Finding Old Galaxies in a Celestial Desert

by Kirsten Gantenbein

Since astronomers first fixed their gazes on the heavens, a great deal has been learned about the universe using only the light gathered from the night sky. Using their eyes and traditional telescopes, scientists revealed the workings our solar system, nearby galaxies, and stars millions of light-years away.

Stars billions of light-years away are a different story. Their light is exceptionally faint and has been impossible to fully decode. That's been frustrating for astronomers since this light has traveled billions of years to reach us, so it carries the images of the universe at its earliest stages.

Dr. Ronald Marzke, now teaching at San Francisco State University, California, and fellow astronomers from the Carnegie Institution of Washington D.C., Cambridge University, England and the University of Toronto, Canada, decided to take on the daunting challenges of deciphering light from such unimaginable distances. They used specialized cameras, immense patience, and other tricks to peer into this remote, unexplored region of space. What they discovered is rewriting the story of how galaxies are born. Current theory holds that galaxies mature incredibly slowly but Marzke and his colleagues found that even in the young universe, galaxies were actually already highly evolved. Their discovery, along with similar ones made at other observatories, have theorists racing to explain the new evidence. But to understand the evolution of galaxies, astronomers must have some sense of how everything began.

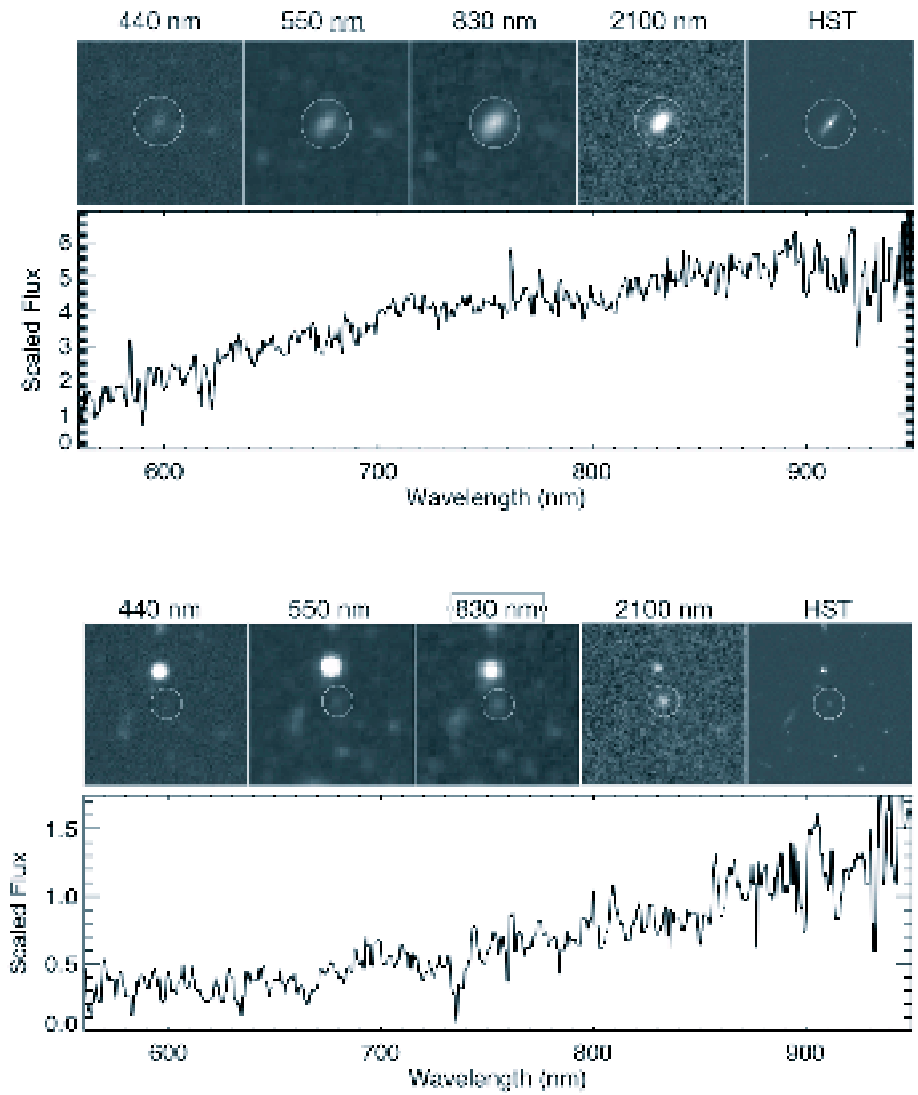
Physicists believe that the universe started with a huge explosion, which hurled all types of matter and energy in all directions. Edwin Hubble and Milton Humason proposed in 1929 that the universe began with a single explosion called the Big Bang. The momentous force from this explosion is still obvious today as most galaxies appear to be moving away from each other.

From these ideas, a theory of galaxy formation called the Hierarchical Model was developed. It predicted that after the Big Bang as stars, clouds of dust and gasses were spreading out, they were also merging together and building themselves up into larger collectives.

Like a rolling snowball, a small clump of stars gathers up other clumps of stars, growing more massive. The end results are huge spiral or disc-shaped galactic structures. "Building mass is a clustering process, and it is one based on gravity," says Marzke. "A strongly clustered population of stars is consistent with gravity being at work and having been at work for a long time." In fact, the Hierarchical Model predicts that gravity can take up to 10 billion years to create the fully evolved galaxies we see neighboring us today. And the estimated age of the universe is only 13.7 billion years.

But much of the evidence that led to the development of the Hierarchical Model comes from local galaxies that can be easily observed by conventional telescopes and instruments. Astronomers use an instrument called a spectrograph, for example, to obtain emission spectra and to learn what atoms a star contains -- its atomic fingerprint.

However, the light from the most distant regions of the universe, which came from galaxies as they were forming,



The montage above shows images and spectra of two galaxies detected in the Las Campanas Infrared Survey and observed in the Gemini Deep Deep Survey. Each galaxy is shown at different wavelengths, ranging from the blue (440 nm) to the near-infrared (2100 nm). In each row, the image at the far right was taken with the Hubble Space Telescope and therefore has much higher resolution than the others, which were taken from the ground. The galaxy at the top is a relatively young spiral galaxy and lies at only moderate redshift (the telltale sign is the spectral feature at 620 nm, which is due to calcium and is observed on earth at approximately 395 nm).

The galaxy at the bottom is an old, elliptical galaxy and lies at much higher redshift in the so-called "redshift desert" (in this case, the primary clue is the feature at 735 nm, an iron feature observed on earth at 280 nm). Note that the older, more distant galaxy is nearly invisible at the bluest wavelengths; this is the primary reason for searching for these galaxies in the near-infrared.

Graphics courtesy of Dr. Marzke

is incredibly faint when it reaches Earth. This makes it hard to record with standard telescopes. And while normally an astronomer can learn a lot from even a small amount of light, flickers coming from this far away pose some additional challenges.

Because the universe is expanding from the Big Bang, the oldest galaxies are moving away from us; this motion affects the light we receive. The same way a siren from an ambulance speeding away seems to drop in pitch, light from a star traveling away from us, with a familiar emission spectrum, stretches and shifts towards the red end of the visible range of light. Astronomers often use the amount of redshift to measure the distance of the star from our vantage point on Earth.

But the light from the regions of space containing the earliest galaxies is stretched beyond the visible range towards the infrared because of their sheer distance. Standard telescopes, instruments and techniques just aren't geared to extracting emission spectra or other data from such faint, redshifted light. "What you're left with is this dead zone which doesn't have any recognizable features," says Marzke. Because the region is difficult to explore, astronomers call it the Redshift Desert. This desert is an area of the universe that is approximately three to six billion years old.

In the desert, when the universe was a quarter of its current age, the Hierarchical Model predicted that baby galaxies were tiny and colliding with each other, in the process of growing larger. But no one had been able to observe light from the universe at this time.

To overcome the challenges of viewing the Redshift Desert, Marzke helped obtain four infrared-sensitive devices for a camera that could record highly redshifted light signals. This camera was mounted onto the 2.5 meter DuPont Telescope at the Carnegie Institution's Las Campanas Observatory, located in a remote desert town in northern Chile.

The light from the Redshift Desert was so faint it took 120 nights, an amount of time rarely granted to astronomers at major observatories, to acquire enough data for what became known as the Las Campanas Infrared Survey. Instead of using standard spectroscopy equipment, they used other techniques to capture light through color filters to more easily measure the redshift of the elusive galaxies. Since the Hierarchical Model predicted that the desert should contain some infant galaxies at best, Marzke says he and his crew were stunned when the first results came in. "These galaxies were just popping up everywhere in numbers we didn't anticipate."

There were two important initial discoveries. First, galaxies in the Redshift Desert were strongly clustered and not scattered randomly as theories previously predicted. Second, there was an abundance of massive, highly evolved galaxies.

However, Marzke and fellow collaborators were skeptical of the data at first. They were using new equipment and alternative methods to measure the near-infrared light and did not want to publish any errors due to miscalculations. To ensure they were doing calculations correctly, the team tried to trick one another by exchanging false data to keep each other critical of everything coming in. "It's a great way to do science," he says. "That's what good collaborations are all about."

By the end of the project, the Las Campanas Infrared Survey catalogued over 100,000 galaxies in the near-infrared range, many of which were located in the Redshift Desert. The results of the survey clearly contradicted the current evolution theory. When the universe was three to six billion years, there supposedly wasn't enough time for so many galaxies to grow from small clusters into enormous structures by the slow process of gravitational clumping. Somehow the growth of these galaxies seemed incredibly accelerated.

The researchers next step was to obtain emission spectra to learn more about what made up these galaxies. To measure the emission spectra of infrared galaxies, they used a new spectrograph built for the largest telescope in the United States National Observatory system, the Gemini eight-meter telescope located on the 14,000-foot summit of Mauna Kea, Hawaii. A team of astronomers focused on galaxies selected from the Las Campanas Infrared Survey to begin the Gemini Deep Deep Survey. They collected as much light as they could from the galaxies and used a special trick to subtract emission spectra from the brighter light of the night sky, which normally obscures the emission spectra of the incredibly faint galaxies in the Redshift Desert.

"We were able to see that the chemical composition of these galaxies was consistent with the idea that they are evolved, whole galaxies that have been in place for some time," explains Marzke.

The galaxy's evolutionary state was evident from the presence of heavy chemical and metal elements from interstellar gas. These heavy elements are cooked up inside stars. When a star dies, it pollutes surrounding star systems with element-rich gases. For example, the iron we have in our blood is the product of stardust. Highly evolved galaxies have collected the elements produced by stars over time. The typical lifespan of a star the size of our sun is 10 billion years. However, the Gemini Deep Deep Survey confirmed that the galaxies in the Redshift Desert were rich in heavy elements during the early history of the universe when stars and galaxies were hypothesized to be just taking shape.

Other telescopes and observatories have recently announced similar findings from observations of infrared galaxies. "The Hubble [telescope] result found a huge structure, a wall of galaxies," says Marzke. So this peek back in time at the early universe has created a new puzzle for theoreticians to solve. There is now a race in the scientific community to explain the new discoveries.

"It's fun to see models being tuned so they can accommodate our observations," says Marzke. Some new ideas suggest that black holes–objects so massive their gravity will not even let light escape from their surface–and other cosmic phenomenon played more of a role in galaxy formation when the universe was so young. These new surveys and discoveries remind scientists that there is still more to discover and learn about the beginning of the universe if they can find more refined and sophisticated ways to gaze at the sky.

"In this branch of astronomy we can't go out and touch things, we can't bring them back into the lab," says Marzke. "We have one thing and that's the light from distant galaxies, so we have to do whatever we can with the light that we have." ✣

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