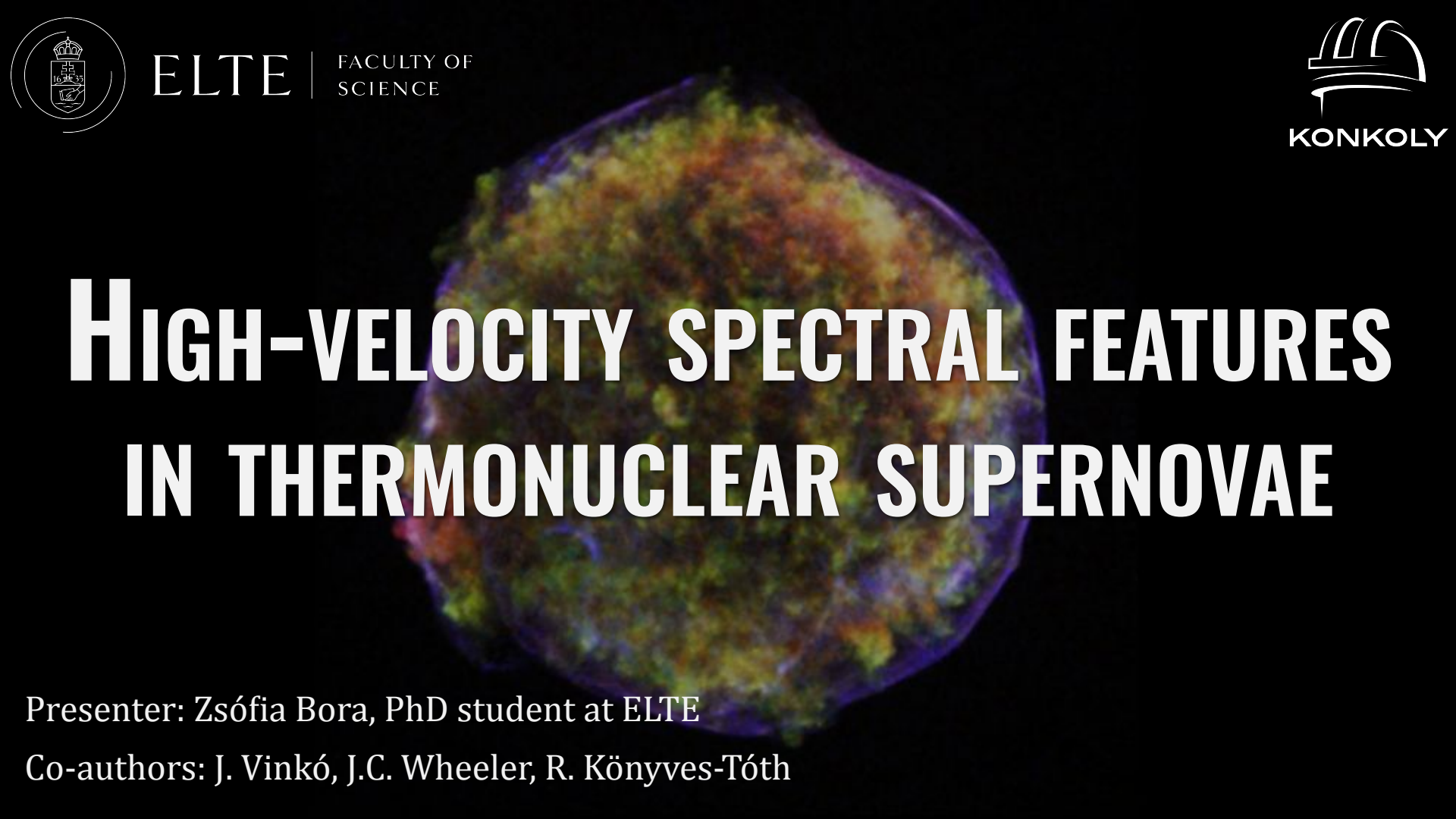


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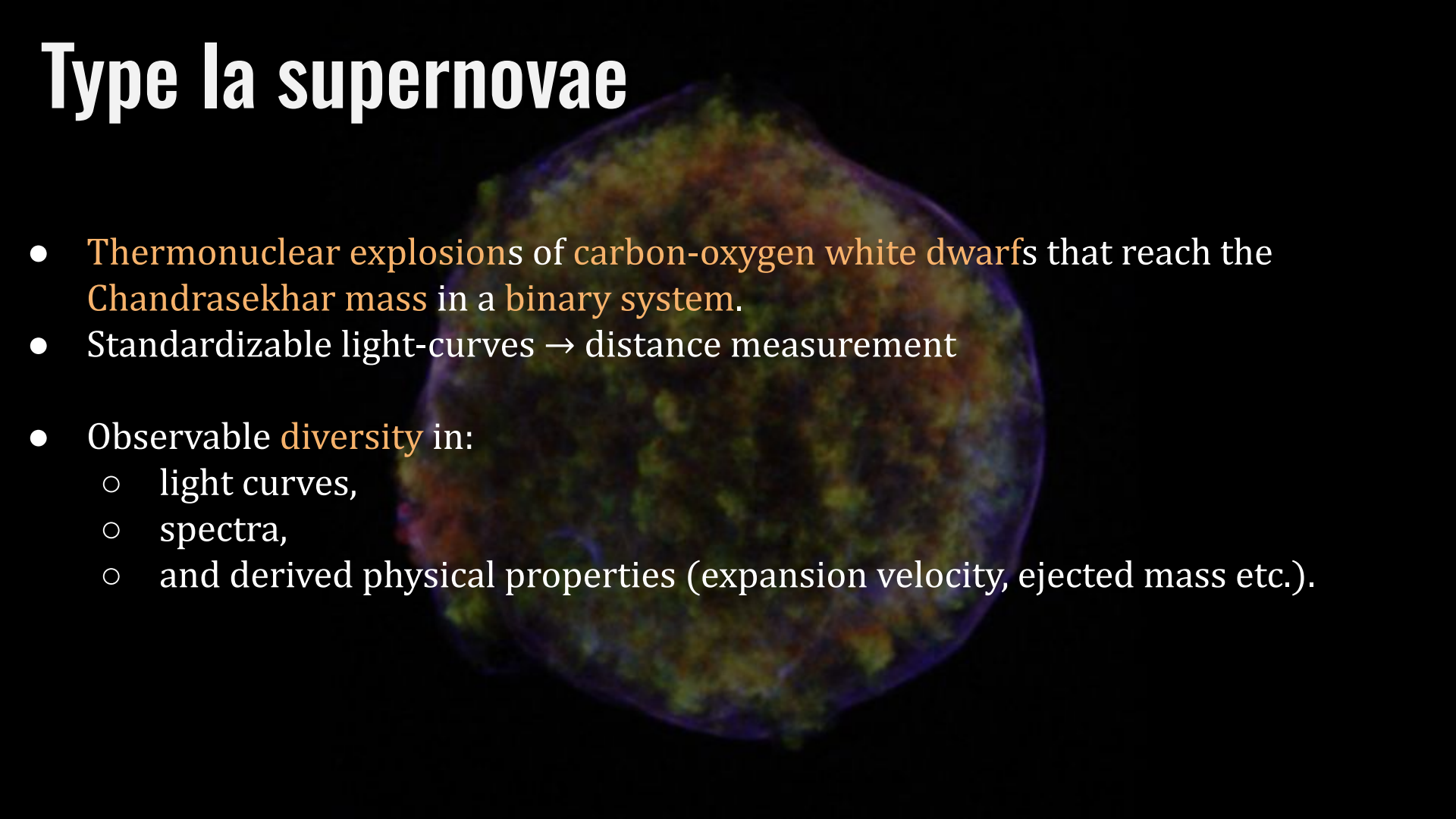
KONKOLY

HIGH-VELOCITY SPECTRAL FEATURES IN THERMONUCLEAR SUPERNOVAE

Presenter: Zsófia Bora, PhD student at ELTE

Co-authors: J. Vinkó, J.C. Wheeler, R. Könyves-Tóth

Type Ia supernovae



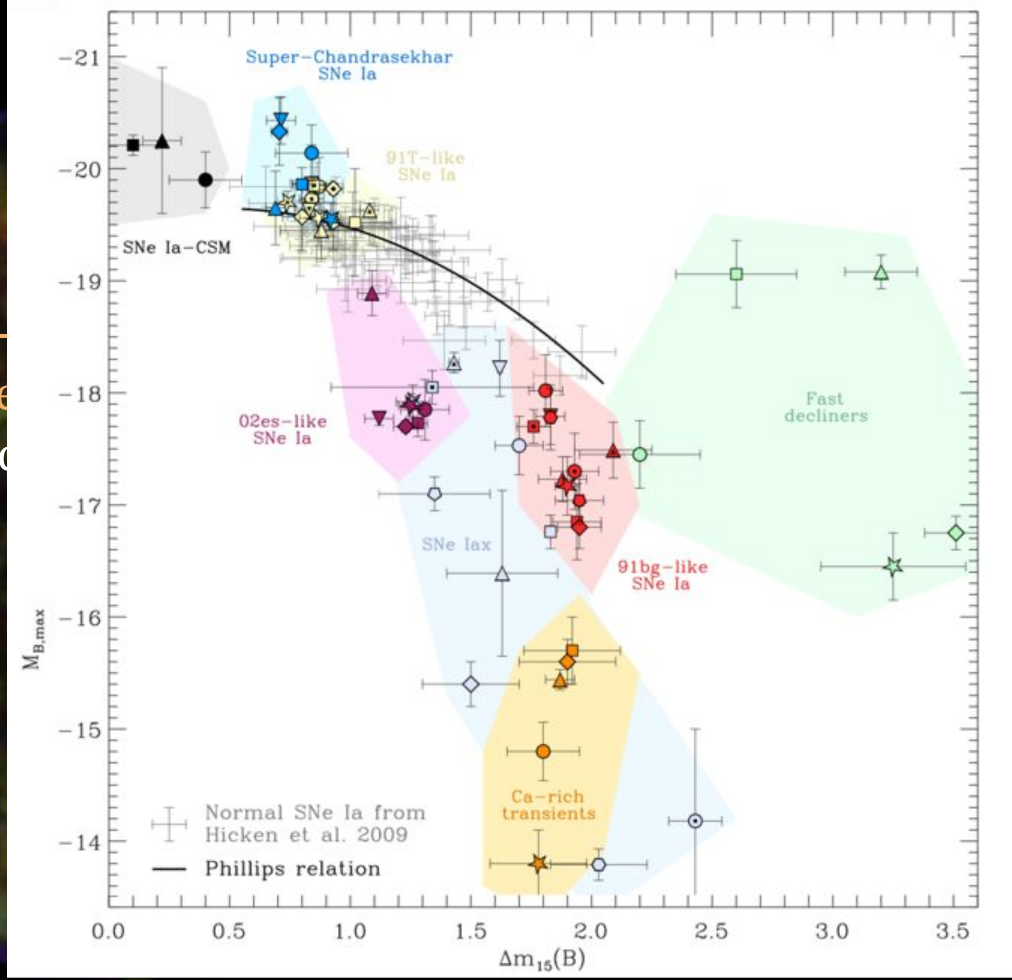
- Thermonuclear explosions of carbon-oxygen white dwarfs that reach the Chandrasekhar mass in a binary system.
- Standardizable light-curves → distance measurement

- Observable diversity in:
  - light curves,
  - spectra,
  - and derived physical properties (expansion velocity, ejected mass etc.).

Type Ia supernovae

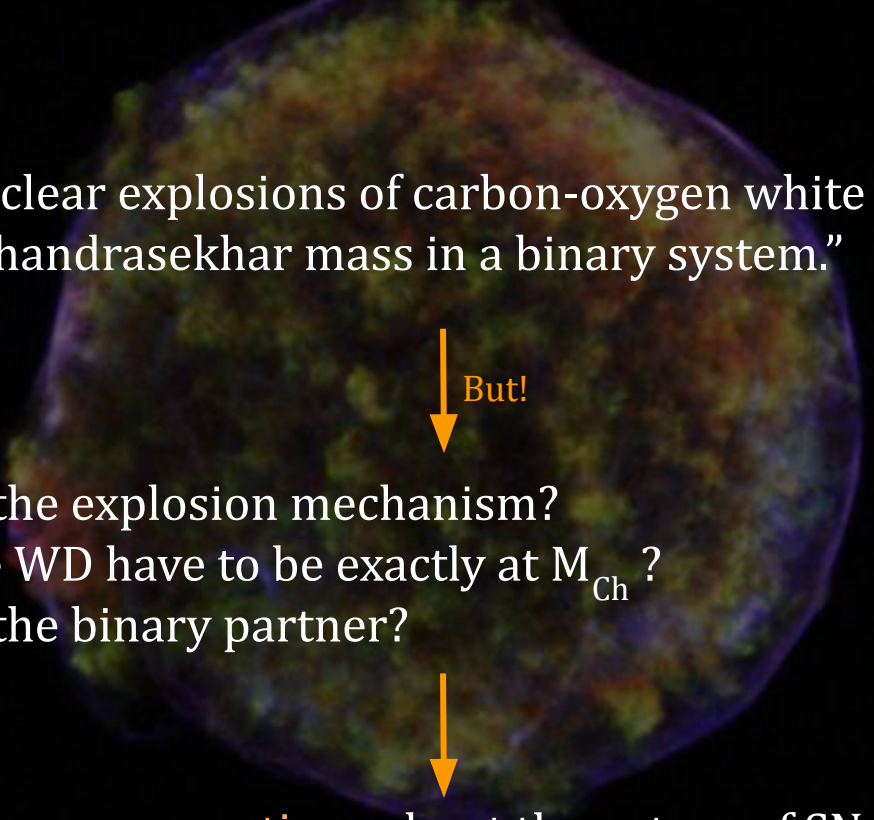
- Thermonuclear explosions of carbon-
  Chandrasekhar mass in a binary syste
- Standardizable light-curves → distanc

- Observable diversity in:
  - light curves,
  - spectra,
  - and derived physical properties.
- Many subclasses within SNe Ia



Taubenberger et al. (2017)

Type Ia supernovae



"Thermonuclear explosions of carbon-oxygen white dwarfs that reach the Chandrasekhar mass in a binary system."

- What is the explosion mechanism?
- Does the WD have to be exactly at M_{Ch} ?
- What is the binary partner?

Still many open questions about the nature of SNe Ia!

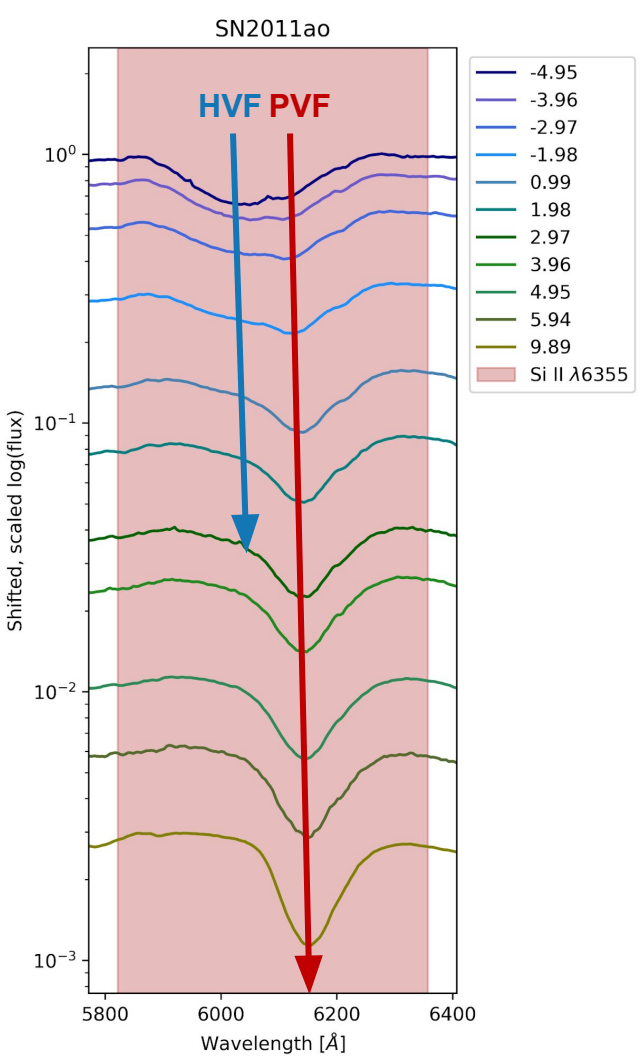
High-velocity features (HVFs)

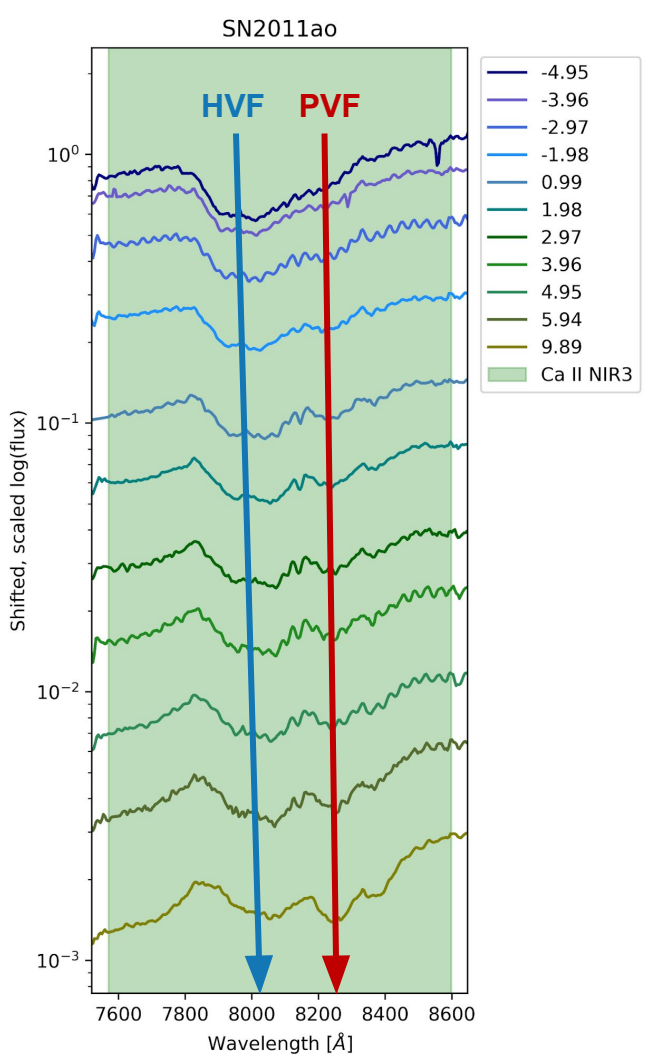
- After explosion: photosphere expands with 10-15000 km/s
- But early on, we can also see high-velocity (25-30000 km/s) components next to photospheric ones (PVFs) of the same line.
  - mostly in Ca II and Si II

- Basic characteristics:
  - HVF is strong (deep) and fast in the beginning, later weakens
  - Eventually only photospheric lines are visible in the spectrum

- Differences in velocity, strength and duration from event to event.
- What is their origin?

Si II λ6355





Ca II NIR triplet

My work

- Data: 60+ SNe Ia with ~200 spectra observed over 15+ years
  - Hobby-Eberly Telescope, McDonald Observatory
  - + publicly available additional spectra
  - + light-curves observed by the Piszkéstető RC80 telescope

- Goals:
  - Modeling the spectra → HVF line velocities and properties
  - Are HVF characteristics connected to other properties of the SN? (color, nickel mass or light-curve shape)
  - Is there an explosion mechanism or progenitor system which can explain their presence?

My work

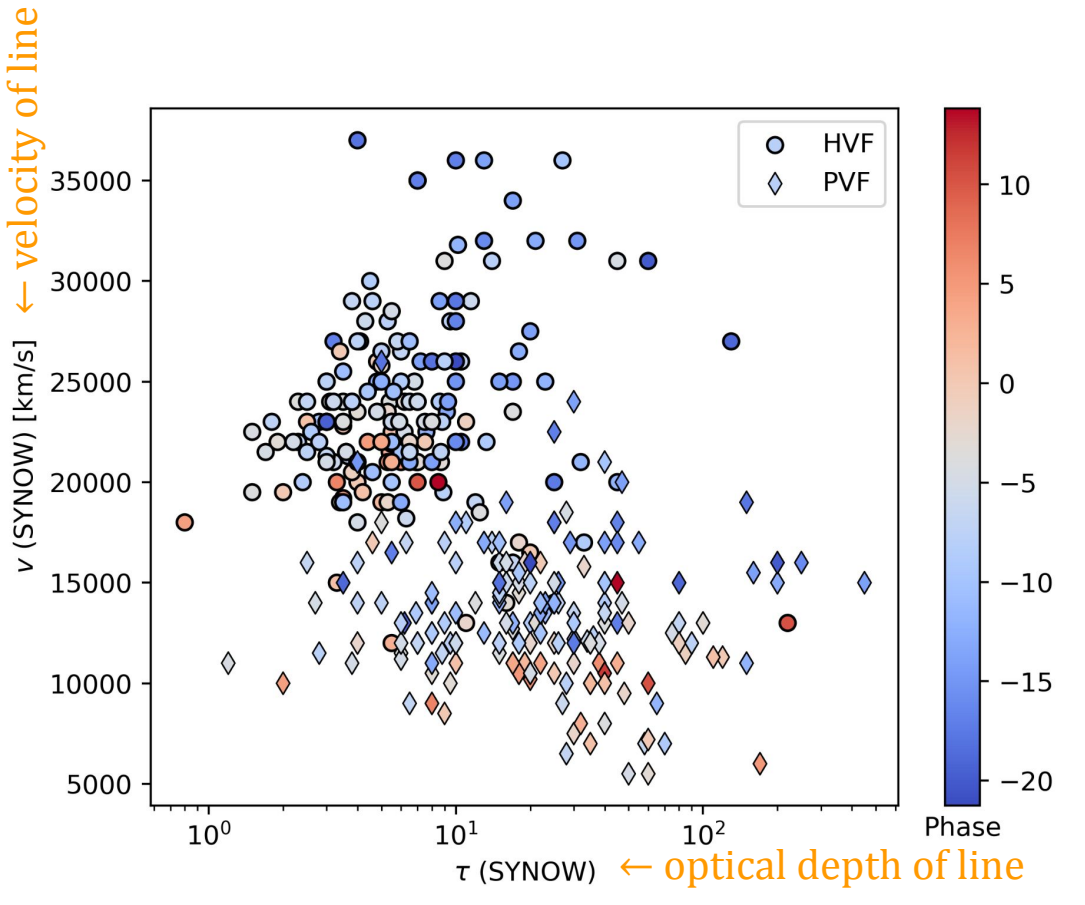
- Built spectral models (τ, v_{HVF}) in SYNOW for all spectra

High-velocity region

- Modeled line velocities and optical depths for Ca II NIR3:

Photospheric region

- HVFs are clearly separated from photospheric region

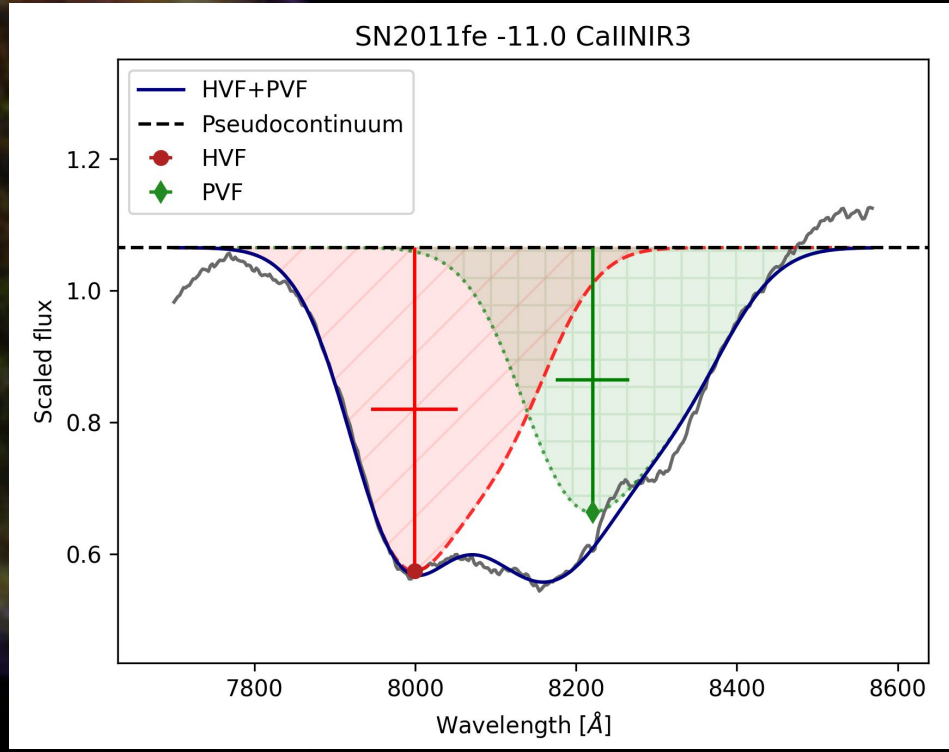


My work

- Also fitted all Si II and Ca II lines with multiple Gaussians
  - determined blueshift and pEWs of the PVFs and HVFs
  - Strength of HVF is defined as:

$$R_{\mathrm{HVF}} = \frac{\mathrm{pEW(HVF)}}{\mathrm{pEW(PVF)}}.$$

example of a line fitting →



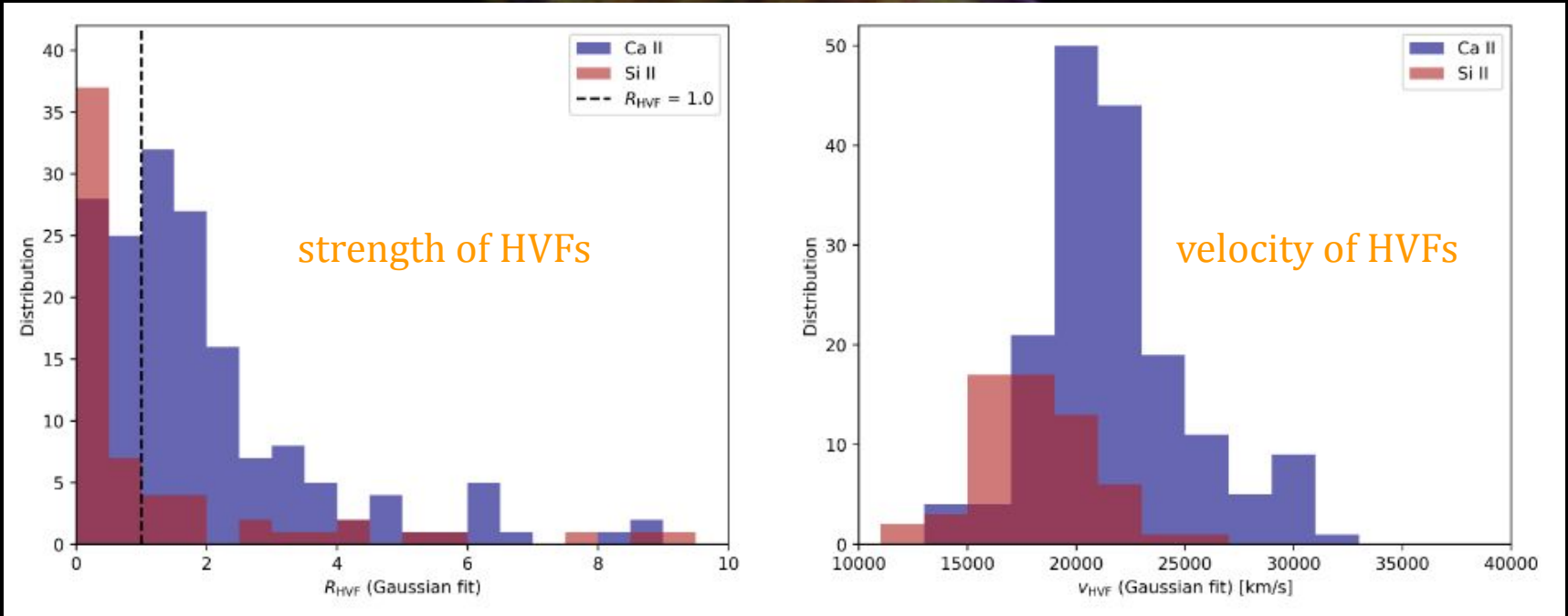
Results

- So we have determined the strength and velocity evolution of these high-velocity spectral features by multiple methods.

- Let's check:
  1. Is there a difference between the Si II and Ca II HVFs?
  2. Do these spectral characteristics show a connection with other parameters of the supernova?
     - One such parameter: the SALT x_1 fitting parameter
       - it describes the light-curve shape
       - Large SALT x_1 = bright, slow-evolving SN Ia

Results

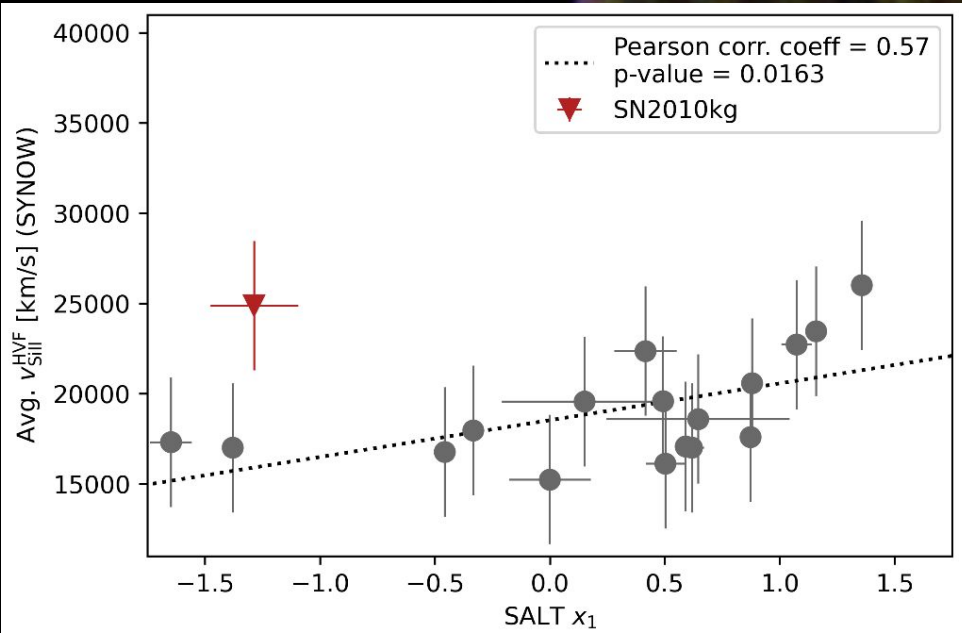
- Si II HVFs are rarer, weaker and slower than Ca II HVFs.

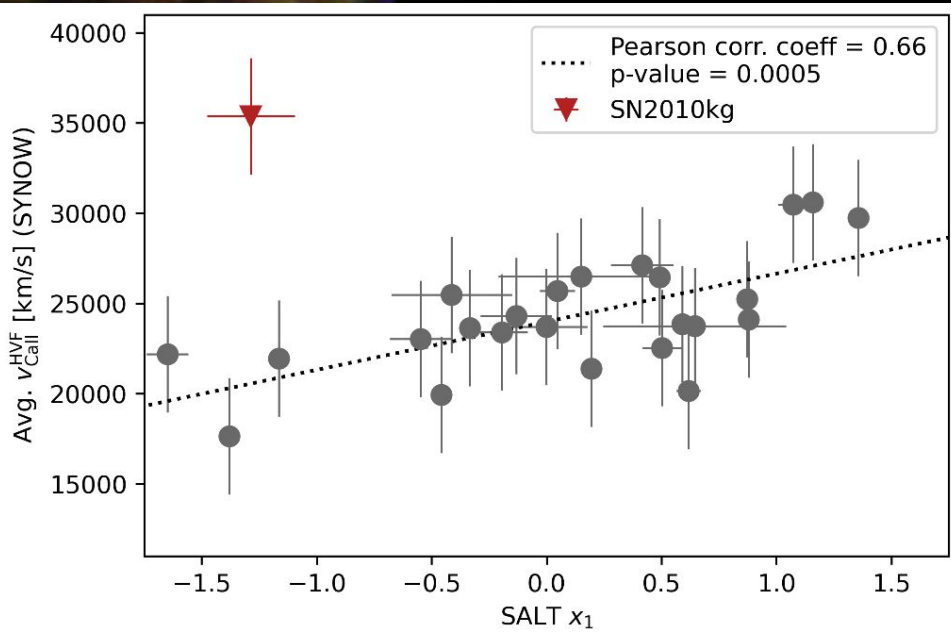


- Most likely because of different excitation energies.

Results

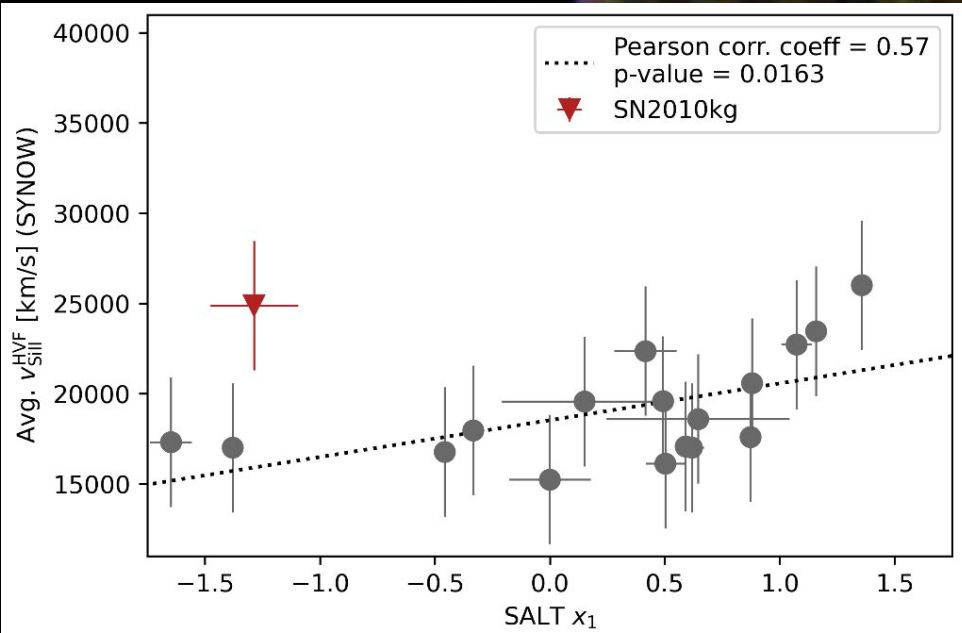
- Average Si II and Ca II HVF velocity correlates with the SALT x_1 parameter

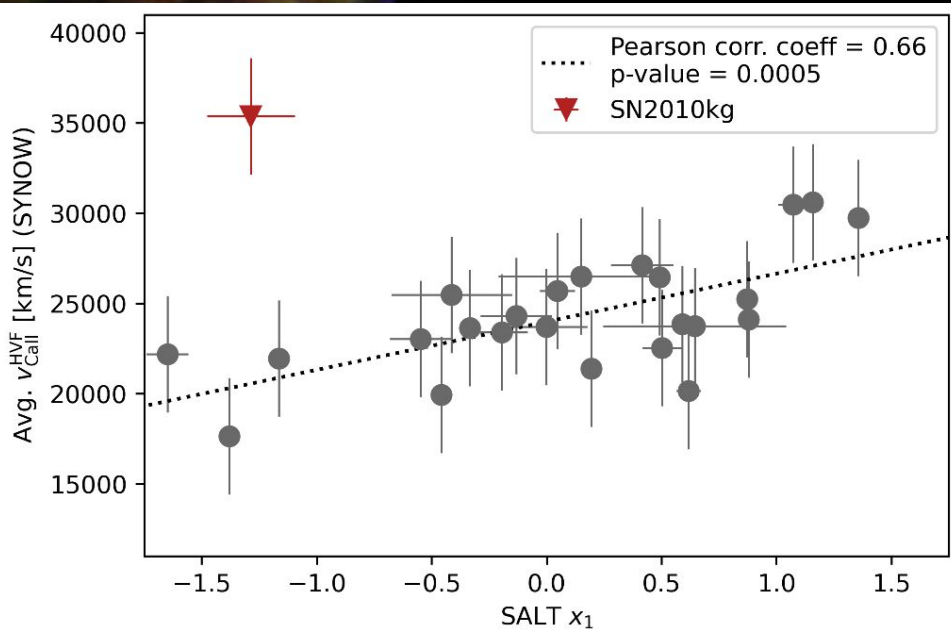




Results

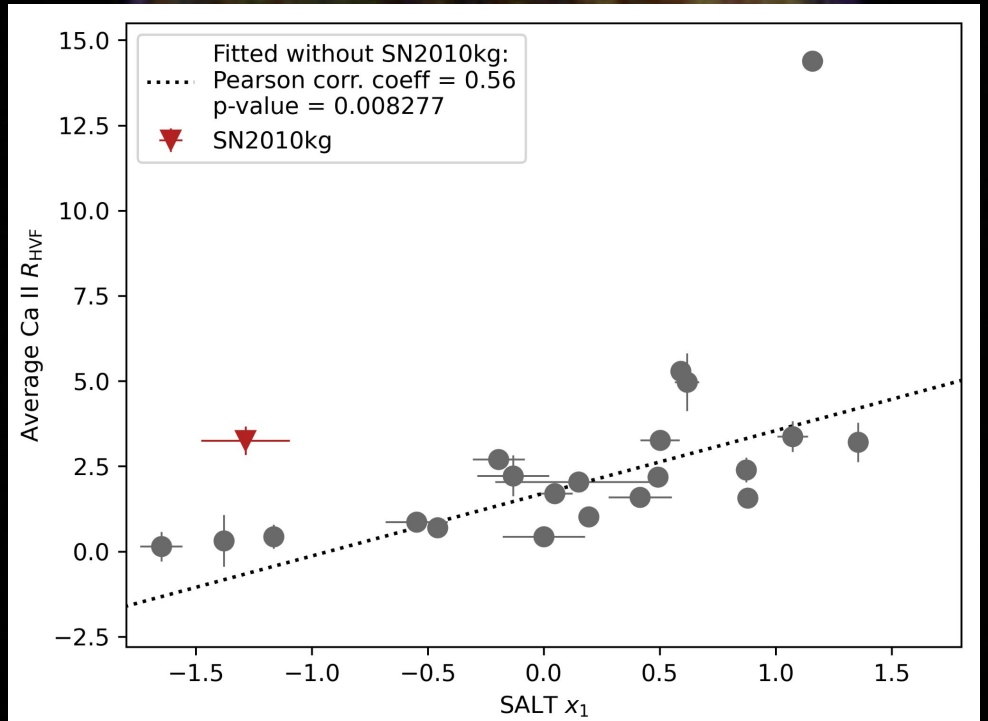
Brighter supernova ↔ higher-velocity HVF





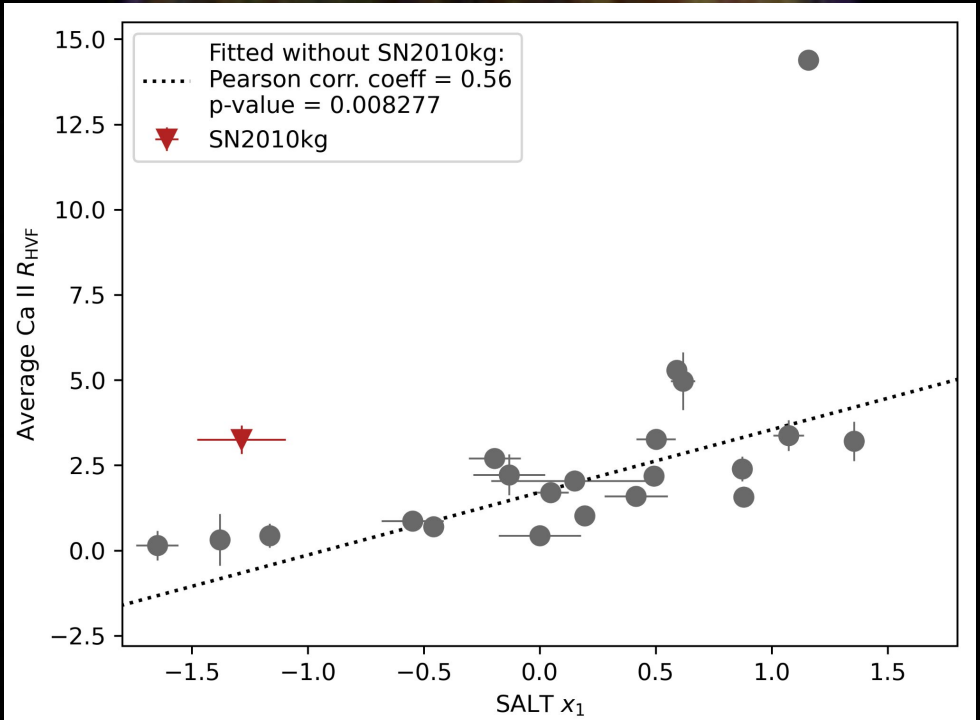
Results

- Average Ca II HVF strength correlates with the SALT x_1 parameter



Results

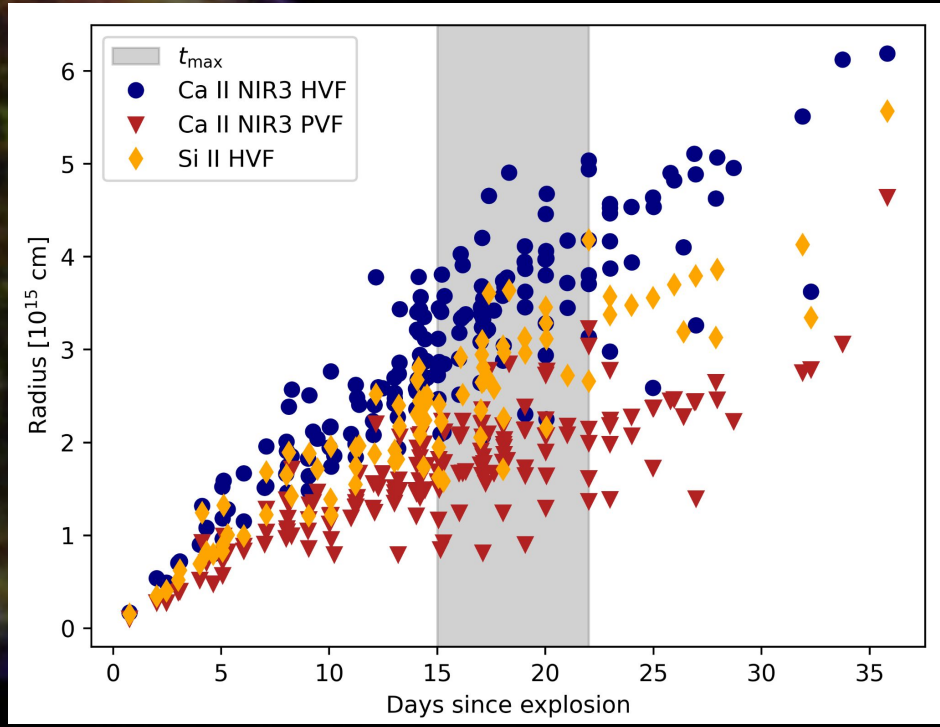
Brighter supernova ↔ stronger Ca II HVF



Results

- What distances do these high-velocity line regions travel (assuming homologous expansion)?

- They travel to $\sim 3 \cdot 10^{15}$ cm from the progenitor by time of maximum light:
  - too far for binary partner,
  - too close for ISM to be causing the HVFs.



Conclusions

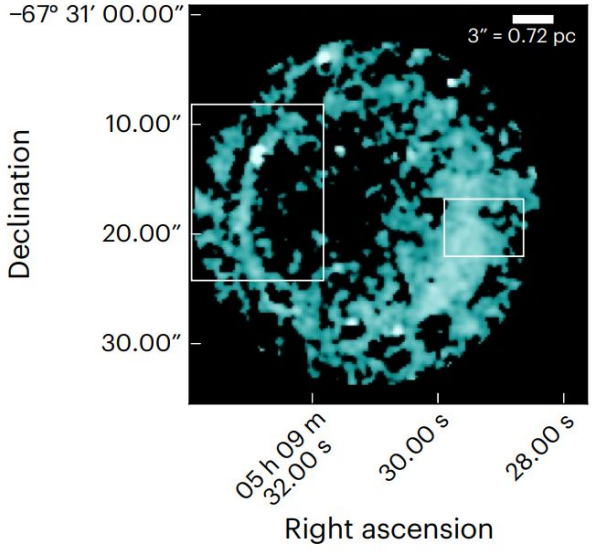
- Probably not caused by interaction with binary partner, or ISM.
- Connected to the parameter that characterizes peak brightness (x_1)
  - diversity in light-curves is connected to diversity in HVF parameters
- HVFs seem to form in a physically distinct region

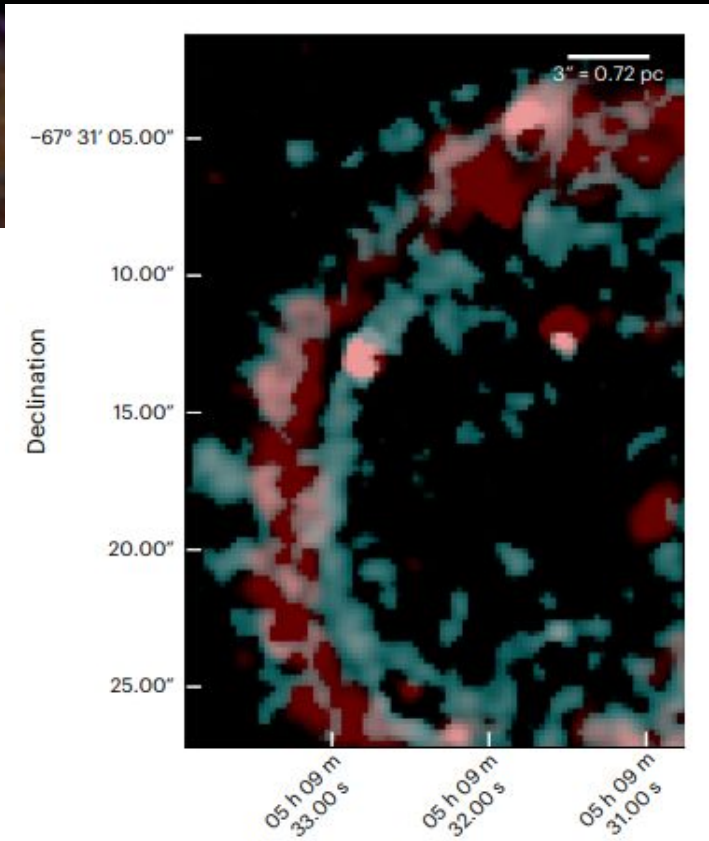


- Are they caused by the explosion mechanism that creates high-velocity material?
  1. Asymmetrical explosion of a Chandrasekhar mass WD ("delayed detonation model")
  2. He-shell on top of a sub-Chandrasekhar mass WD detonates it ("double detonation model")

Conclusions

- What would such high-velocity material resulting from the explosion look like in reality?





Double Ca shell in SNR 0509 (Das et al., 2025)

Summary

- Data: Over 200 spectra of 60+ SNe Ia showing HVFs
- Methods: Spectral modeling (SYNOW) + Gaussian fitting of spectral lines
- Findings:
  - Brighter SNe have stronger and faster HVFs
  - The formation of HVFs is probably connected to the creation of high-velocity material in the explosion
  - Studying HVFs leads back to the basic question of what is the explosion mechanism and progenitor system of type Ia supernovae

- Read more: https://arxiv.org/abs/2609.37719 (accepted for publication in ApJ)

I am happy to answer any questions!

or email me at: bora.zsofia@csfk.org