Astronomers pinpoint elusive galaxy - and find it is not alone

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Four antennas of the IRAM telescope on the Plateau de Bure in the French Alps. With this compound telescope, the research team identified the first of the spectral lines of the galaxy HDF850.1 allowing them to determine the galaxy's distance. Credi: IRAM/Rebus

An international team of astronomers has for the first time determined the distance of the galaxy HDF850.1. The discovery challenges and expands our understanding of how galaxies are born and develop over time.

An international team of astronomers has managed for the first time to determine the distance of the galaxy HDF850.1, well-known among astronomers as being one of the most productive star-forming galaxies in the observable universe.

The galaxy is at a distance of 12.5 billion light years. Hence, we see it as it was 12.5 billion years ago, when the universe was less than 10 percent of its current age.

Even more of a surprise, HDF850.1 turns out to be part of a group of around a dozen protogalaxies that formed within the first billion years of cosmic history – only one of two such primordial clusters known to date. The work is published in the journal Nature.

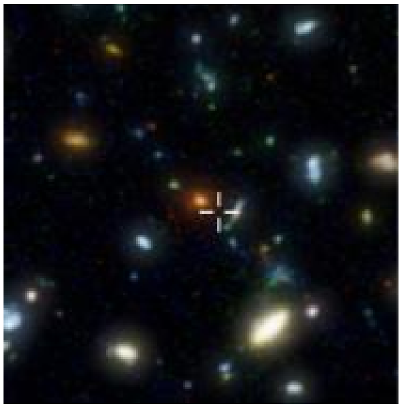
"This galaxy is special because it's so young, it's massive, and it churns out stars at an unexpectedly high rate," said Brant Robertson, an assistant professor at the University of Arizona's Steward Observatory and department of astronomy who studies how galaxies come to be and how they evolve over time.

"Any clue we can get about how those early galaxies formed helps us better understand this process," Robertson said. "We can use them to test our models."

The galaxy HDF850.1 was discovered in 1998. It is famous for producing new stars at a rate that is near-incredible even on astronomical scales: a combined mass of a thousand Suns per year. For comparison: an ordinary galaxy such as our own produces no more than 1 to 4 solar mass's worth of new stars per year.

Yet for the past 14 years, HDF850.1 has remained strangely elusive. Its location in space, specifically its distance from Earth – the subject of many studies – ultimately remained unknown.

How was that possible?



The region of the Hubble Deep Field where HDF850.1 is located (cross) is a glimpse into the abyss of space and time, 12.5 billion light years away. For observations with ordinary, visible light telescopes such as the Hubble Space Telescope, the galaxy is invisible. Credit: STScI/NASA, F. Walter (MPIA

"A vast cloud of dust keeps HDF850.1 hidden from telescopes searching the universe in the visible light range, so even the Hubble Space Telescope can't see it," Robertson said. "If it wasn't for the dust layer, this galaxy would shine bright and blue with the intense light from the newly forming stars."

The "Hubble Deep Field," where HDF850.1 is located, is a region in the sky that affords an almost unparalleled view into the deepest reaches of space. It was first studied extensively using the Hubble Space Telescope.

Yet observations using visible light only reveal part of the cosmic picture, and astronomers were quick to follow-up at different wavelengths.

In the late 1990s, astronomers using the James Clerk Maxwell Telescope on Hawai'i surveyed the region using submillimeter radiation. This type of radiation, with wavelengths between a few tenths of a millimeter and a millimeter, is particularly suitable for detecting cool clouds of gas and dust.

"The galaxy's invisibility is no great mystery," explained team leader Fabian Walter of the Max Planck Institute for Astronomy in Heidelberg, Germany.

"Stars form in dense clouds of gas and dust. These dense clouds are opaque to visible light, hiding the galaxy from sight. Submillimeter radiation passes through the dense dust clouds unhindered, showing what is inside," Walter said. "But the lack of data from all but a very narrow range of the spectrum made it very difficult to determine the galaxy's redshift, and thus its place in cosmic history."

Robertson, together with UA astronomer Daniel Stark, was part of the team and said: "We knew where to look but we didn't know how far away it was."

Taking advantage of recent upgrades to the IRAM interferometer on the Plateau de Bure in the French Alps, which combines six radio antennas that then act as a gigantic millimeter-wavelength telescope, the team identified the characteristic features ("spectral lines") necessary for an accurate distance determination.

The researchers were taken by surprise when they realized that HDF850.1 was the brightest source of submillimeter emission in the field by far, a galaxy that was evidently forming as many stars as all the other galaxies in the Hubble Deep Field combined – and which was completely invisible in the observations of the Hubble Space Telescope.

IRAM's antennas are mounted on rails, combining their signals into the resolving power of a much larger "virtual antenna." At maximum separation, they can resolve 0.5 arcseconds of sky at an observing wavelength of 1.3 mm (230 GHz), equal to the apparent size of an apple at a distance of 60 km, or about 37 miles. Credit: IRAM/Rebus

A combination with observations obtained at the National Science Foundation's Karl Jansky Very Large Array (VLA) in Socorro, New Mexico, then revealed that a large fraction of the galaxy's mass is in the form of molecules – the raw material for future stars. The fraction is much higher than what is found in galaxies in the local universe.

Once the distance was known, the researchers were also able to put the galaxy into context. Using additional data from published and unpublished surveys, they were able to show that the galaxy is part of what appears to be an early form of galaxy cluster – one of only two such clusters known to date.

Previous work by Stark, now a Hubble Fellow at the UA's Steward Observatory, helped place the galaxy in its cosmic context.

Together with Richard Ellis at Caltech, Stark conducted a survey along with of distant galaxies in the Hubble Deep Field, the same area of the sky which contains HDF 850.1, over the last several years. Using an optical spectrograph on the Keck Telescope in Hawai'i, they determined the distances to many galaxies in this field.

"After Fabian Walter determined the distance to HDF 850.1, he contacted us to see whether our survey revealed other galaxies in the Hubble Deep Field at exactly the same distance as HDF 850.1," Stark said. "I looked through my database and quickly found that HDF 850.1 isn't alone. Our Keck survey, combined with the work of another team, contained nearly a dozen galaxies at the same distance, implying that we are witnessing the formation of an early cluster of galaxies."

Another surprise came when the group detected large amounts of carbon monoxide in HDF850.1's dust cloud, a gas that can only be produced by exploding stars ending their lives as supernovae.

"This tells us that even at the young age that we see this galaxy, it has been forming stars for a long time," Robertson said. "A lot of dust means a lot of stars."

At this point, researchers can't be quite sure how representative galaxies like HDF850.1 are of the whole universe, which is why more deep field observations are required to obtain a more complete picture and will greatly improve our understanding of galaxies in general.

"We are only beginning to understand galaxies at that time in the universe, and seeing one with this much dust and star-forming activity throws a wrench into what we currently believe," Robertson said.

The new work highlights the importance of future, more powerful interferometers operating at millimeter and submillimeter wavelengths.

Both NOEMA, the future extension of the Plateau de Bure interferometer, and ALMA, a new interferometer array currently being built by an international consortium in the Atacama Desert in Chile, will cover these wavelengths in unprecedented detail. They should allow for distance determinations and more detailed study of many more galaxies, invisible at optical wavelengths, that were actively forming stars in the early universe.

Robertson said about 10 or 20 such deep field observations would be required, demanding hundreds of hours of observing time, which would be prohibitively costly especially with space telescopes. UA astronomers are heavily involved in learning more about how the earliest galaxies form.

"We are continuing to catalog the distances and properties of some of the earliest-known galaxies," Stark said. "As more ‘optically-invisible' systems like HDF 850.1 are discovered, this work will continue to be important for determining the cosmic environments that these early vigorously-forming galaxies are situated in."

Robertson and Stark are part of a different team planning to make the deepest field image ever taken with any telescope, going back about 13.2 billion years in time, when the universe was just about 500 million years old.

So what does HDF850.1 look like today? Given that by the time its light gets here, the Sun will have long swallowed Earth and flickered out, what is the astronomers' best guess?

"The galaxy is probably extremely big by now," Robertson said. "With all those other galaxies that surround it, it would just get big and bigger and bigger. There is not much else it could do."

Provided by University of Arizona