The Quest for the Youngest Galaxies

By studying shadows in light from the early days of the universe, astronomers are identifying what may be ancestors of today's galaxies–and filling a gap in cosmic history

The universe is mostly light, hydrogen, and galaxies. The light was born with the universe in the Big Bang, 15 billion years ago; the hydrogen was born when elementary particles joined together, half an hour later. But when or how galaxies were born has been anybody's guess. Until recently, observers looking back in time for infant galaxies by searching at great distances found no sign of them—only strange, excessively bright objects called quasars and radio galaxies. Now, however, they have taken another tack altogether: looking not at galaxies themselves but at shadows in the light of distant quasars. And that indirect strategy may be paying off, because astronomers think the objects responsible for the shadows could be young galaxies, taking shape only a billion years after the Big Bang.

Astronomers still have no smoking gun. "At the moment," says Michael Fall of the Space Telescope Science Institute (STScI), "we're at the limit of what's [technologically] possible." The telltale spiral or lens shape of a galaxy can't be detected at those distances, though a repaired Hubble Space Telescope would come close. Moreover, theorists believe that the most certain sign of a young galaxy, a bright line in its spectrum produced by hot hydrogen, will in most cases be obscured by dust. But recent advances in telescopes and detectors have enabled observers to pick up light and radio signals from some of these shadows that indicate the presence of swarms of stars. As a result, astronomers now suspect they are seeing signs of galaxies' lost youth.

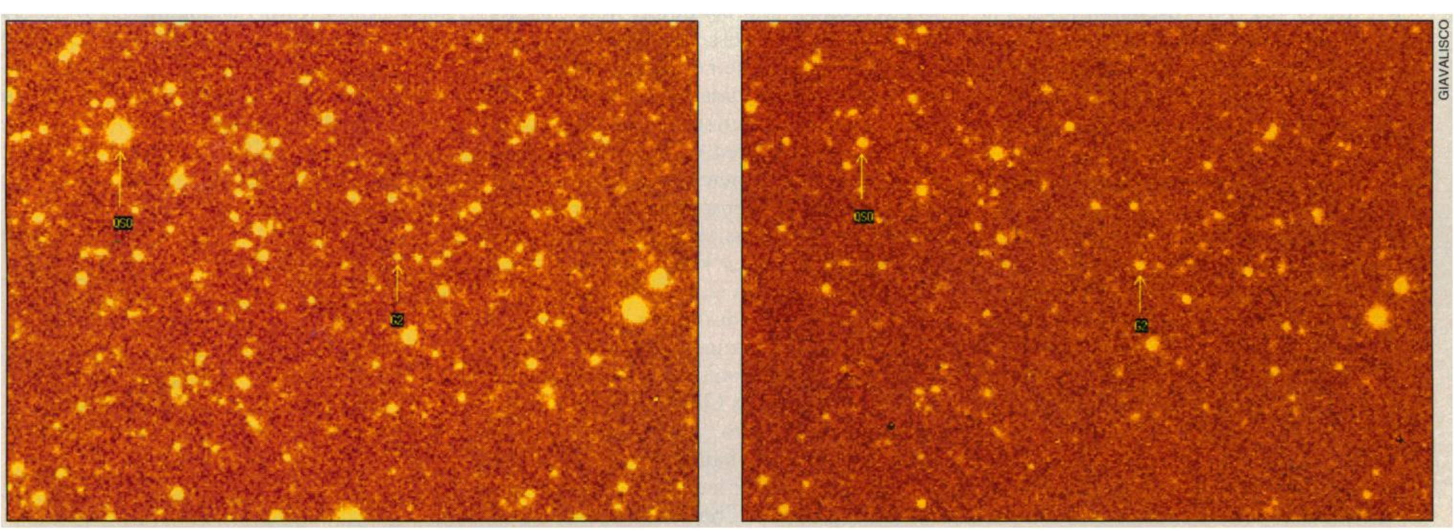
If so, the results—first discussed last summer at a meeting at the STScI—may confirm a picture theorists have had for decades. Young galaxies, called protogalaxies, should look like trees full of blue fireflies: galaxy-sized clouds of hydrogen laced with newborn, short-lived, blue-hot stars. As generations of these blue stars cycle through their brief lives and explode, they should make heavier elements ("metals," to astronomers), scatter the metals into the surrounding gas clouds, and heat the gas to incandescence. This picture implied a characteristic spectrum for a protogalaxy, something for protogalaxy searchers to look for: starlight, traces of metals, and a strong, bright line of excited hydrogen, called Lyman alpha. "As galaxies come into this world," says Mauro Giavalisco of the STScI, one of the searchers, "they give a huge cry in Lyman alpha, the beautiful cry of the baby galaxy."

Chasing shadows

In practice, nothing observed so far has met all the criteria. Observers have detected crowds of faint, blue galaxies that match many of the predictions but lie too nearby in space and time to be the ancestors of normal galaxies. And searches for the beautiful cry of Lyman alpha emission in distant parts of the sky yielded nothing. Worse, recent calculations by Fall and Stéphane Charlot at the University of California, Berkeley, suggested that such searches are hopeless. Even small amounts of metal dust, they predicted, would completely obscure Lyman alpha emission.

But while one set of observers was coming up empty on Lyman alpha emission, a different set was studying shadows in the light from distant quasars. The spectrum of every quasar is crowded with hundreds of dark Lyman alpha absorption lines, marking wavelengths at which the quasar's light is absorbed as it passes through clouds of cool hydrogen along the way from the quasar to Earth. Because the amount by which a spectral line has shifted toward the red end of the spectrum reveals the object's distance, observers know how far away these Lyman alpha absorbers are. In a universe 15 billion years old, the absorbers' red shifts are as high as 4.0, placing them 14 billion light-years away.

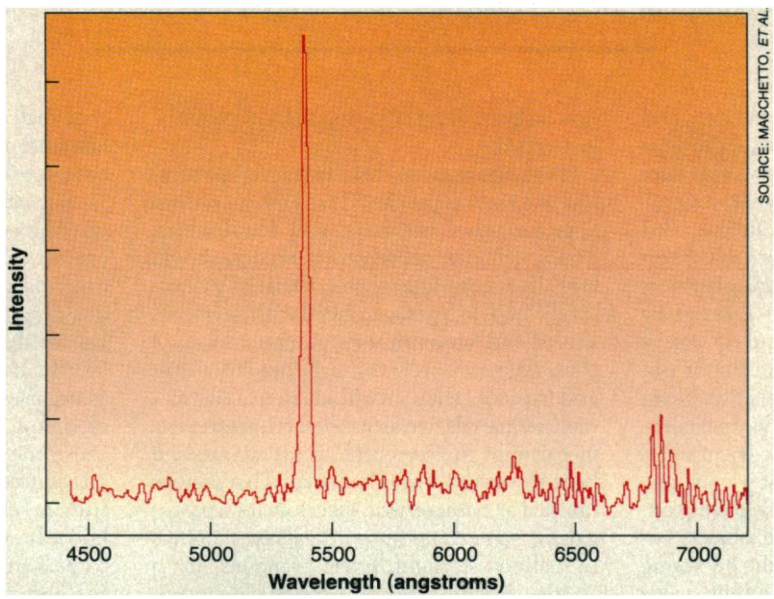
Observers realized all along that a few of these absorbers had galaxy-like features. Although many were so faint that the gas clouds responsible for the absorption could be no more than the airiest intergalactic driblets, others had roughly the densities of the disks and outer halos of spiral galaxies. Many of these denser objects, known as "damped" Lyman alpha and "Lyman limit" absorbers, also absorbed at wavelengths that signaled the presence of metals. Early on, Arthur Wolfe of the University of California, San Diego, proposed that these denser absorbers might actually be young spiral galaxies. But absorption alone—mere shadows—wasn't enough to prove it.



Hunting for newborns. An infant galaxy (G2) is lost in a field of objects around a quasar *(left)*, photographed at the European Southern Observatory at La Silla, Chile. It brightens in a second image taken through a filter specific for wavelengths emitted by a primordial galaxy's excited hydrogen *(right)*.

The problem is that absorption lines from cool hydrogen say nothing about a young galaxy's hot bursts of newly forming stars. What's more, light from a quasar is a skewer that cuts through an absorber at only a single point and says nothing about the absorber's shape or size. To identify the absorbers as infant galaxies, observers needed to see absorbers shining in their own starlight. That is, observers needed emission spectra and images.

In 1991, French astronomers Jacqueline Bergeron and Patrick Boisse were the first to capture the spectra and images that could identify quasar absorbers as galaxies. In this case, the absorbers were hydrogen clouds salted with magnesium atoms—like any metal, circumstantial evidence of stars—lying relatively nearby, at red shifts of 0.4. At the European Southern Observatory at La Silla, Chile, Bergeron and Boisse took a list of 13 magnesium absorbers in the spectra of specific quasars, pointed the telescope near the line-of-sight to each quasar, and in 11 cases detected starlight at the same red shift as the absorbers. This year, Charles Steidel of the Massachusetts Institute of Technology and Mark Dickinson at Berkeley, working at the Kitt Peak and Lick Observatories, expanded the sample of magnesium absorbers, then looked for starlight, and found a total of 50 associated galaxies.



An infant's cry. The Lyman alpha line of excited hydrogen dominates a spectrum of the infant galaxy G2, taken at La Silla.

These are middle-aged, Milky Way-type galaxies, nothing special; lying at red shifts between 0.3 and 0.8 and rich in metals, they aren't the juveniles observers had been seeking. To find juveniles, observers had to look for evidence of stars in damped absorbers at much higher red shifts. Robert Brown and Paul Vanden Bout of the National Radio Astronomy Observatory, for example, aimed a radio telescope at 20 damped Lyman alpha absorbers at redshifts of between 2.0 and 3.0 and, in five of them, picked up radio signals from galaxy-sized clouds of carbon monoxide. Carbon monoxide is abundant in the dense clouds of molecular hydrogen that give birth to stars, so its presence is strong circumstantial evidence of stars. "The observations suggest huge accumulations of gas and some stars," says Brown. Still, the radio emissions aren't as compelling as starlight itself, says Brown. "The next step will be to use optical telescopes to see starlight."

Steidel and Don Hamilton of the California Institute of Technology have done just that with another sample of damped absorbers. They knew that starlight originating at high red shifts would be too faint to produce a clear image or a detailed spectrum. So they decided to look for a rough indicator of protogalaxies that should be visible even at those distances: light with the characteristic colors of new stars and a hole in the spectrum due to absorption by hot, ionized hydrogen. After fitting the 4-meter telescope at the Cerro Tololo Inter-American Observatory with a set of filters designed to pick out those colors and the spectral hole at specific red shifts, they searched the sky around one quasar with known damped absorbers. They found 16 fuzzy blobs, Steidel says, "sticking out like sore thumbs" at red shifts between 3.0 and 3.5.

A nest of galaxies

The blobs are probably galaxies, say Steidel and Hamilton, and for at least one of the 16, the identification is even more certain. While Steidel and Hamilton were making their survey, Giavalisco, Duccio Macchetto of the STScI, and their colleagues were looking near the same quasar at a damped Lyman alpha absorber at a red shift of 3.4. The investigators, who wanted to test Charlot and Fall's discouraging news about Lyman alpha emission, used a filter specifically designed to search for the emission and found it, says Steidel, "before they knew they couldn't." The object, named G2, must be "a baby galaxy with very little dust," says Giavalisco.

By luck, G2 turned out to be one of Steidel and Hamilton's 16 candidate galaxies. As a result, says Giavalisco, he and his colleagues know two "sexy things." One is that Steidel and Hamilton's set of filters does seem to work as a template for identifying protogalaxies. The other is that those 16 galaxies, all at similar red shifts and all found along the line of sight to a single quasar, seem to be a cluster. A cluster at high red shifts is startling, because theories of how matter clumped together into larger structures as the universe evolved can't explain how structures as big as clusters could have formed by a red shift of 1.0, let alone 3.4. Theory, says cosmologist Joseph Silk of Berkeley, may well need "a patch-up job."

As for the protogalaxies themselves, no one knows whether they will poke any holes in theory. For one thing, the evidence that the absorbers are truly infant galaxies isn't conclusive. "They could be little pieces of fluff that had been parts of galaxies," says Steidel, "not the galaxies we know and love." For another, even if the absorbers are galaxies, their presence in the very early universe is no surprise, because current theory suggests that primordial matter would have clumped up into galaxy-sized clouds anywhere between red shifts 4 and 10.

Any surprises will come as observers get a sharper picture of infant galaxies—what they look like and how they form and mature. In the hope of recording clearer images, Wolfe is aiming the 10-meter Keck telescope in Hawaii at some of the distant protogalaxies. Meanwhile, to expand the sample of infant galaxies, Steidel is using his and Hamilton's template to survey other absorbers out to a red shift of 4.0. And the Sloan Digital Sky Survey will take spectra of 100,000 quasars, an effort that should expand the catalogue of absorbers to several million.

Meanwhile, if the repairs completed this month restore the Hubble Space Telescope to health, it will continue its Key Project, taking spectra and making images of nearby quasar absorbers. By adding those results to other observations, researchers hope to compare infant galaxies with ones that are on the verge of middle age and write their life histories. "The goal is to watch galaxies forming," says Fall, "to actually see them do it. We want to watch a movie."

–Ann Finkbeiner

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Additional Reading

S. Charlot and S. M. Fall, "Lyman-Alpha Emission from Galaxies," *Astrophysical Journal* **415**, 580 (1993).

C. Steidel, "Properties of Absorption-Line-Selected High-Redshift Galaxies," in *The Environment and Evolution of Galaxies*, J. M. Shull and H. A. Thronson, eds., 263. Kluwer Academic Publishers (1993).