

SN 2024iss: A Multi-Wavelength Exposé of a Type IIb Supernova with an Early-Time UV Spectrum and Shock Breakout Constraints

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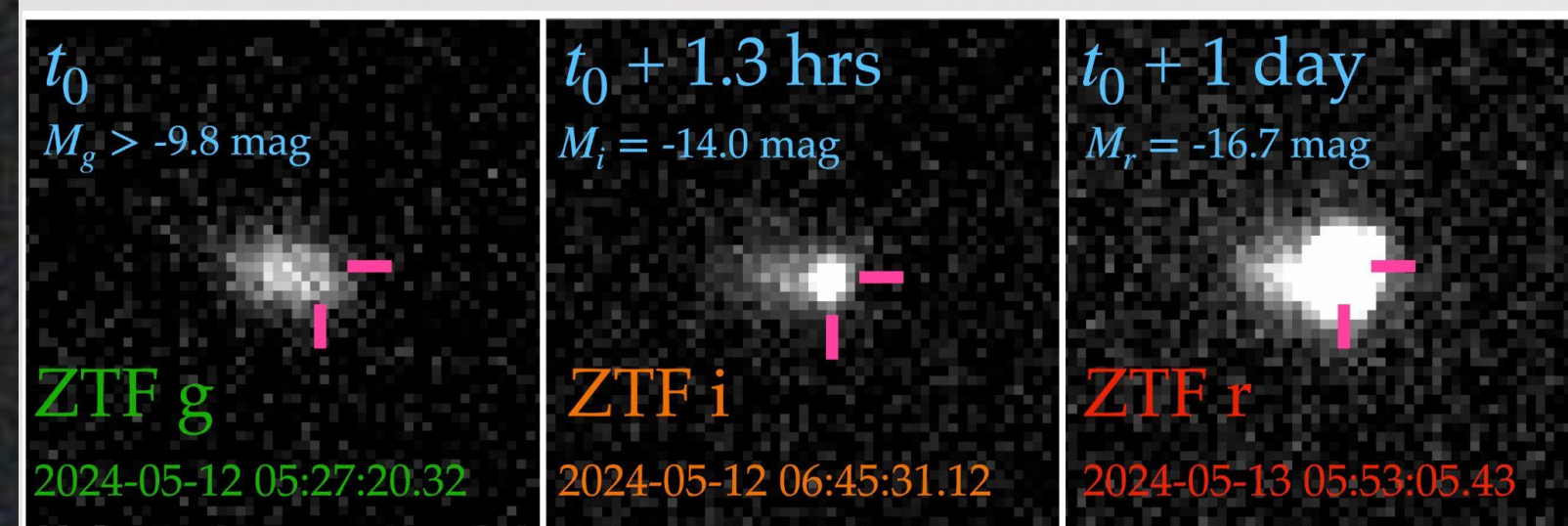
Abstract

We present multi-wavelength observations and analysis of SN 2024iss, a Type IIb supernova (SN IIb) located at ~14 Mpc. The first ZTF detection of SN2024iss is ~40 minutes after first light (one of the earliest detections of a SN IIb to date) and a Hubble Space Telescope ultraviolet spectrum was obtained at 7 days after first light (the earliest HST UV SN IIb spectrum to date). We fit shock-cooling emission models to estimate a progenitor radius of 100 - 320 R_{\odot} and envelope mass of 0.07 - 0.46 M_{\odot} . In the UV, we observe strong Mg II emission extending to ~15,000 km/s as well as weak P-Cygni profiles of iron-group elements (e.g., Fe, Ti, Al, Ni) present in outer SN ejecta. The overall evolution of SN 2024iss is comparable to SNe IIb, but increased brightness at peak is influenced by SN ejecta-CSM interaction. We demonstrate the utility of a rich, multi-wavelength dataset for constraining progenitor systems and explosion dynamics of SNe IIb.

Introduction

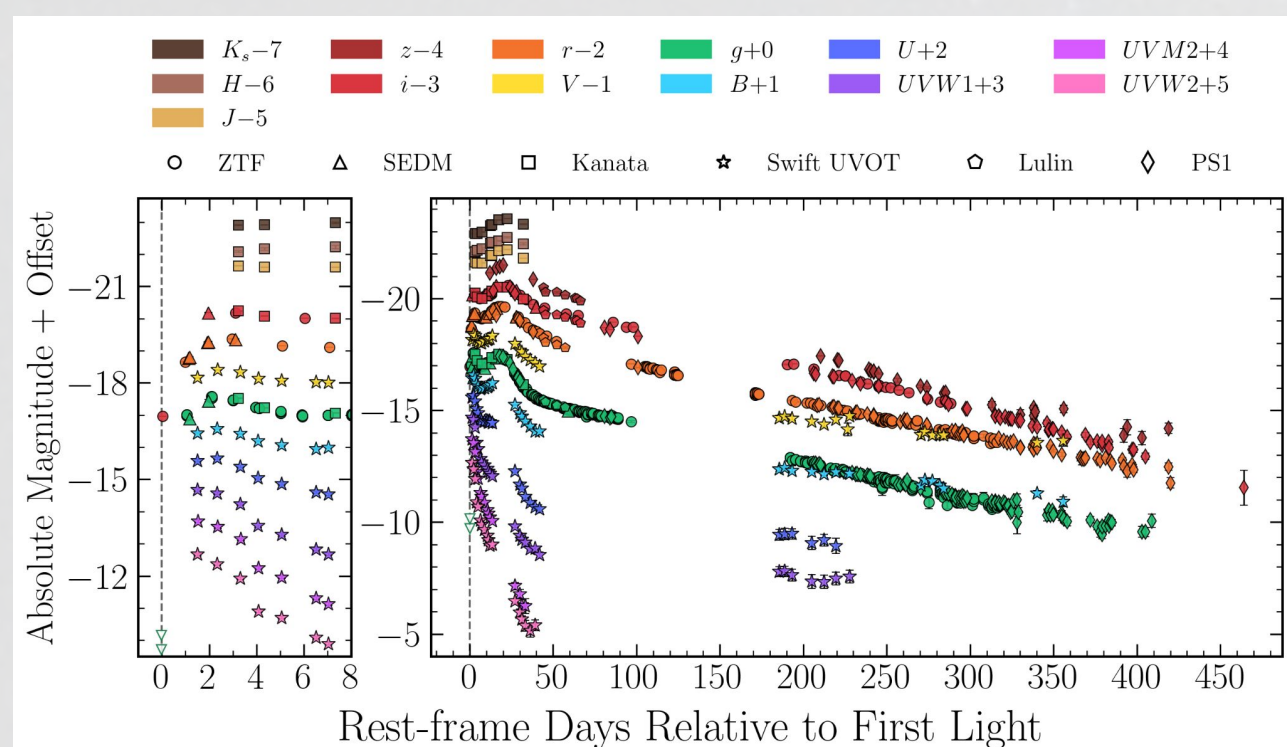
Type IIb supernovae (SNe IIb) occur from the core collapse of massive stars (> 8 M_{\odot}), and are characterized by prominent hydrogen and helium (He I) spectral features. These features are due to the progenitor possessing a low-mass hydrogen envelope, indicating high mass-loss rates in the progenitor leading up to its explosion.

SN 2024iss is one of the closest SNe IIb ever detected at 14.04 +/- 0.14 Mpc. With a ZTF non-detection at ~40 min before explosion, we have one of the most well-constrained times of first light for a SN IIb. Our dataset also includes the earliest HST UV spectrum for a SN IIb at 7 days after first light.



Photometry of SN 2024iss shows a double-peaked light curve characteristic of SNe IIb.

- First peak: Emission from ionization and cooling of stellar envelope after shock breakout, lasts ~7 days
- Second peak: Emission from radioactive decay of Nickel-56 synthesized in the core, lasts ~7-40 days

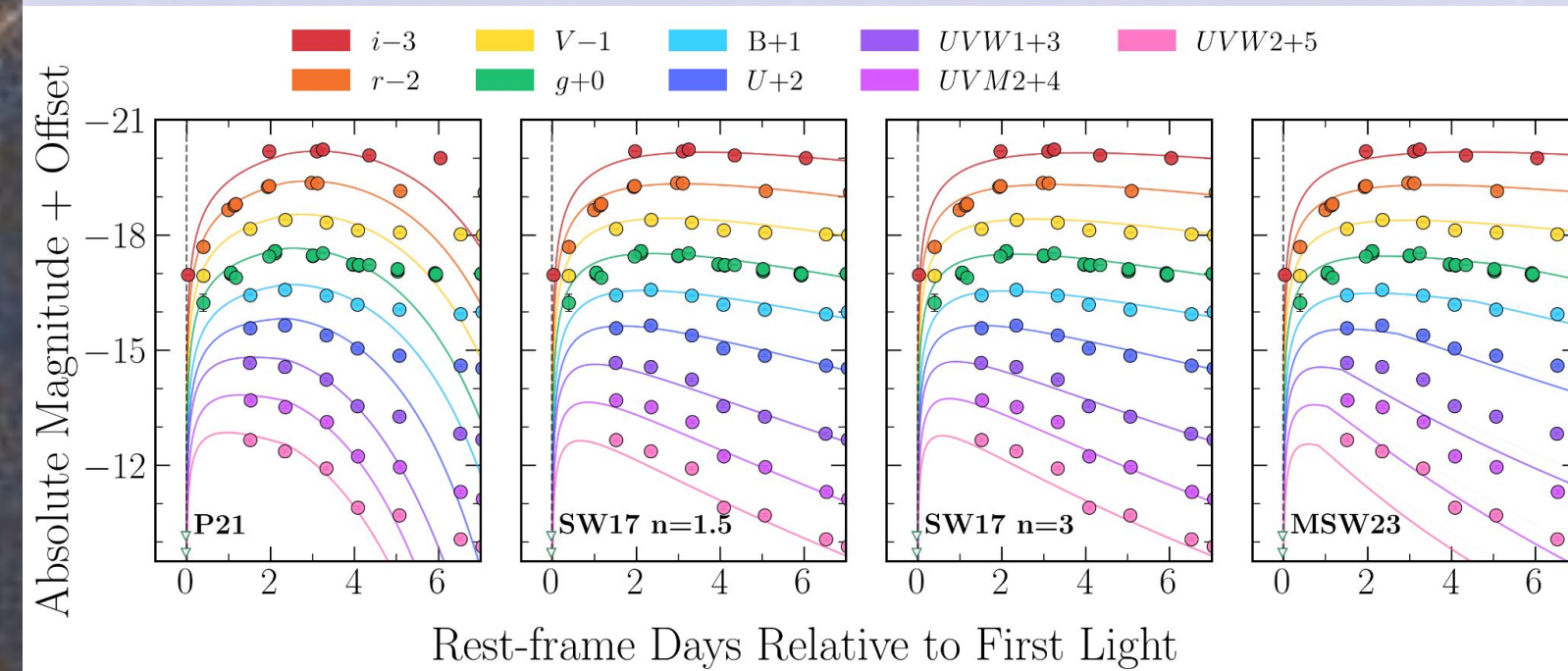


Shock Cooling Emission Modeling

We fit the first light curve peak with shock cooling emission models:

- Piro et al. 2021 (P21) – analytic model for low-mass extended material
- Sapir & Waxman 2017 (SW17) n=1.5 – physically calibrated for red supergiant progenitors
- SW17 n=3 – physically calibrated for blue supergiant progenitors
- Morag et al. 2023 (MSW23) – analytic model based on SW17 n=1.5

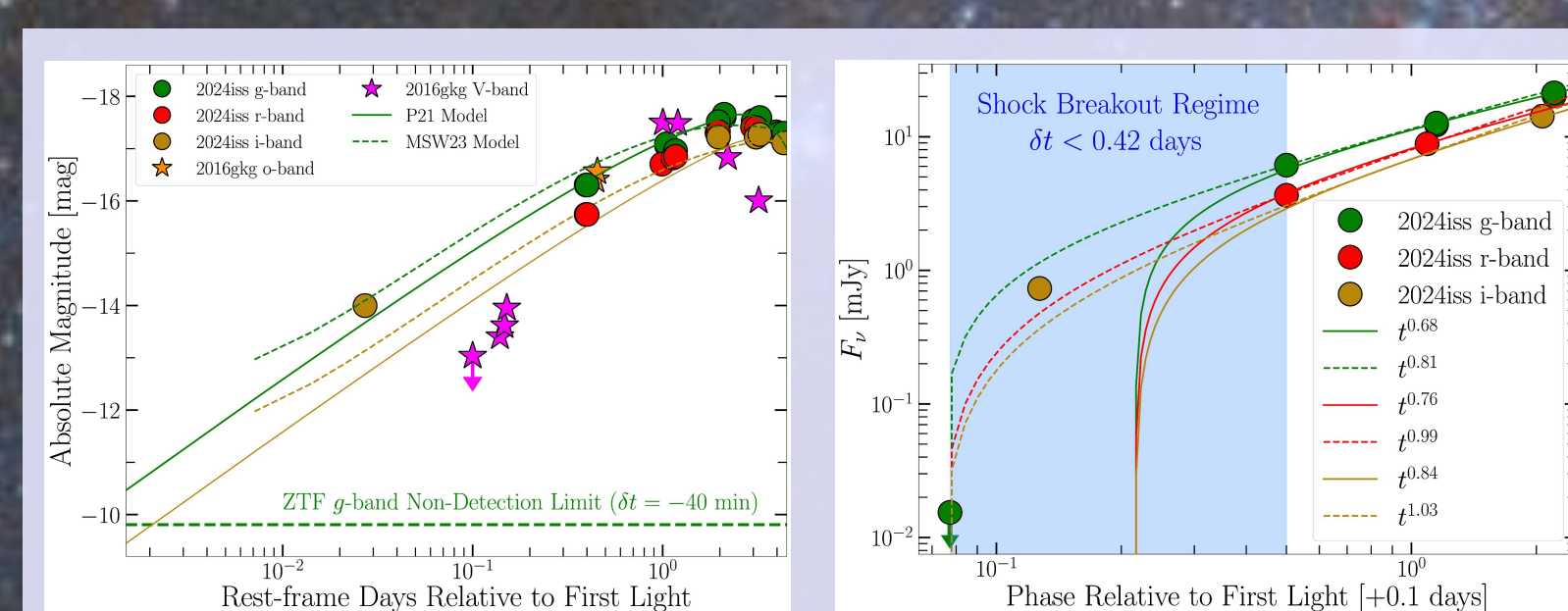
We used the shock_cooling_curve and lightcurve-fitting Python packages to find the best-fit parameters with MCMC fitting.



Best-fit results:

- Progenitor Radius: 100 - 320 R_{\odot}
- Hydrogen-rich envelope mass: 0.07 - 0.46 M_{\odot}

Shock Breakout



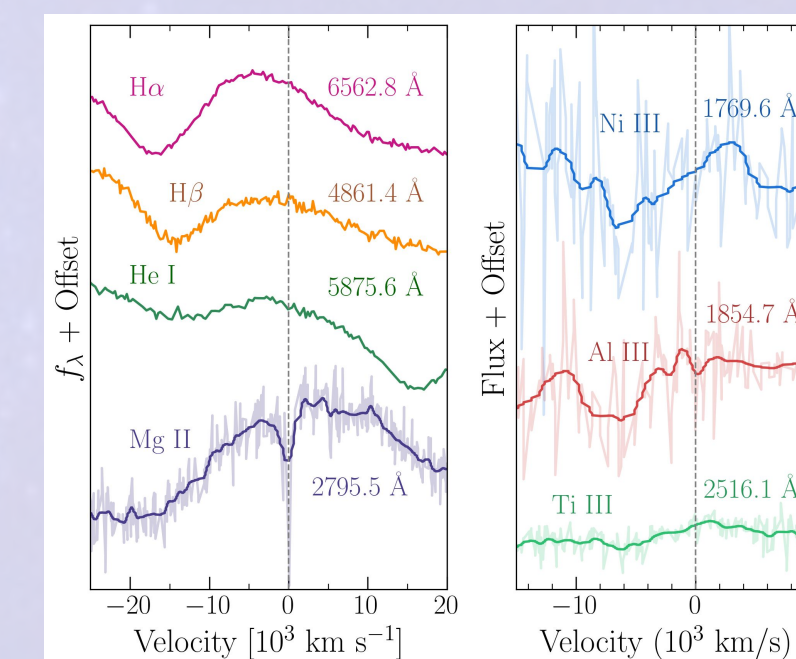
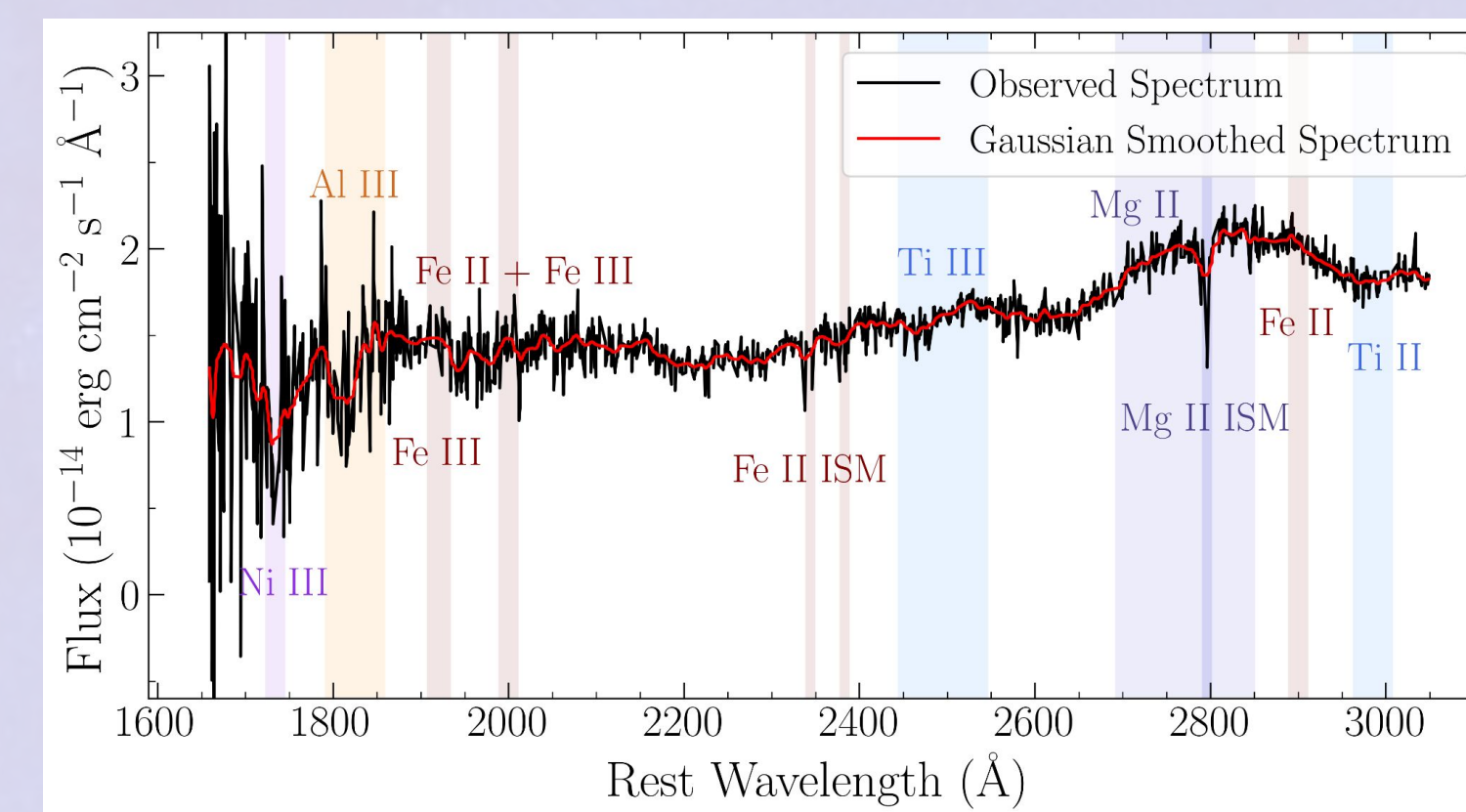
The early ZTF *i*-band detection at +0.027 days allows us to probe emission during earliest phases. We compared the early observation with predictions from shock cooling emission and power-law models for calculating time of first light.

- Significant deviation between observation and prediction from shock cooling emission models → early emission likely not from shock cooling
- Time of first light calculated without fitting early *i*-band point not consistent with known time of first light constraint
- ~1.3 hours between *g*-band non-detection and *i*-band detection consistent with shock breakout timescale
- Shock breakout regime constrained to +0.42 days → *i*-band point consistent with shock breakout emission

UV Spectroscopy

We identified prominent ion signatures in the +7 days HST UV spectrum by comparisons with previous studies of early-time SNe II UV spectra and known atomic transition lines.

- UV spectrum contains continuous features from several elements, making it difficult to identify individual ions.
- Causes UV flux suppression from line blanketing

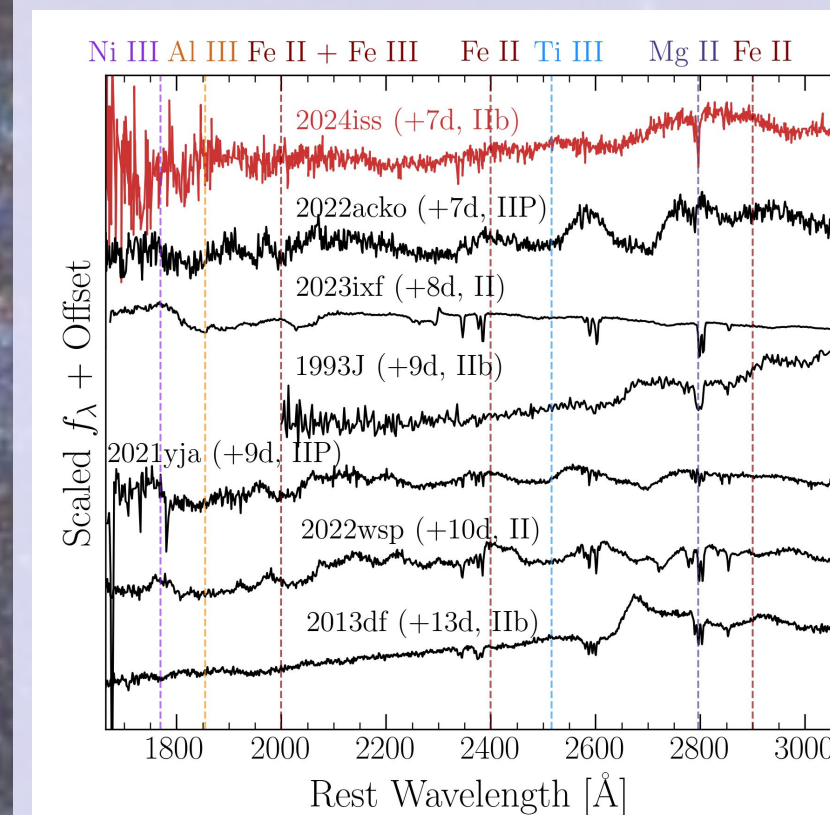


UV vs. Optical Line Velocities

- Mg II comparable to H, He I (~15,000 km/s)
- Ni III, Al III, Ti III at ~1/2 of H, He I velocity (~6,500 km/s)

Likely due to optical depth effects from metals present in circumstellar environment

We compared the +7 days UV spectrum to UV spectra of other SNe II at similar phases.



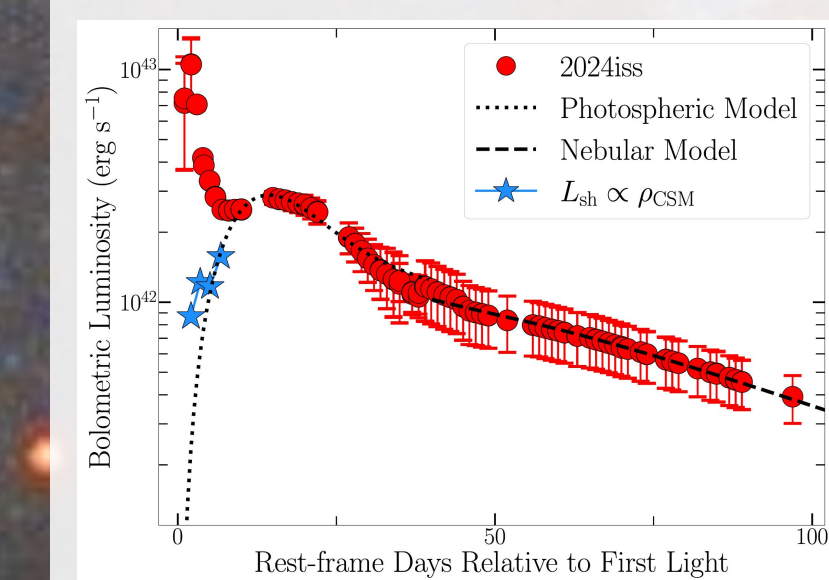
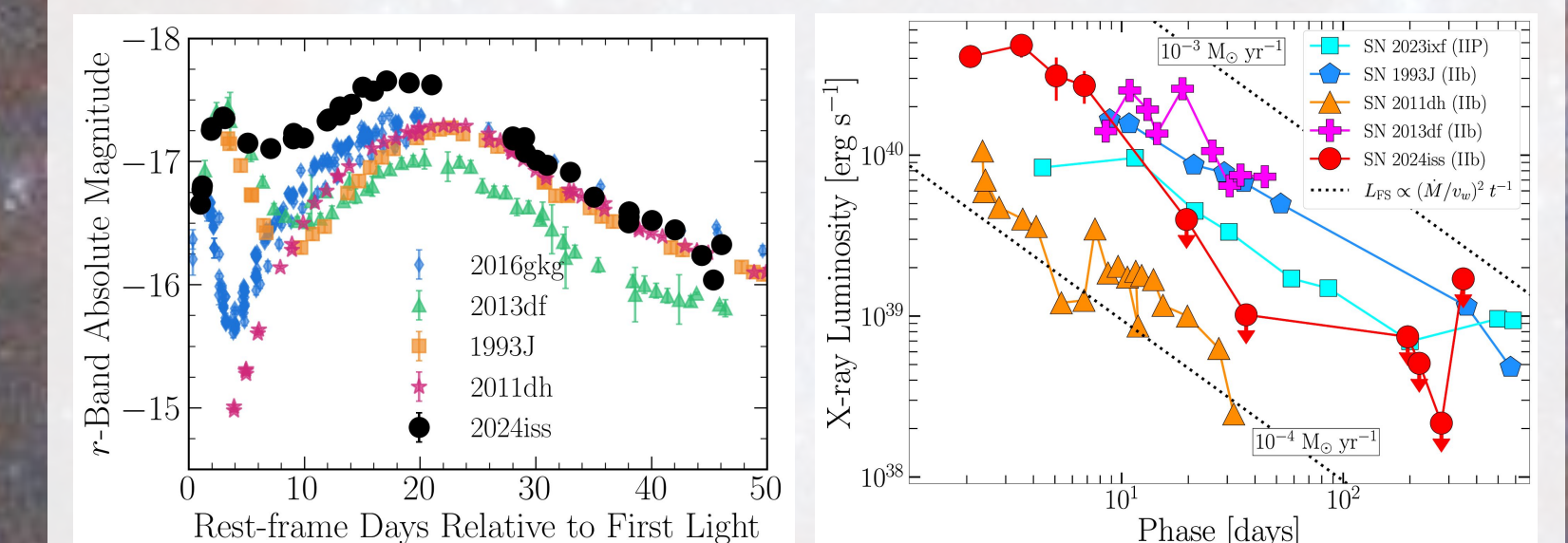
- SN 2024iss appears to have less features than the other SNe → may reflect low-metallicity host galaxy environment ($Z < 0.6 Z_{\odot}$)
- The SNe IIb (SN 2024iss, SN 1993J, SN 2013df) all appear featureless in the ~2,000 - 2,600 angstrom range compared to the other SNe II → may reflect lower-mass H-rich envelopes

Acknowledgements

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CSM Interaction

When compared to other SNe IIb, the transition between the first and second light curve peak in SN 2024iss is significantly less pronounced. In early phases, SN 2024iss is also brighter than other SNe IIb in the X-ray (<7 days).

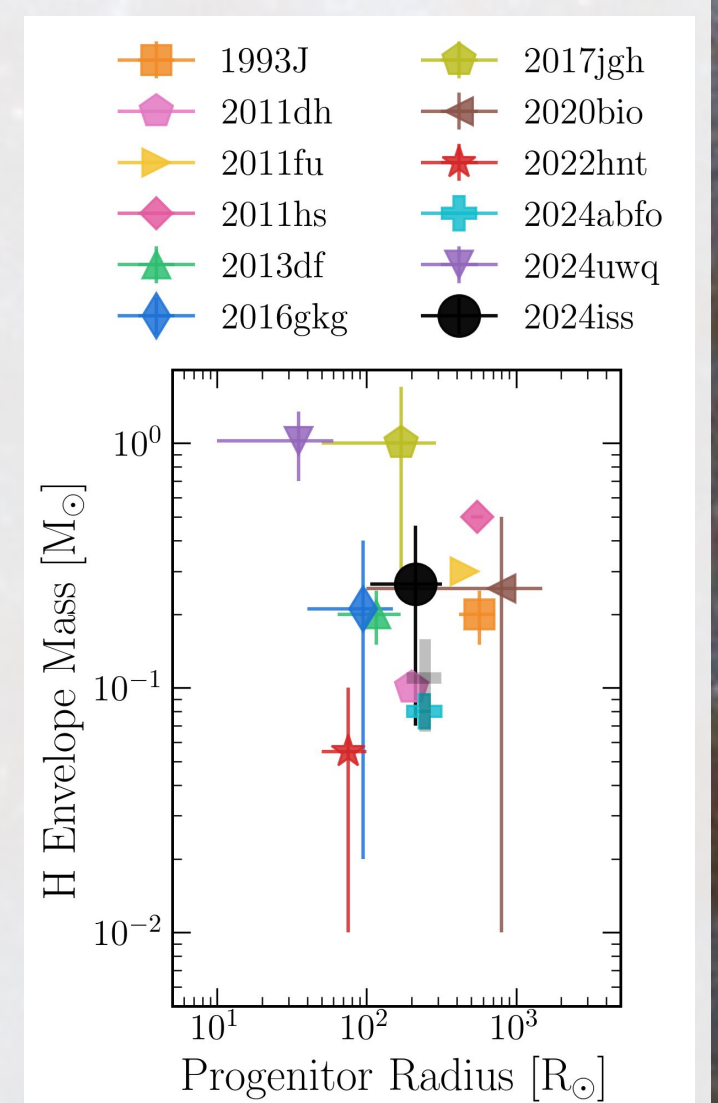


From modeling of X-ray observations, we derive that:

- Progenitor experienced significant mass-loss in 2-5 years leading up to explosion
- Dense, confined CSM present
- CSM interaction can account for ~50% of luminosity between light curve peaks

Conclusions

- The progenitor radius and H-rich envelope mass are most consistent with those of a yellow supergiant progenitor star.
- SN 2024iss displays significant emission from CSM interaction, impacting the ability of models to fit with observations.
- The +7 days UV spectrum provides a unique snapshot of the outer layers of SN 2024iss and its circumstellar environment immediately following shock cooling emission.
- Possible distinctions in UV spectra between SNe IIb and other SNe II emphasize the need for a larger sample of early-time SNe II and IIb UV spectra.
- We constrain the shock breakout emission phase to <0.42 days using a ZTF observation at +0.027 days, highlighting the potential for high-cadence photometry to probe SN explosion properties in the earliest phases.



Check out our paper for more details!



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