CONVOCATION TO CONTEMPLATE QUASARS

Everything you always wanted to know about quasars, but weren't sure you wanted to ask

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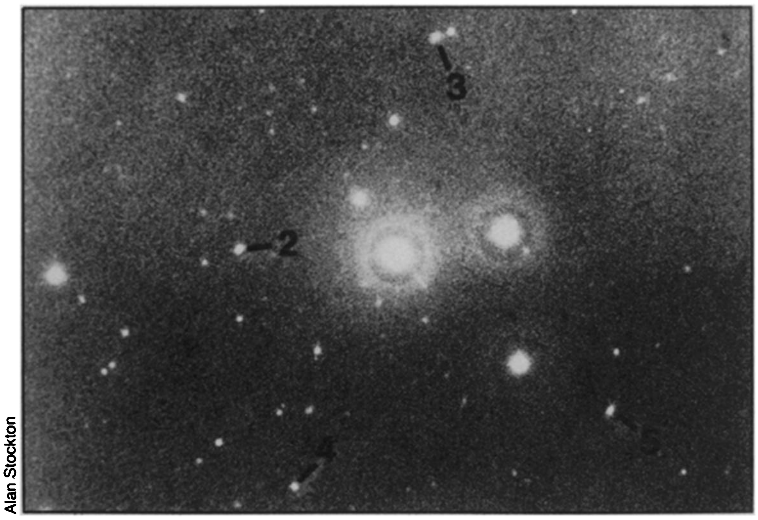

Alan Stockton

The company quasars keep. The central object is the quasar 3C273. Around it are four galaxies (numbered) with closely matching redshifts that would therefore be associated with it.

Do quasars exist? This paraphrase of the question from the famous international elephant joke seems apropos. In the joke, the German entrant in the International Elephant Literary Contest wrote 20 volumes entitled *Does the Elephant Exist?* (The English entry was *Safari in Kenya;* the American, *Building Bigger and Better Elephants,* and so on.) There is probably more than enough data to compile 20 volumes on the existence of quasars, but after such a labor the compiler is likely to find that every page is used by several different people to argue several different things.

Apart from the question of bare existence there are few things about quasars — or quasistellar objects (QSO's) — that astronomers are willing to consider matters of general agreement. Their essence, their astrophysics, their relations to galaxies, their place in cosmology are all subjects of vigorous debate. Throw a snowball in a room full of astronomers and you can hit three or four advocates of varying sides of any of these questions. Snowballs are rarer in Sonoma County, Calif., than they are in some other places, but otherwise that experiment would have worked well at the scientific meeting of the Astronomical Society of the Pacific that was held at Sonoma State University at the end of June. A number of prominent quasar observers and theorists had gathered for a symposium.

In laying out 20 volumes on quasars it might be well to begin, as the symposium did not, with a definition of the objects. That was supplied somewhat down the program by Patrick Osmer of the Cerro Tololo Inter-American Observatory. Quasars are starlike objects but they are not stars because they are obviously outside our galaxy and they don't look quite right for stars. They emit electromagnetic radiation over the whole spectrum from radio to X-ray, but the ultraviolet flux is large in comparison to the rest of the sky, and the light output usually varies over time. Quasar spectra show broad emission lines and large redshifts (which are generally taken to mean that the quasars are way out there somewhere at cosmological distances).

Not every quasar has all these characteristics, says Osmer, but most have at least one, probably two. What seemed striking about quasars when the first ones were discovered in the early 1960s was a conspicuous bluishness. But now, says Osmer, "some quite red objects are included." Being bluish is no longer a deciding factor. For a while it was thought that radio emission was a sine qua non, but now the majority of quasars are "radio quiet." Even the broad emission lines, which relate directly to the physics going on in the quasar, are not decisive. The BL Lacertae objects, which tend to get classed with quasars nowadays, do not have them. There are as many exceptions as there are rules, yet it is still possible for observers to classify objects as quasars, give or take an occasional dispute. Operationally a few of these criteria suffice.

If the definition of what a quasar looks like offers many possible variations, it may serve as a paradigm for every other question about them. It has long been a general belief that quasars are somehow related to galaxies. Some observers say there are associations between quasars and the groups or clusters in which galaxies are found. Some say not. Some propose that quasars are basically the same thing as the central regions of energetically active galaxies (which they resemble). Quasars might be galactic centers around which galaxies never formed. Or they might be galactic centers seen at a time before galaxies formed around them. (The redshifts of most quasars are such that they are being seen as they were billions of years ago.) A variant of this is the insistence that quasars as seen have galaxies around them, but the galaxies are so faint that they are difficult to discover. And then there is the diametric opposite: Quasars are not active centers around which galaxies have formed or will form. They are objects shot out by active galaxies. Proponents of all these opinions come fortified with evidence.

Both Osmer and Alan Stockton of the University of Hawaii reported on sky surveys done in response to the hypothesis that, as Joseph Miller of the Lick Observatory phrased it, "QSO's hang around with galaxies in groups." Not in the rich clusters of galaxies, says Stockton, but he does have evidence for association in small groups. His survey selected 27 quasars with redshifts up to 0.45. The sky within 45 minutes of those objects was searched for galaxies with redshifts concordant with that of the quasar. That would indicate that the galaxies and QSO are at the same distance and raise a presumption of association. They found 29 galaxies in 17 of these search fields, and got redshifts for 25 and a tentative redshift for one. Of these, "13 in 8 fields had redshifts agreeing with the QSO in that field," he says. Adding in the tentative one gives 14 in 9 fields.

That's a suggestive result, but the survey is still incomplete, as Stockton cautions. It should be done at more redshifts, he says. The fields of search around the QSO's should be extended. The diameter used corresponds to a few hundred kiloparsecs, whereas the diameters of small galaxy groups are characteristically a magaparsec or two. Nevertheless, Stockton says, "Give me a QSO, and I'll find a galaxy."

Miller is one of those trying to find that galaxy right around the QSO. "What evidence is there that QSO's are located in galaxies?" he asks. "Can you detect unambiguously a galaxy associated with a QSO?" In the past, observers have thought they did that when they found "fuzz" around some quasars. Fuzz is some kind of nebulous brightness, but when it was examined spectroscopically for evidence that it contained stars, the results were disappointing.

Yet there are things about quasars that

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are suggestive. They seem to be related to Seyferts and N systems, and both of those are galaxies. Quasars also exhibit spectroscopically the normal abundances of metals found in stars, and that argues for the presence of stars somewhere around them. Miller resolved on a spectrographic investigation of some QSO's to see if typical galactic spectra could be found around them. If galactic spectra were there, they would be faint and badly washed out by the quasar in the middle, and might therefore have escaped previous notice. He and co-workers looked for spectra typical of elliptical galaxies. They looked especially for lines like Magnesium beta, which can come only from stars.

They didn't find any. This is puzzling. N systems, which are very similar in general to quasars, do have galactic spectra. Miller suggests that galaxies around quasars, if they exist, may not be ellipticals. Stockton makes a similar remark based on not finding many quasars in rich clusters of galaxies, which is where ellipticals are found in abundance. This circumstance "has been interpreted to mean that QSO's occur in spiral galaxies, not ellipticals," he says.

Failure to find evidence that quasars are galaxies by no means inhibits the search for similarities and relations between them. Halton C. Arp of California Institute of Technology searches for small groups of quasars and galaxies, the relations of which might be dynamic. Arp cited two instances of galaxies with multiple quasar companions: NGC 2859, which has four compact companions with high redshifts, and NGC 2639, which has 10. In both these cases some of the companions can be paired according to redshift, one member of the pair having a redshift that is a certain amount more than that of the primary object, the other member having a redshift about the same amount less. This could suggest that the pairs were ejected from the primary in opposite directions.

Arp then went on to a consideration of a sky survey in search of quasars made by Osmer with an instrument called a Curtis-Schmidt telescope, which is specially designed for wide-field photography. The survey searched 15 fields in high latitudes of the southern sky. Arp concludes from its results that quasars are concentrated in the sky and that their characteristics, such as redshifts, are correlated. He also finds an association between high-redshift quasars (redshift more than 2.5) and "the brightest, nearest galaxies." Arp has been contending for years that quasar redshifts do not represent their distances as simply as galaxy redshifts do. This finding would support such a view. It contradicts the usually accepted relation between redshift (distance) and apparent magnitude called the Hubble relation. According to the Hubble relation all three of those characteristics increase together, in proportion to one another. For his high-redshift quasars Arp gives a more complicated formula (the physical significance of which is not explained) in which 1 plus the redshift equals the magnitude plus 2 divided by 2.

Osmer, commenting on his own survey, comes to quite different conclusions. There were actually two surveys, the one with the Curtis-Schmidt instrument mentioned by Arp and a follow-up in which Cerro Tololo's four-meter telescope was used to survey fields centered on quasars discovered by the Curtis-Schmidt survey. The Curtis-Schmidt work found 108 confirmed quasars and the four-meter survey searched 17 fields centered on selected members of that group. The Curtis-Schmidt survey, which went at random through the sky, found a density of 0.26 quasars per square degree of sky. The four-meter survey, which was centered on known quasars, came up with 13 per square degree. If there are groupings, says Osmer, the four-meter type of survey should be the way to find them.

You can indeed find associations in redshift, he says. "It's nice to find small groups, but how significant are they statistically?" That question can't be answered definitely; the fields of search have to be rearranged and differently shaped to test it.

Osmer also finds that the redshift-magnitude relation for the high-redshift quasars celebrated by Arp appears in both surveys, but he doesn't make nearly so much of it. It's partly statistical, partly technical and partly because the four-meter survey saw bright high-redshift quasars better than it did faint ones. "I don't know whether Chip [Arp] is ready to give up, but I am," Osmer says. No white flag was sent in.

For the future, Osmer emphasizes a serious cosmological question: "Where are redshift 4 quasars?" One of the purposes of surveys of this kind is to contribute to density counts of quasars of different redshifts. Assuming the traditional Hubble relation between redshift and distance, such counts may make it possible to say something about the shape of the far reaches of the universe, whether it is open or closed, etc., and possibly also about the origins of quasars. If quasars with higher redshift than 3.5, the maximum now known, are not found, contemporary cosmology could butt its head against a serious problem. The other continuing question that Osmer thinks is important for the future is the emission and absorption lines in quasar spectra and what they mean for the physics and chemistry of quasars.

One of the people who have been engaged in quasar spectroscopy for a long time is E. Margaret Burbidge of the University of California at San Diego. She doesn't give up easily either. "As an observational person I never like to throw away an observation because theorists can't explain it," she says.

Quasar spectra continually raise new questions, and theorists at least try to answer. Harding E. Smith of the University of California at San Diego remarks that theorists had suggested that the origin of the characteristic wavelengths of hydrogen known as the Balmer, Paaschen and Lyman lines is in a cloud of gas ionized by light from a source within it or nearby. Now that more and more infrared studies are becoming possible — the wavelengths of the strongest of these hydrogen lines are moved to the infrared at quasar redshifts — more investigation of that suggestion can be done. Observers can determine the ratios in the strength of two lines as shown in quasar spectra and compare them with ratios derived from laboratory studies of ionized hydrogen. They don't match. If the hydrogen in quasars were like the ionized hydrogen in ordinary galaxies, the ratios should be the same. "Perhaps we shouldn't expect that the QSO should look like a normal galactic ionized hydrogen region," Smith remarks. Nongalactic suggestions, such as dust in the gas, dust outside the gas or radiation transfer, are being proposed.

In a somewhat different object, but one believed related to quasars, Donald E. Osterbrock, director of the Lick Observatory, states that the source of the magnetically induced or synchrotron radiation observed in the spectrum is usually believed to be in a cloud of ionized gas. The object is the peculiar galaxy called UQ28 or Markarian 668. This object is unique in having two sets of lines in its spectrum, one broad and one narrow. The narrow lines would have to come from a source that was more or less at rest within itself. The broad lines would indicate some motions within their source. The developed model indicates that the narrow lines come from a large central mass, the broad ones from a small mass expanding away from it. As an explanation for this situation, ejection of the broad-line gas from the narrow-line gas "might be right," says Osterbrock, "but I don't think that's solved."

Ejection was what Burbidge referred to when she refused to throw out data that theorists find infelicitous. Quasar spectra show both emission lines and absorption lines. The emission comes from a gas that is very hot; the absorption must be done by a cooler gas outside the emitting region. The absorbing gas may be an atmosphere around the quasar or something that happens to lie between the quasar and the observer, an otherwise invisible galaxy or protogalaxy perhaps.

The hitch here is that there is in many cases a large redshift difference between emission lines and absorption lines, sometimes up to half the speed of light. Those who want to say that the emitting gas is connected to the quasar have to say that it has been ejected from the quasar and is moving away fast.

Speeds of that sort require a lot of energy, Burbidge concedes, and so the temptation to abandon the ejection hypothesis is strong. But Burbidge, in her studies of

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quasar spectra, finds strong resemblances to supernova spectra. Dynamically, if not in its astrophysical details, a supernova is just this sort of situation. A star explodes, throwing off a large gas cloud that expands outward while the core continues to glow in the center of it. Meanwhile, observers have tested the intervening galaxy hypothesis by looking among the absorptions for those prominent in the gas of a galaxy (the 21-centimeter radio line of hydrogen, lines of iron and magnesium) not only to see if they are there but to see whether they have the strength and the ratios to each other characteristic of the usual conditions in a galaxy. So far that cannot be found.

From all this it may be deduced that quasars most probably do exist, and that they will be with us for a while. So will the questions about them. Incidentally, the punch line of the elephant joke concerned the Polish entry. It took the longest time, several years, but when it came it was no more than a newspaper feuilleton entitled "The Elephant and the Polish Question." (That joke has to be explained to people under 30; they have no idea what the Polish Question was.) Quasars are a protean subject, yet when the process of distillation is over, it may be that the final summary will take no more space than a newspaper feuilleton. It is inconceivable that it might be entitled: "Quasars and the Polish Question." But don't bet on it. ☐