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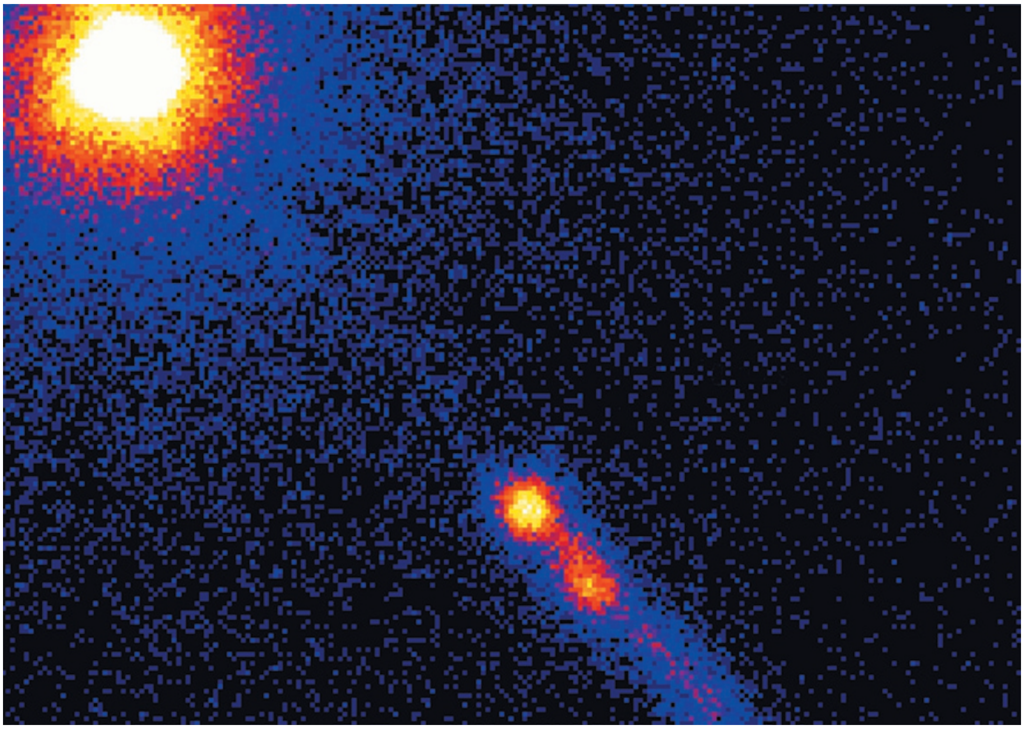


X-ray observations show that quasar 3C273 shoots out a jet of plasma blobs that seem to move faster than light.

Quasars still defy explanation

Fifty years after finding that these cosmic beacons lie far away, astronomers need to think harder about how they radiate so much energy, says **Robert Antonucci**.

Arthur C. Clarke posed one explanation for why no extraterrestrial life forms have been in touch in his 1953 novel, *Childhood's End*. The book describes a Galactic club of advanced civilizations that have a policy not to interfere in cultures at a primitive stage of evolution, such as our own. But once a society masters nuclear weapons and interstellar travel and becomes dangerous, the Galactic authorities introduce themselves and their rules, which include a ban on wars.

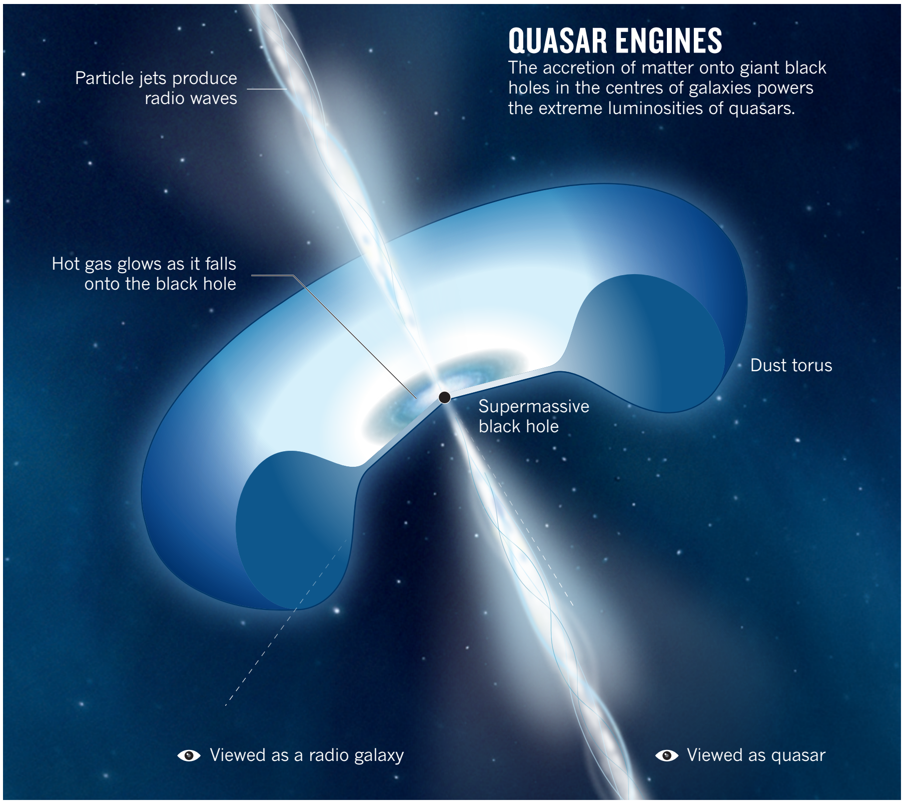
Astronomy's childhood ended 50 years ago with a discovery that made us full citizens of the Universe. In 1963, the first measurement of the distance to a quasar — a radio source that looks like a star in visible light — showed it to be an enormously powerful beacon lying billions of light years away[1]. Until then, astronomy had been limited to exploring our local patch of space time, in which everything looks familiar. Before quasars, the distant Universe was tantalizingly out of reach.

Quasars are immensely bright. From the central point in a galaxy, they emit as much energy as thousands of giant galaxies from a region as tiny as the Solar System. They radiate energy across the electromagnetic spectrum, from radio waves to γ-rays. Many expel jets of particles at near-light speed, which inflate vast particle clouds or 'lobes' that measure millions of light years across and emit radio waves.

Light that has travelled from distant quasars offers us a glimpse back in time. Since the discovery in the 1920s that the Universe is expanding, cosmologists have known that the cosmos has a finite age of about 13.7 billion years. Astronomers have ▶

had great fun detecting distant quasars, pushing ever closer to the Big Bang as technology has improved. But they have yet to understand the detailed physics of how quasars emit such enormous amounts of energy.

There is a consensus that quasars and other active galactic nuclei (AGN) are powered by the accretion of gas and stars onto giant black holes in galaxy cores, but the details are still mysterious (see 'Quasar engines'). Many theoretical models of quasars have little or no predictive power, and so, in my opinion, are of little or no value. Quasar researchers must recognize this problem and focus on understanding the physics of black holes.



LOOKING BACK

The first objects known to lie far beyond the Milky Way were radio galaxies, whose lobes were picked up by radio telescopes in the 1950s. Using optical telescopes, their distances were measured from the 'redshifts' of spectral lines of elements such as hydrogen, stretched to longer wavelengths owing to the passage of light through the expanding Universe. By 1960, radio galaxy 3C295 (the 295th object listed in the third Cambridge catalogue of radio sources) was the champion at a redshift of 0.464, meaning its light departed 4.8 billion years ago. But radio galaxies are dim and hard to spot from far away.

The March 1963 announcement of the first redshift for a quasar made it possible to dramatically expand the cosmic horizon. In a pair of papers in *Nature*, Maarten Schmidt[1] showed that the bright source 3C273 — another object from the Cambridge catalogue — has a redshift of 0.158 and lies 2.4 billion light years (736 megaparsecs) away, and Bev Oke[2] revealed that its spectrum was unlike a normal star. The extreme power implied by its brightness over that distance was shocking. Much higher redshifts for other quasars soon followed.

Astronomers Fred Hoyle and William Fowler realized in early 1963 that the immense energies of the radio lobes could only be created by the gravitational collapse of a very massive object that was a hundred million times heavier than the Sun. In 1969, Donald Lynden-Bell argued in *Nature* that such a monster would be crushed down under its own weight to form a supermassive black hole. The collapse of large masses to tiny sizes, which means almost dividing by zero in the equation for gravitational potential energy, puts much of the zing into astronomy.

Some quasar jets, including one in 3C273, appear to shoot blobs of plasma out of their nuclei at ten times the speed of light — seemingly breaking a rule of relativity. In the 1970s and early 1980s, astronomers Peter Scheuer and, independently, Roger Blandford and Martin Rees explained these 'superluminal' motions of the blobs as illusions. These arise because time delays in the light emerging from bright spots in the jets produce fast-shifting patterns, in a kind of time-lapse photography.

In the 1980s and early 1990s, astronomers realized that several key properties of radio galaxies and quasars were consistent with the idea that these two classes differ only in orientation with respect to the line of sight. This led to 'unified models' that explain how characteristics of AGNs vary with jet angle[3].

Quasar jets that point nearly towards us show superluminal motions; misdirected ones do not. Radio galaxies have jets in the plane of the sky. Separately, it was shown in the 1980s using optical spectropolarimetry and other means that many AGNs apparently lacking the broad emission lines that characterize quasars do show them in polarized light, scattered towards us by clouds of gas[3]. The unified model has allowed astronomers to piece together common characteristics of different classes of AGN. But it has not told us much about the central black hole and how its energy emerges.

We now know that supermassive black holes are common to most galaxies. In the 1980s and 1990s, observations of fast motions of gases and stars hinted that nearby galaxies host inactive central black holes[4]. Since then, astronomers have realized that quasars mark a phase in the life of galaxies, when their central black holes are lit up by accreting matter. This trait was more common in the past, so there are fewer quasars today. Now starved of fuel, black holes linger in galaxies, including our Milky Way.

LITTLE PROGRESS

Have we made good progress in understanding quasars in five decades? I do not think so. The theory of radio sources has not changed significantly in the past 30 years[5]. Basic questions remain: do the jets and lobes comprise electrons and protons or electron–positron pairs? Do the protons carry a lot of energy, as cosmic rays do? Is the energy divided evenly between electric and magnetic fields? Without answers to these, we can set only lower limits on how much energy the jets and lobes hold.

In my opinion, the greatest limiting factor in understanding quasars is not a lack of intelligence, effort or creativity, nor is it a dearth of fantastic new facilities. It is a widespread lack of critical thought among many researchers. Theories are being published that have already been ruled out by observations. Observers cling to falsified theories when interpreting their data. A vast amount of work has been wasted.

Most of the AGN community is mesmerized by unphysical models that have no predictive power. Smart people continue to use and refine overly simple versions of 'accretion disk' models of matter spiralling towards the black hole, including disproved assumptions such as that the disk structure changes only slowly[6,7]. These models simply don't match the observations without lots of special pleading. The properties of small accretion disks that are inferred to exist around stellar-mass black holes cannot be scaled up to explain the spectra of much more luminous quasars. Models and observations of quasar emissions violate even basic rules such as the Stefan–Boltzmann law, which states that the total energy radiated by a black body scales with its temperature by the fourth power. Recent work highlights other problems, such as that much of the optical light from quasars comes from regions that are much larger than disk models predict[8].

One revealing faux pas highlights the fact that some astronomers like to 'see what they believe'. In 1984, many in the field rejoiced when the first sensitive orbiting ultraviolet telescope obtained a temperature for one AGN that agreed with the prediction of the accretion disk model. Then, an amateur astronomer spotted a missing factor of ten in Newton's gravitational constant in the analysis. The model no longer fitted and the authors quickly issued a correction. Yet the erratum[9] is hardly cited, whereas the original paper has more than 100 citations.

The AGN field seemed to see a breakthrough in 1995, when orbiting X-ray telescopes became sensitive enough to detect high-energy iron emission lines that are broadened by rapid motions and gravity close to the black hole. Astronomers have again struggled to find a sensible theory. The prevailing scenario is that the lines are produced by a mysterious X-ray source that hovers above a disk of cold material. Although there have been preliminary claims of validation of this theory[10,11], in my view there is no good evidence yet that the iron line strengths follow variations in the X-ray continuum brightness closely and with little delay as one would expect.

The X-ray evidence for the disk reprocessing model is minuscule compared with more developed studies of optical line variability. Even stranger, bumps on the iron emission-line profiles persist for days, implying that the X-ray source somehow manages to float above the same spot even while the disk spins, which seems impossible. Adjustments to the theory, such as that the bending of light scrambles the responses of the lines to the continuum, only add more complexity. X-ray and ultraviolet AGN astronomers rarely talk to one another, even though both groups work on processes in the inner disk.

I see fewer and fewer serious theory papers on AGNs, but there is a burgeoning effort to find ever more quasars in surveys. It is as if, having given up on understanding AGNs, the community now focuses on the more modest goal of counting them. Sadly, the statistical analysis of astronomical surveys leads to further problems, such as claiming causal links in plots of dependent variables[12].

WHERE NEXT?

We have found thousands of quasars in the past 50 years, but we still don't have good physical models for how they radiate their prodigious energy. Without predictive theories we have nothing — our best hope for understanding quasars is that extraterrestrials might drop in and explain them to us.

Astronomers working on AGNs need to take a cold, hard look at their models and discard those that are unrealistic or have been falsified by observations. We need to use more sensitive X-ray telescopes to make detailed studies of the emission lines arising in the vicinity of the black hole. And we need advanced computational modelling of black holes, including magnetism, fluid dynamics, thermal balance and radiation. I hope to do my bit by elucidating the raw spectrum of radiation produced by the central engines of active galaxies, after removing distortions caused by surrounding gas and dust[13].

I urge my junior colleagues to spend 15 minutes a day thinking, palms down and eyes on the ceiling. That's just 3% of their time. As I saw recently on a Californian bumper sticker: "Don't just do something, sit there." ■

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Scientists are snobs

It is a mistake to dismiss the people and projects coming out of lesser-known institutions, argues **Keith Weaver** — they have strengths too.

We all do it. Pressed for time at a meeting, you can only scan the presented abstracts and make snap judgements about what you are going to see. Ideally, these judgements would be based purely on what material is of most scientific interest to you. Instead, we often use other criteria, such as the name of the researchers presenting or their institution. I do it too, passing over abstracts that are more relevant to my work in favour of studies from star universities such as Stanford in California or Harvard in Massachusetts because I assume that these places produce the 'best' science.

As someone who is based at a less well-known institution, the University of South Dakota in Vermillion, I see other scientists doing the same to me and my students. In many cases, this is a loss: to my students and their projects, which could have benefited from the input, and to the investigators who might have missed information that could have been useful in their own work.

Of potentially greater impact is the effect this scientific snobbery has on citation practices. My laboratory was the first to describe a system in a Gram-positive bacterium that uses a small, non-coding RNA to block expression of a toxin in plasmid-containing cells, ensuring that only those cells survive (K. E. Weaver *RNA Biol.* **9,** 1498–1503; 2012). The system allows the persistence of plasmids that carry antibiotic-resistance genes, and points to a new mechanism for subverting that resistance. If we can find a way to interfere with the function of the regulatory RNA, we could conceivably induce the cells to commit suicide. Follow-up work by colleagues in larger labs has demonstrated that hundreds of related systems exist on plasmids, phage and chromosomes in numerous Gram-positive bacteria, including some important pathogens.

Although these colleagues were diligent in citing my original work, recent papers describing a system similar to my own in another bacterium cited only a more recent study from a large US National Institutes of Health laboratory. Losing this and other worthy citations could ultimately affect my ability to get promoted and attain grants. ▶