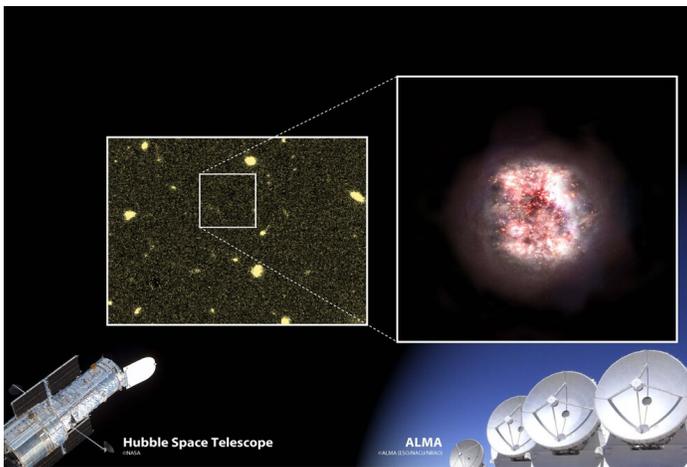


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# Uncovering galaxies buried in dust at the cosmic dawn

Scientists serendipitously discover two heavily dust-enshrouded and previously invisible galaxies that formed when the universe was only 5% of its present age



A schematic showing an image taken by the Hubble Space Telescope of a region of space that looks completely empty (box on left). New research using the Atacama Large Millimeter/submillimeter Array (ALMA) has now revealed that the region contains a previously undiscovered galaxy that was buried deep in clouds of gas and dust. An artist's impression of the galaxy is shown on the right. **IMAGE: ALMA (ESO/NAOJ/NRAO), NASA/ESA HUBBLE SPACE TELESCOPE**

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UNIVERSITY PARK, Pa. — Two previously invisible galaxies completely hidden by clouds of cosmic gas and dust have been discovered by an international team of researchers. While investigating new data of young, extremely distant galaxies observed with the Atacama Large Millimeter/submillimeter Array

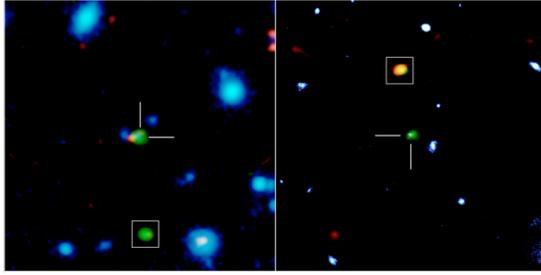
(ALMA) in Chile, astronomers noticed unexpected emissions coming from seemingly empty regions of space. The team, which includes a Penn State scientist, discovered that the radiation was emitted billions of years ago and came from two dust-enshrouded galaxies. This discovery suggests that numerous such galaxies might still be hidden in the early universe, many more than researchers were expecting.

“Studying the most distant galaxies at the cosmic dawn is one of the ultimate frontiers in astronomy,” said Yuexing Li, associate professor of astronomy and astrophysics at Penn State and co-author of the study, which is detailed in a paper appearing today (Sept. 22) in the journal *Nature*. “It is essential for our understanding of the formation of stars and interstellar medium in the early universe, which impacts the formation and evolution of galaxies at the present day such as our own Milky Way.”

When astronomers peer deep into the night sky, they observe what the universe looked like a long time ago. Because the speed of light is finite, images of the earliest galaxies provide us a glimpse of billions of years into the past. A key goal of scientists is to identify all the galaxies in the first billion years of cosmic history and to measure the rate at which the galaxies were growing by forming new stars.

Various efforts have been made over the past decades to observe distant galaxies, which are characterized by electromagnetic emissions that become strongly redshifted — shifted toward longer wavelengths — before reaching the Earth. So far, our knowledge of early galaxies has mostly relied on observations with the Hubble Space Telescope (HST), which probes the ultraviolet (UV) emission from stars. However, recently, astronomers have started to use the unique capability of the ALMA telescope to study distant galaxies at submillimeter wavelengths, which can capture emissions from dust and gas. This could be particularly useful for studying dusty galaxies missed in the HST surveys due to the dust absorbing UV light.

In an ongoing large program, called REBELS (Reionization-Era Bright Emission Line Survey), astronomers are using ALMA to observe the emissions of 40 target galaxies at a time when the universe was only 5% of its current age. While analyzing the images for two of the galaxies, the astronomers noticed strong mysterious emissions at millimeter wavelengths far away from the intended targets. To their surprise, the extremely sensitive HST could not detect any UV photons from these locations.



Distant galaxies as seen with the Atacama Large Millimeter/submillimeter Array (ALMA), the Hubble Space Telescope (HST), and the European Southern Observatory's VISTA telescope. Researchers studying the two target galaxies in the cross hairs discovered by HST with ALMA noticed emissions from the two galaxies in the squares that were missed by HST. Green represents emission from dust, orange is radiation from ionized carbon atoms (both observed with ALMA) and blue is light emission at near-infrared wavelengths from VISTA and HST. The newly discovered galaxies are only seen with ALMA, which suggests that these galaxies are deeply buried in dust.

**IMAGE: ALMA (ESO/NAOJ/NRAO), NASA/ESA HUBBLE SPACE TELESCOPE, ESO, FUDAMOTO ET AL.**

To understand the ALMA signals, the REBELS researchers investigated matters further. Detailed analysis of the data showed that they were in fact emission by dust and singly ionized carbon in two star-forming galaxies completely missed by HST.

“These new galaxies were missed not because they are extremely rare, but only because they are completely dust-obscured,” said lead author Yoshinobu Fudamoto of the Research Institute for Science and Engineering at Waseda University, Japan, and the National Astronomical Observatory of Japan (NAOJ).

One of the galaxies represents the most distant dust-obscured galaxy discovered so far.

What is most surprising about this serendipitous finding is that the newly discovered galaxies, which formed more than 13 billion years ago, are quite similar to galaxies that are known to exist at later times. However, it was unexpected to find such dust-enshrouded galaxies this early, less than one billion years after the Big Bang. This discovery suggests that the current census of early galaxy formation is most likely incomplete, and would call for deeper, blind surveys.

“It is possible that we have been missing up to one out of every five galaxies in the early universe so far,” said Fudamoto.

The researchers expect that the unprecedented capability of the James Webb Space Telescope (JWST), which is anticipated to be launched in December 2021, and its strong synergy with ALMA could lead to significant advances in this field in the coming years.

“Completing our census of early galaxies with the currently missing dust-obscured galaxies, like the ones we found this time, will be one of the main objectives of JWST and ALMA surveys in the near future,” said Pascal Oesch from University of Geneva.

“We need accurate and consistent theoretical models to understand the multi-wavelength surveys,” said Li, who leads cosmological simulations of galaxies and their panchromatic properties at Penn State.

Overall, this study constitutes an important step in uncovering when the very first galaxies started to form in the early universe, which in turn will help researchers to understand the universe today.

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