Bridging our knowledge gap of supernova properties in the infrared

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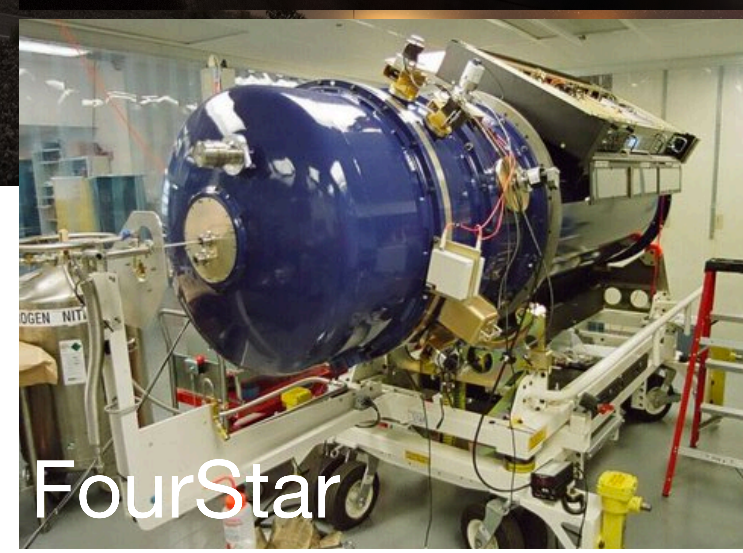
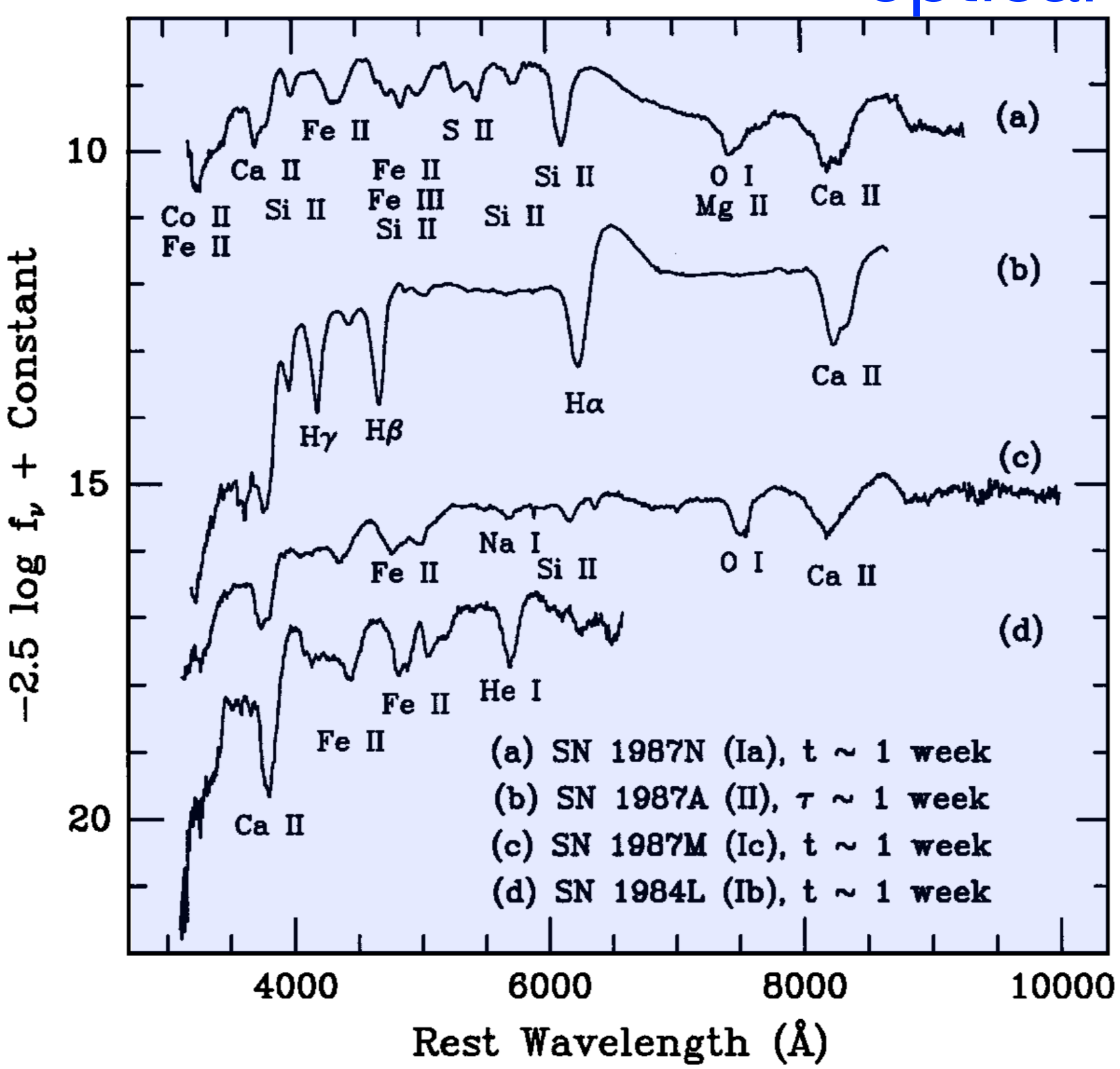
Carnegie Supernova Project-II (CSP-II)



Phillips et al. (2019)
Hsiao et al. (2019)

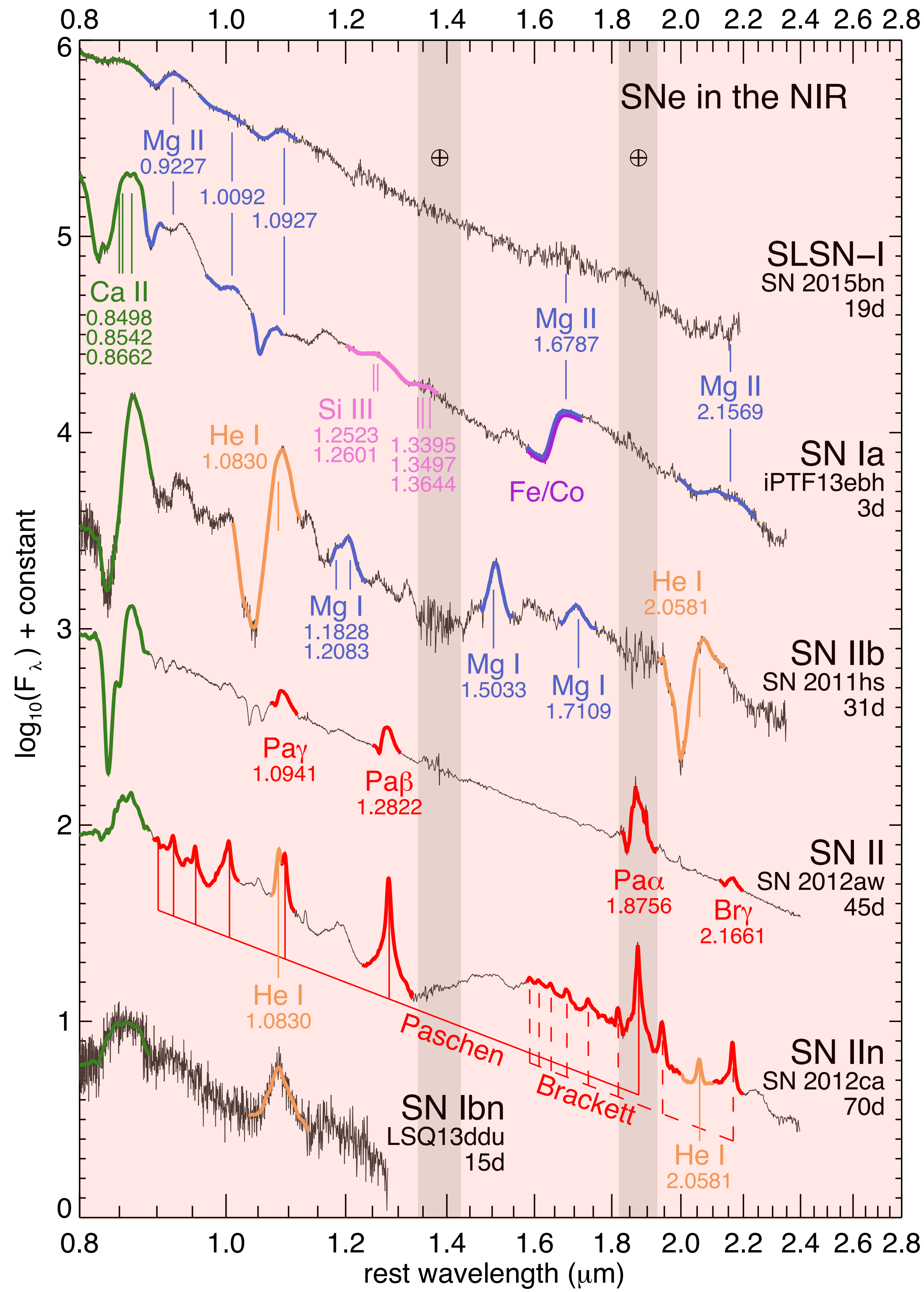
Carnegie Supernova Project-II (CSP-II)

optical

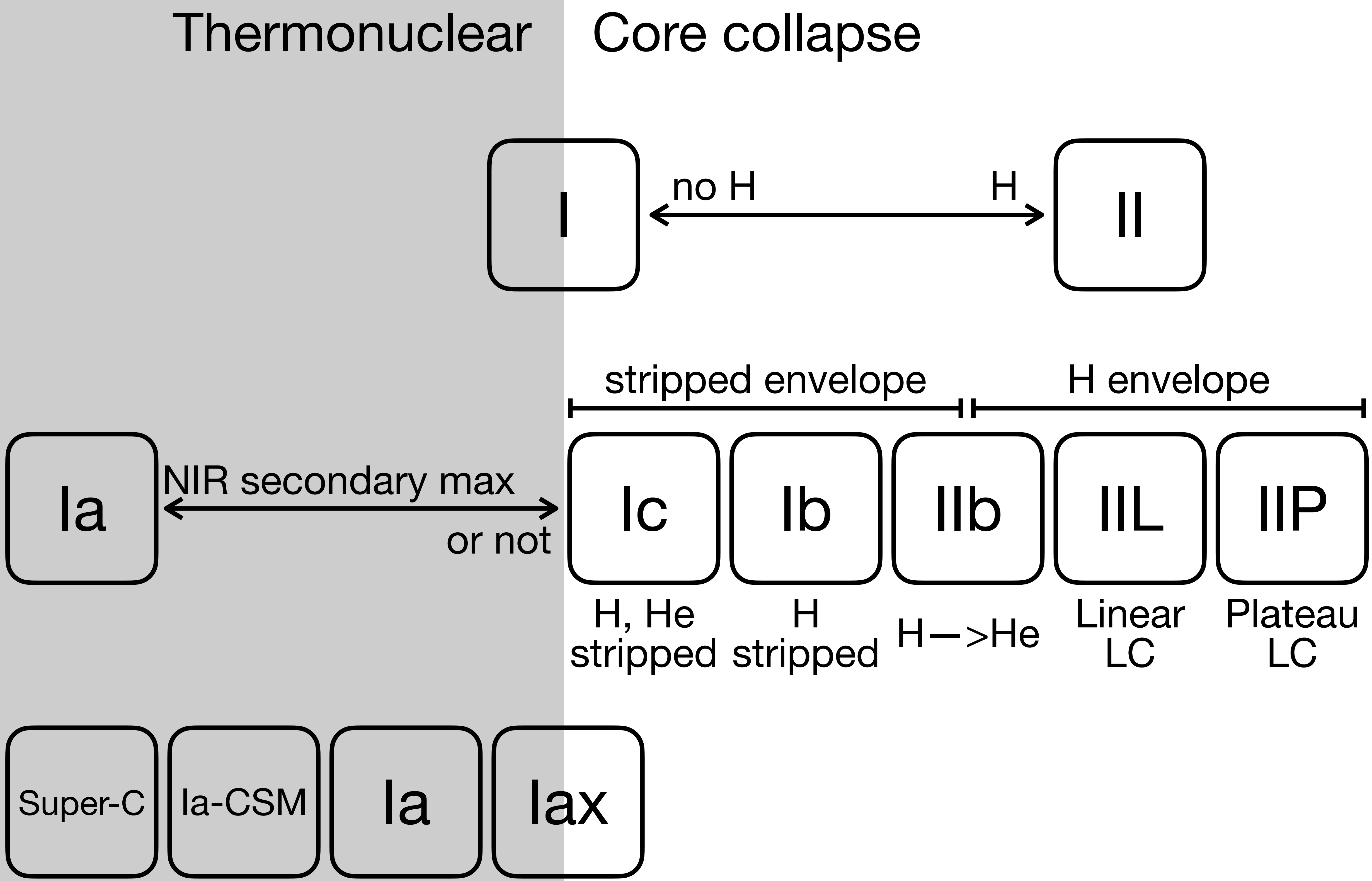


Filippenko (1997)

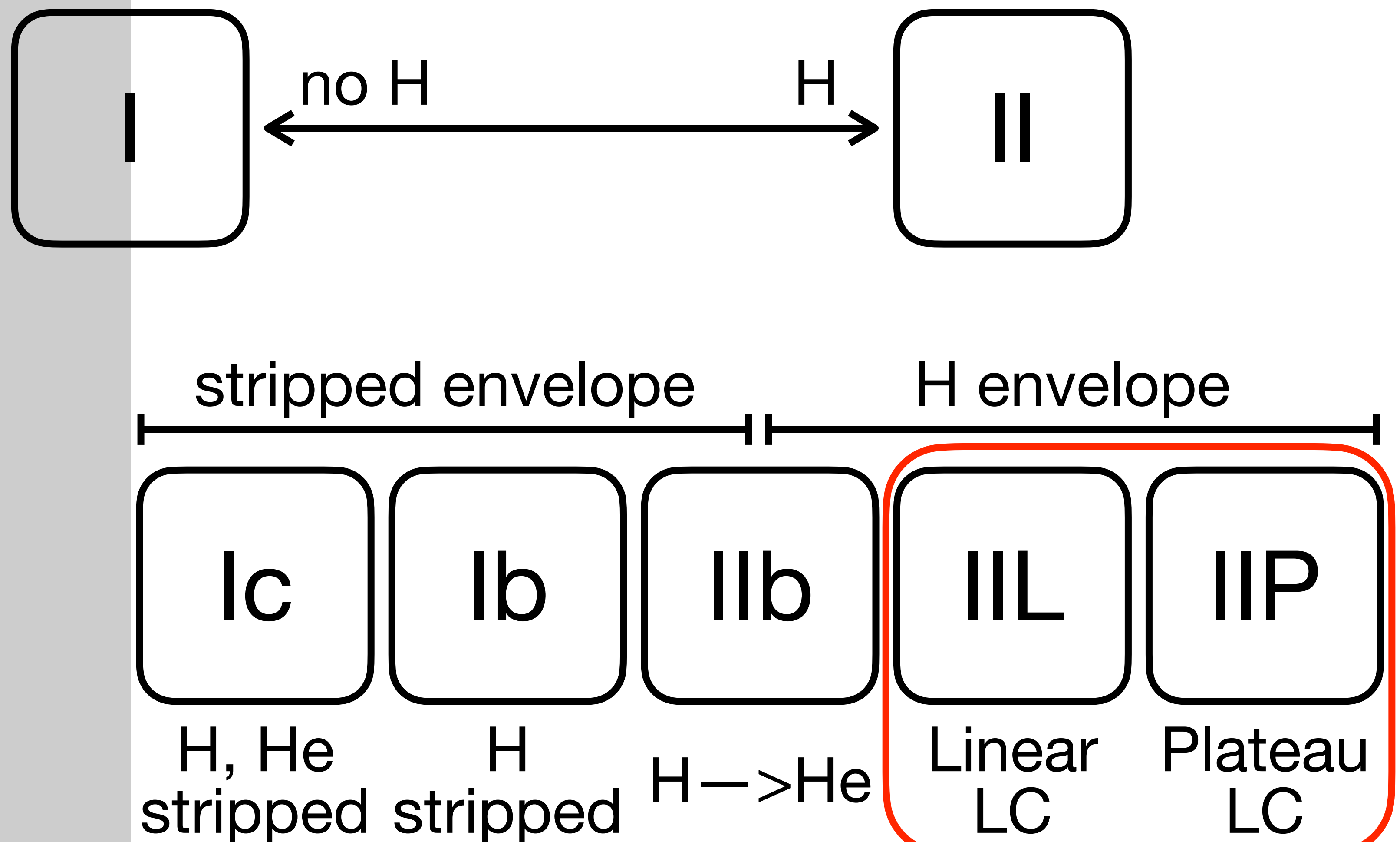
NIR



Hsiao et al. (2019)

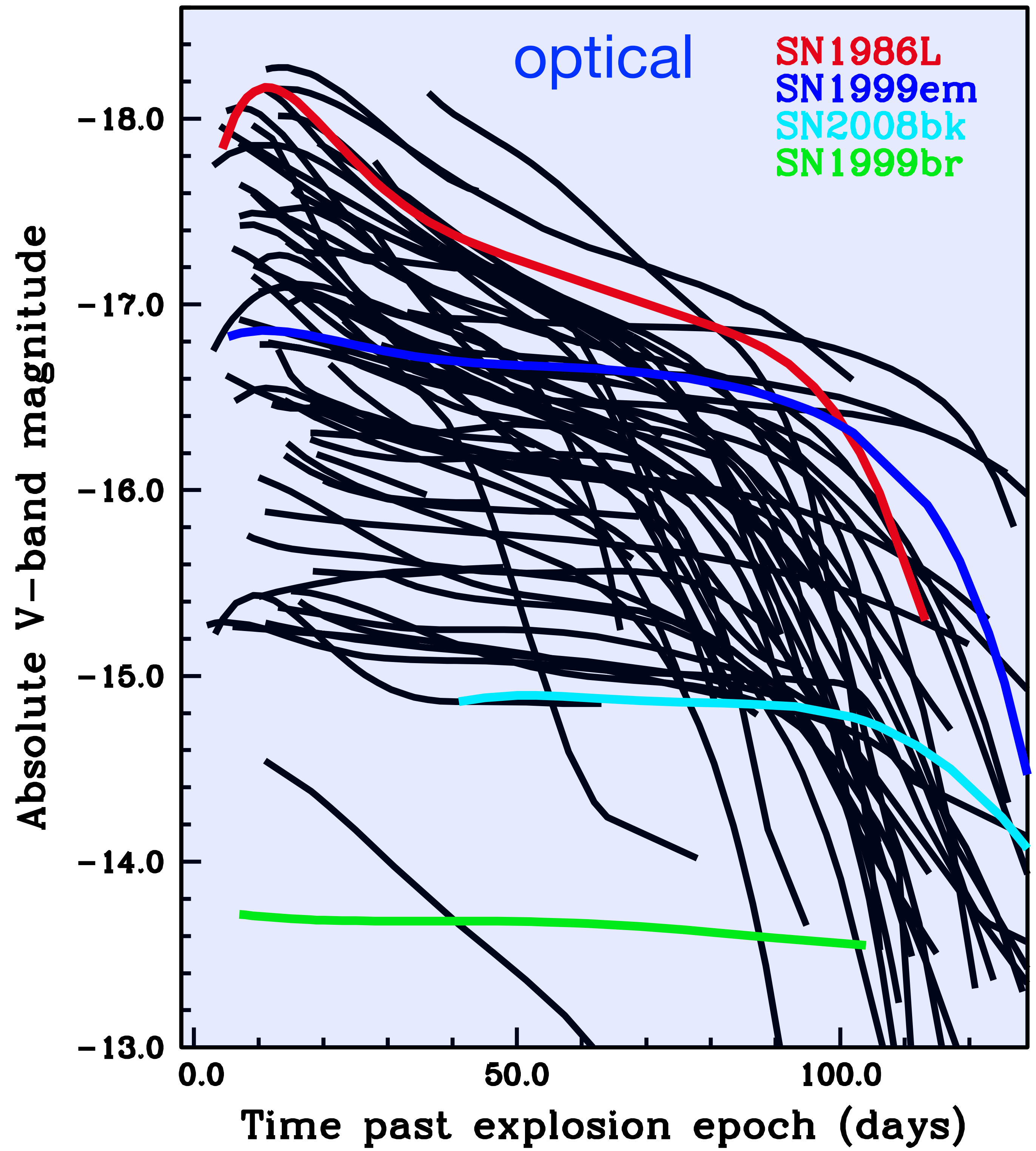

Thermonuclear
Core collapse
I
no H
H
II
stripped envelope
H envelope
Ia
NIR secondary max
or not
Ic
Ib
IIb
IIL
IIP
H, He stripped
H stripped
H—>He
Linear LC
Plateau LC
Super-C
Ia-CSM
Ia
Iax

Core collapse



Type IIP/IIL

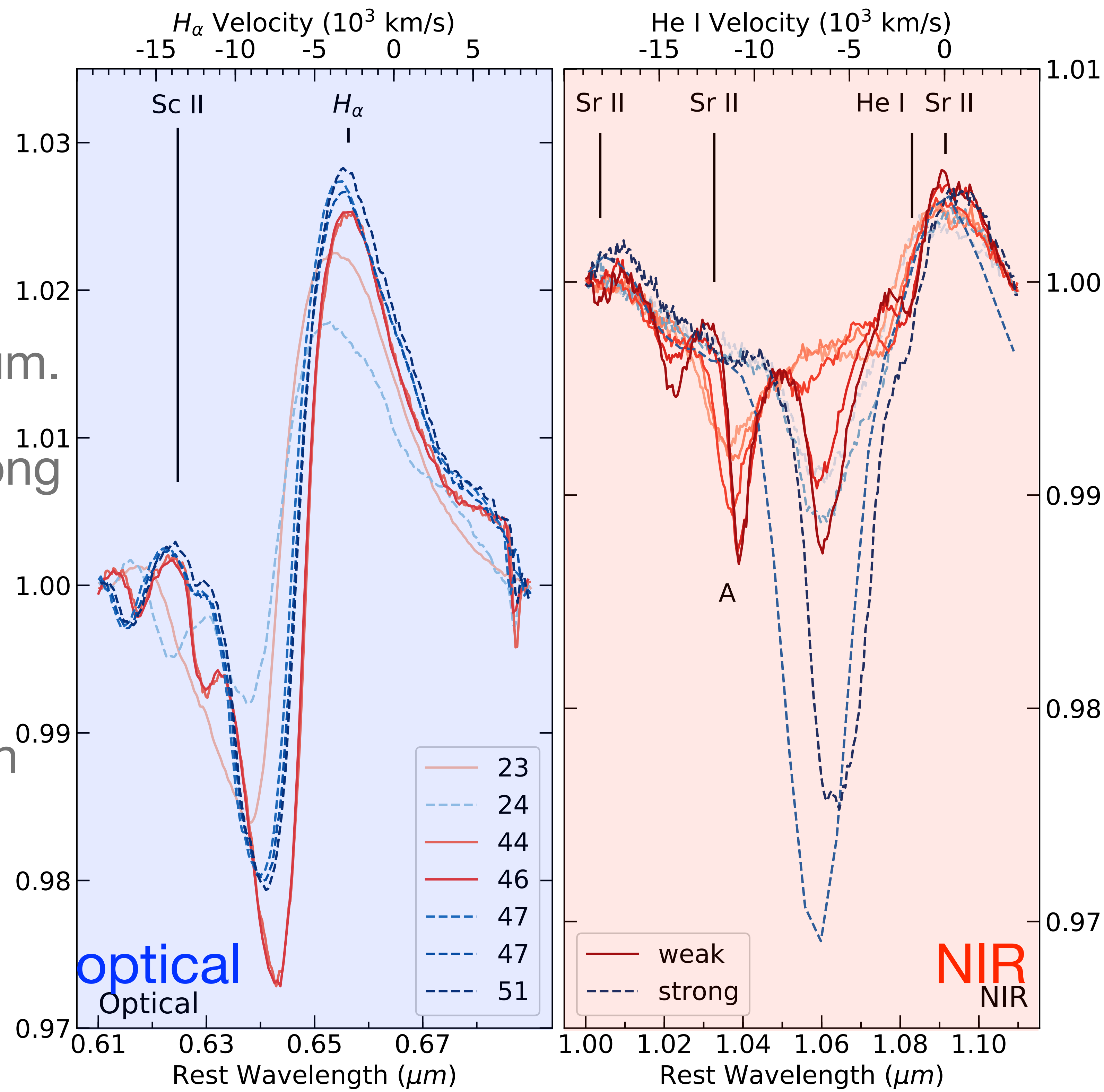
- In the optical, IIP/IIL show a continuous range of photometric and spectroscopic properties.
- Suggests a single family.
- IIP/IIL sub-classifications may be an arbitrary one.



Anderson et al. (2014)

Type IIP/IIL

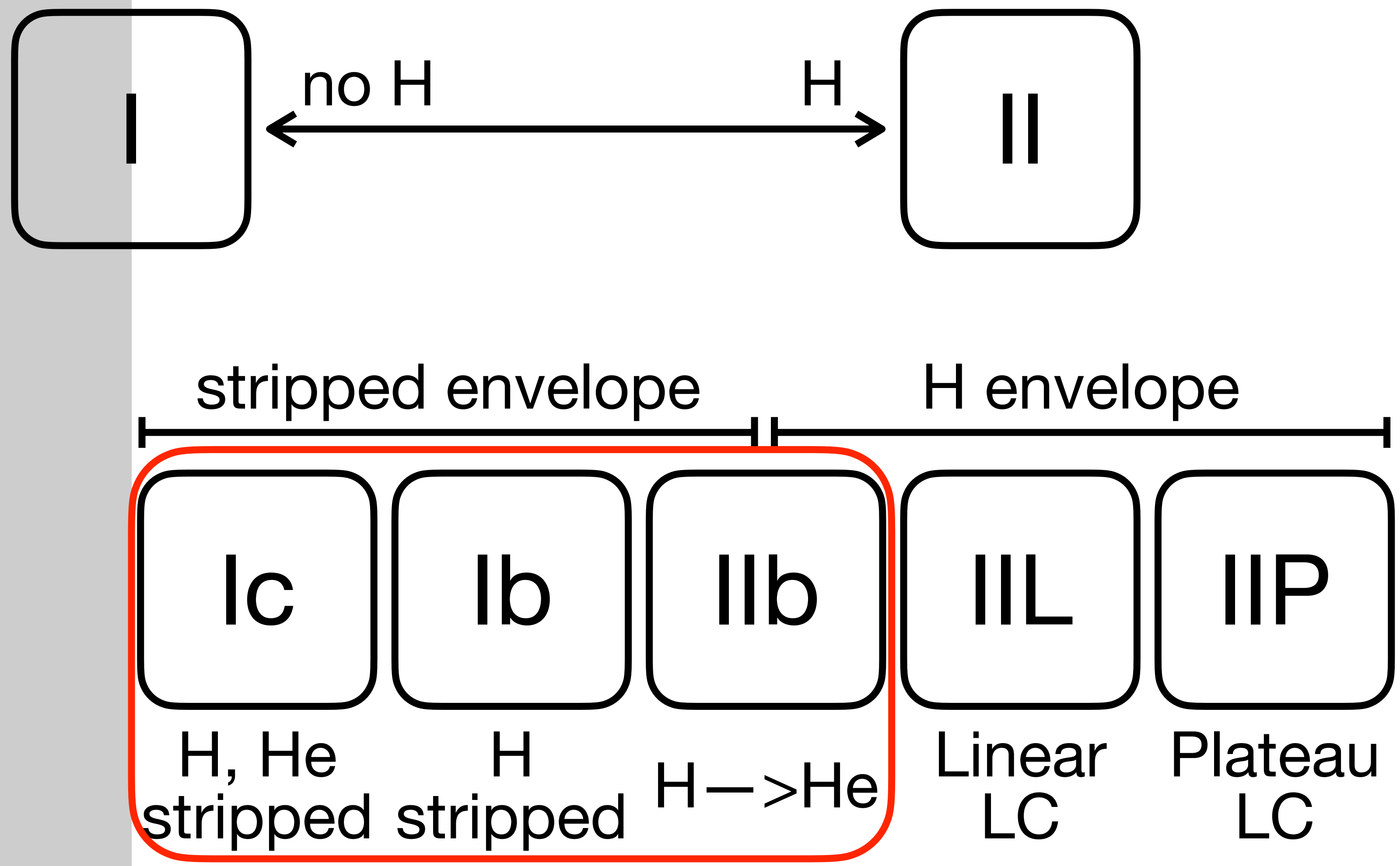
- However, NIR spectra show a clear dichotomy: weak and strong He I 1.083µm.
- Surprisingly, types weak/strong correspond to IIP/IIL, contradicting optical results.
- High-velocity He feature may be formed by interaction with circumstellar material.



Davis, Hsiao et al. (2019)

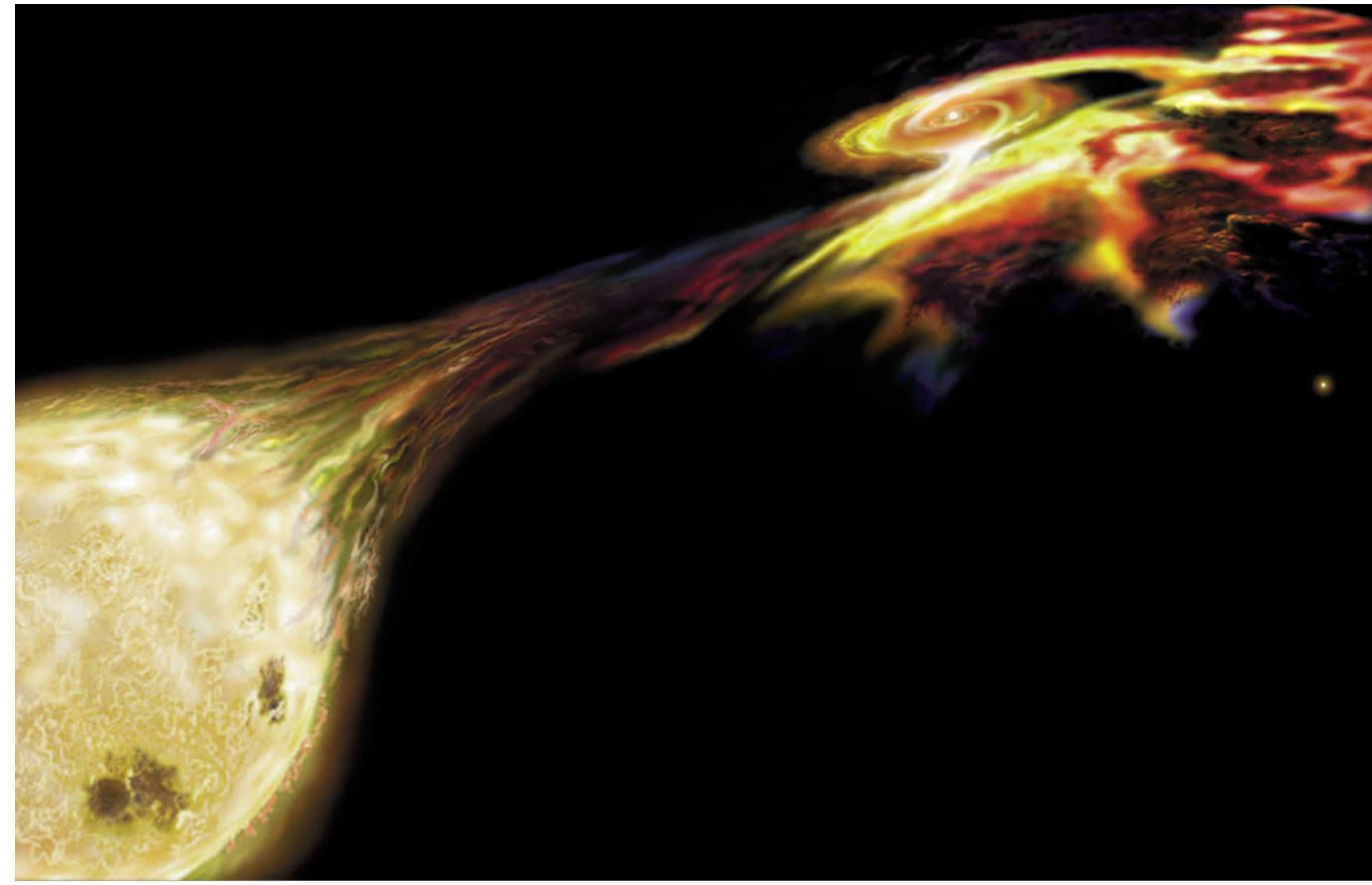
Based on 81 NIR spectra

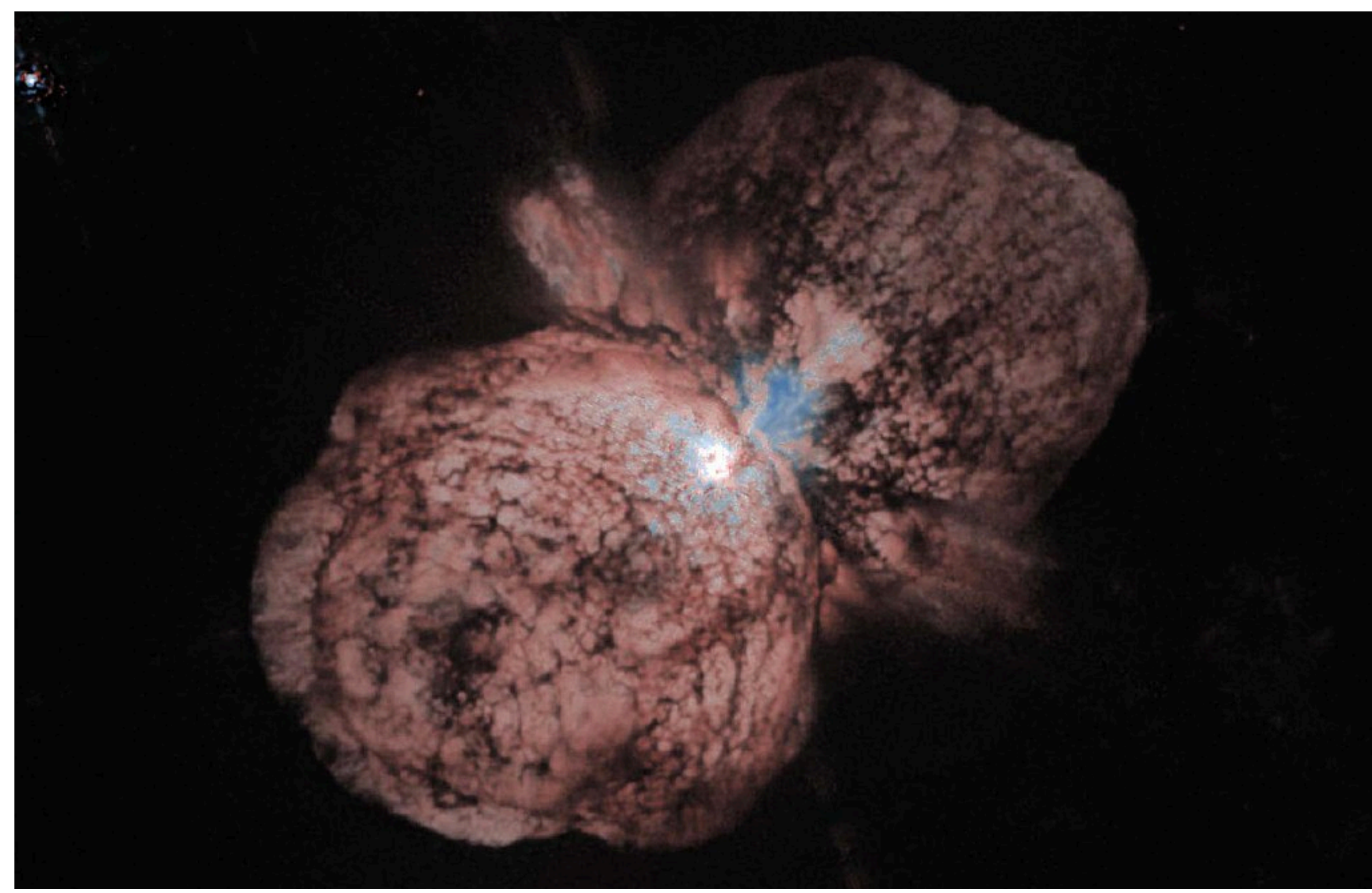
Core collapse



SE-SN

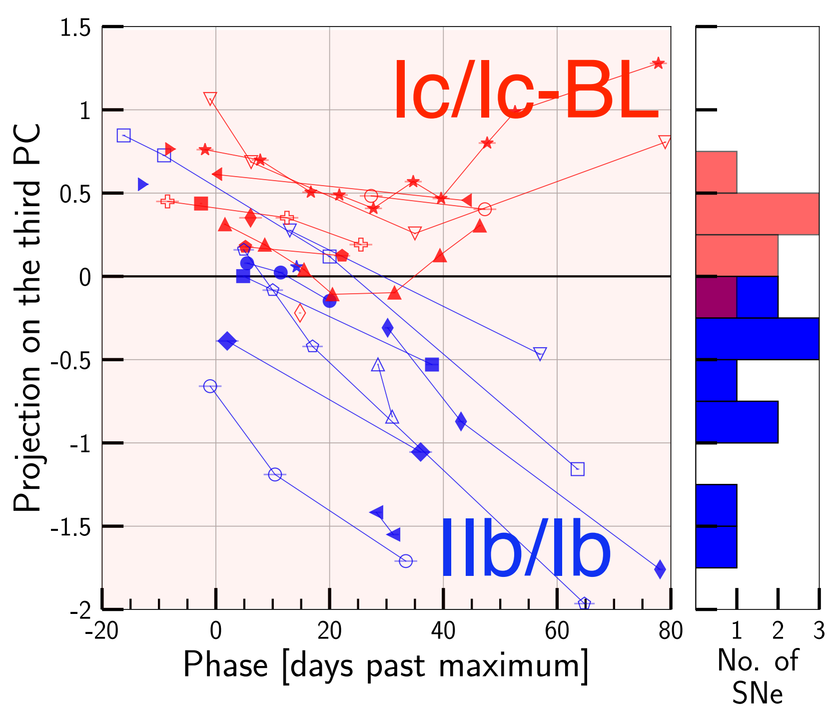
- The mass-loss mechanisms for high-mass stars are uncertain.
- In particular, how does the progenitor star of a Type Ic get stripped of both its H and He envelopes?
- Do Type Ic's in fact harbor He, but not detected in the optical?

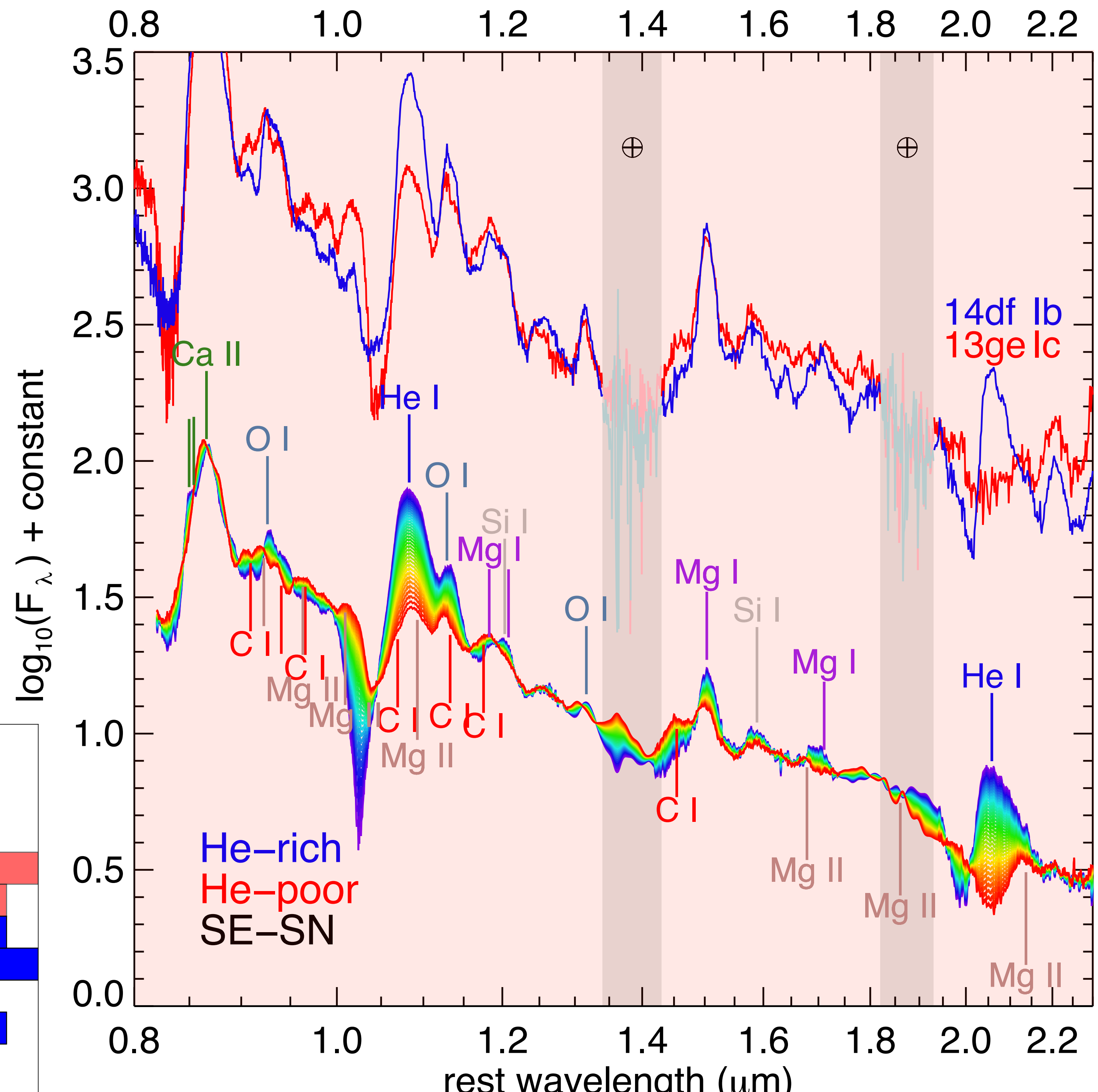




SE-SN

- PCA detects two distinct groups.
  - He-rich: He I, Mg I
  - He-poor: C I, Mg II
- They correspond perfectly to the optical Ib/Ic with the main difference at the 2 μm feature.

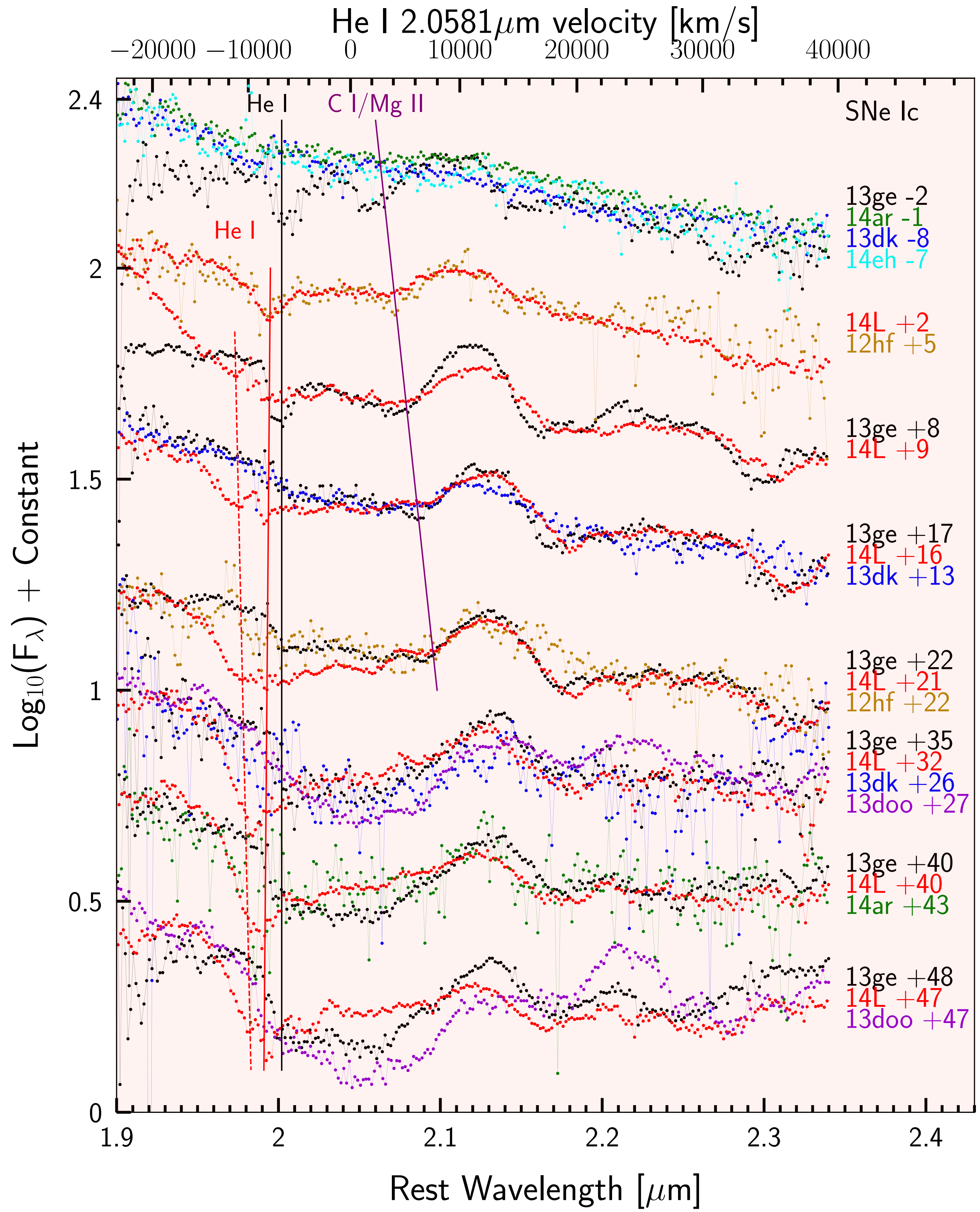




Shahbandeh, Hsiao et al. (2022)
Based on 75 NIR spectra

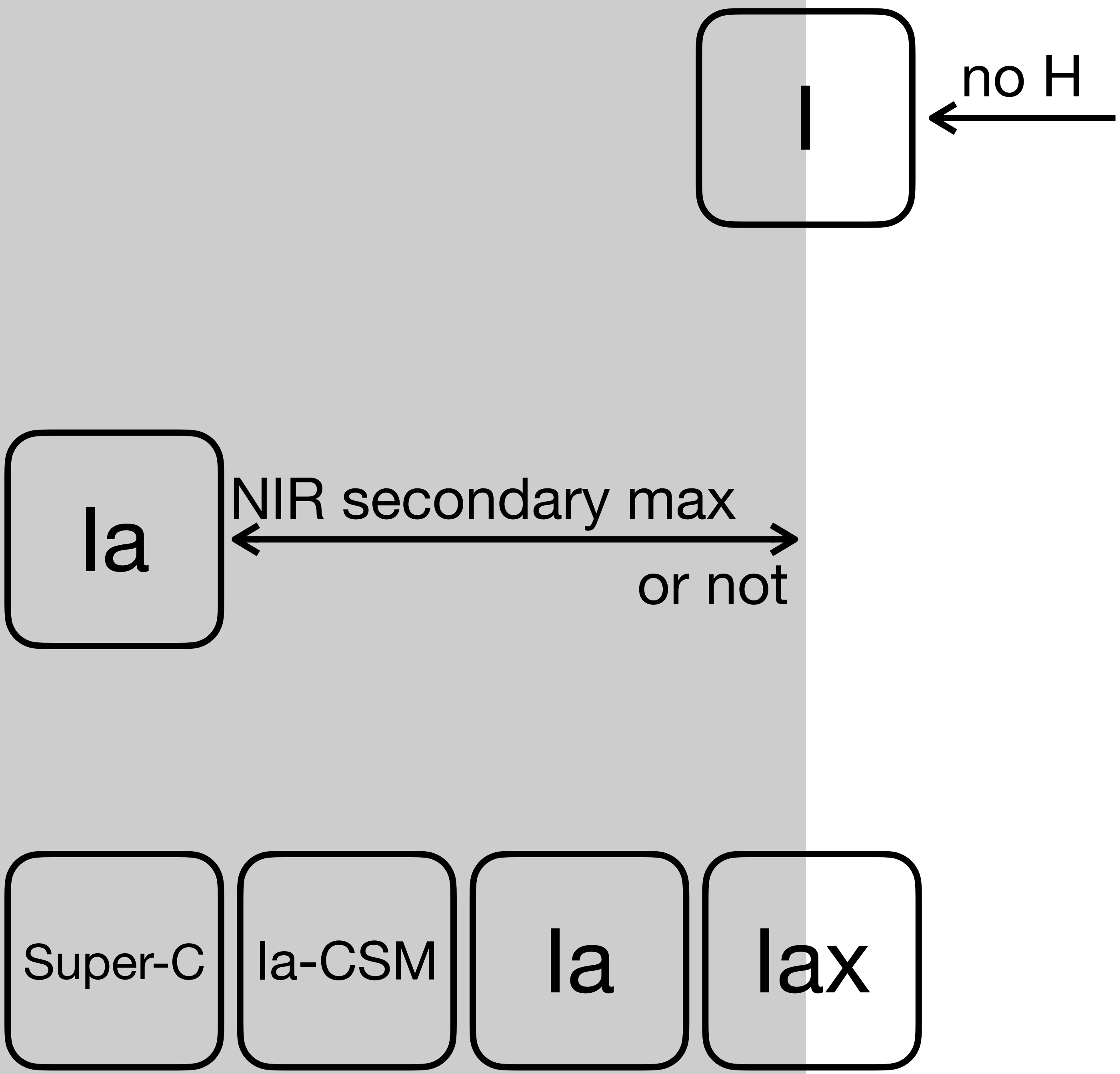
SE-SN

- 1/2 of the SNe Ic in our sample show weak He I 2.058μm features.
- There are sometimes multiple components present at different velocities and phases.



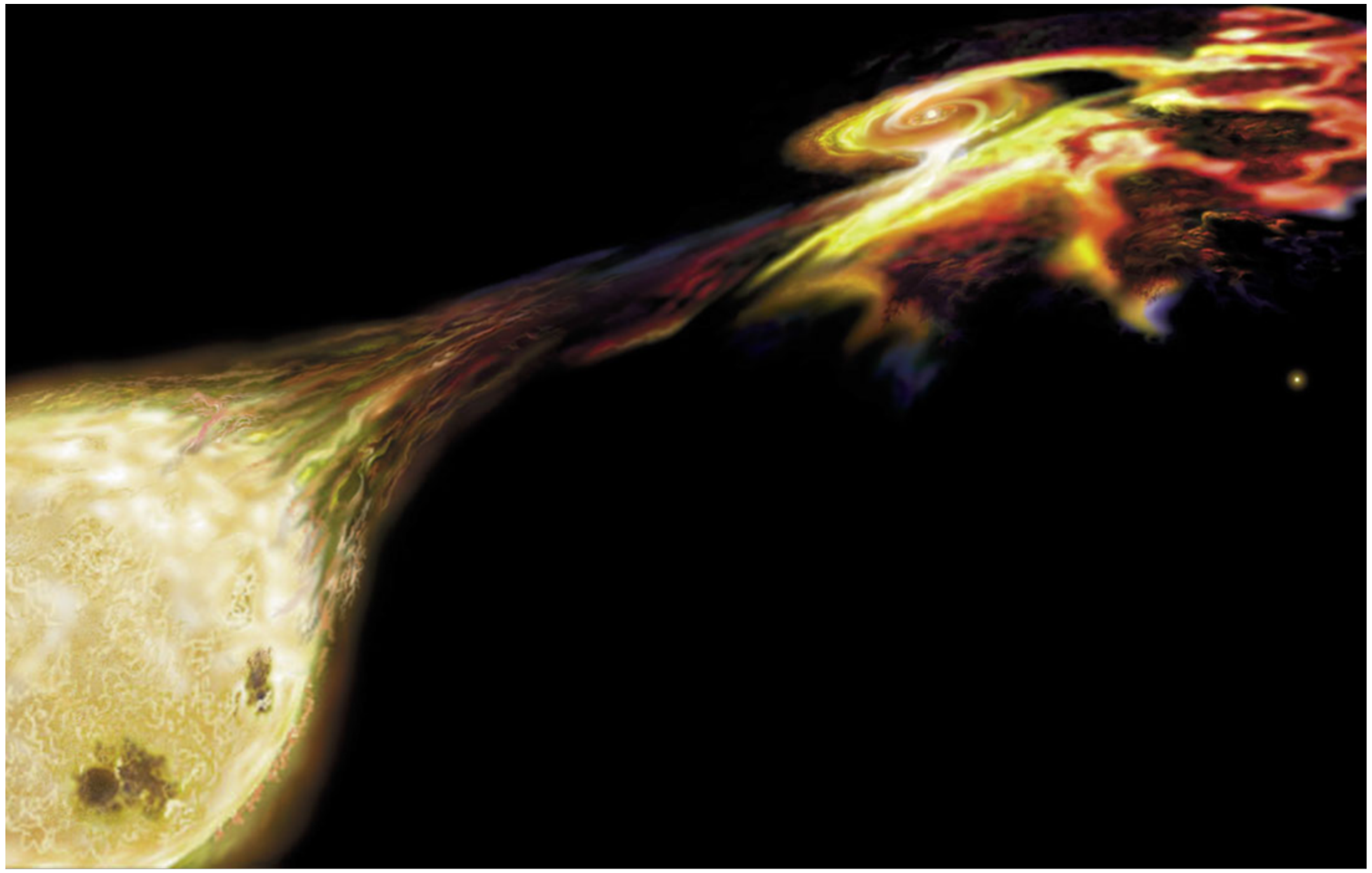
Shahbandeh, Hsiao et al. (2022)

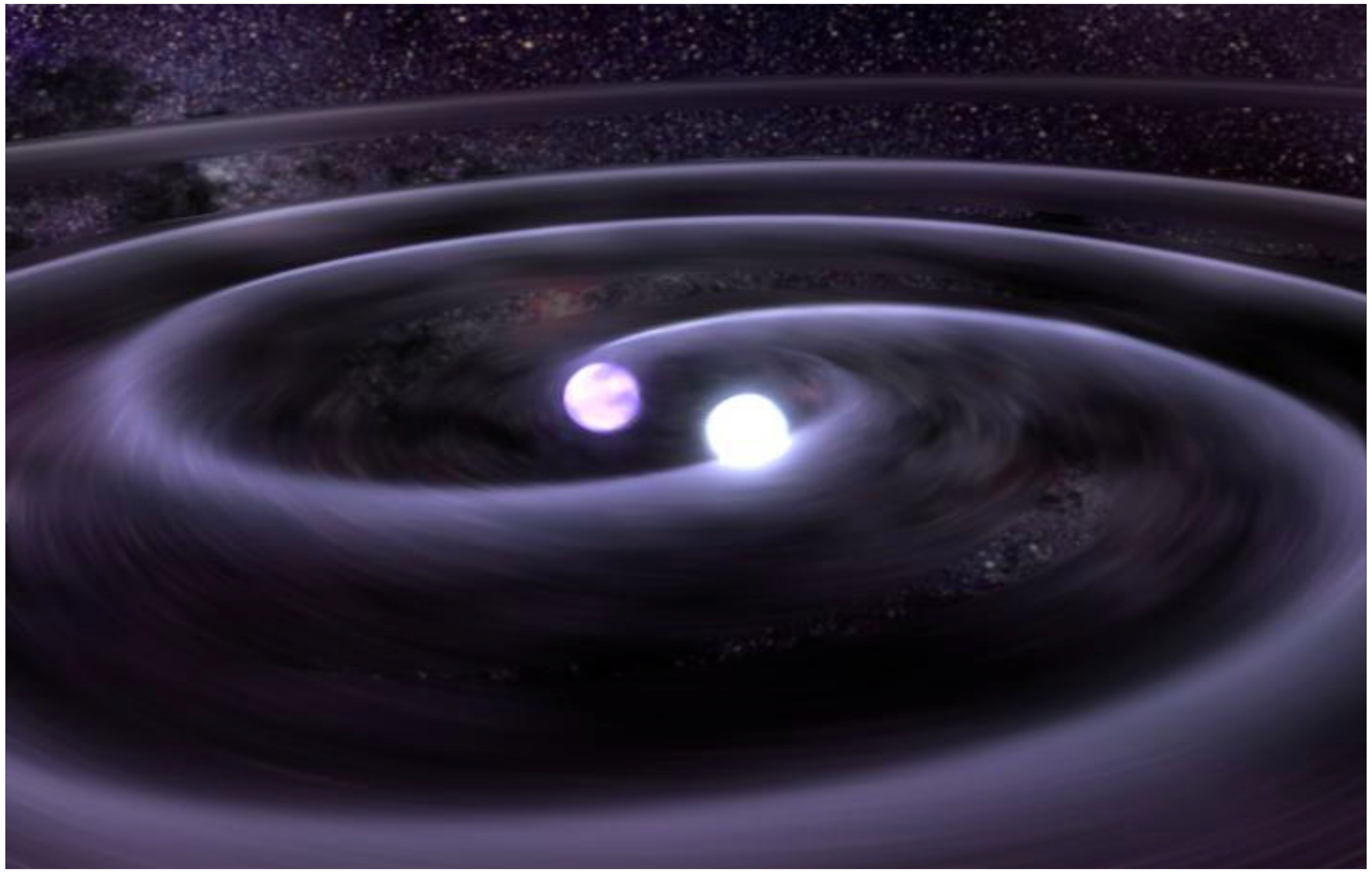
Thermonuclear

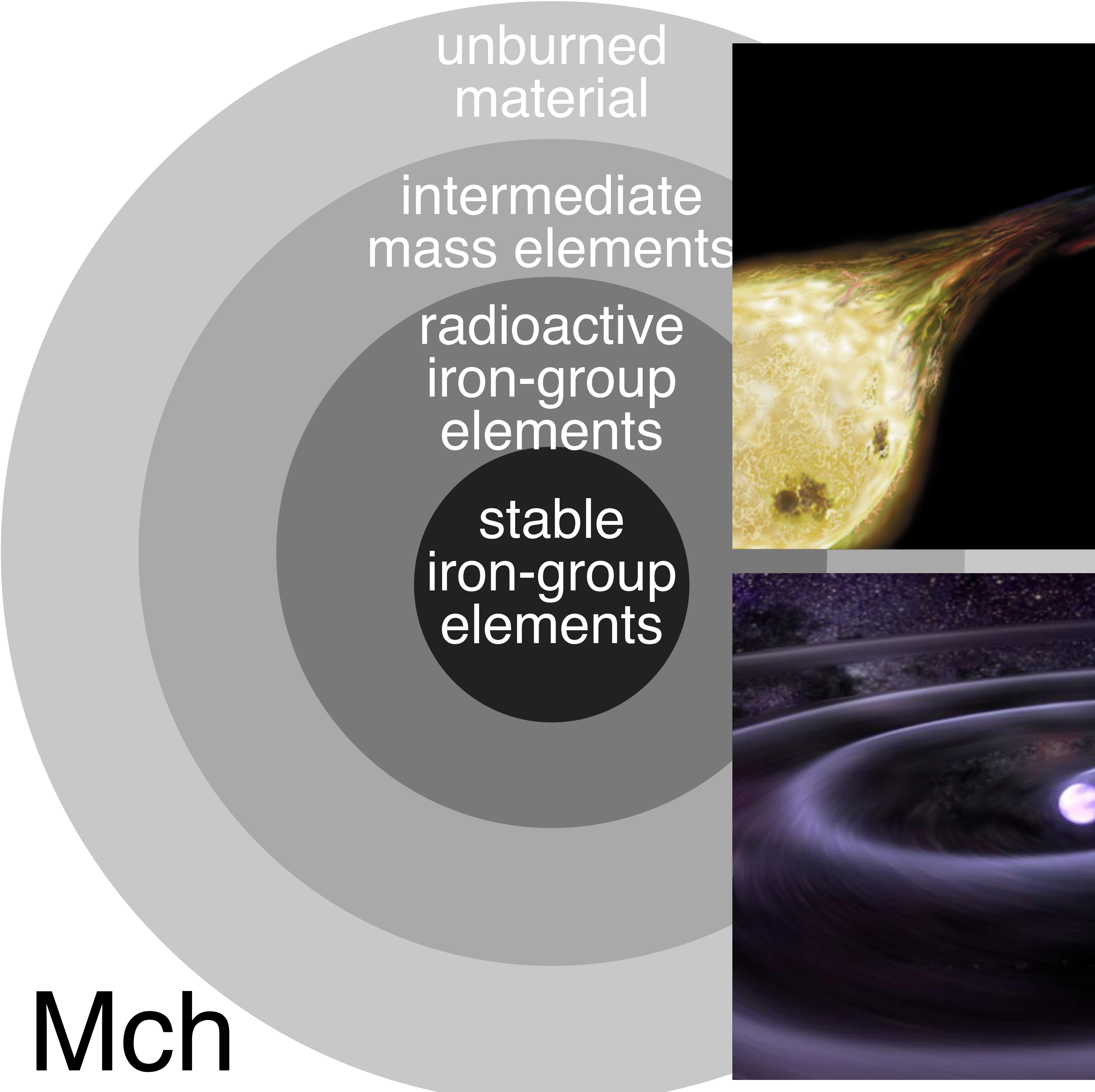


Type Ia

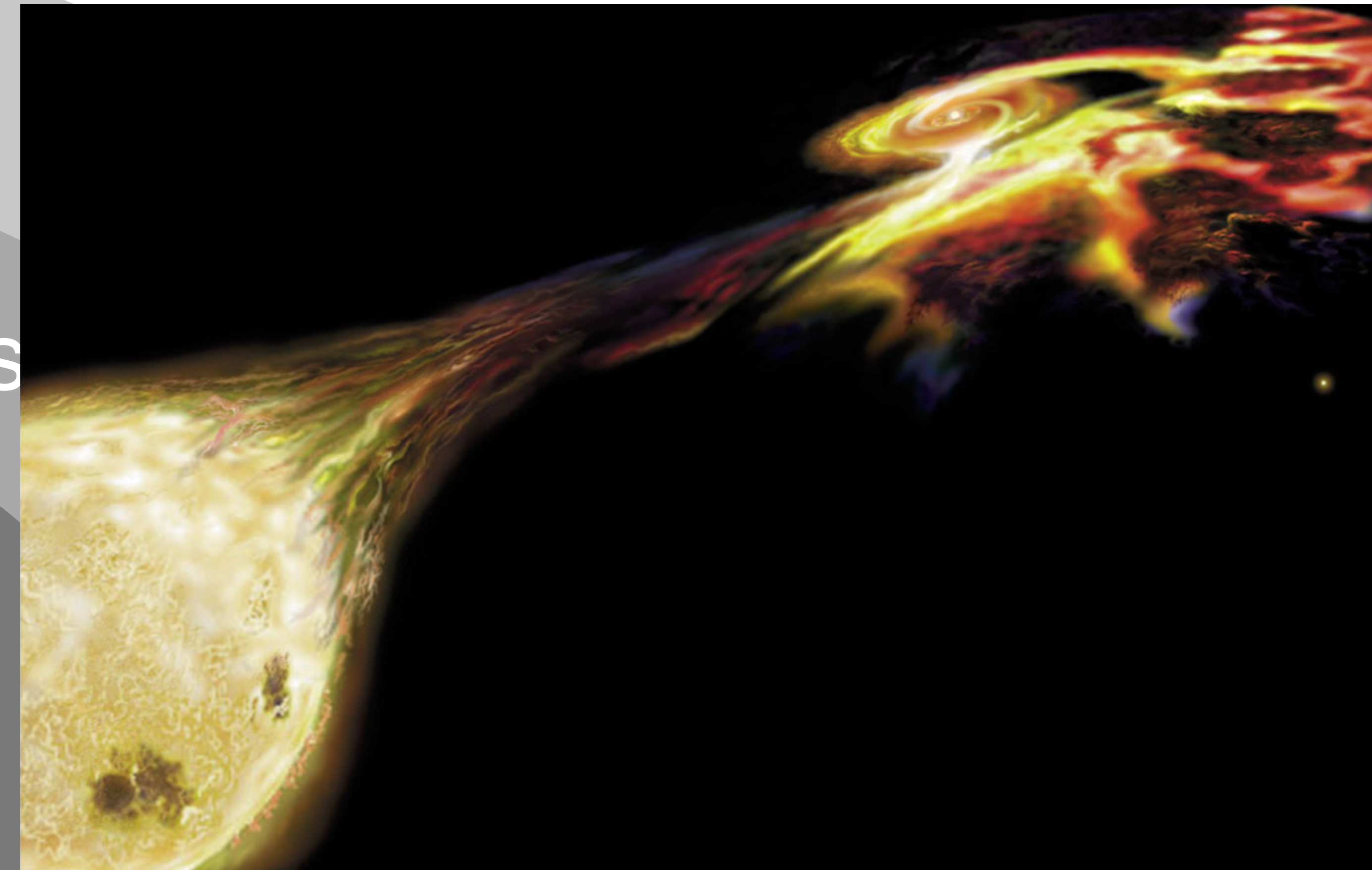
- Consensus:
  C/O WD undergoing thermonuclear explosion.
- But there are intense debates on the explosion mechanisms and progenitor systems, particularly for normal Ia used in cosmology.

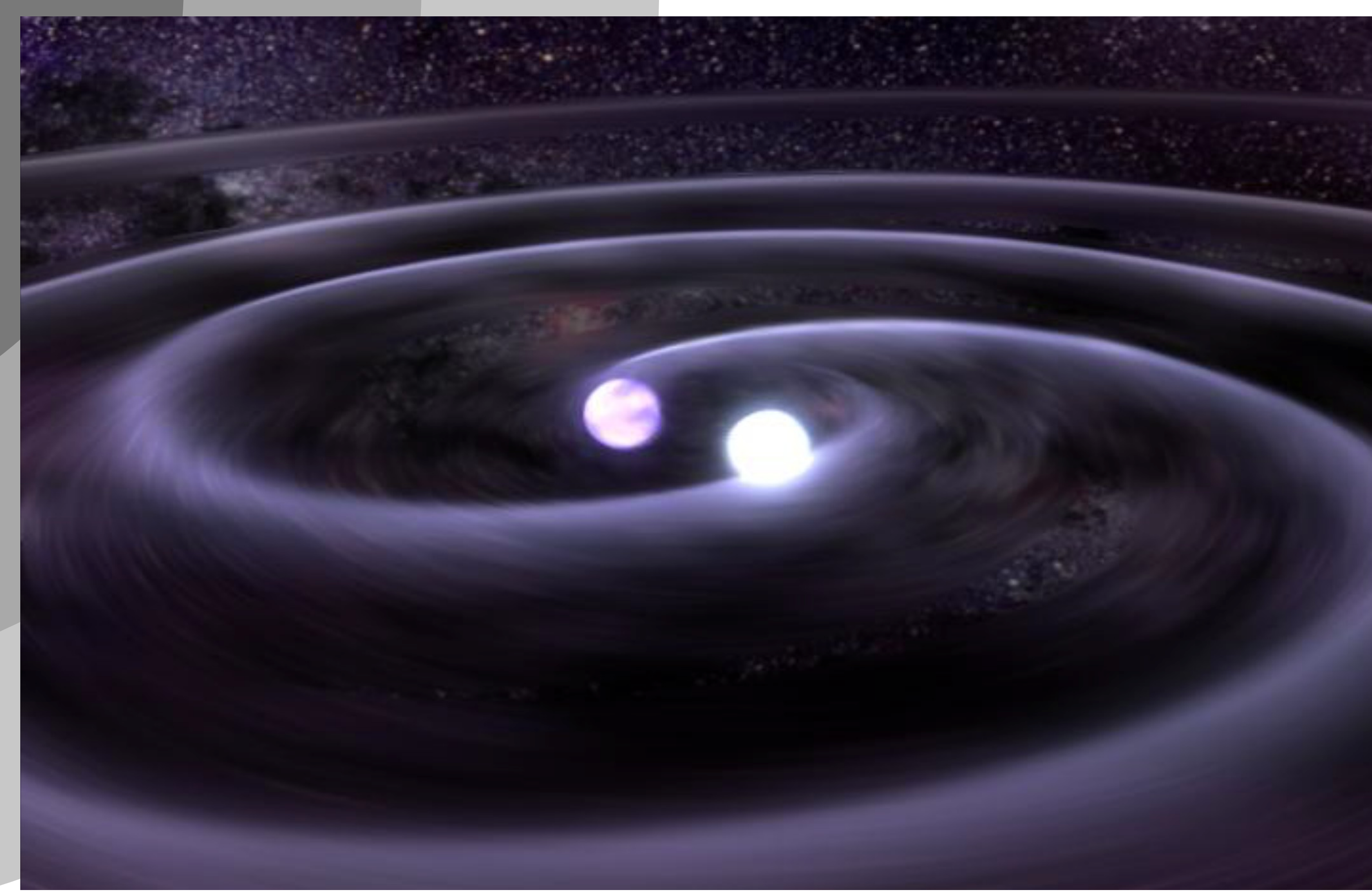




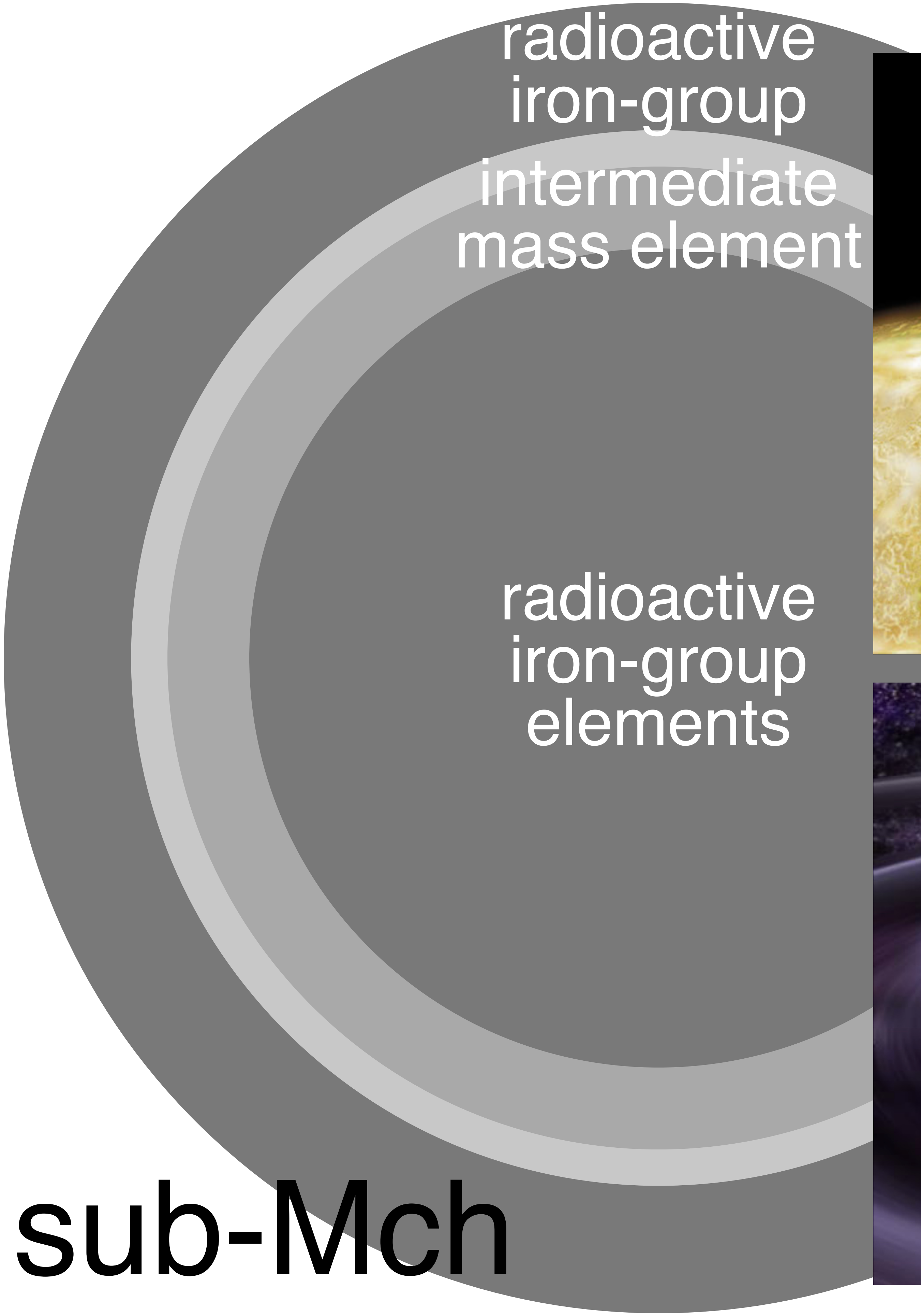


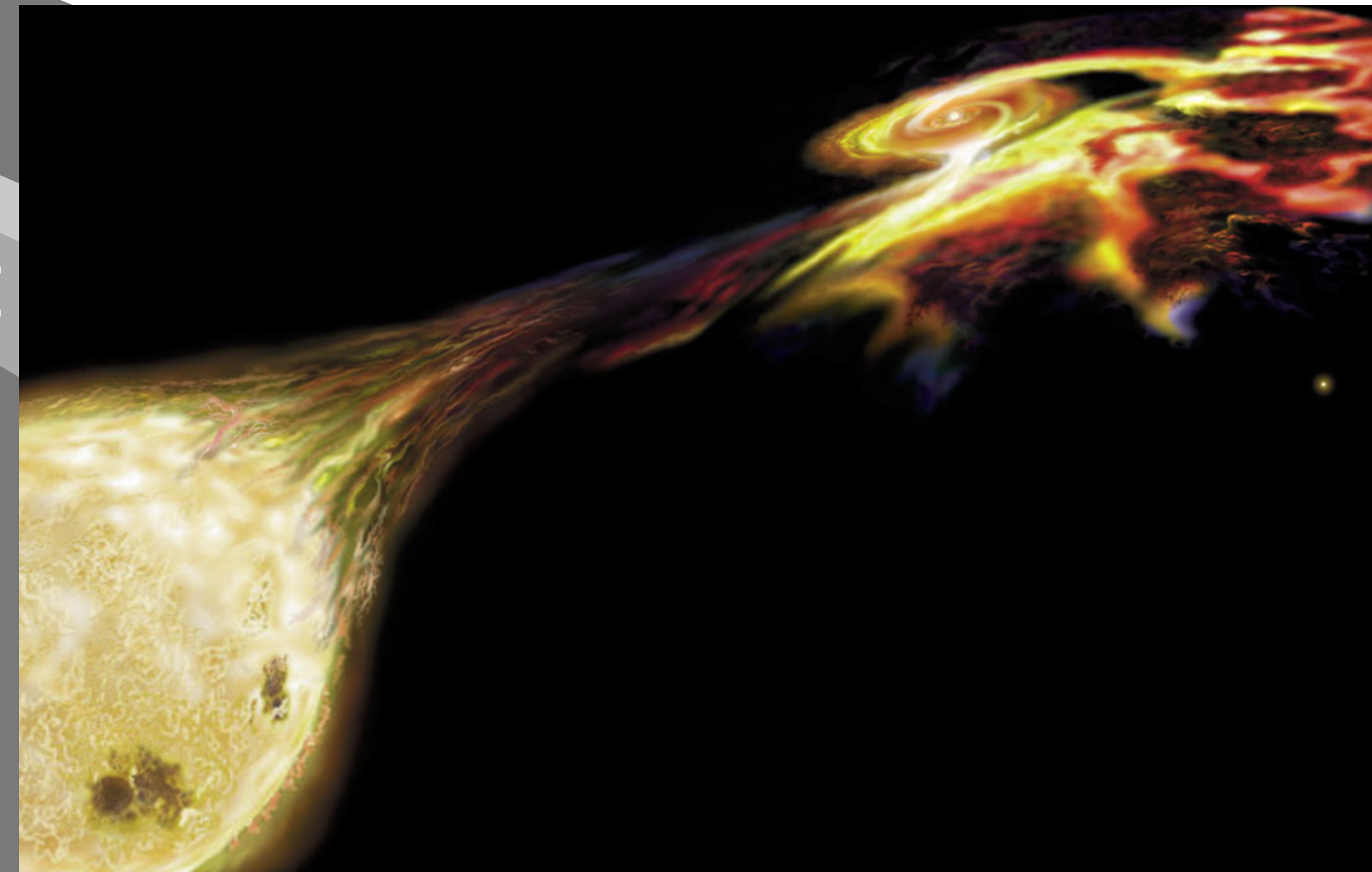
unburned material
intermediate mass elements
radioactive iron-group elements
stable iron-group elements

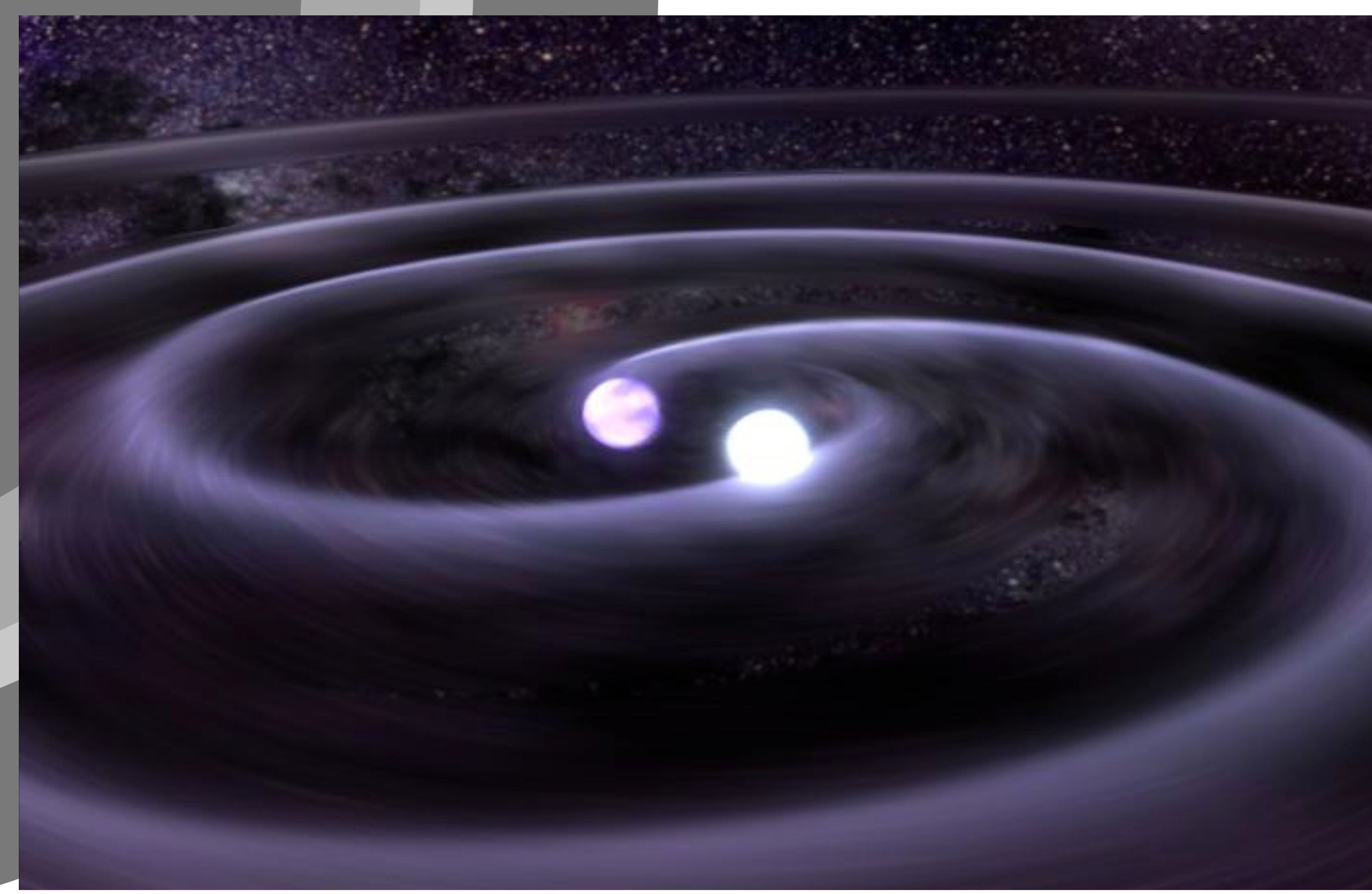




Mch


radioactive
iron-group
intermediate
mass element
radioactive
iron-group
elements

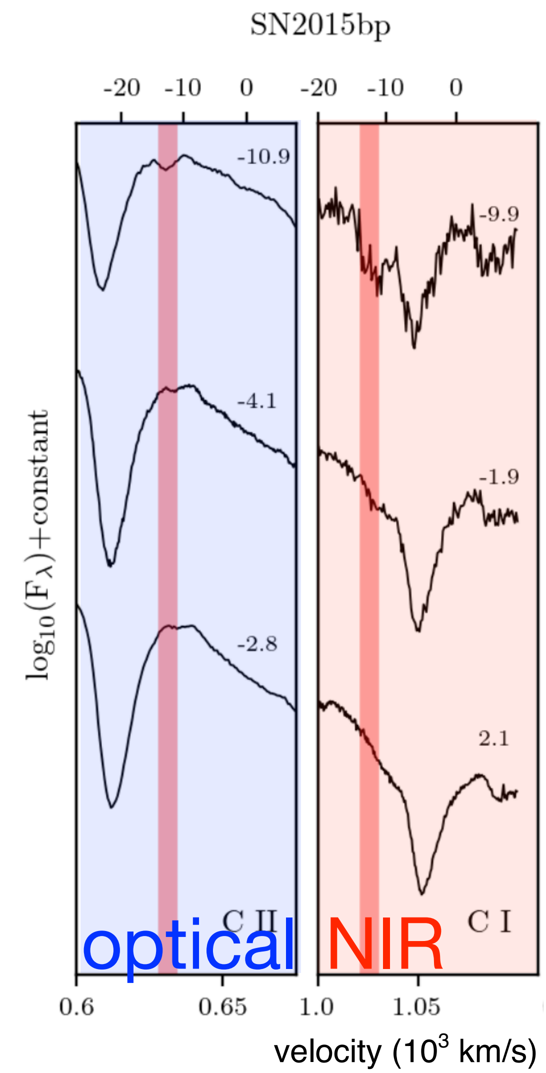




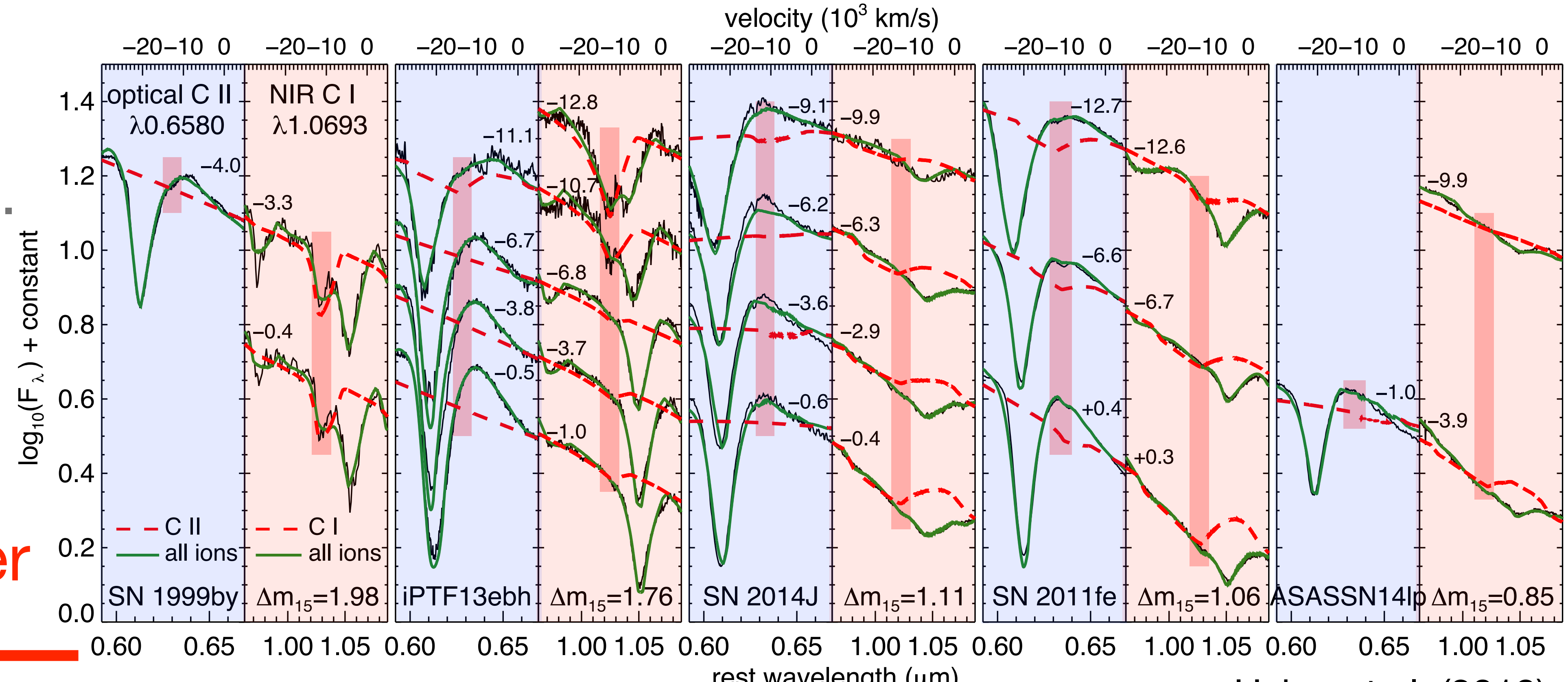
sub-Mch

Unburned C

- C is the most direct tracer of unburned material.
- Mch predicts an increasing amount of carbon for dimmer SNe. (consistent with observations.)
- sub-Mch predicts little carbon due to surface detonation.



Wyatt et al. (2021)

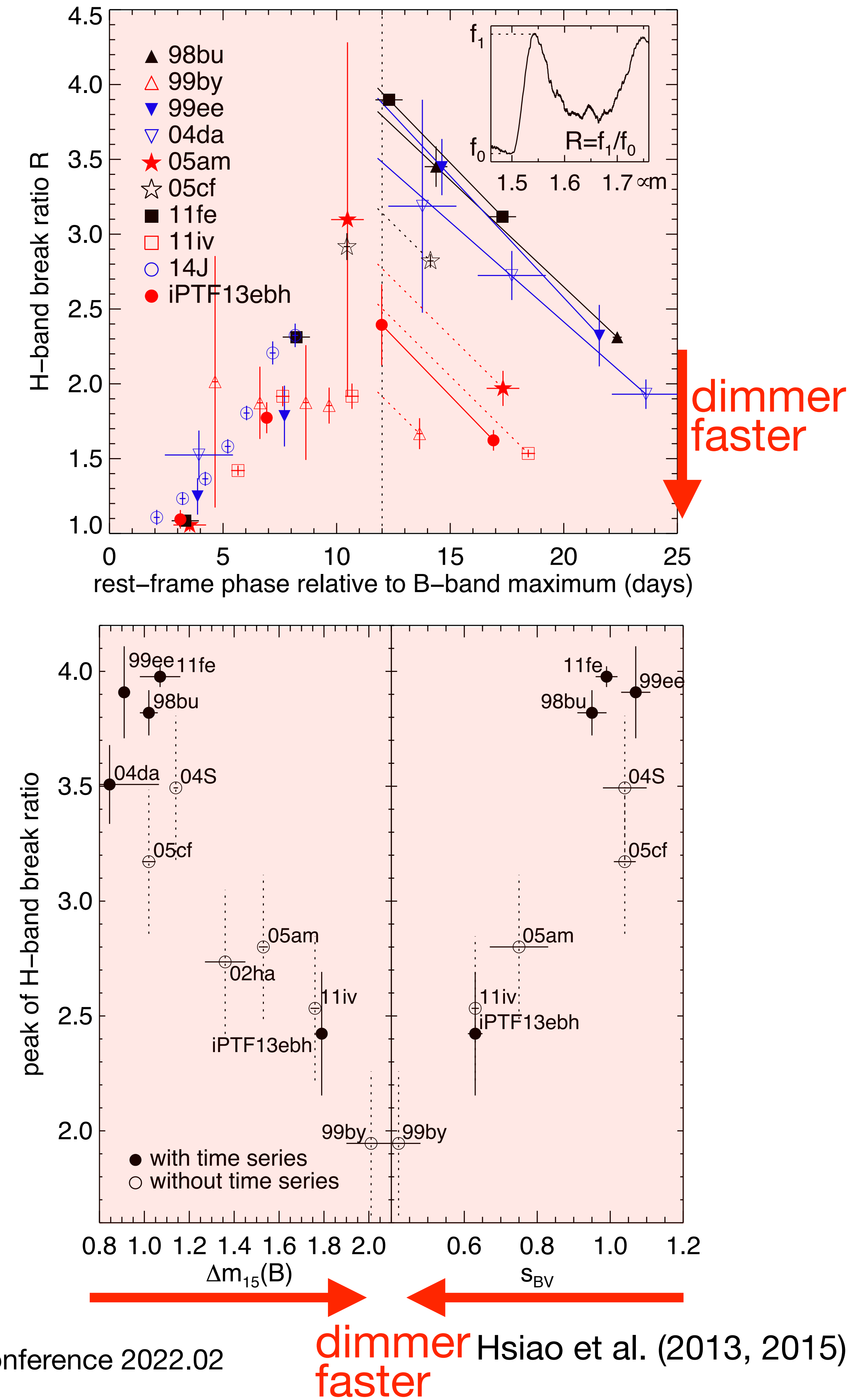


dimmer
faster

Hsiao et al. (2019)

Radioactive Ni

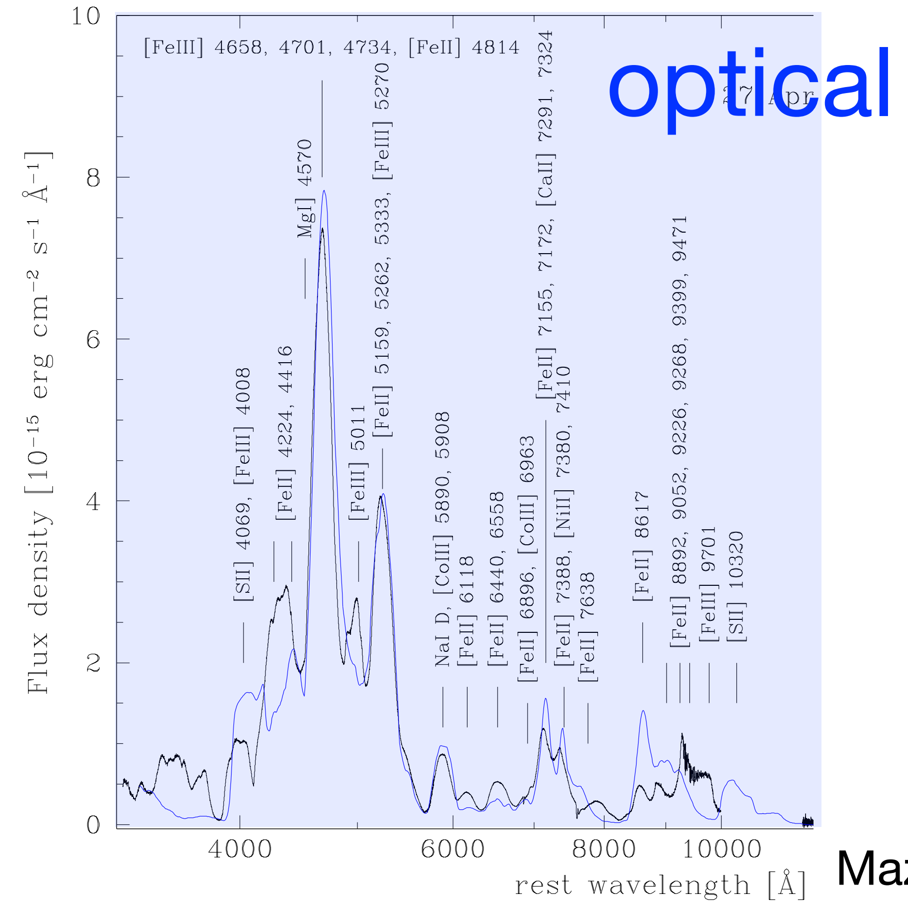
- The NIR H-band break is the most prominent feature for Ia.
- Strength of the break depends on the Ni mass.
- Rate at which it is exposed depends on the mass of the “shielding” intermediate-mass elements.
- Strong correlation between strength and decline rate is observed.



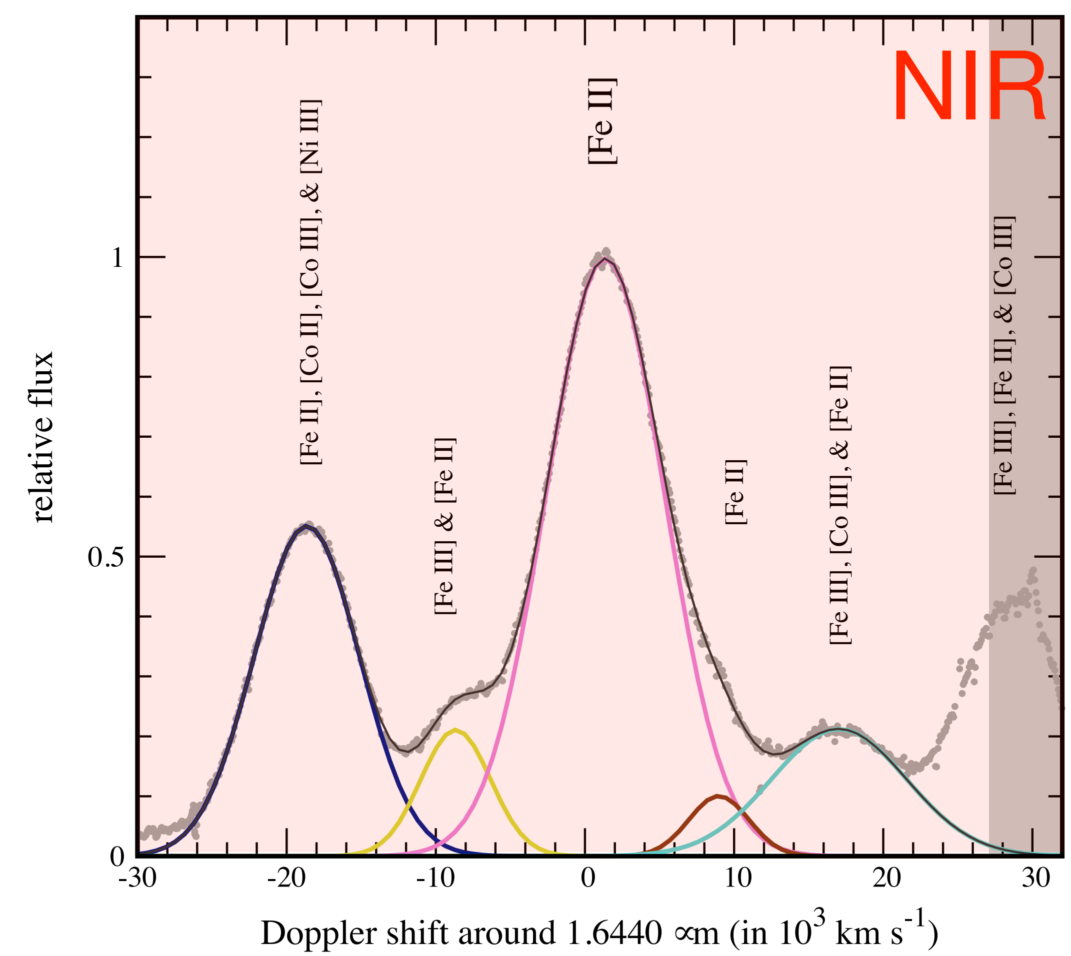
Hsiao et al. (2013, 2015)

Explosion kinematics

- Late-phase nebular spectra probe the center of an explosion.
- Optical nebular spectra are formed by many blends of forbidden lines.
- The NIR [Fe II] 1.644μm line is strong/isolated and allows for detailed studies of central density, magnetic fields, and explosion kinematics.

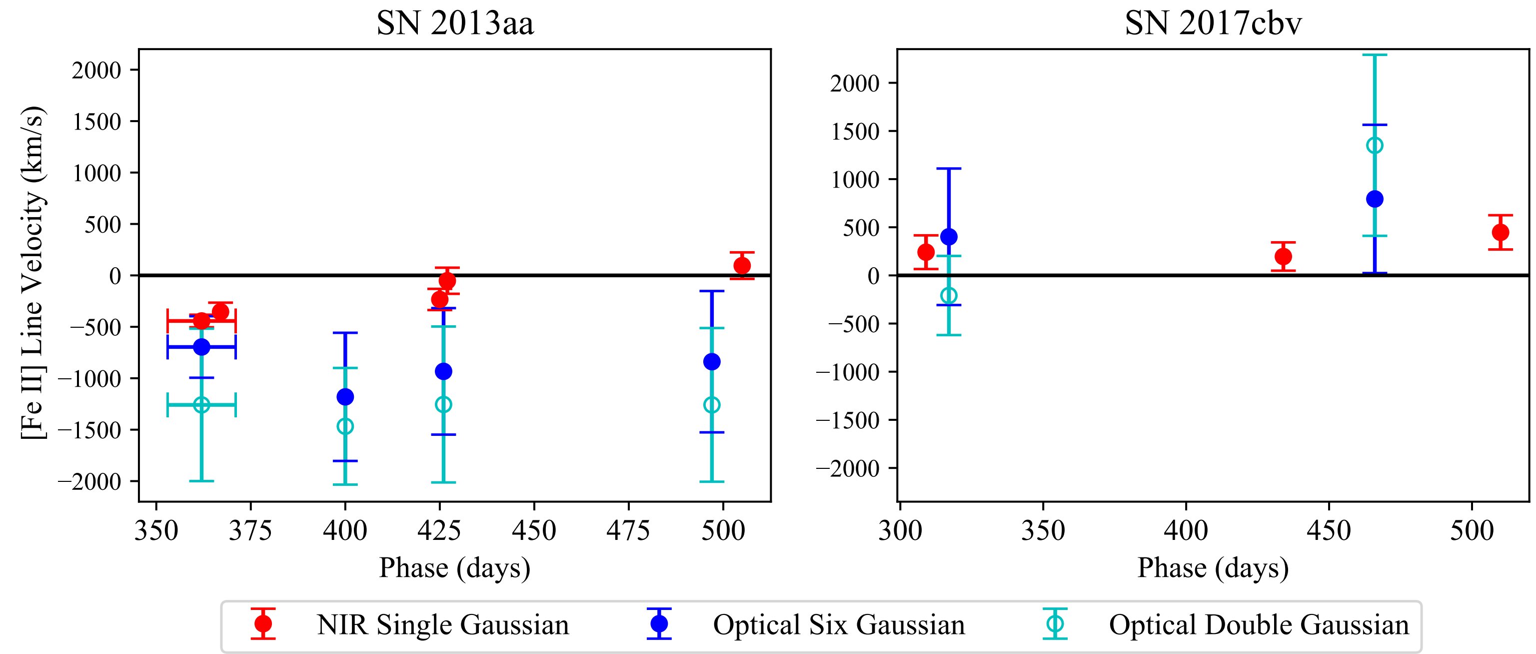


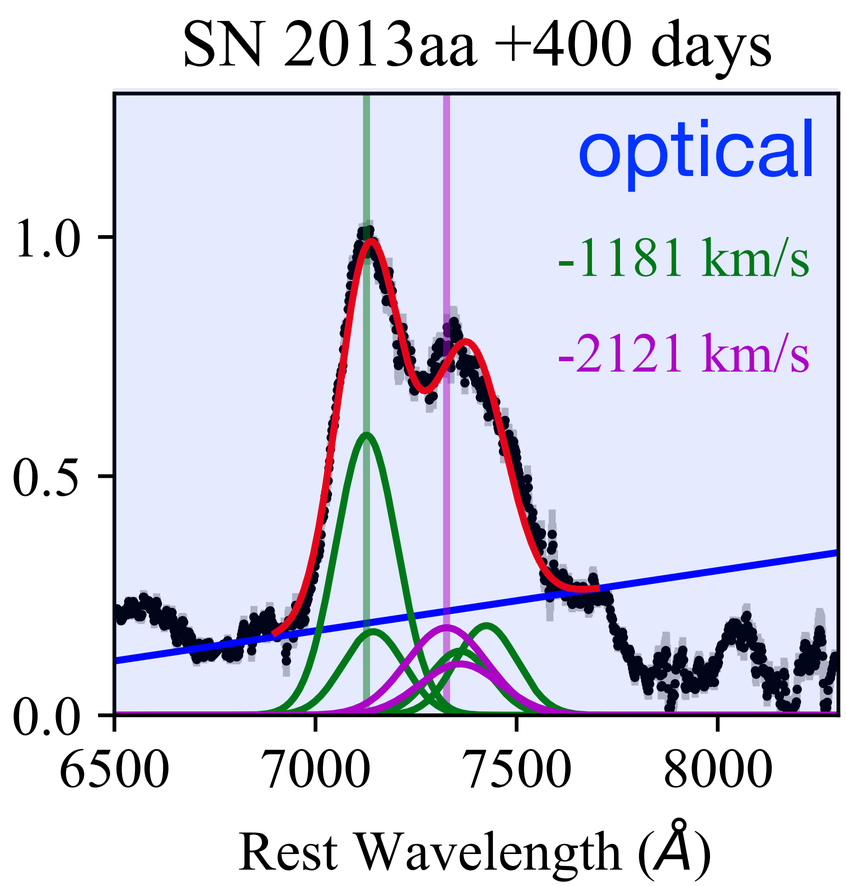
Mazzali et al. (2015)

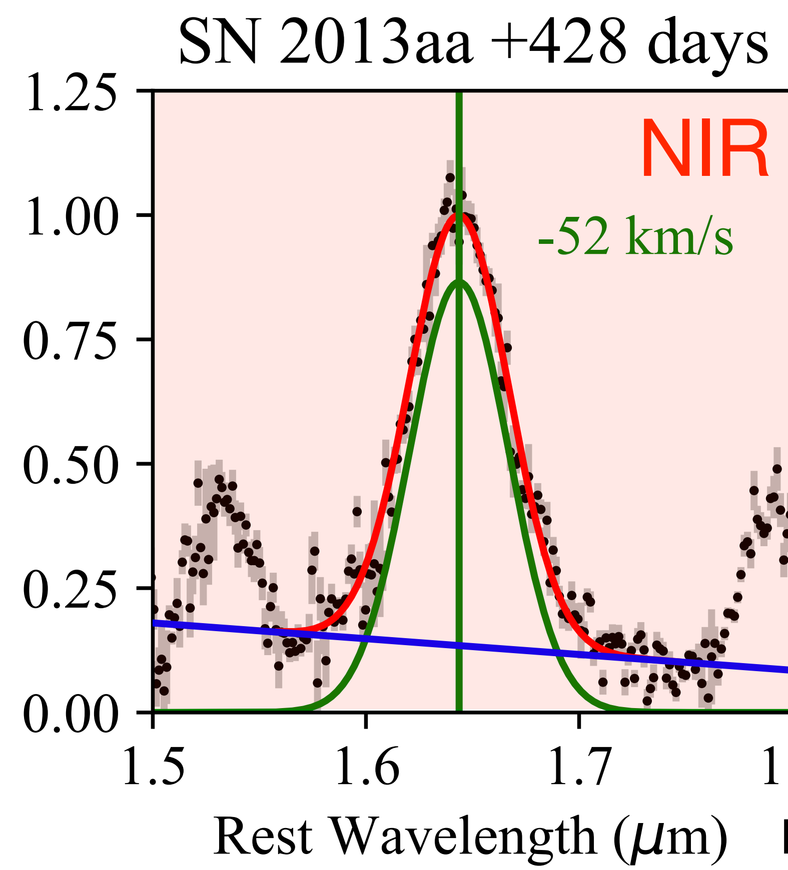


Diamond et al. (2018)

Explosion kinematics





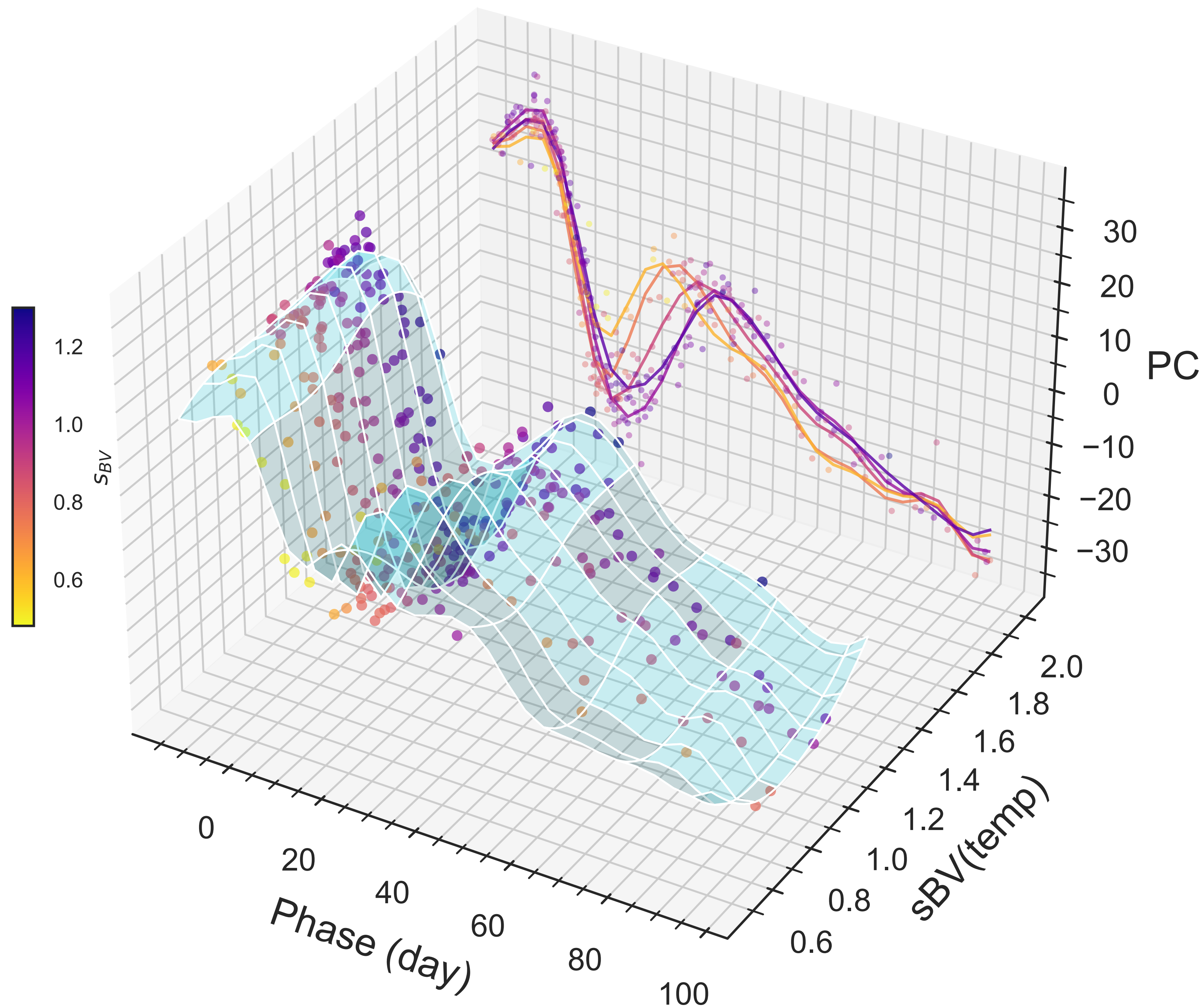


Kumar, Hsiao et al. in prep

- NIR velocity measurements are much more robust and suggest low velocities for these 2 SNe Ia, inconsistent with double-degenerate systems.

NIR cosmology

- We built SED templates crucial for NIR cosmology using a novel technique.
    - Reduce the dimensionality of the spectral data using PCA, quantifying the spectral properties.
    - Model the phase and LC shape dependence of the spectral properties using Gaussian process.

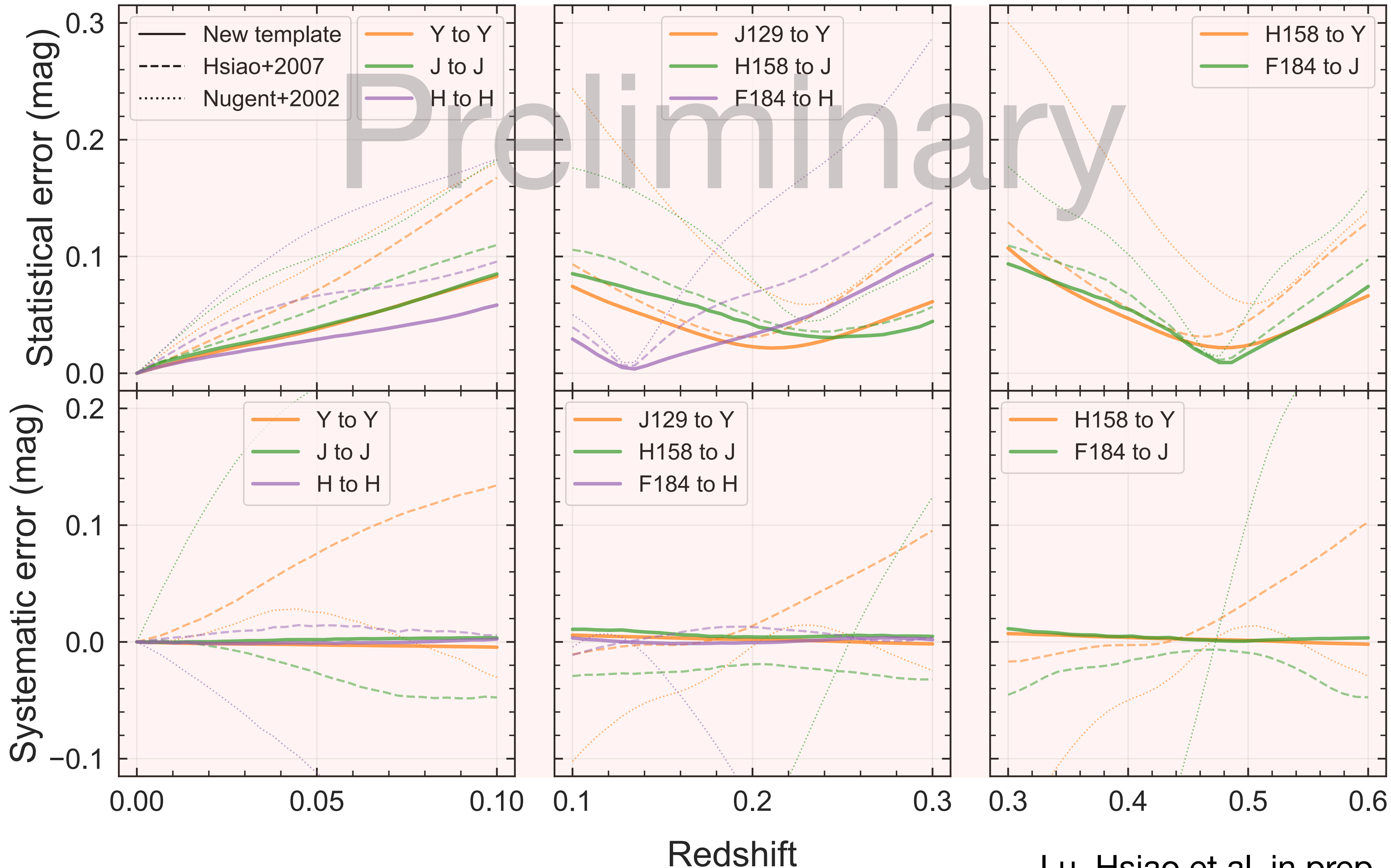


Lu, Hsiao et al. in prep

Based on 331 NIR spectra

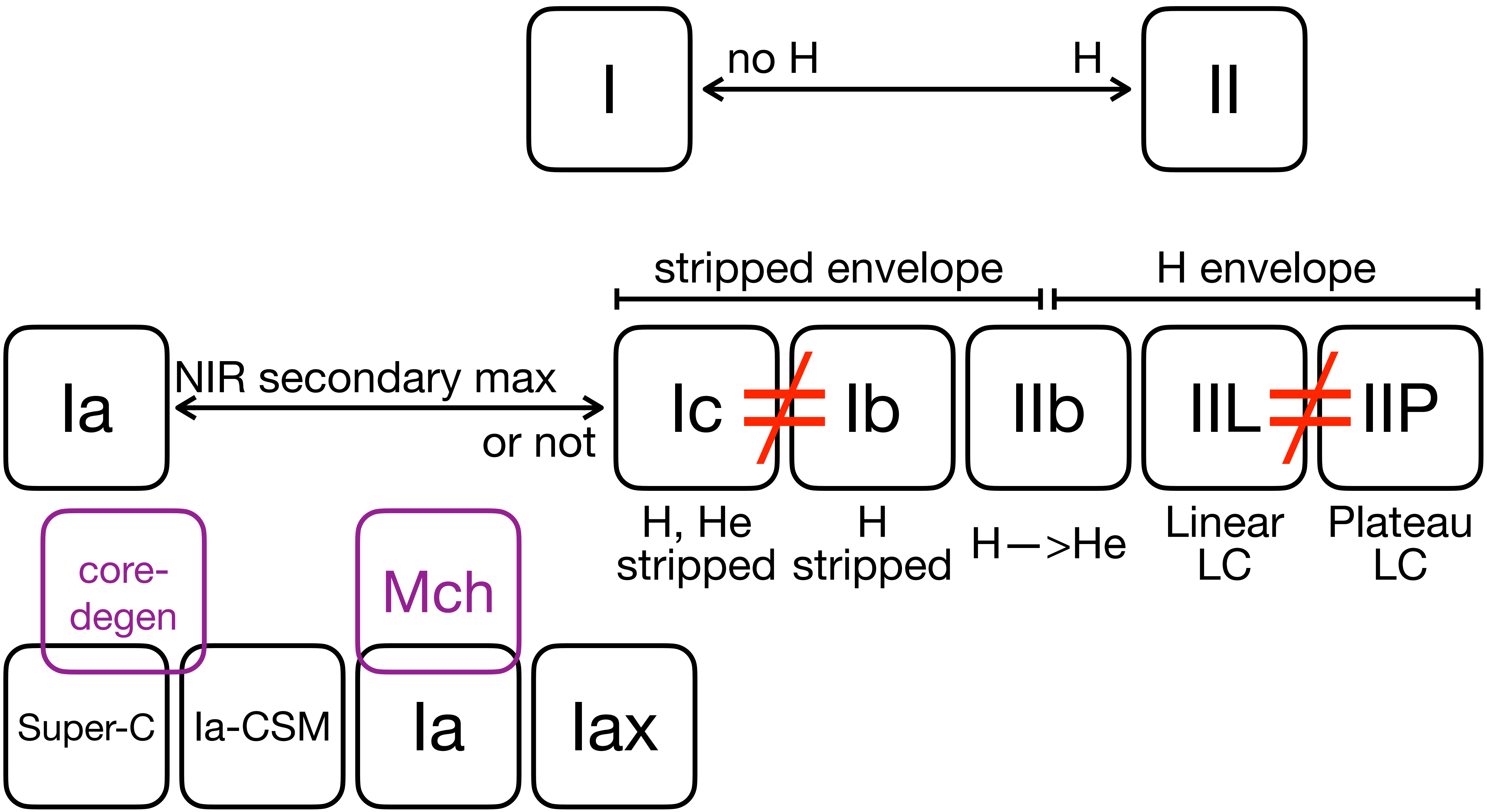
NIR cosmology

- Drastic reduction in k-correction errors over previous templates, on a 10% level.
- Practically eliminating the systematic errors.



Lu, Hsiao et al. in prep

Summary



I
no H
H
II
stripped envelope
H envelope
Ia
NIR secondary max
or not
Ic
Ib
IIb
IIL
IIP
H, He
stripped
H
stripped
H—>He
Linear
LC
Plateau
LC
core-
degen
Mch
Super-C
Ia-CSM
Ia
Iax