Invited Review Paper

Astrophysics in 1994

VIRGINIA TRIMBLE and PETER J. T. LEONARD
Department of Astronomy, University of Maryland, College Park, Maryland 20742

ABSTRACT. 1994 was the year in which we saw the first images from the repaired Hubble Space Telescope; the probable detection of a diffuse intergalactic medium, a black hole in M87, and an enormous primordial deuterium abundance; the discovery of the first (and second) superluminal objects within our own galaxy; not to mention the demise of the Jovian dinosaurs. But, as always, most astronomers continued to work away on the projects that have interested them for years or decades, and we attempt also to report some progress in broader areas, including cooling flows, extragalactic globular cluster populations, disk instabilities, phases of the interstellar medium, and brown dwarfs among microlenses and other populations. Several sections of short items range from the obvious to the remarkable to the unbelievable. As in previous years, the ordering of the topics attempts to preserve the near-to-far custom of elementary astronomy textbooks.

1. INTRODUCTION

Greetings, and welcome to the fourth annual roundup of beasts for the astrophysical zoo. It attempts, like its predecessors, to catch most of the obvious, newsworthy events, but also to highlight areas where less spectacular, yet hard and steady, effort is slowly pushing back the frontiers, or anyhow relocating them. We hope we are at least as successful as Carl Seyfert (of the eponymous galaxies) who used to ride his horse, Silver, in the annual roundup during his days at McDonald Observatory.

The first item cited reached our library shelves on 5 October 1993 and the last on 30 September 1994. Our own papers are not, by definition, highlights; and we have tried to avoid minor updating of topics discussed in previous years, apart from the corrections in Sec. 13.


A more worrisome selection effect has, however, begun to show up. Some years ago, a researcher in the medical community noticed that practicing doctors tended to rate as very important advances in their fields that had been reported in the New York Times. A prolonged New York newspaper strike, during which daily issues of the Times were prepared, but nobody outside the office got to read them, provided an opportunity for a controlled study. During the strike, doctors' opinions about what was important were much less highly correlated with what the Times had chosen to highlight. Apparently doctors get a good deal of their medical information from news sources rather than from their professional journals. By the same token, colleagues who generously provided suggestions for the present review very often mentioned items that had been featured in newspapers and magazines or had appeared in Science News, Sky and Telescope, and the front halves of Nature and Science. We sort of wish we could do the corresponding controlled study!

Finally, we hasten to assure you (as you rush eagerly on to the next section) that, although we are very sure visitors to Jupiter after 16 July 1994 will find no dinosaurs there, we don't really think they would have before either.
2. COMET P/SHOEMAKER-LEVY 9 HIT JUPITER: THEORETICAL PREDICTIONS

In March of 1993, the comet hunting team of Carolyn Shoemaker, Eugene Shoemaker, and David Levy discovered a most unusual "squashed" comet (Shoemaker et al. 1993). The peculiar appearance was due to the comet having roughly 20 nuclei lying in a line. By June 1993, it had become clear that this comet, now called periodic comet Shoemaker-Levy 9 (the ninth discovered by the Shoemaker-Levy team; henceforth S-L 9), had passed very close to Jupiter in July of 1992, and that at least part of the S-L 9 debris train would hit Jupiter in July of 1994 (Marsden 1993). This was the first time that a solar-system body had been discovered that was going to strike another, and a flurry of theoretical predictions and observing proposals resulted. The week of July 16 through 22, 1994, when the main fragments of S-L 9 struck Jupiter, saw an observing campaign and an international exchange of preliminary data via e-mail the likes of which the world had never seen. Some of the observational results were made public quite quickly, but it will take years for the majority of the data to be published and understood. Hence, this S-L 9 review will focus on the theoretical predictions that were accepted for publication prior to the impacts.

Many papers were written on the density and radius of the S-L 9 parent body, and whether it was a "rubble pile" or a solid object. Based on tidal disruption considerations, density estimates range from 0.5 g cm\(^{-3}\) to an upper limit of 1.5 g cm\(^{-3}\), and estimates for the parent body radius range from 1.5 to 2.0 km (Asphaug and Benz 1994; Boss 1994; Scotti and Melosh 1993; Solem 1994). The latter are far smaller than the upper limits to the post-disruption nuclear sizes of 2.5 to 4.3 km estimated from \(\text{HST}\) observations (Weaver et al. 1994). If the parent body was a rubble pile (Weidenschilling 1994), then it was thought that each impact would be an unimpressive "fizzle" (Weissman 1994). The existence of crater chains on Ganymede and Callisto (Melosh and Schenk 1993) and on our moon (Melosh and Whitaker 1994) suggested that the impacts would be significant. As it turned out, most of the S-L 9 fragments impacted spectacularly, while some fizzled.

The first part of Jupiter that S-L 9 encountered was the Jovian magnetosphere, and there were several predictions as to what might happen. Optical emission from cometary ions was expected when the S-L 9 nuclei crossed the Jovian bow shock (Lipatov and Sharma 1994). Increased Jovian auroral activity as well as radio bursts were expected close to the times of impact (Farrell et al. 1994; Herbert 1994; Ip and Prangé 1994; Kellogg 1994). Other researchers suggested that detectable changes in radio emission were unlikely (Boin and Brenning 1994), or that there would be a decrease in synchrotron emission due to the energy degradation of relativistic electrons via encounters with cometary dust (de Pater 1994; Dessler and Hill 1994). Some radio and auroral activity were indeed observed during the S-L 9 impacts, but it will take a while to sort out exactly what was due to the comet, and what is intrinsic to the complex Jupiter–Io system.

Several papers were written on the bolide, fireball, and plume phases of the impacts (Ahrens et al. 1994a,b; Boslough et al. 1994; Chevalier and Sarazin 1994; Hasegawa and Takata 1993; Sekanina 1993; Takata et al. 1994; Zahnle and Mac Low 1994). The main point of contention was the level in the atmosphere at which most of the impact energy would be dissipated, with penetrations well below the tropospheric cloud tops being favored. It was not immediately obvious how deep the large fragments of S-L 9 penetrated, or how much material was dredged up. The larger-than-expected plumes that were observed may have merely been the blow off of heated material resulting from the shallow splash of an extended cloud of small debris. This should be modeled in detail (Rettig et al. 1994). The optical flashes from the bolide and fireball phases were far more difficult to observe than predicted. These emissions must have been largely absorbed by the Jovian clouds. If the fireballs ever did rise above the cloud tops, then they were too cool to radiate much at visual wavelengths.

There were predictions that slowly moving atmospheric gravity waves originating from the impact sites would be detected (Harrington et al. 1994; Ingersoll et al. 1994). These were, in fact, seen. The predictions as to whether seismic reflections from the Jovian interior would be detected (Deming 1994; Gough 1994; Hunt et al. 1994; Lee and Van Horn 1994; Marley 1994) have not yet been tested. They may never be, if the required observations did not achieve the desired signal-to-noise ratio.

The large dark regions that were so prominent on Jupiter were not generally predicted, except perhaps by Bryor et al. (1994), and West and Friedson (1993), who mention that dark cometary dust from S-L 9 may accumulate in the Jovian stratosphere, which would allow the high-altitude circulation patterns of Jupiter to be studied.

Evidence of water from the comet was predicted to be detectable in the Jovian atmosphere (Cravens 1994). The early indications are that the Kuiper Airborne Observatory just barely saw it. No cometary gases were detected prior to the impacts (Cochran et al. 1994; Weaver et al. 1994), although this was not a surprise since the comet was very cold.

3. TWINKLE, TWINKLE LITTLE MACHO

Ap91 proclaimed 1991 to have been the year of the microlens, distinguished, among other items, by the first images intended for use in searching for microlensing by stars, brown dwarfs, black holes, or other compact objects that might be dark-matter contributions in the Milky Way. Ap93 admitted that the popular press had beaten even Nature in getting out the news of the first events detected. And we can now say that the projects are all up, running, and successful beyond all reasonable expectation. (As we have remarked before, if the people who think of, design, and build such things were reasonable, it would never get done.)

3.1 The Lens Population

In summary, compact objects exist in the Milky Way (not a new discovery; stars were known to the ancients). They do gravitationally lens images of stars behind them in both the
galactic bulge and the Large Magellanic Cloud. There have been rather more events seen toward the bulge and fewer toward the LMC than had been anticipated. It is by no means certain that the lenses are located where originally expected (galactic halo for LMC sources and galactic disk for ones in the bulge). And most of the events reported so far are suggestive of lens masses at the low end of the stellar range rather than brown dwarfs or other exotica.

There is some contribution from selection effects. The finite interval between successive examinations of each star field discriminates against very rapid events due to small masses, while the finite length of the projects to date discriminates against multi-year ones, due to large masses. Maximum sensitivity varies among the projects, but is in the few-day to few-month range, most likely to be produced by objects with the masses of F to late-M dwarfs. The mass determinations are, in any case, only statistical, because the time scale and degree of amplification in a given event depend on the source velocity, source distance, lens velocity, and lens distance, as well as on lens mass.

The next few paragraphs examine some of the details of data and interpretation, and we return in the next subsection (contrary to stated policy) to the topic of Sec. 4 of Ap92, concluding that the set of brown dwarfs found by any other method is also a remarkably small one.

The only kinds of acronyms we really like are the ones we understand and somebody else doesn't. So that we will all be on the same side, OGLE=Optical Gravitational Lensing Experiment (first reported event toward the galactic bulge, Udalski et al. 1994); MACHO=MAssive Compact Halo Object (Alcock et al. 1993, one event toward the LMC); and EROS=Experience de Recherche l'Objets Sombres (Aubourg et al. 1993, two events toward the LMC, and “experience” in French does not have quite its English meaning). Eight additional OGLE events are in the archival literature (Udalski et al. 1994a,b), a few more in IAU Circulars (including the first MACHO event in the galactic bulge, Alcock et al. 1994). Additional ones appear in frequently updated conference talks by the three teams and in electronic data bases, which provide real-time information so that other observers can collect spectra, etc.

Such spectra have been taken for the first MACHO event after it returned to normal brightness as an F-G giant in the LMC (Della Valle 1994) and for their first bulge event, which seems to be a K subgiant (Benetti et al. 1994). No surprises.

That not all stars are single should also not be a surprise. The inventory so far seems to include one binary source star in the LMC (Axelrod et al. 1994) and one binary lens star toward the bulge (Udalski et al. 1994c).

Preprints of interpretive papers followed data release at only slightly less than the speed of light (and we are bravely resisting temptation to mention the speed of thought). More sophisticated methods confirmed envelope backs in saying that none of the lenses had to be brown dwarfs, though some might be (Evans and Jijina 1994; Jetzer 1994).

The first paper out on lens location reaffirmed the observers’ assumption that they were looking at Milky Way halo and (thick or thin) disk lenses (Gould et al. 1994). This seems natural because the cross section for lensing is largest when the lens is about half way between you and the source, and so is at a maximum toward the LMC for outer halo stars and toward the galactic bulge for disk stars 4 kpc (half way) from here to there. But the natural answer may not be right. Because there are many more stars per cubic parsec in the LMC and in the bulge than along the line of sight, the LMC lenses may actually be in the LMC (Sahu 1994) and the bulge lenses in the bulge (Kirago and Paczynski 1994). This will be settled when there are enough events to ask whether they are concentrated toward the center of the LMC linearly or quadratically with the density of the star field. The bulge case may already have been resolved (Paczynski et al. 1994a), but you have to hang on for another paragraph for the explanation.

The total rate of bulge events is roughly three times what is expected from disk stars alone (Udalski et al. 1994b). Lensing probability is reported in units of optical depth, which means the probability of finding a source amplified by a factor of 1.34 or more at a given instant. Events seen correspond to \( \tau = 3 \times 10^{-6} \), where \( 10^{-9} \) was predicted in advance.

The microlensing searches automatically produce enormous inventories of variable stars and overwhelming numbers of colors and magnitudes. OGLE has reported (a) a surprising concentration of old stars in the local spiral arm and a significant number of young ones in the bulge (Paczynski et al. 1994), (b) independent evidence for the existence and dwarf spheroidal nature of the Ibata-Gilmore galaxy of Sec. 5.5 (Mateo et al. 1994), and (c) star counts implying that the bulge has a triaxial or bar morphology, tilted 45° or so to our line of sight (Stanek et al. 1994). And (are you still there?) it is the concentration of stars in the front half of the bar that act as lenses and give the large optical depth.

Where do we (or rather they) go from here? More events will pin down lens masses and locations and also, eventually, the abundance and typical separations and mass ratios of binary lenses. With improved angular resolution, M31 becomes a possible target (Jetzer, 1994b, among others), and so do globular clusters, with the potential for counting their brown dwarfs, if any (Paczynski 1994).

3.2 Other Brown Dwarfs, What Other Brown Dwarfs?

This is the one subject that the two authors tracked independently and with the intention of being complete through the year. Disconcertingly, we found the same papers interesting at only about the 50% level. But we had better luck than the brown-dwarf seekers themselves, who still have no unambiguous examples. A continuing contributory problem is that models to connect observed colors and luminosities of stars with the underlying mass remain quite uncertain, especially if you have no independent indicator of star age (D’Antona and Mazzitelli 1994; Kirkpatrick and McCarthy 1994; Saumon et al. 1994). The source (or rather non-source) book for some time is likely to be Tinney (1995).
faintest measured point (Drukier et al. 1993 on the nearby globular cluster NGC 6397; Comeron et al. 1993 on young stellar objects in the ρ Oph region; Jarrett et al. 1994; Hughes et al. 1994 on Hα emission objects in the Lupus dark cloud). Thus you would expect copious brown dwarfs if the IMF slope holds steady for a while.

But when it comes to pinning down any one object and saying “this is truly below the minimum mass that burns hydrogen,” GD 165B is the only candidate most of us would bet even a dollar on, let alone a doughnut (Jones et al. 1994). Two early favorites, now clearly ruled out, are Wolf 424 (Heintz 1993) and Ross 614 AB (Coppenburger et al. 1994).

On the negative side, we record collectively assorted cases where the mass function is not rising, or where the faintest confirmed class members are clearly above the main sequence—brown dwarf cut (David and Simons 1994 on M4; Kenyon et al. 1994 on the Taurus– Auriga molecular cloud region; Hyades investigations by Leggett et al. 1994, Reid 1993, Bryja et al. 1994, and Stauffer et al. 1994a; Nakajima et al. 1994 on limits to faint companions of Gliese stars; and Pleiades investigations by Stauffer et al. 1994b and Marcy et al. 1994).

This last paper is especially significant as an example of what ought to be a definitive discriminant—looking for lithium. If a mature object is fully convective (as all stars below 0.3 $M_\odot$ are) and has not depleted its lithium, then its interior is surely not hot enough for hydrogen fusion. The Hyads were depleted. Because lithium burns at a lower temperature than ordinary hydrogen, the stars could still be brown dwarfs, but they have missed the chance to prove that they are. Other important nondetections of lithium are reported by Rebolo (1995).

A second new approach, dear to our Maryland hearts, is the search for proto-brown dwarfs as dense cores in assorted molecular clouds. Our colleagues have found some cores with masses less than 0.08 $M_\odot$ and some cores that are gravitationally bound, but none that are both (Pound and Blitz 1993, 1994). In the end, the only way to know the mass of something for sure is to measure its mass gravitationally. Thus we are pleased to report the revival by many groups of long-term radial-velocity monitoring of stars to identify insignificant companions. Sensitivities have now reached to Jupiter-sized ones as well as brown dwarfs, and nothing much has turned up (Kürster et al. 1994). An apparent discrepancy between finding candidates in the less precise velocity data and not in the more precise but sparser data can probably be resolved in favor of the more precise data (Marcy 1995).

4. PHASES OF THE INTERSTELLAR MEDIUM

This is intended to cover gas in more than one galaxy, but finding an acceptable plural for ISM leads to the kind of problem faced by the Hollywood casting director who dispatched a telegram saying, “Please send me a mongoose, and while you’re at it, send me another one.” We tackle the phases from cold to hot.

First thought would suggest that galaxy interactions, mergers, and accretion events would tend to heat and dissipate molecular gas. But in fact the net result seems to be formation of excess molecular material (Sage and Galletta 1993; Combes et al. 1994), especially at the centers of the galaxies concerned (Hibbard et al. 1994). Molecular gas can exist in discrete high- and low-temperature phases, with (not surprisingly) density and temperature anticorrelated (Aalto et al. 1994). Whether there is dust as cool as the coolest 15–20 K gas apparently remains under discussion (Chini and Krugel 1993).

Data on external galaxies indicate that the molecular gas is normally concentrated toward the center (Xie et al. 1994). That the Milky Way should be different and have a major component of very cold H2 well outside the solar circle (Lequeux et al. 1993) seemed therefore a bit improbable. It has not, in a next attempt, been confirmed (Wilson and Mauersberger 1994). The molecular clouds so far detected in the zone $R=18–28$ kpc (the current record) all are relatively warm and have larger H I masses than H2 (Digel et al. 1994). Their total contribution to the mass of the outer galaxy is small. High-latitude molecular clouds also include an atomic component, whose C I line at 492 GHz has just been seen (Ingalls et al. 1994). The issue of copious cold molecular gas in the Milky Way is further discussed in Blitz and Binney (1995) with fairly negative conclusions. A similar suggestion of dynamically important cold CO in the Small Magellanic Cloud and other dwarf irregular galaxies (Lequeux 1994) is more difficult to test.

The quasar 3C 48, on the other hand, really does seem to have a sizable supply of molecular gas ($7\times10^{10} M_\odot$ according to Scoville et al. 1993). The authors suggest a recent merger with a gas-rich galaxy (since powerful radio quasars are supposed to have elliptical galaxy hosts), with young stars from the same galaxy contributing to the diffuse appearance of the quasar.

On the H I front, the detection of a large amount in the form of a Zeldovich pancake at $z=3.397$ has not been confirmed (Briggs et al. 1993), but 21 cm absorption at the same redshift is genuinely present. A new Westerbork mapping of the H I in our own galaxy, with careful removal of sidelobes, has led to some spectacular pictures, a few of them scheduled to appear in Sky and Telescope next year. High-velocity H I clouds like those of the Milky Way seem to be a common, but not ubiquitous, feature of spiral galaxies (Schulman et al. 1994), being absent where the supernova rate is not high enough to drive fountains.

The robustness of dust (in the ISM, never mind under refrigerators) continues to amaze. More than 90% of it (based on calcium depletion) can survive passage through a fairly vigorous shock (Crinklaw et al. 1994). This must surely be at least part of the reason for the ubiquity of sub-solar abundances of heavy elements in the gas phases of our own and other galaxies (Peimbert et al. 1994; Kinkel and Rosa 1994). Whether the dust is heated by the gas (Shipman and Clark 1994) or the gas by the dust (Pirogov and Zinchenko 1993; Bakes and Tielens 1994) clearly depends on where you are. (And we wonder idly whether this last paper may have the year’s maximum ratio of initials to authors.)

Two slightly mysterious components of ionized gas in the Milky Way have become slightly less so. First, the ultracom-
pact H II regions may actually be young OB stars evaporating their own left-over disks (Hollenbach et al. 1994). And then there is the diffuse H II that extends as far as 900 pc out of the galactic disk. OB stars in the disk provide enough photons to ionize it, if only they could get out (Dongörgen and Mathis 1994). But it seems that they do, because super-bubbles expand and merge as they rise out of the disk (Dove and Shull 1994).

The hotter ionized gas responsible for coronal lines like [C IV] and [O VI] has a scale height ranging from about 1 up to 5 kpc, depending on which ion you look at (Shull and Slavin 1994). The topology of this $T \sim 10^5$ K phase has often been described as a connected network of tunnels made up of merged old supernova remnants, but individual current SNRs may actually produce all the [O VI] etc. that is seen (Slavin and Cox 1994).

5. WOW!

This heading is probably self-explanatory, though you may well disagree with the selection of items in it, feeling that some should instead be in a section entitled "So What?" or "Queen Anne is Dead." Actually, we had collected a good many items on a page with that title, but decided not to treat them at length. They included a couple of limits on the rates of change of fundamental constants (Potekhin and Vashalovich 1994; Kaspi et al. 1994c; Levshakov 1994), a prediction that cool molecular gas should inhabit the interiors of dense filaments in the Crab Nebula (Rudy et al. 1994—we have in fact already tried to look for its CO emission, and see Sec. 9.7 below), elimination of magnetic fields as a dark-matter mimic (Katz 1994a), and the demonstration that T Tau is not a typical T Tauri star (Böhm and Solf 1994).

5.1 Acronym of the Year

We had not previously heard of the Companion Reinforced Accretion Process (quoted, but not invented, by Wijers and Paczyński 1993) or Partially Ionized Globules (Felli et al. 1993) but prefer in any case the SPAM center (Gailliot et al. 1994) as being a more accurate guide to the contents.

5.2 The Fraction of Binaries among New-Born Stars

Could it be 100%? Four papers from three groups have now said so, based on speckle imaging and lunar occultations of T Tauri and other young stellar objects (Ghez et al. 1993; Reipurth and Zinnecker 1993; Leinert 1993; Richichi et al. 1994). The search strategies guarantee that these are wide systems, and many will not survive bound down to the main sequence. Still, we kind of like the idea.

5.3 Gamma-Ray Bursts from Strange Places

No, we don’t know where most of the 1000+ BATSE and earlier events have come from, though one with an hour-long, very hard tail has provoked a new burst of theoretical activity (Mészáros and Rees 1994; Katz 1994). So quick was the response that the actual data seem still only to be in preprint form (Hurley et al. 1994a). But a handful of bursts per year, with MeV temperatures, are coming from the earth’s upper atmosphere, apparently in regions with strong thunderstorms (Fishman et al. 1994). Presentation of the data at conferences has given us a chance to get used to the idea, but it still seems to rank high in the “news of the weird” competition.

Not perhaps so strange (but also not much of a guide to the main burster population) the three soft gamma-ray repeaters are almost certainly associated with supernova remnants and young neutron stars. The neutron stars show some evidence of high velocity, very strong magnetic fields, or both. The event of 1979 March 5 always was superimposed on the SNR N49 in the Large Magellanic Cloud. But the breakthrough came with an ASCA detection of the source SGR 1806-20 as both a bursting and a steady emitter. (Murakami et al. 1994). This permitted its identification with a galactic, filled-center SNR or plerion (Kulkarni et al. 1994). Its position implies a velocity (since the supernova event) in excess of 500 km s$^{-1}$. The third known SGR, B1900+14, is probably associated with another galactic SNR, G42.8+0.6 (Hurley et al. 1994), though the precise nature of the association is not quite certain (Vasisht et al. 1994). ROSAT X rays from the 1979 March 5 region suggest that the neutron star there is also a high-velocity one (Rothschild et al. 1994).

These SGRs are clearly very rare. The detectors on Phobos saw no new ones (Hurley et al. 1994b). Neither has BATSE (Kouveliotou et al. 1994). In contrast, the known ones can be quite prolific—the 1978–86 ICE database contained 95 events from 1806–20, with a peak luminosity of $1.8 \times 10^{52}$ erg s$^{-1}$, assuming a distance equal to that of the supernova remnant (Fenimore et al. 1994).

5.4 A Superluminal Source (or Two) in the Galaxy

Superluminal sources do not, of course, travel or expand faster than the speed of light. It is a projection effect, predicted before it was seen, on the basis of rapid variability of extragalactic radio sources (Woltjer 1966; Rees 1966), and first seen in VLBI observations of the cores of quasars and radio galaxies (Cohen et al. 1971; Whitney et al. 1971).

Non-experts have long since stopped counting the numbers of these sources, but all were associated with the nuclei of active galaxies. Observed expansion rates of milliarcsec-onds per year would naively imply $\nu = 2–15$ c, but translate into real velocities of 0.8–0.95 c and jet orientations fairly close to our line of sight. Meanwhile, the Milky Way speed record, a mere 0.26 c, was long held by a collimated, precessing jet arising from the X-ray binary SS 433, whose accreting component is generally advertised as a black hole but could still be a neutron star (Sanbuichi and Fukue 1993).

GRS 1915+105 has changed all this. It is a bursting, transient X- and gamma-ray source with infrared and radio counterparts (Harmon et al. 1994a). Placed on a program for radio monitoring of transient sources, it went wild in the summer of 1994, casting out repeated new VLBI components. Mira-bel and Rodriguez (1994) report that its outer bits are moving out at 6.4 and 3.3 arcsec/yr. The distance must be about 12.5 kpc on the basis of intervening gas, leading to apparent component velocities of 1.25 and 0.65 c. A plausible
deprojection yields a real jet speed of 0.92 c at an angle of 70°. The compact component is presumably a neutron star or black hole, but we cannot tell which.

Remarkably, while the press conferences in 1915+105 were still being held, GRO J1655−40 started doing more or less the same thing. Its discovery by the BATSE instrument on the Compton Gamma-Ray Observatory appeared on 4 August 1994 under the title “An X-ray Nova in Scorpius” (Zhang et al. 1994a). Subsequent optical and radio turn-ons, X-ray fading, etc. appear in IAUC 6050, 6052, 6056, and 6060, and subsequent outbursts in IAUC 6075, 6077, and 6078. The repeat interval may be a 31 day binary orbit period. Meanwhile, the radio source had been expanding, and two groups, using different telescopes and time periods, but assuming the same 3.5 kpc distance, report v = 1.9 or 1.1 c (Reynolds and Jauncy 1994; Hjellming and Rupen 1994).

It is hard to avoid concluding that this sort of behavior must be fairly common, once you know how and where to look for it.

5.5 The Local Group Keeps Growing

Our ninth dwarf spheroidal companion and 30th member, though not yet admitted to the van den Bergh (1994) canon, has turned up as a chance finding in a project directed at probing the stellar populations of the galactic bulge (Ibata et al. 1994). The new galaxy is about 16 kpc on the far side of the center of the Milky Way in Sagittarius (making it the innermost of the satellites), has a size of 3 kpc, a radial velocity of +140 km s⁻¹, and a metallicity of [Fe/H] = −1.4. It resembles the Fornax dwarf spheroidal, except for the small detail that IGI (not the official name, just the initials of its discoverers) is in the final stages of being torn apart by ruthless Milky Way tides. It turns up independently in OGLE data (Sec. 3.1).

5.6 As Busy as a One-Armed Spiral

The idea that an m = 1 mode in a protostellar disk could lead to binary-star formation has been around for a few years, and its strength is increasing (Woodward et al. 1993; Burkert and Bodenheimer 1993; Bonnell 1994). It now seems that such modes may also be important in disks of Be stars (Teltig et al. 1994; Savonije and Heemskerk 1993) and in galaxies whose density and kinematic centers are not at the same place (Weinberg 1994). The sad news is that one-armed spiral galaxies are not very interesting after all. Since the m-number of the most unstable mode rises with the ratio of halo mass to disk mass, one might have hoped that the one-armers would be haloless galaxies. But it seems that they are merely the victims of traffic accidents (Phookun et al. 1993).

5.7 Hickson’s Transient Configurations

A Hickson (1982) compact group consists of at least four galaxies in a range of less than three magnitudes contained within a circle on the Palomar Observatory Sky Survey plates whose radius is less than one-third the distance to the next nearest galaxy in the same magnitude range. His original 100 groups have been studied in some detail (Hickson 1993). Casual examination suggests, and dynamical calculations confirm, that most cannot have been around for anything like a Hubble time and that most will not still appear on the POSS Google survey in 3,000,001,994 AD.

Low-level puzzlement about how they form and what becomes of them (mergers to giant elliptical galaxies?) has been endemic for a dozen years, though it is possible to have a whole conference on clusters of galaxies without mentioning them (Oegerle et al. 1990).

A faint bell rang when we read the observation by Vennik et al. (1993) that, despite the criterion intended to guarantee isolation, most Hickson compact groups were part of larger, looser groups. This has now been said often enough that it probably ought to be believed (Rood and Struble 1994; de Carvalho et al. 1994).

The straightforward interpretation is then that the groups form continuously in looser, richer groups, merge in 10⁹ yr or so, and are replaced by newly assembled compact configurations (Diaferio et al. 1994; Ramella et al. 1994; Fasano and Bettoni 1994). Moles et al. (1994) add that some groups may not be fully bound and will disrupt rather than merging, again to be replaced.

Curiously, disagreement seems to persist on whether members of the groups show evidence for large amounts of past interaction and mergers. Voting no are Moles et al. (1994), Ribeiro et al. (1994), and Sulentic and Rabaca (1994). Voting yes are Mendes de Oliveira and Hickson (1994), Caon et al. (1994), and Longo et al. (1994), though these last also conclude that member galaxies have lower ratios of mass to luminosity than the general run of field galaxies. Also not explained in the scenario of transient groups is that members of any given group tend to be of similar morphological type (Prandini et al. 1994).

Now everybody take a deep breath and say in chorus “More work is needed.”

5.8 Dark Matter Illuminated?

“A Faint Luminous Halo that May Trace the Dark Mass Distribution of Spiral Galaxy NGC 5907.” That’s what the authors (Sackett et al. 1994) call it, and a more informative title would be hard to find. They have been doing deep CCD photometry with a 0.9-m KPNO telescope (Are you sure you want to close all those little ones?), looking for thick disks and such. What they found is extra light with the shallowest radial profile ever seen for a component of a spiral galaxy. It has p ∝ r⁻².² thereabouts and extends at least 6 kpc out of the plane of the galaxy, with c/a = 0.5.

This sort of shallow power-law component is just what you need to account for a flat rotation curve, as seen in NGC 5907 and many other spirals. The implication is that this light is actually tracing the dark matter halo. The region imaged has M/L = 540 M☉/L☉. There is no color information yet, but if objects of a single class were required to possess all the mass and emit all the light, they would be M dwarfs.
5.9 The Helium Gunn-Peterson Effect

If anyone is inclined to ask “Who is Dr. Helium?”, the answer is that he is a close relative to Mr. Metro (of Metro-Goldwyn-Mayer). Drs. Gunn and Peterson (1965) are, of course, the people who first presented a careful analysis of the limits on density of intergalactic H I implied by the absence of an absorption trough blueward of Lyman α in 3C 9 and other quasars with redshifts large enough for a rest wavelength of 1216 Å to appear in spectra taken from the ground.

Such absorption by neutral hydrogen has not been seen to this day (Giallongo et al. 1994), with the limits so tight as to make galaxy formation seem most implausibly efficient, especially at large redshifts. The struggle to stretch the limits (Lu and Zuo 1994) or to come to terms with them theoretically (Tegmark et al. 1994) continues. The main weapon is a high degree of ionization of whatever diffuse gas might be there.

A promising test of the ionization explanation is a search for corresponding diffuse absorption by the He II Lyman α line at 304 Å. Attempts from the ground have failed—not just to find the absorption, but even to look for it, because (hydrogen) Ly α clouds pile up to the point where we do not see any of the relevant part of the qso continuum flux! (Jakobsen et al. 1993).

HST has come to the rescue by giving access to λ304 at lower redshift (QSO 00302−003, z=3.3) The absorption trough is there (Jakobsen et al. 1994). The discoverers believe that they are probably seeing a combination of truly diffuse, filamentary, and cloudy gas, with an optical depth τ > 1.7. The corresponding lower limit on extragalactic baryon density is linear in the ionization ratio (He-total/He II) and ranges from $10^{-1}$ to $10^{-3}$ of closure density for plausible ionization fractions, assuming the helium-to-hydrogen ratio expected from a standard hot big bang.

Of course the mere detection of helium at this large redshift might be claimed as a triumph of hot big-bang nucleosynthesis over models in which helium is produced continuously by nuclear reactions in stars. But, truthfully, we have not felt that the outcome of this battle was in doubt since we graduated from reading Mr. Tompkins to PASP.

5.10 Primordial Deuterium

Deuterium (for whose discovery Harold Urey received his Nobel Prize) was the first isotope found with chemical properties demonstrably different from those of its more abundant relative. As a result, Soddy, co-inventor of the isotope concept with Rutherford, denied that it was one. Deuterium has been causing trouble ever since, even if you leave out the bombs.

The deuteron is bound by only 2.2 MeV and is, therefore much more likely to be destroyed in stars than made there. Thus $^2$FH (Burbidge et al. 1957) included it with ordinary hydrogen and the two isotopes of helium as a product of the early universe and/or unknown processes. Its detection in the interstellar medium (Rogerson and York 1974) at a level $D/H=1.5\times10^{-5}$ thus began a voyage (Gott et al. 1974) leading to almost universal agreement that we live in a universe that comes nowhere close to being closed by baryons (Kerrnan and Krauss 1994 and many other papers). We have been living happily with primordial $D/H=something\times10^{-5}$ for the ensuing 20 years. And it seemed to fit in nicely with the abundances of the other light isotopes, allowing for plausible amounts of galactic chemical evolution (Vangioni-Flam et al. 1994).

Inevitably, then, much consternation resulted from the report that $D/H=2.5\times10^{-4}$ in a $z=3.3$ Lyman-limit absorption cloud in the QSO 0014+813 (Songaila et al. 1994a; Carswell et al. 1994). First, in order to get this much deuterium out of the early universe, you need to choose a very low baryon density, perilously close to the minimum allowed without overproducing $\text{Li}^7$ (Krauss and Kerman 1994). Second, and potentially more serious, something must become of it between then and now, where “now” includes the time of solar system formation as well as the current interstellar medium. Of course deuterium burns, but at low temperatures only as far as $\text{He}^3$, not up to $\text{He}^4$. The sun has $\text{He}^3$ (but no deuterium) and, because of the depth of its convection zone, the present $\text{He}^3$ surface or solar wind abundance is generally thought of as setting an upper limit to the amount of deuterium plus $\text{He}^3$ when the Sun formed. The limit is again something $\times10^{-5}$, as is the present interstellar ratio $\text{He}^3/\text{He}^4$ (Balser et al. 1994). Thus we need somehow to get rid of 90% or more of the primordial deuterium without beefing up $\text{He}^3$ very much, which proves very difficult to do (Steigman 1994 and many preprints).

How do we get out of this? You are not allowed to disbelieve the existence of the absorption line; two groups have seen it. And postulating a resonance to increase the rate of the reaction $\text{He}^3+\text{He}^3\rightarrow\text{He}^4+2p$ (Galli et al. 1994) is surely a council of desperation, though it would also reduce the flux of high-energy neutrinos from the Sun, as well as getting rid of $\text{He}^3$ in stars. You are, however, permitted to doubt that the (real) line is made by deuterium. The two groups looked at the same quasar, and it is conceivable that a chance, weak $\text{H}^1$ Lyman α cloud has just the right redshift to look like $\text{H}^2$ from a much denser cloud.

Panic should, therefore, be postponed until a comparably strong deuterium line has been seen in another quasar or two, and people who are concerned about the issue should probably be churning out observing proposals rather than preprints.

5.11 The Universe was Hotter in the Past

We are, most of us, pretty sure we know this, but it is nevertheless encouraging to see preliminary evidence that the 2.735 K background radiation was present and warmer at moderate redshift. Keck telescope data on lines from excited levels of $\text{C}^1$ in two clouds at $z=1.776$ yield excitation temperatures of 7.4±0.8 and 10.4±0.5 K (Songaila et al. 1994b). The expected number at that redshift is 7.58 K. The hotter cloud must have additional sources of excitation energy. As a result, one cannot be absolutely certain that the
cooler one is really telling us just about the background radiation. More clouds at slightly higher redshift will be reassuring, as the authors themselves emphasize.

6. THE PROS AND CONS OF DISK INSTABILITIES

The driver for this section was the revival of a 1977 proposal (Herbig 1977) that FUORs are a lot like dwarf novae (Kawazue and Mineshige 1993; Bell and Lin 1994). This is going to take some explaining before we go on to a somewhat broader look at disk instabilities in general. The FUORs (prototype FU Ori) are a fairly sparse class of (probably) pre-main-sequence stars whose flareups, wildly more spectacular and longer lived than those of the much commoner T Tauri stars, have been attributed to large variations in accretion from remnants of their protostellar disks (Paczynski 1976). Dwarf novae are the fairly numerous subset of cataclysmic variables (white-dwarf+main-sequence close binaries) that flare up by a few magnitudes every few weeks or months, due to variable accretion from the normal star onto the white dwarf. Whether the variation occurs in the donor star or in the accretion disk was long debated. Both, it seems, have a role, according to the results of prolonged monitoring of DQ Her and other stars (Honeycutt 1995; Honeycutt et al. 1994). The semiregular changes arise in the disk, while longer-term cycling between high and low states result from something the donor star is doing.

The classic dwarf nova instability is simply a tendency to switch back and forth between mostly neutral gas (with relatively low viscosity, corresponding to slow accretion and low luminosity) and mostly ionized gas (with relatively high viscosity, corresponding to more rapid accretion and higher luminosity, e.g., Cannizzo 1993; Meyer and Meyer-Hofmeister 1994). Gas from the donor star piles up in the disk during the neutral phase and is deposited rapidly during the ionized phase.

The key idea for FUORs is that similar self-regulated ionization switching occurs in the disks of young stellar objects. The low state, which lasts 1000 years or so, is occupied by ordinary T Tauri stars; the high state, lasting only about 100 years, hosts the FUORs. The instability is present only for (long term!) average accretion rates more than $1-5 \times 10^{-7} M_\odot \text{yr}^{-1}$, for a 1 $M_\odot$ star at the core.

Kawazue and Mineshige (1993) suggest a slightly longer recurrence time of 4000 years, which is supported by the structure of circumstellar ejecta around V1331 Cyg (McM idroch et al. 1993). Van Lagevelde et al. (1994) have put forward an alternative mechanism for FUOR outbursts based on an observation suggestive of gas currently falling into a small point mass on an orbit that pierces a big disk (a star near an active galactic nucleus, for instance) and finds that density and bending waves are excited that can trap the star.

Second, it stands to reason that, if a disk-bearing star has a close, comparable companion, as in X-ray binaries and cataclysmic variables, the disk is bound to be distorted (Lubow et al. 1993). The surprise is that the resulting transport of angular momentum is really quite small (Ryu and Goodman 1994; Savonije et al. 1994).

7. POPULATIONS OF GLOBULAR CLUSTERS AND THEIR PARENT GALAXIES

This is not by its nature a break-through topic, since galaxies outside the Local Group yield up even the simplest statistical properties of their globular-cluster systems painfully, one by one. Thus Rip van Astronomer could have gone directly from the 1986 IAU Symposium on “globular-cluster systems in galaxies” (Grindlay and Philip 1988) to the 1992 Santa Cruz workshop on “globular clusters within the context of their parent galaxies” (Smith and Brodie 1993) without feeling at all lost. In any case, we want mostly to report...
a probable backward step (at the end of the section).

Basic properties of cluster systems have been established for some time (see, e.g., Harris 1988). These include a specific frequency (number per unit luminosity of the parent galaxy) that is higher for ellipticals than for spirals, and highest of all for central cD galaxies; a radial distribution that is much more extended than that of field halo stars; and colors that are bluer than the field at the same radius, meaning lower metallicity. The most massive galaxies have the highest-metallicity clusters. Recent work continues to find these trends in additional galaxies (Grillmair et al. 1994; Pritchett et al. 1994). At least for M87, the cluster system is more elliptical, as well as more extended, than the rest of the halo (McLaughlin et al. 1994).

Study of M31 (second in intensity only to that of our own system) reveals many more similarities than differences—in ultraviolet colors (Bohlin et al. 1993), distribution of cluster metallicities (Ashman and Bird 1993; Cohen and Matthews 1994), and properties of the clusters themselves, like core radii, central surface brightness, and frequency of post-core-collapse structure (Fusi Pecci et al. 1994).

The current hot topic in applied clusterology is their use as a standard candle for measuring galaxy distances. As Harris (1988) and other speakers at IAU Symposium 126 already noted, the luminosity functions of clusters in various galaxies, even of different types, seem to peak at nearly the same absolute magnitude. Efforts have been made to explain this either in terms of formation processes or as later evolution (Capuzzo-Dulcetta 1993). But the M31 distribution peaks at $M_V = -7.6$, vs. $-7.3$ in the Milky Way (Reed et al. 1994). The resulting choice of peak values is just broad enough to entitle you to put the Virgo cluster at either a long-scale or a short-scale distance (20 vs. 11 Mpc, Kissler et al. 1994).

The issue of how, when, and where globular clusters form, or even whether it is the same for all of them, was not resolved in 1994 (and you should not hold your breath next year either). Competing ideas can be categorized as primary, secondary, or tertiary, meaning before, during, or after galaxy formation (not the degree of derivativeness of the idea, as you might have guessed, Fall and Rees 1988), and no one sort is an obvious winner at the moment.

We did, however, have real hopes (Ap92, Sec. 11.4) for the idea that galaxy mergers trigger efficient cluster formation, thereby accounting for higher specific frequencies in elliptical and cD galaxies, and some of the other systematics. This is clearly a tertiary mechanism. Evidence that something of the sort does happen some of the time continues to mount, in the form of additional data on metallicities (Zepf and Ashman 1993) and correlations with galaxy environments (Kumai et al. 1993). There are also galaxies with young clusters likely to develop into globulums that show other evidence for recent mergers (Whitmore et al. 1993 and Schweizer and Seitzer 1993 on NGC 7252, Hunger et al. on NGC 1140, Conti and Vacca 1994 on Wolf-Rayet galaxy He II 2–10). Merger formation predicts detectable signatures in the chemical composition of cluster populations (Fritze and Gerhard 1994).

Why are we clambering down from the bandwagon? Three things. First, there are four central cD galaxies in poor clusters, which must have experienced lots of mergers, but only the one with a cooling flow has detectable globular clusters. These are few enough that its specific frequency is in the range for spirals (Bridges and Hanes 1994). Second, mergers are known also to trigger the formation of lots of stars that won’t end up in globular clusters, raising the total luminosity of the product galaxy, so it is not at all clear that specific frequency will actually increase (Harris 1995).

Third, the field of competing ideas continues to grow, with the latest one often seeming the most exciting. For instance, the clusters of M87 could be in cores of all the disrupted, nucleated dwarf elliptical galaxies that its host cluster started out with (Bassino et al. 1994). And Harris and Pudritz (1994) suggest a specific secondary mechanism in which the immediate progenitors of globular clusters are giant molecular clouds, much like the ones we now see. Then why have they stopped making globular clusters (at least in our galaxy)? Well, that was the question that led to this being an interesting topic in the first place.

8. MY BLACK HOLE IS BIGGER THAN YOUR BLACK HOLE

And M87’s is bigger than just about anybody’s according to data from the newly repaired HST (Ford 1994). Actually, the mass implied by the HST images and spectra, $2 - 3 \times 10^9 M_\odot$, is much the same as what comes from the best ground-based data (van der Marel 1994a). What has changed is our confidence in the actual existence of the collapsed object at the center. The key is better angular resolution, so that the steep central rise in both velocity dispersion and mass-to-light ratio is now known to persist to the inmost 0.1 arcsec. M87 is, of course, a well known active galaxy, with a strong, extended radio source and so forth. It had better have a black hole.

In some ways even more intriguing is the case of NGC 4258, whose central 0.1 pc is studded with water maser sources. The fabulous angular resolution provided by radio interferometry has permitted a map of their velocities versus position. It looks remarkably like a map of Keplerian rotation in a disk with a central point mass of about $10^7 M_\odot$ (Watson and Wallin 1994). That this was not featured in gossip columns the way the M87 black hole was is a statement about the efficient uses of publicity, not about the persuasiveness of the result.

NGC 4258 is not a well known active galaxy, and there have, of course, been reports of probable black holes in other quiescent galaxies for some years (Kormendy 1992). Thus one asks with increasing urgency (a) do all active galaxies have central black holes? (b) do all galaxies, period? (c) do the active ones have bigger black holes, and (egocentric as we are) (d) does the Milky Way have a massive central black hole?

There are a number of reasons to want the answers to be yes, yes, not necessarily, and yes. First and foremost, the standard model of quasars, Seyferts, and the rest invokes accretion on to a central black hole as the primary energy source, so (a) should be yes (Holt et al. 1992). Second, statistics of active galaxies and their properties make more
sense if no one lives more than $10^8$ yr or so (Blandford and Rees 1992). Thus many or most galaxies should have been through an active phase and have a left over black hole, and the answer to (b) should be yes. Whether you see current activity from a particular galaxy then depends mostly on whether material is available for accretion, that is, on what the outside of the galaxy is doing, not its center, so (c) should be “not necessarily.” Finally, the Milky Way is then a non-special case, and (d) should be yes.

What do the data say? Unfortunately, with ground based (optical) and pre-fix HST resolution, what they say most persuasively is that black holes are possible but not absolutely required (van der Marel 1994b), and when the data are better, better models will be added. These are under way (Tremaine et al. 1994; Cipollina and Bertin 1994).

Meanwhile, plausible cases have been made for 7 of 10 galaxies (including M87 and some quiescent ones) examined by the pre-fix HST (Crane et al. 1993) and for NGC 1399 (a normal elliptical, Stiavelli et al. 1993) and NGC 4594 (a LINER of modest activity, Seller et al. 1993), as well as for the better-known and inactive M31, M32, and NGC 3115 (Kormendy 1992; van der Marel 1994b), on the basis of lower-altitude data. M31 might even have two, one for each nucleus (Lauer et al. 1993; Bacon et al. 1994). Our estimate in Ap93 of the time until the burst of gravitational radiation arrived from their merger was probably much too large (having been made ignoring the effects of the surrounding galaxy).

Strangest of all, perhaps, is the suggestion that the dwarf spheroidal galaxies in Draco and Ursa Minor might have $1-2 \times 10^7 M_\odot$ black holes at their centers, to account for their large central velocity dispersions and $M/L$ ratios (Strobel and Lake 1994).

What about correlation of black hole mass with activity level? Masses near $10^9 M_\odot$ can apparently exist in very active (MB7), slightly active (NGC 4594=Sombreiro), and very lazy (NGC 3115) galaxies. But, where there is significant activity, luminosity and black-hole mass are probably correlated in the way you would expect for things operating at a fairly fixed fraction of the Eddington luminosity. Thus the central masses in well-studied Seyfert galaxies like NGC 4051 and 4151 all seem to be less than $10^7 M_\odot$ (Sergeev 1994; Perola and Piro 1994; Bao and Østgaard 1994).

What about the center of the Milky Way? Whatever is there, experts seem to agree that “there” means the location of Sgr A*. It’s a feeble sort of central radio source by quasar standards, though M31 is feeble still [about $\frac{1}{4}$ the flux of Sgr A* after its 1992 brightening (Crane et al. 1993a)]. Similar radio cores are moderately common in other normal spirals (Turner and Ho 1994). The angular scale on which Sgr A* remains unresolved (0.4 milliarcsec=3.3 AU) says that there is not space for a black hole of more than $1-2 \times 10^6 M_\odot$.

What else is there? A gamma-ray source that is not the most spectacular in the region. A weak and variable X-ray source (Pavlinsky et al. 1994). Some diffuse gas whose velocity structure does not definitely prove or rule out a black hole in the $1-3 \times 10^6 M_\odot$ range (Serabyn et al. 1994). Variability in the radio regime down to a time scale of 10 days, which is plausibly explained as variable accretion on to a black hole, but tells us nothing about the mass (Wright and Backer 1993; Dusche and Lesch 1994). And, in infrared images, a handful of very bright stars, some with winds, and a number of faint ones.

The long-standing controversy is whether this concatenation of features is best explained by a small, $10^{1\pm0.5} M_\odot$ black hole, accreting and radiating at a reasonable fraction of the Eddington rate (Mastichiades and Ozernoy 1994) or by a $10^6 M_\odot$ black hole, badly starved for fuel (Melia et al. 1994; Falke et al. 1993; Yi et al. 1994). This last is an interesting dynamical argument for how to build up the 1.7 pc gas torus at the galactic center, which requires roughly equal masses in the central black hole and in the surrounding star cluster.

Mercifully, we don’t need to take a vote. The fainter infrared stars are sufficiently numerous and close to the center that their velocity dispersion will provide a definite answer, after a few more years of imaging permit measurements of their proper motions (Genzel 1995). If this dispersion is 300 km s$^{-1}$ or more, then the $10^6 M_\odot$ black hole is there. The starvation may be a result of winds from the brighter stars keeping open general interstellar gas, while the speed of the winds themselves keeps them from being good feeders of Bondi-Hoyle accretion.

Less well-known examples of black holes in service professions include using a second one from a recently accreted (small, normal) galaxy to drive material into the center of an active one (Polnarev and Rees 1994) and using gas flow around black holes of $10^6 M_\odot$ or more to provide seed magnetic fields for spiral galaxies (Chakrabarti et al. 1994).

9. THAT SETTLES THAT

Well, maybe it does and maybe it doesn’t. But we had been wondering about the questions and kind of like the 1994 answers.

9.1 Mars Had More Water in the Past

The dryness of Mars is a major barrier to thinking of it as a life-bearing planet. That hasn’t changed. Surface features resembling erosion channels have long suggested that fluid water must have flowed once upon a time. Major changes in temperature and atmospheric pressure are needed for rain to be possible, but Squyers and Kasting (1994) propose that the main source of liquid H$_2$O might have been permafrost melted by impacts or internal heat directly, without going through a vapor phase. Evidence for decrease in the total water supply of a planet can come from hydrogen isotope ratios. Evaporation leaves behind an excess of deuterium (heavy hydrogen). Venus shows this excess conspicuously in isotope ratios measured in situ. There are no such Martian data, but the water in a meteorite supposedly kicked off the surface of Mars shows such an excess (Watson et al. 1994).

9.2 Bode’s Law Bites the Dust

Bode’s Law (as we remarked about Olbers’ Paradox in Ap91, Sec. 11.9) is neither holy, nor Roman, nor an Empire; that is, neither a law nor rightly named for Bode. In the ultimate indignity, it turns out not even to be a useful pattern
for testing models of the formation of the solar system (Grana and Dubrulle 1994). Now, can we get it out of the elementary textbooks, please?!

9.3 The Once and Future Sun

Looking backward, the solar-spot cycle did not turn off during the Maunder minimum (Ribes and Nesme-Ribes 1993), though it was, of course, much weaker. There were also other differences, possibly explicable in terms of changes in the balance between dipole and quadrupole components of the magnetic field (Sokoloff and Nesme-Ribes 1994).

Looking ahead, though the Sun will expand greatly during both its red-giant and its asymptotic giant-branch phases and engulf Mercury during both, it will never quite take in the earth, partly because the planets move outward as the Sun loses mass during its late evolution (Sackmann et al. 1993).

9.4 The Mass of Arcturus Is...

Somewhere between 0.2 and 1.2 $M_\odot$, according to the outcome of an entire workshop devoted to the subject (Trimble and Bell 1981). Hatzes and Cochran (1994) have brought the new technique of stellar seismology to bear on the problem. If the 2.46 and 1.84 day periods they record have been correctly identified as $n=1$ and 2 radial modes, then the answer is (May we have the envelope, please?) 0.23 $M_\odot$, remarkably small for a fairly bright giant.

9.5 Pulsars with Planets

Ap92 left us with PSR B1257+12 as a strong candidate for a pulsar with two planets and a definitive test for their existence (as opposed, for instance, to periodicities due to precession) in the form of predicted changes in the periods resulting from their being in a 3:2 resonance at periods of 98.2 and 66.6 days. The predicted effect has now been seen (Wolszczan 1994), and the planet masses are 2.4 and 2.8 times that of the earth. Another pulsar, 1620-26 in the globular cluster M4, apparently also has two planets (Backer et al. 1993a). And there are rumors of a third for 1257+12 (Thorsett 1994).

Elsewhere on the pulsar front, at least one, 1509-581, is quiet enough to have its second derivative be both measurable and meaningful (Kaspi et al. 1994a). The combination $n = PP/P^2$ is not quite the canonical value $n = 3$ expected for a pure electromagnetic dipole radiator (actually $n = 2.837$). But it and the third derivative are within the range explicable with a constant magnetic moment for the neutron star (Blandford 1994).

9.6 One Star in N is a W Ursae Majoris Variable

We grew up on \(N = 2000\), provided by Robert Kraft (Kraft 1976) for a long-forgotten project. Careful searches of both old open clusters and well-defined samples of field stars now yield \(N = 280\) for W UMa stars with detectable eclipses (Rucinski 1994). When you correct for systems lost because we see them too nearly pole on, \(N = 140\). This is a remarkably large number, given that close binaries probably pass through the W UMa phase (when both stars fill their Roche lobes and the stars share an envelope) fairly quickly.

9.7 The Nature of the Missing Mass (in the Crab Nebula)

Now don’t be too disappointed by the qualification. The problem was a real one. It takes roughly an 8 $M_\odot$ star to produce a core-collapse supernova and a neutron star, but the pulsar and the line-emitting gas in the visible nebula add up to only about half that. The obvious candidate has always been an outer halo of material shed by the pre-supernova star, though the absence of limb brightening of the expanding remnant argued against very dense surroundings (Wallace et al. 1994). The lost has been found. Both images and spectra extending across the edge of the nebula into seemingly empty sky have revealed an H-alpha halo extending out to a bit more than twice the 3’ semimajor axis of the bright part (Murdin 1994). This is the old Murdin and Clark (1981) halo, but the new data are much more persuasive. The halo mass of 4–6 $M_\odot$ remains about the same.

9.8 Supernovae, Various

Remaining unsettled are (a) the physics of mass ejection in Type II (core collapse) events and (b) the nature of the progenitors of Type Ia (explosive carbon–oxygen burning) events, with about 10 papers devoted to each in the reference range. If there is progress to report in Ap95 on how SN Ia manage to push off their envelopes, it seems likely to come from two- and three-dimensional investigations of asymmetries, convection, and instabilities. The leading SN Ia progenitor candidates coming into the stretch are symbiotic novae, double degenarates, and the new ultrashort X-ray binaries.

A modest step has occurred on the SN Ia front, with increasing agreement that the detailed physics is a deflagration (subsonic nuclear burning front) that turns into a delayed detonation (supersonic burning front). This is discussed by Livne and Arnett (1993), Kirshner (1993), Müller and Höflich (1994), Timmes (1994), Arnett and Livne (1994), and Khokhlov (1994). Some remaining problems are mentioned by Khokhlov (1993) and Koldoba et al. (1994). A double detonation, in which both He and CO explode, but relatively small amounts of both, in a low-mass white dwarf provides a possible explanation of unusually faint Ia supernovae (Woosley and Weaver 1994).

Supernovae of Types Ib and Ic seem to be core-collapse events, despite their lack of hydrogen. They therefore share the “what makes the explosion?” problem of Type IIa, but, once sufficient energy is somehow transferred to the envelope, their light curves and spectra can be fit by assuming a massive progenitor that has had most of its hydrogen removed (Hachisu et al. 1994; Nomoto et al. 1994). The second paper specifically addresses SN 1994ad, which turned up in the relatively nearby galaxy M51 in April, and is officially supernova of the year (Kirshner 1994). Last year’s stellar event, SN 1993J, is addressed in Sec. 13.

Finally, we look back over our shoulders at SN 1987A and see, with some surprise, in the repaired HST images, not just the ring we were used to, but an additional, off-centered pair,
such as might be traced out by the tip and eraser of a pre-
cessing pencil, viewed from a random angle. Panagia (1994)
shows the picture, but discusses only the main ring, for
which McCray and Lin (1994) have proposed a model. Their
suggestion is a leftover ring of proto-stellar material.

The environs of SN 1987A are, anyhow, very compli-
cated. The recent X-ray reappearance may be ejecta hitting
circumstellar material that started life as the low-density
wind of the progenitor when it was a blue supergiant (Goren-
stein et al. 1994). There are further excitements to look for-
to when the ejecta reach the main ring (Masai and
Nomoto 1994; Luo et al. 1994). And at least one important
encounter has already taken place and can be located at the
edges of the now-resolved radio source (Stavely-Smith et al.
1993).

But where, oh where, is the pulsar?

9.9 Off-Center Central Galaxies

Eh? We mean cD (giant) galaxies that, in two dimensions
at least, are at the centers of their clusters, but do not always
share the velocity of the cluster centroid. The answer is that
they are at the centroids of the clusters they came in with, but
those clusters are now in the process of merging with others,
and the product hasn’t yet got its Virial act entirely together.
This account we have from all quarters received (Zabludoff
et al. 1993; Pinkney et al. 1993; Bird 1994; Oegerle and Hill
1994).

9.10 The Composition of High-Energy Cosmic Rays

The cosmic-ray spectrum extends up to a kinetic energy of
3X10^{20} eV per particle, not quite as much as the Queen
Mary under full steam, but in there with a well-hit golf ball.
The highest energy particles are so rare that you can catch
them only as flashes of Čerenkov light when they hit the
upper atmosphere. This precludes a direct observation of
whether they are protons, iron nuclei, or something else.
Careful analysis of the Čerenkov data from the Fly’s Eye
telescope has, however, now settled that they are mostly
heavy nuclei (and galactic in origin) below the spectral break
at a 3X10^{18} eV and mostly protons (and extragalactic) above
it. The flux remains isotropic to the highest energies, insofar
as a very small number of particles can be mapped on the sky
(Bird et al. 1993). Enough different papers have appeared
propounding different ways to accelerate particles to the
highest galactic energies that we are not inclined to try to
choose among them.

10. COOLING FLOWS TO WHERE?

Many clusters of galaxies harbor diffuse gas at tempera-
ture \( \geq 3 \times 10^4 \) K, set by the depths of their potential wells and
such that most of their emission is at X-ray energies. Quite
often, the luminosity of (at least) the central region is so
large that the gas cannot have enough stored energy to keep
shining for the age of the Universe. Thus the gas must be
cooling and so (pushed by the overlying material) be flowing
inward at rates of 10^{-1000} M_\odot per year. The 1250 M_\odot/yr
reported by Edge et al. (1994) for the cluster Zw 3146 may
or may not be a record.

A feeling as the year went on that this topic was ripe for
review was amply confirmed by the appearance of an excel-
- lent one (Fabian 1994) just as this was being written. An
important recent development emphasized there is that satel-
lite data from the post-Einstein era show directly that some
cluster gas really is cooler at the center, e.g., David et al.
(1994) on the NGC 5044 group as seen by ROSAT; and
ASCA can do even better (Tsao et al. 1994). Such a configu-
ration is clearly unstable, and there seem to be only three
possibilities: (a) kinetic energy is somehow being continu-
ously supplied to the gas from outside (conduction is the
process most often mentioned), (b) the gas continues to cool
and so must eventually turn into other detectable phases, or
(c) we are all making some terrible mistake.

Tempting as (c) may be, it is probably wrong. The gas is
independently seen as a cause of large rotation measures of
central radio sources (Taylor et al. 1994) and through its
interactions with the structure of these radio sources (Zhao et
al. 1993). One promising alternative morphology is even
more unstable and yields wrong spectra to boot (Fabian et al.
1994).

That reheating does occur seems likely from some of the
post-Einstein data, for instance the BBSXT and ROSAT views
of Abell 2256 (Miyaji et al. 1993). But it is sufficient only to
slow the flow a bit, not to halt it.

Thus we are left with alternative (b), that the X-ray gas
must be transformed into something else, and we would like
to focus on the issue of what becomes of it. It should pass
first through a coronal (\( \sim 10^6 \) K) phase. A characteristic
coronal line of [Fe x] has been seen in one of five clusters exami-
ned, though neither the detection nor the limits yet tell us
much about the mass in that phase (Donahue and Stocke
1994). Optical emission from the next temperature plateau
near \( 10^8 \) K will be bright enough to see only where the gas is
highly clumped. Some central galaxies of cooling flow clus-
ters do have filaments of gas in that temperature range (Fa-
bian 1994; Edge et al. 1994), but the mass involved is tiny
compared to the supply.

H i can be limited much more severely both as an emitter
and as an absorber (for clusters with radio sources), because
both diffuse and clumpy gas is bound to show up. A recent
absorption study (Dwarkanath et al. 1994) fully confirms ear-
lier searches for 21 cm emission. Neutral gas is absent, down
to a level about 1/30th that expected from Einstein X-ray
data and models.

Molecular gas can be hunted for either indirectly as infra-
red emission by its dust (Annis and Jewitt 1993) or directly
as a source of CO line emission (Antonucci and Barvainis
1994; McNamara and Jaffe 1994; O’Dea et al. 1994; Braine
and Dupraz 1994). These five papers report only upper lim-
its, ranging from \( 10^{10} \) M_\odot down to \( 4 \times 10^{10} \) M_\odot. If you think
you know a time scale for cool gas to turn into stars, then
you can translate these numbers into much less (0.01–0.1)
gas than you were expecting. Alternatively, you can conclude
that the gas must pass through the molecular phase in \( 10^7 \) yr
or less. Gas very close to \( T = 2.735 \) K is, of course, almost
undetectable in emission or absorption, and this is conceiv-
elably part of the answer (Ferland et al. 1994). An interesting
rial were being turned into a stellar population with its fair
Thus star formation in the last refuge of the cooling gas.
run of giant ellipticals (Crawford and Fabian 1993), but they
be the truth. What remains for the cooling flows is the for-
mation of (almost exclusively) low-mass stars. Whether star-
distribution of star masses (Schombert et al. 1993).
Sherlock Holmes said that, whenever you have eliminated
impossible, whatever remains, however improbable, must
be the truth. What remains for the cooling flows is the for-
formation of (almost exclusively) low-mass stars. Whether star-
formation theory "predicts" this is a little difficult to say in
the present nebulous condition of star-formation theory. But
if the young- and intermediate-age globular clusters at the
center of NGC 1275 are indeed the descendants of cooling
flow gas, then their apparent deficiency in massive stars may
be offering a "yes" answer (Nørgaard-Nielsen et al. 1993).
One could, at least in principle, look for a vast number of
sub-solar-mass stars in central elliptical galaxies using as a
tracer the 2.3$\mu$m CO feature that is diagnostic of dwarf-star
light dominating giant-star light (Kroupa and Gilmore 1994).

"I want one too" is our immediate, childish response to
hearing that other galaxies have cooling flows. Could high-
velocity $H\text{\textsc{i}}$ clouds be the Milky Way analog? Some of them
have roughly the right properties (Danly et al. 1993). Sadly,
however, all right thinking people clearly believe that they
are part of an up-and-down flow driven by supernovae in the
galactic disk (Little et al. 1994; Schulman et al. 1994).
Perhaps at least we had one in the past. Fabian and Nulsen
(1994) propose that part of the basic process of formation of
large galaxies is a cooling flow that leaves them all with
halos of brown dwarfs.

11. HUBBLE’S RANDOM VARIABLE

It would be unfair to claim that there has been no progress
whatever in measuring $H_0$. Surface brightness fluctuations
have been adopted as a distance indicator by a second group
(Shopbell et al. 1993), though unfortunately the method still
does not reach far enough to make contact with the Hubble
flow. Among lensed quasars, another has turned up (MG
1131+0454) with variability in its core-jet ratio that may
provide another leap up the distance ladder (Chen and Hewitt
1993). An analysis of the stellar evolution leading up to the
formation of planetary nebulae has provided some physical
justification for using the nebulae as standard candles (Han et
al. 1994). And, of course, there has been the usual biennial
review of the subject (Fukugita et al. 1993).

But the actual numerical situation remains disorganized.
Two talks at IAU Symposium 168 (Kafatos and Kondo
1995) in August laid down the battle lines. Sidney van den
Bergh (reporting on detection of Cepheids in the Virgo Clus-
ter with the Canada–France–Hawaii telescope) set a firm
lower limit of 83 km s$^{-1}$ Mpc$^{-1}$. Gustav Tammann (making
use of supernovae and several other calibrators tied to Cep-
heids) set an equally firm upper limit of 55 km s$^{-1}$ Mpc$^{-1}$.
The table reports all the definite numerical values we found
during the reference year. To save you getting out your cal-
culator, the mean is 68 and the median 71 km s$^{-1}$ Mpc$^{-1}$.
numbers which will please neither camp. The values are or-
dered from large to small. The CFHT Virgo Cepheid value,
published just after our strange year ended, sits near the top
of the table. The HST key-project value, also based on Virgo
Cepheids, is due out a few weeks later and there is a small
arrow in the table where we are guessing it will fit.

On the other hand, $H_0$ is in good condition compared to
some of the other cosmological parameters. The limit on $\Lambda$
coming from statistics of lensed quasars (not more than 70% of
the closure density) seems to be quite robust (Maoz and
Rix 1993). As for a direct measurement of $\Lambda$, the data base is
now "only" a factor of 20 or so away from having enough
pairs of physically associated quasars to make use of the
sensitivity to $\Lambda$ of the difference between the redshift–
distance relation in angular and radial directions (Phillips
1993). It was more like a factor of 500 (or maybe infinity)
when Alcock and Paczyński (1978) suggested the test. The
rest is silence.

12. ONE, TWO, THREE, INFINITY

We are rapidly running out of section numbers if lucky 13
is to be devoted to removing mud from faces and feet from
mouths, and so will pick just a double handful of favorites
from this year's firsts, seconds, and other extrema.

12.1 The First Intensity Interferometer (and Other
Instruments of Note)

Hanbury Brown and Twiss (1956) you will exclaim. And
it was indeed the first optical intensity interferometer. But,
slightly earlier, Jennison and Das Gupta (1945) had made use
of a radio intensity interferometer in their classic demonstra-
tion of the double structure of Cyg A.

Other interesting instrument news of the year includes (a)
the 60-cm radio telescope at Nobeyama (Sakamoto et
al. 1994), and yes this is the size of the dish, not the operating
wavelength!, (b) the highest-resolution spectrograph cur-
cently in operation, with $\lambda/\Delta \lambda = 10^6$ (Crawford et al. 1994;
they were using it to study the disk of Beta Pictoris), (c) the
first set of Keck telescope papers (Soifer et al. 1994; Graham
et al. 1994; Larkin et al. 1994; Matthews et al. 1994), (d)
adaptive optics under way at ESO (Heydari-Malayeri and
Bezuit 1994), (e) a special issue of PASJ devoted largely to
X-ray results from ASCA, in Vol. 46, No. 3, and (f) the emer-
gence of the first source catalog from the Extreme Ultraviolet
Explorer satellite (Bowyer et al. 1994).
12.2 Galileo's Second Asteroid (and Other Solar-System Items)

Ida was actually imaged more than a year ago (Chapman et al. 1993), but the problem of data retrieval meant that we had to wait some time for a detailed report (Belton et al. 1994). It is bigger (52×24×21 km), faster rotating, and has bigger craters than the first one imaged, Gaspra. And what is Lyttleton on comets as rubble piles, D. Malin on low surface brightness galaxies, R Hertz, and J. Grindlay on cataclysmic model of planetary nebulae, and so forth, without citing Van

Parent planet, but Gor'kavyi (1993) suggests that the outly-

Earth does, too—they are responsible for trade winds, horse latitudes, jet streams, and so forth.

The first two radar measurements of distances to Galilean satellites of Jupiter have been completed (Harmon et al. 1994). Ganymede and Callisto were both more than 100 miles from where their ephemerides said they should be, many times the standard error. These inner satellites with direct orbits are always regarded as having formed with their parent planet, but Gor'kavyi (1993) suggests that the outlying, retrograde moons did too.

12.3 A Class Too Large

We have been keeping lists of people who use Van Kamper's method, Brandt's rotation curve, Shklovsky's model of planetary nebulae, and so forth, without citing Van Kamper, Brandt, and Shklovsky, as well as of people who ignore the pioneers of particular topics (for instance R. A. Lyttleton on comets as rubble piles, D. Malin on low surface brightness galaxies, P. Hertz, and J. Grindlay on cataclysmic variables as globular-cluster X-ray sources, and F. Kerr and P. Henning on 21-cm searches for galaxies in the zone of avoidance), but we cannot figure out any way to mention specific examples without giving still more credit to the wrong people! The two categories are worrisome for different reasons. In the first case, the reader might quite legiti-

mately want to know when and where Van Kamper flour-

ished and more details of his method. In the second case, it is the sheer injustice that rankles. Whom have we forgotten to cite this year in either of these ways??

12.4 First Coronal X-rays from a Single White Dwarf (and Other WD Wonders)

The winner is a very hot (10^5 K) DO star called KPD 0005+5106 (Fleming et al. 1993). Having bet on cool, strongly magnetized ones (Musielak et al. 1994) we can only say that the hardest photon won. The star is actually the hottest helium-surface white dwarf known (Werner 1994).

In other white-dwarf news, the weakest directly detected magnetic fields Zeeman in at 10^5 G (Schmidt and Smith 1994). But a much weaker (dynamo-generated!) magnetic field of 1300 G is indirectly implied by mode analysis of the pulsating helium white dwarf GD 358 (Markiel et al. 1994).

We remain astounded by the thinness of the hydrogen layer on white dwarfs whose optical spectra seem to show nothing else—as little as 10^{-12} M_\odot according to ROSAT data (Barstow et al. 1994). Those white dwarfs that do show optical lines of helium and/or metals as well as hydrogen, despite similarity in temperature, perhaps have systematically lower masses and surface gravities, hence less efficient gravitational settling (Bergeron et al. 1994b). The difference may arise from different progenitors, AGB stars for normal hydrogen-surface DA white dwarfs and post-extended-horizontal-branch stars for DAOs with helium as well. If so, then some progress has been made toward the noble goal of reducing the pattern of white dwarf evolution to something that can be printed on a T shirt. This is Leon Lederman's criterion for a correct theory. One cool white dwarf, LHS 1126 (5400 K) has, however revealed the unlikely spectral combination of lines due to He, H_2, and C_2 (Bergeron et al. 1994a). It will have to go on the left sleeve.

In contrast to the case of single white dwarfs, the surfaces of those in cataclysmic binaries reflect the composition of the

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material being transferred from the other star (Jordan et al.
1994), even unto barium excesses (Schmid 1994). We should
perhaps be ashamed to admit to having been surprised by
this, but at least it permits a relatively smooth transition to
another CV item that surprised twice.
First, Wickramasinghe and Wu (1994) put forward a very
elegant scheme for explaining the distribution of periods of
the AM Herculis CVs (ones with strong magnetic fields). It
is, however, apparently not the right answer, since the post-
ulated magnetic braking of systems does not occur (King et
al. 1994).

12.5 A Second Pulsar with a Real (Non-Degenerate)
Companion (and X-rays from the First)

Ap 92 expressed due amazement at the discovery of a
pulsar with a normal, non-degenerate companion, a Be star
like those in many X-ray binaries. Now there are two, the
second in the Small Magellanic Cloud (Kaspi et al. 1994b).
With a period of 0.925 s, the neutron star cannot yet have
been spun up by accretion, and the system is presumably the
precursor of a massive X-ray binary. Meanwhile, the eccen-
tric orbit of the first such binary pulsar, 1259−63, has now
carried it close enough to the Be star that X-ray emission has
turned on. The primary mechanism could be either accretion
of the Be wind by the neutron star or collision of winds from
the two components (Cominsky et al. 1994). For what it is
worth, the first binary pulsar with a black-hole companion
should turn up any day (Lipunov et al. 1994).

12.6 The Second and Third Galloping Giants

We continue to admire FG Sge and its perambulations
around the HR diagram and were pleased to hear that it has
been a carbon star ever since 1981 (l’ijima and Strafella
1993b). FG Sge cooled and brightened through most of this
century. Thus Th 4-4, which has heated from 22,000 to
54,000 K in the last 20 years (Kondrat’eva 1993) and faded
a couple of magnitudes, and the rapidly evolving HD 161796
(Skinner et al. 1994) are not the same sort of beast. Presum-
ably they are post-asymptotic-giant-branch stars, but rather
spectacular nevertheless.

12.7 “You’ve Had Five, but Who’s Counting?”

As the hostess said to the guest, who had declined another
sandwich on the grounds of having already had four. And
after this we are going to stop counting (a) optical identifi-
cations of pulsars, after the announcement of numbers five
and six (Caraveo et al. 1994), (b) supersoft X-ray sources,
with five in the Large Magellanic Cloud (Greiner et al. 1994)
and at least one each in the Milky Way (Motch et al. 1994)
and the Small Magellanic Cloud (Brown et al. 1994); dispute
about whether the accreting star is a white-dwarf or a neutron
star continues (Hughes 1994), and for the one identified with
a planetary nebula, even a very hot single pre-white-dwarf
star could be responsible (Heise et al. 1994), (c) scenarios for
the chemical evolution of dwarf galaxies (De Young and
Heckman 1994), and (d) 9 Aurigae type variables (Krisicu-
nas 1994; Balona et al. 1994; Mantegazza et al. 1994).

12.8 A Second Great Wall

Apart, of course, from the Chinese one, the first Great
Wall was a long, coherent structure in the distribution of
galaxies found in the Center for Astrophysics survey. The
second one, as hemispherical neutrality would demand, has
turned up in the Southern Sky Redshift Survey (da Costa et
al. 1994). There is also at least one 5000 km s⁻¹ wide void in
the southern distribution. But these are not the largest devia-
tions from homogeneity and smooth Hubble expansion so far
identified. Lauer and Postman (1994) find that Abell clusters
out as distant as 15,000 km s⁻¹ are still not, on average, at
rest relative to the microwave background radiation, and our
velocity relative to them is not the same as our velocity
relative to the 3 K background.

12.9 The Third Thick Disk

This presupposes that you believe the Milky Way to have
a thick disk component, intermediate in age, kinematics,
and chemical composition between the young thin disk and the
old halo (Karchenko et al. 1994 have said it most recently).
Then comes NGC 4565 and a reasonably persuasive new
case, NGC 6504 (von Dorkom et al. 1994). Another project,
reported in Sec. 5.8, also started out to look for thick disks,
so more can undoubtedly be expected soon.

There appears also to be a third galaxy of the very low
surface-brightness (Malin 1) variety. Not surprisingly, it has
a pretty undistinguished name, 1226+0105 (Spayberry et al.
1994). Such objects are, however, rare enough that they are
not a major contributor to either uncounted light or un-
counted mass in the universe (Davies et al. 1994).

12.10 A Gaggle of Oddities

Most Obscure Author? Single-author papers littered with
"we’s" have become the norm, so perhaps one should not be
surprised when two authors (Lynden-Bell and Boily 1994)
speak of themselves several times as "I."
Most Complex Method of Distance Measurement. O’Dell
et al. (1994) point out that, for member stars of an open
cluster, you can combine values for rotational velocity
(u sin i from line widths), rotation period (from light curves
of stars with spots), and angular diameters (from the Barnes–
Evans relation) to get the distance to the cluster. It works,
anyhow, for the Pleiades and Alpha Persei clusters, where
you already know the answer.
Encore, Encore. As the audience said to the tenor, mean-
ing to keep trying until you get it right. We think our col-
league’s names are Golenetskii and Illinskii, but see the ref-
ences of Fenimore et al. (1994) for a total of four possible
alternatives.
Are You Sure You Belong in This Galaxy? NGC 1399 is
the second elliptical galaxy in which the planetary nebulae
constitute a rotating system, while the globular clusters do
not (Arnaboldi et al. 1994). The first one was Cen A (NGC
5128, Hui et al. 1994). Even the planetary nebulae of the
Large Magellanic Cloud have a mind of their own, being
distributed spherically, while field stars and clusters define an
ellipse with b/a=0.7 (Morgan 1994).
Rewriting of History. “Interestingly, the earliest models of radio galaxies and quasars invoked central clusters of supernovae or pulsars,” according to Williams and Perry (1994), who cite papers by I. S. Shklovsky, G. B. Field, and S. A. Colgate written in 1960, 1964, and 1967, respectively. Since pulsars were not presented to the public or named until 1968, none of these authors could have invoked them. Earlier or equally early models that go uncredited include W. Baade and R. Minkowski suggesting colliding galaxies in 1953, and Ya. B. Zeldovich, F. Hoyle and W. A. Fowler, and E. E. Salpeter, all in 1964, who proposed the collapse of single, supernasive objects and accretion onto the resulting compact configurations.

12.11 And All the Rest

The point has been noted in previous years that these roundups exclude 80%–90% of the papers that we originally found interesting enough to read and record in our respective filing systems. This time around, several dozen whole topics also had to be dropped between preliminary indexing and the final paper. We really wanted to mention second and third parameters in globular clusters; the opacity project (Seaton et al. 1993); the various candidates for most distant cluster of galaxies; progress in finding and understanding very small amplitude variable stars, and many other topics. There are three reasons not to: (a) we have surely already exhausted your patience, (b) we have to pay page charges on this, and (c) 1995 is another year.

13. ZE COME OUT OF ZE TRENCHES VISS ZE HANDS UP

First, a hasty assurance that the accent of the heading is Fritzwickese (transcribed for us last year by George Wallerstein), and since this belongs to no known language group, it cannot be politically incorrect. Next we draw attention to our own errors and omissions in Ap 93, before going on to mention some others from this year’s literature. The former are in the order of the sections in Ap 93 where they appear (with the references that caused the slip-ups). For the first time in this series, a correspondent asked for more credit to his own work and less to the people we had cited, ending the message with the words “Pow, Biff, Bam!” No comment.

Section 2.2 erroneously described the second Palomar Observatory Sky Survey as using I–N plates. In fact, IV–N plates are used, and sufficient supplies have probably been reserved to complete the survey. Plates continue to be valuable for a wide range of projects (Surace and Comte 1994). Remarkably, Kodak Tech Pan may actually be better than the traditional IIIa-F for surface photometry of galaxies (Phillips and Parker 1993).

Section 4 concerned drivers of stellar mass loss. A correspondent expressed surprise that magnetic flares were not included for K–M dwarfs, the Sun, and perhaps Be stars. But a paper in the current index year strongly implies that, conversely, solar coronal mass ejections are the cause of the flares (Gosling 1993). We believe that the chicken and the egg have not yet entirely sorted out their differences either. The paragraph on very luminous stars did not adequately differentiate between two classes of instabilities, classical dynamical ones arising only with the new OPAL opacities (see also Stothers and Chin 1994) and a new category of dynamical strange-mode and mode-coupling instabilities.

If you are still hoping to see the solar heliopause (Sec. 5.1), do not give up. First, while Pioneer 11 and 12 will probably die before reaching it, Voyager 1 and maybe 2 have a much better chance to survive. Second, a recent rediscussion of the very local interstellar medium (Lallement et al. 1994) indicates that there is sufficient density out there to provide a sharp termination of the solar wind. Curiously, we seem to have entered this particular cloudlet only within the last few thousand years (Frisch 1994).

In Sec. 5.3 on duplicity of barium and related stars, the kindly Editor sorted us out in a footnote on dwarf carbon stars with white-dwarf companions. One of the items has now been published (Liebert 1994).

We feel somewhat more sinned against than sinning on the issue (Sec. 9.4) of the periodic variability of the iron line in Cen X-3. LMC X-4 was first by at least four years (work by K. Dennerl and colleagues reported at an ESLAB Symposium), and, what is worse, a recipient of the preprint of the 1993 paper pointed this out to the author, but went unheeded.

We were, however, the culprits in the claim of highest-frequency VLBI (Sec. 9.7). The authors had merely said that they were the first at 7 mm, not that shorter wavelengths weren’t already in use.

Supernova 1993J (Sec. 10.5) was by no means the second brightest supernova of the 20th century. Peaking at $V = 10.6$, it was more like 57th. It does, however, seem to have been the second most intensively studied in recent years. It has become the prototype for SNe of Type IIb, which begin with detectable hydrogen lines in their spectra, but lose them early (thereafter resembling Type IIb’s) presumably because the outer hydrogen layer remaining on the progenitor was very thin. Some thirty papers addressed observations and interpretation of 1993J. Apart from the basic fact of a heavily stripped progenitor, arguably in a binary (Woosley et al. 1994; Utrobin 1994; Bartunov et al. 1994; Shigeyama et al. 1994; Ray 1994; Wheeler et al. 1994) the most interesting point seems to be that interpretation of the changes in radio luminosity with time implies that the parent star’s mass-loss rate dropped just before the explosion (van Dyk et al. 1994) while early optical spectra suggest a major increase in $dM/dt$ to $3 \times 10^{-4} M_\odot$ yr$^{-1}$ about a year before the event (Garnavich and Ann 1994). These cannot (we think) both be true; but the surroundings were anyhow denser than expected, accounting for the early X-ray emission (Leising et al. 1994).

NGC 4826 (Sec. 10.8) does indeed have counter-rotating parts, but the stars match the inner disk, so it is the outer disk that is going backwards and the outer spiral arms that lead rather than trail (Braun et al. 1994; Rubin 1994). More misleading, perhaps, was our assumption that counter-rotating parts of galaxies are a rare phenomenon. First, reports of it (and of core/disk misalignments) have proliferated (Braun et al. 1994, Rubin 1994a, and Walterbos et al. 1994, all on the complexities of NGC 4826; Fisher et al. 1994 on NGC 7332; and Rubin 1994b on a sizable sample of E, S0, and S galaxies). Second, theoretical ideas on the formation and stability...
of such systems have also proliferated (Sellwood and Merritt 1994; Antonov and Zheleznyak 1994). An appealing suggestion (Merrifield and Kuijken 1994), based on observations of NGC 7217, is that virtually all galaxies have accreted retrograde stuff, which builds up the bulge and weakens the spiral beyond to 1928 and even earlier. The correlation between binary periods and eccentricities was known to Henroteau (1928), to Wilson (1921) and even to Aitken (1918).

The bright star at the center of R136a, mentioned in Ap91 (Sec. 10.9) as possibly multiple has indeed been resolved into a triple (Lattanzi et al. 1994), an interesting use of the HST Fine Guidance Sensor.

A suitable image for the next few items might be the stars themselves surrendering for the crime of masquerading as something else. The 3.4-hr-period object that pretended to be an eclipse variable (King and Done 1993; Campana and Boccia 1994) is now known (Antonucci, R., and Barvainis, R. 1994, AJ, 107, 448) to be a cataclysmic variable, probably magnetic (Staubert et al. 1994). This gives the most recent models for the Seyfert periodic variability (King and Done 1993; Campana and Stella 1993) the happy status of predictions. Some putative periodic variability (King and Done 1993; Campana and Boccia 1994) the happy status of predictions. Some putative periodic variability (King and Done 1993; Campana and Boccia 1994) the happy status of predictions. Some putative periodic variability (King and Done 1993; Campana and Boccia 1994) the happy status of predictions.

But, to end on a cheerful note, we would like to record an honest recantation (Bradford and Hogan 1994), concerning the 3.4-hr-period object that pretended to be an eclipse variable (King and Done 1993; Campana and Boccia 1994) is now known (Antonucci, R., and Barvainis, R. 1994, AJ, 107, 448) to be a cataclysmic variable, probably magnetic (Staubert et al. 1994).

Our first thanks, as always, go to those who maintain the astronomy library collections consulted by the authors. Our increasingly hectic lives are reflected in the fact that these now include not only University of Maryland, University of California (Irvine), and Los Alamos National Lab, but also UC Santa Barbara, the European Southern Observatory, University of Toronto, Institute of Astronomy (Cambridge), Dominion Astrophysical Observatory, Space Telescope Science Institute, University of British Columbia, and California Institute of Technology.

More people than ever offered input, amplifications, and corrections, first and foremost Christian Jørgensen (of the chemistry department of the University of Geneva), who reminded us that astronomical results are occasionally even interesting outside the field. Our thanks to him and (alphabetically) to Michael A'Hearn, Sidney van den Bergh, Niel Brandt, Roberto Brucato, Drake Deming, George Djorgovski, David Duncan, Roger Griffin, Alan Hale, Kevin Kriessinas, Lucy Ann McFadden, Peter Mészáros, Michael Mumma, Juan Muzzio, Bohdan Paczyński, Simon Radford, Michael Richmond, Allan Sandage, Tod Simon, Myron Smith, Richard Stothers, László Szabado, Saku Vrtilek, Robert Wagoner, and René Walterbos. We wish we could echo Michel (1994) in saying that "no federal funds were diverted to support this curiosity-based research," but, in practice, we are grateful to NASA for partial support of the page charges.

Suggestions of items for Ap95 are welcome between now and about 15 September 1995.

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