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Invited Review Paper

Astrophysics in 1993

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ABSTRACT. After the astronomical excitements of 1991 and 1992, 1993 was frankly a bit of a letdown. More papers by more people were submitted and published than ever before (and this review has twice as many authors as the previous ones). Nevertheless, there seem to have been fewer large, definitive steps. As a result, we have focused on a handful of broad terrains for which the maps have improved, including stellar rotation and mass loss, dynamics of globular clusters, and quasar absorption lines, but have also highlighted many more of the small steps by which astronomy advances toward inventorying and understanding the universe. As a consequence, the ordering of topics is less obviously from near to far than in 1991 and 1992. And the potential for misattributions and unjustifiable neglect is probably somewhat larger.

1. INTRODUCTION

In accordance with a principle enunciated in "Astrophysics in 1992" (PASP 105, 1, cited as Ap92 hereafter), writing the third article in the series has created "a well-known class of astrophysical object." The characteristics of the class have not yet been fully defined, but clearly include some level of arbitrariness and a certain breathless excitement, born of envy and the mad chase to keep up with the contributions of so many productive colleagues.

Ap92 attracted more, but also kinder, feedback than Ap91 (PASP 104, 1), much of it from authors generously reapportioning part of the credit given to them. Some of these inputs are mentioned in Sec. 12 (*Addenda et Corrigenda*).

The ground rules remain much the same. No fine tuning of topics addressed in Ap91 or Ap92. Papers by the present authors can be cited as background or as strawpersons, but are, by fiat, not among the highlights of the year. The set of journals regularly scanned now includes *Nature, Physical Review Letters, Science, Astrophysical Journal* (plus *Letters* and *Supplements*), *Monthly Notices, Astronomy and Astrophysics* (plus *Supplements* and *Reviews*), *Astrophysics and Space Science, Astronomical Journal, Astrofizica, Acta Astronomica, Soviet Astronomy* and *Letters* (now renamed *Astronomy Reports* and *Astronomy Letters*, somewhat unfortunate choices), *Astronomische Nachrichten, Journal of Astrophysics and Astronomy, Publications of the Astronomical Society of Japan, Astrophysical Letters and Communications, Baltic Astronomy, IAU Circulars,* and (it goes without saying) *Publications of the Astronomical Society of the Pacific*. Items appearing elsewhere have been caught by chance or were sought out as background material. The "reference year" includes journals reaching our library shelves between 1 October 1992 and 30 September 1993.

There is no use pretending that the two authors have similar writing styles or even always similar opinions on what is important. Thus you probably won't need to be told that P.J.T.L wrote Sec. 6 and contributed some of the items in Secs. 2, 5, 7, 8, 9, 10, while V.T. is responsible for the rest.

2. DEATHS IN THE FAMILY

Past a certain age, most people read the *New York Times* backwards from the obituary page. We have tried to make this easy for you, but, in addition, many of the events are local, on scales from a few meters to a few parsecs.

2.1 The 17 keV Neutrino

Cosmologists had still not quite decided whether having an unstable neutrino with a rest mass of 17 keV in the early universe would be good or bad for galaxy formation, when it ceased to matter. From the first reports of laboratory evidence for a such a particle a couple of years ago, experimental physicists had been divided into camps pro (mostly using solid-state particle detectors) and con (mostly using gas-filled detectors). Evidence for the parti-

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cle took the form of a small blip in number versus energy of electrons produced in beta decay processes, 17 keV from the end point of the spectrum. The pros accused the cons of insensitivity to small blips, and the cons accused the pros of experimental artifacts.

The definitive experiment (Mortara et al. 1993) deliberately introduced a contaminant (^{14}C) with beta-decay energy about 17 keV less than that of the main unstable nuclide in a gas-filled detector. Sure enough, they saw a blip when the contaminant was present, but not otherwise, thereby refuting the accusation of insensitivity. We are particularly pleased that the senior author was an undergraduate at the time the work was done. He received the American Physical Society's Apker Prize for outstanding undergraduate research in 1992.

2.2 Kodak Spectroscopic Plates

Participants in IAU Symposium 161 (MacGillivray 1994) heard with varying degrees of surprise and horror a communication from Eastman Kodak announcing the immediate termination of the series of glass plates carrying emulsions with numbers IIa, 103a, and IV N. Continued production of the I N and the IIIa series, currently being used for the Palomar and ESO/SERC Schmidt sky surveys has been promised, but there may be supply line problems even with these. A very versatile, high-speed emulsion, Tech Pan, is available on film; and some glass plates suitable for astronomical purposes are produced by other companies (including ORWO in Potsdam, Germany), but astronomers who are still using plates for whatever purpose will have to make some adjustments. It may be wise to plan for the complete disappearance of photographic materials in 10–20 years, given that home videos are replacing home movies, and advertisements for commercial artists now typically specify skills in computer-aided illustration. *Ou sont les LP's d'hier*?

2.3 Homo Sapiens (Comets and Asteroids)

If this death had already happened, you would not need to read about it here. In fact, we guess you couldn't. Nor are we predicting it. But Gott (1993) has. His argument is that if you are a "random intelligent observer" of the universe, then human life expectancy is very probably between 0.2 and 8×10^8 yr. In addition, we have a much larger population than most intelligent species (the authors have come to suspect this independently) and will not survive to colonize the galaxy.

Gott does not propose any specific thanatopic mechanism, but considering astronomical possibilities allows us to sneak in some topics in solar-system dynamics that might otherwise be neglected. First, we will not be done in by comet Swift–Tuttle on its next return in 2116 (Marsden 1993), though Jovian living conditions will not be improved if/when comet Schoemaker–Levy 9 hits Jupiter's backside in July, 1994 (Chapman 1993). Swift–Tuttle will nevertheless come close enough to make an impressive display, whose sociological consequences will depend on how well the peoples of the earth deal with their problems in living together over the next 120 years. (Moses, you will recall, lived to be 120).

Second, we will not be crushed under the accumulation of air conditioners and electric blankets needed to deal with wildly oscillating seasons. Martians are at risk for this, for the angle between the rotation axis of Mars and its orbit plane ("obliquity of the ecliptic") varies, at least in numerical integrations, chaotically up to values of at least 47° (Tuoma and Wisdom 1993). One shudders to think of the amount of "seasonal adjustment" needed for unemployment rates and everything else. The earth is saved from this over-enthusiastic response to gravitational forces of the Sun and the other planets by the large torque exerted by our own Moon (Laskar et al. 1993).

This leaves asteroids as the threat to watch. The 1908 Tunguska event was apparently the explosion of a stony meteorite (rather than a comet or iron–nickel meteorite). Chyba et al. (1993) and Hills and Goda (1993) deduce this from the ≈ 10 km height above ground at which the bolide blew up. Independent evidence comes from the properties of about 150 condensed glassy spherical particles retrieved from tree resin near the impact zone (Korlevic 1993).

So far, no one has spotted the next asteroid likely to damage the earth significantly, but the number of small, nearby chunks of rock is larger than expected, with at least four found so far that passed closer to us than the moon (Rabinowitz 1993). The current record is held by 1993 KA_2, which came within 150,000 km of Earth (Marsden and Rabinowitz 1993).

Debate over whether the hypothetical impact blamed for extinctions at the Cretaceous–Tertiary boundary was more likely to be a comet or an asteroid continues (Hills and Goda 1993), though the distinction is not always a clear one. 1979 VA initially had a tail that would have put it in comet catalogs (West et al. 1992), though it was classified as an asteroid at official discovery. The Permian catastrophe (extinctions at the end of the Paleozoic era) was even more disastrous than the demise of the dinosaurs, in terms of the fraction of existing genera wiped out. It can conceivably be associated with a comet or asteroid impact that produced a 250 km crater whose edge we see as the curl at the tip of South America (Maury 1994).

2.4 Planet X

Pluto is simply not massive enough to account for the apparent perturbations in the orbits of Uranus and Neptune that led to its discovery. You could then choose between postulating a larger, more distant tenth planet or disbelieving the orbit residuals. The skeptics were right. After proper allowance is made for the ambiguities of prediscovery observations and for the improvement in knowledge of Uranus and Neptune that came from *Pioneer* and *Voyager* flybys, discrepancies shrink down into the noise (Standish 1993).

2.5 Life on the Planets of ϵ Eridani

The very first targets of Frank Drake's search for extraterrestrial radio signals were ϵ Eri and τ Ceti. He did not find anything, and perhaps should not have. The level of chromospherical activity and position on the HR diagram of ϵ Eri indicate that it is less than 10^9 years old (Drake and Smith 1993), so that, even given suitable planets, there probably has not been time for intelligent life to develop. And τ Ceti is a binary.

2.6 The Light Curve of SN 1987A

No, it hasn't turned off, and, in fact, remains bright enough that energy from either a central neutron star or decay of radioactive nuclides in addition to ^{56}Co and ^{57}Co must be contributing (Kumagai et al. 1993). But by day 1250, it had faded, relative to its surroundings, to the point where meaningful ground-based photometry ceased to be possible (Caldwell et al. 1993).

2.7 Local Group Member Andromeda IV

Van den Bergh (1992) never admitted this candidate dwarf irregular to his definitive list, but it has appeared on others (Madore 1992)—in error, we must now accept. And IV has not disappeared, but it is not a galaxy either. Joseph (1993) plotted its HR diagram and has concluded that it is simply a large, open cluster or association at the distance of M31 and within its disk.

2.8 The Broad Line Region of NGC 5548

Seyfert 2's have relatively narrow emission lines of both forbidden and permitted lines. Seyfert 1's also sport broader permitted lines. The relationship is widely advertised as one of orientation (Ap92, Sec. 7), so that Seyfert 2's have broad line regions, but our view is obscured. Loska et al. (1993) report, however, that the BLR of NGC 5548 disappeared in February or March of 1992, and they believe that this is not just a matter of increased obscuration.

3. THE EVOLUTION OF STELLAR ROTATION RATES AND ACTIVITY

Rotating stars are a lot like people. They all slow down as they age, but some were not very fast to start with. Having a close companion makes a significant difference to the stars, though perhaps not quite in the way you might have expected. Drawing the human analogy is left as an exercise for the reader, and Chapter 17 of the 2nd edition of Gray (1992) is recommended as an introduction to the measurement and interpretation of stellar rotation.

A generation ago, the standard model had all stars forming from gas clouds with the maximum possible angular momentum. Early-type stars preserved their initial supply, while stars like the Sun had deposited most of their angular momentum in planetary systems. Indeed, if you add in the orbits of Jupiter and Saturn, the solar system total comes quite close to the $J \propto M^{5/3}$ line defined by stars earlier than A0, though the spin down by magnetic winds of F-M stars was also clearly part of the picture. The rotation of binary stars was not considered important enough even to deserve an index entry in Batten's (1973) book.

The 1993 picture is slightly different. It remains true that rotation periods can be extracted either from photometric variability (for stars with surface features, anywhere from spots to pulsar emission cones) or from rotational broadening of absorption lines (the measured $v \sin i$ then requiring a statistical correction for orientation). The two yield consistent results when both can be seen (O'Dell and Collier-Cameron 1993, on G-K dwarfs in the α Persei cluster). A couple of magnetic, chemically peculiar main-sequence stars even have their radio emission correlated with rotation phase (Leone and Umana 1993 on σ Orionis E). But not all stars are rapid rotators, even at zero age.

The present scenario starts with large interstellar gas complexes, not all of which display measurable overall rotation, despite earlier claims (Green and Padman 1993, on Orion). Next, velocity measurements of 43 cloud cores, well on their way to star formation, reveal that the average ratio of rotational to gravitational energy is only 0.02 (Goodman et al. 1993). Then, it should not come as a surprise that F-G-K stars just before and after the zero-age main-sequence phase display a wide range of values of $v \sin i$, not strongly correlated with age and that, therefore, many of them are never rapid rotators with $v > 30$ km s^{-1} (Duncan 1993; Soderblom et al. 1993a). Finally, indeed aging stars do spin down, as seen most clearly when comparing open star clusters of different ages (Soderblom and Mayor 1993; Li and Collier-Cameron 1993).

Intermediate stages are complicated. Three samples of T Tauri stars each show a range of rotation rates or period. Attridge and Herbst's (1992) Orion sample is bimodal, with peaks at 2.2 and 8.5 days, but with rotation not correlated with other properties in any way that suggests a cause. Bouvier et al. (1993) find a range of 1–12 days, with the weak-lined or naked T Tauri stars rotating faster than the classical ones, as if spin up had occurred. This is also the implication of the report by Edwards et al. (1993) that T Tau with disks rotate slower than those without disks—if much of the disk material is accreted, the former will spin up to match the latter. Among late B stars, on the other hand, disks go with rapid rotation (Turner 1993). Presumably these are excretion disks.

Theoretical work confirms that, for pre-main-sequence stars as for neutron stars in X-ray binaries, an accretion disk with jets and magnetic field can spin the central star either up or down, depending on precise values of field strength, disk radius, mass accretion rate, and so forth (Lovelace et al. 1993). HD 197890 displays transient emission and absorption features that arguably represent blobs of gas being added to the spin-down wind (Jeffries 1993).

Now that we have our stars safely rotating on the main sequence, four questions remain: (a) What are the implications for stellar activity, (b) Where do binaries fit in, (c) What else is rotation important for, and (d) Is the Sun normal?

Standard indicators of stellar surface activity include emission of coronal X rays and/or radio waves, flares, chromospheric emission at the centers of strong lines like Ca II H and K and Hα, and quasiperiodic light variations caused by spots on the rotating surface. Mercifully, the several indicators are reasonably well correlated (e.g., Butler 1993), so that, if you have good data for one, you can carry on looking for causes and effects. Activity in the present sense requires a convective envelop. We would love to tell you why, but the really neat idea advertised in Ap92 (Sec. 14) is currently under debate (Judge and Cuntz 1993 versus Garcia Lopez et al. 1993). In any case, activity sets in with the beginnings of convection at $(B-V)=0.25$ and becomes (on average!) stronger as the envelope deepens.

Dynamos begin to operate when the convective envelop takes in about half of the stellar volume (not mass!), and then rotation counts too (except that a few young stellar objects may have retained appreciable flux from their days as clouds contracting via ambipolar diffusion, Andreas et al. 1992). Members of the Pleiades are particularly instructive, because there is a real range of rotation speed at each mass (or temperature or envelope depth) between 0.6 and $1.4M_{\odot}$. Activity levels of individual stars confirm that the dominant parameter is actually the ratio of rotation period to convective turnover time, otherwise known as the Rossby number. Small values of R_0 mean lots of activity (Soderblom et al. 1993b). The activity of many (not all) G-K dwarfs is cyclic with periods of a few to 25 or so years. Curiously, average cycle period, as well as average activity level, seems to change as stars age (Sorn et al. 1993).

This brings us to activity in binary stars. Tidal interactions keep rotation and orbit periods synchronized in close binaries ($P\lesssim 10$ days on the main sequence, but much longer for some giants like the ζ Aurigae system, Griffin et al. 1993). Thus close binaries do not age like single stars. The large number of active RS CVn (G-K) and BY Draconis (M) pairs, as cataloged by Strassmeier et al. (1993) are a conspicuous example. The RS CVns have it all—X rays, radio emission, spots, and high excitation emission lines (Dempsey et al. 1993a; Eaton et al. 1993). And since both stars are kept spun up, both are X-ray sources (Ottman et al. 1993). They remain sources even at the $\gtrsim 5$ Gyr age of M67 (Belloni et al. 1993). Short (orbit, hence rotation) period Algols are probably also active (Richards and Albright 1993).

It is presumably an oversimplification to say that only the Rossby number counts, even for binaries (Dempsey et al. 1993b), but this is a good place to start (Hall 1994; Fernandez-Figueroa et al. 1993).

We continue to find it slightly disconcerting that so uncommon an element as lithium should be so important for studying the structure of outer layers of stars, not to mention the early universe (Reeves 1993; Steigman 1993). But so it is. Correlations of Li/H with stellar mass, age, effective temperature, and so forth are complex and not fully understood (Boesgaard 1991). But the latest round of data reveals differences in lithium abundance between single and binary stars that seem to be associated with synchronized rotation in the latter (Fernandez-Figueroa et al. 1993; Balachandran et al. 1993; Soderblom 1993; Soderblom et al. 1993c). Further progress awaits clarification on whether lithium depletion is inhibited by slow rotation (Fernandez-Figueroa et al. 1993), fast rotation (Soderblom 1993), or by synchronization per se (Balachandran et al. 1993).

The pulsation of δ Scuti stars is similarly esoteric. On the one hand, the population can perhaps be split into two subtypes—high amplitude with slow rotation versus low amplitude with rapid rotation (Rodriguez et al. 1993). And, on the other, the mode structure of the pulsations suggests that only the surface rotation has been synchronized (Goupil et al. 1993 on GX Persei). Such decoupling of core and envelope as rotation speeds up or slows down is arguably fairly common (Li and Collier-Cameron 1993) but not generally easy to verify.

The sun, in contrast, must rotate rather rigidly, according to analyses of its spectrum of normal mode oscillations (Paterno et al. 1993; Lyndon et al. 1993; Christensen-Dalsgaard and Däppen 1993, and many other papers), though there is, of course, some differential rotation in radius and latitude (at the 10% level) and even, it seems, an asymmetry between hemispheres (Nesme-Ribes et al. 1993). For an old star, it has a typical rotation period, activity cycle length, activity down time (Maunder minimum, etc.), flare rate, and so forth (Noyes et al. 1991). Our elderly near neighbor, α Centauri B, is an even slower rotator at 43 days (Chan et al. 1993). But, curiously, while the solar level of chromospheric variability from year to year is normal, its level of white-light variability is very low in comparison (Lockwood et al. 1992).

4. WHAT DRIVES STELLAR MASS LOSS?

All stars lose mass, at rates from $10^{-14}\ M_{\odot}\ \mathrm{yr}^{-1}$ in our own Sun[3] upward through $10^{-5}\ M_{\odot}\ \mathrm{yr}^{-1}$ in Wolf–Rayets, luminous blue variables, and M supergiants, to $10^{+4}\ M_{\odot}\ \mathrm{yr}^{-1}$ during the first few hours of a supernova explosions. Why? Clearly not the same reason for all stars, and three ideas, at least, strike one with the force of revelation upon first hearing.

(a) The total energy of an ionized red giant envelop is actually positive, as was known to Biermann and Cowling (1939) and rediscovered by Hoyle (1956), Paczyński and Ziółkowski (1968), and, doubtless, others.

(b) "...most mass loss of evolutionary significance is closely related to stellar pulsation," according to Willson and Bowen (1984), but with precursors in the work of Deutsch (1960) on Mira variables, and elsewhere.

(c) Radiation pressure is likely to be important (Johnson 1925; Milne 1927; and Pikel'ner 1947), most spectacularly in the context called the Eddington limit, where the outward force exerted by radiation exceeds the inward force exerted by gravitation.

These by no means exhaust the inventory. We have found the following physical processes, some accompanied

[3]We have never entirely recovered from having it pointed out to us that this is roughly the mass flux carried by the Amazon River; the usual small prize is offered to the first three readers to guess who pointed it out.

by explanations or early references, all advocated by someone:

(1) Total positive energy, as in (a) above;

(2) Evaporation or gradient of thermal pressure, as formulated for the solar wind by Parker (1958);

(3) Dissipation of the energy of acoustic waves (Biermann 1948; Schwarzschild 1948; Schatzman 1949), widely accepted as important at least for heating chromospheres and coronae;

(4) Radiation pressure in lines (Deutsch 1956; Wilson 1960) whether resonance lines of neutral atoms in cool stars or of ionized atoms in hot stars (Lucy and Solomon 1970);

(5) Radiation pressure on molecules and dust in cool stars (Weymann 1960; Hoyle and Wickramasinghe 1962);

(6) Dissipation of the energy of Alfvén waves (Belcher 1971; Hartmann and MacGregor 1980);

(7) Radial pulsations in Miras and elsewhere, as in (b) above;

(8) Nonradial pulsation, especially for Be stars (Vogt and Penrod 1983);

(9) Rotation, also mostly for Be stars (Struve 1931; Crampin and Hoyle 1960);

(10) Expulsion by a binary system whose stars briefly share a common envelop (Paczyński 1976) and other less spectacular mass loss from binaries (Paczyński and Ziółkowski 1967);

(11) Driving by flashes or pulses of some nuclear reaction (Trimble and Sackmann 1977).

Now, with all these horses in the running, which are winning in 1993? First, radiation pressure is clearly important nearly everywhere on the HR diagram where mass loss is seen. Among cool stars, where the radiation is largely pushing on molecules and dust grains, the expected correlation of large mass loss with high metal abundance shows up in red giants (Tripicco et al. 1993), asymptotic giant branch stars (Jørgensen and Johnson 1992), and OH/IR stars (Blommart et al. 1993). But even here, radiation pressure is probably not the whole story. The inclusion of pulsation effects yields a better fit to observed mass loss rates for Miras (Anandarao et al. 1993), while at least some OH/IR stars need help from acoustic waves (David and Papoular 1992). That radiation pressure cannot drive more than a certain maximum energy or momentum flux seems clear. That there should also be a minimum, set by the loss of coupling between dust and gas (Netzer and Elitzur 1993) is slightly more mysterious, the more so as the minimum rates ($10^{-7}\,M_\odot\,\mathrm{yr}^{-1}$ for cool, oxygen-dominated atmospheres and $10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$ for carbon-rich ones) fall within the observed range (Loup et al. 1992).

Among hot, luminous stars, radiation pressure (largely exerted in atomic resonance lines) also provides an approximate fit to data on wind velocities and mass fluxes (Bernabeu 1992), but is again not necessarily the whole story. Assuming that it is "predicts" too large a terminal velocity, but too small a flux of mass and momentum (Lamers and Leitherer 1993).

A similar sort of discrepancy arises for Wolf–Rayet stars. There are, of course, lots of ways out. For instance, if you assume a clumpy wind, then the observed line intensities imply a smaller mass flux (Antokhin et al. 1992). Proper allowance for photon trapping by stratified ionization increases to the outward force available (Lucy and Abbott 1993). And, among WN (nitrogen-rich Wolf–Rayet) stars, the absence of correlation of mass loss rate with luminosity suggests that some other driver may collaborate (Hammann et al. 1993). Alfvén waves are one possibility, although the required surface field of 400–600 G seems rather high (dos Santos et al. 1992; dos Santos 1993).

Second, Alfvén waves remain in the running for contributions in cool stars, both dwarfs and giants (Velli 1993). Whether acoustic waves alone can ever do the job needs further investigation (Koninx and Pijpers 1992).

Third, pulsation is clearly important in long period variables (Pijpers 1993). "Pulsation" in this context means radial modes driven by the kappa mechanism (opacity, usually in an ionization zone, that acts like a faucet, alternately trapping and releasing radiation). Though all mass-losing stars may have pulsation in their life cycles, not all pulsating stars are losing mass. An *IUE* search for absorption lines in S Muscae (Cepheid + B5 V binary) has set the interestingly tight limit of $dM/dt \leqslant 7\times10^{-10}\,M_\odot\,\mathrm{yr}^{-1}$ (Rodrigues and Böhm-Vitense 1992).

Fourth, the most massive luminous stars known (η Carinae, the luminous blue variables, and their ilk) really are trying to exceed the Eddington limit luminosity. As a result, they are shedding like Persian cats on a velvet sofa, and the physical process is an inextricable mix of radiation pressure in the continuum and multiple unstable modes (Stothers and Chin 1993; Glatzel and Kiriakidis 1993).

Readers interested in the current status of the countably infinite number of mass-loss mechanisms in binary stars will find wisdom scattered like currants in a fruit cake through the pages of Sahade et al. (1993). We note here only the curious case of RZ Ophiuchi, whose F5 Ib component is encircled by an accretion disk, but whose K5 Ib presumptive donor does not fill its Roche lobe (Olson 1993).

Finally, pulsation and mass loss driven by the epsilon mechanism (helium shell flashes and other instabilities in nuclear energy release) seem to have undergone a modest revival. The very episodic mass loss of S Scuti (Eriksson and Stenhold 1993) and a few other carbon stars (Olafsson 1993) can perhaps be explained this way. Vassiliadis and Wood (1993) calculate that the superwind which transforms an AGB star into a planetary nebula should flow out at the end of each of the last few helium shell flashes in the life of a 3–5$M_\odot$ star. And Frank (1993) has found observational evidence for the process in a few multishelled planetary nebulae (admittedly not the ones that Trimble and Sackmann 1977 had in mind!). The Wolf–Rayet HD 96548 has revealed a 627-s period, and this is conceivably the first case of epsilon-driven pulsation and mass loss in a hot star (Blecha et al. 1992).

5. THAT SETTLES THAT

We debated between this section, consisting of things that have turned out the way most people expected, and one called "sorry folks," consisting of items of the opposite sort, and voted for the cheerful set.

5.1 The Sun has a Heliopause

Somewhere out there, the solar wind must cease to dominate and must give way to the general interstellar environment, presumably in some sort of shock. The expected frontier has moved repeatedly, from somewhere around Jupiter to well beyond Pluto, as the *Voyager* probes failed to encounter it. They still have not, but the sounds of the waves breaking on the beach begin to be heard (Lallement et al. 1993 and Gurnett et al. 1993), indicating that the heliopause cannot be far beyond 100 AU, though sadly both *Voyager 10* and *11* may die before encountering it. Remarkably, the corresponding interface for a handful of other nearby G dwarfs may be detectable (Frisch 1993).

5.2 Pulsating Variables Sorted Out

The Cepheid distance scales determined from main-sequence fitting in open star clusters and from the Baade–Wesselink method now agree to within 0.15 mag (Gieren and Fouque 1993) over the period range 2–60 days. All right-thinking people should reserve the name dwarf Cepheid for objects that are also radial pulsators, but of Population II (Harris 1993). The nonradial pulsators are SX Phoenicis stars, δ Scuti stars, and so forth, depending on their effective temperatures and luminosities. And, for RR Lyrae variables at least, the red edge of the instability strip really is the result of quenching of pulsation by convection (Gehmeyr 1993, and, undoubtedly many other investigations, ever since Douglas Gough told us what to think about the issue in 1972).

5.3 Duplicity of Barium Stars, Dwarf Carbon Stars, and Technetium-poor S-type Stars

For all three of these categories, it is easier to blame the compositional anomalies (excesses of s-process material, weird CNO ratios) on mass transfer from companions, now shrunk to white dwarfs, than on nuclear reactions and dredge up in the visible stars themselves. This does not quite equal having found the right answer, and the demonstration that most or all of the classical barium giants are spectroscopic binaries was a highlight of 1980 (McClure et al. 1980). The case for them has been clinched (Lambert et al. 1993) by the existence of the expected precursors, dwarf barium stars (first found by Bond 1974; Luck and Bond 1982).

Among the dwarf carbon stars, the first recognized, G 77-61, was a spectroscopic binary, and a second has been found serendipitously to have a DA (hydrogen atmosphere white dwarf) companion (Heber 1993).[4]

Similar, the demonstration that the Tc-poor S stars were polluted by companions (while those with Tc have done it to themselves within the last half-life of the most nearly stable isotope) is coming along nicely. A good many have hot (*IUE* dominant, presumably white dwarf) companions (Johnson et al. 1993). In addition, infrared observations show that those with Tc have circumstellar envelopes, presumably accumulated from their dense, AGB winds, while the Tc-poor ones do not (Groenewege 1993; Jorissen et al. 1993).

5.4 Red Giants and Supergiants of Varying Composition and Pulsation Properties

We were taught as children that CO always ties up almost all of whichever of its component elements is the less abundant in cool stellar atmospheres, leaving the other one to make the molecules you see. The result is spectral types M (O>C), S, SC (O=C), and R+N or carbon stars (C>O). It is most satisfactory that an extensive survey in the CO 2.4 μ band finds the expected CO molecules in all three spectral types, M, S, and C, while H_2O is present among the M's, declines through the S's, and is absent among the C's (Noguchi and Kobayashi 1993). The range of lithium abundance among such stars is much less tidily described, but mass loss from carbon stars could contribute 30% of the total now found in the Milky Way (Abia et al. 1993).

Variability among cool, highly evolved stars is correlated (somewhat independently) with effective temperature, surface composition, and mass, hence with galactic population characteristics like velocity dispersion and scale height. The classes include long period variables (LPVs), Miras (in C- and O-dominated subtypes), irregular and semiregular variables (I and SR in catalogs), and the OH/IR stars. In general, the OH/IR stars have the longest pulsation periods (largest radii), C-rich stars are redder (longer periods) than O-rich ones, and the shortest periods go with the largest scale heights (smallest masses). Much more can be said (Jura and Kleinman 1992; Kerschbaum and Hron 1993; LeBertre 1993).

5.5 The Rate of the $^{12}C(\alpha, \gamma)^{16}O$ Reaction

For donkeys' years, this has been the stellar nuclear reaction rate whose error bars contributed most to uncertainties in the later evolution and nucleosynthesis of massive stars. Direct measurement of the cross section at energies relevant to stellar interiors is still not possible in the laboratory. But groups working at TRIUMF and Yale (Buchmann et al. 1993; Zhao et al. 1993) have made sneaky use of the related reaction in which ^{16}N decays by alpha emission. They find that one of the two branches of the desired reaction must have a rate near the upper end of

[4]Because this system is a wide (resolved) one, it cannot be relevant to the phenomenon under discussion, though another recent DA+DC pair may be.–Ed.

the range previously allowed. As a result, production of oxygen is favored over that of carbon, consistent with the composition of material ejected by SN 1987A. The other branch of ^{12}C $(\alpha,\gamma)^{16}$O may eventually yield to a similar trick.

5.6 The Sources of the Extragalactic X-Ray Background Resolved

Ap92 already bet that the answer was going to be QSOs, Seyferts, and other active galaxies adding up to essentially 100% of the observed background over most of the X-ray domain. For the 1–2 keV band, the answer is now in. Virtually all the flux is accounted for by resolved sources, in those fields most deeply surveyed (Hasinger et al. 1993; Hasinger 1994). The continuing problem of making the spectrum come out right if you also use AGNs for 2–100 keV apparently has a solution in terms of thermal comptonization and reflection of the X rays from cool (disk?) surfaces (Zdziarski et al. 1993). We recognize, without citing, at least six papers during the reference year claiming the opposite, that no reasonable assortment of active galaxy sources could be summed to produce the background over the full energy range 1–100 keV. Well, Ap94 will also have a section of corrections, if it is needed.

Meanwhile, data from the EGRET (Energetic Gamma Ray Experiment Telescope) instrument on the *Compton Gamma Ray Observatory* suggest that the gamma-ray background is likely also to be mostly a sum of AGNs (Stecker et al. 1993); and ditto for the ultraviolet background shortward of 912 Å (from an argument involving ionization states of the atoms producing QSO absorption lines, Denda and Ikeuchi 1993). For these backgrounds also, papers claiming the opposite probably dominate.

5.7 Sorry Folks

If we had written the opposite section, it would surely have included the gas that does not belong to the Pleiades (White and Bally 1993), non-hibernating novae (Naylor et al. 1992), the brightest non-member of 47 Tucanae (Thejll 1992), the non-existence of halo B stars in M31 (McCausland et al. 1993), the non-periodicity of the universe (Stevens et al. 1993), and a whole flock of rediscoveries of previously known phenomena (both with and without citations to the earlier work).

6. GLOBULAR-CLUSTER DYNAMICS AND STELLAR POPULATIONS

It was apparent in the literature of 1993 that the concept that the dynamics of globular clusters can affect the stellar populations in such clusters has finally come of age. While dynamically induced stellar interactions in the cores of very dense clusters have been considered for many years, the idea that such interactions can occur in any globular cluster, regardless of density, is more recent, and requires the presence of a significant population of primordial binary stars. The latter is now generally accepted (Hut et al. 1992), and a recent study has even suggested that the binary frequency in the globular cluster NGC 3201 is consistent with that of solar-type stars in the galactic disk (Cote et al. 1993). Indeed, it is now accepted that binary stars are abundant in all stellar populations in the Galaxy, including Population II (e.g., Torres 1992).

One of the first types of star in clusters to have been suggested to have a collisional origin are the blue stragglers (BSs; Hills and Day 1976), which are main-sequence stars (MSSs) blueward of the main-sequence turnoff. Simply merging two MSSs should do the trick (Benz and Hills 1987), and close encounters during collisions between binary stars will increase the number of BSs that can be produced (Hoffer 1983; Leonard 1989). It is important to note that the coalescence of tight binary stars due to angular momentum loss without any external influence is also a popular theory for the origin of the BSs (e.g., Mateo et al. 1990; Ap91 Sec. 5).

HST observations of the cores of the relatively dense clusters 47 Tuc (De Marchi et al. 1993) and M15 (Ferraro and Paresce 1993) have revealed the BSs expected from single–single collisions. Also, some of the BSs at the center of NGC 6397, and possibly M3, appear to be "blue enough" to have been produced by collisions (Lauzeral et al. 1993), which is expected as a result of the increase in helium abundance in the envelope (Bailyn 1992).

The curious result that the BSs in the globular cluster M3 are not very centrally concentrated bucks the well established trend of a high degree of central concentration (Bolte et al. 1993). A similar result was found in NGC 3201 (Brewer et al. 1993). It might be that the binary populations in these clusters are biased to short periods, which would typically give the BSs formed via binary–binary collisions large kicks at birth, which would result in a fairly extended radial distribution (Leonard and Linnell 1992). Alternatively, the existence of a few relatively massive black holes in the cores of the intermediate density clusters (Kulkarni et al. 1993) would result in the formation of binary, triple, and quadruple black holes, which might disrupt the binaries that would otherwise produce BSs (Sigurdsson and Hernquist 1993).

A new class of objects discovered by *HST* in the core of the collapse cluster M15 are the "very blue stars" (De Marchi and Paresce 1993). An excess of blue light in collapsed-core clusters has been noticed for some time (e.g., Djorgovski and Piotto 1992), and the very blue stars probably contribute. Such objects may be red giant stars stripped by collisions (De Marchi and Paresce 1993), and binaries consisting of relatively massive black holes would be good machines to strip red giants so completely (Sigurdsson and Hernquist 1993).

Millisecond pulsars (MSPs) in globular clusters can also be produced via dynamical interactions, particularly those that ultimately result in the dumping of matter onto an old neutron star (NS). Davies et al. (1992, 1993) discuss several mechanisms for producing such spun-up or recycled pulsars. Lyne et al. (1993) found that PSR 1718−19 in NGC 6342 is a member of a binary system, has a large magnetic field, and a spin period of 1 s. This may be a prime example of a pulsar in the earliest stages of being spun up. It is quite certain that globular clusters contain recycled pulsars.

However, in the past year, it has been strongly suggested that not all of the MSPs in globular clusters are spun-up NSs, especially those with the very shortest spin periods (2 to 5 ms), Recycled pulsars are expected to go through a low-mass X-ray binary (LMXB) stage during spin up. It was originally thought that after globular clusters collapse, tidal capture would form LMXBs during the stage of high stellar density, and then MSPs would be produced. However, Chen et al. (1993a) note that while the vast majority of LMXBs are in the clusters with collapsed cores, most of the short-period MSPs are in the pre-core-collapse clusters. That is, the MSPs seem to be formed before the LMXBs, which is exactly the opposite to what is predicted by the spin-up scenario. Also, Chen and Ruderman (1993) model the pulse profiles of NSs that are spun up and those that are born rotating rapidly. The latter can occur via the accretion-induced collapse (AIC) of a massive white dwarf (WD). The pulse profiles of the very shortest period MSPs in M15 (Middleditch 1992) look exactly like those predicted for AIC. That is, they are very broad and single peaked.

One form of AIC that increased in popularity in 1993 is the merger of a pair of WDs with a total mass exceeding the Chandrasekhar limit. If such a merger can indeed produce a NS (as has been suggested by Benz et al. 1990, Mochkovitch and Livio 1990, and Nomoto and Kondo 1991), then it should be a rapidly rotating, low magnetic field NS; a MSP. Collisions between MSS plus WD binaries can result in a common envelope containing both WDs (Sigurdsson and Hernquist 1992; Chen et al. 1993b). After the common envelope is spun off, the pair is doomed to spiral together and coalesce via the emission of gravitational radiation. No prolonged X-ray stage is necessary, and thus the LMXB problem is avoided.

Of course, the slow accretion of matter onto a massive WD may also produce a MSP (Bailyn and Grindlay 1990), which is the standard version of AIC. The required WD plus MSS pairs can be produced via tidal capture. However, the evidence for WDs in globular clusters that are actively accreting matter from binary companions has been rather slim. The situation has changed in the past year, as Paresce et al. (1993) may have found a cataclysmic variable in 47 Tuc, and Cool et al. (1993) have found several low-luminosity X-ray sources in NGC 6397. In addition, Hertz et al. (1993) claim that an X-ray source in M3 is an example of steady burning during the accretion of matter onto a WD at a fairly high rate. It was very important for standard AIC theory to find an example of this. Note that Di Stefano and Rappaport (1993) argue that cataclysmic variables may have lower mass transfer rates than expected, and thus may have smaller X-ray luminosities than previously believed. Consequently, more sensitive X-ray telescopes could reveal many accreting WDs in globular clusters.

Another interesting discovery of the past year is that the binary pulsar PSR B1620−26 in M4 may have a second companion (Thorsett et al. 1993). If the companion is stellar, then it is the first MSP in a triple star system. If the companion is a planet, then it is the second known MSP to have a planetary companion. In either case, a dynamical interaction involving at least one binary star is the likely source of the companion. A planet in a dense cluster requires a semimajor axis less than 1 AU to survive (Sigurdsson 1992), which is much smaller than the likely semimajor axis for the planet around PSR B1620−26. It is possible that the planet could have been scavenged during an encounter between the binary pulsar and a MSS with a planetary companion (Sigurdsson 1992). Note that D'Amico et al. (1993) find that PSR B1802−07 in NGC 6539 has a binary companion in an eccentric orbit, which suggests that binary pulsars do indeed undergo strong dynamical interactions with other stars from time to time.

In summary, it is now widely accepted that the stellar populations of globular clusters can be affected by the dynamics of such clusters. The next step is for the community to accept that the same can happen in open star clusters and dwarf spheroidal galaxies.

7. THE YEAR OF MANY SATELLITES

Most of us have needed so much time this year to scrounge for grants, observing time, and the other "goods" of astronomical life, that we have had none left over to notice the riches of the resources now available. Sadly, the inventory no longer includes *Mars Observer* (but see Armstrong et al. 1993 for the first and last results). We can think, however, of *IUE, HIPPARCOS, Glazar, Sigma/Granat, Galileo, Ulysses, Pioneer 10* and *11, Phobos 2, ROSAT, HST, CGRO, Yohkoh, EUVE, ASCA*, and (if you allow us some more short-lived ones) *HUT, BBXRT,* and *UIT*, all of which have contributed to astronomical knowledge (or, at least, literature) during the reference year. Many items from the older ones of these appeared in Ap91 and Ap92; more are in other sections here. Nevertheless, as a reminder of how much we have to be thankful for, here are one or two more items from each. We decode the acronyms as best we can along the way.

IUE (*International Ultraviolet Explorer*), launched so long ago that the senior author was still eligible for the Warner Prize, is the one about which all the younger satellites can say "we are privileged to sit beside the giants on whose shoulders we stand." It has looked at more than 10^4 targets in the intervening 15 years, including some blazars (QSOs with strong, variable polarization and optical flaring). The UV flux is correlated with optical polarization in a way that suggests that the UV radiation is beamed (Edelson 1992). This is unexpected in the light of standard models which put UV square in the middle of the "big blue bump" supposedly arising from an accretion disk (Blandford and Rees 1992).

Ulysses (not an obvious acronym) is primarily intended to study the Sun from an out-of-ecliptic orbit. Along the way however, it swung past Jupiter and probed the local dust, finding some grains connected with the planet, and, probably, some leaking from the interstellar matter, these latter identified by high-speed, retrograde trajectories (Grün et al. 1993).

Sigma/Granat is the Russian X- and gamma-ray orbiting package, whose data preceded and continue to complement those from *CGRO*, particularly in the attempt to sort out the exceedingly complex assemblage of sources near the galactic center (Sunyaev et al. 1993). Many results are summarized in the conference proceedings edited by Lequeux and Mandrou (1993). These proceedings also contain descriptions of future missions in the X and gamma domains, including *INTEGRAL* (gamma rays, largely European), *AXAF* (X rays, largely US), and *XTE* (the *X-ray Timing Explorer*).

Phebus, also on *Granat*, intended primarily as a gamma-ray burst detector, had been gathering data for about three years up to early 1993. It confirms that solar flares continue to produce deuterium and the associated 2.2 MeV line (Terekhov et al. 1993).

The Japanese *Yohkoh* ("*Sunbeam*") satellite focuses on solar X rays. Results from the first two years (Sakao et al. 1992; Culhane 1993) include some magnificent images of solar flares, showing that material moves as fast as 800 km s^{-1} and reaches temperatures up to $5–6\times10^6$ K; flare X rays at different energies come from different parts of the coronal loops, and there are associated coherent changes in magnetic field structure.

Glazar, the (former) Soviet imaging ultraviolet telescope, is currently in need of in-orbit repairs, but has imaged a number of young stellar clusters and star formation regions. We find particularly puzzling the apparent detection of subdwarf OB companions (normally late products of evolution of intermediate to low-mass stars) of A main-sequence stars in Orion and Carina (Tovmassian et al. 1992).

UIT (Ultraviolet Imaging Telescope), *BBXRT (Broad Band X-ray Telescope*, and *HUT (Hopkins Ultraviolet Telescope*) spent only a few days in shuttle-bound orbit, but the scientific fruits are still ripening. *UIT*, for instance, imaged 24 OB associations in M31. There as here, the biggest, brightest stars top out at $60–100M_\odot$ (Hill et al. 1993). *HUT* results have been reviewed by Davidsen (1993). They tell us about low-mass, hot stars in M31 (several different types must be contributing to ultraviolet flux from the bulge, Ferguson and Davidsen 1993), and the ionization state of the local interstellar gas (about 20% of both hydrogen and helium must be ionized, Kimble et al. 1993). *BBXRT* has much to say about the complexity of X-ray spectra of active galaxies (Marshall et al. 1993a).

EUVE (the *Extreme UltraViolet Explorer*) went up in June, 1993, and the first set of resulting *Astrophysical Journal Letters* was submitted about a year later. Unexpectedly, the detectable sources include some active galaxies (e.g., PKS 2155−304, Marshall et al. 1993b), as well as nearby flare stars, and a new record holder for the brightest extra-solar-system euv source, the B2 bright giant ϵ Canis Majoris, from which we receive about 30 times as much flux at 600 Å as from the hot white dwarf HZ 43 (Vallerga et al. 1993).

ROSAT (Roentgen Satellite) also carries an extreme ultraviolet survey telescope, and its first catalog and finding charts have already appeared (Pounds et al. 1993; Shara et al. 1993a). The biggest statistical surprise is the sparsity of hot white dwarfs in the catalog. Some 1000–2000 were expected; 120 have turned up. The main cause is greater heavy-element pollution of hydrogen (DA) atmospheres than was anticipated from optical data (Barstow et al. 1993).

ROSAT is, however, most famous for its X-ray results. Trümper (1993) has reviewed some of the highlights. Our personal favorites include (a) the class of supersoft X-ray sources, mostly seen in the Magellanic Clouds because of observational selection effects, now well enough defined to make it probable that the energy source is steady hydrogen burning on white dwarfs (rather than something happening on a neutron star), making them promising progenitors for accretion-induced collapse to neutron stars and so for binary pulsars (Orio and Ögelman 1993; Schaeidt et al. 1993; Chevalier and Ilovaisky 1993; Ögelman et al. 1993a), (b) a fine assortment of X-ray sources in the old open cluster M67, including probably both cataclysmic variables and RS CVn stars (surely a strong hint about the nature of the weak X-ray sources in globular clusters, Belloni et al. 1993), (c) the first *ROSAT* detection of a high-redshift radio galaxy (3C 356 at $z=1.079$), probably representing a cooling flow as large as 100 $M_\odot$ yr^{-1} (Crawford and Fabian 1993), (d) pulsed X rays from Vela (Ögelman et al. 1993b), and (e) a catalog of no fewer than 108 sources in the Hyades (Stern et al. 1992), including all four giants, some of the white dwarfs, and an assortment of short-period binaries. The *ROSAT* catalog of M31 (Primini et al. 1993) reveals sources of the same general types as in the Milky Way (globular clusters, supernova remnants, nuclear and bulge sources) and with the same shape $N(L)$ above 10^{36} erg s^{-1}, but the actual number is about four times larger, and there is little sign of the concentration toward the galactic plane that high-mass X-ray binaries would produce if you were looking at the Milky Way from outside.

CGRO (the *Compton Gamma Ray Observatory*) dominated Sec. 6 of Ap92. It has now looked at our favorite supernova (SN 1054=NP 0532), verifying that the pulsed spectrum is softer than the unpulsed between 0.05 and 10 GeV, and also softer than was recorded by *COS B* in the 1980's. The pulse profile actually changed during the two months of *EGRET* observing (Nolan et al. 1993).

HST (the *Hubble Space Telescope*) soldiers on; there is a good chance you will know whether the repair mission has succeeded by the time you read this. Meanwhile, *HST* continues to add to our inventory of familiar and unfamiliar objects. R 136a in the Large Magellanic Cloud, once a candidate for supermassive star, breaks up into at least twelve components, versus eight in ground-based speckle images (Campbell et al. 1992). We still decline to vote on whether the faint globular cluster X-ray sources are cataclysmic variables, RS CVn stars, or something else, but a Faint Object Camera image reveals a variable blue star in the error circle for the 47 Tuc source (Paresce et al. 1993). Optical detection of the radio jet in giant elliptical NGC

3862 (=3C 264) is number five of such identifications, 3C 273 and M87 being the best known (Crane et al. 1993). A GHRS probe into the interstellar medium has added tin to the list of elements seen there (the first from the fifth period of Mendeleev's table). In combination with data on copper, gallium, krypton, and germanium, the tin abundance strengthens the conclusion that depletion of interstellar atoms onto dust grains is better correlated with condensation temperature than with ionization potential (Hobbs et al. 1993). Finally, an item whose meaning is not yet entirely clear: Shaya et al. (1993) have resolved the nucleus of M31 into two, unequal, components. If each is centered around a black hole, then a burst of gravitational radiation will signify their merger sometime shortly after the year 41,667,000,000 (and for the purposes of this calculation, it does not much matter whether you feel the title of this article should be Astrophysics in 1993, 5753, or 1413).

HIPPARCOS (yes, it is an acronym, but we are meant to think of the ancient Greek astrometrist) and *ASCA (Advanced Satellite for Cosmology and Astrophysics;* Asuka with nearly the same pronunciation is a flying bird) were launched, respectively on 8 August 1989 and 20 February 1993. In both cases, the first burst of astrophysical publications should come in 1994.

8. ABSORPTION LINES IN THE SPECTRA OF QUASI-STELLAR OBJECTS

"I have seen enough of the world to suspect that the places I haven't seen are a lot like the ones I have." So says an ex-Navy officer of our acquaintance. Arguably navigation through the seas of quasar absorption lines has reached the same stage. We have not seen (nor can we) all of the world of numbers versus redshift, column depth (H atoms per cm^2), metallicity, velocity dispersion, and angular extent, but we have seen enough to make meaningful maps of the whole.

The presence of broad, high-redshift emission lines originally defined QSRSs (quasi-stellar radio sources, or quasars, Schmidt 1963; the generic name is QSO for quasi-stellar object). The Burbidges (Burbidge and Burbidge 1966) and Stockton and Lynds (1966) described the presence of (generally much narrower) absorption lines shortly thereafter.

Opinion quickly polarized on the nature of the absorbers between clouds in the intervening space and clouds associated with the quasars themselves. The presence of wavelength ratios suggestive of line-locking strongly favored the "intrinsic" hypothesis, while the "intervening" hypothesis suggested only statistical tests of numbers of absorption lines per unit redshift interval (Bahcall and Peebles 1969). Numbers of absorption redshifts sufficient to perform the test were slow in accumulating, and many conference reviewers of "the state of the nucleus" favored the intrinsic hypothesis, including E. M. Burbidge at a Vatican conference, R. Lynds at IAU Symposium 44, both in 1970, and P. Strittmatter at the 7th Texas Symposium in 1974. By 1976, Boksenberg and others at IAU Symposium 74 had accumulated enough redshifts of Lyman alpha lines to show that the statistical conditions for intervening clouds had been fulfilled, while Rees at the 8th Texas Symposium described the situation for metallic absorption lines as still unclear. Further data piled up rapidly, and Weyman's description at IAU Symposium 92 in 1979 of four types of absorbing gas comes very close to the current majority view. Intrinsic absorption at redshifts close to the emission redshift comes from quasar ejecta and from gas within the same cluster, while intervening clouds produce the narrow Ly α lines, metallic lines, damped Ly α lines, and 21 cm absorption lines that have z_a much less than z_e. Closely related is the (absence of) continuum absorption blueward of the Ly α emission lines and at the corresponding helium wavelength.

Our game plan here is to dispose first of the intrinsic lines and then to go on and ask what can be learned from the others about the absorbing clouds, in the expectation that they will be interestingly related to distant galaxies, protogalaxies, or failed galaxies.

8.1 Intrinsic Absorption—the BAL (Broad Absorption Line) Quasars

Once upon a time, the intrinsic versus intervening issue was a bitterly fought one because (a) if most absorption lines are due to gas at distances appropriate to the absorption redshifts and (b) if there are many more QSOs at redshifts near 2 than near 0 (which is unquestionably true), then (c) there were more QSOs in the past, and (d) the universe is not in a steady state.

We do not deny that in some individual cases it may be difficult to decide whether the continuum source is behind or immersed in the absorbing clouds (e.g., Carilli et al. 1992 on PKS 1413+135) or that redshift pairs suggestive of line locking turn up from time to time (Wampler et al. 1993 on Q 2116−358)—they should anyhow by chance. But the BAL quasars have a unique characteristic that suggests that they alone have their absorbing clouds as part of their own structure. This characteristic is that the probability of finding a set of broad, small ($z_e - z_a$) lines is independent of the emission redshift and, therefore, independent of path length to the source (Turnshek 1986). Somewhat similar absorption even shows up occasionally in Seyfert galaxies (Kolman et al. 1993 on NGC 3516). All other classes of absorption lines are much commoner in high-redshift QSOs, where we look through more intervening space.

For these BAL objects, an important residual question is whether they are a physically distinct class. That is, does every QSO harbor the relevant clouds but only 10% or so have them by chance along our line of sight; or is the covering factor essentially unity, but the phenomenon rare? Korista et al. (1992) favor a small covering factor at least for 0226−1024, while Voit et al. (1993) favor a large one. Indications that the BAL quasars may be a physically distinct population, so that we see absorption in most objects capable of it, come from (a) differences in the emission line spectra (Boroson and Meyers 1992) and (b) differences in the distribution of radio luminosity (Francis et al. 1993).

8.2 Continuous Absorption Blueward of Lyman Alpha (the Gunn–Peterson Effect)

Early in his graduate career, J. E. Gunn worried that, because a Gunn effect (in solid state physics) already existed, there would be a nomenclatural problem when he discovered his. Luckily, a fellow student collaborated on the definitive paper (Gunn and Peterson 1965), in which they pointed out that diffuse intergalactic hydrogen would vigorously absorb all radiation emitted blueward of Ly α, and that this absorption was not seen in 3C 9, the first $z \approx 2$ quasar found, hence putting a tight limit on the amount of intergalactic neutral gas. The absorption has not been seen from that day to this (Giallongo et al. 1992), though crowded, discrete Ly α lines smear into a simulacrum if you are not careful (Christiani et al. 1993).

Just what limit you can put on diffuse intergalactic hydrogen depends on how much of it might be ionized. Some ionization naturally comes from QSOs themselves. This shows up as a deficit of absorption lines very close to the emission redshift, a deficit long known as the "proximity effect" at $z \gtrsim 2$, and only recently and tentatively detected at $z \lesssim 1$ (Kulkarni and Fall 1993). Different authors have phrased their conclusions somewhat differently (Giallongo et al. 1993; Espey 1993; Meiksin and Madau 1993), but the consensus seems to be that (a) most of the gaseous baryons are in the clouds, not in a diffuse medium and (b) the total amount of gas is no larger than the 0.01–0.04 of closure density permitted by standard Big Bang nucleosynthesis calculations.

Finally, the absorption edge due to He II should perhaps be even stronger than that due to neutral hydrogen. But it has not been seen either (Miralde-Escude 1993).

8.3 The Metallic-Line and Damped-Ly α Systems and their Associated Galaxies

The relationship between these two sorts of absorption lines can be roughly described by saying that they both come from the same sorts of intervening galaxies, but the metal lines arise in clouds of turbulent halo gas, while the hydrogen lines (including 21 cm absorption) arise in more quiescent disk gas (Lu et al. 1992; Wolfe et al. 1993; Srianano and Khare 1993).

The situation has taken some time to sort out. A gas cloud needs a surface density $\gtrsim 2 \times 10^{20}$ H cm^{-2} in order to produce either metal lines (Mg II at 2798 Å is the commonest at relatively low redshifts, Boisse et al. 1992; C IV at 1550 Å at higher ones, Borgeest and Mehlert 1993) or damped Lyman alpha lines. The latter require sufficient optical depth to reach the damping wings of a curve of growth. But a given line of sight can show one, the other, or both; and the relative frequencies seem to vary with redshift (Wolfe et al. 1993; Bahcall et al. 1993). Secular change in average chemical composition is an obvious explanation, but not necessarily the right one.

The other property that clearly depends on redshift is the absolute number of systems per comoving volume (White et al. 1993). The extent to which the absorbing clouds are clustered in velocity space also varies from sample to sample (Bahcall et al. 1993a; Foltz et al. 1993; Phillipps et al. 1993). Where such clumping occurs, the most likely explanation is clustering of the galaxies responsible. Unfortunately, the samples are not uniform enough (we feel) for statements about whether a particular sort of absorber was more or less clustered in the past to be very reliable.

There are also real (not necessarily redshift-related) differences in chemical composition (Meyer and York 1992; Reimers 1992), highest level of ionization (Lu and Savage 1993), cloud sizes (based on whether or not a given absorption redshift is seen in both members of quasar pairs on the sky; Turnshek and Bohlin 1993; Francis and Hewett 1993; Phillipp et al. 1993), and ratio of molecular to atomic gas, ranging from very much smaller than the Milky Way value (Levshakov et al. 1992, for the damped Ly α system with the highest known redshift of 3.9) to a good deal larger (Brown and VandenBout 1993 on QSO 0528−250, with z_a=2.14).

Such richness of phenomena constitute an open invitation to attempt to study the evolution of the absorbing galaxies. Unfortunately (once again), in order to extract information on how any one property (metal abundance, cloud size, background of ionizing radiation,...) has changed with time, one or more of the others has to be assumed or modeled, and the results are correspondingly not very robust (Vogel and Reimers 1993; Khare and Rana 1993).

Two observations greatly strengthen the basic conclusion that these metal and damped Ly α systems come from normal galaxies. First, *HST* spectra now permit thorough examination of the corresponding absorption lines caused by halo gas clouds in the Milky Way, and their average is very much like the average of extragalactic systems (Savage et al. 1993).

Second, the galaxy responsible can often be seen as a separate emitter of light. It is not enough that a galaxy fall on top or close to a quasar with absorption lines. This is quite common—but it is also quite common for quasars without absorption lines (Nelson and Malkan 1993). You must, therefore, also measure the redshift of the emitter and check that it agrees with z_a. The successes range from Mkn 205 (z_e=0.071) with lines due to NGC 4319 (z_a and z_e=0.0047; Bahcall et al. 1992a; Bowen and Blades 1993), through redshifts of a few tenths (Spinrad et al. 1993), out at least as far as a damped Lyman alpha system at z=2.8 (Møller and Warren 1993). For a few nearby absorbing galaxies, the H I has been mapped (Carilli and van Gorkom 1992). It is typically very disturbed and extended, suggestive of interactions with other galaxies. Such interactions may contribute to the large sizes of higher-redshift absorbers.

8.4 The Lyman Alpha Forest

Hydrogen is the most abundant element, and a neutral atom has a cross section for absorption of 1216 Å photons almost as large as its geometric area. As a results, wisps as tenuous at 10^{12} H cm^{-2} can produce detectable Ly α absorption, while clouds of 10^{17-19} H cm^{-2} also introduce continuous absorption blueward of the Lyman limit at 912 Å. Many quasars at $z \gtrsim 2$ have Lyman limit systems with $z_a \ll z_e$, and virtually all have a dense jungle of narrow, single lines (a subset with associated Ly β) blueward of 1216 Å in the QSOs rest frame. Several hundred resolvable lines in one source is not unheard of (Frye et al. 1993).

Much ink has been expended on the issue of whether these absorbing entities are physically distinct or form a continuum with the denser metallic line and damped Lyman alpha absorbers. We are inclined to feel that this is something of a non-question. Yes, all possible values of N_H occur. And yes, if you co-add enough spectra of regions that seem to show only Ly α, hints of metal lines appear (Peterson 1986). But the average values of surface density, metal abundance, angular and linear extent, and line width are very different. Whether changes in number with redshift are very different still needs some sorting out.

More meaningful and difficult questions are (a) what were the absorbing entities at $z \sim 2$, and (b) what has become of them? First, some statistical properties. Over the range $z=1$–4, there is no doubt that Lyman forest clouds "evolve." That is, there are more per comoving volume at higher redshifts (Frye et al. 1993; Press et al. 1993), to the point where line blending makes it difficult to count the number per unit redshift interval accurately (Trevese 1992), and data with poor wavelength resolution would give you the impression you had seen continuous Gunn–Peterson absorption with $\tau \simeq 0.7$ (Press et al. 1993). Whether the rate of this evolution depends on line strength (Acharya and Khare 1993) and whether surface densities are correlated with line velocity widths (Sanchez et al. 1993; Rauch et al. 1993) are also difficult or impossible to determine owing to line blending and various selection effects. In other words, we really know rather little about the properties of the high-redshift absorbers.

What about present conditions? If there were oodles of Ly α clouds at $z \gtrsim 2$ and even more at $z \gtrsim 3$–4, then natural extrapolation suggests they should be rare now—perhaps only one or two between us and, say, 3C 273. In fact, there are nine or more (Brandt et al. 1993). Data on three other nearby QSOs (Bahcall et al. 1992b; Bahcall 1993; Bruhweiler et al. 1993) confirm that there are many more low-redshift lines than expected. Their distribution of strengths, $N(N_H)$ or $N(W_\lambda)$ is quite similar to the high-redshift one. It is not entirely clear whether their degree of clumping in redshift space is the same (Bahcall et al. 1992; Bruhweiler et al. 1993), though there seems to be some correlation with galaxies along the line of sight. It is conceivable that they are not the lineal descendents of the high-redshift absorbing clouds.

What are we to make of all this? The standard models were put forward to describe the high-redshift clouds, and there are two main contenders. First, the clouds might be pressure-confined high-density (low-temperature) regions of a general intergalactic medium, which will expand with the universe and so gradually disappear (Atwood et al. 1985). Second, they might be gas gravitationally confined within small dark matter halos of the sort predicted by a cold dark matter model for galaxy formation in general (Rees 1988). In this case, they will gradually contract, presumably form stars, and evolve into dwarf galaxies, faint blue galaxies, or (through mergers) normal galaxies. Less popular contenders are (a) gas clouds far from the centers of spiral and irregular galaxies (Mahoney 1992) or (b) unbound, Jeans-length fluctuations in a general intergalactic medium (Bi et al. 1992), at least for the highest redshifts (Bi 1993).

It won't surprise you to hear that the theorists are in disagreement, one set claiming that pressure confinement "predicts" the wrong functional forms for $N(N_H)$ and dN/dz (Williger and Babul 1992), another that it does quite well over the whole range from weak Ly α clouds to the densest metallic line systems (Petitjean et al. 1993). The mini-halo model similarly has its supporters (Miralda-Escude and Rees 1993) and its opponents, or at least modifiers (Murakami and Ikeuchi 1993).

The most complex picture so far presented includes high-redshift clouds with pressure confinement for the smaller values of N_H and gravitational confinement for the larger values; the low-redshift systems are yet a third population (Charlton et al. 1993). The real world may very well be this complicated, but we are inclined to say with Spike Jones (in the lyrics to "John's Other Wife") that "I gotta go away somewhere and figure this out."

9. THE FIRSTEST WITH THE MOSTEST AND OTHER EXTREMA

These are the items most likely to get us into trouble. The numbers are model dependent, or somebody else had the idea first, or a similar object is in another data base without flags and whistles. So be it. Targets are meant to be shot at.

9.1 Supernovae

The most distant. SN 1988U, a Type Ia in AC 118, at $z=0.31$, held the record for several years (Nørgaard-Neilsen et al. 1989). The new champion is 1992bi, also a Ia, at $z=0.45$ (Pennypacker et al. 1993). Both are fruits of searches intended to find enough distant standard candles to carry out cosmological tests for expansion (versus tired light), the linearity of Hubble's law, the deceleration parameter, and so forth.

The faintest Ia. Whether the Type Ia supernovae constitute a sufficiently homogeneous class to permit their use in measuring cosmological parameters remains a topic of acrimonious dispute (on which we have voted elsewhere, but will not here). The existence of at least one event fainter than average by $\Delta M_V=1.6$ and $\Delta M_B=2.5$ is not, however, in doubt (Filippenko et al. 1992; Leibundgut et al. 1993), because SN 1991bg can be directly compared with SN 1957B in the same Virgo galaxy, M84. Its anomalous color evolution prevents confusion with classical SNe Ia. The same can probably be said of SN 1986G in Centaurus A and 1971I (Filippenko et al. 1993). Van den

Bergh (1993,1994) has proposed a similar degree of subluminosity for Tycho's event SN 1572 and for S Andromeda (SN 1885). The former is cosmologically harmless, the latter not entirely so.

The most SNe. The largest number found in one galaxy in one year is only two (1992R and 1992ac in MCG 10-24-007, Gomez and Lopez 1993), and at least five other galaxies have had paired events within less than two years. All combinations of Types I+II have occurred. 1992 set the record for most events identified in a year with 1992bt (Treffers et al. 1993), found by the Leuschner Observatory automated survey, bringing the total to about 72. (Small correction factors are always needed for false alarms and supernovae found long after peak light.) The previous record fell in 1991, with 64 events reported up to 1991bl, found by Pollas (1993) at CERGA. Other important contributors to the 1991 and 1992 totals were the second Palomar Observatory Sky Survey, the CTIO Curtis Schmidt survey, and the UK Schmidt survey from Australia. William Liller found the first event of the new year 1992 (SN 1992A, his first after several years of hard work, and cloudy weather on 23 February 1987). Credit for 1993A goes to Wischnjewski of the University of Chile. With fewer than 26 1993 events in place as September wanes, we fear that the annual total will fall considerably short of these records. 1987 was also a poor year for supernovae, from a purely numerical point of view. Perhaps distraction by a single bright event really is responsible.

9.2 Magnetic Fields

Asteroid Gaspra. The magnetometer on struggling *Galileo* recorded sufficient flux during flyby to suggest metallic composition (Kivelson 1993). Gaspra belongs in this section doubly because it is also the first asteroid to have been imaged (Belton et al. 1992). It is triaxial, with lengths of 19, 12, and 11 km, an irregular shape suggestive of catastrophic origin, and a cratering age of about 2×10^8 yr, indicating time elapsed since it broke off something bigger. Gaspra belongs to the S-type asteroids, supposed to be the source of either chondritic or stony iron meteorites. The imaging did not resolve this dichotomy, which is associated with uncertainty about the amount of chemical differentiation in such bodies, but the magnetic field detection would seem to have.

White dwarfs. Flux conservation from assorted main-sequence stars could easily give white dwarfs surface dipoles of anything from an undetectable 10^4 up to 10^8 G or more; and it is generally believed that this is the dominant source of the fields, rather than any additional dynamo generation in the degenerate stars themselves. The fields show up via linear and circular polarization, cyclotron resonance emission and absorption features in coronae, and Zeeman shifts of Balmer lines and their components. Several properties of the distribution of white dwarf fields arguably call for explanation. First, the distribution among single stars is apparently bimodal, with a few percent at 10^{7-8} G and the vast majority below 10^6 G. Second, strong field white dwarfs make up 20% or so of those in cataclysmic binaries, though only a few percent of the single ones. Third, the range of fields in CVs is narrower, most falling between 20 and 50 MG. Fourth, most of the shorter period CVs have rotation and orbit periods synchronized, presumably by magnetic forces; the longer period ones do not. And if the latter (DQ Herculis stars or intermediate polars) are to evolve into the former (AM Her stars) through loss of angular momentum, the fields need to be the same, on average. Seemingly they are not.

The assorted new measurements, though stretching the range of known fields, leave the puzzles largely intact. The weakest confirmed value is 350 kG (from spectropolarimetry, Schmidt et al. 1992). Only one such field turned up among the first 20 stars examined, suggesting that bimodalism lives. The largest yet, for PG 1031+234 is about 500 MG, though determinations from linear and circular polarization are still not in complete agreement for fields above 100 MG (Jordon 1992). The strongest intermediate polar field is only (?!) 5–10 MG (Norton et al. 1992), and absence of stronger fields in the sample is not just a selection effect (Stockman et al. 1992). The upper limit of 60 MG to any CV field is similarly real.

Finally, Bergeron et al. (1993) have reported the first double degenerate with a magnetic component, G 62-64. The companion is a DC and the pair unresolved, but too faint for determination of a spectroscopic orbit.

Neutron stars. The range of initial values of neutron star magnetic fields, their temporal evolution, and the extent to which field decay depends upon accretion of material and/or angular momentum by the NS are all under debate. We are not optimistic about being able to report consensus on these any time soon. Meanwhile, if the 30–100 keV continuum from GX 1+4 is two-photon emission, then its field sets a record at 2×10^{13} G (Greenfield et al. 1993).

9.3 Normal Stars and Binaries

Not the brightest star. Under improved angular resolution, candidate supermassive superluminous stars have been falling apart into tight clusters for years (Ap91). The latest to go is a supposed superluminous Wolf-Rayet in M33, whose *HST* image reveals an aggregate of 15–60$M_\odot$ stars (Drissen et al. 1993).

The closest star. Yes, we know it's the Sun. Alpha Centauri is the second closest, but the striking item is that its least-massive, outlying component, M dwarf Proxima Cen, may not be physically bound to the K dwarf tighter pair, on the basis of Coravel radial velocity data (Matteus and Gilmore 1993).

The least well-calibrated effective temperatures continue to occur among K giants, where a range of indicators shows that uncertainty of as much as 200 K persists in the range 4000–5000 K (Berdyugina and Savanov 1992).

The hottest post-AGB star. For temperatures in excess of 10^5 K, you must look among the nuclei of planetary nebulae. The transition to these from asymptotic giant branch stars that are still shedding their envelopes is, however, of some interest. LII+34°26, with an *IRAS* dust shell and spectral type B1.5 is furthest along so far (Parthasarathy

1993). Closely related are a half dozen objects just turning on as planetary nebulae (Pottasch 1993). The rapid mass loss, AGB phase of OY Geminorum ended about 2300 years ago (Arkhipova and Ikonnikova 1992) and that of IRAS 17150−3224 less than 150 years ago (Hu 1993). IRAS 17119−5926 has essentially completed the transition. It showed only Hα in emission in 1950, but now displays an assortment of ultraviolet forbidden emission lines characteristic of PNe (Parthasarathy et al. 1993). Meanwhile, IRAS 06562−0037 seems to be having trouble making up its mind. The emission lines turned on in 1990, but were gone again in 1992 (Garcia-Lario et al. 1993). Finally, IRC+10 420 is a sort of high-mass analog to these protoplanetaries. It is an F Ia star with a disk (presumably of material recently shed), but at $M_{bol}=-9.6$, it must be massive enough that it will burn carbon and heavier elements, progressing to a more violent end than white dwarf plus PN.

The first solar-type radio star, seen with the VLA, is Procyon (Drake et al. 1993). Other known radio stars have extensive winds or close companions or both. The authors do not say whether Procyon's distant white dwarf sidekick has anything to do with the detected emission, but we suppose not.

Longest-duration stellar flare. The FK Comae star YY Mensae had a 10^d one, which Cutispoto et al. (1992) think is probably the record for any active star.

The galloping giant. Ap91 chronicled the first 90 years of rapid evolution of FG Sagittae. Quite unexpectedly, in August–September 1992, it faded back from $V=9$ to $V=13$, almost as faint as when it started wandering around the HR diagram early in the century (Jurcsik 1992). The first model into print (Iben and Livio 1993) suggested further evolution connected with helium and hydrogen shell flashes; but the changes in infrared flux (Woodward et al. 1993) and constancy of the spectral type at G-K I–III (Stone et al. 1993) through the decline and partial recovery are more suggestive of temporary obscuration by newly ejected or condensed dust, after the fashion of R CrB stars.

Lowest-mass ratio W Ursae Majoris star. It is not properly understood in any case how the unequal-mass components of W UMa's manage to share energy so as to keep their surface temperatures so nearly the same. But AW UMa, with $M_2/M_1=0.07$, must be the most extreme test of any proposed model (Demircan et al. 1992). The system has a detectable period change, arguably due to continued mass transfer, so you should probably look soon if you want to see it still as a binary.

The lowest-mass nova (model). Early models for nova explosions of hydrogen accreted from a companion on to a white dwarf worked only for WDs with mass $\gtrsim 1M_\odot$ (Starrfield 1989). This was an embarassment, since the vast majority of white dwarfs with masses determined from spectroscopic criteria are down around $0.6M_\odot$ (Weidemann and Yuan 1989). It is, therefore, comforting to report the latest round of calculations (Shara et al. 1993), which show that white dwarfs of $0.6M_\odot$ and even less will explode and eject all the accreted matter, in approved nova fashion. It's just that you have to wait longer between explosions. This conclusion is especially timely in light of an improved mass for the WD in DQ Herculis (Nova Her 1934) of $0.6\pm0.1M_\odot$ (Horne et al. 1993).

First unambiguously expanding outer halo of a planetary nebula. The standard double halos are now attributed to interacting winds, rather than to ejection by sequential helium shell flashes in their parent stars (Frank 1993). The 10 km s^{-1} expansion measured for the outer, faint halo of NGC 6826 (from spatially resolved line profiles) is, therefore, pretty much what you would expect (Bryce 1992).

9.4 Pulsars and X-ray Binaries

Closest millisecond pulsar. PSR J0437−4715 at 150 pc probably holds the current record (Johnson et al. 1993). Its optical companion is a cool white dwarf consistent with the spin-down age of the pulsar, $P/2\dot{P}=1.9\times10^9$ yr (Bell et al. 1992). Apologies that Ap92 (Sec. 6.1) tried to persuade you that Geminga is still closer.

Oldest pulsar. The spin-down age, $P/2\dot{P}$, for another new binary millisecond pulsar, J 1713+0747 is no less than 9×10^9 yr. This is an upper limit, since the object could have started life with a period not much shorter than its present 4.57 ms, but impressive nevertheless (Foster et al. 1993).

Least eccentric orbit. Yet another new recycled binary pulsar has a measured orbital eccentricity near $e=10^{-6}$ (Camilo et al. 1993). Lots of systems, of course, appear in catalogs with the claim $e=0$, but this is really some combination of assumption and upper limit (in the range $e=0.01$–0.03, even for well-studied systems).

Pulsed thermal emission from a neutron star. Ap92 reported *ROSAT* results on PSR 0652+14 indicating steady emission at 3–9×10^5 K. In the case of PSR 1055−52, there is a soft, pulsed emission component that seems to be thermal, with $T=7.5\times10^5$ K. The star is a strong candidate for normal cooling, unaided by pion condensate, quarks, or long-handled spoons, though clearly its surface cannot be uniform (Ögelman and Finley 1993).

The fastest moving pulsars. Pulsars travel much faster than the OB stars that spawned them. Blame has been placed on asymmetric supernova explosions, recoil from binary systems, and gradual acceleration associated with the radiation process. A sample of pulsars with measured (VLA) proper motions has a mean tangential velocity of 355 km s^{-1}, and the largest are 670, 770, and 820 km s^{-1} (Fomalont et al. 1993a). Even the closest OB pairs have orbital speeds smaller than this, and asymmetric explosions, or something more exotic, must be involved. Suggested associations between pulsars and nebulae lead to similar (Cordes et al. 1993) or even larger speeds (Caraveo 1993) for PSR 2224+65, 1610−50, and a few others.

First optical identification of an extragalactic pulsar. That something near the center of the LMC supernova remnant 0540−693 was flashing on and off at the X-ray period of 50 ms has been known since 1984 (Middleditch and Pennypacker 1985). But the region is crowded with both nebular and stellar emission, and only in 1993 did it become clear just which dot of light is actually the pulsar. It has apparent magnitude 22.5 and is quite near the center of the nebula (Shaerer et al. 1993). The year also saw the first radio detection of 0540−69 (Manchester et al. 1993).

Centaurus X-3 seems to earn credit both as the first massive X-ray binary whose wind is mostly X-ray excited and as the first whose iron line emission has been seen as phased with the rotation period (Day and Stevens 1993; Day et al. 1993).

9.5 Star Clusters and Galaxies

Globular clusters with collapsed cores make up 20% or so of the Milky Way inventory and are expected with similar frequency in other galaxies. Deconvolution of an *HST* image of G 105 in M31 reveals it is the first example (Bendinelli et al. 1993).

A much older globular-cluster puzzle is what have they done with the gas shed by their evolving stars? Limits on accumulated H I are $1M_\odot$ or less in some nearby clusters. Careful examination of the planetary nebula in M22 (Borkowski et al. 1993) reveals evidence that it is currently being ram stripped by ambient interstellar gas. For this cluster at least, we understand why gas is not accumulating.

The highest metallicity globular cluster. Iron abundances in excess of solar occur occasionally near the galactic center. Terzan 1 (which also has a collapsed core, a pulsar, and a transient X-ray source) reveals its high metallicity by the strength of the Mg triplet, the amount of blanketing, and the very red horizontal branch (Ortolani et al. 1993).

The most distant H II region is at least 28 kpc from the galactic center, according to de Geus et al. (1993). This sounds further when you remember that we in the solar system have moved in from 10 to 8.5 kpc or less in the last few years.

The brightest QSO? This comes under the heading of aggressively model-dependent claims. But for some choice of H and q, PKS 2126−158 (z=3.2) has optical absolute magnitude −30 and $L_x=7.8\times10^{14}\ L_\odot$ (Ghosh et al. 1992).

The gasiest galaxy? Once again we invite controversy, since not only H and q but also a conversion factor from observed flux in a CO emission band to mass of associated H_2 comes in. But IRAS 10213+4724 (z=2.286) with 10^{11} $h^{-1}\ M_\odot$ of H_2 is anyhow a contender, for highest star formation rate as well as for gasiest galaxy (Downes et al. 1992; Tsuboi and Nakai 1992). If, as Soifer et al. (1993) suggest, we are really seeing two or more galaxies superimposed, one a dust-covered QSO, then the surprise goes down by a factor of 2 or more, analogous to the case of seemingly superluminous stars that resolve into groups.

The youngest galaxies? In a general sort of way, galaxy formation, unlike star formation, ended some time ago. One context where it might continue is in the spawning of gas-rich dwarfs from the interaction of larger galaxies, an idea customarily attributed to Zwicky (1959). The mapping of H I and other gas velocities in the vicinity of interacting or merging pairs has revealed a double handful of candidate objects (Amram et al. 1992; Henkel et al. 1993; Elmegreen et al. 1993).

9.6 Cosmology

Smallest possible H and largest possible Ω. Harrison (1993) suggests that it is more difficult than you would expect to rule out values in the vicinity of H $=10\ \text{km s}^{-1}\ \text{Mpc}^{-1}$ (normal=50–100) for the expansion rate and $\Omega=10$ (normal=0–1) for the ratio of actual density of the universe to density needed to stop the expansion. These extreme values are accompanied by coherent streaming velocities over exceedingly large volumes of space. We have been teased by Harrison before, and we always fall for it.

Lowest possible primordial helium abundance. The standard hot Big Bang counts among its triumphs correct "prediction" of the observed abundances of helium, deuterium, and lithium in relatively unprocessed material. The resulting constraint on total baryon density in the universe is called the nucleosynthesis limit, and is less than 10% of the closure density $\rho=8\pi\ H^2/3G$. But a solution is possible only if the initial helium abundance is at least 0.236 by mass (otherwise the different nuclides lead to inconsistent "predictions"). A determination of Y_p=0.217 to 0.233 from regression of He/H against O/H and N/H in a number of low-metallicity galaxies (Matthews et al. 1993) is, therefore, worrisome. The authors suggest that decaying neutrinos, an inhomogeneous universe, or other epicycles can "save the phenomena."

9.7 Mechanics of Living

These items all pertain to observing techniques, algorithms, and related housekeeping items.

Highest-frequency VLBI. Very long base line interferometry began at decimeter wavelengths, typically with only two antennas. Since a major goal is high angular resolution, pushing to shorter wavelengths is clearly desirable. It is also difficult, since the number of fringes to be counted gets larger and larger. The current record is 7 mm (43 GHz), with three stations at Pico Valeta, Onsala, and Effelsberg (Krichbaum et al. 1993). In addition to demonstrating feasibility, the array has seen core+superluminal jet structure in Cygnus A and 3C 345 and a jet moving at about 1/3 c in 3C 84=NGC 1275.

First operational liquid mirror telescope. The 2.7 m at South Survey, BC has seen first light, though no new science has been reported (Hickson et al. 1993).

The largest optical telescope. The Keck 10 m on Mauna Kea has also recorded its first images, and those of 4C 41.17, FSC 10214+4724, and three gravitationally lensed QSOs have revealed interesting new structure (Nelson 1993, and the four following abstracts).

EROS, MACHO, and OGLE. These are, respectively, the French, Livermore–Australia, and Princeton–Polish projects to look for microlensing of stars in the Magellanic Clouds or galactic bulge by dark, compact objects in our halo. All are now fully operational (Aubourg et al. 1993 on EROS; Udalski et al. 1993 and Szymanski and Udalski

1993 on OGLE). We are aware of the reports of detection of microlensing events by each of the installations (having had our name duly misspelled in the press in this connection), and hope that there will be a large number of archival papers to cite in Ap94.

The successors of UT (Universal Time). As measurements of astronomical time and coordinates become more precise, more precise definitions of just what the words mean becomes necessary. The new systems, TCG and TCB and the relationships to the older TT and TDT are explained by Seidelmann and Fukushima (1992).

A hot new transform technique. We had only just begun to recover from not understanding percolation and fractals, when along came wavelet transforms. Two published astronomical applications (Slezar et al. 1993; Rauzy 1993) are both in the realm of large-scale structure of the universe. The former focuses on identification of voids and concludes that clustering is heiarchical. The latter is a methods-only paper, but emphasizes that wavelets lose less information during smoothing than other methods in current use. This information-conserving aspect makes wavelet transforms a particularly promising approach to the problem of data archiving and storage (Richter 1994; Bijaoui 1994).

9.8 The Publication Process

You undoubtedly have your own list of extrema in this area—the most incompetent referee, the worst written paper, and the slowest journal. Some that we like are (a) the longest interval from submission to acceptance, just under 11 years for Faulkner (1993), (b) the smallest number of references, precisely zero in Israelit and Rosen (1992), (c) the most disoriented figure, a 90° rotation between figure and caption for Fig. 4 of Shelton (1993), (d) the largest number of missing figures and tables (He and Chen 1993), (e) the largest numerical error, "...density of primordial gas in the cluster formation region is high ($=10^{28}$ g cm^{-3})..." (Kowalski et al. 1993, but see Trimble 1989 for a worse one along the same lines), (f) the most papers ever: submitted to ApJ in one year (1992=1844), in one month (March 1993=231), and in one day (12 April=44, Abt 1993), and (g) some favorite figures; for instance, images on p. 678 of MNRAS 261 bear a striking resemblance to the skulls of prehistoric dogs; and you are invited to attach your own Rorschach-like interpretations to those on p. 654 of MNRAS 261 and pp. 460–1, 693, and 770 of ApJ 410.

10. BOTH PLEASE

This section is meant to be conciliatory. It contains two varieties of items (a) topics where competing models, processes, etc., have been proposed and further work seems to reveal that both are needed (for more of these, see Sec. 4 on stellar mass loss) and (b) discoveries of the second example of some class, arguably less competitive than the "firsts" of Sec. 9. In a few cases, events have overtaken us, and a third example is also reported. The title is a quote from Winnie The Pooh, who, when asked whether he would like honey or condensed milk on his bread, said "both, please," but then, so as not to seem greedy, he added "but never mind about the bread."

10.1 The Second Soft Gamma-Ray Repeater in a Supernova Remnant

Gamma-ray bursters in general belong to the realm of Proverbs 30:19. Roughly 1000 events into the data base and 100 models into the theoretical struggle (Owens and Schaefer 1993), convergence is further away than it seemed in Ap92. But the small subset of three soft, repeating sources seems to be going somewhere. The most famous, which first surfaced on 1979 March 5, was notoriously within the confines (at least in two dimensions) of the Large Magellanic Cloud supernova remnant N 49. Now Kulkarni and Frail (1993) have found that the soft repeater 1806−20 (equatorial coordinates) is similarly (2-d) within the confines of the SNR G10.0-0.3 (galactic coordinates). The third member of the class lies in a region of the galactic plane for which SNR inventories are incomplete.

10.2 The Second X-Ray Cluster with X-Ray Diameter Larger than the Distribution of Galaxies

Most of the well-known, X-ray emitting clusters of galaxies are large and rich. *ROSAT* revealed the first small X-ray group, centered around NGC 2300 (Mulchaey et al. 1993). Surprises included the very large total mass, the low metallicity of the gas (about 6% of solar), and the very extended gas distribution. A Hickson compact group of galaxies (HCG 62) has turned up as the second such cluster (Ponman and Bertrand 1993), also in *ROSAT* data. Two implications are that the cluster will merge (presumably to a giant elliptical galaxy with an enormous X-ray halo) in about 3×10^9 yr and that we would be in trouble with the limit to cosmic baryon abundance set by Big Bang nucleosynthesis (Sec. 9.6) if all galaxies and clusters had as high a ratio of baryonic to total mass as this one does. Additional poorly populated, but extended, X-ray clusters are in the unpublished data base, and Hasinger (1994) regards them as an authentic new class of source that can make some contribution to the X-ray background (Sec. 5.6).

10.3 Giotto's Second Comet

Six years after sweeping past Halley, the European spacecraft *Giotto* passed within 150 km of comet Grigg–Skjellerup (Neubauer et al. 1993) on 19 July 1992. It was a less traumatic encounter with a much smaller, less spectacular comet. Nevertheless, the amount of gaseous and particulate matter encountered was a good deal larger than expected (McDonnell et al. 1993) for so inactive a comet.

10.4 Excitation of Masers

The discovery that several interstellar molecules are mased (OH, H_2O, and others) initiated much theoretical work on how the population inversions could be achieved and maintained. The primary competitors have always been infrared radiative excitation and collisional excitation. Each lifts molecules above the metastable level, to which they descend radiatively and pile up waiting to mase. Cragg (1992) concludes that CH_3OH (methanol) masers come in both excitation classes, and that some individual sources can switch between the two mechanisms.

10.5 The Second Brightest Supernova of the Century, SN 1993J

SN 1993J in M81, though 60-some times further away, has a good deal in common with SN 1987A in the LMC. It was a type II which ejected enough ^{56}Ni to power an exponentially tailed light curve. Its progenitor had been photographed (accidentally) beforehand. Its behavior emphasizes the importance both of mass loss by progenitors and of interaction between ejecta and wind material. And the theorists have been faster getting into print than the observers.

Some bits of early light curve, spectra, and polarimetry have been published (Schmidt et al. 1993; Tamguchi et al. 1993; Trammell et al. 1993). Otherwise, the main source of timely information remains the *IAU Circulars* and their electronic clones. We mention explicitly here only the discovery (Garcia and Ripero 1993), the spectral type (Filippenko 1993a) and possible transition to a Ib (Filippenko and Matheson 1993), the radio (Pooley and Green 1993) and X-ray (Zimmermann et al. 1993; Tanaka 1993) turn-ons, and the probably identification of the progenitor (Perelmuter 1993; Filippenko 1993b; Humphreys et al. 1993). SN 1993J counts as the third X-ray supernova, after 1980K and 1987A.

Pre-supernova mass loss and interaction of the ejecta with wind material have become an increasingly important part of our picture of SN 1987A (McCray 1993). The ejecta hitting its outlying, dense (red supergiant) wind are expected to result in a second X-ray turn-on early in the next century. Similar interactions produce the luminosity that has made possible the recoveries of SN 1979C (Fesen and Mattonick 1993) and 1970G (Fesen 1993). They can also determine the overall morphology of supernova remnants (Igumenshachev et al. 1992).

Now about the theories for SN 1993J. Four appeared before our deadline (Nomoto et al. 1993; Podsiadlowski et al. 1993; Ray et al. 1993; Höflich et al. 1993). All agree that the star had lost most of its hydrogen envelope before core collapse (resulting in the transition to Ib—conspicuous helium lines—spectral type as well as the very early visibility of radiogenic luminosity) and that it expelled some newly synthesized ^{56}Ni, though whether rather less or rather more than the canonical $0.07M_{\odot}$ of 1987A is being discussed. All but the Höflich et al. (1993) model attribute this vigorous mass loss to the presence of a close binary companion, which is probably still in a bound orbit with the anticipated neutron star. Watch your neighborhood preprint shelf (and *IAU Circulars*) for further details.

10.6 Alignments of Optical and Radio (etc.) Emission in Active and Distant Galaxies

Lots of astronomical systems might or should be aligned, though not all of them are—spins and orbits of double and triple stars (Lestrade et al. 1993 on Algol) and galaxies (Osterloo 1993; Flin 1993), and galaxies with their clusters (Kashikawa and Okamura 1992). But what we mean just now is the curious and common phenomenon of alignment between (presumably nonthermal) radio emission and (presumably stellar, thermal) optical emission in active galaxies, especially at large redshift.

A typical example is 6C 1232+39 ($z=3.22$), a classic radio double, with the radio, optical continuum, and optical line emissions all aligned, though without any detailed correspondence (Eales 1993). The phenomenon is largely restricted to sources with the highest radio powers (Dunlop and Peacock 1993), and sometimes only the line emission is involved on the optical side (Hippelein and Meisenheimer 1992). No fewer than five mechanisms have been proposed to explain such alignments (Daly 1992), of which the most straightforward are radio jet triggering of star formation and Thompson scattering of AGN core light by electrons in the radio jets. Optical synchrotron or inverse Compton emission from the jets themselves could also contribute (and we are pretty sure we do not understand the fifth one).

Observations of nearby objects that seem to be analogous suggest that at least three of these processes do indeed operate. McNamara and O'Connell (1993) have found two cooling flow clusters of galaxies whose central galaxies have blue, lobe-shaped optical emission associated with the radio blobs. They argue for triggered star formation. The nearby Seyfert 1, Mkn 509, on the other hand, has its radio continuum, polarized Hα emission, narrow line region, and optical and infrared polarized continua all more or less aligned. The combination strongly suggests that both scattering and synchrotron emission contribute to polarization at the same position angle (Singh and Westergaard 1992).

Evidently this topic really belongs in a section called "all of the above," not just "both."

10.7 The Second (and Third) Optical Identifications of Low-Mass X-Ray Binaries in Globular Clusters

A dozen or more of these bright sources have turned up in catalogs from one or more of the X-ray satellites. The one in M15 was bright enough to permit ground-based optical identification with a star called AC 211 (Bailyn et al. 1989), and there have been other proposals. An *HST* faint object camera image provided enough resolution in NGC 6624 to permit picking out the right optical and uv dot at the position of 4U 1820−30 (King et al. 1993). The nearby radio source is a pulsar, not the X-ray binary, and the optical light from the latter is reprocessed X rays, not direct emission from the companion (Arons and King 1993).

And even as we were writing, Anderson et al. (1993) used another *HST* image to confirm the optical identification of X 1850−086 in NGC 6712. Only the M15 source is optically bright. We will also sneak in (a) the third measured orbit period for a globular cluster LMXRB—5.7 hr for 4U 1746−371 in NGC 6441, found in Ginga data by Sansom et al. (1993) and (b) an apology to Ivan King for having implied in Ap92 that the pre-repair *HST* was rather limited in its ability to resolve globular cluster cores. Clearly, if the telescope and the money hold out and Ivan lives forever (all consummations devoutly to be desired), the combination will eventually resolve every globular in the Milky Way.

10.8 The Second Leading Spiral Arm and Second Counter-rotating Disk

Ap92 reported the first unambiguous leading spiral arm—since NGC 4622 has two going one way and one the other, at least one necessarily leads. Retrograde encounter is a likely cause (Byrd et al. 1993). A structure that resembles a leading arm in Maffei 2 (Hurt et al. 1993) is probably also tidal in origin. NGC 4826 is more complicated, with both a candidate leading arm and a counter-rotating central gas disk (van Driel and Ruta 1993). The authors suggest it is the first such disk, but we are inclined to feel that the honor belongs to the Virgo S0, NGC 4550, with stellar disks rotating in both of the possible (oblate) directions, one of which has a gaseous component (Rubin et al. 1992).

10.9 A Second (Failed?) Protoplanetary Disk

Beta Pictoris remains to some extent *sui generis*, according to the 15th paper in a series discussing the infalling-body scenario for the structure and evolution of its disk (Delenil et al. 1993). Some similar traits also appear, however, in 50 Oph (Grady and Silvis 1993) and in Fomalhaut (Stern et al. 1993), though neither was nearly so conspicuous in the *IRAS* data set.

10.10 Quark versus Neutron Stars

The idea that what we normally think of as neutron stars really consist of strange quark matter had its most recent flurry of attention in connection with the (retracted) 0.5 ms pulsar in SN 1987A, because quark stars can spin just a bit faster without flying apart. With the recognition that it will otherwise be quite difficult to tell one sort from the other (Glendenning and Weber 1992), quark stars have nearly sunk into the general pool of nonstandard cooling calculations (Sedrakian and Sedrakian 1993). But, in the spirit of compromise, it has been proposed that neutrons and quarks might be layered (Carinhas 1993) or mixed in some more complex topology (Heiselber et al. 1993).

10.11 A Second Test for Fermi Shock Acceleration

Reynolds and Ellison (1992) have calculated that the spectrum of electrons so accelerated, and, therefore, their radio synchrotron emission, should be concave upward when plotted in the standard way. Such concavity has perhaps been seen in the Tycho and Kepler supernova remnants. The first test was the relative sizes of radio and X-ray SN remnants, as seen in the Large Magellanic Cloud and discussed by Asvarov and Guseinov (1991). This paper was one of many left on the cutting room floor of Ap92 when the section on extrema went unwritten.

10.12 The Second Kuiper Belt Comet

Every elementary astronomy text mentions the Oort cloud, a spherical reservoir $\gtrsim 10^4$ AU away, from which new comets occasionally descend to us when their orbits have been disturbed by passing stars, molecular clouds, or gremlins. Less well known is the toroidal reservoir for short-period comets postulated by Edgeworth (1949) and Kuiper (1951) to lie beyond the orbit of Neptune. The paper reporting the detection of a first object in the Kuiper belt had not yet appeared (Jewitt and Luu 1993a), when the second was found on 28 March 1993 (Jewitt and Luu 1993b). Object 1992 QB1 has a semimajor axis of 44.4 AU, an eccentricity $e=0.11$, and a period of 296 years. 1993 FW disappeared behind the sun in August, but preliminary data indicate a semimajor axis near 42 AU. Both objects probably have diameters of a few hundred kilometers (Hainaut and West 1993). A near approach of one of these to earth, if they are of cometary composition, would be fairly spectacular (cf. Sec. 2.3). Oort cloud objects remain hypothetical.

10.13 Star Bursts and/or Active Nuclei in Galaxies

This final topic is the one that originally motivated the section. It is the issue of the relative contribution of active nuclei and stars to the brightest (*IRAS* and other) galaxies. You are still entitled to advocate one or the other particular galaxies—for instance, the nucleus of the low luminosity Seyfert 1, NGC 4395, shows absolutely no evidence of stellar absorption lines (Filippenko et al. 1993), suggesting strong dominance by nonthermal emission connected with a central monster.

At the other extreme, Terlevich and Boyle (1993) continue to advocate star bursts as the dominant energy source even in most bright quasars. More typical sources, or perhaps more typical papers, are, however, a mix of thermal emission from star bursts and nonthermal radiation from electrons presumably accelerated in the vicinity of a black hole. Majewski et al. (1993) suggest half-and-half for a sample of bright *IRAS* galaxies, on the basis of near infrared imaging. Independent evidence for a similar mix comes from a VLBI survey of bright *IRAS* galaxies (Lonsdale et al. 1993), which revealed radio cores in more than half. Specific objects for which detailed studies indicate a combination of stellar and nonstellar emission include NGC 4945 (Iwasawa et al. 1993), with stellar *IRAS* colors but X-ray evidence for a hidden Seyfert nucleus; the *IRAS* Seyfert 1.5 galaxy NGC 6860 (Lipari et al. 1993); and F 10214+4724 (Lawrence et al. 1993).

Not surprisingly, with more than one primary energy source, there is also seen to be more than one contributor to ionization (Contini and Viegas 1992), excitation (Keto et al. 1993), and polarization (Smith et al. 1993).

TABLE 1
Nonsatellite Reports Concerning Isotropy of the 3 K Microwave Background

Location	Angular scale	$\Delta T/T$	Reference
South Pole—UCSB	1°2	$\leq 1.4\times 10^{-5}$	Gaier et al. 1992
Tenerife	8°	a	Davies et al. 1992
IRAM	11″	$\leq 9\times 10^{-5}$	Radford 1993
VLA	80″	$\leq 1.9\times 10^{-5}$	Fomalont et al. 1993
Owens Valley	7′	3×10^{-5} [b]	Myers et al. 1993
JCMT	17″	$\leq 1.5\times 10^{-3}$	Church et al. 1993
Balloon	0°5	2.5×10^{-5}	Meinhold et al. 1993
Antarctic	40′	4.5×10^{-5} [b]	Piccirillo and Calisse 1993
South Pole	1°5	1.5×10^{-5} [c]	Schuster et al. 1993
Australia telescope	1′	$\leq 2\times 10^{-5}$	Subrahmanyan et al. 1993
Balloon	1°	4.7×10^{-5} [d]	Gunderson et al. 1993

[a] No data yet, but note the match to *COBE* angular scale.
[b] Some contribution from foreground probably remains.
[c] Some contribution from Milky Way probably remains.
[d] Not galactic emission, but anomalously larger than other experiments and than their own previous flights.

11. COBE CONFIRMED

The detection of fluctuations in the 3 K microwave background radiation, after the most careful possible subtraction of foreground sources and diffuse emission, was a star of Ap92. We deviate from the ground rule against "fine tuning" to report here on three important related topics: (1) the cross correlation between the *COBE* data set and an earlier 170 GHz one, (2) other ground- and balloon-based results, and (3) further exploration of the theoretical implications.

First, Ganga et al. (1993) have reported the cross correlation of their 3°8 beam, 1.8 mm data from a 1989 balloon flight with the *COBE* DMR (diffuse microwave background radiometer) data. This cross correlation is nearly as strong as the autocorrelation for the DMR data alone, indicating that the fluctuations are real and that the two experiments see the same parts of the sky as warm or cool. The amplitudes at the several wavelengths remain consistent with a thermal spectrum for the fluctuations. Contrarily, the absence of correlations between the *COBE* data and catalogs of rich clusters, *IRAS*, galaxies, radio sources, X-ray clusters, and so forth argues against a significant contribution from foreground sources (Bennett et al. 1993). In suitable coordinates, the cross-correlated data set projects onto the sky in the form of a heart with an arrow slot through the middle.

Second, an important effect of the *COBE* announcement seems to have been to give ground-based observers added courage in announcing positive results of their own and in attributing the fluctuations to the microwave background, rather than to incomplete noise and foreground subtraction. In the spirit of equality, we tabulate all papers along these lines that we found during the reference year (Table 1).

Third, theorists have continued to batter away on what we ought to think about the early universe and galaxy formation in light of *COBE*/DMR and the properties reported from observations on smaller angular scales. Most papers take the form of identification of contradictions. Gould (1993) and Stark (1993) find that the quadrupole moment of the radiation seen by *COBE* is a good deal smaller than the one initially reported, and so not consistent with extrapolation from the 10° angular fluctuations, assuming a Harrison–Zeldovich spectrum ($n=1$, or equal power on each length scale, as it enters the horizon of an expanding universe).

Other contradictions occur for *COBE*+ground-based data and (1) hot dark matter plus quasars existing at $z\gtrsim 4$ (Blanchard et al. 1993), (2) some combinations of baryon-dominated mass density (Dodelson and Jubas 1993), (3) inflation (Kashlinsky 1992), and (4) cold dark matter and deviations from smooth Hubble expansion of the universe like those seen (Cen and Ostriker 1992; Kashlinsky 1993; Górski et al. 1993). In contrast, strings as seeds for galaxy formation may have been given a new lease on life (Bennett et al. 1992). And the latest (revived) contender for an important role in the early universe is gravitational radiation, because it produces temperature fluctuations in the background with a different angular spectrum from those that arise out of density perturbations, and so (like any additional parameter) gives you a better chance at a fit (Davis et al. 1992, Lucchin et al. 1992; Crittenden et al. 1993).

Finally, we pause for a moment of silence in memory of textures as seeds for cosmic structure, though their demise is not heavily dependent on the *COBE* results (Kamionkowski and March-Russell 1992; Holam et al. 1992).

12. ADDENDA ET CORRIGENDA

A number of colleagues wrote, e-mailed, phoned, faxed, or sidled up to us at conferences to point out errors in Ap92 (or, in a few tardy cases, Ap91). And George Wallerstein has suggested as a suitable subtitle for this section a quote from Fritz Zwicky, "Zey come out of ze trenches viss ze hands up."

1. Ages of open clusters (Ap91, Sec. 4) are almost back where they started from, despite the effects of convective overshoot (Schaller et al. 1993; Meynet et al. 1993).

2. The interacting *IRAS* galaxies of Ap92, Sec. 5 were examined on ESO/SERC images rather than on the Palomar survey. The same group has, however, now looked at a northern sample on POSS plates and reaches very similar conclusions about over-representation of interacting galaxies among the brightest *IRAS* sources (Zou et al. 1993). Please try to think of these reports as occasionally having predictive power!

3. Low-velocity superluminal motion is just what you would expect for lobe-dominated radio quasars in a unified model (Ap92, Sec. 7.2), according to Antonucci (1993).

4. The connection between short binary orbit periods and zero eccentricity (Ap92, Sec. 10.8) was noted earlier by Brownlee and Griffin (1979).

5. Well-behaved RV Tauri stars (Ap92, Sec. 10.10) have minima (not maxima) of alternative amplitude. It is the early models where the maximum alternatived. That each (half) cycle has its own temporal evolution of line velocities was known to Abt (1955).

6. The first dwarf carbon star (Ap92, Sec. 10.11) was found by Dahn (1987).

7. Additional evidence supports the binary nature of RR Lyrae star BB Virginis (Ap92, Sec. 12.2), but TU UMa wa first (Saha and White 1990; Fernley 1993).

8. The first spectroscopic binary orbit determined with the Mark III Mt. Wilson interferometer was actually that of β Arietis (Pan et al. 1990). And the star mentioned in Ap92, Sec. 12.4 should have been α Andromedae not γ And.

13. RIDING OFF INTO THE SUNSET

Ap91 and Ap92 each ended with a list of topics regretfully uncovered. In 1991 it included triggered star formation (Ap92, Sec. 5), globular-cluster populations, morphology of the Crab and Vela supernova remnants, sizes of broad-line regions of active galaxies (meaning the issue of response time between continuum and line variations), rotation periods and magnetic fields of white dwarfs (Ap93 Sec. 9.2), chemical composition of high-redshift galaxies and QSO absorption lines (Ap93 Sec. 8), and supernova rates. The 1992 list was globular clusters again (Ap93, Sec. 6), QSO absorption lines again, alignments (Ap93, Sec. 10.6), efficiency of star formation, extrema, central black holes in nonactive galaxies, and type Ia supernova mechanisms. In retrospect, it must be confessed that treatment of many of these would have considerably expanded Sec. 12 above.

This year, honesty compels the admission that a good many topics on our preliminary lists are missing because we are not sure what to think or say about them, but have hopes for clarification in the next few years. Such questions and issues for which the time is not yet ripe include (a) is there a black hole at the galactic center (yes/no/yes, but it is small)?, (b) what makes gamma-ray bursts?, (c) are cooling flows what they seem to be?, (d) what is the range of stellar initial mass functions, and what all are they correlated with?, (e) ditto for the distribution of galaxy masses and luminosities, (f) are there any real protostars (with luminosity coming primarily from gravitational potential energy)?, (g) a rethinking of the relationships among the several types of supernovae, their explosion mechanisms, progenitors, and remnants, (h) globular-cluster populations and their relationships to their parent galaxies, and (i) galaxy formation and the connection between dynamical and chemical evolution.

Some of these may ripen in the next year. In any case, suggestions of topics for "Astrophysics in 1994" are welcome between now and 15 September 1994.

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