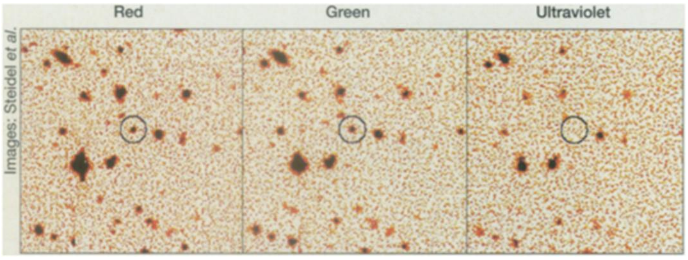
Light from the Early Universe

Discerning patterns in galaxies from long ago

By RON COWEN

Two years ago, astronomer Charles C. Steidel and his colleagues accomplished something no other team of galaxy hunters had done before. Using a novel strategy to ferret out faraway galaxies, they discovered 23 starlit bodies so distant that the light they emitted more than 12 billion years ago—when the cosmos was still in its infancy—has only now reached Earth. Images of these galaxies thus represent snapshots of the early universe (SN: 2/24/96, p. 120).

What was novel in 1996 has now become routine. As of last month, Steidel's team had confirmed the presence of 440 galaxies that lie at least 12 billion light-years from Earth. It has also observed close to 1,000 additional galaxies that may be equally far away. Other teams have found another 20 or so. The sheer number of these galaxies is allowing researchers for the first time to observe directly the architecture of the early universe—the size, brightness, and distribution of some of the first galaxies to form.



Now you see it, now you don't: Objects that show up in the red and green filters but vanish in the ultraviolet may be distant galaxies.

One pattern in that architecture sticks out like a sore thumb, Steidel notes.

In each of the five patches of sky surveyed by the team, the distant galaxies bunch together instead of being distributed randomly in space. "The work is ongoing, but what we're able to say now is that galaxies we are seeing at [great distances] are as strongly clustered in the early universe as they are today," says Steidel, who is at the California Institute of Technology in Pasadena. He presented the findings last month at a meeting of the American Astronomical Society in Washington, D.C.

Steidel and his collaborators, Kurt L. Adelberger and Melinda Kellogg of Caltech, Mark Dickinson of Johns Hopkins University and the Space Telescope Science Institute in Baltimore, Mauro Giavalisco of the Carnegie Observatories in Pasadena, and Max Pettini of the Royal Greenwich Observatory in Cambridge, England, also detail some of the results in the Jan. 10 *Astrophysical Journal*.

"It's like drilling for oil with a big probe," says cosmologist Carlos S. Frenk of the Steidel survey. "You find nothing, nothing, nothing, and then suddenly you hit something with oil there, you get a big signal," notes Frenk, who is based at the University of Durham in England. "Then you go past it, and you find nothing again. That's what [Steidel and his team] did; they were drilling through space and then suddenly they found a huge spike. That big signal was not oil, it was something more precious—it was the gigantic cluster of [distant] galaxies."

Clustering is a relative term—on average, the galaxies within each concentration are 500,000 light-years apart. The findings nonetheless startled some theorists. How could such structures have assembled so early in the history of the universe? Could gravity have had enough time to form fledgling galaxies and gather them into large groupings?

The initial reaction, says J. Richard Bond of the Canadian Institute for Theoretical Astrophysics at the University of Toronto, was, "Wow, maybe there's something really anomalous going on here. . . . People thought this might be a problem."

Upon closer scrutiny, says Bond, the leading theory of galaxy formation could in fact account for the observations. This theory posits that as much as 99 percent of all the matter in the universe is made of an invisible, mysterious material known as cold dark matter.

Cosmologists have an affection for this hypothetical matter because it would begin to cluster earlier than ordinary matter. Suppose some regions of the universe were born with a density of matter ever so slightly higher than the average. Gravity's tug would cause cold dark matter in these tiny regions to congregate faster and grow more quickly than ordinary, visible matter. Indeed, cold dark matter would act as an unseen scaffolding, with the largest clumps of this exotic material subsequently pulling in the largest clumps of visible material.

In these models, the densest concentrations of cold dark matter tend to lie near each other, and the most massive groupings of ordinary matter fall into the same pattern. If this view of the cosmos holds true, the most massive galaxies in the early universe—those that are brightest and thus most likely to seen by a distant observer—should be tightly clustered.

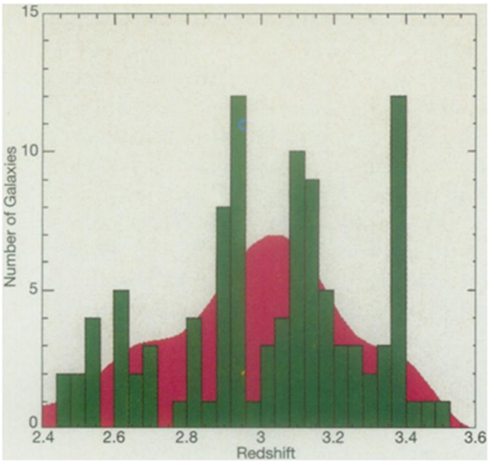
It also means that galaxies, no matter how many billions may exist in the universe, only trace the relatively rare places in the cosmos where there are unusually high concentrations of cold dark matter. Scientists refer to this scenario as biased galaxy formation, since galaxies reside only in the very densest parts of the cosmos.

In this model, says Frenk, "galaxies are a mere afterthought, a pattern painted on the highest peaks in the density of dark matter." It's as if an observer on Earth could see the Alps and Mount Everest, but not the Great Lakes, the Sahara Desert, or the Grand Canyon, he says.

In computer simulations, Frenk and his colleagues traced the evolution of galaxies that would form from ordinary gas coalescing around concentrations of cold dark matter. "Steidel surveyed small patches of sky, but in the simulations we can 'survey' a much bigger patch," he notes. "So we asked the questions, do the galactic groupings exist in cold dark matter theories? If so, how common are they? Should Chuck [Steidel] keep finding these over and over again every time he surveys a reasonably large patch of sky?

"The answer is yes," says Frenk. "They should be very common."

Bond and David N. Spergel, a cosmologist at Princeton University, note that the clustering observed by Steidel's team is easier to explain if the overall density of



Green peaks indicate large groupings of galaxies early in the history of the universe. Galaxies that have a redshift of 2.4 date from a time when the universe was about 19 percent of its current age; those with a redshift of 3.6 date from a time when the universe was about 11 percent of its current age. Theorists believe the groupings are destined to form the clusters of galaxies observed in the universe today. The pink curve shows how the distant galaxies would probably have been arranged if they had been distributed randomly in space.

matter in the universe is less than what astronomers call the critical value—the amount needed to keep it from expanding forever. Cosmologists believe that the universe has been expanding continually since its birth in the Big Bang. In a low-density universe, galaxies would congregate early, when the cosmos is more compact and gravity more effective. Later, because gravity can't win the battle against expansion in a low-density universe, clustering becomes more difficult.

The match with a low-density cosmos is tentative but intriguing, says Bond, since several other lines of evidence already point strongly to it (SN: 1/3/98, p. 4). Further observations of distant galaxies, he adds, will help discriminate between high- and low-density models. The current information "is right on the edge," says Bond, but "there's just not enough stuff there yet to make a definitive statistical statement."

What exactly are the arrangements of galaxies that Steidel's team has observed? Frenk says that astronomers have come face-to-face with primitive groupings of galaxies "destined to turn into galaxy clusters like the ones we see near us today.

"These galaxies are already on the scrimmage line, ready to collapse into a big pile, which is going to be a cluster like the [present-day, well-observed] Coma cluster. What you see is the formation just before the collapse occurs." Individual galaxies in the groupings, adds Frenk, will merge with others in their vicinity, becoming the massive spiral and elliptical galaxies in today's universe.

Michael A.K. Gross of NASA's Goddard Space Flight Center in Greenbelt, Md., agrees. The objects observed by Steidel's team, he notes, are not gravitationally bound, stable clusters but "look as though they may be coalescing to form clusters." In computer simulations using a variety of cold dark matter models, Gross and his colleagues Joel R. Primack and Risa Wechsler of the University of California, Santa Cruz find similar features—some of the first, tentative gatherings of galaxies, which "evolve into large clusters of galaxies by the present epoch."

In the future, Steidel plans to widen his survey to look for larger structures and to extend the search to greater distances. In looking for distant galaxies, the team identifies likely candidates by viewing them through three different filters at the 200-inch Hale Telescope at Palomar Observatory near Escondido, Calif. Taking advantage of the fact that ultraviolet light from a remote galaxy tends to be absorbed by hydrogen both within the galaxy and between the distant body and Earth, they seek objects that show up in green and red filters but not in the ultraviolet.

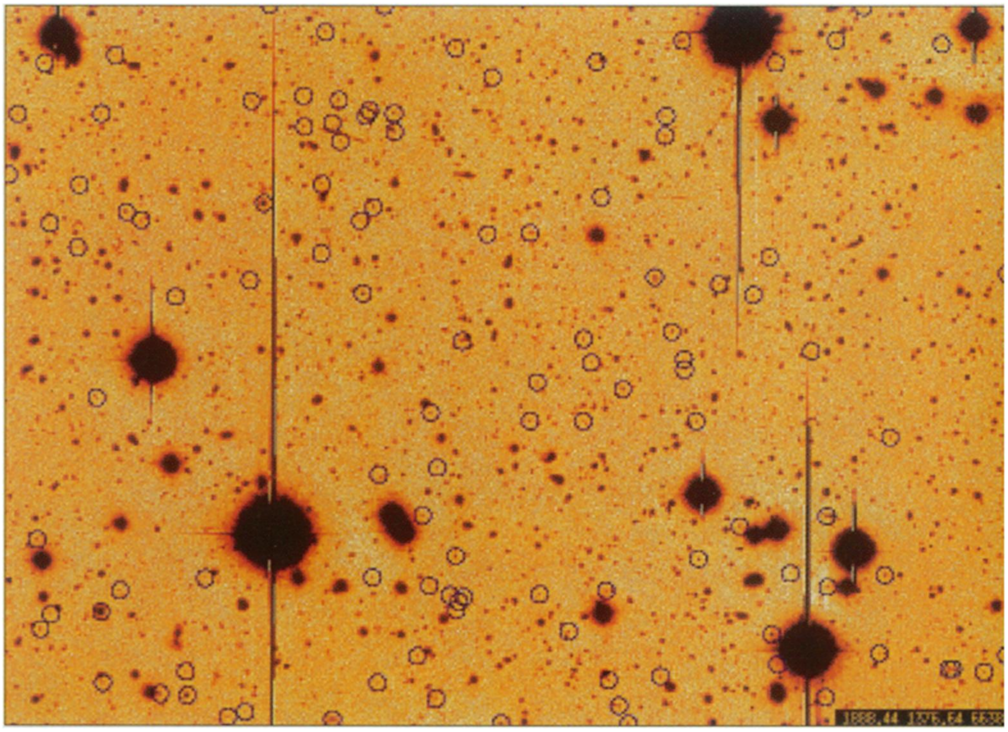
For the galaxies that meet this criteria, the researchers then obtain the distance from Earth by measuring the amount by which the expansion of the universe has shifted the light they emit to longer, or redder, wavelengths. Galaxies that are more distant have a higher expansion velocity and thus a higher redshift.

Relying on the light-gathering ability of the two W.M. Keck telescopes on Hawaii's Mauna Kea, the world's largest visible-light instruments, the astronomers find that all of the 440 galaxies in their survey have a redshift greater than 2.5. This means that the galaxies are so far away that the expansion of the universe has shifted the wavelengths of the light they emit by a factor of 2.5. Such galaxies lie more than 12 billion light-years from Earth in a universe about 15 billion years old.

"This is the beginning of a huge effort which is going to occur worldwide," says Bond. Several big telescopes now under construction will jump-start new studies. By the end of this year, an 8.2-meter telescope in Paranal, Chile, and one on Mauna Kea are scheduled to open for business. Early in the next decade, three more telescopes will begin operation in Paranal, and one in Cerro Pachon, Chile, will join the Mauna Kea instrument. With these and other new devices, "there's going to be a big push toward doing more galaxy surveys at redshift 3."

"Up to this point, there's been no real solid information about the early universe to constrain the models," notes Steidel. "All of the models are designed to automatically give you a universe that looks like the present one by the time the present one comes along. But the models all look different at early times. Now, we can actually make statistically robust measurements of things, saying where the galaxies ought to be, what their clustering properties are, how bright they are, how many of them there are.

"That is exactly what is needed to try to make progress in understanding galaxy formation—and in understanding what kind of universe we live in." □



In this image of a small patch of sky, taken with the 5-meter Hale Telescope at Palomar Observatory, the circled objects—about 150 or so—meet the color criteria for being distant galaxies. Large, extended objects are stars within the Milky Way.