Scattered Light Echoes from SN 1998bu

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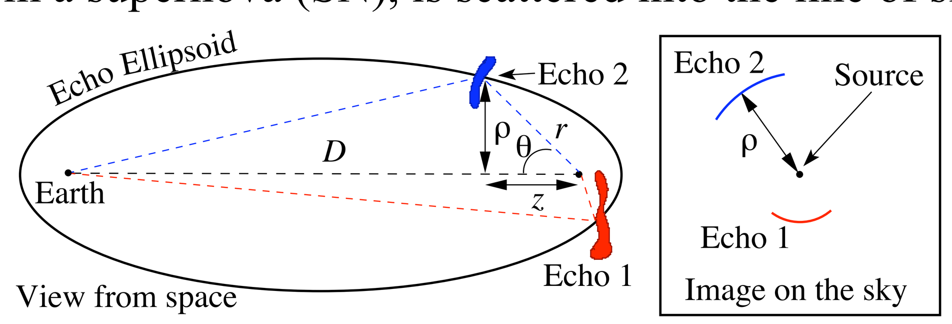
Abstract

Scattered light echoes offer one of the most effective means to study the structure and make-up of circumstellar and interstellar dust and gas. These light echoes not only provide exact three-dimensional positions of scattering dust, but they can also be used to determine the dust's composition, size, and number density. However, they are very rare and have only been unambiguously resolved around a handful of sources. Here, we present new data and analyses of echoes previously discovered around SN 1998bu. Like SN 1991T (see poster by Thormann & Sugerman), this supernova was a type Ia and has illuminated an hourglass-shaped circumstellar nebula up to 30 lt-yr in size. However SN 1998bu has also illuminated a plane of interstellar material 300-700 lt-yr in front of the supernova. We interpret this plane as a 100 lt-yr thick dust lane in the host-galaxy's (M96) disk.

Space Geometry

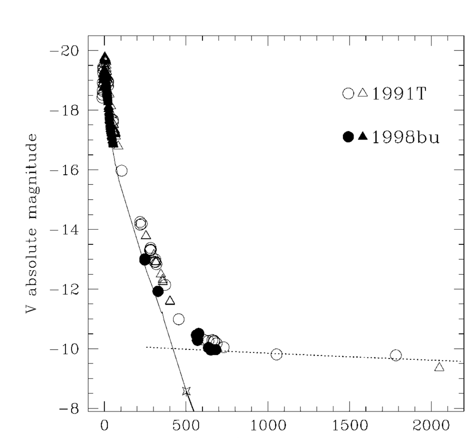
Scattered light echoes offer one of the most effective means to probe circumstellar and interstellar structure. A light echo occurs when a light pulse, e.g. from a supernova (SN), is scattered into the line of sight by dust.

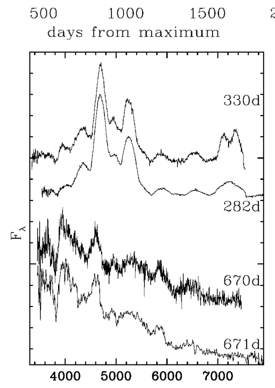


An echo observed a time t after the pulse must lie equidistant in light travel from the source and observer, i.e. on an ellipsoid with known foci (above). Given the echo-source separation, ρ, and the time it is observed, the line-of-sight position, *z*, of the dust can be directly computed uncertain only by the distance *D*. This means there is a one-to-one mapping between observed echo position and the 3-D position of the scattering dust. Echoes can occur both behind (echo 1) and in front of (echo 2) the source.

M96 & SN 1998bu

SN 1998bu is a type Ia (accreting white dwarf) located in the spiral galaxy M96 (left), roughly 11.2 Mpc away. Cappellaro et al. (2001) reported that SN 1998bu showed the same photometric decline and spectral features as SN1991T (see poster by Thormann & Sugerman #412.07), which has been known to have an echo since the mid-1990's. From the data shown below, Cappellaro et al. concluded their observations were caused by a light echo from dust about 230 lt-yr in front of the SN. *HST* imaging in 2000 revealed a ring of radius 0."3-0."6 centered around the SN, as expected.

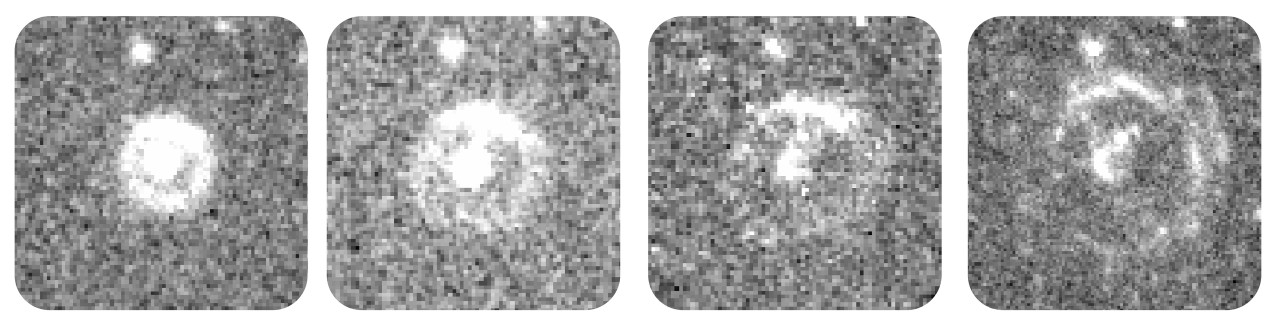




Above: Image sequence of M 96 showing the galaxy before, during, and after the outburst of SN 1998bu. Top right: Light curves from SN 1991T and 1998bu (Capellaro et al. 2001) showing how both SNe deviated from the expected decline after a few hundred days. Bottom right: Spectra from both SNe 1991T and 1998bu at early and late times (Capellaro et al 2001) again showing similar evolution of both SNe.

Hubble Space Telescope Observations

SN 1998bu was observed by *HST* with WFPC2 in 2000 and 2002, and has been subsequently been imaged with ACS in 2003 and 2006. After examination of these images (below) it is apparent that in addition to seeing the echo predicted by Cappellaro et al., the central source is itself an echo, just resolved in 2003 with a radius of roughly 0.12 arcsec.



2000 2002 2003 2006

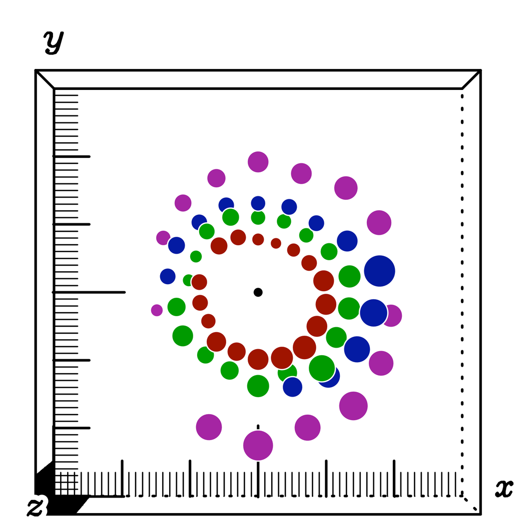
Echo positions on the image were traced out by fitting Gaussian functions to radial flux distributions around the SN. Knowing the 2-D echo position (ρ) and the date at which the echoes were imaged, we can determine the line-of-sight distance *z* to the echoes using the light echo equation

$$z = \frac{\rho^2}{2ct} - \frac{ct}{2}$$

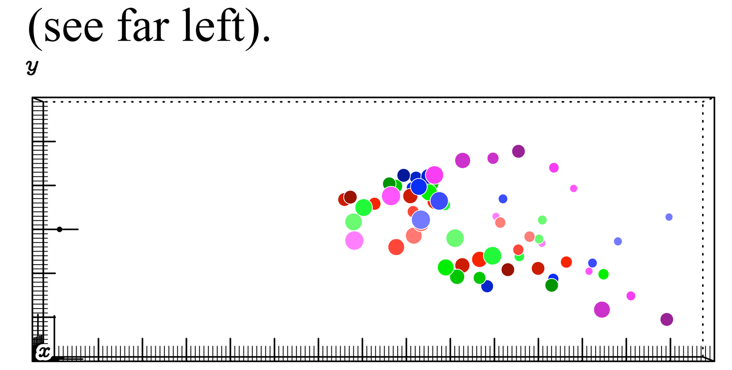
The echoes can then be visualized by plotting the 3-D distribution of points from any orientation.

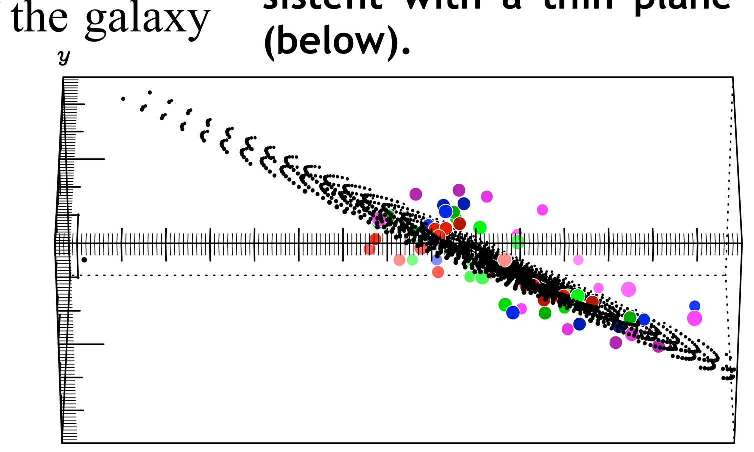
Outer Ring Analysis

The large-radius echo positions are shown in the plane of the sky to the right. When the 3-D positions of these echoes are viewed from the side, they trace a structure that is highly inclined to the line of sight, stretching 300-700 lt-yr in front of the SN. This distribution is well fit by a plane inclined 30° at PA 150, suggesting we are peering through a roughly 100 lt-yr thick dust lane in the disk of the host galaxy (M96). This orientation differs by about 20° from the inclination of 50° at PA 157 reported by Barberà et al. (2004), which could result from disk warp, as suggested by large-field images of the galaxy (see far left).



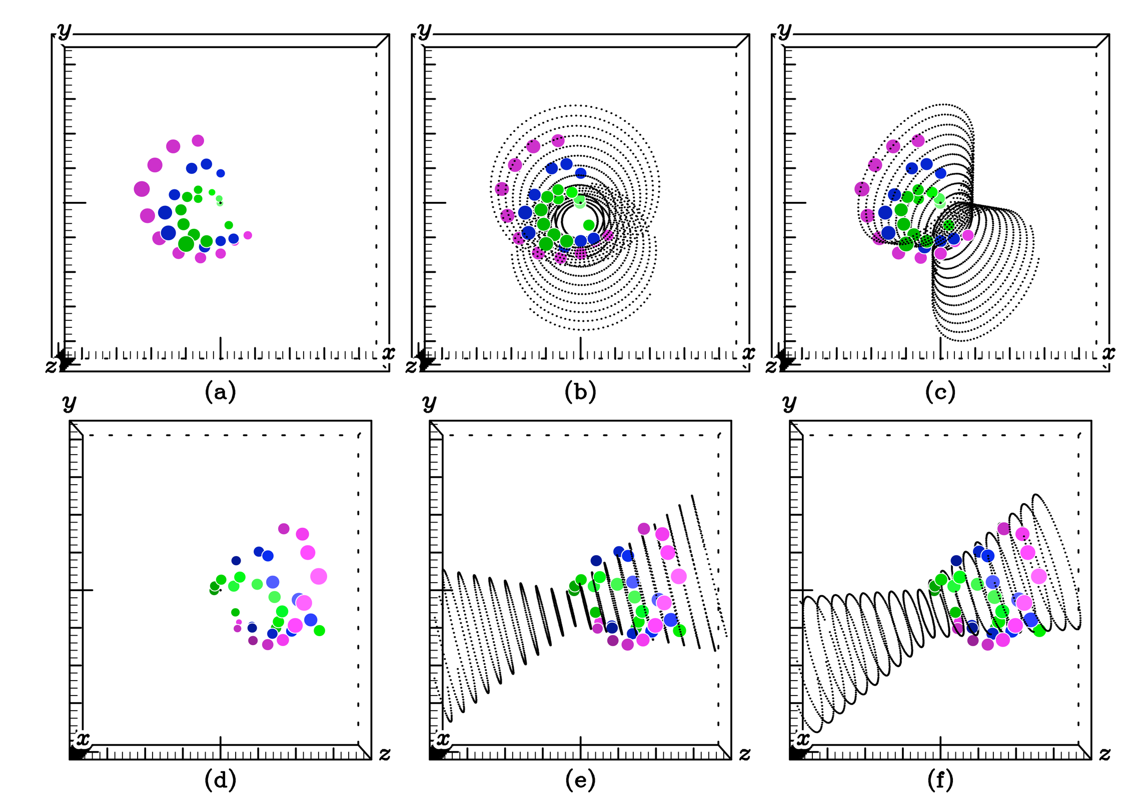
Outer echoes seen on the plane of the sky (above), from the side (bottom right) and rotated to show that they are consistent with a thin plane (below).





Inner Ring Analysis

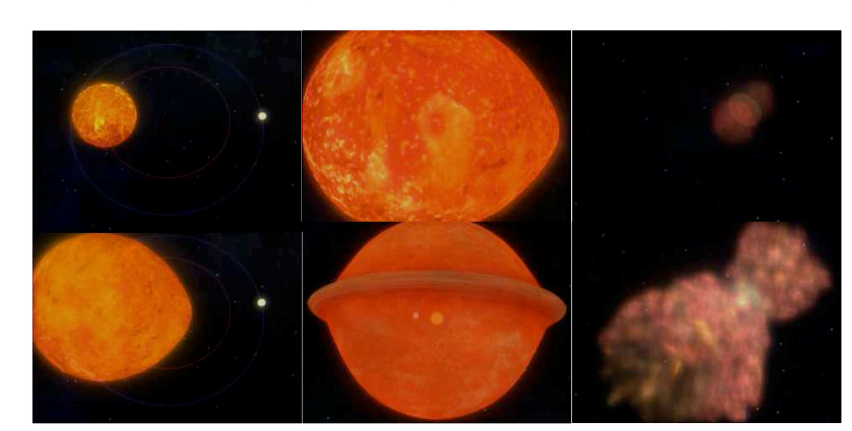
The inner echoes were an unexpected surprise to find as previously there had only been information and speculation about the outer echoes. Their positions from 2002-2006 in the plane of the sky are shown at right. Viewed from the side, we see that this material is up to 30 lt-yr in front of the SN. The available data are reasonably well fit by an hourglass shape with either a circular or elliptical cross-section, both of which are slightly offset from the SN position. These hourglasses represent the best fit from a few common geometric shapes, but do not represent exhaustive series of fits. More observations will be needed to determine, for example, is there is a "cap" to this structure, and if it is indeed hourglass in shape.



Views of the innermost echoes of SN 1998bu seen (top row) on the plane of the sky, and (bottom row) rom the side. The middle and right columns show the best-fit hourglasses with circular and elliptical cross-section, respectfully. In both cases, the hourglasses have inner-waist radii around 4 lt-yr.

Hourglass formation

We suspect that the hourglass seen above may come from the interacting winds of the binary system during its lifetime. Due to the gravitational pull of the white dwarf on its main-sequence companion there would be a natural equatorial buildup on the companion. This would, in turn, cause for an almost bipolar outflow of the companion's stellar wind. If the inner echo is in fact the remnant of bipolar winds, it will be exciting to have imaged a fossil nebula so late after its formation.



References

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Sugerman, B. E. K. 2003, AJ, 126, 1939