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Invited Review

Astrophysics in 2001

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ABSTRACT. During the year, astronomers provided explanations for solar topics ranging from the multiple personality disorder of neutrinos to cannibalism of CMEs (coronal mass ejections) and extra-solar topics including quivering stars, out-of-phase gaseous media, black holes of all sizes (too large, too small, and too medium), and the existence of the universe. Some of these explanations are probably possibly true, though the authors are not betting large sums on any one. The data ought to remain true forever, though this requires a careful definition of "data" (think of the Martian canals).

1. INTRODUCTION

This review covers the first year in a pedant's new century and new millennium and is, in several senses, "Astrophysics Lite." First it is shorter than Ap2000,[1] though not enormously shorter (and the author of § 2 has been more disciplined about this than the squaw of the other two hides). Second, and more important, the more extended author adopted a different rubric for note-taking. The previous one was, "read it all, and allot one notebook line for every 10 pages of regular journal text or 4 pages of letter journal text." The result was about 200 notebook pages per year, representing 5000+ published papers. (See *Sky and Telescope*, 101(2), 50, for a reproduction of part of page 69 of the year 2000 notebook, and a prize to the first reader who recognizes which journals were being read that day, July 2nd.)

The 2001 rule was "read it all, and allot one notebook line for every 100 pages of regular journal text or 40 pages of letter journal text." Strict discipline, of course, faltered from time to time, but the result was 43 versus 180 notebook pages, recording only about 1150 papers. The selection criteria were twofold: First, what the paper was trying to say had to be fairly clear at first reading and, second, the message had to have some "wow" aspect about it, though we admit to a pretty low "wow"-threshold. In an attempt to raise the threshold, stars (well, pencilled asterisks) were assigned to about one paper per notebook page, meaning "this really has to go in, no matter what it does to our page charges." The phrase "starred paper" or synonyms thereof in §§ 3–13 means one of these, and a subset are the drivers of their sections.

Section 2 in both years was assembled using papers found on the Astrophysics Data Service, maintained with support from NASA, with corresponding slight differences in publication dates of the papers considered.

The journals scanned were the issues that reached library shelves between 1 October 2000 and 30 September 2001 (with some slack for journals mailed just before or just after the 11th) of *Nature*, *Physical Review Letters*, *Science*, the *Astrophysical Journal* (plus *Letters* and *Supplement Series*), *Monthly Notices of the Royal Astronomical Society*, *Astronomy and Astrophysics* (plus *Reviews*), *Astronomical Journal*, *Acta Astronomica*, *Revista Mexicana Astronomia y Astrofisica*, *Astrophysics and Space Science*, *Astronomy Reports*, *Astronomy Letters*, *Astronomische Nachrichten*, *New Astronomy*, *Journal of Astrophysics and Astronomy*, *Publications of the Astronomical Society of Japan*, *Bulletin of the Astronomical Society of India*, *Baltic Astronomy*, *Contributions of the Astronomical Observatory Skalnate Pleso* (which seems to be the last of the independent observatory publications series, which once numbered more than 200, from Abastumani to Zusu), *IAU Circulars*, and, of course, *Publications of the Astronomical Society of the Pacific*. Lost from the inventory are *A&A Supplements* (merged into the main journal, on-line version only, by the new publishers), and *Astrofizica*, still advertised in Kluwer catalogues but harder and harder to find. Some of the journals we read for fun, without systematic note-taking, were *Observatory*, *Journal of the American Association of Variable*

[1] The previous 10 reviews are cited here as Ap91, Ap92, etc. to Ap00, and appear in volumes 104 to 113 of *PASP*, further and further from page 1 as the years go on.

Star Observers, *Astronomy and Geophysics*, *Mercury*, *Sky and Telescope*, and *Monthly Notices of the Astronomical Society of South Africa.*

What kinds of astronomical data and theories you will want to collect and pay attention to depend a great deal on the questions you want to answer. The millennium provides an excuse for assembling a few.

1.1. Questions from the Past

Simon Newcomb has, in recent years, been something of a victim of bad publicity, being cited for his reluctance to include spectroscopy (the "new" astronomy of 1901) in our discipline and societies (Osterbrock 1999). He has also been proposed as the original of Walt Whitman's "Learn'd Astronomer" and perhaps even part of the model for Prof. Moriarty. In his own later writing, however, he comes across as the sort of person you might well want to go on an observing run or a country ramble with (Newcomb 1901; the first measurement of the night sky background). He also put forward the best list of "unsolved problems in astronomy" that we have seen from that period (Newcomb 1906; a reprinting of essays written between 1888 and 1902). The "question" phrases that follow are in his words, followed in some cases by additions in ours.

1. Where do the stars come from, and where do they go to? He had in mind proper motions equivalent to 30 km/sec or more, that is, stars that would cross the Milky Way and leave in the age of the universe as then understood. By the way, he invented the technique of statistical parallax for such stars.

2. What is the size of the universe? Has it a boundary? (He thought Olbers Paradox might require the answer, yes, here.) Are its volume and duration infinite?

3. What are the form and extent of the Milky Way? We seem to be at the center; are we perhaps the victim of some fallacy, like Ptolemy? (Way to go, Simon!)

4. What is the source of heat of the sun and stars? (given that contraction does not last long enough—which Newcomb knew, though Kelvin in the same year did not). And is there some connection with the discoveries of Thompson (electron), Becquerel (radioactivity), and Röntgen (X-rays).

5. What becomes of the heat and light radiated by the stars? Is it wasted in empty space? (This is the one that sounds odd to modern ears.)

6. Do other planets in the solar system have scenery, air, and life? What is the nature of Schiaparelli's canals and their meaning?

7. What is the cause and nature of stellar variability? (In 1885, he knew only of flares and spots plus rotation, by analogy with the Sun; by 1902 he had added eclipses to his toolkit.)

8. What are the cause and nature of sunspots and solar flares and prominences and their contrast with the quiet, calm photosphere? Is there some agency passing from Sun to Earth that associates compass deviations and aurorae with solar flares?

9. What is the nature of the corona? The fibrous structure looks like magnetic field lines (as traced out by iron filings, for instance); is this relevant?

10. What is the nature of the zodiacal light and *gegenschein*? He thought the existence of the latter ruled out the obvious explanation of the former in terms of meteoric material in the ecliptic plane.

11. What is the cause of the irregularities in the rotation of the Earth and of the Moon? (The regularities of tidal coupling and slowing of the Earth's rotation were understood.)

12. What is the cause of the rotation of the orbit of Mercury? (The "Vulcan" explanation had just about been ruled out, and Newcomb suggested small deviations from $1/r^2$, though his contemporary Asaph Hall was pretty sure that this would produce observable effects in the motions of Venus and the moon.)

13. What is the cause of new stars which fade into ordinary nebulae, and of nebular expansion that is faster in the plane of the sky than light can propagate information? Early observations of Nova Persei 1901, which had been seen at $m = 13$ before the event and showed nebulosity soon after, entered strongly into this one.

As a modern astronomer, you can, of course, more or less answer all of these. But you can probably also quickly come up with current questions that are close analogues for each, concerning, for instance (1) star formation, (2) the cosmological parameters, (3) dark matter and galaxy formation, (4) details of stellar evolution and nucleosynthesis, (5) the entropy of the universe, (6) exoplanets and complex chemistry thereon, (7) solar and stellar seismology, (8) systematics of stellar activity, (9) coronal heating, (10) protoplanetary disks, (11) the need for ongoing monitoring of Earth rotation and coordinate systems, (12) alternatives to general relativity and other deviations from laboratory physics, and (13) supernova progenitors and explosion mechanisms and jet collimation in gamma-ray bursters and superluminal quasars. There is at least a word or two about every one of these in the sections that follow.

The research papers published between 1901 and, say, 1910 in the main journals of the time (*MNRAS*, *AJ*, *ApJ*, and *AN*) do not instantly make it obvious that the 13 items above were the main unsolved problems of astronomy at the time. Neither is it obvious from perusal of publications today what an astronomer of 2101 will say were our main unsolved problems.

1.2. Questions from the Present

If you have your own list, feel free to skip this section. If you also know the answers, then by all means skip to the last reference (which is probably something by Zwicky). If you would like a starter set (with extra teaspoons), here is one from Vitaly Lazarevich Ginzburg (2001), as reproduced by Burbidge (2001), because *PASP* may be easier for you to find. Scouts' honor, though, we've actually read the book. For many of the questions, some phrase like "What is the nature and cause of …" can be inserted in front.

(1) Gravitational waves and their detection; (2) the cosmo-

logical problem: inflation, Λ term, and relationship between cosmology and high-energy physics; (3) supernovae, neutron stars, and pulsars, (4) black holes, cosmic strings (?); (5) quasars and galactic nuclei, formation of galaxies; (6) the problem of dark matter and its detection; (7) origin of superhigh-energy cosmic rays; (8) γ-ray bursts and hypernovae; and (9) neutrino physics and astronomy, neutrino oscillations.

If you call yourself an astronomer rather than an astrophysicist or cosmologist, you will probably want to add some items about star formation, morphological evolution of galaxies, interstellar chemistry and complex molecules in meteorites and all, very large scale distribution of galaxies, and systematics of planetary systems, but the number remains comparable with Newcomb's.

1.3. Question from the Future

We do not actually have this list, for reasons clarified by, e.g., Gott (2001). Indeed the same considerations preclude our hopping forward in time to 2101 to ask about the items from the previous sections. The only obvious proxy is the questions we would ask, given the opportunity. A group of string theorists came up with a list at a summer, 2000 conference. Allowing for differences in vocabulary, it is not so very different from Ginzburg's (black holes, gravity, and the universe, though also M-theory, proton lifetime, and dimensionless parameters).

Far and away the most pessimistic, though also most interesting, set we've seen comes from David Mermin (2001). He begins with "What are the names of the major branches of science? What are the names of the major branches of physics, if physics is still an identifiable branch?" The rest of the set and the commentaries are too good to paraphrase, so please read them for yourself. BUT many of the items include a caveat concerning whether the question even still makes sense to a scientist as opposed to sounding provincial, trivial, silly, or of interest only to historians.

In contrast, Newcomb's questions (apart from No. 5) all still make perfectly good sense, and seem none of silly, trivial, nor of purely historical interest. What is more, you will probably feel, as we do, that if he stepped in your office door (don't be frightened by the beard!), you could not only provide reasonable answers to most of them, you could do so in language that he could understand with a few minutes' practice. Newcomb, recall, was born in 1835, before the very first stellar parallax had been published, and held only a bachelor's degree (from Harvard, 1858, a few months after his first paper appeared in *AJ*; Lankford 1997). Another way to look at this is to note that, a quarter-century after Harwit (1975) attempted to quantify the number of distinct phenomena in astronomy and the number still to be discovered (by identifying the number discovered independently by more than one technique), we have indeed found some new ones, but by no means as many as he said were out there to be found. Or, under another consideration advanced by Gott (2001, and elsewhere), if the "play" called astronomy has been running for 200 years, its life expectancy (at the 95% confidence level) is between 5 and 7800 years, and, for that matter, the life expectancy of the Apxx series between 3 months and 429 years (if you are a random reader, which we deny utterly!).

2. HERE COMES THE SUN

The additional journals scanned for this section included *Solar Physics*, *Geophysics Research Letters*, *Journal of Geophysical Research*, and portions of *Journal of the Royal Astronomical Society of Canada*, *Physics of Plasmas*, and *Earth Planets Space*. The rubric remains that papers can be highlights, stars, or wows only if they were published during the index year and not by either of the present authors. If you spot one or two out-of-period pieces hiding among the references, you must pretend not to notice.

2.1. Neutrino Flavor Change Uncovered

The long-standing *solar neutrino problem* finally got solved. On 18 June 2001, a press release announced the discovery of transformations of the electron-neutrino into other active flavors, i.e., into the muon-neutrino and tau-neutrino, measured since 1999 with the new Sudbury Neutrino Observatory (Ahmad et al. 2001). This discovery of the "multiple-personality disorder" of the neutrino (Bahcall 2000) solves the 30-year old mystery of the missing solar ^{8}B neutrinos and confirms that the total number of electron neutrinos produced in the Sun are just as predicted by detailed solar models (e.g., Bahcall, Pinsonneault, & Basu 2001; Turck-Chieze et al. 2001). This discovery perhaps will stop particle physicists to blame astrophysicists that they were always wrong with their standard stellar model.

Alternatively, the solar neutrino could be time-varying and oscillate between bimodal states, as revealed by a histogram analysis of GALLEX, GNO, and SAGE neutrino data (Sturrock & Scargle 2001).

2.2. Does the Tachocline Have a Memory of the Solar Dynamo?

The solar dynamo was thought to involve mainly the two basic processes of the generation of toroidal field by shearing a preexisting poloidal field by differential rotation (Ω-effect) and the regeneration of a poloidal field from a toroidal field by helical turbulence (α-effect). Such flux-transport dynamos of the Babcock-Leighton type were successful in reproducing most of the solar cycle features but failed to reproduce the Sun's asymmetry of the magnetic polarity in both hemispheres, which switch during two subsequent 11-year cycles (i.e., the 22-year Hale cycle). An important new ingredient of advanced dynamo simulations with a meridional flow pattern is the α-effect of the tachocline, which could store parts of the dynamo-generated toroidal field for long times (Rempel et al. 2000) and, by virtue of this memory, can produce the antisymmetric coupling between both solar hemispheres (Dikpati & Gilman 2001b). Applying this model to the prolateness of the solar tachocline yields toroidal fields of 60,000–150,000 G in the overshoot layer (Dikpati & Gilman 2001a), while another model that calculates the energy needed to supply the differential rotation during a solar cycle yield fields of ≈10,000 G (Durney 2000).

2.3. Dynamic Whirls beneath Sunspots

The persistence of sunspots presents another solar mystery that exists since Galileo's observations some 400 years ago. The strong magnetic polarities concentrated in a sunspot should repel each other and should cause the sunspot to quickly dissipate. The hitherto unidentified force that holds a sunspot together was recently discovered with a time-distance helioseismic technique, which revealed planet-sized vertical whirls under sunspots. While outflowing motion at the surface has been detected for a long time, *SoHO*/MDI revealed for the first time the subsurface *inflows*. These whirls are driven by self-perpetuating temperature cycles and form a collar around the sunspot, apparently contributing to the dynamic stability of a sunspot. The rolling subsurface collar was found to be surprisingly shallow, extending only about 1500–5000 km deep (Zhao, Kosovichev, & Duvall 2001).

2.4. New Methods to Measure the Coronal Magnetic Field

Most of our measurements of the magnetic field on the Sun refer to the photosphere, where the longitudinal field strength can be measured with the Zeeman effect and Stokes polarimetry. However, to understand how the solar corona is heated, generally believed to be powered by some form of magnetic energy, we desperately need measurements in the lofty heights of the corona. Here some exciting first measurements with new methods: Using a very sensitive infrared spectropolarimeter, the weak Stokes *V* circular polarization profiles resulting from the longitudinal Zeeman effect has been measured in the Fe XIII λ10747 line, and magnetic field strengths of $B = 10$ and 33 G have been reported in two active regions at heights of $h = 0.12$ and $h = 0.15$ $R_{\odot}$, respectively (Lin et al. 2000).

With a complete different method (which we may call *coronal seismology*), using the dispersion relation of the magnetoacoustic kink mode, magnetic field strengths of $B = 13 \pm 9$ G have been inferred from transverse oscillations of coronal loops observed with *TRACE* (Nakariakov & Ofman 2001).

2.5. Where Is the Solar Corona Heated?

A journalist from the *New York Times* told us that even in their editorial office there is a standing joke that every 2 years some solar physicist claims to have solved the *coronal heating problem*. We do not want to add another such claim here, but recent *TRACE* data have clearly shown that the energy losses due to radiation and thermal conduction can be balanced in coronal loops only if they are heated within the lowest 10,000 km above the photosphere (Aschwanden, Nightingale, & Alexander 2000; Aschwanden, Schrijver, & Alexander 2001), regardless how large the loops are (which have been seen with lengths up to a full solar radius). So, real progress has been made in the localization of the elusive heating process, which renders solving of the second part of the coronal heating problem much easier, i.e., what physical mechanism can actually do the job. A number of physical processes that heat coronal loops preferentially at footpoints have been studied recently, such as magnetic reconnection resulting from surface Alfvén waves and colliding plasma flows in chromospheric current sheets (Sakai, Takahata, & Sokolov 2001), viscous dissipation of fast plasma upflows (Mahajan et al. 2001), colliding flux tubes in the chromosphere which launch acoustic and MHD shocks that propagate upward and become geometrically focused by acceleration gradients (Ryutova et al. 2001), or the interaction of newly-emerging loops with overlying pre-existing loops (Mok et al. 2001). The rate of emergence was found to be sufficient to replace the magnetic field of the quiet Sun in 14 hours (Hagenaar 2001). Footpoint heating was also found to be a necessary requirement for prominence formation (Karpen et al. 2001). The ultimate test of any coronal heating model requires a detailed one-to-one correspondence of changes in magnetic features with the locations of coronal heating input.

Promising studies attempt to pin down the relation between magnetic quasi-separatrix layers and soft X-ray brightenings (Longcope et al. 2001; Wang et al. 2000a, 2001). Popular as ever are many nanoflare heating scenarios, regarding theoretical models (Aletti et al. 2000; Galsgaard, Parnell, & Blaizot 2000; Katsukawa & Tsuneta 2001; Klimchuk & Cargill 2001; Vekstein & Katsukawa 2000; Roussev 2001a, 2001b; Walsh & Galtier 2000; Mitra-Kraev & Benz 2001), as well as concerning observational studies (Brkovic, Solanki, & Ruedi 2001; Shimojo & Shibata 2000; Cauzzi, Falchi, & Falciani 2001; Harra, Gallagher, & Phillips 2000; Berghmans, McKenzie, & Clette 2001; Pauluhn et al. 2000; Lin, Feffer, & Schwartz 2001). However, statistics of nanoflare energies generally fall short of the required energy budget for coronal heating. In particular, statistics of magnetic elements in the quiet Sun, called chromospheric network, "magnetic carpet," or "salt and pepper" field, can at best account for a minimal contribution to the heating of the million-degree corona observed in soft X-rays, which is thus believed to be primarily heated by the strong magnetic fields rooted in active regions, rather than in weak photospheric fields (Pevtsov & Acton 2001).

The new high-cadence observations of *TRACE* clearly show that coronal heating is often not a steady process, but exhibits intermittency and rapid changes. Pressure imbalance between the footpoints probably drives siphon flows along many loops, which are now clearly observed with *TRACE* (Winebarger, DeLuca, & Golub 2001). Tracking the temperature evolution of coronal loops in multiple wavelengths reveals eventually catastrophic cooling and high-speed downflows (up to a third of the free-fall velocity) after heating fades (Schrijver 2001).

2.6. The Long-Sought Inflows of Magnetic Reconnection

Although magnetic reconnection processes became a gospel for the solar flare community, direct observational evidence is still hard to come by. One major problem in the chain of proofs is the undetectability of the relevant magnetic field lines during the pre-reconnection phase as well as during the actual reconnection itself, while detection is easiest during the post-reconnection phase, once the relaxed field lines become filled with heated chromospheric plasma. One prediction of standard two-dimensional reconnection models is a transverse inflow of plasma into the reconnecting current sheet, which supplies the Alfvénic outflows out of the diffusion region. A detection of such inflows has now been reported for the first time, from *Yohkoh* observations during the 18 March 1999 flare (Yokoyama et al. 2001). Besides the classical features of reconnection processes, such as plasmoid ejection above a cusp-shaped soft X-ray loop, a lateral inflow could be detected by tracing the movement of threadlike patterns in *SoHO*/EIT movies. A velocity of about 5 km/sec was measured for the inflow speed, corresponding to an Alfvénic Mach number of $M_A = 0.001$ to 0.03 (Yokoyama et al. 2001).

Other new evidence for magnetic reconnection processes has been inferred from rapid connectivity changes shortly before a filament eruption and its associated flare (Kim et al. 2001), from coronal restructuring and electron acceleration after a filament eruption (Marque et al. 2001), or from the magnetic topology of three-dimensional reconnection configurations (Fletcher et al. 2001).

2.7. Fractal Magnetic Reconnection in Solar Flares

On the theoretical side, one unsolved problem is how to produce the required anomalous resistivity for magnetic reconnection in solar flares. Since the current sheet thickness must be as small as the ion Larmor radius, both being of order 1 m in the solar corona, there is large gap between the macroscopic flare size (of some 10^4 km) and the necessary microscopic scale to produce anomalous resistivity. An intriguing new concept of *fractal reconnection* has been proposed, where a macroscopic current sheet is sheared by the tearing mode and produces smaller magnetic islands during the thinning process, spawning successively thinner current sheets and smaller magnetic islands, until a microscopic scale of an ion Larmor radius is reached, which is estimated to occur after about six secondary tearings (Shibata & Tanuma 2001).

2.8. First Radio Image of a Coronal Mass Ejection

Coronal mass ejections have been detected in visible wavelengths with coronagraphs, in EUV (dimmings, Moreton or EIT waves), in soft X-rays, and with radio spectrometers (type II, IV, continua). However, no counterpart to white-light CMEs has been observed in other wavelength regimes, mainly due to sensitivity limits. A first direct imaging of an expanding CME loop at radio wavelengths was reported by Bastian et al. (2001), detected in form of nonthermal synchrotron emission produced by electrons with energies of ≈0.5–5 MeV interacting with magnetic fields of ≈0.1 G in the heliosphere.

Another new phenomenon is "CME cannibalism," also detected for the first time at long radio wavelengths in the heliosphere (Gopalswamy et al. 2001). This crime was uncovered when a fast CME (with a speed of 660 km/sec) was observed to overtake a slower CME. The interaction of the fast CME shock that plowed through the preceding slow CME caused an abrupt radio enhancement during the transit (or swallowing) phase. The detection of such abrupt velocity changes obviously are expected to improve our space weather predictions significantly, in particular the arrival times of CME shocks at Earth.

2.9. Did One Solar Cycle in the 18th Century Get Lost?

Not even counting 11-year-long solar cycles is trivial. It was suggested that one solar cycle was lost in the beginning of the Dalton minimum because of sparse and partly unreliable sunspot observations (Usoskin et al. 2001). So far this cycle was combined with the preceding activity to form the exceptionally long solar cycle 4 in 1784–1799, leading to an irregular phase evolution of sunspot activity (known as a phase catastrophe). Including this missed cycle makes the onset of the Dalton cycle look more like the Maunder cycle and restores the pairing rule (Hale cycle) between subsequent cycles (Wilson 1988) throughout the 400-year interval of sunspot observations.

Another oddity of the not-so-regular solar cycle is its apparent coupling to the secular variation of the interplanetary magnetic field, which was recently discovered to have doubled over the past 100 years. A new model of the long-term evolution of the Sun's large-scale magnetic field that is sensitive to the variation of the sunspot cycle length could now reproduce the observed doubling of the mean interplanetary field strength (Solanki et al. 2000). However, the advertized secular increase of the interplanetary magnetic field implied by the IPM data (Lockwood 2001) was questioned on the basis of the constancy of the mean photospheric magnetic field over the last 32 years (Kotov & Kotova 2001).

2.10. Earthshine Observations

A nearly forgotten method to measure the Earth's albedo, using the "ashen light" of the sunlight reflected from the Earth to the dark part of the lunar disk and retro-reflected from the lunar surface in direction to Earth, has been reinvigorated and modernized at the Big Bear Solar Observatory, since December 1998 (Goode et al. 2001). From these new measurements an average terrestrial albedo of 0.297 ± 0.005 was determined, where the daily variations (of order ≈5%) reveal instructive information on the land-water reflectance ratio, the weather cloud patterns, snow, ice, and vegetation coverage. (This type of lunar-geo-solar observations is one of the rare interdisciplinary examples that naturally fulfills all requirements for NASA funding, from originality of astronomical research to direct benefits for humankind.)

3. THIS LAND IS YOUR LAND

The events, objects, and people of this section are, apart from the very first, largely confined to the surface of the Earth.

3.1. Fundamental Physics: The Bear Necessities

Astronomers cannot do without this necessary evil (like contract monitors and cryogenics), but we are used to being able to count on cosmic physics being identical with laboratory physics, even if sometimes pushed to locally impossible extremes. Thus we have heard surprise, distress, and disbelief among the reactions to a report that the fine-structure constant, $\alpha = e^2/\hbar c$, was smaller by about a part in 10^5 at redshifts of 1–3 (though without any clear trend within that redshift range: Webb et al. 2001; Prochaska 2001).

This is in the right direction if you want electromagnetism and the weak interaction to have had the same strength long ago, but it is a larger change than would have been expected over that time span. Of course $z = 3$ takes you back a large fraction of the age of the universe, but only a small fraction of the way back to a temperature corresponding to the mass of the W and Z bosons. There is no conflict with the tightest previous astrophysical limit (Carilli et al. 2000).

There is, however, a contradiction with an upper limit to the change in α derived from the natural reactor at Oklo (Damour & Dyson 1996), if the change is assumed to be linear with time. The astronomical number is, in some sense, a cleaner determination, because the reactor one requires the assumption that some bits of nuclear physics haven't changed in compensatory fashion.

If you want advice on what to think, remember that betting against neat, new things is nearly always the right call, but when you lose, you lose big. Pickering et al. (2000) might be said to be hedging their bets by determining better ultraviolet laboratory wavelengths for some relevant lines. Just in case you hadn't heard, the measurement comes from a large number of absorption lines in the spectra of a large number of quasi-stellar objects.

General relativity, meanwhile, continues to triumph over everything in its path, including (*a*) binary pulsars (van Straten et al. 2001), (*b*) the measured gas temperatures in X-ray emitting clusters of galaxies (Aguirre 2001 on the unsatisfactoriness of an alternative called MOND), (*c*) a lensed QSO with gravitational lenses in two planes along the line of site (Augusto et al. 2001 and Chae et al. 2001 on the first observed example and its analysis; Bertin & Lombardi 2001 on a more general analysis), and (*d*) a prolonged, unsuccessful effort to find deviations from $1/r^2$ in the force of gravity (Hoyle et al. 2001, who have explored down to $r = 0.2$ mm).

A history of science answer during the year is, yes, Einstein knew about the perihelion of Mercury before general relativity (North 2001), though the source is a letter reproduced in a GR text, rather than in the project that is publishing Einstein's letters completely, systematically, and perhaps tediously. (We have not seen our colleagues running out in droves to buy these volumes since the project got past the prurient bits.)

Two measured values of the constant of gravity appeared: $6.674215 \times 10^{\text{whatever}}$ (Gundlach & Merkowitz 2000) and $6.67559 \times 10^{\text{same number}}$ (Quinn et al. 2001). Each was described as having uncertainties of only parts in 10^5, but of course they differ by parts in 10^4.

What else is truly fundamental and "important for cosmology?" CP violation, we suppose (because it enters into why there is more matter than antimatter in the piles lying around our offices), reported at the 2σ level from measurements at SLAC and KEK (Bourchat 2001) and described as a confirmation of the standard model (of particle physics, not cosmology!) by Smith et al. (2001b). In contrast, a measurement of the magnetic moment of the muon made at Brookhaven National Lab was reported as tentative evidence against the standard model by Kirk (2001), who indicated that the calculations were at least as uncertain as the measurement. Umbrage, or at least exception, was taken by Yndurain (2001) on the grounds that no disagreement has (yet) been demonstrated.

An out-of-period footnote in Ap00 carried the glad tidings that MSW's in its heaven and all's right with the neutrino. The data from SNO (Sudbury Neutrino Observatory) appear in Ahmad et al. (2001) and have been blessed by Bahcall (2001).

Among other things seen during the year, by us on paper and in more concrete forms by others, were (*a*) a quark-gluon plasma, such as has not been witnessed for the last 15 Gyr, at least on Earth, in the Relativistic Heavy Ion Collider at BNL and at CERN (Harris 2001), (*b*) the Kapitza-Dirac effect (Friemund et al. 2001; Kapitza & Dirac 1933; it is, very approximately, the refraction and diffraction of electrons off standing electromagnetic waves, perceived by the electrons as photons), (*c*) entangled particles (Rowe et al. 2000; Grangier 2000); these were Be^+ ions, honorable, upstanding particles that refuse to having to do with hidden variables, (*d*) ionization by a two-photon process in planetary nebulae (Johansson & Letokhov 2001, with theory by Göppert-Mayer 1931); if they are right, then the ionizing stars can be much cooler than you would deduce by the Zanstra method, and (*e*) MgB_2 as a $T = 39$ K superconductor (Nagamatsu et al. 2001), which we mention partly for the pleasure of quoting a colleague at a committee meeting who apologized for the absence of a third party, explaining, "He's up to his knees"—keep it clean guys—"in magnesium dibromide." Also seen, many Bose-Einstein (B-E) condensates, whose behavior was described as a possibly-useful analog to black holes, neutron stars, and white dwarfs (Leonhardt & Piwickni 2000; Cornish et al. 2000), though Donley et al. (2001) opine that the collapse and explosion of B-E condensates are not themselves well enough understood to guide us to anything else.

While black holes are in our minds (or perhaps conversely), there have been words (so far only from Rumour Mills 2001) to the effect that either the new generation of particle accelerators or very high energy cosmic rays hitting the Earth's upper atmosphere might (if certain physics beyond the standard model is correct) be capable of producing very small black holes. Would you consider accepting that this happens and is to blame for our not have answered your last email?

Among the things not seen on Earth during the year were (*a*) Hawking radiation, but with a description of it as tunnelling and not exactly thermal from Parikh and Wilczek (2000), and (*b*) the Blandford-Znajek process for extracting the rotational part of the energy of a black hole, also with a new calculation (Komissarov 2001).

Hovering between the seen and the unseen was the change of state of the universe which occurred on 22 $\pm$ 1 March 1894, when general relativity and quantum mechanics came into operation (von Hohenheim 2000). The more speculative author had suggested long ago, in the privacy of the bedroom,[2] that, for instance, parity was conserved until some time in the 1930s and so forth. This was intended as a feeble sort of witticism, as perhaps was von Hohenheim's version (not the feeble part, of course).

No sooner had we got used to branes (but see Arkani-Hamed et al. 2001a or Cowen 2001 for introductions at slightly different levels, if you still find them lacking in mem or otherwise weird and foreign), when along came the ekpyrotic universe (Steinhardt et al. 2001). Step one in mastering this is, of course, the etymological. We are pretty sure that the *pyro* part is the Greek word for fire, but remain divided on whether *ek* is the Sanskrit *eka* (one, adopted by Mendeleev for eka-silicon and such) or the Greek preface *ek-* (out, more often transliterated in English as *ec-*, as in ecstasy, eczema, and ecphoresis), or perhaps both.

Now, what is it good phore? It is an alternative to inflation, which requires no singularity in our past and which predicts different tensor perturbations in the 3 K background from those of inflation and so is, in principle, testable. Space must have 11 dimensions, of which six are rolled up to a size less than 10^{-4} cm, or we would know about it from things that supernovae do in the privacy of their bedrooms (Hannestad & Raffelt 2001). Our universe is then a flat, four-dimensional sheet in the remaining five large dimensions, which was hit, a Hubble time ago, by a wrinkled membrane shed by a second flat, 4D universe. This set off the expansion of our universe with small perturbations in place (oh dear, wrinkles really are contagious) that have since grown into galaxies and all.

Henry Tye & Wasserman (2001) speak of parallel 3-branes, whose increasing separation is responsible for the decline of the cosmological constant. This sounds rather similar, but a decreasing cosmological constant is generally how you get out of inflation rather than out of a fire. Even more image-provoking is the suggestion (Arkani-Hamed et al. 2001b) that there were no dimensions at all in the early universe. We were reminded of the Limerician novelist, who worried "if causation is not, what will become of my plot?" And this is perhaps why the paper went into the notebook as "deconstructing dimensions." Living in such a universe would perhaps be a bit like trying to tramp around in very hot, very sticky mud.

The reader may well feel that there is a fairly fine line between these considerations and the topics of § 12 (Cosmology). It is, however, be warned, a line of about 40,000 words.

3.2. Site Selection

Some places are better than others for telescopes, and it is uncertain whether Sir William Herschel would be pleased by the temporary relocation of his 18-inch (by 20 feet) reflector from England to the National Air and Space Museum, for their exhibit, "Explore the Universe," which opened near the end of the reference year. But the star went to Smith (2001) for another episode in the ongoing saga of Mauna Kea, where the continued expansion of astronomical activity seems to make long-term residents of the Big Island (whether of native Hawaiian or environmental ancestry) less and less happy. The star was a black one, because reading the account shortly after 11 September made the use of quote marks around "sacred" site (which we suspect Smith was not responsible for) seem particularly inappropriate. Bouquets, therefore, to Tytell (2001) for a later update on the story, without quotation marks.

Similar angst afflicts the Mt. Graham site from time to time, including, recently damage to the power lines (Anonymous 2001a) and what sounds a bit like a threat of divine retribution (Cassa 2001). In comparison, all the events recorded below, including commissionings, decommissionings, first lights, last lights, sky lights, and all, sound a good deal less dire. They have been bifurcated along the lines implied by two favorite remarks of the late Prof. Joe Weber, "Oh, isn't that too bad?" (which covered the territory from broken glassware to the deaths of colleagues) and "Oh isn't that nice?" (which extended from fresh raspberries to Nobel Prizes). You might even disagree about which category some items belong in.

3.2.1. Oh, Isn't That Too Bad?

The "be careful what you wish for" award goes to the restaurant, not quite at the end of the universe, but atop Pic du Midi, income from which was supposed to be part of the plan to keep the Observatory running, but fumes from which will damage the mirror (Colas & Lecacheux 2001). And they had just installed a new speckle camera there (Scardia et al. 2000) called PISCO. PISCO-sour, we guess.

Light pollution is a much more widely recognized, and more widely distributed, threat to optical observatories. The color-

[2] No censorship required. Remember her husband was a physicist.

coded map of levels of night sky light in Europe is pretty sobering (Cinzano et al. 2001; yes, of course, he has heard this joke before, but we just thought of it). The data come from the Defense Meteorological Satellite Program; the main correlation is with city size; and the Oder-Neisse line is quite sharp. The corresponding degradation of the naked eye limit is shown by Cinzano et al. (2001). That this limit is usually about 6th magnitude says that skies are nowhere completely dark, a fact first recognized by Newcomb (1901), who concluded that the limit would otherwise be more like 8th magnitude.

The report that San Diego, whose lights illuminate Palomar Mountain, plans to phase out low-pressure sodium vapor lamps in favor of something worse is not encouraging. The one ray of dark among such stories is that the authorities in Vermont have agreed to shield the lights of a new prison in the four-dimensional direction of the annual Stellafane star party (Burley 2001). Astronomers are not the only sufferers. Korado Korlevich (2001, private communication) of the observatory in Visnjan, Croatia, reports that augmented city lights there now keep some birds singing all through the night, uncertain about when dusk ends and dawn begins, and attended by very little peace.

Non-human demises during the year included: *ASCA*, which reached the bottom of the Pacific Ocean on 2 March 2001 (and was, unfortunately, an X-ray satellite, not an oceanographic submersible); *Mir*, ditto, on 23 March 2001; *EUVE*, which collected its last photons on 26 June and is expected to enter sub-Earth orbit in early 2002; and *NEAR*, which hit Eros on 12 February 2001 (but that was planned, and there is a nice summary of the results in Farquhar et al. 2001). It was five days short of its 5th birthday.

Two items fall (not for the first time) in the intermediate zone between living and dead. The 12-meter millimeter telescope (the big one is the size and the little one the wavelength[3]) was defunded again in April 2001 (Strittmatter 2001), which is "too bad" because many astronomers were still using it. The *Iridium* communication satellite system was revived, which is also "too bad," not because we are against communication (though you might think so from these reviews) but because it is, or will be when operational, a significant source of radio light pollution. Last we heard, *BeppoSAX* had been reprieved to continue the quest for gamma-ray burst counterparts at least until May 2002. This is a Good Thing, and belongs in the next section.

3.2.2. Oh, Isn't That Nice?

A couple more revivals (at least as good as any of the post-Brynner ones of *The King and I*) and an unexpectedly long life, to start with. *Pioneer 10* called home again after a silence of about 9 months (Anonymous 2001b). *Cassini* has been sited about 65,000 km rather than 1200 km from Titan, giving it a small enough orbital velocity that its transmissions will not after all be Doppler shifted out of the bandwidth of the receiver. And it was a happy surprise to find that The Students' Observatory of UC Berkeley, where old friends like Lawrence Aller and Daniel Popper plotted their first comet orbits and variable light curves, still exists and is used (Graham & Treffers 2001).

New, or newish, entities, all useful to astronomers and therefore a priori good, numbered a couple of dozen.

- The other starred item under "site selection" was the transfer of what has long called the Los Alamos Preprint Server (xxx.lanl.gov) to arXiv.org and of its inventory and protector Paul Ginsparg from Los Alamos to Cornell. If there is anyone reading this who did not already know, please get in touch immediately via the Wells Fargo Wagon (which leaves Gary, Indiana, every Tuesday at noon).
- SETI@home now has 3 million private PCs analyzing data during their leisure hours, though the chances of NASA ever again joining in the fun, even through the "origins" program, seem remote (Meyer 2001).
- *MAP* was launched on 30 June 2001 and is at L2 as we type (our fountain pen having sprung a leak).
- Arguably the largest observational window not yet open to astronomers is X-ray polarimetry. There was one rocket-borne instrument, and it measured one source, the Crab Nebula (Novick et al. 1972), followed by a large number of missions whose polarimeters were descoped before launch. The problem has been two-fold: most of the community has expected that there was not much to be learned until one could reach down to a few percent polarization (vs. up to 60% for the Crab; Cash 2001). And nobody quite knew how to build an efficient polarimeter. This now seems feasible (Costa et al. 2001). The prototype laboratory device uses the photo-electric effect, the direction of the ejected photoelectrons preserving some memory of the direction of the E vector of the incident photon. And, of course, the track of the photoelectron also tells you the energy and time of photon arrival.
- Even more difficult than imaging, dispersing, and Stokes-parametering X-rays is doing these things for gamma rays. Skinner (2001) points out that it is possible to make refractive and diffractive gamma optics using Fresnel lenses. The focal lengths are necessarily very large (even by the standards or Herschel's 20-foot and 40-foot reflectors and the 150-foot Hevelius, keep it clean guys). One will need to think of using multiple spacecraft to support them, as is, of course, also contemplated for space-based detection of terrestrial planets, gravitational radiation, and so forth.
- AMANDA (the Antarctic Muon And Neutrino Array) has seen upward-going atmospheric neutrinos at 50 GeV to a few TeV, confirming that it makes sense to instrument a larger volume of ice (available very cheaply at the site) to look for neutrinos from astronomical sources (Andres et al. 2001).
- The Green Bank Telescope (the Byrd in the hand) has seen its first scientific light—radio waves that started at Arecibo and

[3] If you think this is always true, it is because you never met Mr. Yagi. Well, neither did we, but his first name was Hidetsugu, he was born in 1886 (the same year as Grandmother Farmer), and we figure he was about 5′5″.

bounced off Venus (Campbell et al. 2001). It also achieved fringes in VLBI mode on 15 August 2001 (Ghigo & Romney 2001).

• Construction of the Large Millimeter (nearly a centimeter?) Array began in January 2001 as a collaboration between Mexico (the place) and the United States (the time and the girl). ALMA (the two in the Bush) advances only very slowly.

• The telescope at Mt. Saraswati, belonging to the Indian Institute of Astrophysics, Bangalore, was dedicated in late August, and the less said the better about the colleague who was there, went climbing higher into the Himalayas afterward, and complained that he would have liked to do more walking, but the guides insisted on taking a taxi. Anyhow, the extinction there is about 0.1 mag/airmass (Mikulasek et al. 2001) compared with 0.2–0.4 mag/airmass at less elevated places like Brno and Skalnate Pleso itself.

• *Mars Odyssey* was launched successfully on 7 April and was doing well at the end of the index year. Incidentally, we would like to protest the increasing common use of what are meant to be complete sentences of the form "*Mars Odyssey* launched on 7 April". Anyone who thinks these things happen by themselves is cordially invited to fly us to the Moon.

• The GMRT (Giant Meter Radio Telesope) is up and running, though it has been concentrating on 21 cm emission at lower redshift than is its eventual goal (Dwarkanath & Owen 2001). In lieu of the remark about meters being longer in India because things expand at high temperature, we remind you that it takes a redshift of only about 3.76, far from the current record, to stretch 21 cm to 100.

• The Crab Nebula became the first non-solar target of the *Yohkoh* satellite (Kiel 2001), 10 years into the life of the latter and nearly 950 years into the life of the former.

• Both the Keck pair and portions of the VLT were operated in interferometric modes, the VLT using small auxiliary mirrors that we would have called Side Kecks if they had been on the other site; but "VaLidaTes" is the best we've been able to come up with.

• The Solar Sail program flutters gamely on. The attempt at a suborbital launch on 27 July 2001 failed, but the next attempt will be at an orbital one (Friedman 2001).

• A technical summary of SDSS (the Sloan Digital Sky Survey) appears in York et al. (2000). The 142 other authors from Adelman to Yasuda may or may not set any sort of record, but all precede York alphabetically, and, for once, the last really did come first. The first public release of data occurred on 5 June 2001, and the team had luckily not waited for the October 6th dedication to start looking at the universe.

• The atmospheric Cerenkov technique for detecting gamma rays has been pushed below 300 GeV (Oser et al. 2001). The detector, called STACEE, is atop a solar tower, and it saw the Crab Nebula.

• *XMM-Newton* results for the first year of operation appear in a package beginning with Jansen et al. (2001), and 55 following *A&A Letters*. In addition to a description of the instruments and their calibration, the set includes observations of clusters and groups of galaxies, quasars and other AGNs, *IRAS* and star-forming galaxies, nearby galaxies and star formation regions, supernova remnants, assorted X-ray binaries, cataclysmic variables, isolated neutron stars, supersoft X-ray sources, stellar coronae and the FIP effect, absorption features in the Crab Nebula (due entirely to interstellar stuff, Willingale et al. 2001), cooling flow clusters without much cool gas (Peterson et al. 2001), and the distribution of stellar X-ray luminosities.

• Another package, of results from VLBI done with the VSOP satellite, begins with Hirabayashi et al. (2000, and 12 following papers). The baseline is two Earth diameters, and the users have looked at AGN jets, pulsars, regions of maser line emission, and so forth.

• A package of no-results-yet came from Murphy's (2001) SNEWS (supernova early warning system), consisting of neutrino and gravitational radiation observatories owned and operated by others. The absence of early warnings was inevitable given that two groups reported not seeing any gravitational radiation from cosmic sources. They were Allen et al. (2000), with an array of five cryogenic bar detectors (the first of which was operated at the University of Maryland in the early 1970s but is not, of course, part of the array), and Ando et al. (2001), with the 300-meter baseline free mass interferometer (the first of which was operated at Hughes Malibu also before 1972) called TAMA300. No coalescences of neutron star pairs occurred less than 10 kpc from the site in their 10 hours of operation.

• Radio astronomers can measure parallaxes. Brisken et al. (2000) give 3.6 milliarcsec for the pulsar B0950+08, a VLBA result at the lowest frequency so far used for this purpose. They will someday be able to do their own MACHO searches (Honma 2001).

• A mid-infrared map of the Milky Way has come from *MSX*, a ballistic missile defense satellite (Prine et al. 2001). While signal to us, the Galaxy is, of course, noise to DOD, who launched the satellite in order to detect infrared emission from ICBMs in midcourse (and, presumably, remove them from midcourse). DOD is Department of Defense and ICBMs are intercontinental ballistic missiles for readers too young to remember "Drop!" drills and what the DEW-line did.

• The Augustine Panel recommended against transferring NSF astronomy programs to NASA (Anonymous 2001d) but urged increased communication and cooperation between the agencies. You may be tempted to think most of the panelists were well beyond standard age for motherhood, and even past their best apple-pie-baking days, but remember where they had to start from, and be grateful for the report.

3.3. Too Many Astronomers Spoil the Loupe

Wait a minute! There is no such thing as too many astronomers, and anyhow nobody uses loupes anymore; even we have only two in our desk. Nevertheless, here are some favorite astronomers and their supporting casts, past, present, and future.

3.3.1. Astronomers of the Past

Could life itself have arisen elsewhere and arrived at Earth panspermically? Wells et al. (2000) deduce that the Martian meteorite ALH 84001 was never so hot, while passing through the atmosphere or hitting Earth, as to have destroyed amino acids and such, since the pattern of its magnetization was not smeared out. And, while we're on organics and Martian meteorites, Jull et al. (2000) have interpreted the supply in Nakhla as demonstrating that comet debris have accumulated on Mars. The Los Angeles meteorite is also from Mars (Rubin et al. 2000), and if you say you already knew that, the Angelena author will be offended.

The photosensitive pigment rhodopsin is found in some single-celled organisms (S. Conway Morris 2001, private communication). Thus we can deduce that the first astronomer lived several Gigayears ago and discovered the Sun. You have heard ad nauseum that, were it not for an asteroid striking Earth about 65 Myr ago, present astronomers would all be dinosaurs (instead of just some of them). The possibility that the Permian catastrophe nearly 300 Myr ago may also have been initiated by an impact (Becker et al. 2001a) raises the possibility that we might all have been trilobites. The evidence is a nonterrestrial mix of noble gases trapped in a layer with fullerenes (whose geometry would surely have been appreciated by groups of 20 trilobites).

Writers of panel reports may feel that the climate for astronomers is not, at the moment, terribly clement, but it has certainly been worse at various times over the past 65 Myr. A set of about eight items, ending with Zachos et al. (2001b), provides a serious introduction to paleoclimate indicators on various time scales, cycles, human responses and so forth, as does Alley (2000), a prize-winning book. Weiss & Bradley (2001) focus specifically on climate change as a driver of social collapse, including the end of pyramid building in Egypt.

This brings us naturally to the astronomers, or anyhow surveyors, who aligned some of these pyramids to the cardinal directions. Spence (2000) concludes that it was done by observing the simultaneous transits of β UMi and ζ UMa (Kochab and Mizar) and thereby dates the accession of Khufu (builder of the largest) to 2480 $\pm$ 5 B.C.E. Rawlins & Pickering (2001) prefer a different pair, Thuban (then nearly a pole star) and 10 Draconis, used somewhat differently. We are probably not entitled to an opinion, but if Spence is correct, the great pyramid is about 200 years younger (as well as 38 years older) than when we first wrote about it (Trimble 1964).

Next, logically, come the units in which astronomers of that era and succeeding ones were paid. Mederos & Lamber-Karlovsky (2001) have attempted to identify the weights of metal represented by the mina, the shekel, the talent, the dbn, and other common coins of the realms. Some of these you know, in the form Mene, Mene, Tekel, Upharsin, the modern currency of Israel, the talents of silver that were hidden away rather than invested, and the mina as a tenth part of an *ephah* (so the Good Book tells us somewhere). Mederos and Lamberg-Karlovsky do not mention either the ephah or the upharsin, but their real point is that the weights of these units were well enough standardized to permit money changing and trade among the Hittites, Syrians, Hurrians, residents of Ur,[4] and all. Dbn, by the way, is not misspelled. The Ancient Egyptians were not into vowels, but the conventional pronunciation is deben, and fans of fiction set in 18th Dynasty Egypt will recognize it.

This brings us to Gutenberg, who, according to Aguera y Arcas & Fairhau (2001), invented movable type but not the font, which is use of a single punch for each letter to create many matrices, which, in turn, form many more lead-cast letters. The authors used the same sort of pattern-recognition algorithm on printed letters that we associate with distinguishing the images of various sorts of galaxies. The true inventor of the font is not known, but the first one designed for print that has come down to us was the work of Nicolas Jensen of Venice before 1470. It looks perfectly normal, apart from the shape of the "s" when it appears other than at the end of a word. This shape is also to be found in the words of George Waſhington and Thomas Jefferſon.

The first printed astronomy book came soon after in 1473–1474. It was *Astronomicon* by Marcus Manilius, and the publisher/printer was Regiomontanus of Nuremberg (Brashear & Lewis 2001). Of the first two editions, one looks rather Gothic, the other quite modern, apart from speaking of "*ſtellae*" (it's in Latin, remember) and a few abbreviations that lingered from the time-saving customs of the scribes, like the tilde for n before another consonant (any consonant, not just another n), the ampersand, & (part of the house-style for references in PASP to this day), and q-squiggle for "que." There are periods, colons, and questions marks, but no commas. And 1473 was the year Copernicus was born.

Somehow we had thought Newton's place in history was secure, but Massa (2000) labels G the Cavendish constant. He also expects protons to decay faster inside degenerate matter.

We can see no way to tie the haplotyping of the potato blight virus of 1843–1848 to astronomy (Ristaino et al. 2001), though perhaps it helps explain why no Irish astronomers were part of the group, Bessel, Adams, Leverier, Galle, and all, who were busy finding Neptune and predicting Sirius B.

Hurry on, therefore, to Henry Norris Russell, who, it is perhaps not as widely known as it should be, himself measured a large fraction of the parallaxes that went into his (H)R diagram (Hinks & Russell 1905; Russell 1905). They used a telescope later described as combining all the disadvantages of a reflector with all the disadvantages of a refractor, the Sheepshanks 12-inch coudé refractor, then only seven years old. The

[4] We are still hunting for an algorithm that tells you what residents of various places ought to be called (think New Yorker, Parisian, Angeleno, Baltimoron, …). Residents of Ur were called Chaldeans or Sumerians, but even Geordies defeats our trial algorithms.

index year included a fine biography of Russell by DeVorkin (2001), who also curated the exhibit for which Herschel's 18-inch is visiting the United States.

And, forming a bridge from past to present comes Heck's (2000) compilation of numbers of astronomically-related organizations and their distributions in three dimensions (latitude, longitude, and time).

3.3.2. Astronomers of the Present

Falk (2000) concludes that women scientists are nearly immortal, or, conceivably, just don't get their fair share of obituaries in high-profile publications. Male astronomers sadly and demonstrably are not immortal. Alan Cousins, who seems to have held the record for length of career as a publishing astronomer, died on the very cover date of his last paper (Cousins & Caldwell 2001, in the 11 May issue of *MNRAS*). His first paper appeared in 1924, and this record is now up for competition. The final one, "Atmospheric extinction of $U-B$ photometry," drags us inexorably into the future, however, for it refers to Bougier lines and the Forbes effect without explaining what they are. That first paper (Cousins 1924) dealt with a Cepheid light curve, and the obituary we saw (Kilkenny 2001) is followed immediately by a line explaining that Sir Martin Rees is to be found at the Institute of Astrology, Cambridge).

Other much more modest confusion is offered by AAS meaning the Adib Astronomical Society (Heyn & Naze 2001), a Peterson (1973) diagram previously unknown to us (and concerning period ratios in RR Lyrae stars; Popielski et al. 2000), and a brand new source of atmospheric pollution, ozone from fireworks, detected during Diwali in Delhi (Attri et al. 2001).

Gone but not forgotten are Herb Chen (of UC Irvine), whose name appears on the list of authors of Ahmad et al. (2001, the report of detection of solar neutrinos at SNO, for which Chen was one of the prime movers up until his 1987 death), and Clyde Tombaugh, who is depicted and honored in a stained glass window (described by Levy 2001). We found all the symbols described in the caption except the crow, who was presumably either on a visit to R.A. = 12 hr, decl. = $-20°$ or out auditioning for a role in an Edgar Allen Poem (Addams 1991).

Modern astronomers are every bit as competent observers as their predecessors. Individual human beings, often amateurs, still find comets (Utsonomiya-Jones, spotted with 25 × 150 binoculars, IAU Circ. 7526, for which the discoverers, Syogo Utonomiya and Albert F. Jones received the Edgar Wilson Award) and novae (2001 Nova Cygni No. 2 by A. Tago and K. Hatayam, independently, IAU Circs. 7685, 7687), not to mention supernovae. The unpaid supernova record is held by visual observer Robert Evans of Hazelbrook, NSW, who added 2001du to his bag during the index year (IAU Circ. 7690). Others on the nova stellar honor roll were M. Armstrong of Rolvenden UK (2000dv; IAU Circ. 7510) and T. Puckett of Mountain Town, Georgia (2000cl, IAU Circ. 7523).

And Turner (2000) notes that naked eye observers can produce useful light curves for at least a few of the periodic variables that much surprised astronomers of the 16th and 17th centuries, including δ Cep, ζ Gem, and η Aql. In this context, "naked eye" means no telescope and "visual" means telescope but with a retina as the photometer.

More papers were, of course, published than in any previous astronomical year, of which we mention only three for their "how's" rather than their "what's" (but see § 13 for others). Karpen et al. (2001) show us how to write an abstract, which, in its entirety, says "The short answer: No," following a title phrased as a question. The authors of *Science* 292, 2303, instruct us how to cite their paper (with several lines of details about dates of receipt, acceptance, and on-line publication), and Liu et al. (2001) with 1472 references in their paper on low-mass X-ray binaries (which now include the microquasar GRS 1915+105; Greiner et al. 2001), make clear why these instructions are unlikely to be followed.

Abt (2000b) presents some numbers, from a fairly restricted database, on papers per astronomer published as a function of time. This hasn't changed enormously, though the ratio of multiple-author to single-author papers increased monotonically through the 20th century). The paper also presents a phenomenon common to most sciences in the 20th century, described in 1984 as WIMPI-creep[5] by a suitable author, who, of course, goes uncited by Abt. Yes, the papers really are getting longer, not just duller.

Language, even scientific language, must be learned. Petitto et al. (2001) have found that the babbling of babies is so universal a part of this learning process that it occurs even in sign language among hearing offspring of deaf parents. Another facet, though we neglected to record the reference (which had to do with children inventing and learning sign language in an institutional setting), is that signers who function as interpreters of cultural events, lectures, and religious services virtually always "speak" with the equivalent of a foreign accent.

Such accents pervade all of culture. Daedalus (Jones 2001) writes of sticky putty and the rubber octopus, as if they were "common words; something you find around the house." We are pretty sure that sticky putty is not (quite) the same as Silly Putty. It is perhaps the stuff that a Cambridge (UK) landlord insisted had to be used to put up pictures, so as not to make holes in the wall paper. Instead it left a dark, oily spot, perhaps roughly the shape of the rubber octopus, which remains a mystery.

Like language, visual tasks must be learned. This includes recognizing faces, for which babies need relevant input by about 6 months (Le Grand et al. 2001). The babies in the study had congenital cataracts, removed at various ages. Perhaps this somehow accounts for astronomers Fred and Don Lamb appearing with each others' names attached (*Science*, 293, 1040

[5] It stands for Words-In-Mean-Paper-Index and predates the acronym for Weakly Interacting Massive Particles, though not by much.

and 1436). Admittedly, they are identical twins, and the Paczyński method ("Klaus is the one who recognizes you.") could not have been applied in this context. Even more strangely, the next astronomer profiled in this series, Gregory Benford of UC Irvine (*Science*, 293, 1984), also has an identical twin. And so far, indeed, Greg has always recognized us.

In partial compensation for extraordinary ineptness at facial recognition, the elder author is quite good at names. Admittedly, Szczepanowska is not an easy one to forget, but did you know that she was an astronomer (Szczepanowska 1955) as well as a character in Shaw's *Misalliance*, in which she explains the pronunciation, "Say fish. Say church. Say fish church. Say Szczepanowska." We've got as far as Fishchepanowska.

3.3.3. Astronomers of the Future

Minetti (2001) describes what it will be like to walk on other planets. Both maximum speed and comfortable speed decline with the local acceleration due to gravity, *g*. This has been tested on the Moon, and in falling containers—briefly. The rates are given by v^2/gl = constant, where l is leg length and the constant is 0.5 for maximum speed and 0.25 for a stroll. We hope that testing of this formula in situ over a wide range of *g*'s occurs well before the event described by Gardner (2000). The event is the closure of the last astronomy department, when it is discovered that all the interesting sources are merely the art objects of advanced cultures. The only example we are sure of this year is the galaxy with $z = 6.68$, which turned out to be an artefact of current astronomical culture (Stern et al. 2000; Chen et al. 2000).

Soszynski et al. (2001) reported a gravitational lensing event that would have been maximally magnified if seen on 31 January 2001 … from Jupiter. Well, maybe next year.

4. PLANETARY SYSTEMS: YOURS, MINE, AND OURS

Once there was one, and now there are many, though the system belonging to Alpha Andromedae (as seen from Centaurus) remains the only case where much can be said about moons, minor planets, meteors, and all.

4.1. Exoplanets

This heading represents a reluctant surrender by the author who has made more circles around Sol and who is, therefore, pretty sure that all planets are "extra-solar." The right phrase is surely "extra solar system," but (*a*) it is long, and (*b*) where, if anywhere, will the University of Chicago Press let you put the hyphen(s)?

We thought that the "reality" issue had been laid to rest at large inclination last year (Ap00, § 3.2), but up popped Han et al. (2001), nearly face-on, with an analysis of *Hipparcos* observations of 30 putative hosts that seemed to say many of the orbits are seen at very small sin i, so that small values of $M_2 \sin i$ imply numbers for M_2 in the brown-dwarf domain. That balloon in turn was popped by Pourbaix (2001), who pointed out that the *Hipparcos* data just don't have the precision required for the conclusion. Boss (2001b), in contrast, is not doubting the existence of a 17 M_J companion, but only asking what we should call it. M_J in this context means Jupiter masses; just hope you don't need to mention absolute magnitudes in the J-band in the same paper. Rho CrB A/B yielded a *Hipparcos* orbit, and so B is almost certainly a BD (Gatewood et al. 2001).

The issue of the year, unfortunately, raises another problem of terminology. The scientific questions are, do there exist in significant numbers and have we seen (*a*) planets that do not currently orbit a star, or even (*b*) planets that have never orbited a star? Whether they exist or not, the linguistic issue is, naturally, what shall we call them? A somewhat prolonged discussion of this, followed by a secret ballot, took place in May 2001 at a meeting on origins of starts and planets at ESO headquarters in Garching bei München. Some of the more printable suggestions included isolated planets (but many are in clusters), rogue planets, floating planets, and many phrases not including the words "planet," on the grounds that it is too emotionally charged with the potential for life, at least in minds of non-astronomers. Eight months too late, the gender-challenged author realizes that she should have proposed "Victor Borge's Daughters."[6]

"Orphan planets" seems to carry the idea that the spheroids in question originally formed around stars but have become separated since. This is the sort whose existence seems most probable (based on statistics of papers, if not of planets), so we will use the phrase for all of them.

4.1.1. The Orphans

Planets, says our pre-bolometer Funk & Wagnalls, shine only by reflected light. Thus the database for orphans consists largely of infrared images of nearby groups of stars so young that even a Jupiter will still be detectable from its contraction luminosity. Zapatero Osorio et al. (2000) report on the region near σ Orionis, describing their objects as having temperatures between 1700 and 2200 K, masses of 5–15 M_J, and ages less than 5 Myr. Four spectra are of types L0 to L4. The two competing hypotheses to orphan planets are (*a*) larger masses, in the brown-dwarf regime, suggested by Lada (2001, who also suspects that many of the sources have their own "protoplanetary" disks, which contribute to the red colors); and (*b*) background or reddened non-members.

Martin et al. (2001) come down on the planetary side, confirming membership, spectral types of L0 to T0, and an absence of companions at $a \geq 100$ AU, as you would expect for ejecta from triple (etc.) systems. Lucas et al. (2001) derive planetary masses for about 15 sources in the Orion Trapezium region (and BD masses for a bunch more) by fitting atmospheric models to the spectra. At least 100 starless planets in another region

[6] Of whom he often said that it didn't matter what their names were, because they didn't come when he called them anyway. Compare cats.

now forming stars, S106, are reported by Oasa & Inutsuka (2001).

The present authors (all right, so you wouldn't have us, even as a gift) were sufficiently convinced by the data that our starred (or perhaps planeted) papers were theoretical ones, explaining how such lonely creatures are made (keep it clean guys). Rather similar scenarios have come from Reipurth & Clarke (2001) and Boss (2001a). The idea is that fragmentation of dense cloud cores takes you in the direction of small, multiple systems (specifically quadruples according to Boss), but that one or more of the fragments is ejected before it has accreted enough stuff to call itself a proper star. (Boss's choice of phrase is sub-brown-dwarf.) One is led to expect that such planets should not in turn have companions or significant disks but might have appreciable proper motions.

Indeed Smith & Bonnell (2001) conclude that the expected motions would take the emancipated stars right out of their star formation regions fairly quickly, though globular clusters might keep their orphans in the asylums of their deeper potential wells (Bonnell et al. 2001). (Remember that at 5 km/sec you will travel 10 pc in 10^6 years.) It sounds like the same problem might arise in the scenario described by Papaloizou & Terquem (2001). Their picture has a single protostar, whose disk or envelope fragments into 5–100 objects of planetary mass, extending up into the BD range, followed by dynamical relaxation. The star retains zero to three of the fragments, and the rest go out into the cold, cruel interstellar medium.

If you feel that this section ought somewhere to echo orphan Oliver's "please, sir, may I have some more?" have confidence that ongoing surveys will provide.

4.1.2. The Oftens

Other exoplanet territories in which something fun happened are (*a*) methods of detection, (*b*) compositions of the host stars, (*c*) proliferation of examples and expanded range of properties, (*d*) potential for Earth-like planets, and (*e*) dynamical processes in formation and evolution.

Methods of detection.—The first seven appear in Ap96, § 3. Dimming of the host star during planetary transits is perhaps the most improbable of the successes (with a bit more of what has been learned from HD 209458 in Deeg et al. 2001) and Brown et al. 2001). Brown et al. are of the opinion that even an Earth transit is within the grasp of *HST*, but you have to know when as well as where to look, for the transit blocks less than 10^{-4} of the photons for a few hours each year, for one observer in 10,000. This year, we caught additional methods (8) the appearance of hydrogen recombination lines in the spectrum of a hot white dwarf that ionizes the atmosphere of a surviving gas giant (Chu et al. 2001), (9) pollution of the host star by Phaetonized terrestrial planets (Murray et al. 2001, who think this has happened a good deal in the past to stars we see; and Israelian et al. 2001, who propose Li^6 in HD 82943, already known to have a planet, as a specific example), (10) accelerated decay of the disks of T Tauri stars (Goodman & Rafikov 2001), and (11) if you are prepared to call a comet or KBO a planet (and a tail a leg), the presence of water vapor around carbon stars (Saavik Ford & Neufeld 2001; Melnick et al. 2001, on IRC $+10°216$ the great granddaddy of all the carbon stars; Shevchenko & Ezhkova 2001 on evidence for a 6.3 year period protocomet around BF Ori, a Herbig AeBe star, and other examples).

Host compositions.—A three-star topic this, which begins with the conventional wisdom, goes perhaps astray, and returns whence it came. The conventional wisdom, of at least 3 years' standing, is that planet hosts (including the Sun) are metal-rich compared to the general run of stars and interstellar gas. Gonzalez et al. (2001), more or less the discoverers of the phenomenon, and Naef et al. (2001a) concurred, and Chen & Zhao (2001) were so sure of the answer that they used the metal poverty of HD 190228 as evidence that its companion has a nearly face-on orbit and is really a brown dwarf. BD hosts are not metal-rich (Kirkpatrick et al. 2001).

Up then there reared unexpected announcements that the chemical composition of the local interstellar material is about the same as that of the Sun and nearby young F and G dwarfs (Sofia & Meyer 2001) and that the Sun is about average for its neighborhood (Haywood 2001). Haywood suggested that the anomaly had arisen because earlier samples of stars, selected by spectral type, are biased against $[Fe/H] \geq 0$.

To the rescue came the stellar cavalry of properly selected and uniformly processed samples. Santos et al. (2001) have analyzed consistently hosts and non-hosts found in the CORALIE program. Hosts are more generously endowed (keep it clean guys). Similarly, if one of the Lick samples of 600 stars is split in half at $[Fe/H] = -0.1$, the top half has, so far, yielded 10 planets and the bottom only two (Butler 2000). Santos et al. conclude that the correlation is "primordial," that is, metal-rich stars find it easier to form planets. Pinsonneault et al. (2001) concur, because the alternative, that hosts are metal-rich because they have accreted some planets already, should lead to a correlation of stellar metallicity with depth of convection zone, which is not seen. Contrapositively, Laws & Gonzalez (2001) conclude that 16 Cyg A and B, with A the higher-Z non-host, represent evidence for planetophagia.

We think it is possible to accept all of these results simultaneously, provided that you do not insist that the solar value of [Fe/H] is precisely zero on all calibrations of abundance indicators. The additional factoid that "all" F-type hosts are young, while the G's are not (Suchkov & Schultz 2001) helps. Some of the children of Lake Wobegon are, in other words, simultaneously above and below average.

Proliferation.—"Bringing in more and more and more," as Enoch Snow said about his herring boats, perhaps 100 by the time you read this, more than enough to look at statistical distributions [eccentricity peaks at 0.35 and $N(P) \propto P^{-1}$ say Stepinski & Black 2001], and to find some rather extreme extrema, a largest eccentricity of $e = 0.927$ (Naef et al. 2001b) and the smallest eccentricity at large separation, $e = 0.001$ for the companion of HD 27492 (Butler et al. 2001b).

Multiple planets will probably also soon be fairly common (Fischer et al. 2001). Within the year, Gl 876 and HD 168443 became parents of "Saturn, a brother for Jupiter" (Marcy 2001; Els et al. 2001; Marcy et al. 2001a, 2001b). One naturally wants these to be stable for some reasonable number of years (Giga for instance), but models nevertheless fit the data better if the two planets of Gl 876 are allowed to perturb each others' orbital motion (Rivera & Lissauer 2001), a situation which obtains also for Jupiter and Saturn. The authors describe this as Newton versus Kepler, with Newton winning, though the early history of the topic is more like Euler versus Mayer with nobody winning (Trimble 2002).

And stars and bars, as it were, for ϵ Eridani, both because its planet was discovered from Texas (Hatzes et al. 2000) and because the star was one of the two very first subjected to a Search for ExtraTerrestrial Intelligence (Drake 1961).

Nobody is quite sure whether massive stars should have planets or not. At least one 8–10 $M_{\odot}$ core has a 130 AU "protoplanetary disk" (Shepherd et al. 2001), but such disks may not last long enough for planet condensation to get past the large-grains stage (Throop et al. 2001; Haisch et al. 2001, with data on the members of IC 348).

Will there be any terrestrial planets?—Stars and stripes to Kortenkamp et al. (2001) for an analysis of planet formation in disks leading to the conclusion that the presence of a companion star, brown dwarf, or promptly-formed giant planet actually helps to make an Earth. Some of the terrestrial planets will even have orbits stable long enough for us to learn about them, for instance those of 47 UMa and ρ CrB, though some will not, including Gl 876 and υ And (Jones et al. 2001a). Lineweaver (2001) goes on to be fussier about Earth-like conditions, requiring habitats to have appropriate compositions, ages, and so forth, but still finding enough to permit him to live on one and write the paper. Habing et al. (2001) sound more optimistic.

Dynamical evolution.—The "make and migrate" scenario, in which massive planets normally form at least as far out as our own, but spiral in as the natal disk is dissipated, still rules the paper heavens (Nelson et al. 2000; Snellgrove et al. 2001), but we note, first, that the resulting multiple orbits may not be coplanar (Yu & Tremaine 2000, which spoils co-planarity as a test for "real" planets), second, that pairs can sometimes interact to migrate back out (Masset & Snellgrove 2001), and third, that sufficiently massive disks can also form hot Jupiters at the locations where we find them now (Ikoma et al. 2001). The year also saw about half a dozen papers addressing the stability of the υ And triple system over a few Gyr. Nobody said it wasn't, though the conclusions about the minimum values of sin i and e needed to preserve it varied a bit. Chiang et al. (2001) came somewhere in the middle, both on constraints and in the notebook.

We weren't quite sure where to put the discussion by Murray & Hulman (2001) about various chaotic resonances, which draws a nice analogy with the behavior of a rigid pendulum. No guarantees about the orbital resonances, but we promise you'll know a lot more about pendula after reading this.

4.2. Endoplanets

Well, in truth, you will find here assorted asteroids, comets, moons, and meteorites in larger numbers than the nine (if General Motors says it's a Chevy, it's a Chevy) local wanderers, but the word was irresistible.

4.2.1. The End of the Kuiper Belt

No, it will probably not disappear in the next year, but also the number of members of this asteroid family cannot increase without limit as you look to smaller sizes and larger orbits. The starred paper (Kenyon & Windhorst 2001) addressed the limits specifically as an example of Olbers Paradox, because the counted KBOs must not add up to more than the known background of zodiacal light. They suggest a flattening in the distributions must occur somewhere around radius = 1 km and semi-major axis = 40–50 AU, and that there will be interesting information about albedos and compositions as existing counts extend fainter.

Luckily for fans of dark skies, there are indeed edges to the KBO population. The belt itself stops close to 50 AU (Allen et al. 2001; Trujillo & Brown 2001; Jewitt et al. 2000; Trujillo et al. 2001), at least as determined from the (relatively few) objects big enough to be seen at that distance. Gladman et al. (2001b) present two slightly larger orbits, making clear that the edge is not a sharp one, but they also conclude that the size distribution should level off somewhere between 5 and 50 km. Wayest out on average would seem to be 2000 CR_{150}. Caught only 55 AU from the Sun, it spends most of its life close to its 400 AU aphelion (Gladman et al. 2001a).

What is the meaning of the edge and other structure in the distribution of orbits through the Kuiper Belt? Apparently they are faint traces of the star cluster within which our solar system originally formed. It must have had 500–800 members and lasted at least 500 Myr (de la Fuentes Marcos & de la Fuentes Marcos 2001; Adams & Laughlin 2001).

So much for the edges. What is inside? Because most orbits are based on about 7 years of data out of a 250 year period, more precise orbital elements would be helpful (Wan & Huang 2001; Bernstein & Khushalani 2000), but there are more large angles of inclination than you might have expected (Brown 2001), and a flock of correlations among orbit size, eccentricity, inclination, and surface color, in the direction that big, round = red (i.e., unprocessed surface; Tegler & Romanishin 2000). And the secret word is Kozai resonance (Gomes 2000; Wan & Huang 2001).

What is a Kozai resonance? Well, the concept is important enough that the key paper (Kozai 1962) made the American Top 50 of the Century (Marsden 1999), so we'll try to help, or anyhow enlist Yoshihide and Brian to help. For starters, the paper is called "secular perturbations of asteroids with high inclination and eccentricity." Kozai had in mind asteroids in the main belt, orbiting the Sun, with Jupiter as the perturber, but the same considerations apply for KBOs with Neptune as the perturber. Indeed a classic case is the orbit of Pluto, brightest of the KBOs, which is thereby kept from hitting (Williams & Benson 1971) what may once have been its primary (Lyttleton 1936).

Start, said Kozai, with the Hamiltonian for the restricted three-body problem, eliminate short-periodic terms, apply the energy integral, and solve by quadrature. What you get, says Marsden, is a constant of the motion, $C = (1 - e^2)^{1/2} \cos i$. Thus, when neither is very small, they will alternate being at their largest and smallest values, for instance, $e = 0.29$ at $i = 40°$ to $e = 0.53$ at $i = 30°$ for (1373) Cincinnati. And (here is the bit that helps save Pluto and gives long life to KBOs), the argument (angular location, ω) of the pericenter librates (sloshes back and forth around a central value) rather than circulates (wanders through 360°, eventually to hit Neptune or whatever). Go thou and do likewise!

Strictly speaking, Pluto is guarded by no fewer than three resonances, the well-known 3 : 2 ratio of orbit periods with Neptune, the one you have just met, and a 1 : 1 resonance not shared by any (other) known Plutino (Wan et al. 2001).

The third-largest KBO is Varuna (Jewitt et al. 2001) at 900 ± 130 km, from the combination of its reflected light (albedo = 0.07) and re-radiated infrared. Only fair that Varuna should be feminine, since Pluto and Charon (numbers one and two in size) are clearly masculine.

4.2.2. Orbits of Moons and Planets

No risk of an Olbers Paradox, we suppose, but Saturn gained 12 moons in the past year (Gladman et al. 2001c) and Jupiter 20 (Sheppard et al. 2001). All are of the "irregular" sort, with various combinations of retrograde orbits, large eccentricity, and large inclination implying that they are capture asteroids. Some of the orbits are grouped in *a*, *e*, and *i*, indicating fragmentation after capture (Gladman et al.). Uranus has some of these too. Indeed new discoveries of small moons around big planets have proliferated to the point where the orbit details have been exiled from the IAU Circulars to the Minor Planet Electronic Circulars (IAU Circ. 7555).

A newly-discovered natural moon of Earth would probably still get wide publicity. There haven't been any of these for a while, though frequent false alarms featured in the very-slightly-classified literature of the 1950s. These could not have been space debris, but asteroid 2001 DO_{47} was the *WIND* spacecraft (IAU Circ. 7589).

Meanwhile, the one Moon we do have has been formed again (theoretically, of course) by an impact of a somewhat smaller object than previously proposed (about 0.1 $M_\oplus$) and somewhat later, after core and mantle had separated (Canup & Asphaug 2001).

What other dynamical issues have puzzled over the years? The ephemeral rings of Saturn—but a collision of Prometheus and Pandora will replenish them in less than 75 million years (Poulet & Sicarda 2001), and it's your turn to come in with some suitable remark about letting fire out of the box. The retrograde rotation of Venus—but she could have got there from prograde rotation in two ways, with the other possible end points of the process at rotation periods of +243 days and plus or minus 76.8 days (Correia & Laskar 2001). The dense atmosphere is part of the story; and the retrograde rotation, in turn, strengthens yet another resonance (between precession of core vorticity and nutation) that, last time around, perhaps heated her mantle enough to repave her surface (Touma & Wisdom 2001). Cosmetic surgery we call it on Earth.

And, of course, the moons of Mars, discovered by Asaph Hall, Jonathan Swift, and the astronomers of Laputa. Hall used the nearly-new 26-inch Clark refractor, then the world's largest, at US Naval Observatory. The Laputans, we had always supposed, used pure ratiocination (one for Earth, four for Jupiter = two for Mars). It seems, however, that they borrowed the idea from Kepler, who, in turn, had misinterpreted a Galilean anagram (O'Meara 2001). What Galileo had meant to say was "Altissimum planetam tergeminum observavi" (a report of handles on Saturn, which in turn, were decoded as rings by Huygens). Kepler read it as "Salve umbistineum geminatum martia proles" a greeting to twin children of Mars. The two have the same number of letters, and are indeed anagrams, if $u = v$, as it did back in the days when graffiti were carved on walls, rather than spray-painted. Clever of them all, we say, and a perfectly reasonable alternative to astro-ph.

4.2.3. Moons and Planets: Dry and Wet Counties

Dry counties, where Intoxicating Beverages may not be sold (legally) are not so common in the USA as they used to be. Neither, it seems, are dry places in the solar system. No clearly starred papers here, but we read about lavas made of water ice on Ganymede (Schenk et al. 2001) and hydrated rocks as well (McCord et al. 2001), ocean survival on Callisto (Ruiz 2001), and rain on Titan (Griffith et al. 2000). Admittedly, the rain drops are liquid methane, but the methane in turn comes from methane hydrate (Loveday et al. 2001). So there!

Martian moisture (keep it clean guys) continues to be most discussed and debated from year to year. Malin & Edgett (2000) reported up to 4 km of sedimentary rocks, probably from water deposition, and Phillips et al. (2001) say that a wet, warm epoch in the period 4.3–3.8 Gyr ago was associated with the release of large quantities of CO_2 and H_2O from magma that formed the Tharsis ridge. Venus has also had temperature swings of up to 100 K either direction. These were mediated by her atmosphere, but not liquid water (Bullock & Grinspoon 2001).

On the dry side comes the attribution of the smooth northern plane of Mars to the flow of lava rather than water (Withers & Neumann 2001). The presence of molecular H_2 on Mars results from water-vapor chemistry, say the discoverers (Krasnopolsky & Feldman 2001), but there is not enough even to mist up your glasses, let alone rain. And Venus has atomic oxygen without being rich in precursor O_2 (Slanger et al. 2001).

The starred wet/dry Mars story this year is, however, the rediscovery of flashes or flares of near-specular reflection at opposition. Reported by Percival Lowell in the late 19th century as the glint of ice slopes and sighted again in observations of Edom Promontorium during the close opposition of 1954 by Tsuneo Saheki and other Japanese astronomers, these have now been caught on video tape (Tresch Fienberg et al. 2001; Sheehan 2001) during the June 2001 opposition, when Edom again lay close to the subsolar and sub-Earth points. The observers aren't sure whether to describe the specular reflector as ice, fog, or something else, but lest you think the Promontorium might be a good place to get a drink, remember that Edom (aka Idumea) was south of the Dead Sea and original home of the Herodean kings of Judea.

4.2.4. More Orbits of Fragments and Fragments of Orbits

We'll start with the smallest pieces and a Michelin rating of "two wows" (worth stopping at the library if you are headed that direction anyhow) for the prediction of what the inhabitants of other planets might see in the way of meteor showers caused by the detritus of comets of known orbit. Larson (2001) found 106 showers for Jupiter, 17 for Saturn, 1 for Uranus, and 3 for Earth, two of which actually happen. The author who has seen fewer meteorites was surprised at just how many known (terrestrial) showers there are—more than 50, just counting those associated with asteroids in the Taurid complex, which are really old comets (Babadzhanov 2001). Someone will have to think of a new way to label them if the number climbs above 88—or perhaps sooner. Do you really want to have to tell your students to go out and observe the Piscids?

The meteor shower of the year was, once again, the Leonids, and you could read about (*a*) what is required for them to power flashes said to be caused by their hitting the Moon (conversion of 0.2% of their kinetic energies into light; Bellot Rubio et al. 2000), (*b*) the forecast for 18 November 2001 (Brown & Cooke 2001), which predicted that the specks hitting Earth would include ejecta from all nine of the orbits of the 17th, 18th, and 19th centuries (we couldn't tell them apart because it was foggy in Palo Alto and Irvine), and (*c*) a 7-minute quasi-periodicity in the arrival times of the 1999 Leonids, apparently resulting from asymmetric ejection by Comet 55P/Tempel-Tuttle back in 1899 (Singer et al. 2000). This does not, when you stop to think about it, require the comet nucleus to have a rotation period as short as 7 minutes. Meteor particles themselves apparently have rotation periods less than a second, if this is the cause of some trails flickering at a few Hz (Beech 2001).

Next up in size are the meteorites that actually reach ground. It seems that they have to work fairly hard to get to Earth from the asteroid belt in the time indicated by their cosmic-ray exposure ages, enduring a combination of collisions and the Yarkovsky effect (Vokrounhlicky & Farinella 2000). All we heard about the orbit of the Tagash Lake meteorite was that it intersected Earth on 18 January 2000, but the object is said to be the most primitive (meaning chemically unprocessed since formation) ever found, representing a new type of carbonaceous chondrite (Brown et al. 2000). Judging from the pictures, Tagash Lake did not pick a particularly pleasant time of year for the visit. The pre-impact mass was about 200,000 kg, enough to fill a box 4 meters on a side.

Comets are much bigger (kilometers on a side). Most of them come to us from the Oort cloud, whose inner part, at least, is more disk-like than spherical (Levison et al. 2001), and the trip is no Sunday excursion (Rickman et al. 2001). "Coming" from the Oort cloud does not, however, mean that comets formed there. The accepted locale is in amongst the orbits of the giant planets, though getting out to the cloud is even harder than getting back in (Stern & Weissman 2001). Comet C/1999 S4 (LINEAR) started in the inner part of that zone, near Jupiter, judging from its carbon-bearing molecules (Mumma et al. 2001, part of a package of six papers discussing S4) and so must have had an even more collisional and eroding trip than average.

That no comets arrive on truly hyperbolic orbits is one of those things we learned at least a century before Halley is due back again and so were happy to read is still true (Krolikowska 2001). It is the nature of the comet orbit distribution to have given us about three naked eye ones per century since the year 0 (Hughes 2001), and you may or may not share our surprise that the secular increase in average number from 0 to 1800 is less than a factor two. Perhaps naked eye comets are like elephants—so large that they hardly ever get lost, even when very few astronomers are looking out for them.

It is the nature of the comets themselves to break up now and then, sometimes quite far from the Sun (Biswas 2000) and sometimes up close, as in the cases of Schwassmann-Wachmann 3, whose multiplying fragments can be counted in IAU Circulars 7534 and 7541, and comet 2001 A2 (IAU Circ. 7656). Both have undoubtedly been fine comets in their day, but the name of the former is particularly valuable to astronomers in need of new imprecations, when the intensity of their feelings exceeds what can be expressed in the more traditional, "May your entire 10-meter telescope be covered with pigeon droppings!" ("Oh, ordure!" for short). All together now, "Oh Schwassmann-Wachmann!" Now don't you feel better?

Comets both gain and lose material over the years. Krasnopolsky & Mumma (2001) have caught, with *EUVE*, ions of O v and C v arriving at Hyakutake with the solar wind, thus conclusively demonstrating that comet X-ray emission (a three-star in Ap97, § 2.2) comes from charge exchange. But mostly, of course, comets shed, until they are scarcely distinguishable from small asteroids, except, on average, via their retrograde, high-eccentricity orbits (Fernandez et al. 2001b, and see IAU Circ. 7510 and many others for additional examples of supposed asteroids that still manage an occasional puff of cometary coma).

The hit of the year in asteroid dynamics was the proliferation of their moons. Index 2000 began with the announcement of images of the third and fourth examples (Merline 2000) and ended with our having to take off our shoes to count the cases announced in IAU Circulars. In summary, they were (with four-digit numbers beginning with 1 or 2 being part of the asteroid name and those beginning with 7 being the IAU Circular number, and radar and optical meaning the detection techniques): 2000 DP_{10} (7503, 7504 radar and optical), (90) Antiope (7503 optical), 2000 UG_{11} (7518 radar), (87) Sylvia (7581, optical), 107 (Camille) (7569 with *HST* images showing that the two pieces are the same color), 1999 KW_4 (7632 radar), and (22) Kalliope (7703 optical). The numbers are now large enough that somebody must be looking for correlations between "having a moon" and other (compositional?) asteroid properties.

Meanwhile, in August 2000, just outside the index year, the relevant working group of the International Astronomical Union officially accepted (45) Eugenia I (Petit-Prince) as the companion name for old 45. The Little Prince, in case you might have forgotten, lived on an asteroid with one flower (a rose, in the pictures we've seen).

Ap00 mumbled a bit about the Trojan asteroids of Jupiter (§ 3.4). Not surprisingly, other planets should support similar quasi-stable (though less so) orbit families. Melita & Brunini (2001) found the orbits for Saturn, but no asteroids in them. (We propose Orcs for the family name if any should turn up.). Tabachnik & Evans (2000) considered Venus and Earth (where the orbits should last at least 10^8 years) and Mars, for which there actually are two asteroids deep in the stable region of orbit space. The authors speak of tadpole orbits, suggesting Grunders for the name of the object class (to us, if not to them).

The orbit of spacecraft *NEAR* (*Near Earth Asteroid Rendezvous*) finally carried it to the occupied part of the orbit of asteroid Eros last year, so more of the first family of papers appeared in Index 2001 (Yoemans et al. 2000 and three following papers; Veverka et al. 2001; Cheng et al. 2001). The shape is prolate (34 × 11 × 11 km), the color bland and consistent with chondritic composition; the surface has lots of craters less than 1 km across (and a few bigger ones) and is littered with chunky regolith, suggestive again of multiple impacts. The density is 2.67 ± 0.03 g/cm^3, the most accurate asteroid value so far, because of the $r = 0$ approach of the probe. Vesta weighed in at $1.306 \pm 0.016 \times 10^{-10}\ M_\odot$ and $\rho = 3.3 \pm 0.5$ g/cm^3 (Viateau & Rapaport 2001) during the not-so-NEAR passage of Thetis (11). Notice that more of the uncertainty in density comes from size than from mass.

4.2.5. Meteorites and the History of the Solar System

A dagger rather than a star is perhaps the right ornament for the remarks by pundit Wood (2001) along the lines that meteorite studies didn't really seem to be getting anywhere in recent years on the "origins" issue and that what is needed is a new idea that brings meteoritics together with the more general problem of the formation of stars and planets. He noted that there are currently in the literature 14 mechanisms for making chondrules (those things you have to have to be a chondrite), ranging from gas phase chemistry (cf. Krot et al. 2001 on formation in regions that have been completely vaporized) to irradiation of grains by gamma-ray bursts. He suggested that the X-wind model of young stellar objects may be such an idea. The linking concept is that the young Sun might have been so active that solar high energy particles could have produced all or most of the fossil radioactivities[7] normally attributed to supernovae (etc.) and used to time the formation events in the solar system. (Lee et al. 1998).

Some form of the solar particle idea has been in or (mostly) out of fashion for at least 40 years (Fowler, Greenstein, & Hoyle 1962, for instance), being dismissed as a rule as inadequate for at least the most abundant of the fossils (e.g., Goswami et al. 2001). The most recent wave of enthusiasm thus comes from increasing evidence for very high levels of activity among proto- and young-stellar objects, for instance, Garmire et al. (2000) on a thousand *Chandra* sources in Orion, and Imanishi et al. (2001) on the *Chandra* inventory of the ρ Oph region. They note that Class I sources (the youngest protostars) are brighter, hotter, and flarier than Classes II and III.

Other year 2001 milestones in the history of the solar system included (*a*) its birth in a cluster of a few hundred stars (de la Fuentes Marcos & de la Fuentes Marcos 2001; Adams & Laughlin 2001), (*b*) lack of chemical fractionation of molecular hydrogen where and when Jupiter formed, so that the front of Jove himself (also the rear) has the proto-solar D/H value of $2.25 \pm 0.35 \times 10^{-5}$; Lellouch et al. 2001), and (*c*) the inner solar system sequence of loss of nebula, differentiation of the asteroids (at 5–15 Myr), and finally assemblage of the terrestrial planets over 100 Myr (Alexander et al. 2001). The authors note that this means terrestrial raw materials were already depleted of volatiles (had lost their air and water, to resort to English for a moment). These then must have been brought back in by asteroids and icy planetesimals made near Jupiter. An epoch of extensive bombardment in the inner solar system 3.9 Gyr ago, preserved in the age distribution of lunar meteorites, is plausibly the same event (Cohen et al. 2000a).

And, just in case you don't have enough future threats to

[7] These include I^{129} and Pu^{244} now seen as heavy isotopes of Xe; Al^{26} (Mg^{26}), Na^{22} (Ne^{22}, known as neon-E), Cl^{36} (Ar^{36}), Cr^{53} (Mn^{53}), and Ca^{41} (K^{41}), whose half lives range from a few years to a hundred million. The "fossil" or "extinct" signature is that the decay products are found in chemical contexts indicating that they were incorporated into solids before decay, Mg^{26} as aluminum and so forth.

worry about, in another 2.4 Gyr the Sun will have brightened to 130% of its current luminosity (Bahcall et al. 2001) and (assuming constant atmospheric blanketing) the average terrestrial surface temperature have risen to 310 K. Somewhat later (and contrary to earlier reports) the Sun will expand sufficiently to swallow the Earth (Rybicki & Denis 2001). Korycansky et al. (2001) suggest that we might survive the rising Sun by using engineered asteroid encounters to move the Earth's orbit gradually outward.

4.2.6. Gai, Gaia, Gaiast

Somehow every earthly paper we wowed at this year had a message of the general form "it's much more complicated than you thought it was." At times in the past, this has been a precursor of a significant change in how scientists look at their subject. (Call it a paradigm shift if you must, but the penalty is three "hic, haec, hoc's" all the way through and $5 to the society for precise nomenclature.) In any case, the items appear here in the standard context of a layered, differentiated Earth with mantle convection and plate tectonics.

The solid core has long been known to transmit earthquake waves a bit faster in the north-south direction than perpendicular to it. Simplest would be a single, giant asymmetric crystal there. But the truth is probably a more complex assemblage of a very large number of distorted crystals (Steinle-Neumann et al. 2001).

The rocky mantle hosts convection cells, but whether in two layers or one has been "settled" in these pages a number of times, most recently in favor of two layers (Ap99, § 3.3.6). This year there were two votes for a single layer (Forte & Mitrovica 2001; Helffrich & Wood 2001), but with a zone of very high viscosity about 200 km down (Forte & Mitrovica) and/or transformations of the mineral phase at 410 and 660 km. There is also evidence for megablobs or large igneous provinces[8] feeding the mantle plume part of the convective system (Forte & Mitrovica; Thompson & Gibson 2000; Arndt 2000). Being in a mood to cite Lyttleton (1973), we will recall his contention that all the layers were just phase changes, perhaps involving hydrogen, rather than significant composition discontinuities.

The history of the Earth's rotation is also perhaps more complicated than one might have supposed, and the approximate agreement among the slowing-down rates found from leap second additions, historical eclipse records, and Cambrian coral layers therefore something of a coincidence. Laurens et al. (2001) conclude that the present tidal dissipation of Earth-Moon orbital kinetic energy is larger than the historical average, and that Earth rotation has actually accelerated on average over the last 3 Myr. Their indicator is the Ti/Al ratio in sediments in the eastern Mediterranean (why this works is explained by Loutre 2001), and the adduced cause the Pliocene-Pleistocene ice load, which changed the Earth's rotational moment of inertia. Lyttleton (1986) also claimed that the Earth had effectively shrunk, but not for the same reason.

Next comes the magnetic history, largely consisting (as we all learned some decades ago) of reversals every million or so years. These, however, ceased 118–83 Myr and 312–262 Myr ago, with the field stuck in normal polarity during the more recent episode and in reversed polarity (a north-seeking pole at geographic north) during the earlier eon. Tarduno et al. (2001) have shown that the field was about a factor three stronger during these hang-ups than it is now, consistent with recent dynamo calculations, if not exactly "predicted" by them.

The crust is on the surface. We do not claim this as a new result, but the newest oldest takes the record back from 4.005 Gyr to 4.4 Gyr ago (Wilde et al. 2001). You will not, however, be able to purchase a chunk for your rock collection, since it is represented by only a single crystal of zircon. Once there is some crust, plates of it can move around, and evidence for this process has been pushed back from 2.2 Gyr BP to 2.7 Gyr BP (Kusmy & Li 2000). The evidence is a 20 km segment of midocean ridge of that age found at Dongwanzi.

Atmospheric oxygen comes from plants (also not a new result), but did not become very abundant until about 2.3 Gyr ago, long after the first photosynthetic cells appear in the fossil record. Catling et al. (2001) attribute the rise to the loss of hydrogen from the photolysis of CH_4 (an early greenhouse gas) that had previously required oxidizing, and we would have regarded the issue as settled if we had stopped reading then and there. Instead, we went on to Kump et al. (2001), who are equally firm in support of a rise in atmospheric oxygen when the recycled crust rock had finally all been oxygenated, so that fresh magma no longer ate it all up. Ohmoto et al. (2001) consider those possibilities and others, including burial of organic carbon, and oxygen that was quite abundant earlier but somehow just didn't leave its calling card. Once again, rather more complicated than we had somehow supposed.

The history of terrestrial temperatures or, more broadly, climates is another topic of increasing complexity. A few words about the data appear in § 3.3.1. What might have been the contributing causes? Stirling (2001) considers the ice ages of 630,000 and 330,000 years ago, for which coral reef data support the candidacy of July insolation at latitude 65° N and its variation with Milankovich cycles (in the orbit and rotation parameters of the Earth). The point is that July near the Arctic circle is the last chance ice has to decide to melt each year, and if less melts than formed, you are on your way. Similar cycles appear as long ago as 20–34.4 Myr, with CO_2 amplifying the insolation driver (Zachos et al. 2001a).

Impacts of large asteroidal or cometary bodies are generally also regarded as part of the history of terrestrial climates, having been responsible for cooling at the end of the Mesozoic and, perhaps, the Paleozoic (Becker et al. 2001a) because of the

[8] Your Canadian joke for the year is an alternative last line to the traditional joke about a large number of students of different ethnicities writing about various aspects of elephants: And the Canadian wrote on "Elephants: A Federal or a Provincial Responsibility." The "large igneous province" is Ontario.

dust kicked up into the air. Conversely, Hoyle & Wickramasinghe (2001) propose that a comet landing in the ocean would heat it, increasing the amount of greenhouse water vapor in the air and thus stop ice ages for a while. The ice would, however, return after only 10,000 years.

What might you want to do about all this, apart from emulating the chap who read so much about the dangers of smoking, drinking, and good food that he resolved to give up reading? Well, iron in suitable form dumped into the ocean increases the population of phytoplankton and so draws down atmospheric CO_2 (Boyd et al. 2000). What eventually becomes of this carbon is not clear, and we suspect that the "in suitable form" qualification means that this is not a good way to get rid of old automobiles and filing cabinets. Or, if you are a supporter of "watchful waiting," the Earth's albedo can now be monitored with earthshine (Goode et al. 2001).

Should this last have been classified with "very difficult methods?" Probably not, since there doesn't seem to be an easier one. In contrast, (*a*) the use of annual variation in the intraday variability of quasar 0917+624 to demonstrate that the Earth goes around the Sun (Rickett et al. 2001) and (*b*) the use of the shifting shadow of the Sun in the arrival directions of very high energy cosmic rays detected in Tibet (Amenomori et al. 2000) probably quality.

5. YA WANNA SEE STARS?

"Star's what?" Such was once (and only once) the response to this traditional threat of mild physical violence given by the author whose father was cursed by a pair of family surnames (Lyne Starling) in lieu of Tom, Dick, or Harry and so generally known as Star. No violence is offered here, only some stars doing what they do best.

5.1. Nine Stars A-Quiver

Duly impressed by the scientific equivalent of two ears and a tail—a news write-up in *Science* (Gough 2001), we assigned a star to Bedding et al. (2001), the report of detection of oscillations in radial velocity of β Hydri that are the analogue of the much-analyzed helioseismic oscillations. The velocity amplitudes are about 0.5 m/sec, and finding them required a spectrograph with resolution $\lambda/\Delta\lambda \approx 10^6$, at the Anglo-Australian Telescope (because it is a VERY southern star). You could argue whether the symbolic star got brighter or dimmer when there came a somewhat similar report on α Centauri A (Bouchy & Carrier 2001), though Rigil Kent (Yeah, we had to look it up too) is unquestionably the brighter star, at least as seen from the southern half of Earth. In the case of β Hyd, there are about 10 *p*-modes (with pressure as the restoring force) at 1.7–3 mHz (the expected frequency range), amplitude about 35 cm/sec (yes, you can walk that fast), and characteristic splitting of 106 μHz (corresponding to rotation period). There have also been a couple of "pre-discoveries," e.g., Ap97, § 8.4.

But the real puzzle dawned slowly during mid-September hours in the Maryland library. Why are these oscillations headline news when other stars have been quivering away in obscurity and in a multiplicity of modes for years? The approved answer seems to have two parts, "more like the Sun" and "seen in velocity rather than brightness." But consider XX Pyx, a δ Scuti star with 22 independent periods between 20 and 60 minutes and frequency separations corresponding to its 1.1 day rotation period (Handler et al. 2000). These were extracted from 550 days of photometric measurements, the longest non-solar data stream to date.

Like solar modes, these are useful in deducing properties of the stars (Handler et al. deduce that XX Pyx has an average density 0.29 times that of the Sun). And the physical causes are not terribly different. Solar *p*-modes are said to be driven by turbulent convection (Samadi & Goupil 2001), but so are the *g*-modes (with gravity as the restoring force) of γ Doradus stars (Guzik et al. 2000), though the δ Scutis are driven by the kappa mechanism (incomplete ionization) that you learned for Cepheids in kindergarten (Kurtz & Mueller 2001; Suran et al. 2001; including pre-main-sequence objects). And heaven knows the other stars are not simpler to analyze than the Sun (Balona et al. 2001 on I Mon).

Are some sorts of modes more worthy than others? It is too late to ask Cowling (1941), though the RAS member-author once had the privilege of meeting his middle waistcoat button.[9] The distinctions he drew persist in a more general analysis (Lopes 2000, 2001), but Hansen & Kawaler (1994) note that evolved stars can have modes that behave like *p* in part of the star and *g* in another. Hoping for the latest word, we took out our nail file and used it to strip the wrapper from a brand new copy of Bisnovatyi-Kogan (2002), only to discover that he draws no fundamental distinction between stellar pulsations and stellar seismology. He remarks as have others that all stars will do this at some level (cf. Henry et al. 2000). We will return to other types of vibrating stars after a pause to admire the Springer wrapping paper, which assures the recipient, "Diese PE-Folie is grundwasserneutral." and "Bei der Müllverbrennung völlig unschädlich, somit umweltfreundlich." We wish we could be equally sure of the benignity of the contents.

The δ Scuti variables were first separated off from the classical RR Lyraes by Eggen (1956), but the paper to consult if you are having only one is Rodriguez & Breger (2001), who use data from *Hipparcos*, OGLE, and MACHO to locate not just these but also the SX Phe, λ Boo, γ Dor, and other related types on an HR diagram. The types, our notebook records, are all smooshed together in M_v versus $(B-V)$, and one needs light curves, spectra, and other information to see why all the classes deserve to have separate names and prototypes.

But, in case you think there are not already enough sorts of pulsational variability, Koen (2001) has found a new variety, slowly pulsating A stars (periods of 0.5–3 days vs. hours for

[9] Shame on you for thinking that. Cowling was simply very tall.

the δ Scutis of about the same color and mean density), while Dorfi & Gautschny (2000) have predicted a new sort of radial pulsation, very periodic, at 0.15–4 days, but with amplitudes of only 0.1–0.3 mag, which, they say, has never been seen. And no, the two sorts are not the same. The model stars are much brighter and more massive (living, indeed in the realm of the luminous blue variables) than are the observed, main sequence, ones.

Cepheids are the great grandparents of all pulsational variables. Two groups have now seen Cepheid surfaces move in and out through the pulsation cycle. Lane et al. (2000) used the Palomar Testbed Interferometer, looked at ζ Gem, and went for a high profile publication, while Nordgren et al. (2000) used the Navy Prototype Optical Interferometer, looked at four stars, including δ Cep, and were content with the *ApJ*. Both papers, however, carry the same message. All is well. The radii found and the amounts by which they vary are consistent with expectations based on Baade-Wesselink analysis and with standard distance scales, within the uncertainties. In case you wondered, the mean radius of δ Cep is 45 $R_{\odot}$.

V19 in M33 was recorded as a 54.7 day Cepheid with amplitude 1.1 mag by Hubble in 1926. Macri et al. (2001b) however found it constant in the images recorded by their DIRECT project. Thus either Hubble was wrong, or this is the first Cepheid known to have quit its job. Another dozen or so papers, concerning as many different other kinds of variables, though they rated one or more "wows" on initial reading, go uncited this year as we begin to hear the editor's winged chariot behind us.

5.2. Stellar Activity

The starred topic this year is saturation and supersaturation, that is, the recognition that stars may try to become too active for their own good and discover that not more than 100% of their surfaces can be covered with spots, plages, and all. (In quantum mechanics this is called unitarity.) The paper that seemed to lay it all out most clearly was written by Stepien et al. (2001). They compiled *ROSAT* data on W UMa stars, which co-rotate with their orbit periods, and so might be expected to become ever more active as those periods get shorter, promoting more and more magnetic dynamo generation and driving more and more angular momentum loss in winds. Instead what they find is that the three shortest period W UMa X-ray sources are not very bright. Saturation also sets a lower limit to the orbit periods of these contact binaries. For instance, a 1 $M_{\odot}$ star reaches contact at $P(\mathrm{orb}) = 0.4$ days after 1 Gyr and has by then saturated so that convection is driven largely to its poles. A 0.5 $M_{\odot}$ star takes a Hubble time to get there, at $P(\mathrm{orb}) = 0.2$ days, the shortest seen; and smaller masses never get there at all.

James et al. (2000) also write of supersaturation and the drop at rotation periods shorter than 0.3 days of $L_{\mathrm{x}}/L_{\mathrm{opt}}$ to less than 10^{-3} for both single and binary stars. Messina et al. (2001) report that optical data on star spottiness also show a saturation effect.

The mechanism, say Schrijver & Title (2001), is that, in very active, rapidly rotating stars, the magnetic field is carried to the poles by meridional circulation, and there is only so much room there. Polar spots, like low latitude ones in less active stars, come and go (Barnes & Collier Cameron 2001).

CN Leo, an otherwise fairly obscure (but obviously variable) M6 dwarf, is the second star to display its corona in the optical regime, via Fe XIII emission (Schmitt & Wichmann 2001). And, now, all together in a loud, croaking chorus, "The first was the Sun."

Spottiest of all are the very young stars. Rebull (2001), looking at the Orion region, found that at least 10% of spots last more than a year, and Garmire et al. (2000) reported about 1000 pre-main-sequence *Chandra* sources, also in Orion. Incidentally, the Becklin-Neugebauer object is not an X-ray source, and its nature remains obscure.

Completely convective stars (less than about 0.3 $M_{\odot}$) ought not to be frightfully active, since there is no "base of the convective zone" to host a dynamo. Nonetheless, about half of the M6–L5 stars in the sample of Bailer-Jones & Mundt (2001) have spots (periodic, varying light curves) that come and go.

5.3. Rapidly Evolving Stars

There are three examples known of the most famous class of these, and we recorded exactly one paper pertaining to each (conceivably for the same reason that your car keys are always in the last pocket you examine). FG Sge, the first to be recognized in its gallop across the HR diagram (Herbig & Boyarchuk 1968), looked the same after its year 2000 recovery from R CrB-ish fading as it did before, and the increase in surface abundances of carbon and *s*-process products has leveled off (Kipper & Klochkova 2001).

Sakurai's object (aka V4334 Sgr) also returned to the red giant region of the HR diagram after being faint and blue, and, in only about 2 years, much faster than FG Sge. Herwig (2001) addresses this as a special case of the ancient question, "Why do stars become red giants?"[10] invoking very inefficient convection as the cause and the closeness of the shell flash to the surface as the reason for the rapidity. The third member, which did its thing back in the 1920s, V605 Aql, is now surrounded by a thick dust cloud and something very like a planetary nebula (Hinkle et al. 2001).

The opposite class includes stars whose photospheres are seen to be getting rapidly hotter (20–120 K/yr for at least 10 years) as they strive to become white dwarfs, and they are

[10] To get to the other side. And this is perhaps also the place not to mention an out-of-period article on V4334 Sgr that admits only V605 Aql to its class, forgetting FG Sge completely. But we know who you are, and we're going to tell George and Alexander.

apparently more numerous. At any rate, Jeffery et al. (2001) present *IUE* spectra for four. All are about 0.9 $M_{\odot}$.

5.4. Some Favorite Things

The luminous blue variables.—They have never been red (unlike the progenitor of SN 1987A) according to Lamers et al. (2001), who have analyzed the ejecta of several. They still have a chance in the future at red gianthood, we suppose. LBVs are subject to five kinds of instabilities (van Genderen 2001), none of which are periodic. He also provides an inventory of members of the classes, but even the total numbers are an e-secret from paper readers. The fourth brightest has been expanding at about 4 km/sec for several years and is to be found in the LMC (Drissen et al. 2001). More luminous are η Car, the Pistol star (named for the shape of a surrounding nebula), and HD 5980, all in the Milky Way.

P Cygni is part of a small cluster (as was η Car last year) and if co-eval with the other stars, has a mass of only 30 ± 5 $M_{\odot}$ (Turner et al. 2000). And Eta itself was proclaimed a binary in four papers this year (Seward et al. 2001, looking at the *Chandra* image of its ejecta; Corcoran et al. 2001, giving masses of ≥80 and 30 $M_{\odot}$, from a colliding wind model of the X-ray emission; Feast et al. 2001, who have traced the 2020-day period in line intensities back to 1948 observations by the late David Thackeray; and Soker 2001). Hillier et al. (2001) expressed reservations about a binary model and pointed out that the luminosity (if sub-Eddington, isotropic, and due to a single object—like the case for intermediate mass black holes, § 10.3) implies a mass of at least 120 $M_{\odot}$ now.

Chemically peculiar stars (meaning ones with strange abundances that are confined to their surfaces) exist outside the Milky Way (Maitzen et al. 2001), though the diagnosis is photometric rather than spectroscopic and the LMC is only just "outside." The λ Boo stars are a particularly obscure class of CPs (deprived somehow of their fair surface share of some metals), which make up about 2% of their spectral territory, B8–F4 III–V (Paunzen 2001). Solano et al. (2001) conclude that they form a continuum with normal A stars. Abt (2000a) proposes that all the stars in a slightly more restricted range, A IV–V, may be metallic line stars, oversupplied with some metals and deprived of others, but with the phenomenon concealed by line broadening for rotation speeds greater than 120 km/sec. And, if you are reading only one this year, we recommend Leone & Catanzaro (2001), who address the patchy magnetic fields and surface compositions of the CP stars and include a nice, quick introduction to the history of stellar magnetic fields from Babcock to Trasco.

Supermetalrich stars (ones where the generous supply of metals pervades the whole star, not just the surface) also exist, and are one of the better cases for acronymity, there being no problem of where to put the hyphen in SMR. Malagnini et al. (2000) and Feltzing & Gonzalez (2001) present additional details, but the reality of the phenomenon is perhaps the most important issue.

Be stars have emission lines, typically variable and even transient. We had sworn off them after trying to find a reviewer for the proceedings of a Be star conference and discovering that none of the pundits who hadn't been present were willing to say good things about those who had. Zamanov et al. (2001) have concluded that the disks around isolated Be's are not very different from those around the donors in the Be X-ray binaries. And we were about to trumpet as a major discovery the report that 70% of all Be's have white dwarf companions, when we noticed that this was a calculation, not an observation (Raguzova 2001).

R Coronae Borealis variables are the ones subject to sudden, unpredictable fading, caused by formation of carbon grains in their atmospheres. Some live in the LMC as well as the Milky Way, which is a good thing, since their absolute brightnesses would otherwise be very uncertain. The MACHO project has more than doubled the LMC inventory, from 7 to 15 (Alcock et al. 2001). Most pulsate; they have a considerable range of absolute magnitudes, $M_V = -2.5$ to -5.0; and extrapolation to populations in the Milky Way predicts about 3200 galactic ones, of which 40 or so are known. A less extensive search of the SMC found zero. The authors report, in addition, some LMC members of the DY Per class, which are cooler and fainter at $M_V \geq -2.5$ and fade more slowly than the R CrBs. They have also been scrupulous in citing the great works of the present authors. (We owe you a drink, Charles.)

5.5. Evolutionary Tracks

The stellar stellar evolution paper of the year was Bono et al. (2000). They have calculated a set of tracks for stars of 3–15 $M_{\odot}$ and a wide range of compositions, with special focus on the minimum initial mass required for carbon ignition, that is, roughly, the cut between progenitors of white dwarfs and supernovae + neutron stars. It is 9.7 $M_{\odot}$ for solar composition. They believe that some (single) stars near this dividing line could give rise to Type Ia supernovae driven by degenerate carbon ignition.

Marigo et al. (2001) provide tracks and isochrones for Population III ($Z = 0$) stars. These are considerably brighter and shorter lived than the ones we are used to. A 1 $M_{\odot}$ star, for instance, starts out with $L > L_{\odot}$, versus 0.7 $L_{\odot}$ at solar composition.

Next after mass and composition, rotation is probably the most significant real variable in the life of a star. Maeder & Meynet (2001) note that rotation matters more in stars of small metallicity, because the smaller mass loss rates at various evolutionary stages mean that the loss of angular momentum is also smaller.

The treatment of convection remains the greatest uncertainty in most evolutionary calculations. Although the star presumably knows what to do, we do not. Montalban et al. (2001) point out that honorable theorists will use the same prescription for convection (mixing length theory, full spectrum turbulence, or whatever) for both cores and atmospheres, which seems like a good start. Convection cannot be handled in isolation; Pop III stars of more than 20 $M_\odot$ have nuclear time scales (e.g., for the production of enough carbon to start CNO cycle fusion) shorter than the convective mixing time and so need dynamical convection calculations (Straka & Tscharnuter 2001). Models (at any mass) that include an adjustable amount of convective overshoot (transport of material a scale length or so beyond the region where the radiative temperature gradient is steeper than the adiabatic) give better fits to data on masses, sizes, and luminosities of well-studied binary stars (Ribas et al. 2000; Young et al. 2001). It would probably be unfair to remark that models that include an adjustable amount of anything tend to improve fits.

And a couple of details. Palacios et al. (2001) describe the enhancement of lithium on the surface of red giant bump stars (i.e., core helium burners) as arising from rotation-induced mixing caused by a flash of lithium burning in the hydrogen-fusion shell. One is much reminded of an Escher drawing that shows two hands, each holding a pencil and drawing the other. Finally, de Bruijne et al. (2000, 2001) report what they say is the first direct observation (using *Hipparcos* colors and magnitudes for Hyades) of a gap in a traditional HR diagram [M_V vs. $(B-V)$] at the point on the main sequence where envelop convection sets in. Rapid deepening of the convective zone with decreasing effective temperature reddens the colors suddenly; that is, the effect comes partly from the transformation between theoretical and observed quantities. This is called the Böhm-Vitense (1970) effect, and she is currently working on another puzzle in among the Hyades.

5.6. Stellar Data: More and Better

The items in this section bifurcate into "one" and "many." The "ones" are (*a*) a measurement of the limb darkening of a gravitationally lensed star from the OGLE project (Albrow et al. 2001); there were no surprises except that it can be done at all; and (*b*) a measurement of the angular diameter of Betelgeuse at 11.5 μ (Weiner et al. 2000). The size was 54.7 $\pm$ 0.3 milliarcsec that day, and neither limb darkening nor spots introduce significant error into measurements at such long wavelength. Mira reported in at 47.8 $\pm$ 0.5 milliarcsec at phase 0.9 in a similar set of interferometric measurements.

There was also one example of (*a*) an inverse "first ionization potential" effect in the highly active star V 711 Tau (Drake et al. 2001; the words mean that elements with a large first ionization potential are over-represented in the upper atmosphere, relative to small IP ones), and (*b*) the usual FIP (over-representation of low IP elements) turning on gradually during 2 days above an active region, according to Widing & Feldman (2001), who were watching the Ne/Mg ratio. But, like most "firsts," it was a solar active region, and so doesn't belong in this section. Shoo, shoo, back to § 2, where you belong.

On the "many" side, Alksnis et al. (2001) have catalogued 6891 carbon stars, and the microlensing project EROS II has recorded light curves for 9.1×10^6 variable stars in 3 years, plus seven microlensing events (Derue et al. 2001), but the task is not completed: Paczyński (2000) suspects that 90% of the variables brighter than $m = 12$ have not yet been recorded as such.

5.7. Biparous Stars

A triple star up front to Reipurth (2000) for the demonstration that triples are almost as common as doubles in the youngest sample for which binary statistics exist, the drivers of giant Herbig-Haro flows. Many of the triples are unstable and will fall apart by the time the gaseous placentae of their birth have dissipated. This is almost certainly relevant to the existence of orphan planets (§ 4.1.1).

"Biparous" means "bringing forth two at birth," and honors the recognition by White & Ghez (2001) that this really is what happens—star pairs with separations of 10–1000 AU in the Taurus-Aurigae region of star formation are more nearly the same age than star pairs selected at random. What is more, the distribution of system periods (from 1 to 10^{10} days) is also in place at birth, according to Kroupa & Burkert (2001).

Besides P (period) or a (semi-major axis), you need three more numbers to describe a binary orbit: eccentricity, e, and two selected from M_1, M_2, $M_1 + M_2$ (total mass), or M_2/M_1 (mass ratio). This year you get at most one of each. The distribution of primary masses in the Pleiades marches onward at $dN/dM \propto M^{-0.5}$ through the brown dwarf and into the nearly-planetary region south of 0.09 $M_\odot$ (Martin et al. 2000). The distribution of mass ratios among the MACHO binary lenses is "rather flat." Of course there are only 16 of them (Alcock et al. 2000a, a paper that might well have been catalogued under "difficult methods"). And the smallest eccentricity limit is $e < 8 \times 10^{-7}$ for the binary pulsar J1012$-$5307 (Lange et al. 2001). Notice that this corresponds to drawing a near-circle a million kilometers in radius and having the long and short axes differ by no more than the 0.2 mm width of your pencil line.

Two stars, as we move forward to binary evolution, for the comparison of theory with data by Nelson & Eggleton (2001), which shows that the conventional assumption of conservation of mass and angular momentum already fails at the Algol stage. That more Algols flaunt accretion disks than we had been used to suppose (Vesper et al. 2001) is perhaps related. For systems initially more massive than 12 + 6 $M_\odot$, mass loss is already rampant early in the first stage of Roche lobe overflow, if this occurs before the primary has become a red giant (Wellstein et al. 2001).

5.8. Less Common Binaries

The one-star award ought logically to have gone to a catalogued binary that has turned out to be (or turned into being) single. Not having spotted any of these during the year, we mention instead some examples of relatively rare classes doing their relatively rare things. There is one W UMa (contact) binary for every 65 F-G-K dwarfs, and this number represents a larger fraction than earlier reports because $N(M_2/M_1)$ rises steeply toward small values (i.e., systems that are harder to recognize) before plunging abruptly at $M_2/M_1 \leq 0.1$, the smallest stable value (Rucinski 2001). The components of HD 172481 are an asymptotic giant (M-type) branch star plus a post-AGB (F2 Ia) star according to Reyniers & van Winckel (2001). Given the transitoriness of these stages, the two stars must initially have had $M_1 - M_2$ very small, though probably not so small as 8×10^{-7} in any sensible units. In contrast, the largest mass difference between components close to the main sequence would seem to belong to HR 7329, made up of an A0 dwarf and an M7–8 brown dwarf with $M_2/M_1 = 0.01$ (Guenther et al. 2001).

Blue stragglers go back to the beginning (Ap91, § 5), and we note only their penchant for living in dense star clusters (Pych et al. 2001 on the SX Phe stars in globular cluster M55, such an old friend that we call it NGC 6809), and the dynamical reasons that they should live there (Portegies Zwart et al. 2001a; Hurley 2001; Shetrone & Sandquist 2000). Blue stragglers, in case you do not go back to the beginning, live in HR diagrams on upward extensions of otherwise eroded main sequences, as if they were too massive for their homes. They are generally attributed to some sort of binary evolution with mass transfer and/or merger. The triple straggler S1082 in M67 (an old, dense galactic cluster) consists of an inner close pair, with total mass larger than the current turn-off and an outlier that itself straggles. Thus the system must originally have consisted of at least five stars, worth a special trip around the galaxy in Michelin code (van den Berg et al. 2001). Ryan et al. (2001b) advocate lithium-depleted halo stars as the precursions of blue stragglers, some of which do display mild anomalies in surface abundances (Schoenberner et al. 2001).

Among the cataclysmic variables of the year, you will find, as expected, (*a*) that systems that have evolved through and beyond minimum orbit period have secondaries eroded down to brown dwarf status (Howell & Ciardi 2001), (*b*) some secondaries show activity cycles which affect various botanical aspects of the system light curves (Ak et al. 2001), (*c*) that it is possible to resuscitate a red giant if a companion dumps enough material on what was formerly its degenerate core and is now a white dwarf (Whitelock & Marang 2001 on HD 172481, which you just met a paragraph or two above, masquerading as a post-AGB star. Well, we said this was a rapidly evolving phase). You will also find, and perhaps did not expect, (*a*) radio emission from Nova Puppis 2000 (V445 Pup) that looks like self-absorbed synchrotron (IAU Circs. 7717, 7725), (*b*) LMC Nova 1991, which was very bright, leading you to think of a massive (ONeMg) white dwarf, but whose ejecta were enriched only in CNO (Schwartz et al. 2001), and (*c*) a way to allow dwarf nova instabilities (the sort that come from sudden ionization and recombination changing the gas viscosity) to move through the accretion disk from either inside out or outside in (Buat-Menard et al. 2001). The additional bit of physics is disk heating by the impact of the gas stream as well as by tidal dissipation, and the authors do not mention whether it is also possible to make DNe outbursts with the skinside inside, like Hiawatha's mittens.

Last, and arguably also least, a bright star for the faint system KPD 1930+2752, consisting of a white dwarf plus a B subdwarf and advertized by Maxted et al. (2000) as the first binary of this type that should evolve into a Type Ia supernova. Just now it has a total mass of 1.47 $M_\odot$ and an orbit period of $2\frac{1}{4}$ hours. But, say Ergma et al. (2001), poor old KPD may not get there after all, because the subdwarf will continue to lose mass, until the total may well be less than the Chandrasekhar limit by the time the two stars spiral together and merge. If this has left you feeling as if you came in during the second act of an Ionesco play, recall that Type Ia supernovae are the sort powered by explosive burning of carbon and oxygen; that one way to accomplish this is for two white dwarfs to merge (prodded together by loss of angular momentum in gravitational radiation); but that it works only if the post merger mass is big enough to trigger degenerate carbon ignition in the merger product, which, in turn, must not happen for single white dwarfs of less than a critical mass, or such stars would not exist.

6. THE STARS IN THEIR COURSES

That the "fixed stars" move was one of the many astronomical discoveries of Edmond Halley, who found that Sirius, Arcturus, and Aldebaran were not quite where Hipparchus said they should be. Fittingly, several of the key papers on the following topics in stellar dynamics make use of *Hipparcos* satellite data.

6.1. Run-away Stars and Walk-on Clusters

A runaway star is one with large velocity relative to the population you think it belongs to. Thus Kapteyn's star, with heliocentric radial and transverse velocities both in excess of 100 km/sec, is not a runaway, but merely a nearby member of the halo population, while the slow-moving μ Col and ι Ori count as runaways because they deviate from the galactic disk rotation they ought, as young OB stars, to share. Explanations followed close on the heels of recognition of the property—liberation from a short period binary by the supernova explosion of a companion (Blaauw 1961) and expulsion from young clusters by encounters, perhaps also involving binaries, therein (Poveda et al. 1967), and, of course, Zwicky (1957), riding all possible horses rapidly in all directions.

Our starred paper (Hoogerwerf et al. 2000) demonstrates that both processes occur, since three classic runaways, AE Aur, μ Col, and ι Ori, can be traced, via their *Hipparcos* parallaxes and proper motions, back to the Trapezium cluster, while another, ζ Oph, was close to PSR J1932+1059 (surely a post-supernova) about a million years ago.

In fact the history of ι Ori is even more checkered, for the stars that make up the present 29-day binary are not co-eval or co-evolved, and must have changed partners in the ejection process. Their original partners are the previously noted μ Col (B2 III–IV, originally a secondary) and AE Aur (O9 III, originally a primary) according to Bagnuolo et al. (2001).

Hoogerwerf et al. (2001) expand the database to 21 of 56 runaways traceable to specific clusters and remark that the former binary, consisting of ζ Oph and the progenitor of PSR J1932, once lived in the Sco OB2 association. Other Sco OB fugitives include the runaway neutron star RX J18535−3743 (Walter 2001), and the high-mass X-ray binary 4U 1700−37 = HD 153919 (Ankay et al. 2001), which departed about 2 million years ago. Because the star that actually exploded in the "supernova runaway" mechanism is always by then the less massive of the pair (remember Roche lobe overflow), it is at least as easy to make a runaway binary as a runaway single, and both require non-spherical ejection of something during the explosion. We swore off talking about neutron star kick velocities several years ago, but anticipating that it will be well into the Year of the Horse before you read this, we note that the velocities of neutron stars are so large that they can sometimes be measured in X-ray images (Neuhauser 2001) and that there are quite a few ways of noticing that the explosions are indeed aspherical (Nakamura et al. 2001).

Time is, of course, just as important as direction in tracing runaways back to their origins. HIP 60350 is aimed away from the young cluster NGC 3603, but the star must have left the Galactic plane 20 million years ago, and the cluster is only 3–4 million years old (Tenjes et al. 2001).

What is the Gum Nebula doing in here? Well Woermann et al. (2001) say that the star which exploded to make this supernova remnant liberated the runaway ζ Pup (based again on *Hipparcos* measurements). The senior author of this paper is perhaps a candidate for the Zwicky prize, since he turned up in Ap00 (§ 4.4) proposing that the Gum Nebula is not a supernova remnant at all, but merely an ordinary thermal H II region. He has competition, however, from Wallerstein, whose email fairly oozed eau-de-Fritz as he pointed out that he had made the same suggestion some time ago (Wallerstein et al. 1980).

Expelling whole clusters is bound to be harder than single or binary stars. Thus we are not surprised that the motion of the η Cha and TW Hya groups is a mere stroll away from the Sco-Cen association, starting 10 or 15 million years ago (Mamajek et al. 2000). For a brisker excursion, continue on to the next subsection.

6.2. Gould's Belt and Friends

Gould's belt, the Sirius supercluster, and the local arm had a common origin in a 20 million solar mass, 400 parsec supercloud, from which they have all been fleeing for the last 50–100 million years, says Olano (2001). This expansion is, in turn, responsible for the local deficit of OB stars (Maiz-Apellaniz 2001, another *Hipparcos* application), though in truth we had hardly missed them. In case you need to find the Sun in all this, it is between the center and outer edge of an arm (Fernandez et al. 2001a, *Hipparcos* again) and 27 pc above the plane (Chen et al. 2001).

In seeming contradiction to the "expansion" scenario just advertized, Fernandez et al. also report that their sample of OB stars and Cepheid variables out to about 4 kpc displays a negative K term of −1 to −3 km/sec. "Hoo hee?" kindly New Yorker editors of long ago would have said (though that generation knew about K terms; we think the notation was invented by Kapteyn, or anyhow initialed for him). The K term was and is a fudge factor, introduced by Campbell (1913) to take care of net residuals when you are trying to find the motion of the Sun relative to some stellar population. Campbell's was positive, at 2–4 km/sec, and has been blamed on systematic errors in the rest wavelengths assumed for spectral features. This is the context in which Hubble (1929) spoke of a positive K term. His we think was physically significant.

Readers inclined to roam historical highways and byways may want to check on whether Einstein was aware of Campbell's K term when he decided to build a static universe. So that you don't have to get out your slide rule, 3 km/sec over 1 kiloparsec is an expansion time scale of 3×10^8 yr, not totally impossible for a pre-nuclear, Kelvin-Helmholtz population of stars.

The starred paper in this category came from Comeron (2001a) and reports that M83 has a Gould's belt of its own, visible in the distribution of OB stars, H-alpha emission, and so forth in images he obtained with the Very Large Telescope. This should seemingly carry us forward to the kinematics and dynamics of other galaxies (§ 6.4), but we will hang around the Milky Way just a bit longer.

6.3. Tip-toeing through the Asters

Starting at the center of the Milky Way, it seems that the black hole in Sgr A* is eating young star clusters that originally formed further out, rather than living in the midst of a nuclear starburst (Gerhard 2001). There are a bunch of such clusters available (Portegies Zwart et al. 2001b).

Next comes the Galactic disk, which still seems to be trying to violate our Copernican assumption of normality ("mediocrity" cuts a little too close to the bone). For its total luminosity, mass, and type, the Milky Way has a disk of remarkably small scale length, 2.8 ± 0.3 kpc according to an analysis of public data from the 2MASS survey (Ojha 2001), while a number of other similar spirals rejoice in scale lengths of 5–25 kpc (Cunow 2001). Our spiral pattern is probably a fairly ordinary one (which seems particularly strange as the scale length is anomalous) and can be described as a superposition of $m = 2$ and 4 harmonics (Lepine et al. 2001).

The disk really has two parts, thin and thick (and the spiral pattern is most conspicuous among the youngest stars and gas of the thin disk). The oldest stars in the local part of the thin component date from about 7.5 Gyr ago (Liu & Chaboyer 2000). The stars of the thick disk are systematically older (about 9.7 Gyr), as you would expect if they represent an earlier generation of thin disk, puffed up by a lifetime of living with giant molecular clouds, passing globular clusters, and so forth (Chen et al. 2001). All stellar ages are, of course, model dependent. These are on the scale where the massive globular cluster 47 Tuc celebrated his 12,500,000,000th birthday last year (Liu & Chaboyer 2000).The disk, of course, rotates, with a circular speed versus radius pattern that remains a good deal less well known than those in many other spirals. Branham (2000) finds a local circular velocity of only 185 km/sec and, harking back to Gould's belt as part of an expanding structure, a positive K term for O and B stars of +1.3 km/sec out to 200 pc. He did a least total squares fit to data on 197,835 *Hipparcos* stars, leaving the ghast of Ghos agausst, er the gauss of Ghast aghost, er …

And so onward from disk to halo. Olling & Merrifield (2001) have compared their models of galactic structure with data on stellar motions and conclude that, interior to the location of the Sun, most of the mass (25–45 $M_{\odot}/\mathrm{pc}^2$ locally) is in the disk or a flat halo. They also find inconsistencies unless we are closer than 8 kpc to the center and moving at a circular speed less than 200 km/sec. In contrast, counts of 5.8×10^5 stars in early SDSS data imply that the dark matter distribution has an axial ratio $c/a = 0.85 \pm 0.06$, that is, far from flat (Chen et al. 2001). Velocities for some large fraction of these stars will be needed to determine the local two- and three-dimensional densities. Meanwhile, we like Olling and Merrifield's unit, 0.42 GeV/c^2 per cubic centimeter, or, if the forces of political correctness dominate, 0.42 GeV cm^{-5}. This is 0.011 $M_{\odot}/\mathrm{pc}^3$, in case you have misplaced your pocket currency converter.

The halo itself, at least as traced by its blue horizontal branch and blue straggler stars, has lots of substructure, consisting of units of 10^6 $M_{\odot}$ or more (Yanny et al. 2000). This was the equivalent of a starred topic last year (Ap00, § 7.3), but has quickly come to seem familiar. Yanny et al. are again making use of early SDSS data, and you may or may not want to worry that their halo has $c/a = 0.65$, a good deal flatter than that of Chen et al. (2001) in the previous paragraph. Ibata et al. (2001b), in another analysis of star streams in the halo, also vote for round.

The cold gas in our galactic halo is also highly structured. Wait a minute, you are hollering, there IS no cold gas in the galactic halo. Sure there is. It's called the Magellanic Stream (and so we don't normally think of it as part of the halo). Its metals have now been seen (as absorption against background galaxies), but the derived abundances of magnesium and sulfur are sufficiently uncertain that the gas could have come from either the Large or Small Magellanic Clouds (Gibson et al. 2000a) at least on compositional grounds. And so onward and outward to other galaxies.

6.4. Mostly Spirals and Mostly Dynamics

M31 is nearest and like the Milky Way in many ways (Durrell et al. 2001 on chemical abundances and Liu & Melia 2001 on the nuclei). In particular, it also has substructure in the motions of its halo stars, in the form of streams derived from M32 and probably NGC 204 (Ibata et al. 2001a). Neither our galaxy nor theirs looks like the propinquity has yet done much damage, suggesting at most one close encounter in the past, given how much havoc NGC 5195 has wrecked on 5194, and conversely, in a single passage (Salo & Laurikainen 2000).

Somewhere between halos and disks come polar rings of stars and gas, many hosted by S0 (lenticular) galaxies, and, as a rule, perpendicular to the main plane. In some sense, a counterrotating component near the disk center sounds like an even more extreme version of the same thing, and it has been customary to blame both on capture of a less-evolved small companion. Bettoni et al. (2001) conclude, however, that there is no evolutionary sequence from gaseous polar ring to counterrotating central gas, because the rings have 10 times as much gas. One wonders a bit about gas being expelled or turned into stars in the process. The observed correlation between spiral type and prevalence of counterrotating gas (late = less; Kannappan & Fabricant 2001) indeed suggests that dynamically decoupled gas, if not exactly lost with time, is liable to get stirred into other stuff.

In the case of stellar rings and counter-rotators, there need not even have been a capture. Tremaine & Yu (2000) have managed to make them by trapping initially respectable disk stars in funny resonances characteristic of triaxial (halo) potentials.

Spiral disks are rarely perfect circles (Andersen et al. 2001). We aren't sure about the Milky Way in this regard, but the authors say that the mean $e = 0.05$ is sufficient to account for half the scatter in the Tully-Fisher relation as a distance indicator for spirals.

No papers on this topic were initially starred, but we did spot one "odd!" and one "interesting if true" (something like the equivalent of a bull fighter being awarded one kidney and the private parts). The "odd" is a determination of the ages of the patterns in grand-design spirals, based on distributions of stars of various ages. Vera-Villamizar et al. (2001) report, for three galaxies, 1200 Myr (a pure $m = 2$), 800 Myr (with an $m = 1$, single-arm component), and less than 80 Myr (with an $m = 3$ pattern). The "odd" flag was triggered by feeling that we had been told in early childhood that spiral patterns had to last through many rotation periods or they would not be so common as they are. Perhaps 1 to 12 = "many" should not distress astronomers who are used to counting elements as one, two, metals. And this may be as good a place as any to note that a good many spirals have what looks like a separate nuclear spiral pattern. Laine et al. (2001) show, however, that at least for NGC 5248, the two spirals have the same pattern speed, suggesting a common mechanism (whatever it is).

The "interesting" flag was attached to the conclusion of Binney et al. (2001) that typical spiral disks must eject about $\frac{1}{2}$ of their initial baryon content in winds of small specific angular momentum. This simultaneously solves the problems of (*a*) excess central concentration of cold dark matter halos in many formation scenarios, (*b*) the disks coming out too small, (*c*) the sparcity of low-metal G dwarfs near us (G dwarf problem for short), (*d*) the existence of gas able to produce absorption lines in spectra of quasars in clouds far from visible galaxies, and (*e*) accounting for the presence of heavy elements in intracluster gas. Buchalter et al. (2001) agree about at most modest loss of angular momentum from spiral disks, but find that there has not been much mass loss either.

Finally, we look back over our ink-stained shoulders at the issue of maximal disks. That is, can you stuff enough mass into spiral disks to fit rotation curves out to roughly the optical edges without needing much dark halo material in these inner parts? (Palunas & Williams 2000).

7. SING TIDDLE IDDLE UM FOR THE MIDDLE

The rest of this poetic allusion continues "… of the month, for the middle of the month is Mammy," and comes from Ogden Nash via a choir director who could have found impropriety in a Victorian drawing room, if only by virtue of having brought it along. But what is meant here is items that come somewhere between individual stars and whole galaxies.

7.1. Globular Clusters

Not a star but a gas for Freire et al. (2001), because they have seen some in 47 Tuc. It's ionized, as it ought to be, given the presence of hot stars. The total amount is something less than 0.1 $M_{\odot}$, which, given the expected rate of mass loss by red giants in the cluster, means that the gas must also be departing within 10^4–10^5 yr and at a speed (80 km/sec) close to the escape velocity. This is just what you would have expected if you had read (Spergel 1991). The winds of millisecond pulsars (of which there are a bunch in globular clusters and in § 7.3) are the drivers. Another deduction is that there must not be a central black hole of more than 100 $M_{\odot}$ or we would have seen it as an accretion-powered X-ray source. The weak X-ray sources found in many globulars might, however, say Pfahl & Rappaport (2001), be caused by this self-same gas falling onto isolated neutron stars.

The 22 other papers on globular clusters in our fiscal 2001 notebook were, on the whole, less of a gas. Herewith some of the answers they provided. If it isn't obvious what the question was, we'll be happy to sell you a vowel or let you make a phone call at the next AAS meeting.

Young massive globular clusters exist (Gorjian et al. 2001 on L29 in NGC 5253; Larsen et al. 2001b on NGC 6946). Not, however, in the Milky Way, though NGC 6712, with its 108 blue stragglers and despoiled initial mass function, used to be one of them (Paltrinieri et al. 2001; Andreuzzii 2001). And a few galaxies may still have a bit of ongoing halo star formation. Comeron et al. (2001b) point to NGC 253, where the trigger is perhaps a superwind hitting cold gas (like our own high latitude molecular clouds, which, however are generally not star formers). They draw an analogy with Cen A, whose jets are hitting H I clouds.

Planets are the second parameter (Soker & Harpaz 2000; Soker & Hadar 2001). What they mean is that some globulars, but not all, have planets orbiting many of their stars and that this affects evolution via redistribution of mass and angular momentum in the stars so as to produce different colors of horizontal branch at fixed metallicity. 47 Tuc is one of the ones that does not have such planets (Gilliland et al. 2000), but it is metal-rich and so does not fall on either side of the second-parameter dichotomy. M22 may have copious planets (Sahu et al. 2001), but they are free floaters, which (perhaps) microlens the star field behind the cluster. Paczyński (2001) labels the events as mere "candidates" in any case. We suspect, though, that his "wow" threshold is higher than ours.

The Oosterhof types, defined by the mean periods of the RR Lyraes in various clusters, are not so distinct as we (meaning Oosterhof, at least one of the present authors, and perhaps Queen Victoria) had thought, since (*a*) ω Cen has some stars of each kind (Clement & Rowe 2000) and (*b*) contrary to long-held opinion, the average masses of the RR Lyraes in the two sorts of clusters are the same when you have properly calibrated your metallicity scale, enhanced your opacities,[11] and so forth (Bragaglia et al. 2001 on LMC samples).

The idea that a few/some/many/all of the globular clusters might be the remnants of impoverished dwarf spheroidal galaxies (Ap00, § 7.3) has gained on the competition, with a published candidate in M31 (called Mayall II; Meylan et al. 2001) and several more galactic examples camping out in Preprint Park. An interesting related idea is that the dwarf elliptical galaxies with nuclei are the ones whose own globular clusters have been driven into their centers by external perturbations, due to other galaxies in their groups and clusters (Oh & Lin 2000). Probably both scenarios can be true, but not for the same dwarf galaxies.

Another dozen papers at the "wow" level or above dealt with populations of globular clusters belonging to various galaxies and, especially, their implications for whether the process of galaxy formation is dominated by hierarchical mergers or monolithic collapse (§ 11.3). These cannot all be forced into a coherent story, even if you allow footnotes.[12] For instance:

[11] Frankly our opacity is already about as large as we would like.

[12] OK, so the wolf didn't really swallow the grandmother.

(1) McNamara (2001) concludes that all members of the galactic supply are the same age (11.3 Gyr), independent of metallicity, while (2) Borkova & Marsakov (2000) find that there is not even any overlap in age between a metal-poor population (with no net rotation) and a metal-rich one, with mean rotation speed of 165 km/sec. They suggest that a monolithic collapse (Eggen, Lynden-Bell, & Sandage 1962) took place between the two formation episodes. Incidentally, the correlation among cluster compositions, galactic location, and kinematics is not at issue, only the range of ages and formation mechanism(s).

We have the impression that the lead is held by a horse that formed at least a fraction of the globulars in galaxy components of 10^8–10^9 $M_\odot$ for later assembly. Burgarella et al. (2001) say just this, and Rejkuba (2001 on the clusters belonging to NGC 5128 and the resemblance to galactic ones) seems to imply it. Ditto for Kundu & Whitmore (2001) on the non-correlation of numbers of clusters (specific frequency) with host composition.

There were, however, also a number of votes in favor of formation as part of a monolithic process for populations of clusters found in galactic spheroids and bulges (Larsen et al. 2001a; Davidge 2001; Forbes et al. 2001; Forbes & Forte 2001). In striking a balance between/among these, you have the choice between a quote from Winnie-the-Pooh ("both please") and one from Perry Mason ("That goes to the weight of the evidence, not its admissibility.").

If red clusters = monolithic and blue clusters = assembled, then the ratio of the two sorts in different galaxies ranges from 7 : 1 down to less than 1 : 25 (van den Bergh 2001a).

7.2. Interstellar Materials

"With devotion's visage and pious action we do sugar o'er the devil himself," said Polonius (Act III, Scene I, Line 47). He was probably not thinking of glycoaldehyde, the sugar found by Hollis et al. (2000) in Sgr B2. The name, which means sweet, dehydrogenated alcohol, is perhaps not as informative as the number of syllables led you to expect, but the recipe is CH_2OHCHO, in case you want to stir some up. It is a diose, the first interstellar sugar reported, and probably made on grains (Sorrell 2001). Butler et al. (2001a) have checked the wavelengths in their laboratory, so you can be fairly sure the observers are not being fooled by, say, acetodeoxynixon (which means sour, deoxygenated president).

A few other favorite molecules include (*a*) hydronium, formerly a character in A Funny Thing Happened on the Way to the Forum, and now H_3O^+, newly discovered by Goicoechea & Cernicharo (2001), also in Sgr B2, (*b*) benzene (which means incense of Java), reported in the protoplanetary nebula CRL 618 by Cernicharo et al. (2001), who also found C_4H_2 and C_6H_2, and we haven't a clue what that means (keep it clean, guys), (*c*) amino acids, which should not be found in either interstellar gas or dust because they are so easily destroyed by UV radiation (Ehrenfreund et al. 2001, on laboratory experiments), and (*d*) polycyclic aromatic hydrocarbons, which are the third-best fit to unidentified infrared emission bands, according to Stoldt et al. (2001) and Holmlid (2001). Better, they say, are hydrogenated buckminsterfullerene (medieval fullers used impure hydrous aluminum silicates) and Rydberg matter (no, not the dust from his grave, but very big atoms, like the sort that might emit or absorb H109-alpha). Verstraete et al. (2001), contrarily, stand by PAHs as the dominant sources of the frequently identified 3–11 μm bands.

Speaking of dust, however, the Milky Way sort can be adequately described as a combination of carbonaceous material (including PAHs) and silicates, in grains of various sizes (Weingartner & Draine 2001). There is also dust in active galaxies, but it is different, lacking features at 2175 Å and 9.7 μm (Maiolino et al. 2001b). Notice that this is evidence that AGNs are PAH-deficient only if you agree that these features are PAH products, perhaps the PAHs that refreshes, though truthfully we are not quite sure how it is pronounced.

After "what is in the ISM" comes "how much is there?" to which we noted at least four answers. First, Lee et al. (2001) have inventoried all the molecular clouds more massive than 10^3 $M_\odot$ in a $C^{13}O$ map of the region $l = -5°$ to $+117°$ and $b = -1°$ to $+1°$. They found 1250 clouds. The brightest are in the 3 kpc ring (not the Galactic center), with others concentrated in spiral arms and a rapid drop in numbers beyond our distance from the Galactic center. Second come estimates of the total amount of molecular gas, particularly the very cool sort that has been claimed as a dark matter candidate in earlier years. Enough to contributed significantly to the mass of the Milky Way say Trewhella et al. (2000). Not, says Lawrence (2001), though dusty clouds at about 7 K are source of confusion to SCUBA observers looking for extra-galactic sources.

Third, measured values of the deuterium abundance in our neck of the woods range from D/H = 0.74 to 2.18×10^{-5} (all with 10%–15% error bars), according to ORFEUS data reported by Sonneborn et al. (2000). Fourth, and with a star all its own, is the deduction by Sofia & Meyer (2001) that the abundances of CNO, Mg, Si, and Fe in the local ISM are as large as the solar allocation and that of young F and G stars. This largely resolves the "carbon crisis" (so if you weren't worried about it before, you don't have to learn about it now—many things in life are like this). The result clearly has implications for the nature of exoplanet host stars (§ 4.1). In contrast, nearby B stars remain less well endowed with heavy elements than are we, despite their youth.

7.3. Supernovae, Supernova Remnants, and Neutron Stars

Quick! Name one object that belongs to all three categories. You said CM Tau, right? Or NGC 1952. Or NP 0532. Or SNR 184.6−5.8. Or 3C 144. Or Tau X-1. Oh. You said the Crab Nebula. Well, that's all right, because they are all the same object and were all the same place in about July 1054. The light curve ("visible by day like Venus," and "after more than a year it gradually became invisible") has been re-examined by Sollerman et al. (2001), to whom a star or even a supernova.

They conclude that the long duration required one of three possible energy sources, (*a*) about 0.06 $M_\odot$ of Ni^{56}, (*b*) collision of the ejecta with dense circumstellar wind material, or (*c*) immediate input from the pulsar. Observations of the composition of the nebula and of its surroundings pretty much rule out (*a*) and (*b*), leaving (*c*) and the first example of an answer "Yes" to the question, "Do pulsars make supernovae?" (Ostriker & Gunn 1971).

Another 77 papers or thereabouts fell into one or more of the categories, forcing us to be picky, choosy, and arbitrary.

7.3.1. Additional Crabbiness

X-ray images of Tau X-1 and also the Vela remnant from the *Chandra* satellite have added to the evidence (*a*) that they are rather similar and (*b*) that the major axes of the nebulae, the spin axes of the pulsars, their directions of proper motion, their polarization axes, and the axes of the surrounding tori are all roughly aligned (Lai et al. 2001; Helfand et al. 2001). We thought this odd 30-some years ago, when we first heard that the star whose proper motion we had measured to be heading right into the densest side of the nebulae was a pulsar, and still think it a bit strange. Explanatory models exist (Spruit & Phinney 1998) and tend to require the initial pulsar period to have been quite short (Laine et al. 2001), contrary to popular superstition and some calculations (Stergioulas & Font 2001; Lindblom et al. 2001), but consistent with the pulsar having made a large initial contribution to the SN light curve. One difference between the two remnants is that Vela has magnetic field and particle energy densities in rough equipartition in its central region, while in the Crab, the particle energy is larger by a factor near 300 (Helfand et al. 2001).

X-ray emission from NP 0532 never quite turns off (Tennant et al. 2001) but does not include a 440 keV feature due to redshifted $e^{\pm}$ annihilation, unless the feature is sporadic (Ulmer et al. 2001). The pulsar glitched six more times between 1995 and 1999 (Wong et al. 2001), though it will do so less often as it ages (Wang et al. 2000b). It remains the only non-recycled pulsar to exhibit giant pulses (Romani & Johnston 2001, discussing the second millisecond pulsar to do so).

Other temporal phenomena include (*a*) the lengthening of the 60 sec optical pulsation period (free precession) along with the rotation (Cadez et al. 2001), (*b*) a slowing-down index less than the $n = 3$ expected for pure electromagnetic dipole radiation, explained as torquing down by a disk (Menou et al. 2001a, and see Alpar et al. 2001 on the distribution of pulsars in the P–$\dot{P}$ plane), (*c*) occasional echoes of the radio pulses, lagging by 0–7 msec and caused by fine-scale shells in the nebula (Lyne et al. 2001), and (*d*) a current production rate of $e^{\pm}$ pairs that is only one-fifth of the average since 1054 (Hibschman & Arons 2001).

7.3.2. SN 1987A and Cas A

The remnant of SN 1987A continues its morphing from supernova to remnant and currently looks like a shell with hot spots in both optical and X-ray images (Burrows et al. 2000; IAU Circs. 7520, 7623). In another year, it will be old enough to drive, at least in California, after which we can reasonably expect further, probably damaging, morphological changes in the remnant and its surroundings. *HST* has also visited a few other aging SNe (IAU Circs. 7700, 7701, 7705), and finds that 1994ao, 1995by, and 1996cl, cp, and cq are still there.

Did Flamsteed (first Astronomer Royal) see the birth event of the remnant Cas A? Kilburn (2001), describing a recently discovered set of plates from John Bevis's *Uranographia Britannica*, says so unequivocally. (He also says that Tycho's SN may have been a Type II plateau event on the basis of its reconstructed light curve.) The chief objection to the Cas A identification has been that the remnant seemed to have started expanding a good deal earlier than Flamsteed recorded his star, 1658 vs. 1680. A reassessment of the nebular expansion has reduced the discrepancy to less than a decade (1671 vs. 1680; Thorstensen et al. 2001), a paper to which we would happily have affixed a star and a maple leaf if the authors had acknowledged the heroinic efforts of their referee. Other news from Cas A includes details of the asymmetry of the ejecta (Fesen 2001), continued non-detection of pulsed emission from the core (McLaughlin et al. 2001) or even of an unpulsed central radio source (Ryan et al. 2001a), and the suggestion that the stellar remnant is an anomalous X-ray pulsar or a neutron star fed by fall back of disk material (Chakrabarty et al. 2001), which brings us to

7.3.3. Magnetars, Soft Gamma Repeaters, and Anomalous X-Ray Pulsars

The key question here is whether the best-buy model for the SGRs and AXPs is indeed a slowly rotating neutron star with magnetic field $\gtrsim 10^{14}$ G. If the answer is yes, we then want to find out why this small subset of neutron stars is different from the general run. The background (skip to the next paragraph if you know all this; skip to the next section if you wrote much of it) is that both are sources of hard photons, with evidence for rotation periods of 6–10 sec, sufficiently slow that pulsar-type, magnetic dipole emission cannot account for their luminosities, unless their sizes are those of white dwarfs rather than neutron stars or their fields are very strong (e.g., Ibrahim et al. 2001, on a giant flare in SGR 1900+14). The SGRs, of which there are only about four, seem to be associated with supernova remnants (though not with enormous security; Lorimer & Xilouris 2000). For the AXPs particularly, the absence of bright optical counterparts rules out mass transfer from a companion as the main energy source, and perhaps even rules out accretion from a residual disk. Finally, some of the sources have measured slowing-down rates which translate, via the usual proportionality, $B \propto (P\dot{P})^{1/2}$, into fields of 10^{14} G or more. A close relationship between the classes is widely assumed, and Kaspi et al. (2001) suggest that AXP 1E 1048.1−5937 will be the next to break out as a soft gamma repeater.

The "best buy" magnetic fields for the groups and for specific members have oscillated up and down several times in recent years and in these reviews. On the low field side of the net this year, we find both Marsden et al. (2001) and Istomin & Komberg (2000), who concur that the AXPs (and the SGRs in Marsden et al.) have normal fields of about 10^{12} G and owe their peculiarities to the high density of their gaseous surroundings. Chatterjee & Hernquist (2000) regard fueling by accretion from a disk of material that fell back after the supernova explosion as the most likely situation for the AXPs. Usov (2001) has SGR pulse trains being initiated by comets hitting the bare quark surfaces of strange stars (though we would be just a tad surprised to hear that he regards this as the most likely combination).

Returning the serve from the high field side of the net were (1) Hulleman et al. (2000), reporting the first optical counterjet belonging to an AXP (4U 0142+61), (2) Li & Wang (2000), analyzing the distribution of AXPs in a P–$\dot{P}$ diagram, (3) Suh & Mathews (2001), deriving the energy for SGRs from boson condensate inside magnetars, and (4) Woods et al. (2001), using instead energy from reconfiguration of the internal magnetic field (which somehow sounds closer to "mainstream" than the alternatives).

The vote would seem to be a tie, at 4 to 4, but many papers went unrecorded, and we suspect that the magnetars have the advantage on at least the preponderance of the evidence.

How then do they relate to other magnetic, rotating neutron stars? Normal, young pulsars (with short periods, associated with SNRs etc.) extend up to 4–6 × 10^{13} G (Gotthelf et al. 2000 on J1846−0258 in Kes 75 and Camilo et al. 2000 on two others whose telephone numbers you can get from directory assistance—we remember when it was called "information," sometimes with justification). Indeed Regimbau & de Frietas Pacheco (2001) suggest that the magnetars are "just" the high end of the normal distribution of pulsar fields and that one with $B \gtrsim 10^{14}$ G should be born every 750 years in the Milky Way. If so, then they don't age well, according to Rutledge (2001), who found that there are no old, isolated single neutron stars whose accretion is magnetically channeled.

Why are the AXPs and such not also seen as normal radio pulsars? At least partly because above a critical field of 4.4 × 10^{13} G, magnetic photon splitting eats up most of the high energy photons that would otherwise make $e^{\pm}$ pairs (which make more photons, which make more pairs, etc. until you have enough in bunches to yield coherent curvature radiation). So say Baring & Harding (2001). One photon in seven still makes pairs according to Wei & Lu (2000, but in a journal where the number of mean readers per paper is even smaller than the discipline average of 0.7; R. A. Lyttleton 1969, private communication).

There is, incidentally, still a good deal of magnetic phase space for neutron stars on beyond magnetars. At $B = 10^{16}$–10^{17} G, nuclear structure, especially the magic numbers for closed proton shells, is affected (Kondratyev et al. 2001). But only beyond about 10^{18} G is no static structure possible (Cardall et al. 2001). Think GM^2/R = volume × $B^2/8\pi$, though of course the authors worked much harder. They also report that a near-maximal field increases the maximum possible mass of a neutron star by about 10%, more than you add with maximal rotation.

We aren't quite sure how to make one of these magnetically-precarious neutron stars. The corresponding main sequence field would be something like 100 MG, not physically impossible, but you don't see very many in the HD catalogue. King et al. (2001a), however, would like to make plain old magnetars from the merger of two white dwarfs adding up to more than the Chandrasekhar mass limit. They also associate the process with Type Ia supernovae, but we wonder whether there will be enough extra material to account for normal Ia ejecta.

7.3.4. Supernovae

The question about Type Ia supernovae (the sort that can occur in any sort of galaxy and that have no hydrogen in their spectra) has been for many years the nature of their progenitors. This year we caught votes for (*a*) binary white dwarfs, from Nelemans et al. (2001), who deduced an event rate of 1/300 years in the Milky Way, (*b*) recurrent novae, from Hachisu & Kato (2001), who report white dwarf masses of 1.35–1.37 $M_{\odot}$ for four RNe and expected explosion dates only 10^7 years ahead, since mass transfer is going along at 10^{-8} $M_{\odot}$/yr, and (*c*) a white dwarf plus some other sort of companion (Marietta et al. 2000), and a vote against known WD plus subdwarf pairs (Ergma et al. 2001). Multiple mechanisms are at least suggested, if not required, by the curious fact that 36% of all Ia events are peculiar (Li et al. 2001, authors who have apparently never been to Lake Wobegon).

Progenitors of Type II supernovae (the sort that happen only among young stars and that display strong hydrogen features in their spectra) have not been in serious doubt during the epoch of Apxx. The answer is massive stars, though not necessarily grossly massive say Smartt et al. (2001), who have set a limit of $M_v > -5.1$, and so mass less than 9^{+3}_{-2} $M_{\odot}$ for the star that became SN 1991gi, which does not show up in a pre-SN image of its host galaxy recorded by *HST*.

It remains, we suspect, true that Type II SNe are better informed than their modellers about how the ejection actually occurs. Calculated outgoing shocks, started by post–core-collapse bounce, tend to stall, at least the spherically symmetric ones. Hanawa & Matsumoto (2000) have contributed a vortex mode to the potential requisite asymmetry.

The index year included reports of the discoveries of 193 supernovae (2000dk in IAU Circ. 7493 to 2001en in IAU Circ. 7725), though at least two, 2001bh and 2001bn, were later retracted. For perspective, recall that SN 1987A appeared on 23 February (vs. 1 January for 2001A), and that in 1987 and many other years, not even the first alphabet, A to Z, was used up. The large current totals are largely dominated by automated searches overseen by professional astronomers, but the Rev. Robert Evans (now retired from his pulpit in the Uniting Church of Australia and living in Hazelbrook, NSW) continued to add to his remarkable record of visual discoveries (SN 2001du, IAU Circ. 7690). Other amateurs contributing to the total, but using CCD detectors, included M. Armstrong of Rolvenden UK (2000dv in IAU Circ. 7510) and T. Puckett of Mountain Town, Georgia (2000e1, IAU Circ. 7523, and 2001dv, IAU Circ. 7690). We then wasted a lot of time trying to locate some information about Puckett's Charge before (*a*) deciding that it was not anyhow probably of enormous relevance to supernovae and (*b*) ordering a copy of the *Oxford Companion to American History*.

The SN false alarms during the year were merely galactic stars, one at least variable, and one perhaps with not even that excuse. SN 1997bj, on the other hand, seems to have been an interesting event in its host galaxy, M66, though, say Van Dyk et al. (2000), more like η Carinae and the members of Zwicky's Type V (prototype 1961V) than like earlier types (meaning I and II, not "bluer" or "with more conspicuous spiral arms").

7.3.5. A Statistical Puzzle

Some years ago (Ap93, § 6), we brought to you the collective worry of the community that millisecond pulsars (recycled by accretion back to rapid rotation, after decay of their magnetic fields) were a good deal commoner than their supposed immediate predecessors, the low-mass X-ray binaries, in which the recycling (spin up) was supposed to occur. Not having heard much about this lately, we had sort of thought the problem had gone away. It is back this year. Grindlay et al. (2001) have researched globular cluster 47 Tuc for LMXRBs in *Chandra* images, finding only one for every 20 millisecond pulsars. The obvious answer—that the LMXRBs live 20 times as long—fouls afall of the rate of mass transfer needed to keep them shining, unless, note Bildsten & Chakrabarty (2001), many LMXRBs have mass transfer rates so small that they still aren't being seen, even with *Chandra*.

Help with the discrepancy comes from the generic idea that there are two populations of millisecond pulsars (Camilo et al. 2001; Miller & Hamilton 2001, each with a specific source as an example), so that not all millisecond pulsars are born from LMXRBs. (This sentence started out, "they didn't all do it that way," and has been recut for a general audience.)

The starred, indeed a collapsed star, paper in this territory is Garcia-Senz et al. (2001), who advocate accretion-induced collapse of white dwarfs as a source of MSPs that have never been through an X-ray binary phase. It's always good to see an old friend again. They add that the collapse may set off a blast wave that wipes out the remaining 0.3 $M_\odot$ or thereabouts companion, giving birth not just to an MSP but to a single MSP, as half or so of them are.

8. OUT OF PHASE: GASES YOU DIDN'T KNOW YOU HAD

Traditionally, one finds diffuse gas in a handful of components, characterized by temperature, density, and degree of ionization or dissociation, whose properties are set by some combination of pressure equilibrium, chemical composition, and a balance between heating/cooling and ionization/recombination. These include (1) molecular gas, usually traced by CO, at about 7–30 K, (2) much warmer molecular gas, in which the UV features of H_2 can be found, often in the process of boiling away, (3) cold neutral gas, H I, with an average temperature near 100 K, (4) warm neutral gas (newly recombined around supernova remnants, for instance, and not necessarily an equilibrium phase), (5) ionized, H II, gas at about 10,000 K, (6) more highly ionized, coronal, gas at 10^5–10^6 K, and (7) ionized gas at a temperature in equilibrium with the velocity dispersions of stars in elliptical galaxies or galaxies in groups and clusters (1000 km/sec $= 6 \times 10^7$ K and so forth). OK, not even in the Burgess Shale do you find creatures with seven-fingered hands (though Canadaspis had a seven-segment abdomen; Gould 1989), but in the Milky Way, most of the gaseous mass is in phases (1) and (3), with typical densities of 10^2–10^3 and 1 atom/cm^3, and a good deal of the volume in phase (6).

This section explores evidence for gas phases whose properties fall outside or between these sets of characteristics and their significance in the great scheme of things.

8.1. The Milky Way

Our starred paper (two "egads" and a "what?") was Heiles (2001), which reported new 21 cm observations from Arecibo. The two main results were, first, that a large fraction of the line features found in both emission and absorption had spin temperatures of 25–75 K, rather than the more popular range of 100–125 K, and, second, that nearly half the gas seen only in emission has line profiles suggestive of temperatures of 500–5000 K, in the traditionally unstable region. The stability of a two-phase interstellar medium can be found in Field, Goldsmith, & Habing (1969). McKee & Ostriker (1977) added our phase (6) to the (3) plus (5) of Field et al.

Heiles's (2001) numbers for H I temperatures are consistent with theoretical expectation for at least some ISM compositions (Wolfire et al. 1995). Other examples of copious cold gas were reported during the index year by Gibson et al. (2000b), who found many spin temperatures $\leq$50 K, and by Knee & Brunt (2001), who found a cloud of $2 \times 10^7\ M_\odot$ at only 10 K. Its density is much less than those of molecular clouds of similar masses and temperatures, and it shows no trace of star formation.

The gas at 500–5000 K is more problematic. One expects that small perturbations would send it rapidly toward either denser, cooler or warmer, more tenuous conditions. The high level of confidence expressed by the author is also a surprise, given that the paper states repeatedly that these temperatures are firm only as upper limits, and hold as measured values only if the entire (emission) line width is thermal broadening, with no contribution from turbulence, rotation, unresolved cloudlets, and so forth. It is also true that spin temperatures and kinetic temperatures of neutral hydrogen are not always equal (Kanekar et al. 2001 on a $z = 0.22$ absorber) and not expected to be (Liszt 2001), but this is not the issue. The components are emission-only, so the spin temperatures are not measured. Perhaps this is the key: if the clouds were at cooler, stable temperatures, absorption should be seen. But the paper does not quite say this. More works are needed, perhaps.

8.2. The Total Baryon Burden

The index year started with a loud ringing of alarm bells, clappered by data on the cosmic microwave background (CMB) radiation (e.g., Balbi et al. 2000). These seemed to require a larger baryon component ($\Omega_b h^{-2} = 0.03$–0.04) than would be consistent with getting the right answer in calculations of Big Bang production of helium, deuterium, and lithium ($\Omega_b h^{-2} = 0.0205 \pm 0.0018$, O'Meara et al. 2001; Burles et al. 2001). Notice that both numbers have the same dependence on h (Hubble's constant in units of 100 km/sec/Mpc). Thus, although the uncertainty in h (0.45–0.85 perhaps) dominates the error bars on Ω_b, the fraction of closure density contributed by baryons, it does not enter into this particular discrepancy. The data are discussed by Hogan (2000), Tegmark & Zaldarriaga (2000), and McGaugh (2000).

Don't panic (Adams 1980), because everything comes out OK. But let's follow the footsteps of the Cosmic Holmes by one and by one. The critical observations are peaks in the power spectrum of the intensity fluctuations of the CMB. They are called acoustic peaks because they are the result of sound (pressure) waves in the gas at the epoch of recombination ($z \sim 1000$). You met the first peak last year (Ap00, § 12.3). It happens at the angular scale on the sky now that corresponds to a causally connected volume at recombination (i.e., waves can cross once in the age of the universe as it was at $z \sim 1000$) and is about 1°. If you burrow into the equations of general relativistic cosmology, you will discover that such an angle is a measure of the flatness of the universe, and so of the total density-plus-pressure in both matter of all sorts and cosmological constant. For an angle of 1°, this sum comes very close to the closure density, flat space, or $k = 0$.

The second peak is on the angular scale that waves could cross twice, and, once you have decided that $k = 0$ from the first peak, it depends primarily on the baryon density (that is, the speed of sound, since you already know the temperature at which recombination occurs). And the data reported in fall 2000 seemed to show almost no peak where it was expected, though the observers (Balbi et al. 2000) and the discussors (e.g., Hogan 2000) had done a proper, simultaneous fit of all the adjustable parameters to all the data, not just the simplified calculation outlined here.

Public lifting of the clouds of excess baryons occurred at lunchtime, in an extraprogrammatical session at the April (Washington) meeting of the American Physical Society, where representatives of each of the three groups of peak hunters spoke on behalf of the BOOMERANG, MAXIMA, and DASI collaborations. In summary, somewhat longer data streams and, particularly, more accurate calibrations of zero points and such had yielded results (*a*) consistent among the three sets of observations and (*b*) consistent with the values of the assorted parameters found from supernovae and large scale structure and, especially, the value of $\Omega_b h^{-2}$ implied by Big Bang nucleosynthesis.

We were there, and so were Carlstrom & Ruhl (2001) and several hundred other people, many of whom applauded wildly (at least by astronomical standards). We sat blasé, having overheard at morning coffee A Reliable Source remark to A Reliable Sink, "It's amazing how often the obvious answer is right." Not only right but, in best scientific tradition, independently confirmed. The power spectrum of the very large scale distribution of galaxies and clusters in space also shows acoustic peak structure on scales attributable to a similar Ω_b. Lahav (2001) described results from a survey called 2dF (two-degree field, not two-dimensional something, because, with measured redshifts, it provides portions of the third dimension). Miller et al. (2001a) looked at a combination of data from the *IRAS*, APM, and ACO surveys and found peaks at $k = 0.035$ and 0.090 h Mpc, that is, structure at 13.5 and 28.6 h^{-1} Mpc, in case your k-meter isn't working. Indeed, how could it be, when we told you to reset it at $k = 0$ just a couple of paragraphs back. Yeah, they are different (though related) k's.

8.3. The Distributed Baryon Burden and Reionization

In translation, $\Omega_b h^{-2} = 0.02$ is $2.4 \times 10^{-7} h^{-2}$ baryons per cubic centimeter, or one baryon in the volume of your desk, if it formerly belonged to the CEO of a large insurance company. Where are they all? That depends on when you look. At $z = 1000$, they were all in a diffuse sea as homogenous as a school of 10^5 goldfish and one guppy, ionized somewhat before that and neutral somewhat after. The same faithful baryons went back from being neutral atoms of hydrogen and helium to being ionized ones, it now seems, rather suddenly (see also Ap00, § 8.5.3). The data were shown at the June 2001 meeting of the American Astronomical Society, though they are not manifest in the published abstract (Schneider 2001).

What you would have seen if you had been there included the spectra of three QSOs found in the Sloan Digital Sky survey to have redshifts of about 5.8, 6.0, and 6.2. Only the $z = 5.8$ is actually in our database so far (Fan et al. 2000). For it, space is still pretty transparent, though, as Madau & Rees (2000) remark, QSO photons can tunnel their own way out quite a ways, so that seeing Lyman alpha emission from one doesn't quite guarantee that it is living in the post-reionization era. But the $z = 6$ and especially $z = 6.2$ sources truly inhabit a pre-reionization universe, with a strong, continuous absorption trough blueward of their rest-wavelength Lyman alpha. In other words, Gunn-Peterson (1965) absorption has been seen.

Why does this count as an unexpected gas phase? Well, basically, after 36 years, our expector was just all worn out (Ap94, § 5.9). If you would like to see the spectra for yourself, the public data release of the first chunkum (a very large quantum) of SDSS is to be found at http://archive.stsci.edu/dss.

As the time coordinate gets bigger, the redshift gets smaller, and by $z = 2–3$, a large fraction of the baryons have rearranged themselves among clumpy phases that we can study because they introduce absorption lines into the spectra of QSOs. The phases are called Lyman alpha forest clouds (densities and line widths both small), Lyman limit systems (meaning they are not opaque in the lines but are at the ionization edge), and damped Lyman alpha clouds (optically thick in the lines). These are ordered from most to least total gas at $z = 1.75–3.25$ according to Corbelli et al. (2001). Storrie-Lombardi & Wolfe (2000) concur that the damped Lyman alpha clouds are not most of the gas near $z = 3$, not even most of the gas now found in stars (a modification of views expressed earlier).

Now ($z = 0$, $t =$ Hubble time × a factor of order unity), some of the baryons are in the pages or screen you are flipping through and many more in the stars and gas of recognizable galaxies and clusters. And at least a few QSO absorption clouds persist. But there has been something of a year 2001 bandwagon carrying a large fraction of the stuff into a phase that didn't even exist at $z = 3$ (or in 1991, depending on your vantage point). These are sheets, filaments, and other woofly structures of gas at 10^5–10^7 K, with average density only 10–30 times the cosmic average, versus 10^6 times for gas in the disk of the Milky Way (Dave et al. 2001).

Such gas ought to contribute to a background of soft X-ray photons, which is not ruled out by current data (Kuntz et al. 2001; Voit & Bryan 2001), but which will inexorably be ruled out (or revealed) as more and more of the background is resolved into discrete sources or left varying only gradually across the sky, as the case may be (Dave et al.; Croft et al. 2001).

An independent confirmation is possible by looking for intergalactic scintillation of distant radio sources. The 50–100 GHz band is the best bet, and the expected time scales are days to months (Ferrara & Perna 2001). This is a topic for which the less scintillating author feels a great deal of sympathy, because, once, long ago, invited to do a calculation of *interstellar* scintillation on a final exam in a course on radio astronomy, taught at Caltech by the late Peter Scheuer, she misread the question, calculated intergalactic scintillation, and showed that the amount of gas required did not exceed the Gunn-Peterson limit of the time (about 10:30 A.M. or 1966, again depending on your vantage point). The instructor, most broad-mindedly, concluded that it was really the same calculation he had wanted done and gave full credit. Luckily no marks were assigned for reading comprehension.

Gas of 10^5–10^6 K does not count as surprising in the Milky Way. Here it is the phase known from emission lines of O VI, made of old SNRs, heated by Sofue & Vogler (2001) and employed to confine high velocity clouds by Bruens et al. (2001).

In rich, X-ray emitting clusters of galaxies, however, 10^5–10^6 K is well below the temperature in equilibrium with the gravitational potential well and ought to be found only as part of cooling flows (below). Such gas has been proposed as the source of an excess of very soft X-rays and extreme ultraviolet photons coming from some clusters (Bonamente et al. 2001 during the index year, but also earlier). Dixon et al. (2001) counter that such gas cannot be present in Coma or Virgo, because it would emit more O VI than the *FUSE* limit. Maloney & Bland Hawthorn (2001) are even more contrary, saying that the EUV excesses must be some sort of calibration error rather than photons, which would ionize the neutral hydrogen in disk galaxies in the clusters, leading to more H-alpha emission than is seen. Both Dixon et al. and Maloney & Bland Hawthorn were starred, and eyes should be kept peeled (at all wavelengths from H-alpha to 0.25 keV) for the next salvo on this issue.

Cooling flows, in case you might have forgotten, are a long standing problem (Ap94, § 10) of the following sort. The cooling time of the X-ray gas in most of the volume of most clusters is a Hubble time or longer. But in some cores, it is a good deal less, so that anything from 1 to 1000 $M_\odot$/yr should be dropping down into cooler phases. There remains only sparse evidence for such gas, including extra X-ray absorption (Sanders et al. 2000), modest O VI emission consistent with the modest flow expected in one giant elliptical (Bregman et al. 2001) but not, for instance, X-ray emission lines at 1–2 keV that ought to be detectable in *XMM-Newton* (Fabian et al. 2001).

Not surprisingly, then, a good many theorists have turned their attention to preventing or at least reducing the flows. Candidate mechanisms include frequent disruption of the flows by galaxy mergers (Soker et al. 2001), additional pressure in support of the central gas provided by convection (Kritsuk et al. 2001; David et al. 2001), or (and this is our favorite) continuous reheating of the gas caused by interactions with WIMPs (Qin & Wu 2001). If you have looked at the page number of the reference and recoiled with horror, be assured that even today the creeping green of *Phys. Rev. Letters* does not run to more than 61,000 pages per volume. The new numbering scheme is one of the benefits of e-first publication.

8.4. The Re-ionizing Photons

Re-ionization is an honest description of what we think happened, since the gas was neutral for a good long while after $z \sim 1000$, unlike "recombination" as a label for what happened near $z = 1000$, since there is no reason to suppose that the gas had ever been neutral before. Atoms can be ionized by collisions having a center of mass energy in excess of their ionization potential or by photons, also with $E >$ I.P. Collisional ionization, in turn, can be divided between cases where the two particles have comparable kinetic energies in the rest frame of the fluid (that is, heating, sometimes in shocks) and those where one particle has most of the energy (cosmic-ray ionization).

All the papers we spotted in the index year considered only photoionization, by ultraviolet photons far out of equilibrium with the atoms being attacked (though of course photons at the gas temperature can be important in other contexts).

The main competitors are thus reduced to UV photons from first generation hot stars and ones from quasi-stellar objects. Oh (2001) has, however, proposed UV photons that have been Compton up-scattered from the microwave background by electrons accelerated in the first generation of supernovae. At least some collisional ionization must then also occur, but the author concludes that the photons win.

Even ignoring this variant, we do not find complete consensus on the dominant UV source. Scott et al. (2000) vote firmly for "all QSOs" apart from some extra ionization here and now ($z = 0$) and perhaps at $z \geq 4$. McDonald & Mirada-Escudé (2001) endorse QSOs at $z > 5$, but stars at lower z, while Bromm et al. (2001) say Population III stars of $M \geq 300\ M_{\odot}$ at $z > 6$. Steidel et al. (2001) favor stars (formed in Lyman break galaxies) all the way, at five to one (ratio of photons, not odds). Haehnelt et al. (2001) are also star people, no odds given.

Surely there ought to be some definitive signature that could distinguish the thermal photons of stars from the power-law photons of active nuclei. There is, but it requires measuring the degree of ionization of at least two species, at most one of which can be hydrogen. The reionization sequence is, necessarily (because of the IPs) H I → H II, He I → He II, He II → He III. But, Kriss et al. (2001) conclude that the ratio of He II to H I is such a signature (the total amounts of each element being known from nucleosynthesis calculations). They use *FUSE* data to find He II/H I = 1–1000 or more (by number) in a bunch of Lyman alpha forest clouds with $z = 2.3$–2.85. Calculations show that ratios less than 100 imply QSO ionization and larger ratios ionization by the softer photons of starbursts. And by now, from the lead up, you already know that the answer is (all together now, shout along with Pooh and the author of very little brain), "Both please!" That is, some clouds have been zapped by starlight and some by quasar light.

9. GAMMA-RAY BURSTERS

For nearly a quarter of a century, GRBs emitted only gamma rays and were widely supposed to be happening on the surfaces of relatively nearby neutron stars. Ap97 (§ 11) carried the news of the first X-ray and optical tails and redshifts, placing at least those events at cosmological distances. Year 2001 did not contain anything quite so overwhelming, but we do wish to confess having misjudged the beginnings of what now looks like a 1.5 "wow" highlight. Page 33 of the 1999 notebook records Piro et al. (1999) with the words "GRB 970508, *BeppoSAX*, Fe lines w/ energy z consistent w/ z of host = .835. Gory details, like hypernovae w/ goo around versus naked NSX2, 0.5 $M_{\odot}$ @ 3×10^{15} cm. L_x up & α up flatter @ ∼ .9 when Fe lines gone; significant?". This is verbatim, except that the word "up" was actually an arrow not available in the present type face. But the paper ended up on the cutting room floor of Ap99; and a similar report from Yoshida et al. (1999) never made it out of the collective citation, "GRB Workshop, Rome 3–6/11/98." This year, with three iron-bearing events in the database, they are clearly a "must."

9.1. Bursters and Supernovae

The underlying reason that additional data have raised the profile of this subject is that, if supernovae make iron (which most of us accept) and gamma-ray bursts make iron, then GRBs must have something to do with supernovae, and conversely. There is a catch to this. Iron has a habit of dominating X-ray spectra, and, until the recent era of high-precision X-ray spectroscopy, was also the first and sometimes the only element detected in spectra of X-ray binaries, clusters of galaxies, and so forth, without implying any closer connection to supernovae than is implied by the presence of heavy elements in general. The models associated with the 2001 data similar divide between "lots of iron" and "iron is always what you see."

First the data. GRB 990705 had a 3.8 keV absorption edge in its prompt X-ray emission, consistent with the K-shell of iron at $z = 0.86$ (Amati et al. 2000). The other events showed an emission feature in their after-glows, the iron equivalent of Lyman alpha or a combination feature: GRB 991216 at $z = 1.00$ (Piro et al. 2000), GRB 000214 at $z = 0.47$ (Antonelli et al. 2000), and, digging back into the archives, GRB 970828 (Yonetoku et al. 2001; Yoshida et al. 2001).

Now the simple, natural, straightforward interpretation of these observations is that there is a considerable amount of iron (0.1–1.0 $M_{\odot}$ perhaps) located about as far away from the business end of the GRB as the distance light or a highly relativistic jet can travel in hours to days. This is pointed out by most of the papers reporting the observations and also by Vietri et al. (2001), Ruffini et al. (2001), Lazzati et al. (2001), Boettcher & Fryer (2001), Rees & Meszaros (2000), and probably others, a subset of whom explicitly indicate that the most probable source of the iron is a supernova event in the same progenitors days to months before the GRB photons set out on their beamed journey.

However, Rees & Meszaros (also Meszaros & Rees 2001) point out that it is possible to get away with the very much smaller amount of iron—say $10^{-5}\ M_{\odot}$—that would already be present in the slow wind and envelope of the progenitor, just sitting there, waiting to be illuminated by post-burst wind or outflow. Indeed an earlier version of this (Meszaros & Rees 1998) can claim the status of a prediction. In this case, there is no need for a visible (or even invisible) supernova at about the same time and place as the GRB.

Finally, as we go to keyboard, it must be confessed that SN

1998bw = GRB 980425 remains unique, and fairly tight limits can be set on a supernova contribution to the fading light of a couple of GRBs near $z = 0.4$. It remains true, of course, that all GRB events to date with counterparts, redshifts, magnetar models, and all are of the long-duration variety. Last year, we nearly promised you (Ap00, § 9.2) that events localized by *HETE-II* would include some of the ones lasting less than a second. This hasn't really happened, and we can only hope that *SWIFT* is launched SWIFTly and without the obvious accompanying Tom Swifty ("My rocket blew up," Tom said explosively.). It is scheduled for 2003, which typically comes sometime in 2004.

9.2. GRB Hosts

That (some of) the gamma-ray bursts of relatively long duration occur in galaxies was a highlight of Ap97 (§ 11). Numbers of hosted bursts and papers per host have climbed, inviting statements about classes, statistics, error bars, and environments. The generic host description is "star forming galaxies with luminosity less than $L*$ [the break in the Schechter luminosity function]" (Castro-Tirado et al. 2001; Holland et al. 2001; Sokolov et al. 2001; Vreeswijk et al. 2001).

There are, however, a number of qualifications in order. First, estimates of star formation rate in $M_\odot$/yr are no more certain in this context than in others (§ 11). Thus the $z = 0.706$ host of GRB 991208 is credited with 100 $M_\odot$/yr by Sokolov et al. (2001) and only 11.5 $M_\odot$/yr by Castro-Tirado et al. (2001). Second, the galaxy isn't always seen. Smette et al. (2001) say that the host of GRB 000301C must be rather like the entities producing damped Lyman alpha absorption lines in QSO spectra—no visible galaxy, but more than 10^{18} H atoms/cm^2. It may or may not be relevant that this is, at 2 sec, the shortest duration GRB so far caught with an optical afterglow (Jensen et al. 2001). The redshift was about 2.

Third, the rate of star formation isn't necessarily more than is found in field galaxies at the same redshift (Bloom et al. 2001 on GRB 970228, the grandfather of them all). Fourth, GRB 970508 went off less than 70 pc from the nucleus of its host galaxy (Fruchter et al. 2000), but many are outliers. And, fifth, the immediate environments of the events cannot all be the same, if the models of afterglows are being properly transformed into ambient density. Ap00 (§ 9.2) noted some for which the surrounding gas was like our local ISM or even more tenuous, while GRB 000926 seems to have lived in a molecular cloud or large circumstellar shroud of about 4×10^4 H/cm^3 (Piro et al. 2001).

9.3. Statistical Issues

Where are we on correlations of GRB properties? Not obviously any place one would want to remain for long periods. There are, for instance, correlations of variability and spectra with both peak flux and total flux (Reichart et al. 2001; Ramirez-Ruiz & Merloni 2001), assuming isotropy and all. Modelling these, however, requires a mix of intrinsic and cosmological effects (Lee et al. 2000), thus at most one of peak and total flux can be a standard or standardizable candle.

Total luminosity and extent of beaming are inseparable, at least as long as you have only gamma-ray data, and Schmidt (2001) points out that the difference in values of V/V_{max} for the hardest versus the softest sources could be explained by the hardest ones being either 20 times as bright or 20 times as tightly beamed as the softest events. Many pundits now agree that, when you correct for beaming, the total energy involved in each GRB is something $\times 10^{51}$ ergs, an approximate constant. Unfortunately, the clearest pundits (is this an oxymoron?) were still in transit from xxx at Los Alamos to arXiv at Cornell at the end of the reference years. In any case, the cone angles (meaning those into which the sources are beamed, not the pointedness of the pundits heads) vary over a wide range.

An archeological expedition down into burst events recorded by BATSE but not quite bright enough to trigger instant attention has augmented a 6-year supply of 1820 by another 873, plus 50 events of unknown origin recorded only in the 20–50 keV band (Kommers et al. 2001). You might be tempted to call these X-ray bursts, but the name is already taken.

Our favorite burst statistic (two tails and a Student) of the year is that the ratio of GRBs to Type II supernovae is 10^{-6} (Porciani & Madau 2001). This is, as you may have deduced, not an observation but a calculation based on simulation of stellar populations in galaxies. If you would like an observed ratio for comparison, it is probably a bit inefficient to keep your eagle telescope[13] trained on galaxies known to have had supernovae in them, watching for GRBs, but there might be some sense to a close watch for supernovae in known GRB hosts.

9.4. Energy Sources

The gamma-ray energy per event, if they are isotropic, is $3–20 \times 10^{51}$ ergs or thereabouts, and the total could be larger by an order of magnitude (Rhoads & Fruchter 2001). The beaming buys you back a factor of 10–100, at the price of needing correspondingly more events per galaxy per eon to match observations.

Where does it all (however much "all" may be) come from? Received opinion remains centered around collapse of massive, rapidly rotating stars (perhaps with companions) to rapidly rotating, highly magnetized black holes, for the long-duration events with multi-wavelength afterglows, and mergers (NS $\times$ 2 or NS + BH) for the short duration sort so far lacking counterparts (Narayan et al. 2001; MacFadyen et al. 2001). But

[13] This was meant to suggest a parallel with eagle eye, but somehow sounds more like a telescope to be used only for observing eagles. Remember the Blue Seal Laundry and the Doberman Pincher, of whom there are none in the Orange County phone book. We mean no people named Doberman, not dogs, though there aren't any dogs in the Orange County phone directory either. Oh never mind.

the subject has not yet solidified to the point where dissidents have been exiled to outer ApSSolia, and you are entitled to consider the following alternatives: (1) delayed collapse of a differentially rotating neutron star (Shapiro 2000), (2) energy extraction from a Kerr black hole with a plasma torus by the Blandford-Znajek process (Li 2000), (3) collapse of an ONeMg white dwarf to a neutron star with transiently very large magnetic field and millisecond rotation (Ruderman et al. 2000), (4) a star disrupted by a 10^6 $M_\odot$ black hole (Cheng & Lu 2001), and (5) our favorite, at 2.5 "Oh?'s" and an X-ray tail, collapse of a quantum electrodynamic magnetized vacuum bubble around a neutron star with a field of 10^{15}–10^{16} G, analogous with sonoluminescence (Gnedin & Kiikov 2000).

Looking ahead, the review of gamma-ray bursters, especially theoretical considerations, by Meszaros (2002) will carry the story somewhat ahead of this snapshot in, of course, much greater detail.

10. AT LEAST AS BLACK AS HE'S PAINTED

We explore here a subset of the black holes found in the 2001 literature. All exploration has been done from outside.

10.1. Sagittarius A*

The starred paper on this topic appeared at the very beginning of the fiscal year and on page 1 of the notebook. It is the observation of curvature (that is acceleration) in the motions of a few stars in the immediate vicinity of the center of the Milky Way (Ghez et al. 2000; Kormendy 2000). The largest stellar velocities reach 1350 km/sec, and even a cluster of stellar mass neutron stars or black holes or a neutrino ball would not be compact enough to fit into the volume allowed by the observations. This leaves as the only possible alternative a single compact mass of about 2.5×10^6 $M_\odot$, occupying a space not much larger than the Schwarzschild radius for that mass. This is, within the astronomical meaning of the term, a black hole.

And staring back from the other end of the year comes X-ray flaring on time scales as short as 10 minutes (a *Chandra* result; Baganoff et al. 2001; Melia 2001). This draws the noose even tighter, to $r \approx 1$ AU, on the causality principle that flux varying on time scale t must come from $r \leq ct$, unless the source has a component moving almost directly toward us along the line of sight.

Modern astronomers are an ungrateful lot. Not content with having our own black hole, we complain and conjecture because it is so very much fainter (in units of the Eddington luminosity) than the black holes of other galaxies. The basic choices are (*a*) not much falls in all the way or (*b*) lots falls in but the energy goes with it. The latter is called ADAF (advection-dominated accretion flow), and the former is clearly ripe for acronymization. We offer Mostly Just Accretion/Very Little Turbulence as a candidate. The year 2001 votes went largely to (*a*).

Coker (2001) suggested that the mechanism is gas piling up outside Sgr A* for the last thousand years. This is not a stable situation, and the author predicts that low frequency emission will start to increase in a few decades (followed, presumably, by higher frequencies). Sakamoto et al. (2001) noted similar situations in M81, which also has gas hung up on a ring about 300 pc from its nucleus, and which is also faint at about 2×10^{40} erg/sec. It may or may not answer to M81*. Liu & Melia (2001) compared the conditions at the cores of the Milky Way and M31 (another shrinking violet of a galactic nucleus) and concluded that both have piled up gas and that many of the differences between the two (e.g., the much larger ratio of radio to X-ray luminosity in the Milky Way) can be explained by different temperatures for the piled up gas, 10^{10} K for Sgr A* and 10^4 K for M31*.

Quataert & Gruzinov (2000) proposed a polarization signature (of about 10% at 150–400 GHz) for the limited-infall explanation, which has perhaps been seen (Aitken et al. 2000). Does this mean that ADAF will never again darken the (published) doors of Sgr A*? Probably not. Astronomers are not only ungrateful but persistent.

10.2. BHXRBs and Micro-Quasars

We declared unilaterally several years ago that these are "black hole X-ray binaries" not just "black hole candidates" (a term which should be reserved for your favorite politician), on the same grounds that the Milky Way can be said to have a central black hole. There is a compact component, with size not much larger than its Schwarzschild radius, too massive to be a neutron star. Additional evidence for something sufficiently black to have a horizon into which mass-energy disappears has, in past years, been adduced from advection-dominated accretion flow. This year, Dolan (2001) pointed to another sort of evidence for a horizon, in the form of a dying train of optical pulses from Cygnus X-1, representing perhaps an emitting blob spiralling down and in. The *HST* observations date from 1992, but this is a short interval compared to the lifetime of the black hole. Garcia et al. (2001) note that BHXRBs tend to be fainter in quiescence that neutron star XRBs and that this is probably also an effect of the horizon.

The starred BHXRB paper is a measurement of the angular momentum of the BHXRB called (only of course by its oldest friends) GRO J1655−40. Strohmayer (2001) has observed a second quasi-periodic oscillation (QPO) frequency at 450 Hz, along with the previously known one at about 300 Hz. Now, the mass of the compact object (determined in the usual way from the binary orbit) is in the range 5.5–7.9 $M_\odot$, and an orbit period as short as $P = 2.2$ msec is possible for this mass only if the orbiting material can be closer in than the $R = 3GM/c^2$ that is the last stable orbit for a Schwarzschild black hole. This is possible for a rotating (Kerr) black hole, and the measured mass plus orbit period lead to a lower limit on the angular momentum of the black hole $a = 0.15$–0.5, in the dimensionless units where $a = 1$ is a naked singularity. The units are $a = Jc/GM^2$, where J is the angular momentum in conventional (cgs) units and the ratio is dimensionless (we checked). In these units, the horizon is at $r = M^2 + (M^2 - a^2)^{1/2}$, and the angular frequency in the last stable orbit is given by

$$\Omega = \frac{M^{1/2}}{M^{3/2} + aM^{1/2}}.$$

Abramowicz & Kluzniak (2001), looking at Strohmayer's data, deduce a slightly looser limit of $a > 0.2$–0.67. The limit turns into an equality if the material emitting the QPOs is actually on the last stable orbit about to take the plunge.

In contrast to our broad church view of the use of BHXRB (vs. candidates) is a narrower one that the term "microquasar" should be restricted to sources that display (apparent!) superluminal velocities. This makes them a subset of the BHXRBs, just as ordinary quasars are a subset of the galaxies with active black holes at their centers. Under this definition, there have been for many years precisely two microquasars (Ap94, § 5.4). Two and a half points (half a star), therefore, to Orosz et al. (2001) for a reanalysis of optical observations of SAX J1819.3−2525 (=V4641 Sgr) and its evolved B companion. Their revised distance is 7.4–12.3 kpc and, therefore, the previously measured proper motion of its radio jet (Hjellming et al. 2000, out of period, but we miss him!) corresponds to a pseudo-velocity on the plane of the sky of 9.5c.

The other half star belongs to Fomalont et al. (2001) for the jet proper motion at $v/c = 0.45$ in Sco X-1, well and truly a neutron star, and to Massi et al. (2001) for a very similar $v/c \approx 0.4$ radio jet velocity in LS I +61°303, another neutron star XRB, though a less famous one. Thus, for the moment at least, the sub/superluminal cut at least keeps out the neutron stars, and thus the microquasar inventory is now three. At 10^3, the collection presumably becomes a milliquasar. It will take a while to accumulate these. M82, for instance, has just revealed a handful of BHXRBs in its *Chandra* images (Griffiths et al. 2000). Proper motions of associated radio jets (expanding at c for a year or so) would be within the angular capability of VLBI, but we think the jets will be too faint.

No symbolic stars this year for the other 7-year-old μQSO, GRS J1915 + 105, but (*a*) Zdziarski et al. (2001) have fit the broad-band X-ray spectrum with a more physically-motivated model than is typical and (*b*) Greiner et al. (2001) report having seen the companion star via the absorption band heads of $C^{12}O$ and $C^{13}O$. The star is a K–M giant (seen only in infrared). The system affects its environment in somewhat the same way that SS 433 affects its (Chaty et al. 2001; Ostrowski & Fuerst 2001). And somewhere in there is a quasi-periodic ejector (keep it clean guys), which tossed out radio and IR-emitting stuff about every 20 minutes, more than 700 times over 10 days (Fender & Pooley 2000). Our gloss on this is that, because J1915 is surely not a binary black hole and 20 minutes is not its orbit period, this observation casts some doubts on a binary black hole interpretation for the 12-year periodicity of blazar OJ 287. If the physics scales, it will take 700 × 12 or 8500 years to see whether the festivities come to a similar end (and you can expect to read the answer in Astrophysics in 10,401, which on present model, will occupy roughly 10^{504} pages of volume 10,515 of the *Publications of the Astronomical Society in the Pacific*).

XTE J1118+480, the first BHXRB in the galactic halo (with $Z = 1.7$ kpc and a compact mass in excess of 6 $M_\odot$; Wagner et al. 2001), was going to be a first on the cutting room floor, until Mirabel et al. (2001) pointed out that it is not a runaway star from the disk (and § 5), but a native haloian.[14] Thus it gets a star with two points for belonging to Population II.

10.3. Black Holes of Intermediate Mass

"Intermediate" in this context means between the sorts found in X-ray binaries, which have masses of 6–10 $M_\odot$ and might plausibly be the remains of single massive stars and the sorts found in galactic nuclei, which have masses of 10^6 $M_\odot$ or more and are probably assembled from smaller ones somehow. The case for the intermediate class is made very clearly by Fabbiano et al. (2001). If the brighter, off-center sources recorded in *Chandra* images of NGC 4038/39 (the Antennae) are isotropic and not brighter than their Eddington luminosities, then the underlying masses are at least 10–300 $M_\odot$ for the several sources. Actually there is one further caveat: the images must be resolving individual sources.

Much the same case can be made for compact bright sources in the Circinus galaxy, which is nearby despite its M-lessness (Bauer et al. 2001). In M82, the most massive (on the same assumptions) is at least 460–700 $M_\odot$ (Matsumoto et al. 2001; Matsushita et al. 2000) and less than 10^5–10^6 $M_\odot$ or dynamical friction would have carried it on in (Kaaret et al. 2001). Watarai et al. (2001) present some others.

Of course there are contrary votes. We wouldn't be scientists without Alternative Hypotheses to test. Angelini et al. (2001) focus on a specific source located in a globular cluster of NGC 1399 and suggest that it may be an unresolved group of LMXRBs each with a stellar-mass primary. Another specific case is the source in NGC 5264, for which Roberts et al. (2001) provide an optical identification with an O star, plus the idea that the now-collapsed members should have been more massive than the secondary, but not enormously so. King et al. (2001b) take on the whole class, suggesting that they are a beamed (into 1%–10% of 4π steradians) and short-lived phase of BHXRBs with the usual 6–10 $M_\odot$ accretors.

We hardly need assure you that it is not necessary to doubt the existence of the IMAXRBs on the ground that theorists can't figure out how to form them. For M82, Matsushita et al. (2000) suggest mergers of ordinary stellar-mass black holes left from the starbursts whose waning we now see. Madau & Rees

[14] Haloite? Haloer? We are still struggling with this problem of finding an algorithm for nouns indicating birth or residence in particular places.

(2001) regard the hole class as Population III relicts that have been gradually migrating toward the cores of their galaxies and will eventually merge with the massive black holes there. Some of each is, of course, also perfectly OK, as is the thought that many $L = 10^{38}$–10^{40} erg/sec X-ray sources can be powered by intermediate mass black holes without them all having to be like that. We also wouldn't be astronomers without two or more classes of everything.

10.4. The Black Hole Bulge Connection

Progress in tracing out and understanding the fixed(?) ratio of mass in the bulges and spheroids of galaxies to that in central black holes has been at best modest, though not for lack of trying. Even with the "wow" barrier to notebook entry, 22 papers ended up in the BH/bulge category, despite which, we can really only echo the conclusions laid out in Ap00, § 11.1.

- There is such a correlation, with $M(\mathrm{BH})/M(\mathrm{bulge}) \approx 10^{-3}$ (Gebhardt et al. 2000; Merritt & Ferrarese 2001b).
- It has real noise (Sarzi et al. 2001).
- A correlation also appears in active galaxies (Nelson 2000; Ferrarese et al. 2001), but the ratio varies with flavor of activity, among quasars, broad and narrow line Seyferts, radio galaxies, and such (Czerny et al. 2001; Mathur et al. 2001).
- Late-type spirals are different, in the shapes of their bulges (Graham 2001), in how these were formed (Abraham & Merrifield 2000; Prugniel et al. 2001; Hammer et al. 2001), and in the correlation (Laor 2001; Merritt et al. 2001).
- All or most of the black holes have luminosities considerably less than the Eddington limit if the masses extracted from reverberation mapping are correct (McLeod & McLeod 2001; Marconi et al. 2001), and, a fortiori, for those whose luminosities are too small to permit reverberation mapping.
- Models abound, some best suited to universes in which galaxies arise out of monolithic collapse and others to universes where mergers dominate galaxy formation (cf. §§ 11.3, 7.1).

Now, how do we form thee? Let us count the ways. Burkert & Silk (2001) say that the bulge stars were made in a self-gravitating disk around the black hole, and Najita et al. (2000) concur that observations of a particular BAL QSO imply that the BH got there first. Bekki & Couch (2001) on the other hand start with super-star-clusters (of the sort seen by *HST* to be very luminous infrared sources), whose mergers and devolution via dynamical friction co-produce the black hole and bulge. In that context, it is notable that a seed black hole in even just a small fraction of the "galaxy parts" at large redshift will result in one per galaxy now (Menou et al. 2001b). Ciotti & van Albada (2001) is another merger model and Adams et al. (2001) a monolithic collapse. Haehnelt & Kaufmann (2000) would like some of each, for black holes larger and smaller than $10^6\ M_\odot$. And somewhere in here we ought to mention that the correlations look better if you use velocity dispersion rather than luminosity as the indicator of bulge mass (Merritt & Ferrarese 2001a), but presumably this would be true for either formation mode.

Just how much blackness is there in the world? If all galaxies were average, the sum would be a local density of $5 \times 10^5\ M_\odot/\mathrm{Mpc}^3$ in black holes, according to Merritt & Ferrarese 2001b). Strangely, this is not very different from the supply at $z = 2$ as calculated from the luminosity density in active galactic nuclei, though one would have supposed that most of the detectable (accreting) BHs would have grown a factor of two or thereabouts in the interim. Something like half a tail, bent into the shape of a question mark for this one.

10.5. Black Holes on Active Duty

You can't have a review of astronomical highlights without mentioning quasars and all the rest, so here they are.

10.5.1. Oddities

Most sections reserve the items that puzzled us for the end. Here, they come at the beginning, and all are, in some sense, statistical. Benitez et al. (2001) find, not by any means for the first time, more correlation on the sky of QSOs with foreground galaxies than can be attributed to weak lensing, while Cappi et al. (2001) report an excess of faint *Chandra* X-ray sources around two clusters of galaxies near $z = 0.5$. They conclude that extensions of the clusters are more likely to be responsible than is lensing.

Arp (2001) expects such correlations and presents an additional set, involving ultra-luminous infrared galaxies and dust, gas, X-ray emitting material, and QSOs, which he describes as ejecta from the ULIRGs with ejecta redshifts that decline as they move out and age. Some clusters of galaxies are also characterized as the fragmented, aged products of such ejection (Arp & Russell 2001).

Arguably related (though it is not entirely clear how) are the redshifts of a new sample of extra-galactic objects, which Burbidge & Napier (2001) find are quantized with a period of 0.089 in $\log (1 + z)$. Hawkins (2001) reports that there is no evidence for time dilation in the variability of an assortment of QSOs (meaning no correlation of time scale with redshift). This could be put forward as evidence for non-cosmological redshifts, though the author himself prefers an explanation in which the variability is caused by microlensing and the absence of correlation caused by all the lenses being quite close to us.

At this point, you may (or may not) want to second the star we attached to a paper by Richards et al. (2001). They report redshifts for 2625 QSOs, distributed in a way that indicates the QSOs form a continuum with the Seyfert galaxies, along which the variable is degree of domination of the host galaxy by nuclear light. Just, in other words, what the conventional wisdom lead you to expect. Summing the spectra of most of those to get a composite revealed more than 80 emission lines (VandenBerk et al. 2001). We remember when there were three, Mg II, C IV, and Lyman alpha. Both papers come from commissioning data of the Sloan Digital Sky Survey. The latest QSO catalog tabulates 23,760 (Veron-Cetty & Veron 2001), but the number is clearly destined to grow by another order of magnitude or more fairly soon. We also remember when there were nine.

10.5.2. Half of All Three-Sigma Results Are Wrong

The topics addressed here include (*a*) unification, (*b*) host galaxies, (*c*) evolution, and (*d*) BAL quasars. All of these words are somewhere between technical terms and secret code, do not mean exactly what a reasonable, uninitiated reader would suppose, and are somewhat more interesting than they sound. The section title is a joke, which we first heard from Fred Reines, and means simply that systematic errors are very often larger than random ones. But be careful who you share it with. We tried on a particle physicist this year at a conference where not everyone knew everyone else and were forced to endure a lecture on the statistics of normal distributions that would have left the Gausst of Ghass Aghoost. Oh the hell with it.

Unification is an intrinsically statistical idea—that active galaxies have relativistic jets that can be oriented any old way in space with equal probability, and what we see depends a good deal on the angle between the jet and our sight line. Lister et al. (2001, who have some new space VLBI data) say the concept accounts for many of the correlations they see among core strength, polarization, variability, and so forth, while Fernini (2001) says that radio polarization data disfavor an orientation connection between radio galaxies and quasars. "Type II" or "Type 2" in this connection means a jet which is aimed roughly in the plane of the sky by a torus that therefore obscures our view of the active nucleus. The phenomenon is well established among Seyfert galaxies (Levenson et al. 2001), except for the sort that are really just bursts of star formation (Gu et al. 2001). Type II QSOs (Crawford et al. 2001; Matt et al. 2000) and even Type II blazars (Ma & Wills 2001) at least exist this year, though earlier increments of Apxx have reported both no and yes. But the prediction that there should be half as many of them as there are of unobscured QSOs (Maiolino et al. 2001a) disagrees with observations at any confidence level you choose. QSO unification of a different sort is presented by Elvis (2000), who has in mind accelerated gas outflow in the shape of a funnel (cylinder plus cone) as the source of the full range of emission and absorption features (broad, narrow, associated, and all) that the sources inflict upon their own photons.

Hosts of active galactic nuclei might or might not differ from the general run of galaxies. They do, but not by much, according to the various votes we counted this year.

• Radio galaxies are selected at random from normal giant ellipticals, apart from favoring the bright ones (Scarpa & Urry 2001; Impey & Petry 2001).

• Ditto for both radio-loud and radio-quiet AGNs, including presence in a full range of environments, from groups to rich clusters, at moderate redshift (McLure & Dunlop 2001; Wold et al. 2001, though with a contrary vote in favor of dense environments from Finn et al. 2001).

• Honest hosts of both radio-loud and radio-quiet QSOs and radio galaxies are ellipticals or S0s, dominated by very old stars (Nolan et al. 2001) and ditto for blazars (Falomo et al. 2000, who remark, however, on an excess of hosts with companions, and a vote for some disk galaxies from Percival et al. 2001).

• The evolutionary sequence of radio sources from those with spectra peaking in the Gigahertz range, to compact steep spectrum, to Fanaroff-Riley II is one of the radio-emitting material only, while the host types abide (de Vries et al. 2000). Incidentally, it is not necessary to remember precisely what GHP, CSS, and F-R II sources are to catch the point of this.

• QSOs are also clustered pretty much like other galaxies at the same redshift from $z = 0.7$ to 2.4, another 2dF result (Croom et al. 2001).

A star and garter, however, for Ridgway et al. (2001), who conclude that the hosts of radio-quiet QSOs at $z = 2$–3 are less luminous than nearby ones. This would be so strange as an effect of observational selection that we opine it must represent "evolution."

Evolution, in the quasar context, is a code word meaning "there were more of them in the past." (The opposite is anti-evolution.) Long ago, the burning issue was whether we saw more sources at large *z* because the sources had been on average brighter (luminosity evolution) or on average more numerous (density evolution). If the population happens to have a power-law distribution of radio luminosities, $N(L_r) = N_o \times (L_r/L_{ro})^{-x}$, no counting of sources will ever distinguish these cases. This does not, however, mean that there is no physical difference.

"Density evolution" implies that nearly every large galaxy is likely to have had an AGN in its past, while "luminosity evolution" implies that a few brave sources have endured, though fading, for a Hubble time and can be expected to have very big black holes by now, with none in the other galaxies. Every galaxy should have its black hole in the case of density evolution, as indeed seems to be the case, but we've warned you before about affirming the consequent. Boyle et al. (2000) have come out in favor of "pure luminosity evolution" for the 6000 QSOs in their southern, 2dF redshift sample. Martini & Weinberg (2001), on the other hand, deduce short lifetimes of 10^6–10^8 yr for bright QSOs, which would imply density evolution.

Significant density evolution is also implicit in the conclusion by Willott et al. (2001a) that bright radio sources (quasars) have evolved more (i.e., were even more numerous at large redshift) than fainter radio galaxies. One of their source catalogs is called 3CRR (meaning Third Cambridge Revised Revised), and the bright/faint distinction was already discerned by early examiners of 3C. Some of the same people (Willott et al. 2001b), looking at the Seventh Cambridge Catalogue (apparently unrevised), opine that AGNs are active twice in their lives, first when the central black hole forms and later when fueled again, perhaps by a cooling flow (Cattaneo 2001). This initially went into our notebook as the somewhat improper sounding "typical AGN does it twice."

Broad absorption lines are broader than the quantum mechanical damping width (those are called damped Lyman alpha systems) and occur at redshifts close to the emission redshift of the QSO. They are to be found in 15%–20% of radio-quiet ones, and, it was long thought, in 0% of radio-loud quasars (implying something more than just the effect of partial coverage of the core by the absorbing clouds). That percentage is no longer zero (Gregg et al. 2000 on FIRST J161614.3+530916, which is an authentic F-R II, that is, a strong, extended source). But the BAL fraction does decline monotonically with radio luminosity, somewhat differently for those with ions of large and small ionization potential producing the lines (Becker et al. 2001b, some more of the FIRST catalog results). We particularly like the complete set of optical spectra shown in this paper, allowing the untrusting reader to see for herself what the authors mean by "broad" (some more so than others, this one concluded). The authors also point out that still larger complete samples of assorted AGNs are needed to shrink the error bars on correlations like that of radio luminosity with BALnicity, in order to trace out very large scale structure and streaming with them, to count numbers of damped Lyman alpha clouds versus redshift (i.e., locate the baryons currently floating around § 8.3), and to decide the relative importance of true binary QSOs versus lensed pairs. For instance, the sample of 13,213 objects catalogued by Zhdanov & Surdej (2001) includes all of 11 confirmed physical pairs. They don't show all the spectra.

"*Six of one and half a dozen of the other*," or, "some of them are and some of them aren't" are answers from the radio version of *20 Questions* (which we were allowed to stay up until 8:30 to hear if we had been very good), meaning, in this context, a few last AGN factoids that sound more or less statistical.

One to three percent of field galaxies have active nuclei (Sarajedini et al. 2000). A range of 4–5 orders of magnitude in radio luminosity can be fit by jets with bulk gammas in the narrow range 3–10 say Giovannini et al. (2001), but the sources that also emit gamma rays are, on average, faster (Jorstad et al. 2001).

10.5.3. The Other Half

No, we don't exactly mean that these results are more right than those of the preceding section, but only that they are not (primarily) issues of correlations, complete sampling, and such.

Do all active galactic nuclei center around black holes? Yes, if that is part of your definition, and just about unavoidably in the case of the gamma-ray emitters, whose brightness varies in an hour or so (Xie et al. 2001), on the same "too compact to be anything else" grounds that apply to Sgr A* and the BHXRBs. Indeed two black holes each in the radio-loud ones, say Britzen et al. (2001). And no, in the case of Arp 220, once also claimed as a binary black hole, but, this year, described as containing merely hot spots of star formation and orbit crowding (Eckart & Downes 2001).

Which radiation mechanisms produce most of the photons; and (when it is synchrotron) are the energy densities in magnetic fields and relativistic particles roughly equal? Most of the relevant 2001 observations come from the *Chandra* X-ray satellite (which we still wish had been grandfather-acronymed as *AXAF* by calling it the *Asimov X-ray Astronomy Facility*). In the longest X-ray jet yet seen, PKS 0637−753, either synchrotron self-Compton emission or inverse Compton scattering of 3 K photons will work (Schwartz et al. 2000). Sambruna et al. (2001) opt for C^{-1} for the jet of 3C 273, while Pesce et al. (2001) prefer electron synchrotron for the X-ray jet of 3C 271. 3C 295 seems to present another combination—inverse Compton processing of softer photons that started out in the galactic nucleus (Brunetti et al. 2001).

On the equipartition issue, Leahy & Gizani (2001) deduce a magnetic field less than the equipartition (≈minimum total energy) value for the jet of 3C 288 and also a flux of kinetic energy in excess of the total photon luminosity. On the other hand, field strengths close to equipartition can be derived from the combination of radio and X-ray observations of the extended lobes of a couple of well-known radio galaxies, assuming that the X-rays are C^{-1} scattering of CMB photons. Tashiro et al. (2001) derive 3×10^{-5} G for Fornax A, observed with *ASCA*; and Wilson et al. (2000) find 1.5×10^{-4} G for the hotspots in the lobes of Cygnus A (a *Chandra* result). The stronger field is presumably part of what makes the hot spots hot.

We wrap up this section with a few of our favorite small whole numbers. There are five X-ray core sources in galaxies of the Local Group. In order of descending luminosity, they live in M33, M32, M31, WLM, and the Milky Way (Zang & Meurs 2001), and we refuse to believe that the correlation with M number is significant. The authors conclude that a certain minimum optical luminosity is required for such mini-AGNs to form, though there are no data in their set for the Magellanic Clouds, and NGC 6822 has a comparably bright, but off-center source, presumably an XRB.

The four components of the lensed QSO 2237+0305 (called the Einstein cross and other things) all vary in the OGLE database (Shalyapin 2000). The author believes that the source is currently crossing a caustic of the microlens.

Three kinds of disk instabilities contribute to the variability of AGNs. They are called gravitational, magnetorotation (Balbus-Hawley), and ionization (dwarf nova). Of these, the dwarf nova instability is the least important, say Menou & Quataert (2001). It is, we think, more important in dwarf novae and, indeed, low-mass X-ray binaries (Lasota 2001). We also think we understand it, at least on Tuesdays and Thursdays, which is two more days per week than for the others.

At least one example of two things going on at once is to be found in 3C 236, a star formation episode and strong radio emission (O'Dea et al. 2001). Both are encouraged by a supply of gas to the nucleus. Less than one is the average number of 3C radio sources in nearby ($z = 0.016$–0.022) Abell clusters, but if you count all the faint sources, the Perseus cluster has 43 (Miller & Owen 2001). The brightest is Perseus A, also of course a 3C source. So many of these have appeared in this section that we feel we ought to say something nice about the number 3 (I think that I shall never see, A number lovelier than three), or Cambridge (but while there the less acculturated author flunked napkin rings), or the compilers (they were radio astronomers).

11. GALAXIES

It has been a good many years since galaxies were in truth "the building blocks," "basic units," or "smallest isolated entities" in an evolving universe, though we would bet our money on the bob tailed nag that a good many lecturers and some Astronomy One textbooks still say it. The present section touches on an assortment of questions and answers about galaxies, including our own, some of which pertain to this absence of isolationism.

11.1. The Milky Way

Several inputting colleagues (keep it clean guys) mentioned among the highlights of the academic year the increasing resolution into sources of the X-ray background at various energies. Thus we were naturally attracted by a converse case, where *Chandra* imaging of the ridge of X-ray emission along the Galactic plane has found it obstinately diffuse (Ebisawa et al. 2001). Sugizaki et al. (2001) note that this was also so in the *ASCA* database, where most of the sources along the ridge are extra-galactic and anyhow add up to only 10% of the total. Sekimoto et al. (2000) point out that shocks around giant molecular clouds are also not the dominant component in the *ASCA* emission. If you find it difficult to get excited about this (we did for a while), keep in mind that if the emission is truly diffuse, then the energy content of the gas is at least 10 times that of any other component of the galactic interstellar medium. A small bouquet of ideas has come from Mokai (2001; many dwarf novae), Koyoma (2001; many old supernova remnants), Makashima (2001; energy drawn from galactic rotation via the reconnection of magnetic fields), and Valina (2001; low energy cosmic rays ionizing heavy atoms whose recombination photons we see). This last, at least, would seem to predict associated emission lines and edges.

Hopping to the other end of the electromagnetic spectrum, we find another mild surprise in radio maps that extend down to 0.2 MHz (Dulk et al. 2001; Manning & Dulk 2001). A moment's consideration will persuade you that these must come from above the Earth's atmosphere—WAVES on WIND, in fact, which naturally leads one to fear breakers ahead. At frequencies larger than 3.6 MHz, the galaxy is brightest at the equator (known to Jansky and Reber), and at 3.6 MHz, the sky is isotropic. But at frequencies less than 2–3 MHz, the poles are the brightest part of the sky. The data do not begin to admit of resolving this into sources, but presumably the explanation is extra-galactic emission, less absorbed in the polar directions than in the Galactic plane.

Just what you would expect, in contrast, are the relative ages of the stellar populations of the Milky Way, at least in the case of a classic, monotonic collapse (§ 12.3), though this is no longer widely supposed to be the right answer. Liu & Chaboyer (2000) report 12.5 ± 1.5 Gyr for the halo, 9.7 ± 0.6 Gyr for the thick disk, and 7.5 ± 0.7 Gyr for the oldest stars of the thin disk. The relative ages are, as always, better established than the absolute ones.

11.2. Dwarf Galaxies

These are the commonest sort in the universe, though still not so numerous as theorists (are they never satisfied?) of formation expect, by factors of 10 or more, for instance about 10 satellites belonging to the Milky Way, rather than many hundreds. The index year included several examples of "many" and of "why not so many." There are lots of dwarf galaxies in the Doradus group (Carrasco et al. 2001), in the Fornax group (Drinkwater et al. 2001), and in the Leo I group (Flint et al. 2001), though rather fewer in the UMa cluster, for which the authors (Trentham et al. 2001) of course have an explanation.

None of these luminosity functions extends faint enough to reveal the presence or absence of most of the analogs of the "disappeared 1000" of the Local Group, which, say Bullock et al. (2001), have simply been torn up to make our halo. Confirmation could come from further studies of dynamical substructure in said halo. The tearing up part is happening right now to the dSph in Sagittarius, without even telling us whether the poor thing has its own dark halo (Helmi & White 2001).

In other, seemingly circular, relationships, Bekki et al. (2001) have found a new class of galaxy, the ultracompact dwarfs, which they say are the stripped cores of nucleated dwarf ellipticals (current sizes around 100 pc and $M_B = -11$ to -13), but, alternatively, some of the large globular clusters are those cores (Meylan et al. 2001) and the galaxies have nuclei in the first place because of having engulfed their own globular clusters (Lotz et al. 2001).

11.3. Baby, You're the Top: Formation of Galaxies

For a number of years, we and the papers cited have been asking and answering (discordantly) a question of the general form, "Does the formation of galaxies and other structures begin with little things (meaning $10^8\ M_\odot$ or less) in a scenario called bottom up or hierarchical, or with big things (meaning cluster-sized entities or more) in a scenario called top down, monolithic, or Eggen, Lynden-Bell, & Sandage (1962)?" This was arguably a well posed question with a potentially definitive answer for as long as the universe was though to be made mostly of baryons (plus photons and neutrinos) and the dominant process was the conversion of gas to stars. The search for protogalaxies, undergoing a single, major, early burst of star formation was part of that picture.

We now suspect that we (and perhaps others) have been asking the wrong question, though many of the answers may well still be right. If, as is now very generally accepted, most of the density of the universe is in assorted forms of dark matter, in which inhomogeneities develop for baryons to flow into later, then it is entirely possible for the underlying potential wells to grow in a bottom-up pattern (e.g., Fuller & Couchman 2000), while most of the star formation is deferred until the wells have grown to modern galaxy masses and the gas can experience a monolithic collapse (Binney et al. 2000). Indeed the converse may well also be possible, with most of the star formation occurring early in small entities that occupy shallow wells, while the underlying dark halos then experience something like monolithic collapse when they later unite.

Or, in the "worst case scenario" for those who like their universes simple, there might be both bottom up and top down in the behavior of both the dark stuff and the baryons, so that star formation is spread fairly uniformly over the age of the universe and happens in both deep and shallow wells. Affirming the consequent as usual, we note particularly Chapman et al. (2001), Hopkins et al. (2001), and Cole et al. (2000), who emphasize approximate constancy over $z = 0.5$–5. The first two report their star formation rates in units even we can understand, $M_\odot/\mathrm{Mpc}^3$/yr, though with somewhat different numerical values of 0.1 and 0.2–1.0 (the latter paper may have a more complete sample of the galaxies than the former, which depends heavily on SCUBA data). The third is a bird of a still fairly sparse flock, a calculation which assumes a universe with $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.

Here and now (this is not a new discovery), star formation is down from its extended peak value, back to what prevailed near $z = 6$ (Thompson et al. 2001b). A sense of the error bars can be gleaned by comparing rates determined from different indicators (Bell & Kennicutt 2001 on H-alpha vs. far-UV; Williams et al. 2000; Casertano et al. 2000; Hopkins et al. 2000). The last three are part of a campaign directed at galaxies and proto-galaxies in the Hubble Deep Field South. They carry the important caveat that, despite using the same wavelength band and methods of analysis for HDFN and HDFS, the rates differ by about 50%. South is bigger, and this is more likely to reflect place-to-place variations on small scales than a giant cosmic dipole. In general, data at longer wavelengths yield larger rates of star formation, but be warned that, if you rely only on photons reprocessed to the infrared or submillimeter regime, the "evolution" of dust is even more important than that of "number of bright stars" (Archibald et al. 2001).

What about the development of the wells? It has historically been rather difficult to look for things that neither emit nor absorb light or other photons. Multiple dark stars, therefore, to Wittman et al. (2001) for the recognition of a mass-selected cluster of galaxies, that is, one which initially revealed itself by causing weak lensing of background sources in a nominally empty field. The authors report a redshift of 0.276 for it, so there must be some photon-emitting baryons as well, though the velocity dispersion of 615 km/sec could be inferred entirely from analysis of the deflection of background light rays.

It will take a while before additional applications of lensing surveys yield a complete sample of wells at various redshifts, selected for their masses rather than their brightnesses. Meanwhile, one must be content with the recognition that there are shallow (in their potentials; their emotional maturity we cannot say much about) wells at redshifts of 4–5 that act a bit like proto-galaxies were supposed to, but are only about 1% as bright, because they are not forming stars for the whole of a modern galaxy (Tissera et al. 2001; Rhoads et al. 2000).

Given the "everything happens at once" viewpoint, formation of galaxies elides smoothly into evolution of galaxies, but the section break can be used for eating, drinking, or other biological purposes (keep it clean guys).

11.4. Morphological Evolution

The elder author can say with complete honesty that she looks just like pictures taken in 1970. Unfortunately, they are pictures of her mother. Galaxies find themselves in somewhat the same situation. Here and now, they are more massive and less twinkly than they were there and then.

The first step is to be sure we know what we are seeing here and now. This unquestionably depends on the wavelength of your images. More galaxies display bars and grand-design spirals in the infrared than in visible light (Block et al. 2001), not to mention ambiguities in core structure (Ravindranath et al. 2001). Conversely, Hubble types (the tuning fork of barred and unbarred spirals, meeting at S0 and pointing onward to the ellipticals) and their definitions are not a good fit to far ultraviolet (e.g., 1500 Å) images (Kuchinski et al. 2000; Marcum et al. 2001). Thus one should not be surprised that, even if you start with $z = 0$ galaxies on whose (visible light) types everyone agrees, take UV images and artificially redshift them through the Hubble Deep Field filters to $z \geq 1$, they then become difficult to classify.

The conclusions of colleagues brave enough to attempt assigning Hubble types to objects at large redshift should, therefore, be treated with both salt and sympathy. Herewith a sprinkling (or sprinkled) of their deductions. There were both big and little galaxies by $z = 3$ at the latest (Metcalf et al. 2001). The little ones could be either a somewhat late arrival or just too faint to see earlier. The $z = 3$ galaxies also come in more than one type, since the SCUBA and *Chandra* sources in HDF are almost completely disjoint (Hornschemeier et al. 2000). The first sort of morphological evolution generally recognized was the Butcher-Oemler effect (excess of blue galaxies in clusters at $z = 0.2$–0.3). Ellingson et al. (2001) show that the phenomenon can be recognized out at least to $z = 0.58$ and attribute it to a monotonic decline with time of the rate at which field galaxies fall into clusters, a bottom-up process that can be traced back to $z > 1$ (Stanford et al. 2001).

When it comes to more detailed classification than big/little or red/blue, then sort of number that would be easiest to interpret would be the number of galaxies of a given type per comoving volume at redshift z. Nobody seems to report the findings this way. Thus we are not quite sure whether or not all of the following, especially (*c*) and (*d*), are mutually consistent.

a. As you look backward from $z = 0.3$ to $z = 0.8$, you gradually lose the grand-design spirals and barred spirals (this part might be consistent with just wavelength effects) and most Sc and Sd spirals, but gain in on-going mergers, especially those with three or more components, and in unHubbleable types, until the unclassifiable images amount to a third of the total (Abraham & van den Bergh 2001; van den Bergh et al. 2000).

b. The correlation we find at $z = 0$ between morphology and star formation rate (late = big) no longer works by $z \approx 1$ (Hall et al. 2001).

c. Half of all early-type (E, S0) galaxies were transformed from other types since $z = 1$ (van Dokkum & Franx 2001), but

d. The fraction of all galaxies that are recognizable as ellipticals has held fairly steady from $z = 1.2$ down to 0.25 (van den Bergh 2001b) and onward from $z = 0.25$ to the present (Fasano et al. 2000) at 15%–20%.

Notice that if you think mergers might have significantly reduced the total number of things recognizable as galaxies over that period, (*d*) at least could be interpreted as meaning that the absolute, co-moving density of ellipticals is smaller now than at $z = 0.5$–1.0. Perhaps they too have merged.

Not knowing quite where else to put it, we end with the thought that mergers are generally supposed to produce starbursts which, in turn, should be providing lots of supernovae. Neither we nor Mattila & Meikle (2001) are the first to remark that there have not been absolutely oodles of SNe found in the classic starburst galaxies. Indeed, they note that the only apparent case, 1940E in the direction of NGC 253, was probably a foreground event. The paper includes a list of candidate galaxies that should be watched more carefully, especially at IR wavelengths, for the expected couple of SNe per decade. The list includes NGC 253, M82, NGC 4038/39, Arp 220, and some we hadn't heard of before, except as one has heard of 2146 as the number between 2145 and 2147.

What successes there have been in finding supernovae in starbursts have come to radio astronomers. NGC 7469 had one within its nuclear formation region in 2000, recognized by Colina et al. (2001). The peak luminosity was about 1500 times the present brightness of Cas A (SN 1580?) for which, unfortunately, there are no early-time radio data. And at least one of the putative 10–100 year old SNRs in M82 is expanding on the angular scale probed by VLBI, in a way that again invokes Cas A as a prototype (McDonald et al. 2001).

11.5. Chemical Evolution of Galaxies

This topic, along with others in the general area of origin and abundances of the chemical elements, is being saved for a separate review of the topic in Another Publication (Trimble 2003).

12. COSMOLOGY

The word here is used to mean a good deal more than Sandage's proverbial "A search for two numbers" (Sandage 1970), and a good deal less than "everything about the universe that might work as a press release; send it to Steve Maran just in case." That is, the usual parameters from H outward, dark matter candidates, bits about distance scales and intergalactic environments (though baryon density and reionization are in § 8), alternatives to inflation, and so forth. The subsections are roughly in order of increasing weirdness, difficulty of comprehension (at least by us), and so forth.

12.1. A Quick Trip between the Galaxies

It has to be a quick trip because we are not bringing along any oxygen (because chemical evolution is deferred to a different review), though of course there was already a bit there anyhow (Loewenstein 2001; Schaye et al. 2000, on O VI in gas at density less than the cosmic mean).

Many other things are to be found there. There are gamma rays, though the ones we see are, given our vantage point, inevitably some mix between extra-galactic (Ruiz-La Puente et al. 2001 on the supernova contribution) and Galactic (Dar & De Rujula 2001 on inverse Compton scattering of 3 K photons and starlight by cosmic-ray electrons). The same can be said for X-rays (Helfand & Moran 2001, on the contribution from star-forming galaxies that are still too faint to be recorded individually by *Chandra*; Kuntz & Snowden 2001 on the Galactic soft stuff).

In the optical regime, it is generally agreed that the photons come from the sorts of galaxies (etc.) that we observe anyhow and that the whole should be equal to the sum of its parts. The most recent numbers for the local luminosity density are 2.5 and $2.4 \times 10^8\ h\ L_\odot/\mathrm{Mpc}^3$ (Cross et al. 2001; Yasuda et al. 2001 from SDSS). This does not differ enormously from the number we learned in childhood (probably from Oort). As usual, a power of $h = H/100$ lurks in the number, and it is left as an exercise for the reader (*a*) to verify that if $h = 1$, this luminosity density plus a closure density in something would require $M/L = 1104\ M_\odot/L_\odot$, and (*b*) to track the h's through to get the h-dependence in your answer to (*a*). Cross et al. (2001) note that differences between their value and others probably result from selection effects on surface brightness in picking out which galaxies to sum. No numbers were reported for any diffuse optical flux beyond what is accounted for by the sum of galaxies.

As one looks to longer wavelengths, there is increasing evidence for unresolved flux (Totani et al. 2001; Wright 2001; Cambresy et al. 2001) all in the 1–3 μm regime, and the last saying that the excess of the total DIRBE flux over the sum of sources found by 2MASS indicates a contribution from pregalactic stars, black holes, decaying particles, or other modestly exotic emitters. Beware, however, the Jabberwock of the zero point. An extrapolation of early source counts from SDSS leads to an integrated contribution that is 2.3 times that from 2MASS as the same wavelength (Wright et al. 2001). At least one is therefore probably wrong.

In the mid and far infrared, the problem remains that the best estimates of the intergalactic photon density, measured from either DIRBE/*COBE* or *ISO*, exceed the number penetrable for TeV gamma rays, and yet we see TeV sources (Finkbeiner et al. 2000; Renault et al. 2001). It was proposed a year or two ago that the problem would disappear if the photons could be persuaded to travel to us in a Bose-Einstein condensate bunch. HEGRA data have now ruled this out (Aharonian et al. 2000). We were not too disappointed, having missed the idea when it first came out, but the proposer must have been, and his agreement that this is not the answer (Harwit 2001) is therefore particularly meritorious. All that seems to be left is a large bathing machine or small second-class carriage.

Magnetic fields are also to be found between the galaxies, and if you are feeling sufficiently expansive, you might consent to regard them as photons of *very* long wavelength. For all we know, this may be part of the answer. We are pretty sure we didn't bring them (along with the oxygen), and remain unsure who did. The two carriers who came forward in the index year represented the extremes of the range, from "yeah, that makes sense" (Furlanetto & Loeb 2001, endorsing the "out of QSOs" picture of Rees & Setti 1968 and Hoyle 1969) to "eh?" (Forbes & Zhitnitsky 2000, advocating "out of domain walls"). Well, wouldn't you hate to be stuck inside one if you were a magnetic field, or even if you weren't.

12.2. How Far Is It to Alpha Cen?

This answer is actually known very well, but you probably don't need to be told that, of the two quantities that enter into measurements of the Hubble parameter, H, distances are, as a rule, considerably more difficult to determine than redshifts. A good many papers discussed calibrations of the more popular distance indicators, for instance Lane et al. (2000) with interferometric measurements of the radii of Cepheid variables and Hamuy et al. (2000) on various aspects of Type Ia supernovae. It remains true that not all methods give the same answer to the same question. The smallest distance to the LMC we spotted during the year was 44.5 kpc (Udalski 2000) and the largest (unrecorded) in excess of 50 kpc.

Techniques with less need for underlying theory (or faith) are coming (Macri et al. 2001a, on eclipsing binaries in M33; Thompson et al. 2001a, ditto in ω Cen). These have not entered into any of the values of the Hubble constant published during the reference year.

In case you were still worried about whether Hubble's law truly implies expansion of the universe, Lubin & Sandage (2001) have assembled the evidence, including time dilation of distant supernovae, the temperature of the microwave background at large redshift, the surface brightness normalization of the Planckian shape of the CMB, and the redshift dependence of the surface brightnesses of distant galaxies. We didn't star this in the notebook, but it surely deserves it. The last contrary paper ever may well be Segal & Nicoll (2002), because the senior author, proponent of chronometric cosmology and of redshift proportional to distance squared, has been called to a higher dimension. Occasionally there are also disagreements about the redshifts of distant galaxies (Fernandez-Soto et al. 2001 vs. Cohen et al. 2000b, a case of photometry battling spectroscopy).

The median value of H has crept back up to 70 km/sec/Mpc, based on only 13 papers, though we tried to be complete on this one particular issue. Perhaps it is, finally, going out of fashion. The last word, or rather the last number from the *HST* Key Project Team was 72 ± 8 (Freedman et al. 2001). Values from the Sunyaev-Zeldovich effect remain a smidge smaller than those from Cepheids and supernovae (e.g., Patel 2002, on Abell 1995), but the ones based on surface brightness fluctuations are no longer anomalously large (Liu & Graham 2001). And, if you're reading only one this year, we recommend $H = 67 \pm 2 \pm 5$ (statistical and, larger, systematic errors), the median of 331 values published between 1920 and 1999.5, subjected to a Bayesian analysis by Gott et al. (2001).

Once you have some distances that you trust, Kantowski et al. (2000) will loan you their expressions for calculating luminosity distance as a function of the various Ω's and such in what they call a Friedmann-Lemaître-Robertson-Walker universe, even the sort with inhomogeneities.

The next section deals with some of the "and suches," particularly the total density in matter of all forms, Ω_m, and the density in something like a cosmological constant or quintessences, Ω_Λ. Of the others, k is spatial curvature in dimensionless units, and some more are defined as we go.

12.3. How Much Is That Doggie in the Window?

Enough to add up to a matter density (in the usual units of ratio to closure, thereby cancelling some of the H-dependence) of $\Omega_m = 0.16$–0.24, say 790 galaxies from the Las Campanas redshift survey who weakly lens the fields behind themselves (Smith et al. 2001a). This is, of course, a lower limit to the total in galaxies, but the measurements extend out to radii of 200 h^{-1} kpc and so may well take in most of that total. Indeed, and contrary to earlier received opinion, several authors opined this year that luminous baryons are actually a pretty good tracer of the underlying dark matter distribution, whether baryonic or other (Eder & Schombert 2000; Hoekstra et al. 2001a; Gaztanaga & Juszkiewicz 2001). The last pair notes that they have seen in their database an inflection in the power spectrum $\xi(r)$ at $\xi = 1$ for $r = 5\ h^{-1}$ Mpc that is a smoking gun of the gravitational instability picture of galaxy formation (Gott & Rees 1975).

Unchanged for some years now is the agreement among several methods that the total matter density of the universe amounts to about $\Omega_m = 0.3$, ± 0.05 or so. So also this year say Miller et al. (2001b, who note that they have been able to make a smooth connection between power spectra of the density distributions determined from the microwave background radiation and from galaxy catalogues), Susperregi (2001) and Peacock et al. (2001), both based on large scale structure, the latter including the new 2dF database, and Hoekstra et al. (2001b), a result from weak lensing by small groups of galaxies. But, if once again you have time for only one, a paper that brings together data from the CMB, from Type Ia supernovae, and from large scale structure is Bridle et al. (2001). In addition to values for the quantities already mentioned ($H = 74 \pm 1$, $\Omega_m = 0.28 \pm 0.11$), they deduce $k = 0$ (flat space), so that the Λ contribution must amount to $1 - 0.28 = 0.72 \pm 0.15$; $n = 1$ (a Harrison-Zeldovich spectrum of primordial fluctuations), $\sigma_8 = 1 \pm 0.2$ (which is $\Delta\rho/\rho$ on a length scale of 8 Mpc), $Q = 19.7\ \mu$K (the normalization of the CMB fluctuations at the quadrupole scale), and $t = 13.2$ Gyr (time since $z =$ infinity).

The age had better be larger than any other age found for objects in the universe. All is well, at least this year, with the globular clusters at 11.5 Gyr (McNamara 2001), the onset of uranium synthesis at 12.5 ± 3.0 Gyr ago (Cayrel et al. 2001), and the epoch of formation of halo stars in which thorium still lingers 11.4 Gyr ago (Johnson & Bolte 2001). But, if you would like an addition to your collection of discordant values, $\Omega_m = -0.25$ (Guerra et al. 2000) is not a misprint, but the best fit to data on a single large double radio galaxy, taken to be a standard meter stick under the assumption $\Lambda = 0$. It shifts to $\Omega_m = 0$ to $+0.35$ for flat space.

And now a few words from our sponsors, er, from the theorists. The "accelerating universe" has been accelerating only since about $z = 0.4$ to 1 for the best-buy values of Ω_m and $\Omega_\Lambda = 0.3$ and 0.7 (Riess 2000). And, as we have had to be reminded once or twice, such a $k = 0$ universe has no coasting phase (to pile up QSOs at $z = 1.95$ for instance) and simply inflects from deceleration to acceleration. Such conditions are, in some sense, "fine tuned," and you can easily find particle types to tell you that the situation is so unlikely that the whole constellation of observations—CMB, SNe Ia, very large scale structure and lensing, and all—must somehow be wrong. The index year, however, also found four teams with mechanisms for locking in a ratio like 0.3/0.7. They were (1) Hebecker & Wetterich (2000), who used a Brans-Dicke field coupled to the vacuum energy, (2) Arkani-Hamed et al. (2000), who suppose that we currently live in a false vacuum (almost as uncomfortable as under false pretenses), (3) Armendez-Picon et al. (2000), whose scalar field locks onto a negative pressure at the moment when the energy densities in matter and vacuum are about equal, and (4) Dodelson et al. (2000). Observations should eventually yield information on the time dependence, if any, of the w in the quintessence or dark energy equation of state, $P = -w\rho$, but tests that rely on the luminosity distance, like the apparent brightnesses of SNe Ia, are not the right strategy (Maor et al. 2001).

12.4. Very Large Scale Structure and Deviations from Smooth Hubble Flow

Simulators have been telling us for some years that the large scale distribution of matter in the universe is largely in filaments and sheets, whose intersections are marked by conspicuous clusters and such. The new observation of the year is the first detected filament, for which there are two avowed candidates. Ensslin et al. (2001) present a case where two gaseous ones have collided and messed up the structure of a giant (Mpc) radio galaxy. The filament of Möller & Fynbo (2001) is further away (about $z = 3$) and is also largely gaseous, being made up of faint emitters and absorbers of Lyman alpha radiation.

If you want to track down the simulations, Thacker et al. (2000) is a good place to start. They compare results from 12 different SPH (smoothed particle hydrodynamics) codes and find that no one is good at everything, though they have their favorite. The prescription used for artificial viscosity is the most important variable among the codes.

The largest scale structure reported this year is coherent polarization of QSOs over an extent of 10^9 pc (Hutsemekers & Lamy 2001). The QSOs are at $z = 1$–2. BUT the structure is aligned with our local supercluster plane, and a suspicion of some effect of relatively nearby magnetic fields and plasma naturally arises. The second largest is 200 Mpc for galaxies and clusters in the Las Campanas redshift survey (Best 2000), very much like earlier numbers. Tanaka et al. (2001) report a configuration at $z = 1.1$ consisting of 23 QSOs and an excess of faint red galaxies stretched over $35\ h^{-1}$ Mpc. This is presumably somewhere between a small filament and a Great Wall. It is not, however, our local Great Wall seen all the way around a multiply connected universe. Roukema (2000) reports that there continues to be absolutely no evidence for anything exotic in the topology of the observed universe, but that you shouldn't give up looking. He traces discussions of the issue back to a 1900 paper by Karl Schwarzschild (translated in Schwarzschild 1995), and we suspect that Adam and Eve may have looked for paths in the Garden of Eden that might lead them back to where they had started from.

For contrast, here is a "smallest" of sorts. A new evaluation of the local Hubble flow finds a dispersion of only 38 km/sec over distances of 1–8 Mpc (and a global value of $H = 57$

km/sec/Mpc) from 14 galaxies with Cepheid distances (Ekholm et al. 2001). Despite the "urgent" status of a Letter, the authors remark that the smallness of the local velocity dispersion was known to and remarked upon by Sandage et al. (1972). Such numbers are a challenge to modellers no matter what the value of Ω_m. The local bulk flow relative to smooth Hubble expansion is also quite small, 70^{+100}_{-70} km/sec, according to Courteau et al. (2000). They make use of a new data sample and suggest that the larger values found in the past were artefacts of inhomogeneous samples from multiple telescopes and such. Notice that their error bars are consistent both with zero and with something close to 200 km/sec. Their galaxies extend out to 6000 km/sec (pick your H to translate this to Mpc). Colless et al. (2001) reported on a sample continuing on out from 6000 to 15,000 km/sec. Their central value for the bulk flow of our neighborhood is about 175 km/sec, but again the 95% confidence interval extends down to zero and up to 325. Both results provide modest support for the predictions of a lambda plus cold dark matter model of structure formation, normalized to the measured motion of the Local Group relative to the CMB (about 600 km/sec). Colless et al. (2001) also briefly consider prior reports of much larger bulk flows from samples at 8000–12,000 km/sec and conclude that two have larger uncertainties than the authors had attached and that the third should be "treated with reserve" (though only one of the authors is British).

12.5. Dark Matter's Blue, Dilly Dilly, Dark Matter's Green

The dark matter candidate of the year bid fair to be old, cold white dwarfs in the halo of the Milky Way. These were presaged in a study of the northern Hubble Deep Field (Ibata et al. 1999) and are good for making MACHO (gravitational lensing) events, for which Alcock et al. (2000b) presented the final report of their team, deserving of a star for promptness.

The official announcement was Oppenheimer et al. (2001), reporting the results of a proper motion survey toward the south polar cap, and the paper is actually a good deal less flamboyant than were some of the parts of the fringe festival. The survey identified 38 candidates. The 10 brightest of these were in existing proper motion surveys carried out by Willem Luyten (for two views of the completeness of these, see Ruiz et al. 2001 "bad" and Monet et al. 2000, "good") and have spectra about equally divided between DA and DC types at $B_J =$ 17.5–21.7. Oppenheimer et al. estimated that white dwarfs like the ones they had found would add up to at least a few percent of the dark matter in the galactic halo and fit the MACHO numbers. But scarce had they put down their CCDs, when in rushed the critics, beginning with the Technical Comments paragraphs of *Science* (Anonymous 2001c) and continuing with Hansen (2001). The criticisms are (*a*) that the sum would be less than 2% of the dark matter and (*b*) that many of the white dwarfs were anyhow disk objects. Flynn et al. (2001) then came forward with another search for stars of large proper motions and DA-type colors and found none.

Like neutrinos in the total DM inventory (Durrer & Novosyadlyj 2001), old white dwarfs now sound like they belong to the "marginally significant other" category—yes there are some, but no more than you had previously supposed. None of these limits (except the one on total baryon density, § 8) apply to the dark matter candidate propounded by Lynden-Bell & Tout (2001). They consider the possibility of white dwarfs assembled so slowly and gently out of ordinary galactic gas that they never experience any nuclear reactions, and may be supposed to have disposed of their 10^{50} ergs of gravitational potential energy long ago.

A quick summary of the MACHO final report before we go on to other candidates. The project (Alcock et al. 2000b) eventually found 13–17 microlensing events, with durations between 34 and 230 days, in the direction of the Large Magellanic Cloud. This is not as many as would have been extrapolated from the first year or two of data, because as time went on and increased their sensitivity to events of longer duration, not many turned up. The events add up to a halo optical depth in lenses of $1.2 \pm 0.5 \times 10^{-7}$, about 10% of the initial, optimistic estimates. If the lenses are distributed through an extended galactic halo, their masses are 0.15–0.9 $M_\odot$, and the population contributes a mass of 9×10^{10} $M_\odot$ out to 50 kpc (comparable with the mass of the luminous disk). Once upon a time, this would have sounded like most of the galaxy, but the total mass required to keep our companion dwarf spheroidals in attendance is in excess of 1.2×10^{12} $M_\odot$ (Gallart et al. 2001).

Last year's dark matter best seller, the self-interacting sort (Ap00, § 12.4.2), has been remaindered this year and is available very cheaply from Yoshida et al. (2000), who found it not a good fit to the rotation curves of their dwarf galaxies, and Kochanek & White (2000), who conclude that it produces central cusps in the density profiles of large galaxies that are even less like observed centers than are the cusps made by plain old cold dark matter, which anyhow isn't so bad after all in either of these contexts (van den Bosch & Swaters 2001).

Many old, dark, familiar friends got at least one positive or negative vote during the year. Some of the votes in favor were:

- Tau rather than sterile neutrino (Fukuda et al. 2000), at least the ones that reached Superkamiokande before its (out of period) tubal ligation.
- Hot plus cold (Mikheeva et al. 2001).
- Warm, for making disk galaxies (Sommer-Larsen & Dolgov 2001); their candidates are mirror or shadow neutrinos or majorons. Narayanan et al. (2000) and Barkana et al. (2001) agree that warm particles must have masses in excess of 0.25–0.4 keV or something bad will come down the chimney (probably reionization that smears out the Lyman alpha forest clouds).
- Decaying DM (Cen 2001), to account for there being dwarf

galaxies in halos with velocity dispersions of 20 km/sec and not in 10 km/sec halos.

• Repulsive (keep it clean guys) DM (Goodman 2000), which serves the same purpose as hot DM in promoting large scale structure and discouraging excessively cuspy galaxy cores.

• Domain walls, which are then also the source of a primordial magnetic field (Forbes & Zhitnitsky 2000).

And there was at least one vote against, or one observation that might have revealed evidence but did not, for each of the following:

• WIMPs with masses of 1–10 GeV/c^2 and cross sections of a few picobarns (Collar et al. 2000). A barn, recall, was the unit of cross section in nuclear physics when not being able to hit the broad side of one was an insult.

• Axions with masses close to 3×10^{-4} eV (Blout et al. 2001, who did not see any pairs of photons at 36–44 GHz that would result from their decays).

• Stellar mass black holes, quark stars, or boson stars (Miller 2000), because early accretion on them would produce reionization at larger redshift than is seen (§ 8).

• Black holes of 10^5–10^{11} $M_\odot$, because they gravitationally lens neither compact radio sources (Augusto & Wilkinson 2001) nor gamma ray-bursters (Nemiroff et al. 2001).

• Decaying neutrinos, and certain lepton asymmetries, which would show up in CMB measurements from BOOMERANG (Hannestad 2000).

In the on-beyond-zebra class, we spotted (or perhaps striped, definitely not starred) only two: (*a*) the vacuum energy of a simple quantized free scalar field of low mass (Parker & Raval 2001), and (*b*) a fluid with negative energy density (Thomas & Schulz 2001). This violates the "positivity condition" of the singularity theorems of general relativity (Hawking & Ellis 1973) and so permits solutions to the equations of cosmology in which the universe alternately expands and contracts without experiencing a singularity. It is also no harder to explain to a telejournalist than matter with positive density but negative pressure, avers the author whose writing of this section was bifurcated by such an effort.

13. YOUR BATTERY IS FAILING AND YOUR SCREEN HAS BEEN DIMMED TO CONSERVE POWER

This, according to Jepson (2001), was the surtitled response of Rudolfo (the tenor) in *La Boheme* to the anguished, last-act surtitle of Mimi (the soprano), "Rudolfo, do not leave me," at a recent performance by the Washington Opera, where a volunteer laptop had been pressed into emergency service to drive the projector. Here, then, some astronomical literature failings and dimmings and results of attempts to conserve editorial power, beginning with our own from Ap2000 (with the section numbers indicated).

The search for light echoes from Tycho's and other historical supernovae has a longer history than suggested in § 5.3, with an attempt by van den Bergh (1966) and the idea traceable back at least to Shklovskii (1964).

Remaining with the Brahe family for a moment, you might well have doubted that Sophia really lived to be 107 (§ 5.7, which gives her dates as 1536–1643). His were 1546–1601, and whenever she died, it was probably with nose intact.

Section 8 is surely the only review of "instertellar matter" written the entire year. One hopes so, anyhow.

The significance of magnetic fields in the morphology of planetary nebulae may have escaped us (§ 6.6.2), but it is well enough known to the rest of the community to have received two updates this year (Blackman et al. 2001 on the nature of the underlying dynamo, and Gardiner & Frank 2001 on self-collimation).

Turning to the works of others, we report a few favorite phrases: "Clusters last stand" (*AJ* 121, 613, title; the cluster is Pal 13, which has led a dissipated, or at least dissipating—keep it clean guys—life). "Nucleophilic banana orbits" (*MNRAS* 320, 379, abstract). "Model independent interferences" (*ApJ* 545, No. 1, cover). "Using a serious of dedicated satellite missions" (*ApJS* 132, 365, introduction), and "Binary RX J0019.8+2156 (QR AND DROMEDAE)" (contents page, 1677, of AJ 122, and followed you might expect by QR OR DROMEDAE).

Having the length of sentences, if not always quite the structure, we found, "Molecular gas in infrared excess, optically selected and the quasars connected infrared luminous galaxies" (*AJ* 121, 1893, title). The paper (Evans et al. 2001) is also missing from the table of contents and out of subject order in the issue. And, "The range of parameters is between the Vela-like pulsars and the Three Musketeers" (*ApJ* 551, L151, introduction).

The "Vaz you there?" award goes to Clark (2001), who remarks that the AAS audience in 1990 gave the CMB fluctuations from *COBE* a standing ovation. It was the spectrum (an incredibly perfect blackbody, based on just a few days of data), and the audience remained largely seated. The chair (who was largely standing) inquired, "What are you applauding for? The Universe?" Another sort of "not quite there" prize belongs to text on page 306 of *PASP* 113, where an author reports being "grateful for the Mount Wilson night assistants, especially XX and YY, for the highly efficient operation of both the 60 inch and the 200 inch reflectors". Well, you have to be efficient to operate a telescope from nearly 100 miles away, the 200 inch being generally found on Palomar Mountain.

Mislocation is probably also the underlying explanation for the variable star CV Aqr, which in retrospect seems to have been asteroid (52) Europa (Schmeer & Hazen 2000). Page E7 of the *Los Angeles Times* on 15 November 2001 provided some good advice, "The astrological forecast should be read for entertainment." Personally we prefer root canals.

Numbers too can go astray. In the table on page 219 of

MNRAS 324, a star with a main-sequence mass of 0.40 $M_\odot$ leaves a remnant of 0.45 $M_\odot$, the result, perhaps, of accretion from the luminiferous ether. "3.142857 = 176 and 3.14 = 175" (Vickery 2001) fails even as a ratio of some sort, but this book review also describes John Michell (the discoverer of binary stars, predictor of black holes, inventor of the Cavendish balance and so forth) as a philosopher and historian. And Eddington must be engaged in subterranean rotation at the description of, "A temperature of one trillion Kelvin, ten thousand times hotter than the inside of the Sun" (*Nature* 408, 903). Not quite wrong, but a tad unusual is a number to be found in *MNRAS* 324, 267. It has 30 references, 20 of which are self-citations to others of the authors' works.

You have long known that the answer is 42. Scoccimarro et al. (2001) suggest that the question may have been, "How many galaxies can fit in a halo?"

As was bound to happen eventually if we tried to correct enough errors, here is a correction to a correction. Section 13.1 of Ap00 "attempted to clarify … the phrasing of onset of declines in R CrB stars." Yeah, it should have been "phasing of onset of declines …" But the forgiving colleague involved has followed on his bicycle with words of encouragements, in the form, "All are forward: outburst, discoveries etc." with "LS And at the list of new year's wishes."

These reviews could not exist without ready access to the literature (but it is probably not worth trying to burn down libraries just for this reason). Author Aschwanden made use of the Astrophysics Data System (ADS, whose primary, if not onlie, begetter, Michael Kurtz, received the much-deserved 2001 Van Biesbroeck Award of the American Astronomical Society). His work was partially supported by NASA contracts NAS 8-00119 (*Yohkoh*) and NAS 5-38099 (*TRACE*). Author Trimble made use of the libraries of the University of California, Irvine, the University of Maryland, the University of Western Ontario, and the Institute of Astronomy, Cambridge (with thanks to Katherine Kjaer, Dorothea Zitta, Amelia Wehlau, and long overdue, to David Dewhirst). Her page charges were partially supported by prizes and honoraria from the American Association of Physics Teachers, the American Physical Society, the Gruber Foundation, and KNG (Netherlands).

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