Pushing Back the Redshift Limit

A flurry of recent discoveries has set new distance records for quasars and normal galaxies alike; one finding, if confirmed, could force a major overhaul in the prevailing models of galaxy formation

ALTHOUGH 1987 will clearly go down in astronomical history as the Year of the Supernova, it will also be remembered—albeit less dramatically—as the Year of the Very High Redshift. The recent meeting of the American Astronomical Society in Austin, Texas,* sounded at times like a kind of observational Olympics, a parade of new world records.

Consider the traditional redshift champions, the quasars. Until recently the redshift record was 3.78, held by a Southern Hemisphere quasar discovered in 1982. (That is, its spectral wavelengths were found to be stretched by 378%, which corresponds to a cosmic recession velocity exceeding 90% of the speed of light.) Since August 1986, however, no less than seven new quasars have been discovered with a redshift greater than 4. Six of these objects have been announced since April 1987. Said one of the discoverers, Patrick Osmer of the National Optical Astronomy Observatories (NOAO), "We're having a bull market in quasars!"

Indeed. In recent years a combination of computer-assisted search techniques and old-fashioned serendipity has begun to turn up these objects in record numbers. The list of quasars at all redshifts now stands at about 5000, and will doubtless continue to grow at an accelerating pace. However, that very abundance only highlights a major puzzle. If quasars were uniformly distributed in space and time, then modern telescopes could see them out to redshifts of about 5,† a value that corresponds to distances well in excess of 10 billion light years. And yet the actual number of observed quasars drops precipitously beyond a redshift of about 2.5. Beyond a redshift of about 3.5 the number quickly tapers off toward zero.

Thus the astronomers' ongoing efforts to find new champions—and their enthusiasm over this new flurry of redshift-4 objects. Assuming that quasars really are powered by supermassive black holes sitting in the middle of otherwise normal galaxies, as theory suggests, then the redshift cutoff may very well correspond to the epoch of galaxy formation. Indeed, the sudden appearance of the quasars may be telling us that galaxy formation happened relatively quickly, and that normal galaxies and quasars all over the universe began to catch fire almost simultaneously. Alternatively, it may be that more distant quasars (and galaxies) really do exist, but are being screened from view by some unknown kind of primeval, intergalactic dust. Either way, the cutoff is clearly saying something important about the early universe. And the astronomers are understandably eager to find out more about it.

If the results are true, then the theorists are going to have to do a lot of rethinking.

As always, serendipity plays an important role in that effort. A prime exhibit is the announcement made in Austin by Mark Dickinson and Patrick McCarthy, two graduate students working under astronomer Hyron Spinrad at the University of California, Berkeley. While examining the gaseous regions around a relatively nearby radio emitting galaxy last fall, Dickinson and McCarthy stumbled across a quasar having a redshift of 4.4. The coincidence was either "incredibly lucky," they pointed out, or less likely, "it changes some basic assumptions" about what the quasars are.

On the other hand, serendipity is no substitute for a systematic survey. One highly effective tool for that job is the automatic plate-measuring facility developed at Cambridge University. Also known as the Kibblewhite machine after its inventor, Edward Kibblewhite, now at NOAO, the laser-scanning device takes only a day to read off the positions of all the objects on a 35-centimeter photographic plate covering a 30-square-degree patch of sky. By comparing the results from two plates in each of five different color bands—ultraviolet, blue, visual, red, and infrared—the system's computers can then pick out a handful of prime quasar candidates in the midst of several hundred thousand starlike objects. (Characteristic emission and absorption features tend to give high-redshift quasars a distinctly unstarlike color profile.)

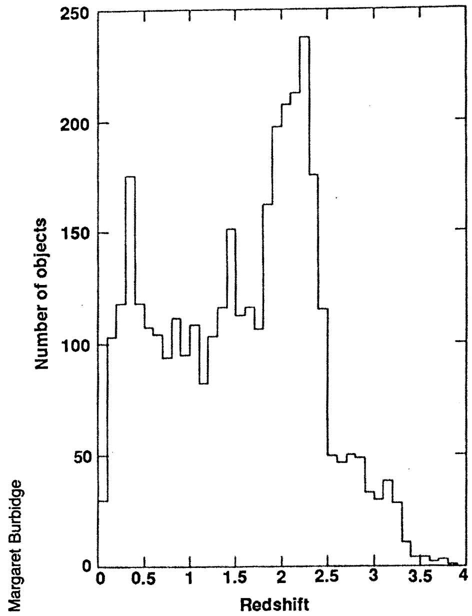
The result is a huge gain in search efficiency, not to mention sampling completeness. A good example is the patch of sky centered on the south pole of our Milky Way galaxy, which lies in the direction of the Southern Hemisphere constellation Sculptor. This area had been a favorite hunting ground for high-redshift quasars in the past because it is free from obscuration by gas and dust in the disk of our galaxy. And yet only a handful of quasars beyond a redshift of 3 had ever been found there. "It helped create the idea of a 3.5 redshift limit," says NOAO's Osmer. However, by putting the Kibblewhite machine to work on a new series of plates taken by the United Kingdom Schmidt telescope, a NOAO/Cambridge group was able to find some 80 quasar candidates in that same region. A subsequent round of spectroscopic observations showed that 24 of these objects are real quasars with redshifts greater than 3—including 16 that were previously unknown. Moreover, two of them have redshifts greater than 4. One, verified in August 1987 by Osmer, has a redshift of 4.07. The other, found in September 1987 by Stephen Warren, Paul Hewett, and Michael Irwin of Cambridge University, is the holder of the new redshift record: 4.43.

These new findings do not undermine the idea of a redshift cutoff so much as they flesh out the statistics. Indeed, Osmer estimates that this same 30-square-degree patch of the sky probably contains roughly 1000 to 1500 lower redshift quasars, which means they are still by far the dominant population. Presumably, this same imbalance will be found elsewhere in the sky.

The question now is what one can learn as such systematic surveys are extended. What really causes the redshift cutoff? Were the very early quasars different in structure or composition from those that came later? And were they arrayed in clusters, voids, and "strings" the way the relatively nearby galax-

*The 171st meeting of the American Astronomical Society, 10 to 14 January 1988, Austin, Texas.

†Because of the Hubble relation, redshifts are a direct measure of cosmic distances. But because the light from a distant object can take billions of years to get here, redshifts can also be used to locate the source in cosmic time. Unfortunately, this particular clock runs backward. The Big Bang lies at redshift infinity, the present is at redshift zero, and larger redshifts always come "before" the smaller ones. This can be confusing, to say the least. Yet astronomers do it all the time: redshifts, unlike any other cosmic clock, are directly observable.



A redshift barrier? *The precipitous falloff in quasars beyond redshift 2.5 is readily apparent in this histogram, which includes all the known quasars as of 1987. The more recent discoveries extend the tail beyond redshift 4 and improve the statistics, but do not substantially change the conclusion.*

ies are? Stay tuned.

Meanwhile, even as the redshift records are falling for quasars, astronomers are also pushing farther and farther outward in their quest for a much fainter class of objects: the youngest normal galaxies. Using a combination of very long exposure times and ultrasensitive charge-coupled device (CCD) detectors, for example, researchers have begun to obtain direct images of very young galaxies well beyond a redshift of 1, which corresponds to a time when the universe was about one-third its present age. In an even greater leap, Harding E. Smith of the University of California, San Diego, reported at the Austin meeting that he and his colleagues had identified a young galaxy at a record redshift of 2.3: it showed up as a characteristic, galaxy-like absorption feature in the spectrum of a background quasar.

However, the most dramatic single announcement at the Austin meeting was surely the one made by University of Arizona graduate student Richard Elston: working with his advisers, Arizona astronomers George Rieke and Marcia Lebofsky Rieke, Elston had found evidence for newly forming galaxies at a redshift of 6 to 25, or more than 95% of the way back to the Big Bang.

If these results are true—and Elston is the first to point out that they are a long way from being confirmed—then the theorists are going to have to do a lot of rethinking: the prevailing wisdom in cosmology is that the epoch of galaxy formation began no earlier than a redshift of 5.

Perhaps the most striking thing about the new objects is is how easy they were to find. "Like shooting fish in a barrel," Elston described it. Indeed, he and the Riekes made their original observations from the University's 1.5-meter telescope located atop Mount Lemmon near Tucson—a relatively small telescope at a less than ideal site.

What made the difference, he said, was the use of a new technology: the infrared detector array, which is a long-wavelength version of the CCDs used in optical astronomy. Originally developed for classified military use, infrared arrays have only recently begun to make their way into the civilian sector. And yet their impact on such fields as the study of star formation is already being hailed as revolutionary. For the first time, infrared astronomers can examine a region of the sky by simply taking a picture, instead of painstakingly scanning their telescopes point by point. "If I had started this research with the detectors available when I started doing infrared astronomy 16 years ago," says George Rieke, "it literally would have taken the age of the universe to complete it."

As it happens, the infrared arrays also open up a new window on the epoch of galaxy formation. As Elston pointed out, "looking in the infrared is a good way to find young galaxies, because as they get redshifted they ought to stay relatively bright." Theorists have divergent views on precisely what newborn galaxies ought to look like, he said. Yet most of their models agree that the spectra of these galaxies ought to show a telltale "step-function" feature: bright at longer wavelengths from the emissions of hot, young stars, and then abruptly dimmer at shorter wavelengths where the photons become energetic enough to ionize hydrogen. If the galaxy were stationary relative to the observer then the dropoff would occur at the so-called Lyman limit: 912 Å, which is located well into the ultraviolet. But a sufficiently large redshift would move it into the visible region, or even into the infrared.

And that, said Elston, is what he and his colleagues seem to have found. His original images—8-hour exposures of apparently empty sky at a 2-micrometer wavelength—were taken principally as a test of Arizona's new mercury-cadmium-telluride array using an imaging system built by Marcia Rieke. When Elston and his colleagues compared those images with conventional images taken in red light, however, they found two objects that showed a striking discrepancy in brightness: 17th magnitude in the infrared versus 23rd magnitude in the visible. (They did not count several other sources that were not even detectable in the visible.) Not only was this discrepancy consistent with a step function of about the right height, but the infrared brightness was about what one would expect from a very distant galaxy undergoing a rapid burst of star formation. Moreover, the objects were definitely not foreground stars; both of their images showed fuzzy, extended structures about 6 arc seconds across—again, about what one would expect.

And finally, said Elston, the objects seemed to occur with roughly the right frequency for protogalaxies. He and the Riekes found two protogalaxy candidates in a total of 8 square arc minutes of sky. Unless those particular arc minutes are grossly atypical, that translates to about 1000 such objects per square degree—which is a density of galaxy formation sufficient to account for all the galaxies seen today.

The one thing Elston and the Riekes do not have, unfortunately, is a precise redshift for the objects. During the next few months they plan to rough out the spectra by taking a series of images in different wavelength bands. Assuming that these objects really are what they seem to be, and that the spectra really are steplike, the location of the steps and their displacements from 912 Å will then give the redshifts directly. Pending that, however, all the researchers can say is that their data are consistent with any redshift between 6 and 25.

It is here that the astronomical eyebrows start to go up. Although everyone at the Austin meeting seemed willing to take these protogalaxy candidates very seriously—"fantastic candidates, the best we have," said NOAO's Osmer—the fact is that conventional wisdom puts the era of galaxy formation at a considerably lower redshift (and thus at a later time). The most successful theory of galaxy formation to date, the so-called cold dark matter model, has trouble getting many galaxies to coalesce before a redshift of about 5. Other models do worse.

Thus, the general attitude was one echoed by Margaret Burbidge of the University of California, San Diego: "very interesting—but I'd like to see it confirmed." On the other hand, if these protogalaxy candidates are confirmed they could force a major reformulation of the prevailing theories, not to mention constraining any replacement theories with an abundance of new data. Indeed, if these objects are really as abundant as Elston and the Riekes suggest, one can even start to contemplate a meaningful analysis of clustering and pair correlations in the early universe. And that, noted Berkeley's McCarthy, "would put severe constraints on the models." ■ M. MITCHELL WALDROP