Quasars: Are They Near or Far, Young Galaxies or Not?

Whether quasars are really at the edge of the universe or not, they pose difficult problems for astronomers and physicists alike. The astronomers would like to learn where quasars are most often found, and to trace the evolution of quasars over the last 14 billion years, for it appears that the population of quasars, unlike that of ordinary galaxies, was larger at earlier times than it is now. The physicists would like to understand what produces the enormous energy that quasars seem to emit, because not even nuclear processes appear to be powerful enough to stoke the fires of such distant and luminous objects.

Running through all the discussions on either subject is the question that has been vigorously debated ever since quasars were first discovered: Are they really at the very great distances indicated by their red shifts? Most of the observational problems are inseparable from the question of the validity of quasar red shifts. Sometimes it is assumed, as in tracing quasar evolution, and at other times various observations are used to argue the validity of the red shifts. Such arguments are almost invariably subtle. In the past five years observational evidence has been gathered for both points of view in the red shift debate, and each side thinks that the accumulated evidence goes more than half way to proving its case.

Evidence against an interpretation of the quasar red shift as a measure of its distance has been compiled by Halton Arp, at the Hale Observatories in Pasadena, California. Arp has produced several examples of galaxies close to or apparently connected with companions that have a different red shift. Some of the examples include quasars and others do not. A chain of five close galaxies called Vorontsov-Velyaminov 172 was photographed by Arp. When W. L. Sargent, at the California Institute of Technology, Pasadena, measured the red shifts of the members of the chain, four galaxies had similar red shifts, but the fifth (which is a compact galaxy) had a much larger red shift. Arp argues that it is highly unlikely that the odd galaxy appears to fill the slot in the chain but is actually far in the background.

Direct evidence that two objects with different red shifts are at the same distance comes from photographic plates that show luminous bridges of gas or dust between the objects, but some of the evidence is disputed. Arp has collected several examples of compact and peculiar galaxies connected by a luminous bridge to an "ordinary" galaxy with a different red shift. In 1971 he reported that the quasar Markarian 205 appears connected with the spiral galaxy NGC 4319, when photographed in Hα light. The quasar and the spiral galaxy have very different red shifts. However, the evidence has been contradicted by C. R. Lynds, at Kitt Peak National Observatory, Tucson, Arizona, and A. Millikan, at the Eastman Kodak Company, Rochester, New York, who analyzed the light coming from the luminous bridge and found no significant Hα component. The evidence for other bridges (not involving a quasar) could be at least partially due to the property of emulsions whereby images tend to diffuse. Furthermore, the proponents of a cosmological red shift counter Arp's evidence by pointing out that the associations and apparent connections could be accidental.

Evidence favoring the cosmological interpretation of the red shift has come from the observations that at least four quasars appear to be in clusters of galaxies, with red shifts the same as those of the galaxies. James Gunn, of Caltech, has looked for galaxies around those quasars that have a red shift of 0.4 or less; galaxies with greater red shifts are generally too faint to be seen. Figure 1 shows the quasar PKS 2251 + 11 surrounded by a small cluster of seven galaxies. The quasar red shift is 0.323 and the red shifts of two galaxies are 0.33 ± 0.01. Gunn has found three other quasars, 3C 323.1, PHL 1093, and PKS 1049 − 09, that are in clusters of galaxies. In each case one galactic red shift was measured and agreed with the quasar red shift. Gunn's findings seem to indicate that quasars as distant as most visible galaxies have reliable red shifts. The recent radio observations of Brown and Roberts (see box) suggest that quasars twice as far away (at a red shift of 0.8) as most known galaxies have valid cosmological red shifts. But 70 to 80 percent of the quasars known have still larger red shifts. The skeptics do not think that Gunn's findings can be extrapolated to red shifts of 3. They argue that while Gunn's quasars may be at cosmological distances, most quasars are relatively local, and have large red shifts either because they were shot out of our galaxy at very high velocities, or because some unknown physical process, not related to velocity, has reddened their light. The rejoinder is that such a division of quasars into two classes is artificial and unscientific.

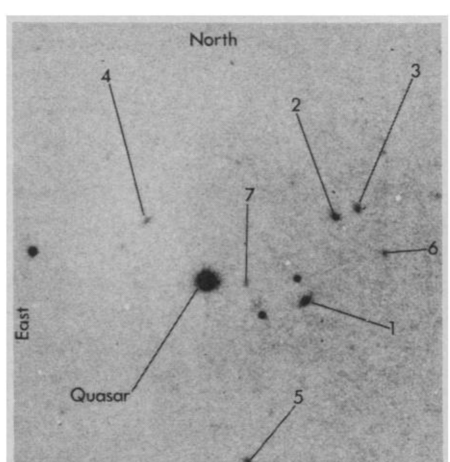

Fig. 1. The quasar PKS 2251 + 11 is surrounded by a small cluster of galaxies. Two galaxies have the same red shift as the quasar. [Source: Hale Observatories]

Thus the protracted debate over the meaning of quasar red shifts goes on, as the adversaries try to prove whether quasar red shifts are somehow different from those observed for galaxies. At stake, if validity is proved, is the "steady state" model of the universe, which is inconsistent with an increasing population of quasars at ever greater distances. But it appears that the evidence is slowly accumulating in favor of a valid red shift.

Where Does the Energy Come From?

As the red shift origin has been disputed, the question of the energy source in a quasar has been almost completely neglected because there were no data relevant to the question. The intuitive objection that quasars could not emit more energy than fusion could produce was refuted by the discovery that Seyfert galaxies, which are clearly at "normal" distances, produce approximately as much energy as quasars. Quasars appear like point sources on photographic plates, and it has been almost impossible to see their structure. The physical mechanism that drives a quasar is still obscure, but recent evidence suggests that quasars are often centered on galaxies. If astronomers can learn what quasars are, particularly whether they are peculiar sorts of young galaxies, they may find out more about the energy source.

The spectra and colors of quasars are similar to those of the nuclei of N galaxies. By varying the aperture size of a photometer, Allan Sandage, of the Hale Observatories, has found that N galaxies consist of central blue sources superposed on extended red components. Sandage refers to the blue nucleus of an N galaxy as a mini-quasar. Furthermore, he found that the underlying galaxy has the same colors as a giant elliptical (E) galaxy, and has a cosmological red shift. The nuclei of N galaxies are fainter than quasars, but the distributions of the two objects are continuous in such a way as to suggest that quasars are also nuclei in galaxies, but are so much brighter than similar phenomena in N galaxies that their light completely swamps that of the underlying galaxies.

Although the similarities between N galaxies and quasars are important, the link developed by Sandage is indirect. More recently, Jerome Kristian, at Hale Observatories, has studied 26 objects that at one time or another have been called quasars, looking for underlying galaxies with the 200-inch telescope on Palomar. The steps in a quasar search, as it was undertaken until quite recently, were to catalog the positions of radio sources and to compare them with plates from the Palomar Sky Survey, a sky map made with the wide-angle 48-inch Schmidt telescope at the Hale Observatories. Because the resolution of radio telescopes is limited, positions given by radio survey catalogs are not points, but large boxes that encompass many visible objects. Those starlike images that showed an excess of blue light on the Palomar Sky Survey plates would be chosen as quasar candidates, and a rather large investment of time with a major telescope would be required to record the spectrum and determine if the object was a quasar. Large telescopes are more sensitive to the possible presence of a galaxy underlying a quasar than the Schmidt telescope, but astronomers did not always go back to the large telescope to make a better picture.

Kristian has begun to approach the problem systematically, by classifying the 26 quasars as cases where an underlying galaxy should be detectable if present, an underlying galaxy should not be detectable, or the detectability should be marginal. The difficulty is that the image of a quasar on a photographic plate is enlarged because of "seeing" effects, and the brighter the quasar, the more its image is enlarged. A galaxy image, on the other hand, will be large compared with seeing effects for moderate red shifts. Using a calibration of image size versus red shift for the brightest known galaxies (giant elliptical galaxies in clusters), Kristian delineated the cases in which galaxies should be seen in spite of the quasar brightness and those where they should not be seen. The results were consistent with the predictions. Furthermore, if quasar red shifts are cosmological, the sizes of the galaxies observed are about 50,000 parsecs, which is consistent with the sizes of N galaxies and giant E galaxies.

Distant Quasars May Not Be Blue

At the same time that astronomers at Palomar Mountain have been finding evidence that quasars may just be unusually bright sources in the centers of galaxies, astronomers at other places have found two new quasars with red shifts greater than any known before. On 6 April 1973, R. F. Carswell and P. A. Strittmatter, at the University of Arizona, Tucson, reported that the radio source OH 471 has a red shift of 3.4. The previous record for a large red shift was held by the quasar 4C 5.34, with a shift of 2.88. Then only 2 months later, on 8 June 1973, the radio source OQ 172 was discovered to be a quasar with red shift of 3.53. E. M. Burbidge, of the Royal Greenwich Observatory, Sussex, England, and the University of California, San Diego, and E. J. Wampler, of the Lick Observatory and the University of California, Santa Cruz, discovered OQ 172's quasar properties.

The meaning of the red shift of such a distant object is slightly different for different models of the universe, but in any case the time required for light to reach the earth would be a substantial fraction of the age of the universe (*Science*, 10 November 1972). According to the model of the universe that would have it eventually stop expanding and begin to contract, the light from OH 471 must have been emitted before 89 percent of the age of the universe had elapsed, and the light from OQ 172, before 91 percent. Both objects would then be more than 10 billion light years away.

About 1 year ago, Allan Sandage pointed out that quasars seemed to run out beyond a distance indicated by a red shift of 3. Now that it is clear that quasars definitely exist with red shifts greater than the proposed limit, does it prove there is no well-defined time when the matter in the universe began to shine? Sandage thinks not. The real significance of the red shift limit, he says, is that there are no examples of red shifs of 6, 8, or 10. The "limit" of 3 has only been exceeded by 5 or 10 percent so far, and the change in the "lookback" time is even smaller.

Were there some selection effects in the procedure for a quasar search that led to the apparent red shift limit of 3? More specifically, did reliance on the criterion of a blue excess actually lead astronomers to ignore the most distant quasars? At a red shift of 2 strong emission features in the quasar spectrum are shifted from the ultraviolet to the blue region, and the quasar appears extra blue. As the red shift increases beyond 3 the same features are shifted further down the spectrum, and at a red shift of 4 even the strong ultraviolet Lyman alpha emission feature is shifted until it is red, so the quasar looks neutral or even red.

The discovery of the two new quasars and the excellence of new radio position measurements seem certain to have a great influence on observational techniques for finding quasars. OH 471 and OQ 172 were not blue, but neutral in color, and they were not selected by using Sky Survey plates to determine the probable source of a radio signal. Instead, they were found as optical astronomers searched methodically through a list of 20 very accurately known radio sources compiled by I. W. A. Browne, at the University of Manchester, and J. H. Crowther and R. L. Adgie of the Royal Radar Establishment, Great Malvern, England, with the assistance of C. Hazard at the Institute for Theoretical Astronomy, Cambridge. Because of improvements in the techniques of measuring the positions of radio sources in the last 3 years, it is now possible to establish radio positions nearly as accurately as optical positions. Thus the blue criterion can now be dropped, and most astronomers agree it should be. As more observations are made with interferometers, the list of quasar candidates that is unbiased by color selection is bound to grow longer. Then astronomers will have the chance to determine if the list of very distant quasars will grow longer too.

—WILLIAM D. METZ