Trying to Put Quasars in Their Place

Although quasars have often been regarded as a kind of astrophysical freak show, recent research seems to be converging on a place for them in the ordinary hierarchy of astrophysical objects

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First of two articles

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Astrophysical connections between quasars and other astronomical phenomena, especially highly active galaxies, but even more ordinary ones such as this spiral, seem more and more likely as study continues.

Quasars are concentrated sources of energy in the sky. On photographs they look like stars but they emit energy in amounts characteristic of galaxies (10^{46}, 10^{47} ergs per second, for example). In the 20 years since the discovery of quasars, astronomers have tried to elucidate the nature and structure of quasars, and their relation, if any, to other astrophysical phenomena. Widely varying opinions have been heard, and the debate has often been heated. Now it seems opinion is converging on a number of fronts, particularly the relationship of quasars, which were once seen as anomalies, to the rest of astrophysics. Some of this came out at the recent meeting of the Astronomical Society of the Pacific in San Diego.

More and more, quasars seem to be a class of centers of galaxies, probably related to active galaxies such as Seyferts. The information on which these conclusions are based comes from the light, radio, X-ray and other electromagnetic radiation put out by quasars. The largest part of it comes from spectroscopy, the analysis of the radiation into its component wavelengths. Prominent in quasar spectra, as in those of most other astronomical bodies, are bright or dark lines superimposed on the background continuum or rainbow. These represent resonant emissions or absorptions by specific chemical substances, and they tell much about the composition and physical conditions of the place where they were produced. Lines have different widths — that is, spread over different ranges of wavelengths — according to the motions of atoms and molecules within the bodies that produce them.

Quasar spectra can have both emission and absorption lines, and these can be both broad and narrow. They can be grouped into sets according to these characteristics, and the different sets seem to have different sources. Some of these sources appear to be related to the quasar phenomenon itself; others appear to be contributed by things the quasar light passes through on its way to us. This article will deal with the sources that appear related to the quasar; a subsequent report will take up things illuminated by quasar light in its travels.

At the center of every quasar is the mechanism that produces all this energy. It is believed to be fueled by gravitational collapse, by the energy generated by matter falling into it from its surroundings. The exact nature of that central object, whether it is a supermassive black hole, an immense concentration of very massive stars or one of a number of other exotic astrophysical artifacts, is still a matter of intense controversy. For the purpose of this article, the quasar energy source will remain simply a black box, or rather a very bright box, pumping out energy.

The nature of the region that is the source of broad emission lines in quasar spectra has been a matter of controversy for many years. Now a consensus seems to be shaking down. Clouds of gas and dust near the central quasar sources have long been the prime suspect as sources of the broad emission lines, but there was plenty of room for differences of opinion over the relation of those clouds to the central source and the precise processes that produce the emission lines.

Are these clouds material being ejected from the center of the quasar? Are they falling into it? Or are they rotating around it? It is the shape of the spectral lines, the profile of brightness across the breadth of the line, that may contain the information that enables scientists to decide. Reviewing the question at the ASP meeting, Ray Weymann of the University of Arizona indicated how difficult the analysis is. But in the end, he says, it seems to support a model in which a quasar wind, a stream of matter pumped out of the central engine of the quasar at relativistic energies, is driving some rather thick clumps of gas and dust away from the center of the quasar.

Prominent in the spectra are various emission lines of ionized hydrogen, oxygen and carbon. The basic mechanism for their production, Weymann says, is photoionization of the gas in the clouds by white light emitted by the core of the quasar. The ionized atoms then recombine, and the loss of energy involved in the recombination produces the observed line emissions. From relative brightness of the various lines and related information Weymann concludes that the clouds are optically thick — that is, fairly opaque — and that they are thickest close to the core of the quasar.

In studies of many of the same lines, which are in the ultraviolet, Chi-Chao Wu of Computer Sciences Corp. and the Goddard Space Flight Center in Greenbelt, Md., comes to similar conclusions. He finds evidence for a central source with discrete clouds moving away. Photoionization and recombination is the mechanism for production of the lines, he agrees. Like Weymann, Wu locates the lower ionization states, such as those that produce the famous Balmer series of lines of hydrogen, on the insides of the clouds, "a thin skin facing the central source," he says.

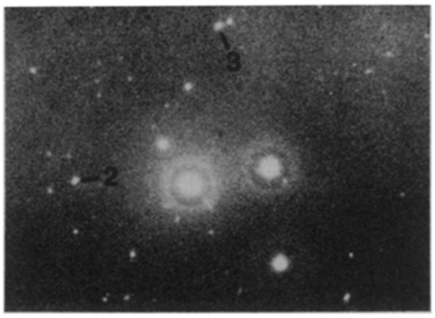
Similar structures appear in a study of the Seyfert galaxies NGC 4151 and NGC 1068 by Joseph S. Miller of the University of California Lick Observatory and Robert R.J. Antonucci, a graduate student at the University of California at Santa Cruz. Seyfert galaxies have extremely energetic, active centers. Many astronomers believe that Seyfert centers and quasars are the same or similar phenomena and that comparisons will demonstrate some relationship between the two.

Miller and Antonucci analyzed the circular polarization of the light from these galaxies. It is not an easy thing to measure, Miller says. The amount of polarization is only 1 or 2 percent, so very sensitive equipment is needed.

Light may be circularly polarized because it is emitted that way as synchrotron radiation. Synchrotron radiation comes from electrons spiraling in a magnetic field. The electrons are going in circular orbits around the direction of the magnetic field, so the light has to come out circularly polarized. Light that is emitted unpolarized may also become circularly polarized if it is later scattered off electrons or dust grains.

Previous investigators had interpreted the polarizations in light from Seyfert galaxies as due to dust scattering. Miller says that he and Antonucci have come up with a "dramatically different conclusion." It is based largely on their investigations of NGC 1068, in which case they could compare their optical observations with a newly done radio map.

In the core of the Seyfert galaxy in their model is some kind of power source similar to that in a quasar. Its energy seems to be generated by the infall of matter from a so-called accretion disk that surrounds it. The minor axis of this disk, which is not circular, points in the direction of a jet of radio-emitting material that shows up on the radio map. Both the plane of the disk and this radio jet are perpendicular to the axis of the circular polarization of the continuum or white light from the center. This geometry is compatible with either synchrotron emission or scattering from electrons, but not dust scattering, as the source of the polarization for the continuum light.



Alan Stockton

Quasars sometimes seem physically associated with galaxies. Here a quasar (brightest image, lower center of picture) and some galaxies (numbered images) appear to be part of the same cluster.

For two groups of emission lines, the permitted and the forbidden lines, the scenario is different. (The terms "forbidden" and "permitted" are from laboratory spectroscopy, where conditions are such that the probability of emission of the forbidden lines is so low compared to the probability for the permitted ones that the atoms invest the available energy in the permitted lines and the forbidden ones don't appear. In astrophysical bodies conditions are often different, and the forbidden lines can get a large enough share of the energy to show up.) The polarization axes of these two groups of lines are different from that of the continuum, and the polarization of the permitted lines could be contributed by dust. The source of polarization of the forbidden lines seems to be far out from the center, and its axis is perpendicular to the rotation axis of the thing in the center. The accretion disk, however, is tilted with respect to the rotation axis of the center, not perpendicular to it.

Finally, in the hydrogen emission there is a line that appears at a wavelength that seems strangely shifted from where it ought to be. Antonucci deduced that this strange shift could be the result of reflection of emitted light back onto the accretion disk by the backside of an optically thick cloud. So the completion of this picture is also similar to the proposal for quasars, having fairly thick clouds around the center of the Seyfert galaxy and moving away from it. There are still a number of questions about the details of the model, especially how to reconcile certain differences between the data from NGC 4154 and NGC 1068.

Although the details of the energy mechanism in the center of a quasar (or a Seyfert galaxy) lie outside the scope of this report, there is at least one suggestion that fairly distant environs play a significant part in the energy mechanism, that it isn't all a matter of events deep in the intimate center of the phenomenon. It comes from a study of the shapes of 10 examples of fuzzy quasars by John Hutchings of the Dominion Astrophysical Observatory in Victoria, B.C., Canada. (Quasar fuzz is a faint glow, a kind of nebulosity seen around the bright centers of some quasars.) Half of these show irregular, asymmetric shapes. This asymmetry could be due to the gravity of a massive body nearby, according to Hutchings, a blue companion interacting with the quasar (that is, in a collision or a near swipe) and providing gas for a burst of star formation in the fuzz and possibly also to fuel the quasar in the middle of the fuzz. "Many nearby quasars are powered by interactions with companions," Hutchings says.

Quasar fuzz is a main piece of evidence cited by those who believe that quasars are a variety of galactic center. If a quasar is surrounded by fuzz and fuzz contains stars, that would be a galaxy for the quasar to be the center of. Hutchings's conclusion about the 4 or 5 symmetric examples of fuzz in his survey is suggestive. He finds isophotes (contours of constant brightness) with a shape suggesting a spiral structure for the fuzz.

Todd Boroson of California Institute of Technology in Pasadena is one of the observers who first found evidence for stars in quasar fuzz. By blanking out the light from the bright center, Boroson and J. Beverly Oke of Caltech were able to detect absorption features of stars in the spectrum of the fuzz of quasar 3C48. At the ASP meeting Boroson reported on a study of fuzz around about 16 quasars. More instances of stellar emission and absorption were found. Boroson says the results convince him that "all [quasars] live in galaxies." Some, he says, appear to be in spirals dominated by early type stars, that is, stars fairly young in evolutionary terms.

Seyferts are spiral galaxies, but not all spirals are Seyferts. Not all spirals seem to have the bright energetic cores characteristic of Seyferts. William C. Keel of the Lick observatory did a study of emission lines from a group of 30 "normal" spirals over the wavelength range from 3,727 to 4,600 angstroms. The analysis leads him to assert, "Virtually every normal spiral has a small version of what we see in Seyferts." He found spectral lines from ionized gas in these spectra, but the ratios of the strengths of the different lines to one another seem to rule out ionization of interstellar gas by starlight or by shock waves. That leaves some mechanism in an active center. "Seyferts are the high luminosity end of something virtually universal among spiral galaxies," he concludes.

So the consensus that seems to be gathering links quasars to Seyfert galaxies in both gross and fine detail and then links Seyferts to the whole continuum of spiral galaxies, which includes as one of its members our own Milky Way. □