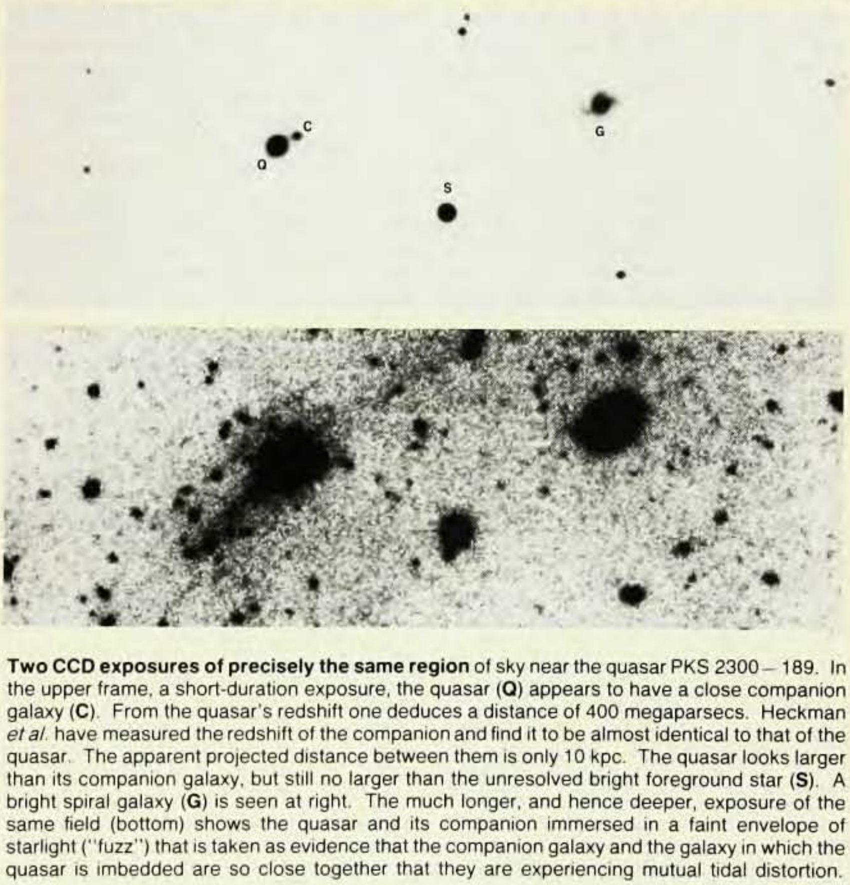
Companion galaxies match quasar redshifts: the debate goes on

"Apostles of the noncosmological origin of quasar redshifts must now . . . recant, or else maintain that the unknown laws of physics which fix [these] redshifts. . .extend [over] appreciable distances to apparently normal galaxies. . ." The style may evoke the 17th century Holy Office, but the arguments, and the interesting new data that support them, are to be found in a recent issue[1] of the *Astronomical Journal.* Timothy Heckman (University of Maryland) and his collaborators in this new investigation of the perennial quasar-redshift problem trust that their mock-theological tone will be taken in a spirit of good humor.

But the debate is serious enough. Quasars are the best beacons we have for elucidating the large-scale structure of the Cosmos, *if* we believe, as most of us do, that their prodigious redshifts are indeed simply Doppler shifts due to the general expansion of the Universe. The obvious difficulty that has attended this standard "cosmological" interpretation from the beginning is, of course, its implication that these point-like "quasistellar objects" are able to generate luminosities orders of magnitudes greater than those of typical galaxies.

Assuming the great distances implied by these redshifts, the fact that optical telescopes cannot resolve quasar nuclei tells us that their diameters do not exceed a few hundred parsecs. Long-baseline radio interferometry has been able to resolve a number of quasars, yielding core diameters on the order of ten light years—again assuming the redshifts are cosmological. These incredibly small dimensions are corroborated by observations of periodic luminosity variations in some quasars.

Thus, believing the redshift distances, one has eventually to explain how objects ten thousand times smaller than a galaxy (in linear dimension) can radiate a hundred times as much energy. We have as yet no satisfactory theory to explain this prodigious phenomenon. The prevalent conjecture is that quasars are the nuclei of hyperactive galaxies of a sort more common in the early Universe than they are today. Thus they would be seen predominantly at great distances.



Two CCD exposures of precisely the same region of sky near the quasar PKS 2300 − 189. In the upper frame, a short-duration exposure, the quasar (**Q**) appears to have a close companion galaxy (**C**). From the quasar's redshift one deduces a distance of 400 megaparsecs. Heckman *et al.* have measured the redshift of the companion and find it to be almost identical to that of the quasar. The apparent projected distance between them is only 10 kpc. The quasar looks larger than its companion galaxy, but still no larger than the unresolved bright foreground star (**S**). A bright spiral galaxy (**G**) is seen at right. The much longer, and hence deeper, exposure of the same field (bottom) shows the quasar and its companion immersed in a faint envelope of starlight ("fuzz") that is taken as evidence that the companion galaxy and the galaxy in which the quasar is imbedded are so close together that they are experiencing mutual tidal distortion.

If the quasar redshifts were not cosmological, but rather misleading artifacts of some as yet unknown physics manifesting itself in these strange celestial objects, one would no longer have to believe them to be enormously distant. Their observed brightness would then suggest much more modest intrinsic luminosities. Thus one would be trading the unsolved luminosity problem for an unsolved redshift problem.

Most astronomers accept the cosmological interpretation. Two very general arguments in its favor were pointed out by us by Maarten Schmidt (Caltech), who discovered the large quasar redshifts twenty years ago:

▶ Counting quasar populations as a function of observed brightness, one concludes that the population density of quasars increases with distance from us in all directions. If we assume that quasars are indeed at cosmological distances, this presents no particular problem. It suggests simply that quasars were more common in the early Cosmos. But if one believes that quasars are much closer than their redshifts indicate, this population distribution raises a troubling implication. Violating the very general assumption that the large-scale Cosmos at a given time looks about the same to all observers, it suggests that *we* are located at a unique point of minimal quasar density. Presuming these shorter distances, one can no longer involve the long evolutionary time scale.

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▶ We observe a pervasive, isotropic x-ray glow of uncertain origin (somewhat like the universal 3-K microwave background, but at much shorter wavelengths). If one assumes the quasars and active galactic nuclei are at cosmological distances, they would account for about 40% of this x-ray background. If, however, one assumes the observed quasars and active galactic nuclei are 100 times closer than their redshifts imply, then the summed contributions of these quasars (and active galactic nuclei) and of those too far away to see would yield an x-ray background 40 times greater than that we observe. This argument is due to Giancarlo Setti (Bologna) and Lodewijk Woltjer (European Southern Observatory, Garching).

A few prominent holdouts, however, keep the debate alive. Geoffrey Burbidge (now at University of California, San Diego), Halton Arp (Mt. Wilson Observatory) and Fred Hoyle (University of Cardiff) continue to argue that the quasars are much closer than their redshifts would have us believe. "Eighteen years ago, when Hoyle and I concluded that evidence existed on both sides of the argument, we sat on the fence," Burbidge told us. Now, however, Burbidge has been convinced by a decade of statistical and morphological studies, mostly by Arp,[2] that "the larger-redshift quasars are in fact associated with comparatively nearby galaxies."

If the quasar redshifts are not due to great recessional velocities, what could be their cause? Ten years ago, Daniel Greenberger (City College of New York) developed a generalization of the canonical quantum-mechanical formalism, treating rest mass and proper time as conjugate dynamical variables, and predicting that clocks on decaying particles run at different rates from those on stable particles. This "decay redshift" he argues,[3] could be responsible for at least part of the observed quasar redshift.

Heckman and his colleagues, Gregory Bothun (Caltech), Bruce Balick (Leyden) and Eric Smith (Maryland), now offer us what they describe as "in our view. . .the most convincing demonstration to date that quasar redshifts are of cosmological origin." Availing themselves of the extraordinary new imaging and spectroscopic capabilities of charge-coupled-device (CCD) detectors, they have measured the redshifts of 19 nebulous objects that appear to be companion galaxies of 15 relatively low-redshift quasars. Observing at the Kitt Peak 4-meter telescope, they have determined that, in 18 of these 19 cases, the apparent companion has a redshift very close to that of the quasar. While Burbidge, Arp and their partisans may argue that quasars are so peculiar that they can generate redshifts of unknown origin, this position becomes difficult to maintain for companion galaxies that otherwise look perfectly ordinary.

Redshifts are generally quoted in terms of the parameter z, defined as $\Delta\lambda/\lambda_0$, the wavelength redshift of an identifiable spectral line divided by its normal, unshifted wavelength. Assuming that the redshift is due to the general expansion of the Universe, one concludes that z is (to first order) simply proportional to the distance from the observer to the redshifted object; $D = zc/H$, where H is the Hubble constant. The group chooses to take $H = 100$ km/sec per megaparsec, although estimates of the Hubble constant range as low as 50 km sec^{-1} Mpc^{-1}.

The group has restricted itself to quasars with $z < 0.5$ (implying a distance of less than 1500 Mpc), because ordinary galaxies are optically resolvable at these distances. Availing themselves of various compilations of the optical images of such low-z quasars and their neighborhoods, the group scrutinized the images for nearby nebulous objects that might be companion galaxies. To qualify as "nearby" in this study, the putative companion had to have a projected distance from the quasar of less than 50 kpc, calculated from the observed angular separation and the overall distance implied by the known quasar redshift.

Having found 21 such apparent companions, the group was able to obtain good CCD redshift measurements for 19 of them at Kitt Peak. An important feature of these new data is the fact that 15 of these 19 redshift determinations were obtained from stellar *absorption* lines, strengthening one's confidence that these nebulous companions are indeed galaxies. If one had only emission lines, one might conclude that such low-luminosity nebulous structures seen near quasars (generally referred to as "fuzz") are not galaxies at all, but rather material ejected from the quasar or clouds of gas ionized by quasar radiation. If the quasar is indeed the source of such a nongalactic nebula or its excitation energy, opponents of the cosmological interpretation are wont to argue, the two might very well share the same outlandish physical phenomena and the deceptive redshift they engender.

But the observation of the nebular redshift in conventional stellar absorption lines, Heckman argues, makes it quite clear that the companion is indeed a galaxy. Ejected material or excited gas clouds, he points out, would exhibit only emission lines. Absorption lines come from the photospheres of stars. Of the 19 companions for which good CCD redshifts were obtained, 18 were so close to the redshift of the companion quasar that they corresponded to a radial velocity of less than 1000 km/sec in the quasar rest frame. For the absorption-line subsample, the score was 14 out of 15.

An earlier investigation in the same spirit was carried out by Alan Stockton (University of Hawaii) seven years ago. But Stockton's results were less conclusive. Undertaking a systematic investigation of galaxies near high-luminosity quasars, he employed an angular proximity limit that was, in effect, considerably looser than the 50-kpc limit imposed by Heckman and his colleagues.

The result was an intriguing mixed bag. Obtaining redshifts for 25 apparent companion galaxies, Stockton found that 13 of these were very close to the redshift of their presumed partners, with relative recessional velocities of less than 1000 km/sec. The probability of such good agreement by chance coincidence, Stockton argued, was negligible, "making the cosmological nature of quasar redshifts a virtual certainty."

But if Stockton could point with pride to the close correspondence of the redshifts in half his sample, his adversaries could point out that for the other half, the redshifts of the quasars and their apparent companions seemed totally unrelated. The problem was that by going as far afield as 300 kpc (apparent projected distance), Stockton was including in his sample almost as many accidental foreground and background nebulae as true companions.

Heckman suggests that a useful lesson can be learned from the recent results of his group. The spectroscopic observations necessary for redshift determinations are of course much more demanding than is straightforward imaging. For imaging studies of companion objects, one would like to be able to eliminate accidential coincidences with foreground and background objects near the line of sight, without having to resort to redshift measurements. The 95% success rate of his group's 50-kpc limit, Heckman argues, now gives us a convenient and reliable rule for this purpose. If the angular separation between a quasar and a nearby nebula translates into a distance of less than 50 kpc at the quasar's known redshifts, the group contends that one may assume with better than 90% confidence that the apparent companion is a true companion, and very likely a true galaxy.

Interactions. It is now known that quasars like to live in regions of unusually high galaxy population. A recent survey by Richard Green (Kitt Peak) and Howard Yee (Dominion Astrophysical Observatory, Victoria, B.C.) has shown that an observer sitting on a quasar is more likely to see a galaxy nearby than is an observer sitting on an ordinary galaxy. That is to say, the tendency of quasars to occur in high-population areas goes beyond the general clustering tendency of galaxies.

The question is, why? Because we do not know the mechanism that generates the enormous energies of quasars, we may imagine that dynamical interactions with nearby galaxies play a crucial role. This is one of the questions to which Heckman and his colleagues had hoped to address themselves.

The typical rotational velocity at the periphery of a galaxy is a few hundred km/sec. If the gravitational perturbation engendered by an object passing near a galaxy is to be significant, the relative velocity of the two systems should not be much faster than the rotational velocity of the galaxy. Do the very small redshift differences measured by Heckman and company suggest such strong gravitational interactions between companions? The measurements, unfortunately, are not quite sensitive enough, Heckman told us. "We know that the relative velocities between these companions is less than 1000 km/sec, but we don't know whether it's 800 km/sec or 200 km/sec, and that's crucial for the question of interaction." The group is eager to obtain more detailed measurements of relative velocity in the near future.

Green and Yee see an excess of galaxies around quasars only for quasar redshifts less than $z = 0.5$. This makes sense if one believes the great distances implied by the quasar redshifts. At larger z, galaxies become too faint to see. On the other hand, Green argues, this cutoff would be difficult to understand if the quasars were close by.

Burbidge and Arp are upset by what they see as a distressingly one-sided approach to the quasar redshift question by the community of astronomers. "Observational evidence exists on *both* sides," Burbidge argues, "Both sides are probably right. What is unfortunate . . . is the great prejudice in the field. Arp's papers and others suggesting that some quasars are nearby are held up, interminably refereed or rejected. Heckman's polemic [calling for recantation] would not be published, were it on the other side."

If Heckman's call for recantation is meant in such 'good humor,' Arp asks angrily, "why has telescope time been cut off for proponents of the [opposing] viewpoint?" Arp makes two principal observational arguments against the generally accepted cosmological interpretation: He points to examples of apparent bridges of luminous material connecting high-z quasars with low-z galaxies. He also makes a statistical argument[2] based on the nonuniform distribution of observed quasars on the celestial sphere. He concludes that there is a statiscally significant clustering of quasars around the angular positions of certain galaxies known to be quite close to our own.

"Much is at stake," says Burbidge. "If it is accepted that just one large redshift is not due to the universal expansion, Pandora's box is open. Much of our currently claimed knowledge of the extragalactic universe would be at risk, as would a number of scientific reputations." This, he suggests, is a large part of the reason why Arp's observations are widely attributed to statistical accident. —BMS

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The following piece of doggerel was delivered in an after-dinner talk by Harvard particle theorist Sheldon L. Glashow, once a California physicist himself. He spoke at the APS New England Sectional Meeting on 12 October at Northeastern University.

To Abalone Unbound:

What with chromodynamics and electroweak too
  Our Standardized Model should please even you,
Tho once you did say that of Charm there was none[1]
  It took courage to switch[2] as to say Earth moves not Sun.
Yet your state of the union penultimate large
  Is the last known haunt of the Fractional Charge,[3]
And as you surf in the hot tub with sourdough roll
  Please ponder the passing of your sole Monopole.[4]
Your Olympics were fun, you should bring them all back
  For transsexual tennis or Anomalon Track,[5]
But Hollywood movies remain sinfully crude
  Whether seen on the telly or Remotely Viewed.[6]
Now fasten your sunbelts, for you've done it once more,
  You said it in Leipzig of the thing we adore,
That you've built an incredible crystalline sphere
  Whose German attendants spread trembling and fear
Of the death of our theory by Particle Zeta,[7]
  Which I'll bet is not there say your articles, later.

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