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High Velocity Features in Type Ia Supernovae -- A puzzle still waiting to be solved after 26 years

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Abstract
We used 181 optical spectra of 56 Type Ia supernovae (SNe Ia) that show high-velocity features (HVFs) in the Ca II NIR triplet (Ca II NIR3) to better understand the nature of high-velocity features. To model the profiles of HVFs we applied gaussian fitting as well as spectrum synthesis modeling with the SYNOW code. In accord with many previous studies, the observed properties of HVFs (velocity, strength, duration) were found to correlate with the general observables of SNe Ia (decline rate, spectral subtype): brighter, slow-declining SNe usually exhibit stronger and faster HVFs.

Introduction

- Type Ia supernovae (SNe Ia): thermonuclear explosions of carbon-oxygen white dwarfs (CO WDs)
- High-velocity features (HVFs):
  - First discovered by Hatano et al. (1999)
  - $v \approx 20-30\,000$ km/s lines of most often Ca II and Si II, appearing in early-time spectra next to their photospheric features (PVFs, $v \approx 9-20\,000$ km/s)
  - Strong and fast in early phases, usually **fade by the time of maximum**.

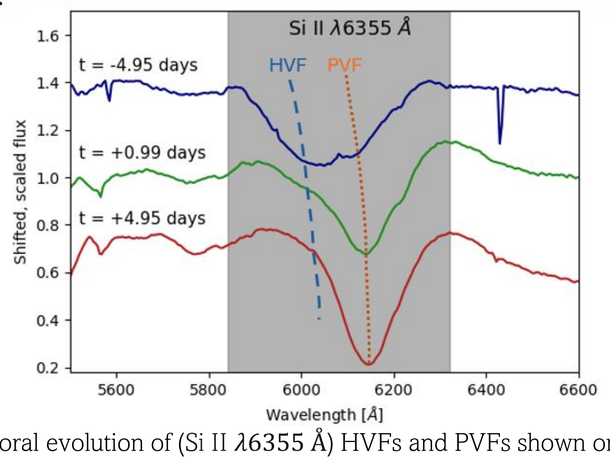

Fig 1: Temporal evolution of (Si II $\lambda 6355$ Å) HVFs and PVFs shown on 3 spectra of SN2010ao.

Data

- collected over **15 years**
- early phase optical spectra from the **Hobby-Eberly Telescope** (HET) at McDonald Observatory: 124
- additional **public spectra** (TNS and literature): 57
- photometric observations at **Piszkéstető Observatory**, Hungary → for time of maximum estimations for 9 SNe

Methods

1. **Gaussian fitting** of lines
   - Doppler-velocity of line center
   - pEW of HVF and PVF lines → **strength of HVF** is defined as $R_{HVF} = \frac{pEW(HVF)}{pEW(PVF)}$
2. **SYNOW spectral modeling** of spectra
   - **velocity (v)** and **line optical depth (τ)** of HVFs and the photospheric lines

- Comparing velocities from gaussian fitting and spectral modeling → **gaussian fitting underestimates** the true velocity of spectral lines.

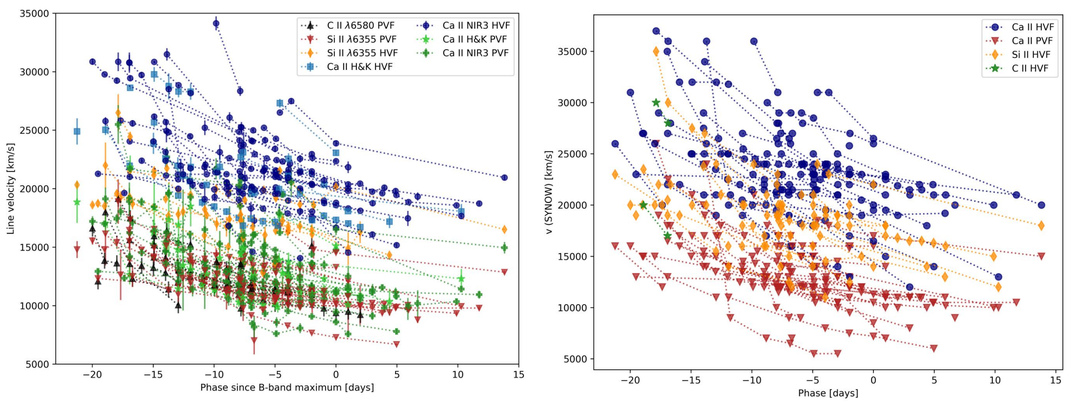

Fig 2,3: Temporal evolution of line velocities from Gaussian fitting (left) and SYNOW modeling (right). Different lines are shown with different markers and colors.

Results

- **Velocity and strength of the HVFs correlate** with the light-curve stretch (**SALT x_1**)
- The brighter the SN → the higher velocity and stronger the HVF is

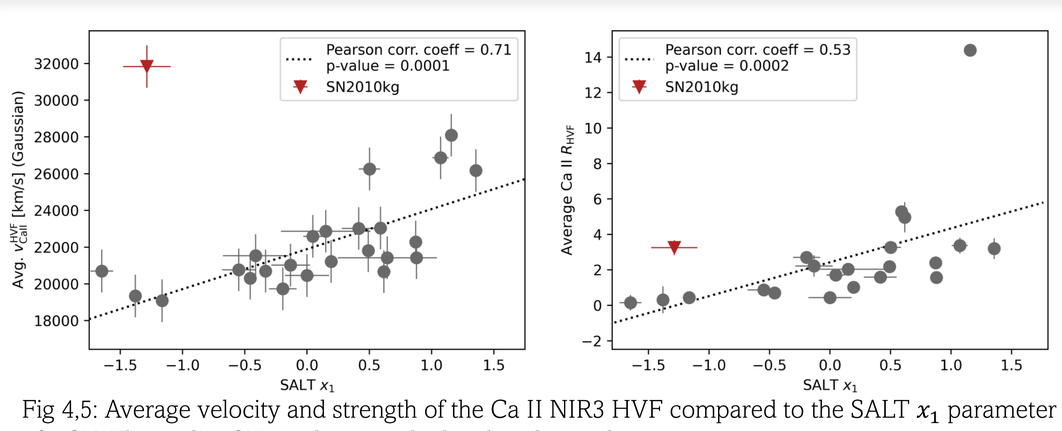

Fig 4,5: Average velocity and strength of the Ca II NIR3 HVF compared to the SALT x_1 parameter of a SN. The outlier SN2010kg is marked with red triangles.

- Strength of the Ca II NIR3 HVF seems to decrease with increasing Si II $\lambda 6355$ Å photospheric velocity at maximum brightness ($v_{Si\,II}^{tmax}$)
- Wang et al. (2009) HV subtypes rarely display HVFs

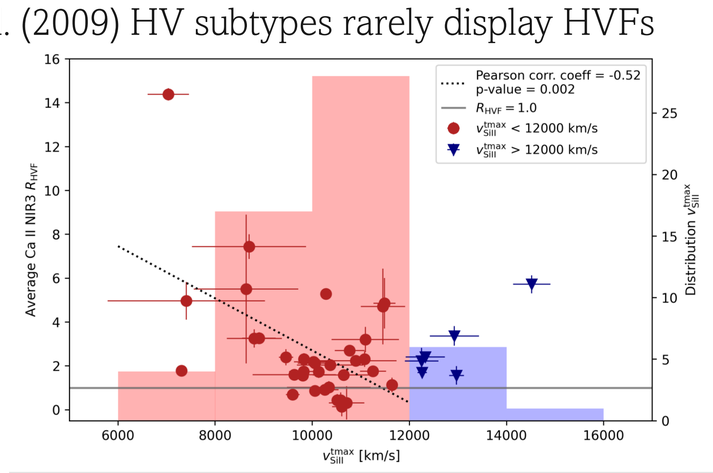

Fig 6: Average strength of the Ca II NIR3 HVF against the photospheric velocity. Wang NV events are marked with red, HVs with blue. Histograms in the background show the distribution of each subtype.

- Si II HVFs are rare, fade quickly, and are **generally lower velocity and weaker** than HVFs of Ca II
- Our sample **mostly exploded in late-type galaxies** (32/56), and those in early-types hosts (5) tend to have lower $v_{Ca\,II}^{HVF}$ and R_{HVF}.

Conclusions

- The characteristics of HVFs **(velocity, strength) correlate with the other observables** of SNe Ia.
- The creation of HVFs is **most likely connected to the explosion mechanism** (a double detonation or asymmetric delayed detonation).
- The wider environment (host galaxy) of an SN could have some influence over the HVFs.
- **More detailed modeling is needed** of the formation of HVFs through different effects to compare observations to.

References:
Hatano, K., Branch, D., Fisher, A., et al. 1999, ApJ, 525, 2,881. doi:10.1086/307947
Wang, X., Filippenko, A. V., Ganeshalingam, M., et al.n2009, ApJl, 699, L139.doi:10.1088/0004-637X/699/2/L139

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