

The

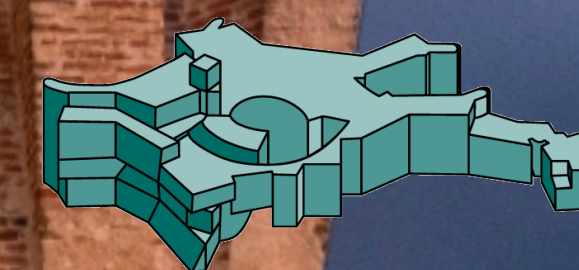


of thermonuclear explosions
- revisited

An Extraordinary Journey
Into The Transient Sky

Padova, 2025 April 1-4

Stefan Taubenberger (TUM, MPA)



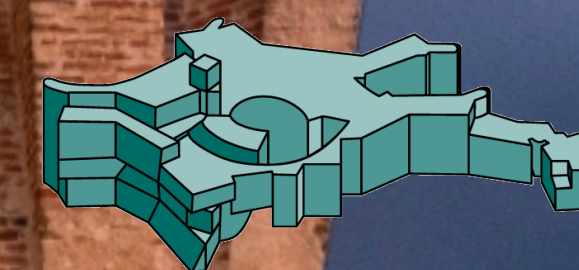
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FOR ASTROPHYSICS



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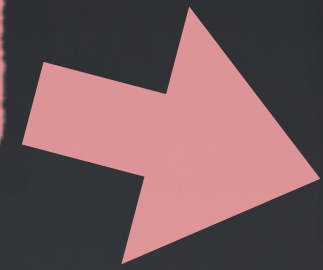
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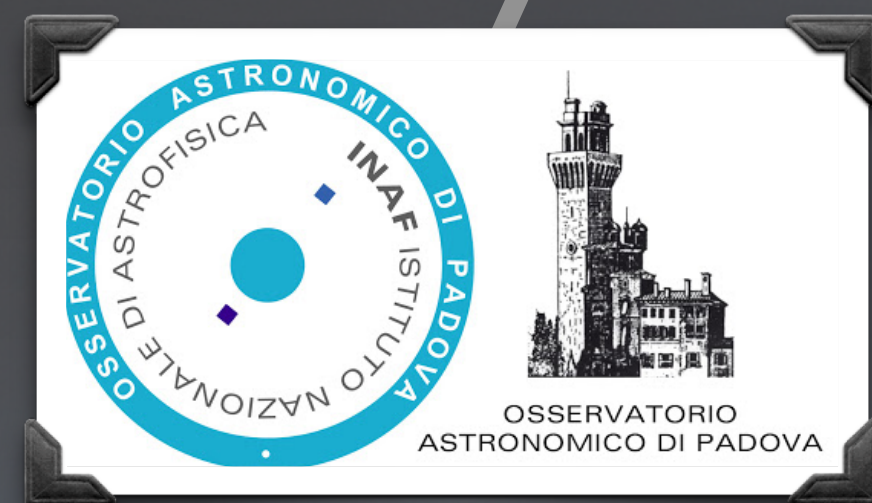
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2002-2006: EU RTN on the physics of SNe Ia

Theoreticians



Observers



- ◉ I was a Diploma student at MPA in 2004, and the only one working on data there
- ◉ Trained by Padova and ESO people
- ◉ Eagerly waiting for my first real target ...

2002-2006: EU RTN on the physics of SNe Ia

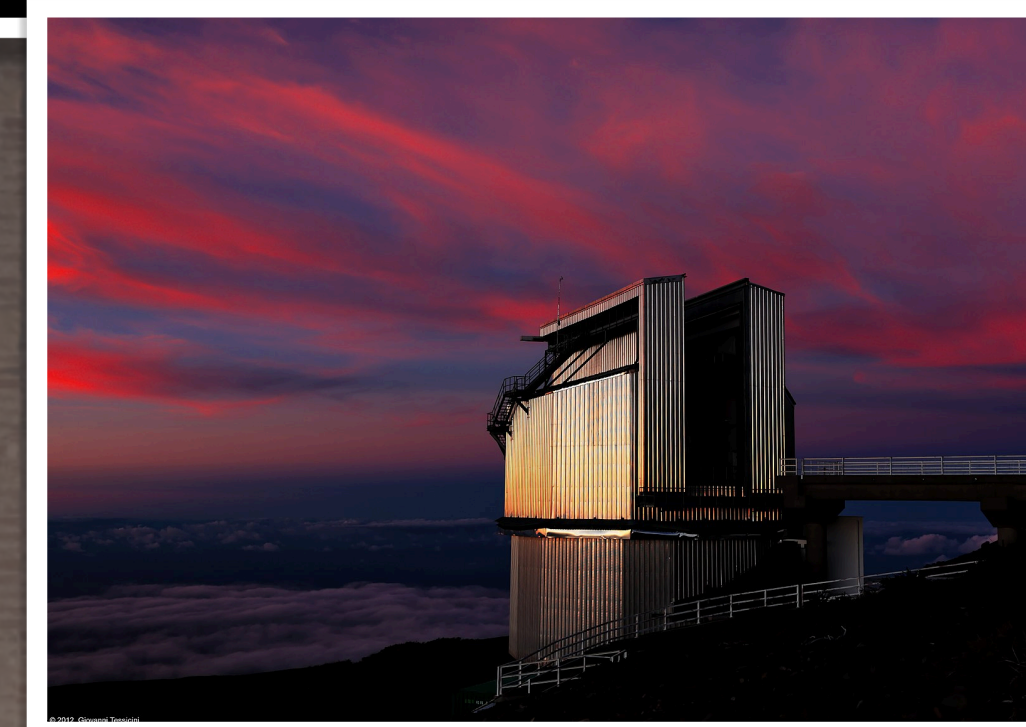


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SUPERNOVA 2004aw IN NGC 3997

S. Benetti, N. Elias-Rosa, G. Blanc, H. Navasardyan, M. Turatto, and L. Zampieri, Osservatorio Astronomico di Padova; E. Cappellaro, Osservatorio Astronomico di Capodimonte; and M. Pedani, Telescopio Nazionale Galileo (TNG), on behalf of the ERTN ([IAUC 7987](#)), obtained a spectrum of SN 2004aw (cf. [IAUC 8310](#), [8311](#)) with the TNG (+ Dolores; range 335–995 nm; resolution 1.4 nm) on Mar. 24.94 UT. The supernova has now evolved to resemble the spectrum of SN 1991T, a few days after maximum, and is therefore classified as type Ia. This also accounts for the fact that the narrow interstellar absorption line seen in the supernova spectrum indicates a reddening of $E(B-V)$ about 0.30 in the host galaxy. The expansion velocity deduced from the Si-II 635.5-nm feature is about 12600 km/s.



2002-2006: EU RTN on the physics of SNe Ia



Now I had my extreme
SN Ia.
So extreme that it ended
up being a SN Ic ...

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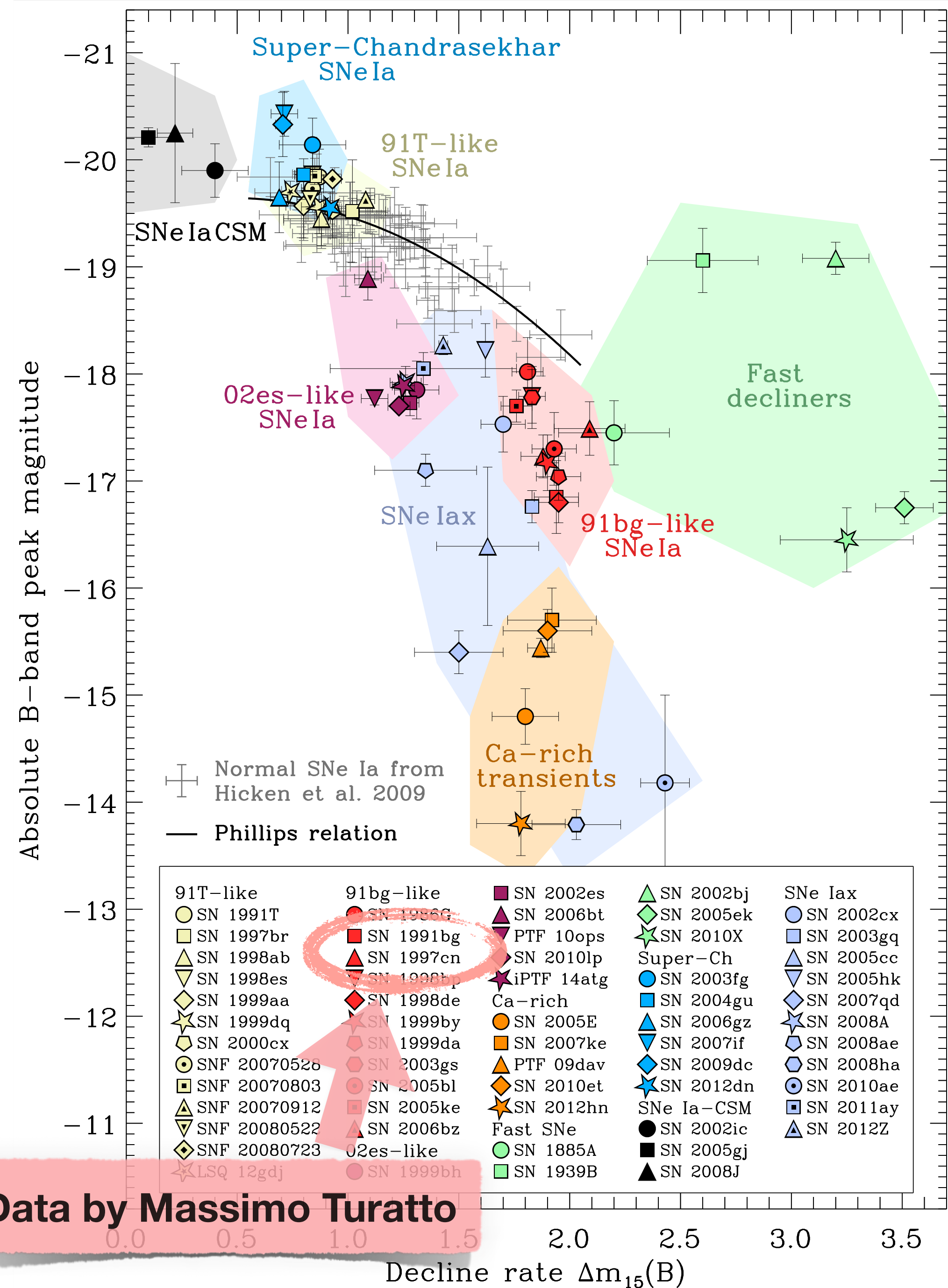
SUPERNOVAE 2004ax, 2004aw, 2004bh, 2004bi, 2004bj, AND 2004bk

A. V. Filippenko, L. Desroches, M. Ganeshalingam, and R. Chornock, University of California, Berkeley; and F. J. D. Serduke, Lawrence Livermore National Laboratory, report that inspection of CCD spectra (range 330–1000 nm), obtained on Apr. 24 UT with the Shane 3-m telescope at Lick Observatory, reveals that SN 2004aw ([IAUC 8310](#), [8311](#)) is of type Ic, similar to SN 1991A (Filippenko 1992, Ap.J. 384, L37), rather than of type Ia as stated in [IAUC 8312](#). SN 2004ax ([IAUC 8311](#)) is indeed a supernova,...

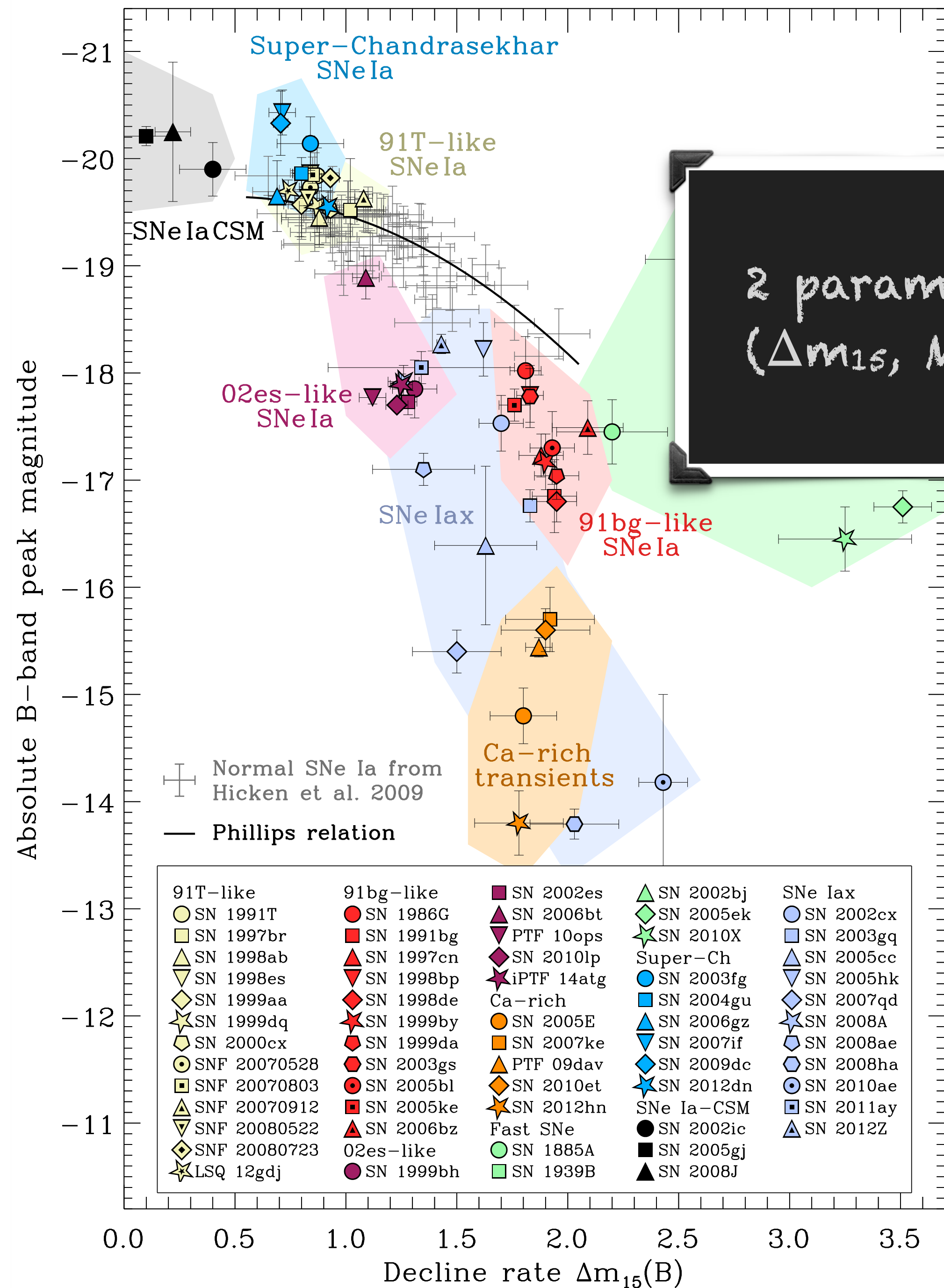
Training in Asiago



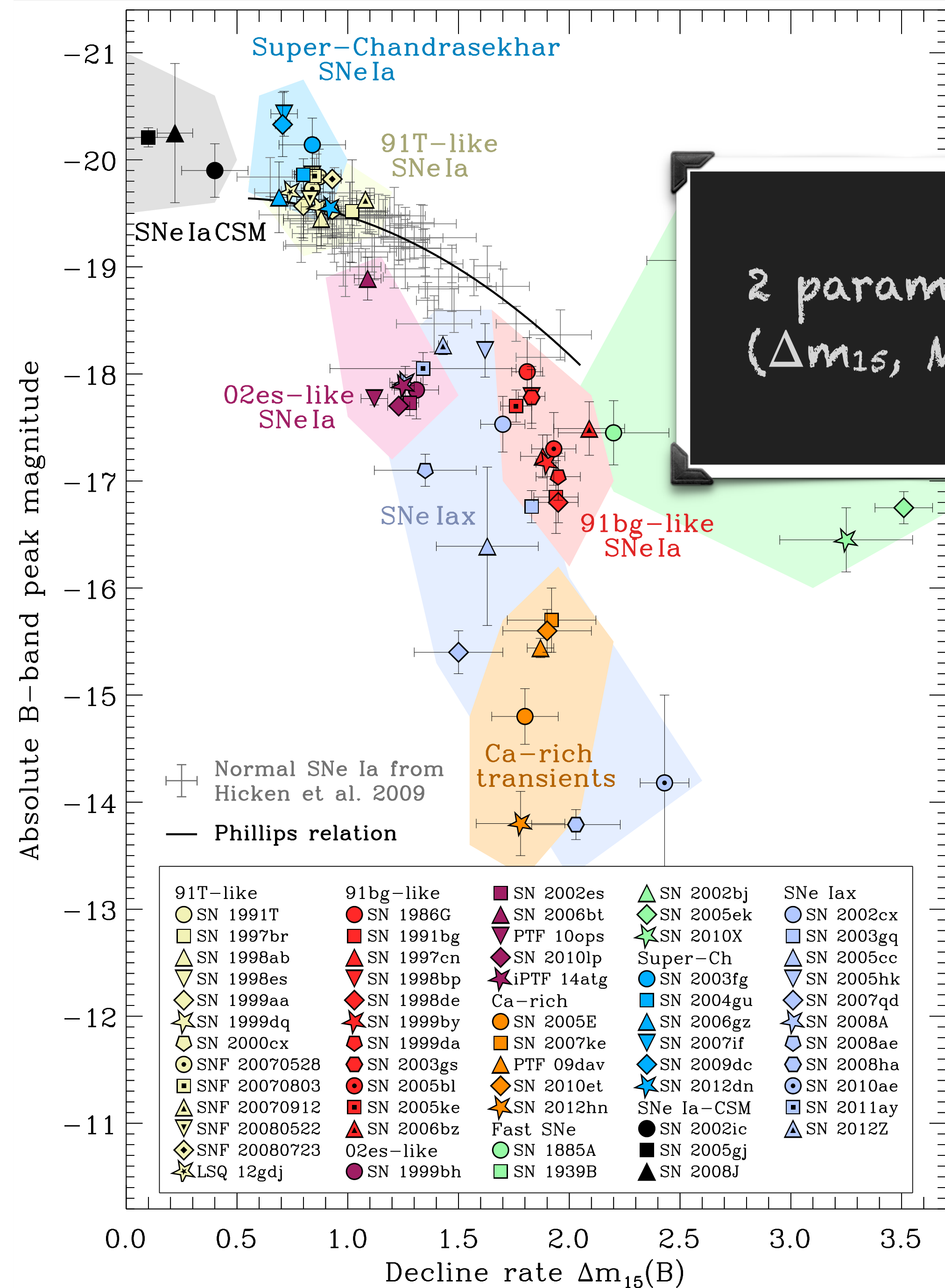
The "Taubenberger plot"



The "Taubenberger plot"



The "Taubenberger plot"

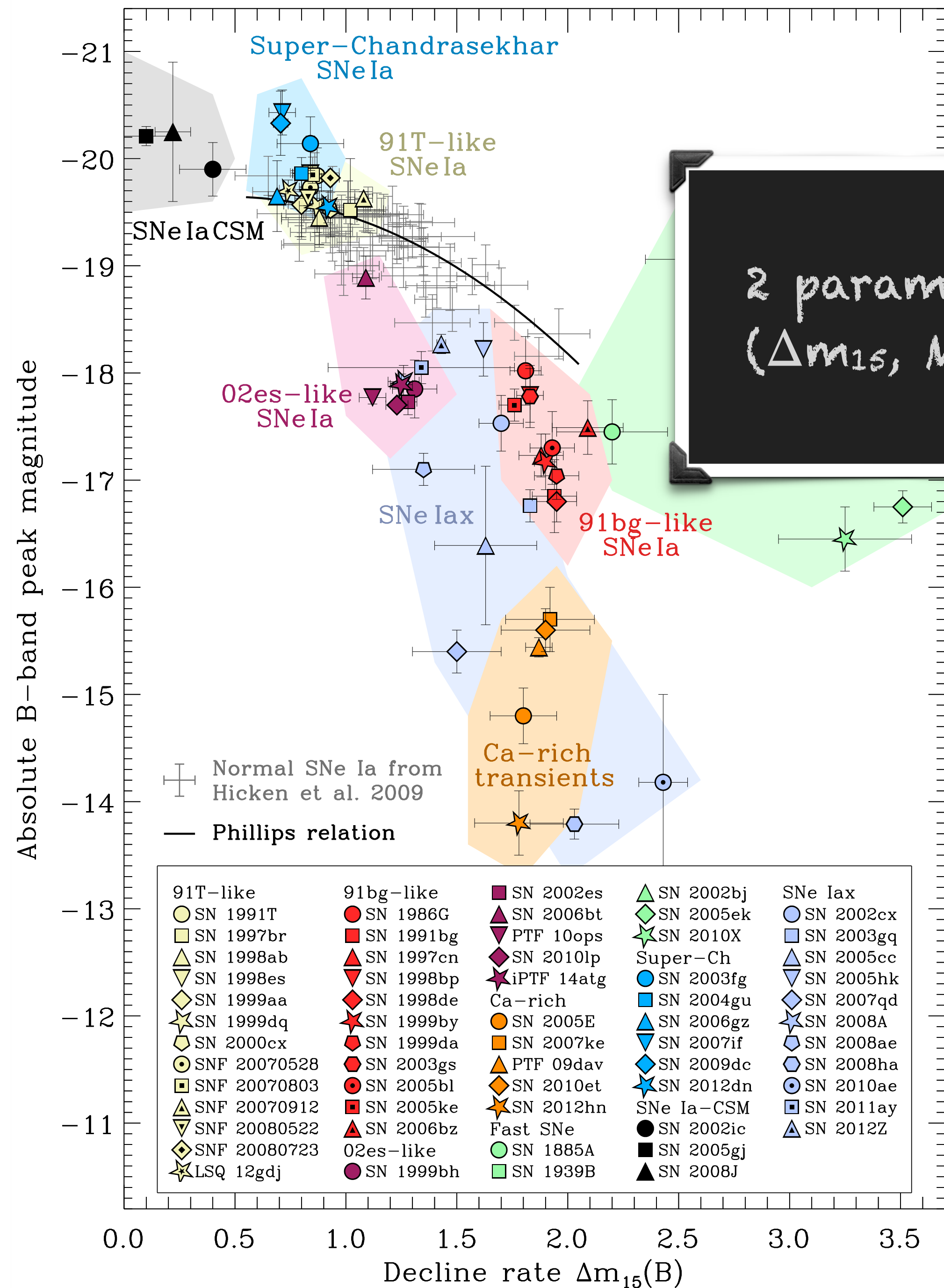


2 parameters
(Δm_{15} , M_B)

Add ejecta velocity

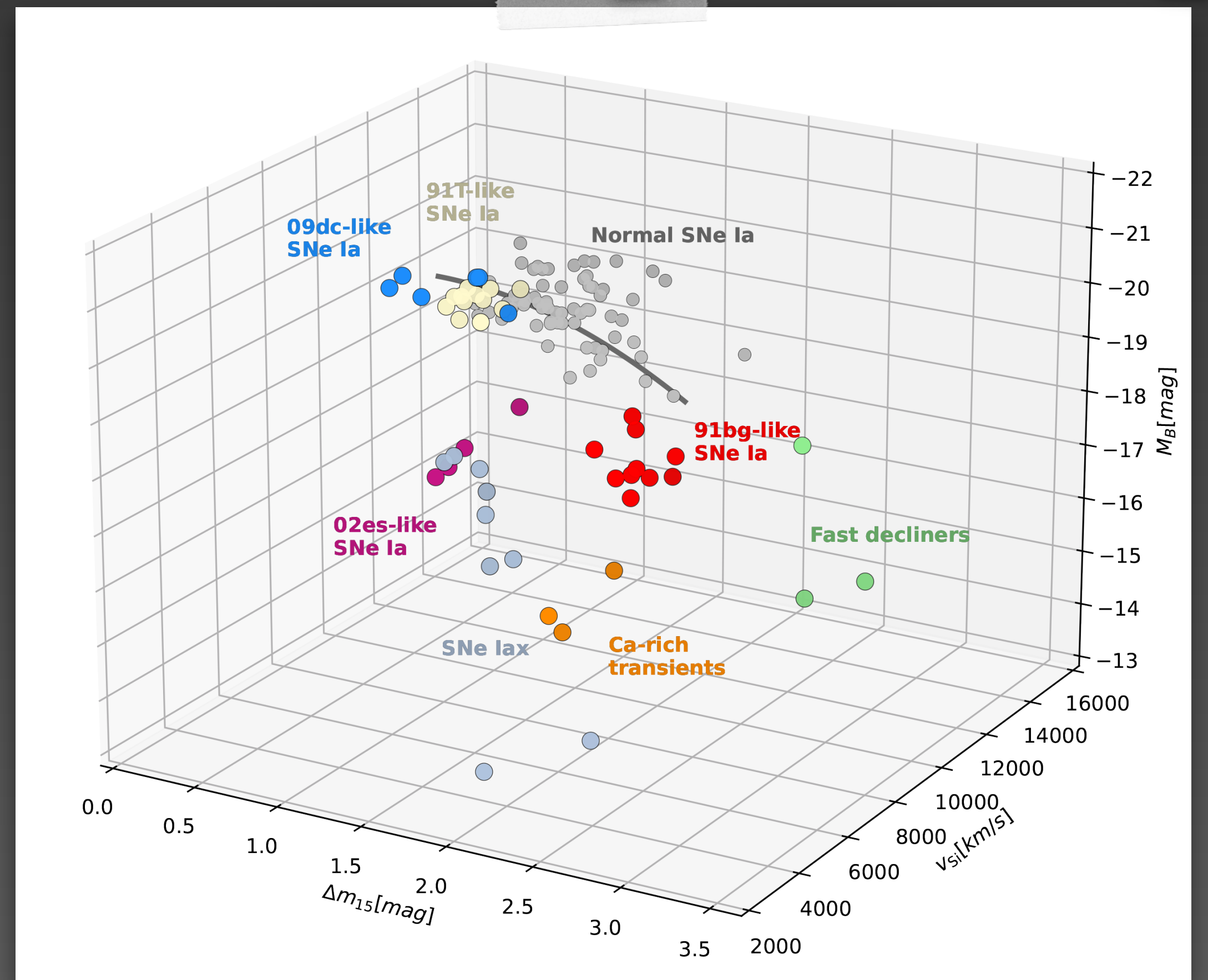
3 parameters
(Δm_{15} , M_B , v_{Si})

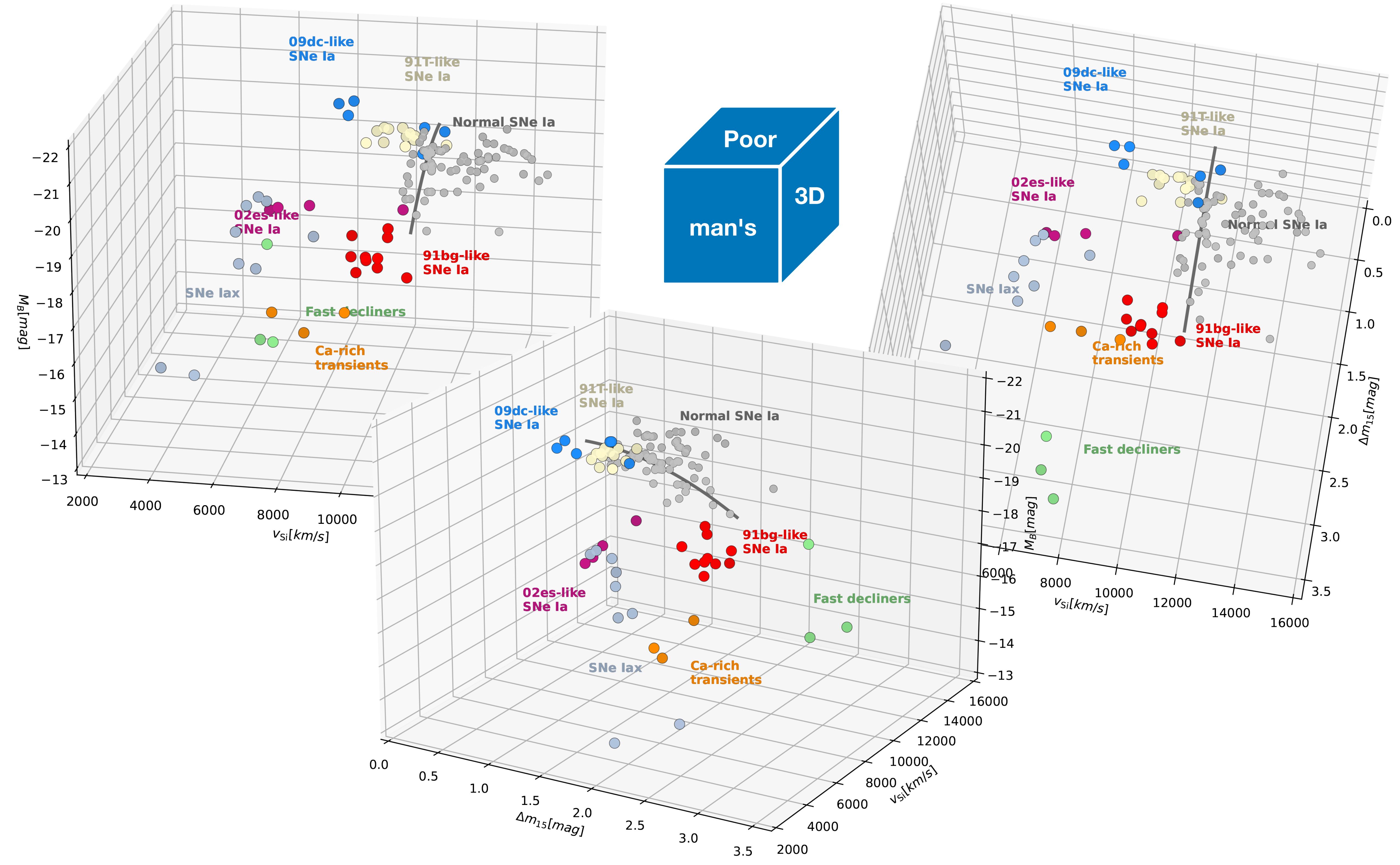
The "Taubenberger plot"



Add ejecta velocity

3 parameters (Δm_{15} , M_B , v_{si})

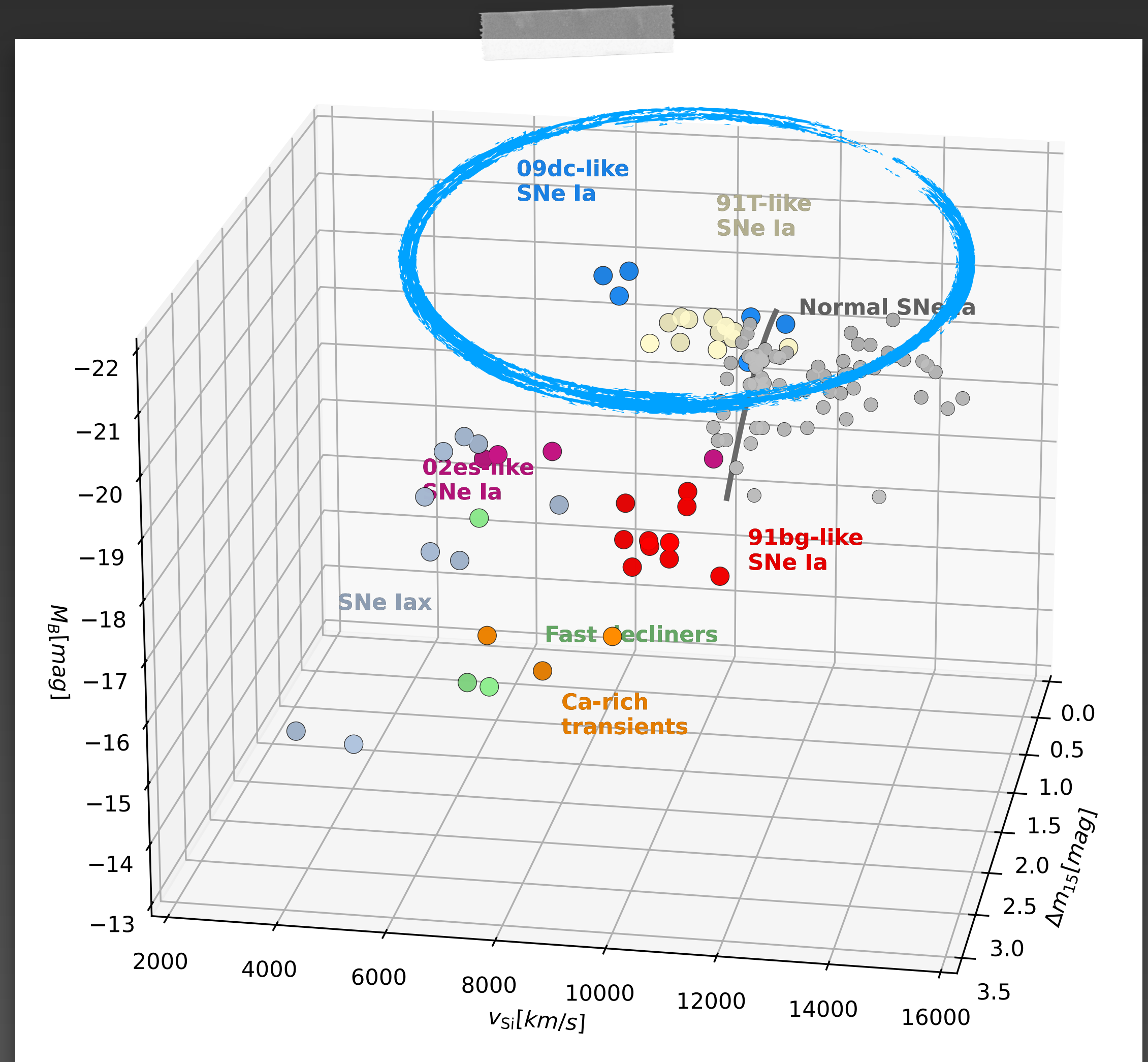




Focussing on 09dc-like SNe Ia

5-10 yr ago:

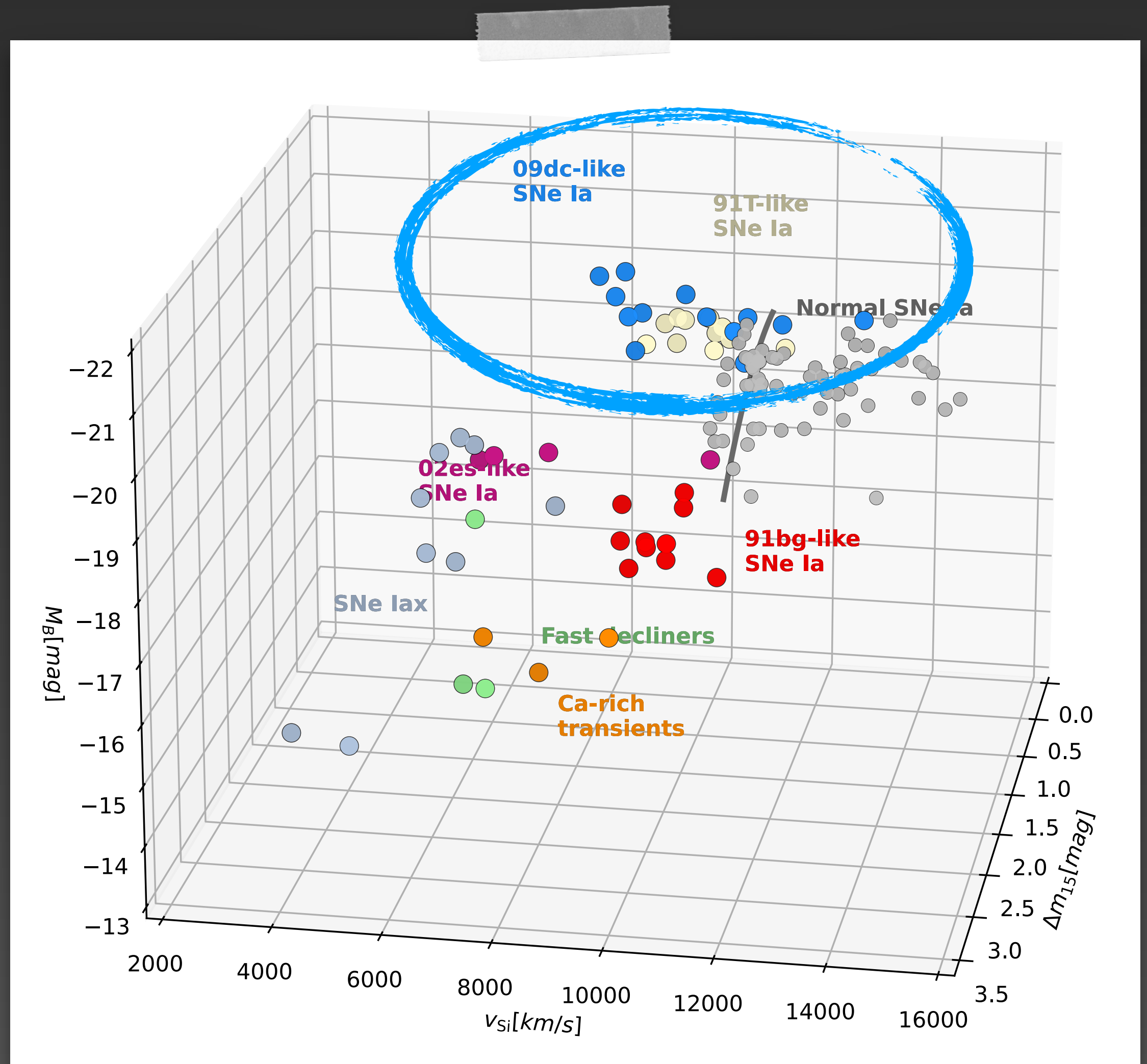
- About 5 well-observed objects
- Still not 100% clear where the luminosity comes from
- Probably NOT super-Chandra WDs
- Speculation on interaction with H/He-free CSM
- Wild speculation on molecule/dust formation after 50-200 days



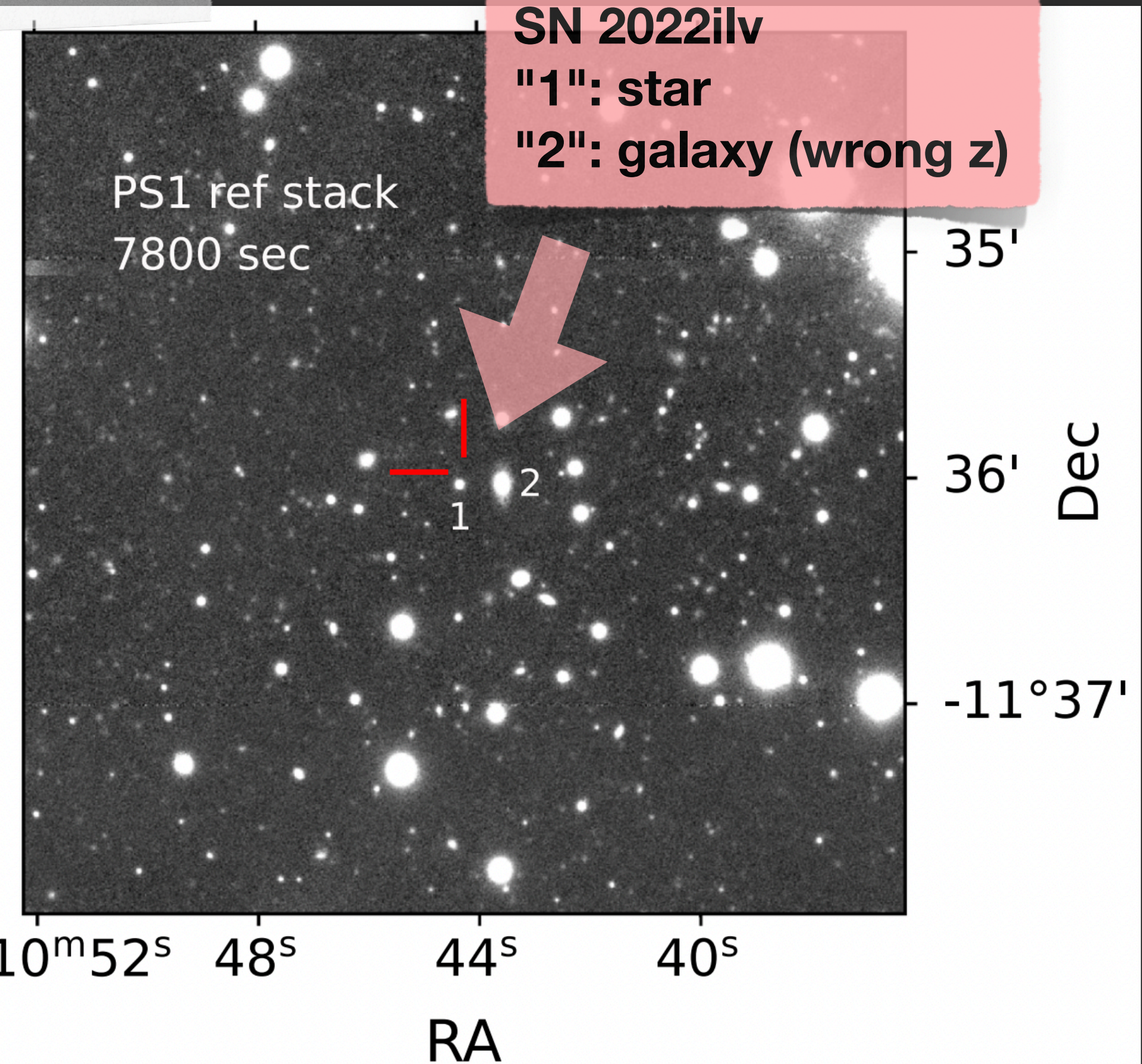
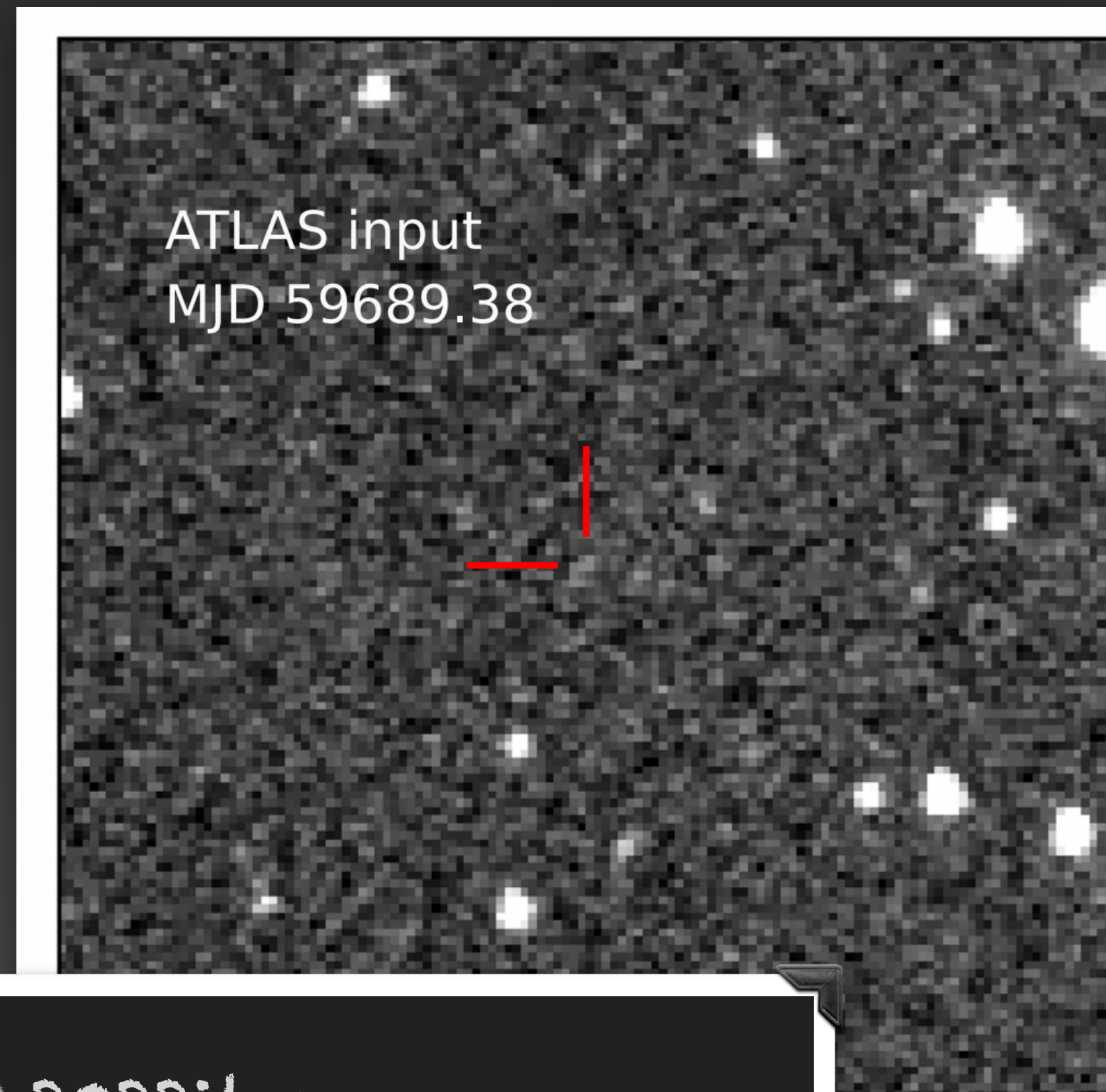
Focussing on 09dc-like SNe Ia

Now:

- About 10 additional well-observed objects
- Excellent data sets



Explosion in low-mass, low-metallicity hosts



• 2022ilv:

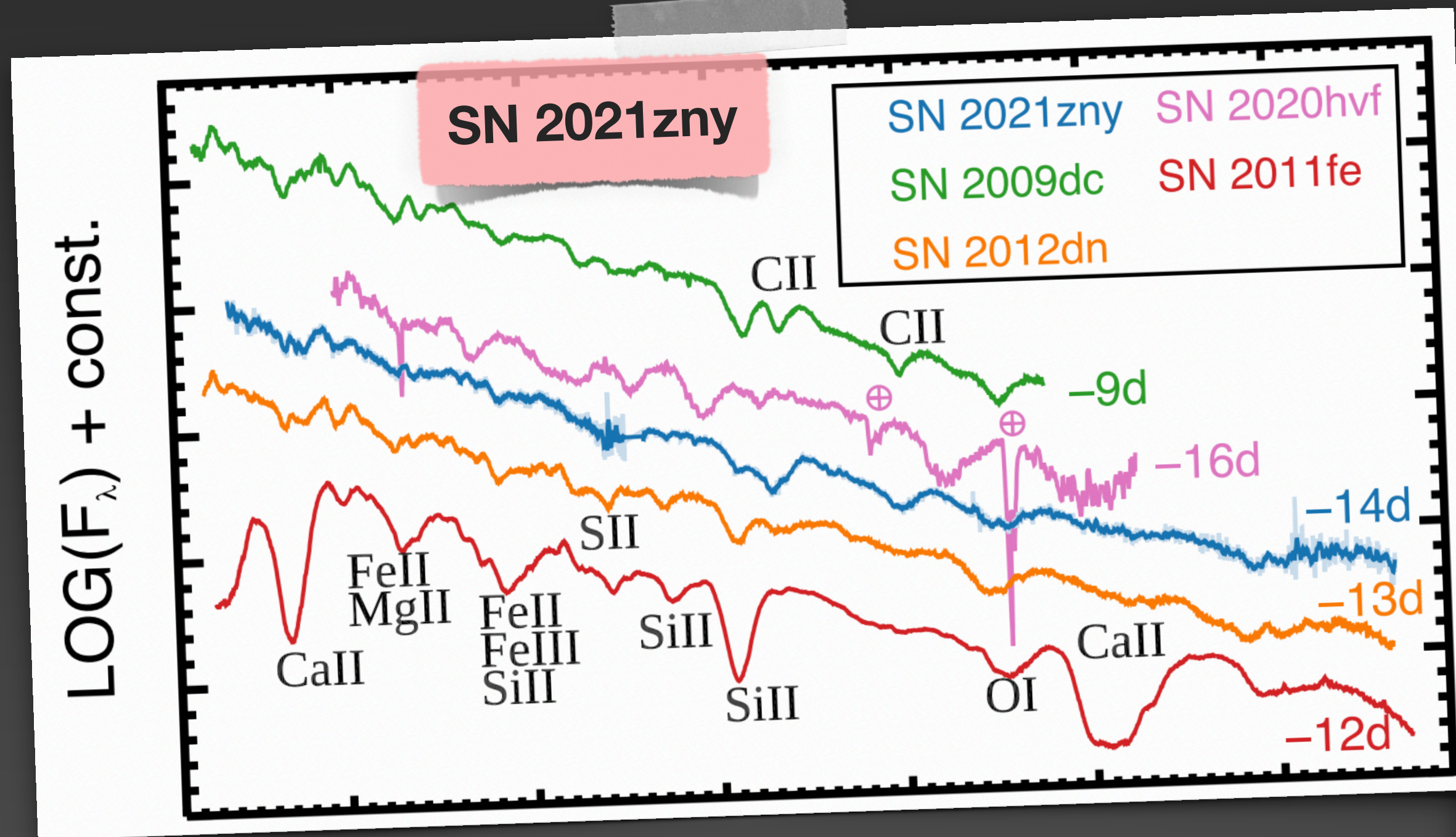
$M_{\text{host}} > -11$ to -10

• LSQ14fmg:

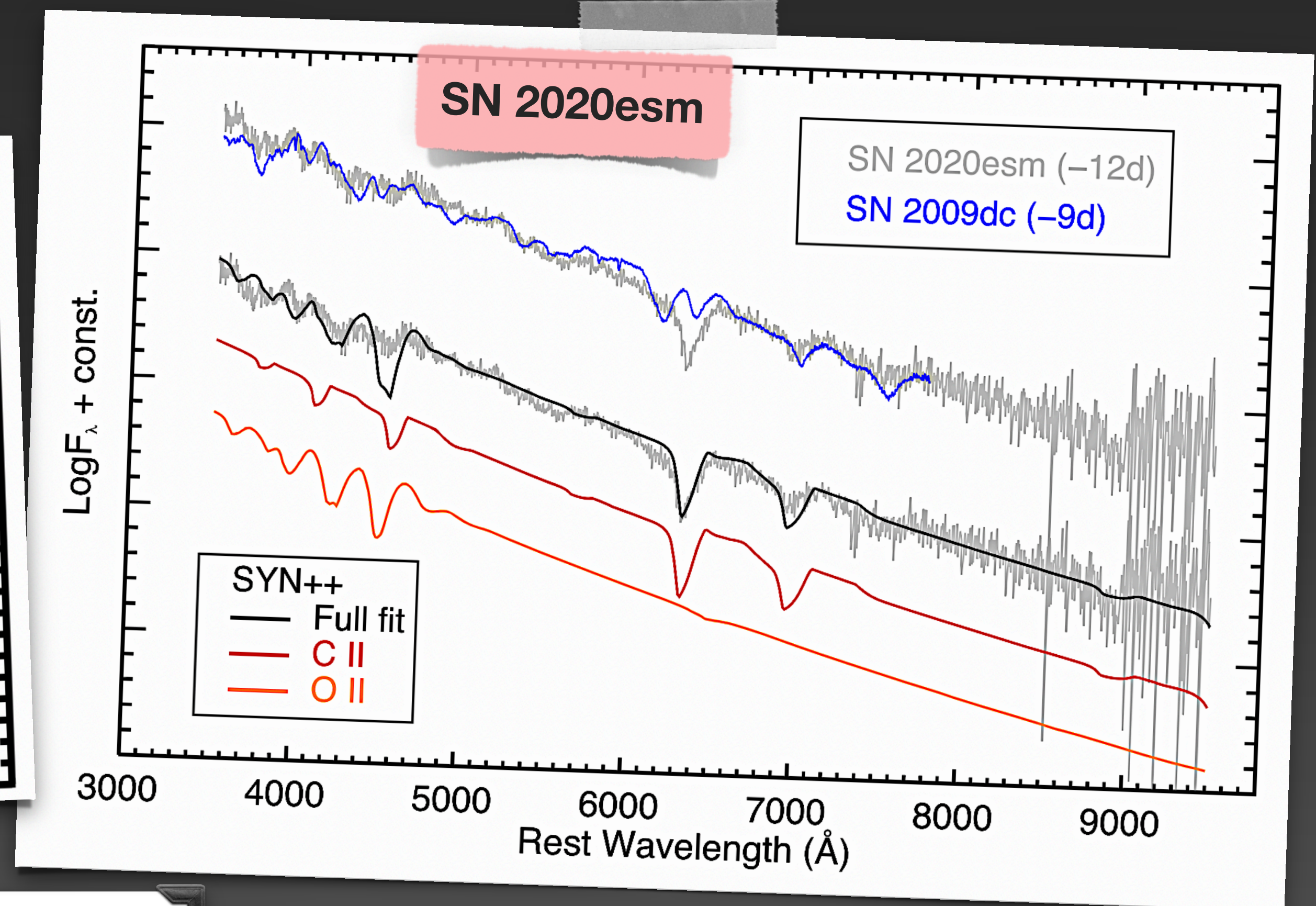
$M_{\text{host}} = -15$ to -14

Srivastav et al. 2023

Unburned material in early spectra



Dimitriadis et al. 2023

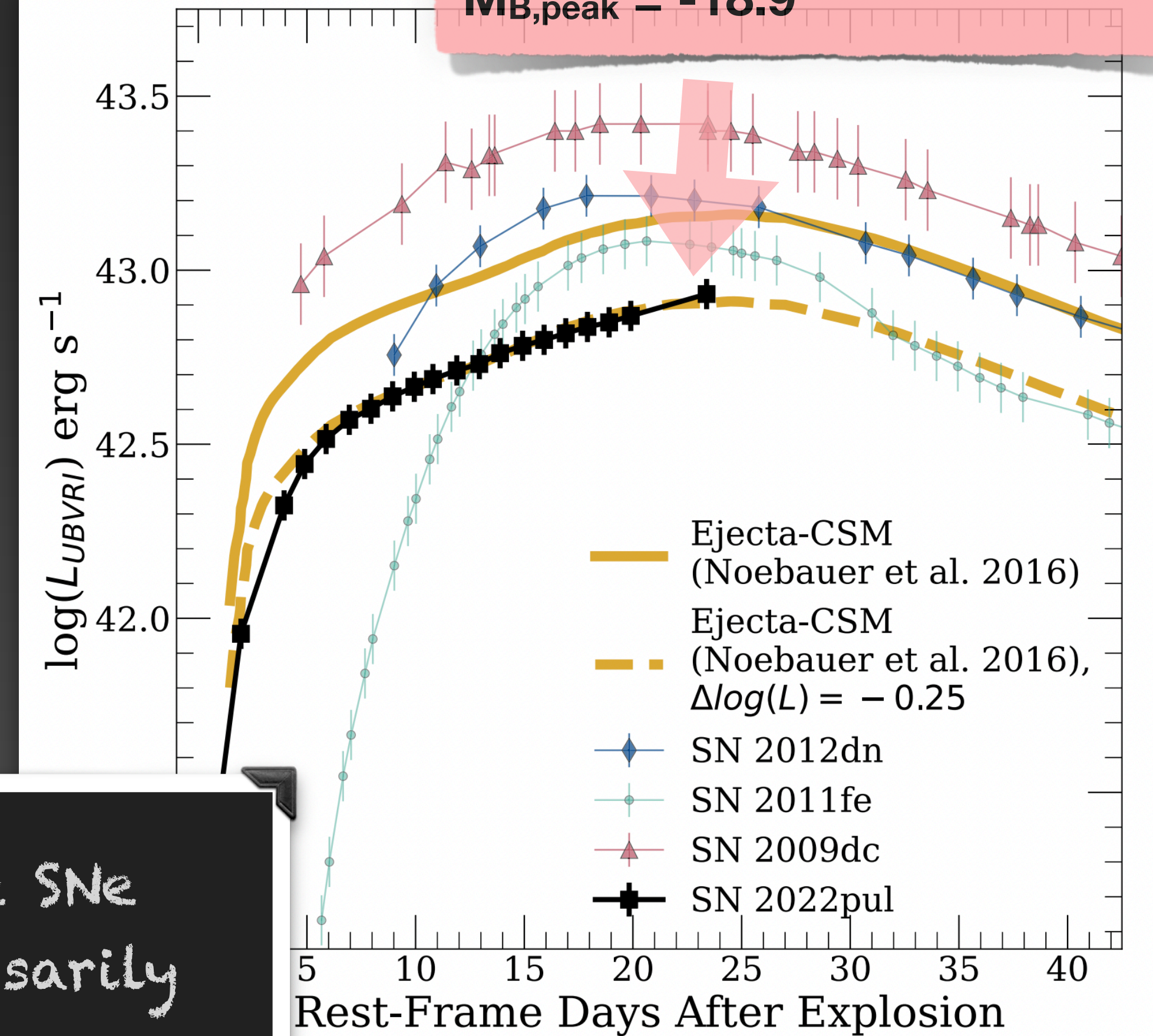
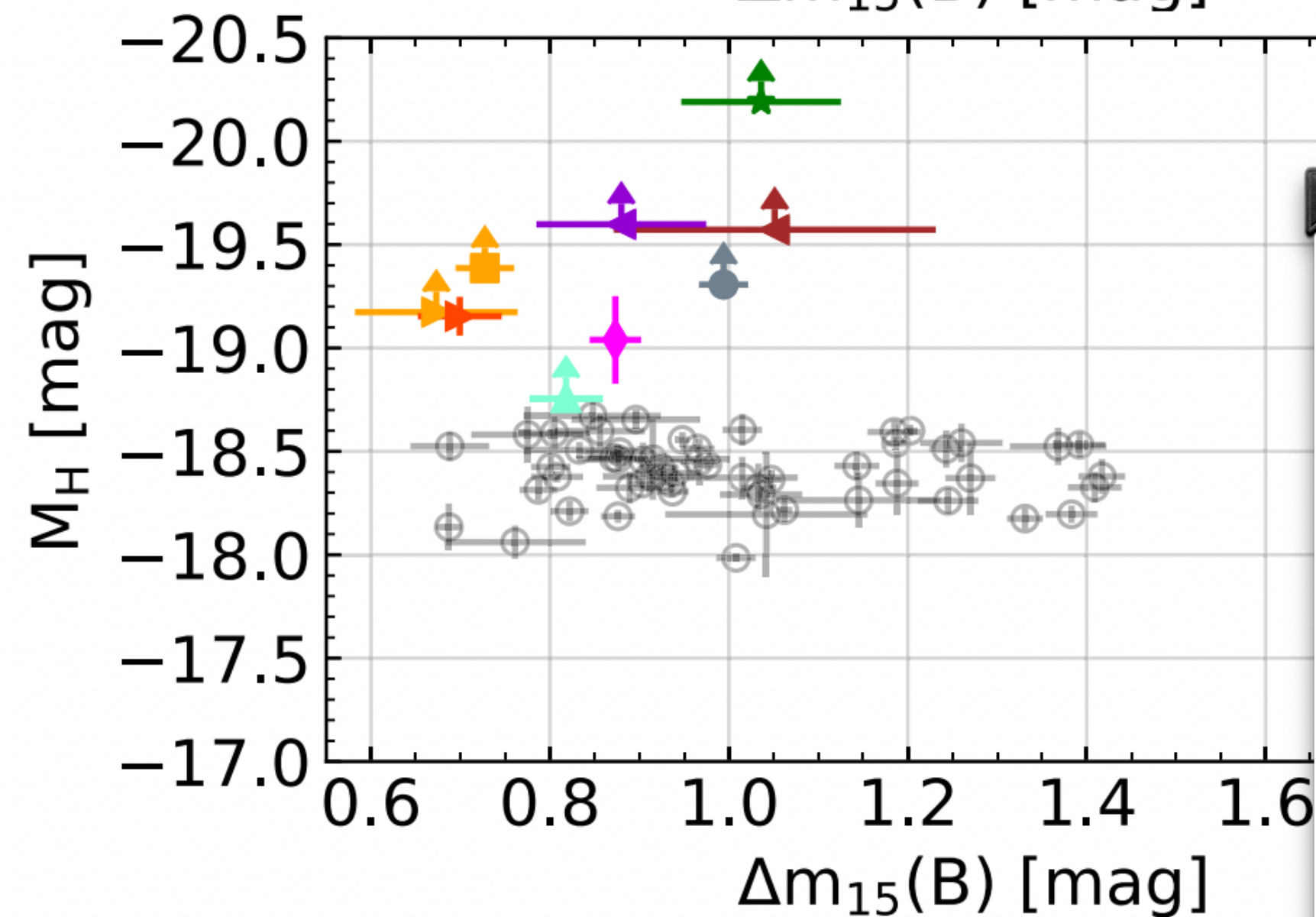
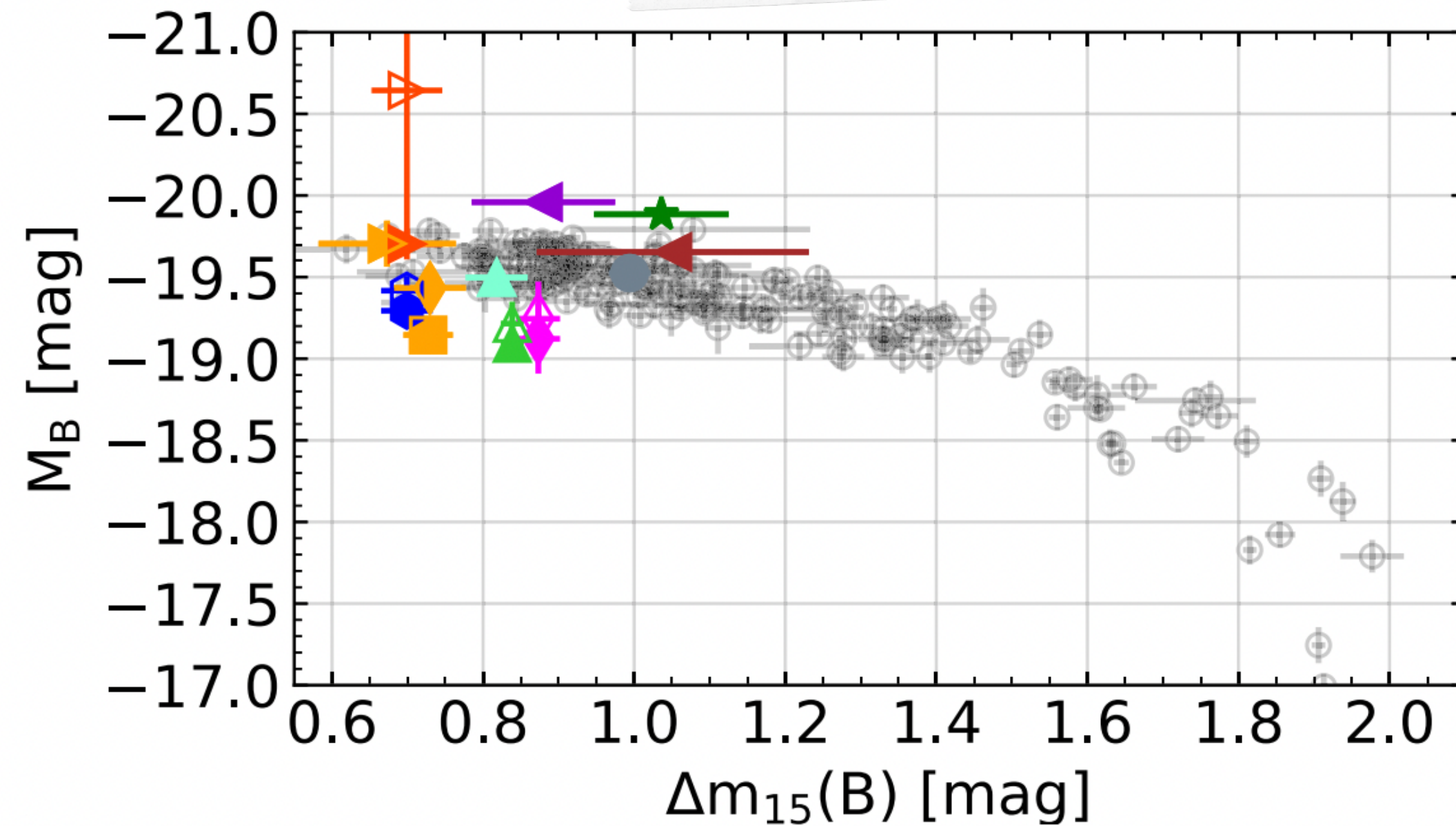


Dimitriadis et al. 2022

2020esm and 2021zny:
early spectra show
almost exclusively
C and O lines

Peak luminosities

2022pul is the least luminous
09dc-like SN so far, with
 $M_{B,\text{peak}} = -18.9$



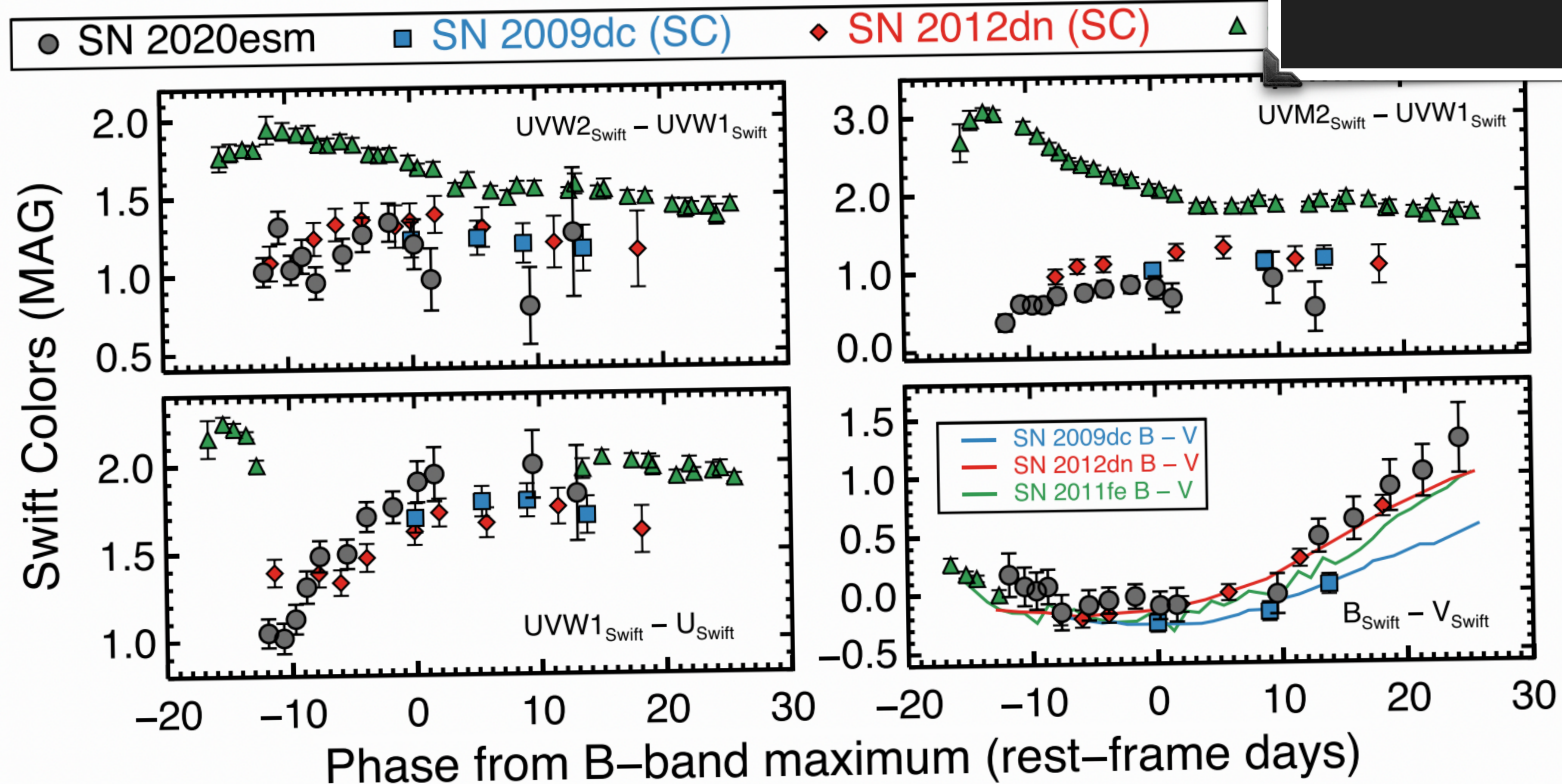
• 09dc-like SNe
not necessarily
overluminous
in the optical

• overluminous
in the near IR

Siebert et al. 2024

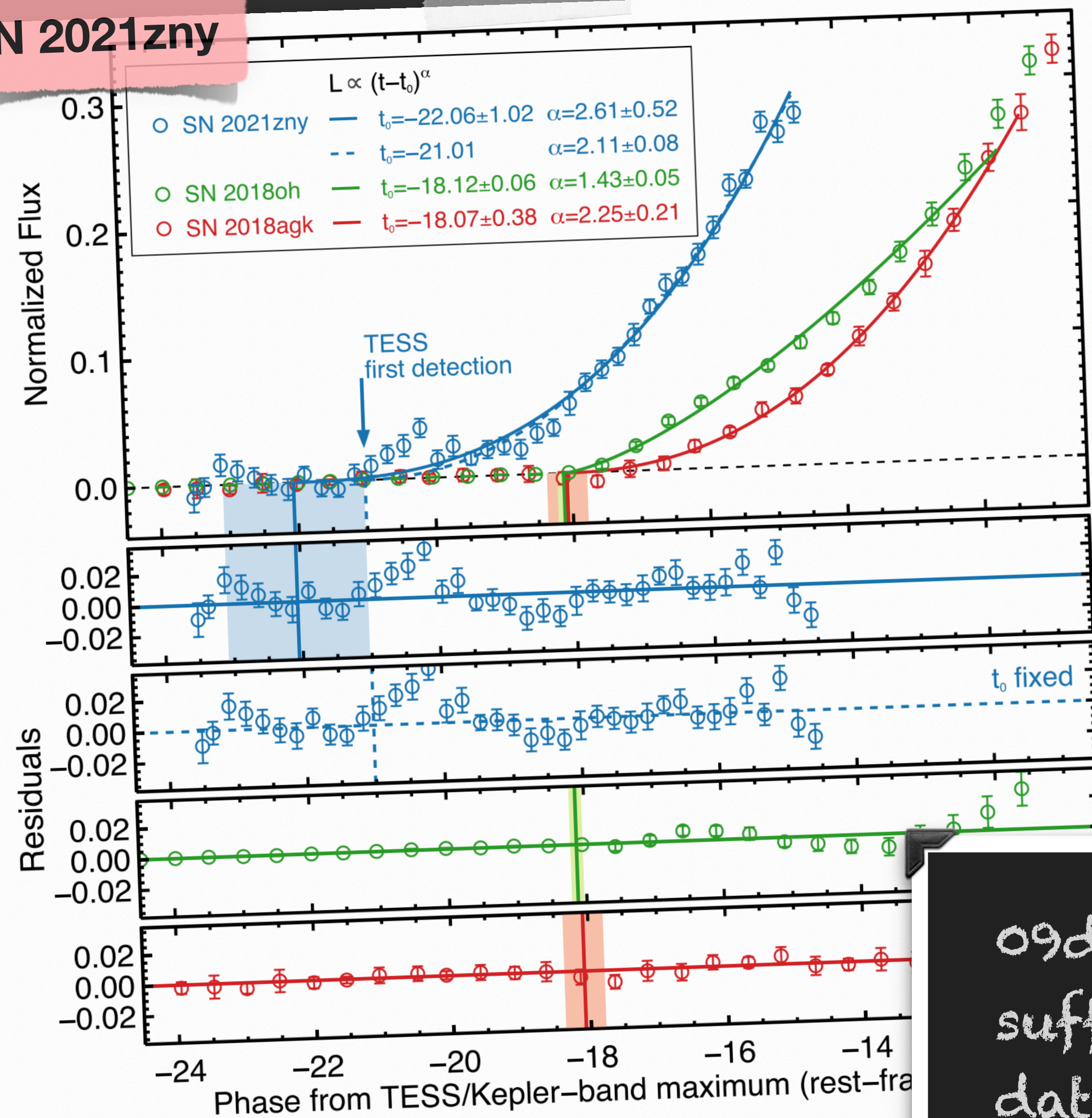
UV - optical colours

UV - optical colours
much bluer than in
normal SNe Ia



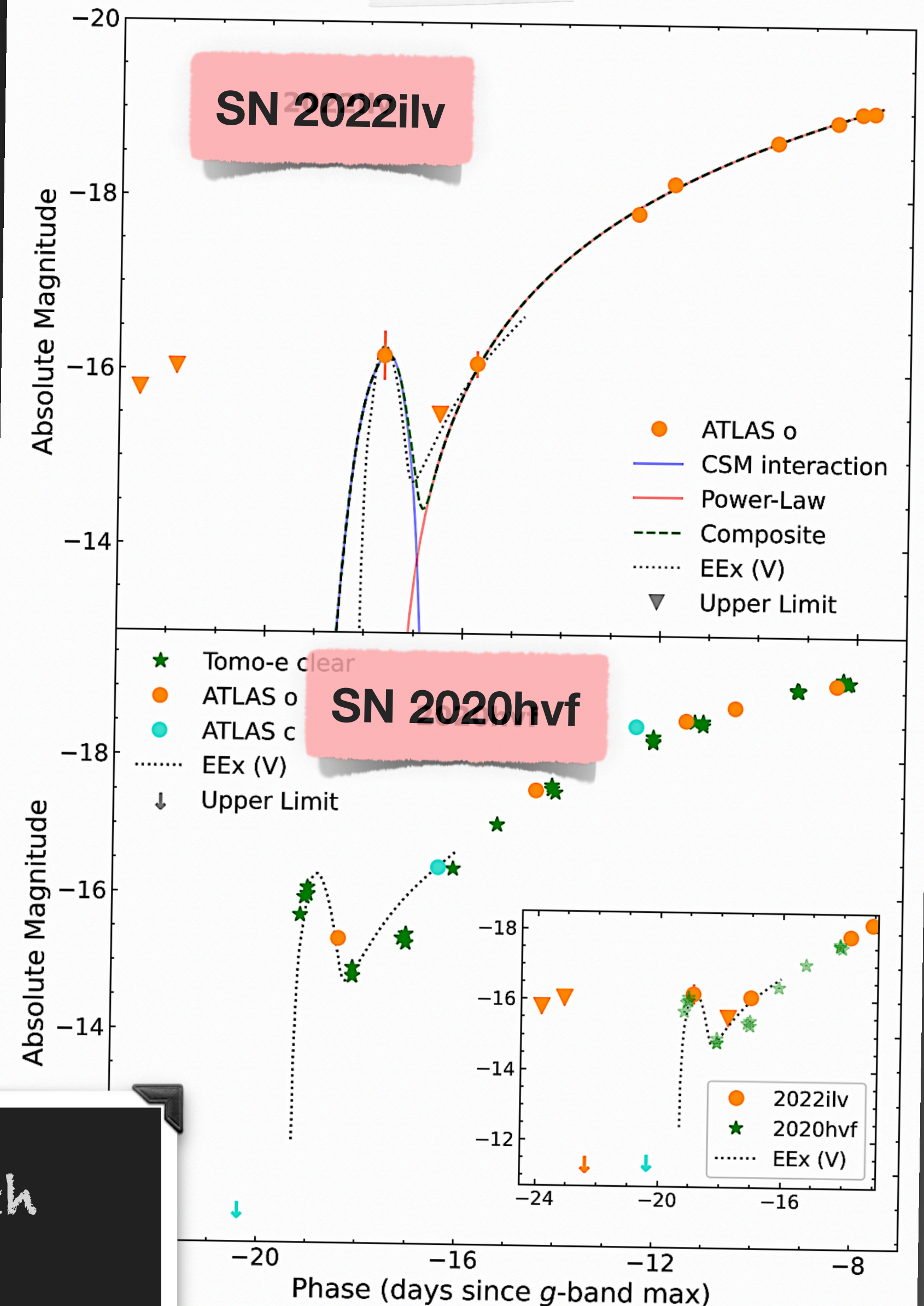
Early flux excess

SN 2021zny



o9dc-like SNe with sufficiently early data show lightcurve bump of 1-2 days

SN 2022ilv

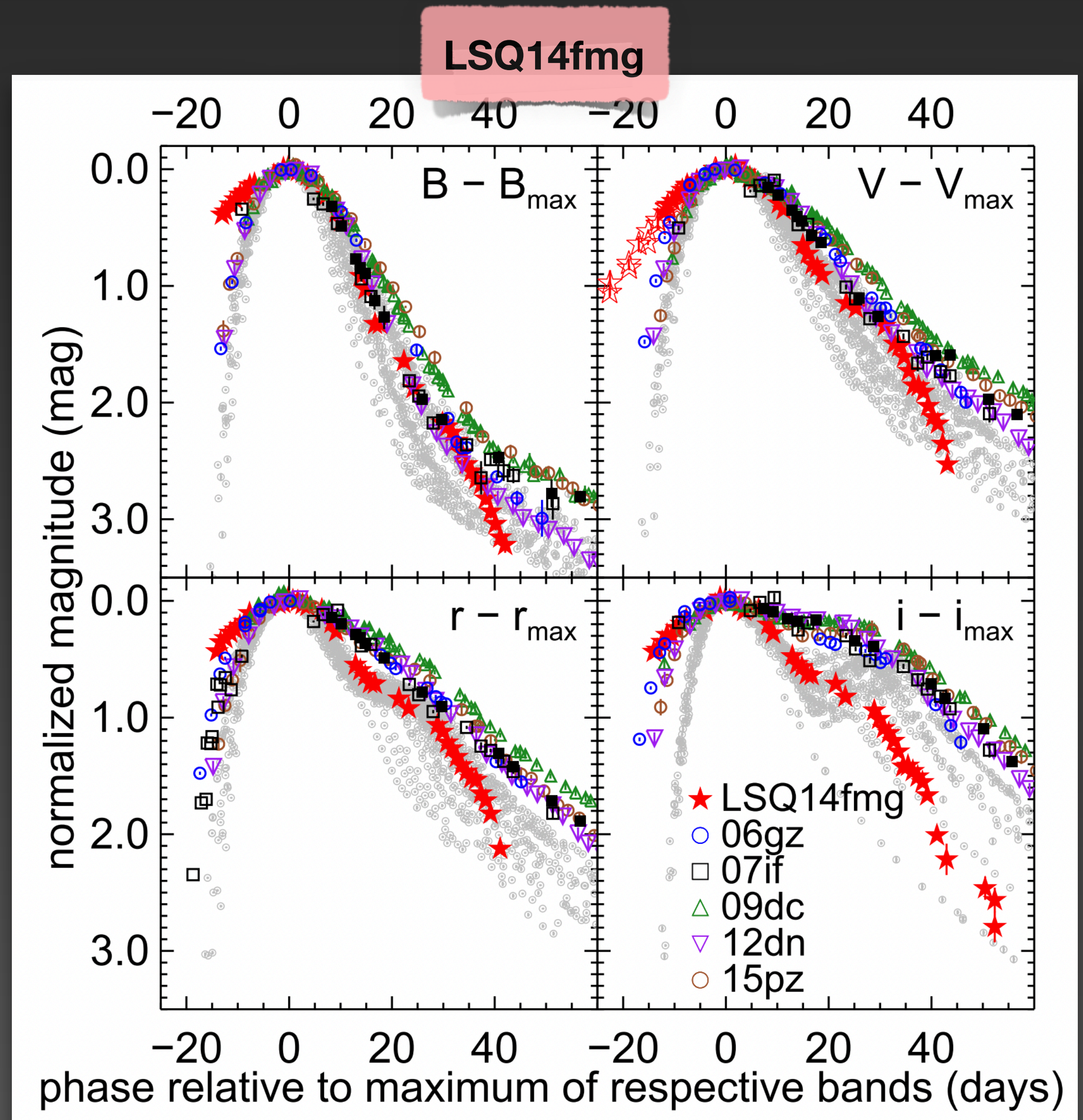


Srivastav et al. 2023

Dimitriadis et al. 2023

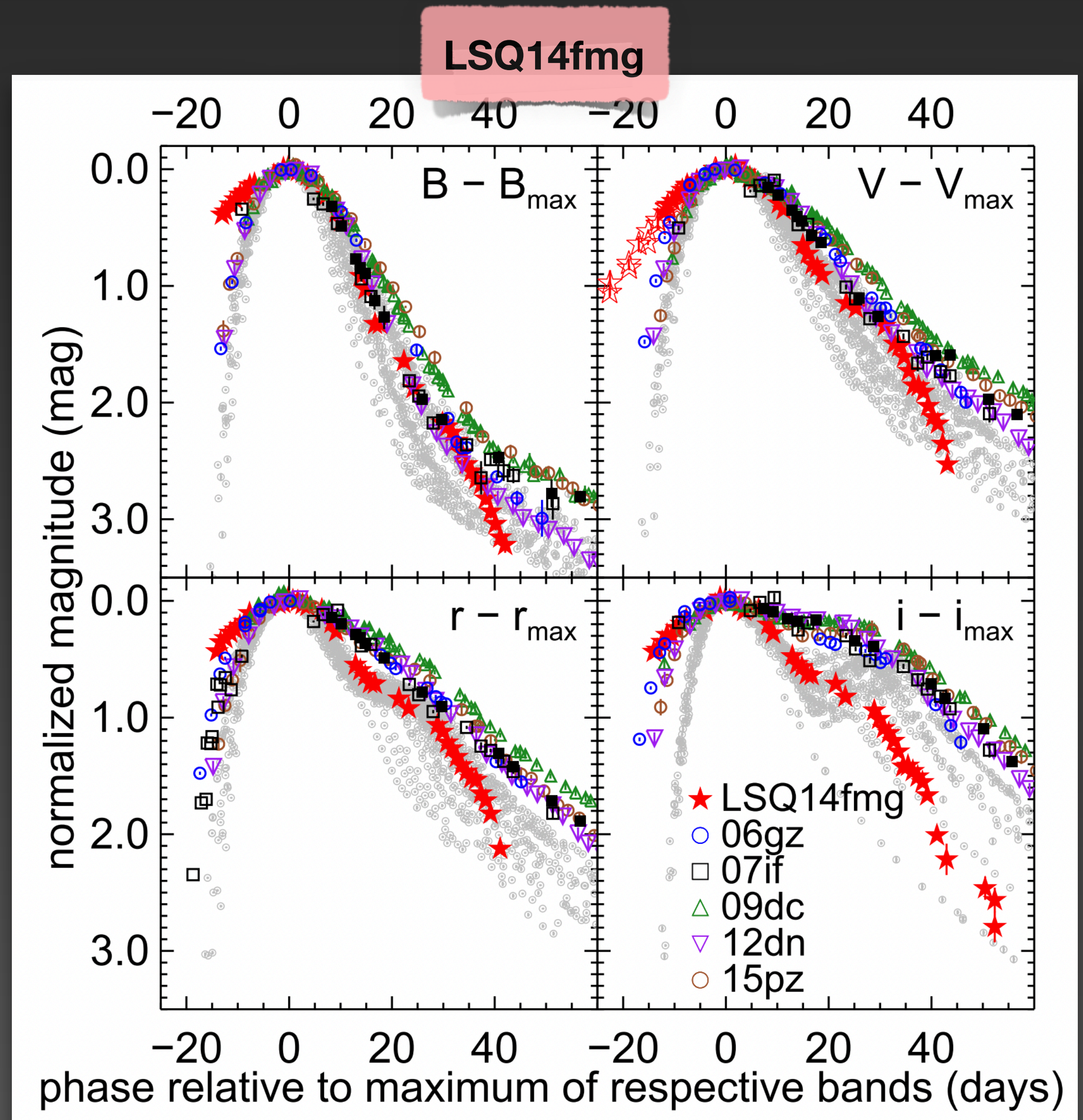
Early flux excess

LSQ14fmg even shows
a long-lasting excess
during the rise ...

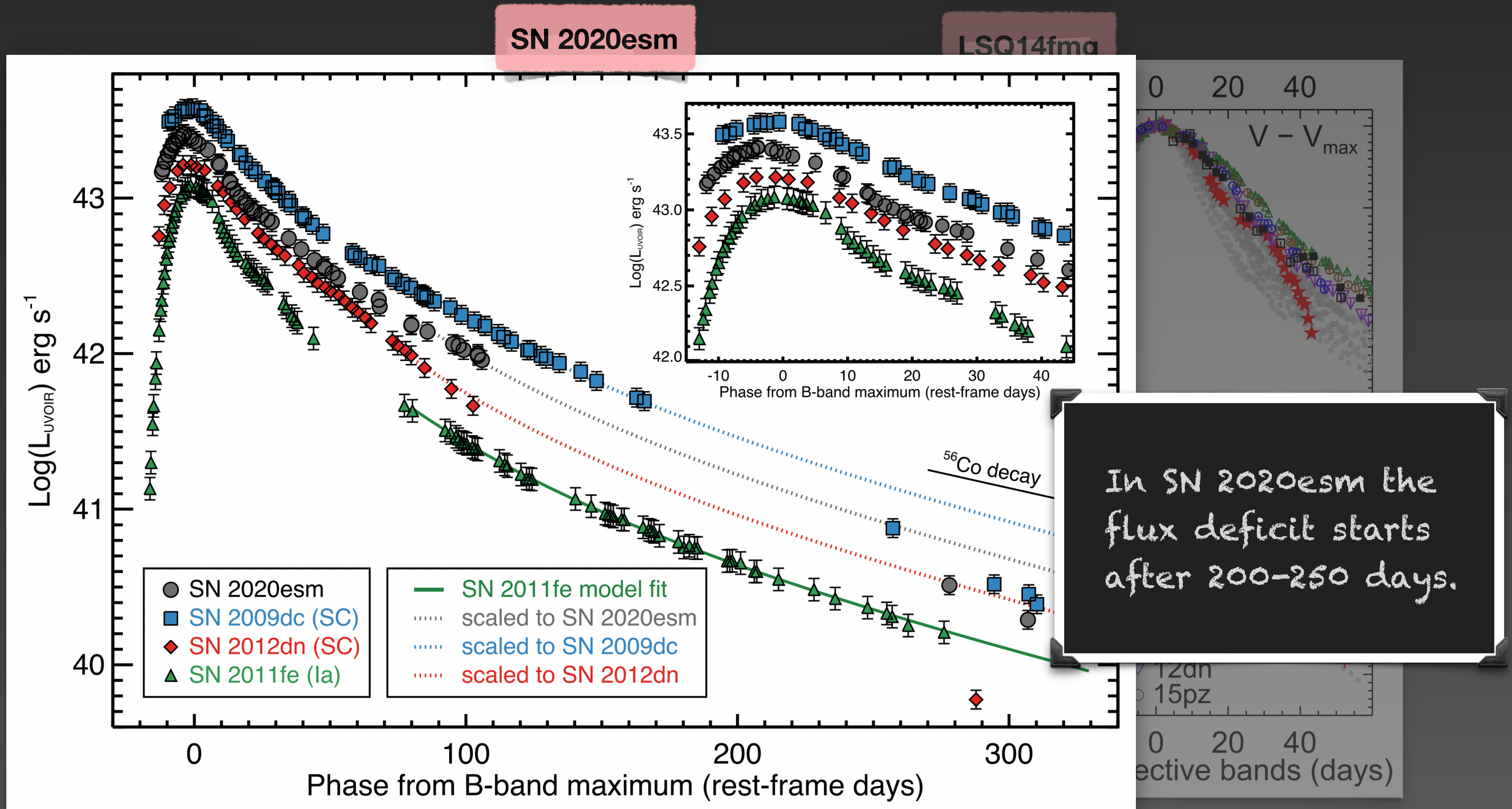


Late-time flux deficit

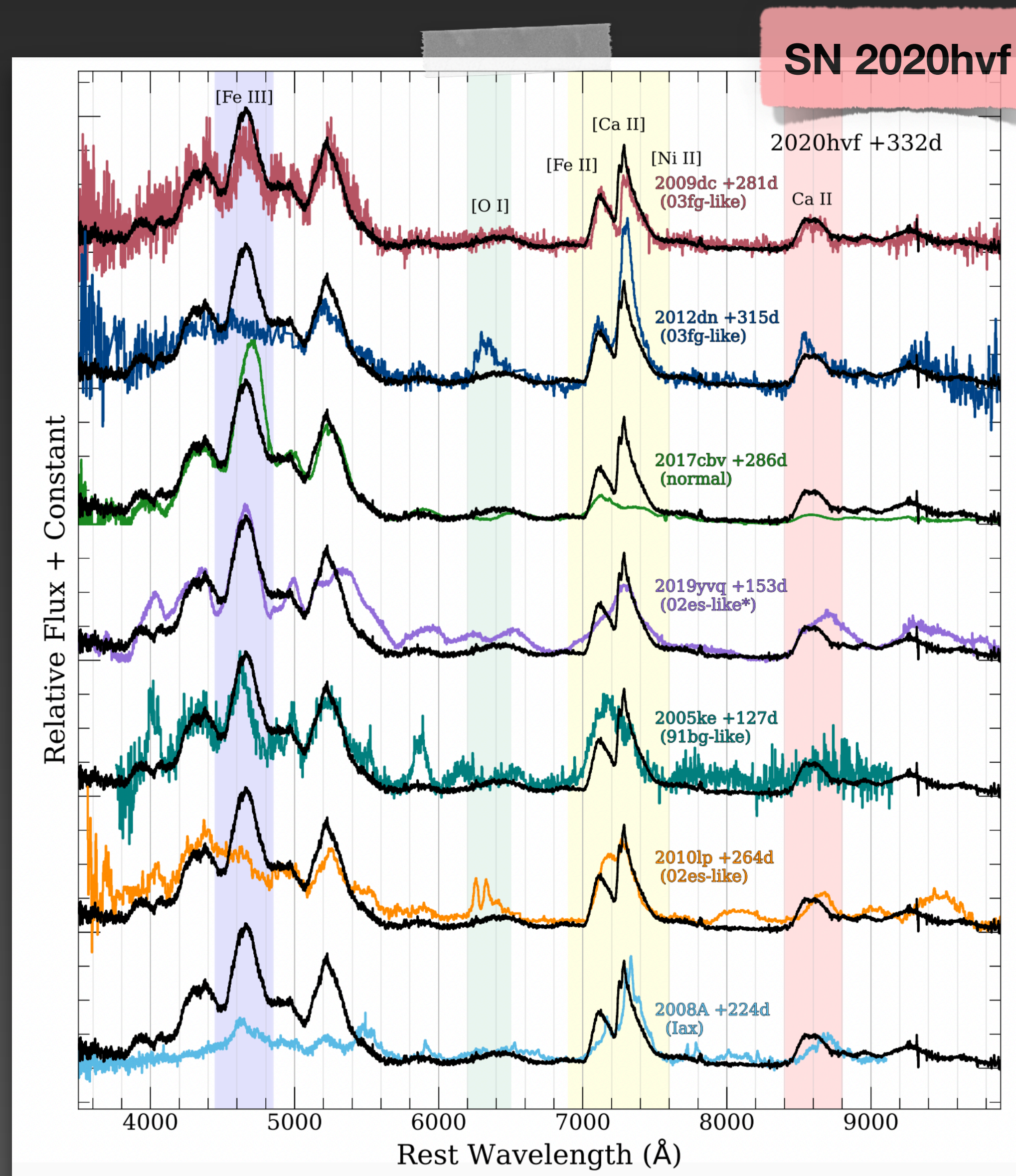
... and a flux deficit starting very early, around day 30.



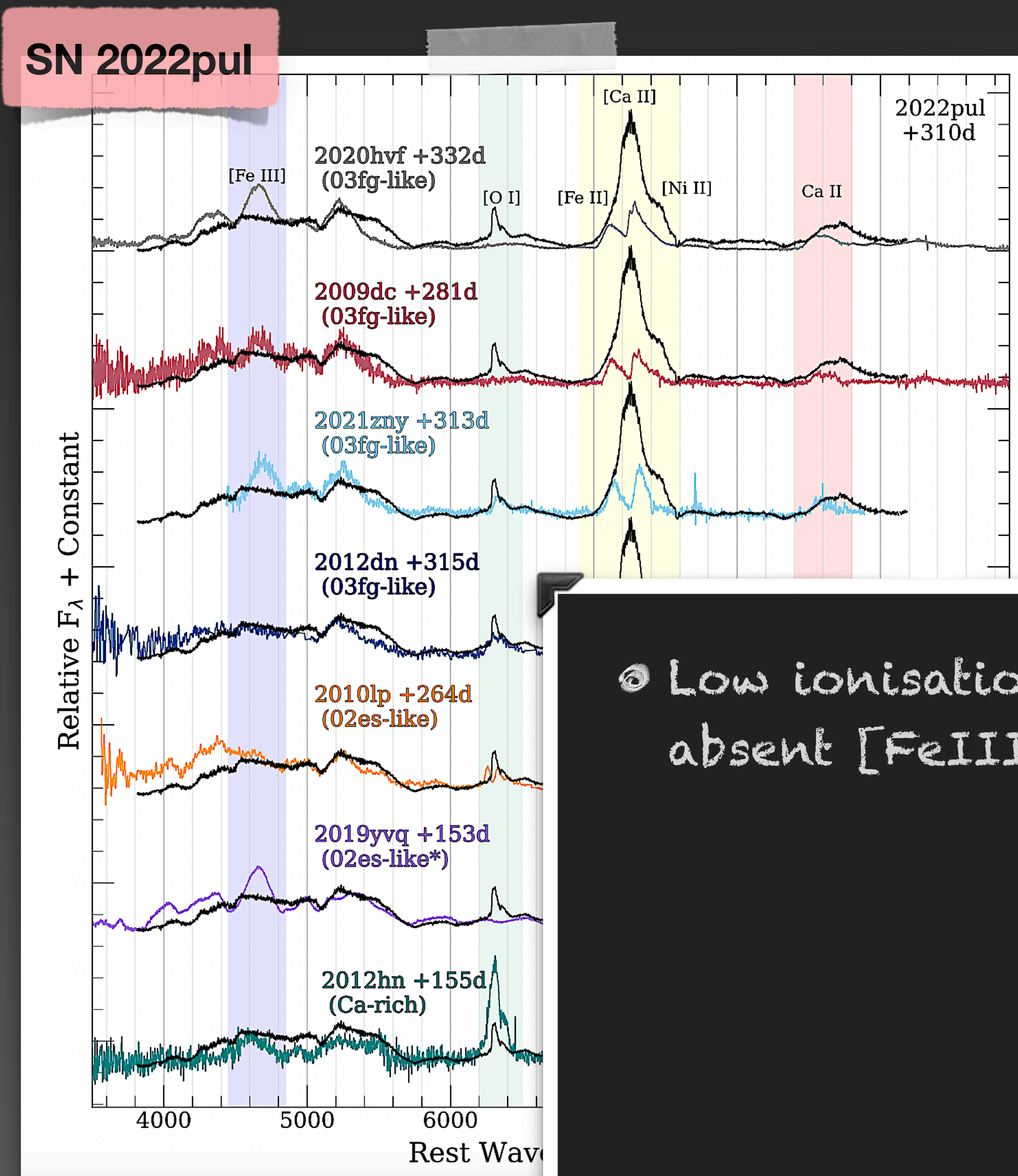
Late-time flux deficit



Nebular spectra



Siebert et al. 2023

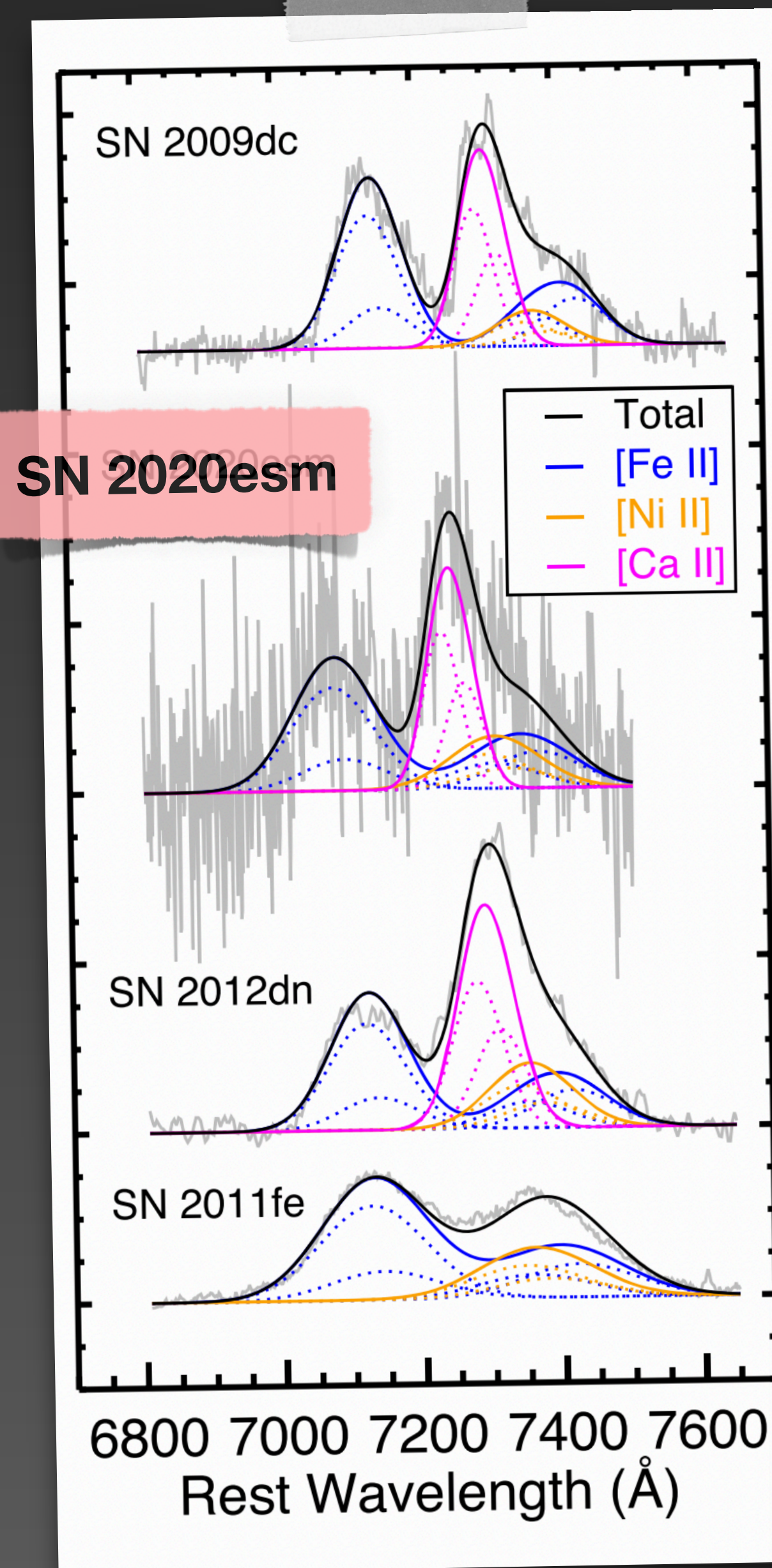


Siebert et al. 2024

⊙ Low ionisation (weak/absent [FeIII] lines)

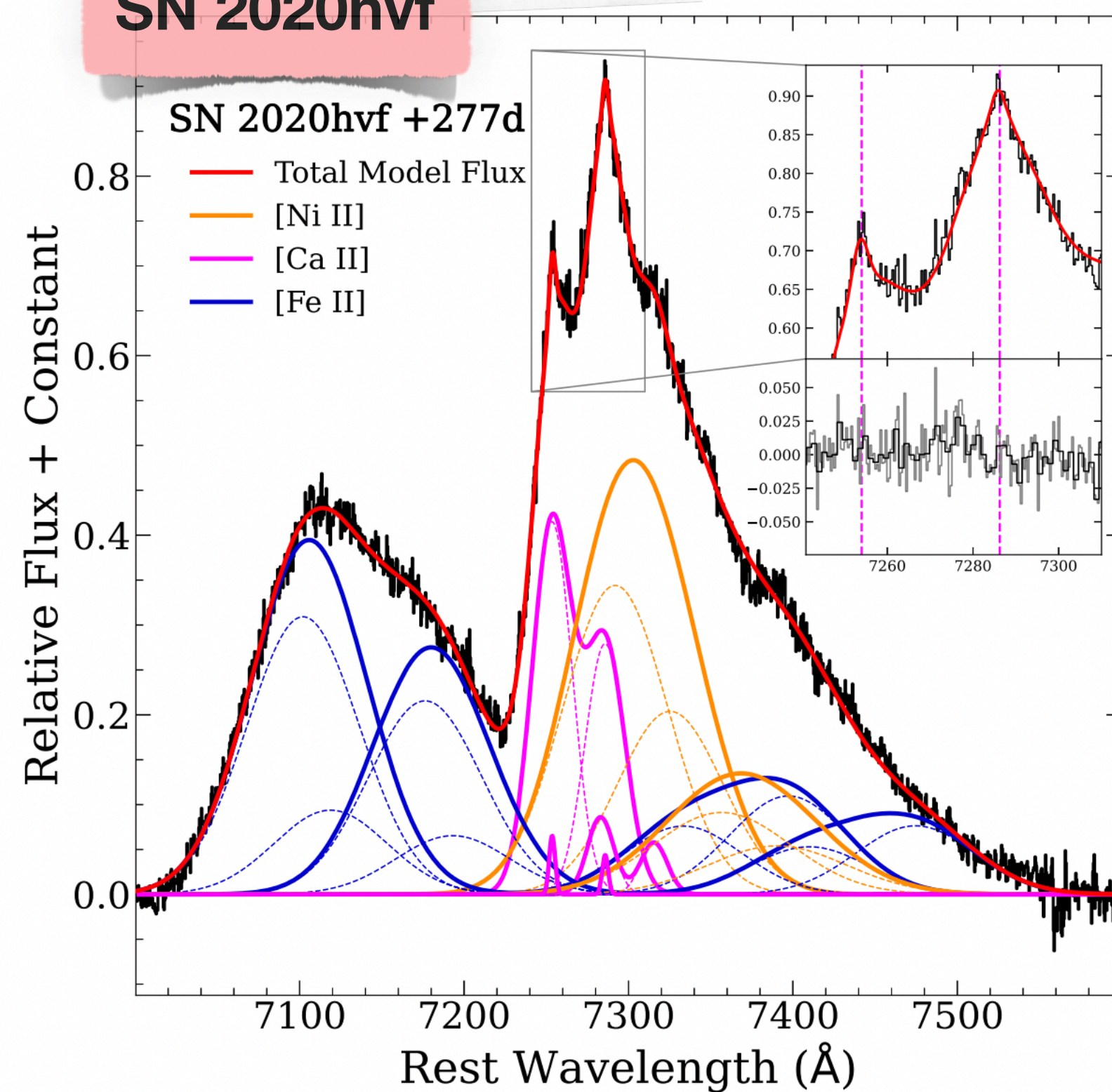
Nebular spectra

Dimitriadis et al. 2023



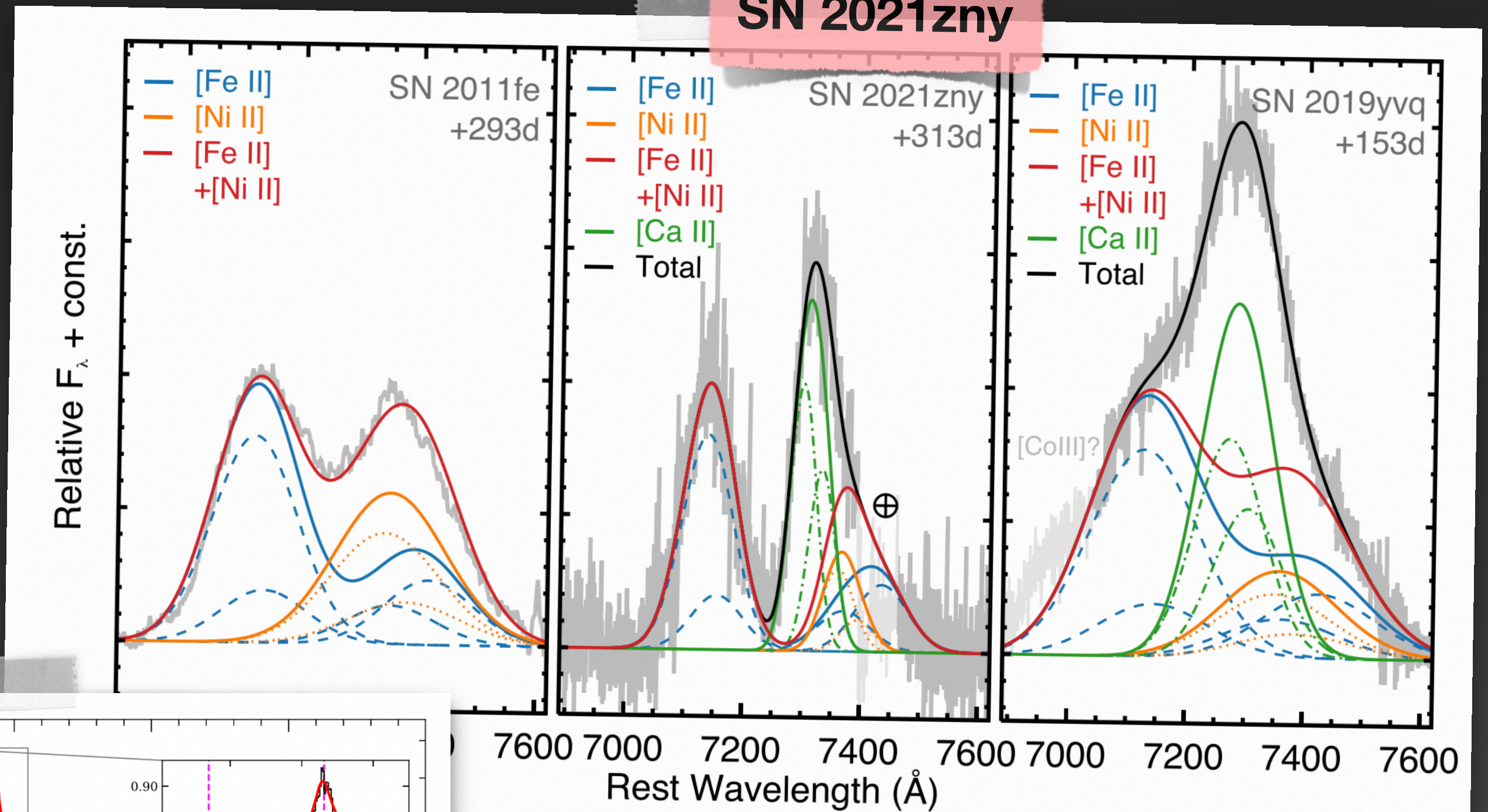
Dimitriadis et al. 2022

SN 2020hvf



Siebert et al. 2023

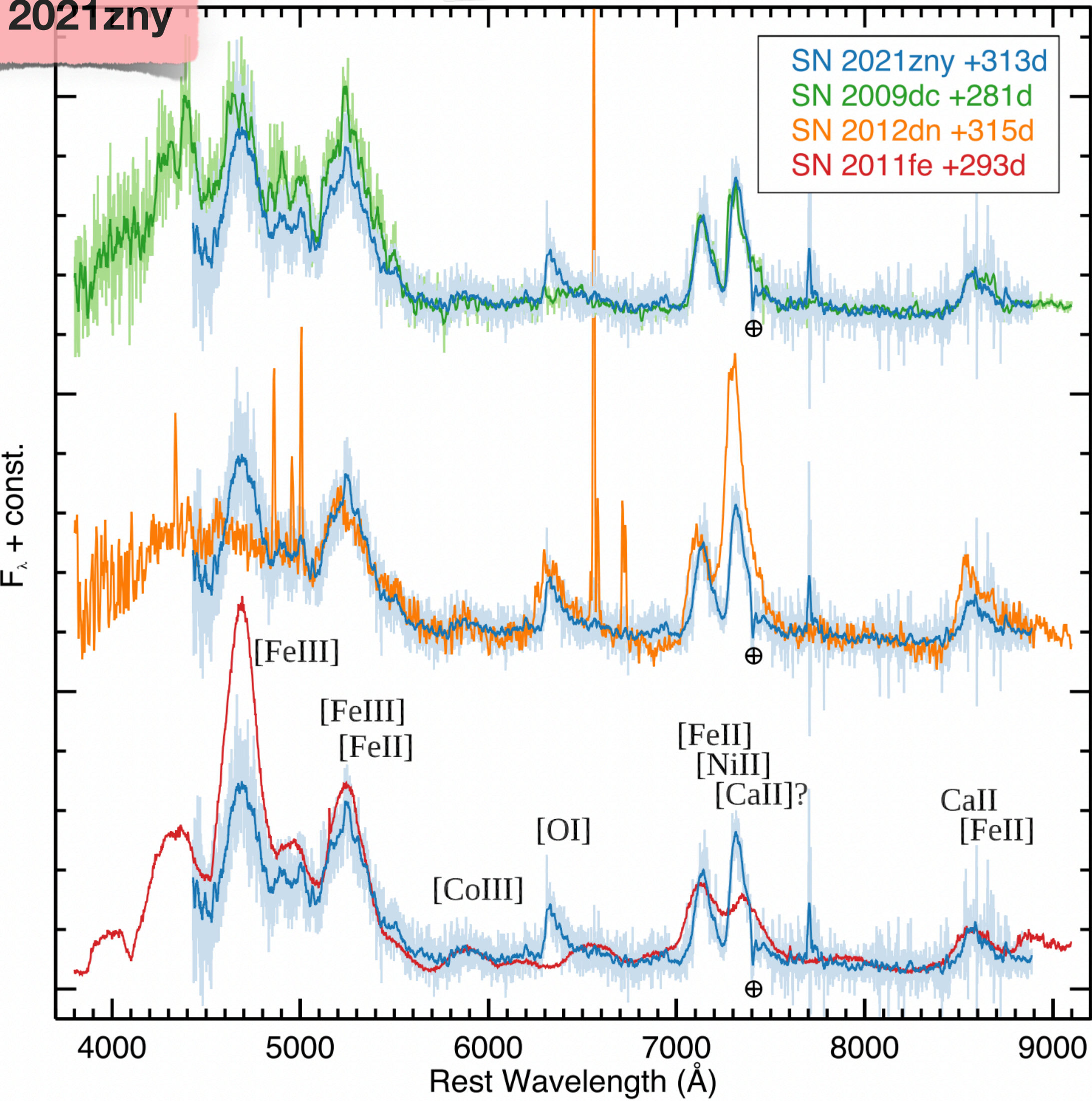
SN 2021zny



- Low ionisation (weak/absent [FeIII] lines)
- Strong [CaII]

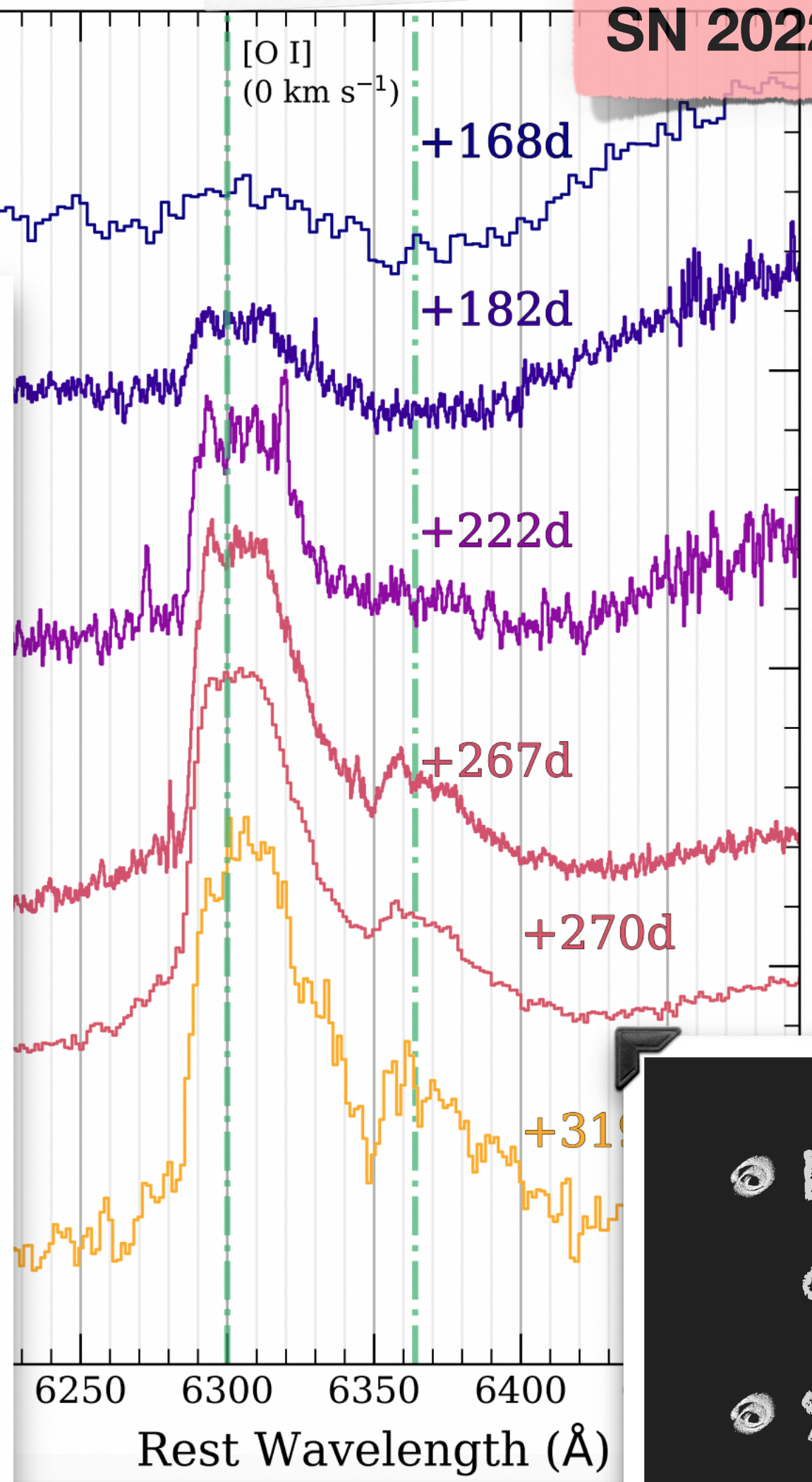
Nebular spectra

SN 2021zny



Dimitriadis et al. 2023

SN 2022pul

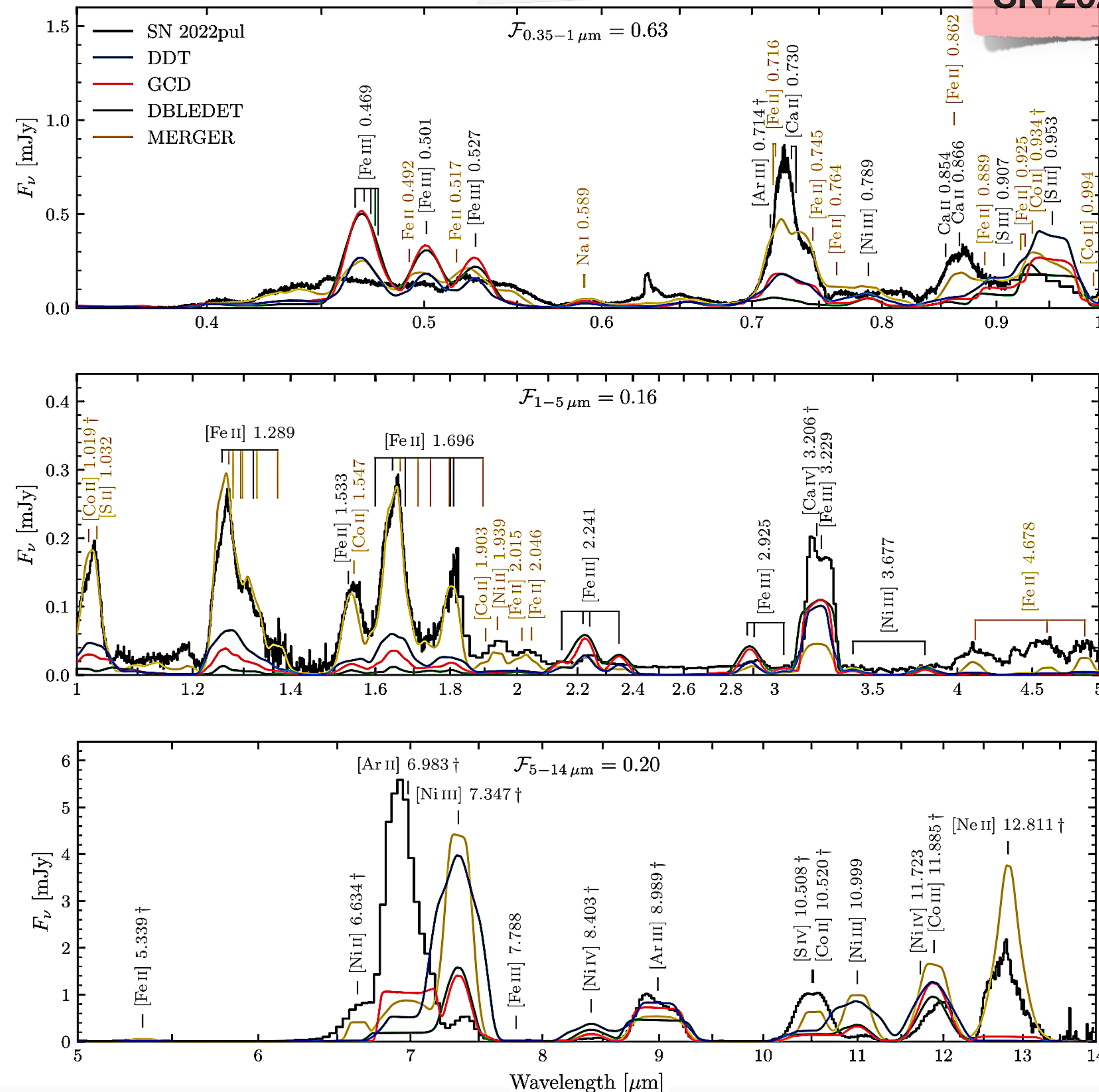


Kwok et al. 2024

- Low ionisation (weak/absent [FeIII] lines)
- Strong [CaII]
- Occasional [OI] ...

Nebular spectra

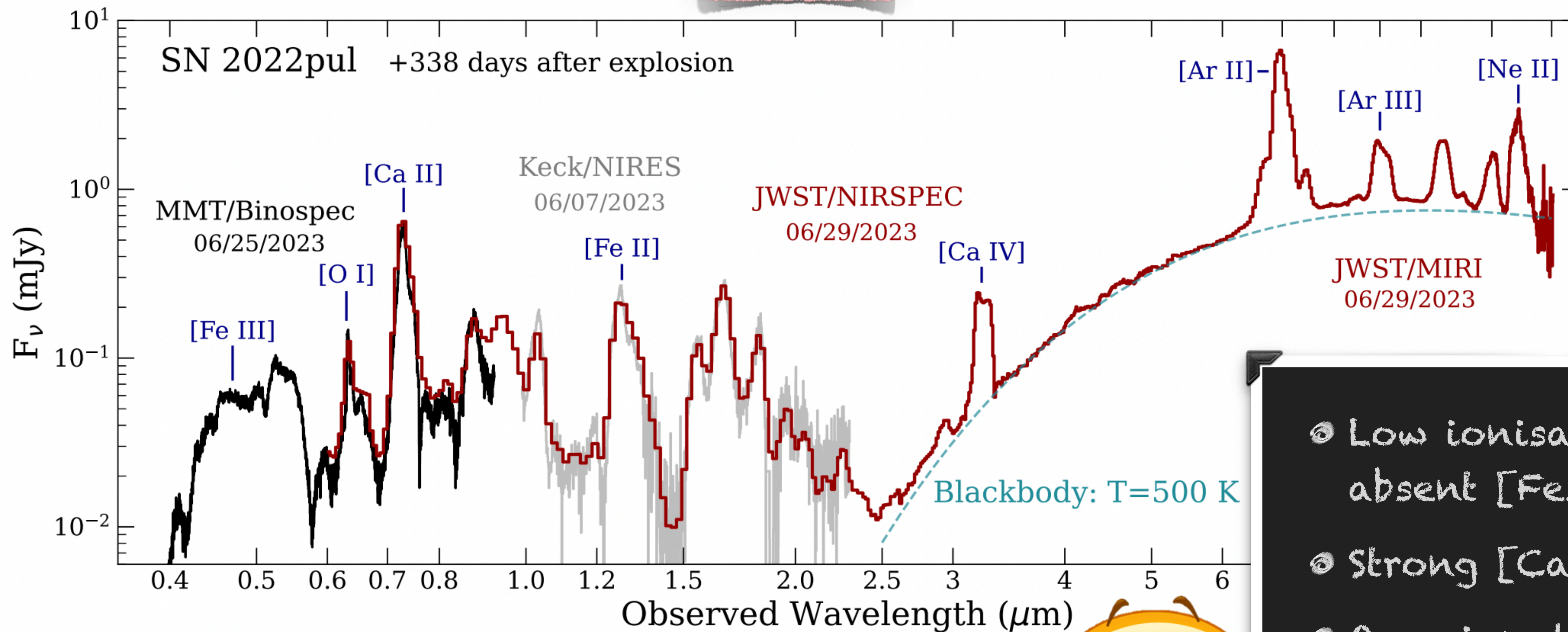
SN 2022pul



- Low ionisation (weak/absent [FeIII] lines)
- Strong [CaII]
- Occasional [OI] and [NeII]

Nebular spectra

SN 2022pul



Siebert et al. 2024



- Low ionisation (weak/absent [FeIII] lines)
- Strong [CaII]
- Occasional [OI] and [NeII]
- Blackbody emission from warm dust

Models

- Most people agree that 09dc-like SNe are NOT super-Chandra WDs
- WDs exploding in H/He-poor envelopes
- Two leading scenarios:

CO-CO WD mergers where the less massive WD gets disrupted and forms the envelope

Pros: no H/He in system, oxygen at centre of the ejecta plausible

Cons: most likely aspherical (polarimetry)

Core-degenerate scenario: explosion of the degenerate C/O core of an AGB star

Pros: spherical symmetry

Cons: hard to get envelope H/He-free, no oxygen at centre of explosion

Possible link between 09dc-like and 02es-like SNe

- ALL SNe Ia with an early bump are either 09dc- or 02es-like
- Their UV-optical colours are similar and distinct from all other SNe Ia
- [OI] detected in nebular spectra of six 09dc-like or 02es-like SNe, but not in a single normal SN Ia

Hoogendam et al. 2024

