Searching for late-time signals of SNe interacting with circumstellar material

Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

J. H. Terwel

Background

- The progenitor systems and explosion mechanisms causing Type Ia SNe are still poorly understood.
- Interaction between ejecta and circumstellar material (CSM) can constrain possible scenarios.
- CSM interaction is rare, and most studies focus on interaction near the SN peak.
- What if the CSM is more distant and the interaction only starts months to years after the explosion? Are these events systematically missed?

Samples

Finding rare events occurring long after the original explosion requires a large sample of regularly observed SNe. All-sky surveys such as the Zwicky Transient Facility (ZTF) that monitor the sky every 2-3 days for years are ideal. We studied three different samples:

1. ZTF SN Ia DR2 (Mar 2018 - Dec 2020): 3628 SNe Ia
2. Pre-ZTF transients within the ZTF footprint: 4491 SNe Ia + 2727 other transients
3. Real-time monitoring of ZTF SNe Ia: 6914 SNe Ia monitored for 240 days

Analysis

late-time CSM interaction likely results in a weak signal. Pushing the detection limit is crucial to increase chances to detect these. Binning post-SN observations achieves this at the cost of time sensitivity.

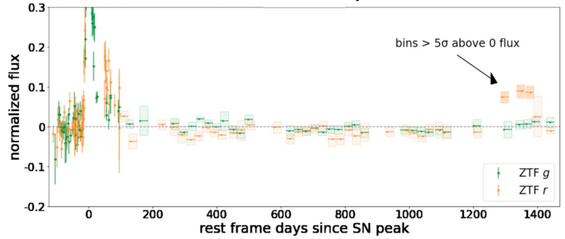

Fig 1: Lightcurve of SN 2018grt with 25 d bins

Candidates are carefully checked for possible alternative explanations, including sibling transients, host nuclear activity, and image errors.

Results

- > 10 000 SNe Ia analysed → 7 candidates.
- Signal start up to 6 years after explosion.
- Signal duration up to hundreds of days.
- Most are close to the host nucleus.

Real-time monitoring allows for fast photometric and spectroscopic follow-up, resulting in 1 confirmed case of late-time CSM interaction: SN 2020qxz

SN 2020qxz

- Known Ia-CSM with Hα signature during interaction around peak light.
- 50 d rebrightening > 2 years after fading.
- Immediate follow-up campaign with the Nordic Optical Telescope.

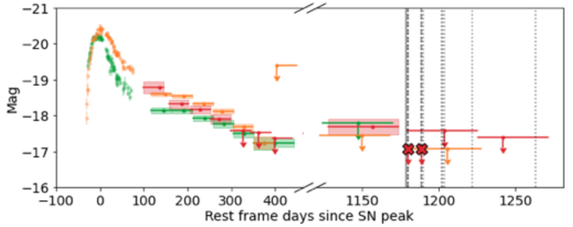

Fig 2: Lightcurve of SN 2020qxz with 25 d bins

- *Photometric* non-detections as signal was already fading at the time of discovery.
- 4 emission lines in spectra that disappeared after a month.
- Difficult to match to known elements.

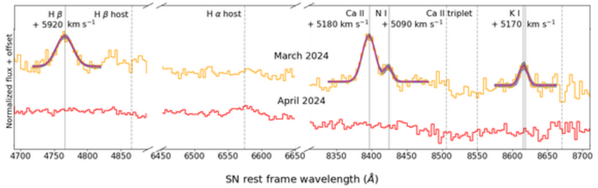

Fig 3: Stacked spectra of the late-time rebrightening in SN 2020qxz. The figure is zoomed in on the emission lines associated with the rebrightening event.

Conclusion

- Lightcurve binning is a powerful technique to recover faint signals.
- Late-time CSM interaction is very rare. (< 0.5% of SNe Ia)
- Large variety in start epoch and duration of the late-time signal.
- Most candidates have a similar location → environmental factor?
- Fast (spectroscopic) follow-up essential for candidate confirmation and further analysis.
- 1 confirmed case, showing transient emission lines that are difficult to interpret.

Next generation surveys such as the Vera C. Rubin Observatory's Legacy Survey of Space and Time will be ideal for discovering more of these rare events. By following them up swiftly we will be able to discover more about the nature of these rare events.

References

1. J.H. Terwel et al. ZTF SN Ia DR2: Searching for late-time interaction signatures in Type Ia supernovae from the Zwicky Transient Facility, A&A, 694, A11 (February 2025)
2. J.H. Terwel et al. ZTF-observed late-time signals of pre-ZTF transients, A&A, 697, A143 (May 2025)
3. J.H. Terwel et al. A real-time search for Type Ia Supernovae with late-time CSM interaction in ZTF, A&A, (Accepted)