RESEARCH NEWS STORY

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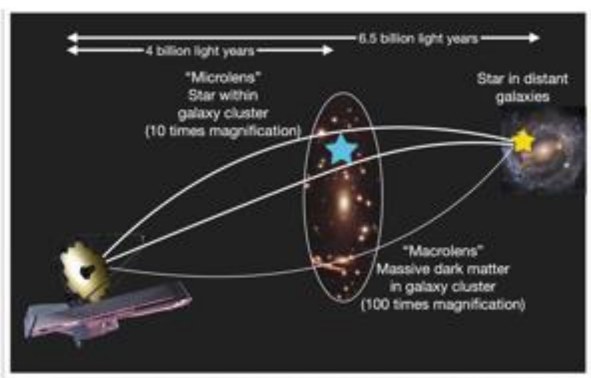
Chiba University

Beyond the 'Dragon Arc,' a treasure trove of unseen stars

Astronomers took pictures of more than 40 individual stars in a galaxy so far away its light dates back to when the universe was only half its present age.

Looking halfway across the observable universe and expecting to see individual stars is considered a non-starter in astronomy, a bit like raising a pair of binoculars at the moon in hopes of making out individual grains of dust inside its craters. Thanks to a cosmic quirk of nature, however, an international team led by astronomers at the University of Arizona's Steward Observatory did just that.



Left: The massive, yet invisible halo of dark matter of a galaxy cluster works as a "macrolens,", while lone, unbound stars drifting through the cluster act as additional "microlenses, multiplying the factor of magnification.
Credit: Yoshinobu Fudamoto

Right: Hubble image of Abell 370. Abell 370, a galaxy cluster located nearly 4 billion light-years away from Earth features several arcs of light, including the "Dragon Arc" (lower left of center). These arcs are caused by gravitational lensing: Light from distant galaxies far behind the massive galaxy cluster coming toward Earth is bent around Abell 370 by its massive gravity, resulting in contorted images. Credit: NASA
Dragon Arc: In this zoomed-in detail of the Hubble image of Abell 370, the host galaxy where the 44 stars were discovered appears several times: in a normal image (left), and a distorted image appearing as a drawn-out smear of light.
Credit: NASA

Using NASA's James Webb Space Telescope, or JWST, the research group observed a galaxy nearly 6.5 billion light-years from Earth, at a time when the universe was half its current age. In this distant galaxy, the team identified a large number of individual stars, made visible thanks to an effect known as gravitational lensing and JWST's high light collecting power.

Published in the journal Nature Astronomy, the discovery marks a record-breaking achievement – the largest number of individual stars detected in the distant universe. It also provides a way to investigate one of the universe's greatest mysteries – dark matter.

Most galaxies, including the Milky Way, contain tens of billions of stars. In nearby galaxies such as the Andromeda galaxy, astronomers can observe stars one by one. However, in galaxies billions of light-years away, stars appear blended together as their light needs to travel for billions of light-years before it reaches us, presenting a long-standing challenge to scientists studying how galaxies form and evolve.

"To us, galaxies that are very far away usually look like a diffuse, fuzzy blob," said lead study author Yoshinobu Fudamoto, an assistant professor at Chiba University in Japan and a visiting scholar at Steward Observatory. "But actually, those blobs consist of many, many individual stars. We just can't resolve them with our telescopes."

Recent advances in astronomy have opened new possibilities by leveraging gravitational lensing – a natural magnification effect caused by the strong gravitational fields of massive objects. As predicted by Albert Einstein, gravitational lenses can amplify the light of distant stars by factors of hundreds or even thousands, making them detectable with sensitive instruments like JWST.

"These findings have typically been limited to just one or two stars per galaxy," Fudamoto said. "To study stellar populations in a statistically meaningful way, we need many more observations of individual stars."

Fengwu Sun, a former U of A graduate student who is now a postdoctoral scholar at the Center for Astrophysics | Harvard & Smithsonian, stumbled on a treasure trove of such stars when he was inspecting JWST images of a galaxy known as the Dragon Arc, located along the line of sight from Earth behind a massive cluster of galaxies called Abell 370. Due to its gravitational lensing effect, Abell 370 stretches the Dragon Arc's signature spiral into an elongated shape – like a hall of mirrors of cosmic proportions.

In December 2022 and 2023, JWST obtained two pictures of the Dragon Arc. Within these images, astronomers counted 44 individual stars whose brightness changed over time due to variations in the gravitational lensing landscape.

"This groundbreaking discovery demonstrates, for the first time, that studying large numbers of individual stars in a distant galaxy is possible," Sun said – as long as nature is there to lend a helping hand.

However, even extremely strong gravitational magnification from a galaxy cluster is not sufficient to magnify individual stars in galaxies even farther away. In this case, the discovery was made possible by a serendipitous alignment of "lucky stars."

"Inside the galaxy cluster, there are many stars floating around that are not bound by any galaxy," said co-author Eiichi Egami, a research professor at Steward Observatory. "When one of them happens to pass in front of the background star in the distant galaxy along the line of sight with Earth, it acts as a microlens, in addition to the macrolensing effect of the galaxy cluster as a whole."

The combined effects of macrolensing and microlensing dramatically increase the magnification factor, allowing JWST to pick up individual stars that otherwise would be too far and faint to be detected at all.

Because the stars inside the magnifying cluster move relative to the target stars in the distant galaxy and Earth, the alignment of microlenses in this natural "telescope" changes slightly over short timeframes – from a few days to a week. When they are perfectly aligned, the brightness and magnification of the distant stars increase dramatically, only to fade again shortly afterwards.

"By observing the same galaxy multiple times, we can spot stars in distant galaxies because they appear to pop in and out of existence," Fudamoto said. "This is a result of the varying effective magnifications from the macro- and microlensing effect as the microlensing stars move in and out of the line of sight."

The research team carefully analyzed colors of each of the stars inside the Dragon Arc and found that many are red supergiants, similar to Betelgeuse in the constellation of Orion, which is in the final stages of its life. This contrasts with earlier discoveries, which predominantly identified blue "supergiants" similar to Rigel and Deneb, which are among the brightest stars in the night sky. According to the researchers, this difference in stellar types also highlights the unique power of JWST observations at infrared wavelengths that could detect stars at lower temperatures.

Future JWST observations are expected to capture more magnified stars in the Dragon Arc galaxy. These efforts could lead to detailed studies of hundreds of stars in distant galaxies. Moreover, observations of individual stars could provide insight into the structure of gravitational lenses and even shed light on the elusive nature of dark matter.

Reference:
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