SN1991T: Circumstellar Dust Modeling using Light Echoes

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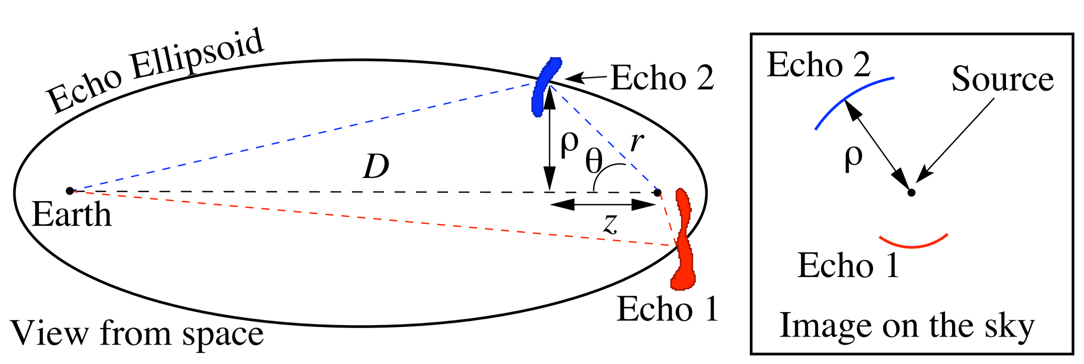
Abstract

Scattered light echoes are very rare and have only been unambiguously resolved around a handful of sources. They offer one of the most effective means to study the structure and make-up of circumstellar and interstellar dust and gas. Light echoes provide exact three-dimensional positions of scattering dust, and also can be used to constrain that dust's composition, size and number density. Here, we present new data and analyses of echoes previously discovered around SN 1991T. These echoes appear to trace out a shell around the progenitor, either hourglass shaped or ellipsoidal, and with a size scale of 20-30lt-yr. Also, the supernova may be significantly offset from the center of this shell. Like SN 1998bu (see poster by Lonsdale & Sugerman), SN 1991T was a type Ia, thus it is unclear yet whether we are tracing the fossil remnant of the progenitor's outflows, or those of its binary companion.

Introduction

Scattered light echoes offer one of the most effective means to probe circumstellar and interstellar structures. 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 lie equidistant in light travel from the source and observer, i.e on an ellipsoid with known foci (see figure 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 the observed echo position and the 3-D position of the scattered dust. Echoes can occur both behind (echo 1) and in the front (echo 2) of the source.

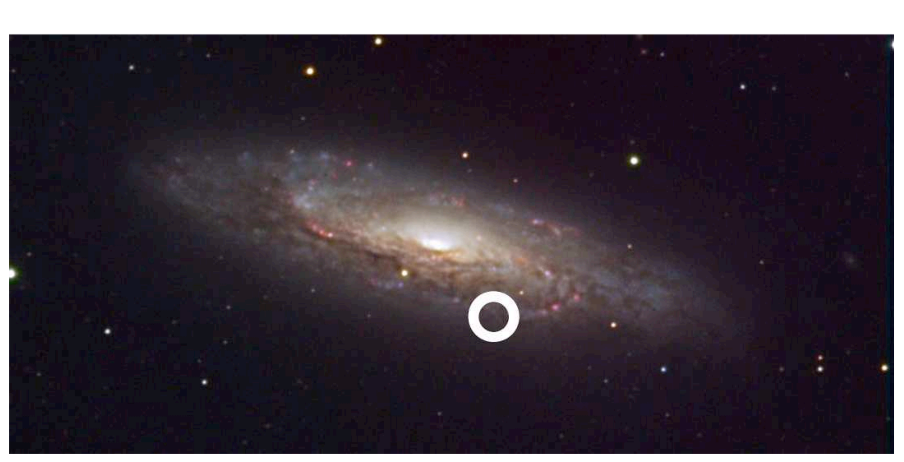
For distant source ($D >> z$), the echo ellipsoid is well approximated by a paraboloid

$$z = \frac{\rho^2}{2ct} - \frac{ct}{2} \quad (1)$$

Echo colors also probe the dust properties, such as the grain sizes, density, and composition (see Sugerman 2003).

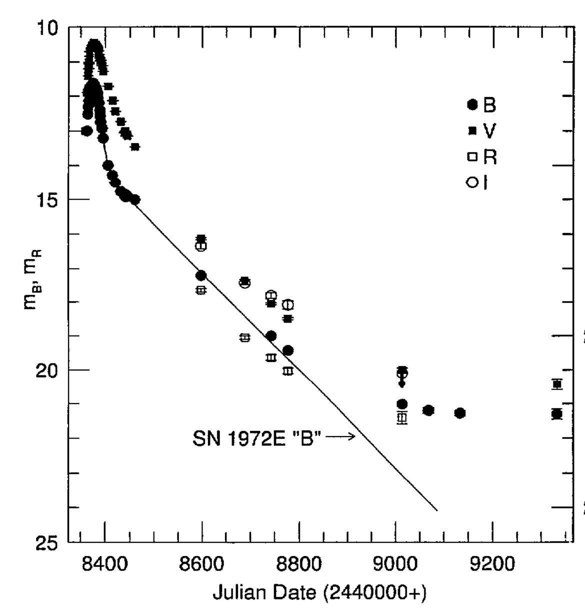
NGC 4527

SN 1991T occurred in NGC 4527, a spiral galaxy in the direction of the Virgo Cluster estimated to be 14-16 Mpc away by Sparks et al. (1999)



NGC 4527 with the position of SN 1991T indicated. Image from M. & J. Kollander/ Adam Block/ NOAO.

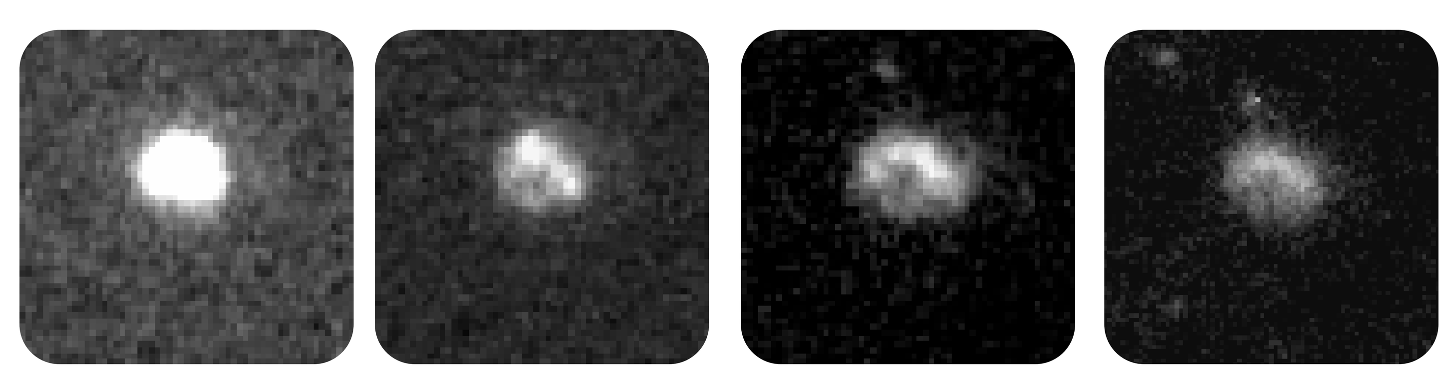
SN 1991T



***B* and *V* photometry of SN 1991T compared to a *B*-band photometry of SN 1972E (Schmidt et al 1994)**

SN 1991T is a type Ia supernova (thermo-nuclear runaway in a accreting white dwarf) in the galaxy NCC 4527. At late times, the characteristic exponential fading of the supernova ceased (see left). Furthermore, at late times, Fe as well as Co lines were found in the spectra, which is typical only for a young SN. These were interpreted by Schmidt et al. (1994) as strong evidence of a light echo located 10–100 lt-yr in front of the SN. Sparks et al (1999) confirmed the existence of an echo by marginally resolving it with the *HST* FOC between 1996 and 1998. Additionally, they used polarization measurements to estimate a distance to the SN, and hence to NGC 4527, of 14-16 Mpc.

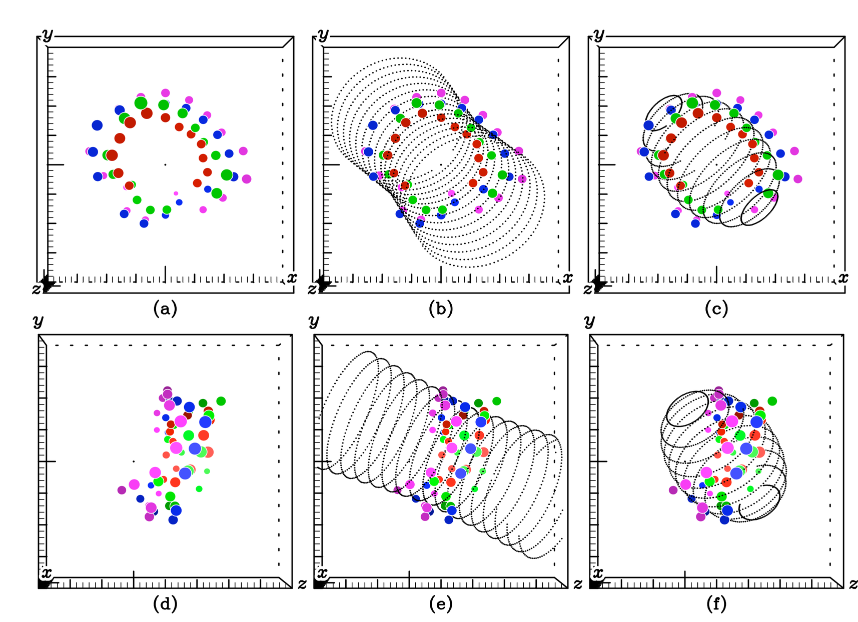
Most recently SN1991T has been revisited with WFPC2 and ACS in 2002 and 2006, respectively (see below). Clearly, the echo around the SN is ring-like with a radius of 0".08. These observations have stretched the observing limits of the *Hubble Space Telescope*.



1996 1998 2002 2006

***HST* images of echoes from SN 1991T between 1996 and 2006. Each image is x by x arcsec.**

For the 1998–2006 data, the observed echo positions (on the sky) were translated into 3-D positions using the light equation (1). The positions of these points are shown below in the left column. By fitting simple geo-metric structures to the 3-D positions of these echoes, we found two equally good alternatives for a complete structure illuminated by the echoes. First, a nearly-cylindrical hourglass with a radius at the waist of 18.5 lt-yrs (middle column). Second, an ellipsoid with semi-major axis of 27 lt-yrs and a semi-minor axes around 18 lt-yrs (right-column). Unexpec-tedly, the SN is offset from the center of both objects: only a few lt-yrs for the cylinder, but around 13 lt-yrs for the ellipsoid.



Echoes from SN 1991T, seen on the plane of the sky (*a-c*) and from the side (d-f). The left column shows the observed echo position, the middle col-umn show the best fit for an hourglass, and the right column shows the best fit for an ellipse. Major tick-marks denotes 10 lt-yr

In the typical type Ia scenarios, a white dwarf accretes material from its companion until it reaches 1.4 solar masses, which can take millions to billons of years, depending on the initial mass of the white dwarf and its accretion rate. The fact that SN 1991T appears spatially offset from its inferred circumstellar environment could suggest that the binary pair drifted substantially between the time the white dwarf expelled its planetary nebula (which expanded in the large environment now observed) and when it exploded. However, can a fossil planetary nebula remain intact (i.e not dispersed in the ISM) for that duration?

Future Work

The research will continue in the near future, in which we will use colors of the echoes to constrain the chemical composition and density of this dust. Hopefully these will provide clues as the origin of this dust and the evolutionary history of the progenitor of SN 1991T.

For a better understanding of the light echo, data should be collected over the next decade to find an appropriate fit for the shell probed by these echoes.

References:

Schmidt, B. P.,et al 1994, ApJ, 434, L19
Sparks et al. 1999, ApJ, 523, 585
Sugerman, B. E. K. 2003, AJ, 126, 1939