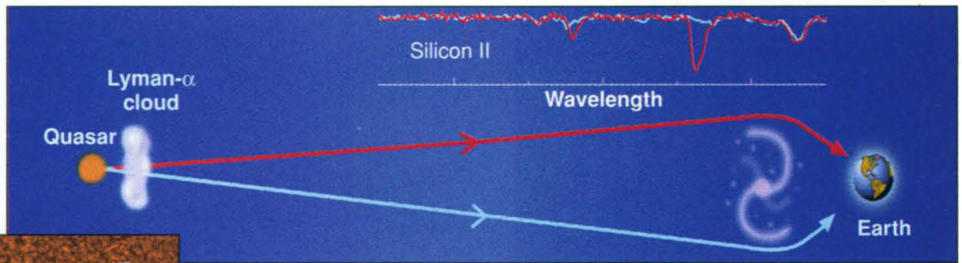
ASTRONOMY

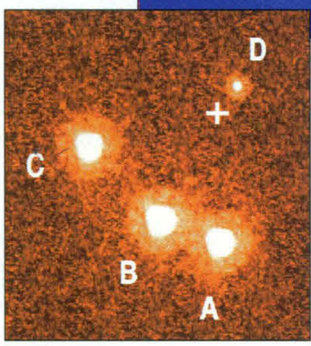
Gravity Teases Details From Ancient Cosmic Birthplaces

By refracting light from the far edge of the universe, gravity is giving astronomers a fine-scale view of the dim clouds that spawned stars and galaxies

Gravity bends light rays, and it is also letting astronomers break a seemingly inflexible rule. Ordinarily, the farther away an object is, the more difficult it is for observers to resolve its finest details. But when the titanic gravity of an entire galaxy bends light from a quasar—a brilliant object at the far edges of the universe—astronomers can sometimes pick up details just 100 light-years across in huge, distant clouds of nearly primordial matter veiling the quasar's light. The feat, recently achieved by a team at the California Institute of Technology (Caltech), depends on the chance alignment of a quasar, a cloud, and a foreground galaxy along a single line of sight. But in sheer resolving power, it beats the Hubble Space Telescope by a factor of 20.

The strategy relies on quasars that appear as multiple images in the sky—a sign that the gravity of the foreground galaxy has captured light rays emanating from the quasar on slightly different paths and slung them all toward Earth. Near the quasar, where the rays have not yet had a chance to diverge much, they may have passed through one of the pristine clouds of material that emerged from the big bang. Traveling on paths just a few tens of light-years apart, the rays can pick up clues as to how the cloud might be swirling and clumping in the early stages of galaxy formation. "It's extraordinary," says Chris Impey, an astronomer at the University of Arizona's Steward Observatory. "You can get a level of detail on the universe billions of years ago that exceeds anything else you could [resolve], except in your own backyard in the Milky Way."





CHRIS IMPEY (IMAGE); RAUCH *ET AL.*

Two views of a cloud. Light from a gravitationally lensed quasar reaches Earth via different paths, creating multiple images *(left)* and revealing variations in a primordial cloud, evident in spectra from different sight lines *(above)*.

In an early fruit of the technique, the Caltech team of Michael Rauch, Wallace Sargent, and Thomas Barlow saw dramatic differences in the density of carbon, silicon, and iron—clues to the presence of stars—along two nearby light paths through a cloud. One ray, but not the other, may have passed through a zone of stellar activity—perhaps a galactic building block. If that connection can be tightened, says Charles Steidel of Caltech, "this really gives you a handle [on galaxy formation] in exquisite detail."

These clouds, at distances of up to 10 billion light-years and more, are thought to be the birthplaces of the universe we know today, containing the raw material for the walls, bubbles, and filigree patterns traced out by galaxies. They are too distant and dim to be seen directly. Instead they are detected as spikes of absorption in the spectra of quasars, strange galaxylike beacons that were among the first objects to form in the universe. Although the same element, hydrogen, is responsible for most of the absorption spikes, the expansion of the universe shifts the spikes toward the red end of the spectrum by an amount that depends on each cloud's distance. As a result, the light of a typical quasar, passing through many clouds on its way to Earth, has a spectrum that bristles with separate absorption spikes—the so-called Lyman-α forest.

A quasar's light ordinarily pierces each cloud at just a single point. This one-dimensional view gives a sketchy picture of the clouds' structure, although astronomers have learned that they tend to be lumpy on scales of millions of light-years. To add the missing dimensions, the Caltech team has analyzed spectra from three multiple-image quasars, captured by the high-resolution spectrograph on the 10-meter Keck Telescope in Hawaii.

For each quasar, they compared spectra from the different images, looking for signs that the light had passed through the same Lyman-α clouds. Then, from the redshifts of the spectral spikes, they worked out how far the quasar's light had traveled before it reached each cloud and how far the multiple light paths had diverged at that point. That gave them the dimensions of any structures that might cause the cloud's spectral fingerprint to vary.

The Caltech team's first result, which has been presented at scientific conferences in Europe, revealed little structure on scales smaller than 1000 light-years in most clouds. But in about a dozen other clouds with higher gas densities, they found factor-of-2 changes in the density of highly ionized carbon over distances of a few thousand light-years. The density changes, along with slight velocity variations, could be the mark of "minigalaxies," about 10 times less massive than the Milky Way—and possibly caught in the act of merging, says Rauch.

Most striking were a few cases where the spectra revealed clouds lying relatively close to the quasars, where the light paths had diverged very little. The team looked along each sight line for the absorption spikes produced by singly ionized silicon, carbon, and iron, and neutral oxygen. These ions should mark the densest parts of the clouds, where plentiful electrons combine with and eliminate doubly and triply ionized atoms. In one case, the team saw factor-of-10 variations in the ion densities over a distance estimated to be less than 100 light-years, along with signs that the atoms are swirling within the cloud.

"It's a wonderful thing to be able to look at the scale of interstellar clouds in our own galaxy, but see it in a galaxy when the universe is 10% of its current age," says David Weinberg of Ohio State University in Columbus. The wind from a single star or a supernova in the early universe could be responsible for the density variations, says Rauch.

He and his colleagues want to collect more examples before they firmly commit themselves to any interpretations. But Rauch thinks the technique could ultimately free astronomers who want to understand the universe's early days from having to depend on the few objects that can be seen directly, such as quasars or especially bright galaxies. "The question," he says, "is to what extent are [observed distant] galaxies giving us a typical picture?" Details gleaned from the dim Lyman-α clouds, he thinks, may give a truer sample of the early universe.

—JAMES GLANZ