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Distant supernova split four ways by gravitational lens

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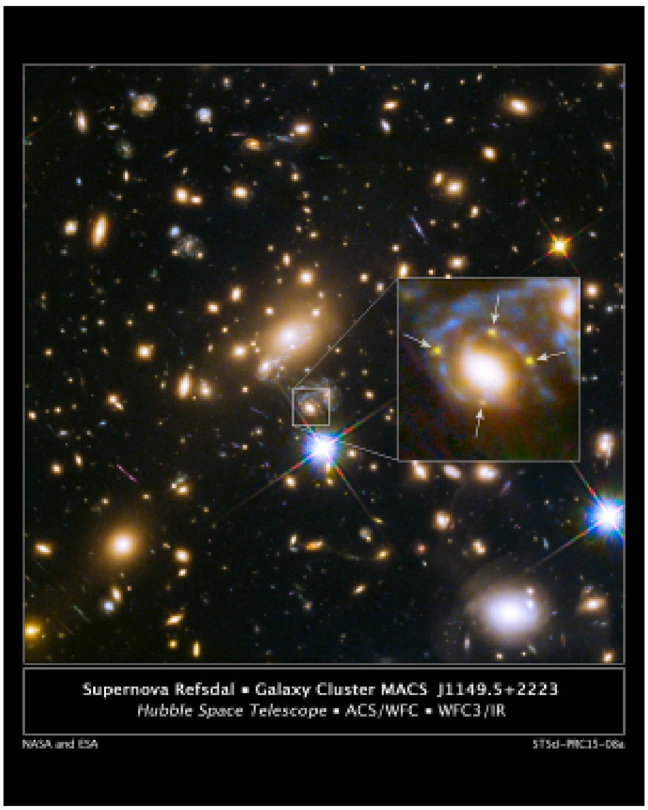


The many red galaxies in this Hubble Space Telescope image are members of the massive MACS J1149.6+2223 cluster, which strongly bends and magnifies the light of galaxies behind it. A large cluster galaxy (center of the box) has split the magnified light from an exploding background supernova into four yellow images (arrows), which form an Einstein Cross. Credit: Image courtesy of Z. Levay at NASA's Space Telescope Science Institute and ESA. Patrick Kelly and Alex Filippenko at UC Berkeley contributed to the discovery and analysis.

Over the past several decades, astronomers have come to realize that the sky is filled with magnifying glasses that allow the study of very distant and faint objects barely visible with even the largest telescopes.

A University of California, Berkeley, astronomer has now found that one of these lenses - a massive galaxy within a cluster of galaxies, both of which are gravitationally bending and magnifying light - has created four separate images of a distant supernova.

The so-called "Einstein cross" will allow a unique study of a distant supernova and the distribution of dark matter in the lensing galaxy and cluster.

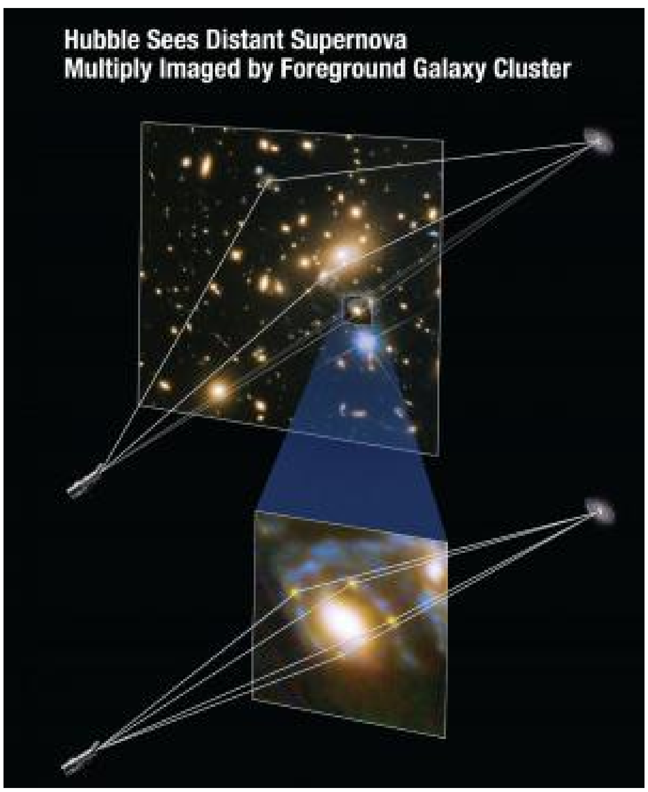
"Basically, we get to see the supernova four times and measure the time delays between its arrival in the different images, hopefully learning something about the supernova and the kind of star it exploded from, as well as about the gravitational lenses," said UC Berkeley postdoctoral scholar Patrick Kelly, who discovered the supernova while looking through infrared images taken Nov. 10, 2014, by the Hubble Space Telescope (HST). "That will be neat."

Kelly is a member of the Grism Lens-Amplified Survey from Space (GLASS) team led by Tommaso Treu at UCLA, which has worked in collaboration with the FrontierSN team organized by Steve Rodney at Johns Hopkins University to search for distant supernovae.

"It's a wonderful discovery," said Alex Filippenko, UC Berkeley professor of astronomy and a member of Kelly's team. "We've been searching for a strongly lensed supernova for 50 years, and now we've found one. Besides being really cool, it should provide a lot of astrophysically important information."

One bonus is that, given the peculiar nature of gravitational lensing, astronomers can tune in for a supernova replay in the next 10 years. This is because light can take various paths around and through a gravitational lens, arriving at Earth at different times. Computer modeling of this lensing cluster shows that the researchers missed opportunities to see the exploding star 50 and 10 years ago, but images of the explosion will likely repeat again within the next 10 years.

"The longer the path length, or the stronger the gravitational field through which the light moves, the greater the time delay," noted Filippenko.



The light from the underlying supernova is deflected by the gravity of a large collection of galaxies and an elliptical galaxy, which thus acts like a magnifying glass and amplifies the light from the distant supernova. This special phenomenon, called gravitational lensing effect, works like nature's own giant telescope and the supernova appears 20 times brighter than its normal brightness. Credit: NASA/ESA/GLASS/FrontierSN team

Kelly is first author of a paper reporting the supernova appearing in a special March 6 issue of *Science* magazine marking the centenary of Albert Einstein's General Theory of Relativity.

Kelly, Filippenko and their collaborators have dubbed the distant supernova SN Refsdal in honor of Sjur Refsdal, the late Norwegian astrophysicist and pioneer of gravitational lensing studies. It is located about 9.3 billion light years away (redshift = 1.5), near the edge of the observable universe, while the lensing galaxy is about 5 billion light years (redshift = 0.5) from Earth.

Einstein cross

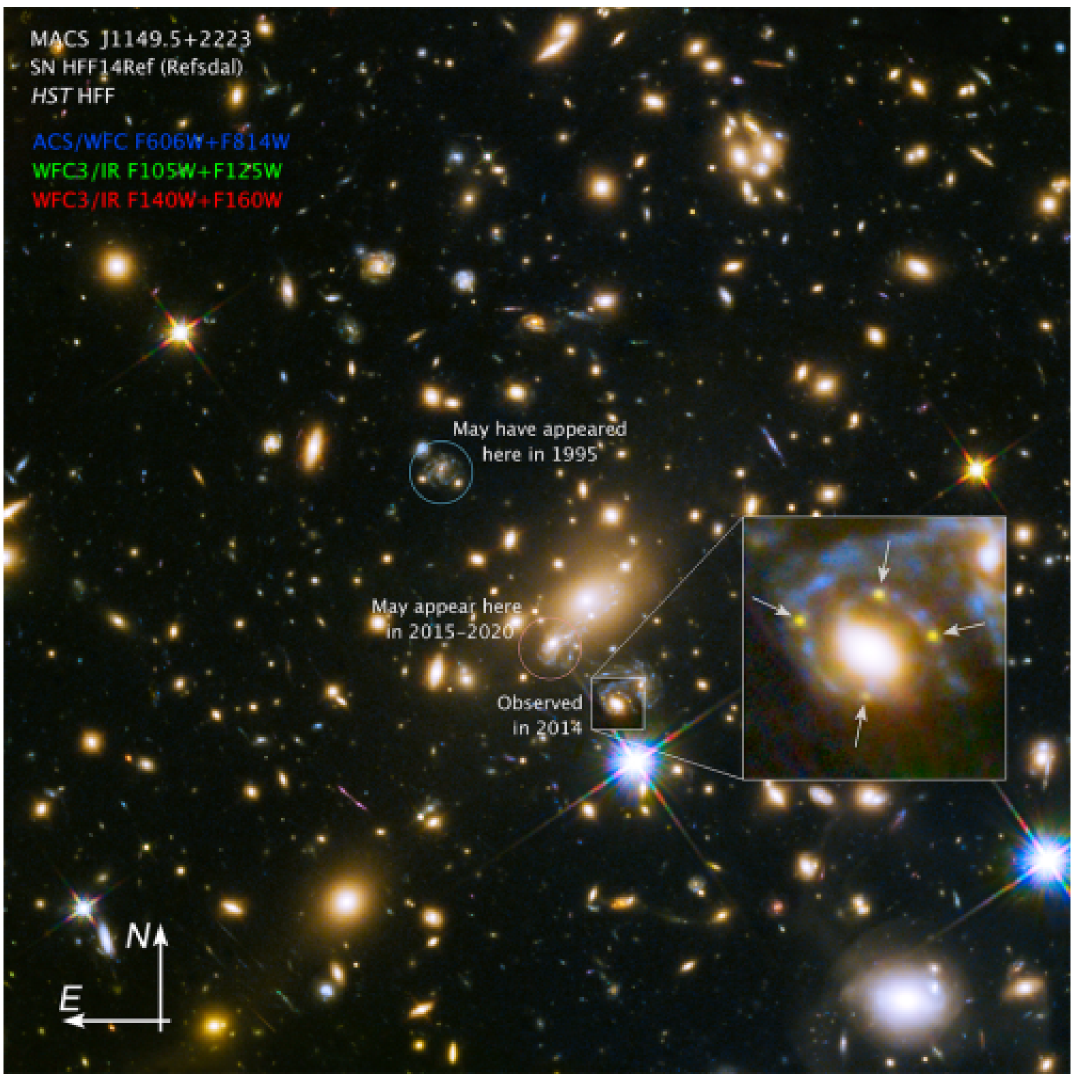
Albert Einstein's General Theory of Relativity predicts that dense concentrations of mass in the universe will bend light like a lens, magnifying objects behind the mass when seen from Earth. The first gravitational lens was discovered in 1979. Today, lensing provides a new window into the extremely faint universe shortly after its birth 13.8 billion years ago.

"These gravitational lenses are like a natural magnifying glass. It's like having a much bigger telescope," Kelly said. "We can get magnifications of up to 100 times by looking through these galaxy clusters."

When light from a background object passes by a mass, such as an individual galaxy or a cluster of galaxies, the light is bent. When the path of the light is far from the mass, or if the mass is not especially large, "weak lensing" will occur, barely distorting the background object. When the background object is almost exactly behind the mass, however, "strong lensing" can smear extended objects (like galaxies) into an "Einstein ring" surrounding the lensing galaxy or cluster of galaxies.

Strong lensing of small, point-like objects, on the other hand, often produces multiple images - an Einstein cross - arrayed around the lens.

"We have seen many distant quasars appear as Einstein crosses, but this is the first time a supernova has been observed in this way," Filippenko said. "This short-lived object was discovered only because Pat Kelly very carefully examined the HST data and noticed a peculiar pattern. Luck comes to those who are prepared to receive it."



In the large square to the right in the image you see the four light representations of the supernova that was spotted on Nov. 11, 2014. The blue circle shows another location in the galaxy cluster where you probably would have been able to see a single image of the supernova 20 years ago and the red circle shows where the supernova will appear again in a few years, according to calculations. This will give the astronomers a rare opportunity to get backward glance at the supernova and will also enable the researchers to improve their calculations of the amount and distribution of dark matter -- both in the galaxy cluster and in the one elliptical galaxy. Credit: NASA/ESA/GLASS/ FrontierSN team

The galaxy that is splitting the light from the supernova into an Einstein cross is part of a large cluster, called MACS J1149.6+2223, that has been known for more than 10 years.

In 2009, astronomers reported that the cluster created the largest known image of a spiral galaxy ever seen through a gravitational lens. The new supernova is located in one of that galaxy's spiral arms, which also appears in multiple images around the foreground lensing cluster. The supernova, however, is split into four images by a red elliptical galaxy within the cluster.

"We get strong lensing by a red galaxy, but that galaxy is part of a cluster of galaxies, which is magnifying it more. So we have a double lensing system," Kelly said.

Looking for transients

After Kelly discovered the lensed supernova Nov. 10 while looking for interesting and very distant supernova explosions, he and the team examined earlier HST images and saw it as early as Nov. 3, though it was very faint. So far, the HST has taken several dozen images of it using the Wide Field Camera 3 Infrared camera as part of the Grism survey. Astronomers using the HST plan to get even more images and spectra as the HST focuses for the next 6 months on that area of sky.

"By luck, we have been able to follow it very closely in all four images, getting data every two to three days," he said.

Kelly hopes that measuring the time delays between the phases of the supernova in the four images will enable constraints on the foreground mass distribution and on the expansion and geometry of the universe. If the spectrum identifies it as a Type Ia supernova, which is known to have a relatively standard brightness, it may be possible to put even stronger limits on both the matter distribution and cosmological parameters.

More information: Multiple images of a highly magnified supernova formed by an early-type cluster galaxy lens, Science, www.sciencemag.org/lookup/doi/ … 1126/science.aaa3350

Provided by University of California - Berkeley