The Evolution of the Light Echo Around Type Ia Supernova 1998bu

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Introduction

Due to their extreme and predictable luminosities, type Ia supernovae (SNe Ia) are powerful distance indicators and crucial tools for measuring the Hubble constant and acceleration of the universe. However, the fundamental physics behind these explosions is not well understood. SNe Ia are thought to occur from either a single white dwarf star accreting material from a main-sequence star (single-degenerate progenitor; SD) or from two white dwarfs merging (double-degenerate progenitor; DD).

Of the two progenitors, the SD system is thought to leave behind more circumstellar dust than the DD system. Light echoes are one way to reveal such dust and are unique solution for probing the progenitor problem because they stay visible long after the explosion itself has faded and can be observed even if other indicators of circumstellar dust have been missed.

SN 1998bu is a Type Ia supernova in NGC 3368 (M96) that was spectroscopically normal around maximum, but declined nearly as slowly as SN 1991T. First evidence of a light echo around SN 1998bu was discovered about 500 days past maximum. The light echo has since been resolved by the *Hubble Space Telescope* in several epochs, where both an inner and outer echo can be seen. We present the archival *HST* data and our analysis of the expansion of both the inner and outer echoes.

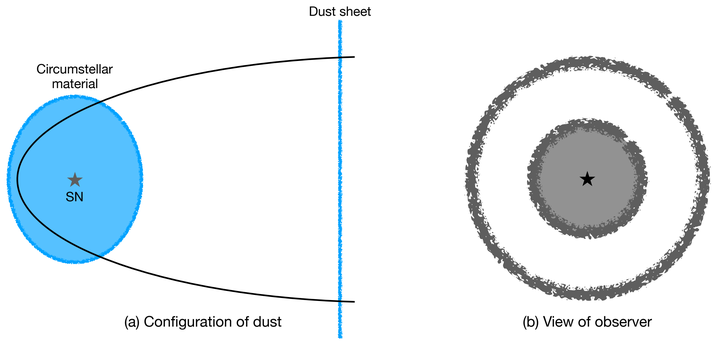
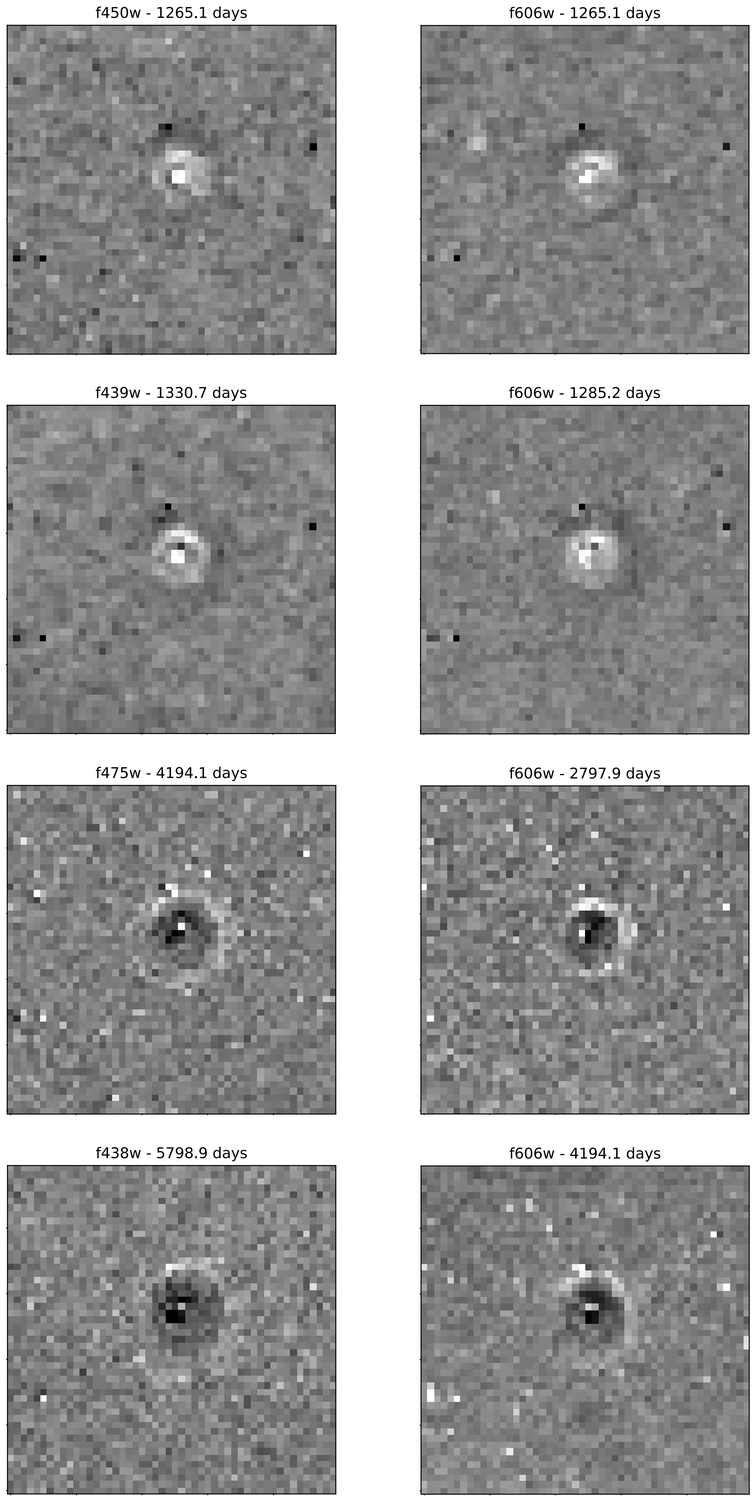


Figure 1: Geometry of a light echo caused by a distant dust sheet and nearby circumstellar material (not to scale). Only the light reflected by dust on the time-delay "surface" (the parabola) is visible to the observer.

Light Echoes

A light echo is caused by photons from an astrophysical explosion scattering off of dust into our line of sight and arriving with a time delay. This time-delay "surface" is shaped like an ellipsoid with the SN at one focus and the observer at the other. Only dust that intersects this surface at a given time creates a visible light echo. When monitored over time, the changes in the light echo can reveal information about the 3-D shape of the dust.

Figure 1 shows an example light echo caused by circumstellar material and a distant dust sheet. The echo caused by the circumstellar dust appears to the observer as a compact disk while the echo caused by the distant dust sheet appears as a ring. For our purposes, the disk light echo would point towards an SD explosion while a ring echo just tells us information about the galaxy.



Methods

Images of SN 1998bu were taken by *HST* over several epochs from 2000 to 2014. There was not much consistency in acquired filters across epochs, so our analysis includes some bluer images (f450w and nearby filters) and redder images (f606w filter). The middle column shows the blue and red images in sequence from top to bottom. These images have been aligned and placed on the same pixel scale for a consistent comparison.

After image correction, we calculated the distance between the supernova and the dust in the outer echo to form a 2D map of the dust distribution. Figure 2 (below) shows our results.

$$z = \frac{(D\theta)^2}{2ct} - \frac{ct}{2}$$

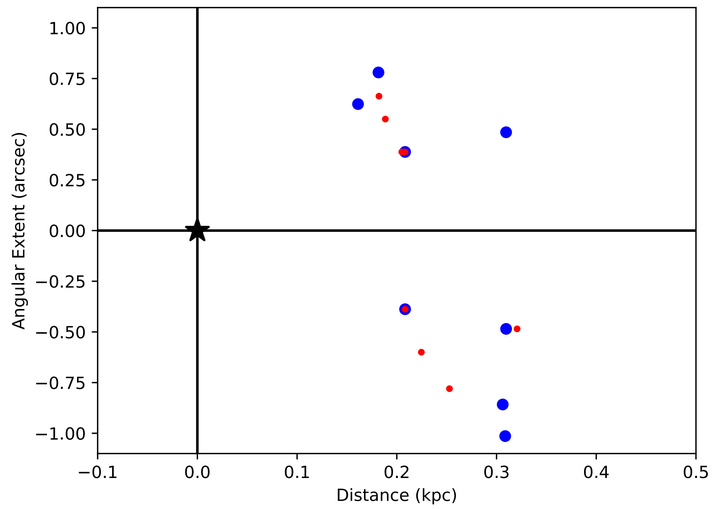


Figure 2: Two-dimensional map of the dust distribution as highlighted by the outer echo of SN 1998bu. The blue points correspond to the f450w and nearby filters while the red points correspond to the f606w filter. The outer light echo is not circular, indicating that the dust distribution is not a face-on plane but is instead tilted. The dust on the bottom of the echo is farther from the SN than the dust at the top.

Conclusions & Future Work

The outer light echo of SN 1998bu is not symmetric, indicating that the dust distribution is tilted towards our line of sight. We plan to perform the same analysis on the inner light echo, which requires subtracting out the expected contribution from the SN at the given time. We also hope to obtain more images of SN 1998bu and other SNe Ia with light echoes in the future.

References

Cappellaro, E., Patat, F., Mazzali, P. A., et al. 2001, ApJ, 549, 215
Jha, S., Garnavich, P. M., Kirshner, R. P., et al. 1999, ApJS, 125, 73

Facilities: Hubble Legacy Archive
Software: astropy, ccdproc, matplotlib, astroalign

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