Cosmic magnifying lenses distort view of distant galaxies

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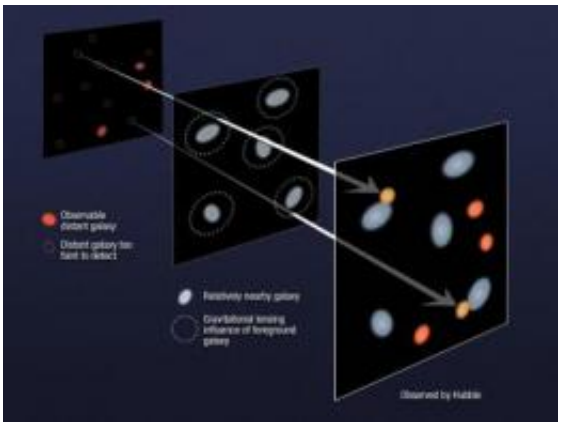
This color composite image of the Hubble Ultra Deep Field was created using data taken by its WFC3 and ACS instruments. The green circles mark the locations of candidate galaxies at redshifts about z =8-10, when the Universe was only 650-480 million years old. About 20-30 percent of these candidates are very close to foreground galaxies, which is consistent with the prediction that a significant fraction of galaxies that we could see at these very high redshifts are gravitationally lensed by individual foreground galaxies. Credit: Photo credit: NASA, ESA, Z. Levay and A. Feild (STScI). Data Credit: S. Beckwith (STScI) and the HUDF team; G. Illingworth and R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team.

Looking deep into space, and literally peering back in time, is like experiencing the universe in a house of mirrors where everything is distorted through a phenomenon called gravitational lensing. Gravitational lensing occurs when light from a distant object is distorted

by a massive object that is in the foreground. Astronomers have started to apply this concept in a new way to determine the number of very distant galaxies and to measure dark matter in the universe. Though recent progress has been made in extending the use of gravitational lensing, a letter published in *Nature* on Jan. 13 makes the case that the tool may be even more necessary than originally thought when looking at distant galaxies.

Albert Einstein showed that gravity will cause light to bend. The effect is normally extremely small, but when light passes close to a very massive object such as a massive galaxy, a galaxy cluster, or a supermassive black hole, the bending of the light rays becomes more easily noticeable.

When light from a very distant object passes a galaxy much closer to us, it can detour around the foreground object. Typically, the light bends around the object in one of two, or four different routes, thus magnifying the light from the more distant galaxy directly behind it. This natural telescope, called a gravitational lens, provides a larger and brighter – though also distorted – view of the distant galaxy. These distortions, which stretch beyond the limits of the Hubble Space Telescope, can be effectively handled by a new space telescope on the drawing boards – the James Webb Space Telescope (JWST).



As many as 20 percent of the most distant galaxies currently detected appear brighter than they actually are, because of an effect called "strong gravitational lensing," astronomers have discovered. This graphic illustrates how, when astronomers view distant galaxies in a telescope (upper left panel), some of those galaxies line up with our view of nearby galaxies (center panel). The gravity of the nearby galaxies bends and magnifies the light coming from some of those distant galaxies, so that they appear brighter than they actually are (lower right panel). Thus galaxies that would normally be too faint to detect become visible in telescope images. Credit: Artwork Credit: NASA, ESA, and A. Feild (STScI) Science Credit: NASA, ESA, S. Wyithe (University of Melbourne), H. Yan (Ohio State University), R. Windhorst (Arizona State University), and S. Mao (Jodrell Bank Center for Astrophysics, and National Astronomical Observatories of China)

A very massive object – or collection of objects – distorts the view of faint objects beyond it so much that the distant images are smeared into multiple arc-shaped images around the foreground object. According to Rogier Windhorst, one of the letter's authors and a professor at the School of Earth and Space Exploration in Arizona State University's College of Liberal Arts and Sciences, this effect is analogous to looking through a glass coke bottle at a light on a balcony and noticing how it is distorted as it passes through the bottle. Cosmologists such as Windhorst believe that gravitational lensing likely distorted the measurements of the flux and number density of the most distant galaxies seen in the recent deep near-IR surveys with the Hubble Space Telescope Wide Field Camera 3.

When you look back to when the universe was young, you are seeing extremely early objects (also known as "First Light" objects) that are very far away. The older and farther away the object, the more foreground universe there is to look through, which means the greater the chance that there will be something heavy in the foreground to

distort the background image. This research suggests that gravitational lensing is likely to dominate the observed properties of very early galaxies, those that are at most 650-480 million years old (now seen with Hubble at redshifts of z > 8-10, respectively). The halos of foreground galaxies when the universe was in its heydays of star formation (about 3-6 billion years old and at a lower redshift of z=1-2) will gravitationally distort most of these very early objects.

"We show that gravitational lensing by foreground galaxies will lead to a higher number of galaxies to be counted at redshifts z>8-10. This number may be boosted significantly, by as much as an order of magnitude. If there existed only three galaxies above the detection threshold at redshifts z>10 in the Hubble field-of-view without the presence of lensing, the bias from gravitational lensing may make as many as 10-30 of them visible in the Hubble images," explains Windhorst. "In this sense, the very distant universe is like a house of mirrors that you visit at the State Fair – there may be fewer direct lines-of-sight to a very distant object, and their images may reach us more often via a gravitationally-bent path. What you see is not what you've got!"

Future surveys will need to be designed to account for a significant gravitational lensing bias in high-redshift galaxy samples. Only the JWST – if it gets finished as designed – can ultimately make sense out of this gravitationally biased distant universe because it will have exquisite resolution and sensitivity at longer wavelengths to disentangle these very distant objects from the foreground lensing galaxies. This work is too hard to do with Hubble's Wide Field Camera 3 at redshifts z >= 10, because at Hubble's resolution one literally can no longer see the forest for the trees at these extreme distances.

"Our suggestion of the possibility of large gravitational lensing biases in high redshift samples is of crucial importance to the optimal design of

surveys for the first galaxies, which represent a central part of JWST's mission," says Windhorst. "This work clearly shows that we now need JWST – and its superb infrared resolution, dynamic range, and sensitivity – more than ever to disentangle the First Light forest from the foreground trees. We will also need a next generation of object finding algorithms, since the current software is simply not designed to find these rare background objects behind such dense foregrounds. It's like finding a few "nano-needles" in the mother-of-all-haystacks."

Provided by Arizona State University

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