Quasars in the Sky with Uncertainty

Twinkle, twinkle little quasar.
How I wonder if your rays are
Made in an accretion disk.
Is there deep within your inner
Works a black hole or a spinar,
With a field where protons frisk?

BY DIETRICK E. THOMSEN

They are called quasistellar sources, and the prefix suits them. *As if.* Roger Blandford of California Institute of Technology, a prominent observer of their behavior, began a talk with the phrase "spontaneous cosmic comedians." Whatever you say about them, however you model them, wherever in the universe you put them, they are still very quasi.

When quasistellars, or quasars or sometimes QSO's for short were first discovered about 20 years ago, "quasi" meant that they looked like stars. Most of them do. They are compact looking objects that could pass for stars, but unlike well-behaved stars that are being neither spontaneous nor comedic, quasars stand apart from galaxies. If one considers their energy output or the radio emissions of some of them, quasigalaxies might be a better term. And in fact lately the stellar part of quasistellar is getting raggedy at the edges: Astrophysicists tend to throw BL Lacertae objects into the quasar bin. BL Lacertae objects are irregularly shaped and do not look like stars. And interest now extends to compact galaxies, such as Seyferts and Markarian objects. The title tends to become "Objects with Active Nuclei."

But what sort of active nuclei? If it is a little hard to define quasars by the way they look, it is much harder to agree on what it is that drives them. The question of where they are cosmologically is not completely settled, and it, too, affects to some extent the question of what they are.

Blandford was leading off a discussion of what are called accretion disk models, essentially those with black holes in the middle, at a Summer Workshop on QSO's and Active Galactic Nuclei that lasted for most of July at the University of California's campus at Santa Cruz. The black hole models are popular now, as are black hole models of almost everything else astrophysicists can make a black hole model for. With perhaps less Einsteinian panache one can try to explain a quasar by postulating a spinar at the core of it. A spinar is a large and very massive star or group of stars that coalesce together without becoming a black hole and rotate in unison. In addition to these two there are white holes. White holes are, as A. Starobinsky of the University of Moscow described them, time-reversed black holes. Among other things, that means that if a black hole is where things disappear from the universe to points unknown, a white hole is where things enter from somewhere. The listening astrophysicists reacted to Starobinsky's talk as if it were very old-fashioned, and a number of objections were made including the telling one that after a certain time white holes come to look just like black holes so how can you tell? White holes used to be something of a white hope in cosmology. Here they had this lone proponent.

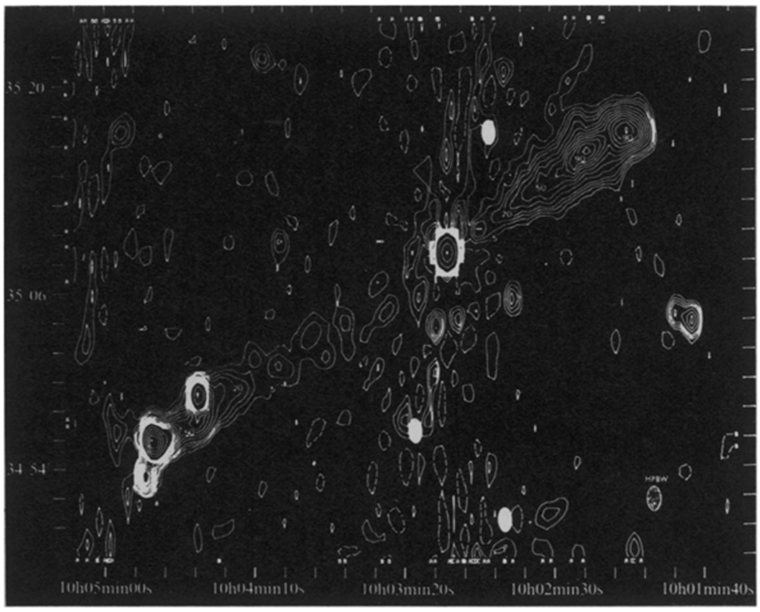
The years of observing quasars have yielded large catalogues of data, but to some extent, says Blandford, however an astrophysicist may interpret particular data depends on the model he or she favors. The data are not always unambiguous judges of the models, but they are numerous and varied enough to set quite a number of constraints on the models one might choose to make.

First of all, the things have a certain appearance, and whatever it is that the model says is in the heart of the quasar must make that appearance come to pass without being too severely tortured. The most spectacular of the geometric constraints on quasar models is one that is not immediately apparent to the eye, the large double radio sources that seem to be attached to some of them. Characteristically the radio sources consist of lobes of matter (which would have to be tenuous clouds of electrically charged particles to emit radio) lying on either side of the visible quasar.

The geometry leads to the assumption (seldom questioned) that the matter in the radio lobes has been driven out of the visible object. This requires a driving engine operating along the axis of the radio lobes. An object that rotates on that axis, gathers up matter and spews it along the axis seems right. It has to stay on the axis. It must be a good gyroscope, to use Blandford's term, and, as he says, black holes and spinars make good gyroscopes.

The mechanism must also focus the outgoing material into a very narrow cone. There are jets that appear to be coming from the centers of some of these objects that are only 3° to 5° wide. This argues also for a compact object. If a rotating disk, for instance, were spewing material in the direction of its axis, it might achieve 30° or 45°. There is thus a very narrow channel along the axis of the typical quasar out of which the matter comes. It is tempting to think that in the case of the BL Lacertae objects, where there is evidence that conditions very close to the core are being observed, observers are seeing down along this axis.

Blandford cautions that this analysis applies strictly only to about five percent of all quasars. The other 95 percent are "radio quiet" and show no evidence of this kind of morphology. Nevertheless, he goes on to suggest some fiducial numbers for the compact mass in the center: about a billion solar masses, slightly less than that recently discovered in the galaxy M87 (SN: 5/13/78, p. 308), and 3 × 10^{14} centimeters in extent. This basic central condensed object seems to be surrounded by a kind of "photosphere," a collection of filaments of matter that emit light with broad bands in its spectrum. From the light it can be de-



Nature

3C236 is a galaxy, but the two-lobed structure of the radio source associated with it is characteristic of many quasars, too. This map was made by A. G. Willis, R. G. Strom and A. S. Wilson of the Leiden Observatory.

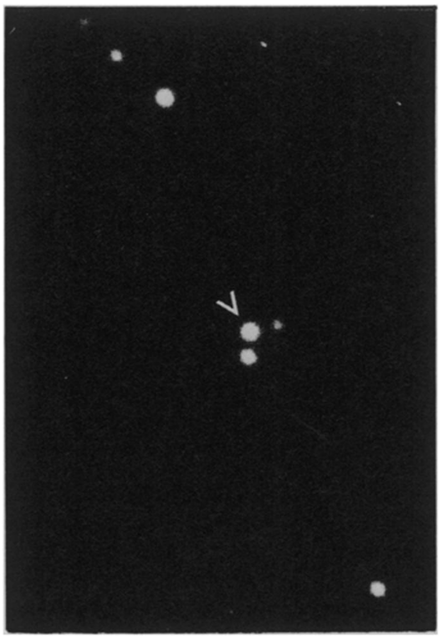
termined that these filaments have a temperature of about 10,000° K. They occupy a region that is characteristically a tenth of a parsec across, a characteristic size for one of them being 30 billion kilometers. Their existence and characteristics lead to the conclusion that the object is embedded in some kind of gas that exerts a pressure on them, an intergalactic medium.

Whatever the nature of the engine in the core of the quasar, it is limited in the rate at which it can pump out energy by a basic principle of physics, Eddington's limit. For an object of a billion solar masses, the maximum rate is 10^{47} ergs per sec. For an efficient mass to energy converter, the rate at which new mass must be accreted to make that rate of radiation is 10 solar masses a year. It is this infalling matter that proponents of accretion disks use to get the light and X-rays emitted by quasars.

The infalling matter is usually depicted as arranged in an astronomically thin disk that partakes of the rotary motion of the central mass (we can now probably say "black hole" for the duration of the next paragraph or two), so that the motion of any single piece of matter on the way in is a kind of lazy spiral. Compression heats this disk, and the hot electrons in the disk are responsible for the light, etc., that gets radiated.

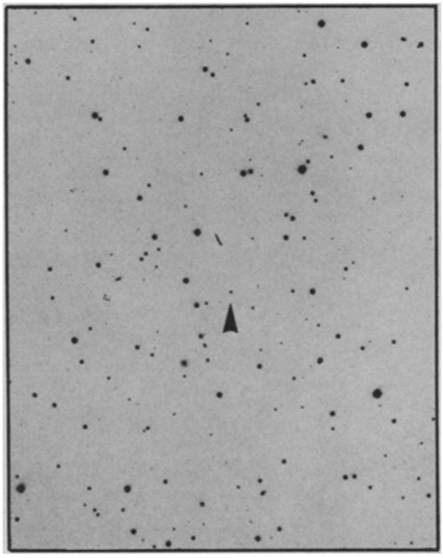
The exact structure and details of behavior in the disk can lead to very complex discussions based on particular aspects of quasar spectra—for example, on the basis of certain data and certain assumptions, it is possible to deduce 10,000 gauss as a characteristic strength for the magnetic field in the disk—but there are a few very important criteria. The first is size. We know from other measurements the range of size for stars, and we think we know it fairly well for galaxies. The size of the light-emitting part of a quasar can be estimated because its light output can vary sharply over just a few days. Any disturbance that could cause such a variation of the whole body has to propagate across it, and it must do that in less than the duration of the variations. The disturbance can't go faster than light, and probably grows much slower, so the visible quasar can be no more than a few light-days across.

Another question is cooling. It seems possible for the particles in an accretion disk to cool themselves down by radiating the energy that they gain (by friction in the disc) to the 10,000° temperatures of the inner regions. The slow descent takes care of that. In a variation of this model, which has the infalling matter coming straight down from all sides (accretion sphere), there doesn't seem to be enough time to cool.

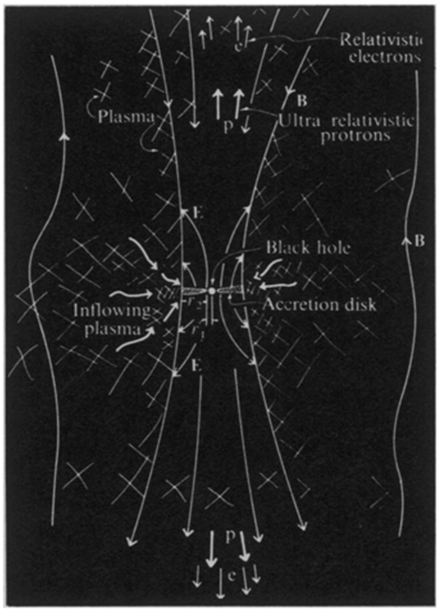


Hale Observatories

They are hard to tell from stars by looking. These are 3C147 (above) and 3C9 (below).



National Geographic Society Palomar Sky Survey



Lovelace/Nature

Model of black hole pump by Lovelace.

On the whole the accretion disk seems best to Blandford. It has the capabilities to produce the observed spectrum. He favors the black hole as the central motor, saying that it is stabler than a spinar and more efficient. His opinion is not universally acclaimed. S. I. Blinnikov of Moscow State University remarked: "I'd like to discuss the models for quasar energy sources not connected with accretion onto black holes. The quasar source is not consistent with accretion on a black hole."

Franco Pacini and M. Salvati of the European Southern Observatory (which is located in Chile) would agree with him. Their recent work has been concerned with showing how pulsar radiation could be derived fron non-accretion sources, that is, from within the object itself. "The energy comes from a central mass vortex," Salvati says. "It can be a spinar... or even a black hole... like those Dick Lovelace [of Cornell University] just talked about." But that energy is transferred to the outside world by a giant electromagnetic field. It is the relation between the central mass, that field, and the particles that do the radiating of the light and radio that makes the model.

The field accelerates the particles, which exist in the "atmosphere" of the central mass. These particles then become the radio lobes or, staying nearer to the center, radiate much of the rest of the observed spectrum. Blinnikov places similar stress on electromagnetism: "The existence of the magnetic field is necessary to explain the radio lobes and the nonthermal spectrum."

Although it seems clear from Pacini's remarks that he prefers a spinar of some kind as the engine for his quasar, he does allow a black hole without an accretion disk. It has almost been a reflex to associate accretion disks with black holes, possibly because accretion disks are something to fall down a black hole, and what is a hole for but falling down?

But friends of black holes with or without accretion disks have one final argument in their favor: stability. A black hole of a billion solar masses, the size Blandford estimates, will last, if not forever, at least longer than we can know how to worry about. A spinar may not. Presumably a spinar would form from the coalescence of a gang of stars of more normal size. Such a thing might come to spin so fast that it would be completely flattened—possibly to a disk, Blinnikov points out. Would the disk then fragment? What would be the role of the magnetic field in this case? (Magnetic fields don't go away.) Would it contribute to collapse? And to go back a few steps, how about the formation of the spinar. If such a large and heavy gang of stars comes together, why don't they go all the way and become a black hole? What's to stop them at the spinar stage? There's a lot of touchy general relativity to be worked out here and Blinnikov's "Moscow group," among others, is working on it. Until somebody gives convincing answers, not all astrophysicists will be willing to believe a spinar can form. On the other hand, they all believe a black hole can form. Or do they? □