EIR Science & Technology

Hubble's quasar images: a moment of truth

The space telescope's observations tend to confirm some highly original theories about galactic nuclei and quasars, which also upset some fashionable theories. David Cherry reports.

The following article was provided to EIR *courtesy of* 21st Century Science & Technology. *It will appear in that publication's Summer 1995 issue.*

The Hubble Space Telescope has been trained on 14 of the brightest quasars, with the result that the standard model of the quasar for the past 30 years is now decisively overturned.

Quasars are the stars that aren't any kind of star at all. According to the usual story, Allan Sandage, in 1963, was the first astronomer to bag a quasar and nobody knew what it was. Its spectrum, taken repeatedly, was indecipherable. Eventually, his colleague Maarten Schmidt, at the California Institute of Technology, agonizing over another quasar's indecipherable spectrum, realized that the familiar pattern of certain hydrogen lines was present, although greatly shifted toward the red.

Actually it was Fritz Zwicky, also at Caltech, who first noticed quasars, and some of their high redshifts had already been identified when Sandage announced his find.[1]

When initial excitement over the work of Sandage, Zwicky, and Schmidt had subsided, it was clear that a new class of objects had been identified, objects with high redshifts, nonthermal emission, and more ultraviolet in their light than any stars have. Additionally, unlike most stars, the energetic output of these objects was unstable. It could increase or decrease in just a few days—or in a month or a year. And quasars might, or might not, emit radio waves and x-rays.

1. Dennis Overbye, *Lonely Hearts of the Cosmos—The Scientific Quest for the Secret of the Universe* (New York: HarperCollins, 1991), pp. 79-82).

What sense could be made of these characteristics? The redshifts could only mean that quasars were speeding away from us as part of the universal expansion or, at least, almost everybody agreed to say so. Such high redshifts—under this interpretation—also meant that the quasars must be exceedingly distant. Despite such distances, however, the quasars were often very bright. Their intrinsic brightnesses (energies) would therefore have to be incredibly great.

Some bright quasars' rapid variability, however, was the basis for concluding that the tremendous energies must be pouring out of objects of relatively tiny physical dimensions. The argument for this is that an object, as a whole, cannot vary its output faster than the time required for an internal change to communicate itself throughout at the speed of light. The argument, based on textbook (Galilean) physics, was and is generally believed (although false) and shaped the discussion of quasars.[2]

Quasars had to be emitting 10 to 100 times the energy of an entire galaxy like the Milky Way, but—according to textbook physics—it had to emerge from a region only a millionth of the diameter of our galaxy (not more than 0.1 light-year). For some quasars, according to this calculation, it was not clear how so much energy could escape from so small an object without blowing it apart.

How could such great energies be produced in the first place?

Stars are generally believed to be powered by nuclear

2. It is actually false because we cannot assume that quasars' variations are controlled by a means that has anything to do with the speed of light, nor that we know the upper limit of the speed of light under the internal conditions of quasars.

fusion, but fusion is not efficient enough to explain the quasar phenomenon. The simplest model was to suppose that quasars were outpourings of energy resulting from the infall of galactic material onto a black hole at the galaxy's center. Although black holes—those theoretical constructs—do not allow any light to escape, the infall itself would cause intense emission of light at a safe enough distance from the black hole's threshold.

The black hole model had the advantage that it solved (at least in the sense of a mathematical solution in textbook physics) the problem of intense energy emission from a small object.

But where was the galaxy of which the quasar was the putative nucleus? Wisps of matter could be detected around some quasars, and so it was concluded that all were at the center of galaxies, but that the brilliance of the quasar simply obscured the galaxy by washing it out. No other mechanism for such prodigious energy production could be found within the bounds of Einsteinian physics.

The standard model of the quasar thus emerged with very serious problems relegated to a large quantity of very fine print. There was a reluctance to take the salutary step of admitting ignorance. Science suffered as astronomers bought into the only game in town.

Years later, another serious problem with the energy-producing mechanism crystallized. Quasar specialist Daniel Weedman wrote in 1988: "[N]one of the black hole models can make sufficient predictions to lead to true observational tests. In fact, the primary observations that led to the black-hole model in the first place turn out to be inconsistent with its theoretical predictions."[3] This remarkable defect didn't seem to damage the model's popularity, however.

The Hubble observations

In 1994—three decades after the character of quasars was seemingly settled for good—John Bahcall of the Institute for Advanced Study at Princeton and his colleagues[4] took advantage of the Hubble Space Telescope's long-awaited capabilities to get a closer look at 14 quasars. In January 1995 at a meeting of the American Astronomical Society in Tucson, Arizona, Bahcall told a news conference what they had found.

He announced that 11 of the 14 quasars had no surrounding galaxy and only 3 showed host galaxies of moderate brightness. One of the 11 had faint, wispy material near it, proving that if there were any faint matter near the quasar, it would have been detected by the Hubble.

"We were shocked to see them," Bahcall said of the "naked" quasars. "It's in nobody's theory. . . . All I can say is, 'Who ordered them?' " Co-investigator Donald Schneider commented, "This is the most enigmatic data I have ever analyzed." Bahcall added, "This is a giant leap backwards in our understanding of quasars."[5]

In 'nobody's' theory?

Surely John Bahcall knows whose theory has for years considered quasars as the precursors of galaxies, thus predicting the existence of some quasars with, and some without, a surrounding galaxy. Bahcall chaired the 1989-1991 Astronomy and Astrophysics Survey Committee of the National Research Council, appointed to chart the future of the field. It would mean a substantial gap in his knowledge if he did not. Let us see who his "nobody" is.

Even before quasars had been identified, Victor Ambartsumian, founder and director of the Byurakan Astrophysical Observatory in Armenia and a member of the Soviet Academy of Sciences, had developed a theory of types of activity in galactic nuclei. According to Ambartsumian's theory, explosive ejections of "pre-stellar" matter from the nuclei were the seeds from which new galaxies formed.

Ambartsumian's theory was most unwelcome to the mainstream of academic astronomy in that he rejected the prevailing concept that gravitational condensation and collapse are the general rule in the universe. Instead he began his theoretical work in the 1930s and 1940s by noting that the processes we *observe* are diffusion, explosion, and ejection. The general direction of astrophysical evolution, he argued, runs from dense states to diffuse ones.[6]

His work was hardly obscure. After an address on the evolution of galaxies at the 1958 physics conference of the famed Solvay Institute in Brussels and an invited discourse on problems of extragalactic research at the General Assembly of the International Astronomical Union in Berkeley, California in 1961, Ambartsumian served as the president of the latter association from 1961 to 1964.

Today it is still true that what we observe are diffusion, explosion, and ejection. In 1988, astronomers wishing to observe the process of gravitational condensation in the birth of stars had to report that "not a single object in the actual act of stellar formation has been conclusively identified. . . .

3. For details, see Daniel Weedman, 1988, "Quasars: A Progress Report," *Mercury* (Jan.-Feb.), pp. 12-17.

4. Donald Schneider, Pennsylvania State University, and Sofia Kirhakos, Institute for Advanced Study at Princeton.

5. "A Galactic 'Smoking Gun" by Kathy Sawyer, the *Washington Post*, Jan. 13, 1995, p. 2, and Space Telescope Science Institute press release 95-04. The press release says "no current models predict. . . ."

6. For an overview of Ambartsumian's work on the origin of stars, see Ludwig V. Mirzoyan, "The Origin and Evolution of Stars: An Observational Approach," *21st Century Science & Technology*, Winter 1991, pp. 43-51. For his work on stars and on galaxies, see "The Problem of Protostellar Matter" by the same author, *21st Century*, Fall 1994, pp. 68-74.

There is, however, no substitute for reading Ambartsumian's papers themselves. A significant number are in English, as seen in the references to these *21st Century* articles. He is no advocate of Big Bang or Steady State cosmology, both of them being essentially mathematical elaborations of General Relativity, and to his mind, insufficiently grounded in the observations.

The unambiguous identification of such a proto-stellar object is . . . crucial. . . . It is a vital test of our present theoretical conceptions. It requires the direct detection of infall motions. . . . During the last decade or so extensive millimeter-wave molecular line observations of proto-stellar candidates have been made. . . . However, these studies have produced the unexpected result that most embedded infrared objects are sources of energetic *outflow* of molecular gas rather than infall. Convincing evidence for infall motions around infrared proto-stars has so far eluded detection."[7]

Ambartsumian on quasars

With the discovery of quasars, Ambartsumian made the case that they were one of the kinds of explosive ejecta that evolved into new galaxies. *Problems of Modern Cosmogony* (1969), written by Ambartsumian and his students, states:

"Finally, to the forms of activity of [galactic] nuclei already mentioned must be added explosions, which lead to the formation of quasars. In scale and magnitude these explosions exceed all other forms of nuclear activity and indicate the formation of a new galaxy, even of a galaxy cluster or of a group of galaxies."[8]

As the ejecta of galactic nuclei, quasars would not initially be surrounded by a galaxy, which would develop later. What Bahcall and colleagues reported in January—some quasars surrounded by a galaxy and some not—is predicted by Ambartsumian's theory. The finding by itself does not, of course, prove the theory.

Ambartsumian's theory, however, was just the beginning. After the close of the 1960s, Ambartsumian did not elaborate further his theory of the activity of galactic nuclei. In early 1966, the American astronomer Halton Arp, then on the staff of Palomar Observatory, independently reached the hypothesis that luminous bodies, including quasars, were ejected by galactic nuclei and represented the kernels of new galaxies. The idea emerged from studying images in the *Atlas of Peculiar Galaxies,* which he had just finished compiling. Later Arp discovered Ambartsumian's work.[9]

Arp asked, where do we see quasars in the big picture? If quasars are always at the distances indicated by their redshifts, then they should be concentrated in those parts of the sky where distant galaxy clusters are found. They were not. He also asked, if quasars are always at their redshift distances, then, on average, fainter quasars should have greater redshifts—that is, they should form a linear or near-linear Hubble diagram as galaxies do. But a plot of quasars in terms of brightness versus redshift forms a blob.

Conclusion: Redshift is not a reliable indicator of distance for quasars, which must therefore acquire some variable part of their redshift from a property that is not distance-related. Further conclusion: Without the hindrance of redshift as an erroneous measure of distance, the contradiction of impossibly great energy emerging from too small a body can be resolved by "bringing the quasars in." If quasars are not so distant, their intrinsic brightnesses are less stupendous.

But if quasars are nearer, where do they fit into the picture? If quasars were ejected from galactic nuclei, they should be found in greater numbers immediately around galaxies. The quasars bright enough to be readily detected should be mostly concentrated around the nearest galaxies. Were they? In a bitter, 20-year fight, Arp showed that they were.

This success came in several steps.[10] First it was conceded that there was an *apparent excess* of bright quasars around nearby galaxies, but this was explained away as the result of gravitational lensing of background quasars by faint stars in the spherical halos around the galaxies—the quasars' light would be made brighter by this gravitational effect, without the effect being so strong as to create double images of the quasars (microlensing). The phenomenon would affect the counts of bright quasars by bringing fainter ones into the bright category.

Then some diligent astronomers (with no sympathy for Arp's views) sought a rigorous test of the *adequacy of observed quasar counts* to produce by microlensing the necessary excess of apparently bright quasars around galaxies. They showed that to produce the effect, there had to be a rapid increase in quasar counts as one went to fainter apparent magnitudes. But they found that there was no such rapid increase.

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7. From a conspectus of the tasks and the technology of the now-completed Heinrich Hertz Submillimeter Telescope on Mt. Graham, Arizona, issued in early 1988, Sec. 2.3.1. In September 1993, astronomer John Bieging of the Hertz telescope confirmed to the author that the state of affairs had not changed.

Richard N. Thomas and his colleagues concur: "Unfortunately for such conjectures, mass-infall models do not well represent the strong and variable H-α emission profiles characterizing [T Tauri] stars. . . . The authors of Chapter 4 of this Volume 7 [Lawrence E. Cram and Leonard V. Kuhi] . . . conclude that the observations are best represented by a mass outflow. . . . Based on my own efforts at modeling T Tauri atmospheres, I accord." T Tauri stars are believed to be stars still in the process of formation. The quotation is from Thomas's "Perspective" that opens *FGK Stars and T Tauri Stars* (Volume 7 in the NASA-CNRS Monograph Series on Nonthermal Phenomena in Stellar Atmospheres, edited by Lawrence E. Cram and Leonard V. Kuhi, NASA SP-502, 1989).

8. This work is available in Russian, German, and French. The passage quoted here, translated by this author from the 2nd German edition of 1976 (*Probleme der modernen Kosmogonie*), appears there in Sec. 2.3, p. 115.

Much of Ambartsumian's argument in this section is stated or strongly foreshadowed in his English-language publication, "On the Nuclei of Galaxies and Their Activity," in *Proceedings of the 13th Conference on Physics* of the Solvay Institute, Brussels, September, 1964 (New York: Wiley Interscience, 1965).

9. Halton Arp, 1987. *Quasars, Redshifts and Controversies* (Berkeley, Calif.: Interstellar Media), pp. 7-16, 134-135.

10. The microlensing story that follows here is told in more detail, and with references, in "Why Are There More Quasars Around Nearby Galaxies?" by David Cherry, *21st Century,* Fall 1991, pp. 78-82.

A new attempt confirmed the excess of quasars around galaxies at "more than the 99.99% confidence level," but resurrected the microlensing thesis by invoking dark matter in the spherical halos around galaxies—matter that does not radiate enough to be seen, but can be known by its gravitational effects.

Again, this explanation was tackled by astronomers unsympathetic to Arp's hypothesis, but with detailed knowledge of the dynamical (gravitational) behavior of galaxies. They concluded that the required dark matter "is much too close to the luminous parts of the galaxies to be consistent with other dynamical mass measurements." In other words, if it were there, it would have a gravitational effect on the visible matter, an effect that is not observed.

These astronomers concluded, "within a conventional understanding of galactic systems we can find no model to explain the large enhancement" in numbers of quasars around galaxies.

Despite this success of Arp's hypothesis, it continued to be evaded on another front by pointing out that "fuzz" could be seen around some quasars; on that basis it was argued that all would be seen to be the nuclei of galaxies when a powerful enough telescope was available. (Moreover, it was said, since all quasars are the nuclei of galaxies, and since galaxies are at *their* redshift distances—which is not entirely true—quasars must be also.)

The leap from the fuzz to presumed host galaxies was insisted upon even though Arp pointed out that the dimensions of the fuzz in some cases were much larger than those of normal galaxies (under conventional assumptions about the quasars' distances). He also pointed out that there was no spectroscopic evidence for the existence of stars in the fuzz. One would expect a galaxy to have stars.[11]

Later it became generally accepted that all galaxies were formed during a single phase of the Big Bang expansion. This put the idea of ejected quasars evolving into galaxies—and continuing to do so today—at odds with the almost universally accepted Big Bang theory.[12]

The state of affairs today, in sum, is that 1) There is a strong argument that quasars are not always at their redshift distances; 2) it is clear that there are more quasars immediately around galaxies than should be there by chance; and 3) Bahcall's study—showing some quasars as nuclei of galaxies and some "naked"—is at least consistent with the concept of quasars as the ejected seeds of galaxies that later settle in as the nuclei of those galaxies.

It is ungenerous for a scientist to deny the work of a colleague or predecessor.[13] Unfortunately, the practice is widespread in science today, and there is a long and hoary tradition of such ungraciousness running back to Newton and Galileo. But often more is involved than mere self-promotion. There is the more serious matter of the process of scientific discovery being aborted through excessive self-assurance.

To understand this, take the example at hand. Ambartsumian and Arp develop a highly original theory of the behavior of galactic nuclei that includes certain predictions concerning quasars. The theory arises from the use of an unfashionable method, one that gives priority to astronomical observation and to ideas suggested by observation, and does not give priority to Einsteinian theory or the limits of Earth-bound physics results. Method and theory alike are unacceptable to leaders of the field.

A key prediction of the theory, however, proves correct. What to do? The tried and true remedy is to weave the undeniable fact into the preferred theory that did not predict it, while ignoring the theory that did predict it. (Indeed, in this case, Bahcall seems to be considering the idea that quasars are the seeds of galaxies that somehow suddenly emerge in their great compactness from the primordial gas of the early Big Bang expansion.) Repeated applications of this patchwork remedy, however, have a profoundly deadening effect on the minds of those who submit to it.

Ambartsumian's friend, the late Jan Oort, director of the Leiden Observatory in the Netherlands, who never subscribed to either Ambartsumian's method or theory, nevertheless said, "I have ceased to be surprised at how all of Ambartsumian's hypotheses, which he prophetically put forward many years ago, are confirmed one after another."[14]

Isn't it time to ask why this is happening?

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11. Arp summarizes these and other observational arguments against host galaxies that were available long before the new Hubble study, in "Naked Quasars," *Mercury* (Journal of the Astronomical Society of the Pacific), March-April 1995, p. 35.

12. Donald Hamilton, 1985. "The Spectral Evolution of Galaxies. I. An Observational Approach," *Astrophysical Journal,* Vol. 297, pp. 371-389.

13. For Bahcall not to know the Ambartsumian-Arp theory, he would have had to miss not only numerous papers of Ambartsumian and Arp, but a sizable number of articles—especially by opponents of the theory who addressed the microlensing of quasars near bright galaxies—appearing in the *Astrophysical Journal,* in *Astronomy and Astrophysics,* and in *Nature* throughout the 1980s and into the 1990s (see footnote 10 above for references). But Bahcall has studied microlensing and read a paper on it at the January 1995 meeting of the American Astronomical Society in Tucson.

Bahcall would also have had to close his eyes to Arp's book on *Quasars, Redshifts and Controversies* (footnote 9 above), read by many an astronomer under the covers by flashlight; the quasar chapter of an important recent Russian-American collaboration, *Astrophysics on the Threshold of the 21st Century,* edited by N.S. Kardashev (Philadelphia: Gordon and Breach, 1992); and numerous other books and articles.

Also, two participants in the controversy over the Ambartsumian-Arp theory of quasars, Claude Canizares and Wallace Sargent, were members of the 1989-91 Astronomy and Astrophysics Survey Committee of the National Research Council, which Bahcall chaired.

Finally, he would even have to have forgotten his own debate with Arp on Dec. 30, 1972, at the meeting of the American Association for the Advancement of Science in Washington, D.C., published in *The Redshift Debate,* edited by George Field (Reading, Mass.: W.A. Benjamin, 1973).

14. Quoted on the flyleaf of a Russian-language biography, *Victor Ambartsumian,* by Ludwig V. Mirzoyan (Yerevan, Armenia: Aiastan, 1985).