Four revelations from the Webb telescope about distant galaxies

Astronomers are analysing spectacular snapshots of the faraway Universe.

NASA built its state-of-the-art James Webb Space Telescope to peer into the distant Universe and back towards the dawn of time — and it's already doing so spectacularly. In the three weeks since Webb's first science images and data became available to astronomers, they have reported a flood of preliminary discoveries, including multiple contenders for what could be the most distant galaxy ever seen.

Webb's images reveal a wealth of galaxies glimmering in the distant cosmos, appearing as they did just a few hundred million years after the Big Bang, 13.8 billion years ago. The telescope's astonishingly sharp pictures have shattered astronomers' preconceptions about the early Universe.

"We had in mind an idea of what galaxies at these [distances] would look like, and how much detail we'd be able to see, but I think the reality is just kind of blowing our mind," says Jeyhan Kartaltepe, an astronomer at the Rochester Institute of Technology in New York.

Here are some things astronomers are learning from Webb's first observations.

NASA/ESA/CSA/STSCI

This deep-field Webb telescope image was revealed by US President Joe Biden on 11 July.

There are an awful lot of galaxies

Because Webb detects infrared light, and because the expansion of the cosmos stretches light to redder wavelengths, the telescope is well suited to spotting galaxies that formed early in the Universe's history. In its first observing programmes, which began in June, Webb discovered many galaxies that lie beyond the reach of other observatories, such as the Hubble Space Telescope.

"It suggests what many of us have been arguing, that there are galaxies out there beyond what we saw with Hubble," says Richard Ellis, an astronomer at University College London.

The era of early galaxies began at 'cosmic dawn', starting perhaps 250 million years after the Big Bang, when the first stars formed and lit up the Universe. Later generations of stars amassed themselves into galaxies, which are the faint red blobs that Webb is beginning to discover.

Many of the Webb images are peppered with never-before-seen galaxies in the distant Universe. "There's hardly any empty space that doesn't have something," Kartaltepe says.

One study combed through data from many of the distant galaxy fields that Webb has observed so far, to analyse the rate at which stars formed in the early Universe. It found 44 previously unknown galaxies stretching back to within 300 million years of the Big Bang. Combined with 11 previously known galaxies, the findings show that there was a significant population of galaxies forming stars in the early Universe[1]. The results "re-affirm the enormous potential of forthcoming larger [Webb] programmes to transform our understanding of the young Universe", wrote the team, led by Callum Donnan at the University of Edinburgh, UK, in a preprint.

Many galaxies could be the 'most distant'

Perhaps the highest-profile rush is the stampede of research teams vying to identify the most distant galaxy in the Webb data. Researchers have spotted several candidates that will need to be confirmed through further studies; all would break Hubble's record for the most-distant galaxy, which dates to around 400 million years after the Big Bang[2,3].

One contender popped up in a Webb survey called GLASS that included another, slightly less faraway galaxy in the same image[4]. "The fact that we found these two bright galaxies, that was really a surprise," says Marco Castellano, an astronomer at Italy's National Institute for Astrophysics in Rome. He and his colleagues weren't expecting to find any galaxies that distant in this small part of the sky. (A second team also spotted the two galaxies[5].)

Astronomers characterize the distance of galaxies with a measure known as redshift, which quantifies how much a galaxy's light has been shifted to redder wavelengths; the higher the redshift, the more distant the galaxy. The

GLASS candidate has a redshift of about 13. But on 25 and 26 July, days after astronomers reported the GLASS galaxies, papers claiming even higher redshifts flooded the arXiv preprint server. "This is just the beginning of the beginning," says Rohan Naidu, an astronomer at the Harvard–Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

One candidate, at a redshift of 14, emerged in a survey called CEERS, one of Webb's highest-profile early projects. Its principal investigator, Steven Finkelstein at the University of Texas at Austin, nicknamed the object Maisie's Galaxy, after his daughter[6]. Another study looked at the very first deep-field image from Webb, released by US President Joe Biden on 11 July, and found two potential galaxies at a redshift of 16, which would place them at just 250 million years after the Big Bang[7]. And arXiv papers speculate on other candidates, with redshifts as high as 20 (ref. 8).

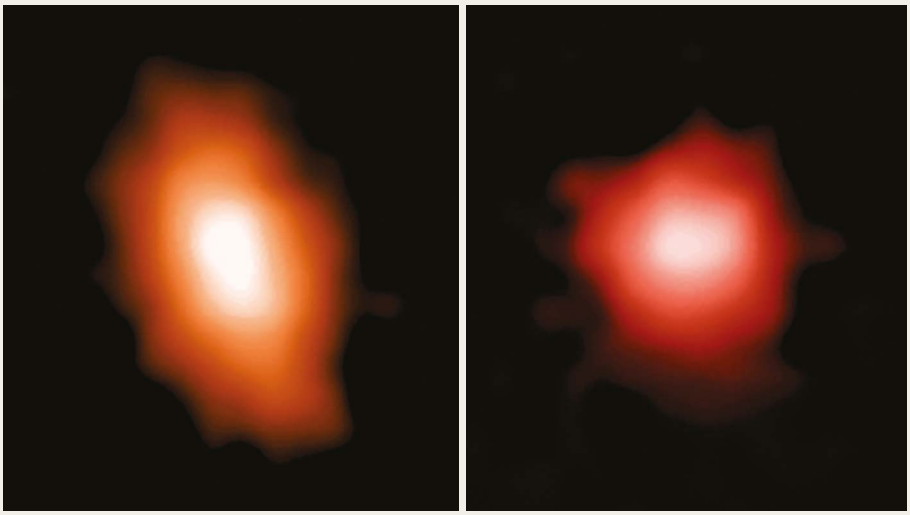
Some early galaxies are complex

Webb's distant galaxies are also turning out to have more structure than astronomers had expected. One study of Webb's first deep-field image found a surprisingly large number of distant galaxies that are shaped like disks[9]. Using Hubble, astronomers had concluded that distant galaxies are more irregularly shaped than nearby ones, which, like the Milky Way, often display regular forms such as disks. The theory was that early galaxies were more often distorted by interactions with neighbouring galaxies. But the Webb observations suggest there are up to ten times as many distant disk-shaped galaxies as was previously thought.

"With the resolution of James Webb, we are able to see that galaxies have disks way earlier than we thought they did," says Allison Kirkpatrick, an astronomer at the University of Kansas in Lawrence. That's a problem, she says, because it contradicts earlier theories of galaxy evolution.

Another preprint suggests that massive galaxies formed earlier in the Universe than was thought. A team led by Ivo Labbé at the Swinburne University of Technology in Melbourne, Australia, reports finding 7 huge galaxies in the CEERS field, with redshifts between 7 and 10 (ref. 10). "Massive galaxy formation began extremely early in the history of the Universe," the scientists write.

And studies of galactic chemistry also show a rich and complicated picture emerging from the Webb data. One analysis of the first deep-field image examined the light emitted by galaxies at a redshift of 5 or greater. It found a surprising richness of elements such as oxygen[11]. (Spectral lines that are observed at various wavelengths of light correlate with the chemical elements composing the galaxies.) Astronomers had thought that the process of chemical enrichment — in which stars fuse hydrogen and helium to form heavier elements — took a while, but seeing it in early galaxies "will make us rethink the speed at which star formation occurs", Kirkpatrick says.



JWST GLASS SURVEY NASA/CSA/ESA/STSCI; PASCAL OESCH/UNIV. GENEVA

Astronomers found these two distant galaxies in the same small part of the sky.

"We are able to see that galaxies have disks way earlier than we thought they did."

Closer galaxies are smaller than expected

The surprises from Webb continue even a little later in the Universe's evolution. One study looked at Webb's observations of 'cosmic noon', the period roughly three billion years after the Big Bang, when star formation peaked in the Universe.

Wren Suess, an astronomer at the University of California, Santa Cruz, compared Hubble images of galaxies at cosmic noon with Webb images of the same galaxies. At the infrared wavelengths detected by Webb, most of the massive galaxies looked much smaller than they did in Hubble images[12]. "It potentially changes our whole view of how galaxy sizes evolve over time," Suess says. Hubble studies suggested that galaxies start out small and grow bigger, but the Webb findings hint that Hubble didn't have the whole picture, so galactic evolution might be more complicated than anticipated.

With Webb just at the beginning of a planned 20-year run, astronomers know a lot of changes lie ahead. "Right now I find myself lying awake at three in the morning," Kirkpatrick says, "wondering if everything I've ever done is wrong."

By Alexandra Witze

1. Donnan, C. T. *et al*. Preprint at https://arxiv.org/abs/2207.12356 (2022).
2. Oesch, P. A. *et al*. *Astrophys. J.* **819**, 129 (2016).
3. Jiang, L. *et al*. *Nature Astron.* **5**, 256–261 (2021).
4. Castellano, M. *et al*. Preprint at https://arxiv.org/abs/2207.09436 (2022).
5. Naidu, R. P. *et al*. Preprint at https://arxiv.org/abs/2207.09434 (2022).
6. Finkelstein, S. L. *et al*. Preprint at https://arxiv.org/abs/2207.12474 (2022).
7. Atek, H. *et al*. Preprint at https://arxiv.org/abs/2207.12338 (2022).
8. Yan, H. *et al*. Preprint at https://arxiv.org/abs/2207.11558 (2022).
9. Ferreira, L. *et al*. Preprint at https://arxiv.org/abs/2207.09428 (2022).
10. Labbé, I. *et al*. Preprint at https://arxiv.org/abs/2207.12446 (2022).
11. Trump, J. R. *et al*. Preprint at https://arxiv.org/abs/2207.12388 (2022).
12. Suess, K. A. *et al*. Preprint at https://arxiv.org/abs/2207.10655 (2022).