REPORTS

ASTROPHYSICS

Multiple images of a highly magnified supernova formed by an early-type cluster galaxy lens

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In 1964, Refsdal hypothesized that a supernova whose light traversed multiple paths around a strong gravitational lens could be used to measure the rate of cosmic expansion. We report the discovery of such a system. In Hubble Space Telescope imaging, we have found four images of a single supernova forming an Einstein cross configuration around a redshift z = 0.54 elliptical galaxy in the MACS J1149.6+2223 cluster. The cluster's gravitational potential also creates multiple images of the z = 1.49 spiral supernova host galaxy, and a future appearance of the supernova elsewhere in the cluster field is expected. The magnifications and staggered arrivals of the supernova images probe the cosmic expansion rate, as well as the distribution of matter in the galaxy and cluster lenses.

The possibility that the light from an exploding supernova (SN) could follow more than a single path around an intervening strong galaxy lens to the observer was first explored about 50 years ago (*1*). Many decades of searches for SNe, however, have not identified an explosion visible at multiple positions around a gravitational lens. Here we report a strongly lensed supernova found in resolved multiple images, which we identified in the MACS J1149.6+2223 (*2*) galaxy cluster field on 11 November 2014 (Universal Time dates are used throughout this paper).

Although the apparent positions of galaxies that are multiply imaged by a foreground galaxy or cluster are now widely used to map the matter distribution within the lenses, a strongly lensed background source with a varying light curve allows distinct and powerful measurements of the lens and cosmology, because the delay between each pair of images can be measured. This difference in arrival time, owing to the difference in geometric and gravitational time delay (*3*), is directly proportional to the so-called time-delay distance and thus inversely proportional to the Hubble constant and weakly dependent on other cosmological parameters (*1*, *4*–*6*). Conversely, for an assumed cosmological model, the time delays are a direct measurement of the difference in gravitational potential between the multiple images, and hence greatly improve the reconstruction of the mass distribution in the deflector (*7*).

After the discovery of the SBS 0957+561 A/B system 26 years ago (*8*), a handful of quasi-stellar objects (quasars) multiply imaged by an intervening galaxy lens have been identified (*9*). Quasars strongly lensed by clusters are even more rare events, with only several known (*10*). The use of lensed quasars as robust probes of the distribution of matter in the lenses and of cosmology has only become possible relatively recently, given the long time periods of monitoring needed to match their complex light curves (*6*, *11*–*13*). In contrast, all SNe have much simpler light curves and evolve comparatively rapidly, which makes the measurement of time delays and magnification among the multiple images substantially more straightforward.

It was recently shown that a different SN, PS1-10afx (*14*) at redshift z = 1.38, was strongly magnified (by a factor of ~30) by an intervening galaxy at z = 1.12 (*15*, *16*). The available imaging, taken from the ground, had insufficient angular resolution to separate potential multiple images of the SN, so time delays and magnifications could not be measured. In the case presented here, the four images of the SN are clearly resolved (Fig. 1), with an image separation of over 2″, thereby presenting an ideal opportunity to carry out for the first time an experiment similar to that suggested by Refsdal (*1*), leading us to name the supernova "Refsdal."

The Grism Lens-Amplified Survey from Space (GLASS) program [GO-13459, principal investigator (PI) T.T.] is a 140-orbit Hubble Space Telescope (HST) project that is acquiring near-infrared grism spectra of massive galaxy clusters with the primary goals of studying faint high-redshift ($z \gtrsim 6$) galaxies (*17*) and spatially resolved intermediate-redshift galaxies (*18*), as well as characterizing the cluster galaxy population. Wide-band near-infrared F105W and F140W exposures are taken using the Wide Field Camera 3 (WFC3) to align and calibrate the grism data, and we have been searching these images for transient sources.

In the F140W GLASS images acquired on 10 November 2014, we detected the component images of a quadruple lens system, which we label sources S1 to S4 (Fig. 1). Table 1 gives the coordinates of the variable sources. In Fig. 2, the color-composite image shows the red galaxy lens at z = 0.54 (*19*) surrounded by an Einstein ring formed by light from the distorted spiral host galaxy with z = 1.49 (*20*), whose nucleus is offset by ~3.3″ from the center of the lensing elliptical galaxy. Although sources S1 and S2 do not exhibit a significant change in their fluxes during the imaging taken from 3 to 20 November 2014, the light curve of S3 is consistent with a rise in brightness during this period, which corresponds to approximately a week in the rest frame (Fig. 3; see also fig. S1). The light curve of S4 is difficult to characterize with the currently available data, because it is comparatively faint.

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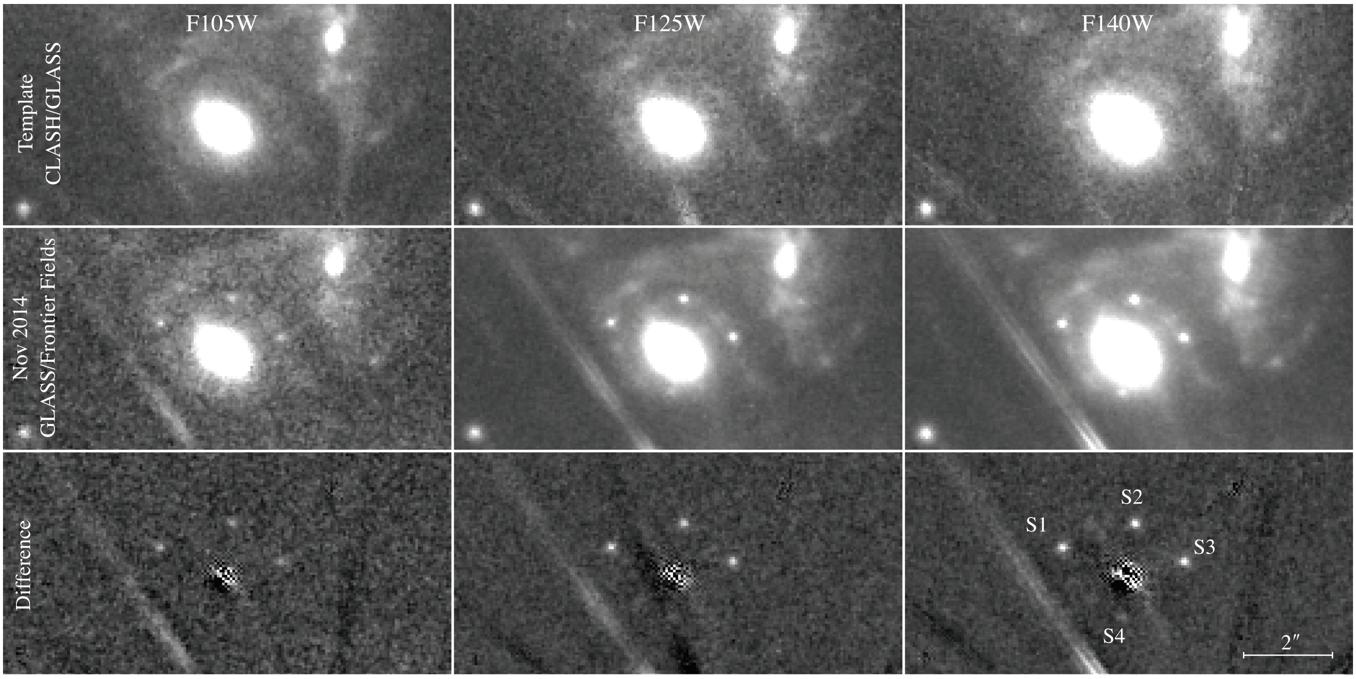

Fig. 1. HST WFC3-IR images showing the simultaneous appearance of four point sources around a cluster member galaxy. From left to right, the columns show imaging in the F105W filter (*Y* band), F125W (*J*), and F140W (*JH*). From top to bottom, the rows show archival imaging from the Cluster Lensing And Supernova survey with Hubble (CLASH, GO-12068; PI M.P.) program, discovery epoch images from GLASS and the Hubble Frontier Fields programs, and the difference images. The template images in the top row comprise all available archival WFC3-IR imaging in these filters, collected from 5 December 2010 through 10 March 2011. The images in the middle row are the composite of all available HST imaging collected between 3 November and 11 November 2014 (for F105W, left), on 20 November 2014 (F125W, middle), and between 10 November and 20 November 2014 (F140W, right). The sources S1, S2, S3, and S4, which form an Einstein cross, are absent from all images obtained at earlier epochs but are clearly detected in the difference images along the bottom row. The line segments below S4 and in the lower right corner are diffraction spikes from a nearby bright star in the foreground.

Table 1. Coordinates of the transient point sources detected around the cluster galaxy lens, in J2000 right ascension and declination.

Name	α (J2000)	δ (J2000)
S1	$11^h49^m35.57^s$	+22°23′44.26″
S2	$11^h49^m35.451^s$	+22°23′44.84″
S3	$11^h49^m35.369^s$	+22°23′43.95″
S4	$11^h49^m35.472^s$	+22°23′42.62″

Based on the available data, we can attempt a first preliminary classification of the SN. All known type Ia SNe reach their peak brightness in fewer than 20 rest-frame days (*21*). The light curve for image S3 of SN Refsdal (fig. S1) through >30 days in the rest frame shows that its brightness continued to rise for a longer period than could be expected for a SN Ia, suggesting that it belongs to a different spectroscopic class.

Archival HST imaging and the configuration of the multiple images demonstrate that the source is not an active galactic nucleus (AGN) behind the galaxy and cluster lenses. A search of WFC3 F105W, F110W, F140W, and F160W images of MACS J1149.6+2223, acquired across 10 separate HST visits beginning on 4 December 2010, finds no evidence for previous variability. Several epochs of registered and coadded F140W imaging exhibit no significant variation (fig. S4); seven archival epochs of F160W imaging likewise show no significant changes. Evidence for previous variability would have suggested that the source is a flare from an AGN instead of a SN. The transients detected in November 2014 are additionally several magnitudes above the upper limits of ~28.5 obtained at previous epochs (all magnitudes are in the AB system). Such a large increase in brightness would be very unusual for an AGN, whose light curves typically vary at the level of a few tenths of a magnitude over several-month time scales (*22*–*24*). Finally, the positions of the multiple images also constrain the redshift of the source to 1.1 to 1.7 with 95% confidence, consistent with the z = 1.49 redshift of the spiral galaxy lensed into the observed configuration (fig. S2).

The four images of SN Refsdal form an Einstein cross configuration around the massive elliptical galaxy at z = 0.54, which adds onto and locally perturbs the cluster potential. Because the elliptical galaxy is located close to the critical lines of the cluster lens (*25*), the contribution of the galaxy cluster to the gravitational potential needs to be taken into account. As a first, simple approximation of the lensing system, we construct a single isothermal ellipsoid embedded in a strong external shear (*26*). This yields time delays on the order of several to tens of days. S1 is generally the leading image, typically followed by S2, S3, and then S4. Magnifications are ~2 for the least magnified image S4 and ~10 for the other images. These magnifications, however, do not include the additional contribution from the cluster, which is expected to be very substantial, especially because earlier modeling has found a relatively flat, nearly convergent central mass distribution, which is evident from the relatively undistorted shape of the magnified spiral images (*25*).

To account more completely for the effects of the cluster potential, we have constructed a detailed set of lens models of the entire cluster potential, including the elliptical galaxy, for several different prior probability distributions and sets of constraints. These models, which are also constrained by the positions of the SN images, generally yield magnifications of ~10 to 30 at the positions of the four images, and time delays on the order of days to months, in agreement with independent models (*27*, *28*). The typical arrival sequence is consistent with the predictions of the simpler galaxy-lens model (S1, S2, and then either S3 or S4), although some models also predict different arrival orders. These time delays are also in accord with our identification of the four newly detected sources as a multiply imaged SN, because the luminosity of a SN is not expected to vary dramatically over the time scale of less than a week in the rest frame. The spiral host galaxy itself is multiply imaged by the galaxy cluster (*20*, *25*). Consequently, our models predict both that the SN could be detected at future

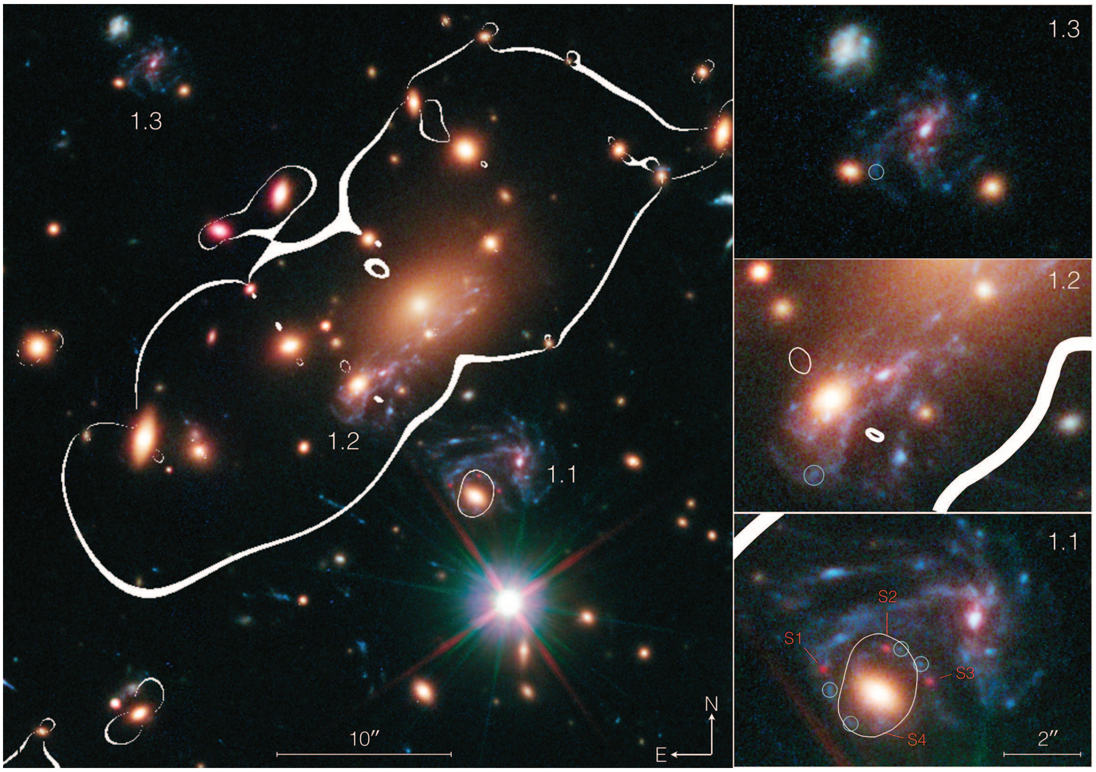

Fig. 2. Color-composite image of the galaxy cluster MACSJ1149.6+2223, with critical curves for sources at the z = 1.49 redshift of the host galaxy overlaid. Three images of the host galaxy formed by the cluster are marked with white labels (1.1, 1.2, and 1.3) in the left panel, and each is enlarged at right. The four current images of SN Refsdal that we detected (labeled S1 to S4 in red) appear as red point sources in image 1.1. Our model indicates that an image of the SN appeared in the past in image 1.3 and that one will appear in the near future in image 1.2. The extreme red hue of the SN may be somewhat exaggerated, because the blue and green channels include only data taken before the SN erupted. In image 1.1, both a single bright blue knot (cyan circles) and SN Refsdal are multiply imaged into four distinct locations. The image combines infrared and optical HST imaging data from the Frontier Fields and GLASS programs, along with images from the CLASH and the FrontierSN programs (GO-13790, PI S.A.R.).

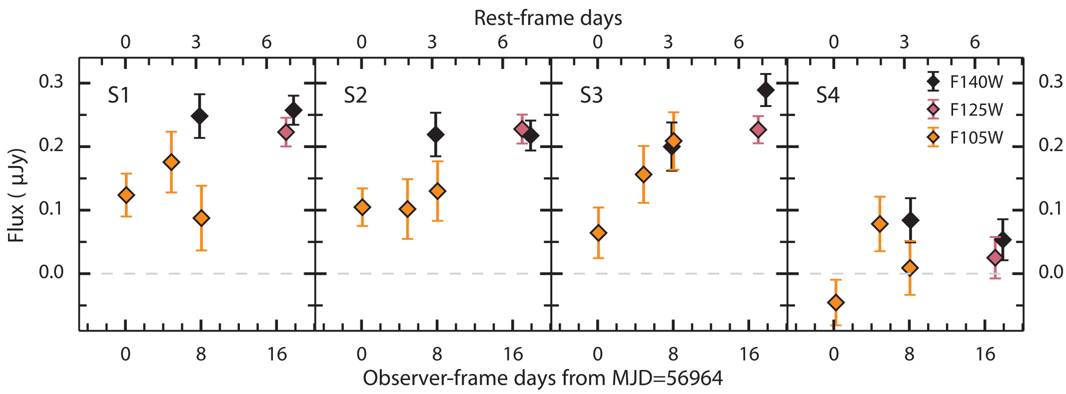

Fig. 3. Light curve of the images S1 to S4 of the strongly lensed SN taken from 3 November 2014 through 20 November 2014. Rest-frame days assume that the SN is at the redshift of the multiply imaged spiral galaxy (z = 1.49). We plotted the fluxes measured in the WFC3 F105W, F125W, and F140W images of the MACS J1149.6+2223 galaxy cluster field. The expected time delays between images of days to weeks suggest that the transient must evolve over a time scale similar to that of a SN. Our lens models generally predict that image S3 is delayed relative to S1 and S2, which is consistent with the early photometry. Flux uncertainties are calculated by injecting a thousand point sources into the difference images and comparing the fluxes recovered using point-spread-function fitting with the input fluxes. Error bars throughout correspond to the standard deviation of a normal distribution fitted to the histogram of the difference in flux.

epochs in a different image of the spiral host galaxy and that it has already appeared elsewhere in yet another image of the spiral. A search of archival HST imaging in both the optical (F606W, F814W, and F850LP) and infrared (F105W, F125W, F140W, and F160W) at the locations of the multiple images of the presumed host galaxy has revealed no evidence for SN Refsdal when these data were taken. Our set of cluster lens models predicts that the SN will appear in the central image of the spiral host galaxy, at an approximate position of $\alpha = 11^h49^m36.01^s$, $\delta = +22°23'48.13''$ (J2000.0) at a future time, within a year to a decade from now (2015 to 2025). This is in broad agreement with independent model predictions (*27*, *28*). The uncertainties highlight the power of a time-delay measurement to constrain lens models.

The archival HST imaging and the configuration show that this is a multiply imaged SN. This discovery demonstrates in principle the feasibility of the experiment suggested five decades ago by Refsdal (*1*), consisting of using the time delays between the multiple images of the SN to constrain the foreground mass distribution and eventually the geometry and content of the universe.

REFERENCES AND NOTES

1. S. Refsdal, *Mon. Not. R. Astron. Soc.* **128**, 307–310 (1964).
2. H. Ebeling, A. C. Edge, J. P. Henry, *Astrophys. J.* **553**, 668–676 (2001).
3. I. I. Shapiro, *Phys. Rev. Lett.* **13**, 789–791 (1964).
4. T. Treu, *Annu. Rev. Astron. Astrophys.* **48**, 87–125 (2010).
5. E. V. Linder, *Phys. Rev. D Part. Fields Gravit. Cosmol.* **84**, 123529 (2011).
6. S. H. Suyu *et al.*, *Astrophys. J.* **788**, L35 (2014).
7. C. S. Kochanek *et al.*, *Astrophys. J.* **640**, 47–61 (2006).
8. D. Walsh, R. F. Carswell, R. J. Weymann, *Nature* **279**, 381–384 (1979).
9. N. Inada *et al.*, *Astron. J.* **143**, 119 (2012).
10. K. Sharon *et al.*, *Astrophys. J.* **629**, L73–L76 (2005).

11. L. V. E. Koopmans, T. Treu, C. D. Fassnacht, R. D. Blandford, G. Surpi, *Astrophys. J.* **599**, 70–85 (2003).
12. M. Tewes *et al.*, *Astron. Astrophys.* **556**, A22 (2013).
13. S. H. Suyu *et al.*, *Astrophys. J.* **766**, 70 (2013).
14. R. Chornock *et al.*, *Astrophys. J.* **767**, 162 (2013).
15. R. M. Quimby *et al.*, *Astrophys. J.* **768**, L20 (2013).
16. R. M. Quimby *et al.*, *Science* **344**, 396–399 (2014).
17. K. B. Schmidt *et al.*, *Astrophys. J.* **782**, L36 (2014).
18. T. Jones *et al.*, arxiv.org/abs/1410.0967 (2014).
19. H. Ebeling *et al.*, *Astrophys. J.* **661**, L33–L36 (2007).
20. G. P. Smith *et al.*, *Astrophys. J.* **707**, L163–L168 (2009).
21. M. Ganeshalingam, W. Li, A. V. Filippenko, *Mon. Not. R. Astron. Soc.* **416**, 2607–2622 (2011).
22. S. Kaspi *et al.*, *Astrophys. J.* **659**, 997–1007 (2007).
23. M. C. Bentz *et al.*, *Astrophys. J.* **705**, 199–217 (2009).

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/347/6226/1123/suppl/DC1
Materials and Methods
Figs. S1 to S4
Tables S1 to S2
References (*24*–*32*)

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STELLAR DYNAMICS

The fastest unbound star in our Galaxy ejected by a thermonuclear supernova

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Hypervelocity stars (HVSs) travel with velocities so high that they exceed the escape velocity of the Galaxy. Several acceleration mechanisms have been discussed. Only one HVS (US 708, HVS 2) is a compact helium star. Here we present a spectroscopic and kinematic analysis of US 708. Traveling with a velocity of ~1200 kilometers per second, it is the fastest unbound star in our Galaxy. In reconstructing its trajectory, the Galactic center becomes very unlikely as an origin, which is hardly consistent with the most favored ejection mechanism for the other HVSs. Furthermore, we detected that US 708 is a fast rotator. According to our binary evolution model, it was spun-up by tidal interaction in a close binary and is likely to be the ejected donor remnant of a thermonuclear supernova.

According to the widely accepted theory for the acceleration of hypervelocity stars (HVSs) (*1*–*3*), a close binary is disrupted by the supermassive black hole (SMBH) in the center of our Galaxy, and one component is ejected as a HVS (*4*). In an alternative scenario, US 708 was proposed to be ejected from an ultracompact binary star by a thermonuclear supernova type Ia (SN Ia) (*5*). However, previous observational evidence was insufficient to put firm constraints on its past evolution. Here we show that US 708 is the fastest unbound star in our Galaxy, provide evidence for the SN ejection scenario, and identify a progenitor population of SN Ia.

In contrast to all other known HVSs, US 708 has been classified as a hot subdwarf star [subdwarf O- or B-type (sdO/B) star]. Those stars are evolved, core helium-burning objects with low masses around 0.5 times the mass of the Sun ($M_\odot$). About half of the sdB stars reside in close binaries with periods ranging from ~0.1 to ~30 days (*6*, *7*). The hot subdwarf is regarded as the core of a former red giant star that has been stripped of almost all of its hydrogen envelope through interaction with a close companion star (*8*, *9*). However, single hot subdwarf stars like US 708 are known as well. Even in this case, binary evolution has been proposed, as the merger of two helium white dwarfs (He-WDs) is a possible formation channel for those objects (*10*).

The hot subdwarf nature of US708 poses a particular challenge for theories that aim to explain the acceleration of HVSs. Within the slingshot scenario proposed by Hills, a binary consisting of two main-sequence stars is disrupted by the close encounter with the SMBH in the center of our Galaxy. While one of the components remains in a bound orbit around the black hole, the other one is ejected with high velocity (*4*). This scenario explains the existence of the so-called S-stars orbiting the SMBH in the Galactic center and provides the most convincing evidence for the existence of this black hole (*11*). It is also consistent with the main properties of the known HVS population consisting of young main-sequence stars (*12*, *13*). However, more detailed analyses of some young HVSs challenge the Galactic center origin (*14*), and most recently, a new population of old main-sequence stars likely to be HVSs has been discovered. Most of those objects are also unlikely to originate from the Galactic center, but the acceleration mechanism remains unclear (*15*).

In the case of the helium-rich sdO (He-sdO) US 708, the situation is even more complicated. In contrast to all other known HVSs, which are normal main-sequence stars of different ages, this star is in the phase of shell helium burning, which lasts for only a few tens of millions of years. More importantly, it has been formed by close binary interaction. To accelerate a close binary star to such high velocity, the slingshot mechanism requires either a binary black hole (*16*) or the close encounter of a hierarchical triple system, where the distant component becomes bound to the black hole and the two close components are ejected (*17*). Similar constraints apply to the dynamical ejection out of a dense cluster, which is the second main scenario discussed to explain the HVSs.

Close binarity requires specific modifications of the canonical HVS scenarios. However, it is a necessary ingredient for an alternative scenario, in which US 708 is explained as the ejected donor

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Science

Multiple images of a highly magnified supernova formed by an early-type cluster galaxy lens

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Finding four for the light of one

Seeing double may cause concern for some, but seeing quadruple? It's just what astronomers have been hoping for. Kelly *et al.* have now detected four images of the same distant supernova with the sharp eye of a space telescope. The supernova shines brightly from the arm of a spiral galaxy that lies far beyond another galaxy between it and us. This intervening galaxy is massive enough to bend the light from the supernova and its host galaxy into multiple images. This behavior relies on the curvature of spacetime and will provide insight into the luminous and dark matter in the lensing galaxy.

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