SN 2023ixf : Closest CCSN in Over Two Decades after SN 2004dj

Captured at Higashihiroshima
Equipment: Nikon Z6, 200-500mm f/5.6

Seimei Users Meeting 2023, Kyoto University

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Overview

First Paper is Out!
Rishabh Singh Teja *et al* 2023 *ApJL*
954 L12
DOI 10.3847/2041-8213/acef20

24 Papers in arXiv!

Collective Team Effort in Follow-up
1) Kanata Telescope
2) **Seimei Telescope**
3) Growth-India Telescope
4) Himalayan Chandra Telescope
5) Kottamiya Telescope
6) Steward Observatory
7) Subaru

The Astrophysical Journal Letters, 954:L12 (10pp), 2023 September 1 https://doi.org/10.3847/2041-8213/acef20

Far-ultraviolet to Near-infrared Observations of SN 2023ixf: A High-energy Explosion Engulfed in Complex Circumstellar Material

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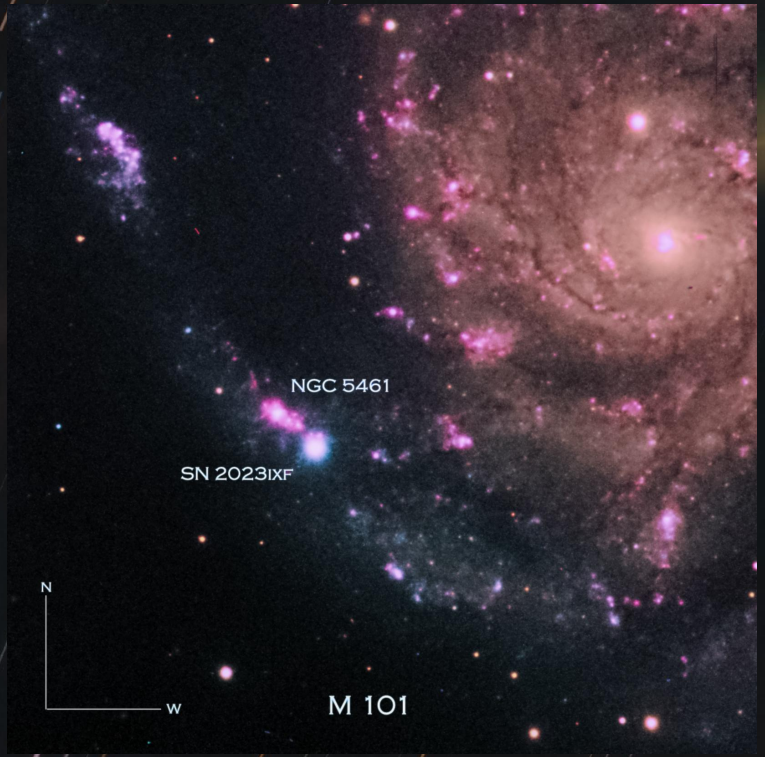
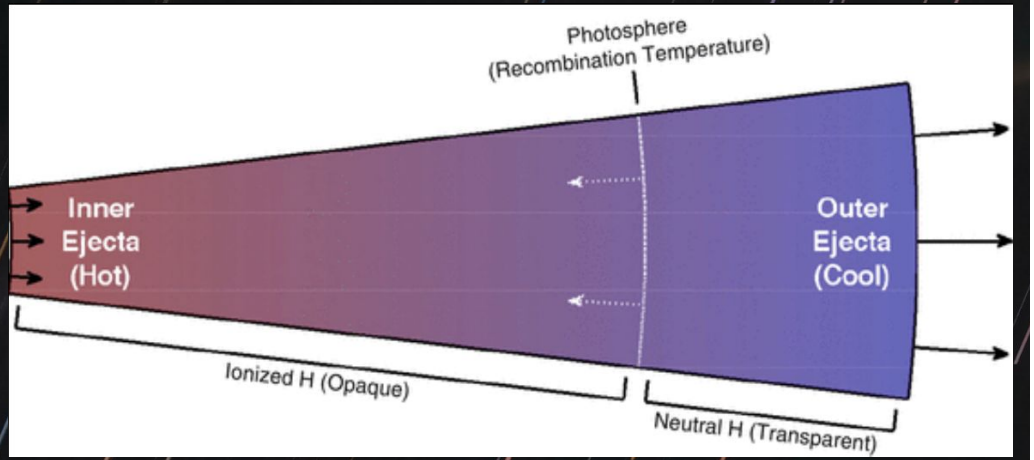


Discovered by Itagaki-san!

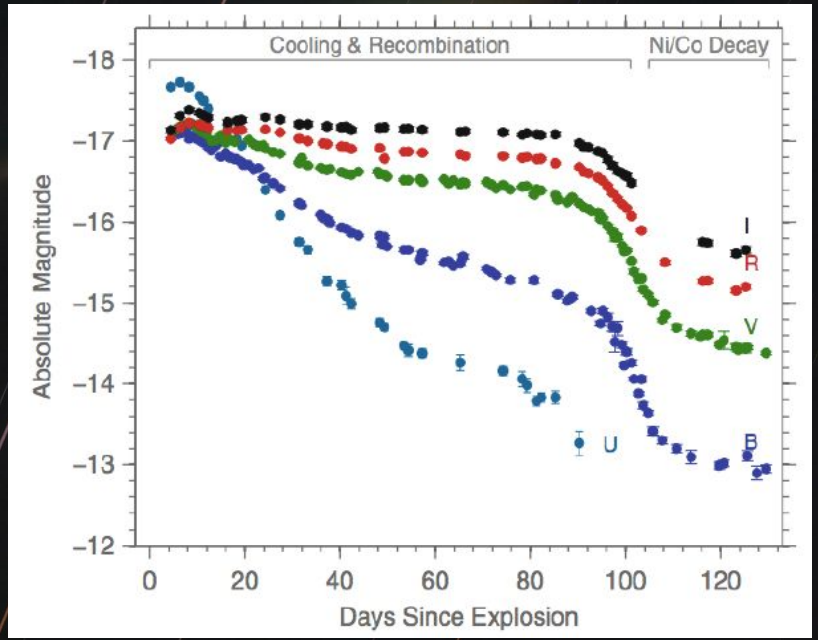
Host - M101
(RGB Composite from 2m HCT)
Distance - 6.82 Mpc

Brief Introduction

1. Shock breakout ionises the outer ejecta (T >10,000 K)
2. Envelope expands -> Recombination wave moves inwards in mass (and opacity), staying at roughly the same radius (and temperature)



1. Almost constant phase of luminosity - 'PLATEAU'
2. P-Cygni features of hydrogen visible in their spectra



Arcavi et al. 2016

Ultraviolet–Optical–Infrared Light Curves

Optical (ugriz)

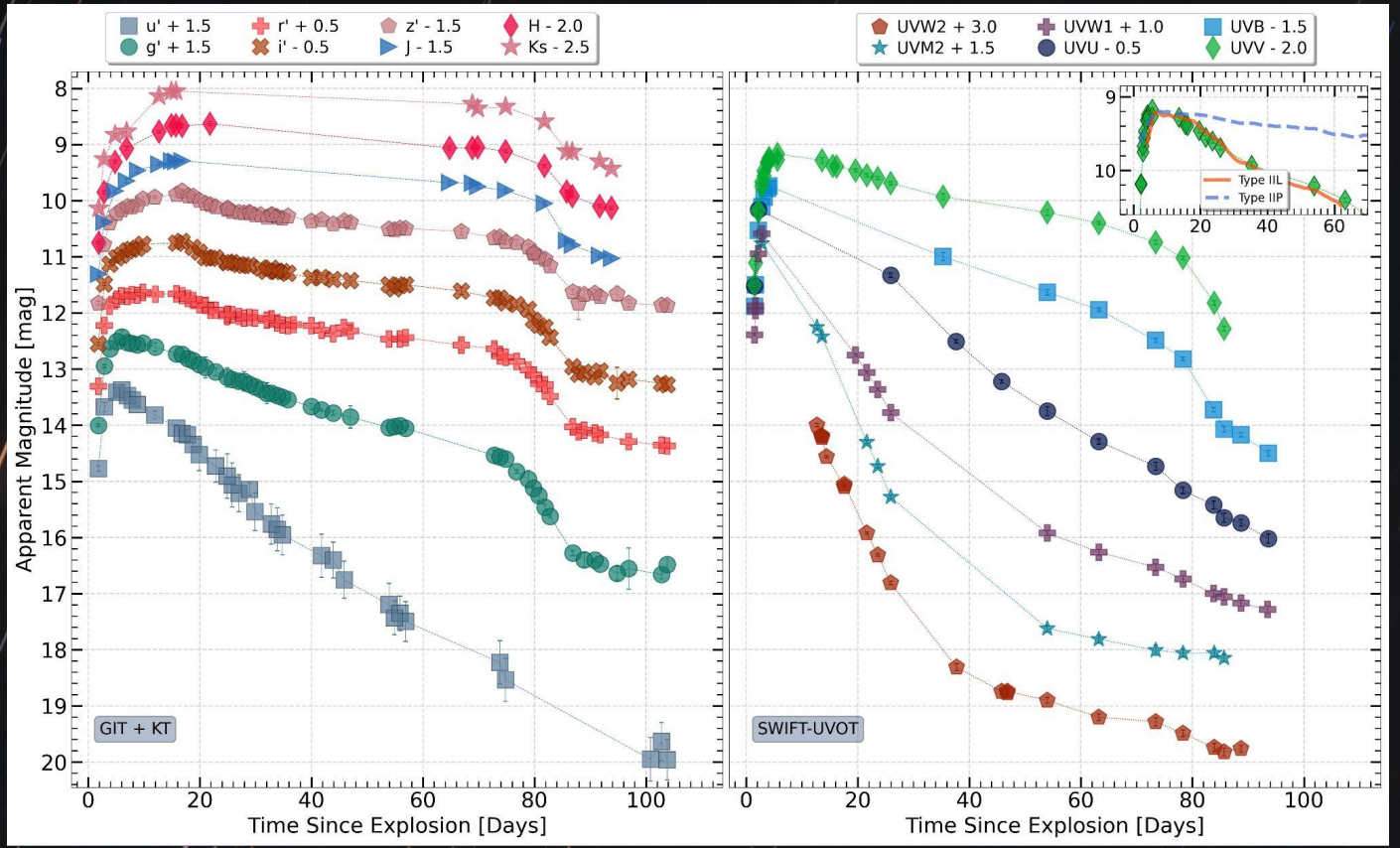
Growth-India Telescope

NIR (JHK)

Kanata Telescope (HONIR)

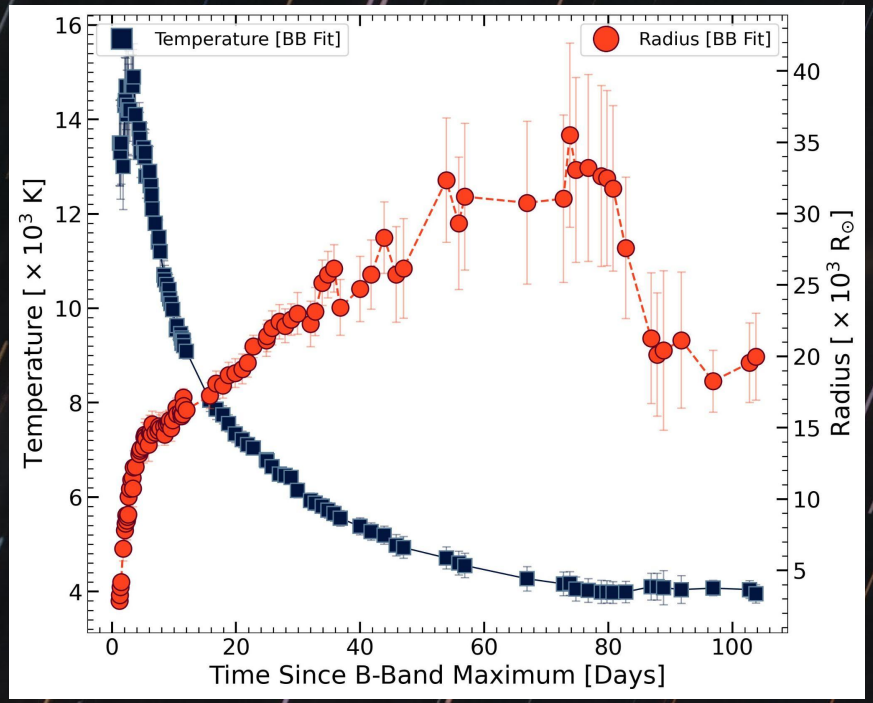
Ultraviolet

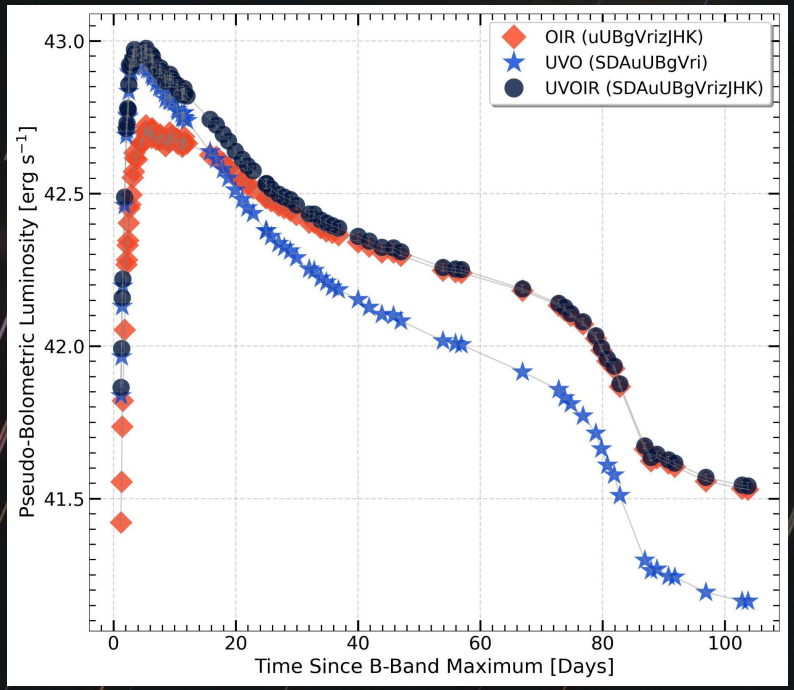
Swift-UVOT



Bolometric Light Curve and Temperature Evolution

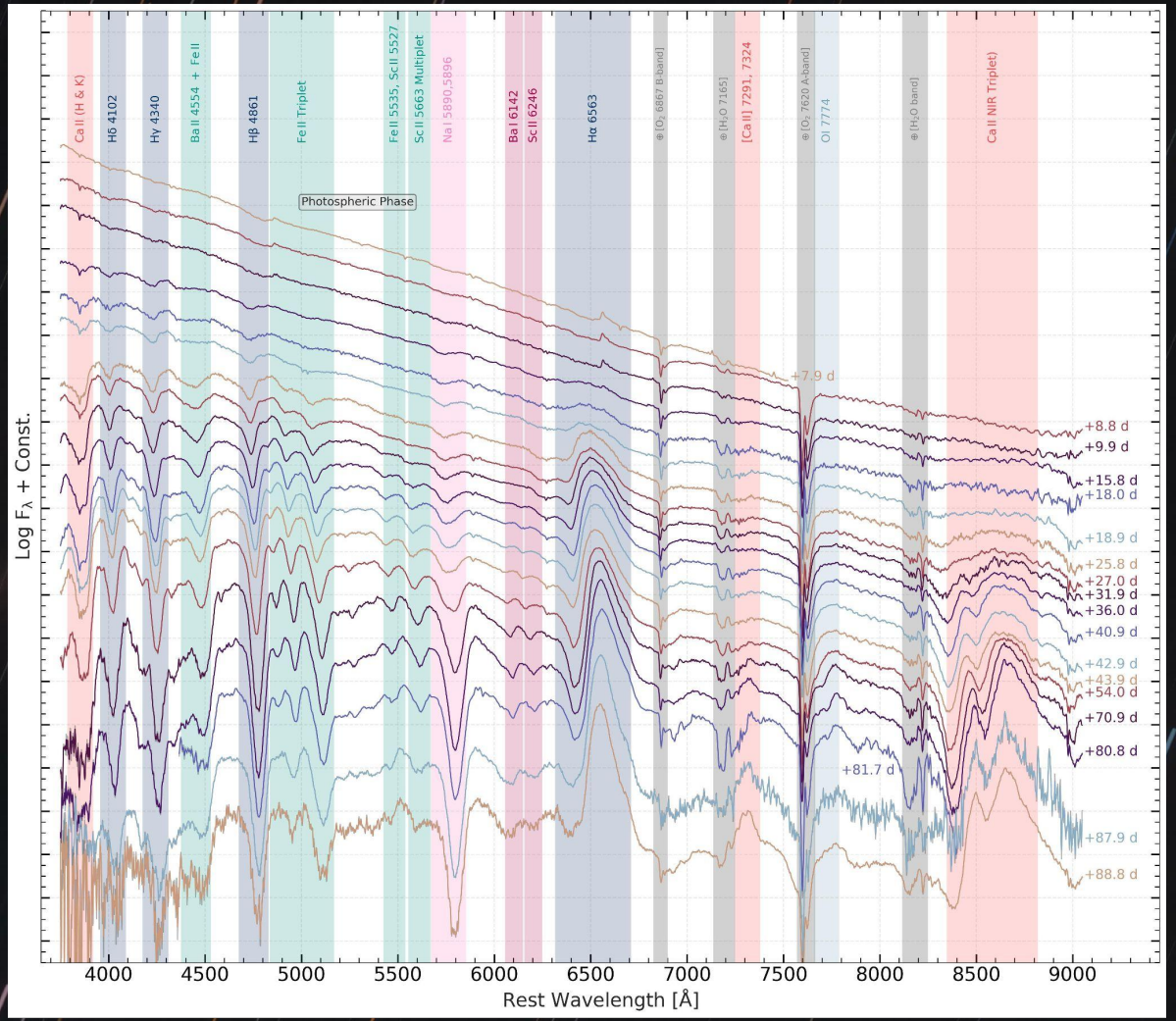
- Shock Breakout inside a dense CSM. Hence, No shock Cooling phase as in a standard SN ejecta.





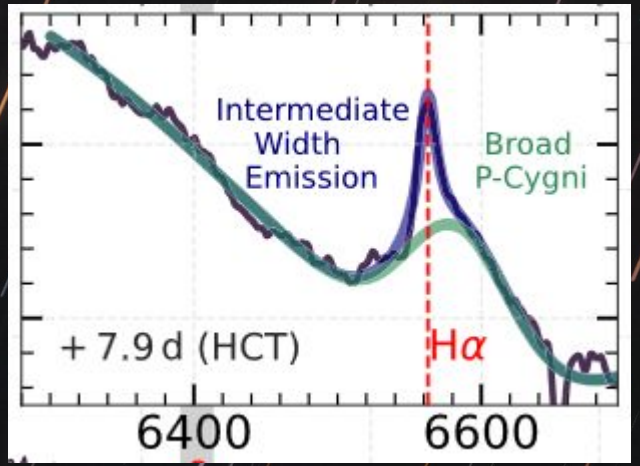
Spectroscopic Sequence

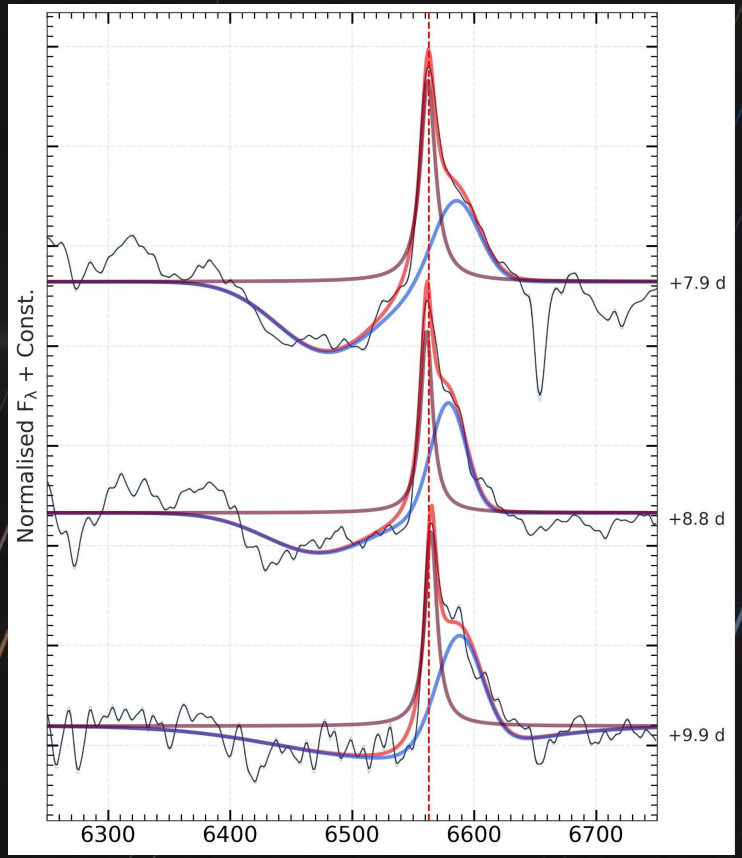
1. Flash Spectroscopy (High ionization features) up until 7 days.
2. Shows a plethora of features indicating CSM interaction. (Will discuss in following slides)
3. Features of Na, Fe, Ba and Sc are seen - Normal as a Type II SN



Evolution of Balmer Features – 1

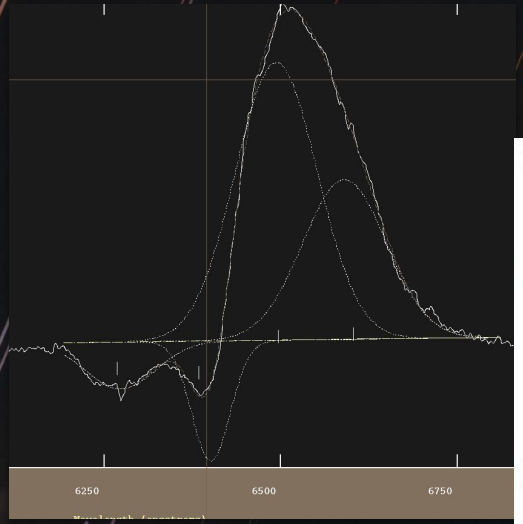
- In the Spectrum of 7.9-9.9 d, we observe intermediate-width Hα emission at 1000 km/s , in addition to the emergence of a broad P Cygni-feature with an absorption trough.
- This could possibly be due to a residual of ongoing interaction with the dense CSM along with the presence of photospheric emission from the SN ejecta.

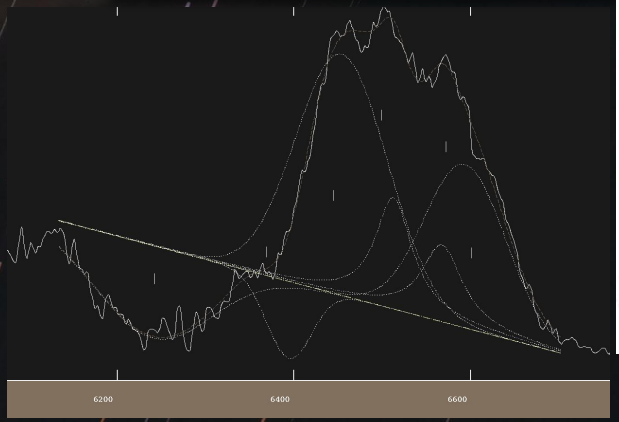


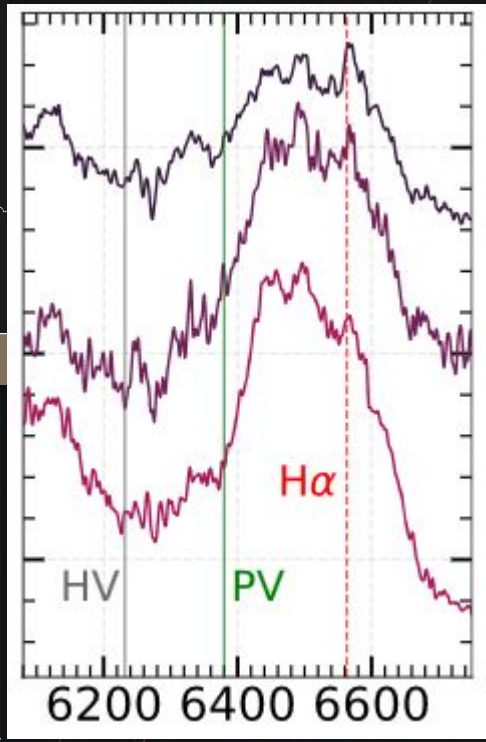


Evolution of Balmer Features – 2

- Spectra from June 03-06 (which is transitional from Flash Phase to the Photospheric phase) shows multiple broad Gaussian and Lorentzian features
- There are two absorption features at the blue-wing of Hα at 8000 km/s and 15000 km/s.
- We also detect an analogous profile blueward of Hβ with a similar velocity as seen in the Hα
- profile, indicating that the feature is likely due to hydrogen.
- Using the ejecta velocities, we estimate an inner radius of 75 AU and an outer radius of 140 AU.
- Assuming a standard RSG wind, we estimate that this ejection of mass happened 35-65 years before explosion.

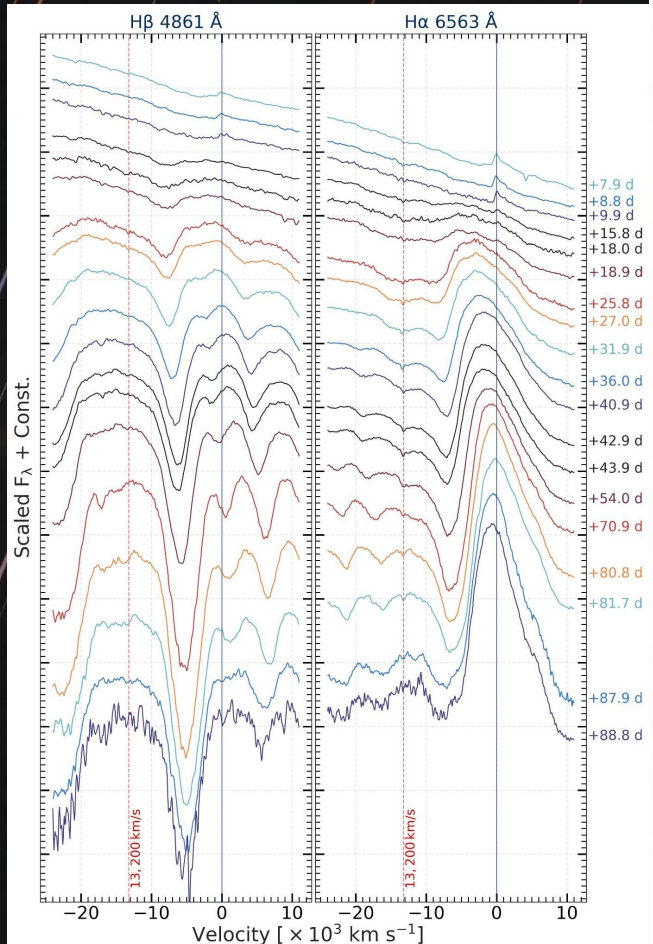


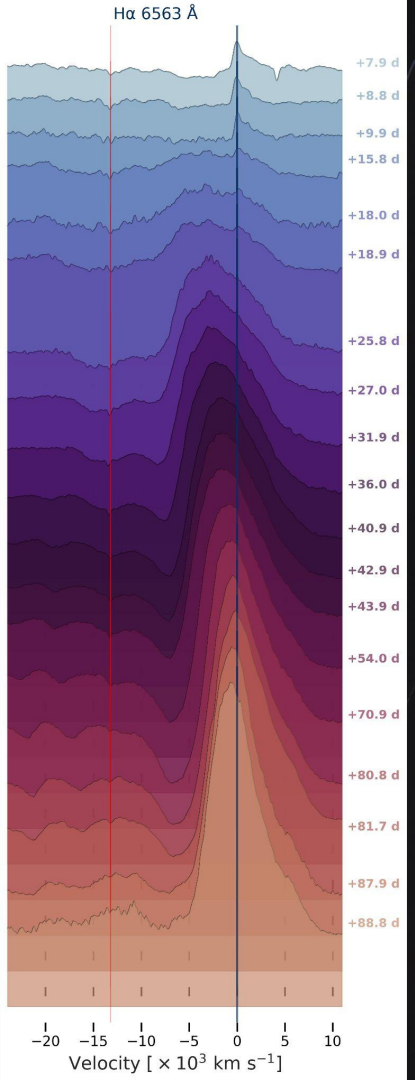




Evolution of Balmer Features – 3

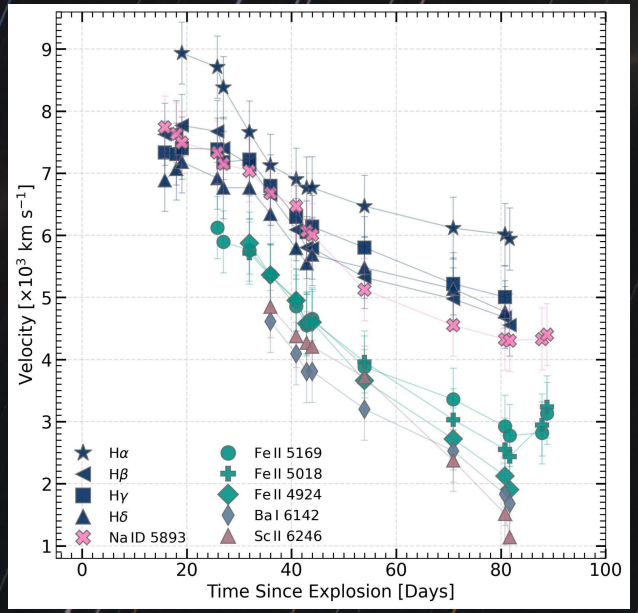
- We see dual Absorption component in the Blue-wing of Halpha from 15 d to 80 d.
- Absorption Feature at -13,200 km/s of Halpha (Wavelength 6278 Angstrom) present through all the spectra (both Seimei KOOLS and HCT HFOSC).

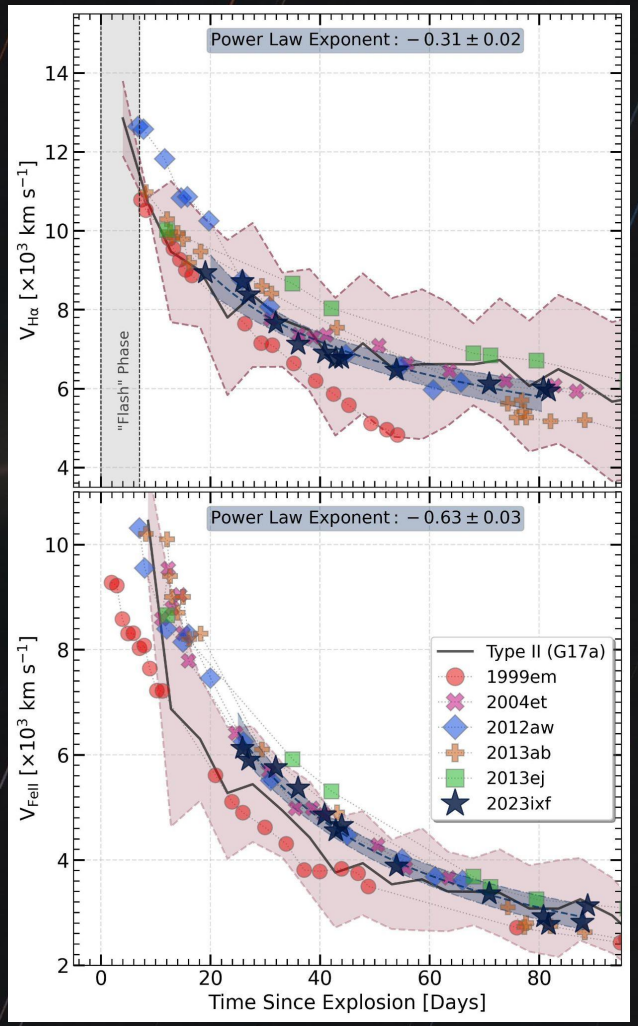




Line Velocity Evolution

1. Photospheric velocity shows evolution to a normal Type II SN.
2. It is similar to an average Type II SN despite a much brighter absolute magnitude of the SN and several instances of CSM interaction

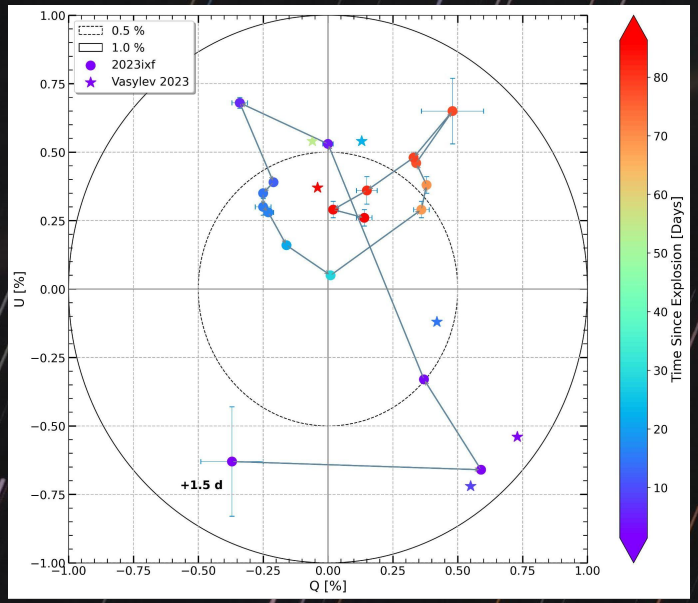


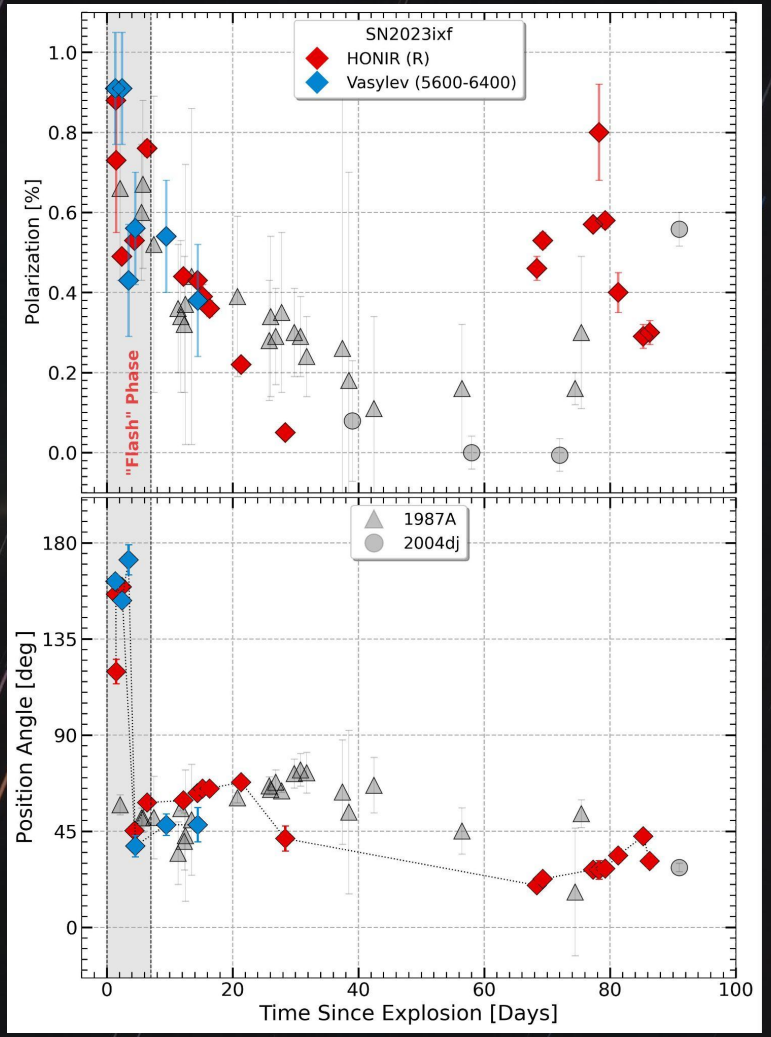


Polarisation Signatures

- We see 2 peaks in the polarisation light curve.
- one during the flash CSM (peak at 0.9%)
- and one during the extended wind CSM (at 0.5%),

Conformation with our spectral signature that we are seeing a CSM with a complex geometry.

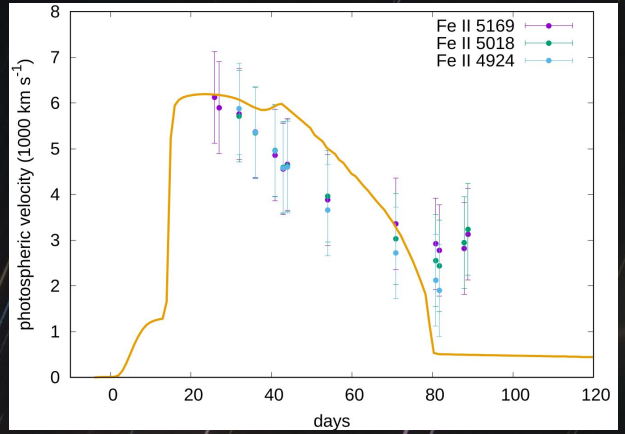


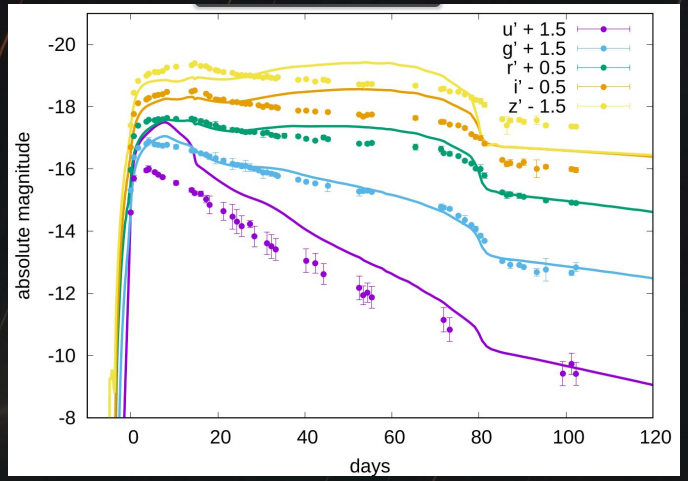


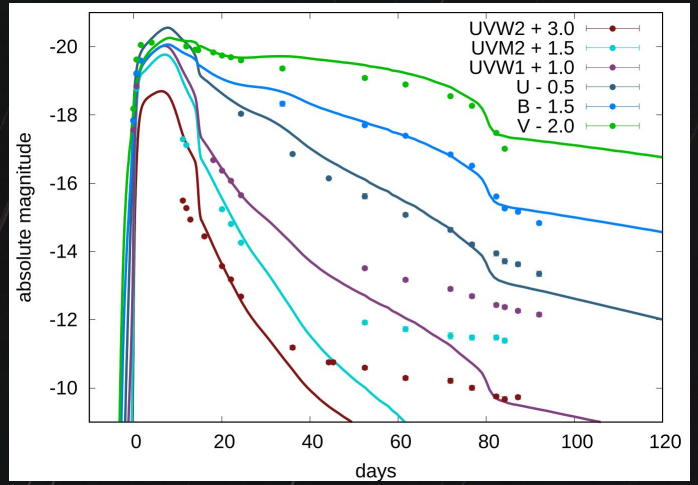
MESA-STELLA Hydrodynamical Modelling

Preliminary model fits suggest:

1) a low-mass progenitor - 10 M_{solar}
2) Explosion energy - 2e51 erg
3) 56Ni mass - 0.06 M_{solar}
4) mass-loss rate - 10^{-2} Msun/yr
5) Beta = 3.0 (0..084 M_{solar})
6) dense CSM extent - 10^{15} cm.







Discrepancies:

1) Overestimating late-plateau bump
2) UV Luminosity is underestimated at later phase indicating that CSM interaction is still ongoing and needs to be accounted with an even more extended CSM.

Summary

SN 2023ixf is one of the nearest Type II SNe in the last 2 decades and it offers us a rare opportunity for comprehensive observations and progenitor characterization. We plan to submit a paper within a month for the photospheric phase!

Signs of a Inner Dense CSM :

- Presence of Flash features till 7 d
- FUV-NIR Bolometric LC rising and temperature increasing indicates shock breakout inside a dense CSM

Extended Wind CSM:

- CSM inner Radius of 75AU and an outer radius of 110 AU.
- Enhanced mass-loss episode 35-65 years before the SN (assuming 10 km/s RSG wind)

Type IIL SN and Light Curve Modelling

- Light Curve decline rate is 1.5mag/100d, indicating it to be a Type IIL SN
- Preliminary modelling suggests a 10 solar mass progenitor having mass-loss rate of 10^{-2} solar mass/year with a solar metallicity.
- Explosion parameters : 2e51 erg with a mass with 0.06 solar mass of 56Ni synthesized

Polarisation Features

- Polarisation light curve has 2 peaks indicating a multi-faceted CSM geometry congruent with our spectral sequence.

Any Questions?

Comet C/2023 ZTF

Equipment: Nikon Z6, 250mm f/4.9 APO, SkyGuider Pro,
EXIF: (30s * 257 Frames), Flat and Dark Corrected

Captured From Higashihiroshima