ZTF Spectroscopic Sample of Superluminous Supernovae with narrow Balmer lines

Stockholm University

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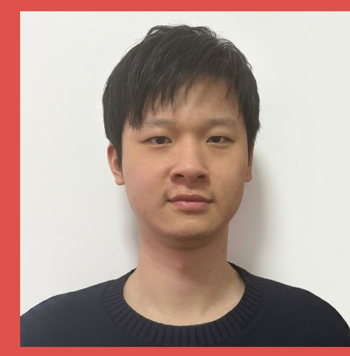
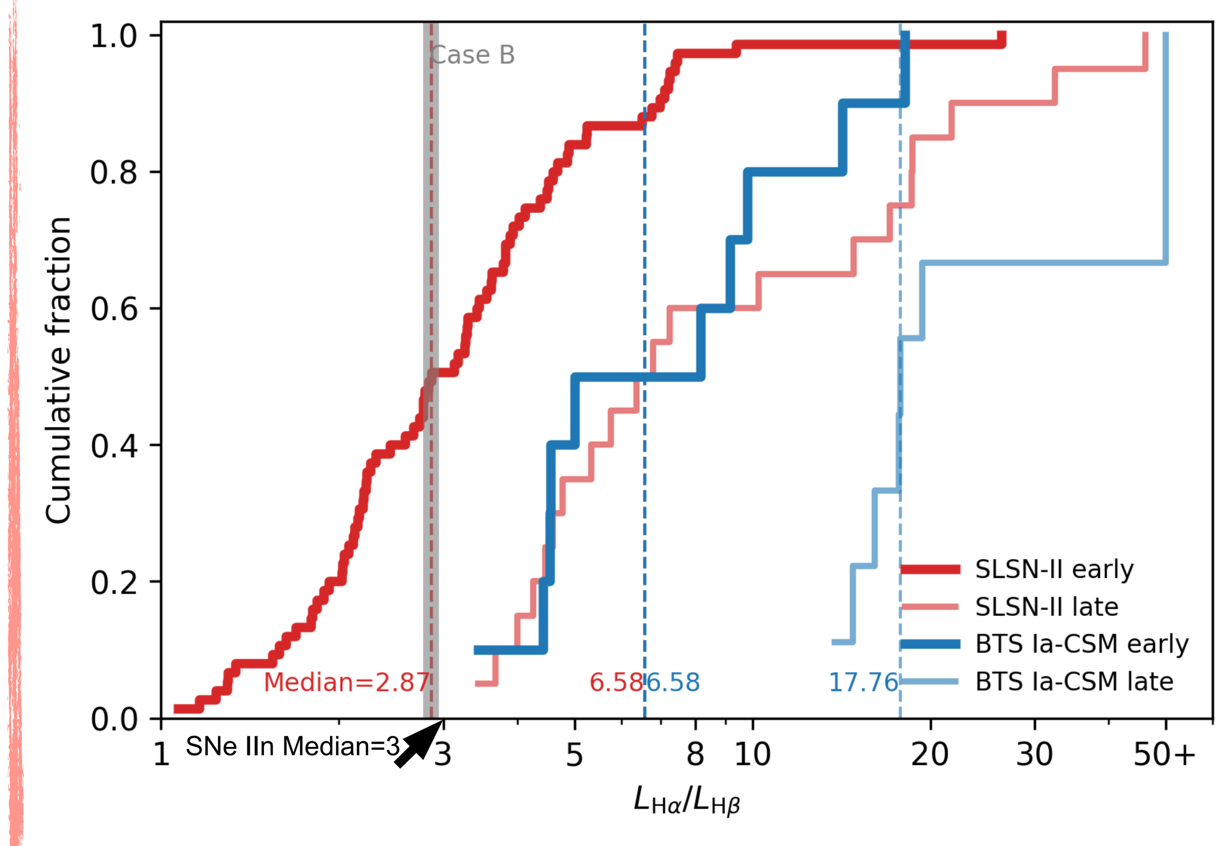


Key Takeaways

- **The largest spectroscopic sample of SLSNe-IIn:** 106 events, 314 spectra
- **Balmer decrements:** similar to normal SNe IIn in the early phase, but consistently lower than SNe Ia-CSM
- **Subgroups:** brighter events show symmetric Balmer lines; fainter ones show asymmetric Balmer lines
- **Model:** asymmetry implies higher $V_{\rm shock}$
- **Implication I:** many SLSNe-IIn may have similar $E_{\rm total}$ but differ in the partition between KE and radiation
- **Implication II:** this partition reflects different CSM properties => diverse mass-loss histories and progenitors

Sample Comparison

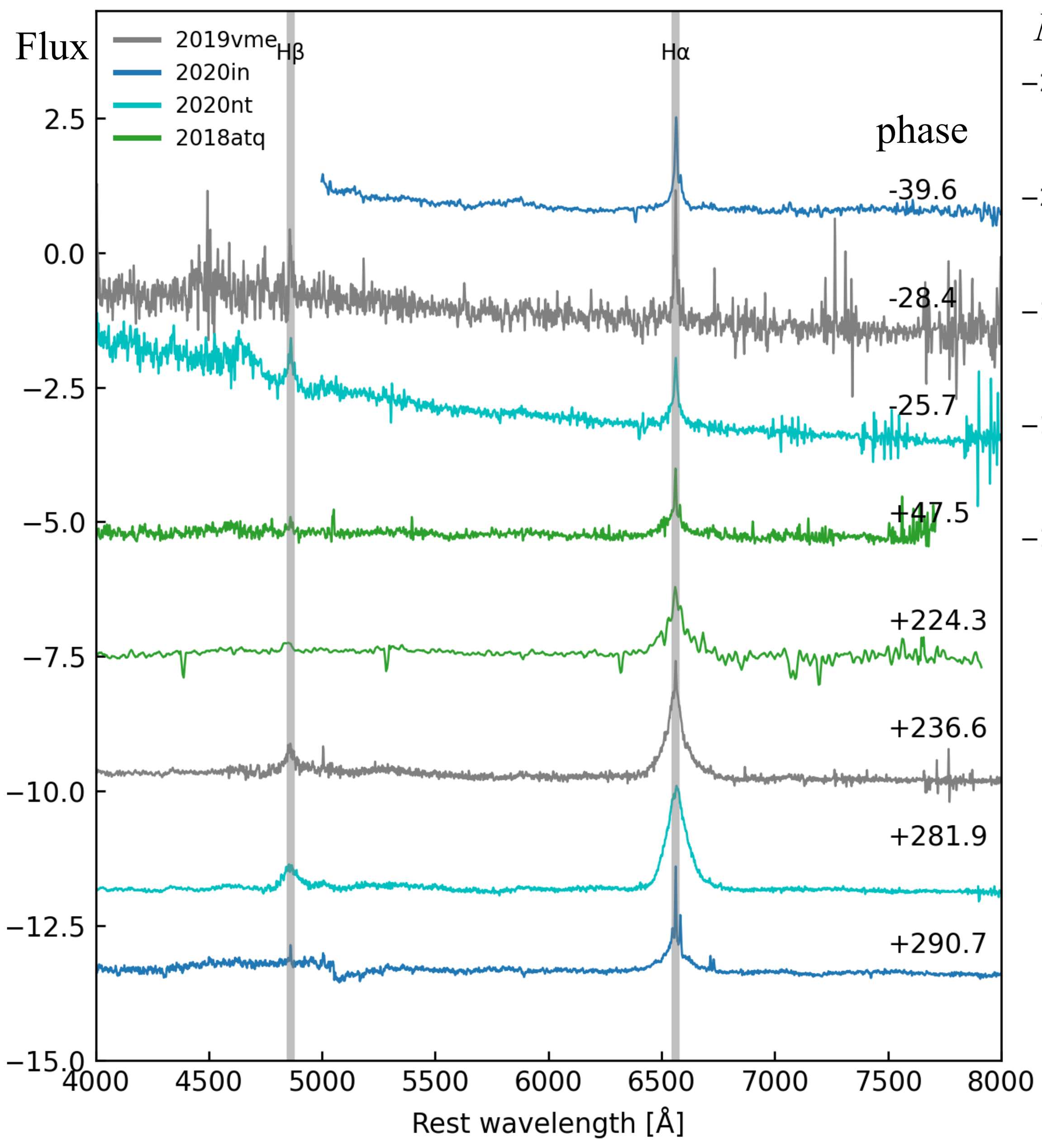
- **H-rich Superluminous Supernovae (SLSNe-II)** are extreme and mysterious stellar explosions, with peak absolute magnitudes brighter than −20 mag. About 90% of them show narrow Balmer lines and are further classified as **SLSNe-IIn**.
- Their luminosity is largely powered by **interaction between the SN ejecta and dense circumstellar medium (CSM)**. To probe the interaction conditions, we compare their Balmer decrement (Hα/Hβ flux ratio) with other interacting SNe.
- SLSNe-IIn in our sample show consistently lower Balmer decrements than SNe Ia-CSM in the BTS sample[1], but are similar to normal SNe IIn in the early phase[2].

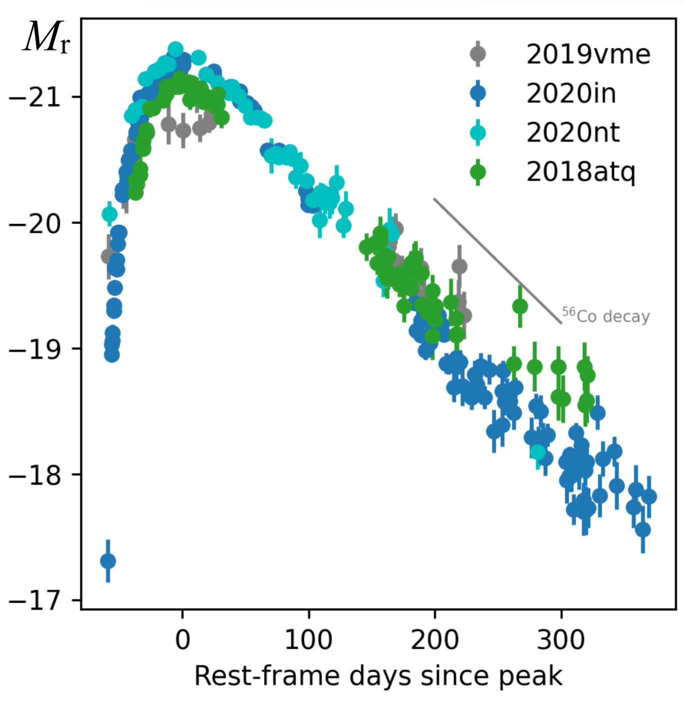


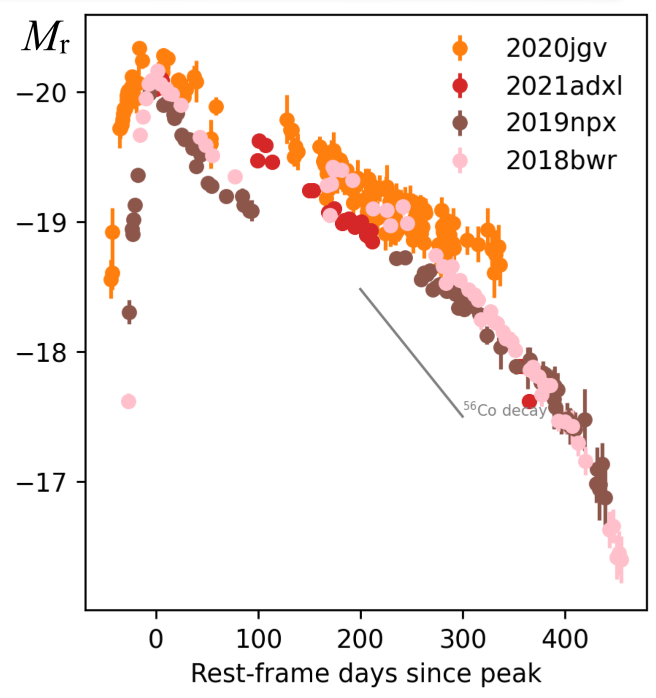
- The early-time median of SLSNe-IIn is 2.87, close to Case B recombination value, suggesting emission from **photo-ionised CSM**. The late-time median rises to 6.58, likely due to **collisional excitation, optical-depth effect, and/or dust extinction**.

Subgroups and Trends

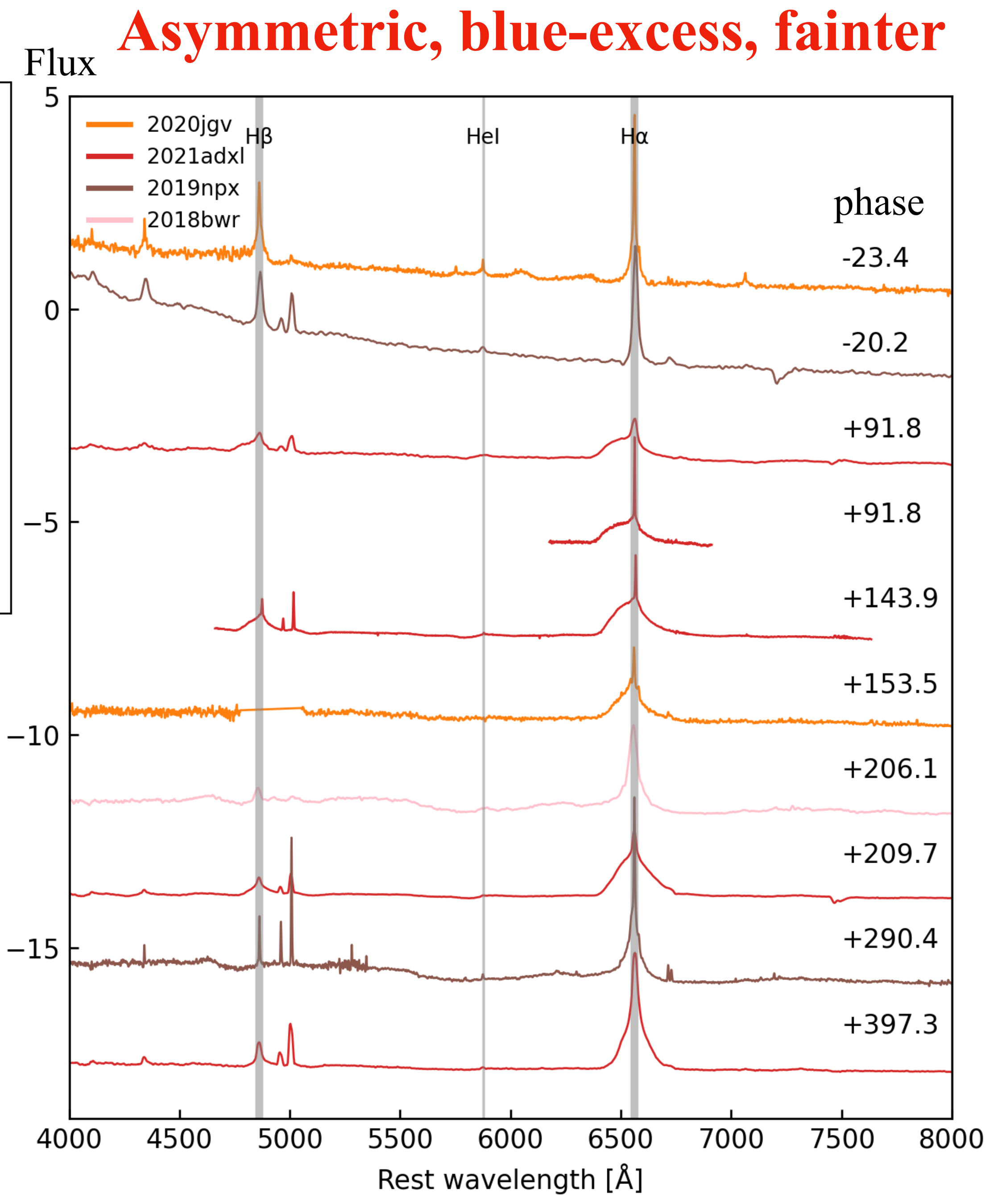
Symmetric, Lorentzian, brighter







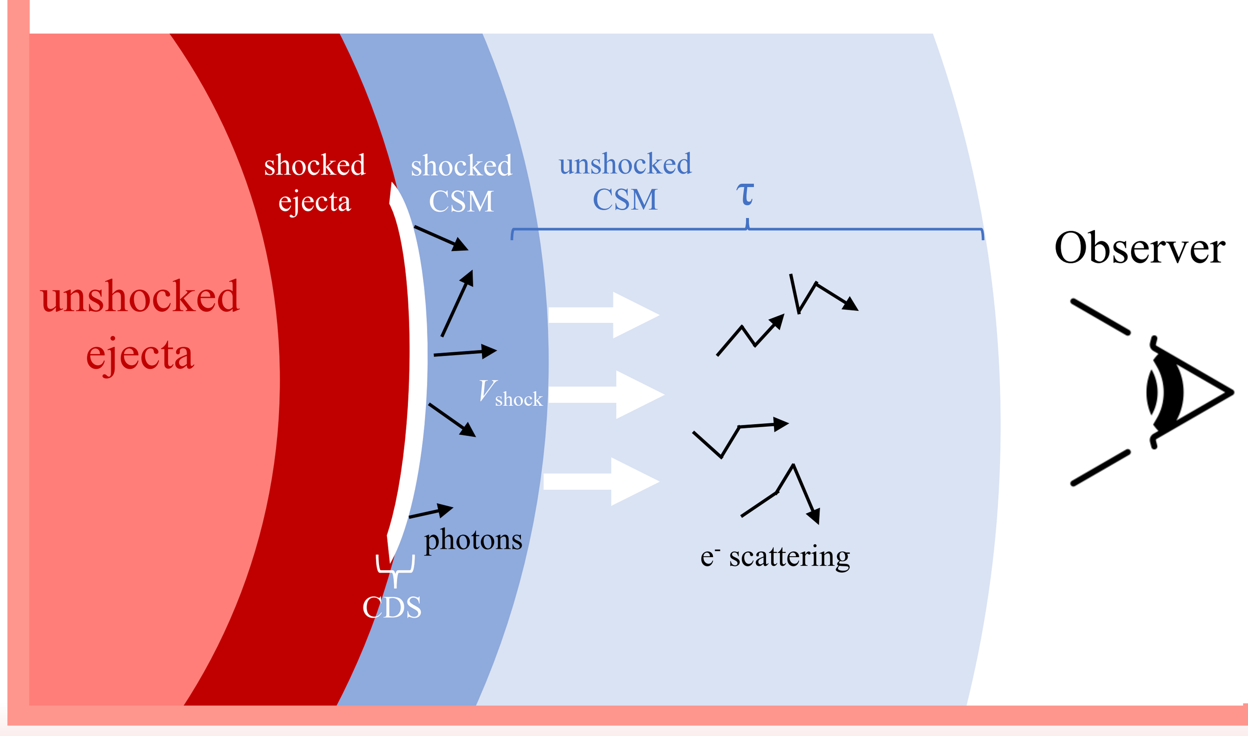
Asymmetric, blue-excess, fainter



- **(LEFT)** Objects with persistent symmetric, Lorentzian Balmer lines tend to be brighter, with surprisingly uniform light curves peaking at ~ −21 mag and evolving on similar timescales.
- **(RIGHT)** Objects with Balmer line blue-excess tend to be fainter, peaking at ~−20 mag. The late-time dip in light curve may indicate dust extinction.

Line-Profile Modelling

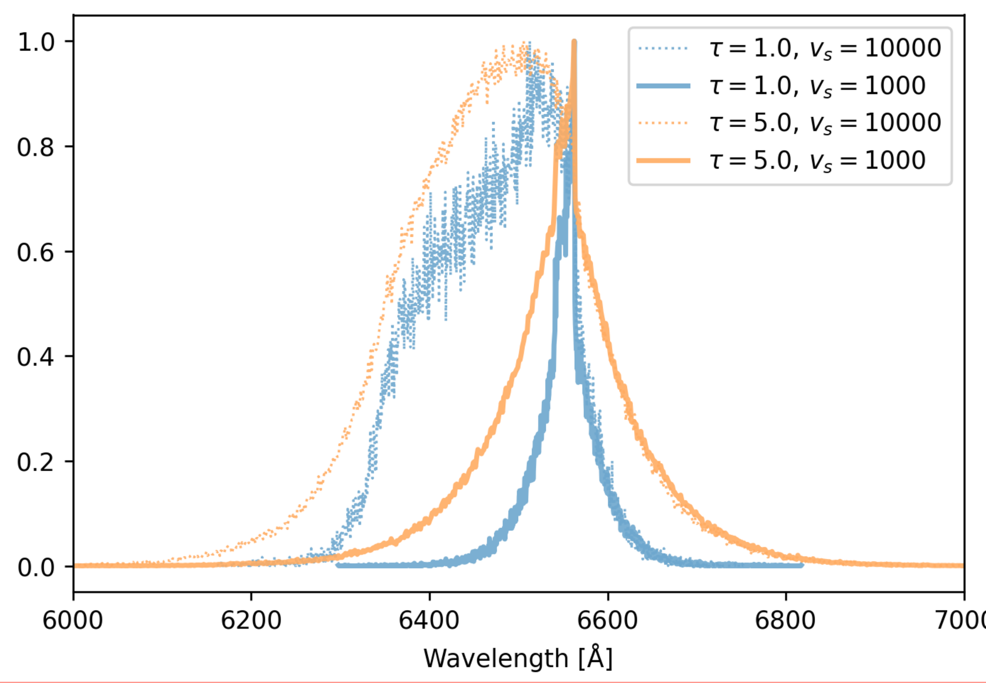
- **e⁻ scattering** explains the line profiles.
- During the interaction, a **cold dense shell (CDS)** forms between the shocked ejecta and shocked CSM. $V_{\rm CDS} \lesssim V_{\rm shock}$
- Photons are produced near the CDS boundary and pass through CSM with optical depth τ. Before reaching the observer, they are Thomson-scattered by electrons in the CSM.



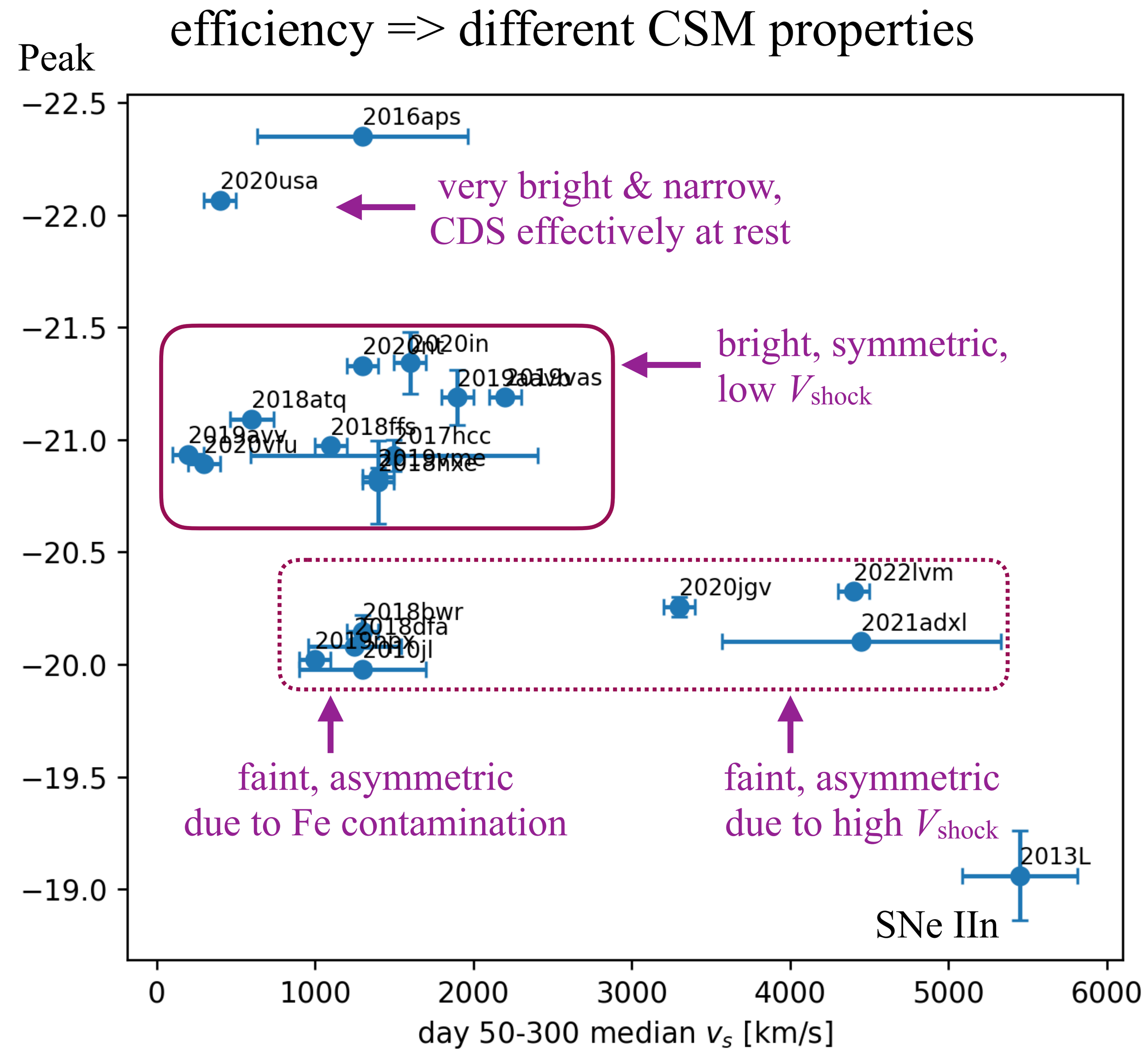
- Modelling with the Monte Carlo code `escatter`[3] shows:

1. higher shock velocity produces more blue-excess in the Balmer line profile,
2. higher optical depth produces broader, more extended wings.

- We can compare peak M_r with inferred $V_{\rm shock}$ to search for trends.



- Objects with lower $V_{\rm shock}$ have brighter peak M_r
- If $E_{\rm total}$ is similar => different E partition between KE and EM => different conversion efficiency => different CSM properties



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References

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2. Silverman, J. M., Nugent, P. E., Gal-Yam, A., et al. 2013, ApJS, 207, 3
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