Galaxies near the dawn of time

The Hubble Space Telescope's latest and greatest deep-field image uncovers a population of compact and ultra-blue galaxies more than 13 billion light-years from Earth. **by Richard Talcott**

Thirteen billion years of cosmic history show up in this panoramic view taken by the Hubble Space Telescope. The scene contains thousands of galaxies from the nearby universe to more than 13 billion light-years away — the most distant objects astronomers have ever seen. The image combines photos taken through 10 filters from ultraviolet through visible light and into the near-infrared. NASA/ESA

Twenty years after space shuttle astronauts deployed the Hubble Space Telescope, the orbiting observatory continues to reach new heights. Now, astronomers have used Hubble's Wide Field Camera 3 (WFC3) to scale a fresh peak — by plumbing uncharted depths. The newly installed camera peered deeper into the universe than Hubble ever had before and revealed galaxies more than 13 billion light-years from Earth.

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These galaxies also give us a look far back in time. The most distant galaxies in the new images existed just 600 million years after the Big Bang. These objects are much smaller than the Milky Way and other big galaxies that dominate the universe today. In effect, they give researchers a look at the baby galaxies that ultimately grew into the mature objects surrounding us.

The latest results come from two sets of Hubble observations. The first targeted a pencil-thin slice of sky in the northeastern corner of the southern constellation Fornax. Astronomer Garth Illingworth of the University of California, Santa Cruz, led the team that pointed WFC3 at the spot for 48 hours. The camera took images through three filters that isolate different wavelengths in the near-infrared part of the spectrum.

This region coincides with the original Hubble Ultra Deep Field (HUDF), taken in visible light by the Advanced Camera for Surveys (ACS) in late 2003 and early 2004. Many of the discoveries from the new HUDF09 come through comparing it with the original Ultra Deep Field.

A second team, led by Rogier Windhorst of Arizona State University, observed a slightly larger area just north of the HUDF09. For this panoramic photo, the team combined WFC3 observations at three near-infrared wavelengths and three ultraviolet wavelengths with earlier ACS images through four visible-light filters. The resulting 10-color mosaic provides an unprecedented view of thousands of galaxies.

Both fields lie within a wider region targeted by the Great Observatories Origins Deep Survey (GOODS), an extragalactic laboratory for studying cosmic evolution. Astronomers have viewed this area with Hubble, the infrared-sensitive Spitzer Space Telescope, the Chandra X-ray Observatory, and large ground-based telescopes. The region appears nearly empty without a big telescope — the brightest star glows at 14th magnitude, some 1,000 times dimmer than the faintest naked-eye star.

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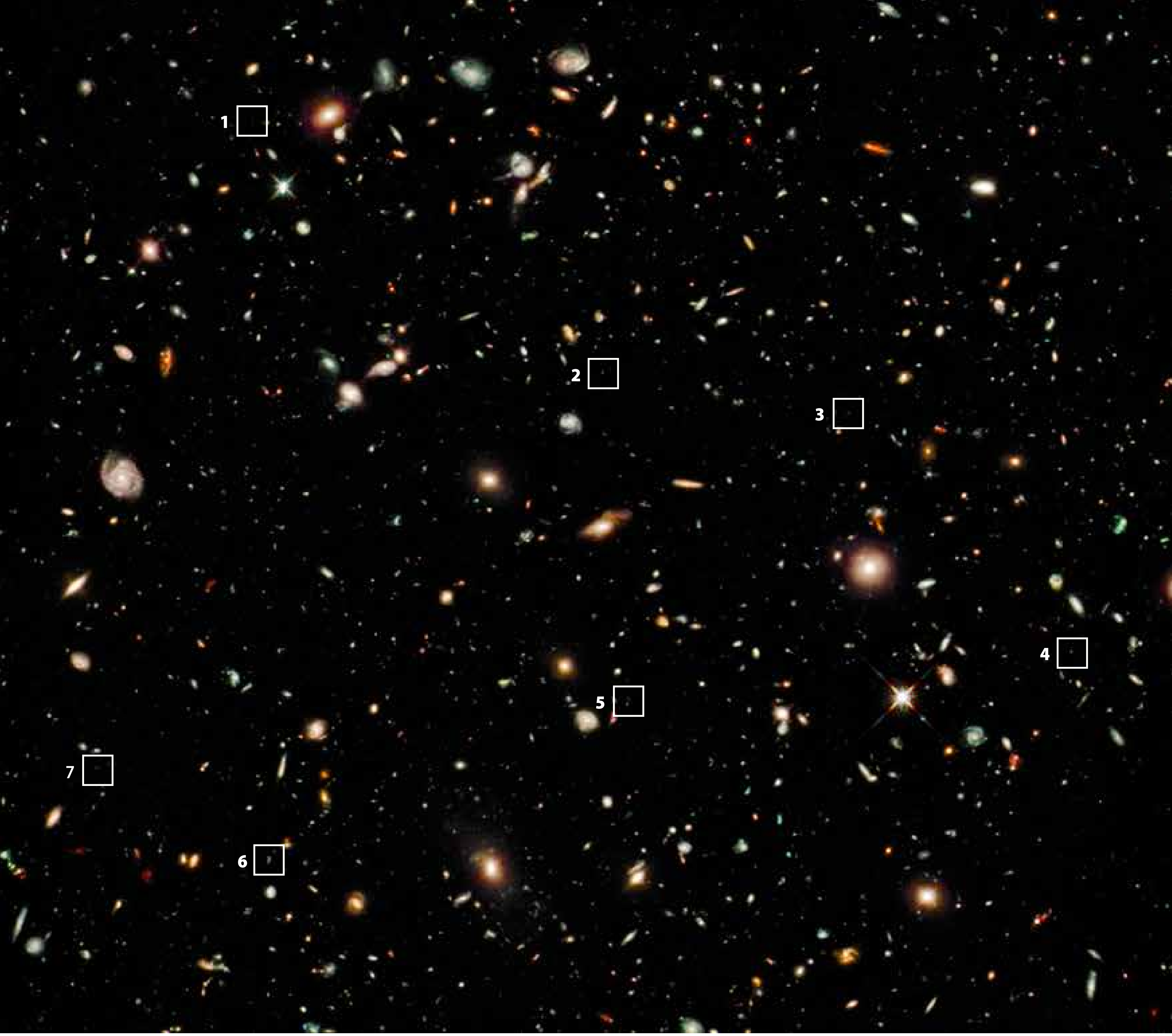
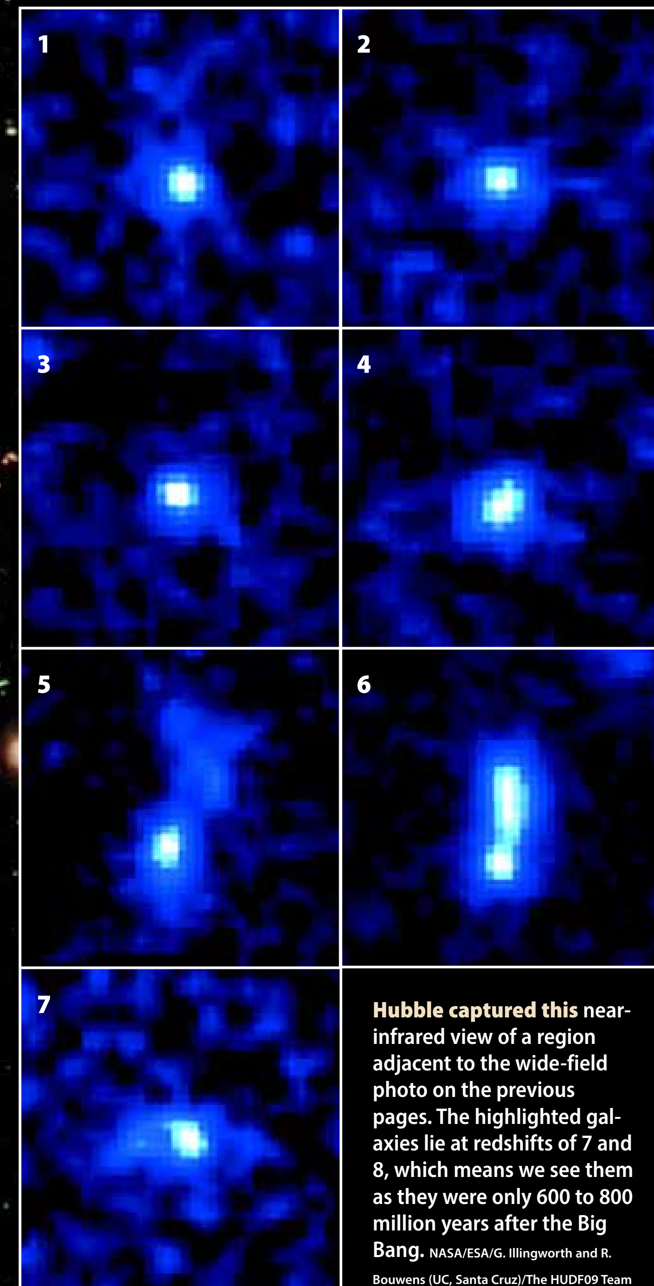
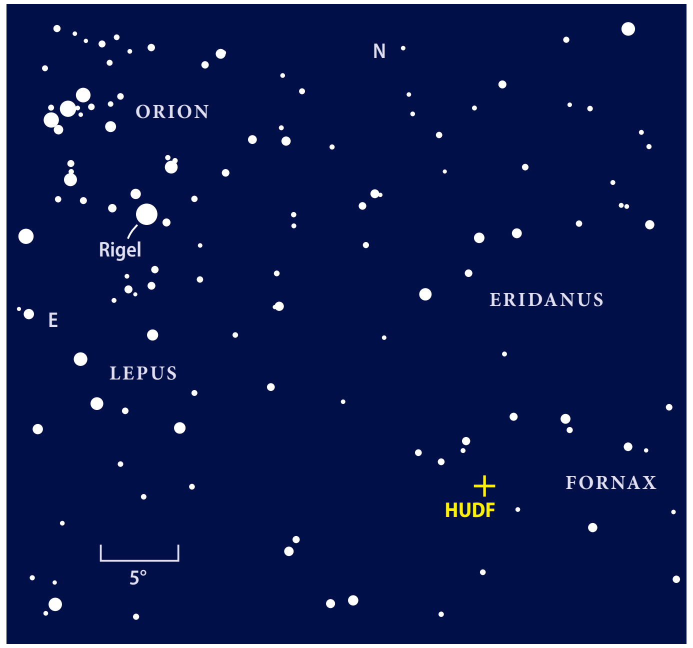




Hubble captured this near-infrared view of a region adjacent to the wide-field photo on the previous pages. The highlighted galaxies lie at redshifts of 7 and 8, which means we see them as they were only 600 to 800 million years after the Big Bang. NASA/ESA/G. Illingworth and R. Bouwens (UC, Santa Cruz)/The HUDF09 Team



The Hubble Ultra Deep Field lies in a nondescript part of the southern constellation Fornax. At the scale of this map, the field is far smaller than the size of the cross. *Astronomy*: Roen Kelly

Age vs. redshift

A galaxy's redshift is a measure of how far away it lies, and thus how long after the Big Bang its light left. A redshift of 0 means the light hasn't shifted at all, so it represents the current universe. A redshift of 1 means the light has shifted by 100 percent, so the wavelengths are twice as long; a redshift of 2 means the wavelengths are 3 times as long. The most distant confirmed galaxies in the Ultra Deep Field have redshifts between 8 and 9, so we see them as they were only 600 million years after the Big Bang. — *R. T.*

Redshift	millions of years since the Big Bang
0	13,700
0.5	8,700
1	5,900
2	3,300
3	2,200
4	1,600
5	1,200
6	950
7	780
8	650
9	560
10	480

Hunting the cosmic edge

Within weeks of Hubble's observations, astronomers discovered a slew of distant galaxies in the fields. Finding these far-flung objects isn't as easy as you might expect. For brighter and nearer galaxies, the task is pretty simple: Take a spectrum of the object through a large scope, and determine its redshift. The redshift measures how much the universe's expansion has shifted the light to longer (redder) wavelengths.

Not only are the new galaxies exceedingly faint, but they also lie so far away that their light has been shifted out of the visible spectrum. No telescope on Earth or in space can capture a spectrum of the farthest galaxies. Instead, astronomers determine their redshifts, and thus distances, from how bright they appear through different near-infrared filters. (See "How to find a galaxy's distance" on page 61.) That's where WFC3 comes in. Only it has the capability to see the faint light from these remote galaxies.

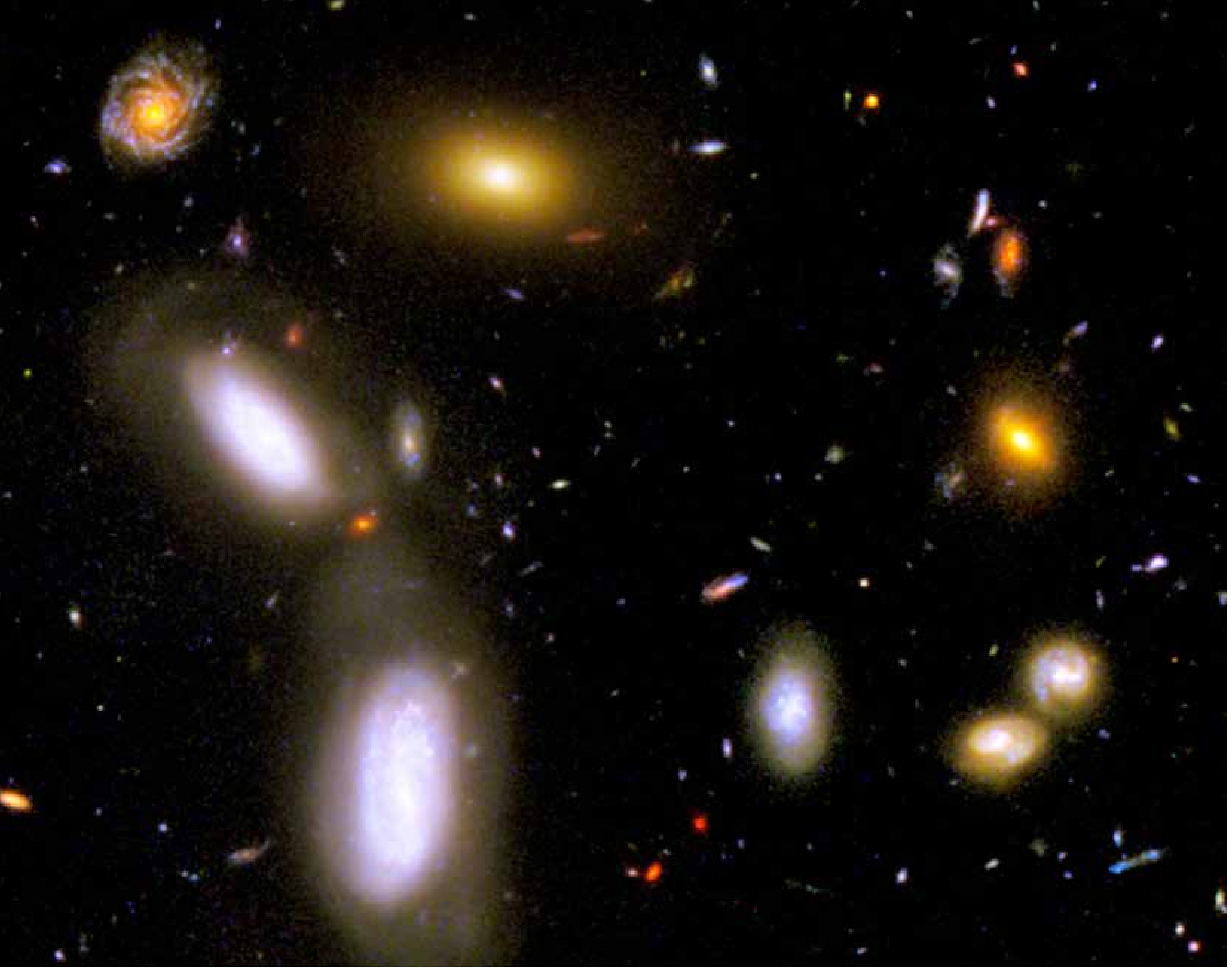
Illingworth's team, one of six exploring the new data, discovered 16 galaxies at redshifts of around 7 and five more at redshifts of 8. The farthest one has a redshift of about 8.5, which corresponds to an era just 600 million years after the Big Bang. (See "Age vs. redshift" on page 59 for the relationship between the two.) And this comes just 6 years after Hubble's ACS set the previous record by uncovering galaxies at redshifts slightly greater than 6, some 900 million years after the Big Bang.

Illingworth even claims evidence for three galaxies at redshifts of about 10, which pushes their ages back to within 500 million years of cosmic genesis. These galaxies show up through only the longest-wavelength WFC3 filter, however, so the team isn't quite as confident in these detections.

Small and blue

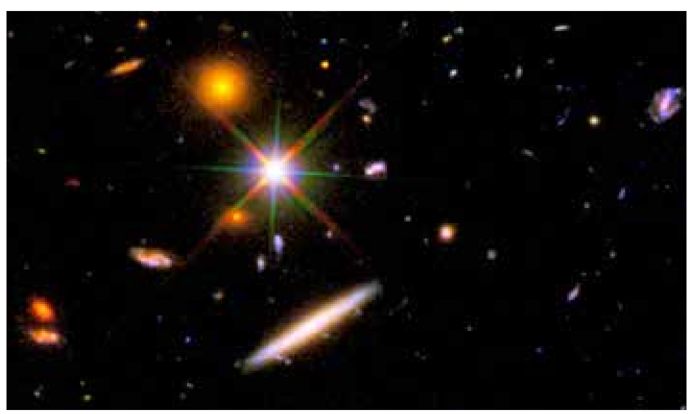
The newfound galaxies don't bear much resemblance to the majestic spirals and great ellipticals prominent in the nearby universe. They have diameters only about 5 percent that of the Milky Way and masses less than 1 percent that of our galaxy. Still, Hubble reveals them as more than mere dots. Several appear ragged and distorted, no doubt through encounters with their neighbors. These baby galaxies are the seeds that grow through mergers into large galaxies like ours.

These distant objects also are much bluer than galaxies today. (Don't get confused by this color reference; they still *appear* red to our telescopes. But when scientists factor out the redshift caused by universal expansion, they realize these galaxies emit light at the blue end of the spectrum.)



Two apparently interacting galaxies dominate the left side of this close-up from Hubble's panoramic deep field (at the bottom center of the image on pages 56 and 57). These two have redshifts of 0.08, which means they lie just 1 billion light-years from Earth. The pretty face-on spiral galaxy at top left has a redshift of 0.68, which places it more than 6 billion light-years away. The faintest galaxies here are more than 10 billion light-years distant. NASA/ESA

The large ring-shaped spiral galaxy at the bottom of this detailed close-up image lies 1.3 billion light-years from Earth. It has a redshift of 0.1, which means cosmic expansion has shifted the light it emits 10 percent toward the red end of the spectrum. NASA/ESA



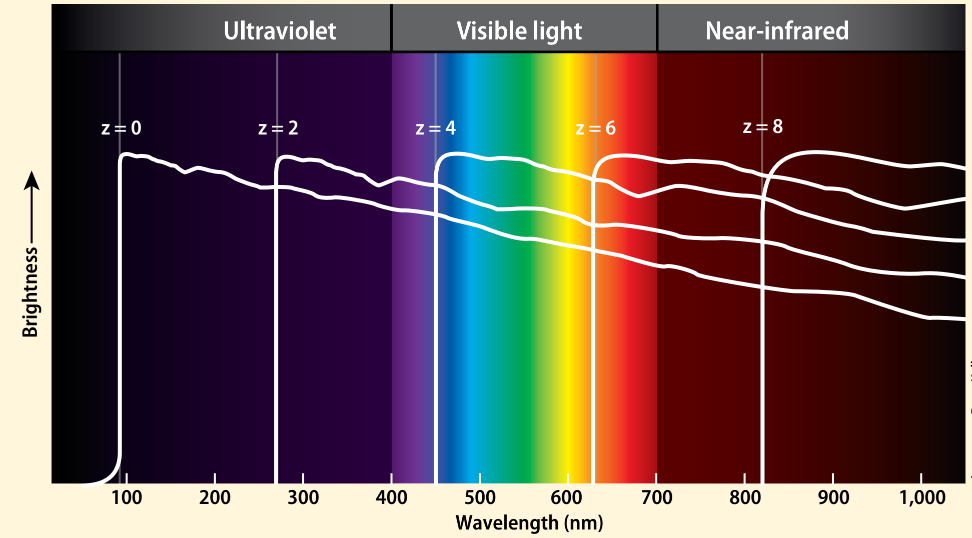
Spying distant galaxies in the Hubble Ultra Deep Field involves finding faint red objects that appear as more than points of light. The bright object just left of center with spikes coming from it is a star in our own galaxy, one of only a handful in this tiny region of sky. NASA/ESA

How to find a galaxy's distance

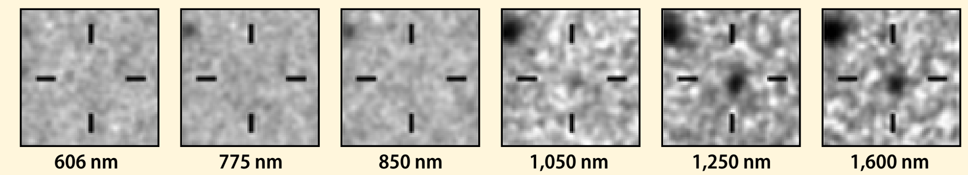
To gauge how far away a distant galaxy is, astronomers need to measure its redshift. Cosmic expansion shifts the light of any object to longer wavelengths, and the farther away it lies, the more the light is redshifted. Usually, an object's spectrum will give you its redshift. Unfortunately, the most distant galaxies are too faint and too red for any telescope to get a spectrum.

But nature provides an alternative. Neutral hydrogen in a galaxy absorbs almost all light with wavelengths shorter than 91.2 nanometers. So, a galaxy's spectrum has a sharp break at that wavelength. For more-distant objects, cosmic expansion causes the break to shift to longer wavelengths.

If astronomers take images of the sky through different filters, a distant object will show up at longer wavelengths and not at shorter ones. The wavelength at which the object disappears, or "drops out," gives an estimate of the redshift. This drop-out technique gives results accurate to about 4 percent. — *R. T.*



The most distant galaxies show up only at near-infrared wavelengths because the light they emit gets redshifted beyond the visible. This graphic shows the effect of redshift on a typical galaxy's light.



A distant galaxy leaps out of the background when viewed at near-infrared wavelengths. This newly discovered galaxy, at a redshift of 8.4, does not appear to Hubble's Advanced Camera for Surveys (the three wavelengths at left) but comes into view at the near-infrared wavelengths the Wide Field Camera 3 can record (the three wavelengths at right). NASA/ESA/G. Illingworth (UC, Santa Cruz)

Astronomers interpret this blueness to mean that the galaxies contain significantly less dust than closer galaxies and few heavy elements. Heavy elements build up in stars over time. Supernova explosions then disperse those elements, which form dust, and the dust scatters and reddens starlight.

"The faintest galaxies are so blue that they are likely to be quite deficient in heavy elements, and thus represent a population that has nearly primordial characteristics," says Illingworth's colleague Rychard Bouwens of the University of California, Santa Cruz. Although they may have some primordial characteristics, these are not primordial galaxies. Combining the new Hubble observations with those made by Spitzer at longer wavelengths shows that galaxies at redshifts of 8 must have been making stars about 300 million years earlier — just 300 million years after the Big Bang.

Into the Dark Ages

These early galaxies lie well within the universe's so-called Dark Ages. This era began some 380,000 years after the Big Bang, once the universe had cooled enough for electrons to combine with protons. The resulting hydrogen atoms allowed light to travel unimpeded for the first time, and the cosmic background radiation started to permeate the cosmos.

Eventually, sometime between 400 and 900 million years after the Big Bang, the young universe generated enough radiation to reionize the hydrogen. But nobody knows for sure what objects contributed to it. Most astronomers think young galaxies did much of the heavy lifting. However, galaxy counts of the youthful cosmos show that they may not have produced the radiation alone. Other scientists suspect mini-quasars fueled by supermassive black holes could have done the trick, or at least helped.

Astronomers hope to glean further clues from additional observations in the GOODS region. The HUDF09 data used to date covers only about one-third of the area researchers plan to observe. Hubble went back and viewed more in February and will wrap up the imaging later in 2010. But it likely will take the James Webb Space Telescope to make real headway. This 6.5-meter telescope, due to launch in 2014, is optimized to observe infrared radiation and take spectra of faint objects.

"This is about as far as we can go to do detailed science with the new HUDF09 image," says Illingworth. "This shows just how much the Webb Telescope is needed to unearth the secrets of the first galaxies."

To learn about the Hubble Space Telescope's earlier deep fields, visit www.Astronomy.com/toc.