Quasars: Finding a Handle for a Complex Problem

After 9 years of research there are still more questions than answers associated with the study of quasars, but recent observations have provided evidence for an object that appears to be an intermediary between quasars and galaxies. This evidence supports the growing conviction that quasars are not an isolated phenomenon—as originally believed—but are related to normal galaxies through some kind of evolutionary sequence. Such a relation would aid researchers by making it possible to compare the mysterious quasars and the relatively well understood galaxies.

When quasars were first observed with optical telescopes, they appeared as point sources like stars and were therefore originally called quasi-stellar objects. Determinations of red shifts indicated that the most distant quasars were tens of billions of light years away, and energy measurements—especially those in the radio region—showed that quasars emit hundreds of times more energy than normal galaxies. Astronomers naturally concluded that the small, energetic sources at such great distances were unlike anything previously observed.

Although many questions associated with the distances and energies of quasars remain unanswered, results from several research efforts during the past few years have provided evidence that they are not completely unlike galaxies. Optical studies have shown that quasars and many galaxies have common spectral features, radio observations have revealed that both types of objects often have energetic central cores, and infrared measurements have provided evidence that much of the energy in these central cores is emitted at infrared wavelengths.

For some time there has been evidence that explosive events occur in the cores of galaxies and quasars. Part of this evidence is simply the observation that a few of the objects appear to be situated in positions that can be explained if it is assumed that they were thrown off by a central object (or objects) during some catastrophic event. Spectroscopic evidence indicates that the cores of a few quasars are expanding and that there are several clouds of matter leaving the central region of an unusual type of object known as a Seyfert galaxy. This month work published in *Nature* provides evidence for the relativistic expansion of several quasar cores, and an article in *Astrophysical Journal* shows that matter is probably being blown out of the core of a Seyfert galaxy fast enough to escape.

Galaxy or Quasar?

Only about a dozen Seyfert galaxies have been observed, but they play an important role in quasar studies. They are named after Carl Seyfert who selected galaxies with bright cores for study while working at Mount Wilson Observatory in 1943. Because of the cores and some spectral characteristics, Geoffrey and Margaret Burbidge (University of California, San Diego) and Alan Sandage (Mount Wilson and Palomar Observatories) suggested in an article in 1963 that they may be related to quasars.

In an attempt to demonstrate a connection between galaxies and quasars, John Bahcall of California Institute of Technology (now on leave at the Institute for Advanced Study, Princeton, New Jersey) has been cataloging quasars that are in the direction of clusters of galaxies. His assumption is that the position of the quasars might be the result of actual physical association with the galaxies.

The first of these candidates studied was B264, the 264th object in a listing of faint blue objects thought to be quasars that was published in 1968. Bahcall, along with Maarten Schmidt (also of Caltech) and James Gunn, of Princeton University, showed that the red shift of the object is the same as that of four other galaxies in the cluster. This work, published in the *Astrophysical Journal Letters* last July, provides almost irrefutable evidence that it is physically associated with the cluster.

(For some time astronomers have questioned the validity of using red-shift measurements to determine the distance of quasars. This work shows that at least in one case the procedure is valid.)

In the October *Astrophysical Journal Letters*, J. Beverly Oke of Mount Wilson and Palomar Observatories, and California Institute of Technology, reports results of a more detailed spectral analysis done with a spectrometer attached to the 200-inch Hale telescope. He concludes that the luminosity and spectral characteristics of B264 are indistinguishable from Seyfert galaxy 3C 120, and that except for its lower luminosity B264 is similar to 3C 323.1, a typical quasar. In short, B264 seems to be an intermediary between a galaxy and a quasar.

Suspected Association

The idea that there may be a connection between quasars and galaxies is based on several years of evidence accumulated from optical, radio, and infrared investigations. Optical spectra are often complex, and there are still a number of objects with doubtful classifications; but most typical quasars have many optical features in common with Seyfert galaxies.

Radio observations have strengthened the evidence of similarity not only by demonstrating that some spectral features are common to both types of objects, but also by showing that both contain small energetic cores. Two years ago a technique (known as long baseline interferometry) of coordinating signals received by widely separated radio receivers allowed radio astronomers to resolve the size of extragalactic objects to within a few thousandths of a second of arc.

About 80 or 90 quasars and 15 or 20 galaxies have been observed with this technique. In normal spiral galaxies most of the radio emission comes from the central region. Cores a few light years in diameter have been measured in three Seyfert galaxies, which have radio emission that is several orders of magnitude greater than that of normal galaxies. Quasars have radio emission that is several orders of magnitude greater than that in Seyfert galaxies, but the cores of several quasars seem to be about the same size as Seyfert cores.

It is likely that many of the answers to questions about the central cores of extragalactic objects will come from infrared studies because much of the energy is radiated at infrared wavelengths. Since 1964 the infrared emission of about a dozen quasars and an equal number of galaxies has been determined—most of them by Frank Low of Rice University in Houston, Texas, and the University of Arizona.

The brightest galaxies with well-established distances typically radiate with infrared energies that are about 10^{12} to 10^{13} times greater than the emission from our sun at all wavelengths. Infrared emission from the best-studied quasar, 3C 273B, is about a hundred times greater than from the brightest galaxies.

In both bright galaxies and quasars the infrared emission is orders of magnitude greater than the energy of these objects at all other measured wavelengths.

Since so much of the radiation of quasars and galaxies is at infrared wavelengths, it is likely that infrared studies will reveal much about the physics of these objects. Low believes that in addition infrared emission follows an overall pattern that may have cosmological significance. Noting that infrared cores have been found in our own galaxy and in all external galaxies and quasars that are bright enough for suitable measurements, he believes that there is a sequence of "infrared galactic phenomena." The weakest infrared radiation is found in older objects such as our Milky Way galaxy and nearby galaxies; intermediate strength radiation is found in galaxies of intermediate age; and the strongest radiation is in the youngest objects—the quasars. Low is currently working on a theory that ties these observations and ideas together.

Energy

For many years it has been assumed that much of the energy of extragalactic objects is the result of synchrotron radiation that is produced as high-speed electrons move through magnetic fields. For the past 3 years a model involving this process has been evolving to explain the emission of variable radio sources—both quasars and galaxies, including several Seyfert galaxies. Since most sources with energetic cores have variable emission, this mechanism may be applicable to a large percentage of galaxies and quasars.

The model postulates that, in addition to their random high-speed motion, the entire dense cloud of electrons is rapidly expanding. Different rates of expansion give characteristic radio spectra, and therefore it is possible to fit the model to specific observations. With a few notable exceptions, the model successfully accounts for the time and frequency changes in the variable component of the spectrum of a number of radio sources. Direct measurements of the apparent rate of expansion of the core of the galaxy NGC 1275 show that the core is expanding at one-fifth the velocity of light, and the measured radio spectra fit the model for this rate of expansion.

Three years ago Martin Reese, a British astronomer now on leave at the Institute for Advanced Study in Princeton, New Jersey, showed that if the electron cloud were actually expanding near the speed of light, the measured apparent velocity could be greater than the speed of light. (The actual rate of expansion is the rate at which particles are moving away from the center of the source and cannot be directly measured in extragalactic objects. What is measured is the angular increase in the size of the core, and when this is translated into a linear rate it is greater than the velocity of the individual electrons.) In the 13 December issue of *Nature* a team of Australian and American astronomers reported that the apparent velocity of expansion of the quasar 3C 273 is greater than the speed of light.

A tamer sort of expansion is also observed in Seyfert galaxies. The spectra of the cores of Seyfert galaxies have often been explained by assuming that they contain expanding clouds of matter, and this assumption has been directly verified by the observation of low velocity clouds in the core of NGC 1068.

In the December issue of *Astrophysical Journal*, Robert Kraft and Kurt Anderson of Lick Observatory presented evidence indicating that matter is in the process of being ejected from the core of NG 4151. They have measured three absorption red shifts associated with the galaxy and interpret their results to mean that three clouds of matter are being ejected at velocities of about 300, 600, and 900 kilometers per second. They are not sure whether this is escape velocity, because the mass of the galaxy is not known; but they believe that reasonable estimates of mass make it likely that at least the cloud of matter moving at 900 kilometers per second can escape.

No Fast Answers

Although recent work has demonstrated a relation between quasars and galaxies and a start has been made toward solving some of the questions about energy production, all the major problems associated with quasars remain.

The work of Bahcall, Schmidt, and Gunn shows that the red shift of one quasar is a reliable measure of its distance, and it is likely that the relation between the red shift and the distance holds for other relatively close quasars. However, B264 has a red shift of 0.095 (the ratio of observed wavelength to the laboratory wavelength of the same line). The largest red-shift values for quasars are more than 20 times this value, and these objects are definitely not associated with galaxies. It is not at all certain that the near and far quasars are so closely related that their red shifts are produced by the same mechanism.

Even if these large red shifts are "cosmological," that is, the product of the motion of the object in an expanding universe, astronomers still have to face the problem of their deviation from the Hubble distribution of the red shifts. When Edwin Hubble showed in 1929 that there was a direct relation between the apparent brightness of galaxies and their distance as inferred from red-shift measurements, his results were taken as direct evidence that we live in a uniformly expanding, homogeneous universe. The discovery of quasars with very large red shifts sparked hopes that the new objects would soon provide cosmological information about objects at great distances, but quasar studies have failed to reveal any simple relation between brightness and distance.

Seyfert galaxies appear to follow the Hubble relation, and presumably objects that appear to be indistinguishable from them, such as B264, will also follow the relation. However, because quasars as a class do not follow the relation, a point will be reached as more distant objects are studied, where astronomers may study specific objects that account for the scattering of the Hubble distribution. Such studies will undoubtedly be fruitful, but it will take a long time to get to them.

For example, a reasonable first step would be to see if B264 has any of the same structural features as Seyfert galaxies. This would involve studies to see whether it contains stars and has a spiral structure—studies that would strain the capabilities of the largest telescopes. The B263 object is only one of dozens of quasars in the direction of clusters of galaxies, and only one of tens of thousands of all quasars. However, observing time on large telescopes is so much in demand that only a few of these objects can be studied each year.—ROBERT W. HOLCOMB