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Quasar

by Dr. John Bahcall

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Recent investigations suggest that quasars, once regarded as uniquely mysterious, have many properties in common with certain galaxies.

Galaxies. A galaxy is a collection of stars and gas whose image on a photographic plate taken with a large telescope appears diffuse. One of the telescopes most frequently used for photographing galaxies is the Mount Palomar 48-in. Schmidt telescope, which can reveal the diffuse character of images as faint as nineteenth magnitude (10^8 times fainter than the brightest star). The limit of resolution of the Palomar Schmidt telescope is about 1 second of arc on the sky (2.8×10^{-4} degrees) when atmospheric conditions are good; similar limits of resolution exist for other Earth-based telescopes.

Galaxies have masses that vary from about 10^5 Sun masses (for the Draco Galaxy in the local group of galaxies) to about 10^{12} Sun masses (for giant elliptical galaxies seen in some clusters of galaxies). The luminosity, or light output, of galaxies varies over a similarly huge range, from about 10^5 times the Sun's luminosity to a few hundred billion solar luminosities. The properties of galaxies have been studied extensively by astronomers since pioneering work (performed in the 1920s) showed that these diffuse objects are really outside the Milky Way Galaxy. Edwin Hubble first established the linear relationship between the distance of a galaxy and the amount by which the emission and absorption lines in its spectrum appear shifted to the red (red shift). Some of the observed absorption lines, such as the H and K lines of once-ionized calcium, are characteristic indicators of the presence of stars. See GALAXY, INFRARED.

Quasar characteristics. The puzzling, mysterious characteristics of quasars were immediately apparent when they were first discovered in 1963 by Maarten Schmidt, Jesse Greenstein, Allan Sandage, and colleagues. The quasars appeared as starlike images (that is, unresolved) on photographic plates at the positions of known strong radio sources (hence the name quasi-stellar radio sources, or quasars). They had large red shifts (shift in wavelength divided by laboratory wavelength) which ranged up to 40%; subsequent discoveries revealed quasars with red shifts that were greater than 2. Their continuum light emission is much bluer than that of ordinary stars, and their emission lines are unusually broad (of the order of 100 A wide). Substantial variations in the intensity of light emitted were detected on practically every time scale on which variations were searched for, from days to years. The combination of these characteristics (starlike appearance, large red shifts, and rapid variations of light) were unexpected in extragalactic objects. In fact, the first quasars discovered had to be more distant, and brighter by a factor of 100 or so, than the brightest and most distant known galaxies if the relation between distance and red shift established by Hubble for galaxies also held for quasars. Yet the volume occupied by a quasar, as indicated by their unresolved images on photographic plates, is at least hundreds of times smaller than that of a normal galaxy (and many billions of times smaller if the time over which the light varied significantly is taken as a measure of their size).

These features of quasars were difficult to understand and led several scientists, especially James Terrell, Fred Hoyle, and G. R. Burbidge, to propose that the Hubble law connecting red shift and distance was not valid for quasars. They suggested that quasars were really much closer than indicated by the conventional interpretation of their red shifts. Most astronomers and physicists did not accept the arguments for the "local" nature of quasars because the characteristics of quasars inferred on the basis of the local hypothesis were at least as peculiar as the characteristics inferred using the more conventional interpretation of red shift as an indicator of distance.

Nevertheless the proponents of the "distant" (or cosmological) origin for the red shifts of quasars were necessarily cautious in their claims because of the unusual nature of the objects with which they were dealing and because of the lack of any direct proof that, for quasars, red shift indicated distance.

Galaxies with quasar characteristics. In recent years a number of galaxies have been studied that have various properties previously regarded as unique to quasars. J. B. Oke investigated galaxies whose continuum emission has the same blue, nonthermal character previously associated only with quasars. In one galaxy, the radio source 3C 371, Oke detected light variations of about one magnitude (a factor of 2.5) over a period of 2 years and a tenth of a magnitude (about 10%) in the course of several days. Light variations in galaxies have also been detected by other workers. A series of galaxies that were selected by F. Zwicky because of their compact appearance on photographic plates were studied by W. L. W. Sargent. Some of these compact galaxies have properties that are intermediate between those of quasars and galaxies. For example, the object Zwicky 0051 + 12 has broad emission lines (of the order of 50 A) and a continuum spectrum similar to that of the famous quasar 3C 273, and is as bright as the fainter quasars if the latter are at the cosmological distances indicated by their red shifts. The bright nuclear region of Zwicky 0051 + 12 (which has a red shift of 6%) might well have been classified as a quasar if it were somewhat more distant, in which case the faint surrounding nebulosity would have been unobservable and the nuclear region unresolved.

Some remarkable observations have also shown that galaxies can have emitting regions that are extraordinarily small. Observations by a group from Princeton University using a 36-in. telescope that was carried in a balloon flying high above much of the Earth's atmosphere have established that much of the light from the Seyfert galaxy NGC 4151 comes from a nuclear region less than 0.2 second of arc in extent. A group of radio astronomers operating telescopes simultaneously in California and Australia have shown that the famous radio galaxy Virgo A has a radio-emitting component that is less than, or of the order of, 0.001 second of arc in size (which corresponds to a size of about 3 light-months at the distance of Virgo A). See OBSERVATORY, ASTRONOMICAL.

Quasars associated with galaxies. In 1966 Sandage and William Miller performed a crucial observation. They used an especially sensitive photographic emulsion provided by Eastman Kodak to search for a cluster of galaxies in the directions of the quasars 3C 273 and 3C 48, whose red shifts (16 and 37%, respectively) were among the smallest of any quasars known at the time. Their careful search revealed no obvious cluster of galaxies in the direction of either quasar. The observation was of special importance because both sides in the "local" versus "cosmological" controversy were agreed that one of the very few ways to establish definitely the cosmological nature of quasars would be to find a quasar in the same direction as a cluster of galaxies with the same red shift as the cluster. The effect of such a discovery would be to link the red shift of the quasar to that of a cluster of galaxies whose red shifts had been demonstrated to be an indicator of distance. The negative result of Sandage and Miller discouraged hopes of finding quasars in clusters of galaxies, and subsequent discussions in the standard scientific articles on the subject assumed that quasars were not associated with galaxies.

In the meantime, Sandage had discovered that there are many more quasars with weak or unobservable radio emission than with strong radio emission. He also found a technique for identifying these "radio-quiet" quasars by means of their colors as revealed by photographic studies with optical telescopes. By the spring of 1969, six quasars (including 3C 273) were known with red shifts less than 20%. John Bahcall and James Gunn decided to repeat the observations of Sandage and Miller on the five recently discovered quasars with relatively small red shifts, searching for clusters of galaxies in the direction of these objects. The photographic techniques used were sufficiently powerful that large clusters of galaxies around the quasars could be recognized out to red shifts of about 20%.

BaLcall had an unusual piece of scientific luck in his first night ever using a telescope; he found that the quasar B 264 was in the direction of a previously studied cluster of galaxies. In fact, earlier estimates of the brightness of the galaxies in the direction of B 264 had led to estimates for their red shifts that were not inconsistent with those of the galaxies having the same red shift as that of the quasar. Moreover, comparison of the known positions on the sky of the quasars with catalogs of previously known clusters of galaxies showed that five of the six small red-shifted quasars (all but 3C 273) lay in the direction of previously known clusters of galaxies. Schmidt obtained spectra for four galaxies in the direction of B 264 that had the same red shifts as that of B 264, thus establishing a physical association between B 264 and the galaxies.

The above result has not settled completely the "local" versus "cosmological" controversy over the nature of quasars despite previous agreement that finding a quasar associated with a cluster of galaxies would end the debate. Two reservations about this agreement are possible: The finding of one quasar in a cluster of galaxies might be by chance and be atypical, and B 264 might have been wrongly classified as a quasar. Both these reservations could be overcome if another object whose quasar credentials were unquestioned could be shown to be in a cluster of galaxies. The most promising case discussed so far is TON 256, a quasar with a red shift of 13% that (as Sandage has emphasized) has a completely stellar appearance and is brighter than the brightest giant elliptical galaxies. Work by Neta Bahcall and John Bahcall has shown that there is a clumping of galaxies in the direction of TON 256 that is unexpected unless there is a physical association between the quasar and the galaxies. Estimates of the apparent brightness of the galaxies lend some support to the possibility that the quasar and galaxy red shifts are the same. It is hoped that some of the difficult measurements of the red shifts of galaxies in the direction of TON 256 will be completed soon.

For background information see GALAXY, EXTERNAL; QUASARS; RADIO SOURCES (ASTRONOMY); RED SHIFT in the McGraw-Hill Encyclopedia of Science end technology. [JOHN N. BAHCALL]

Bibliography: J. N. Bahcall, M. Schmidt, and J. E. Gunn, *Astrophys. J. Lett.*, 157: L77, 1969; J. B. Oke, *Astrophys. J. Lett.*, 150: L5, 1967; A. Sandage, *Astrophys. J.*, 141: 1560, 1965; A. Sandage and W. C. Miller, *Astrophys. J.*, 144: 1238, 1966.