Galaxies and Quasars: Puzzling Observations and Bizarre Theories

Starting with the discovery of radio galaxies in the mid-1950's, astronomers have shown that many types of galaxies and (since 1963) quasars release more energy than can be accounted for by known physical processes. From the beginning theorists have postulated that some form of gravitational energy or matter-antimatter annihilations must be involved in energy production, but observational astronomers have continually placed tighter restrictions on the theories by showing that the energy is greater and the size of the objects is smaller than previously believed. As a result no theory has emerged that has gained the confidence of the astronomical community.

The most recent chapter in the observational side of the story comes from astronomers observing at infrared wavelengths who have shown during the past year that many extragalactic objects emit more radiation in the infrared region than at all other wavelengths combined. Thus, estimates of total energy output of some galaxies and quasars have jumped another order of magnitude or more.

The latest addition to the theoretical side of the story comes from Frank Low of the University of Arizona and Rice University. Low, who is one of the leading astronomers observing at infrared wavelengths, has authored (or coauthored with D. E. Kleinmann and H. H. Aumann of Rice University) three papers in the March issue of *Astrophysical Journal Letters*. In the third paper he proposes that there are hundreds of cells in the centers of galaxies and quasars that continuously create matter and antimatter, and that the mutual annihilation of these forms of matter produces the observed energy.

This speculation has the attractive feature of accounting for the observed infrared spectrum and the total energy release of a number of galaxies and quasars, and it may help explain the variability in the emission of these objects. These are more specific correlations between observation and theory than are provided by most theories, but several astronomers have said that Low's neglect of several theoretical and cosmological factors is a serious omission.

The theory implies a steady state cosmology, and therefore requires an alternative explanation for the 3-degree background radiation, which has generally been interpreted to be the result of the beginning of the "big bang" universe. It will also be necessary to postulate some mechanism for the separation of unannihilated matter and antimatter. Although these big questions remain unanswered, there appear to be no observations that immediately rule out the theory, so it joins the growing ranks of somewhat awkward theories that are being proposed to explain the perplexing observations of galaxies and quasars.

Energy

Estimates of the energy emitted by extragalactic objects depend not only on the amount of radiation received but on measurements of their distance and size. Determination of size is made directly as an arc angle measurement (used with a value for distance to calculate diameter) or indirectly by measuring variability. Techniques used for all but the distance measurement set lower limits on energy and upper limits on size; so as the techniques improve the energy values increase and the size determinations decrease. For example, both galaxies and quasars radiate much of their energy at wavelengths that are difficult to measure, and therefore the total energy flux has become apparent only as techniques for measuring at these wavelengths have been developed.

The use of variability as a means of estimating size is based on the assumption that if the diameter of the object emitting the radiation divided by the speed of light was larger than the period of variability, then coherent phenomena would not be observed. Since the importance of variability has become apparent, more observations designed to detect short periods have been made and shorter and shorter periods have been detected. A number of galaxies and quasars with periods of a few months (implying diameters of a few light months) are known, and in last month's *Astrophysical Journal Letters* René Racine of the David Dunlap Observatory of the University of Toronto reported on a strange object with a period of variability of a few hours. Although no red shift has been determined for this object, so its distance is not known, it has several characteristics of a Seyfert galaxy and may be extragalactic. If this is true, then a very large amount of energy is coming from a source only a few light hours in diameter.

As long base line interferometers—widely separated radio telescopes that can measure the arc size of distant objects by recording the intereference patterns produced—have been improved, smaller energy-emitting regions have been observed. Structures with diameters of 10^{-3} second of arc have been measured, and upper limits of 5×10^{-4} second of arc have been set. The radio observations have been especially important in establishing the fact that most of the energy comes from small, presumably dense, cores at the centers of both galaxies and quasars.

The simplest way to mitigate problems introduced by observations which indicate such large energy fluxes is to assume that the objects are not at the great distances implied by their red-shift measurements. A number of papers have been written in an attempt to show that the large red shifts measured for quasars could be produced by some mechanism other than their recession in the expanding universe (local gravitational fields or intervening dust, for example). Many astronomers, however, find these arguments no more palatable than the strange theories that are developed to explain the tremendous energies required if quasars are at the distances implied by their red shifts.

The distances of many galaxies have been determined by more or less direct methods, such as measurements of variable stars, and these measurements have been correlated with red shift determinations. There is also a well-accepted correlation between red shift and apparent brightness of galaxies, so any attempt to argue that galactic red shifts are not a true indication of their distance would not be taken seriously. The similarity of quasars and some galaxies, especially Seyfert galaxies, has become increasingly apparent in recent months (*1*), and the consensus of most astronomers now seems to be that quasar red shifts are cosmological.

If quasar and galactic red shifts are true indications of their distance, then they must emit tremendous amounts of energy to produce the effects observed on earth. When recent infrared observations are considered, the energy released from the cores of bright galaxies is greater than 10^{46} ergs per second, and the energy from quasars is almost 10^{49} ergs per second. (The sun emits 3.86×10^{33} ergs per second.) A relatively well-accepted lower limit for the age of galaxies is 10^{9} years. If this age is assumed for both galaxies and quasars, then they must emit about 10^{62} and 10^{63} ergs per lifetime, respectively. The mass required to produce 10^{63} ergs is about 10^{42} grams. Since only a fraction of the total mass will produce radiation that can be observed on earth (for example, particles will also be produced), one is left with the conclusion that galaxies and quasars must consume masses equal to or greater than their own mass to generate the energies we observe.

Instruments

William Herschel demonstrated that the sun radiates at wavelengths beyond red in the electromagnetic spectrum as early as 1800, but almost all infrared observations have been made within the past decade. Two small surveys of stars were made after Herschel's discovery, but the first extragalactic infrared source—the quasar 3C 273—was not observed until 1964, and the first comprehensive star survey was not completed until 1966.

The technology required for infrared observations involves solid-state devices to be used either as photo detectors to change infrared photons into electrical pulses or (as Herschel used) as a thermal detector that changes the radiation into heat. Since all warm objects emit infrared radiation the detecting apparatus must be cooled. This requires known but troublesome technology. The atmosphere—primarily because of its water vapor and carbon dioxide content—adsorbs strongly in the infrared, especially beyond 10 micrometers. It is therefore necessary to get instruments above the atmosphere to make many observations.

Perhaps the most widely used detector is the germanium bolometer, a thermal detector that is cooled with liquid helium to 2 kelvins, that was developed by Low in 1961. (It was the development of this instrument that got Low into astrophysics.) Low has used this device both to make ground-based observations from 1 to 25 micrometers and, with a 12-inch Cassegrain telescope flown in a Lear jet at about 50,000 feet, to make observations out to 1000 micrometers, G. Neugebauer and E. E. Becklin have used a lead sulfide detector with several telescopes—including the 200-inch Hale telescope—at Mt. Wilson and Palomar Observatories. Their observations are from 0.32 to 2.2 micrometers. Several other research teams have made infrared observations, and at least two more are now preparing equipment; but just about all of the extragalactic infrared observations made to date have been done by either Low and his colleagues or Becklin and Neugebauer.

Observations

The dust between us and the center of the galaxy strongly absorbs most radiation; therefore most of our knowledge of this area has been derived from indirect studies. But radio measurements, especially those made since 1966, have enabled astronomers to make a relatively detailed map of the radio intensity at the center of the galaxy.

In 1968 Becklin received a signal at 2.2 micrometers that was located near the radio center. Since then, Becklin and Neugebauer, and Low have made measurements at several wavelengths. This work has shown that the structure of the infrared source and the radio source are similar, if not identical.

In the first of the three papers in the March *Astrophysical Journal Letters*, Aumann and Low discuss infrared measurements of the galactic center, including previously unpublished results obtained last August. Their main conclusions are that the spectrum of the infrared curve has a maximum at about 70 micrometers and that the total infrared luminosity is about 8×10^{7} times the total luminosity from the sun, or about one one-hundredth of the total energy of the galaxy. In addition, they believe that they have observed three or four discrete sources. They reiterate an argument given in a previous paper which states that the type of radiation observed could not be produced by a homogeneous mass of matter and a single magnetic field, but must come from discrete sources.

In the second paper Kleinmann and Low discuss observations of extragalactic objects. There are many difficulties in the measurements. For example, the more energetic infrared sources are farther away, so all sources from our galactic center out are about equally difficult to detect. Since the observations are right at the limit of current technology, many objects cannot be measured directly. For example, it has been possible to make direct measurements of the galactic center and of the galaxy M 82, but it was only possible to set an upper limit on the intensity of the neighboring galaxy M 31. Also, the sources are variable and observations are infrequent, so it is difficult to accurately calculate average intensity.

Considering these difficulties, Kleinmann and Low conclude that they can (i) "establish the main character of the infrared continuum" as a curve with a maximum near 70 micrometers, and (ii) "estimate total infrared luminosities of 11 galaxies" (including our own) plus the quasar 3C 273. Luminosities range from 3.2×10^{41} ergs per second for our galactic center to 6.2×10^{48} ergs per second for the quasar.

Theory

Low refers to the observation that all the objects appear to have the same characteristic spectrum as the "infrared galaxy phenomenon," and in the third paper uses this phenomenon as the basis for his speculation. He proposes that a number of discrete cells called irtrons (for infrared bodies) continuously create matter and antimatter in roughly equal amounts. He notes that about "17 percent of the energy released in the annihilation of protons and anti-protons goes into 100 Mev [million electron volts] electrons and positrons." If a magnetic field of about 100 gauss is present, then these particles could radiate by a coherent synchrotron process. (That is, they spiral around the magnetic lines "in step" and lose their energy in a manner analogous to the loss of energy by atoms in a laser.) The spectrum of such a process would have a peak at 70 micrometers.

The half-life of 100-Mev electrons and positrons in a 100-gauss field is such that the irtrons could not be much smaller than about 200 light seconds in diameter. Considering the size of the infrared radiating source in our galactic center, Low concludes that it should contain about 800 irtrons.

Low's ideas are in agreement with several current theories in which it is assumed that there is an evolutionary sequence starting with quasars as the youngest objects and progressing through Seyfert galaxies, normal bright galaxies, and finally old galaxies like M 31 and our own. By assuming that more matter is created in younger objects and that the more matter created the more likely it is to have violent disruptions of individual irtrons, Low can account for the fact that the younger objects are both more energetic and more variable.

Considering the unique character of matter-antimatter annihilations, it seems reasonable that a search for antimatter would be the first observational test of Low's theory, but discussions during the past few years in connection with another matter-antimatter theory have reinforced earlier ideas about the impossibility of proving or disproving the existence of antimatter outside of our own solar system. However, several specific properties of irtrons have been predicted, so if they exist in the galactic center, it should be possible to detect them and determine some of their properties. The most obvious task, of course, is to see if the three or four discrete sources mentioned by Aumann and Low have any properties attributed to irtrons.

Low has noted that as early as 1929 the British astronomer James Jeans suggested that matter might come into being (or come from another dimension) at the centers of galaxies. The Soviet astrophysicist Viktor Ambartsumian has used the same idea since the 1950's to support his view that not only is the universe at large expanding, as shown by the Hubble red shift, but that individual objects within it are expanding. (The general view supported by "big bang" cosmologists is that matter was once evenly distributed in the universe and has subsequently condensed to form quasars, clusters of galaxies, galaxies, and stars.)

Ambartsumian's ideas are based on observations that seem to indicate that clusters of galaxies are expanding. The idea has received additional support recently from observations which seem to show that some galaxies are being blown apart by catastrophic events and that others are ejecting matter continuously. Also, in the same issue of *Astrophysical Journal Letters* as Low's papers, there is a theoretical paper by Peter Noerdlinger of the New Mexico Institute of Mining and Technology that treats the problem of expanding clusters of galaxies.

Fred Hoyle of the Institute of Theoretical Astronomy in England has used reasoning along the lines of both Jeans and Ambartsumian in support of the steady-state cosmology. In earlier versions of this theory he had argued that matter was created evenly throughout the universe, but recently he and J. Narliker (also of the Institute of Theoretical Astronomy) have argued that matter is created preferentially in areas of great density, specifically in the centers of galaxies and quasars. Hoyle has considered ideas about the possibility of both matter and antimatter being produced.

Although Hoyle and several other astronomers have considered matter-antimatter annihilation as the source of energy for extragalactic objects, the only astronomers besides Low currently holding such a theory are Hannes Alfvén of the Royal Institute of Technology, Stockholm (and visiting professor at the University of California, San Diego), and Aina Elvius of the Stockholm Observatory. The motivation behind their theory is—in addition to getting around the stringent energy requirements—the esthetic one of having a universe with equal amounts of matter and antimatter.

Starting with a suggestion by the Swedish physicist Oskar Klein, Alfvén and Elvius have developed a theory that keeps the "big bang" cosmology and accounts for the energetic cores of galaxies (including our own) and quasars in terms of matter-antimatter annihilations (*2*).

The lion's share of the work on galaxy and quasar energy theories has gone into gravitational considerations. These theories include the relatively simple but somewhat vague ideas about dense collections of stars that release energy by multiple explosions of supernovae that are brought about by stellar collisions (as proposed by Stirling Colgate of New Mexico Institute of Mining and Technology, for example) or the accretion of matter by massive stars (as proposed by Thomas Gold of Cornell University).

A more esoteric speculation has developed from work by Edwin Salpeter of Cornell University who showed how matter can be accreted by the "black holes" that are formed when very massive bodies undergo gravitational collapse. Donald Lynden-Bell of the Royal Greenwich Observatory has developed this work into a theory of energy production in quasars and galaxies. The theory accounts for the fact that most of the energy comes from small, central regions, but it does not explain the irregular variability of quasars and galaxies.

The same weakness is found in a theory proposed by Philip Morrison of Massachusetts Institute of Technology and almost simultaneously by A. Cavalier, F. Pacini, and G. Setti in Italy. Impressed by the efficient energy production by a dense, rotating object with a strong magnetic field—a model that has been developed to explain pulsar radiation—these scientists proposed that essentially the same mechanism on a much larger scale is at work in extragalactic objects.

In the February *Astrophysical Journal Letters* Geoffrey Burbidge of the University of California, San Diego has proposed that the energy spectrum of the jets that are apparently being ejected from the nucleus of the galaxy M 87 could be produced by collections of pulsar-like objects. This theory combines the advantages of pulsar-like objects as efficient energy producers and of discrete objects as an energy mechanism capable of producing random variations. Burbidge came to this idea while attempting (along with Fred Hoyle) to explain the x-ray emission from the Crab Nebula. Burbidge and Wayne Stein of the University of Minnesota have concluded that a similar mechanism may explain the infrared emission observed in many extragalactic objects, and a paper on the topic is in press.

It is not likely that any of the new theories will find immediate acceptance, but they seem to bring two trends to the surface. First is the idea that a collection of discrete sources helps get around the severe limitations placed on the size of the radiating object and may help account for the random variability observed in the emission of many extragalactic objects. Second, the idea that many collections of matter may be expanding seems to be making a small dent in the long-held view that all objects are condensing from a homogeneous universe.—ROBERT W. HOLCOMB

References

1. R. W. Holcomb, *Science* **166**, 1609 (1969).
2. H. Alfvén, *ibid.* **164**, 911 (1969).