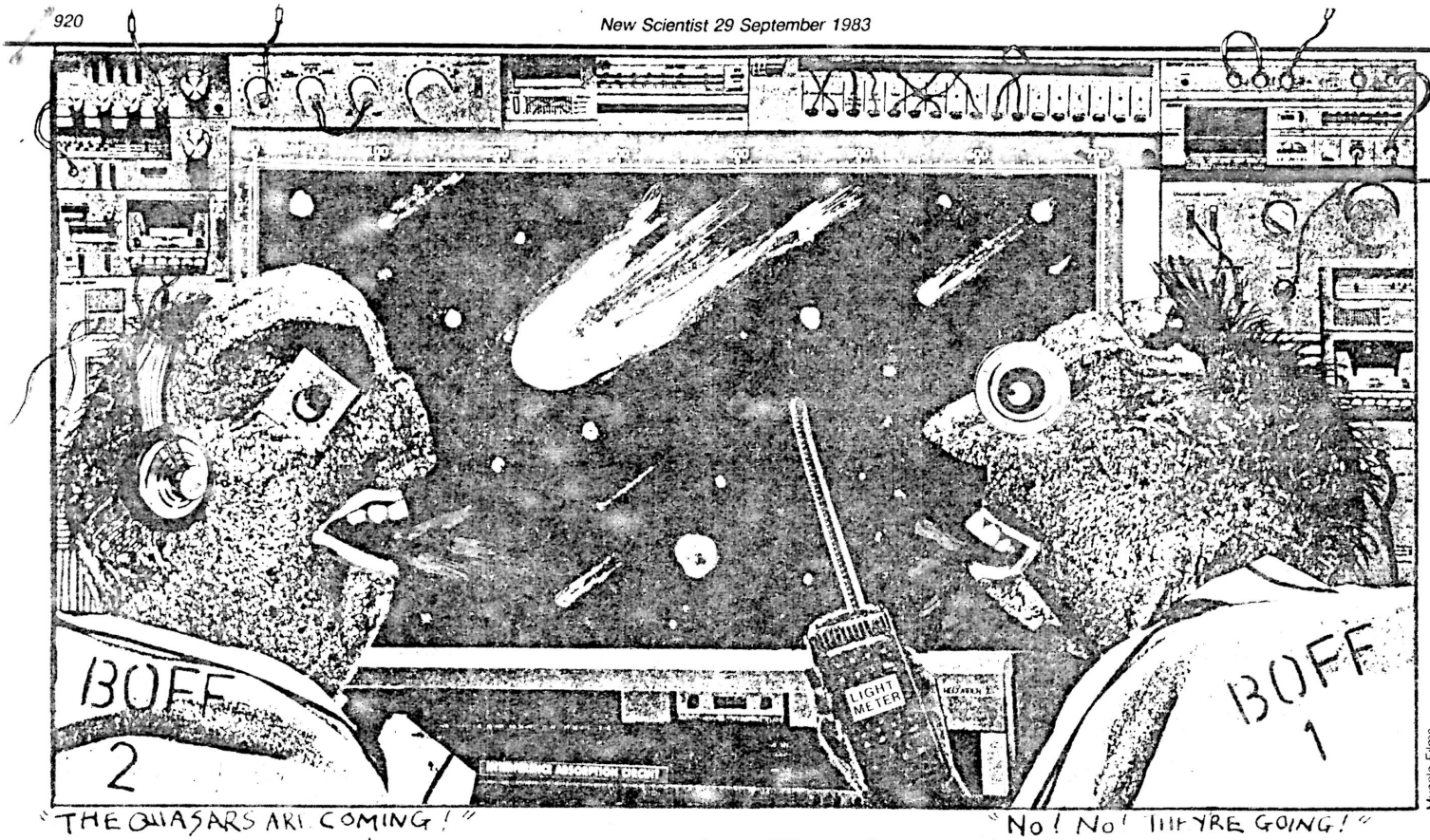


Are quasars really far away?

Most astrophysicists think that quasars are distant objects—thousands of millions of light years away. But new data and new theories could change this picture

Jayant V. Narlikar

DISCOVERIES of new types of astronomical phenomena are few and far between. Astronomers were therefore unusually lucky during the 1960s to discover two new classes of objects: quasars in 1963, and pulsars in 1968. Capturing the excitement generated by the first of these discoveries, Fred Hoyle wrote in the *New Scientist* of 28 March, 1963, "How far are these discoveries likely to affect radio astronomy and cosmology? I suspect we are now close to understanding the origin and nature of radio sources. John Bolton and Hanbury Brown were almost certainly correct in attributing them to violent events in the centres of galaxies. . . ." Today, two decades later, we are no closer to understanding the nature of quasars, although most astronomers would agree with Bolton and Hanbury Brown.

Quasars are remarkable because they give every indication of packing huge energy reservoirs into highly compact volumes. Indeed, because the first two quasars to be discovered, 3C 48 and 3C 273, had such point-like images, astronomers originally mistook them for stars in our Galaxy. (3Cn denotes the nth object in the 3rd Cambridge catalogue of radio sources.) Today, with more than 1500 quasars known, "starlike appearance" remains a key feature.

Quasars possess another characteristic which will concern us in this article. This is the property of *red shift*, a property which has generated far more discussion and controversy than any other attribute these objects display. When astronomers first studied the spectrum of the quasar 3C 273 carefully, they were able to identify the elements whose excitations produced the lines in it. But these lines appeared at wavelengths 15·8 per cent higher than for similar lines in a laboratory spectrum. This fractional increase, 0·158, is called the red shift—because the lines have shifted towards the

Red shift and the expanding Universe

TO A LABORATORY physicist, red shift almost invariably suggests the doppler effect. This is a familiar effect with sound waves: a train's whistle will appear to get shriller and shriller as the train approaches, and then the whistle's pitch will fall as the train recedes. The equivalent with lightwaves is that an approaching source of radiation will appear blue shifted; if the source is receding its light will be red shifted. The general relativist, however, can think of another possible cause of red shift. When a light photon leaves the surface of a massive body then it undergoes an increase in wavelength. Known as gravitational red shift, this phenomenon requires the source of light to be located in a region of strong gravitational field.

Cosmological applications of general relativity provide another likely cause of red shift for an astronomical object located outside our Galaxy. If the source of light is distant enough to be subject to the expansion of the Universe, its spectrum shows red shift. Moreover, there is an elegant law, discovered by Edwin Hubble in 1929, which tells us that the red shift increases in proportion to the distance of the source from us. At present astronomers are not unanimous about the magnitude of the constant of proportionality in Hubble's law. For this article we will adopt the rule that the red shift increases by 0·1 for every thousand million light years of distance. At this rate the quasar 3C 273 should be about 1580 million light years away from us.

Hubble's law appears to hold very well for galaxies in general, and it was this law that gave the observational justification for the expanding universe models that cosmologists rely on today. For this reason the Hubble red shift described above is often called *cosmological red shift*. The other two types of red shift, the doppler and gravitational are non-cosmological. □

longer wavelengths occupied by the colour red in the visual spectrum.

This was a surprising result and it generated the first doubt that 3C 273 was an ordinary star in our Galaxy. In fact its substantial red shift suggested that far from being a nearby object, the quasar was located well beyond the Galaxy in a remote part of the Universe. As the second quasar, 3C 48, has an even larger red shift of 0·367, astronomers believe it to be even further away.

However, doubts began to set in as more and more quasars were found and studied by various astronomical techniques. Although today the majority of astronomers still believe the quasar red shifts to be cosmological in origin (see Box), there is a small minority (to which the author belongs) who feel the issue to be open.

Alan Stockton has produced examples of close pairs of quasars and galaxies where both members of the pair have nearly the same red shift. It is highly unlikely that their directions happened to be so close by chance, hence they must be physically close. Since Hubble's law, which relates an object's red shift to its distance from us (see Box), applies to a galaxy it must therefore also apply to its companion quasar. Thus Stockton's finding supports the view the red shifts are cosmological in origin.

But how should we interpret quasars and galaxies which are close, but which have very different red shifts? Several such examples have now emerged where the quasar's red shift can be as much as 10 times that of the galaxy. Are these cases of chance projection, although this is very unlikely, or are the quasar and the galaxy really in the same place? If the latter is the case, the quasar has an anomalously high red shift. We may also suspect some association if we see an unusually large number of quasars grouped round a galaxy. Not only is the probability of finding many quasars near a galaxy very small, but the alignments across the galaxy can be very striking. In a recent symposium on quasars at Liège (21-24 June 1983) Halton C. Arp presented several examples of quasar concentrations near galaxies, including pairs of quasars with the same red shift.



According to conventional theories, this quasar and galaxy, which are clearly connected, should be far distant from each other

Arp has argued that red shift anomalies are found among pairs of galaxies also. He has found examples of pairs of galaxies which are physically interacting with each other. Arp has detected luminous filaments connecting the galaxies, yet the red shifts of the two are different enough to rule out (according to Hubble's law) their physical proximity or physical interaction. Although the red shift anomalies for galaxy-galaxy pairs are numerically small, they are nevertheless difficult to reconcile with a cosmological origin of red shifts. Arp suggests that the cosmological picture may have even greater difficulties in explaining the larger red shift anomalies of quasars.

How do supporters of cosmological red shift react to such data? Some simply ignore the data, feeling that in time they will go away. (They have not. On the contrary, evidence of red shift anomalies has been steadily growing.) There are others who suspect observational errors in some of Arp's data so that the connecting filaments are not really there. (A closer examination by Jack Sulentic of one such celebrated case has vindicated Arp (*New Scientist*, vol 98, p 148). Some opponents have advanced statistical arguments to show that Arp is in fact observing juxtapositions which do happen by chance, but the probability of such chance juxtapositions is really not very small. Finally, there are those who turn back and ask, "If cosmological red shift is wrong, what alternative do we have? Since there is none we have to work within the framework of this hypothesis."

To some extent the last point is valid. Because the cosmological interpretation is commonly accepted, astrophysicists have not taken work on other possibilities very seriously. Also, those who have proposed non-cosmological red shift models have not taken them far enough, because of the general belief that the data do not warrant alternatives to the cosmological interpretation. With the evidence of red shift anomalies in associated galaxies and quasars generating some doubt in the cosmological interpretation, it is now worthwhile exploring the alternatives offered by non-cosmological red shifts. I will discuss mainly the doppler option in the remaining part of this article.

In 1964, in the early days of quasar search, J. Terrell suggested that quasars were actually stars ejected from the centre of our Galaxy at speeds approaching the speed of light. Thus a quasar of red shift 2 is moving away from us at 80 per cent of the speed of light. The main objection to Terrell's idea was that the nucleus of our Galaxy does not show any signs of the violent activity which should be associated with so dramatic an event as the ejection of quasars at high speeds.

There are, however, other galaxies whose nuclei do show signs of violent activity. In 1966, Geoffrey Burbidge and Fred Hoyle argued that the quasars were ejected from such active nuclei and that most quasars are nearby objects located within about 300 million light years. Although it got round the objection raised against Terrell's theory, the Burbidge-Hoyle hypothesis had a serious drawback: the blue shift catastrophe.

If an active nucleus is ejecting quasars randomly in all directions then, if we are far enough away, we should see some quasars moving away from us and some moving towards us. Because of the doppler effect, the latter class of quasars would show blue shift. What is more, the light reaching us from an approaching quasar would be enhanced in intensity because of the blue shift. The light from a receding quasar by contrast gets attenuated by red shift. Therefore we are more likely to pick up quasars with blue shift than with red shift. Detailed calculations by Peter Strittmatter in 1966 showed that we ought to be able to see perhaps 80 times as many blue shifted as red shifted quasars. In actual fact, no blue shifted quasars have yet been found.

It was several years before cosmologists could make progress against this difficulty. In 1980 Fred Hoyle showed (*University College, Cardiff, Astrophysics and Relativity Preprint No 63*) that if, as it moves through intergalactic space, a quasar radiates all its energy in a backward-facing cone, no blue shifted quasar will be seen. Thus a quasar heading towards us will be invisible because it radiates away from us. Hoyle was able to relate the opening angle of the

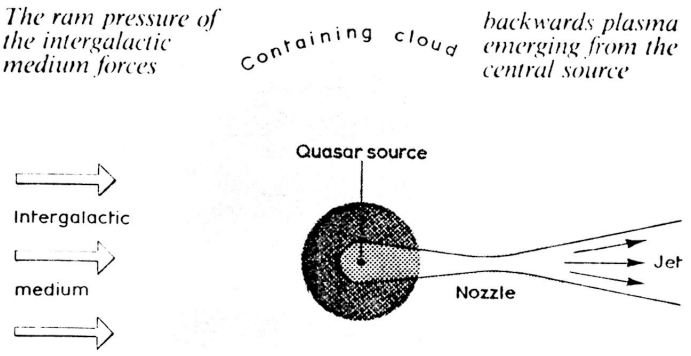
cone to the velocity between the quasar and the observer.

Why should a quasar radiate backwards? The idea that backward emission would resolve the blue shift catastrophe had indeed occurred to Peter Strittmatter back in 1967. However, no viable model emerged from his efforts. After Hoyle's conjecture of 1980, Kandaswamy Subramanian and I took up the challenge again. After several mishits we feel that we may have finally arrived at a working model (see *The Astrophysical Journal*, 1 October, 1983, for technical details).

In our work we have adapted the popular "twin exhaust model" of Roger Blandford and Martin Rees, first proposed in 1974. This model envisages a gas cloud surrounding a concentration of gravitating matter which in turn contains an energy machine generating a fast-moving plasma. Normally, the plasma should emerge equally in all directions; however, in the Blandford-Rees model the system is supposed to rotate about an axis. The pressure distribution in the gas cloud is therefore not equal in all directions, and the emerging plasma selects channels of least resistance which lie along the axis of rotation. In this way two oppositely oriented jets of plasma, emerge from the centre. The jets are narrow—highly collimated—and issue out of what fluid dynamicists call the de Laval nozzles.

Although a quasar may seem to be moving fast relative to us, looked at from the quasar's point of view the intergalactic medium appears to rush past it at relativistic speeds. Although the medium is not dense, its high speed is sufficient to generate a sizeable ram pressure on the quasar. Of course the ram pressure is felt only in the forward direction. This leads to the generation of a single jet in the backward direction. For, as the plasma issues out of the central source, it selects the line of least resistance, which naturally lies in the backward direction.

In this model, two factors work against the detection of



blue shifts. First, the bulk of the optical and radio emission is supposed to come out of the jet, which is directed backwards. Secondly, the gas cloud contains a tiny fraction of dust (about 0·1 per cent by mass) which is sufficient to kill any line radiation in the forward direction. Thus the blue shifted quasars, being intrinsically faint, would be difficult to spot; and even if they are spotted, they may appear as lineless objects whose spectral shifts cannot be measured.

The model has certain observable and testable features. That all quasars with jets seen so far are single-jet objects seems consistent with this model. The recent cases found by Arp of groups of quasars linearly aligned with a galaxy suggest that the quasars were ejected by the galaxy. The extent to which the gas cloud survives around the ejected object depends on its speed and hence is indicated by its red shift. The size of the cloud will be smaller for large red shift than for small red shift quasars. Astronomers have detected luminous fuzz around some low red shift quasars. In this model the fuzz could generate the surrounding cloud.

But the final test of the doppler model must come from actual detection of motion relative to the intergalactic medium. Techniques of very long baseline interferometry may be able to measure proper motions of quasars, and to verify if the jets are in the backward direction.

The alignments observed by Arp and others naturally suggest the doppler model. Nevertheless, non-cosmological red shift could arise also through gravitational effects. As early as 1967, Fred Hoyle and William Fowler had suggested that the quasar's red shifts could be gravitational, with light emerging not from the surface of a massive object but from its interior. The amount of red shift from the central part of the object can be considerably higher than from the surface, provided light photons from the interior can escape unabsorbed. So this quasar model needs a concentration of matter dense enough to produce a strong gravitational potential at the centre, but sparse enough to allow light to get through. Hoyle and Fowler had conjectured that this matter could be in the form of a cluster of neutron stars. Recently Hoyle (*University College, Cardiff, Astrophysics and Relativity Preprint No 88*) has argued in favour of a monopole distribution to provide the gravitational field.

What else is there, if both the doppler and the gravitational explanations turn out to be inadequate to account for the peculiarities of quasars? Then it may be necessary to cross the boundary of known and tested physics and look for a fourth type of red shift. Astrophysical literature already contains a few such ideas (J. V. Narlikar and P. K. Das, *The Astrophysical Journal* 1980, vol 240, p 401; J. C. Pecker *IAU-CNRS Colloquium Paris 1976*, eds C. Balkowski and B. E. Westerlund, p 451). Only future observations will decide if quasar's require such unusual explanations. □

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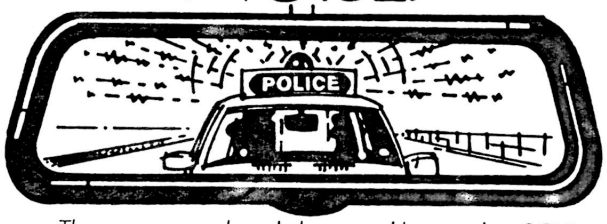

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