An Extraordinary Journey Into The Transient Sky:
from restless progenitor stars to explosive multi-messenger signals

“Early Flash Ionisation Signatures in Type IIP SNe”

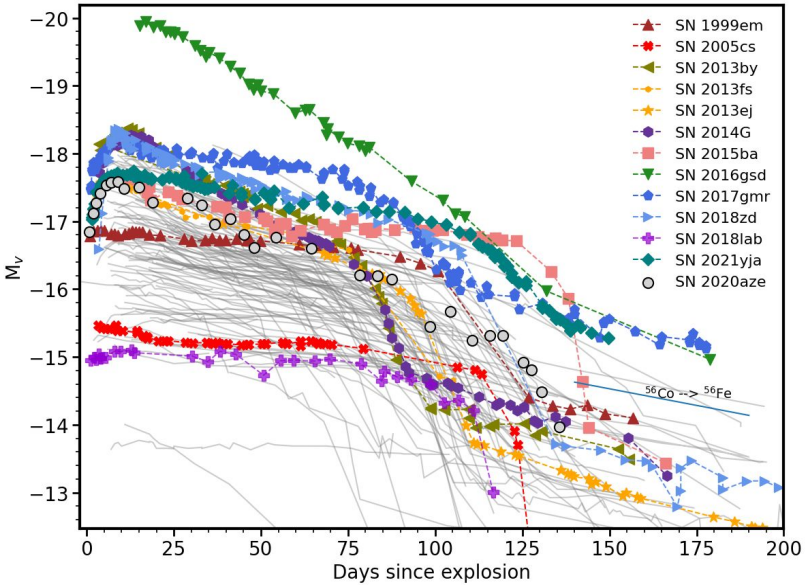
Bhavya Ailawadhi

Aryabhatta Research Institute of observational sciencES (ARIES)

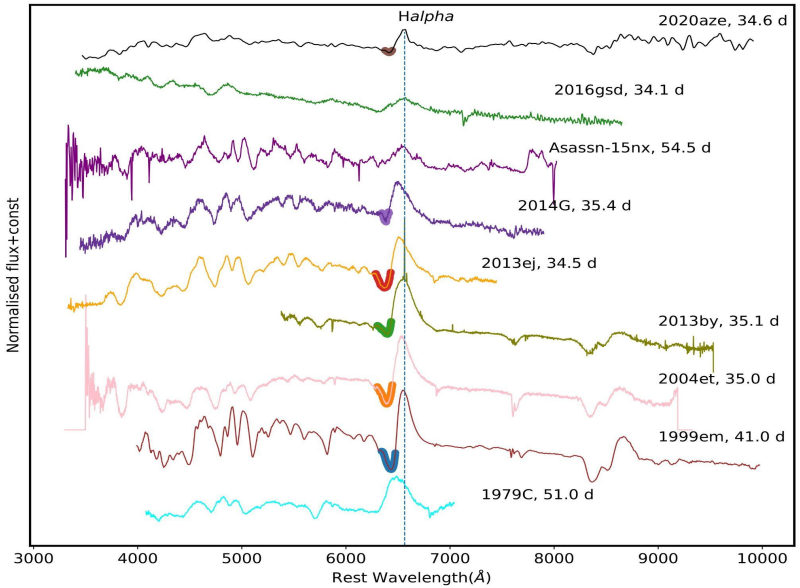
Supernovae (SNe)

- Supernovae→Explosive death of massive stars
- Type II SNe→Core-collapse of massive stars (CCSNe)
  - Exhibit hydrogen lines in the spectra

Credit: Hiramatsu et al. (2023).



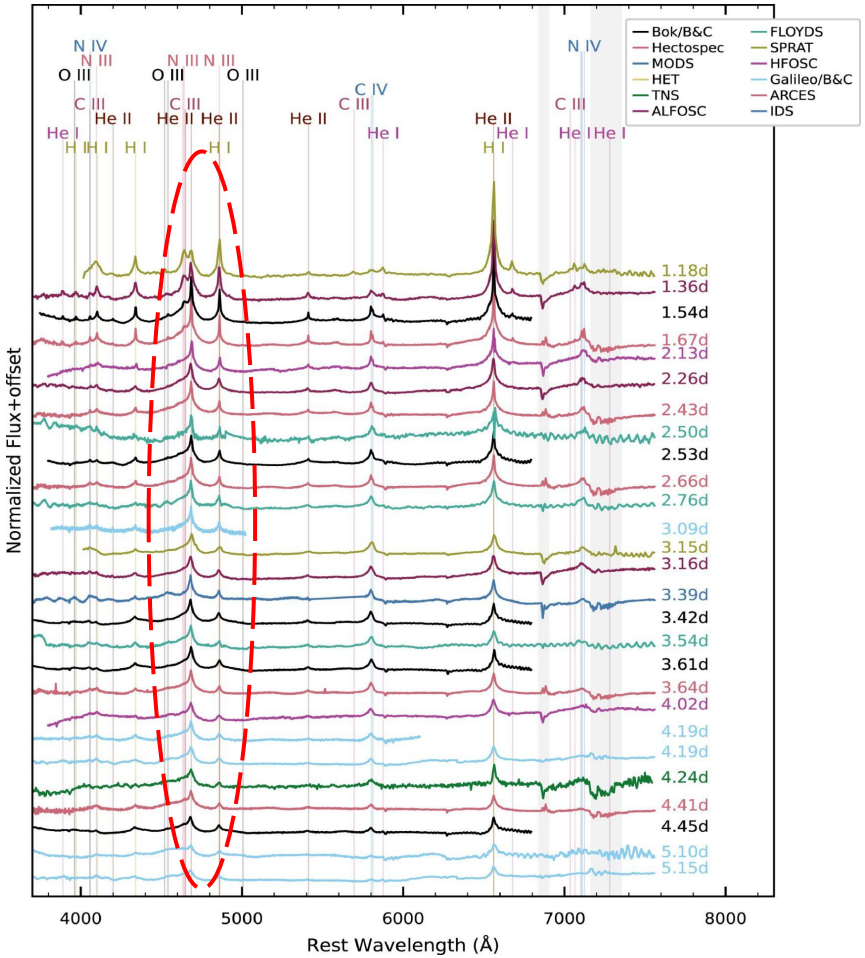
V-band absolute lightcurve of Type II SNe.



Photospheric phase spectra of all Type II SNe.

Flash Features

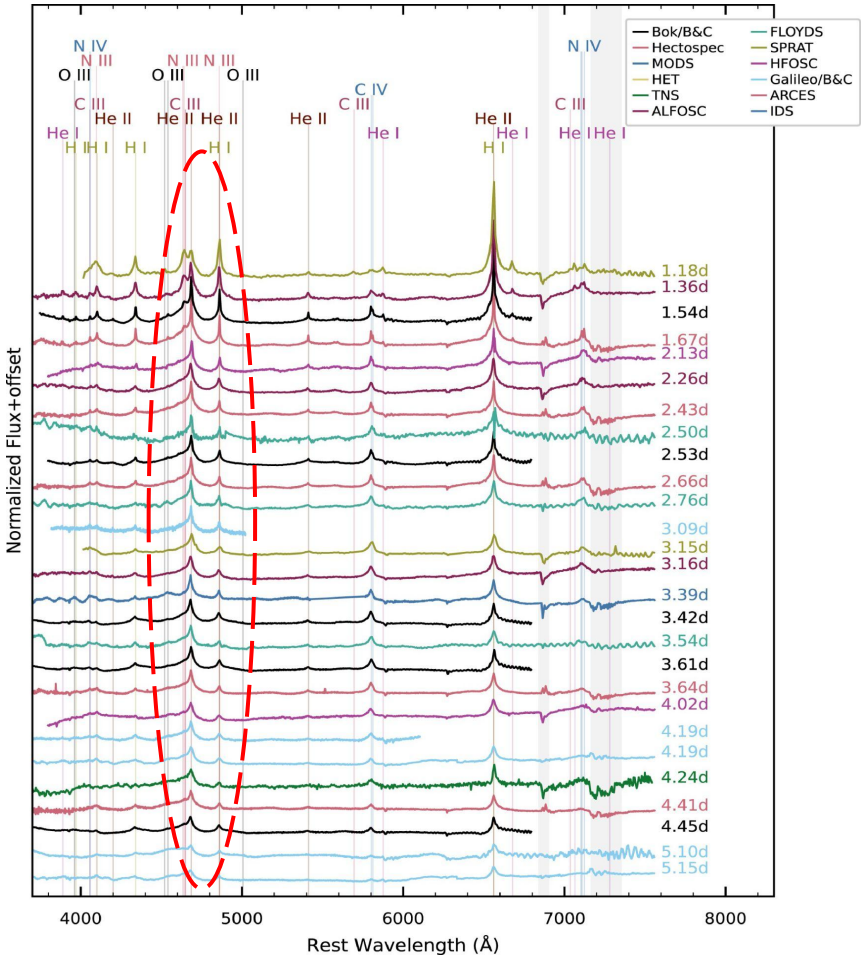
- Highly-ionised emission features of various elements like He, C, N, and O
- First Type II SN observed with flash features was SN 1983k containing lines of N III and He II
- 36% of early-stage SNe observed within 2 days post-explosion showed these spectral lines (Bruch et al., 2023)
- Cause: Interaction of SN ejecta with surrounding CSM
- They will sustain until the CSM is swept away by the SN ejecta



The early-phase spectral evolution of SN 2023ixf represents the evolution of flash features (Bostroem et al., 2023).

Flash Features

- FWHM of these features lies between 100 to 1000 km/s
- Material ejected from the progenitor ~1000 days prior its explosion
- Progenitor mass-loss rate shortly before the explosion
- Physical characteristics of CSM like density, velocity, temperature and composition



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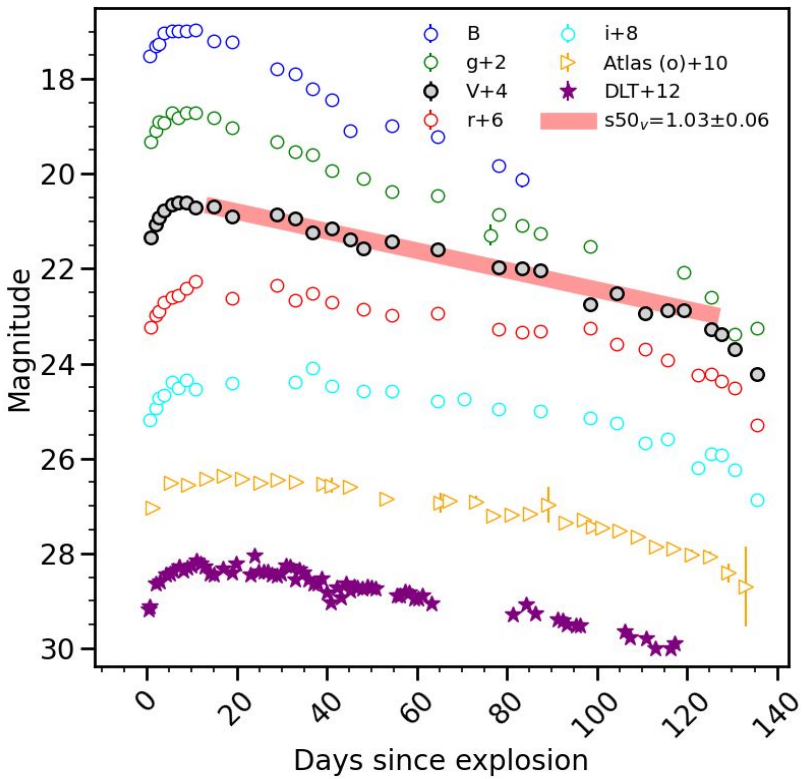
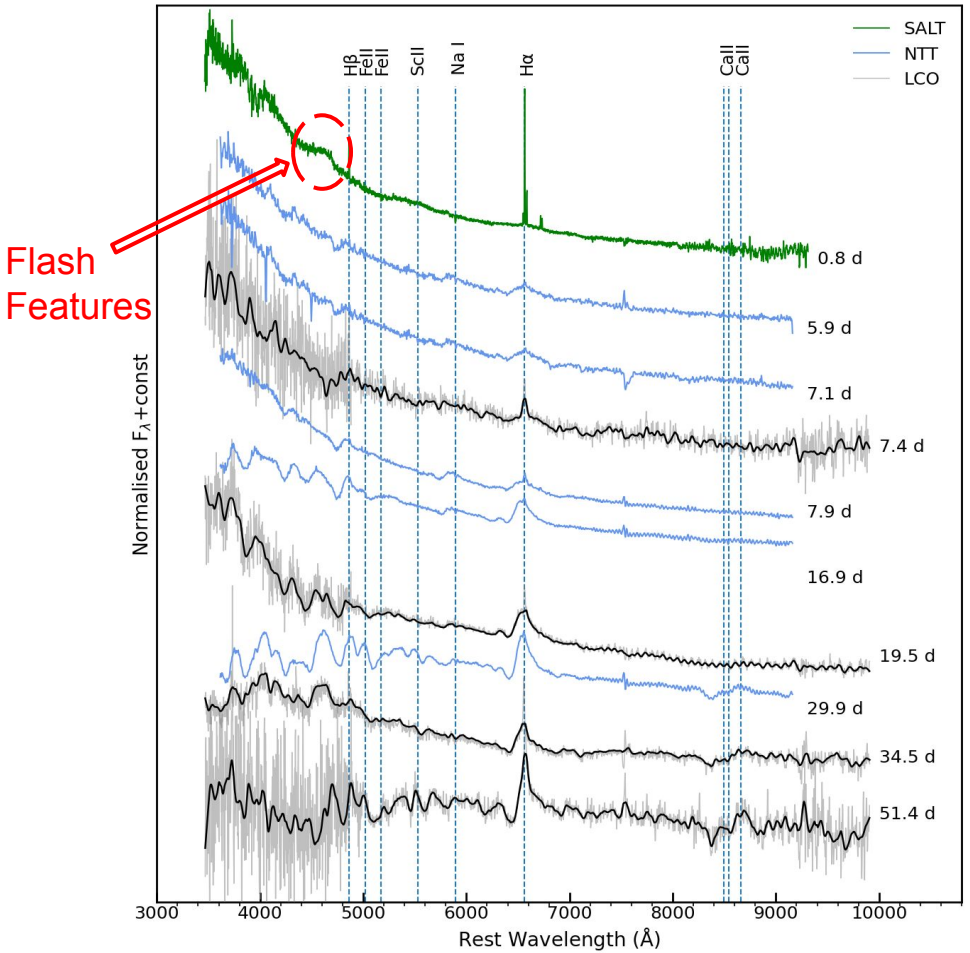
SN 2020aze



Optical lightcurve of SN 2020aze since the date of explosion also including ATLAS and DLT data.



The early-phase spectral evolution of SN 2023ixf represents the evolution of flash features (Bostroem et al., 2023).

Gaussian Fitting

➢ Composed of 3 gaussian components:

a. Broad blue-shifted He II (4686 Å)

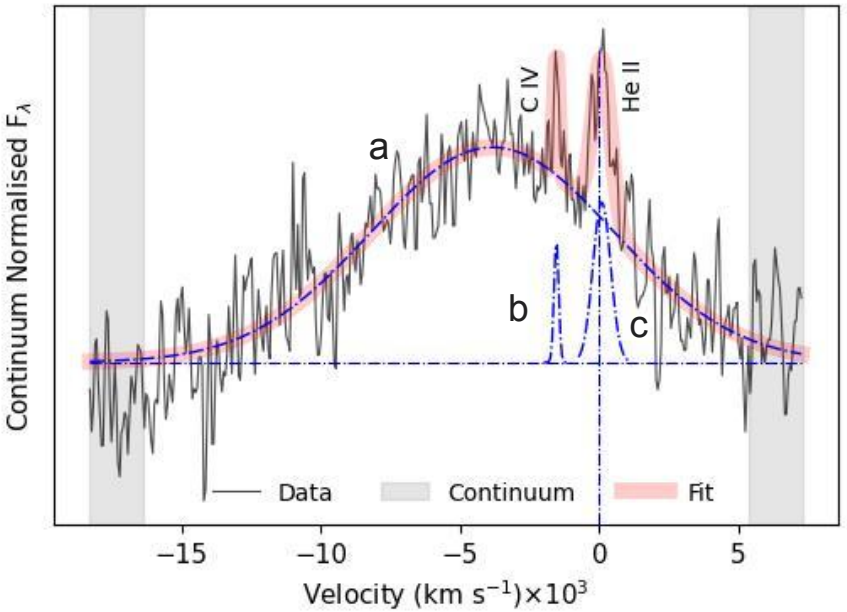
FWHM velocity: ~10000 km/s

b. Narrow C IV (4658 Å)

FWHM velocity: ~200 km/s

c. Narrow He II (4686 Å)

FWHM velocity: ~750 km/s



Feature is modelled using two narrow Gaussian components and one broad Gaussian component.

Implications of Gaussian Fitting

- Does the broad feature result from blending of various narrow line?

  → No (Presence of narrow lines)

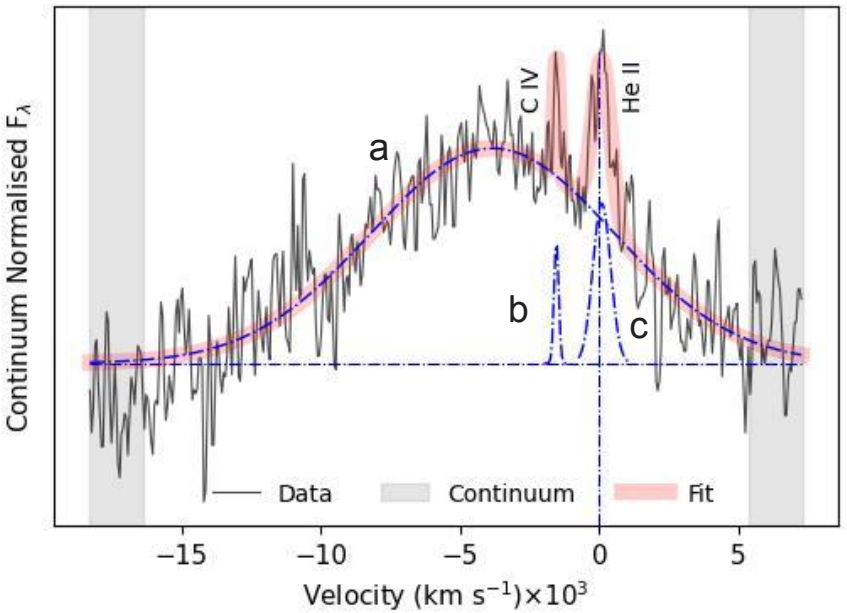
- Does the broad feature represent the radiative acceleration of CSM?

  → No (Velocity should be ~1000 km/s)

- Is it a blue-shifted He II profile at 4686Å?

  →Yes (Originates from the outer layer of SN ejecta)

  →Narrow lines are from outer CSM, exhibiting velocities of the order of 100 km/s



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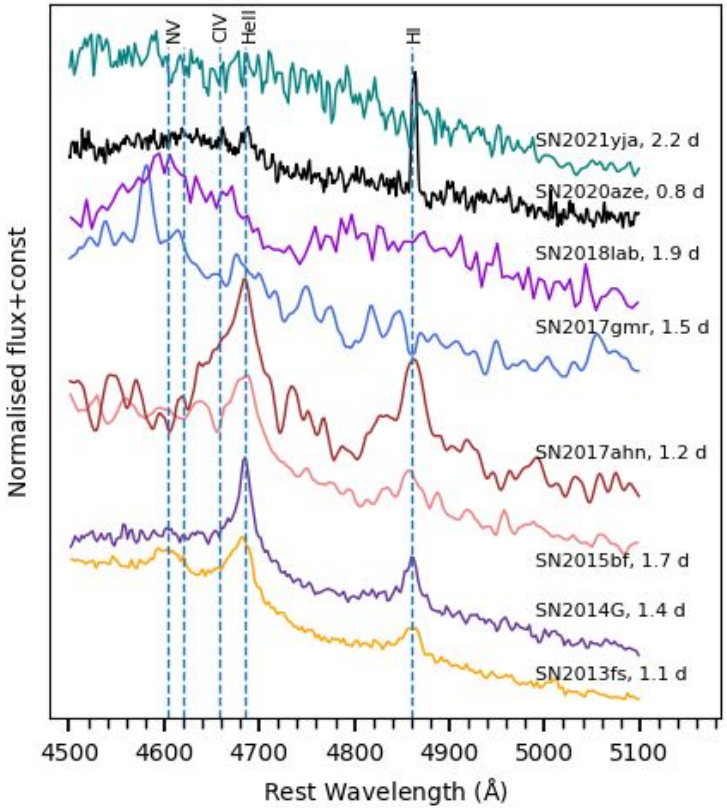
Comparison with other SNe

- Narrow and high intensity flash features are present in SNe 2013fs, 2014G, 2015bf and 2017ahn
- Broad feature or ledge kind of feature is present in SNe 2017gmr, 2018lab, and 2021yja, similar to SN 2020aze.

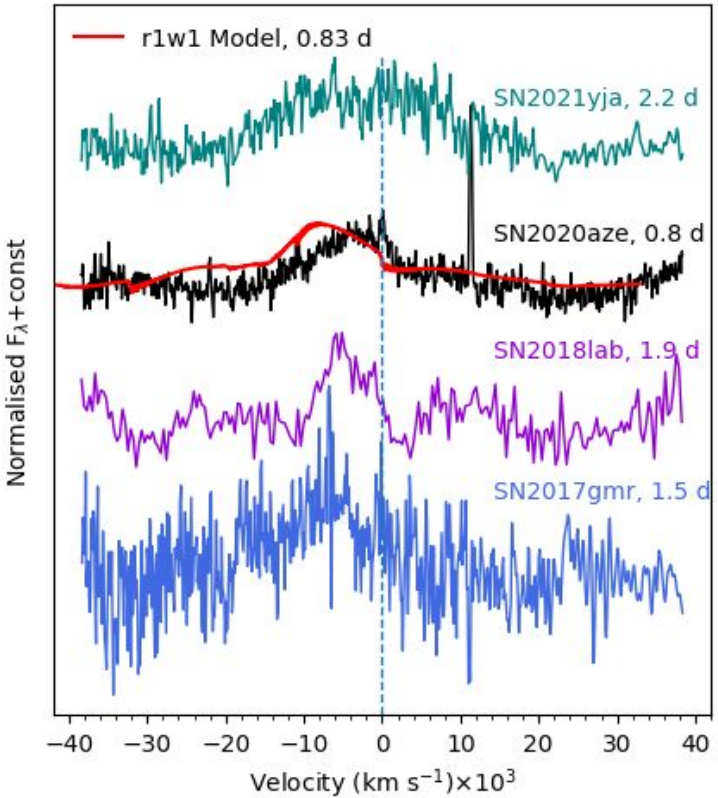


Comparison of early flash features visible in SN 2020aze and other Type II SNe.

Cross-match with Modeled spectrum

- Using 1-D NLTE radiative transfer model (CMFGEN), Dessart et al. (2017) analysed RSG's explosions spectral characteristic.
- Different parameters ranges are:

  Progenitor Radii: 501 R⊙ and 1107 R⊙
  Mass loss rate: 10^{-6} to 10^{-2} M⊙/yr
- The model spectrum matching with SN 2020aze's spectra belongs to progenitor have 501 R⊙ radius and 10^{-6} M⊙/yr mass loss rate.



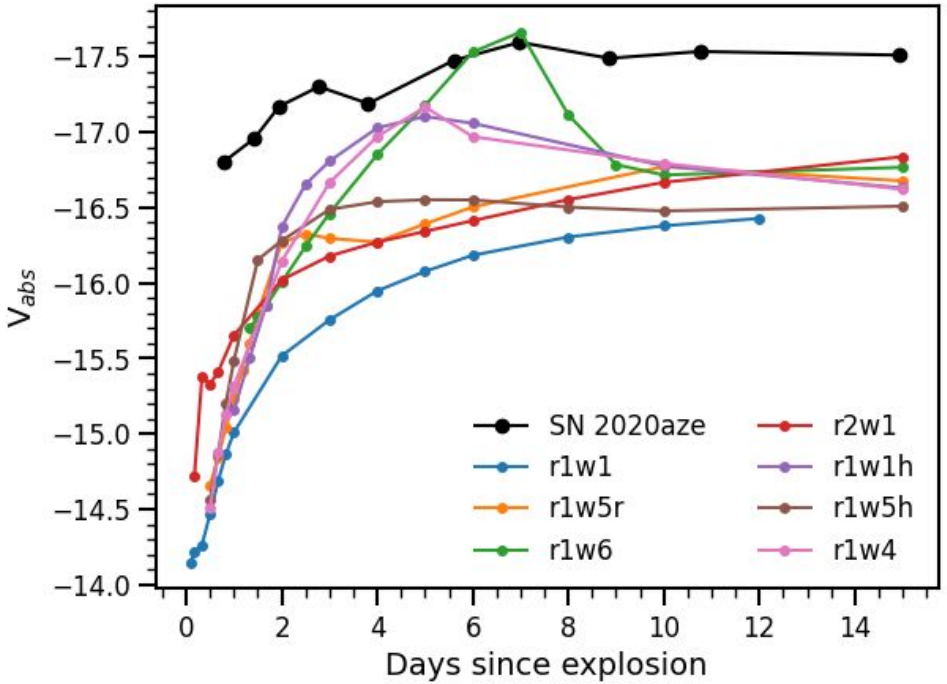
Comparison of the ledge feature profile around 4686 Å with other Type II SNe. The 0.83 day r1w1 model spectrum from Dessart et al. (2017) is overplotted on the SN 2020aze spectrum and displayed in red.

Cross-match with Modeled lightcurve

- Using these following parameters ranges and considering the progenitor mass to be 12.52 M⊙, modeled lightcurves are generated:

  Progenitor Radii: 501 R⊙ and 1107 R⊙
  Mass loss rate: 10^{-6} to 10^{-2} M⊙/yr

- High flux values of SN 2020aze indicates its progenitor to be more massive than 12.52 M⊙

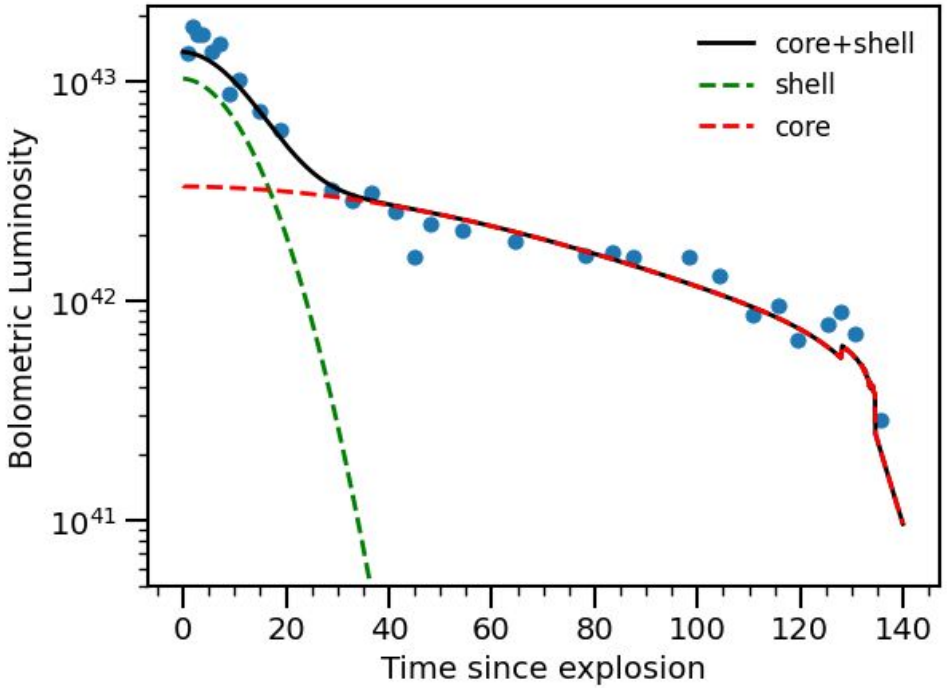


Comparison of the modeled V-band lightcurves with SN 2020aze.

Contribution of CSM interaction over lightcurve

➢ Using semi-analytical model of Nagi Nagy & Vinkó (2016), the parameters leading to such modeled lightcurves are:

Parameter	Core	Shell
Radius (cm)	$10x10^{13}$	$12x10^{13}$
Ejecta Mass (M□)	12.5	0.55
Kinetic Energy (foe)	1.5	1.3
Thermal Energy (foe)	0.5	0.2



The evolution of the bolometric light curve of SN 2020aze is plotted alongside the modeled light curves from Nagy & Vinkó (2016).

Summary

- **Composition of CSM :– He II (~750 km/s) and C IV (~200 km/s)** and they are superimposed over a broad feature having a FWHM velocity of ~ 10000 km/s
- **Mass loss rate :– Around 10^{-6} M⊙/yr** (through spectral comparison)
- **Constraint on progenitor mass :– > ~12 M⊙** (through lightcurve comparison)

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Thank you for your attention