Astronomers observe a unique multiply-lensed supernova

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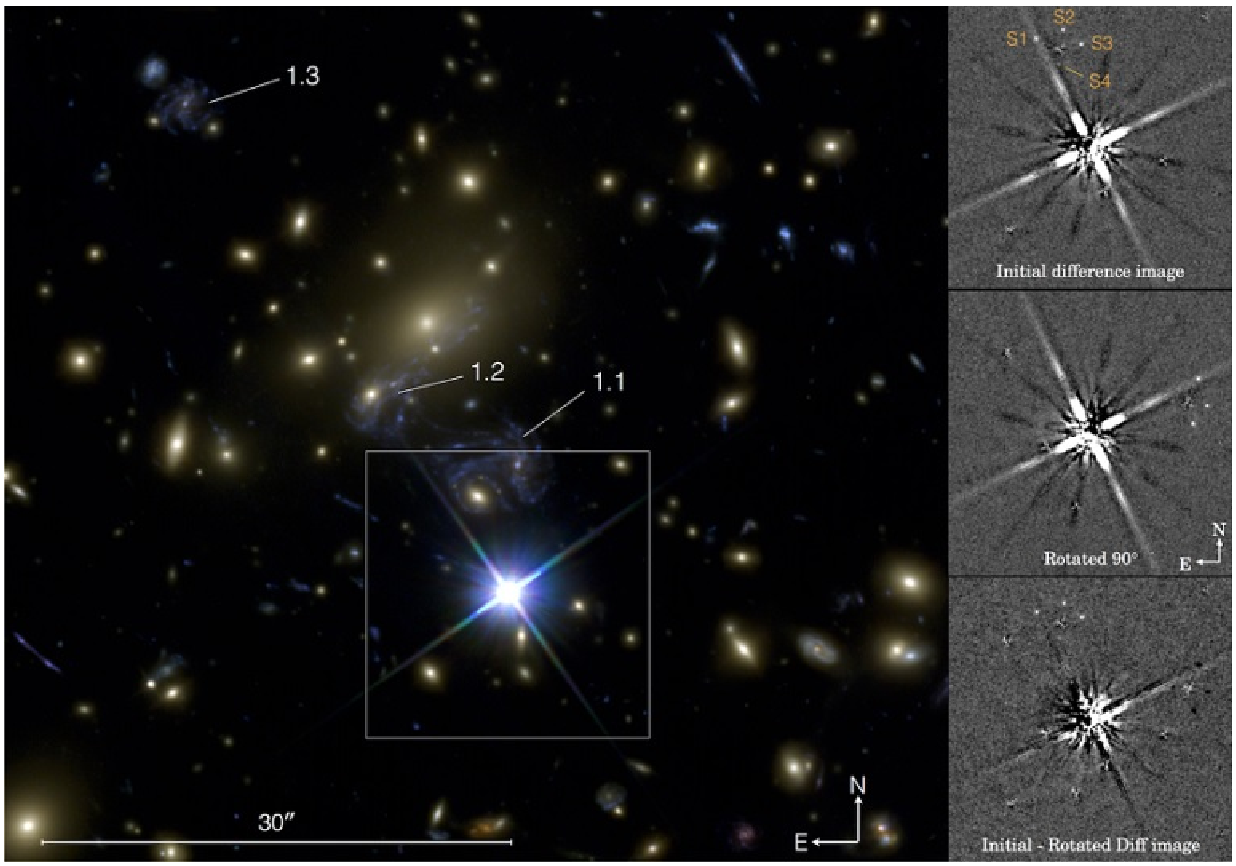

The MACS J1149.6+2223 field, showing the positions of the three primary images of the SN Refsdal host galaxy (labeled 1.1, 1.2 and 1.3). SN Refsdal appears as four point sources in an Einstein Cross configuration in the southeast spiral arm of image 1.1. The highlighted box is shown at the same scale in panels on the right side, which illustrate the removal of contaminating diffraction spikes from a difference image. Each difference image is centered on the location of the contaminating star (top panel), then rotated clockwise by 90 degrees (middle panel). The rotated difference image is then subtracted from the initial difference image, removing most of the flux from the contaminating diffraction spike at the location of the SN Refsdal point sources (bottom panel). Credit: Steven A. Rodney et al., 2015.

(Phys.org)—SN Refsdal is a peculiar supernova visible within the field of the galaxy cluster MACS J1149+2223. Discovered in November 2014 using the Hubble Space Telescope, this supernova is the first that was seen multiple times thanks to gravitational lensing. Now, an international team of astronomers has published a paper on Jan. 15 summarizing one year of Hubble observations of SN Refsdal. The research is available online on the arXiv pre-print server.

More than a year ago, four images of SN Refsdal were detected by Hubble as part of the Grism Lens-Amplified Survey from Space (GLASS) program. GLASS acquires near-infrared grism spectra of massive galaxy clusters with the primary goals of studying faint, high-redshift galaxies and spatially resolved intermediate-redshift galaxies, as well as characterizing the cluster galaxy population. The images obtained by Hubble show SN Refsdal shining brightly from the arm of a spiral galaxy that lies far beyond another galaxy between the supernova and our planet. SN Refsdal as a background source is strongly lensed by galaxies and a galaxy cluster massive enough to bend the light into multiple images.

The astronomers then predicted that the supernova will soon reappear in the cluster field. Their predictions were correct, as SN Refsdal reappeared once more between mid November and Dec. 11, 2015. The exact date is uncertain by approximately one month, which is the interval between two consecutive Hubble observations.

This reappearance was a great occasion for a team of scientists led by Steven A. Rodney from the University of South Carolina to sum up the findings since previous sightings of SN Refdal in 2014. Moreover, the team managed to measure time delays for the four images obtained over a year ago.

The researchers found that the observed shape of SN Refsdal has distinct similarities with supernova SN 1987A. They also noted that the studied supernova is most likely a member of the peculiar Type II sub-class defined by the SN 1987A prototype.

To conduct precise measurements of relative time delays and also magnification ratios from the SN Refsdal data, the scientists used two methods: light curve template matching and flexible polynomial light curve models. They constructed their models based on supernovae like SN 1987A, which has a well-sampled light curve coverage. The researchers note that the use of two different methods yields complementary results.

"Even the best fit, template-based model shows systematic residuals and does not provide a good representation of the observed data. SN Refsdal is not quite a clone of other observed 87A-like Type II supernovae. Thus, as a second approach for measuring the time delays between the four Refsdal sources, we used a series of flexible light curve models—splines and polynomials—to represent the underlying light curve shape. By adopting these free-form curves in place of the rigid SN light curve templates, we can derive time delays that are agnostic about the classification of SN Refsdal," the astronomers wrote in the paper.

Rodney and his team determined these time delays with a precision of two to eight days. According to their study, the time delay between the first and the fourth image is about 26 days.

"This level of precision is promising, as it suggests that a similarly cadenced monitoring campaign could deliver a relative precision of 1 percent on the time delay to the next image," the paper reads.

SN Refsdal, as the first multiply-imaged supernova ever seen, will be a target of numerous observations conducted by scientists studying lens modeling methods. The researchers concluded that with a sufficiently rapid observational cadence and concerted lens modeling efforts, it will be feasible to use measurements of these lensed time delays as cosmographic tools. Cluster-lensed supernovae such as SN Refsdal could, indeed, contribute to future time delay cosmography efforts.

More information: SN Refsdal : Photometry and Time Delay Measurements of the First Einstein Cross Supernova, arXiv:1512.05734 [astro-ph.CO] arxiv.org/abs/1512.05734

Abstract
We present the first year of Hubble Space Telescope imaging of the unique supernova (SN) 'Refsdal', a gravitationally lensed SN at z=1.488±0.001 with multiple images behind the galaxy cluster MACS J1149.6+2223. The first four observed images of SN Refsdal (images S1-S4) exhibited a slow rise (over ~150 days) to reach a broad peak brightness around 20 April, 2015. Using a set of light curve templates constructed from SN 1987A-like peculiar Type II SNe, we measure time delays for the four images relative to S1 of 4±4 (for S2), 2±5 (S3), and 24±7 days (S4). The measured magnification ratios relative to S1 are 1.15±0.05 (S2), 1.01±0.04 (S3), and 0.34±0.02 (S4). None of the template light curves fully captures the photometric behavior of SN Refsdal, so we also derive complementary measurements for these parameters using polynomials to represent the intrinsic light curve shape. These more flexible fits deliver fully consistent time delays of 7±2 (S2), 0.6±3 (S3), and 27±8 days (S4). The lensing magnification ratios are similarly consistent, measured as 1.17±0.02 (S2), 1.00±0.01 (S3), and

0.38±0.02 (S4). We compare these measurements against published predictions from lens models, and find that the majority of model predictions are in very good agreement with our measurements. Finally, we discuss avenues for future improvement of time delay measurements—both for SN Refsdal and for other strongly lensed SNe yet to come.