Searchlight on the Cosmos

Studying the universe by the light of distant quasars

By RON COWEN

On photographic plates crowded with celestial mug shots, quasars typically look no different than the blob of a Milky Way star or the smudge of a nearby galaxy. Yet some of these seemingly undistinguished objects lie near the edge of the observable universe and reveal what the cosmos looked like soon after its birth.

Since 1986, British astronomers Richard G. McMahon, Michael Irwin, and their colleagues have found 40 quasars that have a luminosity as great as 10 billion suns and rank as the most distant objects known in the cosmos (SN: 6/20/92, p.410). Even as they search for quasars that lie still farther from Earth, McMahon and his coworkers at the University of Cambridge in England devote much of their time to studying the powerhouses they've already found.

After all, most of these 40 objects reside so far away that the light they emit must traverse nearly the entire breadth of the universe to reach us. That long travel time means the radiation captured by a telescope today provides a snapshot of what the quasars — and the host galaxies believed to house them — looked like some 10 to 12 billion years earlier. During this long-ago era, the universe was a mere 10 percent of its current age.

Like cosmic searchlights, distant quasars also illuminate the vast expanse of space through which their light travels, probing huge reservoirs of gas that could be the primeval ancestors of galaxies existing today.

Fascinating objects in their own right, distant quasars also guide astronomers grappling with some of the most fundamental questions in cosmology: When did galaxies first form, and when did stars first shine? Using a variety of new techniques and observations, researchers have begun finding some partial answers to these intriguing riddles.

It isn't easy studying a distant quasar's immediate surroundings. Thought to reside at the center of galaxies, these bodies far outshine anything else in their neighborhood. For this reason, researchers must use indirect means to explore the ages and birthrates of stars in these galaxies. Measuring the abundance of two features — molecular gas and dust — helps characterize a quasar's galactic environs. Molecular gas, notes McMahon, provides the building blocks for stars and can indicate their age. Dust often lies at the edges of star-birth regions.

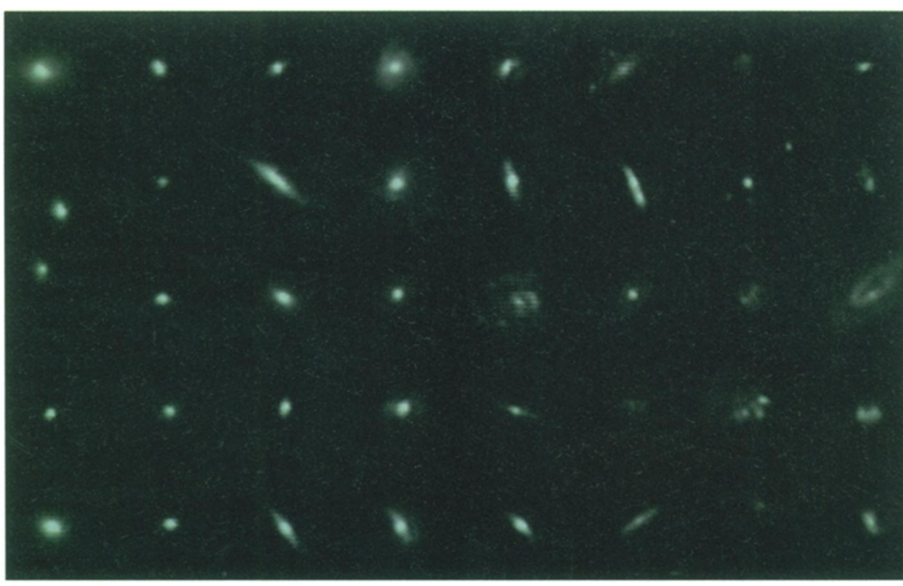
Molecular gas and dust both radiate in the infrared. Indeed, an observer near the distant quasar would see a substantial infrared glow. But in an expanding universe, the most distant objects recede the fastest and the wavelengths of light they emit become reddened, or lengthened, by the greatest amount. Viewed from Earth, infrared light emitted by a galaxy some 13 billion light-years distant gets redshifted to much longer wavelengths — into the radio region of the electromagnetic spectrum.

Welcome to the realm of millimeter-wave astronomy, a burgeoning field in the study of distant objects. Using two large radio receivers — the 15-meter James Clerk Maxwell Telescope atop Hawaii's Mauna Kea and the 30-meter IRAM telescope in Pico Veleta, Spain — McMahon and his collaborators, including University of Cambridge graduate student Kate G. Isaak, have now surveyed at millimeter wavelengths the surroundings of 20 of their sample of 40 distant quasars. The researchers have so far failed to find molecular gas, but they did discover evidence that huge amounts of dust surround two of the quasars.

One of the objects, known as BR1202-0725, lies an estimated 13.8 billion light-years from Earth. The astronomers found that at a wavelength of 1 mm, this body radiates much more strongly than expected. McMahon and Isaak also believe they have found the most likely explanation for the excess radiation. In the July 15 Monthly Notices of the Royal Astronomical Society, they and their Cambridge colleagues propose that a warm dust cloud more massive than 100 million suns surrounds the quasar and produces the extra emission.

Says McMahon, "We may be seeing this quasar and its surrounding galaxy a few hundred million years after it switched on. If this is true, we may be seeing this galaxy as it first [shone] through the dusty cloud that covered it while it was forming."

It remains uncertain, the researchers note, which of two sources warms the dust. The quasar itself may provide the heat; if it does, the dust would lie several thousand light-years from the luminous body. Alternatively, a large group of new-



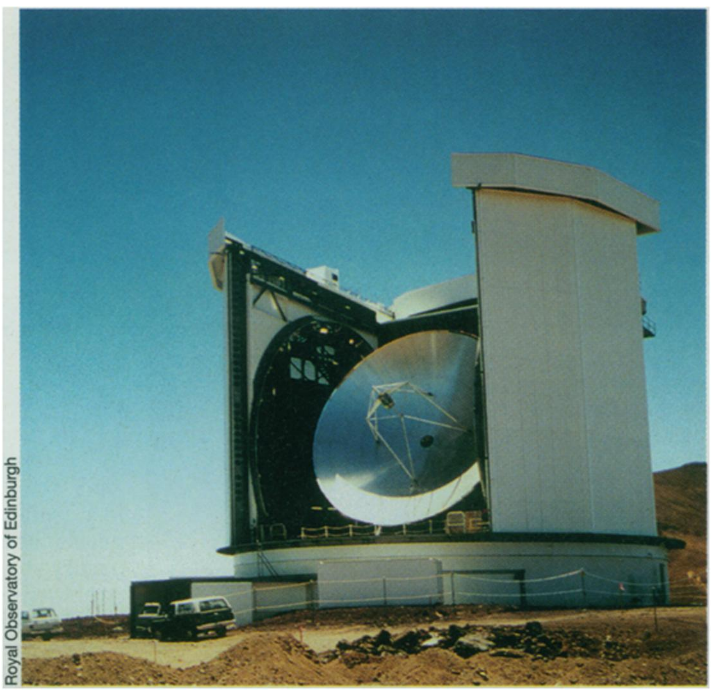
NASA/Space Tel. Sci. Institute

Menagerie of galaxies seen by the Hubble Space Telescope. Using distant quasars as a searchlight, astronomers are attempting to determine when galaxies like these first formed.

ly formed stars within the quasar's home galaxy may provide the energy. In this second scenario, the star-birth region would be millions of times wider than the Orion nebula, a key stellar nursery in the Milky Way. Moreover, the mass of the stars the region generates in just 1 year would equal 1,000 times the mass of the sun.

McMahon admits that his team has only deduced, not proved, the existence of a dust cloud. "Some of the arguments may seem a bit obscure...but we really are scratching around for every little bit of information we can get. Since these [quasars] are the most distant objects we can get to, the question is, Are we seeing galaxies that are actually forming?"

A new set of more sensitive millimeter-wave detectors now under development may enable astronomers to glean even more information about the quasars. McMahon also plans to use the European Space Agency's Infrared Space Observatory, scheduled for launch in a year, to search for molecular gas emissions in the far infrared — wavelengths not easily visible from the ground because Earth's atmosphere absorbs them.



Royal Observatory of Edinburgh

James Clerk Maxwell Telescope.

Observing the character of distant quasars and the galaxies in which they reside offers but one type of clue to the evolution of structure in the universe. Some researchers dismiss quasars as bizarre, rare objects that have little to do with the formation of the more typical galaxies that exist today.

"The issue is whether quasars are peculiar objects that can only exist in peculiar galaxies or whether they also exist in normal galaxies like the Milky Way," McMahon says.

But the typical galaxy that resides a large distance from Earth is too faint to study directly. Instead, McMahon and a host of other astronomers use quasars as beacons to probe these dim bodies.

On its way to Earth, quasar light passes through a vast array of gas clouds and galaxies, each of which absorbs some of its radiation. Analyzing how much light is absorbed and at what wavelength tells astronomers how far from Earth the intervening clouds and galaxies reside and how much gas and dust they contain.

Most of the radiation that quasars emit lies in the ultraviolet. The strongest spectral line in the ultraviolet occurs when an electron in a hydrogen atom jumps from the first excited state to the ground state, losing energy in the process. The radiation emitted is known as Lyman-alpha.

The expansion of the universe shifts the ultraviolet light emitted by faraway quasars into the visible range. The absorption lines created by hydrogen found in intervening clouds and galaxies are also redshifted. But because these gas clouds lie closer to Earth and recede more slowly than the quasars, their absorption lines shift by a smaller amount.

As a result, a typical quasar spectrum consists of a line of strong emission — the Lyman-alpha radiation shifted to visible light — followed by a series of weak absorption lines at shorter wavelengths. This thicket of absorption lines, known as the Lyman-alpha forest, reveals the presence of a group of very-low-density clouds of hydrogen gas at varying locations between the quasar and Earth.

In the mid-1980s, Arthur M. Wolfe of the University of California, San Diego, discovered that a few of the clouds absorbed much more of the quasar light, indicating that they contained much higher densities of hydrogen. Dubbed "damped Lyman-alpha absorption systems," these clouds collectively contain enough neutral hydrogen gas to equal all the gas and stars found today in spiral galaxies, and possibly elliptical galaxies as well.

The absorption systems studied by Wolfe's team lie at redshifts between 2.5 and 3.5, roughly corresponding to a distance between 12.5 billion and 13.5 billion light-years from Earth. Wolfe and his colleagues speculate that hydrogen gas in the absorption systems went on to condense and form star-studded galaxies much like those that now abound in the neighborhood of the Milky Way.

To test that idea, Kenneth M. Lanzetta of the State University of New York at Stony Brook, David A. Turnshek of the University of Pittsburgh, and Wolfe recently examined damped Lyman-alpha absorption systems closer to home. They reasoned that if the distant gas clouds are the ancestors of modern-day galaxies, the clouds nearer to Earth should contain considerably less hydrogen gas. Presumably, some of that gas would already have condensed to form stars.

Nearby absorption systems recede from Earth at a much slower speed, and the ultraviolet light they absorb from quasars gets shifted to only slightly longer wavelengths. The shift is so small that the absorption lines remain in the ultraviolet, which can't easily penetrate Earth's atmosphere. So to examine these systems, Lanzetta and his coworkers relied on data from an observatory in space, the International Ultraviolet Explorer (IUE).

Spectra taken with the IUE reveal that the nearby absorbers do indeed contain considerably less hydrogen gas than their more distant counterparts. The total amount of atomic hydrogen in the nearby gas clouds is only one-seventh the amount present in the distant systems, the team found. They will report their work in the Feb. 20, 1995 ASTROPHYSICAL JOURNAL.

McMahon says he generally agrees with the results of Lanzetta's team, with one important exception. On the basis of his studies with graduate student Lisa Storrie-Lombardi, McMahon suggests that the more distant clouds contain less hydrogen gas than Lanzetta and his coworkers calculate. The Cambridge astronomers detail some of their work in the May 20 ASTROPHYSICAL JOURNAL LETTERS.

McMahon proposes that the gas clouds spawn only the current population of spiral galaxies, not ellipticals. Elliptical galaxies, he notes, have much older populations of stars and may have formed earlier than spirals, with a different set of ancestors.

For their part, Wolfe, Lanzetta, and their colleagues plan to study the spectra of distant gas clouds with the 10-meter W.M. Keck Telescope on Mauna Kea. If they find that the abundance of hydrogen gas levels off in more distant systems, this may indicate the epoch when many galaxies formed.

The alternative may prove equally intriguing, says Lanzetta. If the astronomers find that the faraway clouds contain more hydrogen gas than can be accounted for by all the visible material in galaxies today, then it could indicate that these gaseous reservoirs hold some of the dark matter that galaxies are thought to harbor. □