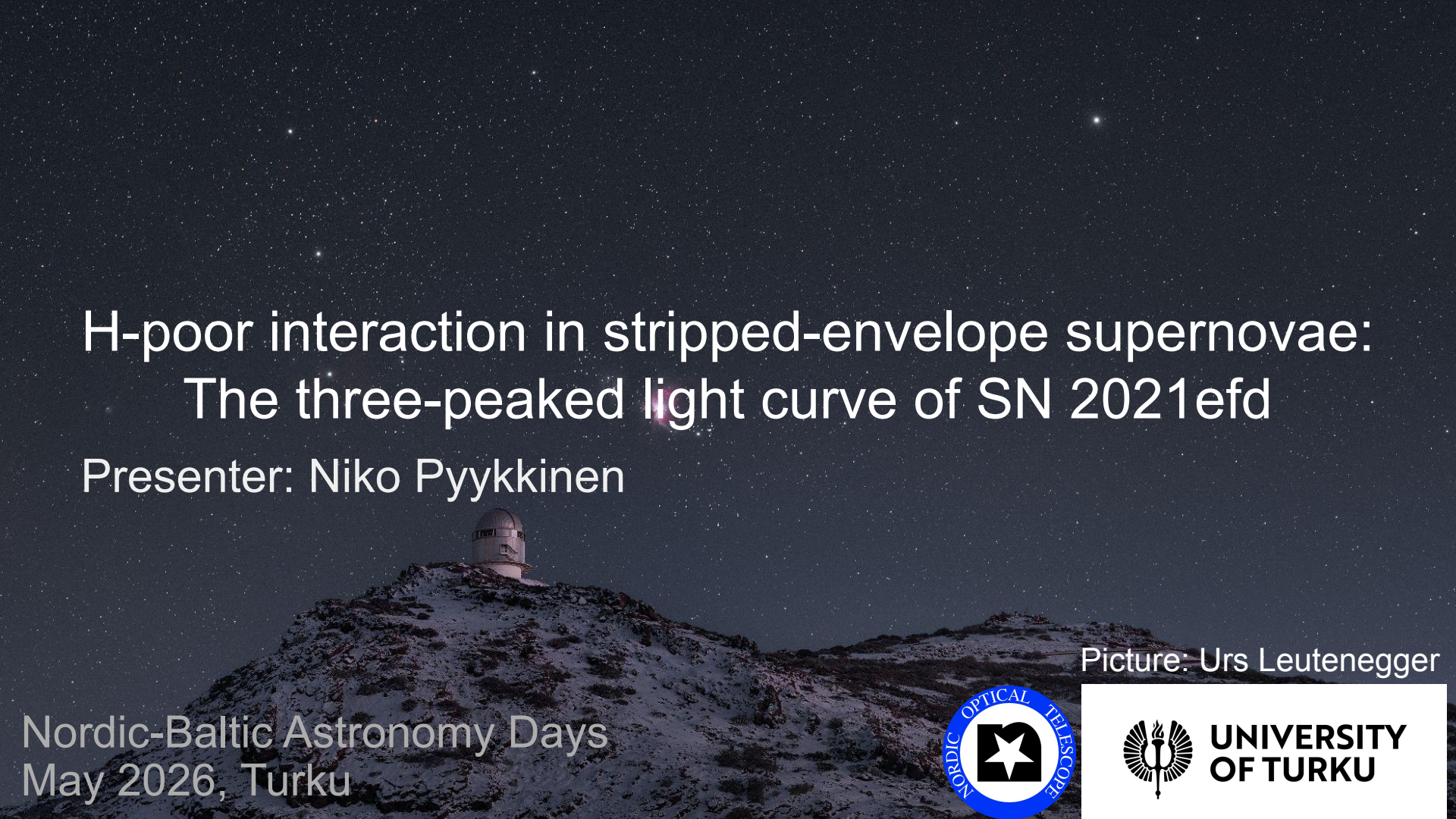
H-poor interaction in stripped-envelope supernovae: The three-peaked light curve of SN 2021efd

Presenter: Niko Pyykkinen



Picture: Urs Leutenegger

Nordic-Baltic Astronomy Days
May 2026, Turku

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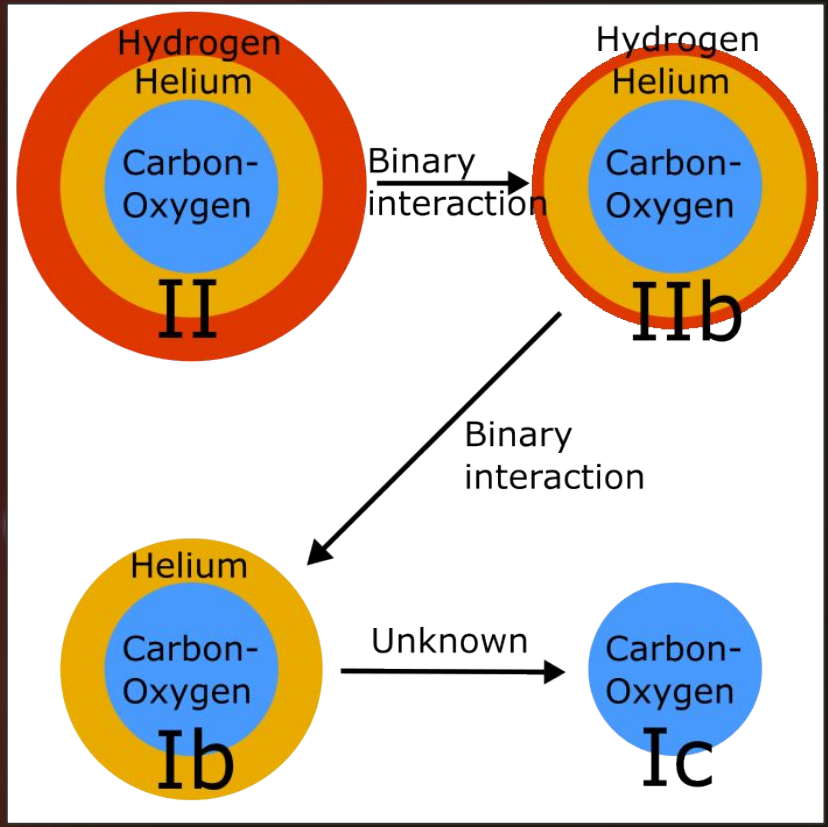
Stripped-Envelope Supernovae

- Stripped-Envelope Supernovae (SESNe) are a sub-class of Core-Collapse Supernovae
- The progenitors have suffered significant mass loss
- The hydrogen layer stripping is thought to be cause by Roche-lobe overflow in a binary system
- He-layer stripping of the Type Ic progenitors is not supported by binary system simulations
- WR-stars are not likely progenitors for the SESNe population

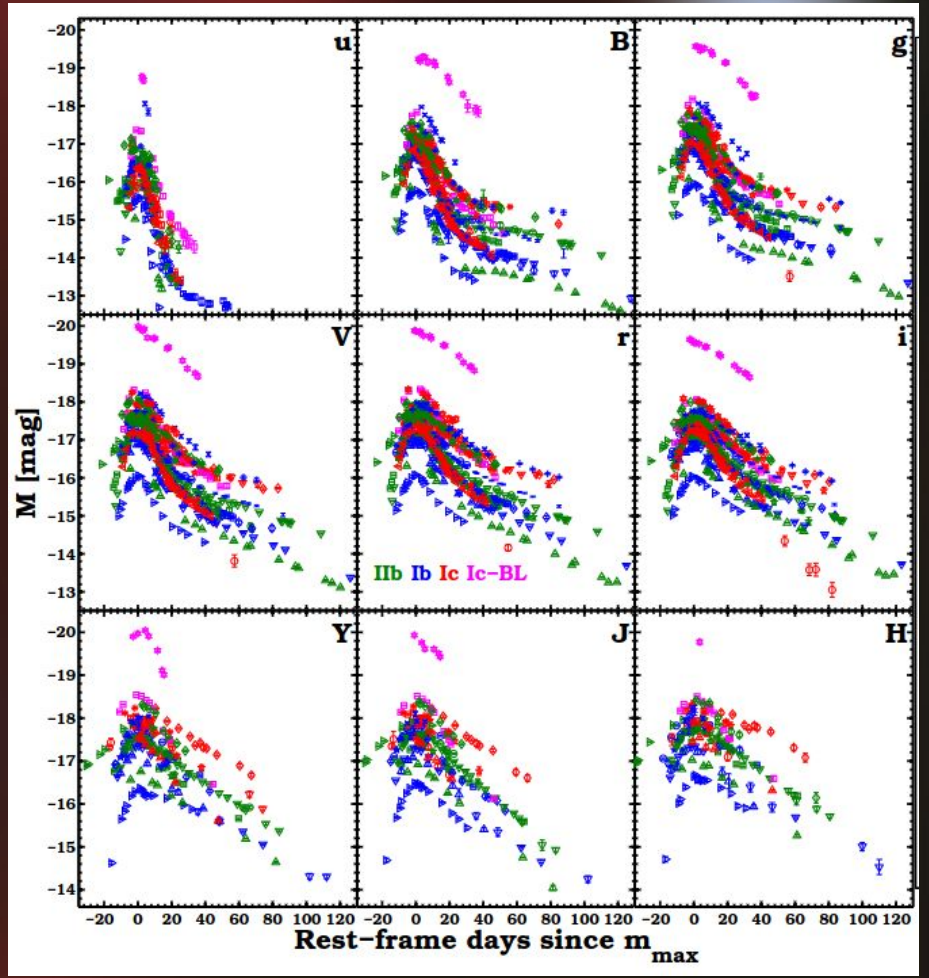


SESNe light curves

- SESNe have relatively homogenous light curves
- The light curve is mainly powered by radioactive decay after the initial peak

$$^{56}\mathrm{Ni} \rightarrow {}^{56}\mathrm{Co} \rightarrow {}^{56}\mathrm{Fe}$$

- The tail phase decays at slightly higher rate than ^{56}Co-rate

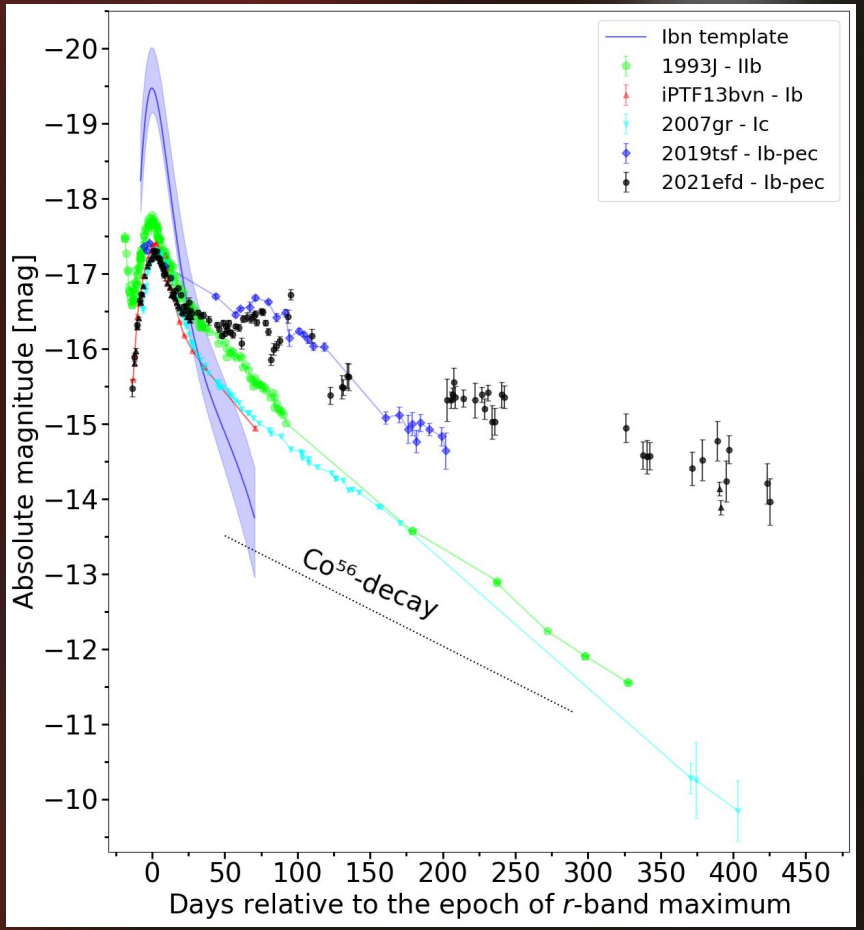


$$L_R = (6.45 \times 10^{43} e^{-t/8.800} + 1.45 \times 10^{43} e^{-t/111.3}) M_{Ni}\ \mathrm{erg\ s^{-1}}$$

Taddia et al. 2018, A&A, V. 609, A136,

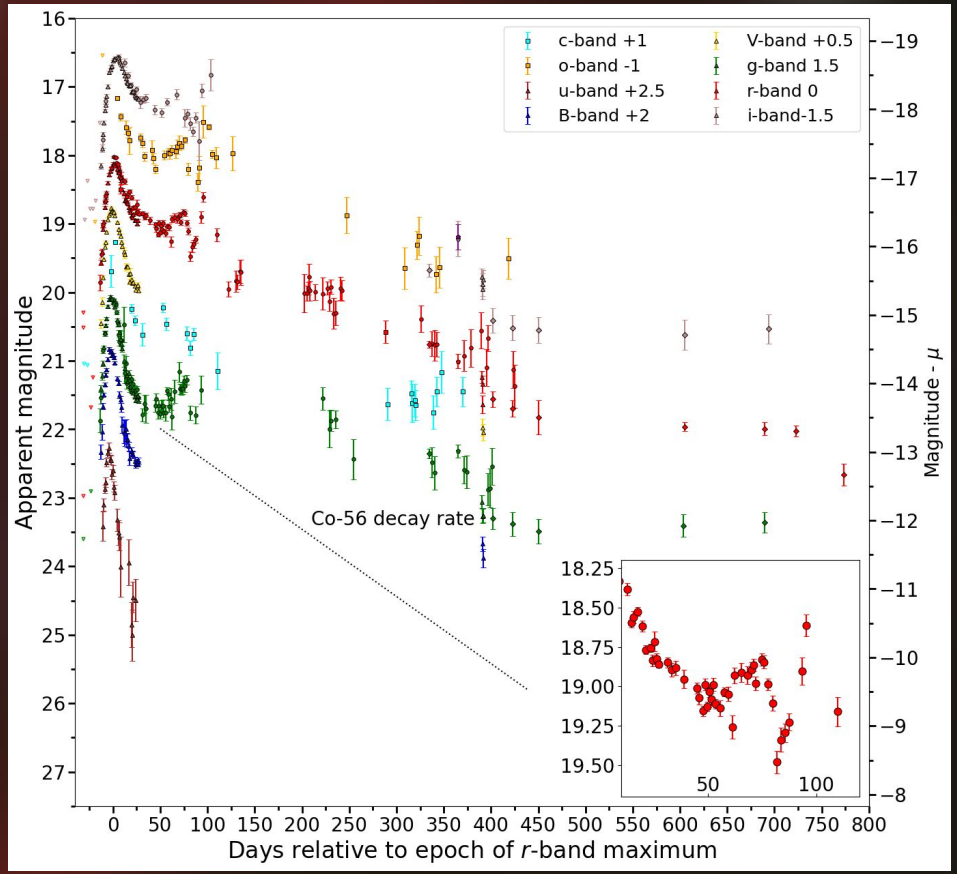
Peculiar SESNe

- Some SESNe have been observed with peculiar features most often in the LC
- These objects usually have some excess in their light curves
- The excess luminosity could be powered by many different mechanisms
  - Interaction with Circum Stellar Material (CSM)
  - Magnetar spin down radiation
  - Fall-back accretion to a black hole



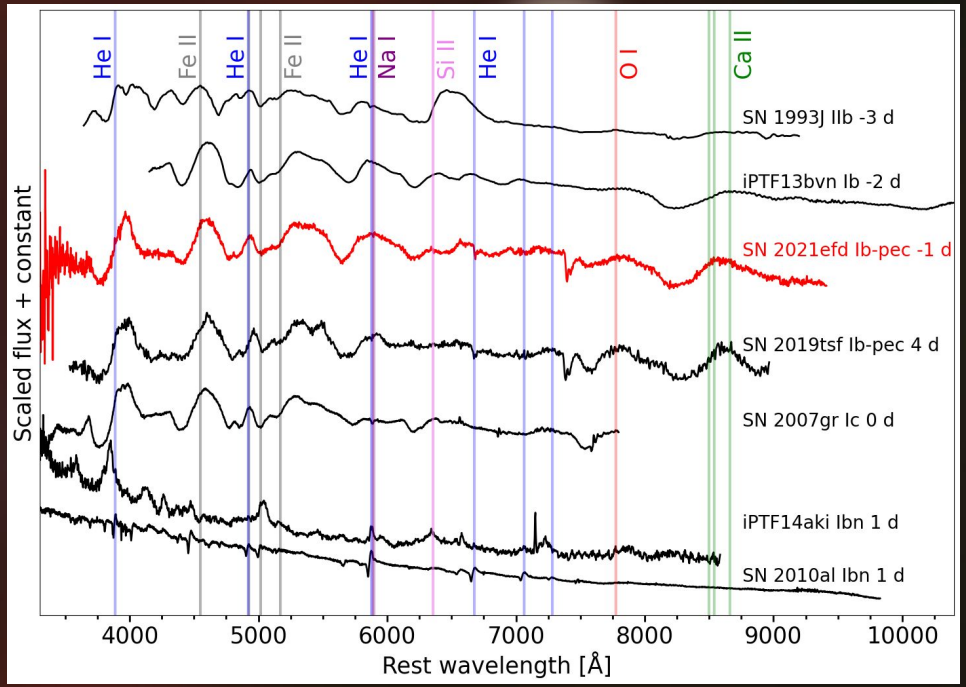
Light curve of SN 2021efd

- Normal evolution until ~30 days after the peak
- Interaction dominates the late time radiation
- SN 2021efd is much brighter at late phase than normal Type Ib SNe



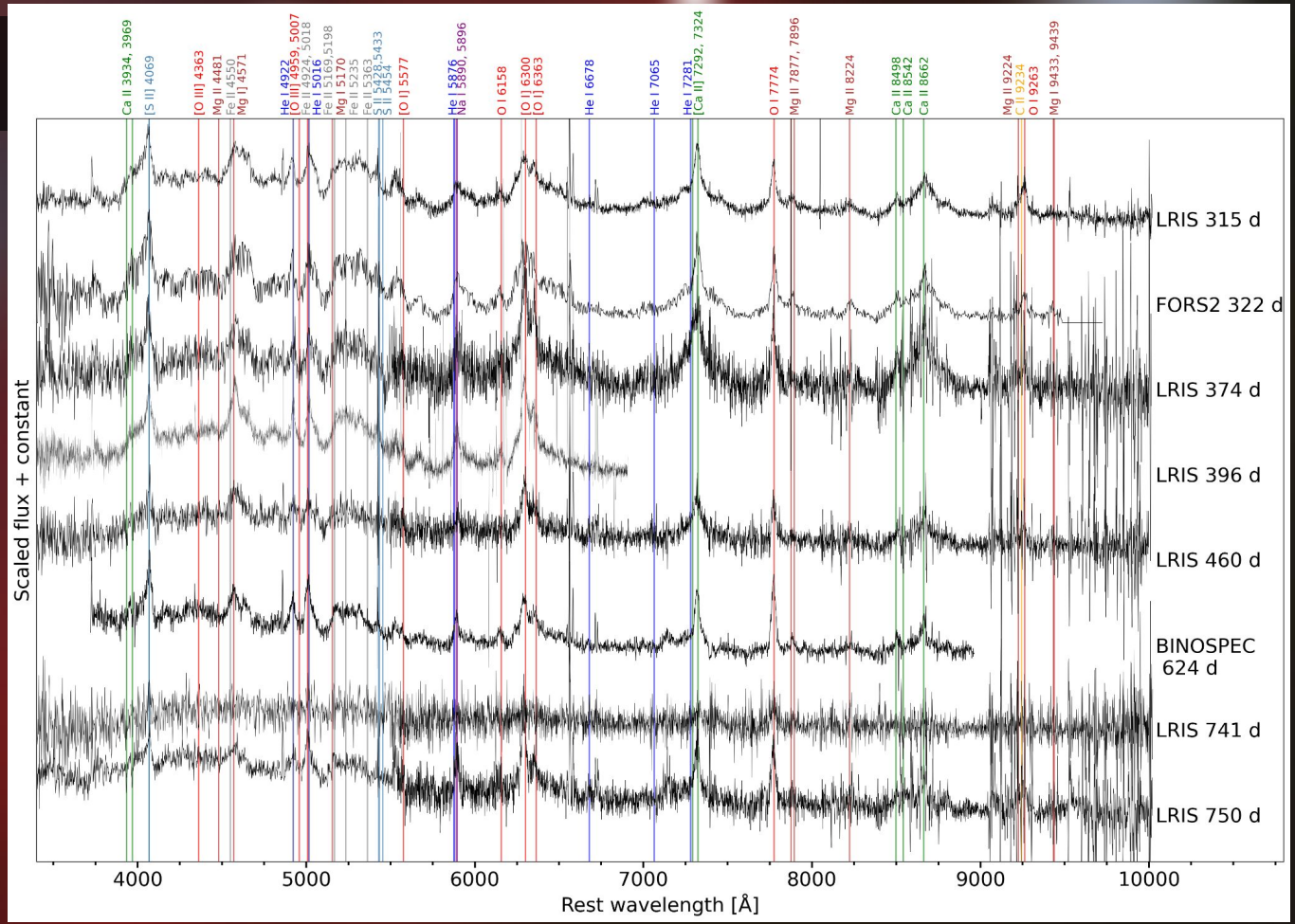
Other parameters

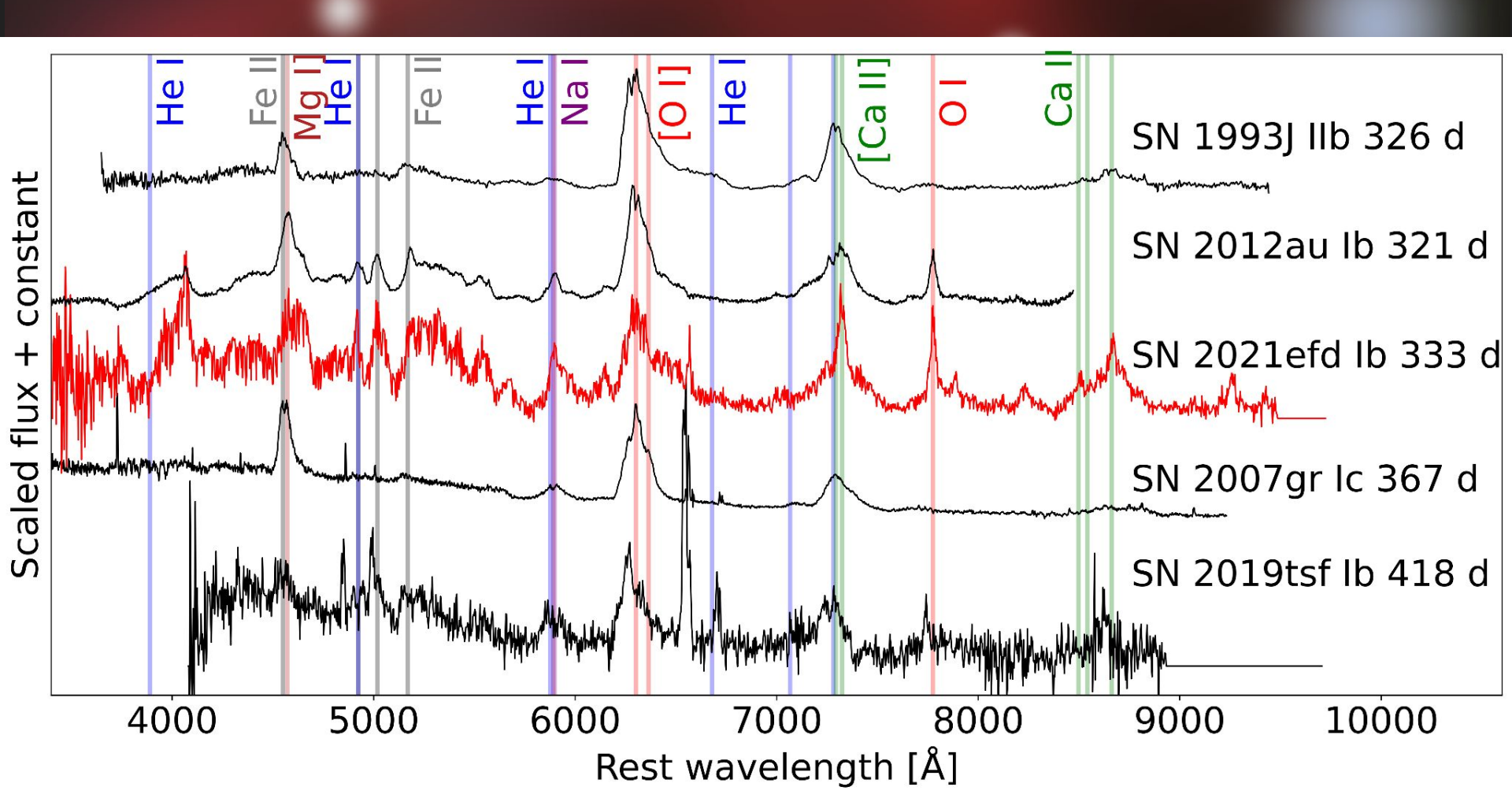
- Appears typical in early phase
- Spectra very similar to other Type Ib SNe
- Ejecta mass, explosion energy, ^{56}Nickel mass, and line velocities are all consistent with SESNe
- Likely SESNe progenitor population



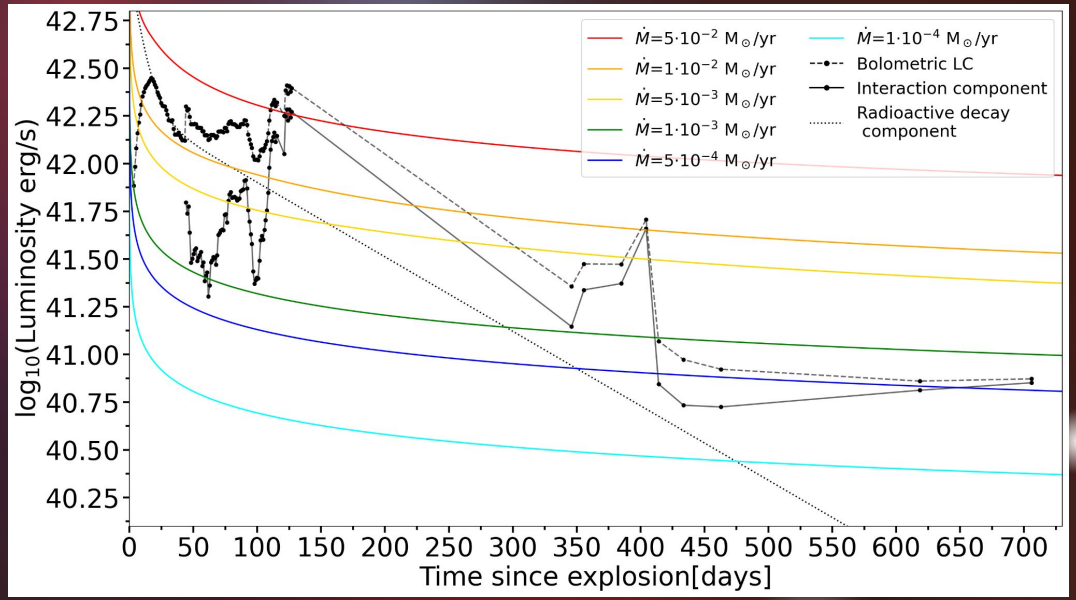
Nebular phase

- Narrow peaked lines
- No hydrogen
- “Blue excess”
- No apparent CSM lines




He I
Fe II
Mg I]
He I
Fe II
He I
Na I
[O I]
He I
[Ca II]
O I
Ca II
SN 1993J IIb 326 d
SN 2012au Ib 321 d
SN 2021efd Ib 333 d
SN 2007gr Ic 367 d
SN 2019tsf Ib 418 d
Scaled flux + constant
4000
5000
6000
7000
8000
9000
10000
Rest wavelength [Å]

Comparison to interaction model



- Order of magnitude estimate from semi-analytical calculation
- Mass loss rate ~10^{-2} - 10^{-3} M⊙/yr
- CSM mass at minimum several times 0.1 M⊙
- CSM speed is the biggest uncertainty,
  - We used 100 km/s as lower limit estimate

Interpretation

- Non-steady CSM distribution
- High mass-loss rate 10^{-3}-10^{-2} $M_{\odot}yr^{-1}$
- Forbidden and permitted ejecta lines have narrow peaks in late phase spectra
- CSM is H-poor and likely He-rich

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- CSM distribution?
  - Spherical
  - Multiple shell
  - Multiple ring

Interpretation

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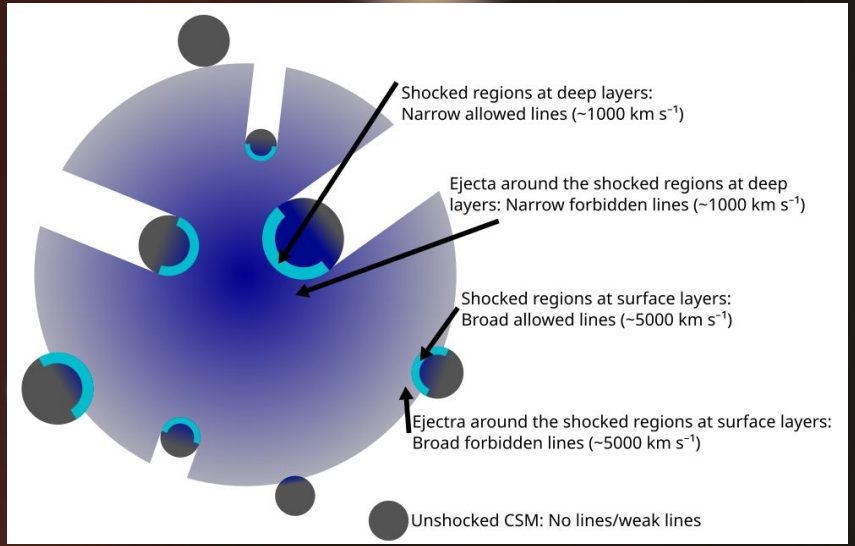
➢ We favor clumpy CSM distribution
➢ Suggesting multiple ejections of material from the progenitor

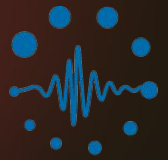


The future excessively bright

- At the era of the frequent allsky surveys (ZTF, ATLAS) we have started capturing more of these objects
- SN 2021efd was only noticed to be peculiar from the ZTF and ATLAS all-sky surveys after initial follow-up ended

大视场巡天望远镜

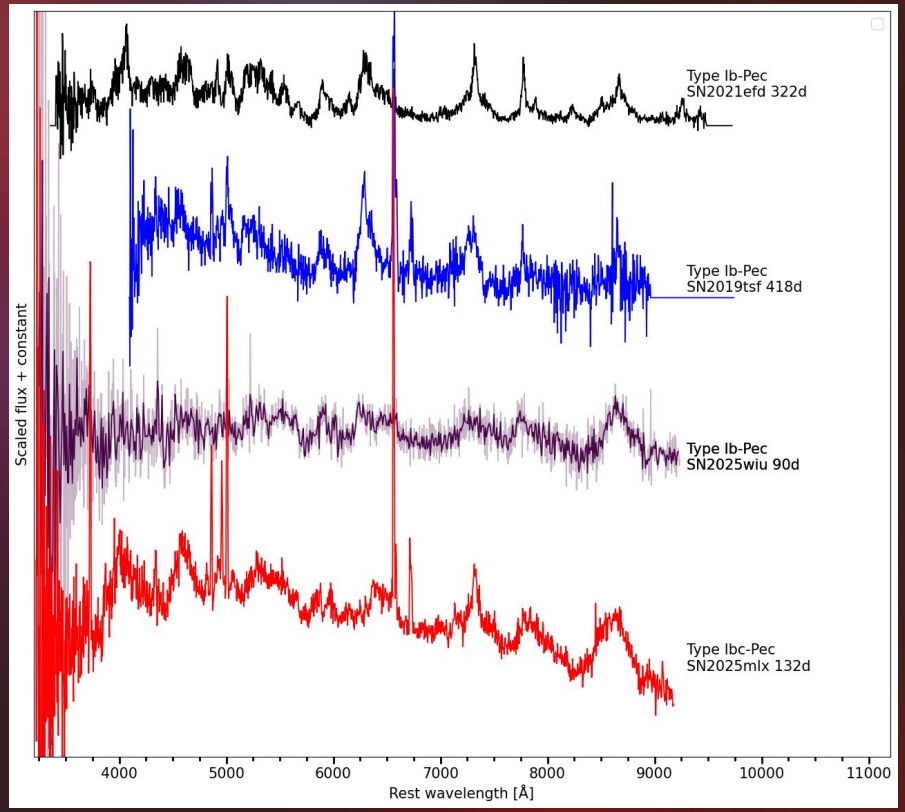
Wide Field Survey Telescope

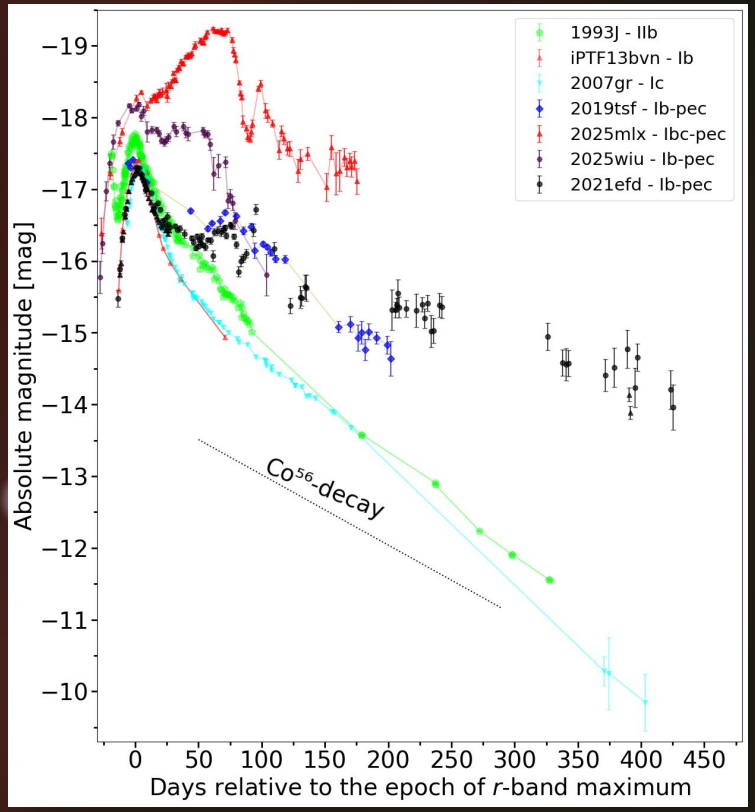


GOTO

GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

The future excessively bright





The Legacy Survey of Space and Time (LSST)

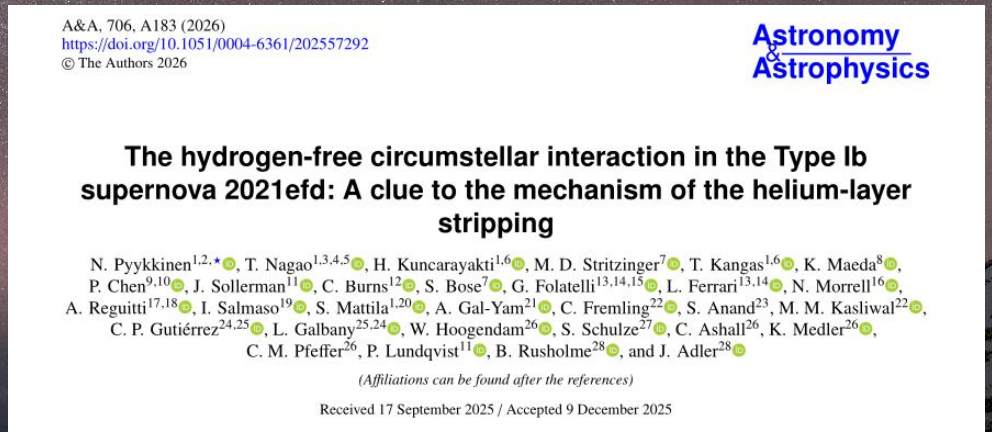
- LSST will be completed on the Vera C. Rubin observatory
- Scan the whole sky every three days in u,g,r,i,z and y filters
- Perform a deeper scans of specific areas
- Operations have started on the deeper scans

Thank you!

Questions?

Article on SN 2021efd has been published in A&A,

Pyykkinen, N., Nagao, T., Kuncarayakti, H., Stritzinger M. et al. 2026



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Astronomy & Astrophysics

The hydrogen-free circumstellar interaction in the Type Ib supernova 2021efd: A clue to the mechanism of the helium-layer stripping

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Picture: Urs Leutenegger

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Secret extra slide!