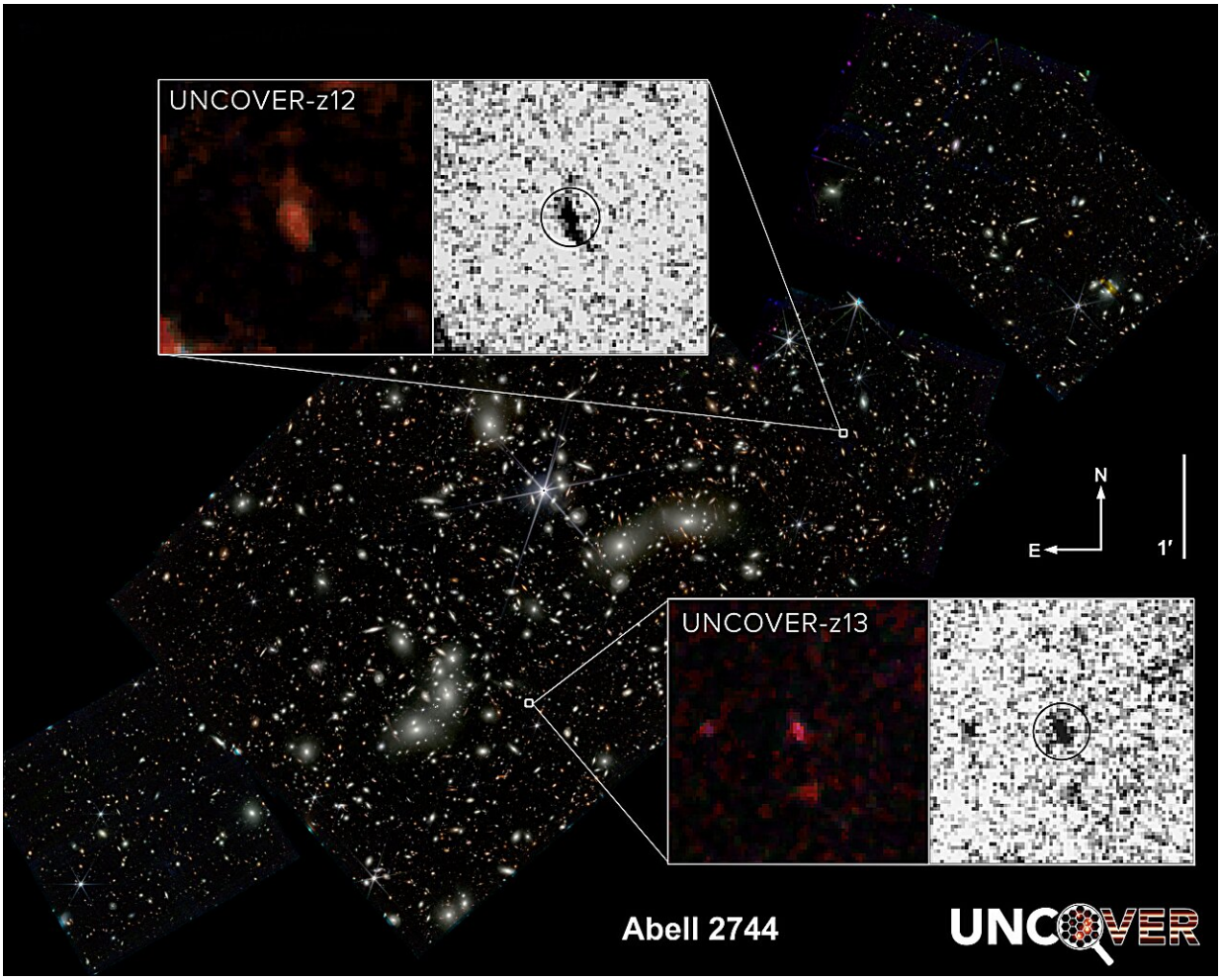
Second-most distant galaxy discovered using James Webb Space Telescope

November 13 2023



The second- and fourth-most distant galaxies ever seen (UNCOVER z-13 and UNCOVER z-12) have been confirmed using the James Webb Space Telescope's Near-Infrared Camera (NIRCam). The galaxies are located in Pandora's Cluster (Abell 2744), show here as near-infrared wavelengths of light that have been translated to visible-light colors. The scale of the main cluster

image is labelled in arcseconds, which is a measure of angular distance in the sky. The circles on the black-and-white images, showing the galaxies in the NIRCam-F277W filter band onboard JWST, indicate an aperture size of 0.32 arcsec. Credit: Cluster image: NASA, UNCOVER (Bezanson et al., DIO: 10.48550/arXiv.2212.04026) Insets: NASA, UNCOVER (Wang et al., 2023) Composition: Dani Zemba/Penn State

The second- and fourth-most distant galaxies ever observed have been discovered in a region of space known as Pandora's Cluster, or Abell 2744, using data from NASA's James Webb Space Telescope (JWST).

Following up on a deep field image of the area, an international team led by Penn State researchers confirmed the distance of these ancient galaxies and inferred their properties using new spectroscopic data—information about light emitted across the electromagnetic spectrum—from JWST. At nearly 33 billion light years away, these incredibly distant galaxies offer insights into how the earliest galaxies might have formed.

Unlike other galaxies confirmed at this distance that appear in images as red dots, the new galaxies are larger and appear like a peanut and a fluffy ball, according to the researchers. A paper describing the galaxies appears in the journal *Astrophysical Journal Letters*.

"Very little is known about the early universe, and the only way to learn about that time and to test our theories of early galaxy formation and growth is with these very distant galaxies," said first author Bingjie Wang, postdoctoral scholar in the Penn State Eberly College of Science and a member of the JWST UNCOVER (Ultradeep NIRSpec and NIRCam ObserVations before the Epoch of Reionization) team that conducted the research.

"Prior to our analysis, we knew of only three galaxies confirmed at around this extreme distance. Studying these new galaxies and their properties has revealed the diversity of galaxies in the early universe and how much there is to be learned from them."

Because the light from these galaxies had to travel for so long to reach Earth, it provides a window into the past. The research team estimates that the light detected by JWST was emitted by the two galaxies when the universe was about 330 million years old and traveled for about 13.4 billion light years to reach the JWST. But, the researchers said, the galaxies are currently closer to 33 billion light years away from Earth due to the expansion of the universe over this time.

"The light from these galaxies is ancient, about three times older than the Earth," said Joel Leja, assistant professor of astronomy and astrophysics at Penn State and a member of UNCOVER. "These early galaxies are like beacons, with light bursting through the very thin hydrogen gas that made up the early universe. It is only by their light that we can begin to understand the exotic physics that governed the galaxy near the cosmic dawn."

Notably, the two galaxies are considerably larger than the three galaxies previously located at these extreme distances. One is at least six times larger at about 2,000 light years across. For comparison, the Milky Way is approximately 100,000 light years across, but, Wang said, the early universe is thought to have been very compressed, so it's surprising that the galaxy is as large as it is.

"Previously discovered galaxies at these distances are point sources—they appear as a dot in our images," Wang said.

"But one of ours appears elongated, almost like a peanut, and the other looks like a fluffy ball. It is unclear if the difference in size is due to

how the stars formed or what happened to them after they formed, but the diversity in the galaxy properties is really interesting. These early galaxies are expected to have formed out of similar materials, but already they are showing signs of being very different than one another."

The two galaxies were among 60,000 sources of light in Pandora's Cluster detected in one of JWST's first deep field images taken during 2022, its first year of science operations. This region of space was selected in part because it is located behind several galaxy clusters that create a natural magnification effect called gravitational lensing.

The gravitational pull of the clusters' combined mass warps the space around it, focusing and magnifying any light that passes nearby and providing a magnified view behind the clusters.

In a matter of months, the UNCOVER team narrowed down the 60,000 light sources to 700 candidates for follow up study, eight of which they thought could potentially be among the first galaxies. Then, JWST again pointed at Pandora's Cluster, recording the candidates' spectra—a sort of fingerprint detailing the amount of light given off at each wavelength.

"Several different teams are using different approaches to look for these ancient galaxies, and each have their strengths and weaknesses," Leja said.

"The fact that we're pointing at this giant magnifying lens in space gives us an incredibly deep window, but it's a very small window so we were rolling the dice. Several of the candidates were inconclusive, and at least one was a case of mistaken identity—it was something much closer that mimics a distant galaxy. But we were lucky, and two turned out to be these ancient galaxies. It's incredible."

The researchers also used detailed models to infer the properties of these

early galaxies when they emitted the light detected by JWST. As the researchers expected, the two galaxies were young, had few metals in their composition, and were growing rapidly and actively forming stars.

"The first elements were forged in the cores of early stars through the process of fusion," Leja said. "It makes sense that these early galaxies don't have heavy elements like metals because they were some of the first factories to build those heavy elements. And, of course, they would have to be young and star-forming to be the first galaxies, but confirming these properties is an important basic test of our models and helps confirm the whole paradigm of the Big Bang theory."

The researchers noted that, alongside the gravitational lens, JWST's powerful infrared instruments should be able to detect galaxies at an even further distance, if they exist.

"We had a very tiny window into this region, and we didn't observe anything beyond these two galaxies, even though JWST has the capability," Leja said. "That could mean that galaxies just didn't form before that time and that we're not going to find anything further away. Or it could mean we didn't get lucky enough with our small window."

This work was the result of a successful proposal submitted to NASA suggesting how to use JWST during its first year of science operations. In the first three cycles of submissions, NASA received four to ten times more proposals than available observing time on the telescope would allow and had to select only a fraction of those proposals.

"Our team was very excited and a little surprised when our proposal was accepted," Leja said. "It involved coordination, quick human action and the telescope pointing at the same thing twice, which is a lot to ask of a telescope in its first year. There was a lot of pressure because we only had a few months to determine the objects for follow up. But JWST was

built for finding these first galaxies, and it's so exciting to be doing that now."

In addition to Penn State, the team includes researchers from the University of Texas Austin, the Swinburne University of Technology in Australia, Ben-Gurion University of the Negev in Israel, Yale University, the University of Pittsburgh, Sorbonne Université in France, the University of Copenhagen in Denmark, the University of Geneva in Switzerland, the University of Massachusetts, the University of Groningen in the Netherlands, Princeton University, Waseda University in Japan, Tufts University and the National Optical-Infrared Astronomy Research (NOIR) Lab.

More information: Bingjie Wang et al, UNCOVER: Illuminating the Early Universe—JWST/NIRSpec Confirmation of z > 12 Galaxies, *The Astrophysical Journal Letters* (2023). DOI: 10.3847/2041-8213/acfe07

Provided by Pennsylvania State University