Title
Astrophysics in 1995

Permalink
https://escholarship.org/uc/item/53f5w4mg

Journal

ISSN
0004-6280

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Publication Date
1996

DOI
10.1086/133687

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Peer reviewed
Invited Review Paper

Astrophysics in 1995

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Received 1995 October 26; accepted 1995 October 27

ABSTRACT. Ap95 differs from Ap91 to Ap94 primarily in Ap number. That is, it once again attempts to highlight some areas of our mutual science where a major event has occurred during the year (a possible solution of the Type II supernova problem, the faintness of quasar host galaxies, the collision of Shoemaker-Levy 9 with Jupiter), but also to focus on some topics where dogged determination is producing more gradual advances (dense star clusters, the second-parameter problem, inventories of nearby objects, and dark-matter candidates). In moderate departure from the rules of Ap92-94, there has been some deliberate up-dating of topics discussed previously. The topics are only partly ordered from nearby to far away.

1. INTRODUCTION

“For crying out loud,” we can hear you saying, “is it them again?” Well, yes. This is the fifth annual mustering of the sheep and goats of astronomical/astrophysical research, based on journals that reached library shelves between 1 October 1994 and 30 September 1995. Astrophysics in 1991, 1992, 1993, and 1994 appeared as page 1 of volumes 104, 105, 106, and 107 of PASP. They are cited as Ap91 to Ap94 below.

In contrast to previous years, we find ourselves doing a good deal of updating, fine tuning, and rediscussing of topics mentioned in earlier round-ups. Possible explanations include: (a) all the good subjects have already been done, (b) progress in astronomy is more rapid than it used to be, or (c) the index year 1995 did not witness vast numbers of exciting new discoveries.


The old order changeth. Progress in Astronomy (edited in Shanghai) now publishes about a third of its papers in English. You are probably aware of the recent changes of chief executive officers at Science, Nature, and Scientific American and the upcoming restructuring of Astrophysical Journal. Another, less publicized, change of editors has modified the journal so much that Vinod Krishan’s Bulletin of the Astronomical Society of India (BASI in the references) has been added to the list of journals to be scanned regularly.

Last year, we worried a bit about paying too much attention to astronomical news that appeared in secondary sources. This year, we were accused of having slighted a major subdiscipline. Clearly there is no one definition of “fair coverage” that would suit all (citing every member of the AAS at least once lying outside the realm of possibility). Table 1, however, compares the fractions of items in Ap91 to Ap94 in various subfields with the fraction of AAS members working recently in those fields. For the purposes of bean counting, a subsection was counted as equal to one-third of a section, and the distribution of American astronomers across subfields was taken from Trimble (1993), with the dynamicists reallocated among solar system, Milky Way (galactic structure), and galaxies and clusters. Indeed, certain fields are under-represented, particularly solar and solar-system astronomy. This is no surprise, since they were originally assumed not to be part of the job description. Galactic structure and the interstellar medium have also received rather short shrift, but the field supposedly neglected is, in fact, one of the over-represented ones. Nine subsections on history and sociology of astronomy were not included in the arithmetic, and “high-energy astrophysics” means quasars, pulsars, X-ray binaries, gamma-ray bursters, and their ilk.

Finally, although the tone of this review remains relentlessly upbeat, we would like to ask for a moment of thought in memory of four colleagues who left us during the year.

Edith Müller of Basel, Switzerland (July 1995), the first woman to serve as General Secretary of the International Astronomical Union. Her passing leaves a national delegation to the IAU of about 44 members, none of them women.

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2. A PLACE FOR EVERYTHING AND EVERYTHING IN ITS PLACE

This section does extreme violence to the principle of “no fine tuning” by tidying up a number of loose ends left at various points in Ap94.

2.1 You Saw the Theory, Now Read the Data

Section 5.3 of Ap94 reported theoretical interpretations of one gamma-ray burst that lasted at least an hour and had, toward the end, a very hard spectrum indeed. The data have now been published (Hurley et al. 1994).

The 1987A three-ring-circus image has appeared many places (including, unfortunately, the logo of the University of California, Irvine Department of Physics and Astronomy). It has not, however, yet appeared in a refereed paper signed by the HST users who obtained it. Nevertheless, one theoretical interpretation appeared early enough to be mentioned in Sec. 9.8 of Ap94. Since then, Martin and Arnett (1995) have argued that the three rings form from the collision of the fast wind of a blue supergiant with the slower, highly flattened wind of an earlier, red-supergiant phase. Lloyd et al. (1995) suggest, in addition, that the slow wind was shaped into a double cone structure by a binary companion. And Meaburn et al. (1995) estimate that the structures all formed 2–3×10^8 yr ago. Meanwhile, if you must have data, the bipolar structures can already be glimpsed in the mountain-top images provided by Crotts et al. (1995) and Plait et al. (1995). This is perhaps as good a place as any to mention the probable discovery of a second supernova light echo (indirectly, through its influence on the late-time light curve of SN 1991T, Schmidt 1994) and the optical recovery of the light echo gas in the very first such source ever, Nova Persei 1901 (Tweedy 1995).

The custom of “sentence first, verdict afterwards” naturally continues. Index year 1995 saw two measurements in the realm of particle physics with implications for astrophysics. These were the discovery of the top quark and another round of evidence for neutrino oscillations (that is, non-zero rest mass). The mass and other properties of the new (and, it is expected, last) quark have been duly reported (Abe et al. 1995; Abachi et al. 1995—the enormous numbers of authors of each can be guessed from how early in the alphabet the lead ones come, and also from the spacing of the page numbers; PRL waived its normal four-page limit to accommodate a whole page of authors!). And, of course, the publication was preceded by various discussions of its meaning for processes in the early universe (e.g., Bhattacharjee 1995). The official version of the new neutrino oscillation data from Los Alamos (Athanassapoulos et al. 1995) just misses the index year and is being disputed by one of the original collaborators (Hill 1995). But the unofficial value of the rest mass of the more massive neutrino involved is about 2.5 eV (White et al. 1995). Because neutrinos of finite rest mass are likely to be important in a proper account of dark-matter candidates and of the solar-neutrino problem, the prepublication attempts to incorporate the data into models and scenarios are not at all surprising (Primack et al. 1995; Pal 1995).

2.2 The Galactic Superluminal Sources

There were two of these in Ap94, Sec. 5.4; that is, transient X-ray sources whose corresponding radio sources seem, owing to projection effects, to be galloping across the sky at more than the speed of light. There are still two (as far as we know), but more details of the radio data for the second one, GRO J1655–40, have been published (Tingay et al. 1995; Hjellming and Rupen 1995; Herman et al. 1995). The source
displayed repeated ejection events, with a possible three-day period and a real space velocity of the jets of 0.92 c. The modellers were, of course, at work in real, or even slightly advanced, time; for instance Liang and Li (1995), who suggested acceleration of electron–positron pair plasmoids by radiation pressure.

Perhaps most exciting yet, the second superluminal source has an optical identification (Bailyn et al. 1995a), whose optical spectrum shows broad emission lines of variable radial velocity (H alpha, He I, etc.) and F–G-type absorption lines (Bailyn et al. 1995b). The period is 2.62 days and the amplitude (K_o) is 231 km s^{-1}. This translates into a mass function of 3.35 M_o, establishing the compact component as a “black-hole candidate.” The optical spectrum shows absolutely no evidence of emission lines at relativistic speeds like those seen, still uniquely, in SS 433 (Margon 1984).

At least one additional X-ray transient, similar to these and to the black-hole candidates A 0620–00 and Nova Muscae 1991 is known not to have a superluminal radio counterpart (Shrader et al. 1994) and not to have a mass function greatly in excess of the neutron-star limit (Bonnet-Bidaud and Mouchet 1995). It is GRO J0422+32, in case you want to phone.

### 2.3 Massive Black Holes in Galactic Nuclei

Several colleagues have complained that we jumped the gun in Sec. 8 of Ap94 by citing news reports on M87 and preliminary (though refereed) data on NGC 4258. We hasten to mention the more definitive work. Images and spectra of M87 from the post-repair HST support a central compact mass of 2.4±0.7 × 10^6 M_o (Ford et al. 1994; Harms et al. 1994). Data and models of the same general sort indicate the presence of a black hole of 1–2 × 10^6 M_o in M32 (van der Marel et al. 1994; Qian et al. 1995; Dehnen 1995) and one of about 7 × 10^5 M_o in the nucleus (well, one piece of the binary nucleus) of M31 (Tremaine et al. 1995).

NGC 4258 is the not-very-active galaxy with lots of H_2O maser sources in a 0.1 pc disk around its center. Radial velocities of the maser lines in combination with VLB1 imaging indicate motion in a Keplerian disk around a central mass of 2–4 × 10^7 M_o (Haschick et al. 1995; Miyoshi et al. 1995). The components should be moving at about 35 μ arcsec/year, detectable in VLB1 images within a few years. That the motion has not already been seen implies a lower limit to the source distance of 5.4 Mpc (Greenhill et al. 1995), though a typographical error has converted the limit in the abstract to 5.4 pc (which we never doubted).

Modellers hope that such maser sources in molecular disks around black holes in active (and other) galactic nuclei should be common, with some of them bright enough to be detectable at much larger distances (Neufeld and Maloney 1995). If sources more than 20–30 Mpc away can be resolved and studied, the combination of radial-velocity and proper-motion measurements would provide an estimate of the Hubble constant completely independent of all previous ones.

Yet another sort of evidence for a black hole in another active galaxy comes from the very broad, asymmetrical X-ray emission lines of MCG 6-30-15, if the line profile can be attributed to gravitational redshift (Tanaka et al. 1995; Corbin 1995, on asymmetries of redshifted lines).

This brings us to the center of the Milky Way, where a 1–3 × 10^6 M_o black hole has been lurking (at least in the literature) for decades, and the jury is still out. The most likely X-ray counterpart of the radio core, Sgr A*, remains remarkably feeble at about 7 × 10^{35} erg s^{-1} (Predehl and Truemper 1994). It is heavily absorbed (2 × 10^{25} H/cm^2 compared to 5 × 10^{22} H/cm^2 expected for a visual extinction of about 30 magnitudes), suggesting some sort of analogy with the picture of two Seyfert galaxies as obscured type 1’s (Ap92, Sec. 7.1). There is no emission at all, down to about 10^{-7} of the Eddington luminosity of the putative black hole, at energies higher than about 35 keV (Goldwurm et al. 1994). Improved angular resolution in the infrared has, however, put one of the cluster of imaged point sources within 0.5 of Sgr A* (Close et al. 1994). The rest are stars (Eckart et al. 1995).

The potential central IR source is, perhaps, variable with a period of 10.4 minutes (Close et al. 1994). This is a reasonable period for the last stable Keplerian orbit around a 10^6 M_o black hole (Hollywood et al. 1995—and we are bravely refraining from the obvious remarks, recognizing that every human being in the world over the age of three has already heard every possible joke that can be made about his name). Velocities of a subset of the stars in the central cluster favor a somewhat larger black-hole mass (Krabbe et al. 1995).

Why, if there is a sizable black hole hanging around, should its accretion luminosity be so small? The idea that it is starving, with an accretion disk fed only by stellar winds that keep out the general interstellar medium, still has its supporters (Falcke and Heinrich 1994; Krabbe et al. 1995).

In that connection, attributing the cluster of stars to fragmentation, a million or so years ago, of what was formerly a much more massive accretion disk is most seductive (Zylka et al. 1995). The high profile idea of the year is, however, advection (Narayan et al. 1995). Despite what your dictionary may tell you (“horizontal movement of a mass of air that causes changes in temperature or other physical properties”) advection in this context means that disk accretion is actually quite rapid, but that most of the available gravitational potential energy is dragged down into the black hole with the inflowing hot gas, instead of being radiated as X-rays and such. In other words, the cooling time of the disk gas is longer than the inflow time. Incidentally, advective is a small-dictionary word, but the back-formation, advect, is not.

Advection seems, in fact, to be the word of the year, and it has turned up in connection with disks around young stellar objects (Narayan and Yi 1995), accretion in black-hole X-ray binaries (Chen 1995), explosions of Type Ia supernovae (Khoklov 1995), and the decrease of surface magnetic fields in accreting neutron stars (Young and Channugam 1995), though competing mechanisms for this last abound (Urpin and Shalybkov 1995; Mushkin 1995).

### 2.4 Brown Dwarfs

Stars that hover right around the hydrogen ignition line continue to abound. But the real news is two apparently authentic successes. One is a star in the Pleiades so much
fainter than all the rest that it just can’t be more than 0.07M☉, no matter how slowly non-stars cool (Rebolo et al. 1995). Its friends call it Teide 1, for the observatory where the preliminary work was done. It has not yet been subjected to the lithium litmus test, but will be. Lithium is so fragile that any object hot enough for even marginal hydrogen burning (and thus not a brown dwarf) will have consumed it all in the age of the Pleiades.

The other star is another Pleiad, called PPL 15. It is a magnitude or so brighter than Teide 1, but has already passed the lithium test (Basri et al. 1995). A Pleiad that failed is reported by Martin et al. (1994). And we have seen at least ten other papers during the reference year pointing to additional candidates in the ρ Oph region, ESO survey regions, and elsewhere. There continue, of course, to be substellar mass objects among the mass donors in cataclysmic binaries (Augusteijn 1994) and in X-ray binaries (Corbet et al. 1994).

2.5 MACHOS, Galactic Dark Matter, and the Princes of Serendip

AP93 reported, with credit to Rumour (1993), the first detections of gravitational microlensing events attributable to stars in our own galaxy as seen by three collaborations. AP94 (Sec. 3) considered a handful of archival papers reporting and interpreting events as well as the first “spin-offs”—independent discoveries of a new, Local Group galaxy and of barred structure in the Milky Way. Observations, interpretations, and by-products have continued to appear.

First, a new group has joined in the searches. DUO (Disk Unseen Objects) is concentrating its (photographic) images in regions where disk stars are likely to be the lenses and has reported its first two events, one of them apparently a binary lens with the smaller star probably in the brown-dwarf mass range (Alard et al. 1995). Welcome and congratulations to this collaboration, whose prime mover is apparently still a graduate student!

Data, in the sense of multi-color light curves of individual events, have been leaking out rather slowly, mostly in conference proceedings. It is, however, impressive that one event was caught by both MACHO and OGLE (Szymanski et al. 1994). The EROS collaboration has added a CCD program to its photographic search. They report (Aubourg et al. 1995) a total absence of events with time scales between 30 minutes and 7 days. These would be caused by lens masses between 5×10⁻⁸ and 5×10⁻⁴ M☉. Larger masses produce events with longer time scales to which other projects are sensitive; smaller masses of hydrogen are probably not stable for long periods of time in the galactic ultraviolet flux.

Second, there have been a few analyses of real and virtual events, including a probable binary lens (Dominik and Hirshfeld 1994), the non-grayness of the light curves that should result from limb darkening of target stars (that is, limb reddening, Bogdánov and Cherepashchuk 1995), and the possibility of getting actual (vs. merely statistical) masses of the lenses if both distances and proper motions can be measured (Miyamoto and Yoshi 1995; Paczynski 1995). Surely all collaborations are aware of the need to allow for unlensed light from close companions, optical doubles, and so forth; but Di Stefano and Esin (1995) are theorists-on-the-spot just in case.

Third, and still not entirely free from dispute, come various statistical analyses of where the lenses are, what they are likely to be, and how much the lens population contributes to dark matter in the galactic halo.

Where? Sahu (1994) refined his analysis showing that stars in the Large Magellanic Cloud are mostly lensed by other LMC stars. Xu (1994) said that at most 10%–20% of them could be, even if the LMC has a halo made of massive, compact objects. And Gould (1995) concluded that really very few of them are, since the halo velocity dispersion in the LMC is not large enough to account for the shortness of the event durations.

What? Since the obvious answers were already in print before the first events were seen, 1995 witnessed the appearance of some much less obvious ones. These include quark stars (Cottingham et al. 1994); 10⁻⁸ M☉ compact clusters of neutron stars, black holes, and brown dwarfs (Wasserman and Salpeter 1994), in which case the events should cluster on the sky and you make some contact with gamma-ray bursts produced by NS-BH (etc.) binary collisions; low-mass clusters of brown dwarfs and molecular hydrogen gas (De Paolis et al. 1995); Population III stars (Fujimoto et al. 1995); and, our private favorite, “red dwarfs” (Komberg et al. 1995).

How much? The optical depth to gravitational lensing is the instantaneous probability that any one sight line to a background star will pass within the Einstein radius of a possible lens object, making the star look at least 34% brighter than it really is. Plausible values are around 10⁻⁷, which, of course, is why you (or, rather, mercifully, they) have to look at so many stars. Papers published during the index year on various sight lines through the Milky Way halo (Alcock 1995; Gates et al. 1995; Alcock et al. 1995a) and on sight lines toward the galactic bulge (Alcock et al. 1995b; Metcalf 1995) confirm the preliminary impression that lenses are more common toward the bulge but less common through the halo than expected. The implications are that we live in a barred spiral and that no more than 1/3 of the halo dark matter is likely to be made of MACHOS of any kind.

At this point, we naturally tangle with the topic, brown dwarfs, of the previous section and will further complicate the knot by mentioning three photometric results. A field at high galactic latitude imaged by HST contains very few stars that are either very faint or very red (Bahcall et al. 1994c). Red or brown dwarfs that might have been seen, but were not, therefore contribute at most 10⁻⁸ to lensing optical depth, 6% of halo dark matter, and 15% of the mass density in the disk. Infrared photometry limits the halo component of M8 dwarfs (0.1M☉ stars) to less than 3% of the total dark matter in the Milky Way and less than 1% in Abell 2029 (Baughn and Uson 1995). Old white dwarfs will also radiate mostly in the infrared, and they are not more than 10% of the dark matter in typical spirals (Charlot and Silk 1995).

Fourth, and absolutely last, come an assortment of catalogs of variable stars that are by-products of finding the lens events. EROS has reported a number of eclipsing binaries in the bar of the LMC, roughly doubling the known inventory.
(Grisón et al. 1995). MACHO is finding all kinds of things (including a rumored new class of “blue bumpers”), but has so far published only a subset of their Cepheids, the ones whose light curves show two periods beating against each other (Alcock et al. 1995c). OGLE has weighed in with two assemblages of variable stars in the direction of Baade’s window (Udalski et al. 1994, 1995). Many are the expected RR Lyrae variables, Delta Scuti stars, and eclipsing binaries. But there is also an interesting class of red giants and subgiants whose variability seems to result from rotation (perhaps linked to binary periods) plus spotted surfaces. Also recently archived are small groups of W Ursae Majoris stars (mostly 1.8 to 5.8 kpc from us, Rucinski 1995) and of variables in the Sagittarius dwarf spheroidal galaxy (ten stars, including seven RR Lyraes and one probable W UMa, Mateo et al. 1995).

We had intended to swear that Ap96 (even if our critics let us live to write it) would say not a word about either brown dwarfs or MACHOS, but the sounds of yet another Rumor (1995) would make this a rash promise.

3. THE IMPACTS OF COMET SHOEMAKER-LEVY 9 ON JUPITER: OBSERVATIONAL RESULTS AND PROPOSED EXPLANATIONS

In the 2.5 years following the discovery of comet Shoemaker-Levy 9 (henceforth S-L 9), more than 500 papers and abstracts have been published on the subject. There have also been three meetings devoted entirely to S-L 9, and at least four others where the comet has been a dominant topic. There was certainly more work on S-L 9 published in 1995 than can be reported here in ≈2000 words, and so this review will focus on the main observational results and their preliminary interpretations. The interested reader can find more in the review by Beatty and Levy (1995). A fairly complete list of S-L 9 papers can be found on the World Wide Web at http://pdssbn.astro.umd.edu/c1993eh.html.


Perhaps the scientifically most important result to come out of the S-L 9 experience is the density of the comet before disruption. Hahn and Rettig (1995) estimate a density of ≈0.6 g cm⁻³ based on a tidal impulse model that results in ≈20 fragments via the Jeans instability. This is similar to the earlier estimates listed in Ap94. The idea that comet nuclei (Weissman 1994).

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Photometric and spectroscopic studies of the cometary fragments prior to impact yielded rather inconclusive results. The pre-impact colors (Cochran et al. 1995; Rauer and Osterloh 1995; Stüwe et al. 1995; Trilling et al. 1995) are consistent with the hypothesis that S-L 9 was a comet, but do not rule out that it was an asteroid. Searches for gas in the pre-impact fragments (Cochran et al. 1995; Weaver et al. 1995) only resulted in upper limits. But realistically, it’s just too darn cold beyond 5 AU from the Sun to have expected much gas.

Many papers presented infrared lightcurves of the impact events based on Earth-based observations. Several of these note one or two “precursors” before the “main event” (Collas et al. 1995; Drossart et al. 1995; Graham et al. 1995; Herbst et al. 1995; Lagage et al. 1995; Nicholson et al. 1995a; Schleicher et al. 1994; Takeuchi et al. 1995). There was initially some difficulty in reconciling the Galileo observations (Carlson et al. 1995; Chapman et al. 1995; Hord et al. 1995; Martin et al. 1995) with those from Earth. The big breakthrough came when it was finally appreciated that large Earth-based telescopes had more sensitivity than Galileo, and so the former could detect events that the latter could not. Clark Chapman came up with the following chronology at IAU Symposium 156. Seen first was a gradual increase in brightness as debris in the coma struck the jovian atmosphere ahead of the nucleus. The meteor phase followed as the nucleus entered the atmosphere. This was the earliest event detected by Galileo. These first two phases were visible from Earth in reflection off material in the coma. The next event was the hot, rising fireball (or plume) from the impact, which cooled after a few minutes. Galileo saw nothing afterwards. The main event, as seen from Earth, began roughly six minutes after impact, and was due to heating of the stratosphere as the plume came crashing down.

The predicted optical reflections off the Galilean satellites were not convincingly seen (Barwig and Bämbantner 1995; Foryta et al. 1994; Mantel et al. 1995; Orton et al. 1995b). Particularly disappointing was the lack of a reflection off Europa during the impact of Fragment K, which occurred when this moon was in Jupiter’s shadow and unocculted (A’Hearn et al. 1995; Yanagisawa 1994). The reasons for the disappointment are that the fragment masses were smaller than expected, and perhaps the optical efficiency of jovian meteors is smaller than anticipated.

The year 1995 witnessed a shift in preference from large fragment masses to much smaller values. Such changes in majority opinion very seldom reverse. Before the impacts occurred, the tidal-disruption people were already telling us that the parent nucleus was likely <2 km in diameter, so the largest of the 20 fragments was likely <1 km in diameter (e.g., Asphaug and Benz 1994). The lack of satellite reflections also argues for the smaller size. In addition, the lack of observable effects on Jupiter’s thermal continuum at 3 mm (Gurwell et al. 1994; Kundu et al. 1994) suggests that the impactors did not penetrate very deeply. McKinnon and Schenk (1995) estimate that the typical crater in the chains of craters on Callisto and Ganymede was produced by a cometary fragment with radius <0.5 km. Modelers Mac Low and Zahnle (1994a, b) argue for a largest fragment diameter of ≈0.5 km.

Work on the plume dynamics includes the following. Boslough et al. (1995) claim that the almost constant plume of —0.5 km. Modelers Mac Low and Zahnle (1994a, b) argue for a largest fragment diameter of ≈0.5 km. Work on the plume dynamics includes the following. Boslough et al. (1995) claim that the almost constant plume of —0.5 km. Modelers Mac Low and Zahnle (1994a, b) argue for a largest fragment diameter of ≈0.5 km.
Boslough et al. find that it is the diameter of the entry tunnel in the upper atmosphere which determines how high the plume goes. Boslough et al. also model the collapse of the plume, and its horizontal flow across the jovian stratosphere, as did Shoemaker et al. (1995). The larger-than-expected twist in the dark impact ejecta (Hammel et al.) can be explained by the coriolis deflection during the flow. Cacciani et al. (1995) may have detected this slide across the jovian atmosphere via Doppler observations.

The chemistry of the impacts also provides an important constraint on how deep the largest fragments penetrated. Noll et al. (1995) observed Jupiter with HST shortly after the G impact and found several sulfur-containing molecules, including more than $10^{14}$ g of $S_2$. This seems too much to have come from the impactor, and therefore penetration down to and dredge up from the NH$_4$SH cloud at 1 or 2 bars appears likely. Noll et al. also note that oxygen-containing molecules were conspicuously absent. Zahnle et al. (1995) claim that this means that the largest impactors did not penetrate down to the water level at 3 to 5 bars. As for the origin of the $S_2$, Zahnle et al. argue that it is naturally formed as a byproduct of hydrogen recombination, and is quickly converted into $S_8$. Moses et al. (1995) reach the same conclusion.

Trace amounts of water were detected shortly after the impacts, and it is believed that it came from the impacting body. Water associated with the G and K impacts (Bjoraker et al. 1994) and the R and W impacts was observed from the KAO (Sprague et al. 1994). Meadows and Crisp (1995) detected it in the K impact with the AAT.

The emission lines of metals (e.g., Na, Fe, Mg, Ca, Mn, Li, K) were detected at several impact sites (Churyumov et al. 1995; Fitzsimmons et al. 1995; Noll et al. 1995; Roos-Serote et al. 1995). These metals came from the comet.

One of the more interesting phenomenon associated with the S-L 9 impacts were the "waves" that were seen by HST to be moving radially away from the larger impact sites at a constant speed of $454\pm20$ ms$^{-1}$ (Hammel et al. 1995a). Ingersoll and Kanamori (1995) propose that these are a consequence of gravity waves traveling horizontally through the jovian tropospheric water cloud. This requires deep impacts, and more oxygen than expected in Jupiter. A small temperature decrease in the jovian stratosphere results as this tropospheric wave passes, and some unknown substance, popularly known as the "brown stuff," condenses and then evaporates to produce the effect of an expanding ring.

The much hoped for seismic waves were not detected (Catalano et al. 1995; Dombard and Boughn 1995; Marley et al. 1994; Mosser et al. 1995), which represents the second largest disappointment of the S-L 9 impacts (the lack of satellite reflections was the biggest bust). The explanation is that the fragment masses were smaller than expected, and there was too much wishful thinking in the predictions.

The nature of the ubiquitous "brown stuff" remains unclear. Suzuki et al. (1994) found featureless optical spectra, and conclude that the dark spots were low-albedo clouds in the stratosphere. Tozzi et al. (1994) reach the same conclusion based on infrared imaging. Field et al. (1995) suggest that the dark spots were composed of silicate dust that condensed from vaporized comet material. They estimate a particle radius of $\approx0.1$ μm, which would allow the dust to remain suspended in the jovian stratosphere for long periods. These authors also predict a silicate feature at $\approx10$ μm, and Nicholson et al. (1995b) identified such a feature in the R impact plume. Hasegawa et al. (1995) also prefer silicate grains, which they suggest condensed in the impact plumes within 100 s, and did not reevaporate during plume reentry. Knacke and A’Heam (1994) estimate an equivalent diameter of 100 to 300 m of dust is required to produce the dark spot associated with the G impact. West et al. (1995) suggest the color of the dark spots is similar to that of organic material rich in sulfur and nitrogen, such as poly-HCN. Matthews (1994) is also a big supporter of the HCN-polymer interpretation. An argument against the silicate interpretation is the condensation and reevaporation of the brown stuff as the wave passes; once silicates recondense in the impact plumes, they are likely to remain condensed.

The dark spots produced by the S-L 9 impacts are believed to be the most prominent features ever seen on Jupiter (Hockey 1994). Sanchez-Lavega et al. (1995) estimate an initial diameter of perhaps 8000 km for the dark core of the largest impact site, and $1.4\times10^9$ km for the largest ejecta blanket. Jupiter is big enough for clouds this large to laterally disperse. On Earth, there is no place for a stratospheric dark cloud the size of Earth to go, except to filter downwards after many years. Clearly, the concept that "nuclear winter" follows a cometary impact on Earth has been pounded home.

The impacts increased auroral activity on Jupiter. Clarke et al. (1995) recorded some unusual auroras after the impact of Fragment K. These emissions occurred in the hemisphere opposite to where the impact occurred near the northern magnetic conjugate point. Three other spacecraft witnessed the same event: ROSAT (Waite et al. 1995), EUVE (Gladstone et al. 1995), and IUE (Ballester et al. 1995). The X-ray bremsstrahlung was probably the result of a cloud of electrons that moved along the magnetic field lines and collided with the upper jovian atmosphere. Hill and Dessler (1995) propose that the K impact jetted electrons into the jovian ionosphere, while Waite et al. suggest that the impact freed existing magnetospheric electrons. Ground-based infrared observations revealed enhanced and prolonged northern auroral activity (Miller et al. 1995; Orton et al. 1995a; Schulz et al. 1995).

The Io plasma torus was closely scrutinized for changes, but nothing very unusual was found. HST observations by McGrath et al. (1995) revealed that extreme ultraviolet emissions dropped and far-ultraviolet emissions increased. However, no new emission lines were seen, and the torus morphology did not change. Brown et al. (1995) and Stern et al. (1995) saw little change in the torus. The simplest explanation is that the fragments were too small and in the wrong place to make much difference.

The radio emission from Jupiter during impact week changed in different ways at different wavelengths. Stankevich et al. (1995a, b) report dips in thermal emission at 0.81 and 3.66 cm, perhaps due to shielding by an optically thin cloud layer in the stratosphere. An undisputed enhancement in synchrotron emission at 6 to 90 cm occurred during impact week (Bolton et al. 1995; de Pater et al. 1995; Dulk et
Several explanations for the surge in synchrotron emission have been put forth. Brecht et al. (1995a, b) explain it as being due to the acceleration of magnetospheric electrons by shock waves that propagate into the magnetosphere from the impact points. Bolton and Thorne (1995) discuss several mechanisms, and prefer pitch-angle scattering. De Pater et al. (1994) suggest that an increase in the inward radial diffusion of electrons may have also contributed to the synchrotron enhancement.

4. OBSERVATIONS OF DENSE YOUNG STAR CLUSTERS

The literature of 1995 included several papers on dense young star clusters. Most prominent were studies of R136 in the 30 Doradus star-formation region of the LMC based on HST observations. Hunter et al. (1995b) observed the intermediate-mass stellar population in R136 down to 2.8M☉. Perhaps their most surprising result is that they were unable to detect the core of the cluster; apparently R136, which is much less than a half-mass relaxation time old, has a central density cusp. Hunter et al. also find a density inside 0.11 pc of at least 5.5×10^5 M☉ pc^-3, and an overall mass function that is consistent with the Salpeter initial mass function. Malumuth and Heap (1994) find evidence for mass segregation in R136, which is interesting in such a dynamically young cluster. Heap et al. (1994) carried out spectroscopy of individual stars in R136, and in one case found a mass-loss rate of 1.8×10^-3 M☉ yr^-1. This is rather high, given that the cluster is 3 to 4 Myr old (Hunter et al. 1995b). Other work on R136 includes the identification of several candidate WR stars (Parker et al. 1995), the resolution of three compact clusters in the periphery of 30 Dor (Walborn et al. 1995), and a study of the complex gas distribution in the nebula (Hunter et al. 1995a).

Other observations of extragalactic clusters include those of O'Connell et al. (1995), who used HST to find more than a hundred "super" star clusters in the inner few hundred pc of the starburst galaxy M82. Each one of these clusters is more luminous than R136! At the other extreme, Demers et al. (1995) find only one stellar aggregate in five dwarf spheroidal galaxies. Interestingly this one aggregate lies at the very center of the Ursa Minor dwarf spheroidal.

There were several studies of dense young clusters in our Galaxy published in 1995. McCaughrean and Stauffer (1994) carried out high-resolution, near-infrared imaging of the Trapezium Cluster at the heart of the Orion Nebula, and find a stellar density of ~4.7×10^5 pc^-3 in the inner 0.1 pc. At least 80% of the cluster members have ages less than 1 Myr (Prosser et al. 1994). Stauffer et al. (1995) used HST to find that 25% to 75% of the Trapezium Cluster members have circumstellar disks, and so the dense stellar environment appears to have had little effect on the disk phenomenon. The embedded young cluster IC 348 was the subject of a near-infrared study by Lada and Lada (1995). They find a central subcluster with a density of ~10^4 pc^-2 within a 0.1 pc radius, and several less dense subclusters surrounding it. They find infrared excesses indicative of protostellar disks, and conclude that star formation has taken place continually and uniformly in IC 348 at one twentieth the rate in the Trapezium Cluster. In Bok globule CB 34, Alves and Yun (1995) have detected 12 proto-stellar objects within 0.1 pc, which implies a density of hundreds per cubic parsec. The young stellar system NGC 3603 may be the densest observable cluster in the Galaxy. Moffat et al. (1994) observed it with HST, and find that it shares some of the properties of R136, including an apparent cusp in central density, and mass segregation. The main difference between the two clusters is that NGC 3603 lacks the extensive halo that R136 has. Hofmann et al. (1995) used speckle observations to estimate a mass density of ~10^7 M☉ pc^-3 in NGC 3603 around the central star, HD 97950.

The theoreticians did their best to explain what is observed in these clusters. Gorti and Bhatt (1995) argue that massive clumps in molecular clouds suffer more gas drag than small clumps, which results in their sinking more deeply into the potential well of the cloud. This can account for mass segregation in a protocluster. This new idea may or may not push aside the earlier picture, where collisions between cloudlets in the protocluster produce larger cloudlets with reduced random velocities, which sink more deeply into the protocluster potential. Assuming that the most massive cloudlets produce the most massive stars, then the star cluster is born with mass segregation. Price and Podsiadlowski (1995) consider collisions between pairs of protostellar cores (low-mass cores with central accreting protostars) and between protostellar cores and protostars. Such interactions can expose the cores and terminate accretion, and the resulting initial-mass function can be quite realistic. Also, lots of binaries naturally result. McDonald and Clarke (1995) prefer to form binaries via dissipative encounters between stars with circumstellar disks.

Interestingly, central density cusps have also been detected in elliptical galaxies that have been closely scrutinized with HST (e.g., Kormendy et al. 1994). These cusps extend over far too large a radius to be accounted for by central black holes. In the young star clusters R136 and NGC 3603, the cusps are likely the result of the star-formation process. In contrast, the cusps in elliptical galaxies simply correspond to the innermost parts of power-law density profiles, which commonly show up in N-body simulations of structure formation (e.g., Crone et al. 1994). The dynamics of central density cusps in ellipticals is already a hot topic among theoreticians (e.g., Fridman and Merritt 1995). It makes one wonder if some of the so-called core-collapsed globular clusters in our Galaxy were actually born with central density cusps, rather than the commonly accepted explanation that their cusps resulted from gravothermal catastrophes.
5. THE(?) CAUSE OF EXPLOSIONS IN TYPE II SUPERNOVAE

The main stream here can be traced right back to a spring, 1934 paper by Baade and Zwicky (1934) proposing that "a supernova represents the transition of an ordinary star into a neutron star, consisting mainly of neutrons." The details were left as an exercise for the reader. You might have thought this should be safe enough. After all, the gravitational potential energy released when a 1.5M☉ core collapses to a 10 km neutron star is about 1053 ergs; and the photons and gas tossed out by a typical Type II supernova (the kind with hydrogen lines in the spectrum) carry only about 1051 ergs. Surely, anybody ought to be able to devise a process with 1% efficiency. In fact, though, filling in the details has taken most of the ensuing 60 years.

Just about half way from their year to ours, Colgate and Johnson (1960) suggested that the collapsing iron core of a fuel-exhausted massive star would bounce at high density (due to adiabatic compression and the hardening of the equation of state at nuclear density), sending a shock back out that would eject the stellar envelope and make something looking like a supernova. Soon after, Colgate and White (1966) considered an alternative possibility, that neutrinos made by electron capture would deposit much of their energy and momentum at the base of the envelope, thus ejecting it.

Most interested participants quickly agreed that such a shock must form and that neutrinos were probably somehow relevant to whether it could actually impart positive energy to part of the stellar envelope. Trimble (1982) traces out the next 15 years of oscillation between "yes, it gets out," and "no, it stalls into an accretion shock." That period ended with near concensus that the shock would stall and have to be revived by deposition of neutrino energy after most of a second had passed—the "delayed" vs. "prompt" shock model. Calculations pertaining to all aspects of supernova physics proliferated after the explosion of SN 1987A, and it didn't require much of a crystal ball for us to say in Ap94 (Sec. 9.8) that "progress seems likely to come from two- and three-dimensional investigations of asymmetries, convection, and instabilities."

The first paper fulfilling that prediction (Herant et al. 1994) landed on library shelves three days after Ap94 was accepted. The authors had identified three-dimensional convection, driven by neutrinos, that, acting like a Carnot cycle, would deposit 4×1051 ergs per solar mass involved in the convection. The calculation led to an explosion with adequate energy, even though an analogous one-dimensional calculation had failed completely. The authors expressed their confidence that the result was a robust one, with no fine tuning required.

Curiously, prompt convection (before the shock stalls) helps hardly at all (Bruenn and Mezzacappa 1994). And, contrary to earlier claims and perhaps to intuition, core rotation is an absolute hindrance to the explosion (Yamada and Sato 1994), because it slows down the core contraction required to make the initial, bounce-induced shock. This core contraction or collapse is initiated by different processes in stars of different mass (e.g., electron capture on 23Na or 24Mg in the low mass range, Garcia-Berro and Iben 1994). The type of trigger apparently doesn't matter much to the explosion, though it will, of course, matter to potentially observable relationships among progenitor mass, products of nucleosynthesis, and so forth (Young et al. 1995).

The inhomogeneities and anisotropies inherent in convection, turbulence, plumes, and so forth also matter a great deal to what you see after the supernova, including nucleosynthesis (Bazan and Arnett 1994) and the motion of the remnant neutron star. A "kick velocity" of up to 500 km s⁻¹ is possible (Janka and Mueller 1994), which is still not quite large enough to account for the full range of pulsar speeds implied by proper motions and associations with supernova remnants. There must be additional kicks or gradual accelerations from a binary companion, asymmetric radiation, or something not yet thought of. The main argument for asymmetric radiation processes used to be an advertised correlation of pulsar velocities with magnetic-field strength. But the correlation is not a physically meaningful one (Itoh and Hiraki 1994; Lorimer et al. 1995). Rather, it is an artefact of strong field pulsars dying off quickly, while high velocity ones soon leave the surveyable galactic disk.

A second, independent calculation has confirmed some, but not all, of the results of Herant et al. (1994). Burrows et al. (1995) carried out a two-dimensional simulation of neutrino-driven convective overturn. The effect is to raise the entropy behind the stalled shock for about a tenth of a second, which is enough to get the shock turned around again. Soon after, a neutrino wind from the surface of the remaining proto-neutron star develops. This prevents fall-back of material, thus reducing the risk of continued collapse to a black hole. In fact the wind is so efficient that the remnant neutron star will have a gravitational mass of only about 1.2M☉, rather smaller than measured values and also significantly smaller than the Chandrasekhar mass limit for stable white dwarfs (see also Janka and Mueller 1995).

Other interesting aspects of the Burrows et al. (1995) model include outgoing fngers of 56Ni, which may correspond to the nickel bubbles inferred for SN 1987A and to the sharpnel seen in Cas A. The total amount of 56Ni produced is less than in earlier, one-dimensional models and so in better accord with the quantities contributing to the light curves of SNe 1987A, 1993J, etc. There may, on the other hand, be some overproduction of neutron-rich isotopes of elements in the iron peak (Mn–Co).

In contrast to the robustness of the result claimed by Herant et al. (1994), Burrows and his collaborators say that the details and even the existence of their explosion are quite sensitive to the algorithm used to describe neutrino transport. The amount of "kick velocity" imparted to the central neutron star is also very dependent on the details of plumes and bubbles in the inward and outward flows. Their results appear, in highly edited form, in Hayes and Burrows (1995). Both versions include a wealth of full-color images of the collapse, bounce, and explosion process. Only the reality of page charges for color images prevents our having stolen some of these for this article.

More calculations, pertaining to a range of collapse-core masses, envelope masses, compositions, transport physics, and so forth are undoubtedly on the way. One analytic one
convection. Meanwhile, we note one bit of good news and two bad. The good news is that a strange quark star will have a larger binding energy than a neutron star, giving the shock a better send off (if this is the right minimum energy state for dense matter, Vartanyan et al. 1995). The dispiriting bits are that some Type II supernovae really need every bit of that 4\times 10^{51} \text{ ergs} (e.g., W51C, Koo et al. 1995) and that full incorporation of general relativity into the calculations has happened, so far, only in one dimension (Baumgarte et al. 1995), and it may well once again impede the explosion.

6. MOMMY, WHERE DOES THIS GO?

The list of items (astrophysically important or just fun) not covered grows longer each year. Some of them deserve whole sections, and all at least an explanation plus a punch line. Here, faute de mieux, are a subset of the punch lines.

6.1 In and Around the Earth

Our own home planet is 0.02 K warmer during full moon than new (Balling and Cerveny 1995), is still visited by frequent naked-eye comets that go almost unnoticed owing to light pollution (Kidger 1994), is destined to be hit by a significant fraction of all known Earth-crossing asteroids (Steel 1995—this is not a tautology; “earth-crossing” means only that the orbits cross), and bears a not-very-obvious resemblance to the third companion orbiting pulsar B1257+12 (Mazeh and Goldman 1995).

As for how it all got here, two rather impressive studies, one observational (Zuckerman et al. 1995) and one theoretical (Ward and Hahn 1995) conclude that planetary systems, or at least planets as massive as Jupiter and Saturn, are going to be rare, because they must form in 10–30 million years, before the raw materials disappear, or not at all. More positive messages came from Miyake and Nakagawa (1995) and Tutukov (1995), and some distinctly strange ones from Reyes-Ruiz and Stepiński (1995) on magnetic effects and Barge and Sommeria (1995) on vortices.

If you feel you must go looking for other solar systems, then 5 AU from the parent star is the right place for Jupiter, even if the star is only an M dwarf (Boss 1995). And, as when attending the after-Christmas sales, it pays to shop early, within the first billion years, when Jupiter is still fairly bright from its contraction phase (Burrows et al. 1995).

6.2 In and Around the Sun

On the Sun you will find a bit of water vapor (Wallace et al. 1995), and comet Halley is now so far away that only the bare nucleus remains at V=26.5 (Hainaut et al. 1995). A second comet nucleus, that of P/Faye 1991, has been directly imaged with the (pre-fix) HST Planetary Camera (Lamy and Toth 1995); and the asteroid 1620 Geographos is the most elongated object in the solar system, at about 3:1 (Ostro et al. 1995).

But the real growth industry has been helioseismology. The cover page item is the detection of known solar modes that strict limits on mass loss can be obtained (Guzik and Err 1983). Three sets of ground-based frequency data exist, with continuing disagreements about some details (Bachmann et al. 1995) and corresponding uncertainty about what can be learned. We feel safe in noting that the frequencies change through the solar cycle (Elsworth et al. 1994), without endorsing any of the models, and would like to believe that strict limits on mass loss can be obtained (Guzik and Cox 1995), because this eliminates one sneaky way of making globular clusters younger than they look. Of the five or more papers that deconvolved modes to trace out stellar rotation as a function of radius and latitude, no two got exactly the same answers. A little Goddard bird has promised that SOHO will sort everything out by providing a continuous data stream unconfounded by atmospheric effects.

A strong case (not the first reported) for similar modes in another star has been made for Eta Boo by Kjeldsen et al. (1995) and the modes successfully modeled by Christensen-Dalsgaard et al. 1995). Procyon has withdrawn from the competition (Bedford et al. 1995).

6.3 In and Around the Physics Lab

Lots of things don’t change very much. The constant of gravity has held steady over the life of the Sun to within a percent or so (Demarque et al. 1994; Guenther et al. 1995), though this is admittedly based on analyses of solar oscillation data that we just finished casting nasturtiums on. The fine-structure constant is not going anywhere faster than a time scale of 10^{13} \text{ yr}, based on wavelength ratios of QSO absorption lines out to z=3.7 (Vashalovich and Potekhin 1995). The rest mass of the photon probably hasn’t changed either, but 10^{-46} \text{ g} is a nice firm upper limit, based on the structure and stability of the Earth’s magnetic field (Fischbach et al. 1994).

The equivalence principle remains unviolated by the effects of dark matter on the Earth and Moon (Nordvedt et al. 1995). General relativistic time dilation occurs, at least in supernova light curves (Perlmutter et al. 1995, a paper which casts new light upon the urgency of ApJ Letters, having been submitted 18 months before publication), if not in gamma-ray bursts (Mitrofanov et al. 1995; Fenimore 1995). The latter case is “controversial” (not here, as it often is, a euphemism for “violates the second law of thermodynamics”). Among alternatives to general relativity, Brans-Dicke lives, at the level of a scalar contribution of 10^{-7-8} of the tensor part now (Lange 1995). This is the expected value from a particular theory incorporating a massless scalar field (Damour and Nordvedt 1993). The observational limit on this particular deviation from GR is still a factor of about 10^{-4} larger. It comes from the gravitational deflection of radio waves from quasars 3C 273 and 3C 279 near the limb of the Sun (Lebach et al. 1995).

And the best clock is probably not at the National Institute of Standards and Technology but in the binary pulsar J1713+0747 (Camilo et al. 1994). It has an rms error of 0.4 \mu\text{s} in about 9\times 10^{9} \text{ yr} (they have not actually been watching it that
long). This NS+WD system is not as good a testing ground for GR as the double neutron star ones.

6.4 In and Around the Editor’s Desk

The oldest paper to appear (for the first time) during the index year was Ioffe (1994), written in 1952–53, on the effects of polarization on the escape of high-energy photons from ionized gases. Originally a “bomb” paper, it may have some application to active galaxies that emit gamma rays (Ap92, Sec. 6.4). The longest time elapsed between Papers I and II of a series was, however, a mere decade, leading up to Lucy (1994). We had thought that the record for archival observatory plates on loan belonged to images of M55 taken from Harvard by I. R. King and returned by V. Trimble 40 years later, but they cannot compete with the “plates that were lent to Prof. Fickering 1912 June 28” (Goffin 1995).

We had several candidates for most senior author, but realize that all must yield to McCrea (1995), and extend apologies for having written the paper that prompted a somewhat unhappy discussion of the British astronomical community among old friends. The last possible acceptance date for a predictive paper on SL9 was presumably 15 July. Field and Ferrara (1995) just made it!

6.5 In and Around Stars

It is hard to avoid feeling something like sympathy for Beta Pic, which is quite probably so young that its disk is not terribly remarkable after all (Lanz et al. 1995); for FK Comae, whose rapid rotation has not spared it the additional indignity of non-radial pulsations (with rapid period changes, Welty and Ramsey 1994); for Kappa Draconis, whose 23.01 yr period in luminosity and emission-line strength gives new meaning to the name “long-period variable” (Juza et al. 1994); and for HD 5980 embarrassed in the act of changing from a Wolf-Rayet star to a luminous blue variable (Barba et al. 1995).

Chromospheres and coronae are supposed to be found around stars late (cool) enough to have convective envelopes, but the former persist to A7 (Walter et al. 1995; Friere Ferrero et al. 1995) and the latter to F6, at least in Orion (Gagne et al. 1995). The advertised first X-ray flare on a hot star (Eta Ori) presumably also says something about hot-star coronae, but the authors neglected to mention either spectral type or peak X-ray luminosity (Berghoefer and Schmitt 1994).

Among compact stars, the most massive white dwarfs are only 1.1\,M_{\odot} (as a result of stripping by AGN winds) according to Bragaglia et al. (1995), but 1.31\,M_{\odot} according to Wolff et al. (1995), who give the example of PG 1658+441. The mass of a main-sequence star that can make a neutron star rather than a black hole has risen to 50\,M_{\odot}, based on an analysis by Kaper et al. (1995) of the evolution of the X-ray binary Wray 977 (but see Sec. 6.8 for SN 1987A as a counterexample). And for stars that have successfully hung up at nuclear densities, the longest rotation period (for a single star) is now 5.09 s (Camilo and Nice 1995).

6.6 In and Around Binaries

The most eccentric orbit (ADS 1106) has $e=0.9754$ (Tokovinin 1995) and the second (HD 2109) has $e=0.949$ (Mazeh et al. 1995). We were briefly tempted to include them along with asteroid Geographos in a section titled “The Most Eccentric Examples,” but worried that some colleagues might object to being mentioned in it.

As the inventories of all kinds of binaries grow, inevitably the distances between upper and lower limits on their periods, masses, and so forth draw further apart. The index year saw at least a half dozen cases. The smallest stable mass ratio for W Ursae Majoris (contact) binaries is $M_2/M_1=0.09$, a direct insult to AW UMa at 0.075 (Rasio 1995). The most massive primary may be that of LT Pav at 2.87\,M_{\odot}, though the error bars are large enough that AG Vir at 2.48\,M_{\odot} may not have been dethroned (Cerruti 1995).

The strongest magnetic field in a binary white dwarf is now 70–80\,MG in RX J1938.6-4623 (Schwope et al. 1995), which is still far short of the hundreds of Megagauss seen in some single WDs (no, we don’t know why). The range of periods for magnetic cataclysmic binaries (AM Her stars) now extends from 76.69 min for RE 1307+535 (Osbourne et al. 1994) to 9 hr for RX J0515.6+0115 (Buckley and Shafter 1995). Whether the magnetic systems show the same gap in period distribution at 2–3 hours as the non-magnetic CVs display is still under discussion (Wheatley 1995; Shafter et al. 1995).

A subset of CVs show longer periods or quasi-periods between outbursts, normally three months or more. A new subset (Osaki 1995) extends this down to about 20 days. At the other extreme, a handful of systems brighten only every decade or two (WZ Sge is the prototype). They share unusually short orbit periods and very large outburst amplitudes (Howell et al. 1995). Warner (1995) has suggested that they share one more trait, degenerate secondaries.

How and when nova explosions (the nuclear ones; dwarf novae are accretion instabilities) turn off has been a continuing source of mild astrophysical distress. Pleasingly, incorporation of new, larger, OPAL radiative opacities into one set of models leads to winds strong enough to remove the incendiary hydrogen layer and stop the burning, in months to years as really happens (Kato and Hachisu 1994). When should the models turn off? Well, Nova Cygni 1992 lasted only about a year as a bright X-ray source (the last waveband to fade), while GC Muscae 1983 hung in there for about a decade (Shanley et al. 1995). They do not, however, turn off completely. The index year saw the optical (HST) recovery of T Sco (Nova 1860) in the globular cluster M80 (Shara and Drissen 1995) and a detailed study of the flickering of V841 Oph, the first of the 19th century novae (1848; Warner et al. 1995).

Finally, a couple of X-ray binary extrema. X0146+612, whose companion is a Be star, has set a new high for neutron-star rotation periods at 1412 s (Hellier 1994). That it is probably a member of the open cluster NGC 663 makes it a candidate “first” as well. GX 1+4 is currently changing its period at 2% a year. But the sign oscillates frequently and (unpredictably), so you need not worry about its spinning out of control (Greenhill et al. 1995b). Another oddity of the
system is its combination of strong magnetic field (about \(10^{13}\) G), normally a signature of youth, and its M6 III, seemingly elderly, companion.

### 6.7 In and Around Star Clusters

The traditional old open clusters include M67, NGC 188, and NGC 6791 at 5 to 10 Gyr, depending on who you ask. Most are found outside the solar circle (a survival effect), and they apparently rotate with the thin disk of the Milky Way at about 210 km s\(^{-1}\) (Scott et al. 1995). Be 29 is a similar beast, and at a galactocentric radius of 19 kpc counts as way out (Kaluzny et al. 1994). NGC 6791 is, somewhat disconcertingly, both old and metal rich—\(10 \pm 0.5\) Gyr and \([\text{Fe/H}] = +0.15\), according to Tripicco et al. (1995). Pal 1, though it looks rather similar on the sky and in a color-magnitude diagram to the old open clusters, is an authentic globular cluster at least a few billion years older (Borissova and Spassova 1995). Ortolani et al. (1995) have proposed BH 176 as a transition object between the two classes, but it is at low galactic latitude and their data do not reach down to the main sequence.

Globular-cluster metallicities span the range \([\text{Fe/H}] = -2.4\) (for NGC 5053, Sarajedini and Milone 1995) to \(+0.25 \pm 0.3\) (for Liller 1, Frogel et al. 1995). That field stars come in much purer condition, down to \([\text{Fe/H}] = -4.0\) is not, of course, a new result, though just which star sets the limit is still under discussion (McWilliam et al. 1995; von Winckel et al. 1995). The distributions of metallicities for clusters and for field stars are different over the full range, not just at top and bottom, at the 99.8% confidence level (Geisler et al. 1995).

### 6.8 In and Around Supernovae

Poor old SN 1987A still has no pulsar, and we, at least, are going to stop going out every night to look for it. The current limit on pulsed optical flux is \(V = 24\) at any period from 0.2 ms to 10 s (Percival et al. 1995). The Crab pulsar at 50 kpc would flash in at \(V = 23.5\). One possible explanation is that neutron stars are born with weak magnetic fields and build them up gradually (Muslimov and Page 1995). More popular is the belief that the stellar core of Sk \(\sim 69^\circ 202\) collapsed on beyond nuclear density to a black hole a few seconds after the 1987 February neutrino burst (Brown and Weingartner 1994; Bethe and Brown 1995; Glendenning 1995). This more extreme scenario then also accounts for the lack of accretion luminosity coming from the SN site, which was at most \(8 \times 10^{36}\) erg s\(^{-1}\) at any wavelength in early 1995.

Speaking of the Crab Nebula, as one ought to every few years, \(ROSAT\) and \(HST\) images, along with ground-based Fabry–Perot spectroscopy, suggest somewhat complicated bipolar and cylindrical symmetries (Lawrence et al. 1995; Hester et al. 1995). Another much-loved SNR, Vela, is at the position of a compact source of \(^{26}\text{Al}\) decay gamma-ray emission (Diehl et al. 1995a). The line radiation is, in general, quite lumpy over the galactic plane, suggesting production in regions of recent star formation and a total galactic mass of only 1 \(M_\odot\) of \(^{26}\text{Al}\) at the present time (Diehl et al. 1995b).

### 6.9 In and Around the Milky Way

The inventory of molecules seen, mostly via radio lines and infrared "features," continues to grow. Recent additions include N\(_2\)O, whose discoverers (Ziurys et al. 1994a) are presumably laughing all the way to Jodrell Bank; fullerenes in the Allende meteorite (Becker et al. 1994) and perhaps the interstellar medium (Ugarte 1995); AlF (Ziurys et al. 1994b), and MgCN (Ziurys et al. 1995). Very accurate laboratory measurements of line frequencies have been critical to the recognition of most of these.

Ap92 (Sec. 9.2) hailed PAHs (polycyclic aromatic hydrocarbons) as the molecule of the year. In a sort of gaseous backlash, we noticed a number of 1995 authors stopping to note that quite a lot of things were not due to PAHs, including the infrared emission from galactic cirrus seen by DIRBE (Bernard 1994), most of the molecules in Orion (Giard et al. 1994), the dominant source of ultraviolet interstellar extinction (Aaenstad 1995), the diffuse interstellar bands (Snow et al. 1995), and infrared emission by carbon stars (Goebel et al. 1995).

The chemistry of molecular gas remains hellishly complicated (particularly when you consider its low temperature), but at least it is not bimodal. The vagaries of the editorial process brought to our shelves the demonstration that a region with a particular \(T, n,\) and composition will have a unique equilibrium solution for ionization and molecular abundances (Shalabiea and Greenberg 1995) shortly before the suggestion of bistability (Le Bourlot et al. 1995).

There are, of course, also interstellar grains. And if you want them to produce as much far-infrared polarization of starlight as is seen, you had better arrange for exceedingly efficient alignment (Hildebrand and Dragovan 1995). It has nothing to do with this review, but the first author of this last paper is the son of Joel Hildebrand of UC Berkeley, who survived a near-fatal 1918 shooting by an angry graduate student and went on—and on—to become the oldest professor of chemistry ever.

### 6.10 In and Around Galaxies and Clusters

We are happy to report that a search of the \(Einstein\) IPC data base by Tucker et al. (1995) shows that there are very few X-ray clusters with no galaxies in them. Among clusters that do exist, a surprisingly large fraction have brightest members that are not cD galaxies and do not show conspicuous radial color gradients (Andrew et al. 1995).

Closer to home, M31 has now provided evidence within a single galaxy for a gradient in the ratio of carbon stars to oxygen-rich M giants. There are relatively more carbon stars on the outskirts because lower initial metallicity makes it easier for a star to produce enough carbon from helium burning to lock up all the oxygen in CO (Brewer et al. 1995). The most massive main-sequence star in M31, according to images of OB associations recorded with the Ultraviolet Imaging Telescope, is a light heavyweight of 85 \(M_\odot\) (Hill et al. 1995). Whether this is larger or smaller than the Milky Way limit depends on what you think the Milky Way limit is.

Another near neighbor hosts, in addition, at least eight X-ray sources considerably brighter than Milky Way X-ray
binaries. They are not readily explainable as young supernovae, black-hole candidates, or anything else (Marston et al. 1995). It also has had at least one very soft X-ray transient not very different from galactic and Magellanic Cloud ones (White 1995).

Nobody quite knows where the most energetic cosmic rays come from. They are, however, not magnetically confined in the Milky Way, but also cannot have travelled more than 10–30 Mpc through the 3 K background radiation (Hayashida et al. 1994; D. J. Bird et al. 1995). This places them somewhere in “the realm of the nebulae.” Whether they (all two or three of them) are protons or iron nuclei also cannot be determined from existing data.

A few galactic extrema include the most distant H2O masers (Braatz et al. 1994), the first inverse Compton gamma rays from a non-active galaxy, NGC 253 (which is, however, a classic star burster, Goldschmidt and Rephaeli 1995), and the first detection of calcium H and K and sodium D lines in absorption in an SO galaxy (against the emission of SN 1994D in NGC 4526 in Virgo; King et al. 1995). The senior author is often accused (mostly by Geoff Burbidge) of being hostile to new ideas, and so hastens not to comment on the suggestion that spiral galaxies are Abelian Higgs vortices (Samga 1994).

6.11 In and Around Quasars

Our favorite new class of active galaxy is the optically quiet quasar (Kollgaard et al. 1995). They used to be called “empty fields.” Compositions of radio measurements of “radio-quiet quasars” (Kellermann et al. 1994; Blundell and Lacy 1995; Papadopoulos et al. 1995) may sound equally oxymoronic. But, in fact, they represent a triumph of technology over nature. Though the radio powers are a factor of a thousand or more less than those from traditional, radio-loud quasars, such sources are now readily detectable over a wide range of wavelengths. The radio-luminosity function, \(N(L_r)\), is genuinely bimodal. A third favorite item was the discovery that well-studied radio sources are more variable than casually observed ones, and so hastens not to comment on the suggestion that spiral galaxies are Abelian Higgs vortices (Samga 1994).

6.12 In and Around the Universe

Deviations from smooth Hubble flow grow ever larger, even if you neglect the era after recontraction begins (Björnsson and Gudmundsson 1995). The Great Attractor seems to be going with the flow rather than causing it (Mathewson and Ford 1994). The loosest limit published in the reference year was a velocity of less than 0.05 c for the Local Group, based on the relative symmetry around us of QSO Lyman-alpha forest lines (Rauch 1994). Just how rapid that smooth Hubble flow is, we do not propose to say. At least 19 papers reported values of \(H_0\) during the year. Some of the error bars even overlap.

For those of you tired of the hide-bound limits of conventional physics, Harrison (1995) has suggested that non-conservation of energy on cosmic scales is real enough that you could power your computer by connecting distant galaxies with an elastic string and extracting energy as tension develops in it. We think that this is likely to slow the expansion of the Universe by just the smidgeon required to make all the beans come out even when the Creator returns to count them.

7. THE METALLICITY OF H II REGIONS AND THE \(H_2/CO\) CONVERSION FACTOR

These two topics have in common, first, that they ought to be influenced by place-to-place variations in total heavy-element abundance and, second, that the standard answer remains slightly unsatisfactory. H II regions persist in being metal poor relative to the solar system, and many investigations assume a single, fixed ratio to turn observed CO emission into the mass of molecular gas, though carefully observed clouds actually cover a wide range.

7.1 The Metallicity of the Orion Nebula

The Orion Nebula went through a period of having nearly solar composition (Peimbert and Costero 1969; Aller 1972) but has been slipping. The most recent analysis of emission lines leads to an oxygen abundance about half of solar (Meyer et al. 1994). Is the missing stuff in grains? No. There is indeed a good deal of dust, which locks up more than half the atoms of calcium, magnesium, and aluminium (Kingdon et al. 1995), but you can tie up only a couple of atoms of oxygen with each of them, and there were many more oxygen atoms to start with. Since Orion is about the same distance as the Sun from the center of the galaxy but 4.5 billion years younger and we all believe in chemical evolution, this is a bit awkward.

The suggestion that apparently low metallicity in H IIs is an artefact resulting from failure to allow for temperature fluctuations goes back a generation (Peimbert 1967). In the most recent round of fire, Walter and Dufour (1994) said this resolved the discrepancy, while Liu et al. (1995a) and Kingdon and Ferland (1995) said it was a real, but minor, effect in Orion, though of greater importance in planetary nebula (Liu et al. 1995b).

Can one claim that there is still some critical bit of astrophysics missing from the analysis? Perhaps. Dogged attention to the physics—fluorescent excitation in one case and atomic data in the other—has finally dragged the Orion nickel abundance down to normal (Lucy 1995) and the Fe/O ratio to solar, at least in some places (Bautista and Pradhan 1995). Do stars as they form grab more than their fair share of heavy elements out of their parent clouds? Maybe (and if
they lock lots of it up in “Oort cloud” comets instead of returning it to the ISM when star and planet formation is finished, then the missing factor of two is accounted for; Stern and Shull 1990). But the standard mantra is simple “place-to-place variation” (Roy and Kunth 1995). It is indeed true that there exist young, nearby stars with less than solar metallicity (Nordstrom and Johansen 1994; Gimenez and Claussen 1994). Pick a card. Any card.

7.2 The $H_2/CO$ Conversion Factor

Molecular gas in our own and other galaxies consists mostly of cold $H_2$, which Higher Authority neglected to endow with any conspicuous spectral features in any wavelength band. Thus arises the need for tracers, of which CO is by far the most common (and most commonly used). Simultaneous measurements of emission from a couple of its levels can tell you whether there is molecular gas somewhere, what its temperature is, and whether there is more or less in that place than next door. Figuring out the actual total amount is much more difficult. We do, however, really need to know for the purposes of estimating the efficiency of star formation, tracing chemical evolution, and so forth.

The customary approach is to calibrate an average $H_2/CO$ conversion factor and apply it wholesale. Potential calibrators include (a) Virial masses of large clouds, (b) the gamma rays produced when cosmic rays hit gas molecules and make pions that then decay (the cosmic-ray flux is believed to be fairly constant through the galactic disk), and (c) star counts and extinction (optical or infrared) produced by moderately dense clouds. The conversion factor is necessarily to molecules per unit area, since a given CO measurement integrates over all the gas in the line of sight at a given velocity. The units (you are going to love this) are $13$ molecules per square centimeter per unit antenna temperature of CO line in K km s$^{-1}$, that is, $H_2$ cm$^{-2}$K (K km s$^{-1}$)$^{-1}$. Then the mass of a particular cloud is just the two-dimensional integral of the CO profile over the cloud face times the conversion factor.

Naturally, none of the calibrators is foolproof. Not all clouds are in virial equilibrium. The cosmic-ray flux may vary with location. And extinction methods require one to know something about the amount and kind of dust in molecular clouds. You can even create pseudo-disagreement by neglecting to mention whether your conversion factor includes the mass of helium that ought to go with the $H_2$.

Experts in the field disagreed until just a few years ago about the correct value even for clouds near us. Dame (1993) provides a nice discussion of how the issue was sorted out and recommends a standard ratio of $2.3 \times 10^{20}$ H$_2$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$, where earlier work had found values from 2.0 to 3.6. The most important recent development is the recognition/acceptance that the real ratio varies a good deal both within the Milky Way and elsewhere, in ways that (sometimes) make sense in terms of composition and physical state of the gas. To take an extreme example, pure, unpolluted, “big bang” gas would have $H_2/CO=\infty$. (But this is not the answer to why cooling flow gas in X-ray clusters is typically not seen in CO, Ap94 Sec. 10 and Braine et al. 1995a.)

Data from the Compton Gamma Ray Observatory have been used to re-evaluate that form of calibration, with somewhat inconsistent results. Strong et al. (1994) report $2.2 \times 10^{20}$ H$_2$ (K km s$^{-1}$)$^{-1}$ based on COMPTEL fluxes. Hunter et al. (1994) and Digel et al. (1995), on the other hand, find a much lower value, near $1.1 \times 10^{20}$, based on diffuse emission recorded by EGRET (the two latter groups include some of the same people). These gamma-ray values are necessarily rather global averages. Williams et al. (1995) have concentrated on the Rosette nebula, making use of $^{13}$CO measurements as well as $^{12}$CO. They find consistency among the emission fluxes and the Virial mass if and only if $H_2/CO=1.1 \times 10^{20}$.

Most striking are the numbers reported by Magnani and Onello (1995) for an assortment of individual clouds. They used CH emission as an intermediary, and conclude that $H_2/CO$ ratios range from 0.3 to $6.8 \times 10^{20}$ H$_2$ cm$^{-2}$ (K km s$^{-1}$)$^{-1}$ for translucent clouds and 0.8 to $8.6 \times 10^{20}$ for opaque ones, though the average is indeed somewhere around $2-4 \times 10^{20}$, justifying its use for cases where an antenna beam takes in many clouds. Should we be surprised? Taylor et al. (1993) attempted an a priori calculation of what $H_2/CO$ should be under various conditions. The sensitivity to cloud density is fairly low if, as seems probable, CO is excited primarily by collisions with $H_2$ molecules. The temperature sensitivity is, however, large, and CO emission will be much brighter if a cloud is somewhat clumpy, so that cosmic rays can penetrate far in and heat more gas.

Looking outside the Milky Way, we see most conspicuously a correlation with gas composition—lower Z=less CO. The correlation is not, however, as steep as linear. Wilson (1995), for instance, compares IC 10, the SMC, NGC 6822, M33, and M31 and concludes that $H_2/CO$ varies only a factor of 4.6 over a range of 10 in O/H and C/H. NGC 3310, with a metallicity close to that of the LMC, also fits into such a sequence (Mulder et al. 1995). Lequeux et al. (1994) attribute the low ratio in the SMC to CO surviving only in clumps denser than $10^3$ H$_2$ cm$^{-3}$. An extreme case is the dwarf irregular GR 8, in which a non-detection of CO leads to a lower limit on $H_2/CO$ that is at least 30 times the Milky Way average (Verter and Hodge 1995). High values, from 2 to 25 times the galactic ratio, are found in other dwarf irregulars. The correlation with galaxy mass and luminosity, in the sense of little galaxies having high ratios, reported by Boselli et al. (1995), is probably also a composition effect. Not surprisingly, galaxies more or less like ours, including M100 and NGC 4631, have similar $H_2/CO$ ratios (Rand 1995; Braine et al. 1995b).

In contrast, $H_2/CO$ ratios smaller than the galactic one by factors of 2–10 must apply to an assortment of Seyfert, starburst, and IRAS galaxies, because you would find a molecular gas mass exceeding the entire dynamical mass of the galaxy or some other contradiction if you assumed the galactic conversion factor (Shier et al. 1994; Genzel et al. 1995).

Abundances in these galaxies are typically not very well known, and it is conceivable that they are sufficiently metal rich to account for the difference. It is perhaps more likely that the general high level of activity is responsible for more
efficient heating of the CO and so for brighter emission from a given gas mass.

Something similar—extra activity=extra CO flux—may explain the peculiarities of the Virgo spirals studied by Boselli (1995). The authors find two odd effects. The star-formation rate is better correlated with H I mass than with H$_2$; and even noticeably disturbed, interacting galaxies seem to have normal H$_2$ content, although their H I has been lost. Both abnormalities would disappear if vigorous interactions and star formation lower the real H$_2$/CO ratio below the standard value by promoting CO emission.

Finally, the index year witnessed detection of CO in several very high redshift objects, including F10214+4724 at $z=2.28$ (Tsaboi and Nakai 1994), the lensed BAL QSO H1413+117 at $z=2.5$ (Barvainis et al. 1994), and a damped Lyman $\alpha$ absorption cloud at $z=3.137$ in the spectrum of PC 1643+4631A (Frayer et al. 1994). For all of these, application of the galactic H$_2$/CO conversion factor leads to remarkably large masses of molecular gas, but by now we hope you will not be too much disturbed by this.

8. PRIMEVAL GALAXIES

The reference year began with a thorough review of unsuccessful searches (Pritchet 1994) for what the author defined as elliptical galaxies and spiral spheroids experiencing their first, main bursts of star formation. It was not necessary to review the successful searches because there hadn’t been any. Several interpretations were possible. First, maybe it didn’t happen that way because elliptical galaxies were assembled from smaller units in which star formation occurred in smaller, merger-induced bursts. Second it might all have happened behind a dust curtain, at redshifts larger than those yet explored, or under cover of still brighter emission from an active nucleus. Third, the searchers hadn’t tried hard enough. Or, fourth, they were looking under the wrong lamp-post.

The commonest lamppost has been Lyman-alpha radiation at redshifts between 2 and 5, and not looking hard enough there can probably be ruled out by the latest round of (unsuccessful) searches using suitably tuned filters and slit spectra (Pahre and Djorgovski 1995; Thompson et al. 1995; Thompson and Djorgovski 1995). Critics have been simultaneously declaring the lamp to be unlit owing to dust either in the hypothetical galaxies themselves (Dey et al. 1995) or in intervening globs of stuff like those responsible for QSO absorption lines (Madau 1995), though Mannucci and Beckwith (1995) thought there might still be hope for Lyman alpha.

Support for the “really big z” explanation comes from the I-K color of the $z=4.25$ radio galaxy 8C 1435+63 (Spinrad et al. 1995) which, if the light comes mostly from stars, suggests a formation epoch before $z=5$. The alternative lamppost school is represented by an H alpha search, which, however, found only one, previously-known galaxy with the modest star formation rate of 19h$^{-1}$M$_{\odot}$/yr (Bunker et al. 1995), an H I protogalaxy that is not actually at high redshift (Chengalur et al. 1995), and the designers of the GMRT, an enormous meter-wave radio telescope under construction in India. It will see proto-clusters at $z=5-10$ if at least 2.5% of their baryonic mass is in neutral hydrogen (Kuman et al. 1995).

Meanwhile, the secondary scientific press has been on the side of the big PR agents, highlighting three candidate primeval galaxies, found by somewhat different methods, and none precisely corresponding to the original definition of first, major star burst. Frayer et al. (1994) reported CO emission at the redshift of a damped Lyman-alpha absorber at $z=3.137$, a record high redshift at the time. It is also a record mass of molecular gas, 4.5x10$^{12}$ M$_{\odot}$, hence the relationship with primeval galaxies, if the standard factor for converting CO emission into H$_2$ mass (Sec. 7.2) is correct. We should perhaps call this a primordial rather than primeval galaxy, since starlight has not been seen. Second comes 2.4x10$^{11}$ M$_{\odot}$ of molecular gas (again based on CO) in a quasar host galaxy at $z=2.5$ (Barvainis et al. 1994). And the third is a $z=2.5$ faint red galaxy with strong H$\alpha$ and [N ii] emission at the same redshift as absorption lines in a background QSO (Malkan et al. 1995). Two more candidates are also high redshift active galaxies with lots of gas, seen directly as CO (Yamada et al. 1995 on Q1235+0857) or indirectly as re-emission by dust at far infrared and millimeter wavelengths (Ivison 1995). Absorption line clouds themselves are typically not strong Lyman-alpha emitters (Deharveng et al. 1995).

And so, as the Sun pulls away from the shore of the realm of primeval galaxies and our ship sinks slowly in the west, it seems that no candidate yet actually corresponds to Pritchet’s (1994) definition.

9. UNDISCOVERIES AND UNRELATED TOPICS

Some things are seldom what they seem, and others never were.

9.1 0918-0023B

This object of unmemorable name had a brief, happy life as a brown-dwarf candidate based on its very red J−K color, before it turned out to be a compact galaxy (Becklin et al. 1995). This somehow makes up for the periodically variable Seyfert galaxy that was really a cataclysmic binary star (Ap94, Sec. 13).

9.2 FSC 10214+4724

This anomalously bright IRAS source appears briefly in Sec. 7.2 as an example of possibly anomalous H$_2$ to CO ratio. It is, however, very probably a Seyfert 2 galaxy at $z=2.28$, gravitationally lensed by a giant elliptical galaxy at $z$ near 1. In this interpretation, the actual galaxy remains fairly spectacular, but not unique. The implied molecular mass doesn’t change much, because the CO emission is too extended for lensing to make much difference to the flux we see (Graham and Liu 1995; Broadhurst and Lehar 1995; Scoville et al. 1995).

Gravitational lensing is also plausibly to blame for QSOs with absorption lines looking on average brighter than the others (Drashik and Drashik 1995) and for assorted apparent correlations on the sky of quasars and galaxies with different redshifts (Thomas et al. 1995; Zang 1995; Benitez and...
Martinez-Gonzalez (1995), though Wu and Han (1995) and, presumably, Arp (1995) disagree. And contemplation of one of these papers led us to realize, as you undoubtedly already knew, that a number of common Hispanic surnames, like those in lots of other languages, were originally patronyms.

9.3 The Incredible Shrinking Galaxy

We both took our first graduate astronomy courses precisely 10 kpc from the galactic center (Oort 1964) and moved only with some reluctance inward to 8.5 kpc when the IAU insisted (Kerr and Lynden-Bell 1986). It is therefore a cause of some distress to note that most of the papers on the subject published during the index year encourage additional relocation somewhere around 8 kpc, according to van de Steene and Zijlstra (1995) and Zhang (1995) who used a new distance scale for planetary nebulae;

7.5 ±1.0 kpc, according to Nikiforov and Petrovskaya (1994), who calibrated the galactic H I rotation curve anew with distances to H II regions;

7.1 ±0.5 kpc, according to Dambis et al. (1995), who made use of distances and three-dimensional velocities of Cepheid variables; or even

7.0 ±0.5 kpc, according to Rastorguev et al. (1994), who looked at globular clusters; and to think Harlow Shapley got 20 kpc or more that way!

The only consolation comes from the 8.9±0.7 kpc found by Glass et al. (1995) who made used of Mira variables in the galactic bulge. It is left as an exercise for the reader to figure out what these numbers mean for the galactic mass to light ratio, the ages of globular clusters, and other parameters of mystical significance.

9.4 A Gaggle of Galaxies, Mostly Nearby

Our inventory of galaxies in incomplete, even up close. This is obvious statistically from the fact that 21 cm surveys of objects in optical catalogues find an average H I mass that increases with distance, even within 3000 km/sec (Gallagher et al. 1995). It is still more obvious from the continuing discoveries of new neighbors. Ap94 recorded the appearance of the Sagittarius dwarf only about 20 kpc from us. It now has several globular clusters of its very own (Sarajedini and Layden 1995; Da Costa and Armandroff 1995). Nothing quite so proximate has turned up this year, but the Pegasus dwarf irregular has moved inside the Local Group (Aparicio 1994), and (like an inventory of what is being worn by the upper classes), LGS 3 and WLM are In; UGCA 86 is Out; and EGB 0427+63 is hovering (Hodge and Miller 1995; Lee 1995).

In the 1–3 Mpc range, Dwingeloo 1, a 21 cm discovery by Kraan-Korteweg et al. (1994) and two companions to Maffei I (McCall and Buta 1995) have joined the throng. And “moving right along,” the distance out to which we know that dwarf spheroidals are the commonest sort of galaxy now extends as far as the Coma cluster (Karachentsev et al. 1995).

On the fringes of the local supercluster lurk the nearest voids. Not only are they not entirely empty (known for some time), but they contain a range of galaxy types not so very different from those found in more populous regions (Weistrop et al. 1995; Hopp et al. 1995; Pustil’nik et al. 1995; Thorstensen et al. 1995). Since no model of galaxy formation had predicted this mix, the finding “justifies the existence of observers,” in the words of one of the authors just cited.

At the other extreme, we note the most distant (to date) radio galaxy, 8C 1435+635 at z = 4.25 (Lacy et al. 1994) and the most distant E+A galaxies (meaning ellipticals still recovering from a star burst, so that they show a combination of A-type spectrum and normal giant elliptical features) at z = 0.82 and 0.895 (Thimm and Belloni 1994).

Who has the most galaxies? Well, if the field imaged with the Keck telescope by Smail et al. (1995a) is typical, there are 3 × 10^10 over the whole sky, almost as many as the 10^11 one feels should be in the “observable universe” on the basis of local number densities.

9.5 Humans 6—Neural Networks 1

Actually the score should probably be phrased the other way around, since one neural network has been taught to classify galaxy images in the same way and about as accurately as six people (Naim et al. 1995). And the people were experts: Ronald Buta, Harold Corwin, Gerard de Vaucouleurs, Alan Dressler, John Huchra, and Sidney van den Bergh. Neural network techniques have also been applied to the classification of stellar spectra (Weaver and Torres-Dodgen 1995) and to enough other problems to generate a first conference on the subject (Lahav and Storrie-Lombardi 1995).

In a competition whose protagonists are even less likely to take an interest, Lagrange and Euler (or at least their modern imitators) are battling it out over whose methods do a better job of simulating the formation and evolution of large scale structure in the universe (Munshi et al. 1994; Susperregi and Binney 1994; Bouchet et al. 1995).

In a couple of more unequal battles, Chandrasekhar (Hazelhurst 1994) and Eddington (Lamb and Miller 1995) were declared to have triumphed over the field.

9.6 What Have You Done With....

The Great Dark Spot on Neptune, as seen by the Voyager encounter in 1989. It was gone by the time HST returned a post-fix image (Hammel et al. 1995b). There was, however, a new spot in the north, and the banding hadn’t changed much.

The White Dwarfs in the Hyades, of which 28 are expected and only 8 seen (an old result). In addition, Böhm-Vitense (1995) had expected to find three as ultraviolet (IUE) companions to A and F stars, but found zero. This latter deficiency, at least, cannot be the result of stars evaporating from the cluster.

In contrast, globular cluster white dwarfs are increasingly present and accounted for in HST images (Paresce et al. 1994 on NGC 6397; Elson et al. 1995 on ω Centauri; Richer et al. 1995 on M4). The M4 sample is large enough to say that the luminosity function and colors over the absolute magnitude range +9 to +12 are just about what you would expect from the numbers of turn-off stars and cooling theory for white dwarf main sequence stars.
dwarfs of $0.5M_\odot$ in their first $3\times10^8$ yr. Much fainter images will be needed to probe the critical cooling age range of $5-15\times10^8$ yr. We note, however, that a contradiction has already arisen for a couple of open clusters with ages near $10^9$ yr, for which the white-dwarf data from HST are inconsistent with other isochrone-type age indicators, no matter whose models you use (von Hippel et al. 1995).

The Oceans of Titan. They haven't exactly evaporated, but liquid hydrocarbons can be present on the surface only in localized lakes and seas or tidal dissipation in them would have circularized the Titanic orbit (McDermott and Sagan 1995).

The $^{44}$Ti Gamma Ray Line from Supernova Remnant Cas A. This indicator of recent nucleosynthesis there was reported on the basis of COMPTEL data, but has not been confirmed by the independent OSSE data set (The et al. 1995). The two results are inconsistent at the 98% level.

Socket Stars. These seemed to be an interesting class of object that had affected the surrounding interstellar medium more than you would expect (Feibelman 1989). They turn out to be an artefact of photographic image processing (dodging) and of chance coincidences (Schaefer 1995).

Basalt on the Surface of Mercury. It is sparse or non-existent, and the crust consists mostly of feldspars and such (Jeanloz et al. 1995). The implication is a complex history for the planet, with melting and differentiation after a hypothetical initial mantle was removed by impacts during the era of bombardment.

The Great Annihilator. Electrons and positrons are wiping each other out all over the place every day, but it is not entirely clear that there really is a highly variable, compact source near the center of the Milky Way (Harris et al. 1994; Ap91, Sec. 7).

The Red Halo of Galaxy IE 1111.0-3743. This might have been evidence for red or brown dwarfs as dark matter (Maccagni et al. 1989), but a deeper image has not recovered it (Joy et al. 1995).

A Periodic Universe. It would now have to have a cell size of at least $4320h^{-1}$ Mpc, larger than the horizon size, to avoid detectable effects in the microwave background radiation recorded by COBE (de Oliveira-Costa and Smoot 1995) Thus the model is no longer particularly interesting. In contrast, the standard model looks better as time goes on, revealing that COBE and ground-based observations see the same fluctuations in the radiation and that they show Planckian spectra (Lineweaver et al. 1995; Gunderson et al. 1995; Bond 1995). Furthermore, the known dipole anisotropy cannot be a real isocurvature or adiabatic perturbation in the expansion of the universe, or the associated quadrupole distortion would be larger than the observed one (Jaroszynski and Paczynski 1995). This leaves the conventional interpretation of the dipole as a reflection of our own motion relative to the surface of last scattering.

Dr. Millimoss. Any reader who has information on his whereabouts is urged to communicate with us immediately.

10. BE MY HOST—THE GALAXIES OF WHICH QUASARS (ETC.) ARE THE NUCLEI

The discovery of quasars (Hazard et al. 1963; Schmidt 1963; and two papers immediately following) quickly spawned the suggestion that they were associated with bright galaxies (Burbidge et al. 1963) by analogy with Seyfert and N-type galaxies, known since 1943 and 1958, respectively. (See Trimble 1992 for a more extensive history.) That this would put quasi-stellars at the distances indicated by their redshifts was emphasized by Greenstein and Schmidt (1964), who showed that the alternative of a gravitational redshift was not tenable.

The counter-proposal of local quasars quickly followed (Arp 1966; Hoyle and Burbidge 1966). These first three proponents remain the most conspicuous advocates of local quasi-stellars down to the present, though no very clear mechanism for producing large redshifts nearby has ever been added to the argument.

The opposing ideas make at least one clear prediction. If QSOs (meaning both radio-loud and the more common, radio-quiet ones) are nuclei of normal galaxies, then you should be able to see the galaxies and their near neighbors by working hard. If not, not. The hard work is unavoidable. Quasars have, as a rule, large redshifts and are, by definition, themselves bright. This means you will be looking for a few slightly diffuse photons in company with many more point-source, but spreadable, ones.

A handful of hard workers had put several faint quasars and at least one very bright one within the confines of clusters of galaxies at the same redshifts by 1972 (Bahcall et al. 1969; Gunn 1971; Robinson and Wampler 1972; Oemler et al. 1972). Fuzz of the right size and color to be bright elliptical galaxies surrounding the point sources followed shortly (Kristian 1973).

Most of us then lost interest in the problem for roughly 20 years, though acquiring at some point along the way (perhaps subliminaly) a strong feeling that radio-loud quasars are the nuclei of large elliptical galaxies, like the lower-redshift strong radio sources from 3C and other catalogs whose optical counterparts really are gEs, while the radio-quiet ones are inside spirals (by analogy with Seyfert galaxies).

Interest revived with the advent of HST and its potential for resolving faint structure close to bright points, perhaps to the extent of revealing host morphological types and permitting redshift measurements. A handful of relevant papers appeared during the index year, and most of the publicity has focused on non-detections or unexpectedly faint detections of hosts of about ten assorted radio-loud and quiet QSOs.

But let's start with the non-controversial bits. Seyferts and LINERS are still spirals (Moles et al. 1995; McLeod and Riecke 1995), often with companions, while radio galaxies are still ellipticals, despite one major false alarm (Veron and Veron-Cetty 1995; Colina and de Juan 1995).

Ground-based optical and near-infrared observations of "objects generally recognized as QSOs" continue to show a general pattern of radio=elliptical and brighter than $L^*$ (the bend in the luminosity function of galaxies), while radio quiet=spiral and rather fainter, though both are likely to
have emission lines (Durret et al. 1994; McLeod 1995; Lowenthal et al. 1995; McLeod and Riecke 1995). The maximum redshift for quasar fuzz seen from Earth has grown to \( z = 2.3 \) (Aretxaga et al. 1995), and a host was even found for one radio-loud BL Lac object (Falomo et al. 1995). It has both bulge and disk components.

Next come a few objects that used to be called radio galaxies (more or less elliptical in shape) or IRAS galaxies (any old shape, with lots of dust and gas), but which have recently been promoted to quasars on the basis of broad absorption lines or evidence for hidden nuclei, analogous to Seyfert 2 galaxies being Seyfert 1's with hidden cores (Sec. 7 of Ap92). The best-known is Cygnus A (Antonucci et al. 1994), followed by 3C 22 (Economov 1995) and some IRAS galaxies (Lonsdale et al. 1995). Since we already knew about the galaxies in these cases, if they are really quasi-stellars on luminosity or other grounds, then they clearly have hosts!

This brings us to the boundary of the Hubble Space Telescope era. The first message from across the border was negative—no extended emission around four QSOs \( (z = 0.16 \) to 0.24) down to 0.5 to 1.4 mag fainter than \( L^* \) (Bahcall et al. 1994). No subsequent report has been quite so bleak. Hutchings and Morris (1995) went two for two (one radio loud, one quiet) at \( z = 0.3 \). The shapes and luminosities of the fuzz are at least consistent with giant ellipticals. Bahcall et al. (1995a) reported their first bit of fuzz for a radio-emitting object at \( z = 0.17 \), along with a companion galaxy of unknown redshift, but having a luminosity about that of the Large Magellanic Cloud if it is at the quasar distance.

An independent observation of four low-redshift QSOs (Disney et al. 1995) found extended emission (resembling giant ellipticals) and evidence of close companions for all of them. The first sample at \( z = 2.3 \) (Hutchings 1995) had five hits out of six tries. The extended emission is consistent with normal, bright galaxies, and the radio-quiet hosts are fainter than the radio-loud ones by about 2 mag.

A more extensive report from Bahcall et al. (1995b) contains a detailed discussion of the image processing. It concludes that nothing has been done that might erroneously have wiped out real host galaxies. Of their eight galaxies, three have extended emission 0.2 to 1.7 mag brighter than \( L^* \) and the others have limits fainter than \( L^* \) by 0.5 to 1.9 mag. A statistically significant excess of companion galaxies is also evident in this sample. One QSO has been observed by both Disney et al. (1995) and by Bahcall et al. (1995b). The former report detection at \( m_u = 18.0 \), the latter an upper limit somewhere in the range \( m = 17.9 \) to 21.0. This is almost, but not quite, a contradiction. A little preprint-bird has told us that at least two more papers by Bahcall and his colleagues are currently on the way, reporting two galaxies slightly brighter than \( L^* \) around a couple of not very famous radio-quiet QSOs and detailed morphology of the galaxy around 3C 273.

What does all this mean? At first, of course, there was rejoicing and "I told you so"-ing from the local camp over the negative results. That seems to have died down. Within the conventional camp, many theories of large-scale structure formation predict that the largest, densest lumps are the first to acquire their identities and do whatever (proto) galaxies have to do to become QSOs at high redshift. Thus one probably expects the hosts of the highest redshift active nuclei to be very bright, massive galaxies (or objects that will evolve into very bright, massive galaxies). But as time goes on, those first QSOs die off and are (incompletely) replaced by ones forming in other galaxies or galaxies to be (cf. Blandford and Rees 1992). Living as we do at very small redshift, we should not be too surprised to find that QSO hosts are mostly fairly average galaxies (in accordance with central black holes having apparently turned up in some fairly average galaxies). Within this framework, 3C 273 is a sort of survivor from the past and illustrates the well-known principle that prototypes are hardly ever typical. After all, Beta Lyrae probably isn't a Beta Lyrae star (De Greve and Linnell 1994).

## II. X-RAY CLUSTERS AND THE BARYON DENSITY PROBLEM

Trying to figure out the average mass density of the Universe and to identify all the entities that contribute to it are elderly problems, dignified by many review articles and conferences, usually with the phrase "dark matter" in their titles. This is another one (mercifully short by the standards of the genre), focussed on the specific issue of whether you end up with a contradiction by considering simultaneously the baryonic and total masses of clusters of galaxies and the upper limit to baryon density permitted by observed amounts of the products of big-bang nucleosynthesis.

The answer will be yes if you simultaneously believe (a) that many clusters have 20%–30% of their mass in gas and that the error bars on \( M_{\text{baryon}} / M_{\text{total}} \) for them are small, (b) that these clusters represent the ratio for all mass in the Universe, (c) that you cannot make the right amounts of helium, deuterium, and lithium if the baryon density is more than about 10% of the closure density, and (d) that the total cosmic density is indeed the one that just closes the Universe (stops its expansion in infinite time). The more of these you are prepared to give up, the smaller the problem. Only first-time (and perhaps last-time) readers will be surprised to hear that we are not exactly worried to distraction.

Recent papers that reported a contradiction (that is, 20%–30% of total cluster mass in X-ray gas (White and Fabian 1995; Elbaz et al. 1995; Davis et al. 1995) naturally attracted more attention than papers that concluded all was well (that is 10% or less of the total mass in hot gas, Bryan et al. 1994; Dell’Antonio et al. 1995). Rich and poor clusters appear in both classes. Davis et al. (1995) report, however, that small groups store most of their baryons in galaxies and rich clusters in gas. The same paper concludes that the gas is less centrally condensed in the clusters than is the dark matter. This is generally taken as an argument against the obvious interpretation that rich clusters simply have a good deal more than their fair share of baryons.

What is the evidence; how is it derived; and what do we have to believe? For the first 33 years, all studies of cluster masses made use of velocities of member galaxies measured from optical spectra (Zwicky 1933 on Coma; Smith 1936 on Virgo; and a countably infinite number of later workers). Only one velocity component, along the line of sight, can be
measured this way. Thus you learn a mass only by making some dynamical assumption. The commonest is an isotropic velocity distribution. If the galaxy orbits are really mostly radial, your answer will be too big, and if they are mostly circular, too small, by factors of about three in each case. Contamination by foreground or background galaxies or real, unrelaxed substructure in the clusters will always push the derived mass upward above the correct one. The integrated brightness of the galaxies tells you the amount of stellar baryonic material in the cluster, but this is normally a small part of the total mass for rich clusters.

A second window opened with the report of diffuse X-rays from Zwicky’s Coma cluster by Boldt et al. (1966). Feltén et al. (1966) quickly modeled the emission as thermal bremsstrahlung from intracluster gas. X-ray data can tell you both the mass of the emitting gas (from the total X-ray flux, its spectral temperature, and some assumption about degree of lumpiness) and the total mass of the cluster (because its potential has to be able to confine gas at that temperature). X-ray analysis is not subject to errors from either interlopers or anisotropic velocity distributions. Feltén et al. tried putting the entire binding mass of the cluster in the form of smooth, $1-2 \times 10^8$ K gas and found this consistent with the X-ray flux seen. They recognized, however, that lumpy gas could produce the same flux from a much smaller mass of gas (since emissivity scales as $n_e^2$) and that variations in temperature could either raise or lower the amount of gas needed. Modern discussions of X-ray emission from clusters usually incorporate such variations, often associated with substructures visible in the pattern of galaxies on the plane of the sky.

Our third handle on cluster masses is a much more recent one, coming from distortions of the apparent shapes of galaxies located behind the clusters, otherwise known as weak gravitational lensing (Tyson et al. 1990). The background galaxies look like small arcs of circles centered on the foreground cluster, and the amount of distortion is proportional to the mass of the cluster interior to point where photons from the background galaxy pass closest to it. Such lensing reflects the real distribution of mass in the cluster even more directly than does the X-ray flux. For instance, it makes no difference whether the cluster is virialized or not. Nor is the derived mass very sensitive to the assumed shape of the galaxies being lensed. It is, however, quite sensitive to the shape of the lens, in the direction that an elliptical cluster, if unrecognized as such, will seem more massive than it is (Schramm and Kayser 1995; Bartelmann 1995).

Now, obviously, at the end of the day, a correct analysis of a given cluster must find the true total mass (and gas mass if appropriate), at least out to some particular radius where the data give out, whichever method or combination of methods is used. The subject has not reached that level of accuracy yet. Talks at conferences leave the impression that practitioners of each of the three techniques feel that only their own is fully reliable. We suspect that this also affects how authors phrase their conclusions but have made no attempt at normalization in the paragraphs that follow.

First, a few authors conclude that substructure in clusters is rare and that two or even all three methods often yield consistent results without any need to modify standard, simple models (Girard et al. 1995; Gerbal et al. 1994; C. M. Bird et al. 1995; Smail et al. 1995b).

A second group has focussed on substructure and non-equilibrium distributions of galaxy velocities and gas temperatures and densities and found them both common and important (Markevitch et al. 1994; Roettgering et al. 1994; Henry and Briel 1995; Davis et al. 1995b; Slezak et al. 1994). Most of the messiness seems to be the aftermath of mergers that assemble rich Abell clusters. Some may be g mode structure in just the gas (Lafkin et al. 1995). Deviations from simplicity can go both ways. Lumpy, turbulent gas with a non-thermal pressure component will give you an incorrectly high impression of gas mass and incorrectly low impression of total mass. Zabludoff and Zaritsky (1995) and Kim et al. (1995) address the implications for clusters with mergers or cooling flows. A merger product can have a non-equilibrium velocity distribution, and so seem more massive than it is, even after obvious substructure on the sky has disappeared (Crone and Geller 1995). Conversely, a fully relaxed cluster can have the velocity dispersion of the galaxies 15% or so smaller than that of the dark matter (whatever it is), making your estimated mass too small (Carlberg 1994a). The phenomenon is called velocity biasing, though naming it is not quite the same as understanding it.

Third, there is considerable agreement that, when you use both weak lensing and some other method to trace out mass distributions, the total mass found from lensing is always the biggest, often by factors of three or more (Loeb and Mao 1994 on Abell 2218; Fahlman et al. 1994 and Carlberg 1994b on MS 1224; Wu 1994; Miralda-Escude and Babul 1995). The implied mass per galaxy is sizable, something like $8 \times 10^{12} M_\odot$ (Fahlman et al. 1994). But the X-ray emission from two Coma galaxies suggests that this really is the right answer, at least some of the time (Vikhlinin et al. 1994).

If you decide that lensing by clusters provides the most accurate measurements of their masses, then results from the other two approaches can be reconciled by saying, first, that the velocity dispersions of the galaxies have been affected by velocity biasing (i.e., are too small), and, second, that the X-ray gas has a good deal of non-thermal pressure support, so that the X-ray temperature is an underestimate of what the gravitational potential has to confine. Turbulent pressure support is particularly likely to be associated with density fluctuations, in which case the implied amount of hot gas goes down at the same time the total mass goes up. Under these circumstances, even clusters that appear from their X-ray properties to be 20%–30% gas could be typical without presenting a problem.

Three stray ends remain to be tied up. These concern possible flexibility in the nucleosynthesis limit, gas not confined to clusters, and the real value of total cosmic density.

The main-stream view remains that $\Omega_b h^2 = 0.009$ to 0.024 (Copi et al. 1995a; Linsky et al. 1995). Larger error bars on observed quantities permit expansion of the range in both directions, upward to at least 0.2 (Sasselov and Goldwirth 1995), though the observations may really not be that poor. The ratios of the products vary if you include the possibility that the Universe was inhomogeneous at the time the $^4$He,
3He, 4He, and 7Li were formed (Jedamzik et al. 1995), though not by very much (Copi et al. 1995b). Additional flexibility comes from allowing for a possible degenerate sea of neutrinos or anti-neutrinos (Kim and Lee 1995). We have been hoping for several years that someone would do a modern version of this calculation, originally advocated by Fowler (1971) under the title “How now, no cosmological helium?” It is particularly interesting that neutrinos with a high chemical potential can reduce the primordial helium abundance a few percent, while leaving the other products more or less unchanged from the standard model. A residual problem in integrating the whole picture is that the amount of 3He seen around us is rather less than you would expect from cosmological production plus converted deuterium minus destruction in stars (Palla et al. 1995).

Next, there is certainly to be some diffuse gas between the clusters, and there could, of course, be enough to get us right back into a contradiction. Ap94 (Sec. 5.9) and Ap93 (Sec. 8) drew attention to evidence for diffuse and clumpy gas at high redshifts. How much, if any, of the former has been seen remains in dispute (Zheng and Davidsen 1995; Reisenegger and Mirada-Escude 1995). But there is reasonable agreement that gas clouds, pre-galactic or not, seen as absorbers of quasar light probably contain an appreciable fraction of the total allowed baryon density at redshifts of more than 1–2, and that much of it has been turned into stars and galaxies since (Rauch and Haehnelt 1995; Lanzetta et al. 1995). It is of interest in this context that a couple of moderate-redshift X-ray clusters may have lower values of \( M_{\text{gas}}/M_{\text{total}} \) than the ones here and now (Donahue and Stocke 1995; but see Luppino and Gioia 1995 for a contrary view).

Finally, is the Universe closed? We don’t pretend to know. But the density of material revealed by dynamical studies adds up to 20%–30% of the closure value (Bahcall et al. 1995). Thus, coming at the problem from the other side, evidence that half or more of the total mass of typical clusters was baryonic would lead us back into a contradiction in the sense described at the beginning of this section.

12. YOU READ IT LAST HERE

This section consists of items that could have been written up anything from one to one hundred (or more) years ago. The intellectual tone is set by a 1995 re-enactment (reported in Nature, 376, 372) of the discovery of solitons by John Scott Russell. Waves of this shape-preserving type were first noticed on the Edinburgh Grand Canal in 1834, when a horse was pulling a barge along it. The report of the re-enactment nobly refrains (as we shall not) from mentioning (a) that this was presumably the first scientific discovery ever made by a whole horse, and (b) that this joke surely goes back to ancient Roman times, when Caligula’s fellow citizens, informed that Incitatus had been named to serve as consul four years ahead, consoled each other that it would be the first time they had had a whole horse as consul. In case you wondered, Incitatus never actually served, owing to the sudden decease of his mentor, whom he survived.

12.1 Emission Lines in Stars

It took a long time for these to be regarded as important. The classic 1926 two-volume astronomy text by Russell, Dugan, and Stewart devotes only a couple of pages to them, and has the basic physics badly wrong, though they were 80 years old then. The first report came from Huggins (1866) and Huggins and Miller (1866), based on their observations of the recurrent nova T CrB, seen from Tulse Hill, London, about 16 May. Secchi’s (1866) discovery of Gamma Cas followed shortly. Georges Rayet and C.J.F. Wolf were later.

12.2 Blue Stragglers

Stars on the part of the main sequence brighter and bluer than the nominal turn off go back to Sandage’s (1953) PhD dissertation, but the name came a little later (Burbridge and Sandage 1958) and did not fully triumph until about the time of a 1965 conference on magnetic and related stars (Cameron 1967). Embarassingly, we now find that this topic (Ap91 Sec. 5) also counts in the “prediscovery” category. Though Sandage’s work is normally cited as the first to find blue stragglers (which he called “main-sequence stars brighter than \( M_p = +3.5 \)”), Coma Berenices and Praesepe each have one clearly shown in HR diagrams published by Weaver (1952) and Eggen (1951). Sandage, incidentally, attributed his handful to “absence of composition discontinuity,” which leads us inexorably to the next item.

12.3 Why Stars Become Red Giants

Because the equations say so is the only answer that everyone agrees upon, and it is somehow not emotionally very satisfying. The first entry in the competition was a discontinuity in mean molecular weight outside the core in which hydrogen had been completely burned to helium (Opik 1938; Hoyle and Lyttleton 1942). The most recent (Renzini and Ritoso 1994) is increased envelope opacity. This means that the phenomenon is a purely local one. The same applies, they say, to envelope contraction after helium ignition, for instance.

12.4 The Cause(s) of Pulsar Glitches

Early entries in the field were starquakes (Pines and Shaham 1972), whose greatest charm was being easy to understand and subject to straightforward tests (which they failed), and at least one even more purely mechanical model (Rees et al. 1971) that gave the Crab pulsar a planet (does this count as a prediscovery?). But uncoupling and recoupling of neutron superfluid vortices from and to the charged component and magnetic field has been the standard for a decade or so (Pines and Alpar 1985). It is generally credited to Anderson et al. (1982) or some other combination of the same authors. Hence our surprise at reading “The sudden speed changes observed in the Vela and Crab pulsars may be caused by transitions between metastable flow states in the superfluid interior of the star” as the (complete) abstract of a 1972 letter by Packard (1972). A recent entry in the glitch sweepstakes is “the total Magnus force [which] brings about
collective uppinning of frontier vortices” (Mochizuki and Iizumiyama 1995). Now if only they had told us who Magnus was.

All papers on neutron-star structure before 1968 obviously count as predictions, and a surprising fraction of them are worth re-reading. Just now, however, we are struck by a pair that predicts the neutrino flux from a single core-collapse (supernova) event (Zeldovich and Guseinov 1965) and then addresses the detectability of the background flux due to the sum of all past events (Guseinov 1966). A bit esoteric you say? Well, one of us has just accepted for Another Journal a paper on precisely that issue. And the earliest cited discussion is 1984.

12.5 AC vs. DC

Thomas Alva Edison, though he invented devices that used both, strongly preferred direct current. This prejudice influenced the development of the electric chair, and, shared a generation later by Carl Norden, retarded the development of his bombsight (McFarland 1995). Astronomers are great exponents of “both please” (Ap93, Sec. 10), and the standard model of resistive heating of the solar corona has both DC and AC components (Ionson 1985). Narain and Kumar (1995) have confirmed that the AC modes are most important for long loops and dissipation times and the DC for short loops and dissipation times. Come to think of it, we supposed we ought to have known this. After all, the great triumph of AC for terrestrial purposes is its relative ease of transport over long distances.

12.6 We Don’t Remember that Year Very Well

This is a Mickey Mouse’s handful of things that began earlier than we thought. For instance, wasn’t speckle interferometry invented by Antoine Labeyrie of CERGA, (for which he won the 1990 Tinsley Prize of the AAS)? Apparently not. It was discussed by Ramachandran (1943). The paper has been recently reprinted in the Journal of Astrophysics and Astronomy; we wish they had said what has become of the author in the intervening 52 years.

Fritz Zwicky often claimed to have been the first to think of things. There is, at any rate, not much time for competitors between Hubble’s discovery of systematic galaxy redshifts and Zwicky’s (1929) blaming it on tired light. Domain walls are two-dimensional singularities left behind by phase transitions and symmetry breakings in the early Universe. (Zero-, one-, and three-dimensional ones are monopoles, strings, and textures, respectively.) That you can’t stand having very many around went from new discovery to aged hat in the last five years or so. But Zeldovich et al. (1974) knew it decades ago.

The Sun is very close to 15 pc north of the galactic mid-plane (Cohen 1995), when that plane is defined by counts of stellar sources observed with IRAS and FAUST. Using only optical data, van Tulder (1942) said it was $13.5 \pm 1.9$ pc.

12.7 They Don’t Remember that Year Very Well

And, for balance, here are a similar number of ideas that we remember go back further than recent authors thought.

RS CVn stars are close binaries with emission lines coming from one or both of two slightly evolved F-G components. Anyone (e.g., Eker et al. 1995) who wants to place recognition of the class as interesting earlier than Dan Popper’s (1970) talk at IAU Colloquium 6 will need to obliterate a table of examples of the class from the proceedings of the colloquium.

Dalton and Sarazin (1995) are undoubtedly correct in concluding that Wolf-Rayet stars are formed preferentially in binaries. But they have caught only one of the two 1967 papers that first said so, missing out Paczynski (1967). No heads can be held up very high on the issue of the positive total energy of red-giant envelopes when you include the ionization energy and how this might apply to ejection of planetary nebulae. We (Ap93, Sec. 4) mentioned one of the 1967–68 rediscoveries of the idea. Wagenhuber and Weiss (1994) mention another (Lucy 1967). But we all left out Roxburgh (1967). For the fourth item in this section, you have a choice of several rediscoveries, including line locking in quasars, an assortment of instabilities in dwarf novae, and the existence of solar limb darkening. But it doesn’t matter which you pick, because, of course, effects are always named after the last person to notice them. This used to be the Bobrowsky effect, because Matt Bobrowsky mentioned it to us a while ago. But it is now the Trimble–Leonard effect.

12.8 The Clue of the Second Parameter

We have put off for so many years saying something about the second parameter for globular clusters that you probably already know the answer. Age is a second parameter, but it is not the only second parameter. Now, what was the question?

The color–magnitude diagrams of globular clusters are all rather similar and different from those for disk stars (Baade 1944). They are not, however, identical. The first thing you notice, after dereddening, getting a good distance, and otherwise tidying up your data is that some have all branches (main sequence, red giants, horizontal branch) redder than others. This is a metallicity effect, as has been known for all or most of our lives (e.g., Morgan 1956; Helfer et al. 1959).

The next level of subtlety comes when you compare clusters that all have the same metallicity, as measured by [Fe/H], the abundance of iron relative to the solar abundance. They are still not quite all the same (van den Bergh 1965). Some low metallicity clusters have redder horizontal branches than you expect (Sandage and Wildy 1967), and a few, like NGC 2808, have HB stars extending both too red and too blue for their metallicity. Historical candidates for the second parameter have included (a) variations in initial helium abundance, (b) dynamically important rotation or magnetic fields (both of which affect the mass of the helium core that is burning in HB stars), (c) non-solar ratios of CNO/Fe (affecting the atmospheric opacities and CNO cycle hydrogen burning), and (d) age. For a number of years, (c) was the most popular second parameter, but it was finally ruled out by the demonstration that a classic “second parameter pair” NGC 288 (blue HB) and NGC 362 (red HB) have essentially identical CNO/Fe ratios (Dickens et al. 1991).
By the time of Ap92, consensus had nearly developed that
age was “the” second parameter (Bolte 1992; Da Costa et al.
1992; Armandroff et al. 1992). It goes in the direction of
clusters with red horizontal branches being younger. A dili-
gent attender of conferences would, however, already have
realized that it was not the only second parameter. Some still
totally unknown piece of physics must be affecting mass loss
between main sequence and helium burning to account for
the bimodal horizontal branch of NGC 2808 (Rood et al.
1993). This process must also be important for understanding
the blue and ultraviolet excesses in elliptical galaxies and
such (a point to which we will return).

Stepping forward to papers from the index year, we dis-
cover that things haven’t changed very much. Age is unques-
tionably an important determinant of globular cluster color–
magnitude diagrams, and it is correlated with orbit
parameters of the clusters (Da Costa and Armandroff 1995)
and with metallicity (Sarajedini et al. 1995; Samus et al.
1995).

But it is not the only second parameter. Catelan and de
Frietas Pacheco (1994) have returned to the classic pair NGC
288 and 362 and find that you cannot fit them both with the
same composition and different ages, no matters whose evo-
olutionary tracks you choose. They reach a similar conclusion
for M3 and M13 (Catelan and de Frietas Pacheco 1995).
Kraft et al. (1995) address the anticorrelation of oxygen and
sodium abundances in stars of several clusters, finding that it
is not a unique function of horizontal-branch morphology,
and so must somehow be responding to a third parameter.

Gregg (1994) opts for four—metallicity, age, CNO/Fe,
and a dynamical factor that he describes as the number of
coalesced binary stars in clusters that have gone through core
collapse. Something similar is implicit in the color gradients
found for NGC 5946 and 7099 by Davidge (1995). The
stubby red-giant branches of four low-metallicity clusters in
the galactic bulge (Kavelaars et al. 1995) also suggests the
existence of another, unknown (dynamical or environmen-
tal?) parameter, as advocated by Buonanno (1993).

One is tempted to run on from here in two different di-
rections to explore (a) how, if at all, the various second pa-
rameters fit in with other measured properties of globular
clusters and (b) to explore analogous phenomena in other
populations, including the field, dwarf-spheroidal galaxies,
and giant ellipticals. Stepping vigorously out on the left foot,
we note that something like 13 quantities describing structure,
location, etc. of the clusters can be correlated to yield a
three-dimensional family (Djorgovski and Meylan 1994;
Djorgovski 1995). But, unlike the case of giant elliptical gal-
axies, these structure parameters do not correlate well with
metallicity. Whether there is any correlation with horizontal-
branch morphology per se is not clear from the data given.

The mention of gEs shifts us naturally onto the right foot,
which lands promptly in a muddy puddle left by the histori-
cal near-impossibility of separating age from metallicity for
an unresolved population of stars (Buzzoni 1995; Jones and
Worthey 1995). Large elliptical and SO galaxies continue to
have more UV-bright stars than you would expect. The re-
ponsible populations are given names like extended (mean-
ing to the blue) horizontal branch and AGB manque. The
standard picture is that extensive mass loss has stripped the
envelope from what would otherwise be first a red HB star
and then later an asymptotic giant, so that it is blue from
helium ignition to death. Two recent papers agree that older
populations have more of these, but disagree about whether
high metallicity also favors UV-bright stars (Dorman et al.
1995; Bertola et al. 1995).

Do field stars display some analog of the second param-
eter? Not so’s you would notice (though it would not be
surprising). In both the Milky Way and M31, blue horizontal-
branch field stars are metal poor (Kinman et al. 1994) and
red ones are metal rich (Durrell et al. 1994).

Dwarf spheroidal galaxies are, however, “second param-
eter” systems. Yet another byproduct of the OGLE search for
gravitational microlensing (Sec. 2.5) is a catalog of the vari-
able stars in the Sculptor dwarf spheroidal (Kaluzny et al.
1995). The distribution of stars on the horizontal branch and
the periods of the RR Lyrae variables show that the stars are
metal poor and have a range of ages. Similar conclusions
based on data of other kinds for dwarf spheroidal galaxies
says that age is a wide-spread second parameter in them
(Smecker-Hane et al. 1994)

13. OPEN MOUTH, EXTRACT FOOT

This year’s section title is a quote from Christopher Mar-
lowe Anderson (who has undoubtedly not needed to do it
nearly so often over the years as we). The section corrects
errors in Ap94 pointed out by sharp-eyed, and often sharp-
tempered, colleagues, arranged by section number.

4. The coronal lines of C iv and O vi seen in the hot gas
outside the plane of our galaxy. These are honest permitted
lines, not forbidden ones. No excuse, sir (but it is such fun to
make those little square brackets that a quantum-
mechanically sophisticated colleague once claimed ought
to mean “retarded nitrogen” and so forth).

5.10. The sins of deuterium. A colleague attempted to as-
sure us that there had never been any in bombs. For a coun-
terexample, see Bethe (1995b) discussing the “alarm clock”
design in a book review.

9.5. The companions of pulsar 1620-26. Yes, it has (at
least) two, but (at most) one is of planetary mass, and even
that is now quite unlikely. We understand how we came to
blow this one and need to remember a principle laid down
long ago by an editor at the New York Times: “Never write a
sentence whose meaning is dependent upon the correct
placement of a comma.”

11. Hubble’s Random Variable. One error is ours: a value
tabulated as 86±1, which should have been 86±7. The tra-
duced author tells us that it will be some years before we
know H to 1%. Agreed. Also to 10%. At least equally an-
noying is the publisher’s omission from Table 1 of the arrow
that was advertised in the text as indicating our guess at the
value to be published by the HST key project team shortly
after our closing date (Freedman et al. 1994). The really
distressing aspect is that the arrow was actually right in the
preprint (inserted between 77±5 and 81±3). But, like BC
and Dagwood Bumstead hitting their holes-in-one when no
one was watching (and on the same day at that), we can’t
really expect anyone to believe this!
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12.1. Dates of the Jennison and Das Gupta intensity interferometer. The paper cited appears in 1954, not 1945 (as in text) or 1956 (as in references). Still earlier results appear in Brown et al. (1952).

As always, many topics ended up on the Xerox-room floor, including bipolar outflows from a wide range of kinds of objects, developments in convection theory beyond the mixing-length approximation and its bandaged versions, a number of items concerning supernovae and less violently variable stars, improvements in adaptive optics and other technological topics, the ages of the oldest globular clusters, the reality of Hickson compact groups, and an assortment of extrema, curious errors of the printed page, and so forth.

Also as always, corrections to this compilation and previous ones, and suggestions of items for inclusion in Ap96 are welcome between now and 15 September 1996.

Our thanks as usual to the librarians who maintain the astronomical journal collections at University of Maryland, University of California (Irvine), Space Telescope Science Institute, European Southern Observatory, and California Institute of Technology (whose Helen Knudsen will be very much missed from Robinson Library in her retirement).

Colleagues who provided input that may not be obvious from the references (or perhaps sometimes is!) include Michael F. A'Hearn, Sidney van den Bergh, Sergei Blinnikov, Mark Boslough, George Djorgovski, Oktay Guseinov, Michael F. A'Heam, Sidney van den Bergh, Sergei Blinnikov, Martin Rees, Gerald Share, Ed Shaya, and George Wallerstein.

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