Looking for the edge of the universe

Earlier this year a team of Australian and British astronomers concluded that the universe is a little bit larger and a little bit older than previously thought. They reached this conclusion when they detected an object that may be 18 billion light years — that is, 17 x 10^{23}km — from earth. It's the most distant object found as yet, and it's moving even further away from us at close to the speed of light.

The lines mark the distant quasar in a photo taken by the United Kingdom Schmidt Telescope. Most of the other objects are stars in our galaxy.

The discovery came just 50 years after a chance finding that led to a revolution in astronomy. During 1932, a Bell Laboratories scientist was trying to track down sources of interference in trans-Atlantic telephone connections. When he pointed his antennae at the sky, it became obvious that the Milky Way itself was one source of interference. It seemed that our earth is constantly bathed in radio noise, and a new tool for probing the mysteries of our universe — the radio-telescope — had been discovered.

World War II broke the pace of development, but research into radar and electronics had direct application to radioastronomy, and in the post-war years scientists incorporated the new technology into radio-telescopes constructed in Australia, the United States, Britain, and Europe.

One of the many sources of radio noise discovered in the early fifties, by astronomers at Cambridge in England, took the code name 3C48 (because it was No. 48 in the third Cambridge catalogue). This object languished unremarked until 1960, when a California Institute of Technology group led by Dr John Bolton, formerly with the CSIRO Division of Radiophysics, obtained an accurate 'fix' on its position in the sky.

When the giant Palomar 200-inch optical telescope looked at the part of the sky containing 3C48, the object appeared to be a star. This was the first time such a coincidence had been found; previously all sources of radio noise had been associated with large objects such as galaxies or supernova remnants.

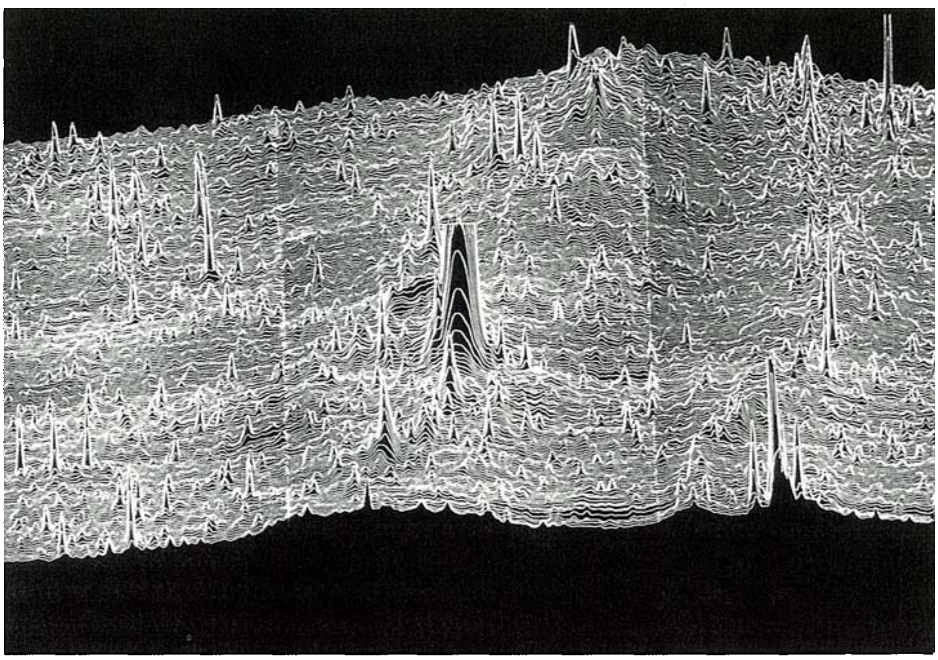
Another surprise was that 3C48, when the telescope recorded its spectrum, was found to be unlike any other star that had been investigated. It had an excess of light at the blue end of the spectrum, which could not be explained with the then-current knowledge. Half a dozen similar objects were uncovered in the next few years and still no sense could be made of their unusual spectra.

It was only in 1963 that Dr Maarten Schmidt, at Palomar, made the great intuitive leap. After a very clear night's viewing he was puzzling over an excellent spectral analysis of the light from 3C273 when he wondered what would be the case if these objects were showing an unusually large redshift (see the box on page 12). Suppose that 3C273 was very far from us and its spectrum had been shifted a long way towards the red end of the spectrum: could the various spectral lines of 3C273 fit into such a scheme?

They did! For example, he found that the very strong 'Magnesium II' peak, associated with ionized magnesium atoms and normally found in the ultra-violet, had been shifted 16% into the blue part of the spectrum. The clear conclusion was that these objects were much further away than even the most distant galaxies known at that time.

And another puzzle arose: those galaxies were extremely faint — at the limits of the resolving power of the big telescopes — yet here were clearly visible objects billions of light years further away. Huge amounts of energy must be expended if their radio and light waves could reach us. As they looked like stars but obviously weren't, the term 'quasistellar radio source', or quasar, was applied to them.

A 3-D representation of some of the radio emanations from part of the Milky Way. The band is approximately 10 moons long.



Redshift, distance, and quasars

Measuring cosmic distance is one of the recurring problems in astronomy. In earlier days, astronomers used simple trigonometry, utilizing the change in position of the earth as it moved around the sun. Later, they linked this with the relative brightness of certain stars to give estimates of galactic distance. These techniques were only suitable for stars and galaxies in our immediate neighbourhood.

After World War I, Edwin Hubble — working at the Mt Wilson Observatory, above Los Angeles — analysed spectrographically the light coming from a wide range of galaxies, some of which had distance estimates derived from the earlier measuring techniques.

The crucial feature of Hubble's observations was that, as the distance increased, the light from these galaxies was shifted further towards the red end of the spectrum, in a cosmic example of the familiar Döppler effect. Apparently, the further away these galaxies are, the faster they are moving away from us and the greater the redshift they display. This observation fitted one aspect of Einstein's theory — the idea of the 'big bang' and an expanding universe.

Hubble's constant — correlating redshift and distance — provides the only technique available for measuring large distances. The 'constant' has been revised several times since its formulation in 1931, and this makes many astronomers sceptical about its accuracy. The degree of uncertainty is such that the distances given in this article may be wrong by a factor as large as 2 — in other words, it is possible that the quasar 2000-330 is only 9 billion lights years away rather than 18 billion.

So far as quasars are concerned, this uncertainty plus the huge size of the redshift involved and their massive luminosity have led many astronomers to search for alternative explanations of the redshift.

One alternative suggests that it may be due to gravitational effects — the quasar having such a huge mass that light trying to escape from it is 'dragged-out' or redshifted, meaning that quasars are much closer to us than Hubble's constant indicates.

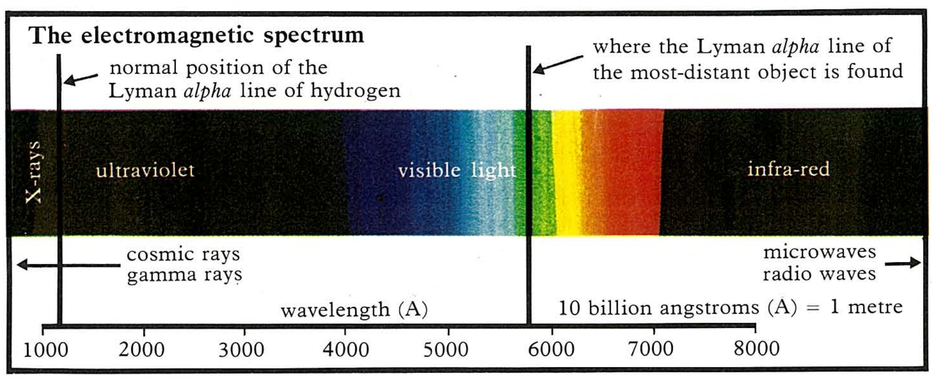
Gravitational redshift is a well-known phenomenon. Unfortunately, to produce the large redshifts measured, the main body of a quasar would need to be so massive that, if it actually was that much closer to earth, it would create such a range of gravitational perturbations that more problems would arise than would be solved.

Dr Alan Stockton of the University of Hawaii recently analysed the spectra of some of the closer quasars along with those of closely associated galaxies. The redshifts of both quasar and galaxy were very similar, and this seems to indicate that the redshift of the very distant quasars is a true phenomenon.

They are 'seeing' a portion of the universe as it was just after its creation.

Once astronomers knew that these strange objects displayed strong redshifts they found them easier to detect. One early trick was to compare photographs of the sky using photographic emulsions slanted towards the blue and ultraviolet end of the spectrum. The quasars are strong in the ultraviolet region and, by this means, many more quasars were detected. It soon became obvious that not all quasars emitted radio signals — only about one in eight of the blue 'stars' had any radio emissions associated with it.

Using very long baseline interferometry — where radio-telescopes separated by thousands of miles work as one (see the box on page 15) — radio-astronomers soon established that quasars were, in cosmological terms, very small objects. A typical quasar occupies a volume only a few light years across — but from this relatively small volume the energy of a billion suns radiates into space. Neither nuclear fission nor nuclear fusion could explain such a prodigious output, adding one more facet to the quasar enigma (see the box on page 14).

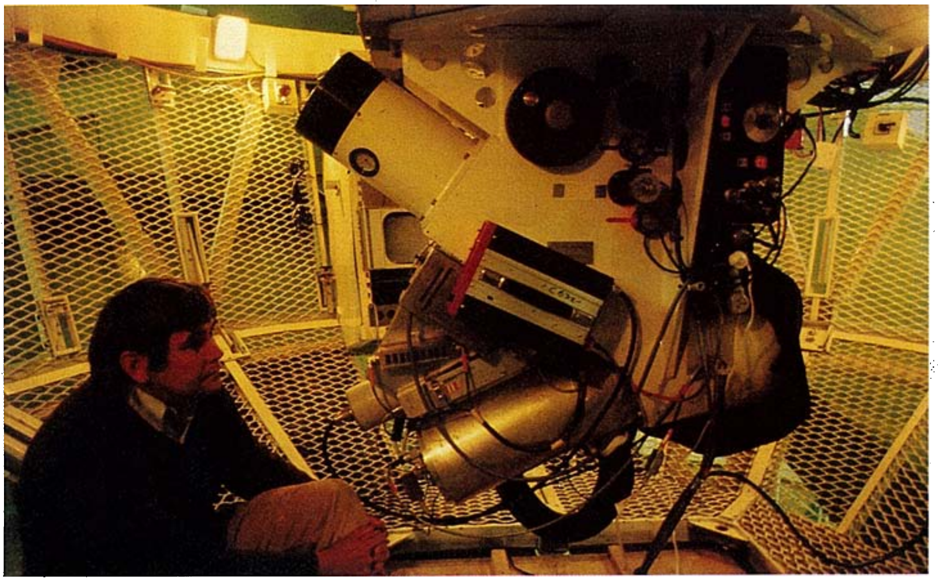


The electromagnetic energy from cosmic sources stretches from the long (hundreds of metres) wavelength radio waves to the very short cosmic rays. Hydrogen, the dominant element in the universe, when excited emits waves in the far ultraviolet and is the main component in the spectra of stars, galaxies, and quasars.

Searching the southern sky

Dr Bolton rejoined CSIRO and from 1966 worked with Dr Bruce Peterson, from the Australian National University's Mount Stromlo Observatory, in the search for more quasars. Using the Parkes radio-telescope for some identifications and the blue photographic emulsions for the 'radio-quiet' quasars, they discovered more than 100 quasars in the next 5 years. These included the quasar with the then-record redshift of 2 — a redshift implying that the light from it began its trip more than 13 billion years ago.

Apart from the intrinsic curiosity surrounding these strange objects, a powerful motivating influence in the search was the desire to find ever more-distant objects. And slowly the records crumbled



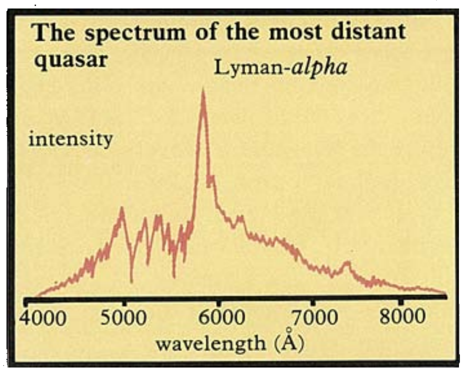
Dr David Jauncey alongside the spectrograph on the Anglo-Australian Telescope. It was here in the early hours of March 26 that the light from the distant quasar was first analysed.

> *From a relatively small volume the energy of a billion suns radiates into space.*

— the distances being pushed up and up until what appeared to be the limit, a redshift of 3, was reached.

Most of the known quasars — we now know some 1500 of them — are found at redshifts of around one to three. This corresponds to a distance of between 5 and 15 billion light years and implies that we are looking back at what the universe was like soon after its formation. Perhaps there was nothing more to see!

Then in 1973 a group of American astronomers got an accurate radio position for a new quasar, analysed its spectrum, and announced a new record. This quasar, with a redshift of 3·53, was more than 15 billion light years from earth and moving away from us at 91% of the speed of light.



Because the quasar is moving so rapidly away from us, the Lyman *alpha* line has been shifted from its normal position in the far ultraviolet part of the spectrum into the red end of the visible spectrum.

However, it differed from most other quasars; its large redshift had caused a change in its colours, so it no longer had any blue or ultraviolet excess to distinguish it from the billions of other faint stars in the sky. Clearly, such quasars can only be found with optical telescopes if their radio positions can be located very precisely, to within a few arcseconds.

An Australian attempt

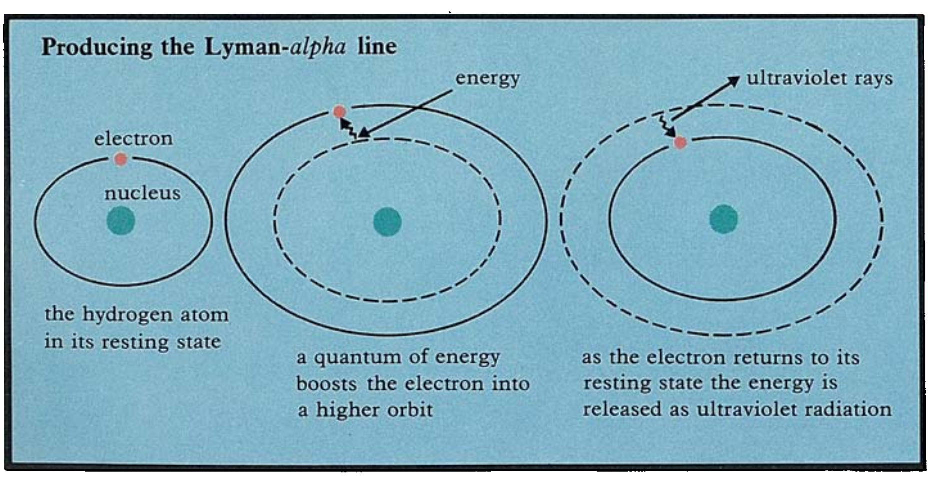
Despite major advances in the technology behind radio- and optical astronomy, that record stood until March 26 this year. It was only broken because in 1975 an Australian group — including Dr Peterson, Dr Ann Savage from the Royal Observatory in Edinburgh but based at the United Kingdom Schmidt Telescope Unit near Coonabarabran, N.S.W., and Dr David Jauncey and Dr Alan Wright, from the CSIRO Division of Radiophysics — realized that they would have to refine their approach in searching for these far-distant objects and get extremely accurate positions.

This was where the Tidbinbilla interferometer came into the picture. The scientists — along with Dr Mike Batty, also from CSIRO, and Dr Sam Gulkis from NASA's Jet Propulsion Laboratory — used the two NASA Deep Space Antennae at Tidbinbilla, near Canberra, to obtain positions accurate to within a few arcseconds for a number of quasars. When they combined these with a selection of quasars from the Parkes catalogue that coincided with very faint objects, the group had a total of 40 quasars that could provide a new record.

It takes about an hour's observing time on the Anglo-Australian Telescope near Coonabarabran to position, lock onto, and then analyse the light from a faint quasar, star, or galaxy. The first night of observing, in November 1981, produced nothing of consequence. The second night, March 25, 1982, looked as if it would go the same way, especially when around midnight clouds and misty rain settled over the area and completely obscured the view. Then, just before dawn on the 26th, the clouds began to disperse and some patches of clear sky appeared.

The telescope was positioned and the spectrograph began its analysis of the light from a quasar located in the constellation of Sagittarius.

As soon as the light from the quasar, code-named 2000-330, began to appear on the video display, the astronomers watched the spectral analysis intently. A convenient marker for their purposes was the strong emission line from the night sky. If the dominant peak in a quasar's spectrum, the Lyman *alpha* line, coincides with this line, the quasar's redshift is 3·58. When the Lyman *alpha* line from 2000-330 appeared on the right-hand side of this, they knew they were looking at a new record. The final result was the identification of a quasar with a redshift of



Hydrogen makes up 70% of the universe's mass, and its electrons are in a constant state of flux.

'Black holes' and quasars

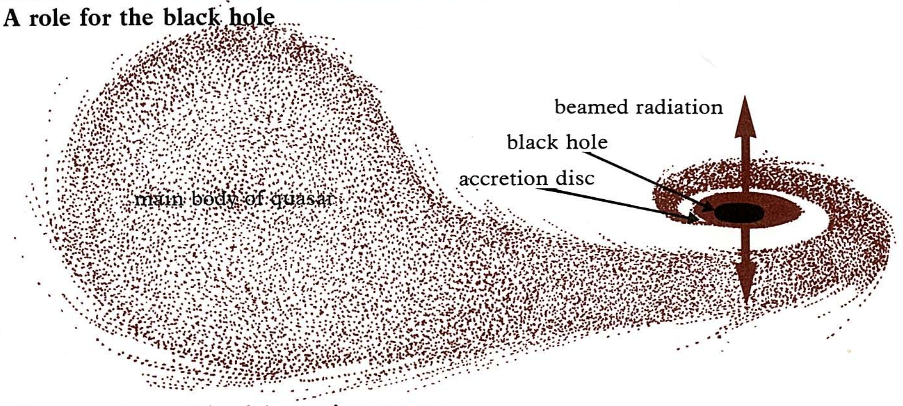
To help explain the prodigious energy output from quasars, astronomers are falling back on one of the more popular topics in modern cosmology, the black hole. Although black holes have never been positively identified, there has long been speculation about their existence and in 1971 the British mathematician Steven Hawking provided the theoretical basis to understand them.

In essence, the processes in any star provide a balance between the competing influences of energy and gravity. In the bowels of the star, nuclear fusion (whereby hydrogen combines to form helium and helium combines to form heavier elements) releases radiation that forces the various particles apart and keeps them in a relatively thick state of suspension. However, once the hydrogen and helium are used up and fusion stops, no energy-influence remains to stop gravity getting its grip on the dying star's matter.

If the star is a large one, the matter collapses under the influence of its own gravity into what can only be described as a void. The gravitational effect is so strong that nothing, including light and radio waves, can escape from its grip. To an outside observer, nothing apparently remains where a star once was — the only possible sign is an unexplained gravitational perturbation of nearby stars due to the highly concentrated mass of the black hole.

Even though astronomers have not positively identified a black hole, the story has parallels with other developments in modern physics. For example, that very common component in atoms — the neutron — was only a theory for the 12 years before its eventual discovery in 1932. Gravitational waves, analogous to light waves, have never been demonstrated experimentally, yet their presence is essential to Einstein's theory of general relativity and few doubt their existence and eventual discovery.

A role for the black hole



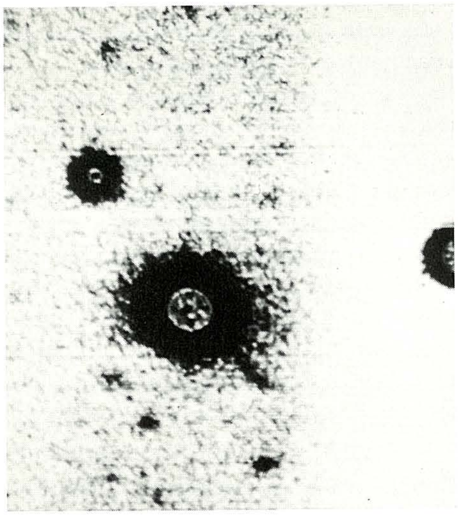
One way to explain the massive energy output of quasars is through the intervention of a black hole.

The hypothesis linking black holes and quasars is that a black hole, near a quasar, would drag matter into its void. As electrons accelerated towards the black hole, they would emit radio waves at right angles to their direction — this helps explain why only some quasars are radio objects: we are outside the reception area of the others.

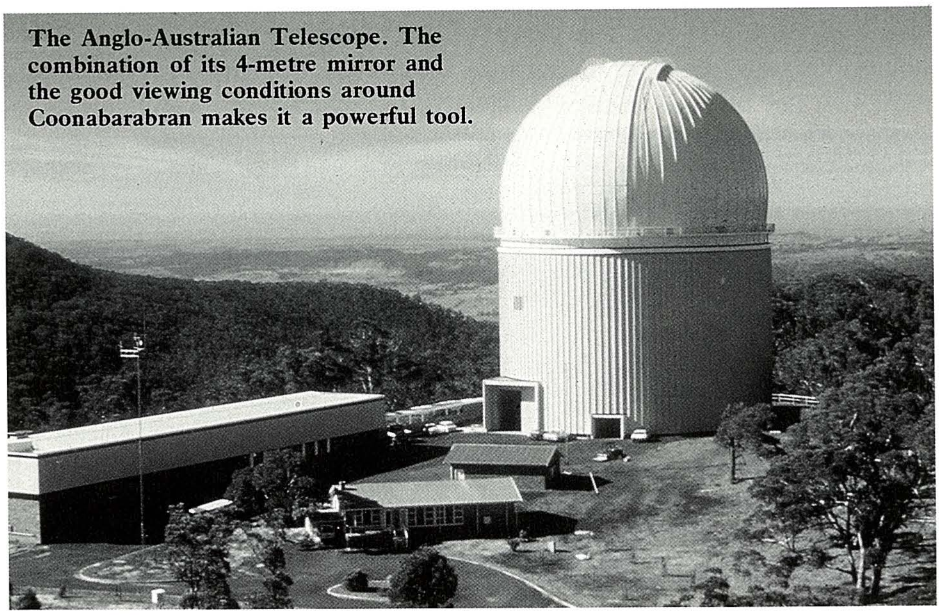
Other atomic particles, accelerating along the black hole's gravitational field, would approach the speed of light before meeting an 'accretion disk' surrounding the black hole. This disk would be a slowly revolving circle of matter that builds up temporarily before entering the black hole, and would be similar to, for example, the rings of Saturn, or the scum that circles the edge of a whirlpool. The accretion disk would represent a barrier to the incoming particles, which, upon colliding with it, would convert the gravitational energy obtained during their fall into the black hole into radiant energy.

The process postulated is much more efficient than nuclear fission or fusion, which convert only a small fraction of the atomic particle's mass into energy, and may explain the massive release of energy from quasars.

Observations of a number of quasars have revealed jets of matter associated with the main body. It is possible that these are generated by matter accelerating into the 'nothingness' of black holes.



One of the first of the quasars discovered — 3C273. A long jet can be seen at the bottom right.



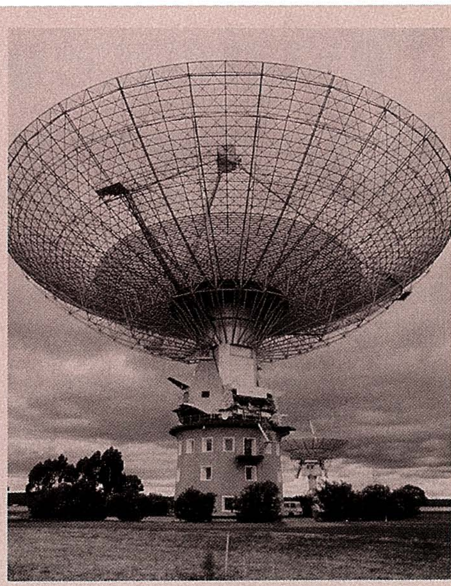
The Anglo-Australian Telescope. The combination of its 4-metre mirror and the good viewing conditions around Coonabarabran makes it a powerful tool.

Finding the source

Accurate position-finding is crucial to the success of radio-astronomy. Modern radio-telescopes are fairly crude devices, having a resolving power less than that of the naked eye.

For example, the CSIRO 64-metre radio-telescope at Parkes is considered to be remarkably accurate for its size, but positions measured with it have a circle of uncertainty varying from about 12 arcseconds for strong radio sources to about 30 arcseconds for relatively weak sources. (For comparison's sake, the moon is 1800 arcseconds and Jupiter 60 arcseconds across.) That circle of uncertainty contains numerous stars and galaxies — any one of which could be the source of the radio noise detected.

To narrow down the possibilities, a second radio-telescope has to give a position or, better still, two or more radio-telescopes work together in a technique called interferometry. In this case, the telescopes are linked electronically. If they are separated by, for example, 2 km, the synthesis of their observations creates a resolving power equivalent to that of a single telescope with a 2-km-diameter receiving dish. Resolving power of the order of thousandths of arcseconds can be achieved through interferometry, especially when the telescopes are on different continents and their baseline extends over thousands of kilometres.



The Parkes radio-telescope.

3·78, a figure that implies that the object is 18 billion light years away and moving further away at 92% of the speed of light.

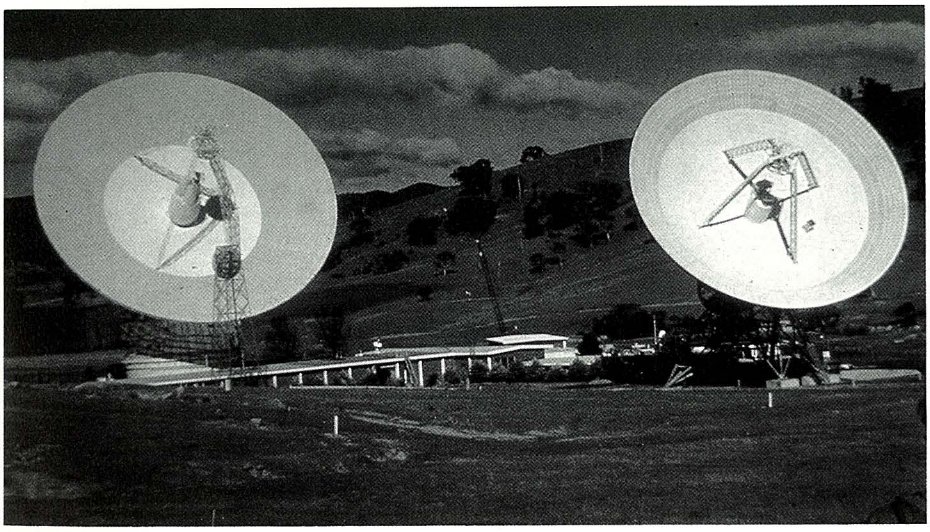
In total, the members of the Australian group have found six new quasars with redshifts greater than 3 and expect to find more. When they catch traces of energy coming from those distant quasars they are 'seeing' a portion of the universe as it was just after its creation. Whether they will find anything beyond that 3·78 redshift remains an open question. At even higher redshifts quasar light may become too dim to be seen from earth-based observatories, but possibly sightings will be made using orbiting telescopes. Sooner or later astronomers may confront the 'big bang' — that moment when space and time had no meaning and the universe was suffused with an energy that man can only theorize about.

A continuing puzzle

The quasars have undoubtedly evolved into something else since the light and radio waves that we now observe left them. In many respects, our understanding of quasars is as incomplete as that of the astronomers who first puzzled over the strange spectrum of 3C48.

Quasars are the most exciting discovery in modern cosmology.

NASA's deep space facility at Tidbinbilla, A.C.T. Usually only involved in communicating with spacecraft, the two dishes can be tuned to receive cosmic radio waves. Linked together, these two telescopes functioned as an interferometer, playing a crucial role in identifying the quasar 2000-330.



Many theories have been put forward about their nature. Probably the most popular involves the mechanisms of 'black holes' (see the box on page 14), but others suggest that quasars are the evolutionary forerunners of galaxies or the product of collisions between millions of stars. Closer to the realms of science fiction is the theory that quasars are 'white holes', or the other side of black holes, where all the matter and energy sucked up by black holes re-enters the universe.

Despite the uncertainty about their nature, quasars are the most exciting discovery in modern cosmology. A new generation of earth-bound telescopes — including the Very Large Array in New Mexico and the planned Australia Telescope, which will link radio telescopes across Australia as one — will be targeted on quasars. So will the space telescopes, soon to be launched. Together they may help unravel the puzzles surrounding these objects at the very edge of our universe.

Wayne Ralph

More about the topic

Pks 2000-330: quasistellar radio source with a redshift of 3·78. B.A. Peterson, A. Savage, D.L. Jauncey, and A.E. Wright. *The Astrophysical Journal*, 1982, **227** (in press).

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