morgan et al. 2004). The damping of propagating waves and loop oscillations is currently a very hot topic, because we are just at the brink of learning which the underlying physical mechanisms are: wave leakage (Cally 2003; Díaz et al. 2004), resonant absorption (VanDoorsselaere et al. 2004a; Ruderman 2003; Aschwanden et al. 2003; Luo et al. 2004), loop curvature (VanDoorsselaere et al. 2004b), gravitational stratification (Mendoza-Briceño et al. 2004), collisional and viscous damping (Khodachenko et al. 2004), thermal conduction (DeMoortel & Hood 2004; Klimchuk et al. 2004; Carbonell et al. 2004), or magnetic null points (McLaughlin & Hood 2004).

Another hot topic is the search for fast MHD pulsations (with periods of seconds or shorter), which were searched for in high-cadence optical (Rudaway et al. 2004) and radio data (Nakariakov et al. 2003; Cooper et al. 2003; Gelfreikh et al. 2004). A new discovery is also the directionality of kink-mode oscillations: besides the traditional horizontal direction, there were also vertical oscillation directions identified (Wang & Solanki 2004). The question about the excitation of impulsively generated waves in coronal loops triggered also a number of theoretical and numerical studies (Nakariakov et al. 2004a; Selwa & Murawski 2004a, 2004b; Selwa et al. 2004; Voitenko et al. 2003).

2.4.4. *The Architecture of Quiescent Filaments*

An impressive three-dimensional reconstruction of a quiescent filament has been accomplished by Schwartz et al. (2004), using a combination of EUV mapping (with *SOHO*/CDS and SUMER) and spectroscopic Lyα modeling from VTT/MSDP data. The height extent of the EUV filament was found to have upper and lower boundaries at heights of 40 and 15 Mm, but otherwise the published three-dimensional surface renderings by Schwartz et al. (2004) look as fractal as the Rocky Mountains or the Atlantic coast of Norway. The disentangling of the Hα and EUV emission of a filament was accomplished more easily at higher latitudes, where we see the filament from the side, yielding a bottom height of ≈10–20 Mm and a top height of ≈60–100 Mm (Schmieder et al. 2004b). Other multiwavelength studies focused on the EUV-UV spectral catalog of a prominence (Parenti et al. 2004), leading to models of their temperature structure (Stellmacher et al. 2003), which essentially consists of cool threads embedded in hot coronal plasma (Del Zanna et al. 2004). A first magnetic map of a prominence was demonstrated from inversion of spectropolarimetric data in He I D3 (Casini et al. 2003). Filament oscillations have been observed for a long time, but a new study showed that they are caused by EIT waves (Okamoto et al. 2004). A new victory of the computer age is the automated detection of filaments (Shih & Kowalski 2003). Theoreticians worried about the supporting force balance (Ashbourn & Woods 2004), their normal or inverse helicity (Low & Zhang 2004), or magnetic diffusion in filaments (VanBallegooijen 2004).

2.4.5. *Debate on Nanoflare Heating Chilling Down*

A couple of years ago we saw a number of studies bolstering the claim that nanoflare heating is important for the corona, based on the observed frequency distributions with an inferred power-law slope steeper than the critical value of 2. Today some are convinced that those early results were not representative because of a bias resulting from a too-restricted wavelength range and thus incomplete temperature coverage, while others blame the large range of published power-law slope values on a number of other systematic biases. The debate seems to have quieted down, because we did not see any new studies during this year that claimed a power-law slope for nanoflares above the critical value of 2. In contrary, a new study on microflares sampled with *RHESSI* reproduced a power-law slope of 1.75 (Qiu et al. 2004a), fully consistent with larger flares (Liu et al. 2004a). This actually implies that neither microflares nor nanoflares are energetically important for the overall heating of the corona, which occurs to 99% in active regions anyway, but nanoflares probably indicate the smoke of the gun of the (1%) heating in the quiet corona.

Observational studies focused on the line profile evolution of explosive events (Ning et al. 2004), confirmed that explosive events and blinkers are different phenomena (Brkovic & Peter 2004), identified the Hα counterpart of blinkers (Brooks & Kurokawa 2004), as well as the EUV counterparts in a coronal loop for the first time (Doyle et al. 2004), or monitored chromospheric magnetic reconnection in an emerging flux region (Liu & Kurokawa 2004a).

Theoretical studies on nanoflares inferred differential emission measure distributions based on a nanoflare-heated corona with many fine unresolved loop strands and cyclical heating-cooling phases (Cargill & Klimchuk 2004), simulated MHD turbulence dissipated in nanoflares (Nigro et al. 2004), and determined the frequency distribution of the free energy in unstable magnetic discontinuities, finding power-law indices (-1.3, -1.6) consistent with flare energies (Vlahos & Georgoulis 2004).

2.5. Flares

2.5.1. The Magnetic Field Before and After

Theoretically, if we monitor the magnetic field before, during, and after a flare, we should be able to deduce what currents and magnetic field changes were triggering the flare, what kind of magnetic reconnection happened during the flare, and how much magnetic energy was dissipated during the flare. These quantities can be extracted even more easily if one assumes conservation of currents and helicity, as was done for a quadrupolar configuration (Melrose 2004). When the (fractal) structure function of the magnetic field was monitored, the degree of intermittency was found to increase 6–33 minutes and to reach a maximum 3–14 minutes before the (hard X-ray) flare peak (Abramenko et al. 2003), although the variation of the fractal dimension during flares was found to be small (Meunier 2004). Permanent changes of the magnetic field have been observed after a flare (Meunier & Kosovichev 2003; Yurchyshyn et al. 2004), rapid penumbral decay (Wang et al. 2004b), or even a magnetic sign reversal (Qiu & Gary 2003). The prelude to a flare is orchestrated with topological changes of the photospheric magnetic field, i.e., the scaling behavior of the current helicity (Sorriso-Valvo et al. 2004), with magnetic shearing and sudden emergence of magnetic flux (Wang et al. 2004c; Zhang et al. 2003a; Moon et al. 2004), or even with precursor shock waves (Klassen et al. 2003b). Statistically, however, changes in the magnetic field twist parameter and kurtosis were found to be insufficient to discriminate between flaring and nonflaring active regions (Leka & Barnes 2003a, 2003b), but flare-related changes can be seen in photospheric lines (Abramenko & Baranovsky 2004). Magnetic modeling of flares revealed that the onset of a flare was due to reconnection of an emerging flux in a sheared magnetic field (Berlicki et al. 2004; Brooks et al. 2003). Moving blueshift events, indicators of upflows from chromospheric reconnection events, were found to be 5 times more frequent before eruptive flares than in noneruptive flares (DesJardins & Canfield 2003), and upflows in the range of 40–80 km/sec were detected in O III, O IV, O V, Fe XIX, Ca XIX, and S XV during the preflare quiescent phase (Brosius & Phillips 2004). More spectacularly, a multiple-turn, helical magnetic flux tube was imaged during an eruptive flare, supporting the magnetic breakout model (Gary & Moore 2004). After the flare, inflows (or downflows) with initial speeds of 100–600 km/sec were observed that form postflare loops (Sheeley et al. 2004; Asai et al. 2004b), or downflows of 800–1000 km/sec above flare arcades (Innes et al. 2003), probably direct witnesses of the relaxation of newly-reconnected magnetic field lines (Aschwanden 2004).

While magnetic field changes before and after a flare can be detected by diligent observers, the magnetic reconnection in between is elusive and thus left to theoreticians. Previously believed observations of a reconnection inflow were reexamined and found to be attributed rather to the rising motion of the reconnection X-point (Chen et al. 2004a). Signatures of fragmented current sheets (due to tearing and coalescence) have been sought in radio dynamic spectra (Karlicky 2004a). New theoretical work and numerical simulations of magnetic reconnection dealt with three-dimensional spine, fan, and separator solutions (Heerikhuisen & Craig 2004), with trigger mechanisms in reversed magnetic shear regions (Kusano et al. 2004), with the outflow structure and reconnection rate in a self-similar current sheet (Nitta 2004), with Kelvin-Helmholtz and tearing instabilities in reconnecting current sheets (Hirose et al. 2004), and with formation of current sheets and sigmoids by the kink instability in flare loops (Kliem et al. 2004).

2.5.2. Flare Waves and Oscillations

After we talked about waves and oscillations in the solar interior (§ 2.1.2), in the photosphere (§ 2.2.3), in sunspots (§ 2.2.4), in the chromosphere (§ 2.3.2), and in the corona (§ 2.4.3), we cannot resist raising this popular and trendy theme also for flares. Fast pulsations with periods of 14–17 s have been discovered in radio images with the Nobeyama Radioheliograph, which have been interpreted in terms of the fast MHD global sausage mode (Nakariakov et al. 2003), the last MHD mode to be discovered by spatial imaging. Acoustic (slow) MHD oscillations at the second harmonics have also been found in numerical MHD simulations and are thought to apply to solar and stellar flare loops (Nakariakov et al. 2004b; Tsiklauri et al. 2004). Postflare pulsations with typical periods of ≈10 s were mostly detected in radio (Subramanian & Ebenezer 2003; Stepanov et al. 2004), interpreted in terms of fast MHD modes modulating plasma emission or gyrosynchrotron emission, but also somewhat longer periods (25–48 s) were found in hard X-rays (Farnik et al. 2003). In a new scenario, Moreton waves are thought to excite coronal perturbations associated with radio type II bursts (Warmuth et al. 2004a, 2004b).

2.5.3. RHESSI Puzzles of High-Energy Particles

The *Ramaty High Energy Solar Spectroscopic Imager* (*RHESSI*) mission became the main workhorse for solar flare research during the last 3 years. We count a total of 181 *RHESSI* publications at the time of writing, with 52 during this report year. Although *RHESSI* was launched late in the solar cycle, a number of large X-class flares (some producing gamma-ray lines) have been imaged and analyzed: the X1.5 flare on 2002

April 21 (Gallagher et al. 2002; Share et al. 2002; Kundu et al. 2004a; Innes et al. 2003), the X4.8 flare on 2002 July 23 (Lin et al. 2002, 2003; Hurford et al. 2003; Krucker et al. 2003; Emslie et al. 2003; Share et al. 2003a; Smith et al. 2003a; Gan 2004; Yurchyshyn et al. 2004; Holman et al. 2003; Kontar et al. 2003; Piana et al. 2003; White et al. 2003; Firstova et al. 2003; Kozlovsky et al. 2004), the X1.5 flare on 2002 August 30 (Karlicky et al. 2004; Karlicky 2004b), the X10 flare on 2003 October 29 (Xu et al. 2004; Wang et al. 2004b), and the X3.9 flare on 2003 November 3 (Liu et al. 2004b).

Some intriguing new highlights of recent *RHESSI* research are the following: (1) The first gamma-ray images of a solar flare, which were found to be displaced from the hard X-ray flare loop footpoints (Hurford et al. 2003), a completely unpredicted and still not understood phenomenon, although explanations have been attempted, e.g., in terms of the (MHD-turbulent cascade) stochastic acceleration model, where ions and electrons are accelerated by different (and probably not cospatial) resonant waves (Emslie et al. 2004). (2) The parallel and antiparallel footpoint motion of hard X-ray sources, which constrain the reconnection rate, currents, and electric field $\boldsymbol{E} \propto \boldsymbol{v} \times \boldsymbol{B}$ (Krucker et al. 2003; Asai et al. 2004a). (3) The vertical motion of coronal cusp hard X-ray sources, which reveals the formation and dynamics of current sheets in the reconnection region, starting with an (unexpected) initial downward and subsequent upward motion (Sui & Holman 2003; Sui et al. 2004; Liu et al. 2004b). (4) The prompt de-excitation gamma-ray lines of Fe, Mg, Si, Ne, C, and O, which were for the first time spectrally resolved in flares and were found to show mass-dependent redshifts of 0.1%–0.8%, implying a downward motion of accelerated protons and α-particles along magnetic field lines (Smith et al. 2003a). (5) The 511-keV positron-electron annihilation line that was resolved for the first time in a flare, which (unexpectedly) exhibited a transition-region (rather than a chromospheric) temperature range (Share et al. 2003a). (6) The directionality of flare-accelerated α-particles inferred from ^{7}Be and ^{7}Li gamma-ray lines, which indicate isotropic pitch-angle distributions in forward direction (Share et al. 2003b). (7) A spectral Fe/Ni feature has been discovered at $\approx$7–8 keV, which provides a sensitive diagnostic on the temperature and Fe abundance of the flare plasma (Phillips 2004). A novel *RHESSI* observation is also a class of high-density flares in which the coronal flare loops become so collisionally thick at electron energies up to $\gtrsim$50 keV that they "scoop out" footpoint hard X-ray sources (Veronig & Brown 2004). In some flares, the acceleration of electrons can be back-mapped from in situ particle measurements at 1 AU using the *Wind* spacecraft and from radio type II and IV bursts all the way back to the coronal flare site (Classen et al. 2003).

There are more puzzling flare issues that have been brought to light with instruments other than *RHESSI*. A statistical study of 32 flares observed with *Yohkoh* revealed that one-third of the cases show the brighter hard X-ray footpoint at the stronger magnetic field side, contrary to expectations from the customary trapping model (Goff et al. 2004).

2.5.4. Superluminal Velocities?

Radio type III bursts have been detected with a drift rate that corresponds to a superluminal velocity of 2.5*c*. However, there is no breakdown of fundamental physics laws; these superluminal velocities could be explained in a way similar to that of superluminal blazars (Fan et al. 2004), by relativistic electron beams that propagate nearly along the line of sight toward the observer with velocities near the speed of light (Klassen et al. 2003a).

2.5.5. Detection of Axions?

In search of signals from radiative decays of new, as yet undiscovered, massive neutral particles, it was found that the recent observation of a continuous emission from the nonflaring Sun of X-rays in the 3–15 keV range made by *RHESSI* fits the generic concept of axions of the Kaluza-Klein type (Zioutas et al. 2004; see § 8.7).

2.5.6. Flare Studies in Soft X-Rays, EUV, Hα*, and Radio*

Besides the *RHESSI* observations of flares in hard X-rays (38 papers) and gamma-rays (12), we find also complementary multiwavelength studies in soft X-rays (15), EUV (5), Hα (8), radio (38), and white light (4). Although white-light flares are very rare, a catalog of 28 events with clear white-light signatures was compiled (Matthews et al. 2003).

Some intriguing new results regarding soft X-rays are the following: (1) Evidence for flaring was discovered in the probably largest possible coronal structure, i.e., in a gigantic transequatorial loop (Harra et al. 2003). (2) Rapid downflows/inflows with velocities of 800–1000 km/sec in Fe XXI have been detected above flare arcades, which is roughly the expected Alfvénic speed, but they are dark and not bright as expected in the standard reconnection model (Innes et al. 2003). (3) The energy deposited in soft X-ray radiation in flares is typically much lower than the radiative losses calculated in these areas (using radiative transfer and non-LTE modeling), requiring some additional energy source besides electron beam precipitation during the gradual flare phase (Berlicki & Heinzel 2004). (4) Low-FIP Ca and Fe were found to be enhanced in flare plasmas by a factor of 8–10 relative to chromospheric abundance, leading the authors to the conclusion that local coronal compression produces the hot flare plasma rather than the widely-accepted chromospheric evaporation process (Feldman et al. 2004b; see § 9.11). (5) The observed correlation between peak soft X-ray flux and time-integrated hard X-ray flux (Neupert effect) is found to be in disagreement with the expected scaling law based on the hydrodynamic response of impulsively-heated flare loops (Warren & Antiochos 2004).

Among the flare-related radio observations, here a few highlights: (1) A new solar radio burst spectral component emitting only in the (>0.4) terahertz range, extending to far-infrared and white-light wavelengths (Kaufmann et al. 2004). (2) First observations of a solar X-class flare in the submillimeter range with KOSMA, a new radio telescope on the Gornergrat in the Swiss Alps (Luethi et al. 2004). (3) A statistical study confirmed that most of the type II radio bursts originate at the top or flanks of CMEs, based on their velocity-height profile after correction for geometric effects (Mancuso & Raymond 2004). (4) The first simultaneous imaging of multiple radio burst types (pulsations, type IV, zebra-type fine structure) suggests that all emissions are controlled by common quasi-periodic electron injections into diverging magnetic fields (Aurass et al. 2003; Zlotnik et al. 2003).

2.5.7. Using the Ionosphere as the Largest Solar Flare Detector

The period of 18 October to 5 November 2003 was extremely active: we witnessed 140 solar flares and 11 large X-class flares, including the X17 flare on 28 October and the X28 flare on 4 November (Woods et al. 2004b; Thomson et al. 2004).

The largest flare ever recorded with *GOES* (since 1976) occurred on 4 November 2003 and saturated the *GOES* X-ray detector, from which a magnitude of X28 (2.8 mW m^{-2}) has been extrapolated. However, using the Earth's ionosphere as a giant X-ray detector, a more accurate value of X45 was determined. The clever radio astronomers used the trick to measure the large phase changes recorded in New Zealand on long VLF radio paths across the Pacific from transmitters in the continental USA and Hawaii. The trick works because the enhanced X-ray flux from the giant solar flare causes a dramatic lowering of the height of the D-region of the ionosphere.

2.6. CMEs

2.6.1. Eruptive Filaments and Prominences

In most flare models the eruption of a filament is the first step in a chain reaction that culminates with a coronal mass ejection (CME). However, since exceptions confirm the rule, filament eruptions were also found (in three out of 12 cases) that were not associated with CMEs, called "confined filament eruptions" (Choudhary & Moore 2003). From filaments that disappear on the solar disk (disparition brusque), all eruptive ones were found to be followed by the formation of postflare arcades (Tripathi et al. 2004) and to be associated with CMEs, while no CMEs were found following the quasi-eruptive ones, which are followed by localized changes in soft X-rays and EUV only (Morimoto & Kurokawa 2003). The following precursors of filament eruptions have been identified: gradual external reconnection (Sterling & Moore 2004; Gary & Moore 2004), a constant gradual acceleration of the filament in height for up to 1 hr before eruption (Kundu et al. 2004b), blueshifted upflows (DesJardins & Canfield 2003), heating of the filament mass or ejection of heated plasma (Ding et al. 2003), and coronal dimming before CME onsets (Howard & Harrison 2004). Generally some kind of magnetic reconnection in or near the chromosphere plays a role in the initiation of filament eruption (e.g., Lin et al. 2004; Gary & Moore 2004; Moon et al. 2004), or tether-cutting magnetic reconnection in the corona (Sterling & Moore 2003; Vrsnak et al. 2003). The onset of a filament eruption has been detected as early as 2 hr before the first detectable enhancement in soft X-ray flux (Schuck et al. 2004).

Helicity conservation is not always simple. To make things more complicated, a case was observed with formation of right-handed helical fields in a rising dextral filament that is embedded in a CME with helical field in the (opposite-sign) left-handed sense (Liu & Kurokawa 2004b). Analytical models distinguish between normal and inverse configurations (of the magnetic field orientation) and find that normal configurations are more likely to lead to CME expulsion than inverse cases (Zhang & Low 2004).

2.6.2. The CME-Flare Connection

The correlation between different eruptive phenomena, such as flares, eruptive prominences, and CMEs, is expected to be better the larger the stored energy is in the relevant magnetic structure that drives the eruption; otherwise the correlation is poor (Lin 2004). Actually, 40% of M-class flares do not have CMEs (Andrews 2003). The fastest and most powerful CMEs are always associated with flares. For example, three very fast CMEs were all associated with X-class flares and showed spectral signatures different from most other CMEs, in terms of very rapid disruption of the pre-CME streamer, very high Doppler shifts, and high-temperature plasma visible in the Fe XVIII emission line (Raymond et al. 2003). Also, CMEs associated with type II bursts were found to be bigger than those without type II bursts (Shanmugaraju et al. 2003).

Earlier classifications into flare-associated (high-velocity) CMEs and prominence-associated (low-velocity) CMEs have been dismissed as a height-dependent bias, depending on how high the erupting structure forms (Feynman & Ruzmaikin 2004). On the other side, flares associated with CMEs were found to show clear footpoint-separating, two-ribbon brightenings during flares, which was less the case for slow CMEs or flares without CMEs (Zhang & Golub 2003).

A new temporal correlation was also found between the reconnection rate and the directly observed acceleration of the accompanying CME (Qiu et al. 2004b). Another empirical relationship was found between the initial speed of a CME and the potential magnetic field energy of the associated active region, which supports the idea that the magnetic energy of the active region drives the CME (Venkatakrishnan & Ravindra 2003).

2.6.3. Geometry of CMEs

Geometric concepts of CMEs still range from the so-called three-part structure: helical flux ropes (Amari et al. 2003; Cheng et al. 2003), looplike, shell-like (Ciaravella et al. 2003) or convex-outward pancake structures (Riley & Crooker 2004), to “ice-cone”models (Xie et al. 2004a). Of course, projection effects do play an overriding role in the correct inference of the three-dimensional geometry and dynamics of CMEs (Burkepile et al. 2004). A novel method of deducing the three-dimensional geometry of CMEs has been developed using white-light polarization data (which yields the centroid position along the line of sight due to the scattering angle dependence), exhibiting the shape of an expanding loop arcade for one particular CME (Moran & Davila 2004). One study finds that structured CMEs arise in a self-similar manner from pre-existing small-scale loop systems, overlying regions of opposite magnetic polarities (Cremades & Bothmer 2004). Another study directly maps fast MHD shocks in the flanks of a CME and the interaction of the streamer deflections when the shock impinges on them (Vourlidas et al. 2003). The analysis of CME ray structures show that they are consistent with the existence of a current sheet, trailing the CME, lasting for several hours, and extending more than 5 solar radii into the outer corona (Webb et al. 2003).

2.6.4. Dynamics of CMEs

CMEs have been classified into two categories, depending whether they become accelerated or decelerated with height. The model of Chen & Krall (2003) explains this dichotomy with a current-carrying three-dimensional magnetic flux rope model, which predicts acceleration below a critical height of about 3 times the footpoint separation and deceleration above this critical height.

In a statistical study, the kinematics of more than 5000 CMEs are measured in the distance range of 2–30 solar radii, with the finding of a distinct anticorrelation between the acceleration and velocity: most of CMEs faster than 400 km/sec decelerate, including the associated type II’s (Vrsnak et al. 2004b), whereas slower ones generally accelerate (Vrsnak et al. 2004a; Yashiro et al. 2004). This acceleration-velocity relationship is interpreted as a consequence of the aerodynamic drag (Vrsnak et al. 2004a; Cargill 2004). Case studies also showed close temporal correlations between the CME velocity and soft X-ray flux of the flare and between the acceleration of the CME and the time derivative of the X-ray flux, indicating that the CME large-scale acceleration is coupled to the flare particle acceleration (Zhang et al. 2004c).

Regardless of the type of CME (shock) propagation model, the extrapolated arrival time at 1 AU cannot be predicted to better than ±10 hr (Cho et al. 2003; Michalek et al. 2004). Part of the uncertainty in the trajectory and timing prediction may be due to deflections in interplanetary space: under the effect of the Parker spiral magnetic field, a fast CME will be blocked by the background solar wind ahead and deflected to the east, whereas a slow CME will be pushed by the following background solar wind and deflected to the west (Wang et al. 2004e). Regarding geoeffectiveness, the probability that an interplanetary shock is followed by moderate to intense geomagnetic activity is found to be ≈50%–60% (Echer et al. 2004).

2.6.5. Particle Acceleration in CMEs

There is still a big question whether particles observed after a flare/CME event have been accelerated in the coronal flare site or in interplanetary CME shock fronts. Correlation studies between CME shocks, metric/decametric/hectometric type II bursts, and solar energetic proton events suggest that ≈20 MeV particles are accelerated in strong shocks, most efficiently at more than 3 solar radii away from the Sun (Cliver et al. 2004; Tsurutani et al. 2003). A new supertool that consists of a three-dimensional MHD code and a particle kinetic code simulated the initiation and evolution of a CME, the ejection of the flux rope, the shock formation in the front of the rope, and diffusive shock acceleration at a distance of 5 solar radii, yielding solar energetic protons with a cutoff energy of about 10 GeV (Roussev et al. 2004). The timing of 1 GeV protons could be traced back to the Sun for the Easter 2001 event with an accuracy of 1 minute, confirming that they were accelerated by a CME-driven shock wave at the onset of shock-related radio emission (Bieber et al. 2004).

Kahler (2004a) argues that the acceleration and production of solar energetic particles (SEPs) due to CME-driven shocks favor acceleration sites in the slow rather than in the fast solar wind stream, because (1) the MHD fast-mode and solar wind flow speeds are higher in the fast-wind stream and (2) the shock seed populations in the fast-wind streams consist of weak suprathermal ion tails with soft spectra.

2.7. Heliosphere

2.7.1. Solar Wind

Theoretical studies of the solar wind deal mostly with the ion-cyclotron resonance-driven model: with one fluid (O^{5+}; Chen et al. 2004b) and three fluids (e, p, O^{5+}; Chen & Li 2004; Ofman 2004; Xie et al. 2004b), in particular modeling the proton temperature anisotropy (Isenberg 2004; Li et al. 2004a; Vasquez et al. 2003) and helium abundance (Lie-Svendsen et al. 2003). Complementary models accelerate the solar wind with low-frequency kinetic Alfvén waves (Voitenko & Goossens 2004), with fast and slow shock waves (Suzuki 2004), or with lower hybrid waves, which already works beyond 1.5 solar radii via minor ions (Laming 2004). Supporting data of the proton temperature anisotropy are modeled from *Helios* (Marsch et al. 2004; Tu et al. 2004). The fast solar wind seems to be accelerated almost to its final flow velocity within 20 solar radii (Kojima et al. 2004). A simple robust scaling law explains the anticorrelation between the final solar wind speed and freezing-in temperature results (Schwadron & McComas 2003).

Further phenomena studied in the solar wind are fluctuations of the solar wind related to intermittent magnetic turbulence (Burlaga & Vinas 2004; Carbone et al. 2004) or to interplanetary shocks (Fitzenreiter et al. 2003), and the role of closed magnetic fields for confinement and trapping (Woo et al. 2004).

The solar wind originates in photospheric network boundaries (Popescu et al. 2004), flows through the heliosphere, but comes to a screeching halt at the heliopause, the boundary with the interstellar medium (e.g., Habbal & Woo 2004). Our remotest messenger, the *Voyager* spacecraft, is believed to have exited the supersonic solar wind at 85 AU and re-entered supersonic solar wind again at 87 AU (Krimigis et al. 2003), where streaming anisotropies of charged particles probe the solar wind termination shock (Jokipii & Giacalone 2004; Jokipii et al. 2004; Richardson et al. 2003a). From the echo of 2–3 kHz radio emission detected by *Voyager 1*, the nose of the heliopause is calculated to be at a distance of 153–158 AU (Gurnett et al. 2003).

2.7.2. Interplanetary Magnetic Field

The interplanetary magnetic field is in its simplest topology characterized with a ballerina skirt. The average heliospheric current sheet is shifted or coned southward during solar minimum, called the "bashful ballerina" (Mursula & Hiltula 2003). The details, however, are much more complex: a heliospheric plasma sheet encasing the heliospheric current sheet is supposed to contain a high-β plasma and a current sheet, but it was found that most of these current sheets are associated with fields turned back on themselves (Crooker et al. 2004a), i.e., large-scale magnetic field inversions at sector boundaries (Crooker et al. 2004b).

The long-term variation of the magnetospheric-ionospheric electric field has been analyzed back to 1926, and no secular trend has been found in the solar wind-magnetosphere large-scale coupling over the last 77 years, suggesting that there is no secular trend in the interplanetary electric field, the Sun's open magnetic flux, and in the solar wind speed (LeSager & Svalgaard 2004).

2.7.3. Interplanetary Low-Energy Particles

Low-energy solar electron bursts were detected with *ACE* from 1.4 keV down to 73 eV, the lowest energies yet reported for such events (Gosling et al. 2004a, 2004b).

The timing between 25 keV electrons and interplanetary type III radio bursts has been found to be rather complex, which could not be reconciled with a scatter-free propagation model (Cane 2003).

2.7.4. Solar Energetic Particles

Besides the longitude-dependent variation in acceleration of SEPs (Kahler 2004a), there are also longitude-dependent variations in particle transport due to corotating compression regions (Kocharov et al. 2003b; Richardson 2004), filamentary structures (causing "dropouts" of SEP intensities), anisotropic diffusion, and trapping (Ruffolo et al. 2003; Qin et al. 2004), or refracting coronal shocks (Vainio & Khan 2004).

SOHO/CELIAS measurements of 60 keV–2 MeV protons associated with the Bastille Day flare showed that the proton flux decreases more rapidly with distance upstream from the CME shock than expected from diffusion in solar wind turbulence (Giacalone 2004), probably caused by hydromagnetic waves that have been observed to be enhanced by 2 orders of magnitude, compared with the level of the ambient solar wind (Bamert et al. 2004).

During the 1998 May 2–3 SEP event, the proton intensity parallel to the magnetic field was ≈1000 times higher than in the perpendicular direction, indicating that the magnetic flux rope structure of the CME provided a "highway" for transport of solar energetic protons with a parallel mean free path of at least 10 AU (Torsti et al. 2004).

The analysis of particle spectra in interplanetary shock crossings suggests also that particle seed spectra composed of ions from impulsive and gradual SEP events are re-accelerated (Desai et al. 2004).

Abundance measurements of heavy elements in SEP events reveal a bimodal distribution of enhancements for impulsive and gradual SEP events, with enhancements of 2–4 orders of magnitude in the largest impulsive events (Reames & Ng 2004).

2.8. Solar Cycle

Since the magnetic field is arguably the most controlling parameter inside and outside the Sun, we are not surprised anymore that the solar cycle shows up in virtually all solar phenomena: in the solar interior where the magnetic dynamo sits, in the photosphere where the magnetic field emerges (most conspicuously in sunspots and in active regions), and in all solar activity phenomena in the solar corona (active regions, flares, filaments, prominences, CMEs), as well as in the connecting heliospheric and interplanetary magnetic field.

The solar cycle is seen in low-l p-mode frequencies because the frequency shifts are sensitive to the distribution of activity over the solar surface (Chaplin et al. 2004a). Also the high-degree p-modes reveal a variation of 2 s in the sound travel time down to a depth of 0.8 solar radii during the solar cycle (Kholikov et al. 2004). However, no significant variation is found in deeper layers of the convection zone, which suggests that any solar activity-dependent disturbance is confined to near the solar surface (Verner et al. 2004). Recent theoretical dynamo models that mimic complete solar cycles are given in Dikpati et al. (2004b) and Durrant et al. (2004).

The most traditional indicator of the solar cycle is of course given by the Wolf sunspot number (e.g., DeMeyer 2003), but the total irradiance at the 530.3 nm green line (coronal) index is also a widely used standard (Mavromichalaki et al. 2003).

In addition, UV, EUV, the 2.8 GHz radio flux, Lyα, and Mg II are also used as proxies (Kane 2003). Other photospheric indicators of the solar cycle are the network radiative (Ca II K line, blue and red continua) properties (Ermolli et al. 2003). The network contrast change over the solar cycle was found to be about 0.05% and the network disk coverage change about 6% (Ermolli et al. 2003). The full-disk solar irradiance in EUV/XUV exhibits, besides the magnitude variation, a variation in the power-law index of the frequency distribution of fluctuations during the solar cycle, varying from $\alpha = 1.5 \pm 0.1$ at the maximum to $\alpha = 3.0 \pm 0.2$ during the minimum (Greenhough et al. 2003). Contrary to current model assumptions, the presence of active regions on the disk was found to increase the spectral irradiance at all wavelengths, even in infrared, near 1.6 μm (Fontenla et al. 2004). Variation in radio emission amounts to a factor 1.2 at 15 GHz (in the chromosphere and lower corona), a factor of 3.5 at 1.5–2.5 GHz (in the middle corona), when compared to the averaged maximum/minimum flux ratio during solar cycles 19–23 (Kane 2004).

Correlations between the solar cycle, Earth's climate changes, and cosmic-ray flux have also been found (Ogurtsov et al. 2003; Ozguc & Atac 2003), but the interpretations of physical links that explain these correlations are still controversial.

Theoretical modeling of the long-term solar cycle evolution has inspired modelers over a century. A review of recent achievements, such as determinism and chaos in sunspot cyclicity, cycles during the Maunder minimum, a general behavior of sunspot activity during a great minimum in the 1790s, and persistent 22 yr cyclicity (even-odd effect) has been provided by Usoskin & Mursula (2003). New periods have also been found in the La Rue sunspot area, with possible periods of 330 days and 30–50 days (Vaquero et al. 2003). Solar activity indicators do not necessarily have to peak simultaneously; delays between energy storage (build-up of nonpotential magnetic energy in corona) and energy release (flaring) can induce a time lag between different indicators, which has been modeled with an energy balance model (Litvinenko & Wheatland 2004).

Long-term trends of solar variability have been studied by using radiocarbon measurements for the last 4500 years, based on dendrochronology, the Schove series for the last 1700 years, based on auroral records, and the Hoyt-Schatten series of group sunspot numbers, and the authors predict another Maunder-type minimum, which appear roughly every two centuries (Bonev et al. 2004). So, the Sun has a long-term memory (Ogurtsov 2004). And the relatively high solar activity during the last 60 years is unique throughout the past 1150 years (Usoskin et al. 2003).

3. PLANETARY SYSTEMS

Quite soon, a new name is going to be needed. Just now, solar system does fine for the Sun and all the stuff around it, and planetary systems for the Neptune-to-Jupiter mass objects orbiting other stars. But when the moons, comets, asteroids, and all the rest orbiting other stars begin to turn up, what should the collectivity of systems be called? Stars and their stuff, perhaps?

3.1. The Sun and His Family

This was the title of a distinctly non-PC book for children more than 50 years ago, and we are going to be distinctly non-PC here by starting with a double handful of quirky items, many of which received green dots on first reading, but most of which a typical member of the Division of Planetary Sciences would probably disdain. And you guys from the Division of Solar Physics already know that the paterfamilias lives back in § 2.

3.1.1. Family Scandals

Mars has canals. Giovanni Schiaparelli, Percival Lowell, and all have not had much good press lately, but a modern pair of serious planetary observers (Dobbins & Sheehan 2004) find that the historic drawings actually look a good deal like photographs taken to provide the same level of contrast and angular resolution.

Venus has a quasi-satellite, and it is the first found in the solar system (Mikkola et al. 2004). What is a quasi-satellite? Well its shares the period of its primary and the mean longitude, but it can wander far afield in radius vector. Asteroid 2002 VE68, as seen from Venus, has an elliptical orbit reaching in to Mercury and out to Earth, and even further astray in the direction along its orbit. The ellipse gradually moves along the orbit and so away from Venus, leading to eventual parting of the ways. About 7000 years into the relationship, there is only another 500 or so to go before VE68 latches on to L5 as a Trojan Companion, and then is eventually ejected into a Near Earth Object orbit.

Mercury and Venus will transit the Sun at the same time… on 26 July 69,163 AD (Meeus & Vitagliano 2004). The date is in dynamical time. That is, it assumes that the rotation period of the Earth is constant and there are no calendar changes. Contrarily, we can never see all four Galilean moons of Jupiter cross his disk at the same time, because three of the periods are locked (Sinnott 2004, who is long-sighted enough to quote George B. Airy on this point, someone else who doesn't get much good publicity as a rule).

Titan transited the Crab Nebula in X-rays on 5 June 2003 (Mori et al. 2004). This may well be the first such event, because the last time the configuration arose, in January 1296, the Nebula may have been too small for Titan's path to cross it. Come back in 2267 for the next crossing. The data, which indicate the extent of Titan's atmosphere (880 ± 60 km), come from the *Chandra* X-ray satellite, and, while Saturn must also have passed in front of the Crab, *Chandra* was in the Earth's radiation zone just then and missed it.

Meteor showers associated with known comets can be seen from all the planets except Mercury and Pluto (Selsis et al. 2004)—one from Venus, two from Mars, and bunches for the outer large planets.

The Titius-Bode law fits better if you (*a*) count the asteroid belt as a planet and (*b*) leave out the Earth (Neslusan 2004). I guess we must agree with (*b*), since Earth gets a separate section, but if anyone insists on (*a*) we will quote Abraham Lincoln's question, "How many legs does a horse have if you call its tail a leg?"

Atilla, Essex, Tyson, and Mosquito are not the children of Hollywood celebrities but the names of some particles of interplanetary dust that have found their way to Earth (Ferini et al. 2004). Materials like them can be prepared in the laboratory by irradiating ices. And who are we to criticize the naming who only the other day were asked, "Virginia, do you even name your rental cars?" Actually not; sometimes they tell me their names and sometimes not. But if you aren't polite to Lamont Cranston, The Flying Dutchperson, and Between,[2] we may not give you a ride.

Phobos and Deimos transits of the Sun were imaged by the *Opportunity* lander on Mars (Bell et al. 2004b), the first transits to be seen from any planet other than Earth, at least by humans.

Solar system X-rays come from all the mechanisms you can think of, and a few you might not (Ness et al. 2004, Wargelin et al. 2004). That is, the Moon reflects solar ones; comets experience charge exchange; Venus and Mars provide fluorescent scattering of solar X-rays; Earth and Jupiter have magnetically induced coronal emission; and a good deal of the 0.75 keV background is charge transfer in the heliosphere and geocoronal emission. And the mechanism for Saturn remains unclear. The *XMM* flux from Jupiter is mostly in lines, due to solar wind ions being captured and accelerated, followed by charge exchange. There are also scattered solar X-rays (Branduardi-Raymont et al. 2004).

Solar system radio emission always arises from magnetic fields intrinsic to the emitter, but the currents can be sustained in fluid iron (Earth), metallic hydrogen (Jupiter and Saturn), or salty oceans (Neptune and Uranus). The electrons required are excited by coupling of the solar wind to planetary fields (Lazio et al. 2004).

3.1.2. The Major Planets

Mercury could have its own Trojan asteroids, though they would last only 20 kyr (Warell et al. 2003) and does have its own magnetic field, for reasons that remain under discussion (Aharonson et al. 2004, who have resurrected a fossil field). It used to have a chaotic relationship between its orbital and rotation periods, from which the 3 : 2 resonance was captured (Correia & Laskar 2004).

Venus is rather cloudy, but its surface features can probably be seen on the dark side at 1 μm (Pellier 2004). Venus also transited the Sun on June 8. Well, Venus is always transiting the Sun from somebody's point of view, but this year was the turn of "most of humanity" (Westfall 2004), though not ours for we live in the wrong hemisphere. Our turn comes in 2012.

Mars can probably, just barely, be seen before the Sun has set (Rhoads 2004), meaning, of course, from Earth. It was also seen from up closer by *Spirit* (Squyres et al. 2004 and the following 10 papers, analyzing the first 90 Sols of data), by *Opportunity* (Squyres 2004, on ripples probably due to seas), and by *Odyssey* (Mangold et al. 2004 on rain-fed and snowmelt valleys not more than 2.9–3.4 Gyr old). Mars has a magnetosphere (modeled by Harnett & Winglee 2003). And all the rest was water, not quite ready for drinking, but inferred, whether frozen (Bibring et al. 2004), liquid (Hynek 2004), or departed, owing partly to attacks on the atmosphere by the solar wind (Lundin et al. 2004). Our Mars bag still has a dozen papers in it, of which we mention only three favorites. Navarro-Gonzalez et al. (2003) note that the current Martian surface is not much drier or more a-biological than the Atacama desert. Head et al. (2003) point out that Mars is just now coming out of an ice age, as a result of changing obliquity of its ecliptic. Martian constellations look, of course, like Martian people and animals. And Kiefer (2003) says that if we want to understand Martian ice abundances, we must "learn to think like Martians." He already does; just ask one of our former office mates from graduate school.

Jupiter probably migrated inward about 0.45 AU during a 10^5 yr part of its formation process (Franklin et al. 2004), thereby piling up the Hilda asteroids with their trefoil-shaped distribution (Anonymous 2004b). But just where and how and from what that formation took place remains in some dispute. Hubbard (2004) provides a scholarly overview of core masses and compositions, pointing out the connection on the one hand to various mechanisms proposed for planet formation, extra- as well as intra-solar system, and, on the other hand, to recent laboratory experiments on the compressibility of deuterium. Hubbard also suggests, and we heartily endorse, that, once these matters have been sorted out, the primary definition of a planet should be something that started out with core nucleation. Lodders (2004a) proposes that the basic accumulation process began with carbonaceous material, so that one should think of a "tar line" at 5.2 AU, rather than a "snow line" as determining where that nucleation can occur.

Jupiter also has climate cycles (Marcus 2004) of about 70 yr. The one just ending began with the formation of three white ovals in 1930, two of which are now gone. These sound more like terrestrial climate cycles than like solar activity cycles (though we, unconstrained by detailed knowledge, can think of models of both types). Marcus, however, mentions Karman vortex sheets and new vortices emerging from destabilization of a jet stream. He also predicts major changes in the near future.

Saturn has rings with considerable variation of compositions

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[2] The usual small prize to the first reader to report back why vehicles might wish to be known by these designations.

(lots of water ice to mostly moon dust) from one to another (Poulet et al. 2004; Cassini Team 2004). In some cases, annuli consist largely of dust from the nearest moon, Pan for instance, though it seems unlikely that Pan-dust would produce desirable Pan-cakes.

Uranus and Neptune both have non-dipole, non-axisymmetric magnetic fields (Stanley & Bloxham 2004), implying location of their dynamos in thin convection shells and fields confined to small regions around stable stratified cores (Aurnou 2004). Uranus also has an atmosphere above a cloud deck of H_2S ice (Encrenaz et al. 2004). CO and other trace constituents have been added by icy moons or meteorites, rather than coming from the body of the planet. Neptune has one, and apparently only one, Trojan asteroid (Brasser et al. 2004), compared to 1564 found (so far) sharing the orbit of Jupiter. The Neptunian one is called 2001 QR 322, and the orbit is stable enough for it to be "primordial." Earth also has one Trojan, 3753 Cruithne, a very temporary significant other.

We caught nary a Plutonian paper this year. Perhaps it isn't a planet after all? You might suppose there would have been even fewer papers about the 10th planet, but Liboff (2003) predicts one at $a = 51$ AU, based on an electromagnetic process in the early solar disk which had been ionized by a nearby supernova.

3.1.3. Moons over Miami and Elsewhere

Luna is still the only terrestrial one, and the amount of polar ice was a good deal less than previously advertised after Campbell et al. (2003) looked for Arecibo radar reflections. It would cost about 127 G$ to return there in 2020 (Anonymous 2004c). This is about $30 per (US) person per year, and saying either that one is prepared or is not prepared to pay one's share will surely offend someone (maybe the same people for both). Formation of Luna from a splash-off encounter between Earth and a smaller body is the official best-buy hypothesis at present. Canup (2004) concludes that about 80% of what is now lunar material came from the mantle of the impactor rather than from Earth.

What has the Moon being doing since? This not so certain as you might suppose. The average secular acceleration since the time of James Bradley is 4 arcsec/$(\text{century})^2$ larger than the lunar laser ranging number, which pertains to the last three decades (Kolesnik et al. 2004). The lunier author has been in the habit of telling beginning students that there are consistent numbers for this acceleration coming from (*a*) Mesozoic coral layers (number of days per year), (*b*) locations at which ancient eclipses were seen (Earth rotation rate), and (*c*) modern astronomical data on the retreat of the Moon; she is grateful not to be teaching that course in 2005.

Titan was, not surprisingly, the moon of the year. Many abstracts and papers concluded by saying "*Cassini* will do better," and, since it should have landed well before you read this, let us possess our souls in patience. Is this perfectly safe? Almost. Johnson (2004) finds that the solar wind should not erode the atmosphere of Titan, though it is very hard on Io, Europa, Ganymede, and probably Callisto. Thus the Titanic atmosphere should still be there next year. The health of the lander cannot, of course, be guaranteed.

Io, while you are thinking about it, can indeed accelerate enough electrons to provide the non-thermal radio emission associated with its motions through the magnetic field and ionosphere of Jupiter (Zaitsev et al. 2003). But it must have quiet lava overturn in lakes as well as the observed volcanic activity to keep its surface as young as it is (Geissler et al. 2004). Cosmetic surgeons please take note.

Irregular satellites are the capture sort, but they need not be recent acquisitions. Viera Neto et al. (2004) attribute four Jovian ones to capture when the planet had only 0.62–0.93 of its present mass. As if being captured weren't enough of an indignity, some victims also get broken into pieces, so that there are now orbit families of irregular moons around Jupiter and Saturn (Nesvorný et al. 2004).

And less is more. Well, what we are trying to say is that all four major planets added a good many moons this year, not by capture, but by discovery. Saturn was a big winner, owing to *Cassini*, with 2004 S1, S2, S3, and S4 (IAUC 8389 and 8401). But the others did pretty well too: Jupiter with S/2003 J22 and J23 (IAUC 8276 and 8281); Uranus with the recoveries of S/2001 U2 and U3 (IAUC 8213 and 8216); and Neptune with five more irregular satellites (Holman et al. 2004), and a proper orbit for S2002 N4 (IAUC 8213).

3.1.4. Asteroids, Comets, Both, Neither

As usual, the set of papers about small objects was considerably larger than the set of papers about large objects, and the following is either wisely selective or incredibly prejudiced, depending on whether your paper is mentioned.

The number of binary asteroids (or those with satellites, for small mass ratios) has grown so rapidly that even IAU Circular numbers ran off the edge of the index page, and a theoretical discussion of their formation and the processes of changing partners will have to stand for the whole class (Funato et al. 2004; Burns 2004).

Comets that used to be asteroids (until somebody saw a coma) and asteroids that used to be comets (until activity died away) have also both proliferated in the index year. The NEAT and LINEAR programs are major contributions to this set as well as to the binaries of the previous paragraph. Special favorites include (*a*) (7958) Elst-Pizarro, which is either a dying Jupiter family comet or a Thesis asteroid with material recently kicked off by an impact (Hsieh et al. 2004), and (*b*) 2003EH, which, as the parent body of the Quadrantid meteor shower, was probably also comet C/1490 Y1 at break-up (Jenniskens 2004). Columbus may have seen that comet, but only from the eastern hemisphere!

Among the (unadulterated) asteroids, Yarkovsky has been seen in Arecibo radar data but not cited by Chesley et al. (2003). The observations revealed a small non-gravitational acceleration of NEO 6489 Gulevka caused by anisotropic reemission of sunlight.

Among the transient Trojans, 588 Achilles and 617 Patroclus were the first discovered at L4 and L5 back in 1906 (Karlsson 2004). They are now in the process of leaving. All Trojan orbits with inclinations larger than 40° are inherently unstable (Marzari et al. 2003).

Kuiper Belt Objects reside outside the orbit of Neptune for two reasons. First, Neptune drove them there, migrating outward to 30 AU when we and the solar system were all much younger and more mobile (Levison & Morbidelli 2003). Second, somehow almost no one bothers to mention the several other people who suggested such a belt, before, during, and after Kuiper.

Comets, even those with nanodiamonds in their dust, are not forever. Those that reach within 1–3 AU of the Sun are rapidly eroded, lasting at most a few hundred orbits, and we will lose 30% of the known ones in 3000 years if they cannot stay away from 1 AU (Hughes 2003; Groussin & Lamy 2003; Emel'yanenko et al. 2004). The first calculation you might think of doing would say that some, like Encke, would not even have time to get here. Thus resonances and non-gravitational forces must dominate the orbital evolution (Pittich et al. 2004). Encke, incidentally, has been seen at 59 of 74 perihelion passages since 17 January 1786, the largest number for any comet. Can the supply be kept up in light of rapid destruction and break-up like the events of 326 and 1843 in the life of the object that is now collectively the Kreutz Sun-grazers (Sekanina & Chodas 2004)? Yes, say Neslusan & Jakubik (2004), if there are at least 10^{12} potential comets in the part of the Oort cloud that feeds into the inner solar system because of galactic tidal forces.

Meanwhile, we can study those that have already got here. They have molecules. The ethylene glycol in Hale-Bopp obviously keeps it from freezing (Crovisier et al. 2004a), but we are not quite sure what the acetaldehyde (Crovisier et al. 2004b) is used for, perhaps silvering of mirrors when the comet wants to observe itself. They also have dust, and the grains age after many orbits (Das et al. 2004). Some have very little dust, less than 10%, for instance, in C/1991 H1 (Lara et al. 2004).

Most comets become fairly inert far from the Sun (Hainaut et al. 2004 on Halley at 28.1 AU). But for those that continue to exhibit sporadic activity, you can choose between internal energy sources (Korsun & Chörny 2003) and collisions with other stuff out there (Gronkowski 2004, drawing on an idea from Hughes 1991).

Long-period comets bring a certain sense of comfort. We are, for instance, only 0.17 Ikeya-Zhang years old (Hasagawa & Nakano 2003). It (C/2002 C1) was seen in 877 and 1273 as well as in 1661 (the last by Hevelius) and should be back in 2362.

There should be an opportunity to hold comet dust in your hand in a year or two. The mission to 81P/Wild 2 is alive and well (Weaver 2004 and several following papers; A'Hearn 2004) and due back in 2006 with approximately 2800 particles. The mission is called STARDUST rather than COMETDUST.[3]

3.1.5. *Meteors*

Do most meteors come in showers? We don't know, and no paper read during the reference year addressed this burning point. There are some fine sporadic ones associated with local dust made from both asteroids and comets (Galligan & Baggaley 2004), but the Perseids, Lyrids, and Leonids have been doing it for a long time (Newton et al. 2003). Josiah Willard Gibbs was among those who contributed to the recognition of recurring showers. Your surprise will decline a smidge if you recall that he was at Yale, where meteors were taken very seriously in the 19th century, and where an iron meteorite, a mineral cabinet, and a physical lab are all named for him (Hoffleit 1992). He also had a free energy, but this has proven difficult to keep on a shelf. (Compare Holmberg effect, § 9.5.)

Meteors are normally seen because they heat and ionize air as they pass, but they can also reflect radiation. Beech et al. (2004) have shown that no Perseid pieces are larger than 1 m across before entry from limits on reflected light, while Campbell-Brown (2004) report detection of radar reflections from the most active shower of all, the Arietids. It is left as an exercise for the student to calculate whether this will always be a daylight-only shower and, if not, how long you have to wait to see it by night.

Meteorites are the bits that finally reach ground. New types continue to be discovered, for instance Matrajt et al. (2004) on one that arrived at Tagish Lake a few years ago. It contains phyllosilicates, diphatic hydrocarbons, and other substances different from known types of chondrite carbonates, and also different from the interstellar solids that dominate infrared emission from star formation regions and such.

Some meteorites are slightly magnetized, but this is almost certainly because they cooled below their Curie points within the terrestrial field (Hvozdara et al. 2003). You could perhaps use this to answer the question, "who moved my meteorite?" In any case, no meteorite is a virgin. Even the relatively unprocessed Murchison has had its lithium distribution altered by water and other changes induced, most in the carbonate phase, least in the chondrules (Sephton et al. 2004).

3.1.6. *Dust to Dust*

The planets began that way (Rafikov 2004) and presumably most authors will end that way, although we are slightly inclined to ashes ourselves. Meanwhile, nearly all the dust hang-

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[3] This sort of disparity between poetic and literal truth is not unique to astronomy. A Kipling poem describing what happens "when two strong men stand face to face, though they come from the ends of the earth" prompted a remark by George Bernard Shaw that one would gain in accuracy, though lose in poetry, if he had chosen "two competent electrical engineers."

ing around the solar system is debris from the mutual assured destruction of small bodies, as in the debris disk of Vega.

About 8 particles per year per km^2 (3–45 μm in size), however, reach us from the interstellar medium (Murray et al. 2004). The number is based on observations from satellites and radar echoes. It was not entirely clear how they decided which particles are which, nor whether they have individual names.

Dust grains that survived in the protoplanetary disk to be incorporated in meteorites and retrieved much later by Gerry Wasserburg (Wasserburg et al. 1969) are classic clues to the early days of the solar system. They don't quite get individual names, but Nguyen & Zinner (2004) report the first set of presolar silicate grains—nine of them. Parete-Koon et al. (2003) discuss isotope ratios in five grains known to have come from novae. The rate of $F^{17}(p, \gamma)Ne^{18}$ is, for instance, quite important.

The traditional source of pre-solar grains is the supernovae responsible for the short-lived radionuclides whose daughters are found in the grains. In this context, it is reassuring to hear that some dust survives in the material swept up by the expanding remnant of Kepler's 1604 event (Contini 2004). But the pre-solar granary supply house of the year was undoubtedly asymptotic giant branch stars (Clayton 2003; Savina et al. 2004 on Ru^{99}, the decay product of Tc^{99}; Verchovsky et al. 2004). Clayton for instance deduces the arrival 5–6 Gyr ago of a metal-poor small galaxy, whose crash-landing triggered a starburst. AGBs from this then eventually produced the SiC grains he discusses.

Sitting down here by itself very close to the edge of the solar system (and also, we suspect quite close to the edge of what mainstream journals are likely to publish) is the idea that some isotopic anomalies in grains are not the traces of extinct radio-activities but result from chemical fractionation caused by a "non-mass-dependent effects…due to unrecognized quantum mechanical effects in reactions with indistinguishable isotopes" (Robert 2004).

3.1.7. *Reaching for the Edge*

Discovery of the heliopause, where space becomes dominated by interstellar material rather than by the solar wind, has been pre-trumpeted since before this series began. The latest word is that *Voyager 1*, at 85 AU, is either crossing back and forth across the terminator shock or hovering around it (Krimigis et al. 2003; McDonald et al. 2003; Fisk 2003). This is, however, merely the shock (reverse shock perhaps, say Baranov & Pushkar 2004) where the solar wind drops from supersonic to subsonic. The true heliopause is still further out at 150 AU, and we do not expect to see *Voyager* reach it. (Oh, no. We intend to live forever, but are rather nearsighted.)

3.2. Exoplanets

We are grateful for many reasons to be allowed to compose these reviews in a dialect of English. Yet another is the Spanish equivalent of this subsection heading, "los planetas fuera de nuestra sistema solar" (from a press handout in connection with a visit of the Crown Prince and Princess of Spain to the Instituto de Astrofísica de Canarias, and yes, we got to touch hands with both). But down to business, first the green dots and gee-whizzeries of the year and then some familiar problems (formation, evolution, detection methods, statistics, and so forth) revisited. And be warned, 146 papers are indexed in our exopages.

3.2.1. *Three Firsts, Two Seconds, One Third, and a Fourth*

The first three (non-pulsar) planets outside the solar system with masses significantly less than that of Saturn and not much larger than Neptune were announced in a dead heat by three groups (Mayor et al. 2004a). The host stars are μ Arae (mostly a European discovery, employing the 3.6 meter at La Silla for the first time), Gliese 436 (mostly a UC Berkeley team discovery, employing the Keck 10-meter, not for the first time, and only the second M dwarf host), and 55 Cancri (mostly a McDonald discovery, using the Hobby-Eberly Telescope for the first time, and raising its planetary system to the status of the first quadruple). All three are very close to their host stars and fall firmly within the predicted desert for $M = 10–100\ M_{\odot}$ planets at less than 3 AU (Ida & Lin 2004). Please keep an eye on the real literature for further details.

Also green dotted in the notebook for its unexpectedness is the pulsar (B1620−26) plus white dwarf plus planet combination in the globular cluster M4 (Richer et al. 2003). HD 104985 is the first G giant with a planet say Sato et al. (2003), who have been surveying 180 of them.

And as a warning to you (and us) not to believe everything said here, Gl 436 must surely be the third M dwarf host, because No. 1 was Gl 876 and No. 2 is the microlens planet OGLE 2003 BLG 235 = MOA 2003 BLG 53 (Bond et al. 2004).

3.2.2. *Search, Detect, Do Not Destroy*

"More" continues to be the watchword, from the oldest searches (Mayor et al. 2004b, reporting discovery of another 16, including 3 hot Jupiters, 2 doubles, and 2 with binary star hosts), from more recent on-going projects (Setiawan et al. 2004a, with 83 G–K giants, 11 binaries, 2 brown dwarfs, 2 planets, and 2 active chromospheres, which count as noise in this contest, though they are signal to others), and another new transit search from Berlin (Rauer et al. 2004).

It remains true that the vast majority of exoplanets proclaim their existence by gently wiggling the radial velocities of their host stars.[4] The remaining methods, of which we have counted more than 20, about 15 appearing this year, can be categorized as successful (consensus detections), maybe, could but didn't, and new thoughts.

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[4] Is 0.3 km/sec gentle? Well the faster planes could do it, but would require in-air refueling to match the 1–1000 day orbit periods, and the less said about that 14-hour flight back from Frankfurt the better.

The successes are two. A small fraction of microlens events toward the Galactic bulge have secondary blips due to companions of small mass. The cleanest case (Bond et al. 2004) has already been noted. At least a few other candidates are blipping around (Snodgrass et al. 2004), but for some, data would admit of a brown dwarf or M dwarf companion instead of a planet (Gaudi & Han 2004).

Planets passing in front of their stars get caught by the same microlensing projects but are easier to confirm, because the events repeat and you can look for radial velocity variations the next time around. Bouchy et al. (2004) present three of these. The masses are in the same (Jupiter-plus) range as found in radial velocity surveys (Torres et al. 2004), and the sizes of the planets are more or less as expected, given the floods of starlight in which the poor things live (Burrows et al. 2004), for these are the shortest period planets known (Konacki et al. 2004). Indeed dust that might otherwise have formed cloud decks in their atmospheres has probably sublimed away (Sasselov 2003). The absence of these 1–2 day periods from the radial velocity searches and the absence of 3–10 day periods from the transit inventories count as mild statistical surprises which could either disappear or intensify in the next couple of years.

We caught five "maybes," and there have been others in earlier years.

1. τ Ceti has an analog of our Kuiper Belt Objects, only more (Greaves et al. 2004). The star was one of Frank Drake's two original SETI targets, back when we were at Hollywood High School and you were a pre-follicular ovum.
2. Mira perhaps shows evidence of unsteady accretion from its wind onto a planet or brown dwarf (Struck et al. 2004). Remember it also has a white dwarf further out, credited with most of the variable accretion. But what we really love about this paper is the description of "bursts of dimming in the optical."
3. Inwardly migrating planets may get eaten (Lecar & Sasselov 2003). Israelian et al. (2004a) have been among the most enthusiastic proponents of this mechanism for both increasing and decreasing stellar surface metallicities, though there are contexts where you can say that very little of either has happened (Desidera et al. 2004 on visual binary pairs with matching metallicity). And this is not the dominant reason that planetary host stars are metal rich; they started out that way (Heiter & Luck 2003).
4. A planet passing through a magnetosphere can induce radio emission (consider Io and Jupiter) and other forms of activity. We caught two models (Willes & Wu 2004, for white dwarfs, and Ip et al. 2004, for normal stars) and one tentative detection (Shkolnik et al. 2003 reporting on HD 179949).
5. Light reflected or absorbed by a planetary atmosphere can affect line profiles or total luminosity and color of the host. A weak signal in Doppler tomography of τ Boo has probably been seen (Leigh et al. 2003). Shelton (2004) does some calculations for the line profile variations, attributing the idea to Rossiter (1924). Richardson et al. (2003b) and Green et al. (2003) note that some of the upper limits are beginning to push against the predictions of model atmospheres and how they transport energy.

New is often the most pleasurable class, with two members in index 2004. Lazio et al. (2004) looked for, but did not find, the analog of Jovian radio emission from known exoplanets. The amount they expected comes from a "radiometric Bode's law," based on how the solar wind should fall off with distance from a star and an expression for how planetary magnetic fields might depend on mass and rotation period put forward by Blackett (1947). Specific to exoearths is the thought of Jura (2004b) that, when main-sequence stars become red giants and evaporate the oceans, transit events should include Lyα absorption. Luckily stars take a long time to become red giants, because there may not be anything above our, non-evaporated, atmosphere that can record rest-wavelength Lyα for most of the next few decades.

The oldest of the "could have but didn't" methods is proper motion wiggles of host stars. Within the year, van Maanen 2 did, and then didn't (Makarov 2004; Farihi et al. 2004). It is, after all, a high velocity star (as well as the only white dwarf with an iron-rich atmosphere). Most of the "could have but didn't" methods have, however, lingered at least till the end of the reference year. There are two subtypes: phenomena advertised as planetary with more likely subsequent explanations (not necessarily accompanied by recantations) and search techniques that can be pushed further.

- V838 Mon is strange all right (Tylenda 2004, a pro-planet paper) but it is probably a strange member of some class of cataclysmic variable or last helium flash (Lynch et al. 2004; Boschi & Munari 2004, who draw attention to other similar sources).
- KH 15D indeed has a tilted dusty disk, but not one with a planet lurking inside (Chiang & Murray-Clay 2004; Deming et al. 2004). It too has a clone called NGC 2346 (Roth et al. 1984).
- We really liked the idea that carbon stars with OH and H_2O around were evaporating comets, but Willacy (2004) says that Fischer-Tropsch catalysis is a better bet for IRC $+10°216$.
- Direct imaging is widely perceived as the true goal in exoplanet astronomy. Young nearby stars are obviously the most promising target (Song et al. 2003) but have yielded only upper limits so far (Neuhauser et al. 2003).
- Sublimation and illumination or incorporation of comets and KBOs could show as an IR excess in red giants (Jura 2004a) or as metals on white dwarf surfaces (Zuckerman et al. 2003), but again so far, only upper limits.
- Radial velocities are not the only possible way of noticing the reflex motion of a host star. Well, you have known about pulsar timing since 1992. Timing of pulsation modes of sdB

stars (Reed et al. 2004 on Feige 48) or of binary orbits (Watson 2004) could work the same way, but so far have not.

And now that all these planets have been found, we still need two parts of statistics (to characterize them and their hosts), three parts theory (to produce them, put them where they are, and keep them there), and one part speculation (to explore the connections with SETI).

3.2.3. Two Cups of Statistics

At least 5% of FGK dwarfs have one or more planets compared to less than 1% of M dwarfs, and among the FGKs it is 20% for metal rich stars ($[\mathrm{Fe/H}] \gtrsim 0.3$) dropping to 3% at $[\mathrm{Fe/H}] \lesssim -0.3$ (Marcy 2004; Santos et al. 2004, who say that numbers may be constant at still smaller metallicities). The total could be considerably larger by the time all of period, mass, orientation, and other aspects of parameter space have been explored (Lineweaver & Grether 2003).

None of the exos is yet quite like Jupiter. The closest match in period and mass lives in an orbit of large eccentricity (0.48; Naef et al. 2003). But the planet about which most is known, HD 209458b, has an atmosphere not unlike what Jupiter would have if subjected to the same irradiation. H and Na had shown up in earlier transits, and Vidal-Madjar et al. (2004) found O I and O II in absorption this year. No, there are no exoearths, but future missions called *Kepler*, *COROT*, and *Eddington* might begin the process (Aigrain & Irwin 2004). We think that *Kepler* will get the orbits, *Eddington* will find the relativistic corrections, and *COROT* will paint them.

3.2.4. Three Cups of Theory

Now it is the job of the theorists to create, reposition,[5] and preserve (and you may divide these tasks among Brahma, Shiva, and Vishnu however you wish). Creation has been bimodally attributed to a gradual accumulation of planetesimals (Rafikov 2004) or to an instability to disk fragmentation (Boss 2004). We mention in addition only Rice et al. (2003), because they seem to be saying "both, please" and Johansen et al. (2004), whose anticyclonic vortices are, roughly, "neither of the above." The green dot paper of the year on this topic was, however, indexed under "Chamberlin-Moulton lives" and is to be found in § 9.10.

From the time a proto-planet becomes sufficiently massive to affect its surroundings until the last of the protoplanetary disk is gone, orbit change is likely. Circularization was familiar from binary star processes and also happens to planets (Ogilvie & Lin 2004; Dobbs-Dixon et al. 2004) though there are ways to buy back large eccentricity again (Zakamska & Tremaine 2004). But net inward and outward migration came as a surprise, at least to us, a few years ago. Both are possible (Lufkin et al. 2004; Veras & Armitage 2004, for instance), or, indeed, some of each in a random walk (Papaloizou et al. 2004). Another surprise is that the final system need not be coplanar (Thommes & Lissauer 2003), though co-planarity is frequently assumed in stability analyses and in selecting likely values of the angle of inclination to estimate planet masses. Anyone who spotted the delightful grouping of crescent Moon, Venus, Jupiter, and sunrise in November does not need to be told that our own solar system is roughly coplanar. And if you missed it this time, never mind, such things recur over the years, and we'll be happy to phone in the predawn hours to alert you next time.

Preservation has two parts. First, gaseous planets close to stars must not boil away. OK for the ones we see, report Lecavelier des Etangs et al. (2004a), with hydrogen escaping just fast enough to provide absorption features during transits; well, actually the boiling must be continuous, but you know what we mean. Baraffe et al. (2004) report the minimum planetary masses required for 5 Gyr survival as a function of stellar luminosity and temperature and orbit location. Even the short-period OGLE transit planets seem to be safe.

The second part of planetary conservation is stable orbits. Happily, HD 160691, which had been declared unstable in Ap03, managed to hang on until Bois et al. (2003) could find a new mechanism to preserve its companions longer. Happily also, 55 Cnc was OK as a triple, probably in a mean motion resonance (Zhou et al. 2004). What was then the innermost planet was already expected to have general relativistic precession three times that of Mercury, and theorists are surely busy at this moment (in some time zone) evaluating how long the quadruple planetary system can last and whether there will be detectable non-Newtonian terms in its orbit. Long enough, and no, would be our guesses.

A star with three planets is clearly a special case of the four-body problem, for which both chaotic and stable behavior are possible. Szell et al. (2004) invoked both Caledonian Symmetry and the Szebehely constant without citing either. The more chaotic author knew Victor Szebehely and much appreciated a lunch-time simplified explanation of the 7 : 1 criterion for triple stability, but never met Caledon, and fears it is now too late. The bad news was reported in the form that a star with two or more Jupiter-mass planets probably cannot also support an earth within its habitable zone (Erdi et al. 2004). This would be seriously bad news for us if Saturn were a bit heftier.

3.2.5. And Half a Cup of Speculation

For the connection with SETI, we call upon the punters of Ladbrooks (Lush 2004), who put the odds against discovery of extraterrestrial intelligent life at $10^4 : 1$, very much more pessimistic than the odds at which you can bet for or against LIGO, the Higgs, and various other scientific entities. We would

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[5] Yes, the standard term has become "migrate," but the less transitive author still has problems perceiving this as a transitive verb. The planets may migrate, but can theorists migrate them? But she is inconsistent about these matters, being happy to have corn grow and farmers grow corn, but being very dubious about the grammar as well as the competence of banks growing your money.

not be brash enough to opine on whether the current SETI target list (Turnbull & Tarter 2003) maximizes the probability.

4. STARS IN YOUR CROWN IN HEAVEN

We are still mulling over a referee's report that told us that "stars" encompasses a wide range of research topics with very little overlap and very few "big questions" that are being pursued. Luckily it was not a referee's report on an edition of ApXX, so we feel free to tell you about the following dozen or so topics. The title derives from "Big Virginia's"[6] notion of a proper reward for people who did something deserving of acknowledgement beyond mere thanks. Those astronomers who continue to work on stellar topics in the face of such referees' view are clearly among the deserving.

4.1. The Milky Way Is Made of Stars

You knew that and, if asked, would very probably have credited the discovery to Galileo Galilei (whose house arrest the more refracting author found herself occasionally envying this year as she stood in airport security lines). The first oil painting with a stripe of dots around the sky is the 1609 "Flight into Egypt" of Adam Eisheimer, just late enough to have been influenced by Galileo (Bertola 2004). "Prediscovery" descriptions of a resolvable stellar Milky Way, in 1582 (Thomas Watson's *Hekatompathia*; Altschuler & Jansen 2004a) and 1581 (Sebastian Verro; Altschuler & Jansen 2004b), have been attributed to pre-telescopic optical instruments, perhaps the perspective glasses of Leonard and Thomas Digges. But only the "Mind's Eye" can account for the stellar Milky Way of Democritus (Bignami 2004, reviewing a book by Francisco Bertola) and of the 14th century Macrobius (Hoskin 1997). Hamlet we are not quite sure of, though he knew that the stars are fire and the Sun doth move (Shakespeare 1602).

4.2. Inventories

The closest star is the Sun. The second closest, Proxima Centauri, also flares (Gudel et al. 2004). The third closest we are not so sure about. Recognition of nearby stars continues, from catalogs as old as that of Luyten (Reid et al. 2003, 2004) and as recent as that of DENIS (an acronym, not a saint or sinner; Kendall et al. 2004; Reyle & Robin 2004). Statistical determination of the completeness of samples to, say, 10 or 20 pc, relies on being sure that the 5 pc sample is all in, but this is not totally obvious.

We understand (sort of) why there might be competitions for the woman who looks most like, say, Elizabeth Taylor, but are not quite so sure why the stars should care who looks most like the Sun. Anyhow, 2004 candidates include HD 146233 (Soubiran & Triand 2004), 18 Sco (Anonymous 2004a), and a handful or two presented by Galeev et al. (2004).

Stars in the Hertzsprung gap? Well, if your sample is large enough, there are bound to be some. 31 Com (G0 III) is an example, and Scelsi et al. (2004) focused on it primarily because the rapid evolution means that the dynamo must be very young. It is an X-ray source.

The number of stars with secular changes in a human lifetime (even our very extended one) remains small, and nothing like FG Sge (Arkhipova et al. 2003) or V4334 Sgr (Pavlenko et al. 2004) appeared this year. But the youngest known runaway star (the Becklin-Neugebauer object) may have begun its self-enshrouding mass loss as a result of a close encounter only 500 years ago (Tan 2004).

The most massive star? Some years it shrinks when improved angular resolution yields virtual fragmentation. This year we think it grew. One competitor is the YSO IRAS 07427−2400 at 140 ± 50 $M_\odot$ and still accreting at 0.026 $M_\odot$/yr. Since the Jeans mass for its conditions is 2420 $M_\odot$, it won't literally fragment (Kumar et al. 2003). A couple of massive evolved binary stars must have had very large main-sequence heft: LVB 1806−20 (Figer et al. 2004b) for which the sum of the masses is about 130 $M_\odot$. WR 20a weighs in somewhere around 83 $M_\odot$ (Bonanos et al. 2004). But the winner is still the 200 $M_\odot$ Pistol Star at the Galactic center (Figer et al. 2004b). η Carinae is not now particularly obese, but given the rate at which it is shedding, some 10^{-3} $M_\odot$/yr, it could have been very impressive in Paleolithic times (Aerts et al. 2004). There must be a true maximum possible under current Galactic star forming conditions, near 150 $M_\odot$, or the most massive young clusters would extend above it (Weidner & Kroupa 2004).

And the largest inventory of precision stellar data this year came from Nordstrom et al. (2004).

4.3. Young Stellar Objects

Rather in the way that Holmberg has two effects (§ 9.5), Herbig has two sorts of YSOs, the Ae/Be stars (massive analogs of T Tauri pre-main-sequence stars) and Herbig-Haro objects. These are ribbons or blobs of ionized gas energized by outflows from YSOs, sometimes at distances of many parsecs. You might suppose that at least 666 were known (Smith et al. 2004). But it seems that this team chose the number to emphasize various evil traits of their particular HH, and starting from 1 the inventory has actually reached only 492 and 493 (Walawender et al. 2004). The green dot item, naturally, is that the nearest Herbig AeBe star, HD 104237, has been spotted driving a Herbig-Haro object. The discoverers (Grady et al. 2004) call it HH 669, and we fear that the counts of these may never be sorted out. Like getting the date of Easter right, this is probably important to the people to whom it is important.

Just for fun, and only a green check mark, is the detail that T Tauri itself is at least a triple star (Tamazian 2004). The first

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[6] Improbable as it may seem, the elder author, named for her mother, was once called "Little Virginia."

analogous star in the Large Magellanic Cloud (Romaniello et al. 2004) has a large accretion rate for its age by Galactic standards, $1.5 \times 10^{-8}\ M_{\odot}$/yr at 12–16 Myr, presumably a composition effect.

Another 61 papers appear on our YSO page. Most deal with disks, accretion, outflow, and related phenomena.

Infall comes first (Lee et al. 2004a), and, at some point, the process begins to be described as accretion from a disk at a rate that is larger for larger masses (Calvet et al. 2004). And no, we are not absolutely sure which causes which. The accretion can be quite erratic, in the sense that many classical T Tauri stars have FUOR episodes in their past (McGroarty & Ray 2004). FU Ori itself has a companion at 225 AU, which suggests one possible mechanism (periastron passage) for driving the outbursts (Wang et al. 2004a). Accretion rates decline with time (Sicilia-Aguilar et al. 2004). Magnetospheres appear (von Rekowski & Brandenburg 2004). Jets get collimated (Rosen & Smith 2004). And eventually outflow comes to dominate accretion, though age is not the only factor in when the transitions happens (Comeron et al. 2004). Indeed both can occur at the same time say Menten & van der Tak (2004), who have seen masing by both inward and outward moving gas in CRL 2136. The dust in the disk gradually becomes more crystalline (Meeus et al. 2003) and the grains larger and less fluffy (Przygodda et al. 2003; Sheret et al. 2004).

Most of the same things happen in the more massive Herbig AeBe stars as in Joy's T Tauri stars. Magnetospheres develop (Deleuil et al. 2004). Grains coagulate (Natta et al. 2004), to the point where Chakraborty et al. (2004) say that some of the big ones have crossed the terminology line at 100 km and become planetesimals. In addition, the disk morphology changes in the direction of less flare and more self-shadowing (Leinert et al. 2004; Acke et al. 2004) and stuff gets channeled into biconical or jet outflow (Perrin 2004; Elia et al. 2004). The disks disappear, probably faster than in small stars (Fuente et al. 2003). But then big stars do everything faster than little stars (cf. Elizabeth Taylor).

And if you would like to watch all this happen for yourself (except the Elizabeth Taylor part), pick some of the pre-Bok globules that will start collapsing in the next 200,000 years (Lada et al. 2004b; Garay et al. 2004) and plan to live a long time. We estimate that your stars will eventually drive Herbig-Haro objects. Nos. 2,784,223 to 2,784,941.

4.4. The Brown Dwarf Desert

The general idea is that, if there were oodles of substellar companions (0.01–0.08 $M_{\odot}$, say) with orbit periods of days to years, then the search for exoplanets would have found, well, oodles of them. They didn't. But the desert is not so empty as the Great Sandy Desert Around Oz, and Endl et al. (2004) report the 12th companion of this sort at 1.85 AU from HD 137510, a G0 IV star slightly younger than the Sun (3.4 Gyr) and slightly more metal rich, $[\mathrm{Fe/H}] \sim +0.11$. But the same search space has yielded about 100 planets, vs. 12 BDs.

Does the desert extend out to the size of our own solar system and beyond (the realm of the visual binaries), or is it confined to the near zone? Yes and no say the papers of the year. The desert continues to 75–1200 AU, since an infrared coronagraphic search (McCarthy & Zuckerman 2004) around a couple hundred nearby stars found only one BD (and no planets). Contrarily, the desert stops outside 50 AU say Neuhauser & Guenther (2004), since a sample of 79 stars in young associations revealed three BDs, consistent with the same distribution of masses across the red dwarf/brown dwarf boundary as is found among young single stars. The model of Delgado-Donate et al. (2004b), which says that companions of small mass tend to depart within the first 10 million years or so, would account for the difference, but the model also underproduces single small object and binaries with M_2/M_1 less than 0.2, relative to data for young stars.

Brown dwarf binaries, in the sense of two orbiting each other, definitely exist. Siegler et al. (2003) report three systems with total masses less than 0.185 $M_{\odot}$. All have separations less than 20 AU, which would be unusual for three random MV pairs. The closest (to us) is ϵ Indi (McCaughrean et al. 2004; Smith et al. 2003b). And there are 15 candidates for eclipsing BD pairs found among 8201 stars in the Pisgah Survey (the name of the observatory, not its location) report Lopez-Morales & Clemens (2004). The first dynamical masses for an L dwarf pair are 0.085 and 0.066 $M_{\odot}$ in a 3850 day orbit, not all of which has been seen yet (Bouy et al. 2004a). It is a 2MASS source.

A brown dwarf pair in the R CrA star formation region is probably the first still in an accretion phase, with Hα in emission and lithium (in absorption!) say Bouy et al. (2004b). This inevitably invites the question, are brown dwarfs just the low mass end of the stars? We caught at least two nos, from Delgado-Donate et al. (2004a) who say they have spotted differences in the initial mass functions, which imply manufacture in quiescent accretion disks, and from Jiang et al. (2004) who say that the disks were around future binary stars. And there were a whole bunch of yeses, based primarily on the BDs having early accretion and later dynamos appropriately scaled from those of low-mass stars (Stelzer et al. 2004; Barrado y Navascués 2004; Mohanty et al. 2004b; Barrado y Navascués et al. 2004; Wilking et al. 2004; Martin et al. 2004a).

The faintest and coolest BD so far is another 2MASS source (Vrba et al. 2004; Golimowski et al. 2004; Knapp et al. 2004), rejoicing in the equivalent of 1.5 Social Security Numbers as J04115195−093505. It is a T9 (yes, we are going to need the next spectral type quite soon) at 600–750 K, $\log L/L_{\odot} = -5.75$, and only about 6 pc from us.

Of a baker's dozen of papers on statistics and classification of BDs, the frosted cupcakes are two counts that show variable IMF—that is, the ratio of BDs to M dwarfs varies, even among very young populations (Slesnick et al. 2004; Preibisch et al. 2003)—and one perfectly splendid discussion of atmospheric structure and how it changes with temperature across the M-L-T sequence and on to Jupiter (Lodders 2004b). Yes, the purple cow (a result of strong absorption at the Na D line) is there, and also perovskite, which I had hoped even less to see in a star. There are papers with data (e.g., McLean et al. 2003) and papers with models (Burrows et al. 2003), both of which find that water is important, and papers with both (e.g., Mohanty et al. 2004a) noting regimes of agreement and disagreement.

4.5. Tracks in the HR Diagram

Lots of people make these every year, with mass loss (Jimenez et al. 2004); with rotation and magnetic fields (the former being the more important; Maeder & Meynet 2003, 2004); with anchovies and extra cheese, sorry, semi-convection and overshoot (Pietrinferni et al. 2004); usually with heavy element abundances appropriate to some specific population (Cariulo et al. 2004), but sometimes without any (Harris et al. 2004). And in case you want to make some yourself, a simplified version of the very versatile Eggleton code is now available from a Web site (Paxton 2004).

Issues unsettled for many years include (*a*) how to treat convection (El Eid et al. 2004; Kapyla et al. 2004; truly a random sample from near the end of the year of a dozen papers), (*b*) missing opacity (Bonatto et al. 2004), and (*c*) the widespread need for extra mixing beyond what the (uncertain!) convection provides, in B stars (Hempel & Holweger 2003) and red giants in globular clusters (Pavlenko et al. 2003), an equally random pair near the beginning of the annual ensemble. Sometimes, however, the mixing is just right (Smith & Morse 2004 on η Carinae and Boesgaard et al. 2004 on lithium and beryllium, papers from the middle of the year).

Now you compare your tracks with data on binary stars, clusters, and so forth and pronounce judgement. We found a dozen papers calling attention to problems, but only three reporting that all was well, a situation probably not unique to astronomy. Medical studies that do not rule out the null hypothesis go underpublished, and very few couples take the trouble to go into court to report that their marriages are more or less OK. In any case, you get only one of each, a precision study of the α Cen system, in which all is well for stars of 1.105 and 0.934 $M_\odot$, $Y = 0.275$, $Z = 0.0315$, radii constrained by both interferometry and seismology, and so forth (Eggenberger et al. 2004). And the sad conclusion that none of five sets of evolutionary tracks and isochrones fits all of five open clusters, even for the main-sequence stars (Grocholsky & Sarajedini 2004). It is customary to attribute the misfits to incomplete understanding of opacities and convection (Hillenbrand & White 2004), but you already knew that. Another failure mode applies to the most metal poor giants, where you see so deep into the atmosphere that it is no longer even approximately plane parallel (Israelian et al. 2004b).

4.6. Radio Stars and Other Forms of Activity

Back when the greyer author was the youngest member of a peer review panel, she was reprimanded for suggesting radio emission as an indicator of stellar activity in addition to X-rays, because radio stars were known to be so rare that it wasn't worth the bother to look. She also remembers Jack Benny. It is not, we suppose, that the stars have become brighter in sympathy with our dimness, but that radio telescopes have become larger in sympathy with our BMI. In any case, the year included reports of non-thermal radio emission from (*a*) a quarter of chemically peculiar stars with fields of 1–10 kG (Trigilio et al. 2004), (*b*) a comparable fraction of bright O stars in places like Cyg OB-2 (Van Loo et al. 2004), and (*c*) even a bunch of Wolf-Rayet stars (Cappa et al. 2004). The radio emission from ζ Puppis is, in contrast, thermal bremsstrahlung (Blomme et al. 2003).

Young late dwarfs have been recognized as radio emitters more generally, but it would be unfair to discriminate against one of the most luminous stellar radio flares ever recorded just because the perpetrator is in Orion (Bower et al. 2003).

Stellar activity in general, how it correlates with mass, age, composition, companionship, and whatever else matters, and how this all ought to be explained collected 59 additional highlight papers during the year (plus about 12 concerning the Sun, which belong up in § 2). We really wish someone would produce a reliable overall review. Meanwhile, here are some pieces of the jigsaw puzzle, which must fit in somewhere.

- Flares, X-rays, and such in T Tauri stars are supposed to come from accretion and in more mature stars from dynamo-powered coronae. Kastner et al. (2004), Stelzer & Schmitt (2004), and Argiroffi et al. (2004) all present this pattern, with support drawn from various sorts of T Tauri stars. But in case you don't like the same thing for breakfast every day, Stassun et al. (2004) make the case for very early dynamo-driven X-ray stars in Orion, and Moss (2004b) advocates fossil rather than dynamo fields for a subset of young, main-sequence, and evolved stars.
- Activity in young brown dwarfs forms a continuum with that of late M dwarfs, who are already fully convective anyhow (Stelzer et al. 2004), but the brown dwarfs are rather feeble creatures (Scholz & Eisloffel 2004; Bailer-Jones 2004) at best.
- Activity cycles are common, but X-rays are not the right search strategy, HD 81809 presenting only the second case (Favata et al. 2004).
- Activity cycles are common, in binaries, including AM Her (Awadalla et al. 2004), RS CVn stars (Xiang & Zhon 2004), V889 Her (Strassmeier et al. 2003), V410 Tau (Stelzer et al. 2003), and other YSOs (Pashchenko et al. 2003).
- Activity cycles are common, but NO star other than the

Sun has been confirmed as being currently sunk in a Maunder minimum. The candidates are all actually more than 6 Gyr old, and so simply not expected to be active any more (Wright 2004). Judge et al. (2004) have put forward τ Ceti as another candidate Maunderer; it has occasional spots but no discernible cycle. How can you be sure? We think you have to wait for the star to recover, which could take decades or centuries.

- Yes, the Sun had a Maunder minimum (so called because it was discovered by Gustav Spörer). The 21 yr cycle in C^{14} production, however, continued through it (Kocharov et al. 2003a). There has been more activity recently than any time since about 850 (Usoskin et al. 2003, 2004). But Bonev et al. (2004) argue that there is another extended minimum coming within the next century, predicted by the phasing of the longer Gleissberg and Suess cycles, which (among other things) describe how the 11 yr cycles are beginning to overlap (Forgacs-Dajka et al. 2004).
- Detectable activity can occupy anything from 10^{-4} of a stellar surface (Sanz-Forcada et al. 2003) to all of it (the phenomenon called saturation) to more than all of it, meaning that there are at least a few flares under way at all times (Peres et al. 2004; Feigelson et al. 2004).
- And all the rest. Forty recorded papers still linger, but they, and we, will just have to wait for the ideal review article that will incorporate stellar magnetic fields (Vallee 2003), the evolution of rotation (MacDonald & Mullan 2003; Cohen et al. 2004), active latitudes and longitudes (Moss 2004a; Barnes et al. 2004b), a dozen or more statistical studies of correlations among masses, ages, rotation periods, activity levels, and all, of which only Wright et al. (2004) gets mentioned, because it is such an elegant spin-off from the Keck exoplanet searches. Oh, and may we please have von Zeipel's theorem (M. Ohishi et al. 2004; N. Ohishi et al. 2004)?

4.7. Promethium Unbound

We (not you, who are too young) have known about technetium in a subset of S-type stars for more than half a century, and we apologize to Merrill (1952) for missing the semi-centenary in Ap02. After hiking all over the periodic table since then (chemists take their children on strange expeditions), we couldn't help wishing for promethium. "Possible presence" in Przybilski's star and in HR 965 say Cowley et al. (2004), including W. P. Bidelman (who took the spectra in the 1960s and who has sent out a separate, more speculative preprint on the subject). Wait up, you will say! Aren't those Ap stars, with abundance anomalies supposed to be due to diffusion rather than S-type stars with *s*-process excesses? Well yes, but Tjin a Djie et al. (1973) long ago proposed Nd(*p*, *n*)Pm reactions on the surfaces of vigorously flaring stars as a possible production mechanism.

The Ap star page (p. 19 this year) always ends up with a few excessively peculiar items, this time around a case for the non-existence or extreme rarity of the λ Boo stars (Gerbaldi et al. 2003), in which there is a deficiency of the metals that are enhanced in other chemically peculiar stars. The authors conclude that most of the candidates simply show blended binary spectra.

The hot extreme-helium stars share with the cool ones (R CrB and such) *s*-process excesses, though it is not clear when this might have happened (Pandey et al. 2004a). And nearly all the calcium in a double handful of HgMn stars is Ca^{48} (Castelli & Hubrig 2004). They probably have very heavy bones—the stars, that is; we haven't met the authors. Half of HgMn stars are binaries (Catanzaro & Leto 2004), but half of nearly all kinds of stars are binaries, so this may have little to do with the HgMn flowers of spring.

4.8. Planetary Nebulae

The number of these in the Milky Way is about 1450 (Kerber et al. 2003), minus the one that turned out to be an H II region with a small cluster of B stars at its center (Bohigas & Tapia 2003). They exceed the number of 2004 papers by a factor of 37, but might have gone totally unsung this year were it not for the green-dotted announcement of what may be the first REAL planetary nebula, that is, one that incorporates some material that was formerly in planets of the parent star (Wesson & Liu 2004 on NGC 6543).

The most sobering surprise, however, was the conclusion of Mellema (2004) that the serious geometrical method of distance determination,

$$V_r\ (\mathrm{km/sec}) = 4.74\ \mu\ (\mathrm{arcsec/yr})\ d\ (\mathrm{pc}),$$

may be systematically wrong by 20%–30%, because the radial velocities are gas speed all right, but the proper motions are a pattern speed, larger by that factor in a particular shock model.

Pleasantly reminiscent of our youth are (*a*) the very early establishment of asymmetries (Vinkovic et al. 2004 on the bipolarity of IRC+10°011, less than 200 years old) and (*b*) the triple star formation scenario (Soker 2004). As in the human analogy, the details of which are inappropriate for a family publication like *PASP*, it is not clear that any such stars actually exist.

Known planetary nebulae belong, distinguishably, to the Galactic bulge (Jacoby & Van de Steene 2004) and to the thick and thin disk (Kerber et al. 2004, the first kinematically separated sample). The first UV-selected sample of PNe contains one object (Otte et al. 2004).

4.9. Red, White, Blue, Brown, and Black White Dwarfs

Yes, they probably come in all of these colors. The black ones are not the dark matter or anyhow there are not enough of them in the Galactic halo to be most of the dark matter

(Salim et al. 2004, a partial reconsideration by the group who originally said they were).

By brown ones we mean the coolest achievable in the age of a stellar population. Within the Galactic disk, white dwarfs near 3500–4000 K are rare, and all are of small mass and large radius, meaning that they have cooled faster than the average WD. Thus it is possible that the very coolest and oldest disk white dwarfs are lost among other cool stars and have not yet been identified or counted (Kleinman et al. 2004, looking at an SDSS sample; Farihi 2004). This has interesting implications for (*a*) our understanding of WD cooling and (*b*) the time gap between the youngest halo and oldest disk stars. It was our green dot paper on the subject. There are (probably) no green white dwarfs, though the compiler of a widely-used handbook of the early 20th century described Sirius as having "an emerald green companion."

Possibly not having caught the faintest white dwarfs feels like it ought also to have implications for the more contentious issue of the faintest white dwarfs in globular clusters and their use as age estimators independent of main-sequence turn off and such. The "yes" the faintest have been seen and can be used of a year or two ago was followed by a 2004 "no" (De Marchi et al. 2004), in turn rebutted by a firmer "yes" for M4 (Richer et al. 2004). It would be wrong to cast a vote based only on the fact that the "no" team acknowledged consultation with the "yes" team, and not conversely, but it costs very little to be polite as a rule.

What else has been said about white dwarfs this year? Enough to fill 43 average-length recorded papers, some 430,000 words, in which "white" and "dwarf" will appear much more often than in a random distribution of 430,000 English words.

Contrary to textbook diktat, WDs are not always the endpoints of stellar evolution. Lanz et al. (2004) report a new way to turn them into extended horizontal branch stars (via a late helium flash), while Moehler et al. (2004) use a similar flash to produce blue hook stars (which fall below the zero-age horizontal branch). When there are two to tango, an accreting WD can also experience either accretion-induced collapse or a Type Ia supernova explosion. Ivanova & Taam (2004) say that white dwarfs made of O, Ne, and Mg collapse, while those made mostly of O explode.

There are, say Madej et al. (2003), none made mostly of iron, based on colors and surface gravities of 90 DA stars. Notice, therefore, that van Maanen 2, with its iron-rich surface, was not in their sample. WDs of very small mass in an SDSS sample analyzed by Liebert et al. (2004) presumably have helium cores and either still have (neutron star?) companions like PSR J1012+5307, or used to. Indeed the SDSS sample of more than 2500 WDs (Kleinman et al. 2004; Madej et al. 2004) is a treasure trove of information on the distributions of masses (peak at 0.562 $M_\odot$), spectral types (the DAs win by more than 10 : 1), and other matters. There are also DBs, DOs, DQs, DHs, DZ, and DABs. DHs have magnetic fields that have to be measured in Oersteds or something, because DB for Gauss was already taken. The relentlessly SI might, we suppose, speak of DW stars (Webers/m^2) or DTs for Tesla.

Frankly, we do not understand the evolutionary sequences through or among these types. Krzesinski et al. (2004) explain that PG 1159 stars become DOs which in turn bifurcate into DAs and DBs. But it remains true that the ratio of hydrogen to helium dominated atmospheres varies wildly with temperature. In the range 30–45,000 K that ratio is very close to infinity. Vennes et al. (2004) reported the third WD with some atmospheric helium, PG 1603+432, in that range. It is not, however, a real DB with almost nothing other than helium, but a renegade DA, in which *FUSE* spectra have revealed a bit of helium and carbon. Atmospheric oxygen in DBs is (also) very rare, Liebert et al. (2003) having found examples 2–4. Thus we are prevented from explaining the evolutionary paths to you by Ehrenfest's theorem—that it is difficult to explain things even when you understand them and almost impossible when you don't.

4.10. White Dwarf Pulsation, Masses, and Activity

A good many white dwarfs pulsate. You just heard about the hottest class, named for their prototype, PG 1159. There are non-pulsating ones in the same temperature range. Quirion et al. (2004) show that these have more atmospheric helium (and so less carbon and oxygen) than the pulsators.

Coolest are the ZZ Ceti stars, with hydrogen atmospheres. Like Sir Galahad, their strength is as the strength of 10 (well, actually 70, with the last 30 having come from SDSS; Mukadam et al. 2004) because their instability strip, like his heart, is pure (Bergeron et al. 2004). The implication is that all DAs pass through a pulsating stage of life. Some do so with as many as 12 modes sloshing at once (Castanheira et al. 2004 on G185-32), and some made odd choices ($l = 4$ dominates for PY Vul; Thompson et al. 2004). As they cool, the interiors crystallize, and pulsation frequencies shift, as seen for BPN 37093, the most massive ZZ Ceti at 1.05 $M_\odot$, which has 90% of its mass in a solid core (Metcalfe et al. 2004).

In between come the V777 Her stars or pulsating DBs. Because plasma neutrinos contribute significantly to their cooling down to 25,000 K, and temperature vs. time determines pulsation frequencies vs. time, electroweak theory can be tested by looking for changes in those frequencies (Winget et al. 2004).

We ride two more white dwarf hobby horses, for historic reasons, no longer being capable of changing hobby horses in midstream. First is the existence of significant numbers of fairly massive WDs. LHS 4033 at 1.32 ± 0.01 $M_\odot$ holds the record for masses determined from two different methods (consistently! Dahn et al. 2004). Nalezyty & Madej (2004) provide a catalog of 112 WDs exceeding 0.8 $M_\odot$, with a secondary peak at 1.05 $M_\odot$ (the primary one, remember, is at 0.56 $M_\odot$). The mass distributions for magnetic and non-magnetic WDs are different. The nuclei of planetary nebulae, the putative precursors of white dwarfs, also extend arbitrarily close to the Chandrasekhar limit and down to 0.44 $M_\odot$, but without a peak near 0.6 $M_\odot$ (Pauldrach et al. 2004).

The green anti-dot goes to Karl et al. (2003) on the second most massive, short-period white dwarf binary, pointing out that there are still no confirmed pairs massive enough to produce Type Ia supernova explosions when they merge that are also of short enough period to be expected to merge in the age of the universe.

The hotter horse is the issue of white dwarf chromospheres, coronae, and such. "Our" candidate, GD 356, at least has a star spot (Brinkworth et al. 2004, who are kind enough to cite us), but even Zheleznyakov et al. (2004), who probably started the whole thing, no longer expect much in the way of X-rays. The few *ROSAT* candidates for X-ray emitting white dwarfs include three dMe stars, one BL Lac active galaxy, and one or two hot photospheres (Chu et al. 2004a).

4.11. Stellar Oscillations

These differ from ordinary pulsations in being much harder to detect, so that, apart from the Sun, the number of stars caught in the act hovers uncertainly around zero. Martic et al. (2004) analyzed 45 *p*-modes in Procyon A, which Matthews et al. (2004) immediately turned around and took away, using data from MOST to suggest that the radial velocity variations are really due to granulation. Christensen-Dalsgaard & Kjeldsen (2004) and Bedding & Kjeldsen (2003) have reviewed the general subject, but whether even α Cen A can be safely left in the seising inventory we are not quite sure. If so, it just missed ever having a convective core (Guenther & Brown 2004).

4.12. Pulsation Sequences

All stars undoubtedly wiggle their surfaces one way or another. By "pulsation" for the moment we shall mean wiggles, driven by ionization zones, in, if not the very gravest modes, at least fairly serious ones. And the five green dot papers all describe very large sets of pulsating red giants (etc.) observed with sufficient accuracy that plotting them in diagrams of period vs. luminosity, period vs. amplitude, luminosity vs. color, and so forth shows that there are two to five very sharp sequences rather than one broad one. The samples have been compiled from surveys originally designed to search for gravitational microlensing (MACHO) events, and while some of the variables are of traditional, large amplitude varieties (Miras and such), others live down in the regime that would formerly have been called measurement error, with amplitudes of 0.1 m or less.

1. Kiss & Bedding (2004) report red OGLE II stars in the Small Magellanic Cloud. The period-luminosity diagram has four AGB sequences (with fundamental, 1st, 2nd, and 3rd overtones dominating), three short-period sequences below the red giant tip and two long-period sequences of "ambiguous origin."

2. Ita et al. (2004), employing data from OGLE and Sirius for stars in the SMC and LMC in the period-L_K plane, find four sequences, including Miras in fundamental and first overtone, semi-regular variables, and "and so forth." We think this takes care of one of those "been there, done that" questions—whether Miras are fundamental or first overtone pulsators (cf. Jacob et al. 2004). The answer is lots of each and some of both.

3. Noda et al. (2004) have used MOA data to check on MACHO results. There are five *P-L* relations among red stars in the LMC. Some are harmonics and overtones, some unclear. That convection and pulsation synchronize redward of the Cepheid instability strip is one of the pieces of physics that need to be taken into account in analyzing these. The authors remark, as do Kiss & Bedding (2004), that the LMC and SMC are rather similar in these matters.

4. In the bar of the Milky Way, say Wray et al. (2004), there are two period-amplitude relationships vs. three in the Magellanic Clouds. They are looking at more than 15,000 stars (most of which show multiple periods) with periods of 10–100 days and amplitudes of 0.005 to 0.13 magnitudes.

5. The most complicated pattern comes from 15,000 LMC and 3000 SMC stars with periods up to 1000 days in an 8-year data set (Soszynski et al. 2004). Again these are small amplitude variables, but the *P-L* relation has four ridges above the RG tip and eight (4 AGB and 4 RG) below. The phenomenology is similar, but not identical, among the SMC, LMC, and Galactic bar regions, and multiple periods are again common.

In case you would like to try making plots of this sort for yourself (which are apparently called Peterson diagrams, but no, she didn't get cited), Pojmanski & Maciejewski (2004) tabulate data for another 849 Miras and lots of other variable types from the ASAS survey at Las Campanas. Again there are both long and short periods, large and small amplitudes. Glass & Schultheis (2003) report seeing no major gap between large-amplitude (Mira) and (small-amplitude) semi-regular variables as a function of color or period, which sounds like a partial contradiction of the green dot results.

As long as we are mired down among the Miras, note that (1) accurately observed ones like U Ori are non-spherical (Mondal & Chandrasekhar 2004), (2) major decreases in period over decades (found in about 1% of the stars) probably reflect a sort of instability in opacities due to molecules near the transitions from CS to SC stars (Zijlstra et al. 2004), (3) Mira B's own 14 yr period, discovered by Joy (1954) is still there in ultraviolet data that Joy would surely have rejoiced in (Wood & Karovska 2004), and (4) at opposite ends of the possible time scales, extra periods of more than 400 to 1500 days are fairly common (Wood et al. 2004b), while the transient ones of hours to days reported from *Hipparcos* data seem to have been artefacts of some sort according to Wozniak et al. (2004b). They find at most 0.038 events per star per year in

OGLE data compared to one event per star per year in the initial report (de Laverny et al. 1998). This gives the model of Willson & Struck (2002) the status of a prediction. Since the model invoked a large planet or brown dwarf interacting briefly with the stellar atmosphere, you may refile this item in § 3.2.2 if you wish (or indeed in § 13).

4.13. Fingers on Additional Pulses

The phrase derives from early anesthesiology (Dillon 2004) and is inappropriate as an astronomical analog for at least three reasons: stars are too big to hold in just your left hand; we don't too much care if they stop; and the implied completeness of understanding will elude us. Polaris, notoriously, almost did stop its Cepheid pulsation, though it has since steadied. It brightened about 15% in the process and may now be 2.5 times brighter than it was in Ptolemy's day (Guinan 2004).

No new classes of variables turned up this year to match the γ Dor stars, the pulsating sdBs, and the roAP stars of earlier years, but UY Cam shares some traits with each of: type c RR Lyraes, the dwarf Cepheids, XY Phe stars, and high amplitude δ Scuti stars (Zhou & Liu 2003).

One δ Scuti star, FG Vir, perhaps displays a Blazhko effect, in which one radial and one non-radial mode (out of 23) beat against each other (Breger et al. 2004). Blazhko was thinking of, and indeed observing, RR Lyrae pulsators, and LaCluyze et al. (2004) have reported the fourth star, XZ Cam, in which his period changes. Such changes disfavor mechanisms that depend on rotation period. The amplitude of RR Lyrae itself varies with a 4 yr period, which cannot be an activity cycle (Chadid et al. 2004), another of the candidates for Blazhko and other secondary periods.

Though some snarks are boojums, no γ Dor star is also a δ Scuti star, in spite of their sharing part of the HR diagram (Henry et al. 2004, examining and rejecting some candidates for "both, please").

Ap stars have strong magnetic fields. The subtype called roAp[7] display rapid brightness oscillations. You might, therefore, expect rapid oscillations of the magnetic fields. Leone & Kurtz (2003) and Savanov et al. (2003) reported something of the sort, but Kochukhov et al. (2004) say not for γ Equ, and Hubrig et al. (2004) say no for another six candidates. We think this renders inoperative the mechanism proposed by Saio & Gautschy (2004) that uses a cyclic magnetic field to select certain modes to oscillate by damping others, but won't fight about it if you disagree. The issue has a sort of dog-in-the-nighttime air about it: is the damping of some modes ruled out by the non-detection of others?

The secondary components of some Algol eclipsing binaries pulsate (Lehman & Mkrtichian 2004), which sounds like one of those "done to confuse the enemy" processes.

We love R CrB stars and RV Tauri variables, having written about both many times, and note here that they have more in common than you might suppose in the way of clumpy nonspherical dust shells (Yudin et al. 2003). Photometry from the EROS microlensing search has confirmed the first R CrB in the Small Magellanic Cloud and found four more candidates, two of the DY Per subtype (Tisserand et al. 2004).

"The chromosphere (of R CrB itself) must be crafted by hand" say Pandey et al. (2004b), presumably the hand of a theorist, to match the reality crafted by the star. The infrared environment of RY Sgr looks very much like that of R CrB (de Laverny & Mekarnia 2004). And, as our informant notes, "in the beginning of these image series the observations by Herbig (1969) were." If you are still wearing your Holmes hat (a deerstalker, of course) from the dog incident, you will recognize this as parallel to the construction, "This account of you we have from all quarters received," and discover that Holmes was wrong. It is not *only* the German who is so discourteous to his verbs.

4.14. Lucky Stars and Constellations

If you have the mixed fortune to meet people to whom "stars" mean mostly astrology, you might find it useful to be able to remind them that different cultures have seen very different patterns among the stars, occupying different areas on the sky, even when the objective reality of latitude and phase in the precession cycle was quite similar. Thus Egyptians, more or less contemporaneous and co-latitudinous with the Babylonians who put much of our system into place, recognized a northern hemisphere boat, twin sheep and a sheepfold, two crocodiles, and a very large hippopotamus (Belmonte 2002; Belmonte Aviles 2004), and a couple of dozen other patterns. Our Orion was also the figure of a man (Sah) and their lion (Ma-i roughly) probably our Leo, but most of the others are quite different and many cannot at present be firmly identified with specific stars or groups of stars.

5. SUPERNOVAE AND THEIR REMNANTS

The largest green dot marks the discovery of the first REAL binary pulsar, J0737−3039, that is, two pulsars orbiting each other. One had been previously known. Announcement, basic properties, and initial analysis appear in Lyne et al. (2004), with commentary by van den Heuvel (2004). The rotation periods are 0.023 sec (A, with magnetic field $= 7 \times 10^9$ G) and 2.8 sec (B, with field $= 6 \times 10^{12}$ G). There is a slight eclipse during each 2.4 hour orbit, meaning that sin *i* must be very close to 90°, precise masses determinable, and all sorts of interesting tests of general relativity possible.

Theorists buckled down immediately to predicting geodetic precession and such (Jenet & Ransom 2004; Lorimer 2003; O'Connell 2004). These should be detectable within 15–20 years. Those who remember theoretical response to the 1974 discovery of the first binary pulsar, 1913+16, may agree with our assessment of one change in the intervening decades—the rapid dissemination of information, exchange of e-prints, and

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[7] You see how cleverly we have kept the blue pencil from insisting on RoAp should the class name come at the beginning of a sentence.

all has rapidly choked off the sillier interpretations this time around.

The binary is an X-ray source. McLaughlin et al. (2004) counted 77 *Chandra* photons during one orbit period. Pellizzoni et al. (2004) must have gathered a good many more with *XMM* because they are able to set limits on variability at both the orbit and the rotation periods. The luminosity is 3×10^{30} erg/sec $(d/500)^2$. Scintillation reveals that 0737 is moving through the interstellar plasma at at least 140 km/sec (Ransom et al. 2004). Dewi et al. (2004) suggest that it passed through a mid-life crisis as a Be X-ray binary and experienced a kick velocity (asymmetric supernova event) to produce the present large velocity.

5.1. Supernova Highlights

The last of calendar year 2003 was 20031v (IAUC 8284). This is number 334 for the year, of which the last 100 came in our reference year. Fiscal 2004, in turn, ended with 2004et (IAUC 8413), number 150, and we hope it has remembered to phone home. Lest the counts run off the end of 2005zz, the IAU Supernova Working Group and Central Bureau for Astronomical Telegrams have set up a faint SN Web site for preliminary reports (IAUC 8335). It is http://cfa-www.harvard.edu/iau/CBAT_PSN.html. A subset of worthy events will then receive standard designations. Notable discoveries included:

- One *INTEGRAL* supernova in Abell 2218 (IAUC 8212).
- An assortment of archival discoveries from *HST* (IAUC 8311) and SDSS (IAUC 8218).
- A supernova in the lensed quasar 0957+561 (IAUC 8298).
- The near-synchronicity of SN 20031w with GRB 031203 (IAUC 8308), of which more in § 7.3. Retrospectively named, it became the last event of 2003.
- A supernova in the starburst galaxy M82 (2004am), a combination that ought to be common but isn't obviously so (Mattila et al. 2004).
- A new light echo in SN 2000hh (Barlow et al. 2004), only about the fourth known.
- The *N*th candidate for a supernova with a prediscovery image, 2004dj in NGC 2403. It is an X-ray source (Pooley & Lewin 2004) and a GMRT radio source (Chandra & Ray 2004), and we are not quite sure whether the last word on which of several pre-2004 stars is actually gone has been said (IAUC 8399) but whichever, Sandage (1984) probably imaged it.

Most new supernovae are now picked up by professional automated searches, but a substantial minority continue to come from amateurs. According to Anonymous (2004d), 75 of these are down to one person, Tim Puckett of Mountain Town, Georgia (who, with B. Kerns of Stanton, North Dakota, added to his life record in 2004; IAUC 8214). Anon described this as a personal record, but we can hear the ghostly voice of Fritz Zwicky saying, "In 1924 to 1974 I…"

With all these potential superstars, how could we pick a single green dot? Easy. It is SN 1961V, which was Zwicky's proto-Type V event, downgraded to a luminous blue variable some years ago. It has now (Chu et al. 2004b) been restored to supernova status on the basis of non-thermal radio emission, resembling that of a decades-old supernova. But the LBV is still there. That is, there were two stars involved. Are there any other Type V's? SN 2000ch, say Wagner et al. (2004), in NGC 3432 and probably also an LBV.

5.2. The Events

If you are tired of being told that the mechanism of ejection of Type II (core collapse) supernovae is not well understood and that the progenitors of Type Ia (nuclear explosion) supernovae have not been confidently identified, we would be happy to tell you instead that there are uncertainties in the mechanisms of the Ia's and in the progenitors of the II's. But only an arbitrary one of each of the four puzzles, out of a dozen or so papers on each.

Core collapse events are supposed to occur among massive stars. Most cases where the pre-explosion bit of sky has been imaged must fall at the low end of the expected mass range (Smartt et al. 2004 on 2003gd). SN 1987A at about 22 $M_\odot$ was an exception, and perhaps 1993J from a more indirect argument (Maund et al. 2004).

Incorporation of better physics in the effort to produce shock waves at core bounce that actually get out and look like supernovae continue (Hix et al. 2003, on better calculations of electron capture) but have not solved the problem.

Nuclear explosions appropriate for looking like Type Ia SNe happen when a white dwarf is pushed over the Chandrasekhar mass limit and fuel ignites degenerately. Under discussion are whether initial ignition is central or eccentric and whether the flame propagates sub- or super-sonically. A stalwart of the field has this year voted for off-center ignition almost simultaneously at many points (Woosley et al. 2004a).

What drives the white dwarf mass beyond tolerability and so entitles it to be a progenitor? Accretion obviously, with potential donors including a second white dwarf, a red giant (recurrent novae look like this sometimes), or a main-sequence star (super-soft X-ray binaries look like this sometimes). Yoon & Langer (2003) rate a green comma for concluding that the scenario they explore (via a supersoft phase) cannot be the only channel, since it makes no SNe Ia in stellar populations older than about 10^8 yr. Indeed the thought that one can achieve the same end from a single, intermediate-mass star growing a degenerate core has not vanished completely (Chugai & Yungelson 2004). These hints of diversity would be pleasing if we were recruiting the entering class for a graduate program in supernova hermeneutics, but are less so when one is trying to calibrate a standard candle for cosmological distance measurements (Kasen et al. 2004; Krisciunas et al. 2004; Riess et al. 2004a, 2004b).

Just how many sorts of supernovae are there? At least six if you allow Ia, Ib, Ic, and II with linear and plateau light curves and nebulous (IIn) spectral features, even if you don't admit Type V. It rises to seven including hypernovae or 1998bw-like events (Foley et al. 2003). This begins to be too many for finger counting, but considerations of host galaxies and the distributions of events in them (van den Bergh et al. 2003) can take you back to two—presumably core collapse and nuclear explosion sorts. The pundit who has found a role in early nucleosynthesis for Type I.5 SNe (Zijlstra 2004) is perhaps a fugitive from our AGN section.

5.3. Historical Supernova Remnants

Sometimes this means the event went off since the birth of the first astronomer. (It was Herr C. Magnon who, while looking up at the stars, stubbed his unprotected toe on a rock and promptly hobbled home to invent boots, thereby becoming the world's first stiefelmacher as well as the world's first astronomer.) And sometimes it just means that you are likely to have heard of them before. Ordering them chronologically proved difficult, so the pattern is more like familiar to unfamiliar.

SNR 1006 is more metal rich than the Sun (Dyer et al. 2004), with details from these X-ray data wanted, of course, as ground truth for models of SN nucleosynthesis. Other remnants for which X-ray data are beginning to yield composition information include (1) Kepler = 1604, with extra silicon and iron (Cassam-Chenai et al. 2004) but arranged differently from the heavies in Cas A, (2) Cas A itself, for which a full analysis is under way (Hwang & Laming 2003 on Ti^{44}), (3) the Cygnus Loop, for which data are anyhow consistent with a 16–20 $M_\odot$ progenitor (Leahy 2004), and (4) G292.0+1.8 = PSR J1124−5916, different again from Cas A in having lots of oxygen, neon, magnesium but not silicon or sulfur (Park et al. 2004a).

SN 1181 and 3C 58 really come from two different events say Ivanov et al. (2004), one about 5400 years ago which left the pulsar and a Type Ia event in 1181.

SNR 1572 (Tycho) is hitting a giant molecular cloud (Lee et al. 2004b). Given that it was almost certainly a Type Ia, initial thought is that this must be a chance encounter, but Ruiz-Lapuente (2004) report that the best fit to the light curve implies $E(B-V) = 0.6$, and a dusty, moleculey part of space.

The Crab Nebula light has been fading at 0.5%–1.0% per year for decades (Smith 2003). Thus it could have been a good deal brighter in 1758, looking thereby to Messier that much more like something to steer clear of. The radio is also fading, at about 0.17%/yr, though it was a calibration source for the early years of radio astronomy. Our other Crab dot paper of the year is the suggestion that its pulsar, and the Vela one, may have accretion disks that collimate their jets and distort the pulsar slow-down, so that $P/2\dot{P}$ is not quite the real age and $n = P\,\ddot{P}/(\dot{P})^2$ is not quite three (Blackman & Perna 2004). The general structure of the filamentary envelop has not changed much from 1966–68, when the Crabier author measured it (Trimble 1968), down to the present (Cadez et al. 2004). And if someone offers you green Crabs for dinner, decline politely.

The morphology of the remnant of SN 1987A, on the other hand, is changing rapidly because the ejecta are now encountering and lighting up the innermost ring of pre-supernova stuff around it (Park et al. 2004b). The expansion rate continues to be about 4200 km/sec and there is no core X-ray source brighter than 1.5×10^{34} erg/sec. Efforts are still being made to account for two neutrino bursts (Imshennik & Ryazhskaya 2004) and to connect the event with merger of a binary white dwarf (Middleditch 2004) and the formation of a 2.14 msec pulsar reported there some years ago.

A compact radio core has appeared in 1986J, representing presumably a young pulsar or accretion on a black hole (Bietenholz et al. 2004). On the other hand 1993J still has no such core (Bietenholz et al. 2003).

G347.3−0.5 is said to be one of the three known X-ray synchrotron SNRs in the Milky Way, but its EGRET and TeV emission are not particularly well fit by any of the obvious models (Lazendic et al. 2004).

HMXRB Cir X-1 at age 4000 years or so has a radio nebula around it (Clarkson et al. 2004). Its X-ray counterpart should be below current detectability. Notice that "current" implies that observing facilities will improve faster than the remnant fades.

How many pulsars live in supernova remnants, or conversely? Yes, once there were two, belonging to the Crab Nebula and Vela, but it is now "many" and we mention PSR J1357−642 = SNR G309.8−2.6 (Camilo et al. 2004) and PSR B1757−24 = SNR G3.4−1.2 (Gvaramadze 2004) not because they bring the total to an even 13 or whatever but because the authors are frank enough to leave questions marks attached to the identifications.

5.4. Pulsars and Other Single Neutron Stars

Logically single black holes left by supernova collapses belong here too, but we didn't see any this year, nor, apparently, did anyone else. Mind you, a subset of astronomers will say that no one saw any neutron stars either, because hyperon stars (Yakovlev et al. 2004), quark stars (Xu 2003, Ouyed et al. 2004), or stars made of dark matter particles (Yuan et al. 2004) are a better bet. The last is really a black hole alternative, since 10 $M_\odot$ is possible, but the objects can produce Type I X-ray bursts.

Voting unimaginatively with the majority, however, we chose a neutron star paper for the coveted green dot. McLaughlin & Cordes (2003) point out that giant radio pulses like those coming from NP 0532 could be seen from any pulsar in the Local Group that happens to be aimed at us. Much patience will, however, be required, and they report only upper limits. Meanwhile, the number of Galactic giant pulsers this year reached the foot-baring number, six (Kuzmin et al. 2004). And an assortment of familiar pulsar-related issues were hung out to dry again this year, though we fear it will all need to be done again next year.

Glitches. The Crab twin 0537−69 has so many that no one will ever be able to measure its second time derivative (Marshall et al. 2004). The Crab and Vela pulsars both glitch, and (contrary to most other years) the Crab ones could be star quakes (as they were in our less late youth 35 years ago) but Vela must be vortex unpinning (Crawford & Demianski 2003). You may, however, want to put into the next file the second glitch of the anomalous X-ray pulsar 1RX5 J170849.0−4000910 (Kaspi & Gavriil 2003), which has been described as Vela-like but explicable as a star quake (Dall'Osso et al. 2003).

Anomalous X-ray pulsars and soft gamma repeaters are at least partially overlapping classes (Gavriil et al. 2004), though their optical and infrared properties would seem to be rather different (Israel et al. 2004; Klose et al. 2004). In any case, the transient nature of many of their properties indicates that the present inventory is an iceberg tip (Woods et al. 2004a). We are happy to endorse very large magnetic fields as responsible for the combination of large luminosity and slow rotation for both classes, but the residual disk (Eksi & Alpar 2003) and subsonic propeller (Ikhsanov & Choi 2004) alternatives are still in the fray.

Magnetic field topology and evolution. There has been a ground swell of support for the idea that localized fields on pulsars (which govern resonant frequencies and polarization) can be larger than the dipole (which governs slow-down) by a factor up to 100 (Bonanno et al. 2003; Cheng & Taam 2003; Geppert et al. 2003; Urpin & Gil 2004; Ord et al. 2004). Some of the pulsars considered in those papers are millisecond (old) ones, so the more dissipative author's guess that small scale fields should Ohmically decay away first (Cumming et al. 2004) is clearly wrong. Indeed Rheinhardt et al. (2004) say specifically that Hall drift turns a dipole field into smaller scales.

It is useful to have a range of fields in the toolkit, since different ways of measuring for a particular pulsar don't always give the same answer. X-ray (but real, rotation-powered) pulsar 1E 1107.4−5209 displays 0.7–2.8 keV spectral features implying $B = 8 \times 10^{10}$ G (for electron cyclotron) or 1.6×10^{14} G (for proton cyclotron) field, but the slowing-down value is 2.6×10^{12} G. You get two choices: small field and slowing down accelerated by a surrounding disk, or large field hindered in its work by not being a dipole (DeLuca et al. 2004; Blackman & Perna 2004; Michel & Dessler 1981; Malov 2004).

"Everything faint" neutron stars. Isolated X-ray emitters are rarer than early estimates by factors of 10^2–10^3 (Rutledge et al. 2003; van Kerkwijk et al. 2004), partly because they tear through the ISM too fast to accrete much and perhaps also because they cool faster than initial estimates (Gusakov et al. 2004, who favor Cooper pair neutrino emission, though there are at least three other possibilities). There are also radio-faint pulsars (Halpern et al. 2004, on the non-detection of the X-ray core of SNR CTA1). The limit is 0.02 mJy/kpc^2, and only Geminga is fainter, though they have additional runners-up. B0956+08 is the optically faintest pulsar at $V = 27.05$ (Zharikov et al. 2004) and with $P/2\dot{P} = 17.3$ Myr arguably also the oldest and most feeble in total spin-down flux ($\log E = 32.75$, not much more than a microCrab). And we would like to posit a class of pulsars that are totally invisible at all electromagnetic wavelengths and can be detected only through their URCA neutrino emission and gravitational radiation. Oh, and they must be extragalactic or the MACHO people would have found them. Narayan & Heyl (2003) is an anti-URCA paper, but a good entre to the topic. Outdoing our "both, please" cliche, Yakovlev & Pethick (2004) conclude that some neutron star cooling is too fast, some too slow, and some just right, requiring several different cooling processes, the dominant one depending on the mass and age of the star.

More? More pulsars are to be had (Hobbs et al. 2004) from the venerable 65-m dish at Parkes (Australia). The latest 180 include the third shortest rotation period (1.8 msec), the longest orbit period (40 days), and a fine range of other characteristics. More ideas are to be had from a trio of short reviews (Lattimer & Prakash 2004; Manchester 2004; Stairs 2004).

5.5. Neutron Stars and Black Holes in Binary Systems

We précised 70 papers on these in 2004, and no, that doesn't (quite) exceed the number of sources. The accreting millisecond pulsars, which rose in number from zero to four a few years ago are now five (Rappaport et al. 2004a). We are therefore happy to report that they can be produced in a scenario that resembles the one in which cataclysmic variables reach a minimum period and climb back up (Rappaport et al. 2004). In turn, they should become real (rotation-powered) millisecond pulsars (Kirsch et al. 2004). This probably won't do much to alleviate the old-enough-to-drive discrepancy that the msec pulsars are too numerous for their proposed predecessors, the LMXRBs (Kulkarni & Narayan 1988), but every little bit helps. Pfahl et al. (2003) explore an assortment of helpful other lifetime adjustors; Lavagetto et al. (2004) make things worse by losing a bunch of LMXRBs to accretion-induced core collapse, presumably making black holes.

In addition, here are updates on a few other traditional topics.

Black hole properties. The numbers of numbers now reported are large enough to say that they are not all the same. The error bars on $M = 4 \pm 1\ M_\odot$ for GRO J0472+32 (Gelino & Harrison 2003) and $14 \pm 4\ M_\odot$ for GRS 1915+105 (Harlaftis & Greiner 2004) probably do not overlap. Postnov & Cherepaschuk (2003) suggest that the range from 4 to 15 $M_\odot$ is uniformly populated in the Milky Way, but with selection effects favoring the discovery of the most massive ones with the largest Eddington luminosities. Apparently there is also a real range of specific angular momenta. A guess based on very limited data might be for bimodality rather than a flat distribution, with the peaks centered at $a/M = 0.3$ and 0.9 in suitable dimensionless units (Schnittman & Bertschinger 2004; Miller et al. 2004; Aoki et al. 2004). Recall that $a/M = 1$ yields a naked singularity and is not expected to occur; $a/M = 0$ is a

Schwarzschild black hole. Neutron stars, in contrast, differ by less than a factor of two in mass, for the XRBs as well as binary pulsars (Abubekerov et al. 2004). This is not profound; the minimum is set by what sort of core will collapse (roughly the Chandrasekhar limit) and the maximum by the corresponding limit for degenerate material with a somewhat different, hadronic, equation of state.

Nuclear flashes. Superoutbursts due to degenerate carbon ignition on the surfaces of accreting neutron stars were new in the last ApXX or two and appear to have survived the election year (Cumming 2003; in't Zand et al. 2004; the 8th event on the 7th source). And for an authoritative view of the roles of hydrogen, helium, and carbon in various zones of various bursts, see Woosley et al. (2004b).

Commonalities between neutron star and black hole X-ray binaries. Both display quasi-periodic oscillations, with some similar behavior (Kluzniak et al. 2004; Nespoli et al. 2003) and some similar underlying physics, for instance Rayleigh-Taylor and Kelvin-Helmholtz instabilities (Li & Narayan 2004). We had tagged the superluminal motion of the radio jet in the high mass, neutron star XRB Cir X-1 as another example (Fender et al. 2004, with apparent v at least $15c$), because only black hole (microquasar) systems were supposed to do this. And then one of the first two microquasars, GRS 1915+105, dropped down to $v = 0.7c$ apparent speed (Kaiser et al. 2004), based on a new, smaller distance estimate. Apparently, then, both neutron stars and black holes can drive either sub- or super-luminal jets.

Other wavelengths. Radio emission from low-mass X-ray binaries was a rarity in the days of one X-ray source per constellation (Kato et al. 2004b, a model for radio flares from the core plus one-sided jet source Sco X-1). Migliari et al. (2004) have added a couple to the inventory and say that LMXRB radio jets are fairly common. Cygnus X-1, the prototypical BHXRB, has averaged about one gamma-ray flare per year (Golenetskii et al. 2003), and the less bright author may well be the last person to have noticed that the fluxes, up to 3×10^{-7} erg/cm^2-sec, are comparable with those from ordinary gamma-ray bursts. But the Cyg X-1 events last a lot longer, up to 8 hours, so the total fluence can be very large. Cyg X-1 is, of course, a black hole that has been around for a long time, in contrast to GRBs (§ 7.3), generally modeled as black holes in formation. Some remark along the lines that, once you have one, you can do a lot with it would probably be out of line.

5.6. Ultra-Luminous X-Ray Sources

These are the ones that, though not at galactic centers, are bright enough that, if limited by the Eddington luminosity, they must center on black holes of 20 up to perhaps 1000 $M_\odot$. Some of the fainter ones are almost certainly vigorous BHXRBs (Irwin et al. 2004), the others perhaps not. As frequently seems to be the case in such matters, one has (at least) two choices. Either the radiation, and probably the accretion, are not symmetric, and we get more than our fair share from some sources and less from others, or there are some mighty massive black holes out there.

In the asymmetric camp, Lee & Brown (2004) suggest that something like GRS 1915+105 seen end on would do very nicely, and Ebisawa et al. (2003b) endorse accretion onto a black hole of 10–30 $M_\odot$ with radiation coming out top and bottom, rather like one of the possibilities for forming massive stars by accretion rather than coalescence (§ 6.6).

In the big black hole camp[8] you will find two groups with processes for making them during the formation and evolution of very large star clusters. Gurkan et al. (2004) favor direct core collapse, and provide a charming flow chart of the multiple paths that will eventually get you to a central black hole. It resembles earlier ones for active galactic nuclei, or the design study for a very complicated drug trial. Portegies Zwart et al. (2004a), on the other hand, find that massive stars gather in the cluster core (because of dynamical friction) to make a star of a thousand or more solar masses, which then leaves, for instance, a 350 $M_\odot$ black hole. How do you feed such an enormous hungry mouth? Perhaps by Roche lobe overflow from a tidally captured star, says Hopman (2004).

Another 25 papers in the academic year divided about equally between "asymmetric" and "really big." There are data favoring each. ULXs trace the spiral arms of M51 (Terashima & Wilson 2004, connecting them with recent formation of massive stars, while the ULX in Holmberg II has symmetric emission line gas around it, implying isotropic emission (Kaaret 2004). And our vote? All together now, "both of the above."

If redshift is not a distance indicator, then there are all sorts of other possibilities (Arp et al. 2004). Our quarrel with the authors of this paper is not about the content (given their postulates, their conclusions follow, as is the case for the very different postulates of the conventional wisdom), but with their complaint that they were not awarded observing time with the *Chandra* X-ray satellite to examine their sources and galaxies more carefully. If at first you don't succeed try, try again, and the more persistent author needed four *Chandra* proposals to work up to Garrison Keillor ("pretty good") status and hopes of some photons in the New Year. As long as the satellite is alive and well, the most anyone can say is that she plans to put in a better proposal next year.

6. MOVING GROUPS, APOLOGIES, AND OTHER ISSUES IN STELLAR DYNAMICS

"Olin J. Eggen was right," we squirmed in reaction to the green dot paper on this topic. Some moving groups are co-eval and chemically homogenous, and all the stars are in more or less the same part of the sky and at the same distance, as well

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[8] Where the big black bug bled bad blood. This is the one traditional tongue twister the chattier author has never been able to master. She would be pleased to trade hints with anyone wanting to overcome rubber baby buggy bumpers, the selling of sea shells, and so forth.

as moving together. These were always easy to understand as open clusters and associations in the process of dissolution. But some of the groups proposed by Eggen (1998, the last of a long series) consisted of stars sharing neither age nor composition and were strung out over considerable volumes, despite the shared motions of the stars. Two things have happened. First, Navarro et al. (2004a) have pointed out that one of the groups (of which Arcturus is a member) is likely to be the detritus of a captured, disrupted satellite galaxy. And dwarf spheroidals can have a good deal of range in their stellar ages and metallicities, though this one did not. Good answer, We like it. Let's go on to binary stars, clusters, or something.

Not quite yet, because also in the fiscal year De Simone et al. (2004) have figured out a way to assemble previously existing stars with a range of ages and compositions into a moving group via strong, transient spiral potentials. They credit the general idea of spiral pattern heating of stellar velocity dispersions to Barbanis & Woltjer (1967) and cite also Karl Schwarzschild and Jacobus Kapteyn. This discussion does not have, perhaps, quite the compulsive persuasiveness of the captured satellite mechanism, but if the opportunity should ever arise, we will gladly apologize to Olin on both sets of grounds.

6.1. Binary Stars

Even for folk who love binaries less obsessively than we do, there are bound to be two sorts of topics—dynamical (like formation and circularization) and astrophysical (like activity in cataclysmic variables). You are getting some of each, in that order.

6.1.1. Dynamics of Star Pairs

The words most associated with binary and multiple formation this year were fragmentation (Matsumoto & Hanaw 2003 with six kinds; Sterzik et al. 2003, making only wide pairs) and turbulence (Goodwin et al. 2004a, creating a subpopulation of close systems with mass ratios near 1; Goodwin et al. 2004b, producing 80% multiple systems, the smallest member of which typically departs, leaving binaries). Departure of the smallest members is emphasized also by Delgado-Donate et al. (2004b), who find that they under-produce both small total masses and small mass ratios. And we also will depart, with final glances at two more ideas. First, angular momenta of the product systems come from angular momentum induced by turbulence in the parent molecular clouds (Fisher 2004, whose population peaks at orbit periods of 10^4–10^5 days but extends from 10 to 10^{10}. And, second, although computations have improved in very many ways since a rotating fluid spheroid first fissioned, it remains true that what you get out depends very heavily on what you put in (Machide et al. 2004).

After formation comes circularization, for which the evidence is that the smallest non-circular orbits extend to larger semi-major axes (longer periods) in older stellar populations (Matheiu et al. 2004). The circularization tides seem to have fallen down on their duties in the case of 10 eclipsing binaries with $e > 0.4$ investigated by Wolf et al. (2004). The very largest eccentricity (0.9754) known for a spectroscopic binary, 41 Dra, is probably not long for this world. Tokovinin et al. (2003) point out that the F dwarf components have very shallow convection zones, but as the stars leave the main sequence, convection should deepen and circularization set in. We can't wait.

Synchronization means that rotation and orbit periods should be the same for close systems. The one paper we caught also reported a failure (on the part of the stars, not the observers; Homer et al. 2004). Dwarf nova V426 Oph has an orbit period of 6.85 hours and a second stable $P = 4.2$ hour period, surely the rotation of one star or the other. Both would be even odder.

Other dynamical processes to which binaries are heir are apsidal motions and period changes. On the former and its dependence on stellar rotation, we found no surprises in Claret & Willems (2003) except their gracious citing of Cowling (1938). Period changes are often attributed to third stars in long-period orbits. None seem to have been this year, but the other two mechanisms, mass transfer for secular changes and stellar activity for periodic ones, were both out in full force. Yang & Lu (2003) invoked both for RZ Tau. Baptista et al. (2003) advocated activity cycles in secondary components of dwarf novae, even the fully convective ones. And Zhang & Zhang (2004) described a secular period increase in the W UMa star V523 Cen, based on data covering 43,000 cycles (but no, they didn't see them all).

6.1.2. Statistics of Binaries

What then, are the properties (separations, masses, mass ratios, eccentricities, and all as a function of age, metallicity, or whatever) of the real binaries in the Milky Way? As the less selected author learned (the hard way) some years ago, what you find will be dominated by the sample you choose and whether it includes the fish you think you are trolling for.

In this context, the first application of another search technique is to be applauded. Pourbaix et al. (2004) have succeeded in identifying 346 unresolved binaries in SDSS from the fact that their positions are slightly different in different colors. The idea comes from Christy (1983) and the method should be good for filling in the gap between visual and spectroscopic binaries. Is there such a gap? Yes, though a few are both. The smallest so far resolved has $a = 1.2$ milliarcsec (Konacki & Lane 2004). The length of the longest well established orbit periods, near 1000 yr, is also a selection effect on the number of generations of astronomers since photography was applied to astrometry (Ling 2004).

What comparisons can be made between the ideas of the previous section and available data? The models seem to predict that very young populations will have more binaries, especially wide binaries, than older star groups. True perhaps for the young open cluster IC 1805 (Rauw & De Becker 2004), but apparently not true for the very young group embedded in NGC

2024 compared with field stars (Liu et al. 2003). Well, Melo (2003) had been trying to tell us that not all young populations are the same anyhow. Zapatero Osorio & Martin (2004) report that 15% of T Tauri stars, field Population I, and old Population II stars are binaries with separations of 32–57,000 AU.

What about the distributions of those separations? Peaked at 1 AU in an OGLE sample (Jaroszynski et al. 2004), which also picks out mass ratios near 1. Declining as $a^{-8/5}$ for common proper motion (wide) pairs from the Luyten catalog (Chaname & Gould 2004).

Distributions of mass ratios are probably even more heavily controlled by selection than period distributions and total numbers. Applause, therefore, for the use of lunar occultations, which can reach down to separations of $0''.01$ and brightness ratios of 10 or more, though this is still only a factor 2–2.5 in mass (Fors et al. 2004). Oh well. If Nature had wanted us to see faint stars, she would have given us airline tickets. Oops. Wrong joke. Bigger telescopes.

What do we know about binary populations in other galaxies? Rather little, apart from the occurrence of novae and such. But Norman et al. (2004) suggest that one might estimate the rate of binary formation for whole galaxies from their X-ray luminosities when that luminosity is dominated by the integrated emission of X-ray binaries. Another green dot paper, if there is some independent way to decide whether the X-ray luminosity really is coming mostly from XRBs.

6.1.3. Types and Prototypes

The quintessential process is, of course, mass transfer by winds or Roche lobe overflow. The green-dotted paper of the year reports that the transition between the two forms occurs when the wind velocity at the Roche surface of the donor reaches 0.4–0.7 times $a\omega$ (where a = semi-major axis and ω = angular frequency in the orbit); so say Nagae et al. (2004). And with that simple start, you can not only overcome the Algol paradox (Struve 1948; Budding et al. 2004) but also account for enough additional other named categories to require the fingers of a centipede for enumeration. The subset mentioned here focus on cases where part of the answer is “both of the above.”

- Barium stars, for which the two possibilities are upward mixing of *s*-process products of the polluted star itself and mass transfer from a self-polluted companion (Antipova et al. 2003).
- Am binaries, whose surface abundances reflect diffusion rather than nuclear fusion (Budaj & Iliev 2003).
- sdB stars can arise from common envelope binary ejection as well as from white dwarf mergers (Ahmad et al. 2004), but, curiously, about half are still binaries (Reed & Stiening 2004).
- Blue stragglers must also be multi-causal, because there are two populations, one living preferentially in the dense centers of globular clusters and the other preferring the suburbs or even the field (Davies et al. 2004; Mapelli et al. 2004; Ferraro et al. 2004; Piotto et al. 2004). And yes, three and four star processes can produce blue stragglers with more than twice the mass of the main-sequence turnoff of the parent population, but this requires a very dense environment (Fregeau et al. 2004) and has been happening at least since the time of Ap93.
- W Ursae Majoris stars may well be on one of the paths that lead to blue stragglers, again in globular clusters (Tutokov et al. 2004). The classic W UMa question, however, is how they manage to spend large parts of their lives with two stars of different masses but very nearly equal surface temperatures. Kahler (2004) says it is done by a flow from the more massive star to the little one in their upper atmospheres and M_2 returning the favor deeper down, thereby flattening the expected temperature gradients. It can happen that both stars are spotted (Barnes et al. 2004a) though we don’t think the spots are carried back and forth. And the stars can share a common or mutual chromosphere (Gurzadyan 2003).
- Cataclysmic variables were the subject of 102 memorable 2004 papers (if you allow the more cataclysmic author to include notebooks as part of her memory), but you are going to be fobbed off with ONE nice review (Warner 2004); TWO helium novae (meaning that it is helium that ignites at degenerate density and explodes, Ashok & Banerjee 2003; Kato & Hachisu 2003); the discovery of a THIRD type of oscillation in dwarf novae, with longer periods than the two previous sorts and correlations with the shorter period ones of the same form as the correlations of high and low frequency QPOs in low mass X-ray binaries, though the frequencies are obviously all much lower (Warner et al. 2003); FOUR novae per year per $10^{10}\,L_\odot$ in the K band as a likely rate for spirals (Neill & Shara 2004; Nelson et al. 2004); and MV Lyr, a nova-like variable (Hoard et al. 2004) caught in one of its sporadic low states because, say Honeycutt & Kafka (2004), a dark spot on the donor has moved under the first Lagrangian point, L_1, reducing the mass transfer rate, or, they say, FIVE other possible explanations.
- And yet another example of “both, please.” In recent years, outbursts of dwarf novae have been the result of instabilities in the accretion disk around the white dwarf (Schreiber et al. 2003), but this may have been only because the opposition was otherwise occupied, and we are pleased to report that, after a long career with a “day job,” Bath (2004) is back with his instability in the donor star, complete with a photograph of the process at work. It uses a bucket of water with a syphon and so forth. The outburst itself, by irradiating the donor star, temporarily increases gas loss from it by a factor of 10 or more (Smak 2004).

6.2. $N = 4$ to 6

More than a binary, but less than a cluster, Are there any interesting cases? At least a few. The Trapezium is probably still being assembled and so may not have had a chance to notice its own instability (Lada et al. 2004a). If a theorist starts with six stars, the most likely outcome is a hierarchical triple or very eccentric binary, with the others departing at a few to 30 km/sec (Rubinov 2004). This might cast some light on PV

Cep, which appears to have left NGC 7023 about 10^5 yr ago, travelling at 20 km/sec, and is now passing through a molecular cloud, which would otherwise not be expected to house high velocity stars (White 2003). You may be reminded of the Pleiades and their non-matching surroundings. We filed PV Cep under "jog-away stars" for its relatively small speed. The commoner term is run-away stars, with a classic complex example consisting of AE Aur, μ Col, and ι Ori (Gualandris et al. 2004), and general idea going back to Poveda et al. (1967).

6.3. Open Clusters (of Stars)

As in the case of binaries, the dynamical outline says, "form, preserve, and use or lose." The green dot went to a truly spectacular young cluster, W3 in NGC 7252, with $M_V = -16.23$ and a virial mass near $8 \times 10^7\ M_\odot$ (Maraston et al. 2004). Surely, you are saying, this one cannot possibly fall apart. Perhaps not, but its authors indicate that a compact dwarf galaxy is a more likely outcome than a big globular cluster, which, we suppose, is another way of losing things.

At the $t = 0$ of formation, what you put into your *N*-body calculation has a good deal to do with what will come out (Goodwin & Whitworth 2004, who include substructure in their initial conditions to match the Taurus region, which they conclude will end up as 2–3 separate clusters). Another way to get binary clusters (rare in the Milky Way, but common in the Magellanic Clouds, for instance) is to invite two clouds to collide with largish impact parameter (Bekki et al. 2004a).

Open clusters cannot be counted on to outlive the inhabitants of their planets. The oldest in our disk (e.g., Be 17 and NGC 6791) are at least middle aged in Galactic Rotation years (50, say, Salaris 2004a), but most do not make it past 10^8–10^9 yr (Portegies Zwart et al. 2004b, a calculation including CBS mergers and all).

Krienke & Hodge (2004) provide counts of open clusters in large and small galaxies. The small ones are less hostile, with typical survival times of 2×10^9 yr vs. 2×10^8. Far out in the Milky Way is, not unexpectedly, also less dangerous, and the farest-out cluster at 19.3 kpc is about 5 Gyr old (Carraro & Baume 2003). Some other old livers are also outside the solar circle (Hasegawa et al. 2004).

A case has been made for an unidentified TeV gamma-ray source being part of the Cyg OB2 association (Butt et al. 2003). No rational objection, but two things in that part of the sky, the radio galaxy Cygnus A and the X-ray binary Cygnus X-3, have been claimed in the past as strong gamma-ray sources and were not.

If you would like to get started in open cluster research, Mermilliod & Paunzen (2003) will introduce you to 469,820 stars in 573 clusters.

6.4. Globular Clusters (of Stars)

These touch on interesting bits of dynamics at three fronts—their own formation, evolution, and dissolution; the processes involving binary stars within them; and their role as a probe of the extent to which the current galaxy population was assembled by mergers of an earlier, gassier, population of less massive protogalaxies. (Other aspects of galaxy formation appear in the lima bean section.) The three issues are not completely separable because dynamical evolution of the cluster as a whole depends on what the binaries do, and their use as tracers depends on the extent to which mergers make new clusters.

Let us then start in the middle, with the binaries, which will seem odd only for those old enough to remember when it was generally accepted that there were none among Population II stars. In fact, not only are there the blue stragglers of § 6.1.3 but also (*a*) W UMas that might or might not give rise to them (Pietrukowicz & Kaluzny 2004), (*b*) an assortment of binary pulsars (Possenti et al. 2003; McConnell et al. 2004), including the most eccentric orbit ($e = 0.89$) to date, found in NGC 1851 (Friere et al. 2004) and one engaged in photoevaporating its companion (King et al. 2003, a companion acquired through star exchange, and pretty poor hospitality we call it), and (*c*) a full range of active sorts, picked out initially by their X-ray emission, including BY Dra stars, RS CVn stars, and cataclysmic variables and super-softs (Heinke et al. 2003; Edmonds et al. 2003; Bassa et al. 2004; Edmonds et al. 2004; Webb et al. 2004), not to mention the traditional sorts of X-ray binaries with neutron star receivers (Sarazin et al. 2003).

And a last word on cataclysmic variables. The second nova ever in a globular cluster; and Shara et al. (2004) had to go all the way to M31 to see it (well, not literally). The first was T Sco in 1860, reported by N. R. Pogson of the magnitude system and G. F. Auwers, who owned the best-available angular diameter for the Sun at about the same time (he must have worked very long days). T Sco has, just possibly, been recovered, as an X-ray source (Heinke et al. 2003).

Close binaries in globular clusters, in addition to changing partners in reckless fashion, can destroy some of the largest, coolest red giants, in which the clusters are notoriously deficient. Other processes help (Adams et al. 2004; Beer & Davies 2004).

Pairs of clusters merge (Rey et al. 2004; Hughes et al. 2004). Minniti et al. (2004) have caught a young pair in flagrante in NGC 5128 and expect the product eventually to resemble ω Cen, which has otherwise spent the year in great uncertainty about whether it is merely a rather unusual sort of globular cluster (Law et al. 2003), the nucleus of a tidally stripped dwarf spheroidal galaxy afflicted with later star bursts (Bekki & Freeman 2004), or the stripped remnant of some slightly different sort of galaxy model, given that the names involved are Hernquist and King, rather than, say, Leo I and NGC 6822 (Tsuchiya et al. 2004b). While ω Cen has been hovering, star clusters have gotten bigger and galaxies have gotten smaller (Martin & Ho 2004; Maraston et al. 2004; Bekki et al. 2004b), and we ourselves have expanded and contracted opinions on whether the two classes are really distinct (Bekki & Chiba 2004).

Globular clusters can be stolen by other galaxies (Bekki et al. 2003). This doesn't happen to open clusters if only because they are too fragile to survive the process. Globulars are also less likely to be eaten, Saturn-and-Jupiter-like, by their parent galaxies. Pal 5 has, however, already lost more stars in its tidal tail than remain in the cluster and will be gone in 10^8 yr, after one more disk crossing (Odenkirchen et al. 2003; Dehnen et al. 2004). Pally, we hardly knew ye.

And, finally, the formation/tracer function of globular clusters. The key point, as a fellow student said long ago, is that "they aren't making them any more, at least in our Galaxy." Suppose, then, that one aspires to create an elliptical galaxy by the merger of two or more disk galaxies (Hernandez & Lee 2004; Bournaud et al. 2004; Conselice et al. 2003—an arbitrary paper each from the three largest journals that address such matters, out of a dozen or more in each). One of the questions you can ask, for instance, in a first year graduate course, is whether the specific frequency of globulars, which is larger in giant Es than in Ss, will come out right, provided you wait until any new burst of star formation has had time to die down.

One answer is yes, for all but the largest, most cluster-rich ellipticals (Rhode & Zepf 2003). Ah, but what if the merger process itself makes additional, new globulars? There is observational evidence that this happened in the Milky Way (Van Dalfsen & Harris 2004) and in other galaxies (Strader et al. 2004, on the two populations in NGC 3610), and that it is happening right before our very eyes (well, telescopes) now (Pasquali et al. 2003 on NGC 6240). More massive, gas-rich mergers make the biggest clusters, and Schweizer et al. (2004, on NGC 3921) conclude that the new ones will be more metal rich than the legacies.

A green dot to Wilson et al. (2003) for the strange conclusion that NGC 4038/39 (the classic Toomre^2 merger pair) has made so many new clusters in the last 160 Myr that lots must die soon or the specific frequency of globulars in the product galaxy will be too large for a typical elliptical!

6.5. Nuclear Star Clusters

The general idea is that gas sometimes accumulates at galactic centers and makes some large number of massive stars in a fairly small volume. The Milky Way is an example (Figer et al. 2004a) as is M33 (Milosavljevic 2004). Boker et al. (2004) have found an additional 39 spirals with nuclear star clusters and Bendo & Joseph (2004) a bunch without. Milosavljevic & Loeb (2004) suggest that the actual mechanism is fragmentation in a gas disk (like that of NGC 4258) around a central black hole.

6.6. Formation of Massive Stars

All of star formation is obviously in some sense a dynamical issue, but this section looks only at the specific question of whether the largest stars can form by accretion (like smaller ones) in spite of luminosities approaching or exceeding the Eddington limit for their instantaneous masses. The alternative is that small stars must merge to produce the largest ones. There are at least three schools of thought: accretion all the way, accretion but it needs some help, and coalescence of smaller stars essential.

Accretion is fine, say Beuther & Schilke (2004), who have mapped dust at high angular resolution. Additional observational support comes from Beuther et al. (2004), Forbrich et al. (2004), Shepherd et al. (2004), and Chini et al. (2004), reporting a number of cores of more than 10 $M_\odot$ and lots of material still around in forms suitable for continued accretion. Keto (2003) predicts that the prolonged accretion needed to make the largest masses will leave the product trapped for a while in a hypercompact H II region, and Rigby & Rieke (2004) suggest such trapping as the reason that no stars of more than about 40 $M_\odot$ are seen in starbursts at large redshift.

Yes, accretion works, but it needs a favorable environment, provided by shocks (Zurita et al. 2004), by triggering (Jiang et al. 2004), and especially by non-spherical accretion. Beltran et al. (2004) report on massive accretion disks belonging to four massive YSOs. Su et al. (2004) consider YSOs of 10–100 $M_\odot$ with simultaneous continued accretion and outflow.

And so onward to the firms no's from Edgar & Clarke (2004) and Bonnell et al. (2004), who say that radiation pressure on dust grains stops accretion at about 10 $M_\odot$ and stars must therefore coalesce or capture some combination of smaller stars and nearby gas to grow further.

Perhaps the right answer is that not only are not all observed star formation regions alike, not all model star formation regions are alike.

The two green dotted papers of the year might be labeled "earlier than you think" and "later than you think." First, angular momentum is removed from molecular clouds well before star formation begins, presumably by magnetic braking, Thus clouds seen in M33 have less than 10% of what would be expected from galactic rotation alone (Rosolowsky et al. 2003). Second, full convection is established only slowly. Whether you think in terms of a mixing length approximation or a full spectrum of turbulence, it must be much less efficient in pre-main-sequence stars than in the Sun (Montalban et al. 2004), or young stellar objects will not follow the Hayashi tracks we all know and love.

You may well feel that star formation is too important to be dismissed so summarily. Well, with remarkable foresight, the more decommissioned author ended her tenure as astrophysics editor of *Reviews of Modern Physics* by commissioning a fine review of the topic (Mac Low & Klessen 2004).

7. FIRST LIGHTS, REIONIZATION, GRBs, AGNs, AND BLACK HOLES IN BULGES

In the beginning, about $z = 666$, the baryons were without form and void, and darkness was upon the face of the baryons (unless you had 2-micron eyes). And the Astronomer Royal[9] said, “Let there be ultraviolet.” And his graduate students and postdocs made the first stars, and there was ultraviolet. But being industrious young persons, they also made accreting black holes (active galactic nuclei), gamma-ray bursts, shock waves, and intermediate mass black holes, all of which are also potential sources of UV photons, the sort you want for ionizing hydrogen. Indeed so industrious have the students and postdocs been that all space is now pervaded by about $10^8\ L_\odot/\mathrm{Mpc}^3$. At present, most of the visible light and infrared come from stars in normal and star forming galaxies, but most of the ultraviolet since $z \approx 1$ has come from AGNs (Malkan et al. 2003). They did not have to make decaying dark matter as another possible photon source because the AR’s teacher had already done that (Sciama 1993).

The question of just what the first lights were and how ionization spread from them is important in bridging the gap between the universe at $z = 1000$ (mapped onto the cosmic microwave patterns in the sky) and $z = 6.5$ (the most distant galaxies and QSOs so far seen).

7.1. The Conventional Wisdom

Triumphs of the last few years have included (*a*) detection of widespread (Gunn-Peterson) absorption of Lyα by neutral hydrogen at redshifts a bit larger than 6, meaning that reionization of the general intergalactic baryon supply was not complete until then, (*b*) detection of the same completion of ionization of He II to He III at $z = 2$–3, and (*c*) the first-year *WMAP* measurement of the optical depth of the universe to electron scattering as $\tau = 0.17$. To get this much, reionization must have started quite early, by $z = 15$–20, and a significant subset of theorists have hoped that might shrink a bit when additional data have been analyzed.

Just how and when and where did the essential ionizing (UV and perhaps soft X-rays) radiation come into being? Direct detection of sources helps very little. The most distant galaxies (Rhoads et al. 2004) and QSOs (Richards et al. 2004) hover near $z = 6.5$, and the most distant GRB near $z = 4$, and will continue to do so, absent a lucky, early-emptied sight line, though hints of a $z = 10$ galaxy (Pello et al. 2004) and GRBs in the same range (Yonetoku et al. 2004) appeared.

Despite this, there has been a certain shake-down of papers, opinions, and theorists (who sometimes object to being shaken) around the idea that Population III stars (zero metallicity) of very large masses (100–1000 $M_\odot$ for instance) can and do start forming at $z = 15$–20 (Yoshida et al. 2004; Ripamonti & Abel 2004; Sokasian et al. 2004; Tan & McKee 2004; Oh & Haiman 2003; Stiavelli et al. 2004). Zero metallicity means that these superstars will have high photospheric temperatures even for their masses and so be especially useful for ionization.

Following these stars to their deaths, we spot two important extensions. First, they will eject heavy elements, quickly polluting a 10^5–$10^6\ M_\odot$ halo each up to $z = 0.001$ (Schneider et al. 2004), after which only Population II stars can form. QSOs must then take over the task of furthering and supporting ionization (Bromm 2004; Zheng et al. 2004a; Cooray & Yoshida 2004; Bromm & Loeb 2003).

Second, these very massive stars are going to leave behind intermediate mass black holes of up to at least 100 $M_\odot$. And indeed the black holes must swallow hard, both metals and kinetic energy, or both will be overproduced (Ricotti & Ostriker 2004). Accretion onto these new IMBHs then becomes a brand new, possibly more important, source of ionizing radiation, especially soft X-rays, which can travel further and smooth out the ratio of H II/H I over longer distances than UV (Madau et al. 2004). Unless, of course, all the residual gas is blown out of the shallow halos ($10^6\ M_\odot$ or so) in which these things have been happening, leaving none to accrete (Whalen et al. 2004).

Bromm & Larson (2004) discuss these topics more thoroughly and, of course, more expertly.

7.2. Variants

Of the three conventional UV source, hot stars, accreting black holes, and shocks, Miniati et al. (2004) are inclined to give more credit to shocks that most other authors do, especially for the second ionization stage of helium. The shocks will arise from inflowing gas during structure formation.

Photons from the decay of 200 eV neutrinos (warm dark matter) also still have fans (Hansen & Haiman 2004) and the opposite, folds we suppose (Pierpaoli 2004). Notice that this rest mass is a good deal larger than the 2×13.6 eV that Sciama (1993) had in mind.

7.3. Gamma-Ray Bursters

These may indeed someday be the earliest events detectable from Earth (Bromm & Larson 2004), but they have a role to play even now, concur the authors of the 75 indexed papers on the topic, arguably the only point on which they concur. No green dots here, but two topics that had only just entered the archival literature in Ap03 have now come into their own, to join a bunch of older ones. The two are X-ray flashers and the identification of GRB 030329 with a Type Ic supernova (with another candidate or three for similar associations).

X-ray flashers would surely have been called X-ray bursters had the name not already been taken, and between them and the GRBs come X-ray rich (or gamma-ray poor) GRBs. The populations are almost certainly a continuum, in total energy (X-ray = less), sharpness of collimation (X-ray = wider cone), angle of observation (X-ray = off-axis), part of the jet you see (X-ray = cocoon), or some related parameter (Zhang et al. 2004a; Sakamoto et al. 2004; Zhang et al. 2004d; Dado et

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[9] Whom, you will recall, also is to be blamed for there being 29 days in some Februaries, according to leading authority King (1879). As this introduces an extra day into nearly all American election years, it was a particularly cruel choice.

al. 2004). The last of these predicts that there should also be short-duration X-ray flashers. The first host identification and redshift, $z = 0.25$ (Soderberg et al. 2004b), supports the small total energy part of these relationships. Still, how can one not love the alternative, planet-planet collision scenario of Zhang & Sigurdsson (2003)? Conceivably this is a prediction of a new class of events and not an explanation of the existing one. Oh, and don't worry. The solar system won't.

As for GRB 030329 = SN 2003dh, it was faint for a GRB (Greiner et al. 2003, Berger et al. 2003) and bright for a supernova (Bloom et al. 2004; Mazzali et al. 2003). And before the year was out, along came another, GRB 031203 = SN 20031w (discovery package: Sazonov et al. 2004; Soderberg et al. 2004a; Woosley 2004). It was an *INTEGRAL* discovery (not the first, which was 021125; Malaguti 2003, in an *INTEGRAL* special issue), and has a redshift $z = 0.1055$, the smallest except for 1998bw = GRB 980425 (Cobb et al. 2004). In the great scheme of things, it tends to fall in the middle of the "weak GRB, bright SN" family between 1998bw and 030319 (Prochaska et al. 2004; Watson et al. 2004). It was arguably more like an X-ray flasher than a GRB (Thomsen et al. 2004). Off-the-shelf explanations have included off-axis viewing angle (Waxman 2004b) and jets with relativity parameters, Γ, between the GRB and SN Ic norms (Granot et al. 2004). Additional observations of the two 2003 events are presented by Taylor et al. (2004) and by Malesani et al. (2004).

What is required to catch more of these seems to be either patience (to wait for more intrinsically faint GRBs) or hard work (to burrow down in the late time lights curves for bumps suggestive of SNe). Zeh et al. (2004) have found nine additional candidates of this latter sort, all with $z < 0.7$ and making up half of all the GRBs with redshifts in this range.

Many other GRB questions have accumulated since 1974, and we provide only the 2004 answers to subset of them.

NO, we still don't know what the short duration ones (lasting 2 sec or less) are (Ghirlanda et al. 2004, suggesting that they are a lot like the first 2 sec of longer ones; Yamazaki et al. 2004).

YES, the Milky Way has had some according to Biermann et al. (2004), though when they say the last one was 10^6 yr ago, they mean it was the most recent one, and also perhaps the source of cosmic rays above 10^{18} eV that are now wandering around.

NO the large gamma-ray polarization reported last year for 021206 probably wasn't true (Rutledge & Fox 2004).

YES, GRBs have host galaxies, which are typically SCUBA (star-forming) galaxies, but not the brightest (ULIRG, gE predecessors) of these (Tanvir et al. 2004).

NO, we don't quite have a theory of stellar evolution leading up to them, but there is at least a scenario or two. Tutukov (2003) presents a massive binary system that passes through a Wolf-Rayet phase that turns the second core collapse into a rapidly rotating black hole. Or, say Rosswog et al. (2003), you can start with a pair of neutron stars whose inspiral and merger yield a rapidly rotating BH with a strong magnetic field.

YES, it is reasonable to expect some nucleosynthesis (Pruet et al. 2004; Nagataki et al. 2003), but no, we aren't sure that this is necessary in order to fit the Fe, Si, etc. spectral features that have been reported (Totani 2003; Tavecchio et al. 2004). We caught no one this fiscal year doubting the reality of the features.

NO, the radiation mechanism responsible for the gamma rays is not entirely agreed upon, Stern & Poutanen (2004) preferring synchrotron self-Compton, and Setiawan et al. (2004b) preferring $\nu\bar{\nu}$ annihilation.

YES, they can accelerate relativistic electrons with gravitational radiation, thus keeping it all in the Einstein family, with no need for that guy Maxwell (Vlahos et al. 2004), but it seems like the hard way.

7.4. Active Galactic Nuclei

It is a peculiarity of the quasars, QSOs, BL Lacs and all that, while there have been some around about as long as there have been galaxies, 12 Gyr or so, no one has a lifetime more than about 1% of the total (10^7 yr for little ones, Grazian et al. 2004; 10^8 yr for big ones, McLure & Dunlop 2004, an analysis of 12,698 QSOs from SDSS and an absolute treasure trove of information). This means that questions about the lives of individual sources and questions about changes in populations are decoupled far more than for, say, globular clusters, dwarf galaxies, or solar type stars. We suspect that this somehow contributes to long-standing disagreements (about, for instance, the radio loud/quiet dichotomy) but cannot prove it.

This year, AGNs were topic 53 in the notebook, with 162 papers indexed, and we mention only ones addressing some issue where there is indeed disagreement.

"*Alignments*" means of optical morphology with radio jets. Yes, it is there in Inskip et al.'s (2003) $z = 1$ quasars, and they need all three suggested mechanisms, UV scattering, gas flows, and triggered star formation, to make enough. And no, it is not in a very different, Seyfert, sample examined by Schmitt et al. (2003).

The radio loud/quiet dichotomy. This is our oldest, favoritest. First, is it a dichotomy? A typical definition uses the ratio of fluxes at 5 Ghz and 4400 Å rest wavelength for both. Ratios $\lesssim$2–10 are "quiet" and ratios $\gtrsim$800 to 27,000 are "loud." But radio quiet QSOs nearly always come from optically-selected samples, and radio loud quasars from radio-selected samples. And it turns out that sources chosen from far infrared (Drake et al. 2003) or X-ray (Bassett et al. 2004) surveys nicely populate the excitingly-named radio-intermediate class with $R =$ 10–1000. Thus we should probably look for a cause that can take on a continuous range of values, and spin of the central black hole has seemed promising in recent years. Gallo et al. (2004), however, call attention to the X-ray QSO PHL 1092, which is radio quiet despite being built around an extreme Kerr black hole. To say that this falsifies large spin as the cause of radio loudness is a logical fallacy (the opposite, more or less, of affirming the consequent), but Drake et al. (2004) call attention to other systematic differences between radio loud and radio quiet hosts that would not obviously go with black hole a/M.

We recorded about 10 other papers reporting correlations of radio luminosity with optical luminosity, black hole mass, galaxy mass, location in and out of clusters, and so forth. Unfortunately, some of the correlations are the opposites of others, and correlation is anyhow not necessarily cause. Two possible causes: compression of magnetic fields by gas in X-ray clusters (Reddy & Yun 2004) and jet ejection velocities exceeding the escape velocity (Ghisellini et al. 2004).

My, what broad absorption lines you have, Grandma, and one is left wondering whether all grandmothers do this, but only sometimes, whether you must view them from the right direction,[10] or if they are truly different from other grandmothers. Votes this year only for assorted forms of unspecialness (Willott et al. 2003; Reichard et al. 2003), and the topic appears because of its kinship with an older one. If per chance all QSO absorption features were due to blown-out ("associated") gas, then one of the standard arguments for redshifts as distance indicators disappears. Interestingly, only features with $|\Delta v|$ smaller than 5000 km/sec vary (Narayanan et al. 2004), strongly suggesting that they are truly "associated," and the others are not.

AGNs and star bursts. Well, mergers are supposed to provide fresh fuel for central black holes and to trigger bursts of star formation, so "both, please" ought to be a common combination. It is (Solomon et al. 2004 present an especially bright one). You can't help having noticed, however, in recent years, that SCUBA galaxies (sub-millimeter, generally dust heated by stars) are hardly ever bright *Chandra* (X-ray QSO) sources (Smail et al. 2003), and so may be pleased to hear about (1) the first sub-millimeter-selected QSO (Knudsen et al. 2003), and (2) the detection of some $z = 2$–4 SCUBA galaxies with *Chandra* (Smail et al. 2003). They are big and interacting (Chapman et al. 2003).

M87. There being no other obvious place to put it, we will note here that the jets of M87 are driving a sort of three-ring circus of acoustic and gravity waves (Feng et al. 2004) that, say the authors, resembles the structure around SN 1987A. Somehow this looked more amusing when abbreviated in the notebook shorthand as "M87 = 87A."

MeV and TeV active galaxies are the ones seen, respectively, by EGRET and by ground-based catchers of secondary photons and other particles. The TeV ones now number at least six (Aharonian et al. 2004a) or eight (Kalekin et al. 2003), and the emission mechanisms are not the same in all (Stawarz et al. 2003), including at least inverse Compton (M87) and synchrotron self-Compton (Cen A). The "TeV" total will rise as the detectors push down to thresholds below 1 TeV, and one may hope for MAGIC (on La Palma, with its aluminum plates bravely facing wind-born Sahara dust) to find up to 100. But the author of larger gamma was most surprised by the curious fact that the EGRET sources are much more likely to display superluminal jet motion than are the TeV sources (Piner et al. 2004). Indeed, report Kellermann et al. (2004) of all radio jet AGNs, the EGRET ones have the largest Γ's.

Hosts and populations. There were more active galaxies of assorted types in the past than there are now, a result from radio astronomy celebrating its 50th anniversary this year (but also see Steffen et al. 2003; Wolf et al. 2003), but by the time you look back to $z \sim 6$ there were, once again, not so many. The brightest ones increase in number most rapidly back to $z \sim 2$ and fall off least rapidly further back into the past (Wyithe 2004; Clewley & Jarvis 2004, another result based partly on SDSS). We apologize for running time backwards this way. It is the custom in the field, and "evolution" has nearly always meant "more in the past."

The ones "then" were not quite like the ones "now." In particular, it seems that the biggest black holes, in galaxies that would not now seem enormous, turn on first and by now are no longer active (Croom et al. 2004, McLure & Dunlop 2004, SDDS again). Scannapie & Oh (2004) say that the largest black holes turn themselves off after $z = 2$ because outflow has heated the surrounding gas. If you think of it as X-ray gas, this counts as preheating, and is part of a different story. The early hosts also differed from current ones in having more ionized (depolarizing) gas (Goodlet et al. 2004).

Quasars and all do indeed have host galaxies, also right back to the beginning. Bertoldi et al. (2003) report on a $z = 6.42$ QSO which also counts as the most distant CO detected so far. How special are the hosts? They cluster like other galaxies (Wake et al. 2004, SDSS again) of equal mass. That mass is large and the galaxies are of early types for QSOs and their ilk (Kauffmann et al. 2003; Cheung et al. 2003; Mignoli et al. 2004), and the optical morphology is largely normal. If there are differences, they are in the directions of (*a*) more molecular gas than average (Hainline et al. 2004), and (*b*) less rotational support (Merrifield 2004). Your description of what this means could hardly be worse than ours (recently assembled from mergers of equal components with oppositely directed angular momenta?) Lest you think that "the truth" about these matters is known, remember it is based largely on optical and radio selected samples. An *XMM* sample with CFHT redshifts seems to include all types of galaxies more or less equally, and a wide range of optical luminosities among the hosts (Waskett et al. 2004).

As for Seyfert galaxies, once you ignore the light from the center (not very easy to do), they have normal spiral mor-

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[10] Our grandmother, like Ernestine Schuman-Heink is supposed to have said about herself, had no sideways.

phologies, stellar populations, and so forth (Marquez et al. 2004; Sanchez-Portal et al. 2004).

Two black holes? We saw no papers this year on the classic OJ 287 with its long-standing 12 yr period, widely described as the orbit period of two black holes left from a merger, and we are still wondering about other possible causes. Just seeing two optical nuclei is not enough to deduce a black hole binary. M31 can make that claim and is nicely fit by eccentric stellar disk models (Peiris & Tremaine 2003; Salow & Statler 2004). Indeed Gimeno et al. (2004) report no fewer than 107 fairly ordinary disk galaxies with two nuclei (does it mean anything that there are no triples?) Typical separation is 4 kpc, and most are unlikely to be binary BHs.

Periodicity is also not enough. Fourteen years for PKS 0735+178 from nearly a century of data, of which only the last 6 yr were collected by Qian & Tao (2004). Periods of 2.5–8.5 yr for five blazars (Ciaramella et al. 2004, who express no strong views on causality). Jet precession is, however, advocated by Ostorero et al. (2004) for a $P = 5.7$ yr BL Lac, by Kneib et al. (2004) for the 11 yr period of 3C 120, and by Caproni & Abraham (2004) for the 11 yr period of 3C 345. The last, however, say that the precession happens in the vicinity of a binary black hole having $P = 3$–4 yr. Incidentally, if your instincts about Kepler's third law derive from study of binary stars, you may need to do the arithmetic to realize that, with BH masses typical of AGNs, $P = 3$–4 yr corresponds to $a = 1000$ AU or so! The $P = 5.5$ yr in one Seyfert (NGC 1097) is apparently another sort of precession, that of an $m = 1$ spiral in the disk (Storchi-Bergmann et al. 2003).

What then would count as evidence of two black holes? How about two non-thermal point sources? Radio ones in 0402+379 in a VLBA image (Maness et al. 2004). Radio, optical, and X-ray for 3C 294 and four others at $z = 0.85$–2.4 (Stockton et al. 2004a). You might think that these add up to evidence for six double AGNs in merging systems, but Ballo et al. (2004) say that Arp 299 is only the second example after NGC 6240. This one is also experiencing a starburst and so should produce about one supernova per year (Pasquali et al. 2004), when, presumably, it will look, briefly, a bit like a triple AGN!

These true double AGNs, in order to be resolved, obviously have to have separations of kpc (8 for 3C 294) not just parsecs, and orbit periods comparable with galactic rotation periods, not those of binary stars. Will they ever merge? Not without help from something besides field stars and gravitational radiation, say Makino & Funato (2004). We'll do our best to help them with triaxial potentials and such, say Poon & Merritt (2004). And it has happened lately in M87, according to Feng et al. (2004). That most of the AGNs mentioned in these last few paragraphs are well-known ones suggests that the various phenomena must all be fairly common.

What effects can you expect from the merger process? Thinning out of the central star supply in giant elliptical galaxies (Kandrup et al. 2003). Formation of an X-shaped FR II radio source which evolves to double lobes and an FR I (Liu 2003). And (our favorite) such intense gravitational radiation from 3C 66B ($P = 1.05$ yr) that it should produce detectable timing signals in the pulsar B1855+09, which happens to fall right along our line of sight to the AGN (Jenet et al. 2004; closer to us than to 3C 66B, of course, except in the alternative universes of non-cosmological redshift).

And since the Poon & Merritt (2004) process leads to a relationship between black hole mass and stellar velocity dispersion, it is clearly time to move on to subsection 5.

7.5. The Black Hole/Bulge Connection

The old news is a widespread ratio near 10^{-3} between the masses of central black holes in galaxies and the masses of their stellar bulge populations, applying to both large galaxies and small (Gondoin et al. 2004; Haring & Rix 2004). The new green dot is for evidence that black holes increase their masses primarily by accreting gas, rather than by merging with other black holes (Marconi et al. 2004; King 2003; Dai et al. 2004).

Now you cannot put forward anything that definitive without someone saying, or at least, writing the opposite, as did Merritt & Poon (2004). They conclude that black hole growth is due primarily to mergers, so that the masses you observe at different redshifts will be misleading as tracers of accretion rates. There are even a few dissenters from the "universal ratio": Grupe & Mathur (2004, bigger black holes in broad-line Seyferts than in narrow line ones for a given velocity dispersion of the stars), Bromley et al. (2004) and Hosokawa (2004) on redshift dependence.

Amaro-Seoane et al. (2004) take a sort of middle road on how black holes grow. Theirs accrete stars, as still happens from time to time (Halpern et al. 2004a). Notice that, as a scenario for explaining the BH/bulge ratio, this idea belongs to the "stars first" camp. Hosokawa (2004) and Bromley et al. (2004) incline also to stars first, on the grounds that the "universal" relation at a redshift of 6 would land us with far too much stuff in black holes now. Bromley et al. (2004) also suggest some ways out of the apparent contradiction, for instance nobody gets a black hole till his circular velocity is at least 55 km/sec, unless it forms before $z = 11.5$. And no, we don't entirely understand why both of these can work.

Naturally, there is also a "black holes first" camp. If one takes this to mean that there are already $10^9\ M_\odot$ black holes at $z \sim 6$, whose hosts (and their neighbors) are still the "chicken parts" stage of evolution, without recognizable bulges (Richards et al. 2004; Vestergaard 2004), the point cannot really be disputed. And Weidinger et al. (2004) have imaged a $z = 3$ AGN with enough gas around (still as gas) to make all the stars you expect by now. It must today be a seriously big galaxy, since the halo mass was 2–$7 \times 10^{12}\ M_\odot$ (Haiman 2004) and this can only have grown since.

Some bulges may merely be puffed-up disks, and so not part of the relationship at all (Kormendy & Kennicutt 2004).

The majority view, however, continues to favor co-formation of the bulge stars and black hole. We caught at least eight such papers, each with an explanation of why the two should grow together in a fixed ratio (compare the ratio disturbers of § 8.2, footnote 11). In some, both BH growth and star formation stop when outflow from the AGN removes the gas both require (e.g., Granato et al. 2004). Other descriptions are more complicated (e.g., Wyithe & Loeb 2003, who use outflow to stop the black hole growth, but supernovae to stop the star formation) and Menci et al. (2004) with both as merger driven processes affecting the gas supply. There does, anyhow, seem to be more gas around active galaxies at large redshift than around the few remaining today (Maiolin et al. 2004 on broad absorption line gas; Gallagher et al. 2004 on BAL and X-ray gas; Page et al. 2004 on submillimeter emission and X-ray absorption gas).

We tuck the smallest central black holes here so that they will be protected from harsh winds by strong paragraphs on either side. The main thought is that the smallest (anyhow the smallest that can be measured at present) do not extend below $10^5\ M_\odot$ and so are well separated from the IMBH class of § 5.6 (McHardy et al. 2004; Barth et al. 2004; Greene & Ho 2004). The two smallest live in NGC 4395 and a dwarf Seyfert POX 52.

And the last word on this topic goes to Stirling Colgate (Colgate et al. 2003) because the author who has heard him speak at meetings over the longer period finds that she hardly ever seems to understand what he is saying, but that a few decades later the community notices that he was right (gamma-ray bursts from supernovae to take an extended example). This particular paper says that black holes at galactic centers form from rotating disks due to Rossby Vortex Instabilities which carry angular momentum out very quickly and so mass in. The ratio of black hole mass to central velocity dispersion is then set (at the correct value) by, we think the potential of the galaxy as a whole.

8. COSMOLOGY: THE CURIOUS INCIDENT OF *WMAP* IN 2004

But *WMAP* did nothing in index year 2004. That was the curious incident. Not necessarily true, of course. All we know from outside is that *WMAP*'s handlers did not publish the second year of data, though Ap03 anticipated it, and speakers from April to August and Argentina to Arkhangelsk seemingly shared our expectations. Thus the 239 cosmological papers indexed under various cosmological headings and the seven sections below soldier on with last year's consensus parameters, of which Freedman & Turner (2003) provide a mainstream overview.

In fact, concordance cosmology was declared by the editors of *Science* (Anonymous 2003a) to have been the science breakthrough of the year. We are grateful, therefore, that an absolute majority of the papers on which we took notes endorsed the typical numbers: A Hubble constant near 70 km/sec/Mpc, baryon density 0.04 of closure, total matter density near 0.27 of closure, and the rest (0.73) in some sort of dark energy, cosmological constant, or whatever. Yeses in answer to the semi-literate question "Are you OK with that?" came from supernovae (Knop et al. 2003; Barris et al. 2004), from galaxy formation (Weinberg et al. 2004), from ground-based microwave back-ground data (Readhead et al. 2004, emphasizing smaller angular scales than *WMAP* is most sensitive to), from large scale structure in the distribution of galaxies (Baugh et al. 2004; Hawkins et al. 2003; Pope et al. 2004), and from a relatively late recruit to the concordance team, gravitational lensing (Wambsganss et al. 2004).

Liddle (2004) notes, more in sorrow than in anger, that if $k = 0$ (flat space) and $n - 1 = 0$ (Harrison-Zel'dovich spectrum) are given, this particular elephant needs only five parameters for its specification, for instance the densities in matter and baryons, the CMB temperature, H, and a normalization of the amplitude of the primordial fluctuations. He would like to have to include $n - 1$, tensor vs. scalar fluctuations, an equation of state for the dark energy (so that it isn't just constant with space and time), warm dark matter, interesting topology, features in the observed power spectrum $P(k)$, time derivatives of G and of the fine structure constant, α, strings, and another dozen or more. Be careful, someone once said, what you wish for; you might get it.

Some slightly less direct indicators of the usual parameters also supported "vanilla": the integrated Sachs-Wolfe effect (Boughn & Crittenden 2004), two more ground or balloon CMB projects (Goldstein et al. 2003; Ruhl et al. 2003), QSO absorption lines (Chiu et al. 2003), and the QSO power spectrum (Outram et al. 2004, on this close relative of the classic Alcock & Paczynski 1979 test). A dozen or more other concordant analyses go uncited.

Are there any of the other sort? Yes. We are not quite sure whether it is possible for the universe to have $\Omega_M \sim 1$, but it is still possible to publish it as the best fit to some subset of the available data (Vauclair et al. 2003 on X-ray clusters; Hong et al. 2004 on a superluminal radio source; and Blanchard et al. 2003, who need, however, a 17 Gyr old universe).

Does this mean that Cosmology Is Over and you can go home to Earth (§ 12)? We hope not, given that the more exponential author's institution has just added five young cosmologists to its faculty. Territories still to be explored here include some favorite numbers and poles, assorted models (including the unconventional), and dark, darker, and darkest.

8.1. Some Favorite Numbers

$H = 67$? Is the Hubble constant really something you are still allowed to measure, or is it now defined and you measure other things in terms of it, like c? Permission is available, but less often taken up than in the recent past when 20 or more values appeared each year. We caught 10, from a low of 44 km/sec/Mpc (Sereno 2003) to a high of 110 km/sec/Mpc (Battistelli et al. 2003). This neglects the 461 previous values compiled by Chen et al. (2003a). These center around 67 (rather than the *WMAP* exchange rate of 71 or the Hubble Key Project number) and the distribution is wider at the edges than a Gaussian fit near the middle.

The other omegas: Photons give us 4×10^{-5} of the closure density, most of it from the CMB, but 10% from stars and less than 1% from AGNs (Zurita Heras et al. 2003). Hot dark matter may contributed 0.012 (Allen et al. 2003), but this is only one standard deviation away from zero. And gravitational radiation in the mHz band contributes less than $\Omega = 0.025$ according to Armstrong et al. (2003) who have watched for *Cassini* to be jiggled by it.

The baryons. A hefty majority (though not so hefty as the astronomers of the later paragraph on bias) will say that essentially all is well with the *WMAP* gift of $\Omega_b = 0.04$ (Coc et al. 2004; Romano et al. 2003; Salaris et al. 2004b). This goes with a primordial helium abundance by mass $Y = 0.23$–0.25, a D/H ratio of 2.5–2.8×10^{-5} (Kirkman et al. 2003), rather than the briefly threatened 2×10^{-4} (Crighton et al. 2003) and $\mathrm{He}^3/\mathrm{H} = 0.5 \times 10^{-5}$, all much as you have come gradually to expect.

The over-produced poison is lithium-7, which all agree ought to make up about 10^{-9} of the baryons before stellar and other processes get to work on it. It is seen in the oldest stars at closer to 10^{-10}. A recent reanalysis of the stellar data including non-LTE effects increased the discrepancy a bit, but the authors (Barklem et al. 2003) conclude that it is a factor more like 3 than 10. If this keeps you from sleeping at night, consumption of a bit of the excess will both calm you down and help to reduce the disagreement. And no, don't try this at home; we have no idea whether pure Li^7, the sort left from the big bang is safe, even in very small doses. A dose of SuperWIMPs could also help. Decay of these otherwise nearly undetectable dark matter candidates in the early universe could destroy some lithium, but leave helium and deuterium more or less unscathed (Feng et al. 2003).

Where are these baryons? Not mostly in stars, point out Bell et al. (2003) and many before them. Their inventory comes from the total amount of starlight collected by SDSS and 2MASS. This leaves diffuse media. (Think of television newscasters and tabloid photographs spread VERY thinly through space, and smile.) The buzz word a couple of years ago was WHIM—warm/hot intergalactic medium—as the dominant phase, said to have contained most of the baryons in the past and half or so even now. The largest correction factor we feel inclined to mention is that some of the evidence for a local WHIM may have other, more parochial explanations (Futamoto et al. 2004; Collins et al. 2004).

Why are there this many baryons? Where "this many" could mean Ω_b but is more likely to mean $\eta = n_b/n_\gamma$, that is, the excess of baryons over anti-baryons in the early universe, compared to their sum. New scenarios appear at least annually. Garbrecht et al. (2004) describe one with "coherent production and mixing of different fermionic species" during the phase transition when the electroweak force breaks loose from the strong force. Alternatively, Massa (2003) blame a time-dependent cosmological constant which is currently decreasing. We think this might mean that, if you come back after a Hubble time or two, you might find a different value for n_b/n_γ, which is not the case in conventional models after the first few seconds.

Does it matter what that ratio turns out to be? Well, if it were very different from 10^{-10} (with the other parameters staying about the same), we would not be here to write about it (Rees 2003, a contribution from a conference in memory for Fred Hoyle). Does this embroider on the author's shift (and ours) an "A" for anthropic? Probably. But all parties concerned also have a shirt embroidered with L for election days.

Bias. Does light trace mass in the universe? Of course not, or your 100 Watt authors would have masses near 10^8 kg. But the answer is not quite so clear on the scale of clusters of galaxies. By way of reminder, if the amplitudes of fluctuations in light density $\delta U/U$ are related to the amplitudes of the mass density fluctuations $\delta\rho/\rho$ by $(\delta U/U) = b(\delta\rho/\rho)$, then the bias factor is b, and $b = 1$ counts as unbiased. The papers of the year provided at best a plurality, with $b = 1$ for some kinds of galaxies and colors of light (Kneib et al. 2003, red light; Gavazzi et al. 2004, early type galaxies; Jing & Borner 2004, faint galaxies in the 2dF survey, but $b = 1.5$ for bright ones). Other investigators found $b > 1$ (1.19 to 1.87) for all the entities they looked at (Coziol et al. 2004; Hickson compact groups; Coil et al. 2004 $z = 0.7$–1.5; Ciecielg & Chodorowski 2004, $b = 1.45$ from the acceleration of the Local Group; Blake et al. 2004b, $b = 1.53$–1.87 for local radio galaxies).

σ_8 is the rms density fluctuation on a scale of 8 Mpc (for $H = 100$). The length was chosen to make the parameter come out close to unity, so you should not be surprised that the values reported during the year ranged from 0.72 (Voevodkin & Vikhlinin 2004, assuming baryons trace total mass) to 1.13 (Feldman et al. 2003, from the pairwise velocity differences of galaxies.

$n = 1$ (equal power on each length scale as it comes within the horizon) is the traditional prediction of inflationary cosmology. $n \neq 1$ is called tilted. Khoury et al. (2003) say that both inflation and an ekpyrotic or cyclic universe can predict $n = 0.95$. But more tilt than that, in the direction of less power on smaller scales, is needed to solve the "missing satellite" problem, say Zentner & Bullock (2003) and Yoshida et al. (2003). One of the prices paid is that the universe is not reionized so early. Any $n = f$ (scale length) or non-Gaussian initial conditions will also affect reionization (Avelino & Liddle 2004). This counts as "unhelpful," in the sense that, of the *WMAP* concordance cosmological parameters, the one theorists have had most trouble matching is the large optical depth $\tau = 0.17$ (that is, early re-ionization). But things can be true even when they are unhelpful! (Chiu et al. 2003).

The age of the universe, now officially set at 13.7 Gyr, had better exceed the age of any of its contents. This remains, we venture to hint, marginal, with 13.4 ± 0.8 ± 0.6 Gyr for the oldest globular clusters (Gratton et al. 2003). That's all right, say Hargis et al. (2004), we can make them younger with gravitational settling of helium to the center. Ah, but I can make them older, says Broggins (2004), with a new, smaller cross section for the reaction $N^{14}(p, \gamma)O^{15}$. This delays establishment of CNO cycle hydrogen burning in the thin shells of red giants.

The size of the universe. Ours is as big as it has to be to go in both antennas. Oh, sorry. That's an interferometry answer (to "how big is a photon?"). Our universe, at least as measured in unfinished tasks, is infinite. But others during the year voted for (*a*) about the 4200 Mpc size of the horizon (Rocha et al. 2004, also a vote for non-trivial topology) and (*b*) bigger, by at least a factor five as a lower limit (Cornish et al. 2004). Both studies draw heavily on *WMAP* data.

8.2. Our Favorite Poles

Well, May comes first, and Bohdan Paczynski second, but the cosmic dipole is a close third. A cosmic dipole means that the 3K radiation looks brighter in one direction in the sky than in the opposite direction, or that we seem to be moving in some definite direction relative to the surface of last scattering, introducing a Doppler shift in the measured radiation. Our motion relative to sufficiently distant galaxies should be the same, and indeed it is if you employ 2MASS galaxies as the tracer (Maller et al. 2003). But the galaxy number is only about 300 km/sec vs. 600 km/sec from the CMB if you focus on disk galaxies, report Parnovsky & Tugay (2004). Oh, well, you say. They haven't looked far enough away to reach a co-moving set of galaxies (the redshifts in their sample are 3000–10,000 km/sec). We would like to agree with you, but they say that the quadrupole and octupole fluctuations around the sky in the galaxy velocity field are larger, and it is these that are due to the Great Attractor.

But even if you try to go with the majority, saying that about 600-km/sec dipole peculiar motion has to be accounted for, this still remains a green dot topic for lack of agreement. Kocevski et al. (2004) use X-ray clusters as their tracers (so that the zone of avoidance is not a problem) and say that the direction of our motion is established by stuff within 40 h^{-1} Mpc; the Great Attractor is important; and the amplitude finally reaches 600 km/sec when you take account of everything between 140 and 160 h^{-1} Mpc. A large contribution comes from the Shapley concentration at 150 h^{-1} Mpc and smaller ones from other very massive clusters within the zone of avoidance. Contrarily, the dipole of Hudson et al. (2004) indeed "notices" the Great Attractor and the Shapley concentration, but still needs non-homogeneous distributions of material beyond 200 h^{-1} Mpc to reach the full amplitude. They are using *IRAS* galaxies, and the conclusion would be modified if there is a good deal of matter unprobed by *IRAS*, in the zone of avoidance and elsewhere, surprising in the sense that infrared is supposed to do less avoiding than visible light.

Another sort of rather worrisome "dipole" consists of the amplitudes of the CMB fluctuations being different between northern and southern hemisphere (*WMAP* confirming a *COBE* result). This is best seen, say Eriksen et al. (2004a), in ecliptic coordinates, which, by suggesting a cause in incorrect allowance for emission from solar system material, lowers the worry coefficient a bit.

The cosmic quadrupole question has two parts: Is there a problem? And is there a solution? If there is a problem, it is that inflation has ordained a fixed ratio between the quadrupole and octopole moments of the CMB and higher order moments. It bears some resemblance to the traditional definition of the problem of the ratio disturber.[11] All agree that relative, say, to C_{10}, C_3 and C_4 are smaller than expected. We spotted two votes for "not to worry" (Efstathiou 2003, 2004) and two for "keep worrying" (Gaztanaga et al. 2003; Dore et al. 2004). The latter point out that the worry quotient goes up if the true optical depth back to last scattering of the CMB is less than 0.17.

Also to be counted on the "worry" side are those who offer solutions, with isocurvature fluctuations (Moroi & Takahashi 2004), residual foreground emission (Naselsky et al. 2003), or a finite universe (Weeks et al. 2004). Before being led inexorably to the next topic, we pause for statistical station identification. We observe the universe from only one vantage point and "worry quotients" are set by asking what fraction of observers would see a set of fluctuation amplitudes at least as extreme as the ones we see. You then have to decide whether being an unusual observer in a probable universe is better or worse than being a typical observer in an improbable universe.

Dodecahedrupoles and complex topology. The more recursive author suspects that a significant motivation for considering closed universes with complex topology is akin to the motivation for liking the idea of reincarnation—it is exciting to think about coming back some day. But the index year motivation for a topologically complex (dodecahedral) universe is providing an explanation for the small quadrupole and octopole moments of the CMB fluctuations seen by *COBE* and *WMAP* (Luminet et al. 2003; Ellis 2003; Cornish et al. 1998). This picture predicts a total $\Omega = 1.013$ (not currently distinguishable from 1.000) and temperature correlations in circles on the sky that match across the boundaries in opposite directions. Can such patterns be found in the data? Perhaps, say Roukema et al. (2004) and Rocha et al. (2004). No, say Cornish et al. (2004). What do we say? Please keep us posted, and if the information arrives from a direction exactly opposite from the direction to the editorial offices of the *Astrophysical Journal*, that should settle the issue.

In any case, a dodecahedral universe will have experienced a big bang everywhere and must have both a center and a

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[11] Also called the spare-parts theorem and concerned with the ordained ratio between whole horses and subassemblages.

preferred reference frame (Barrow & Levin 2003). We must travel with the preferred frame (to see an isotropic Hubble's law) but need not be at the center.

8.3. Distance Indicators and Very Large Scale Structure

These share a subsection because you need the former as a rule to detect the latter, though sometimes redshifts alone are enough. The primordial method of distance determination is parallax, with no conspicuous new results this year. But in fact the first actual parallax measurements in the 1830s came after Michell and Herschel applied a standard candle method (Hirshfeld 2001) in which other stars are assumed to be a lot like the Sun. The best-buy standard candle has, for decades, been the class of Population I Cepheid variables. Given this history, the green dot simply had to go to the papers that have put Cepheids on to a new geometric system. Not the parallaxes of *Hipparcos* (or Henderson) nor the statistical and secular parallaxes of Hubble, Shapley, and their predecessors, but $V = 4.74\,\mu d$, in which the same speed is measured in both linear and angular units. If you are going to do this for Cepheids, the proper motions of their expanding and contracting photospheres must be measured with an interferometer (Kervella et al. 2004a, 2004b). The handful of stars measured so far are all well within the Milky Way. Still, it is a start!

A new distance indicator (also only within the Galaxy say the authors; Foster & Routledge 2003) is the comparison of the H I column depth to a source within the Galactic plane to the total column depth to the edge of the Milky Way. Well, it was done for the Crab Nebula a quarter of a century ago, probably while the cited authors were attending Mrs. Greenup's nursery school, making the method new for them, apart from the effects of a dodecahedral universe.

The second very important candle in recent years has been peak luminosity of Type Ia supernovae. Everybody naturally worries that the peak, and the speed of fading and velocity of ejecta used to calibrate it, could depend systematically on redshift via dependences on progenitor mass, products of nuclear reactions, and all. Ropke & Hillebrandt (2004) find little or no dependence on the C/O ratio in the white dwarf being driven to self destruction. Not as reassuring as you might suppose, since there should be such dependence.

Other distance indicators for which you expect differences among stellar populations (age or metallicity or both) are the brightnesses of planetary nebulae (Marigo et al. 2004), the red giant tip (Barker et al. 2004), and surface brightness fluctuations (Gonzalez et al. 2004) across whole galaxies. Whether you see less variation than you expect (first two cases) or a whole bunch (third case), all together now, "More work is needed." More work is under way for Mira variables as distance indicators, with Rejkuba (2004) reporting the first measurement outside the Local Group, 3.84 ± 0.35 Mpc for Cen A, the nearest strong radio galaxy, but a smidge less near than before.

The Tully-Fisher method applies to whole galaxies and is the correlation of absolute brightness with maximum circular rotation speed. It must surely fail at large distances, because galaxies really have formed and evolved systematically with time. Yes, everything was a good bit brighter at $z = 0.25$–1.0 say Kannappan & Barton (2004). No, things were much the same at these moderate redshifts say Ziegler et al. (2003), though the scatter may have been larger, and Swinbank et al. (2003), reporting only one galaxy and so with no discussion of scatter. No, no; you all have it wrong according to Bohm et al. (2004). Bright galaxies show the same Tully-Fisher correlation at $z = 0.5$ as now, but the faint ones were brighter by 2 mag, as a result of mass-dependent evolution of M/L ratios (not perhaps an explanation but only an alternative description). Finally, star bursts are different (Daroust & Contini 2004), which we would have thought would produce the largest difference among bright rather than faint galaxies.

No, you are not allowed to go on to the next section yet because (*a*) with this sort of distance information, you probably won't be able to find it, and (*b*) there is still large scale structure to face. The core query here is whether the general run of clustering (sub, super, and all) vs. redshift can be understood within the framework of existing cosmological models, but let's start with some extrema.

The largest structure proposed this year covers the whole sky at redshifts in excess of one in the form of aligned optical polarization vectors of QSOs (Jain et al. 2004). Since the effect is strongest for the weakest polarizations, suspicion inevitably turns to some sort of observational error, rather than the suggested pseudoscalar photon mixing. In other surveys, radio sources (Blake et al. 2004a) and other active galaxies (Wake et al. 2004) trace out more or less the same 1–150 Mpc structures that other galaxies exhibit.

The second largest, this year anyhow, is a ≈300 Mpc Greater Wall of SDSS galaxies (Gott & Juric 2004).

What is the most distant (=oldest) VLSS? This depends on what you mean by Very, Large, Scale, and Structure. We recorded (*a*) a unique pair of QSOs at $z = 5$ (Djorgovski et al. 2003) separated by a few Mpc, (*b*) a trio of $z = 5.8$ galaxies in the Hubble Very Deep Field (Stanway et al. 2004a), (*c*) an exaltation of Lyman Alpha-emitting Regions found by Kazuhiro Shimasaku et al. (2004)[12] at $z = 4.86$, though the authors describe this as cosmic variance rather than structure, (*d*) 5–10 Mpc voids at $z = 2.38$ (Palunas et al. 2004), and (*e*) a 100 h^{-1} Mpc string of QSOs, galaxies, and Mg II absorption features near $z = 1$ (Haines et al. 2004). Each of these five is mentioned by its authors as being rather bigger and rather earlier than expected.

The deep question, therefore, is the average level of clustering as a function of redshift and whether it presents any major problems for conventional models of galaxy formation in a Λ CDM universe. The extensive redshift surveys from Las

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[12] Any bets on whether our LARKS will survive conversion of capitalization and hyphens to house style?

Campanas (Bharadwaj et al. 2004), 2MASS (Pen et al. 2003), 2dF (Magliocchetti & Porciani 2003; Hoyle & Vogeley 2004), and most recently SDSS (Doroshkevich et al. 2004) have provided much-improved characterization of the average, its dependence on galaxy types and larger scale environment, and so forth, without yielding any show-stoppers (Weinberg et al. 2004; Hawkins et al. 2003). We reserve the right, however, to be slight surprised (*a*) that although 85% of matter lives in over-dense regions (Ostriker et al. 2003), we (including both readers as well as both editors and both authors) live in an underdense one (Frith et al. 2003), and (*b*) that a good many of the mass concentrations look like Zel'dovich (1970) pancakes (Doroshkevich et al. 2004). Remember that such pancakes were a prediction of a universe consisting entirely of baryons.

8.4. Cosmological Models

Readers with very long memories may recall from the beginning of this section that standard hot big bang, lambda+cold dark, matter is doing fine for everything after the first three seconds. Additional and alternative models, therefore, either aspire to deal with still earlier times, to account for the parameters being what they are, or to demonstrate equally good fits to some other set of ideas. The simplest division is between models likely to appear in *Physical Review Letters* and those not, where papers ruling out something a bit weird count as respectable.

The near elimination of Cardassian expansion, $H^2 = (8\pi G/3)(\rho + C\rho^n)$, falls in this category if you concur with Zhu et al. (2004b) that the best fit value of n is essentially zero. You might have supposed that, given the number of "MOdified Newtonian Dynamics doesn't work" papers over the years, it would fall in the same class. MOND is, however, remarkably resilient, and so we refer you only to one set of conference papers (Alard et al. 2002) which are mostly pro, and to Clowe et al. (2004a) who are con, in the sense of pointing out that, even after fitting the best possible MOND model to an interacting cluster studied with weak lensing, you still need some dark matter. Hoekstra et al. (2004) say the same thing about some other lensed systems.

Other models long since pushed to the outer fringes are Rosen's bimetric theory and Brans-Dicke scalar tensor theory of gravity. The latter permits cosmic strings and the former does not (Reddy 2003a, 2003b), but the real problems lie elsewhere.

The Swiss cheese model of Capozziello et al. (2004) is new, but its roots reach back to Einstein (Einstein & Straus 1945, 1946). An unusual characteristic is large quantities of angular momentum lodged in the voids of large scale structure, 90% concentrated in central black holes of 10^{16}–10^{17} $M_\odot$. Bianchi models are homogeneous but anisotropic and are classified according to the Lie algebras of the isometries, from I to IX. The I's had it this year, and we spotted at least six, all in Vol. 288 of *Astrophysics and Space Science* (Bali & Upadhaya 2003; Mohanty et al. 2003; and four surrounding papers).

Now for the models that you might reasonably be allowed to publish in *Physical Review Letters* and take home to mother. Inflation remains the best-established of these (allowed into the kitchen to help wash dishes after supper), though only 67 *e*-foldings of size scale are allowed (Dodelson & Hui 2003). Traditional predictions include total Ω very close to 1 and a Gaussian spectrum of initial density fluctuations. One can also squeeze out $\Omega = 1.02$ (Uzan et al. 2003) and a non-Gaussian component (Mathis et al. 2004). The latter is "a good thing" both in the sense that non-Gaussian terms have perhaps been seen, at least in the northern hemisphere (Eriksen et al. 2004b), and in the sense that they make it a bit easier to achieve sufficient early reionization (Chen et al. 2003). Some variants on inflation provide additional flexibility (Urrestilla et al. 2004; Mazumpar & Perez-Lorenzada 2004; the latter with one infinitely-long extra dimension).

The main alternative to inflation these days is a set of brane-based scenarios with extra dimensions, which can yield cyclic universes and produce some isocurvature fluctuations as well as adiabatic ones (Koyama 2003). These models require about as much fine tuning as the inflationary ones (Khoury et al. 2004), and if the extra dimensions haven't rolled themselves up tightly enough, absolutely horrible things happen in neutron stars (Casse et al. 2004a), and the speed of light will vary with wavelength (Harko & Cheng 2004).

And there is a local NUT. Well, there might be a local NUT. Well, you get larger-amplitude microlensing if the local space is of the Newman-Unti-Tamburino type (Rahvar & Habibi 2004). Since gravitational lensing is one of the traditional sorts of evidence for dark matter, we should probably go there next.

8.5. The Dark Sector

The more brunette author claims some expertise on Twilight, having labored in its Zone for a couple of years and having experienced a sunset that lasted more than 40 minutes (from first contact to last, followed by half an hour of twilight and another half hour of sunrise) on a great circle return trip from Europe in November. That expertise fades rapidly at the approach of cosmic darkness.

We noted last year a fashion for Chaplygin gases, that is an equation of state $P = -A/(\rho^\alpha)$, which during 2004 seems to have evolved from OK (Bertolami et al. 2004, with $\alpha = 0$, a pure cosmological constant disfavored) to less OK, but yielding to a variant called (Dev et al. 2004) quartessence. Please, Joe, say it isn't so.

The other continuing trend was toward considering a single dark sector, with matter and energy as two different aspects of the same (theoretical) entity, though the very nice overview of both by Carroll (2004) should probably not be counted as an example. To be counted as a new example is *k*-essence, with the Lagrangian a function only of the derivative of the potential, not of the potential itself (Scherrer 2004). It shares some advantageous traits with a Chaplygin gas, and tends to suppress the (observationally unwanted) largest scale CMB fluctuations.

8.6. Dark Energies

A continuing trend here, pleasing but unexpected in light of the history of dark matter candidates, is the dominance of relatively mainstream candidates. By way of reminder, Einstein's infamous cosmological constant has an equation of state given by $P = -\rho$ (in suitable units, $c = G = 1$, and with no time or space dependence). We caught four papers during the year reporting various data sets that preferred this simple case to more complex or variable equations of state (Zhu et al. 2004a; Chae et al. 2004; Riess et al. 2004a, 2004b; Wang & Tegmark 2004).

The next level up is $P = -w\rho$, with w between 0 and 1. Two papers favored $w = 0.3$–0.6 (Vishwakarma 2003; Henry 2004). Nobody advocated $|w|$ greater than 1 this year, but this is the sort that eventually tears out your hair because the space around your head expands faster than hair can grow. It will also destroy black holes somewhat earlier when the poor things accidentally eat meals of this phantom energy (Babichev et al. 2004).

Even constant Λ or $w = 1$ will leave us quite lonely in the far future (Busha et al. 2003). Individual stars will be isolated by an era 336 Gyr ahead, and we will see no cosmic backgrounds, but only Hawking-like radiation from the horizon around us.

Two variants help with two very different problems, galaxy formation and the smallness of Λ compared to the expected zero-point energies of fields that might contribute to it. Mota & de Bruck (2004) point out that a "lumpy lambda" facilitates galaxy formation. The other is a bit more complicated, say Mukohyama & Randall (2004). Suppose you have a scalar field with the minimum of its potential at a negative value of the vacuum energy This mean you cannot ever actually reach that minimum and, say the authors, predicts $\Lambda = 10^{60}$ times the other terms in the Friedman equations rather than 10^{120} times them. The observations, of course, say that all the terms are about the same size.

Helpful in quite another way is an association between nonzero Λ and a finite length scale for gravitation. This should be useful in raising funds to continue testing $1/r^2$ down to the 20 μm regime (Sundrum 2004). Still closer to laboratory-based hearts is the suggested use of a Josephson junction to look for dark energy at home (Beck & Mackey 2004).

8.7. Dunkle Materie

We choose Zwicky's 1933 German name rather than the earlier Jeans/Kapteyn English one so as to be able to begin with a paper that points out that dark matter and MOND can both be thought of as an additional potential in Newtonian gravity. Why should we want to start there? Because the author's name is Dunkel (2004).

Just possibly the nature of the dominant stuff has been settled by observations. Two were reported. First is the detection of *INTEGRAL* gamma-ray lines coming from the direction of the Galactic bulge (Jean et al. 2003), discussed by Boehm et al. (2004) as due to the annihilation of 1–100 MeV partons. The second possibility is a signature of the decay of Kaluza-Klein axions in the 2–15 keV spectrum of the quiet Sun, observed by *RHESSI* (Zioutas et al. 2004).

Other decaying flavors have been supported by Sigurdson & Kamionkowski (2004) as a possible way of removing excess small scale structure in the universe (that is, solving the core/cusp and missing satellite problems) and opposed by Oguri et al. (2003) because they will tend to produce too many clusters of galaxies at large redshift compared to the number now.

Another dozen or so DM candidates seeing light of print in index year 2004 have been filed as "Respectable, out of fashion" (ROOF), "Dead, Still Kicking" (DSK), "Minor Constituents" (MC), and "Well, we hadn't thought of that" (WWHTOT).

ROOF dark matter candidates include (*a*) cosmic strings (with a very tentative detection in the variability of the lensed QSO 0957 + 561A,B; Schild et al. 2004, who thereby find a string density of 10^{22} g/cm), (*b*) self-interacting dark matter, which could, just barely, perhaps, solve the core/cusp problem (Markevitch et al. 2004), and (*c*) mirror matter, the same as our old friend shadow matter, with particle properties like those you know and love, but only gravitational interaction between them and us. Foot & Silagadze (2004) would like to have one mirror supernova per 10^7–10^8 yr in the Milky Way to fit some gamma-ray data.

The MC warm dark matter can somewhat improve fits of models of galaxy formation to real galaxies (Governato et al. 2004). Macroscopic superstrings might be seeds for structure formation (Brosche et al. 2003).

In the DSK category come all baryonic candidates, unless they are construed as contributing at the $\Omega = 0.02$ level or less. Faithful friends are old white dwarfs (Salim et al. 2004); magnetic fields to flatten rotation curves (Sanchez-Salcedo & Reyes-Ruiz 2004, who say this is not the answer and that rounding cusps to cores is not a magnetic process either); MACHOs, which exist, but with three papers tending to indicate that the numbers are even smaller than the gravitational microlensing searches first reported (Rahvar 2004; Drake et al. 2004; Belokurov et al. 2004). Baltz et al. (2004) reported one microlens candidate toward Virgo, and no, we will not attempt a statistical analysis. Kicking harder than the others is cool, dense molecular gas in the disks of spiral galaxies. Two "pro" papers (M. Ohishi et al. 2004; Moniez 2003) might be supposed to outweigh one "con" (Clarke et al. 2004), but we are betting on "con."

And there were two wonderful WWHTOTs: tachyon walls, useful for producing spiral structure, and out of the way of which you had better get now, because by the time you see them coming, it will be too late (Cocke & Green 2003) and clumpuscules (Heithausen 2004), another version of molecular gas in disks, but extra credit for the name.

9. BEEN THERE, DONE THAT (AGAIN)

This section and the next each contain a range of topics both far and near that have been part of the ApXX inventory for some years. How should the difference be described? Most of these items are relatively short. The first set of questions is sharply-enough posed that definite yes/no or nuclear/gravitational or mass/angular momentum or whatever answers seem possible, even if they have not yet been achieved. And (now the honest difference), the § 9 items are fun to write about, the § 10s, though very probably of greater importance, are not.

9.1. *P*(*D*)

$P(D)$, which means probability of displacement, is a way to use Poisson statistics to dig counts of faint things out of the noise, and the author who first heard about it from its radio astronomer inventor (Scheuer 1957) is always glad to read of its rediscovery, this year for an analysis of the Lyα forest of QSO absorption lines (Meiksin & White 2004). Radio astronomers these days generally have enough angular resolution to be able to afford to forget the $P(D)$ strategy, and when Seymour et al. (2003) report that they have seen an upturn in $N(S)/S^{-3/2}$ below the mJy level at 1.4 Ghz they mean they are counting individual resolved sources and discovering a new population which persists down to 30 μJy. It consists, they say, largely of star-forming galaxies at $z = 1$–2, plus some active galactic nuclei at the bright end. The earlier FIRST survey saw the same turn-up.

Friedman & Bouchet (2004), attempting to count far-infrared sources, are not re-inventors, though they chase the origins of $P(D)$ back only to 1974 and an article that had, by then, been hovering on the verge of publication for 7 years. Takeuchi & Ishii (2004) extend the method to non-random distributions of sources on the sky. And, since they are careful about credit, we hope they find lots.

9.2. Convection and Radial Velocity Measurements

Stars with convective atmospheres should exhibit slight net blueshifts because up-going cells are hotter and contribute more than their fair share of light. The more convective author was not the first to think of this (Trimble 1974, reporting a calculation done at Smith College in 1969), but it was independent. Should early type stars, with radiative atmospheres, have net blueshifts for the same reason? Presumably not, and Madsen et al. (2003) attribute the 3 km/sec they see in open clusters to upgoing shock waves. They do not mention any connection with the "K term"—the net comparable redshift reported for early type stars in the 1910s. It was some combination of the actual motions of Gould's Belt stars and gravitational redshift, and could have been used by Einstein as evidence for an expanding universe, but was not.

9.3. The G (and K) Dwarf Problem

This means that there are fewer metal-poor, long-lived dwarf stars in the solar neighborhood than you would expect from a simple model of chemical evolution. The problem was already adolescent (e.g., van den Bergh 1957) when we met it in 1972 and is shared by some, but not all, other stellar populations. M32 has a G dwarf problem (Worthey et al. 2004). And the solar neighborhood also has a K dwarf problem (Casuso & Beckman 2004), for which the best-buy solution is continuing infall of metal-poor gas, which dilutes the products of supernovae over billions of years. Alternatives include blowing out metals as they form, changing the ratio of big (metal-producing) stars to small (long lived) stars over the history of the Galactic disk, and concentrating star formation in the most enriched bits of gas.

9.4. High Latitude B Stars

Young stars are supposed to cling to the Galactic plane, where the dense molecular gas that made them lives. Some early type stars do not, and we have had for decades (Greenstein & Sargent 1974) three choices: let them be old; kick them out of the plane; or nudge enough gas up high to form some in situ. An early answer was "all of the above," and this is still the best choice, say Lynn et al. (2004), with a ratio of ejected to in situ formation stars about 5 : 1.

9.5. The Holmberg Effect

An ancient joke focused on Oort having many things named for him (constants of galactic rotation, comet clouds, limits on mass in the Galactic disk, and all), while Eric Holmberg had only the diameter (no, no, he is supposed to have responded…there is also the Holmberg radius). In fact there is also the Holmberg effect, not just one but two. More familiar is the relative deficiency of companion galaxies seen in the planes of edge-on disk galaxies. It appears again in modern data from the 2dF survey (Sales & Lambas 2004). Knebe et al. (2004) attribute the effect and a similar phenomenon for the distribution of galaxies around clusters to large scale structure having formed by infall along filaments. Willman et al. (2004) apparently ignore this Holmberg effect in their estimate of the number of dwarf spheroidal companions to the Milky Way still to be found, saying that most will be at low Galactic latitude.

The other Holmberg effect is the correlation of colors of galaxies in close pairs. It, too, is still found in modern samples (Allam et al. 2004; Franco-Balderas et al. 2004). The Holmberg diameter (or radius!) of a galaxy is defined as extending out to a particular level of surface brightness. It inevitably becomes model dependent at large redshift.

9.6. The Proximity Effect and the Ultraviolet Background

The proximity effect was also good for a giggle in its day (somewhere around Thursday at a BL Lac conference in Pittsburgh a couple of decades ago). The idea is that, when you examine spectra of QSOs at large redshift, the number of absorption features you find increases with z (faster than just a volume effect), except that there is a deficiency very close to the source emission redshift. This is attributed to ionization of nearby clouds by the QSO itself and can be used to estimate the intergalactic UV flux due to the other sources around by how far out the single QSO dominates things.

The deficiency isn't always seen where you would expect it, either along the line of sight to a QSO or transversely (Schirber et al. 2004; Croft 2004), but there are several ways out of the contradiction. Where it is seen, it can lead you into a different sort of contradiction about star formation rates long ago and far away (Nagamine et al. 2004a vs. Maselli et al. 2004). Francis & Bland-Hawthorn (2004) find that gas proximate to a QSO can be ionized away even if it is inside the potential well of a dwarf galaxy.

Meanwhile, Wyithe & Loeb (2004) succeeded in doing the same calculation backwards, to demonstrate that the local intergalactic medium around a $z = 6.3$ QSO must have been at least 10% neutral (implying two stages of reionization in the early universe). How do we know they succeeded? Well, they got a *Nature* News and View (Djorgovski 2004) focusing on their result, which ranks somewhere between mention in these reviews and a Nobel Prize.

The green dot paper on this topic got indexed under Gunn-Peterson, Stromgren, and Proximity, because the authors (Mesinger & Haiman 2004), looking at the same $z = 6.3$ QSO, conclude that the Gunn-Peterson (absorption) trough has a local hole, 6 ± 2 Mpc deep (comoving) right around the QSO, which they call a Stromgren sphere rather than a Proximity sphere. They also conclude that much of the gas (at least 20%) outside that sphere of influence is neutral.

So why was this all worth a giggle? Well perhaps you had to be there. And do the recent results mean that we now have good numbers for the amount of ionizing radiation floating around at large redshift and where it came from? Not entirely. We found two votes for "more at $z = 3$ than at $z = 6$" (Bouwens et al. 2004; Songaila 2004), vs. one vote for "same at $z = 3$ and 6, but different kinds of galaxies contributing" (Dickinson et al. 2004).

On the other hand, as long as you don't insist on numbers that agree to within their nominal errors, there is, we think, a consensus for more UV coming from star formation at the largest redshifts ($\gtrsim$4, say) and more coming from AGNs later (Malkan et al. 2003; Fujita et al. 2003; Meiksin & White 2004).

9.7. Blue Loops

Do the evolutionary tracks of massive stars loop back from cool red giant or supergiant temperatures to higher ones? Yes, though the stars care about details of composition, convection, mass loss, and opacity (Xu & Li 2004; El Eid et al. 2004). Do they always loop back far enough to make Cepheids at the temperatures and in the stellar populations where they are seen? No (Petterson et al. 2004, who also find that evolutionary masses are always a bit larger than pulsational masses).

9.8. Making Carbon Stars

It is easier for newly-synthesized carbon to outnumber the oxygen in a star if there wasn't much of either to begin with. The expected increase in ratio of numbers of carbon-rich (C) to oxygen-rich (M) giants with decreasing total metallicity and with increasing galactocentric radius has been found again by Battinelli & Demers (2004b) and Noguchi et al. (2004). Many of the stars exhibit light curves with both periodic (10–100 days) and secular (decade scales) changes (Dusek et al. 2003).

Dwarf carbon stars might have been relegated to § 11.4 ("Countdown"), because not so long ago there were 2 or 3 and now there are umpteen. They make up about half of the (apparently) faint carbon stars in early-release SDSS (Downes et al. 2004). They might also have lived with "who ordered that?" because Martin Schwarzschild found them almost as distasteful as I. I. Rabi did the muon. But in fact they are really fugitives from § 6.2 (binary stars), because they are the products of pollutional mass transfer from evolved companions that were once themselves proper, giant carbon stars and are now gone (in space, luminosity, or both).

9.9. Equipartition

This noble (Nobel?) sounding concept might mean we all get the same numbers of citations to our papers, which is manifestly false. In fact, it is the idea that, within sources of synchrotron radiation, the energy densities in magnetic field and in relativistic electrons will be the same as a result of on-going interactions. Equipartition comes very close to requiring the minimum possible energy in the sum of the two. Are real sources like this? You can check, if they are also sources of inverse Compton radiation on a known photon sea, because you then have a separate measure of the electron component. And the answer is sometimes yes (Belsole et al. 2004, on three 3C radio galaxies at z near 1). It has been no for some other sources in other years.

9.10. Chamberlin-Moulton Live(s)

These were the chaps who, late in the 19th century, declared that our planetary system had formed out of material dragged out of the Sun by a close-passing star. The hypothesis, which would make planets exceedingly rare, was motivated by considerations of conservation of angular momentum (always a good thing). It was later falsified by the presence of deuterium in the planets, meaning their substance had never been any place hot enough for deuterium to fuse. This objection does not apply if you consider proto-stars not yet heated to 10^6 K, and the rarity objection won't apply either if you think about the case where the proto-stars are still very extended and crowded into a proto-stellar clusters. (Oxley & Woolfson 2004). Not all the planets made this way will survive the dissolution of the cluster, but enough will to account for the ones we see, says Woolfson (2004).

Whether you want the (s) in the subsection heading depends on whether you think of Chamberlin-Moulton as one hypothesis or two people.

9.11. The FIP effect

FIP is not an obscure character from Dickens but a First Ionization Potential, and the idea is that elements will be over-represented in stellar chromospheres and coronae if they are easy to ionize and so easy for electric fields to lift up. Do stars do this? Some yes, some no (Sanz-Forcada et al. 2004, comparing stellar coronae with the photospheres of the same stars and not just with solar abundances). The yeses, however, include the Sun (Mason et al. 2004, confirming abundances in He^3-rich flares first pointed out by Price 1973). Other FIPs are Proxima Centauri (Gudel et al. 2004) and the secondary of V471 Tau (Still & Hussain 2003). Raassen et al. (2003) and van den Besselaar et al. (2003) however report a pair of active M dwarf binaries whose *SMM* spectra imply that elements with large first ionization potentials are enhanced in their coronae, an inverse FIP effect. Well, you should see some of the things that we get backwards.

9.12. Unidentified Sources

This means ones that have no optical counterpart, and our favorite is the unidentified TeV source in Cygnus that is not the X-ray binary Cygnus X-3. It is real (having been recorded by Whipple, HEGRA, and a detector in the Crimea), variable, dignified by the name J2032+4130 (Lang et al. 2004), and in a sufficiently crowded region of the sky that many optical, X-ray, and EGRET counterparts are possible. In the days when its existence was less certain and its identity with Cyg X-3 more certain, it was widely thought to be emitting Cygnettes, hadron-like particles capable of getting from there to here in a straight line. J2032 is currently unique. Real TeV sources are sufficiently rare that the others are all fairly obviously (and, we think, correctly) identified with well-known objects like the Crab Nebula and Mrk 421.

Unidentified EGRET sources are still a large class. Population properties indicate that some are AGNs (Nolan et al. 2003) and some microquasars (Romero et al. 2003). The Blazar class of AGNs has yielded 88 specific identifications so far (Sowards-Emmerd et al. 2004), including BL Lac itself (Beckman et al. 2004). Cases have also been made for Wolf-Rayet stars (Gal'per & Luchkov 2004a), flare stars (Gal'per & Luchkov 2004b), and million-year-old pulsars fleeing from Gould's Belt (Cheng et al. 2004).

What about X-ray sources? Almost 90% of the bright ones (from the *ROSAT* catalog) have "best bet" optical counterparts, with obscured AGNs a likely reservoir for most of the rest (Revnitsev et al. 2004a). The set of 79,763 fainter *ROSAT* sources still needs a good deal of work, with 85% unidentified, minus the one new candidate low-mass X-ray binary pointed out by Suchkov & Hanisch (2004). Only 67,803 to go, guys! *Chandra* and *XMM* are not doing all-sky surveys and so automatically yield many fewer unidentified sources. The ones near our Galactic center might be fast-moving knots from supernovae (Bykov 2003).

The qualifications "best bet" and "we think" should not be forgotten. RX J05335−6854.9 has just been demoted from a supernova remnant with central neutron star in the LMC to a dMe star in the Milky Way (Lowry et al. 2004).

9.13. Unidentified Spectral Features

"Unidentified" in this context means we aren't sure which atom, molecule, or solid goop to blame and are aware of the futility of inventing ISMonium to account for the emission or absorption. The interstellar medium at high density is indeed the richest source of these. For instance, 120 of 218 3 mm lines from Sgr B2 have gone unclaimed (Friedel et al. 2004), though only one of 414 at 6–10 mm in Taurus Molecular Cloud 1 (Kaifu et al. 2004). Since HCCNS, C_6H, and C_3S are among the dozen-plus molecules already recognized in TMC-1, it must be something we don't think of very often.

Infrared often seems to be the home of the unidentified (Gibb et al. 2004 on *ISO* spectra of ices, with, again the obvious molecules having already claimed their share of features), but we note one up for grabs in the ultraviolet near 990 Å coming from the Io plasma torus (Feldman et al. 2004a).

One might think of unidentified features blurred until they are no longer separable as making up "missing opacity" (that is, light has more trouble getting through stuff than you would suppose after adding up all the known absorbers and scatterers). Excess opacity is an ancient and honorable part of the ultraviolet (Castelli & Kurucz 2003), where it is a contributor to uncertainties in calibrating observers' vs. theorists' color-magnitude diagrams, but Gibb et al. (2004) describe the same phenomenon in the infrared.

9.14. The Earth Goes around the Sun

The first evidence was James Bradley's 1729 detection of the aberration of starlight. The 2004 version comes from an observation of the Compton-Getting effect in the fluxes of 6 and 12 TeV cosmic rays recorded at the Tibet Air Shower Array detector (Amenomori et al. 2004). In case you haven't gotten a Compton lately, it works like this: for an intrinsic spectrum shaped like $E^{-\gamma}$, you get an asymmetry

$$\Delta I/I = (\gamma + 2)(v/c)\cos\theta$$

where v is your velocity, not that of the cosmic rays.

Also under "difficult methods" we recorded an attempt to measure the size of the orbit of NY Vir, one of whose components is a pulsating sdB star, by observing phase shifts of the pulsation modes, expected to be less than 1 sec of the 174, 179, and 186 sec periods (Kilkenny et al. 2003). They failed.

Reported during the index year, but considerably after the fact, were "Tycho's observations of the orbits of Cassiopeia and a comet" (Benecke 2004). But if you feel inclined to go out and try this very difficult observation for yourself, please rethink your position. It was published in the *Annals of Irreproducible Results*, and if you make the attempt, we will sing the entire seven-minute setting of "Trees," even the part clearly marked "Refrain."

9.15. Jets and Counterjets

Many strong extragalactic radio sources, beginning historically with Cygnus A, show a well collimated jet, parsecs to kiloparsecs long, coming out of one side of a compact nucleus. The ancient question is whether these are intrinsically one-sided as opposed to an artefact of Doppler boosting toward us and deboosting away. The votes we caught this year were all for intrinsic symmetry. Bondi et al. (2004) report that parsec-scale jets are either one-sided with lots of polarization or two-sided with little polarization, as if the former were being seen end on and the latter more or less in the plane of the sky. All BL Lacs (supposedly end on anyhow) are the one-sided sort. Arshakian & Longair (2004) note that, if you assume intrinsic symmetry, then you derive for the jets in Fanaroff-Riley I and II radio galaxies and quasars, respectively, the perfectly reasonable average jet speeds of 0.54, 0.4, and $\gtrsim 0.6c$. Miller-Jones et al. (2004) warn us, however, that, in the case of Cygnus X-3, where you know the jet v/c and its angle with our line of sight independently (from changing structure), the forward/back flux ratio is not the expected function of $(v/c)\cos\theta$. This is, of course, an X-ray binary, not an AGN, for which the rules may be different.

9.16. Unifications

A firm answer of "sometimes" to the counterjet issue obviously demands an equally firm answer to the question of unification in general. This, in case you haven't been reading much except politics the last year or two, is the idea that many properties of the various classes of AGNs can be understood in terms of the orientations of jets, accretion disks, and obscuring tori relative to our line of sight. The dozen relevant papers this year constitute a typical baker's. We saved you one vanilla (a yes, for Seyfert galaxies, because the type 1's indeed have face-on disks, with a mean angle of inclination = 17°; Bian & Zhao 2004) and one chocolate (a no for radio galaxies and quasars, whose different structures and asymmetries cannot be matched by varying only the angle of inclination; Gilbert et al. 2004), and ate the rest ourselves.

9.17. Turnip Blood

Can you get energy out of a black hole? Sure (§ 9.19), if you are prepared to sacrifice your plasmas, planets, or pleisosaurs. But can you somehow, in practice, extract the rotational kinetic energy part of the mass-energy, which general relativity says is not irreducible? The traditional, mainstream answer has been yes, using processes that are perhaps really a continuum, from breaking up something within the ergosphere (associated with the name of Roger Penrose) to threading magnetic field lines through a plasma near the horizon (associated with the names of Roger Blandford and Roman Znajek).

A pair of papers by Komissaro (2004) holds by the traditional wisdom, making relativistic jets from a black hole and a magnetic field, though the author points out that regarding the event horizon as a unipolar inductor (the so-called membrane paradigm) gives the wrong answers for energy and angular momentum outflow. More phenomenologically oriented theorists tend to assume the correctness of the basic picture while focusing on detailed gas flow patterns (Ghisellini et al. 2004).

At this point, we become confused, in something close to the technical sense of more than one source (or anyhow paper) per beam width.[13] Start with a good quote (Punsly & Bini 2004), "any analysis based on force free, degenerate electrodynamics near the event horizon is serious flawed," followed by a "yes, we can extract" from Semenov et al. (2004, with Punsly among the al.'s), followed by a "no" in the sense that you never seem to get a positive outward energy flux at the horizon (Punsly 2004 reacting to Levinson 2004).

You and we perhaps noticed at about the same moment that (at least) one author appears to be riding both horses, perhaps while changing them in midstream. The last word, therefore, at least for this year, goes to McKinney & Gammie (2004), who are relatively new to this particular fray. They conclude that you (or anyhow they, after more detailed calculations) never get a net outward energy flux at the horizon. Some models indeed have some electromagnetic flux coming out, but there is more mass-energy going in as accretion.

9.18. Turnip Breath

Can you get information out of a black hole? You don't need us to tell you either that Stephen Hawking (2004) has changed his mind and now says "yes" or that there are not yet any published papers to cite in support of the ideas. We mention

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[13] Any comments about our beams being too wide will be taken into account in deciding who to cite in Ap05.

the issue here primarily in order to record our losing entry in *New Scientist's* "What should Hawking think about next?" competition. Clearly, having solved the first two of the classic human sustenance problems of how shall we eat (in an informed fashion) and what shall we eat (Hawking radiation), it is time for him to tackle the third main existential question, Where shall we do lunch?

9.19. ADAF, ADIOS, and Other Forms of Black Hole Accretion

Sometimes an accreting black hole radiates every bit as much as Eddington would have allowed or even more (Kawaguchi et al. 2004 on Ton 5180, whose disk is about as massive as its black hole). Sometimes, when the available inflowing gas is capable of more, you at least get the maximum possible luminosity, and the rest comes out as kinetic energy of winds and jets (Malzac et al. 2004 on XTE J1118 + 480; Fukue 2004 on microquasars and narrow-line Seyfert 1 galaxies at their brightest). And sometimes the available gas is rationed,[14] so that you are glad the radiative efficiency can be as high as 50%, with carefully arranged, magnetically disrupted disks (Narayan et al. 2003).

But other black hole sources are remarkably faint given the amount of gas available for accretion. The quintessential example is our own beloved Sgr A^*, so modest in its output that a detailed fit requires both very little mass inflow and what there is to be radiatively inefficient (Yuan et al. 2003). But Yuan et al. note also that the radiative inefficiency requires better models than the ones currently afloat in the literature. Some version of not much stuff and inefficient even for what is there applies also to X-ray binaries in quiescence, the mildly active galaxies called LINERs, Fanarof-Riley type I radio sources, and even some BL Lacs (Falcke et al. 2004).

The older picture (yet still new enough that even the Polaroid version hasn't faded yet) is called ADAF, for Advection-Dominated Accretion Flow. This is perceived to provide the required faintness for the 14 of 15 known transient X-ray binaries that have been seen in quiescence (Tomsick et al. 2003), for a large sample of AGNs with "known" black hole masses and total luminosities (Merloni et al. 2003), and for BL Lac itself (Cao 2003). The idea in all cases is that mass accretion occurs at something like the Eddington rate, but most of the energy goes down the tubes, rather than being radiated away as it goes (perhaps to radiate another day as turnip blood, turnip breath, or Hawking emission).

"Radiatively inefficient" is, of course, more or less the same thing as "adiabatic" (at least in one direction) though the description briefly puzzled us, as used by Blandford & Begelman (2004) in their fleshing-out of a second such mechanism, called ADIOS, for adiabatic inflow-outflow solutions. The underlying ideas can be found in Shakura & Sunyaev (1973). The most important difference from ADAF is that radial energy transport drives an outflow that carries away mass, angular momentum, and energy in a way that allows the disk to remain bound to the black hole, while in ADAF it is likely to escape to infinity. Observed accretion disks certainly vary, but they do seem to stay around most of the time. The authors note that they still need to add to their calculations (*a*) episodic arrival of material at the disk edge, (*b*) magnetic fields, and (*c*) three-dimensional structure. Gierlinski & Done (2004) remark that the next generation of black hole accretion disk models should have self-consistent calculations of viscosity from magnetic turbulence.

9.20. The X-Ray Background

This might also be called unsourced identities (the opposite of unidentified sources) given that, over the years, the community has repeatedly said that individual X-ray sources indeed add up to the observed background, and then backed away, saying you must count still fainter with the next generation of satellites. This year, the sum of its parts (from *XMM*) is back down to about 80% of the whole (De Luca & Molendi 2004).

10. DO I HAVE TO EAT MY LIMA BEANS?

Succotash is not the answer. It still tastes of lima beans, not to mention the waste of all those kernels of maize that might otherwise have lived useful lives as popcorn, to the joy of cinema goers and dentists[15] everywhere.

In any case, this section contains both important topics that were put off because they are hard to write about and a number of individual green dot papers.

10.1. Nucleosynthesis

All the usual processes were alive and well during the year, but the green dot to Fulbright et al. (2004) for the first star (the red giant Draco 19) which has no detectable *s* or *r* process products down to $[(s+r)/\mathrm{Fe}] = -2$. It is metal poor at $[\mathrm{Fe/H}] = -2.95$ (a record for a dwarf galaxy) but nowhere near so metal poor as some Galactic stars that do have *s* and/or *r* process nuclides, and none of the customary sorts of supernovae can be expected to yield the abundance pattern seen in Draco 19. The poverty record continues to belong to HE 0107−5240 at $[\mathrm{Fe/H}] = -5.3$. Papers concerning it during

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[14] Left and right sided jets on alternate days, like petrol during the 1974 oil crunch, which you are far too young to remember. Alternating jets sides, or flip-flopping is, of course, also another possible answer to the counterjet question.

[15] The source of this bit of wisdom is not the keen amateur dentist of Ap02, but Dr. Jean-Pierre Bouquet of Chevy Chase, Maryland, who informed the author with the longer teeth that his practice on Mondays always included lots of patients with sliced gums because they had gone to the movies, eaten popcorn, and chomped down on a sharp-edge hull. He also pointed out that, unlike many other health care professionals, a dentist's interests run parallel with those of his patients, because it costs more to save a tooth than to yank it out and insert wood, ivory, or whatever George Washington used. The Faustian Acquaintance of Ap03, who in the intervening year has replaced portions of his ears, eyes, knees, and teeth, confirms this.

the year divided between those that said that no very obvious combination of inputs matched well (Bessell et al. 2004, reporting [O/Fe] $= +2$) and those that said their new way was just what was needed (Suda et al. 2004, who need both a nearby supernova in the cloud during formation and an AGB companion; Christlieb et al. 2004). The nucleosynthesis page held 58 papers, from which a handful of well-remembered items.

1. Primary nitrogen: In general, N^{14} and N^{15} are made from carbon and oxygen during CNO cycle hydrogen fusion, but the abundance patterns at very low metallicity indicate that some must come from stars that really had no C or O to start with. Isrealian et al. (2004c) confirm existence in this sense and indicate that there are processes in intermediate mass stars that can do the job.
2. B^{11} made in stars: Yes, says Shapiro (2004), via $N^{14}(n, \alpha)B^{11}$, using what he calls epithermal neutrons around 2 MeV. This is the way the neutrons are initially liberated, in, e.g., $C^{13}(\alpha, n)O^{16}$. There was also a paper on deuterium production in stars, but we managed to lose it.
3. $\Delta Y/\Delta Z$, meaning how much additional helium do stars add to the universe for each increment of metals? $\Delta Y/\Delta Z = 0$ between the formation of the Sun and the Hyades (Pinsonneault et al. 2003); $\Delta Y/\Delta Z = 100$ between populations in the globular cluster ω Cen (Norris 2004). And the average is, may we have the envelope please, $\Delta Y/\Delta Z = 2.8$ (Izotov & Thuan 2004, who looked at a number of compact galaxies and H II regions) leaving primordial helium happily at $Y_p = 0.2421 \pm 0.0021$.
4. The source of Al^{26}. We caught a re-evaluation of the *RHESSI* data (Prantzos 2004), requiring input from Wolf-Rayets or some source other than just Type II supernovae, and a plug for sources in SN Ib/c from binary WR stars (Higdon et al. 2004). Novae are out this year, in that V4332 Sgr allows only an upper limit of 10% as much as the Al^{27} ejected (Banerjee et al. 2004).
5. A third neutron-capture process which is neither *r* nor *s*, and which the inventors (or discoverers?) Travaglio et al. (2004) have dubbed the "lighter element primary process."

If you would like to add a sixth finger to this hand, feel free to choose your own, celebrating that fact that for the first time ever the more synthetic author has a colleague of the same gender in the very next office, who happens also to be a sort of Anne Boleyn fan.

10.2. Chemical Evolution

Nucleosynthesis is making sure you know at least one process that will produce reasonable amounts of each known nuclide. Chemical evolution is putting together all the stars and garters from $t = 0$ to the present and making them add up to the galaxies we see. Or perhaps it is the whole Disney World of which the nucleosynthetic processes are the individual crickets, mice, cats, and dalmations. The papers tend, therefore, to talk about stellar populations, metallicity, and classes of events rather than individual stars, elements, and explosions. Even the simplest grand scheme, a homogeneous closed-box model, fits quite a range of galaxy properties (Bicker et al. 2004), but increasing complexity is more popular (Moretti et al. 2003).

Traditional issues about which one might want to say something include (*a*) the apparent total absence of surviving Pop III stars (zero metallicity), (*b*) the G dwarf problem, (*c*) the weakness of age-metallicity correlations in many stellar populations, and (*d*) the remarkable metal-richness of QSO gas at even the largest redshifts. Here is one "Garrison Keillor" paper on each: (*a*) Beasley et al. (2003), (*b*) Worthey et al. (2004), (*c*) Friel et al. (2003), (*d*) D'Odorico et al. (2004). Notice that these issues all somehow have a similar underlying flavor, that the abundance of heavy elements hasn't changed as much with time as you might expect. To a certain extent, they can also have similar solutions, for instance a population of stars consisting almost exclusively of very large masses (Moiseev et al. 2004b), or initial rapid input of metals, so that your scenario doesn't really start from $Z = 0$ (Di Matteo et al. 2004).

We noticed in addition two slightly less classic issues that, upon consideration, are flavored with some of the same spice (thyme, we suppose). (*e*) It is not entirely easy to get as large a ratio as is seen of metals in intracluster X-ray gas to stellar luminosities producing it (Portinari et al. 2004), and (*f*) only in voids do you find QSO absorption gas that has been enriched only by Pop III ejecta (Simcoe et al. 2004). And even there they do not find a universal metallicity floor down at least as far as [Fe/H] $= -3.5$.

10.3. Interstellar Media

The biggest green dot goes to Dwek (2004a) for showing that interstellar metals really can exist in the form of elongated needles. These must, however, be made in supernova ejecta at low temperatures (Dwek 2004b), which is why they are seen in SCUBA observations of Cas A and Kepler's SNR. They are not available for thermalizing and isotropizing radiation from stars into a cosmic microwave background.

And of the other 108 ISM papers indexed during the year, most of our favorites deal with things that exist but shouldn't (unstable temperature phases, Kanekar et al. 2003), or don't exist but should (high velocity clouds around other galaxies, Pisano et al. 2004). M31 seems to have a supply (Thilker et al. 2004). The gas comes from at least three reservoirs, debris from tidal disruptions, condensations in the cooling flow of the Local Group, and gas confined in dark matter halos of the star-free "missing satellites."

It is your job to decide which category each of the rest of these belongs to:

- The λ2175 feature appears in Milky Way spectra (Iglesias-Groth 2004) and in QSO absorption features (Wang et al. 2004d), but not in the gas around the QSOs themselves (Czerny et al. 2004) or around gamma-ray bursters (Stratta et al. 2004). The key issue is whether the environment permits the existence of very small grains, not much more than large molecules, though we shudder at the name “buckyonions” for these (Iglesias-Groth et al. 2004) and have honorably so shuddered in the presence of the authors, not just behind their backs.

- Amino acids, with Bernstein et al. (2004) explaining why they are, at least, rare.
- Real time changes in an extended nebula. The announcement (McNeil et al. 2004) came from Paducah, Kentucky, and resulted in the name McNeil’s nebula. The nebula has come and gone in the past, and there may be similar events among the FUOrs, EXors, *IRAS* sources, and such (Herbig et al. 2001). We mention only one of the prompt explanations (Reipurth & Aspin 2004), which is of the “flashlight along the brick wall” variety.
- Fine structure on scales down to 100–2000 AU (Chatterjee & Cordes 2004). They see it in changes in the morphology of bow shocks around high velocity pulsars. There are even reports of 10–100 AU scale structure, though it is rare, from H I absorption in high velocity pulsars (Stanimirovic et al. 2003). Cho & Lazarian (2003) are not quite sure the phenomenon exists, but are happy to model it as MHD turbulence in partially ionized gases. Well, that is what theorists are for! Not specifically MHD, but modeling things that might exist, just in case. And if you want to hear all sides on this, Hartquist et al. (2003) call the AU-scale structure the “most remarkable recent ISM discovery” and also have some models consistent with particular high density features lasting only about 10 years.
- Interstellar urea (Raunier et al. 2004), a tentative discovery in the ice of proto-star NGC 7539 IRS 9. And we’ll thank you to keep your rude jokes to yourself until we can think of a better one than “well, extreme cold has that effect on lots of people.”
- Interstellar diazenylium = N_2H^+, seen by Rodgers & Charnley (2004) and interstellar $CH_2OHCHOHCHO$, with a limit from Hollis et al. (2004). The paper also reports new discoveries of propenal and propanal, but wouldn’t you like to be able to go around saying, “I’ve been looking for interstellar cho-cho-cho, so we can cha-cha-cha?”
- The merely triply deuterated CD_3OH (Parise et al. 2004) has nearly lost its power to surprise.
- Really cold dust, seen only at really long wavelengths. A balloon flight recorded 5–15 K stuff in Orion exceeding the mass of the warmer *IRAS* dust by a factor 5–300 (Arimura et al. 2004). There are lots of other sorts of dust as well, whose production is reviewed by Kwok (2004).
- We will jump ship in the local bubble so as to shorten the journey home. It (1) extends to 55–100 pc (Lallement et al. 2003), but has tunnels connecting it to other cavities, (2) is remarkably undersupplied with H_2 (Lehner et al. 2003, a *FUSE* result), (3) has a bit more deuterium, $D/H = 1.5 \times 10^{-5}$, than other, longer sight lines (Wood et al. 2004a, *FUSE* again), and (4) is arguably a gift of the stars in Gould’s Belt (Welsh et al. 2004).

10.4. The Milky Way

This is surely the galaxy we all know and love best, so no surprise that it has four green dots, though it is just conceivable you will not find them to be the most significant of the 109 Galactic papers recorded this year.

The shape of the dark matter halo. How can you measure the shape of something you cannot see? Well, you can’t, says Helmi (2004a), at least from the morphology of the star streams coming off the dwarf spheroidal galaxy in Sagittarius. There was, however, also one vote for oblate (Lemon et al. 2004, from the star streams) and one for prolate (Helmi 2004b, from the star streams). Prolate would be nice, because it would explain the Holmberg effect (§ 9.5) as the result of there simply being more stuff along the apparent minor axes of galaxies. But we dotted Sirko et al. (2004), who report a velocity ellipsoid for 1170 blue horizontal (old, halo) stars in SDSS that is as near a sphere as one could hope for, $\sigma_{r,\theta,z} = 101 \pm 3$, 98 ± 16, 107 ± 16 km/sec.

At least no one seemed to doubt that we have a dark matter halo. Freeman (2003) is the paper to read if you’re having only one this year. Also of interest, (1) the closing of the last MACHO window (Yoo et al. 2003), (2) a total mass near $10^{12}\ M_\odot$ out to 90 kpc (Bellazzini 2004), with circular velocity flat at 200 km/sec from 35 to 100 kpc, and (3) two reports of measurements of the surface mass density in our disk, in comparison with the known material in stars, gas, and all. The two (Korchagin et al. 2003; Holmberg & Flynn 2004) concur that what you see is what you get, with little or no possibility of significant disk dark matter near the solar circle. But the numbers they give are 42 ± 6 and $56 \pm 6\ M_\odot/\mathrm{pc}^2$. Thus they also agree on the size of the uncertainty, but the two ranges don’t quite overlap. Concerning the possibility that the halo DM is entities of $10^6\ M_\odot$, it seems, remarkably, that the evidence in favor, stellar velocity dispersions vs. age, hasn’t changed much in decades (Hanninen & Flynn 2004).

Evidence for assembly. We dotted as exciting the discovery of the parent dwarf galaxy of the stellar ring announced a couple of years ago (Martin et al. 2004b). It is called Canis Majoris, and we would like to vote for it, though Momany et al. (2004) say that the apparent concentration of stars is just a warp in the Galactic disk. The ring, at least (Newberg et al. 2002), apparently survives. A Galactic past more checkered than the present is indicated by two populations of globular clusters, made, say Van Dalfsen & Harris (2004), in the protopieces and in the assembly process.

An age-metallicity correlation. The difficulties in finding these are noted in § 10.2 above. Even when you have very good abundances and ages (Nordstrom et al. 2004 with 14,000 F and G dwarfs, a green-dotted paper in its own right) our stellar neighbors can have come originally from far around, and star-forming gas really does have a radial composition gradient in spiral galaxies (Andrievsky et al. 2004, and MANY others). None the less, Bensby et al. (2004) report that thick disk stars cover an age range of at least a few Gigayears, and the younger ones have more heavy elements. We also green-dotted Pont & Eyer (2004) who find a nice, tight correlation of heavy element abundances with ages for field stars (mostly thin disk) and say that earlier failures to find this arose from inaccurate ages for stars reported to be old and metal rich as well as for those reported young and metal poor. Their chronometer is chromospheric activity, and if you are sure, *sure*, SURE that activity isn't larger in metal-rich stars, we can all go home.

For what it is worth, star clusters (whose ages are well determined compared to most single stars) have their Fe/H ratios better correlated with galactocentric distance than with age (Tadross 2003).

Habitable zones. Some places are nicer to live than others,[16] and within the Milky Way, the best bet is an annulus 7–9 kpc from the center, say Lineweaver et al. (2004). Luckily both Irvine and Palo Alto are within that zone, and Tempe and Victoria marginally.

Spiral arms. Four in our gas and two in our stars, say Martos et al. (2004). A new gaseous one at 17–25 kpc is currently the outermost known in the Milky Way (McClure-Griffiths et al. 2004). Part of it shows in a 1969 H I map by F. J. Kerr. No associated stars have been recognized. Coherent magnetic field extends at least 8.5 kpc along a nearby arm (Caswell et al. 2004), and the field reverses directions between arms (Weisberg et al. 2004). The ordered field is stronger within the arms than between (Han et al. 2002), though we remember reporting the opposite a few years ago. How fast can the real fields change? Nobody said this year, but probably not that fast.

*Sgr A** is our own infant mini-AGN. It is gravitationally lensing its little heart out all the time. We just happen to be at the wrong place and time to see the results (Bozza & Mancini 2004). A suitably placed green dot would brighten by 32 mag on 18 January 2018.

In general Sgr A* is very faint for its mass at all wavelengths (Yuan et al. 2003), but the infrared counterpart has finally been resolved out from the nearby stars this year (Ghez et al. 2004). The 7 mm radiation is coming from no further out than $24R_{\rm Sch}$ (Bower et al. 2004), and at 1.3 mm one might conceivably see down essentially to the horizon. The positron annihilation, on the other hand, comes from an extended spherical region (Casse et al. 2004b, an *INTEGRAL* result) and not from near the black hole or from the Galactic ridge line as previously advertised. The positron source has not been identified, but there is lots of energetic stuff in that part of the world. The EGRET gamma rays are apparently from π^0 decay (Tsuchiya et al. 2004a, a CANGAROO observation), and dark matter decay could be the source of photons at 0.1–1 TeV (Kosack et al. 2004, reporting results from the Whipple detector).

10.5. Other Spirals

Coveted green dots went three places, first to the recognition within the enormous SDSS galaxy sample that there is a rather abrupt change in galaxy properties (colors, morphologies, gas content, history of star formation, and correlations of these) at a stellar mass near $3 \times 10^{10}\ M_\odot$ (Kannappan 2004; Wyse 2004). Second is a measurement of halo shapes from gravitational lensing (Hoekstra et al. 2004). The average eccentricity is $e = 0.33$, somewhat rounder than the light (next item), but not enormously so. The lenses are dominated by galaxies around $10^{12}\ M_\odot$, which one expects to be quite round.

The unequivocal detection of light coming from the halos of edge-on spirals is number three. Zibetti et al. (2004) and Zibetti & Ferguson (2004) found it necessary to stack the images of 1047 SDSS galaxies to see that the average $b/a = 0.6$, as predicted by ΛCDM models (Helmi 2004a) for galaxies like the Milky Way. The colors, however, are odd.

Barred spirals. Nearly all of them are, if you look hard and long (meaning in the infrared) say Laurikainen et al. (2004) and Grosbol et al. (2004). But rather few of them are double barred (Moiseev et al. 2004a), though Corsini et al. (2003) report on the first case with two pattern speeds. Although the absence of very conspicuous bars in most spirals was one of the early arguments for massive dark, spheroidal halos around disk galaxies, the sorts of bars actually seen can co-exist with such halos (Valenzuela & Klypin 2003). Nor are such bars destroyed by central black holes (Shen & Sellwood 2004). Bars were about as common at $z = 1$ (40% with a particular threshold; Elmegreen et al. 2004) as they are now.

S0 galaxies are losers. They have lost their gas, their star formation, and their arms, to the point where a face-on one is hard to distinguish from an E0 (van den Bergh 2004). When and how did this happen? Divergent views during the year as usual. The green dot went to Vogt et al. (2004) for their nice, clear statement that it happens when disk galaxies fall into clusters, in a three stage process, and indeed isolated S0's are rare (Stocke et al. 2004), compared even to ellipticals. But Hinz et al. (2003) and Falcon-Barroso et al. (2004) require a more complex combination of processes. And Dieman et al. (2004) conclude that all these are on the wrong track, because S0 morphology is established before clusters form.

10.6. More Galaxies and How They Grew

Large samples yield new types, not to mention many types, and SDSS is no exception. The first sorting yielded about 3000 types, with nine principal components needed to systematize them (Kelly & McKay 2004). We are not quite sure whether

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[16] You may have noticed that, although your authors first met in College Park, Maryland, both are now permanent Californians.

their new type is the same as the new type of Bentz et al. (2004) or not. Both are compact, bright, and blue, and can have strong Lyα emission, though not of the AGN sort. There are also passive (red) spirals at $z = 0.14$–0.20 (Goto et al. 2004). What else is there, or is there not?

The core/cusp problem. ΛCDM halos have central density profiles that tend to rise to sharp cusps (whether you are thinking about individual galaxies or whole clusters), while the light distributions tend to flatten to isothermal cores. We do not stay awake nights worrying about this (indeed the more somnolent author would not stay awake nights worrying about the end of the world), but, meanwhile, a green dot for the groups of galaxies with redshifts measured by Mahdavi & Geller (2004) which do seem to have cusps, and a couple of purple hearts for (1) an updated calculation (Navarro et al. 2004b) that makes shallower cusps than the same group found earlier, and (2) a model with energy transfer between the galaxies and the central dark matter which results in the light distribution being flatter than the mass near the centers of clusters (El-Zant et al. 2004).

Missing satellites and dwarf galaxies. We reserve the right to be wiser next year than this, but just for the moment are voting for the ideas that the dwarf companions actually seen (some of which have their own dark matter; Piatek et al. 2003) are the massive tip of the distribution of subsidiary halos that theorists expect and that the smaller halos have formed no stars, and so can be probed only by observations of gas (Thilker et al. 2004), or with gravitational lensing (Metcalf et al. 2004a; Cohn & Kochanek 2004). Manning (2003) would disagree, but he reports privately that he seems to spend quite a lot of his time disagreeing, not (just) with the present authors.

Once you have star-bearing dwarf galaxies, they come in several types, irregular, spheroidal, elliptical with nuclei, and probably others. Does one type evolve into another? Sometimes, say van Zee et al. (2004), describing the Virgo cluster, where some of the dE's rotate and probably came from dIrr's and others not, which is the sort of non-overwhelming answer that seems likely to be true. Dekel & Woo (2003) concur.

The time history of star formation. Well, it started a long time ago (§ 7) and is still going on, and we are not 100% certain that the world would be very different if the amount of gas converted into stars (in solar masses per year per comoving Mpc^3) had been constant throughout. The rate (allowing 12.7 Gyr to put 2% of the closure density into stars) would then be about 0.1 $M_\odot$/Mpc^3-yr. You can still make this look funny by plotting in redshift units, because (as we have undoubtedly remarked before) there are many more Gyr between $z = 1$ and $z = 0$ than between $z = 6$ and 5.

The present value, near 0.02 $M_\odot$/Mpc^3-yr does not seem to be in dispute (Hirashita et al. 2003; Brinchmann 2004), nor that it was considerably larger (about 10 times) in the past. Most analyses have found a broad peak at $z \sim 1$–2 (Thompson 2003). Heavens et al. (2004), however, conclude that the peak was later ($z \sim 0.6$) and broader, on the basis of population analyses of nearby (SDSS) galaxies, rather than direct observations of very distant ones. They also note (and this, we believe, would not be disputed) that the galaxies that are now most massive have the largest fraction of very old stars, without need to pontificate on whether those stars formed in the galaxies as now seen, in the pieces later assembled to make them, or some combination.

There are at least three other sorts of disagreements. First and largest is between theory and observation, with Nagamine et al. (2004b) calculating that 90% of all stars were in place by $z = 1$, while a typical observers' number is 1/2 or less (Zheng et al. 2004b; Liang et al. 2004). Nagamine et al. suggest that observations are missing a large fraction of the $z \approx 3$ star formation. Notice that the Heavens et al. (2004) version of SFR(z) with its later peak, makes the disagreement worse. It does not, incidentally, take a rocket scientist to figure out the drop down toward present times. The gas has been blown out of many galaxies and nearly used up in others. We used to call this the "last gasp" problem and worry that is was somehow non-Copernican. We are not, however, observing at a random time, but rather at a time when chemical evolution has managed to produce reasonable numbers of metal-rich stars capable of hosting planets (§ 3.2).

Other discordant numbers concern whether the SFR at $z = 5$–6 was about like $z = 3$ (Bouwens et al. 2003), though coming on average from what will eventually be bigger galaxies (Ouchi et al. 2004), or, contrarily only about 1/8th as much (Stanway et al. 2004b).

It is possible to err in either direction, missing photons because they have been absorbed or scattered, or attributing to stars photons with other sources, and we will leave the last word with Thompson (2003), who provides a nice discussion of "mistakes that have been made" (not just by others). One of the ones that would have distressed Fritz Zwicky is forgetting that surface brightnesses scale as $(1 + z)^{-4}$ in a truly expanding universe, though only as $(1 + z)^{-1}$ with tired light.

E+A galaxies, so called because they are morphologically elliptical but with A-type special features, are somewhere in between. The ones seen at moderate redshift are Es and S0s now (Tran et al. 2004), while the current E+A crop has passive evolution to look forward to (Yang et al. 2004; Quintero et al. 2004).

Elliptical galaxies. When and how did most of them form? Provided you do not insist on being too quantitative, there is a consistent story. Some (destined to be the biggest, though perhaps not obviously looking so at the time) started very early, e.g., 2 Gyr before $z = 2.48$ (Stockton et al. 2004b; Fontana et al. 2004). The peak star formation epoch came about $z = 2$ (Daddi et al. 2004), and most of the fun was over by about $z = 1$ (Miyazaki et al. 2003; Treu & Koopmans 2004; Blakeslee et al. 2003), though a little bit of excitement breaks out even now. An example is the current two-galaxy merger NGC 4038/39, where our remote descendents may reasonably be expected to see an elliptical (Fabbiano et al. 2004). Another is the Hickson compact groups (Amram et al. 2004). One instantly intuits two modes of formation, from equal pairs of big galaxies and from groups of not so big ones. Twas ever thus, say Hernandez & Lee (2004).

The green dot paper was none of these, but a marvelous data set for investigation of galactic evolution since $z = 1$ (Drory et al. 2004; Bell et al. 2004a). Our attempts to summarize their conclusions in two notebook lines yielded the result that reality is too complex for a linear verbal description to do it justice; a truly multi-parameter family.

10.7. Origin of Cosmic Magnetic Fields

Now, my friends, you know and I know that the only thing we have to displace is the displacement current itself. Sorry, wrong speech (though we are not unsympathetic to Lord Kelvin's attitude of distrust toward $\boldsymbol{D}$. Indeed the less magnetic author discovered that it is quite difficult to explain, within a 90-sec radio bite, why anyone should care where magnetic fields come from, as long as Southern California Edison supplies them regularly.

There are, of course, two competing ideas: bottom up, in which small scale fields come first (Schekochihin et al. 2004) and get stretched out (AGNs and GRBs have been suggested as sources, though not in this paper); and top down, in which the early universe leaves a very weak field, amplified when galaxies form and baryons dash about (Banerjee & Jedamzik 2003). Theirs is about 4×10^{-12} G on a 10–100 kpc scale and comes from phase transitions. Semikoz & Sokoloff (2004) start a little later than the electroweak phase transition and use weak parity violation to make many small, random field domains, whose mean is a global field, a thought traceable to Zel'dovich (1965) and reviewed by Kulsrud (1999). The goal, you will recall, is 1–10 μG, not just within galaxies but on cluster scales as well (Ensslin et al. 2003). Where there are large and small scale mechanisms there will, of course, also be intermediate scale ones, for instance the rotation of ionized gas in a radiation field. This works because the extra radiation drag on the electrons constitutes an electric current capable of sustaining a seed field of at least 10^{-15} G (Chuzhoy 2004).

And we would like to mention the Weibel instability, invoked on intergalactic and intracluster scales by Okabe & Hattori (2003) and by Schlickeiser & Shukla (2003), mostly because we thought it might be named for somebody we know, but it is quite a different E. Weibel (1959). And in case, as Watson said to Holmes, there is anything that has escaped our attention, please consult Vallee (2004).

10.8. Cosmic Rays

The long-standing questions have "the origin of" as part of them here, too, but our green dot paper noted that balloon borne collectors for determination of composition and spectrum (e.g., O to Fe at 100 GeV to 1 TeV) fly under an amount of residual atmosphere, 3.3–6.53 g/cm^2, just about equal to what the particles have come through in all their previous (10^7–10^8 yr) lives traversing the Milky Way (Gahbauer et al. 2004).

The ancient custom is to use energy derived from supernova explosions to accelerate the particles in shock waves, presumably associated with the expanding remnants. This just nicely keeps up the observed cosmic ray supply if you can use 10^{51} ergs per supernova. The catch is that, while SNRs certainly contain relativistic electrons (responsible for their synchrotron radiation), the case for relativistic protons (etc.) is a good deal more indirect (Pohl et al. 2003; Ellison et al. 2004). New supportive evidence this year came from the remnant of SN 1006 (Berezhko et al. 2003) and SNR G347.3−0.5 (Fukui et al. 2003), a TeV gamma-ray source that is, just possibly, the remnant of a supernova in 393 CE. The gamma rays in each case are likely to be the result of relativistic proton processes. Lee et al. (2004c) proposed a variant acceleration mechanism associated with time-dependent shocks.

Most other candidate CR sources during the year were slanted toward the highest energies, $E \gtrsim 10^{19}$ eV, for instance, including gamma-ray bursters (Waxman 2004a), hypernovae (Sveshnikova 2004), the Virgo cluster (Yoshiguchi et al. 2004b; Volk & Zirakashvili 2004), Seyfert jets (Uryson 2004), and decaying dark matter (Shchekinov & Vasiliev 2004).

Back in the SNR and pulsar camp, we find the thought that the preponderance of iron nuclei in the 10^{15}–10^{18} eV energy regime (Ogio et al. 2004) favors acceleration right off the surface of pulsars (Bednarek & Bartosik 2004). The case would grow stronger if at least some of the highest energy particles seemed to be coming to us from the directions of known young, energetic supernova remnants and neutron stars. On this point, the observers do not present a united front. Clustering on small angular scales of the arrival directions has been reported from the detector on Mt. Ararat (Chilingarian et al. 2003) in the direction of the Monogem ring and from the AGASA detectors (Yoshiguchi et al. 2004a), but this has not been confirmed by the new Fly's Eye detectors (Abbasi et al. 2004a), which use an air fluorescence technique rather than Cerenkov flashes.

There is also a discrepancy in the reported fluxes, which is at least as important. The Fly's Eye number at energies $\gtrsim 10^{20}$ eV is considerably smaller than the AGASA number (Abbasi et al. 2004b). If the smaller flux value is right, then there is a good deal more scope for getting the required number of particles to us from relatively distant sources, despite their need to plow through a sea of intergalactic infrared photons that, to them, look like hammer-hard gamma rays.

10.9. The Local Group

"To the Milky Way and Andromeda, twin dwarf spheroidals, AND VIII (Morrison et al. 2003) and AND IX (Zucker et al. 2004), siblings for IGI (Monaco et al. 2003; Newberg et al. 2003), Sextans (Lee et al. 2003), Fornax (Dinescu et al. 2004), M32 (Alonso-Garcia et al. 2004), Phoenix (Gallart et al. 2004), WLM (Battinelli & Demers 2004a), NGC 3109 (Demers et al. 2003), LMC (Bekki et al. 2004c), and SMC (Evans et al. 2004)" and all the rest. The cited papers deal with various aspects of stellar populations in these mostly small satellites of M31 and the Milky Way. The family as a whole is, say Leong & Saslaw (2004), quite typical of small groups of galaxies in general, virialized and having only small local departures from Hubble flow.

The senior members of the family, like an old married couple, have grown to look rather similar in, for instance, (1) the presence of high velocity clouds (Thilker et al. 2004), (2) their X-ray source populations (Williams et al. 2004; Di Stefano et al. 2004), (3) their magnetic field configurations (Fletcher et al. 2004), and (4) in producing cold (small velocity dispersion) tidal tails when they eat their children (McConnachie et al. 2004).

Examination of the older stars in each, however, reveals that they were not put together in the same ways at the same time. Here are some of the indicative differences. (1) M31 halo RR Lyrae stars include an intermediate class between Oosterhof I and II types not found in the Milky Way (Brown et al. 2004). (2) The dwarf spheroidal companions of M31 contain only old stars (Harbeck et al. 2004). (3) M31 has a thin disk population of globular clusters (Morrison et al. 2004), meaning that its thin disk arose earlier than ours, or that it continued forming globular clusters later, and (4) its halo is, on average, less metal poor and shaped more like an elliptical galaxy and less like a spiral bulge than ours (Durrell et al. 2004). Dolphin et al. (2004) summarize the differences by saying that the halo of M31 must, long ago, have passed through a stage when it looked like ours now. Does this mean that some Gyr in the future, the Galaxy will look like M31 does now? We aren't quite sure we want to live long enough to find out.

10.10. Other Clusters of Galaxies

The dottier author green-dotted a paper pointing out a fourth way of determining the masses of clusters. One, two, and three are the virial theorem applied to radial velocity data; X-ray temperature vs. radius; and weak gravitational lensing. Number four is gravitational redshift of light from the center of the cluster, that is, of the central galaxy relative to the outskirts. The difference is at most 10 km/sec, and it will be necessarily to average over 2500 massive clusters to see it (Kim & Croft 2004). Could this possibly be worth doing? Conceivably, if you have most of the required data acquired for other purposes!

The current situation is that the three existing methods sometimes agree when you would not expect them to (De Filippis et al. 2004 on the recently merged AC 114), sometimes disagree where you would expect them to (Laine et al. 2004 reporting that the virial mass of the Coma cluster is three times its X-ray mass, because two subclusters are not yet fully merged; that is, the X-rays are right), and sometimes disagree where you would have expected agreement (Ota et al. 2004 on a $z = 0.395$ cluster whose lensing mass is larger than its X-ray mass, and they say again that the X-rays are right). And then, just to make us feel all warm and secure, Ciotti & Pellegrini (2004) opine that X-ray gas is not a very good mass indicator, at least for NGC 4472.

Where is one to turn? Somehow we had supposed that gravitational lensing would be the gold standard, since mass and only mass is at work, at least if general relativity is right! But in practice not, say Clowe et al. (2004b), because an analysis always assumes things about cluster shapes that may not be true. Lensing overestimates are, they say, more likely than underestimates.

A second green dot attached itself to reports (McNamara et al. 2004; Wise et al. 2004) that an answer has finally been found for the question "Cooling flows to where?" The issue, you will recall, is that many X-ray clusters have central gas densities, temperatures, and luminosities indicating that the cooling time is short compared to the Hubble time, so that the gas should visibly (or infraredly or something) cool and flow inward. Yet there is typically little or no emission at X-ray temperatures less than 1 keV, from atomic or molecular gas, or from newly formed stars. In Abell 1068, however, the central cD galaxy has a star formation rate of about 40 $M_\odot$/yr, about equal to the central cooling flow rate. Is this the answer? Clearly not in general, for there are other Abell clusters where absence of cool gas, stars, and all persist (Lecavelier des Etangs et al. 2004b).

Indeed it may not even be the question. Cooling flows are an illusion, say Motl et al. (2004). The central cool gas core has been built up from the accretion of small gas-rich galaxies and has significant rotational support. The paper is marked by some fine sequences of adjectives: (9) "recent high spatial dynamic range adaptive mesh Eulerian hydrodynamic simulation," (8) "coupled *N*-body Eulerian adaptive mesh refinement hydrodynamics cosmology code," and, they say, seven levels of refinement.

Has it happened before that we have belived six things that turned out to be illusions? Oh yes, and sometimes they could be fit by five pink parameters. And that even after Mother had carefully taught us, "beer before wine, everything's fine; wine before beer, everything's queer." Or is it "beer after wine…"?

The subjects of cooling flows and discrepant cluster masses from different methods meet up in Colafrancesco et al. (2004), in whose view the process should be called warming rays, with heating of the gas by hadronic cosmic rays. Their model explains, in addition to the gas temperature structure and the difference between X-ray masses and others, the origin of gamma-ray bursters and the gamma-ray diffuse background. About 28 other indexed papers addressed various aspects of the cooling flow problem, invoking ideas (AGN bubble heating, sloshing of gas, conduction…) that have been around for at least a few years.

Not everything between the galaxies of a cluster is X-ray gas or dark matter. About 10% of the light, coming from old stars, has found its way there (Murante et al. 2004; Muccione & Ciotti 2004). Feldmeier et al. (2004) note that such intracluster light has substructure and is not just a uniform haze.

Lots of individual clusters rated their own papers, but the last green dot goes to a simulation of structure in Virgo. Well, the simulation was carried out in the Local Group by Klypin et al. (2003), but it describes events in and around Virgo. The cluster dominates its surroundings out to 30 Mpc, within which there is a total mass of $7.5 \times 10^{14}\ h^{-1}\ M_\odot$, most of it in a 40 h^{-1} Mpc filament passing through the cluster. We live on an adjacent smaller filament with a peculiar velocity of about 250 km/sec relative to the cluster center (in the sense of diminished recession speed). But the overall velocity field is not as simple as uniform Virgocentric infall, which in any case we think should be described as uniform Virgocentric diminution of cosmic expansion.

11. DOWN TO EARTH

From the laboratory to the lunatic asylum, we examine various aspects of astronomy on the face of the Earth and its practitioners.

11.1. Astrometry

Coordinate systems and catalogs remain essential if we are to know where we are looking and whether anything has changed since last time we looked there. The *Hipparcos* mission yielded the largest set of precision positions, parallaxes, and proper motions that will exist for a long time, but its coordinate system rotates at about 0.001 arcsec/yr (Bobylev et al. 2004), and its distance to the Pleiades, 118 ± 4 pc, is almost surely wrong. Detailed analyses of two different spectroscopic eclipsing binaries in the cluster yield 135 ± 2 pc (Pan et al. 2004) and 132 ± 2 pc (Munari et al. 2004). This is not quite the clock striking 13, but more like it running 10%–15% fast or slow, depending on where in the house you keep it. Paczyński (2004) suspects that the systematic *Hipparcos* errors probably arose from its highly eccentric orbit, where circularity and geosynchronicity had been planned for.

Other astrometric news was largely good: The completion of the Lick Observatory proper motion survey; well, the observatory is still on Mt. Hamilton, but lots of stars have moved between 1920 and 1988 (Hanson et al. 2004). The second USNO Astrograph Catalogue contains 48,330,571 sources, mostly stars (Zacharias et al. 2004), and comparing the USNO catalog with positions from SDSS has yielded a new proper motion catalog (Gould & Kollmeier 2004). MACHO searches are sensitive to proper motions as noise or signal, depending on your point of view (Sumi et al. 2004, a catalog of 5,080,236 from OGLE II).

And as a curious result of precession, the last has become first. The Local Group galaxy WLM was A2359−15 in a 1964 catalog, but is now J000157.8−152751.

11.2. Fundamental Physics

There are four forces in some archaic, pre-standard model. The strength of the strong (color, nuclear, gluon) force permitted element $Z = 113$ to stay together for one whole second after it was made, along with $Z = 115$, at Dubna (Oganessian et al. 2004). Since $Z = 105$ has already been named for their lab, they will have to call these Moscovium and Russium. Compare elements 95, 96, and 97 if this suggestion strikes you as excessively chauvinistic, and be grateful that the discoveries are occurring now, rather than a couple of decades ago, when the third would have had to be Ussrium.

The weakness of the weak interaction revealed itself again in neutrino oscillations observed at the SuperK experiment (Ashie et al. 2004). We are thinking of a new sociological experiment in which one tracks the average number of authors in experimental particle physics papers by examining the ever-closer approach of the first author's surname to Aardvark. We get as far as Abasovin, the D_0 paper on the mass of the top quark and its implications for the mass of the Higgs boson (Collaboration 2004). Witten (2004) has provided a masterful overview of electroweak unification. He looks ahead to quantum gravity and a connection between a small cosmological constant and a small mass for the Higgs.

The mediumness of the electromagnetic force is not in dispute, though we caught a dozen papers on whether it has been constant in historic times (meaning since $z = 6$). Here is one vote for change (Murphy et al. 2003) and one for no change plus an isotope effect (Ashenfelter et al. 2004). Since chemistry is generally blamed on electromagnetism, the possibility that polywater (a superdense phase of water appearing when it is in contact with SiO_2) lives must belong here (Dosch 2004).

The 2004 index holds 23 gravitation papers, many of them mentioning familiar names like Kerr, Lorentz, Tolman, Birkhoff, de Sitter, and Schwarzschild, and familiar holes like black and worm. Today's ration includes two new tests of/for general relativity, so the authors say. The one using the precession of the orbit of the first truly binary pulsar, J0727−2039A,B (O'Connell 2004), can be started immediately. The one employing laser interferometry between two space craft whose line of sight passes close to the Sun (Turyshev et al. 2004) will have to wait a while.

Other things we do not expect to see very soon include Schwarzschild–de Sitter black holes, which have zero angular momentum but significant cosmological constant (Rezzolla et al. 2003), and Morris-Thorne wormholes, which become Einstein-Rosen bridges in a universe with phantom energy, $|w| > 1$ (Gonzalez-Diaz 2004). The "best" or "newest" numerical value of G, Newton's constant of gravity, changes a good deal from year to year, place to place, or experiment to experiment. In New Zealand in 2003 with a torsion balance, it was 6.67387 ± 0.00023 in suitable units (Armstrong & Fitzgerald 2003). Calculations within general relativity are frequently done in a set of units in which $G = c = 1$. This does not, we think, excuse you from having to measure something, probably the length of a standard mass.

11.3. History and Alternative Histories

In Kepler's version of *Harmoniae Mondi*, the Earth sang mi-fa-mi (misery, famine, misery; yes it works in Latin), as we are reminded by Gingras (2004) who, annoyingly does not explain the clefs in use. The universe today, if you scale from 1 cycle per 50,000 yr up to the audio range, sings a sort of rumble and screech (Whittle 2004). The amplitudes of the CMB fluctuations used for this lecture-demonstration are a few parts in 10^5, which is indeed close to the threshold of pain (120 dB) for sound waves.

In keeping with this harmonious beginning, we will avoid all issues of credit and priority to which any of the claimants or disputants are still publishing. Fair game, therefore, is Kelvin, who missed the chance for additional fame twice on the same subject. He greatly underestimated the age of the Earth, thinking (*a*) it had simply cooled and (*b*) the Sun lived on gravitational potential energy (Rigden 2004, reviewing a book by D. Lindley and mentioning only the cooling item). That is, Kelvin was not prepared to consider possible subatomic energy sources. And faced with the discovery of radium, he announced that "it seems to be absolutely certain that energy must somehow be supplied from without" (Kelvin 1904).

Blue ribbons, on the other hand, for (*a*) the subset of old star catalogs (Ptolemy, Ulugh Beg, Brahe, Flamsteed, and all) reliable enough to use in searches for long-term variability (Fujiwara et al. 2004), (*b*) Robert Boyle who, in a lost manuscript from before 1691, considered "On the Fuel of the Solar Fire: A conjectured discovery" (Hunter & Principe 2003). We don't really suppose his answer bore much resemblance to subatomic energy, but a long-overdue green dot for asking the question so early, (*c*) 16th century Copernicans, though they probably numbered fewer than 10 (Westman & Gingerich 2004), compared to the 277 or more copies of De Revolutionibus then in existence, and (*d*) the keepers of the Poulkova Catalogue, conceived by B. P. Gerasimovich ("disappeared" under Stalin), initiated by A. N. Deutsch (who also observed the Crab Nebula) to establish an extragalactic coordinate system, and now complete enough to use (Bobylev et al. 2004).

Also fair game is Halley, whose calculation of the 1761 transit of Venus apparently included sign errors (Anonymous 2004h) in "an odd number of places." Galileo shared the view, persistent down to the time of William Herschel, that close pairs of faint and bright stars must be at different distances and so be potentially useful for parallax measurements (Ondra 2004). Galileo was probably the second astronomer to resolve a visual binary star with a telescope, after Benedetto Castelli, and he caught 3 of the 4 members of the Trapezium, leaving one for Huygens to find 40 years later.

National observatories are usually supposed to have arisen from the needs of navies and others who go down to the sea in ships,[17] but San Fernando (Spain, 1753) began life as the Royal Observatory of the Army (Anonymous 2004e).

Who would presume to disagree with Einstein, who wrote, in 1945, "Nach meiner Meinung sollte das weibliche Kapitel bei Männern eine so geringe Rolle spiel als möglich." We record, therefore, only two gender issues. First, it seems to have been possible for a married woman scientist to keep her own name as early as 1857 (Janvier 2003 on Lydia Fraser), and we wonder whether her father reacted to the news of the impending marriage by saying, "so you're going to become Mrs. Miller!" and was surprised to hear the answer, "No!" (It took the longer-married author's father about 2 years to hear that no in our own case). And second is the quantum of fame, which is either the Newton or the 1/3 Janet Jackson (Bagrow et al. 2004, on Web hits).

In astronomy (Sanchez & Benn 2004), as in science in general (King 2004), the most-cited papers are American, but not nearly so much as they used to be.

11.4. Extrema

As usual, there were both human and non-human records set (and perhaps a few inhuman), 18 of the former and 35 of the latter. Here is the subset we couldn't resist telling you about, beginning with the inhuman, or institutional.

- The oldest science-supporting foundation in the US is the Research Corporation, founded in 1912. It supported the pioneering radio astronomy of Grote Reber, rescued the Large Binocular Telescope from operating in the Moshe Dayan mode, and is slogging away toward the LSST (Schaefer 2004).
- The most expensive telescopes. Well, time on Gemini costs \$1/second (Mountain 2003), but we suspect *HST* is even dearer.
- Longest duration as the world's largest telescope belongs, we think, to Lord Rosse's 72-inch, from 1845 to 1917, when the Hooker 100-inch arrived on Mt. Wilson (Levy 2004). Hooker held the record 1917–1948, and the preceding one was William Herschel's 48-inch of 1789, probably the second longest biggest.
- The oldest person to discover a comet is William A. Bradfield, his 18th, from Australia on 23 March 2004, at age 76. The oldest living person to have discovered a comet must surely have been Fred Whipple at the time of his death, 29 August 2004.
- The smallest laboratory gas pressure is 10^{-84} torr (vs. 10^{-12}–10^{-13} torr in the interstellar medium), but it extended over a volume only about a nanometer across (Han & Zettl 2004).
- Most books published past age 90, undoubtedly Ernst Mayr, who turned 100 this year (Mayr 2004, a review of his autobiography).

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[17] And the ships in rivers, we trust, if this bit of poesy is to be taken literally. Rowing your boat down the Harbor Freeway to San Pedro has long been discouraged.

- Largest number of self-citations, not necessarily a world record, but impressive at 174 (Kato et al. 2004a).
- Last person to write hieroglyphs (until the era of Champollion, Thomas Young, and all) did so in 452 CE at Philae (Stadler & Brown 2004). Cuneiform was by then long gone, the last writer having sheathed his pen (or rather triangular stick) at Babylon about 75 CE. Admittedly the experts quoted on this point have not seen the handwriting of the more uncoordinated author.

And some of the astronomical extremities.

- The closest asteroid, 2004FH, passed within 42,700 km on 18 May (McNaught & Garrada 2004).
- The closest halo star, HD 33793, at 3.9 pc (Woolf & Wallerstein 2004), otherwise known as Kapteyn's star, though a high-velocity object, will keep its title for the next 10,000 years or so.
- The closest cataclysmic variable is WZ Sge at 43.5 pc (Harrison et al. 2004; Howell et al. 2004). The intervals between its outbursts are, therefore, shorter than the light travel time, but not by an enormous factor, as it is one of the longest-period dwarf novae.
- The slowest nova, AG Peg, was at maximum light in 1885, remained steady into the 1970s, and is only just now fading (Eriksson et al. 2004). It had previously done things in 1841 and 1855. It was marginally a naked-eye star at peak light, has an orbit period of about 2 yr (meaning, we suppose, a red giant donor), and a slowly cooling white dwarf, now at 10^5 K.
- The most evolved dwarf nova, IX Dra, has eaten away its donor down to a mere 0.03 $M_\odot$. This must also be a somewhat unusual star, since the orbit period is 95.7 days (Olech et al. 2004).
- The coolest, faintest star, the 2MASS source J0415195 −09305, is a T9 (Vrba et al. 2004; Golimowski et al. 2004; Knapp et al. 2004) at $T = 600$–750 K and $\log L/L_\odot = -5.6$ to -5.7. Knapp et al. add that L and M magnitudes vs. spectral type are better behaved (less lumpy) than I, J, and K. Clearly a new spectral type will be needed soon, and we would like to re-propose P, our suggestion for the class now called L.
- The youngest V471 Tau star has been a post-common-envelop-binary for only 7×10^5 yr (Sing et al. 2004a).
- The biggest lensed QSO has its images separated by 14.6 arcsec (Inada et al. 2003). It displays four images and is a 1 in 10^4 sort of object, about as you would have calculated, and therefore became "likely" only in the SDSS data base. It is also the first to be lensed by a whole cluster (Oguri et al. 2004). Weak lensing by clusters is, remember, common. Strong lensing is rare.
- The intrinsically biggest quasar at large redshift is J1432+158, 1.35 Mpc from radio tip to radio toe (in some cosmology), reported by Singal et al. (2004).
- The largest structure in an Einstein–de Sitter universe could grow to an isothermal sphere containing all the matter within the horizon, given enough time (Baumann et al. 2003). The largest seen so far (SDSS again) is nearly half a Gigaparsec say Gott & Juric (2004), though Bharadwaj et al. (2004) declare that anything larger than 100–120 Mpc is due to "visual effects."
- The most distant supernova is SN 2002fw at $z = 1.3$ (Riess et al. 2004a, 2004b).
- The first GMRT pulsar, noted as such elsewhere, is also the most eccentric binary pulsar, with $e = 0.89$ (Friere et al. 2004).
- A contender at least for most eccentric spectroscopic binary is 41 Dra, with $e = 0.9754$ (Tokovinin et al. 2003). Its companion, 40 Dra, is also an SB.

11.5. Countdown

One generally supposes that astronomers are pretty easy-going folk (compared, say to archeologists) because there are more than enough stars to go around. In fact, however, while some 6.3 Gigapeople live in 200 countries (Anonymous 2004f), doing measurable, often unhappy, things to the Earth (Dietz et al. 2003, and the next 8 papers), there are only 1.040618261 Gigastars in the largest star catalog (Fienga & Andrei 2004). Admittedly, not all the people are (yet) astronomers.

There are zero of some other things, including X-ray binaries consisting of a black holes plus a Be star (Zhang et al. 2004b), γ Doradus stars which are also δ Scuti stars (Henry et al. 2004a), and African-American full professors in major departments of science and engineering (Nelson 2004). He says there are 89,551 full professors in the top 50 science and engineering departments in the US. At 161 per department, this seems large (and we wonder whether "departments at top 50 institutions" was meant). The women and Hispanics are 9 each.

In between 10^9 and 0, we indexed 118 papers with notable numbers. Some of these report an addition to a small, interesting class (like the accreting millisecond pulsars) and are cited in the main text. Many of the enormous numbers are members of some well known class, identified in one of the new OSOTAT's (overwhelming surveys of this and that), of which the MACHO projects and SDSS are the most overwhelming. So, down we go:

8.8×10^7 objects in the second SDSS data release (Abazajian et al. 2004) with more to come.

7.3×10^7 claimed as odds against two SIDS deaths not being murder in the family, as refuted by Bondi (2004).

1.4×10^7 light curves from ROTSE (Wozniak et al. 2004a).

16,781 H I galaxies (Paturel et al. 2003), part of a project that is an updating of the RC3 catalog.

11,317 variable stars in an all-sky automated survey (Pojmanski 2003). The telescope used was a gift from William Golden to Bohdan Paczynski!

10,000 (approximately) X-ray emitting AGNs that appear in both SDSS and the *ROSAT* All-Sky Survey (Anderson et al. 2003).

10,000 (also approximately) solar masses, the average of the 100 largest open star clusters in the Milky Way (Hanson 2003).

7531 asteroids whose colors vary (Szabo et al. 2004).

7000 groups of galaxies in a catalog (Eke et al. 2004) compiled from 2dF data. Out only objection is that it is called 2PIGG.

6135 RR Lyrae variables in the Large Magellanic Cloud, a MACHO sample (Alcock et al. 2003).

4161 spectral types in the Small Magellanic Cloud (Evans et al. 2004). Well, no, that's not quite what we mean. Spectral types for 4161 stars, but apparently only about 10 types.

1450 (approximately) planetary nebulae in the Milky Way (Kerber et al. 2003).

1122 *INTEGRAL* sources having fluxes in excess of one milliCrab (Ebisawa et al. 2003a).

1000, the X-ray flux of the Crab in milliCrabs (Revnivtsev et al. 2004b). We believe this is exact.

950th anniversary of SN 1054, the 400th of SN 1604, the 80th of the founding of *Astronomischesky Zhournal* (in translation now called *Astronomy Reports*), and the 50th anniversary of polio vaccine.

629 bright *IRAS* galaxies (Sanders et al. 2003, with pictures of them all).

608 authors at 79 institutions (Aubert et al. 2004) on a CP violation result from Babar. If you were thinking of the elephant, there was a nice article about him and his family and their books in an October issue of *New York Review of Books*, though the reviewer did not mention what we in childhood thought was the most attractive feature; the early ones had their texts in "grown up" handwriting, rather than printed letters.

451 galaxies within 10 Mpc (Karachentsev et al. 2004). This is comparable with the number of stars within 10 pc, suggesting to our numerological minds that these are the right units for these purposes.

378 O stars, complete to $V = 8$ (Maiz-Apellaniz et al. 2004).

319, the largest number of patents held by a living individual (Anonymous 2004g). In times past, Edison held more than 1000, Jerry Lemelson about 600, and Edwin Land (whose name is not actually mentioned) more than 500. We think this means US patents.

140 Type II QSOs, and yes this is a lot, given that their very existence was questioned fairly recently (Zakamska et al. 2003). These are the sort sufficiently absorbed that you do not see the broad emission lines except perhaps in scattered light.

91, the age to which the elder author can expect to live (Nemoto & Finkel 2004). If she could have the last 30 years over again, this would be fine, but she would surely make all the same mistakes, or worse.

76 pulsars in 23 globular clusters (Possenti et al. 2003).

50–60 generations needed for a new species to evolve from a hybrid (Rieseberg 2003). This would seem to imply some very strange automobiles in about 2060.

54th paper in a series on Atomic Data from the Iron Project (Nahar 2004).

42 Gamma Doradus stars, about half of which are binaries, lying in an instability strip very close to the calculated one, assuming a "convective blocking method" (Henry & Fekel 2003).

40, death begins at, based on changes in brain tissue (Lu et al. 2004).

27 glacial cycles in the last 2 million years (Rayme et al. 2004).

25 (± 2) gamma-ray sources with optical identifications (Shaw et al. 2004). The positions of the 20 keV–1 MeV emitters came from BATSE, using Earth occultation to improve the angular resolution.

22 isotopes per element, the maximum needed in nuclear reaction networks for Type II supernovae (Yoshida & Hashimoto 2004). No, they are not all stable. That record is 10, held by tin.

20 SW Sex stars (Hoard et al. 2003). They are a type of cataclysmic variable, and we are sure they have already heard that joke, just as every human being has heard every joke that can be made about his name by the age of 3. And if you mention either ear borrowing or S. Claus, Pow! Right in the kisser.

15 rotationally powered pulsars known to be X-ray sources, including 3 millisecond pulsars (Wang & Zhao 2004). X-ray luminosity scales as spin-down luminosity, L^{-3}.

12 AM CVn stars (Woudt & Warner 2003), one of which had a shameful early life as SN 2003aw. These are low mass, close binary white dwarfs.

11th edition of the QSO catalog of Veron-Cetty & Veron (2003). Of the 48,921 QSOs (plus 876 BL Lacs and 11,777 Seyfert 1's) 52 are lensed, 14 truly double, and about 10% have measured radio fluxes.

10 magnitudes below sky brightness is how far you have to go to see light from the halos of edge-on spirals (Zibetti et al. 2004).

9 low-mass X-ray binaries in M31 that are known to be Z-sources (Bernard et al. 2003). This refers to patterns in a flux-hardness diagram, not the tendency to nod off.

9 light echoes (Sugarman 2003), belonging to novae, supernovae, V838 Mon (whatever it is), and a couple of other bright variable stars.

9 essential utilities according to Quinn (2004). They are water, electricity, telephone, gas, sewerage, garbage collection, TV, radio, and the GPS. Grandmother Farmer grew up with home-made versions of 1, 5, and 6, and no conception of the others, though she lived to enjoy all but the GPS.

9 transiting planets or late dwarf stars among the 180,000 brightest bulge stars examined by MACHO (Drake & Cork 2004).

8 TeV AGNs (Kalekin et al. 2003).

8 days from receipt to acceptance for Herbig et al. (2004) concerning the source LkHα 101 in NGC 1579. And no, you are not entitled to ask what they did on the 8th day.

8 frog toes is more than the average frog can live without (May 2004). The paper, by the way, deals with cutting off toes

as identity markers, not with toes removed incidental to the preparation of gourmet dishes.

7 = many, in the context of finding superfluid properties in small clusters of atoms (Xu et al. 2003).

6, the Erdos number sold for $1000 (Grossman 2004). The seller was, necessarily, a 5.

6 binary sdB+dM pairs (Heber et al. 2004). The sdB surfaces are on their way toward the very large H/He ratios of DA white dwarfs.

6 pulsars with giant pulses (Kuzmin et al. 2004). The sixth is B0031−07, seen at 111 MHz, and the implied brightness temperature for incoherent emission is 100,000,000,000,000, 000,000,000,000 K.

6 human symbolic systems, according to Premack (2004a), who listed the genetic code, spoken language, written language, Arabic numerals, musical notation, and labanotation for dance. Even we wondered about Inca quipu, Amslan, Roman numerals, and a few others, and the author came back a bit later (Premack 2004b) saying, well, really six out of many (meaning at least 7, see above).

5 sign errors in Ford et al. (2000), but the effect on the evolution of $N = 3$ stellar systems was modest (well, they have a lot to be modest about).

4 cataclysmic variables in open clusters (Mochejska et al. 2004).

4 RR Lyrae stars with changing Blazhko periods (LeCluyze et al. 2004). The new one is XZ Cam, part of Blazhko's original sample.

3rd optical interferometer with at least three telescopes (Monnier et al. 2004). They give credit for coming in one and two to Cambridge University and the US Navy, but we wonder whether they have forgotten the Georgia State University installation on Mt. Wilson, which lowered its 3rd (through sixth) telescopes by helicopter a couple of years ago. Theirs is called IOTA.

3rd black South African Ph.D. in astronomy (Medupe 2004). He is currently on the staff of SAAO and teaching at North West University in Mafikeng. If this rings a cracked bell, under the spelling Mafeking it was major event in the Boer War a bit more than 100 years ago. None of the three is yet an IAU member, but with a total delegation of about 60, South Africa could soon outstrip the US "percentagewise" in black astronomers.

3 female chancellors in the UC system, as Marye Anne Fox recently appointed at UCSD joins France Cordova at UC Riverside and Denise Denten at UC Santa Cruz (replacing M. R. C. Greenwood). There are 9 campuses in total, in case you might have lost count, with a 10th in Merced on its way.

3rd major diamond find was South Africa, after Golconda, India, and Brazil.

3 Arabian stallions sired all Registered Thoroughbreds (Overdorf 2004).

3rd of the major scientific breakthroughs of 2003, as chosen collectively by the editors of *Science* (302, 2038) is global warming. Concordance cosmology ranked first, and the GRB/SN/BH connection was sixth.

2 stellar activity cycles detected in X-rays according to Favata et al. (2004), though we wonder whether their HD 81809 might really be number 3, with the Sun = number 1.

2 pulsars with optical polarization (Kern et al. 2003), and yes, the Crab was first.

2 CVs with carbon star donors (Schmidtobreick et al. 2003). Their V840 Oph joins the nova-like variable QU Car.

11.6. Firsts

Some of these are first examples of new astronomical categories, or members of known categories in a new context, others the firsts of vaguely relevant human achievements. We have selected one of each as candidates for the Lincoln's Doctor's Dog's Favorite Jewish Recipes Prize (otherwise known as the Berlinski Award): The first two-dimensional, multigroup, multiangle, time dependent, radiative hydrodynamics calculations performed in core-collapse studies (Livne et al. 2004), and the first magnetic, helium-strong, early B star with pulsation (Neiner et al. 2003).

The annual grab bag contains 28 of the astronomical sort and 20 of the human sort, of which a baker's dozen each, including the prize winners, seems appropriate. Please supply "the first" in front of each of these phrases.

all-female engineering class (Anonymous 2003b).

submillimeter interferometric telescope, SMA, with 2 of the 6 antennas up, according to Kwok (2003). It lives on Mauna Kea, and its parents are back in Taiwan.

star chart, "the Sky Disk of Nebra" with a radioactive age near 7100 yr (Schlosser 2003). It is said to show the Sun, Moon, and Pleiades and to depict the beginning and end of the harvest season.

pulsar discovered with the Giant Meterwave Radio Telescope (Friere et al. 2004).

astronomical photograph, an 1840 J. W. Draper daguerreotype of the Moon (Hirshfeld 2004).

use of Arecibo as part of the VLBA array (Momjian et al. 2003). They mapped the H I orbiting the center of ULIRG NGC 7674 and found a $7 \times 10^7\ M_\odot$ black hole there (a typical example of "both, please" for AGNs and starbursts). Incidentally, the Chinese radio telescope at Urumqi is now part of the European VLBI network.

planetarium outside Germany, Vienna 1927 (Deans 2004). The only pre-war ones in the United States were Chicago/Adler (1930), Philadelphia/Fels (1933), Los Angeles/Griffith (May 1935), New York/Hayden (October 1935), and Pittburgh (1939).

mention of "six degrees of separation," in a 1929 Hungarian short story by Karinthy & Braun (2004).

Japanese eclipse record, 628 August 10 (Tanikawa & Soma

2004). Records of comets, meteors, lunar eclipses, and lunar occultations of stars begin soon after.

national park (important because they are likely to remain dark as observatory sites) 1778 in Mongolia (Milner-Gulland 2004).

human-controlled fire, somewhere between 790,000 and 250,000 BP (Goren-Inbar 2004). If this had happened before the chillier author's first observing run on Palomar Mountain, she might have ended up an astronomer, instead of concluding that the job description must include "born with fur."

bagpipes, made out of yew wood about the year zero (Holmes et al. 2004), and if you doubt the astronomical relevance of this, consider the problem of clearing tourists out of Stonehenge when you want to observe.

And, on the astronomical side,

mid-infrared resloved thick torus around an AGN black hole (Jaffee et al. 2004).

far-infrared jets, probably ejected from asymptotic giant branch stars (Weinberger & Armsdorfer 2004).

detection of H_2 quasi-molecular satellite lines of Lyman lines (due to transitions when H atoms are close but not bound). It is the 1150 Å satellite line of Lyβ in a *FUSE* spectrum of G226–29, a pulsating DA white dwarf (Allard et al. 2004), and the line had not previously been seen even in laboratory data.

X-ray pre-planetary nebula, He 3–1475 (Sahai et al. 2003).

pre-planetary nebula with a Keplerian gas disk, the Red Rectangle (Bujarrabal et al. 2003).

detection of limb darkening in a solar type star other than the Sun, from the MOA project (Abe et al. 2003).

planetary nebula with a WN central star. It also has an expansion velocity in excess of 150 km/sec, where normal is 10–20 km/sec (Morgan et al. 2003).

presolar grains containing silicates (Nguyen & Zinner 2004). Various isotopic anomalies, including excess Mg^{26}, undoubtedly connected up with various nucleosynthetic processes in the object whose ejecta formed the grains.

QSO sight line with four damped Lyα absorption systems (Prochaska et al. 2003).

dwarf nova outside the Milky Way, in the Large Magellanic Cloud (Shara et al. 2003).

mass-accreting T Tauri star outside the Milky Way. It is, of course, also in the LMC (Romaniello et al. 2004).

first outside the Milk Way that is not in the LMC, the molecule HOC^+ in NGC 1068 (Usero et al. 2004).

12. PISCES NATARE DOCERE

This is, it seems, the Latin equivalent of teaching one's grandmother to suck eggs, and the section contains a number of items that astronomical nature knows perfectly well how to do, though astronomers do not, and some of the converse.

12.1. Interdisciplinarity

We think this is the right word to describe unexpected pairings of methods with astronomical entities, for instance (*a*) "application of group theory to the problem of solar wind expansions" (Kalisch et al. 2003), (*b*) "fractional Brownian motion" as a description of turbulence in the interstellar medium (Levrier 2004), (*c*) the use of Schroedinger's equation to describe electromagnetic modes in a dusty plasma (Verheest & Cattaert 2004), (*d*) a path integral formalism to describe a gravitational instability (Valageas 2004). R. P. Feynman is duly cited, and remember it was not he who made fun of the existence of an institute of "quantum oceanology" but S. W. Hawking, (*e*) a Wein fire-ball as initial conditions for jet collimation in active galactic nuclei (Iwamoto & Takahara 2004), (*f*) generalized entropy as a way of understanding why the lowest-energy state for the interplanetary medium has a bimodal distribution of particle energies (Leubner 2004), and (*g*) solitons, not for spiral density waves or even as a way of preserving the ordained ratios of horses to horse parts, but as a description of the sand dunes called barchans (Schwammle & Herrmann 2003). This is not, of course, the only scientific term to come to us from Arabic recently, but they are rare compared to the older algebra, nadir, zenith, alchemy, and all.

You can, by the way, make soliton-like S-wave patterns in laboratory fluids (Rylov et al. 2004).

12.2. The Universe in an Ehrlenmeyer Flask

In case your last chem lab is some years behind you (or, of course, in front), this is the sort that narrows at the neck to keep you from sticking your hand inside. They are also difficult to wash, which may account for the varied level of success of attempts to produce astronomical materials at home. For instance:

- Planet formation in a microgravity rocket experiment by Krause & Blum (2004). They make only very small planets (1–10 μm in radius), but the general idea that the agglomerations will be fluffy seems to be established.
- Chondrules in the neighborhood of gamma-ray bursters by Duggan et al. (2003). Owing to the large distances of current GRBs, they exposed mm sized pellets to the photon beam of the European Synchrotron Radiation Facility. It worked, sort of.
- Chondrules under high pressure, tackled by Semenenko et al. (2004). We recorded only that the input was "exotic materials," and if these are like exotic dancers, children should leave the room.
- Ices for comets from Munoz Caro et al. (2004). The products include hexamethylenetatramine residues (said to be the

first synthesis of this, called HMT for short—perhaps no one had wanted it before?) attached to amino-aldehydes and other very organic (meaning, we think, they probably smell awful) compounds.

- Absorbers of the 2175 Å feature, assembled by Tomita et al. (2004) and Duley & Lazarev (2004). Because the two structures they built were rather different (fullerene onions and small hydrogenated PAHs), it is not, we think, certain which of these, both, or neither the ISM actually uses.
- Nanodiamonds? Jones et al. (2004) used small bits of the Orgueil meteorite fall and Mutschke et al. (2004) used bits of Allende in attempts to reproduce certain interstellar spectral features. The latter report that nanodiamonds in the ISM could be more abundant than generally supposed.

The flask surely did not survive the laboratory simulations (*a*) of the behavior of a pulsed jet and alpha-omega dynamo (Beckley et al. 2003) and (*b*) of superluminal motions (McDonald 2004). The latter used the “brick wall” method and the electron beam of a Tektronix 7104 oscilloscope.

12.3. Electromagnetic Radiation

If the only way to make photons is by wiggling electrons, why did we index 36 papers on the topic, including 12 devoted to pulsar radiation mechanisms? Well, a handful deal with proton synchrotron and proton cyclotron, e.g., Ho & Lai (2004) on features in the spectra of three isolated neutron star X-ray sources that might be proton cyclotron resonances, and (rating at least a green question mark) gamma-ray emission from M87 interpreted as synchrotron emission by relativistic protons or even $\mu^{\pm}$ or $\pi^{\pm}$ pairs (Reimer et al. 2004).

On the pulsar side, we indexed one review (Rankin & Wright 2003), addressed largely to the authors’ own mechanism, and one description of pulsars as free electron lasers, whose nanosecond pulses gang up to microseconds (Fung & Kuijpers 2004). With bulk Γ’s near 100 and magnetic fields less than 10^{-3} G, they can reach brightness temperatures up to 10^{30} K. Does this, we wonder, mean that it happens at $10^5 R_*$ out from the surface of a 10^{12} G neutron star?

Other photon phenomena included

- Zero-field dichroism (Manso Sainz & Trujillo Bueno 2003) in which electrons can populate substates of different $|M|$ unequally, so that lines arising from them will be polarized. The authors say the effect may possibly have been seen in supernovae.
- The quantum zero effect, in which suppression of decay of excited states results from (too) frequent measurement (Koshino & Shimizu 2004). They say it actually happens.
- Inverse Doppler effect, in which wave frequency increased upon reflection from a receding boundary (Seddon & Bearpark 2003). The shift $\Delta\nu/\nu$ is much larger than v/c, and you must begin by setting up a transmission line with a negative index of refraction. The theory goes back to Franz (1943).
- Pseudoscalar photon mixing, responsible, say Jain et al. (2004), for correlated optical polarization of QSO radiation over the whole sky.
- Electrostatic bremsstrahlung, which, says Schlickeiser (2003), is not a new idea, but will be important only if the energy density in Langmuir waves is larger than that in magnetic field. The radiation will be polarized about like synchrotron. And the name reminds us of an ancient paradox.[18]
- Rayleigh scattering by hydrogen atoms of visible light at wavelengths other than the normal (Bohr orbit to Lamb shift) transitions. Lee & Kim (2004) say their calculation extends beyond the Kramers-Heisenberg formula.

12.4. Building Better ~~Mouse~~ Photon Traps

Obviously this section is going to be about innovative or improved telescopes, detectors, algorithms, and such, but we begin with an arthritic nod to the continued existence of devices of the past: (*a*) photographic plates taken at the Palomar Schmidt telescope between 1950 and 1995 (Deacon & Hambl 2004), simply irreplaceable for certain synoptic studies, (*b*) frequentist methods of statistical analysis (Decin et al. 2004), and (*c*) a last, lingering room-temperature bar detector for gravitational radiation (Gusev et al. 2003). No, it didn’t see any, but a recent sociological history of the search for gravitational waves (Collins 2004) seems to be completely unaware of the existence of this detector.[19] And so on to the new and improved.

- An image restoration algorithm that, unlike the classic Richardson-Lucy method, does not endow Abraham Lincoln with glasses (Esch et al. 2004).
- A detector which goes some ways toward the goal of recording the place and time of arrival and energy of each photon, while being broad band, cheap, and not demanding a separate preamp for each detector element. The paper speaks of “microwave measurement of the complex impedance of a thin, superconducting film” (Day et al. 2003). And the idea is that each incident photon breaks up some Cooper pairs in numbers proportional to its energy. Superconducting tunnel junction detectors share some of the virtues of these films (Shiki et al. 2004). For other competitors, see the proceedings of a conference on three-dimensional spectroscopy (Walsh 2004).
- Better X- and gamma-ray telescopes can be built using

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[18] Accelerated charges radiate, yes? Yes. A local gravitational field, *g*, is equivalent (via a transformation) to an acceleration, yes? Yes. So an electron sitting on the table in your kitchen should radiate, yes? No. Well, perhaps it does if you observe from the frame in which *g* is transformed away. We haven’t tried.

[19] And the author more closely associated with this search (Trimble & Weber 1973) would not have been aware of this book had she not been asked to review it for a journal that will remain anonymous unless acceptance has occurred by the time we read proofs here. To her friends at ApXX, she can say only that there are very few experiences in life quite like reading a 900-page book, the first half of which is devoted largely to attacks upon one’s deceased spouse. The review appears as Trimble (2005)

Fresnel lenses with very long focal lengths, for instance 40,000 km at 20 keV (Skinner & Gorenstein 2003). Not, to coin a phrase, in my back yard.

- A new device to record precise radial velocities, primarily for exoplanet detections, duly saw 51 Peg b affect the radial velocity of 51 Peg A (van Eyken et al. 2004)
- More new telescope designs from the fertile, focusing minds of Willstrop (2004) and Lynden-Bell & Willstrop (2004). This year's crop includes a solar telescope with two concave mirrors separated by 1.25 times their focal lengths, an assortment of spherical mirrors with trumpet-shaped correctors (Arecibo, HET, and SALT work more or less this way), and our favorite, a camera spectrograph with a convex primary and a larger, concave secondary. Both need holes in them for the light to get to where it needs to be, and the idea can be found in a 1905 paper by the elder Schwarzschild.
- Laser guide stars can occasionally appear in the field of view of some other telescope on the same site (Hayano et al. 2003 on Subaru seeing Keck, 221 m away). This gives new meaning to the phrase "light pollution," and enhances our hope that you did not/will not use lasers if you decide to participate in the 18 April 2005 "light relay."[20]

Interference like the Subaru-Keck case arises because more and more telescopes are using adaptive optics, followed often by interferometry, on each of which we recorded a dozen or so papers not cited here. There has also been a proliferation of automated survey projects intended to hunt for gravitational microlensing events, planets transiting their stars, or (secretly and only to be shared with other binary star astronomers, beginning with Bohdan Paczyński) useful eclipsing spectroscopic binaries and other (sometimes very peculiar) variable stars.

Interferometry began at radio wavelengths and remains essential there. Subrahmanyan & Deshpande (2004) explain how to correct for a cockeyed source of error that arises when one antenna picks up reflections from another. You must make the main reflectors into continuous conducting surfaces. Either front or back will do.

All these widgets have to go someplace, and site testing proceeds apace. A few highlights: Maidanak is remarkably unwindy, and San Pedro Mártir has seeing at least as good as Paranal, Mauna Kea, and so forth (Michel et al. 2003; Masciadri 2003). The South Pole at ground level is not really a bargain (Travouillon et al. 2003), though some high Antarctic plateaus have their infrared and submillimeter skies very dark (Lawrence 2004). And Dome C is truly exceptional in seeing and dryness (Lawrence et al. 2004). At the moment, however, it has no electricity, and no one has ever overwintered there.

The three green dot papers on observing all pertain to some mix of old and new. A plot of the growth of telescope aperture from Galileo to OWL, TMT, CELT, and all is the sum of several exponentials for refractor, reflector, segmented, and such (Racine 2004), and one can also draw three separate curves for, at each epoch, state of the art, workhorses, and failures (which have so far always been the biggest).

The August 2003 power outage in the northern US and Southern Canada did wonders for dark skies, as we noted last year. In addition, there was considerably reduced pollution of SO_2, NO_x, O_3, and particulate matter (Marufu et al. 2004).

You have probably always thought of refraction at the horizon as a minor perturbation on the apparent shape of the Sun (perhaps due to Ra changing between his day and night boats), but at the right season, altitude, and latitude, it can affect the apparent positions of the Sun and stars by up to 4° in angle and 2 weeks in time (Young 2004; Sampson et al. 2003). The right time, season, and latitude will also enable you to see very long sunsets and sunrises. Those who live near the Arctic and Antarctic circles are used to this, but the more easily surprised author was astounded by 40 minutes of sunset, an hour of twilight, and another 40 minutes of Sun spraddling the horizon on the way back up during a flight from Frankfort to Los Angeles in November. The experience was only partly spoiled by an on-going fight with the flight attendant to be allowed to keep the window shade up. She seemed to expect blazing sunlight at any moment; perhaps it was her first November flight on this route too.

12.5. Earth and Her Inhabitants

Conceivably, the more scattered author should really have been a geographer, sociologist, paleontologist, or historian, for she indexed about 165 papers under this category (the largest).

12.5.1. The Home Planet

The Earth's magnetic field reverses from time to time, taking on average only 7000 yr to do it (Clement 2004) for reasons understood, if at all, by those who study dynamos (Christensen & Tilgner 2004; Holme 2004). The latter includes laboratory data from Karlsruhe—a small scale simulation presumably, since we didn't notice our compass needles swinging toward Germany last year. The good news is that field reversals are not dangerous (Birk et al. 2004), because the solar wind quickly induces some magnetic field in the ionosphere.

Timing of terrestrial events improves. C^{14} has been calibrated back to 50,000 yr BP (Hughen et al. 2004, who note that "BP" means before 1950, perhaps more present to us than to you). There are new and better numbers for major geological events like the K-T boundary (65.5 Myr ago), end of the Permian (251.0 Myr), and the beginning of the Cambrian (542.0 Myr ago). The Edicarian (era of the first multicelled creatures) began 600 Myr ago (Ogg et al. 2004). Fauna those creatures must have been, since the authors say so, but nearly all the ones

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[20] This is a curious way of celebrating the World Year of Physics, by sending a beam of light around the world, beginning in Princeton on April 18th. If you haven't heard about it, don't worry. If you have, please let us assure you that it was not the idea or the fault of the International Union of Pure and Applied Physics (whose Commission on Astrophysics registered a pained objection to the project), though some early publicity gave that impression.

shown by Narbonne (2004) look to us like ferns and leaves. Apparently the whole issue of what is a species, what is a growth stage, and what is a bit knocked off something larger needs rethinking (Braiser & Antcliffe 2004). The Edicarians are not, it seems, ancestral to anything around now, except, perhaps, a few of our more sessile students.

What caused these datable events? You get a choice between "Earth as a planet" and "VERY near Earth objects." The contemporaneity of the Cretaceous-Tertiary boundary (K-T, end of the dinosaurs) and volcanoes on the Deccan plane of what is now India is discussed by Ravizza & Peucker-Ehrenbrink (2003). Conversely, as it were, the crater left by an impact perhaps responsible for the Permian catastrophe has been found off the coast of Australia (Becker et al. 2004).

Changes in the eccentricity of the Earth's orbit and the obliquity of its ecliptic are still correlated (causally, it is oft supposed) with ice ages and such (Wolff 2004; Liu & Herbert 2004). The previous interglacial, about 125,000 years ago, had summers that were hotter than the present ones (Felis et al. 2004), but you don't need us to tell you that the summer of 2003 in Europe was the hottest on record; that heat waves are likely to get worse (Meehl & Tebaldi 2004), and that none of us is blameless in this (Karl & Trenberth 2003). The second hottest summer was 1757 (Luterbacher et al. 2004). Our favorite method of carbon sequestration remains throwing old automobiles into the seas (Boyd 2004, and three following papers).

And we are still struggling with the concept presented by a Distinguished Colleague walking down the hall with a giant armload of one-sided xerography. He said what he was doing was meritorious, because the trees from which the paper was made were farmed, and when the paper went into land-fill, that carbon would be permanently taken out of the budget. Curiously, the department had a balanced budget the years he was chair.

12.5.2. Some Favorite Animals

Birds have red, green, blue, and UV cones (Prum 2004), all the better, we suppose, to see the first ultraviolet domesticated cats (Vigne et al. 2004), beginning by 9200 yr BP. (Well, the cat was probably cat colored.)

The last dodo was seen in 1662, implying (given scenarios for other species) that extinction may not have occurred until about 1690 (Roberts & Solow 2003).

Kemp (2004) presented a brief study of the biology of Rudolph the Red Nosed Reindeer, and planned to address Frosty in about a year.

Proudman et al. (2004) have examined injuries due to horses falling in the Grand National Steeplechase and suggested changes in the first fence, practice runs, and other methods of reducing these. Not running the race should also work.

Pony Expresses from the time of the Persians (540 BCE) to the American Civil War all had stages 16–28 km in length, horses doing one stage each at 13–16.5 km/hour, and riders doing 4–6 stages at, we hope, the same speed (Minnetti 2003). Injuries were not reported. Some of these, however, may have been due to jealous spousehorses, since the most vigorous stallions appear to have had a mare in every port (Lindgren et al. 2004).

There is a 330 lb tuna at the Monterey Bay Aquarium (Hamilton et al. 2004). Water-packed, probably. The first creature with enough of a humerus to do push-ups was also a fish (Shubin et al. 2004), and the more clueless author was in her late 20s before she got THAT joke.

A sort of millipede was the first animal to breathe air (Wilson & Anderson 2004), about 420 million years BP (before 1950, remember, not before 2005). And archaeopteryx was probably the first bird to fly through it (Dominguez Alonso et al. 2004).

Turtles grow their carapaces from the merging of about 50 rib bones and their plastrons from 9 bones that would otherwise have been part of face and head (Cebra-Thomas et al. 2004), perhaps accounting for their often somewhat vacant expressions.

When turtles get lost, they can use the Earth's magnetic field for navigation (Lohmann et al. 2004). But they very rarely get lost, because it is turtles all the way down (see emys.geo.orst.edu).

Hippopotami sweat (Saikawa et al. 2004), and bovids, well, it has methane in it, but Wright et al. (2004a) have a vaccine for it.

A dog studied by Kaminski et al. (2004) is said to have a vocabulary of 200 words, which may exceed that of some scientists (Snyder 2004). This latter is really a paper about Asperger's syndrome and scientific creativity, with Newton and Ramanujam as candidates and trouble recognizing faces as one of the common correlates.[21]

You should shoot lions when their noses are dark (Whitman et al. 2004), grandfathers rather than grandmothers (Lahdenpera et al. 2004), Pronghorn antelopes when their horns are small (Coltman et al. 2003), and flies before they have a chance to become forgetful (Tamura et al. 2004).

The most embarrassing problem faced by any non-human living creature is surely that experienced by one dexter and one sinistra variant of the snail *Bradybaena similaris* (Ueshima & Asami 2003).

12.5.3. Some Favorite People

The same person is both a Sloan Fellow (an early career award) and director of the Astrophysics Institute of Potsdam (usually not an early career award; *ApJ* 597, 21). If this sort of career compression becomes common, we might look forward to graduate students running observatories!

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[21] Yeah, the author more given to movement disturbances and reduction in facial expression on one occasion each failed to recognize her own father and her own husband, and she had known both for MANY years.

Hall & Marsh (2004) want to set an upper limit to the duration of postdoctoral appointments. We are inclined to think it ought to vary with age at Ph.D. A 24-year old degree recipient might well benefit from more than 4 years of additional mentorship; and 30 year old one probably would not.

The age-gender structure of AAS membership continues to shift (Naeye 2003). The fraction of women in the 65–70 year old cohort is larger now than it was in 1972. Some combination, the nearly 65 author supposes, of late Ph.D.'s and us outliving them.

Human life spans increase as the incidence of childhood infections and inflammations goes down (Finch & Crimmins 2004). The ideal, of course, would be to have everything fail at once. We were much surprised to see mention of the "Wonderful One Hoss Shay" in this context (Kennedy 2004), if only because we supposed we were the only ones old enough to remember this 1858 poem by Oliver Wendell Holmes, which he called "The Deacon's Master-piece." The vehicle was built in 1755, the year of the Lisbon earthquake. That's the one that persuaded John Michell (who discovered binary stars as well) that earthquake energy travels in waves. The event was, in fact, two quakes, about 300 km and a few minutes apart (Vilanova et al. 2003). It (or they) triggered a tsunami, probably responsible for as many Portuguese deaths as the quake and subsequent fire themselves.

Herschel in three? The more Plutonic author notes (courtesy Hurn 2004) that J. G. Galle (1812–1910), the first to be aware that he was seeing Neptune, overlapped the end of the life of William Herschel (Uranus) and the beginning of that of Clyde Tombaugh (1906–1995, Pluto). And yes, she met Tombaugh. She can also claim to be perfectly typical of her culture, gender, and generation. Brown & Moses (2004) point out that "a woman in one of the most developed nations uses as much energy (10 kW continuous average) and has the same reproduction rate (fewer than 2 per lifetime) as a hypothetical primate weighing 30 tonnes." Reproduction rate scales as $M^{-1/4}$ and metabolism a $M^{3/4}$ they say.

Inadequate error bars were used in 7 of 10 items published in *Nature* on 19 February 2004, says Vaux (2004). He does not define "inadequate," and we are inclined to think that this might be something you can be sure of only long after the fact. Hubble, for instance, reported in 1929 a "*K*-term" of 536 km/sec/Mpc, plus/minus 10%. This takes in 71 only at the 8.7 σ level. This one got a green dot, along with the somehow-related remark from a book review (DeVorkin & Hingley 2004), "…distinguished names as Osterbrock, Burbidge, Arp, and Trimble." The review was a belated one of an AAS Centenary volume.

In the days when telescopes had eyepieces, the average astronomer had no doubt which eye should look through it. Rembrandt, it seems, also had strong right eye dominance (Livingstone & Conway 2004), since, in his self-portraits, the right eye always looks straight at the mirror he was using and the left drifts outward. The authors suggested that this may have reflected lack of binocular vision (exotropicism, stereoblindness), but letters a few issues later disputed this. Since Rembrandt probably never had to swing through the jungle from tree branch to tree branch or get on a down escalator, it may not have mattered much to him.

The best-paid director of a scientific society received $721,000 last year (Burke et al. 2004). He runs the American Chemical Society, the largest of them all, and out-earns (in order) the directors of IEEE, AAAS, NAS, and APS. We would not presume to ask where in this hierarchy the executives of ASP and AAS fall. If you left your handy-dandy acronym decoding ring at the office, these are Institute of Electrical and Electronic Engineers, American Association for the Retardation of Science, the National Academy of Sciences, American Physical Society, Astronomical Society of the Pacific, and American Astronomical Society.

Astronomy, we are told, appears in the writings of Poe, Emerson, Hawthorne, Dickinson, Thoreau, Whitman, Twain, and Henry James (Zimmerman 2004). But only Herman Wouk (2003) would have thought of writing a novel about the Superconducting Supercollider. It is called *A Hole in Texas*.

The "tell me more" green dot of the year goes to Mayo (2004), who says that the Mayas had calculated the size of the Earth with reasonable accuracy, but does not say whether by the method of Eratosthenes or some other.

13. THE GAMUT OF EMOTIONS FROM A TO C

Fans of the backhanded compliment will recognize this as a slight extension of a review of a Broadway performance by Katherine Hepburn (the gamut of emotions from A to B, wrote Dorothy Parker). It also describes our first mistake in Ap03, in the abstract of all places, where gamma-ray bursters are associated with Type Ia supernovae rather than Type Ic. So, here, first, are some of our other errors of commission and omission followed by a subset of oddities in the 2004 literature committed (or anyhow not omitted) by others.

13.1. We

All but the last of these arise from Ap03 and are ordered by section number there.

Sec. 2.5.2. The authors of the paper cited for detection of the nuclear de-excitation gamma-ray lines of $C^{12}$and N^{14} during a solar flare advise us that indeed "detection" and "during," but post hoc is not always precisely propter hoc, and the photons came from the Earth's atmosphere after impact by energetic particles from the Sun. No nuclear de-excitation lines of N^{14} or C^{12} originating in the Sun were observed during that 21 April 2002 flare.

Sec. 3.1. The definition of optical depth of the universe since recombination is wrong. At $\tau = 0.17$, and photon has $a(1 - e^{-\tau})$ or 15.6% chance of not getting to us, not a 17% chance. The opacity is correctly ascribed to scattering, and the only reason our error wasn't larger is that the first two terms of a Taylor series are nearly always 1 and x.

Sec. 9.1. The dominant stellar component in the halo of M31 is metal rich, with ages ranging from 6–11 years. Old metal poor stars live there too, but they are, at about 45%, a minority, say the authors cited, not a majority, as we claimed.

Sec. 11.1. A particularly numerate reader notes (*a*) that between 1953 and 1968, Harvard College Observatory was directed by the late Donald H. Menzel (accounting for the absence of those years from some of their plate archives), (*b*) that there was a "pre-discovery" of the correct central wavelength of the 4430 Å feature as 4428 Å by Code (1958), and (*c*) if you are collecting things very close to 1054, Hodge (1961), reporting 1057 field stars in the LMC, deserves at least a mention.

Sec. 11.3 says, "Unusually distant things come first…and human extremities at the end," where any reasonable reader would have expected to see a pile of hands and feet. The claim in that section to have identified the most dilatory series of connected papers has also been disputed, with a case made for Paper 1 in 1967 (*ApJ* 148, 465) and 15 in 1998 (*MNRAS* 293, 151). Other publications in the series can be recognized by their incipit, "Section 0 (Preamble)" rather than the commoner "Section 1 (Introduction)."

Sec. 13. A colleague (capable of both constructive and destructive interference) has disputed the claim that phases normally fall between 0.0 and 1.0, saying, first, that if data are simply reported modulo a period, then the X-axis should have 0.0 at both ends, and, second, that phases 7.34 to 9.44 imply 7–9 cycles after a count started. The choice of time for phase $=$ 0.0 in the case discussed remains mysterious.

Acknowledgements. Dr. Lee Mundy appeared in this paragraph with middle initial C rather than G. We don't actually know what either stands for.

And an extraterritorial error. Back in Ap93, VT claimed that SN 1993J had been the second brightest in living memory (after SN 1987A). It wasn't, as noted in Ap94, and the same colleague who called this to our attention now notes that Trimble (2000) gives a distance of 1.4 Mpc to the host galaxy (M81) of that supernova, apparently a typo for 4.1 Mpc, and 3.7 Mpc is probably a better estimate.

13.2. They

Some of these are classifiable as unfortunate acronyms, genuinely wrong, and so forth, but most went into our indices as either "um?" or "eh?" and are listed here in fairly random order. Most often only a citation is given, the author not necessarily having concurred in what got printed.

"Dog-e-Tag lists the dog's name, home, and e-mail addresses…" from a catalog that also offers T-shirts saying, "When the chips are down, the buffalo is empty."

"Note that you will need your member number (listed above your name if you have one)…" from a letter to donors written by a scientific organization that may prefer to remain anonymous. Indeed the majority of such letters lead us to suppose that our name is "resident," "occupant, "donor," or "V. T. Mble."

"The rings of Saturn never fail to disappoint casual observers today, so we can only imagine the thrill of their discovery…" (*JRASC* 98, No. 2, 79).

"The Chelm Institute of Orange County" (Zatz 2004) is the purported home institution of the authors of a 1 April letter to *J. Biological Rhythms*. The authors include N. I. Lobachevsky, M. Pupique, and Quincy Adams Wagstaff. N. I. L. is explained (Tom Lehrer) and Q. A. W. (Groucho Marx role as college president in *Horsefeathers*). M. Pupique is not.

"…insect-borne virus expert…" (*Los Angeles Times*, 8 February, B16 obituary). Well, it was a very strong insect.

"The Clay telescope" (Magellan II) (*ApJ* 599, 465, abstract). Arguably not the best choice of materials.

13.2.1. New Math

"92 galaxies…distributed over 93 SDSS fields" (*AJ* 127, 704, abstract).

"Cosmologically interesting redshift ($z > 0$)" (*ApJ* 607, 74, abstract). Indeed z less than zero is probably not cosmologically interesting in the standard model.

"An exponential leap in efficiency and energy is needed" (*Science* 429, 792), but they seem to mean a factor a good deal larger than 2.72.

"The morphologies of $491.7 < z < 3.8$ galaxies" (*AJ* 128, 163, abstract). If $<$ is distributive, then 491.7 is less than 3.8.

13.2.2. Acrimoninyms

IOTA $=$ infrared optical telescope array (*A&A* 408, 533, title and beyond). And PICNIC at IOTA (*PASP* 116, 377), where it is a near infrared camera used at the Whipple telescope. They should only remember the real picnics at IoTA! (Institute of Theoretical Astronomy, as directed by Fred Hoyle, 1967–72).

DDT observations, not the insecticide or drop dead twice, but director's discretionary time (*ApJ* 601, 465, acknowledgements).

YORP effect (*A&A* 414, L21).

INTEGRAL (*MNRAS* 348, 369, text), an infrared spectrograph rather than the gamma-ray satellite.

SUMER $=$ solar ultraviolet emission of emitted radiation (*A&A* 418, 737, abstract), which we think should be at least SUEOEMR, presumably located in AHCKAADD.

The Acronym Institute for Disarmament Diplomacy (*New Scientist*, 15 May, 5).

CUDSS (*MNRAS* 351, 447), over which we will have to chew.

13.2.3. Um, Er?

"by equatorial, we mean perpendicular to the major axis" (*ApJ* 603, 7, footnote).

"a dense dust stream may occupy at least part of the orbit of de Vico" (*ApJ* 593, L61, abstract); the part he isn't using, we hope.

"mean-radio luminosity" (*A&A* 417, 39, text). Our radio is a kind and gentle appliance, which always consults a major appliance before attempting changes of voltage and other dangerous operations.

"an ambitious experiment in sidereal time," in a *Los Angeles Times* book review (26 September, p. R10) concerning Truman Capote's *Unanswered Prayers*.

"The sum of all sources in S2 on day 1281 is similar to the maximum observed for this error box by *BeppoSAX* by a factor that is smaller than $1\overset{\prime\prime}{.}5$" (*ApJ* 608, 880, conclusions). This one could perhaps have been fixed by turning "similar to" into "different from."

"There is no simple relationship between scatter in the L_X–T_X relationship nor in the recent overall merger activity" (*MNRAS* 352, 508, abstract).

"Although very small, we are therefore unable to determine whether…" (*MNRAS* 352, 589, abstract). If Mother Nature had intended astronomers to be bigger she would have given us cosmological redshifts. (Compare: Jayant Narlikar explaining some years ago at an AGN meeting that he was actually a small Indian standing close to us, not a large Indian very far away.)

"Astronomical events visible only from East Antarctica" (*Sky & Telescope* 108, No. 4, 72) (presumably by astronomers from the University of South West North Dakota at Hoople).

"…reddened stars that lie behind molecular-rich regions are also heavily reddened" (*AJ* 128, 261, abstract).

"Huge Young Stellar Object Interaction Region" (*AJ* 128, 375), title, leaves us wondering whether it is the object, the interaction, or the region that is huge.

"To easy the reading, the physical parameters…are also reported" (*A&A* 416, 473).

"The authors should have wonder how…" (*A&A* 416, 800, discussion).

"The three components have 10^{10} yr" (*A&A* 419, 449, abstract).

"Check your mailing lable for your renewal date" says the newsletter of an organization we should probably all belong to. The mailing label says S7 P11 2545 1732. And I promise to renew on the 32nd of Seventeen in the year 2545.

13.2.4. Er, Um?

"*Evolution's Rainbow* is written for…and any other people who enjoy either sex or gender." A book review in *Science* 304, 965.

"free advice, which was infinitely more valuable than its price" (*AJ*, 126, 3028, acknowledgements). And we also caught: "Al mio papa" (*ApJ*, 611, 173), "MS wishes to thank past and present Rockets" (*A&A*, 420, 918); "we thank the referee, John Norris, and Raffaele Gratton" (*ApJ*, 412, L128), leaving us uncertain about whether two people or three are being thanked. Are you reminded of *Eats, Shoots and Leaves*?

They have nothing on the Cosmos Club, whose September bulletin (Vol. 57, no. 9, p. 15) has a dinner menu featuring "Grilled breast of Duckling, with pomegranate lime glaze, beet couscous, oven, roasted parsnips, and braised romaine." Could I have extra butter on my oven, please?

13.2.5. The Skies Were Darker Then

This was originally a line from Steve Maran, showing a lithograph of the night sky, with comet, and names of the constellations clearly visible. According to *Physics Today* (October 2003, p. 18), an account of a South American astronomer working in the early 1700's: "He observed eclipses of the Sun and Moon and some of the satellites of Venus and Jupiter." We were also told (*Annals of Irreproducible Results* 10, 406) about "Tycho's later observations of the orbits of Cassiopeia and a comet."

"…we now know quasars to be extremely luminous, distant stars marking the centers of galaxies," and "…redshift is a measure of an object's distance from the earth" both from *Nature* 428, 483, an obituary of J. Beverly Oke, and not, we are reasonably sure, precisely the original words of the author, who is a Vice President of the American Astronomical Society, a task we have undertaken ourselves.

"Not even our children's children will live to take part…." William Harkness to AAAS in 1882 on transits of Venus, quoted in *J. Hist. Astron.* 29, 22. He spoke as a man of 60 or more whose children were well grown and grandchildren perhaps already born. BUT an audience member of 20 might well have had grandchildren alive in 2004, not to mention Harriet the Tortoise who presumably saw both events and may have known Darwin.

13.2.6. Who?

The e-mail addresses in *A&A* 423, 705, are all given as "First_name@astro.univic.ac.at," but the authors have only initials listed on the paper.

"One of us (P. B.) has assembled a large batch of high-quality spectra," but the paper (*ApJ* 557, 793, § 2) has both P. Bergeron and P. Brassard as authors.

From the necrology in *International Astronomical Union Bulletin* 94, 44, "Jack H. Res. Fel. Piddington." Well, at least they didn't call him "resident."

"First Cousins light curves…" (*ApJ* 417, 745), also sisters, aunts, and perhaps second cousins.

"Alcock, who studies comets and asteroids" (*Science* 304, 1241). We think this is actually meant to be the Alcock (Charles) of MACHO and all, though Alcock & Brown also come to mind (leaving us grateful not to have claimed a few lines about that serving as AAS vice president leaves the mind unimpaired).

"I thank Mr. X. for a carefull reading of the manuscript" (*A&A* 413, 804), apparently not including the acknowledgements.

R. Miller is described as "aging researcher" in *Science* 304, 514, an article on Yoda, the second mouse to reach his 4th birthday. They don't say how old Miller is.

The Whipple telescope is both a 1.5-m optical one on Mt. Hopkins and a 10-m aperture at Kitt Peak, designed to look for Cerenkov radiation from ultra-high energy cosmic rays (*Science*, 305, 1393).

And don't forget that Herschel has given his name both to a 42-meter telescope in the Canary Islands and to a satellite earlier known as *FIRST*. But the first FIRST was a radio survey.

"…maximum compression along the principle Hugoniot" (*ApJ*, 609, 1170), sounds painful for him.

13.2.7. Well, I Wouldn't Have Said It Quite That Way (I Hope)

"The primary function of the posterior opening was presumably as the anus, possibly combined with other functions (for example as a gonophore)" (*Nature* 430, 425), concerning an ancestral echinoderm.

"non–observationally determined parameters" (*ApJ* 603, 117), meaning not determined at all, we think.

"All these sources have a common proper motion indicating they are bounded" (*A&A* 423, 155). We are grateful to hear that there are no infinite sources, in light of the next item.

"We present a simple closed-box model of the chemical evolution of the universe" (*ApJ* 606, 113, conclusion). Consider the alternative!

"A-colored stars" (*ApJ* 596, L191, abstract and text). They are, one supposes, closely related to stars of spectral type white.

"…model of general interest because of the ubiquity of the hydrogen spectrum" (*ApJ* 601, 1181).

"His blood was found to have suspicious levels of hematocrit" (*Economist*, 28 February, 83). Hematocrit is the percentage of blood volume occupied by cells (35 or 40 might be typical), so the phrase is analogous to "the star was found to have a bright value of magnitude."

"pions—unstable particles formed from a mixture of matter and antimatter" (*Nature* 430, 825).

"Space vehicles that rely on jet engines" (*Nature* 428, 459), lower space, presumably.

"Non-monotonous" (*ApJ* 606, 444). Two authors are Americans, so perhaps they meant it, but the response "wanna bet?" is tempting.

Source names: HD 2094586 = Osiris, along with many assorted IR spectrographs and such (*ApJ* 604, L69). Balloon 090100001 (*A&A* 418, 298). ESO 215-G?009 (*AJ* 128, 1152, whose authors are kind enough to explain). Pox 186, a galaxy (*A&A* 421, 519) and not, as far as we can tell, either an acronym or portions of names of people or places. Anyhow, next time we excoriate someone with "A pox on you!" we will know it is Pox 186.

"Neck-line model for comet tails…" (*A&A* 422, 357), a fashionable model one supposes.

"…ratio of ejected stars to those who appear to have formed in the halo" (*MNRAS* 349, 831, text). Well, the stars are supposed to be our friends.

"…unfriendly ISM" in 4C 12.50 (*A&A* 424, 119) but not quite clear why.

The Eastern (in *PASJ*) and Western (in *MNRAS*) models for why few X-rays binaries consist of a neutron star plus a black hole (*MNRAS* 348, 955).

Spectral type ON2 III (f*) (*ApJ* 608, 1028).

From a PPARC Annual Report list of abbreviations: SKA = Square Millimetre Array (with, we fear, ominous implications for the budget).

From *Gemini Newsletter* No. 28, p. 11, SN 203gd, one of the earliest recorded.

From the *Economist*, 2 October p. 52, "The miners…put plastic sheets over their windows to keep out the cold—temperatures can dip below 45°C."

From *Europhysics News*, Nov/Dec 2003, p. 209, "…the existence of natural magnets, the 'loadstone'," which was an especially heavy one.

13.2.8. At Least Two Cultures

See *ApJ* 612, L21, for interesting remarks on marriage, divorce, death, fluctuations in economic quantities, incubation periods of diseases, lengths of telephone calls, and a number of other issues of broad concern to humanity.

The quest for connections between the Astronomer Royal Nevil Maskelyne and the magician of the same name who flourished around 1900 continues. The AR had only one child, a daughter, whose son was Nevil Storey-Maskelyne, an Oxford Professor of Mineralogy, so the sometimes-claimed grandfather/grandson is probably not true. Grandson of the brother of the AR is likely, a correspondent informs us, also providing the factoid is that the magician's grandson was Jasper Maskelyne whose exploits (such as making the Suez Canal disappear) are soon to be documented in a motion picture.

"Even the sociology of science can benefit from fruit fly studies" notes Djerassi (2004), pointing out that the percentage of Asian names on US vs. European papers on the topic is 54% for the American one and 0% for the European one.

"X argues that popular writing should be considered a valid academic endeavor" (*Science* 305, 1555).

"Dawkins has been scrupulous in not allowing his science to control his politics," from a book review (*Nature* 431, 21). We rather think one's scientific knowledge should at least inform one's political views!

"The committee is proud of the fact that it was written by historians, not scientists," from another book review (*Nature* 431, 246), and in context it does not sound quite so much as if the committee had been writing itself rather than a book. But the reviewer goes on, "I think that a 450 page book about a great scientist should have at least one chapter dealing with his discoveries."

13.2.9. You Will Be Lucky if You Can Get This Guy to Work for You

The *New Scientist* (23 August, p. 47) reports on a book that "…contains some fine photographs, most of which are the right way round." And reaching back into the past, as *Nature* (137, 229) does weekly, was a reprint of a review of a Herbert Dingle book on spectroscopy: "Concerning the section on astronomical spectroscopy, it need only be said that in lucidity and interest it is quite representative of the author's well known writing on this subject." You might also remember Dingle as a doubter of special relativity and the chap who said about steady state cosmology that one should call a spade a spade, and not a "perfect agricultural implement."

The last word, as in previous years, belongs to a correspondent we have never actually had the privilege of meeting who this year provides a warning to those who do work in astronomy, "By this way the carbon problem may be alleviated: Now we have a new problem when we take a strong hand!" And any who chance to remember the Passover Haggadah will instantly associate the strong hand with a multiplicity of plagues.

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