Deciphering the nature of short-plateau Type II supernovae

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An Extraordinary Journey Into The Transient Sky Conference

1-4 April, Padova, Italy

Type II Supernovae

Spectral Features: Strong hydrogen lines → Progenitors retain a significant H-envelope before explosion.

Diversity in Decline Rates:

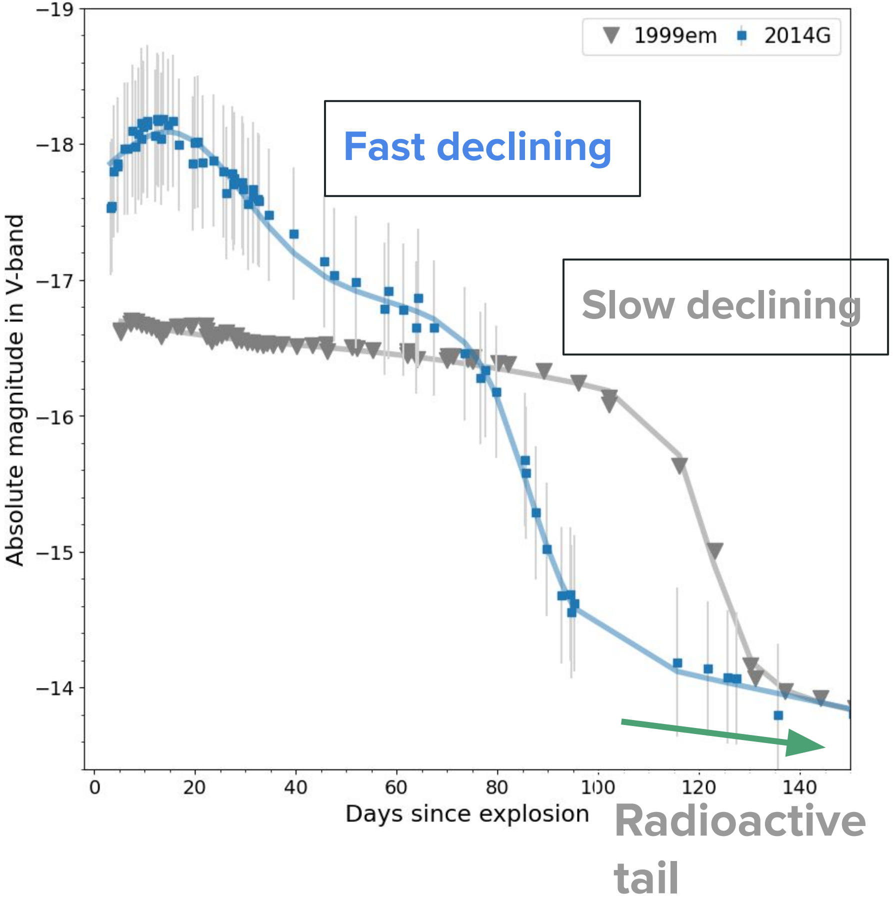
- Fast-declining (e.g., SN 2014G)
- Slow-declining (e.g., SN 1999em)

Photospheric Phase:

- Powered mainly by **hydrogen recombination**
- Ends when the **recombination wave** reaches the base of the hydrogen envelope

Transition to Radioactive Tail:

- Occurs when hydrogen recombination is complete
- Sudden **drop in luminosity**



Type II Supernovae

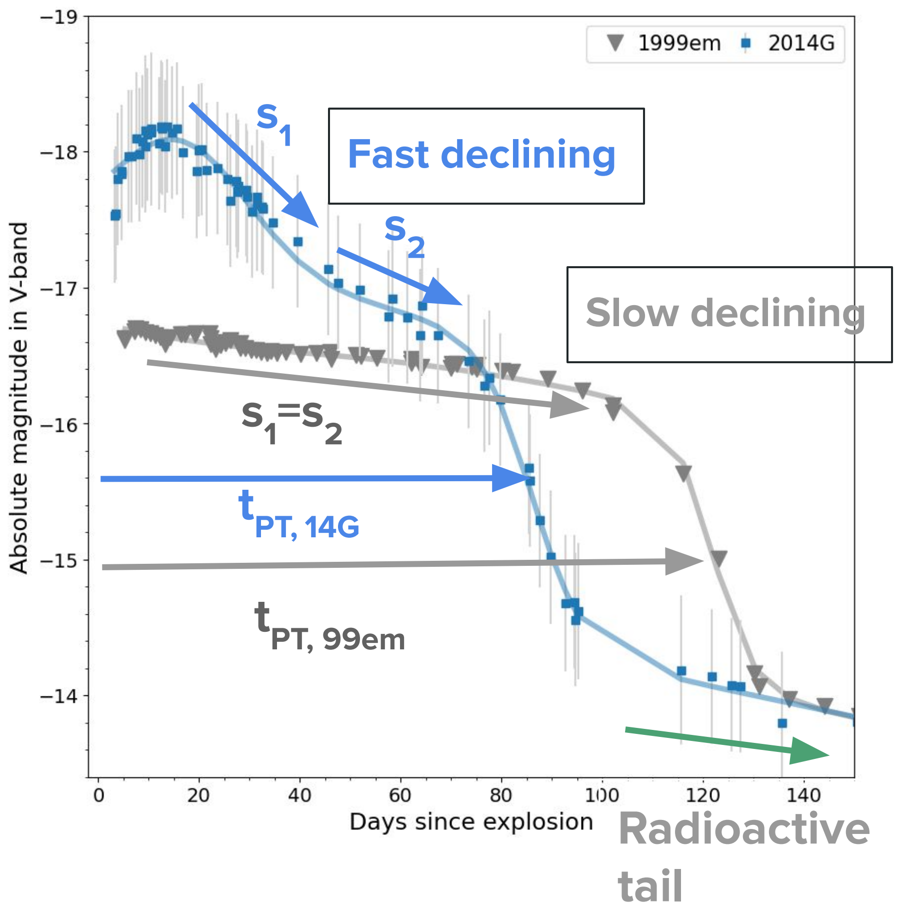
Decline Slopes in Photospheric Phase:

- Two slopes:
  - **s_1 (steep initial decline)**
  - **s_2 (shallower "plateau" phase)**

Duration of photospheric phase (t_{PT}): Time when **photospheric phase transitions** into the **radioactive decay phase**.

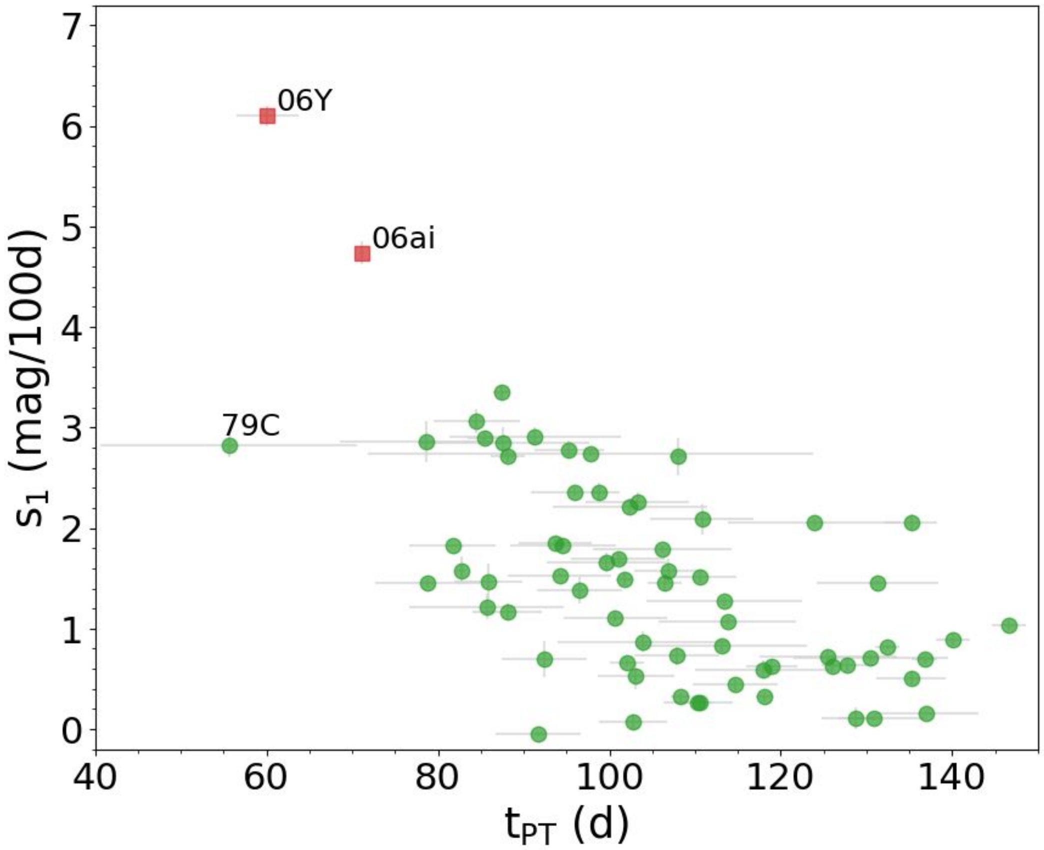
Fast vs. Slow Decliners (light curve properties):

- **Fast-declining SNe** have **shorter photospheric phases** and **higher luminosities**
- Likely due to **lower hydrogen envelope mass** in their progenitors



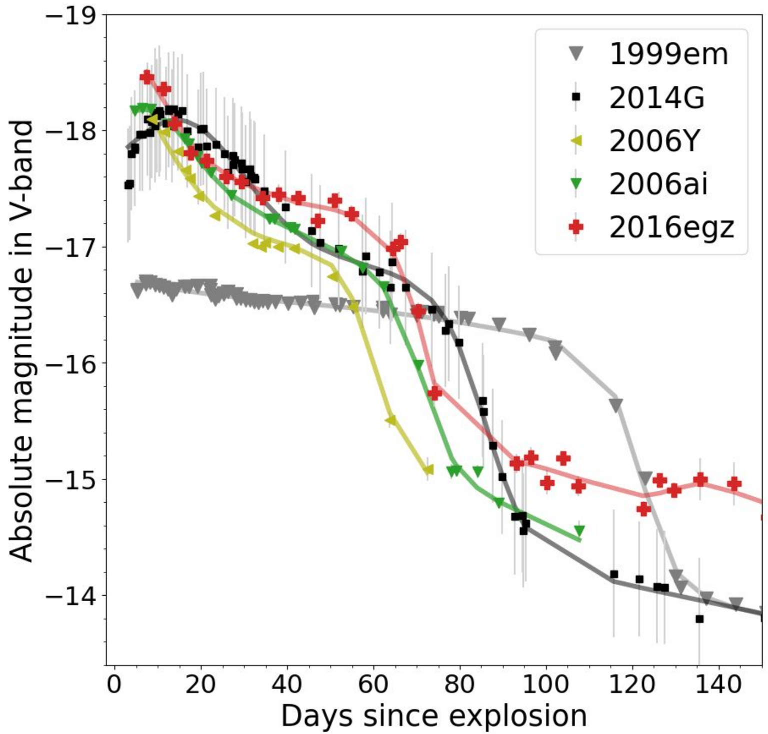
Parameter space

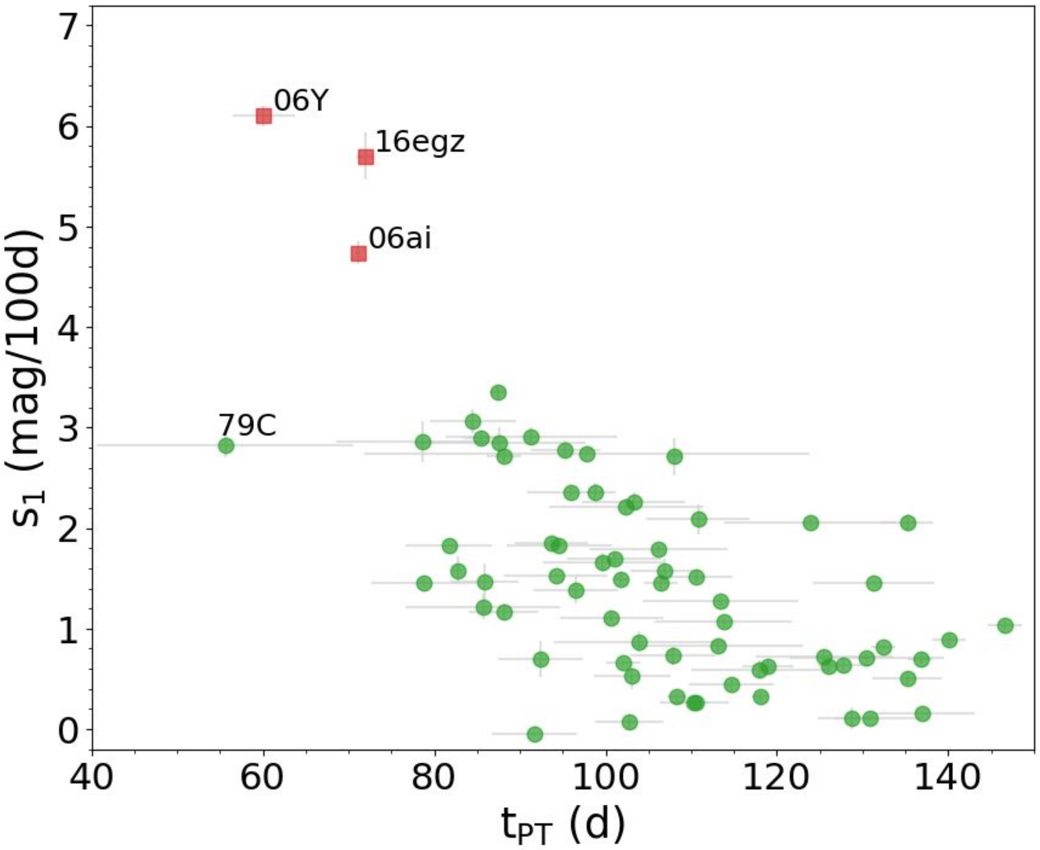
- **Short-plateau Type II SNe (<70 days) are rare**
- **Occurrence in observations & models:**
    - Only **~4%** of all Type IIP SNe
    - Rare in **binary population synthesis** and **single progenitor models** (Gutierrez et al. 2018, Eldridge et al. 2018, Hiramatsu et al. 2021)



Anderson et al. 2014; Valenti et al. 2016

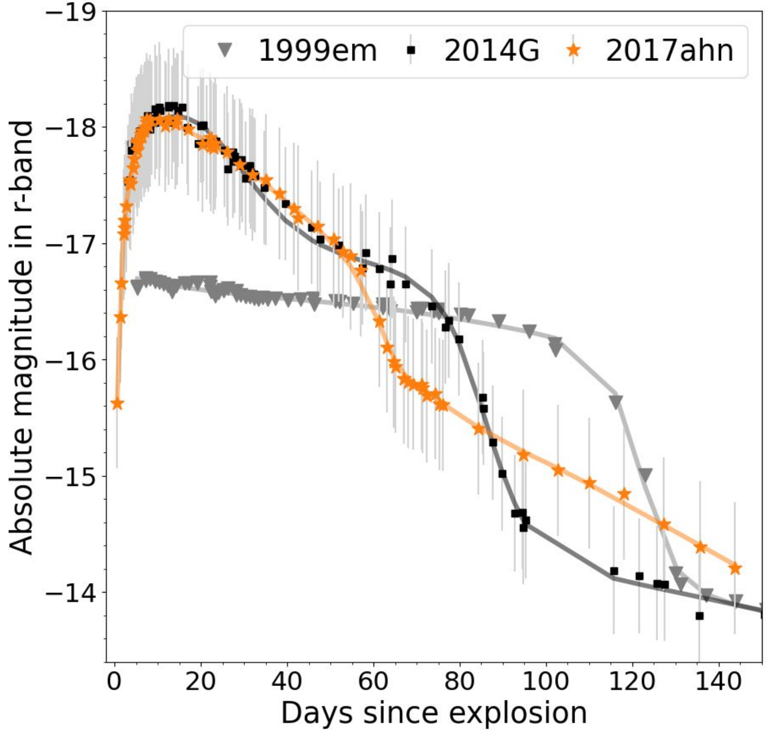
Parameter space

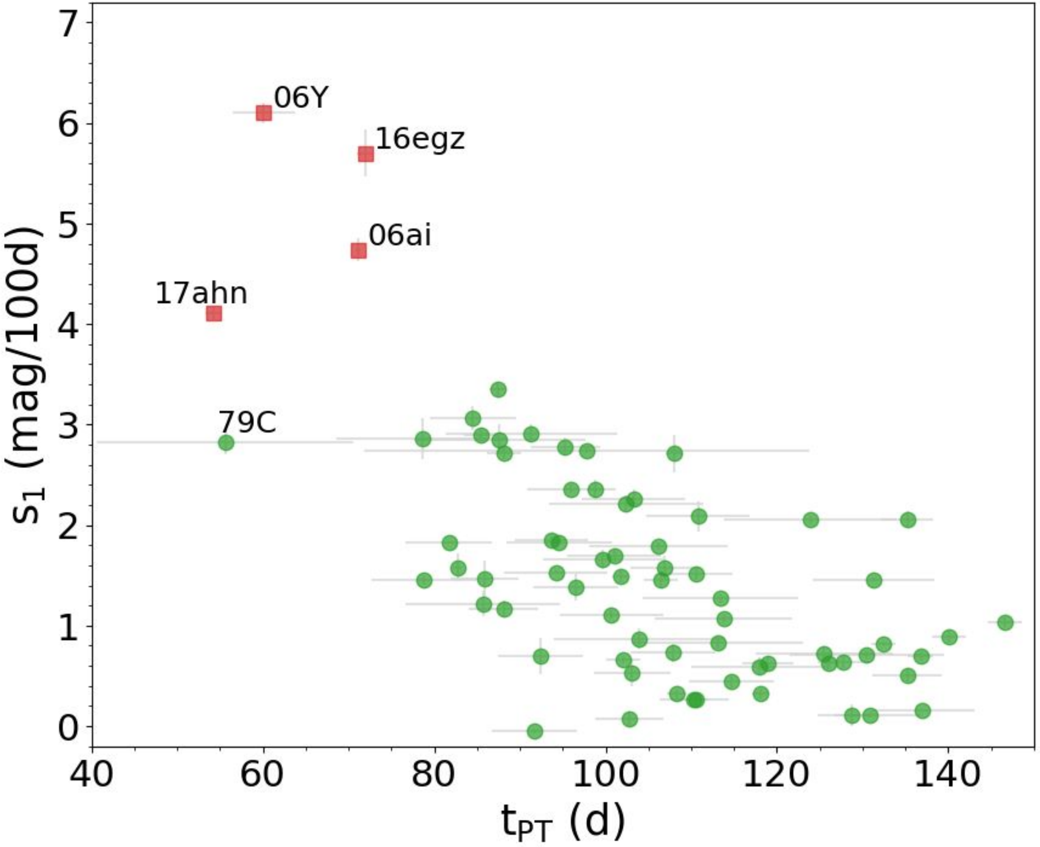




Hiramatsu et al. 2021

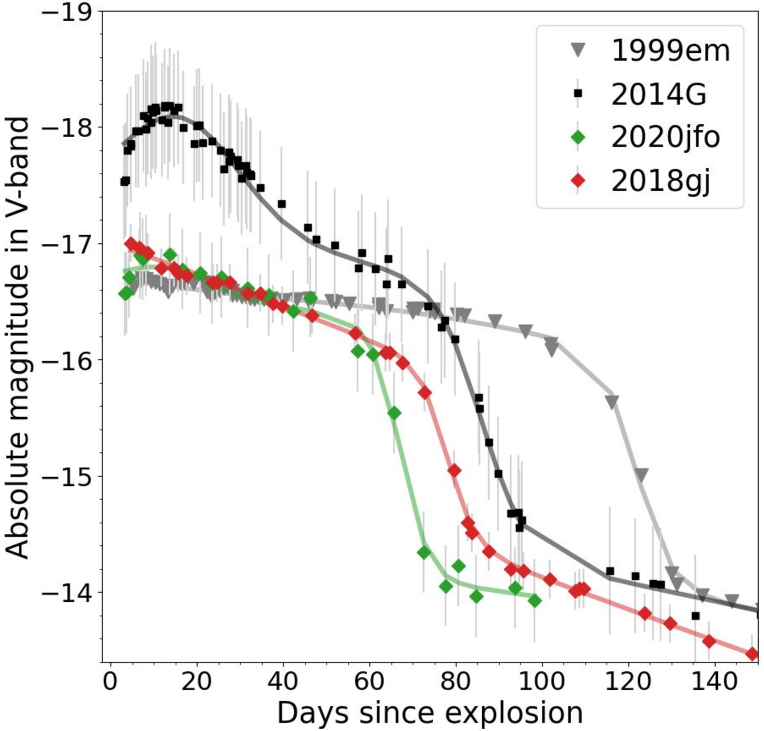
Parameter space

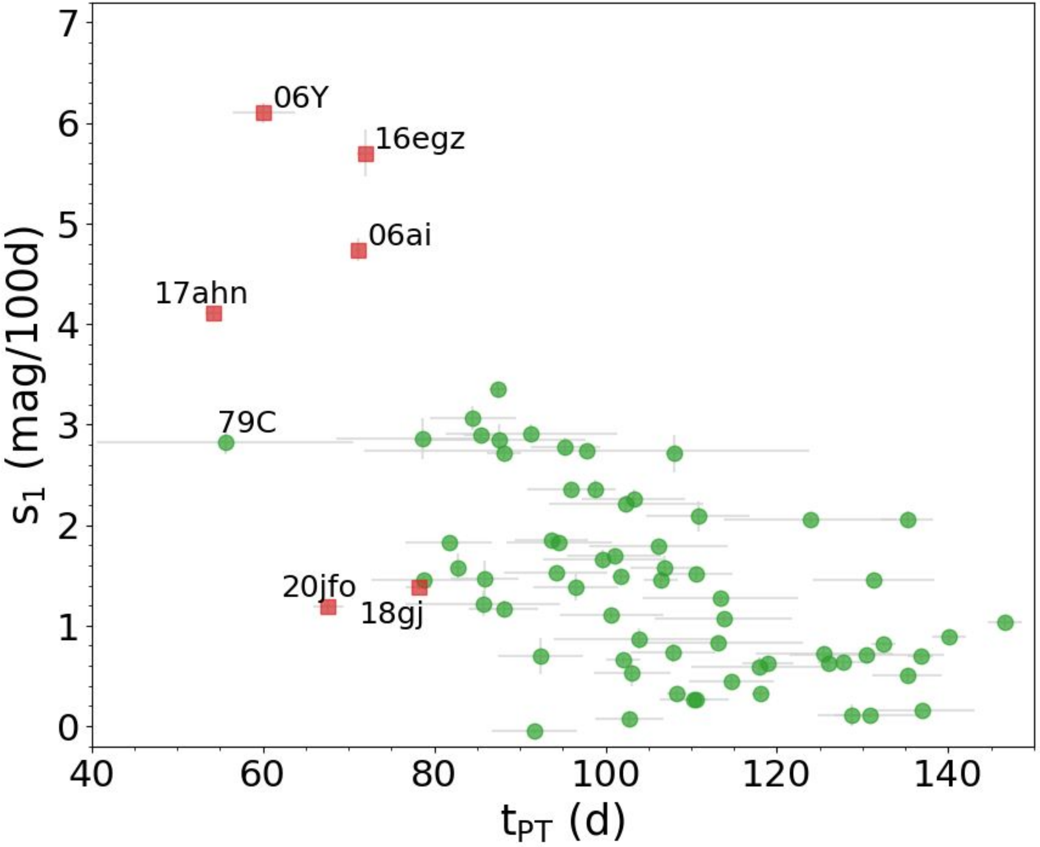




Tartaglia et al. 2021

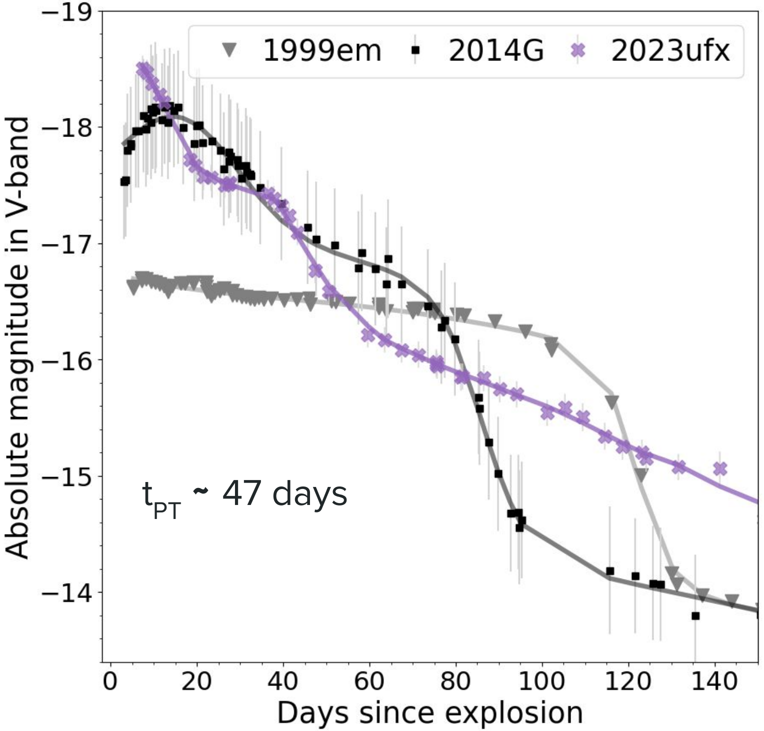
Parameter space

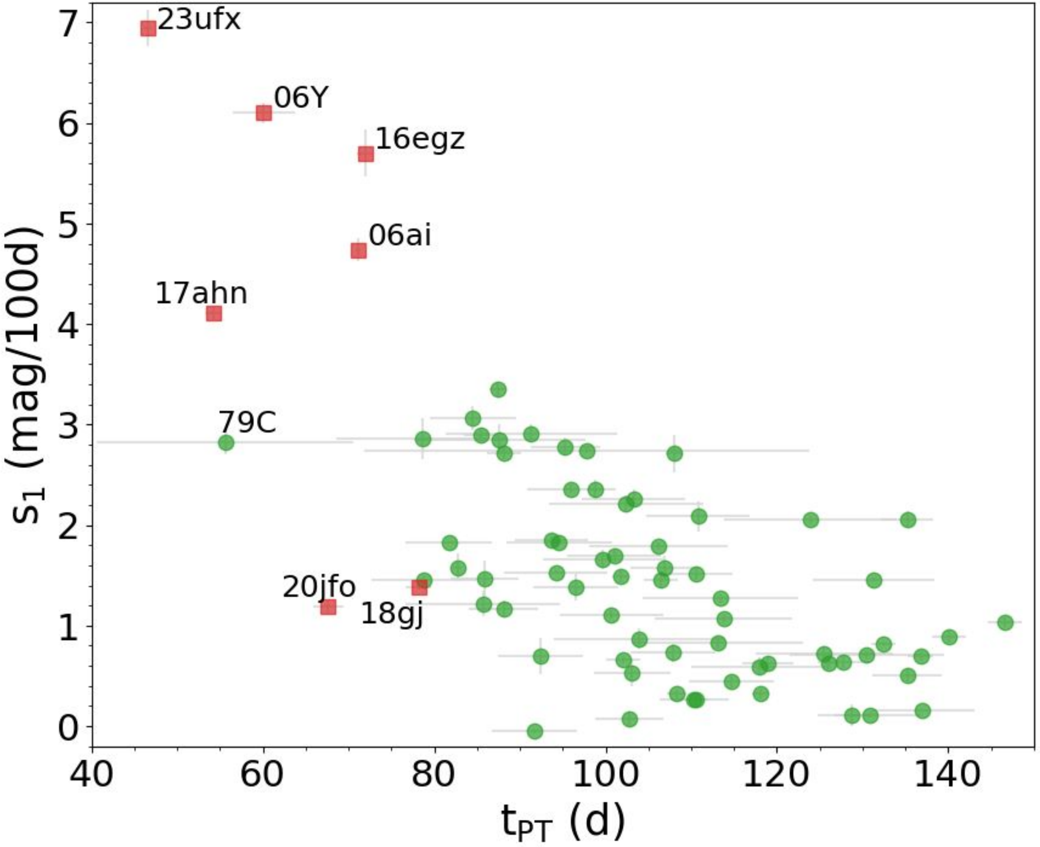




Sollerman et al. 2021; Teja et al. 2022; Ailawadhi, Dastidar, et al. 2023; Teja et al. 2023

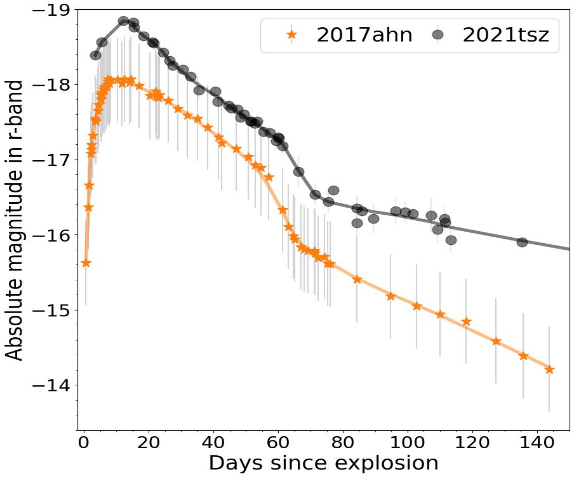
Parameter space

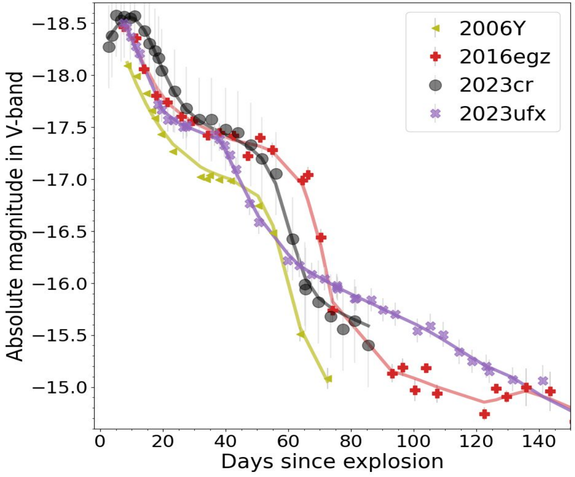


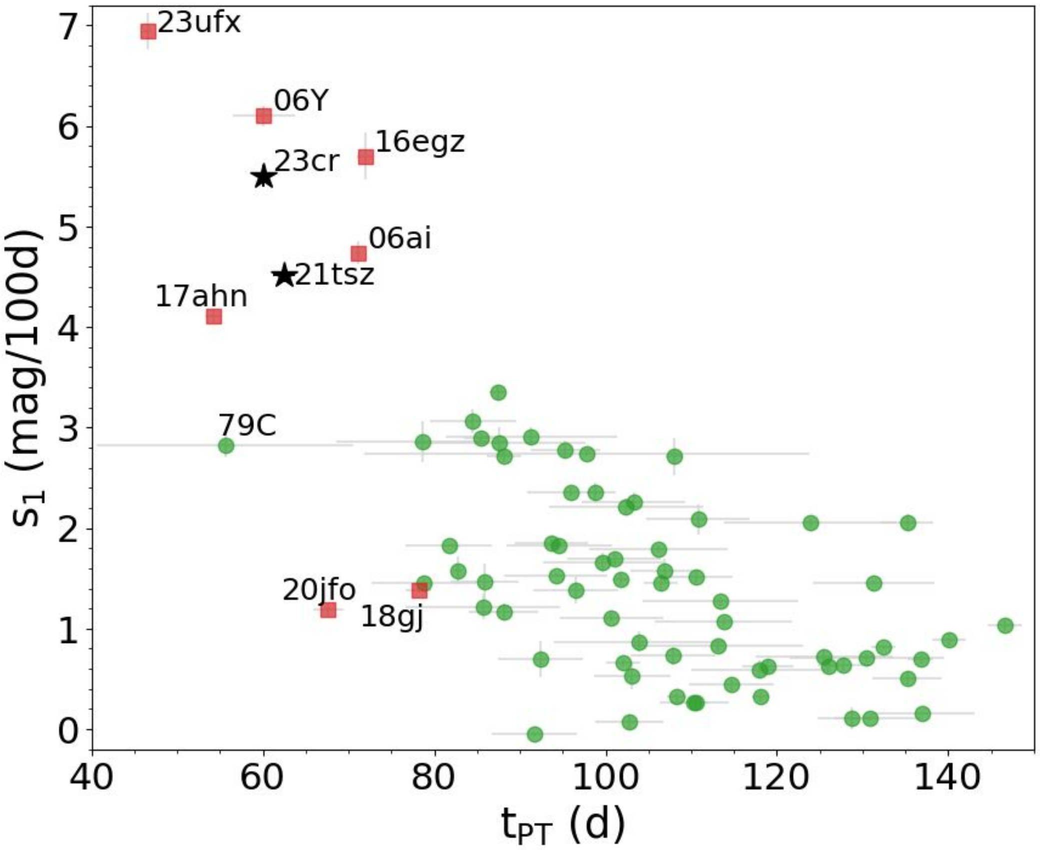


Ravi et al. 2025

Parameter space



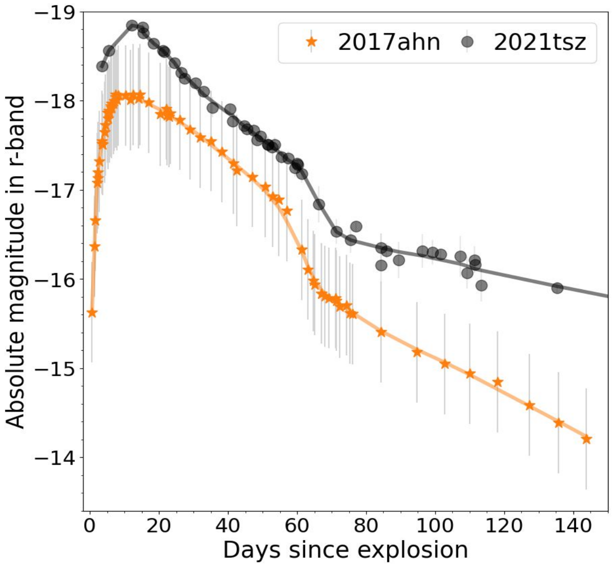




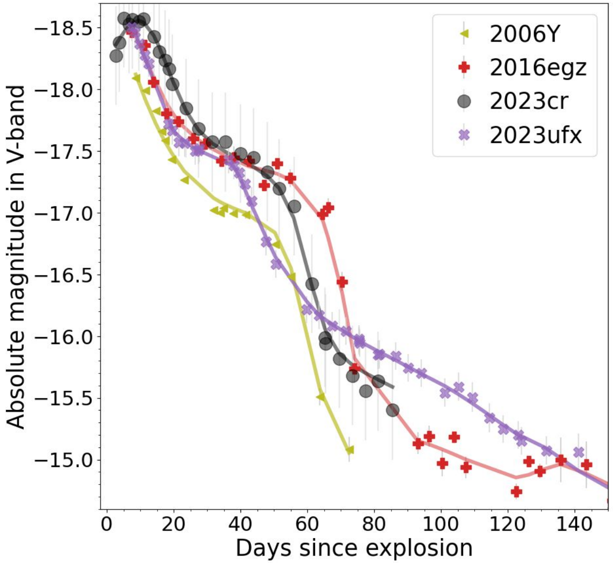
Dastidar et al. (in prep.)

Light curve diversity

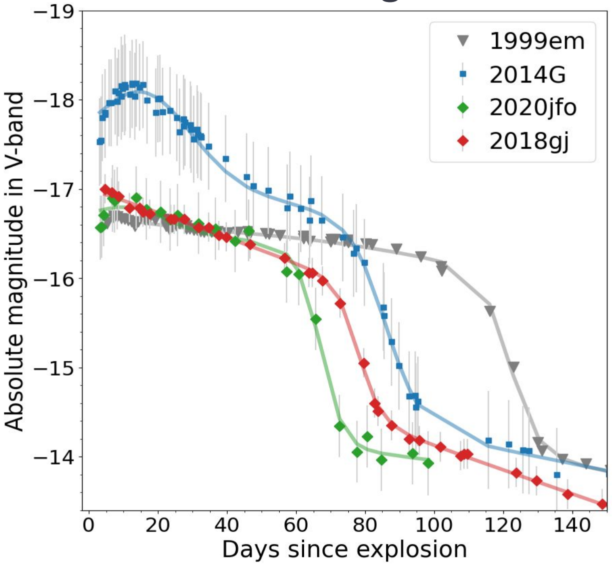
Luminous fast-declining



Luminous fast-declining, with a plateau



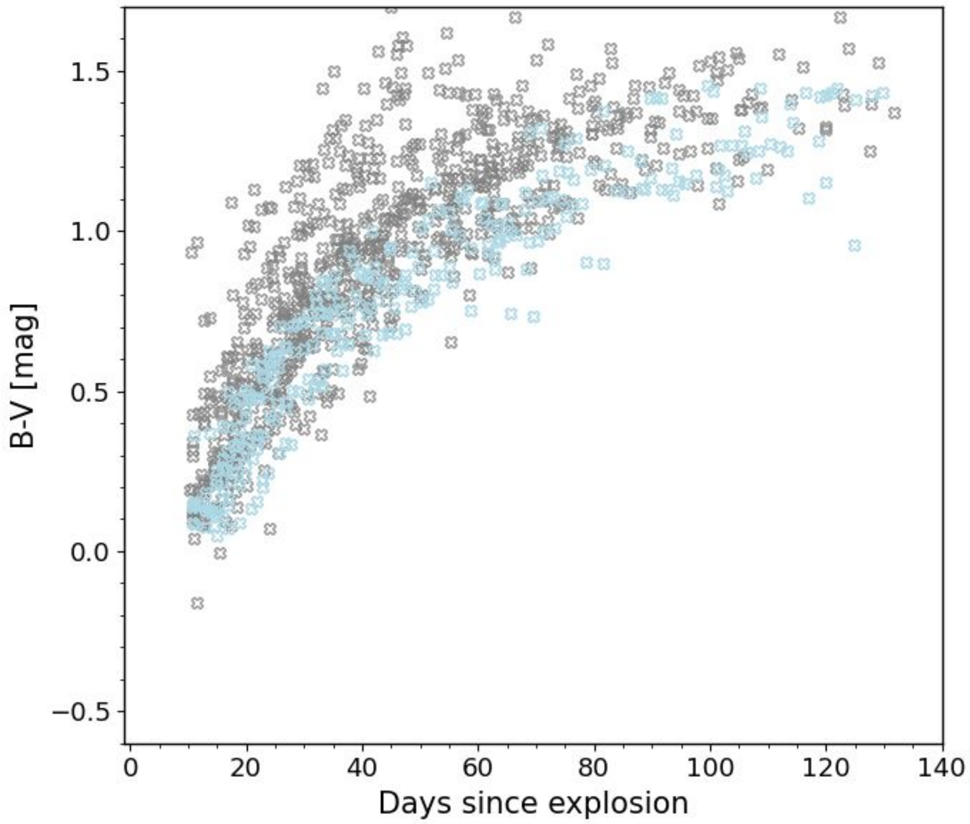
Normal luminosity, slow-declining



Colour evolution

Observed Trend:

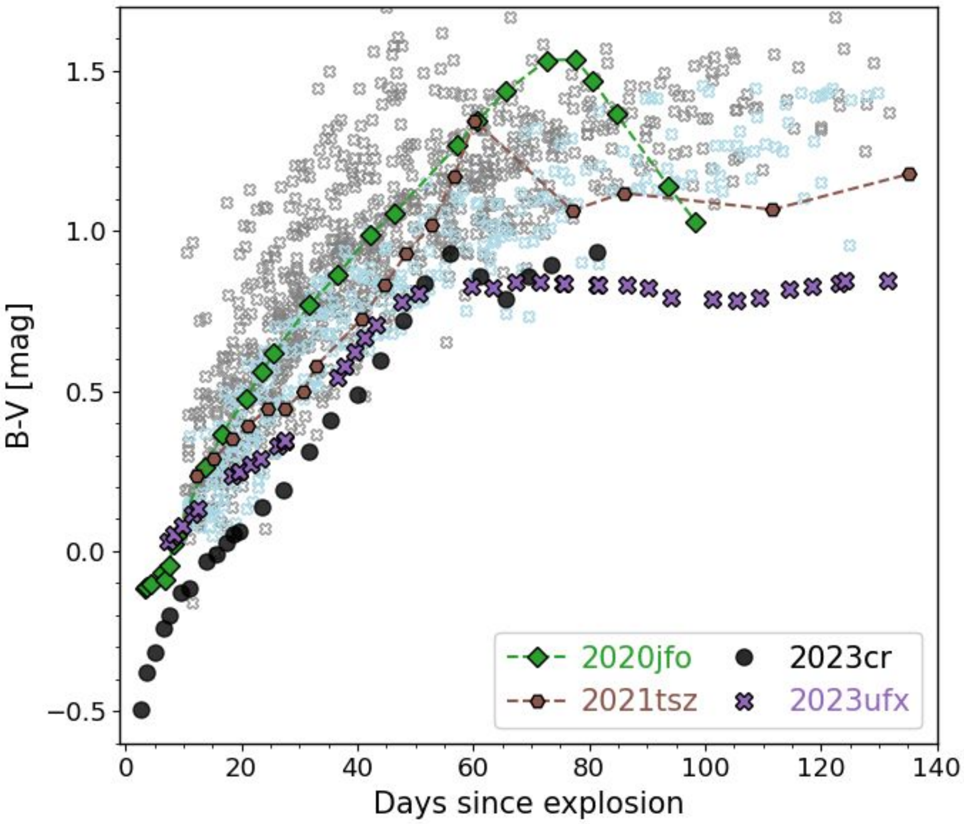
- Initial rapid shift to redder colors
- Followed by a slower redward evolution



de Jaeger et al. 2018

Colour evolution

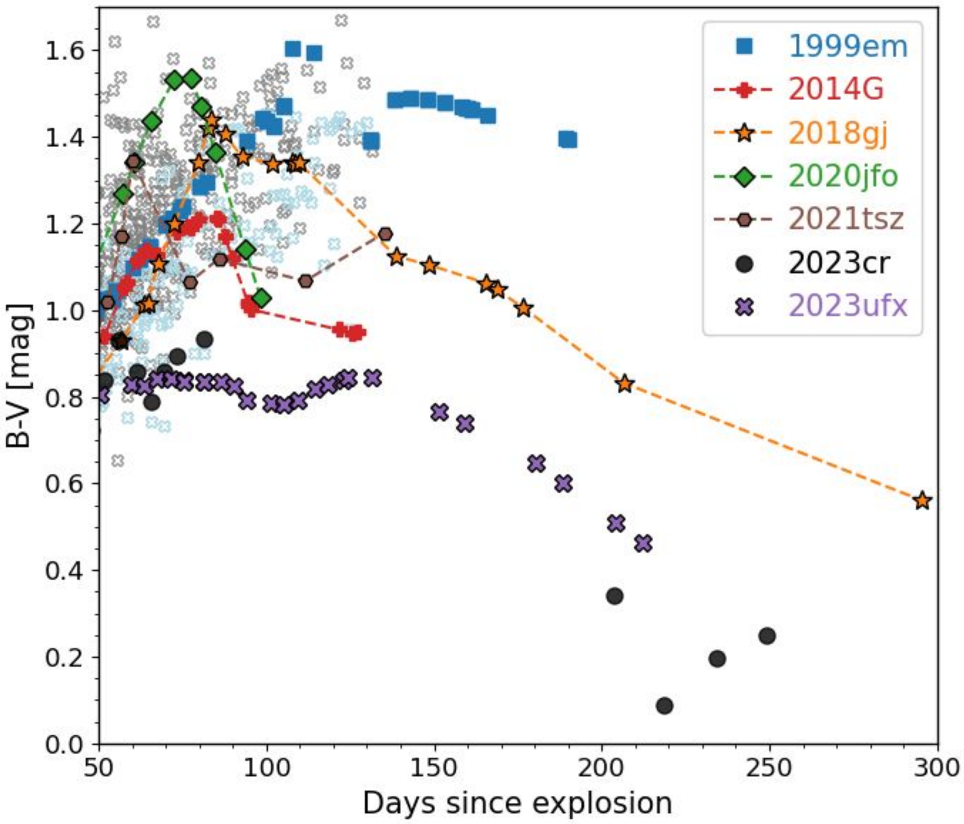
- **Luminous short-plateau SNe** (e.g. 2023cr, 2023ufx) tend to be on the **bluer end** compared to the general population.
- **Luminous SNe remain bluer even after the recombination phase.**
- **Normal-luminosity short-plateau SNe** (e.g. 2020jfo) exhibit colors similar to regular Type II SNe.



de Jaeger et al. 2018

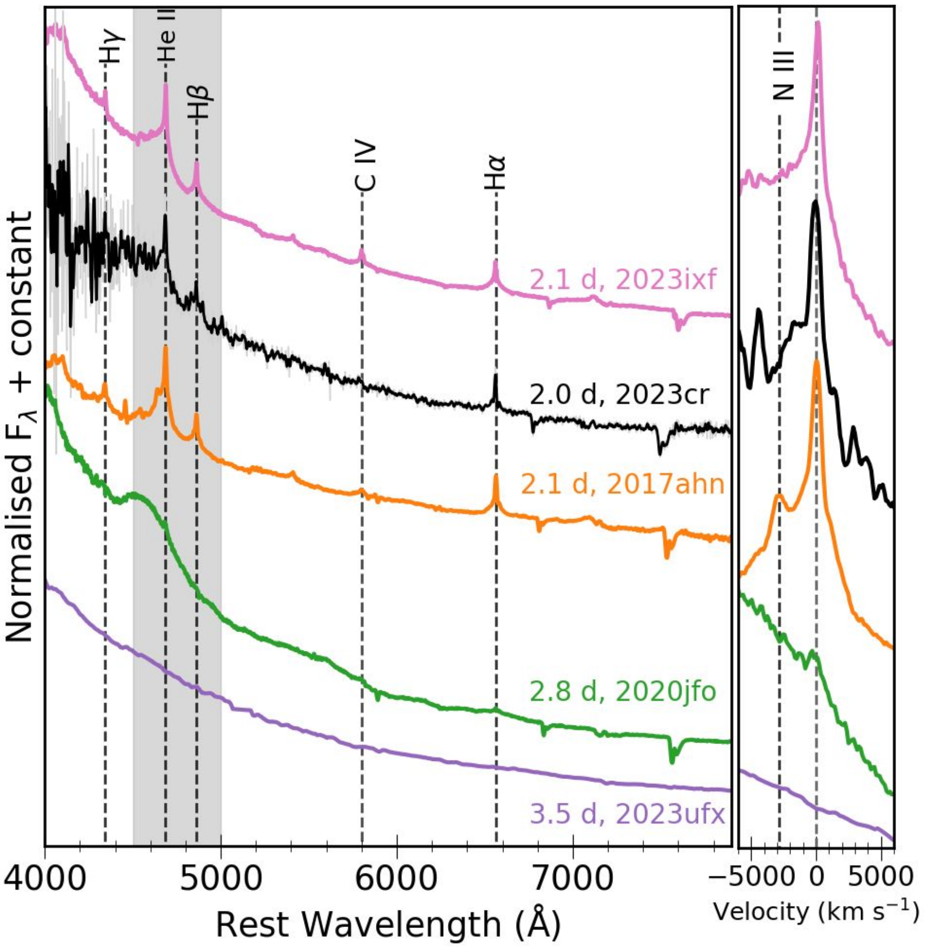
Colour evolution

- **Luminous short-plateau SNe** tend to be on the **bluer end** compared to the general population.
- **Luminous SNe remain bluer even after the recombination phase.**
- **Normal-luminosity short-plateau SNe** exhibit colors similar to regular Type II SNe.
- Raises the question: **Is late time interaction common in these objects?**



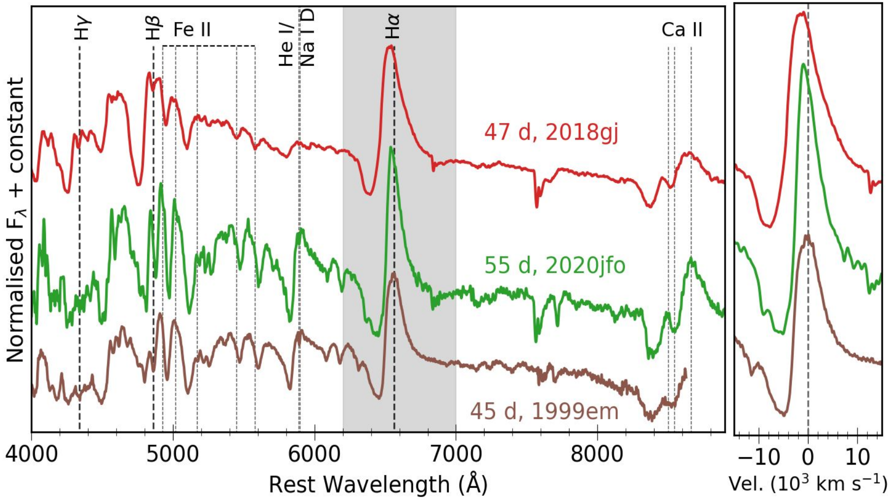
Early flash ionisation features

- **Narrow emission lines** in early spectra
  → Nearby, dense **CSM**.
- **Gradual disappearance** of these lines
  → CSM swept up by SN shock.

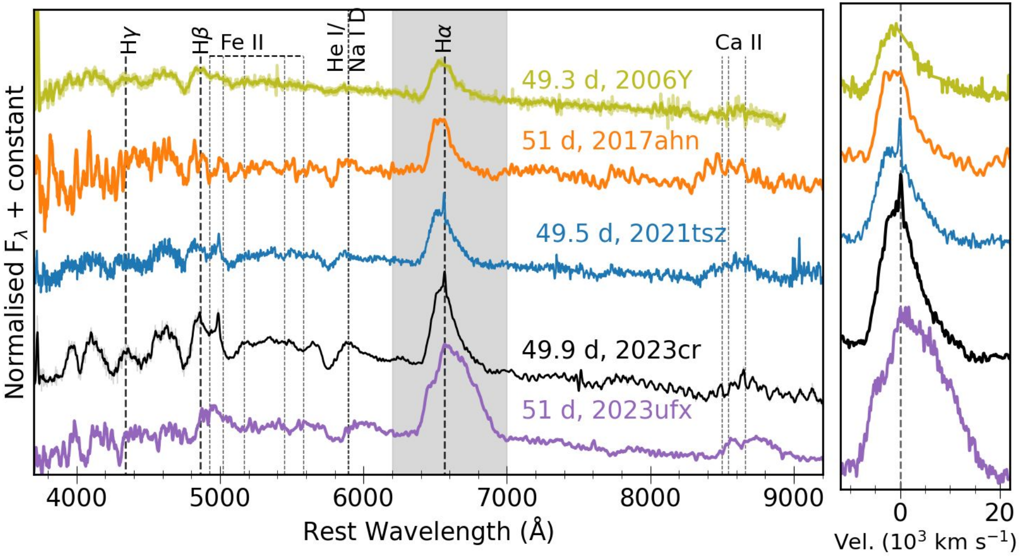


Photospheric spectra

Normal luminosity short plateau

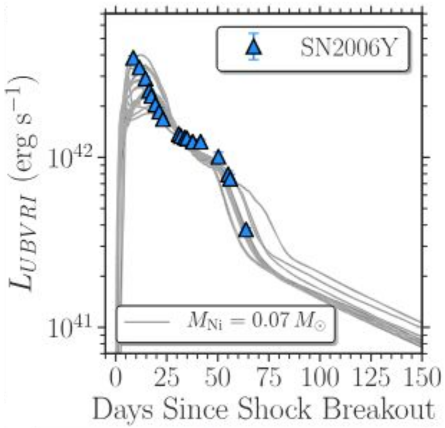


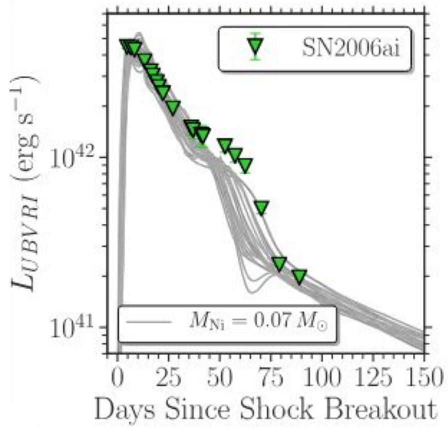
Luminous short photospheric phase

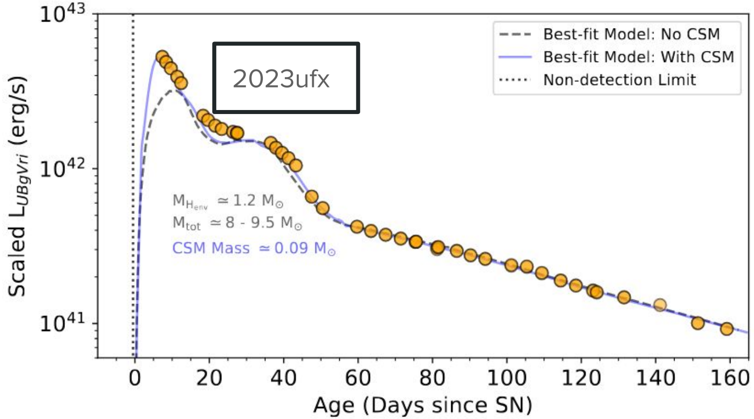


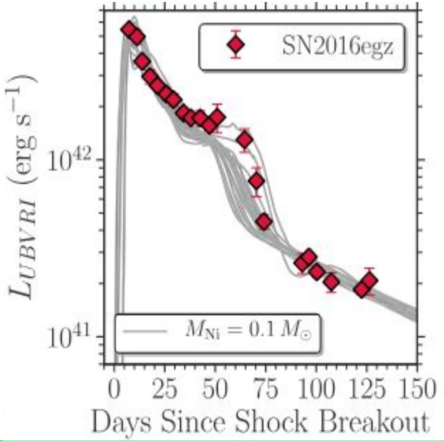
Progenitor constraints: Light curve modelling

- Luminous short-plateau
  - Massive stars: 19-25 $M_\odot$
  - Low H-envelope mass 1.2 - 1.7 $M_\odot$
  - He core mass: 5.4 - 6.9 $M_\odot$
  - Pre-SN mass: 7.1–9.5 $M_\odot$
  - Metallicity: sub-solar
  - CSM mass: 0.1–0.3 $M_\odot$
  - ^{56}Ni mass: 0.07 - 0.1 $M_\odot$





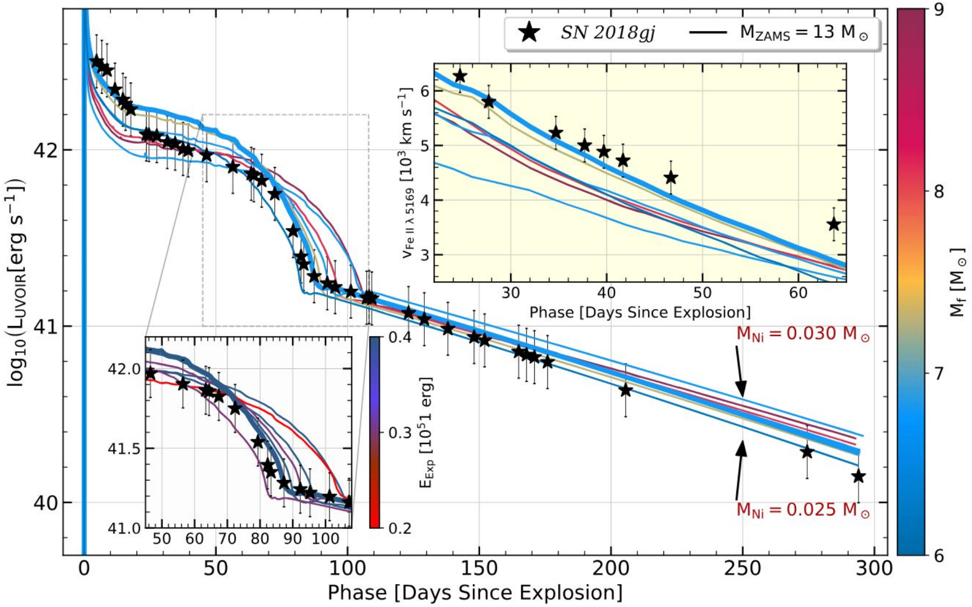




Hiramatsu et al. 2021, Ravi et al. 2025

Progenitor constraints: Light curve modelling

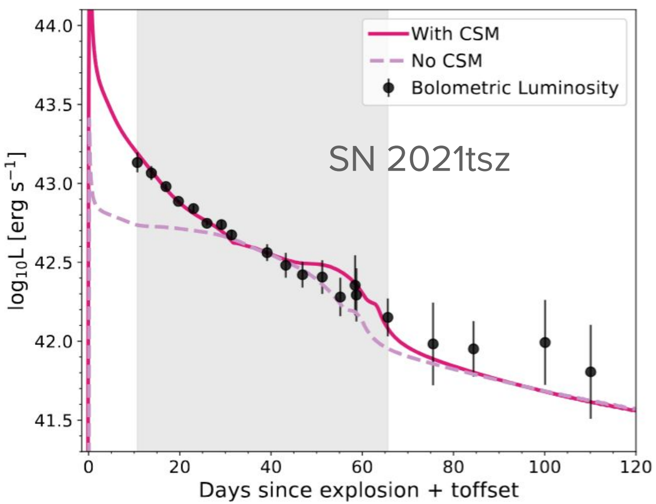
- Normal luminosity short-plateau (e.g. SNe 2020jfo, 2018gj)
    - Massive stars (12-13 $M_\odot$)
    - Low H-envelope ~2.5 – 3.0 $M_\odot$
    - Pre-SN mass: 7 $M_\odot$
    - Metallicity: solar
    - ^{56}Ni mass: ~0.03 $M_\odot$
    - CSM mass: 0.2 $M_\odot$

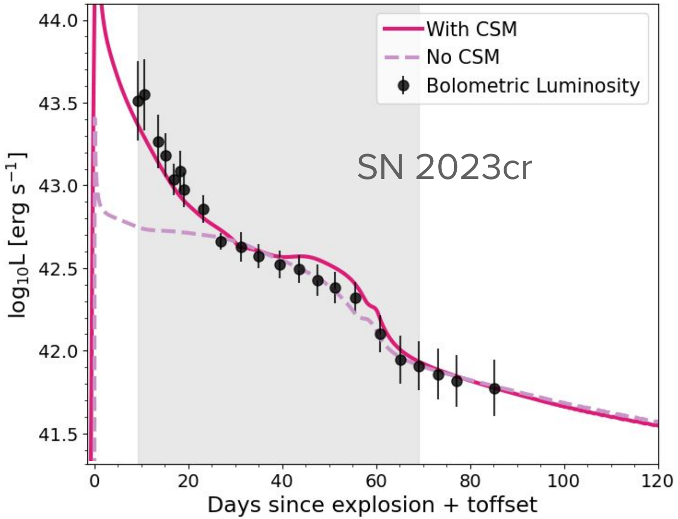


Teja et al. 2022, Teja et al. 2023

Progenitor constraints: Light curve modelling

- Luminous short-plateau
  - Massive stars: 15 $M_\odot$
  - H-envelope mass: 4 $M_\odot$
  - He core mass: 5.1 $M_\odot$
  - Pre-SN mass: 9.17 $M_\odot$
  - CSM mass ~ 0.6 $M_\odot$
  - ^{56}Ni mass ~ 0.07 $M_\odot$

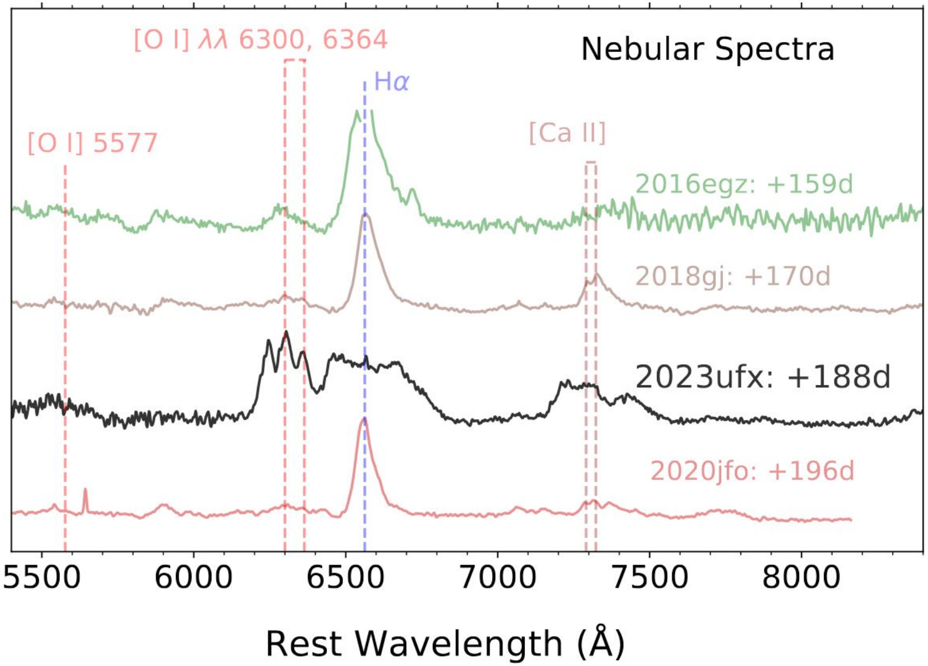




Dastidar et al. (in prep.)

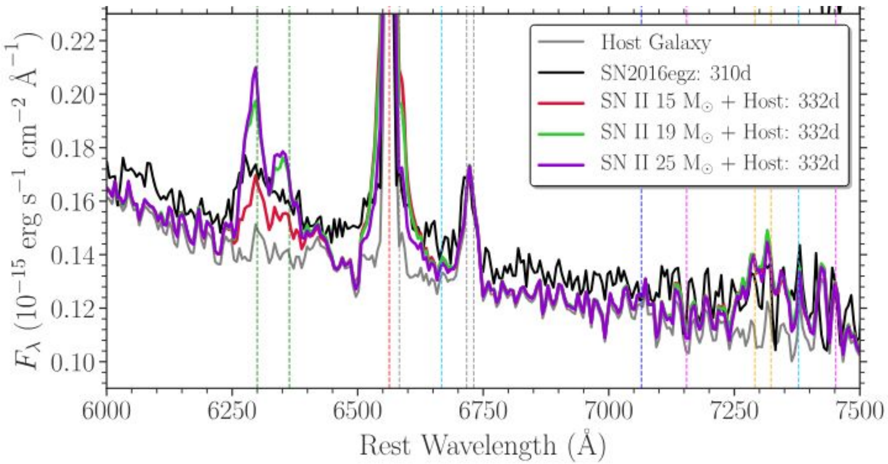
Progenitor constraints: Nebular spectra

Ravi et al. 2025

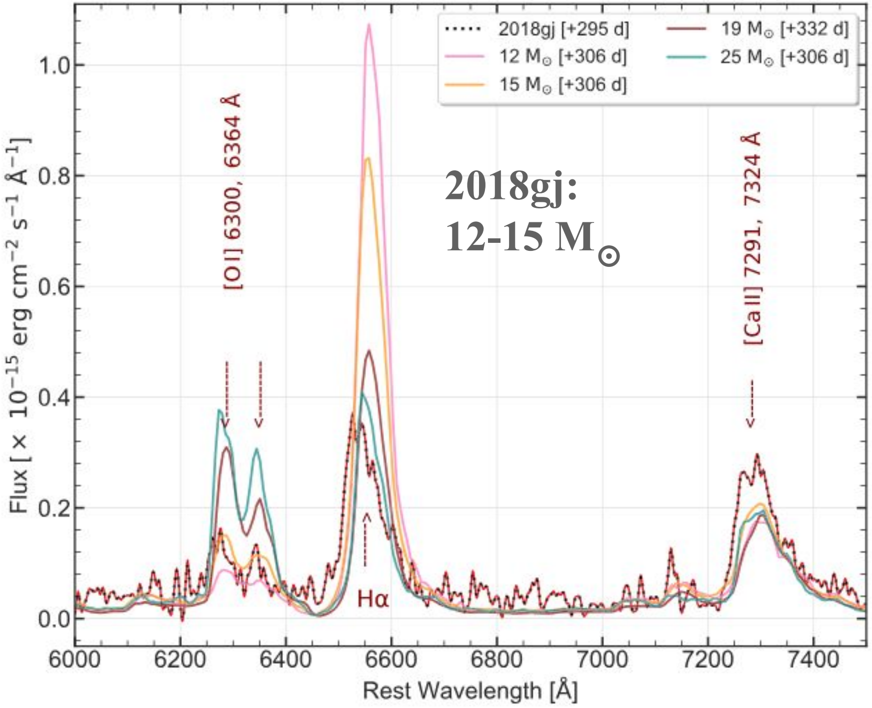


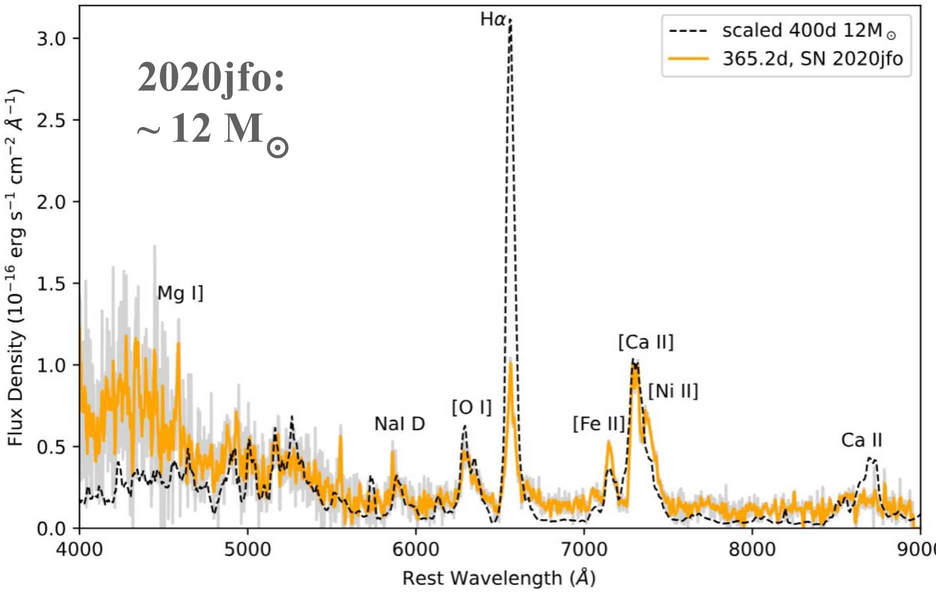
2016egz: 15-19 $M_\odot$

Hiramatsu et al. 2021



Progenitor constraints: Nebular spectra

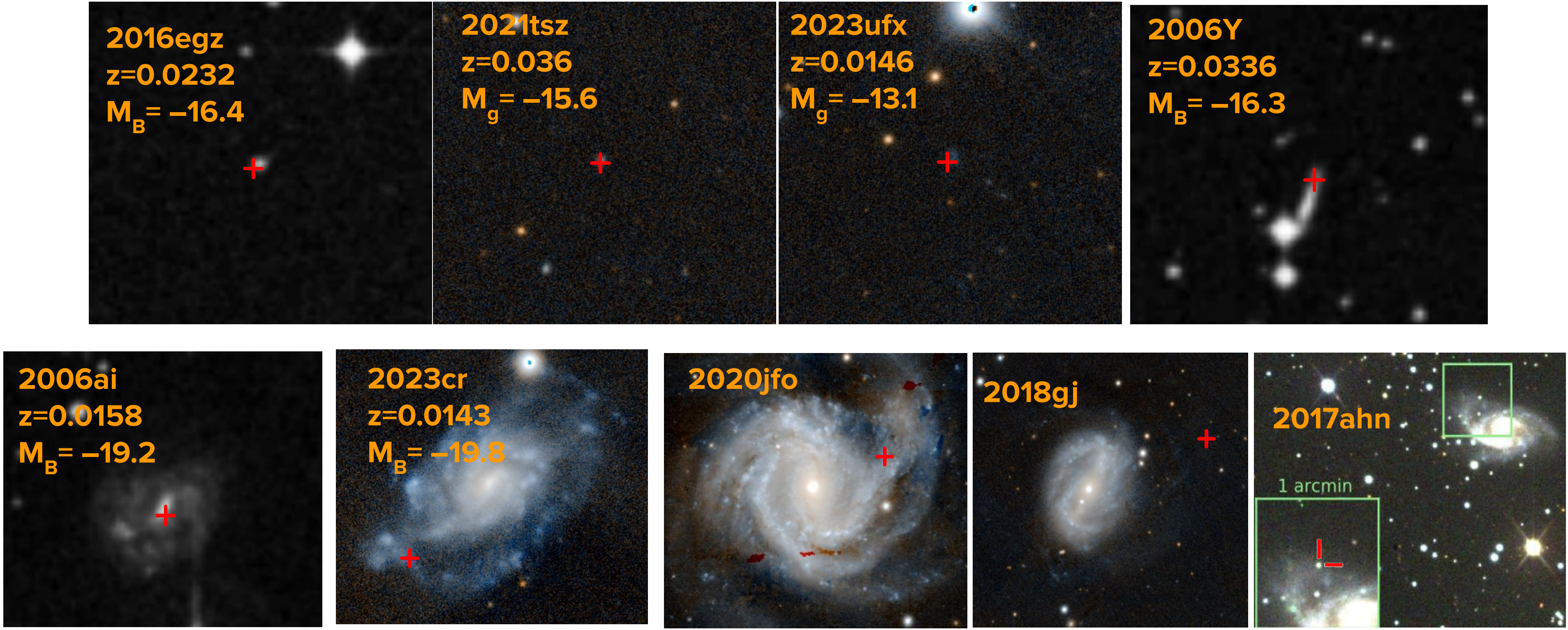




Teja et al. 2023

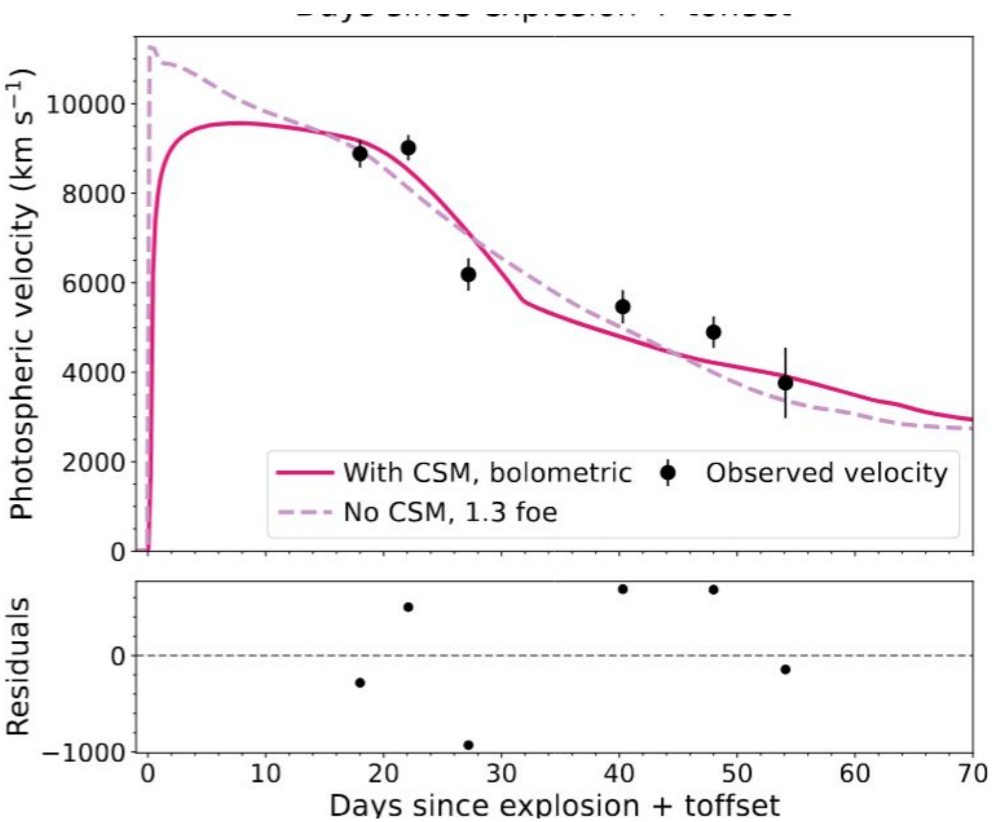
Ailawadhi, Dastidar, et al. 2023

Progenitor constraints: Host Environment



Key takeaways

- Short photospheric phase SNe II are rare as compared to SNe II with photospheric phase duration of ~100 days.
- Typically exhibits bluer colours, possibly indicating CSM interaction.
- Some early spectra show narrow emission features suggesting the presence of nearby dense CSM.
- Luminous counterparts show low to negligible Hα absorption.
- Light curve modelling can only constrain the H-envelope mass, nebular spectra are necessary for ZAMS mass.
- A broader study of RSG and SN II populations across metallicities and mass-loss models is needed to distinguish SPSN formation channels.
- The rarity of short-plateau SNe suggests rare formation conditions, with binary evolution often leading to SNe IIb instead.
- LSST will increase the numbers, and SOXS will be valuable for obtaining nebular spectra.



Photospheric velocity (km s^{-1})
10000
8000
6000
4000
2000
0
With CSM, bolometric
No CSM, 1.3 foe
Observed velocity
Residuals
0
−1000
0
10
20
30
40
50
60
70
Days since explosion + toffset