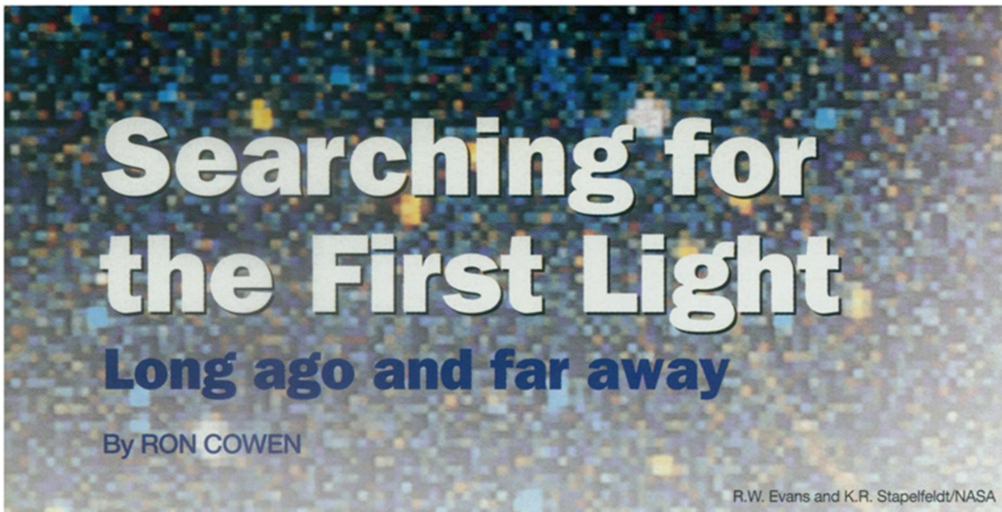


Searching for the First Light

Long ago and far away

By RON COWEN

R.W. Evans and K.R. Stapelfeldt/NASA

When astronomers look through a telescope, it's as if they have entered a time machine. As the telescope peers deeper into space, it delves further back in time. The newest generation of instruments is transporting astronomers farther into the past than ever before—to an era when the first glimmers of starlight set galaxies aflame.

In March, researchers reported the discovery of the most distant galaxy then known, lying 12.2 billion light-years from Earth (SN: 3/21/98, p. 182). That immense distance means that the light now reaching Earth left the galaxy when the cosmos was only about 1 billion years old.

Now, a team of scientists reports having bested that record. A galaxy found by Esther M. Hu and Lennox L. Cowie of the University of Hawaii in Honolulu and Richard G. McMahon of the University of Cambridge in England lies slightly farther from Earth and hails from about 60 million years earlier in cosmic history.

That difference in time may not seem like much, but a small interval may have been substantial when the universe was very young. "As any mother could tell you, a year's growth makes a much bigger difference in appearance and character in a toddler than in someone age 20," says Hu.

Astronomers often express cosmic distance in terms of redshift, the amount by which the expanding universe has shifted the light emitted by a galaxy to redder, or longer, wavelengths. The more distant the galaxy, the greater the redshift. The galaxy reported in March has a redshift of 5.34, while the new record holder, to be described in an upcoming ASTROPHYSICAL JOURNAL LETTERS, has a redshift of 5.64. The researchers have also found several other galaxies that are nearly as distant.

The new find appears to be a harbinger of many more, says McMahon. He asserts that astronomers are on the verge of detecting the very first galaxies—those that were in existence when the universe was only about 500 million years old. The possibility of finding galaxies so soon after their formation flies in the face of conventional wisdom, which holds that astronomers would have to wait until the next decade—and the launch of large, space-based observatories (SN: 4/26/97, p. 262)—before they could find such youthful collections of stars and gas.

"Our paper demonstrates that we have a technique for searching for distant galaxies up to a redshift of 5.6, and we're currently doing work where we think we can find them up to a redshift of 6.5," says McMahon. "We're in new territory here."

"It's quite plausible that some of these [galaxies] are young objects that are going off for the first time and making stars," says Mark Dickinson of the Space Telescope Science Institute and Johns Hopkins University in Baltimore.

Astronomers have been searching for the denizens of the early universe for decades, but until recently they faced a major limitation—the size of their telescopes. With small telescopes, says Hu, researchers were forced to look at highly luminous objects such as quasars, the brilliant powerhouses that lie at the center of some galaxies. As bright as a trillion suns, quasars are relatively easy to spot. Indeed, McMahon and a group of British colleagues have specialized in finding distant quasars—those with redshifts between 4 and 5 (SN: 9/17/94, p. 188).

Quasars are rare, however. Many researchers view them as cosmic oddballs, fueled by galactic black holes, that drown out the light from the stars in a galaxy.

"It's a lot easier to look at something blazingly bright, even if it's extremely rare—perhaps 1 [galaxy] in 10 million houses a quasar—and unrepresentative of the typical galaxy," says Hu.

Researchers who eschewed quasars and insisted on searching for primeval galaxies lacking these powerhouses encountered an additional problem.

Ten years ago, says Hu, astronomers believed that distant galaxies—those from the early universe—would have about the same mass and size as those in today's universe. This supposition, however, "just ain't so," says Hu.

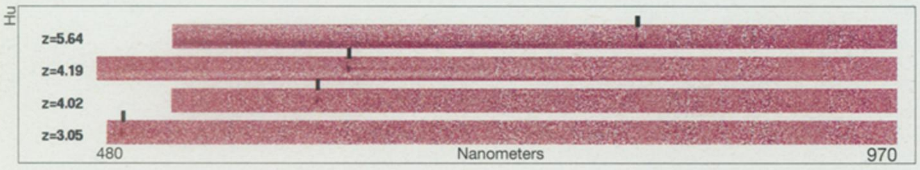
Several recent sky surveys have shown that the typical distant galaxy is surprisingly small, its mass just a few percent that of a present-day galaxy like the Milky Way. Correspondingly, the light emitted by one of these faraway galaxies is much less than had been estimated.

Little wonder, then, that searches in the 1980s and early 1990s came up empty-handed. Finding distant galaxies was much harder than most astronomers had bargained for.

Seekers of distant galaxies were saddled with one additional complication. In their hunt, researchers sought out a particular wavelength of light emitted by hydrogen atoms. Theory suggests that as the first massive stars formed, they emitted high-energy radiation that would easily excite hydrogen, the most common gas in a galaxy. The jazzed hydrogen atoms would radiate much of the absorbed energy at an ultraviolet wavelength of 121.6 nanometers. This radiation is known as the Lyman-alpha emission.

Alas, Lyman-alpha emissions from distant galaxies have remained elusive. Because of their small size, distant galaxies just can't produce much of this radiation. In addition, astronomers have difficulty seeing them because they are obscured by dust—bits of material, heavier than hydrogen and helium, that are produced as a galaxy ages.

Dust readily absorbs ultraviolet light, including Lyman-alpha radiation. Moreover, even small amounts of dust can dim this radiation. Lyman-alpha photons are easily scattered by gas molecules and so take a meandering, zigzag route out of their home galaxy. The zigzag path increases the likelihood of repeated encounters with bits of dust.



Lyman-alpha radiation is a particular wavelength of ultraviolet light, 121.6 nanometers, emitted by hydrogen atoms. When an observer on Earth records Lyman-alpha radiation emitted by a distant galaxy, the light is shifted to redder, or longer, wavelengths. For example, a galaxy with a redshift (z) of 5.64—like the distant body recently found by McMahon and his colleagues—appears in the near-infrared at a wavelength of 807.4 nanometers (top). Similarly, Lyman-alpha radiation emitted by a galaxy with a redshift of 3.05 is shifted by a factor of 3.05 and appears as visible light at a wavelength of 492.5 nanometers (bottom). Two galaxies at intermediate distances (center) display radiation at intermediate wavelengths.

Absorption of a distant galaxy's light may have foiled the Lyman-alpha method of detection, but it proved the key to another. Hydrogen gas, ubiquitous throughout the universe, absorbs ultraviolet light efficiently. The more distant a galaxy, the more hydrogen lies between it and Earth and the more its ultraviolet emission is dimmed. Researchers, including Dickinson and Charles C. Steidel of the California Institute of Technology in Pasadena, have looked for galaxies that shine brightly over a broad spectrum of colors in visible light but vanish in the ultraviolet. To date, about 440 of 1,400 ultraviolet dropouts have turned out be faraway galaxies with redshifts between 2.2 and 4 (SN: 2/7/98, p. 92).

With such an efficient method of ferreting out distant galaxies, why would anyone resurrect the search for Lyman-alpha emissions? Hu, Cowie, and McMahon have hearkened back to the older method because they believe it can reach further back in time than the dropout method. Furthermore, they have a new tool—the twin Keck Telescopes atop Hawaii's Mauna Kea. Each of these 10-meter telescopes can gather more visible light than any other instrument. A survey that took 20 hours on the University of Hawaii's 2.2-meter telescope takes only 1 hour on one of the Keck instruments, and it can discern galaxies that are one-fifth as bright.

"What we're doing now, we can only do with Keck," notes McMahon.

"Previous researchers were not pushing deep enough over a large enough volume to find [distant] Lyman-alpha emitters," says Dickinson. "Now people are, and as usual, it's thanks to a large aperture like the Keck Telescopes."

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The twin Keck Telescopes atop Hawaii's Mauna Kea.

McMahon and his collaborators have two other reasons for carrying the torch for Lyman-alpha light. First and foremost, says McMahon, the very youngest galaxies in the universe, those that had just begun making stars, would not have had enough time to make dust. In these galaxies, Lyman-alpha emissions might not amount to much, but they would not be extinguished.

"The key thing is that we're talking about very short times" after the birth of the universe, McMahon says. "We're preferentially picking out very young objects."

In contrast, the ultraviolet dropout technique relies on emissions over a broad range of colors. These emissions may be muted in newborn galaxies, rendering them invisible. "If these objects are indeed so faint [that the dropout technique] can't find them, then Lyman-alpha may be a better reflection of star formation rates" in the early universe, Dickinson says.

It also turns out that the dropout technique becomes more difficult when applied to extremely distant galaxies. As the light from remote galaxies is increasingly stretched out by cosmic expansion, the wavelength at which they disappear from view moves from the ultraviolet range of the spectrum into the visible range. Astronomers must then search for more distant galaxies in a part of the spectrum that includes long-wavelength emissions from molecules in Earth's atmosphere, making detection more difficult.

Those spurious sources of radiation are much less troublesome for searches that rely on Lyman-alpha emissions, McMahon says. To detect a galaxy at a given distance from Earth, Lyman-alpha surveys require the detection of but a single redshifted wavelength of light emitted by hydrogen atoms. By limiting their search to the many redshifted wavelengths at which Earth's atmosphere does not radiate, the team avoids interference from the atmosphere altogether.

"There are gaps in between the emission lines that come from the sky," says McMahon. "We look [for distant galaxies] in these gaps, where the sky is dark."

One caveat, says Dickinson, is that such studies require highly selective filters, each of which detects Lyman-alpha radiation from galaxies that reside within an extremely narrow range of distances from Earth. Recent observations suggest that distant galaxies tend to clump together. If galaxies in a particular patch of sky don't happen to cluster within the necessarily narrow range of distances employed in the study, researchers could miss them, he says. In contrast, the dropout technique can find galaxies over a larger range of distances.

McMahon agrees that the two search strategies complement each other. "The key questions we're [all] asking is when did star formation begin, and at what speeds are galaxies forming?" Only time will tell which method reveals the answers. □