The Slowly Fading Light Echo Around Type Ia Supernova 2009ig

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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 2009ig is a normal SN Ia in NGC 1015. The galaxy is nearly face-on, resulting in low host-galaxy extinction for SN 2009ig. If any light echo is present with this SN, it is more likely caused by circumstellar dust than by dust unrelated to the explosion. Here we present an updated light curve of SN 2009ig using data from the Large Binocular Telescope spanning nearly a decade (2010 - 2018) and show that it does host a light echo and that it behaves similarly to that of SN 1991T.

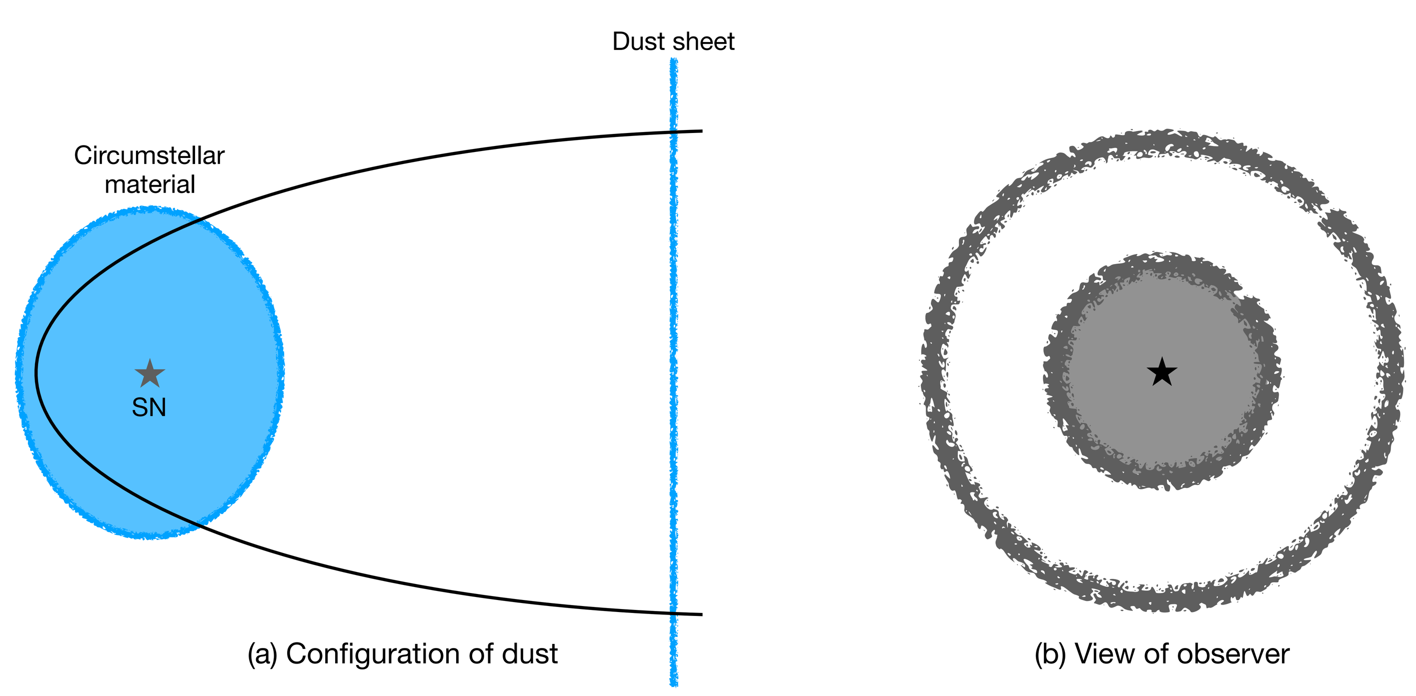

Figure 1: Geometry of a light echo caused by a distant dust sheet and nearby circumstellar material (not to scale). Only the light reflected by dust on the time-delay "surface" (the parabola) is visible to the observer.

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.

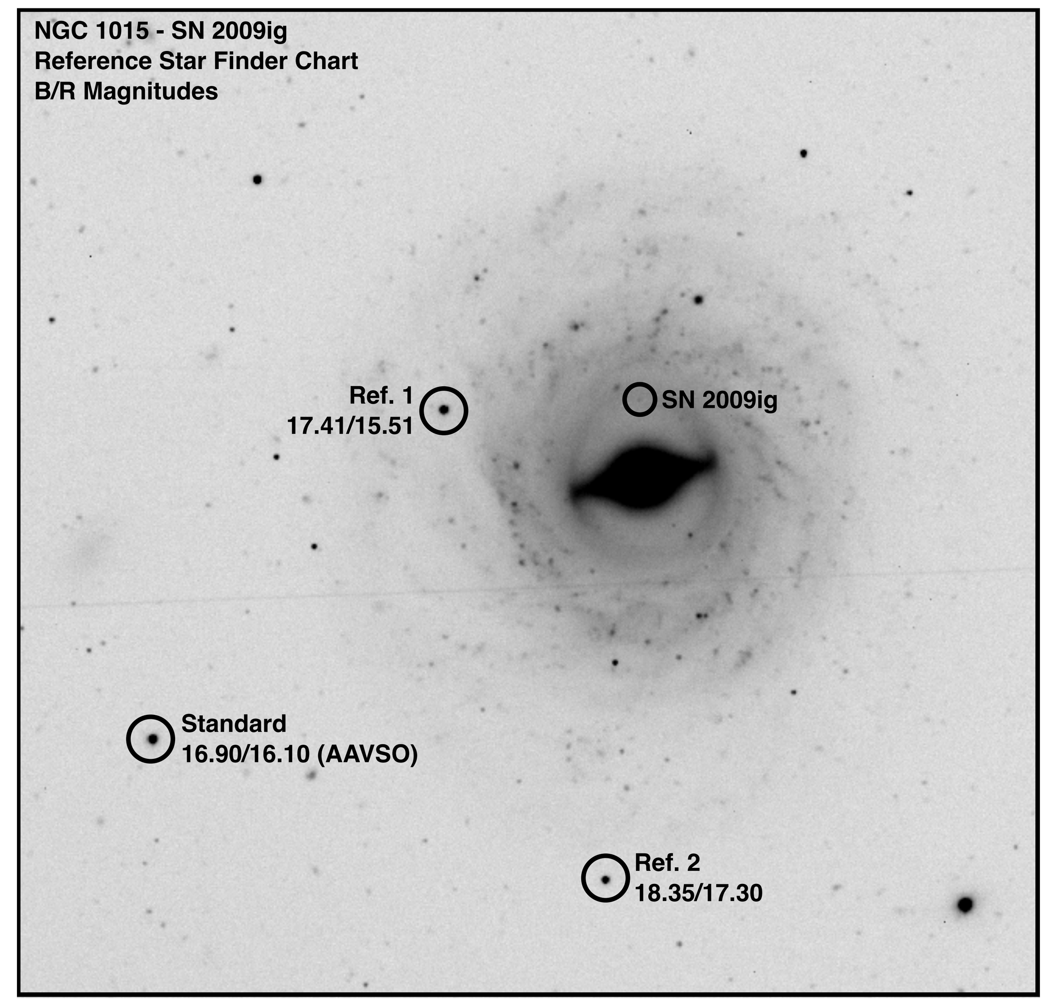

Figure 2: Reference star & SN finder chart. Magnitude data for the standard star from AAVSO, magnitudes for other reference stars determined through relative aperture photometry. These stars were chosen because they were least likely to be saturated in any given R-band image.

Creating the Light Curve

To create the light curve, we use photometry data from the LBT spanning from October 2010 to September 2018. While older LBT data sets (2010 - 2012) include U-, V-, and I-band photometry data on SN2009ig, we only include the B- and R-band data as it is available in every data set considered.

After reducing the data using *astropy.ccdproc*, we aligned and stacked the images to increase our signal-to-noise. Although SN2009ig was still fairly bright in 2010, it is not obviously visible in the latest images individually, especially for the R-band data. We then performed aperture photometry on the supernova and three reference stars (see Figure 2) using *photutils.aperture_photometry*. Below is our updated light curve including both the B- and R-band data (Figure 3).

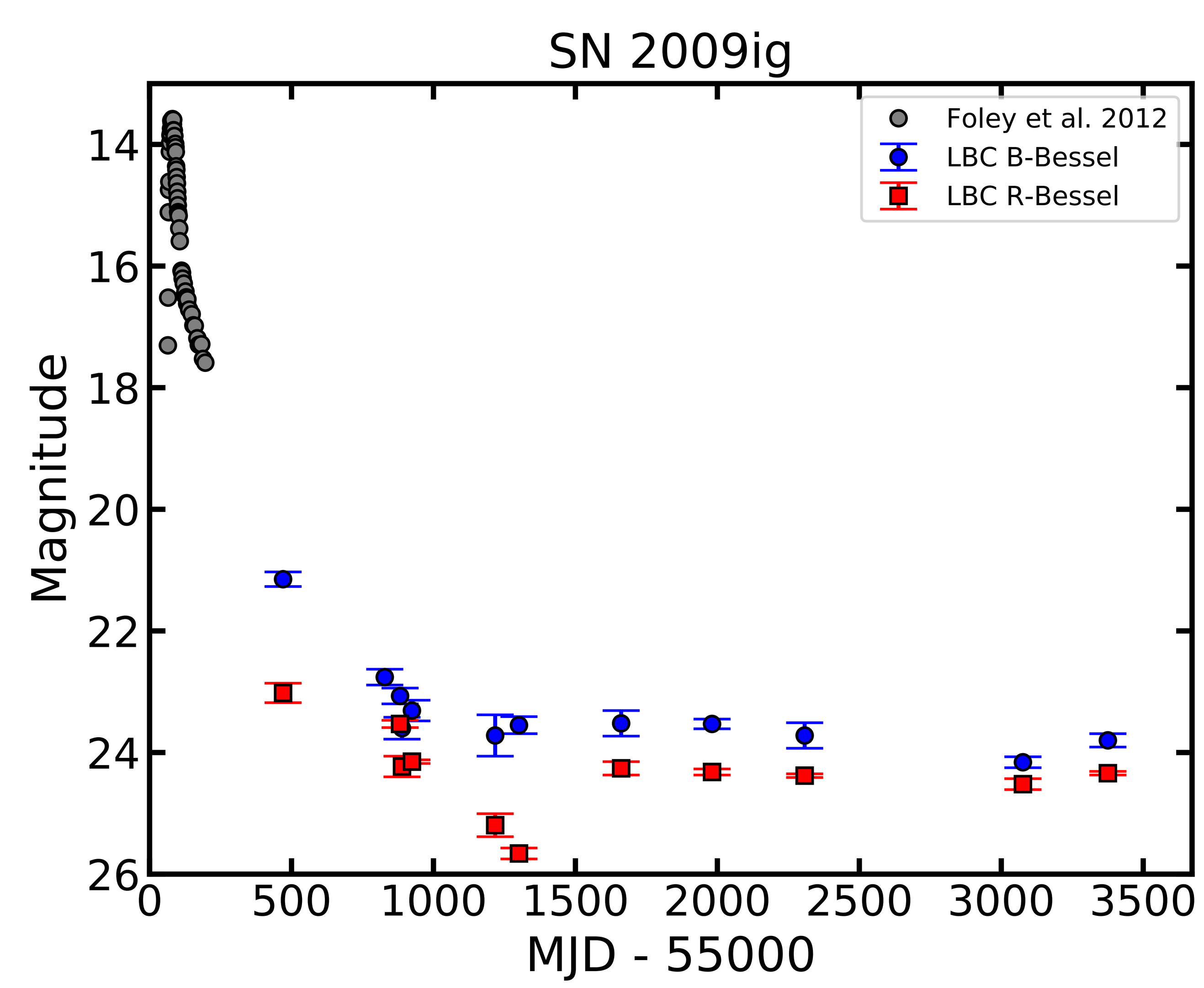

Figure 3: B- and R-Bessel light curve of SN 2009ig from LBT data. The light curve flattens out about 1000 days post-explosion, which is not expected for a normal type Ia supernova event.

Results and Conclusions

The unusual flattening of the SN 2009ig light curve indicates that a light echo is present. We then plot our B-band light curve with the expected behavior for a normal SN Ia when the luminosity is just powered by the radioactive decay of the ejecta (Figure 4). We find that the magnitude of SN 2009ig starts to deviate from expected around 500 days post-explosion, confirming the existence of the light echo. The light echo fades slowly, similar to the light echo found around SN 1991T, the first known SN Ia light echo.

Since SN 2009ig has low host-galaxy extinction, we expect that this light echo is caused by circumstellar material rather than a distant dust sheet, implying that SN 2009ig was cased by a SD explosion.

Future Work

While aperture photometry is a great start, it introduces error by including some of the background flux. This is most important for SN2009ig itself, which is fairly small compared to the reference stars and has a higher background contribution from NGC 1015. Performing PSF photometry on SN2009ig will reduce this error and is a work in progress.

If the light echo around SN2009ig is resolved in high-resolution data, we can determine the 3-D distribution of the gas and dust. Like the Milky Way dust distribution, this can then be corrected for when using SN2009ig as a standard candle for measurements of H_0.

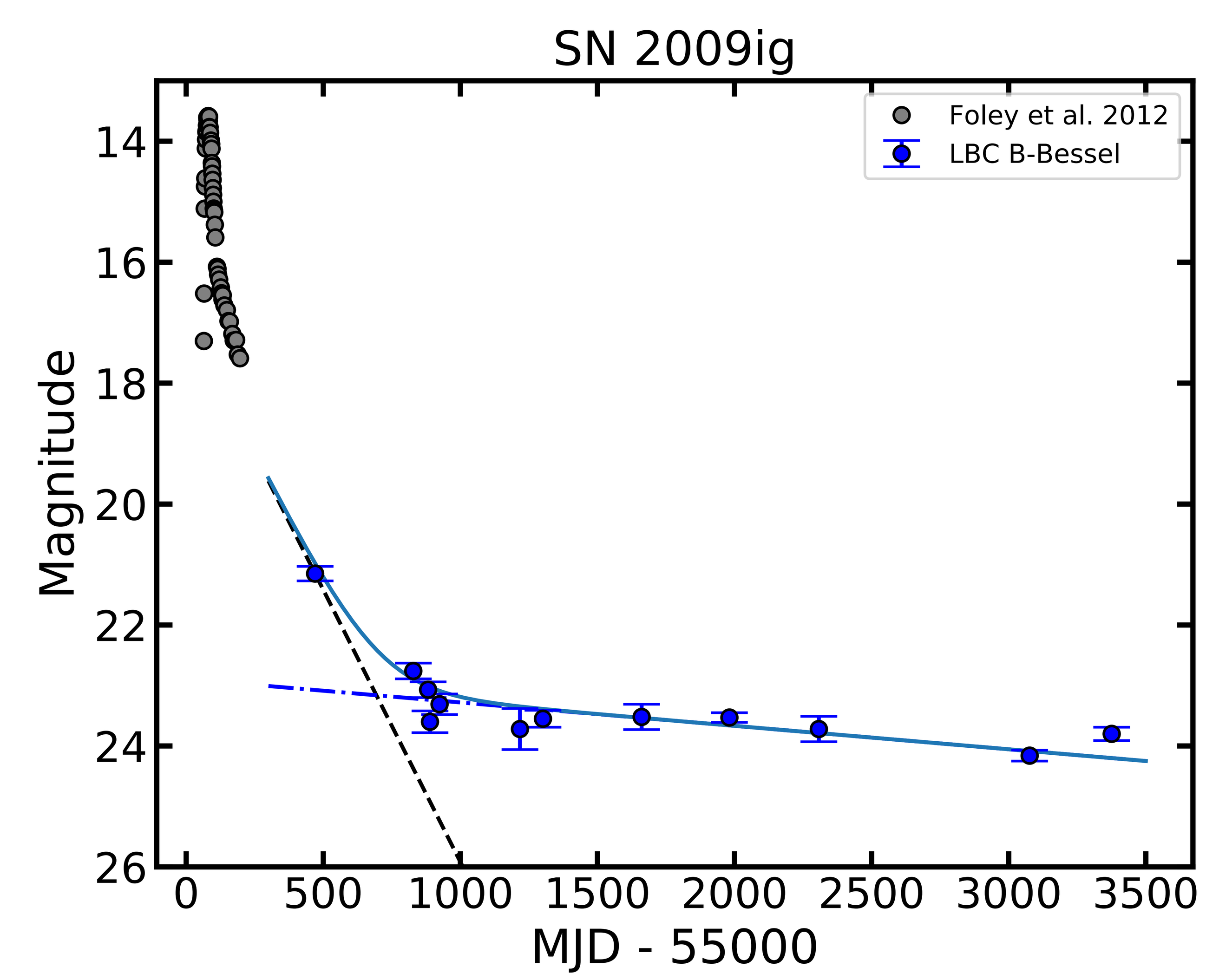

Figure 4: B-Bessel light curve of SN 2009ig from LBT data compared to the expected behavior of a normal SN Ia light curve (dashed line). The presence of a light echo became apparent about 500 days post-explosion and is still visible now.

References

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