QUASARS: RECENT DEVELOPMENTS

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English IV

March 4, 1997

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INTRODUCTION

Although quasars were discovered in the 1960s and have been subject to thorough research since, scientists have so far been unable to demystify them and answer the questions they pose. In recent years, several new observations have led to new theories and controversies that may force scientists to remodel their entire view of the universe.

HISTORY OF QUASARS

In the late 1950s astronomers were trying to find the optical counterparts of objects in space that had previously been detected by their strong radio signals. In 1960, observers noticed a faint blue star at the location of the radio source 3C48 and recorded its spectrum; however, it took more than two years until scientists were able to interpret it. Prominent features of the spectrum were shifted towards red wavelength by 37 percent, an until then unknown amount. Light is subject to this so-called redshift if the emitting source recedes from Earth at great speeds, and according to Hubble's law, the percentage of the redshift is proportional to the object's distance from Earth (Irwin 1995, 1). In the case of 3C48, the object is located at almost five billion light years from Earth, and moves away at nearly one-third of the speed of light. Since these objects are certainly not stars but exhibit star-like characteristics, they became known as *quasi-stellar radio sources*, or quasars. This term was changed to *quasi-stellar objects* (QSO) after the discovery was made that 90 percent of all objects in this category did not have a radio signal. The term quasar is still in use, though (Chaisson and McMillain 1997, 550).

Quasars are generally considered the universe's most distant and most luminous objects, with average luminosities ranging from 10^{38} W to 10^{42} W. An object at 10^{40} W outshines our Sun more then twenty trillion times, and is still hundreds of times brighter than the most violent active galaxies. Despite this unequaled energy output, the great distance from Earth leads to a rather unimpressive optical appearance as seen from our point of view.

Quasars display many similarities to active galaxies. The radiation emitted has been found to consist of radio, infrared, optical, ultraviolet, and X-ray waves; some quasars can even be observed in the gamma ray spectrum. The major part of a quasar's energy is given off as infrared, though. As in active galaxies, the radiation is nonthermal, meaning there is no relation between the emission and the temperature of the radiating body. Many quasars vary irregularly in brightness, sometimes over periods as short as hours, which leads to the conclusion that quasars must be very small, probably of the size of our solar system. Some quasars seem to have ejected matter in so-called jets (Chaisson and McMillain 1997, 552).

RECENT THEORIES AND CONTROVERSIES

Energy Source of Quasars

The small size of quasars immediately poses the problem of how enough energy can be created in such a limited space. In the classic theories, there are basically three models involving very dense star clusters with multiple supernovae and pulsars; extremely massive stars; or supermassive black holes (Fang and Ruffini 1985, 71).

All three models share the fact that the mass in question must be on the order of 10^6 to 10^9 solar masses, and that the power is primarily supplied by gravity. Since all massive stars and star clusters would eventually collapse and form a black hole, the latter model is most promising today. This model assumes that a black hole is located at the center of a large galaxy. With its exceedingly strong gravitational field it strips matter from nearby stars or gas nebulas and pulls it inward into a spiral-shaped orbit called accretion disk. As a result of friction in the disk, the molecules heat up as they come closer to the black hole, and begin to glow (Chaisson and McMillain 1997, 553).

This is a very efficient way to convert mass into energy, and it is currently estimated that between 10 and 40 percent of the swallowed mass undergoes this conversion; the fusion process in stars operates at merely 1 percent (Fang and Ruffini 1985, 71). Calculations based on these estimates show that a 10^8- or 10^9-solar-mass black hole can emit enough energy to power a 10^{42} W quasar by pulling about one thousand solar masses per year into the accretion disk.

Several problems arise with this model, though. Scientists estimate the universe to be roughly 10 billion years old. By multiplication it is possible to calculate the number of stars swallowed by a quasar's black hole in its lifetime; for a bright quasar this would be about ten trillion or 10^{13} solar masses. This alone is very unlikely, unless the host galaxies that supply the black hole are much larger than ordinary galaxies like the Milky Way, which contain between 10^{6} and 10^{12} solar masses of matter. It is possible, though, that the density of matter was higher several billion years ago, which would be the case in an expanding universe predicted by the Big Bang theory. Even if density was higher, by now there should be plenty of burned-out quasars; however, scientists have no evidence for those invisible supermassive black holes yet (Chaisson and McMillain 1997, 554).

Furthermore, the black hole theory relies on host galaxies that surround the black holes and that should be noticeable from Earth; in a 1994 survey by Bancall and others, however, the Hubble Space Telescope showed either quasars completely without surrounding nebulosity, or with a very low nebulosity just slightly above the cosmic background noise.

The *laser star* theory by Y. P. Varshni predicted this discovery, saying the large redshifts of quasars were not cosmological in nature, but instead created by "laser interactions within a rapidly expanding and cooling stellar atmosphere." This model is rather unknown, though (Talbot 1996, 2).

Quasars in Galactic Evolution

Some scientists consider the possibility that quasars are a very early stage in the evolution of galaxies. The fact that there are more quasars at a greater distance leads to the assumption that quasars were more common in the earlier years of the universe; at the same time, normal galaxies like our Milky Way were less common several billion years ago. These two pieces of evidence suggest that all galaxies originate from quasars. The black hole theory for quasars even strengthens this model of evolution since black holes are also thought to be in the centers of normal as well as active galaxies. It is consistent with the view that quasars generate their energy by pulling matter into black holes in their centers. Thus, normal galaxies would be quasars that are almost "burned out."

According to these scientists, a quasar may develop into a so-called BL LAC galaxy, a type of radio galaxy; or a Seyfert galaxy, which closely resembles a normal spiral galaxy. Both of these galaxy types are active and still very luminous. The end stages of these two paths of evolution would be a normal elliptical galaxy or a normal spiral galaxy, respectively (Chaisson and McMillain 1997, 558).

Superluminal Motion of Quasars

One of the properties of many quasars is the irregularly changing apparent intensity. Using very-long-baseline inferometry (VLBI), which uses several radio telescopes as far apart as possible, it has been found that some quasars seem to undergo dramatic structural changes, often over periods of only a few month. The core of the quasar 3C273, for example, is made up of two separate radio sources, or lobes, which have moved apart about two milliarc seconds over a time span of three years. If the redshift of 3C273 is used to get the distance, it is possible to calculate the velocity of the two objects relative to each other. Surprisingly, this velocity is almost seven times higher than the speed of light.

The notion that the speed of light is the highest attainable velocity is central to Einstein's theories of relativity, which are well-proven and generally accepted today. These apparently superluminal (that is, faster than light) movements must be explained differently. One of the current theories assumes that quasars are not subject to changes in structure, but to differences in intensity that create the illusion of motion. It is unknown what could create these sequences of changing brightness, though, but the theories include charging and uncharging of particles moving through a magnetic field, and some complex ways of rotation and internal motion. A different explanation suggests the ejection of matter in a jet, moving almost exactly at or away from the viewer at slightly less than the speed of light. Calculations show that this would indeed cause a projection effect, making the jet appear to move at a speed greater than the speed of light.

All of these models are very complex and require peculiar geometries to work. No model works in all cases, and no explanation is agreed upon by all scientists (Chaisson and McMillain 1997, 558).

Local Quasars

One design that would explain the superluminal motion detected in some quasars calls for local quasars. If quasars were much closer than calculated using their redshifts, the parts in a quasar would not have to move as fast to reach the same angular velocity, thus not having to move faster than the speed of light.

The idea of local quasars, proposed first by the respected astronomer Halton Arp, also provides solutions for other problems, like the luminosity. Since the law to calculate the apparent luminosity is an inverse-square law, the energy needed for a quasar to have a certain brightness increases very rapidly as distance becomes larger. A quasar 100 times closer would need to radiate

10,000 times less intense and would still have the same apparent brightness. This way, a very bright quasar may have to produce only 10^{36} W, which is still a large amount of energy but easier to explain with familiar stellar events, like supernovae or the formation of heavy new stars.

Observer Halton Arp also claims to have evidence for physical connections between quasars and nearby galaxies, which often have a much lower redshift. If this is true, the quasars have to be placed physically close to their neighboring galaxies (Arp 1987, 31).

The difficulty with this approach, though, is that it requires a noncosmological cause of the redshifts, that is, a redshift not produced by recession velocity and distance according to Hubble's law. The large redshifts may have been created by light moving through a strong gravitational field, but again there is no proof for the existance of such fields, and few astronomers are willing to abandon Hubble's law and cosmological redshifts. A decision against Hubble's law would render almost all cosmical distance measurements wrong, posing a serious threat to all current theories (Chaisson and McMillain 1997, 560).

CONCLUSION

Even after more than thirty years of study, scientists are still unable to fully understand quasars, and no theory provides a solution that gives convincing explanations for all of the phenomena. The huge luminosity of quasars can be explained nowadays, but the black hole theory leaves other questions open. The idea of local quasars reduces the energy output needed to power quasars, and makes physical connections between quasars and galaxies possible, but it does not answer the question of how the redshifts could have been created.

Without really understanding quasars, they have become part of the scientists's delicate network of how the universe works. If the new theories prove to be true, the whole network may have to be torn apart.

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