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Echoes of Silence

Probing Type Ia Supernova Progenitors and Local Dust Environments Using Scattered Light Echoes

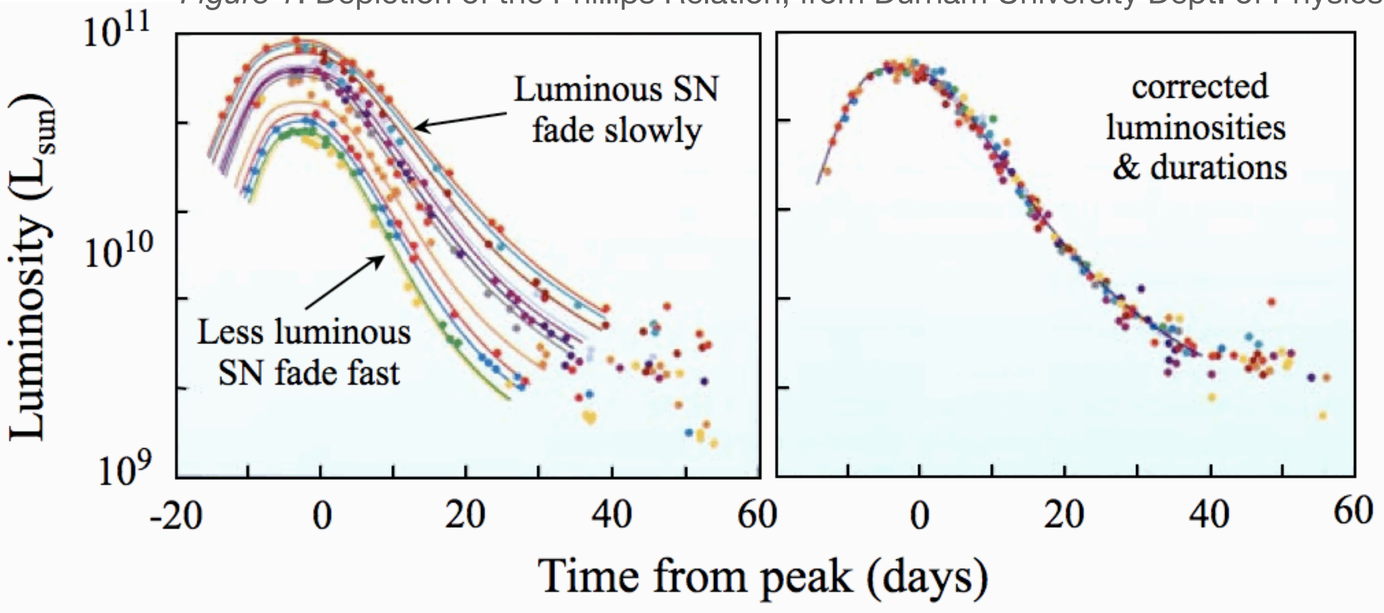
Charlotte M. Wood - The Transient & Variable Universe - Session 4B - June 21, 2023

Variations in SNe Ia

Standard vs. Standardizable

- Correlation between peak luminosity and decline rate (Phillips relation)
- Correlation with color at peak and peak luminosity
- Correlation with host galaxy properties (galaxy type, mass, metallicity, current star formation)

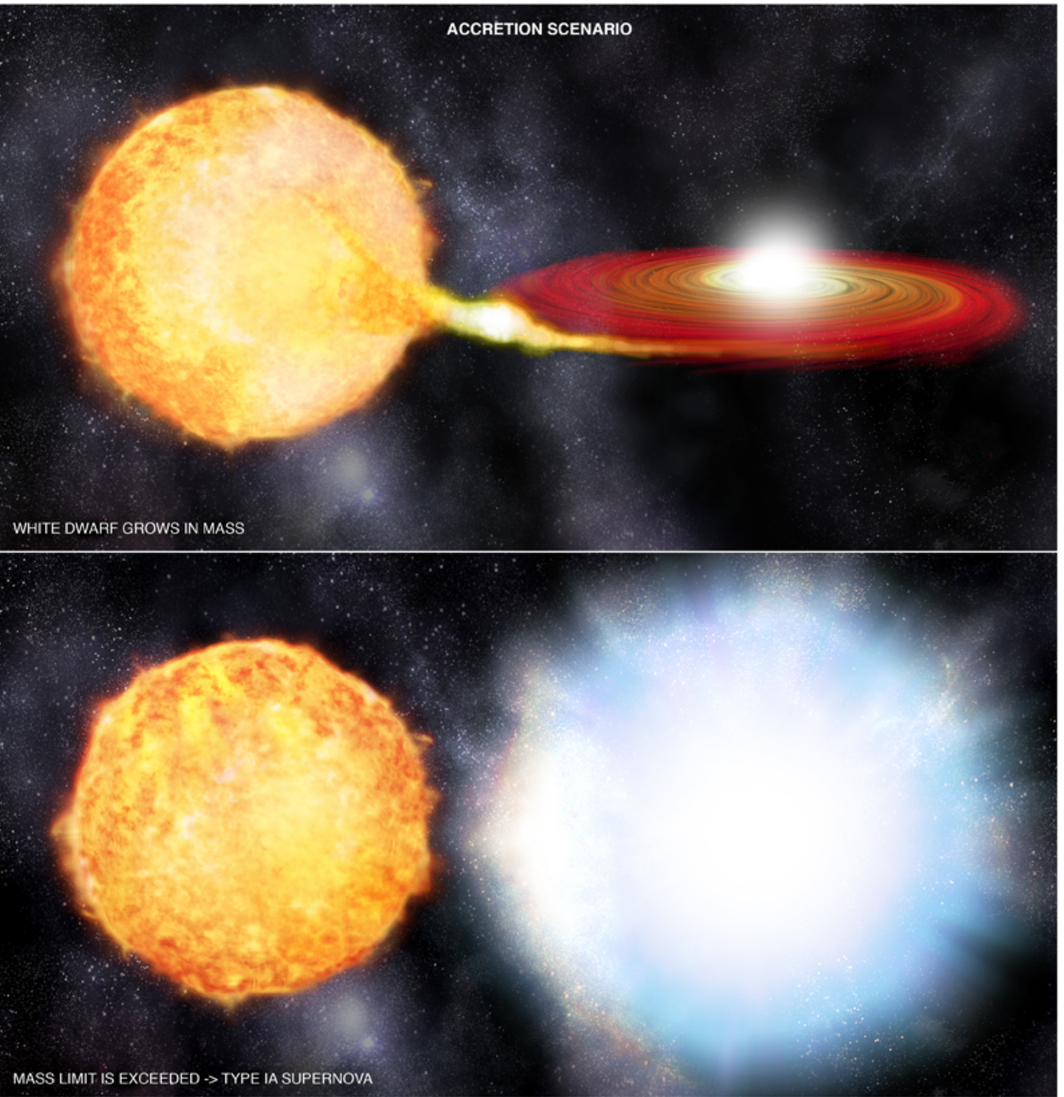
Figure 1: Depiction of the Phillips Relation, from Durham University Dept. of Physics



Correlations are most simply interpreted as resulting from different progenitor *masses*, but could also indicate different progenitor *types.*

SNe Ia Progenitor Types

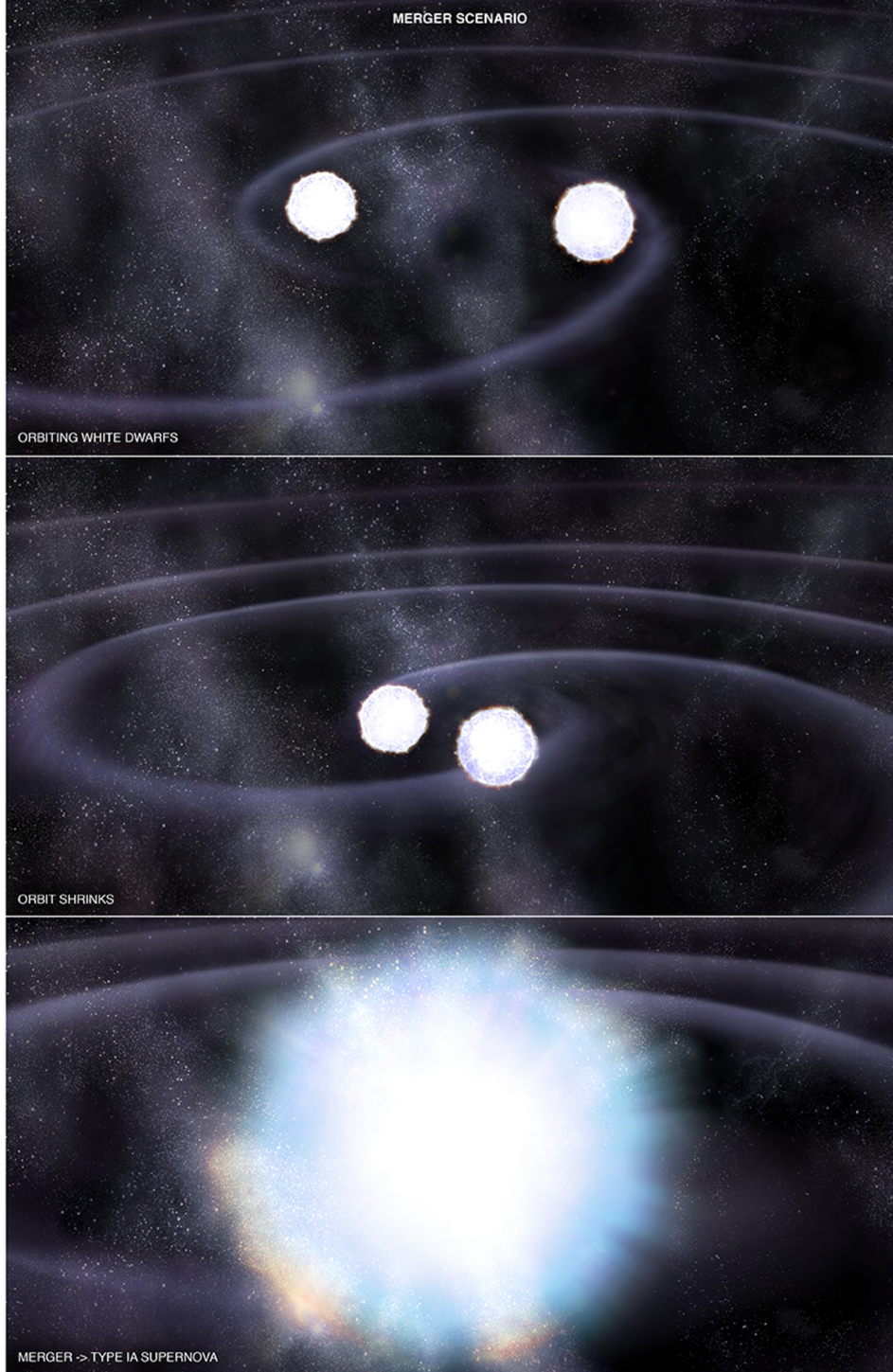
Single- vs. Double-Degenerate



← *Figure 2*: Depiction of the single-degenerate scenario

Figure 3: Depiction of the double-degenerate scenario →

From NASA/CXC/M. Weiss



Observational Differences

How do we distinguish between progenitor scenarios?

- SNe Ia progenitors *have not* been observed directly
- Single-degenerate systems are expected to host more dust in the immediate vicinity of the explosion
- Creative methods — look for evidence of circumstellar dust

Caveats: interactions occur early and are quite transient in nature, it's rare to get high-quality data to prove interaction occurred

Figure 4: NUV image of SN 2015cp ~650 days post-peak. Label "**A**" denotes observed interaction emission. (Graham et al. 2019)

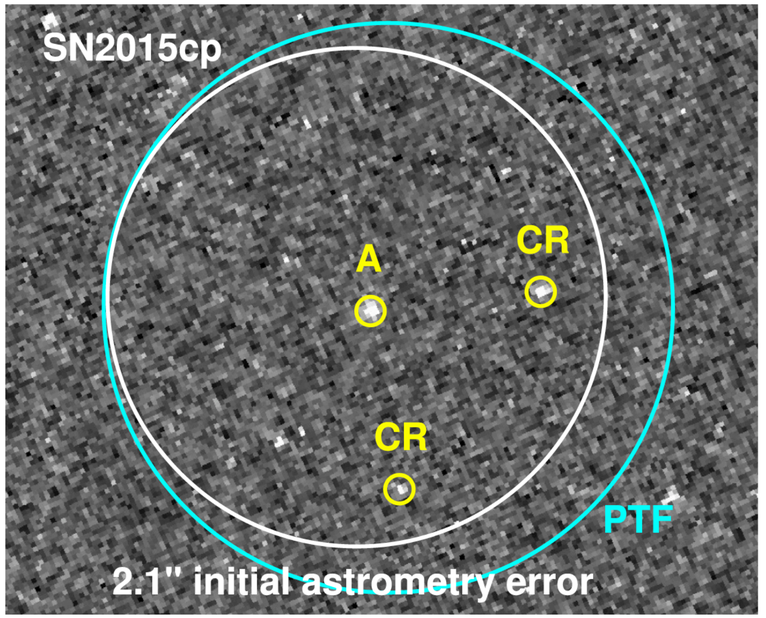
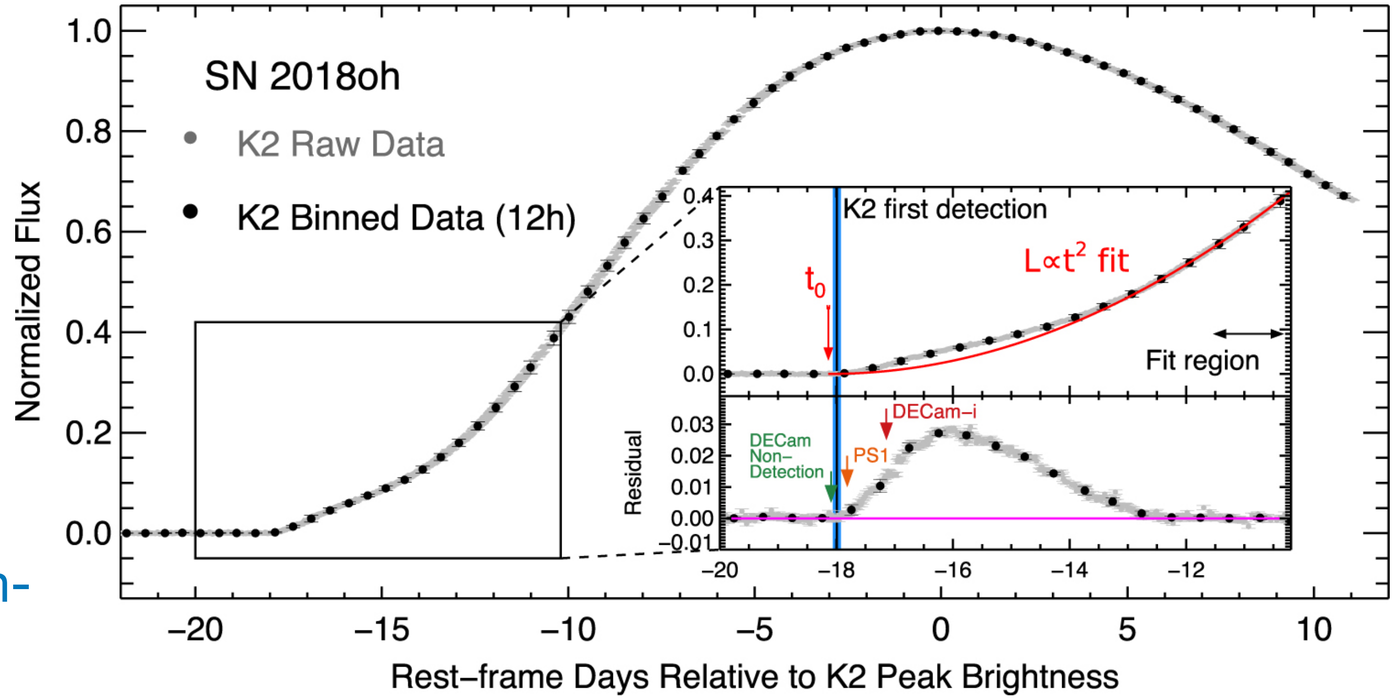


Figure 5: K2 light curve of SN 2018oh. Inset shows zoom of -20 to -10 days pre-peak and the typical power-law fit to the rise. Additional flux indicates interaction with nearby material. (Dimitriadis et al. 2019)



Light Echoes

What they are and how they work

Light echo: a transient reflection nebula caused by dust scattering light from any bright, variable/ transient source into our line of sight

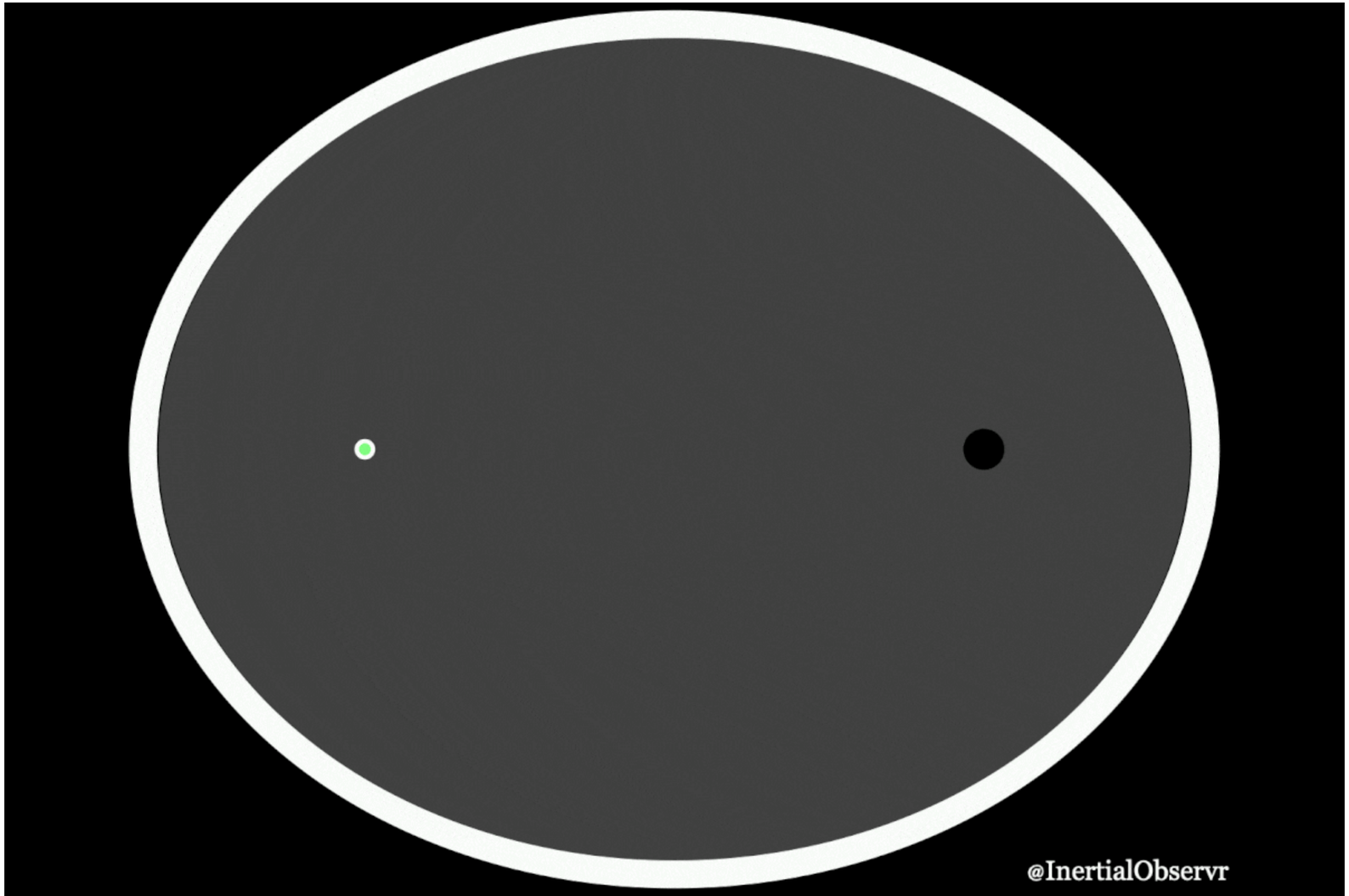


Figure 6: animation showing the principle behind a light echo

SNe Ia Light Echoes

Interstellar vs. Circumstellar dust

Large, rapidly expanding rings are caused by ***interstellar*** material while compact, slowly changing disks are likely ***circumstellar***.

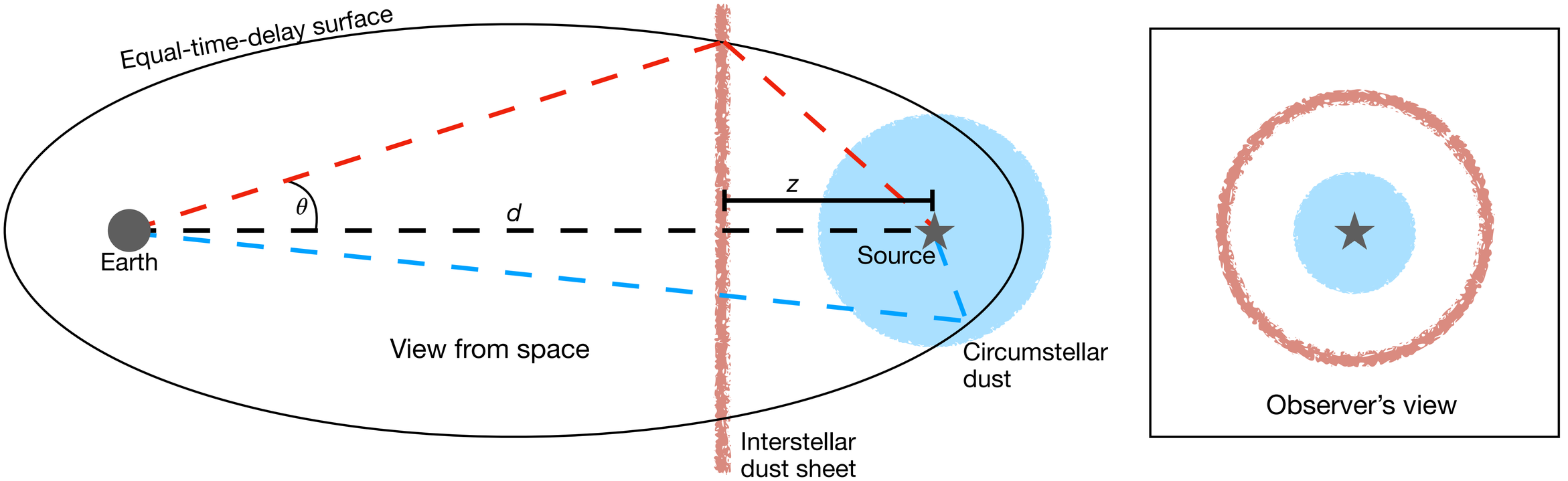
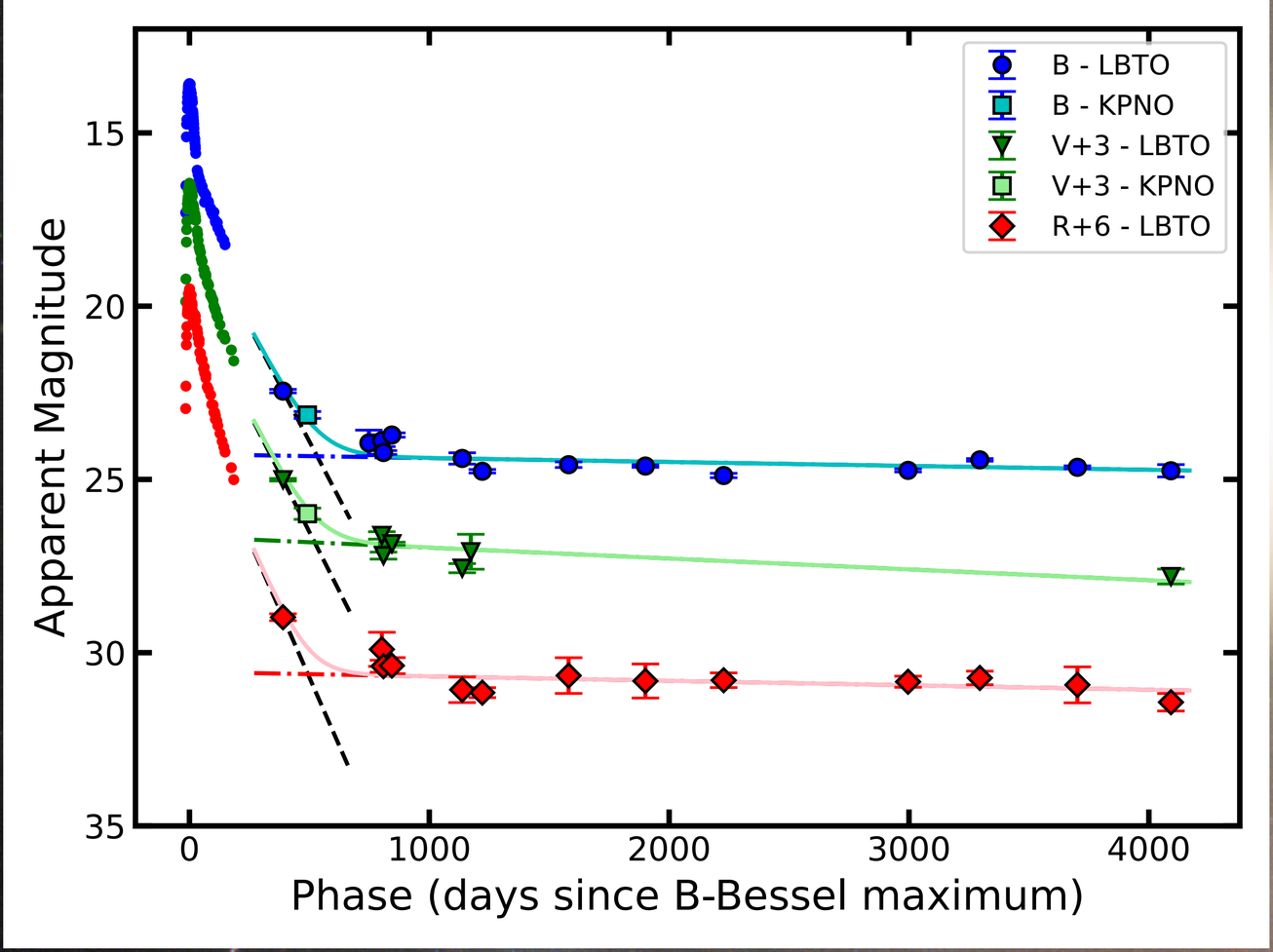


Figure 7: cartoon showing the geometry of a light echo as created by interstellar material and by circumstellar material. Left shows external view, right is observed.

SN 2009ig

Figure 9: the ground-based, late-time light curve of SN 2009ig. Wood et al. (2023), in prep



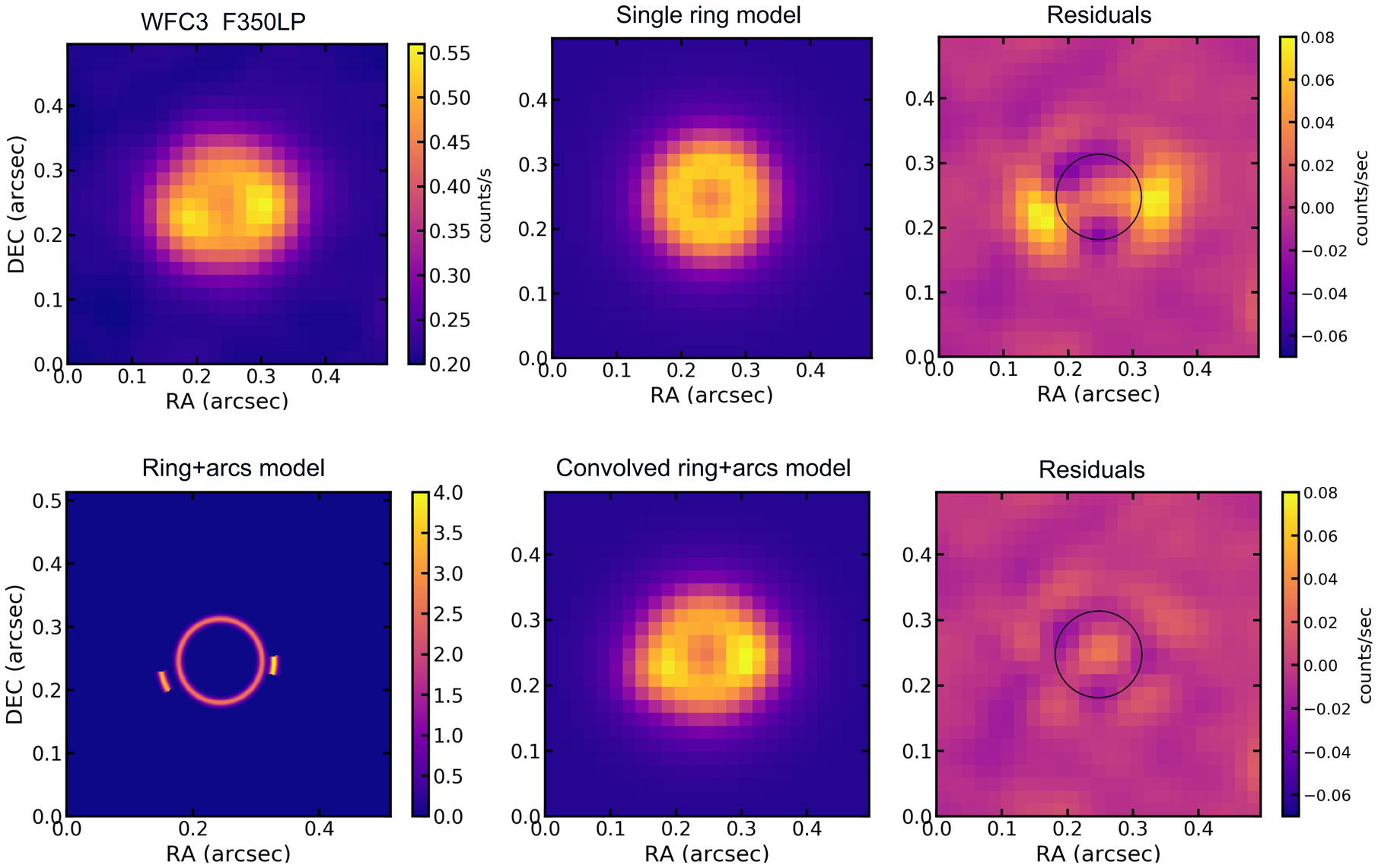
Type Ia supernova **light curve shape** is determined by the radioactive decay of nickel to cobalt to iron.

For SN 2009ig, the light curve deviates from expected behavior starting ~700 days post-peak.

This suggests some **other source** is dominating the observed flux - like a **light echo**.

Figure 8: HST color image of NGC 1015, host galaxy of SN 2009ig. Credit: ESA/ Hubble & NASA, A. Riess (STScI/JHU)

What does HST imaging reveal?

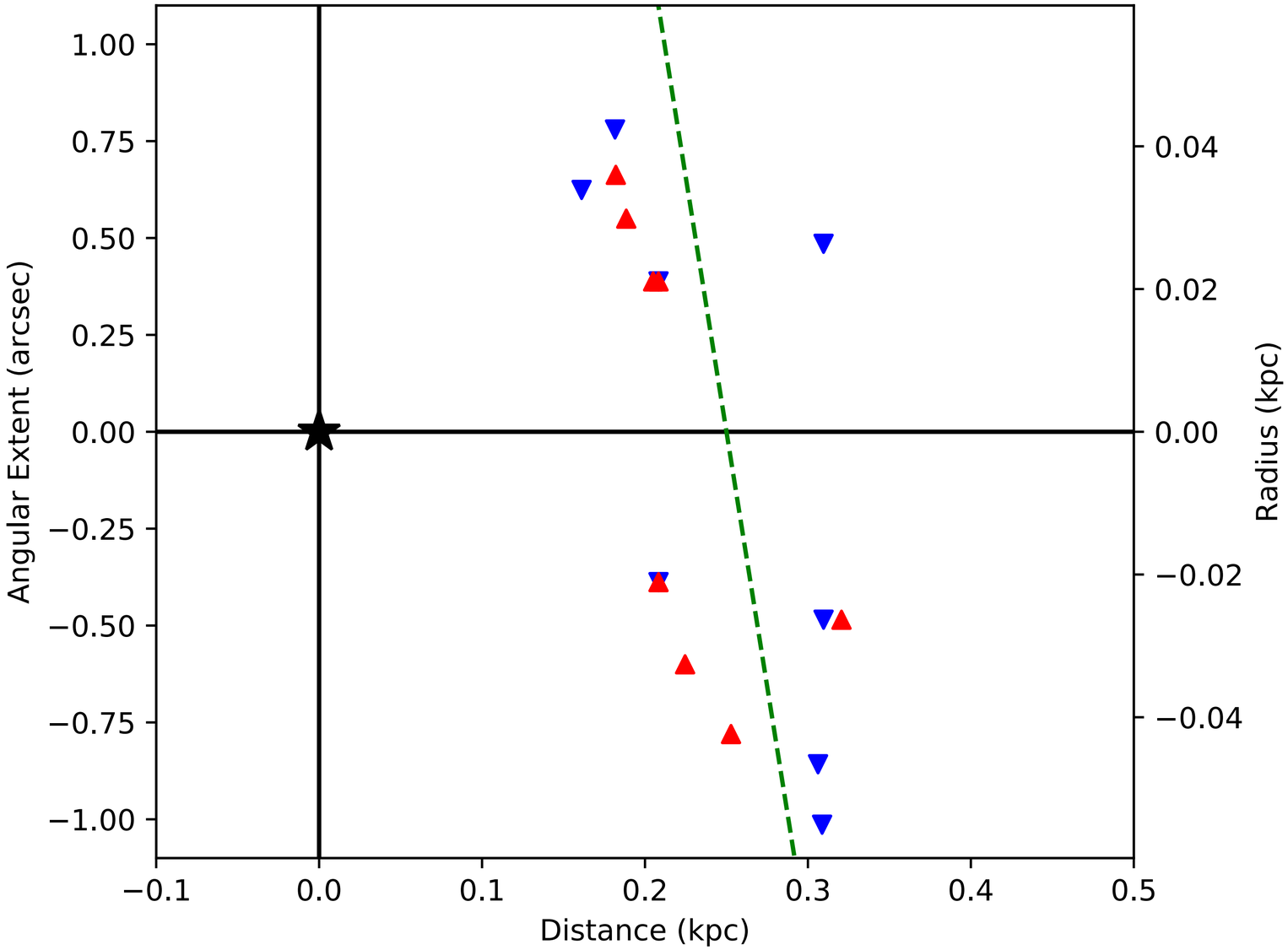


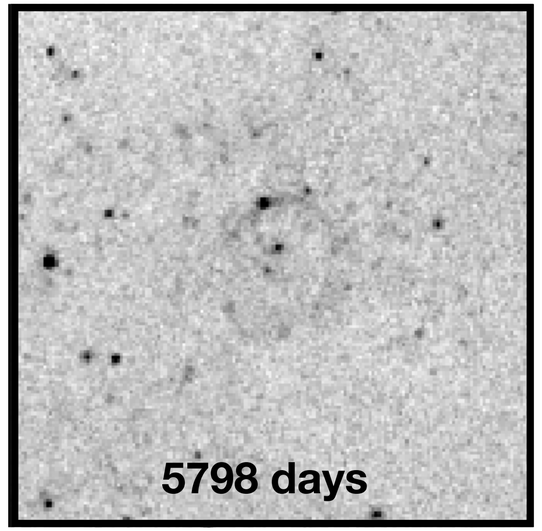
- WFC3 imaging shows a ring with two bright lobes on either side
- Consistent with light echo from dust sheet (~130pc in front) and parsec-radius clouds (~150pc in front)
- Residual with best-fit ring+lobes model shows some excess flux in center
- Circumstellar light echo?

Figure 10: Comparison of observed flux to best-fit models, one just a ring and one ring with lobes. Wood et al. (2023), in prep.

SN 1998bu - Preliminary

Figure 12: Two-dimensional map of the interstellar light echo around SN 1998bu





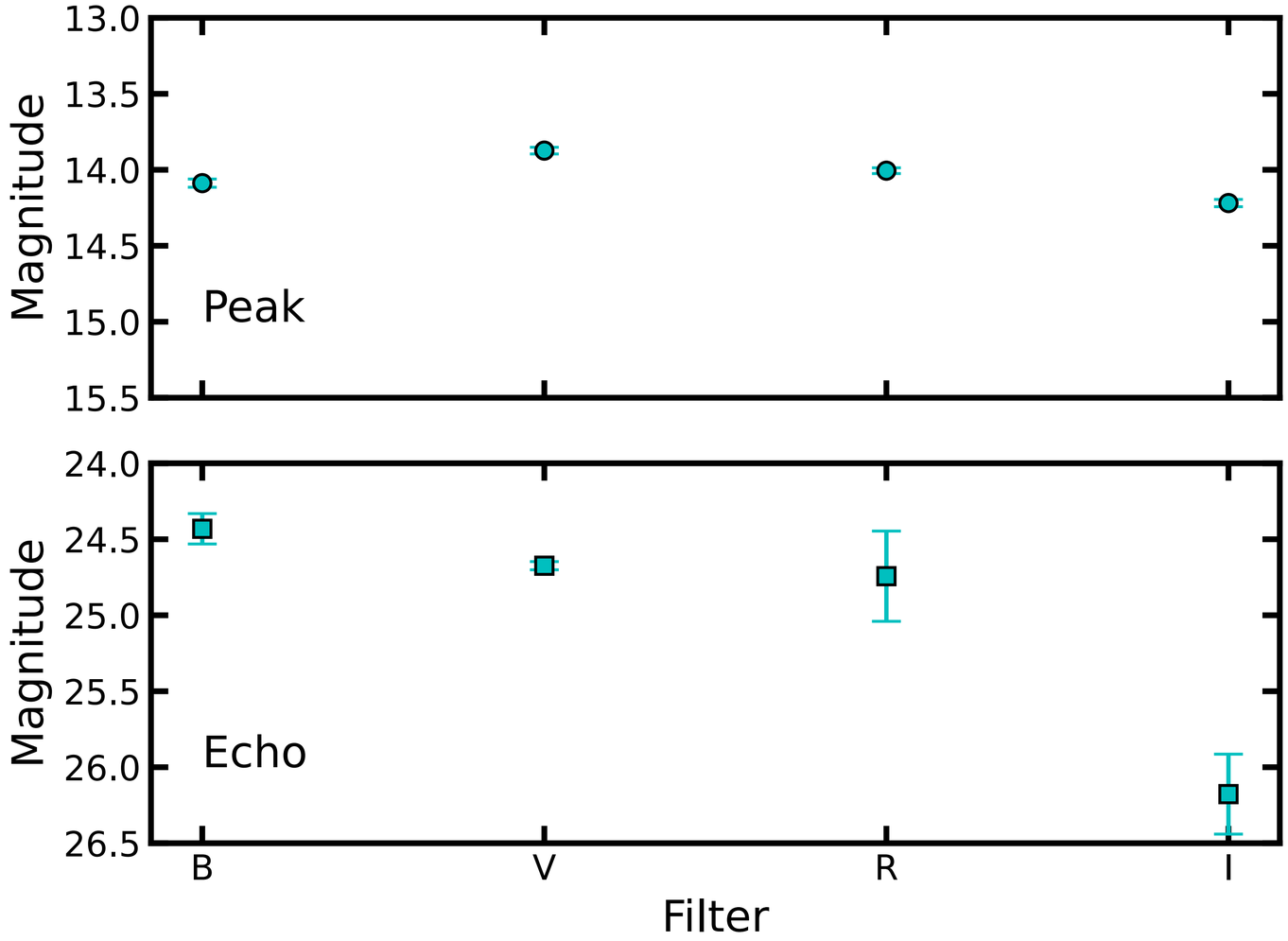
SN 1998bu has an interstellar light echo which shares the inclination of the host galaxy, M96.

Extracting Dust Properties - Preliminary

Given an object's spectrum, either *template* or *observed*, one may construct a series of expected spectral distributions against which the actual echoes may be compared to constrain the **dust size distribution, composition, and gas density**.

Sugerman (2003)

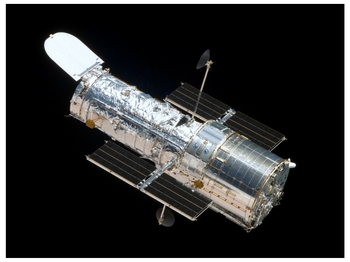
Figure 13: The BVRI magnitudes of SN 2009ig at peak and the light echo ~4 years post-peak

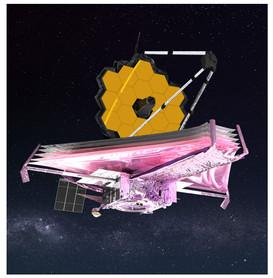


Future Work

Combining HST, JWST, LSST, and Roman

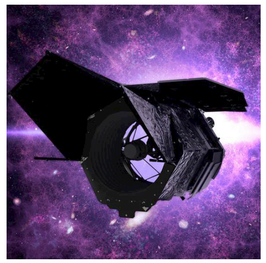
- Look for light echoes in SH0ES data (extend to SBF/TRGB datasets)
- Fill the archival gaps, include new SNe





- IR data for circumstellar light echoes in HST to better constrain the dust properties

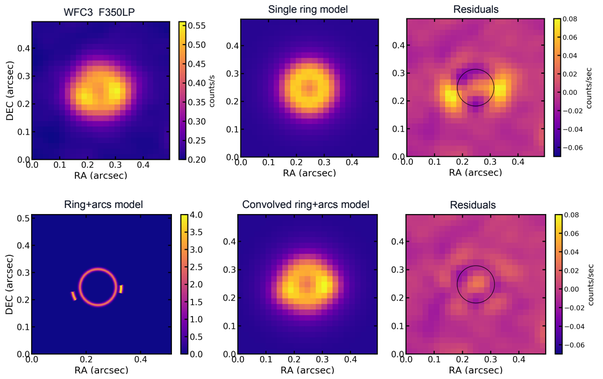
- Exquisite ground-based light curves for preliminary light echo identification

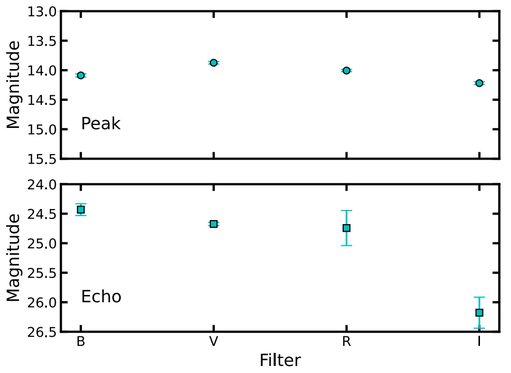


- Bluest filters can provide same functionality as HST for light echo detection

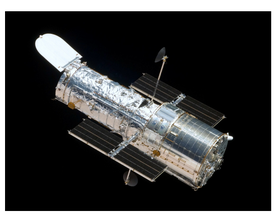
Summary

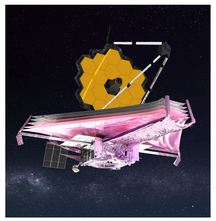
- Light echoes provide a method for both probing the progenitor systems and the local dust environments of SNe Ia used for cosmology

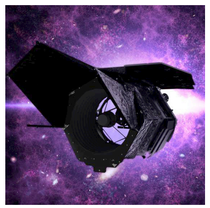




- A wide range of current and future facilities can contribute to both searching for and analyzing light echoes around SNe Ia







Collaborators:

- Dr. Peter Garnavich, University of Notre Dame
- Dr. Stephen Lawrence, Hofstra University
- Dr. Peter Milne, University of Arizona
- George Nassif, Iowa State University

IOWA STATE UNIVERSITY

UNIVERSITY OF NOTRE DAME

Barbara A. MIKULSKI ARCHIVE FOR SPACE TELESCOPES

cwood12@iastate.edu

astrocmwood