CSP-II Stripped-Envelope SNe Spectroscopy in the NIR

Melissa Shahbandeh

Florida State University
May 2019

E. Hsiao, P. Hoeflich, C. Ashall, M. Phillips
Carnegie Supernova Project II

Outline

- Introduction
- Sample characteristics
- Why do we care?
- Optical vs NIR
- Methods to identify the lines
- Preliminary Conclusion

What is a SE-SN?

- SN explosion from a progenitor which has lost most of its envelope
- Found in the H II regions and spiral arms
- Core Collapse explosion of massive stars (ZAMS > 8 - 60+ $M_\odot$)
- The envelope is lost due to:
  - Radiation driven winds
  - Common envelope phase in a binary system
  - Fast rotation (Be stars)
- Asymmetric explosion

W49B

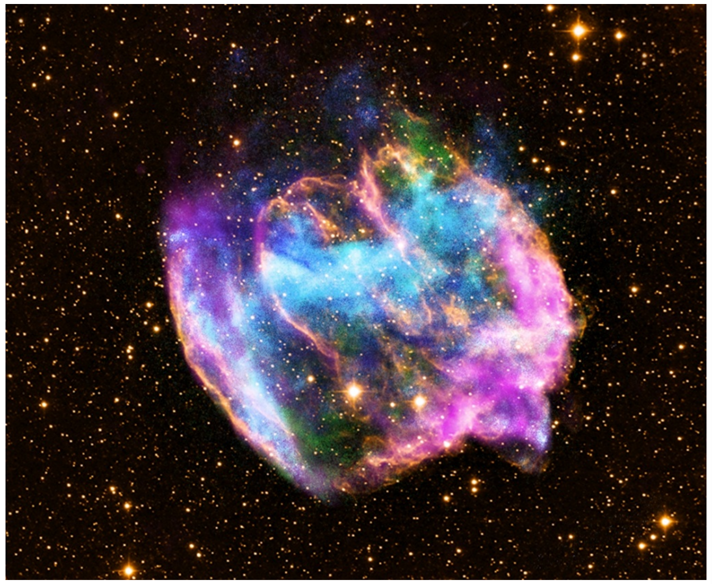
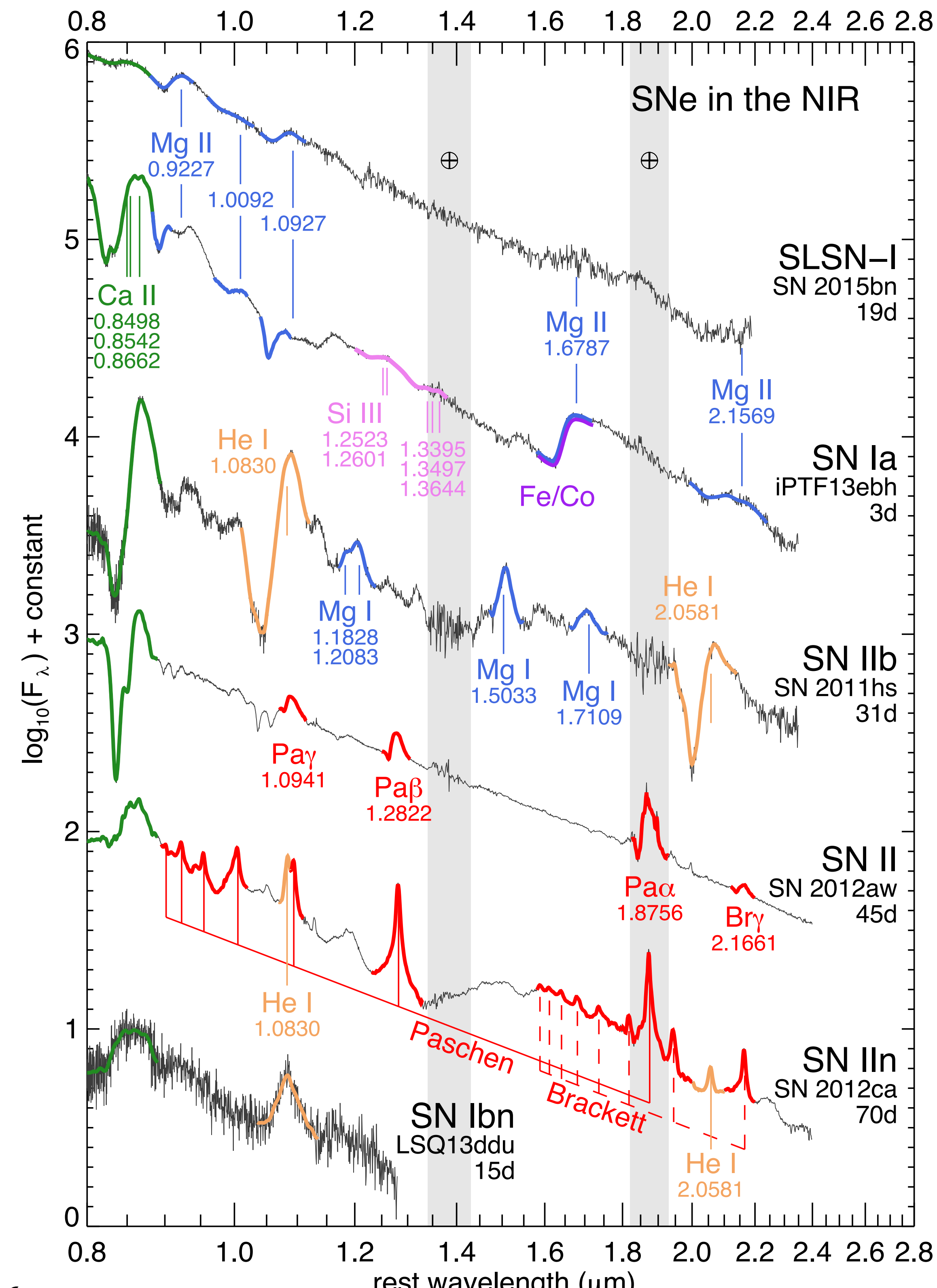


Image Credits: X-ray: *NASA/CXC/MIT/L.Lopez et al.*; Infrared: *Palomar*; Radio: *NSF/NRAO/VLA*

The Carnegie Supernova Project II (CSP-II)

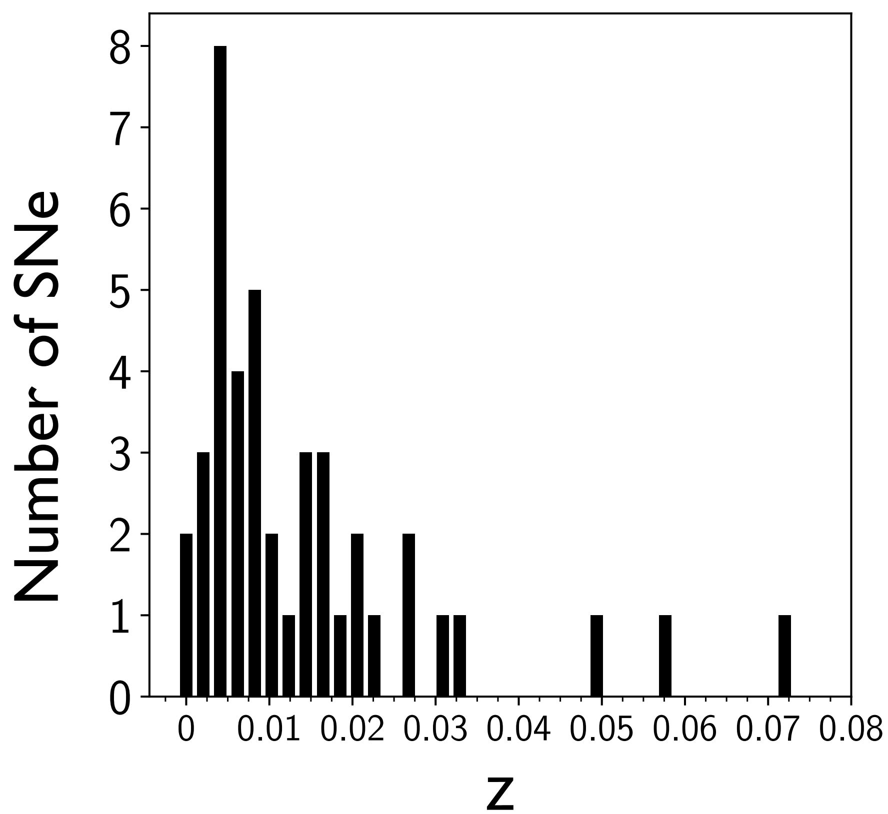
- 2011-2015
- One of the emphases was on the NIR spectra (0.82 - 2.5 µm)
- Las Campanas Observatory: Magellan II (Baade+FIRE), Swope, du Pont

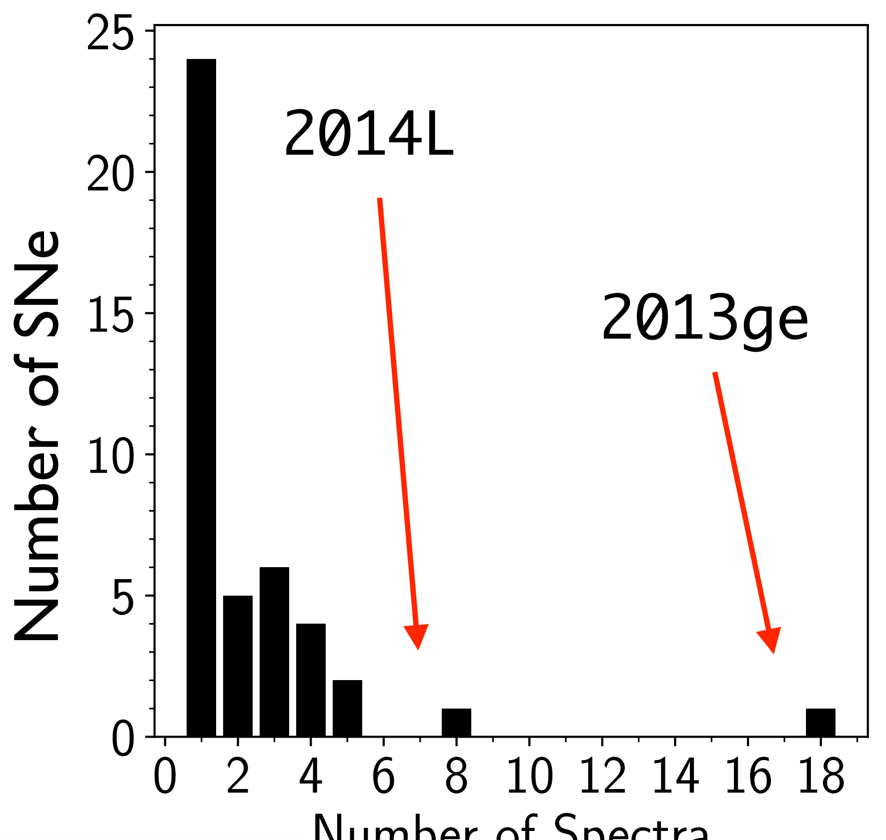


Hsiao et al. 2019

CSP-II sample of IIb, Ib, Ic, Ic-BL

- Largest sample of SE-SNe NIR spectra
- 109 spectra of 40 SNe
- Average redshift of 0.015
- Best covered is SN 2013ge with 18 spectra

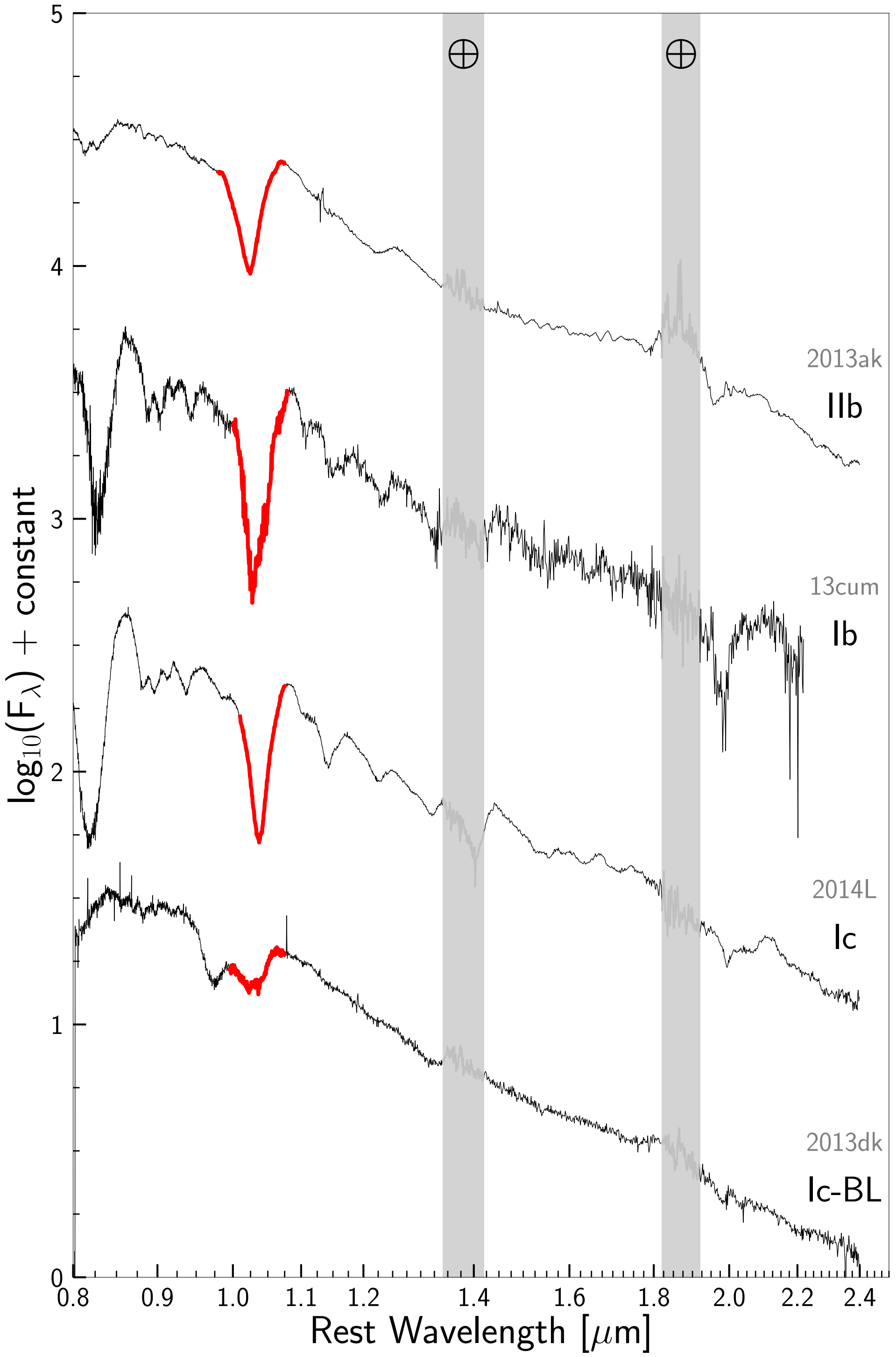




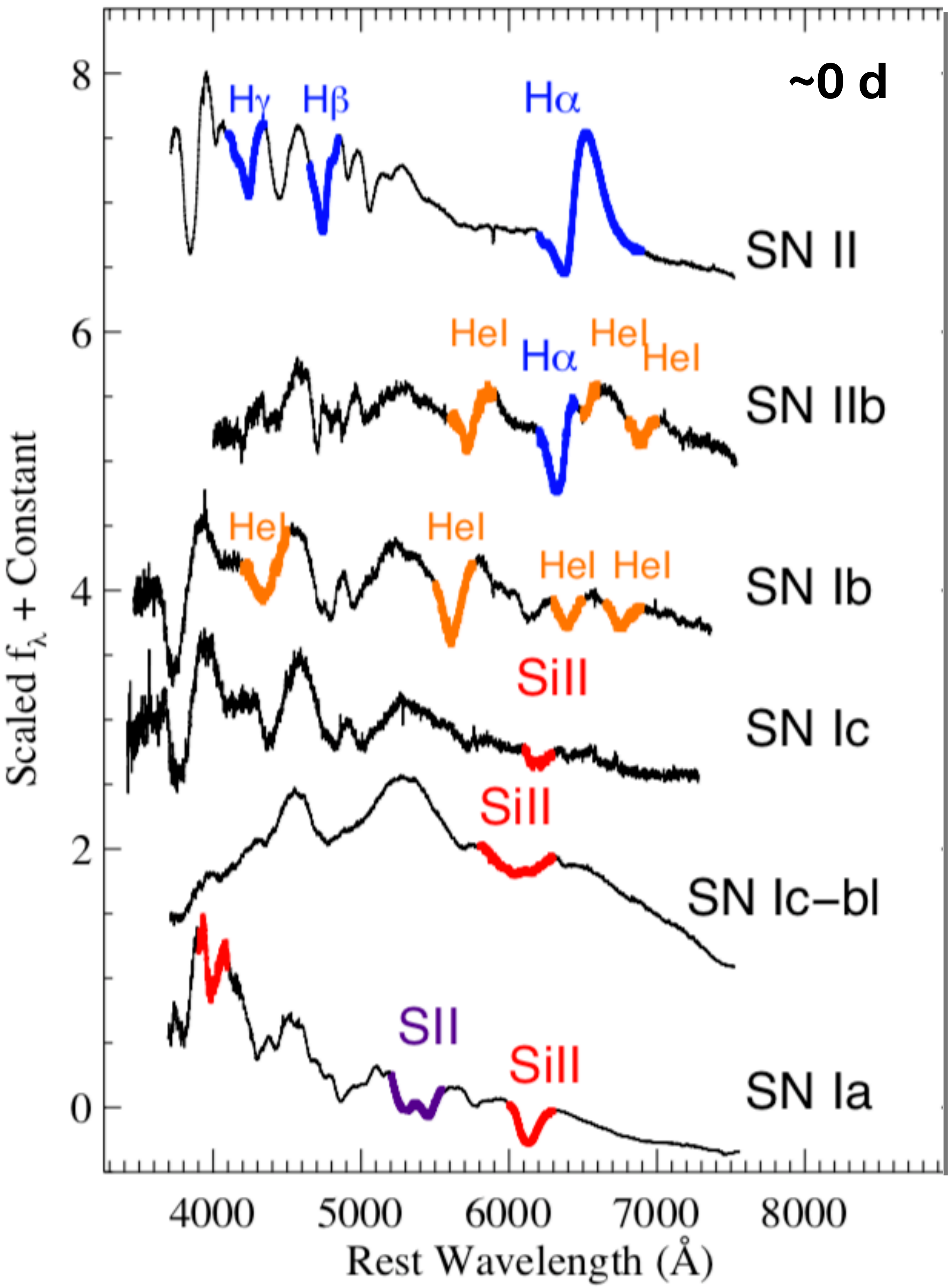
Why NIR?

What is the most interesting feature in our dataset?

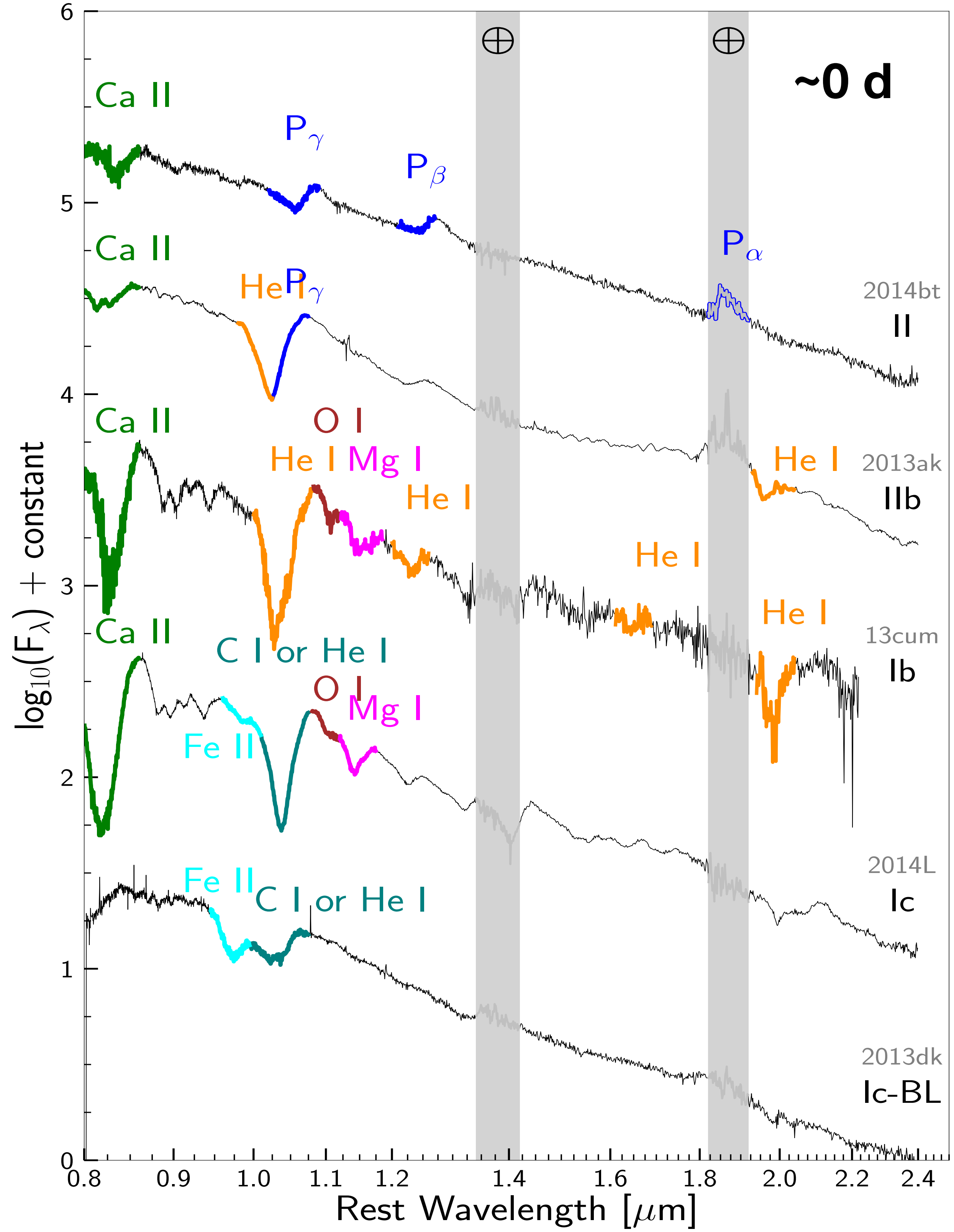
- The strongest feature is ~λ 1.083 μm
- Is it He I?
- Is it C I?
  (why did I jump to carbon?)
- Is it both?



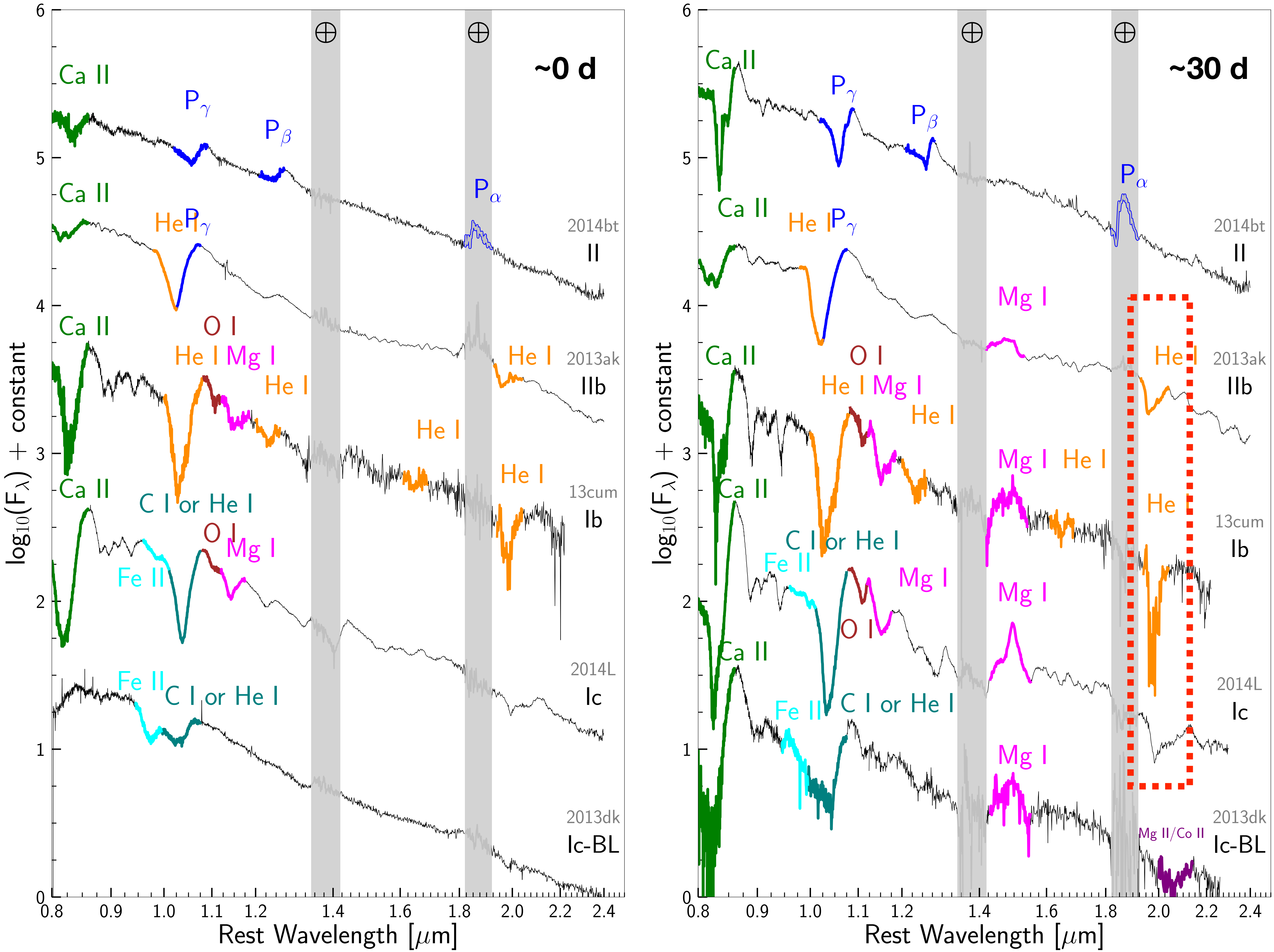
Optical vs Near-Infrared



Modjaz et al. 2014



Shahbandeh et al. 2019 in prep



~0 d
~30 d
Ca II
Pγ
Pβ
Pα
He I
O I
Mg I
C I or He I
Fe II
Mg II/Co II
2014bt
II
2013ak
IIb
13cum
Ib
2014L
Ic
2013dk
Ic-BL
log10(Fλ) + constant
Rest Wavelength [μm]

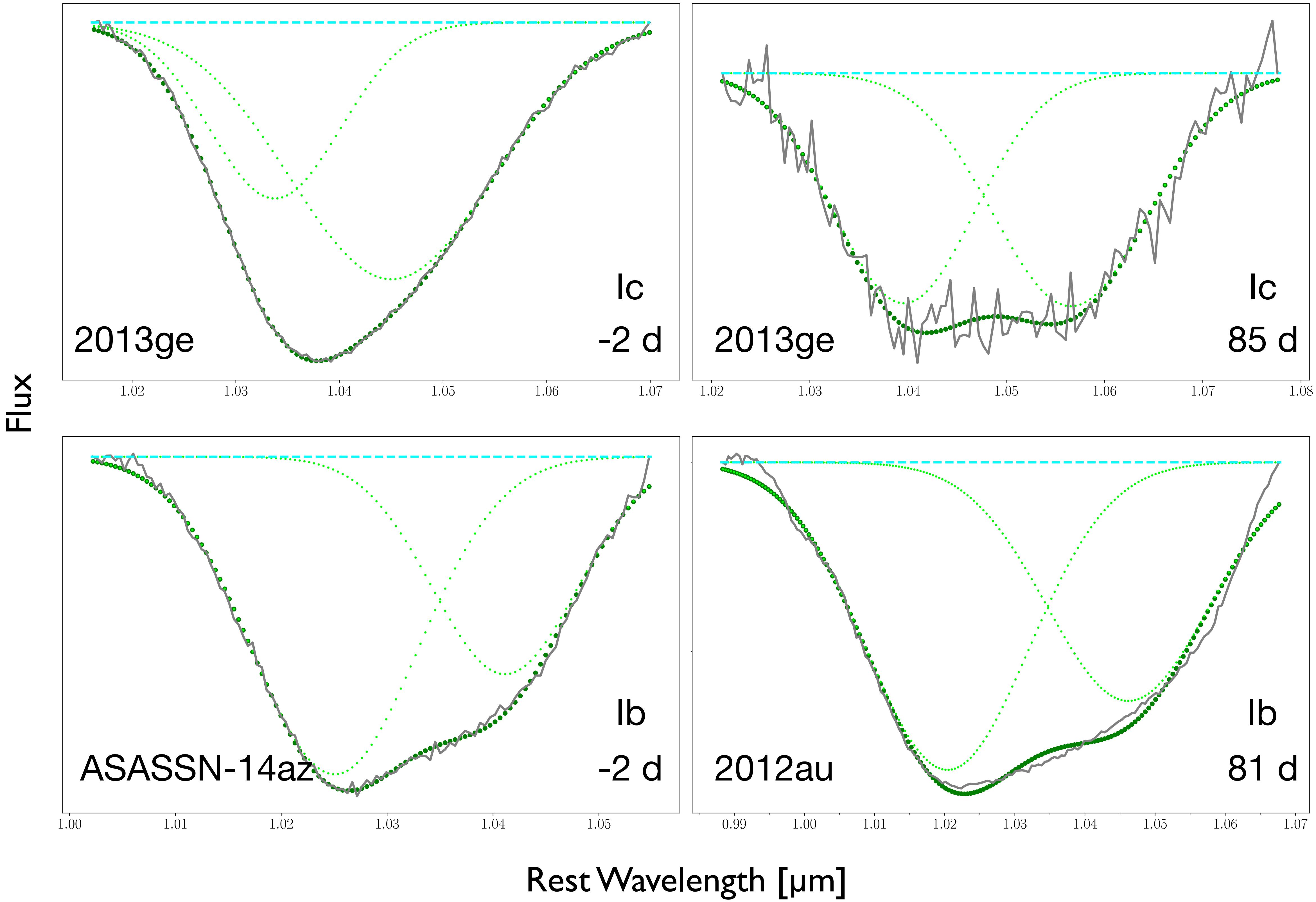
In order to identify the features we used three different methods

Method I:

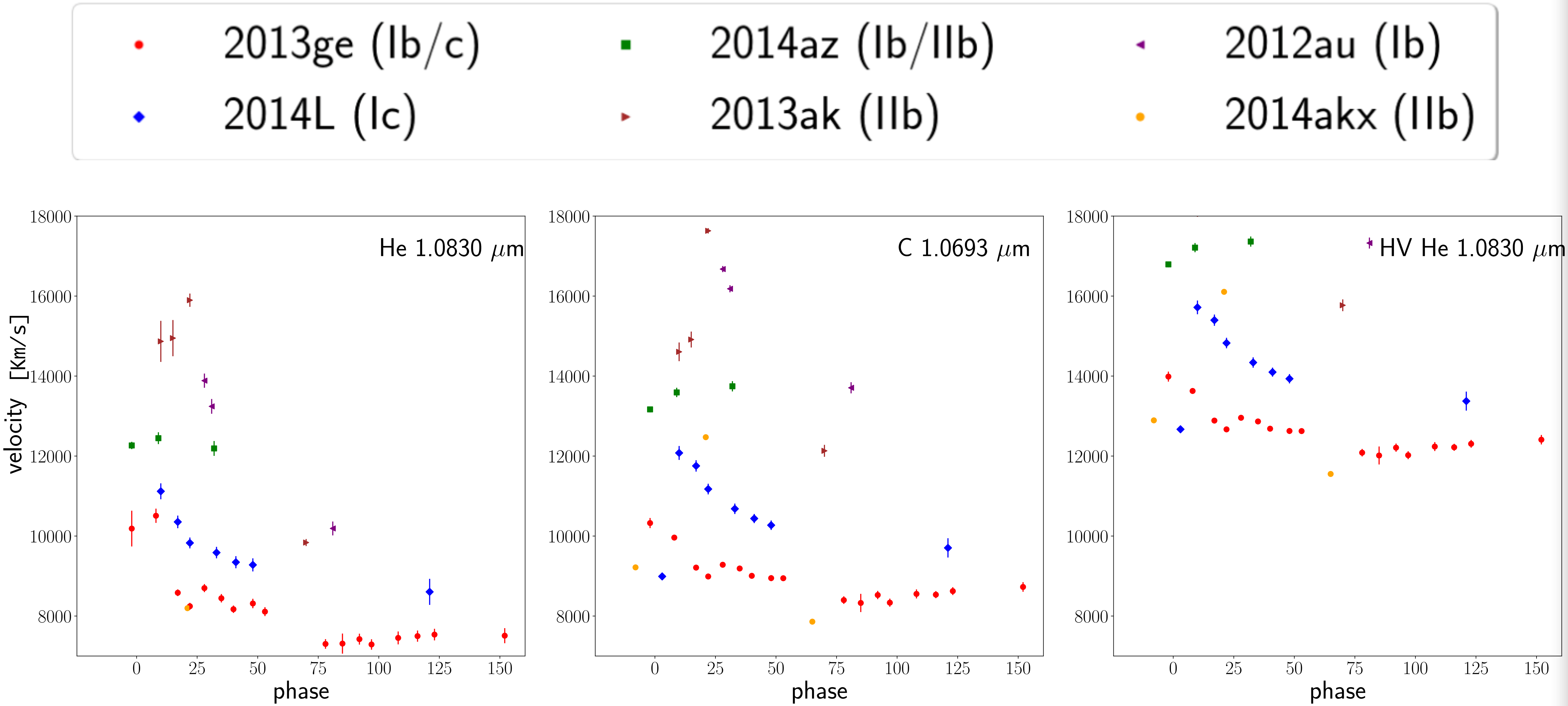
Fitting the feature and measuring velocities

- Using 2 gaussians to fit the two components
  - Left component as either HV He I or C I
  - Right component as He I
- Do the two components belong to the same element? Or two different elements?

Examples of double components and gaussian fits



Velocity vs Phase



- These identifications would imply that C is outside the He layer!

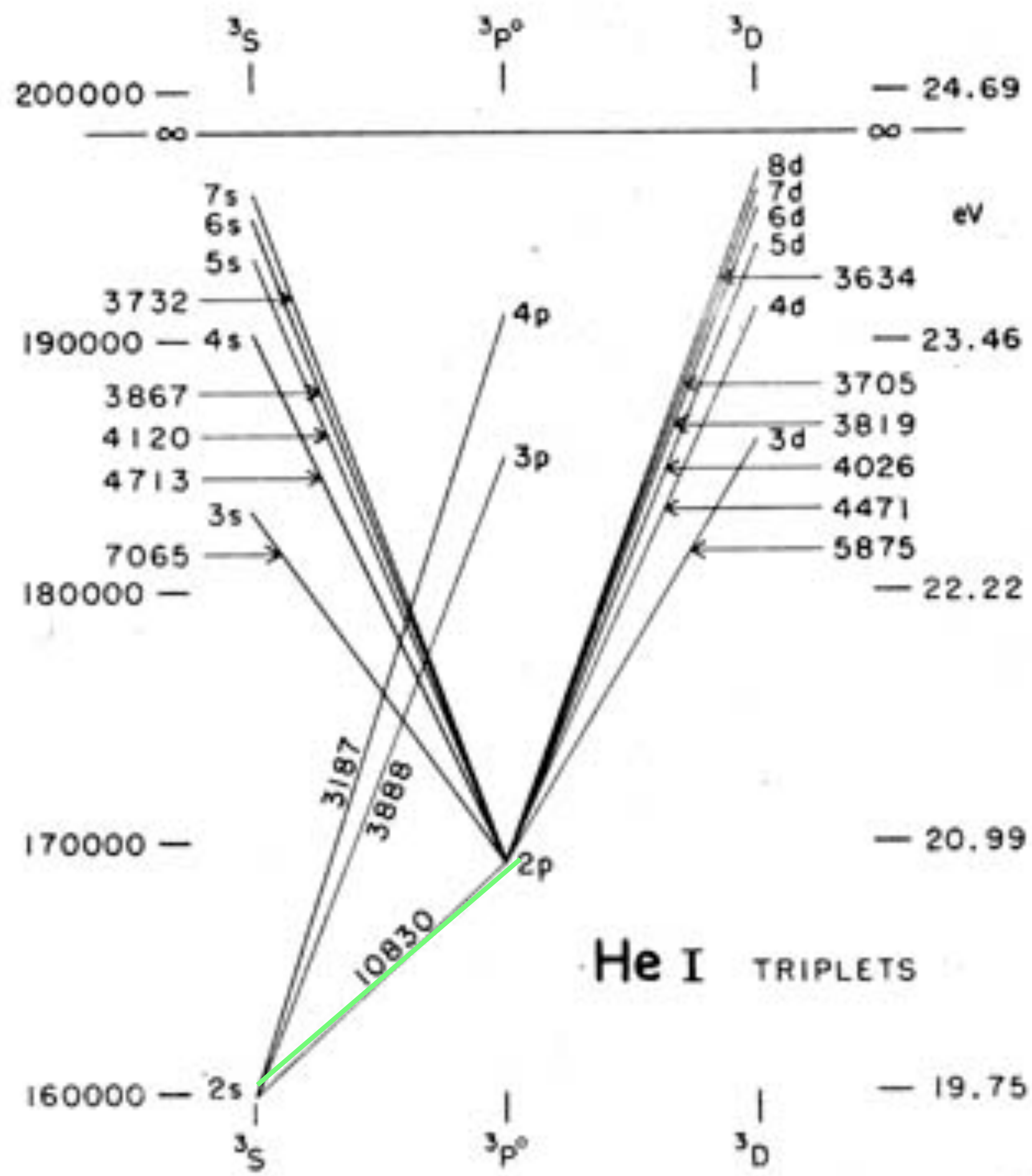
Method II

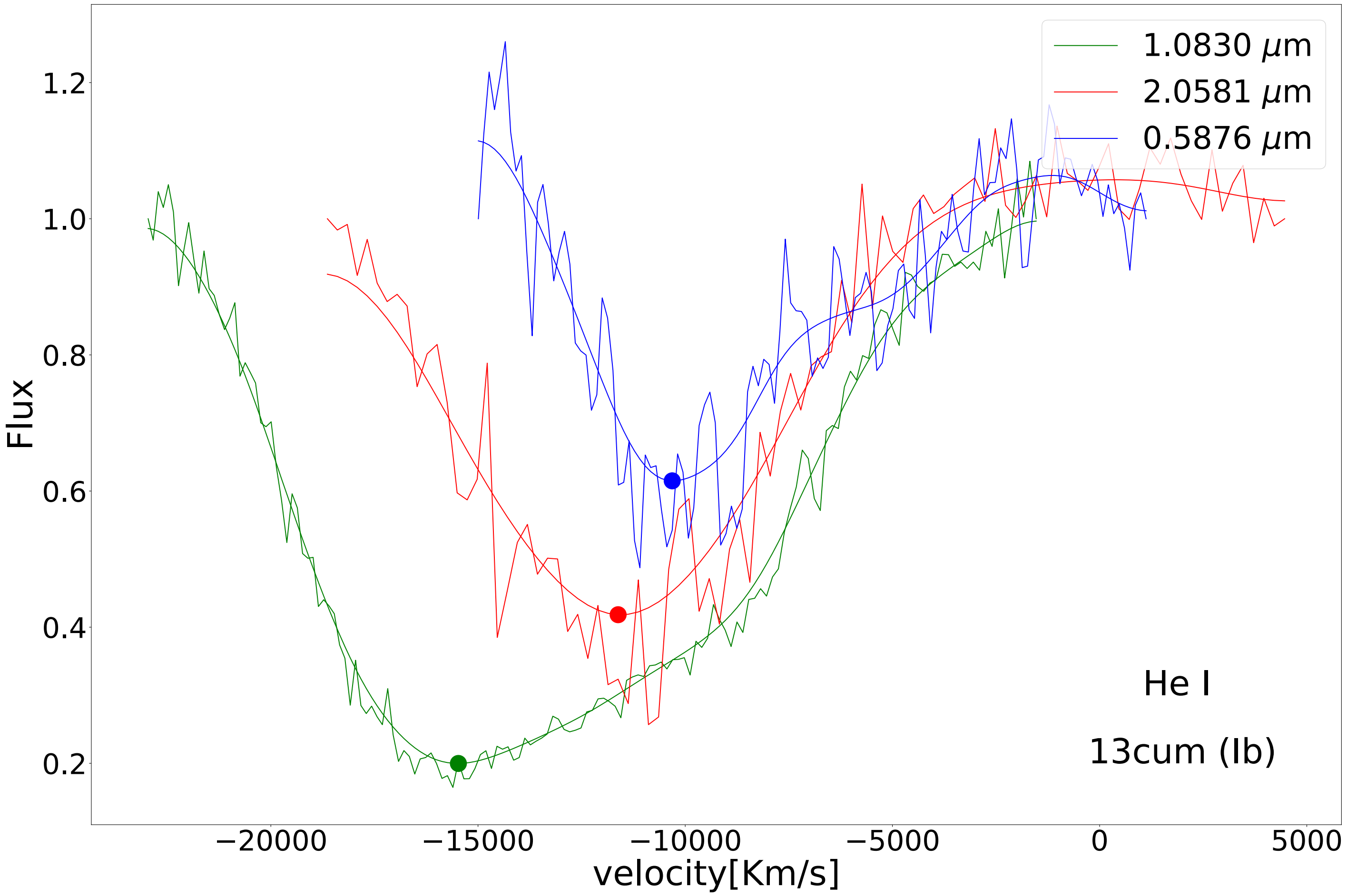
Comparing the strongest features in the velocity space

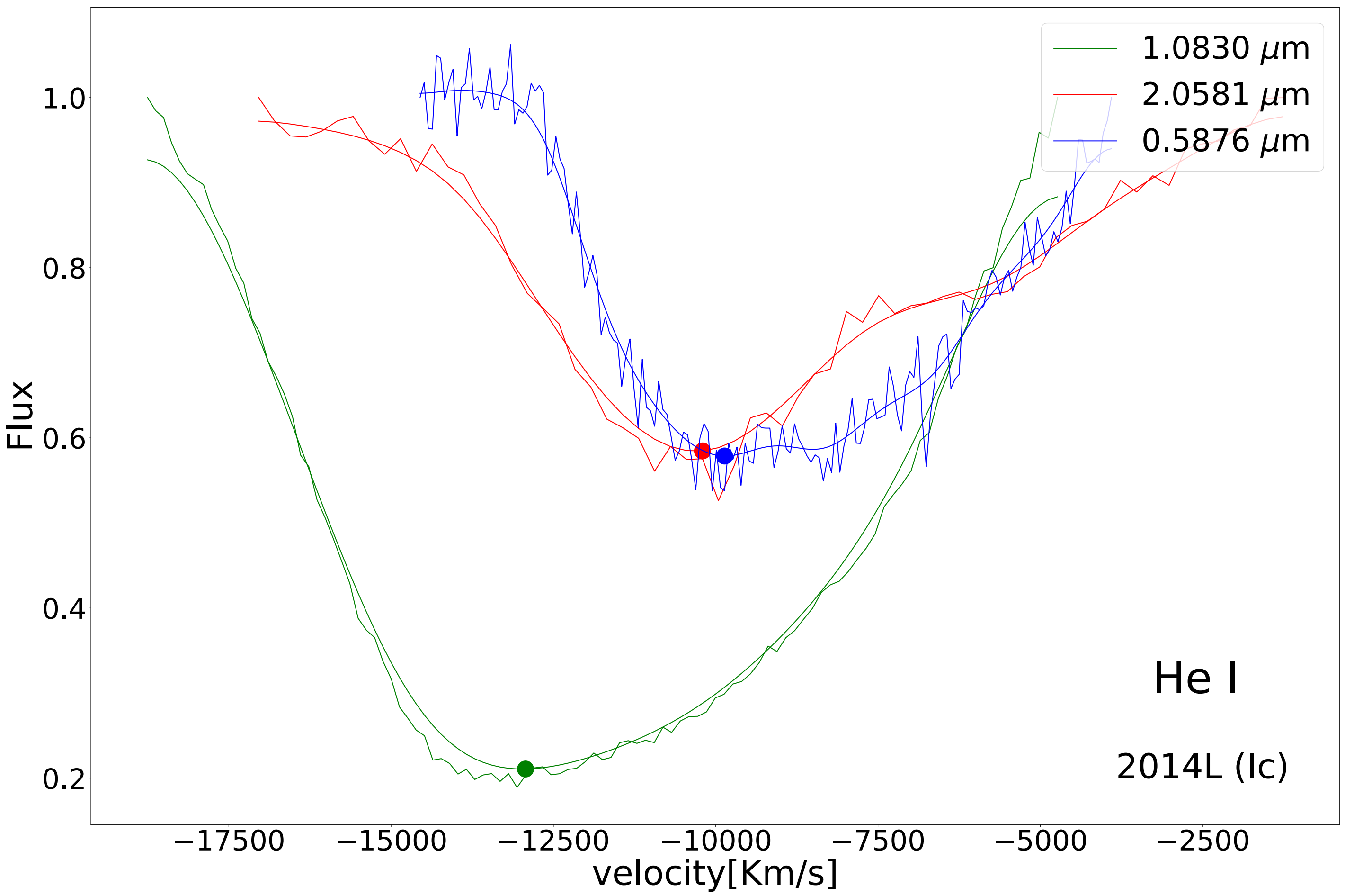
- Compared Ib to Ic
  - He I: λ 0.5876 μm, 1.083 μm, 2.058 μm
  - C I: λ 0.9093 μm, 0.9658 μm,1.0693 μm, 1.1330 μm, 0.9658 μm
- Using grotrian diagrams to confirm the results

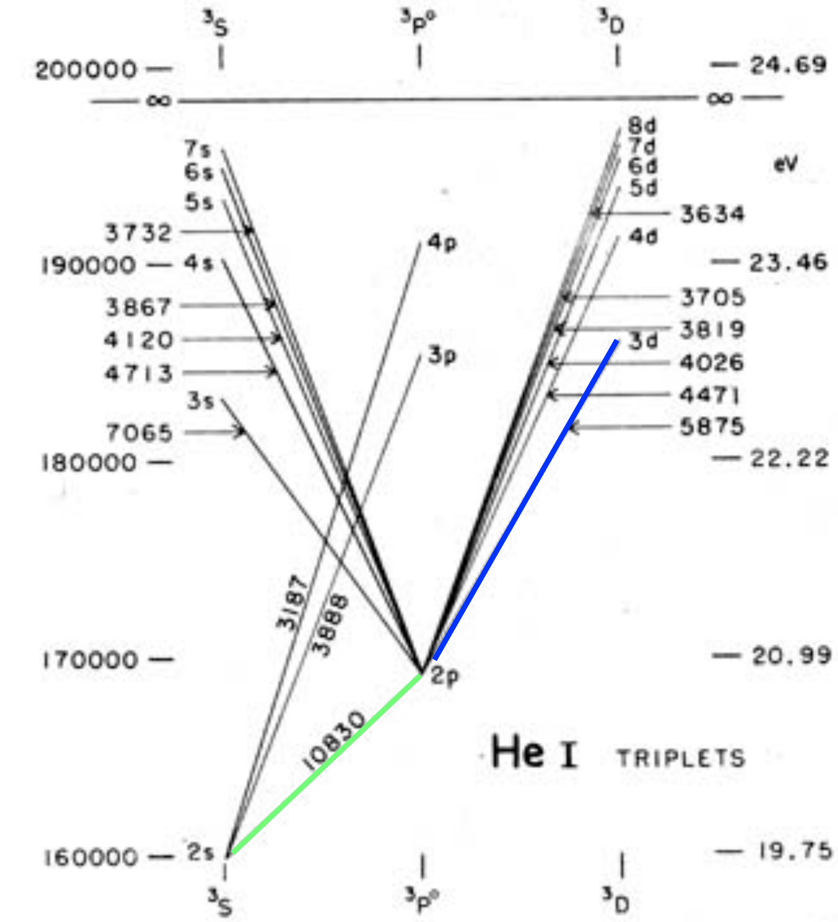
What is a grotrian diagram?

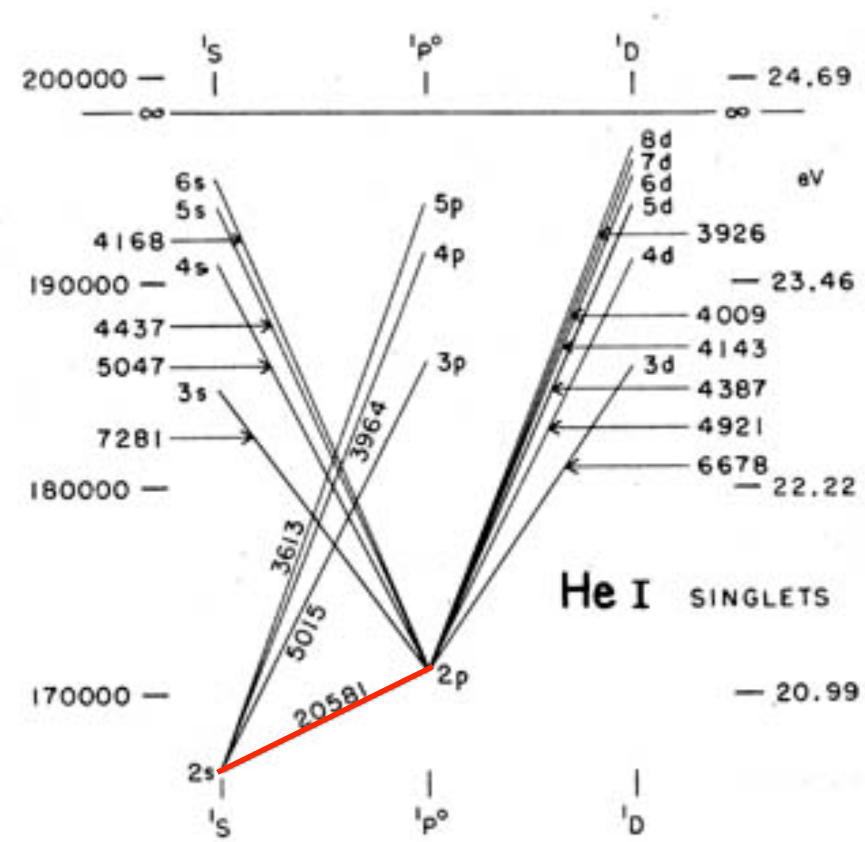
- To choose the lines that are more likely to happen (ΔE)
- To eliminate the profiles that don't match in the velocity space

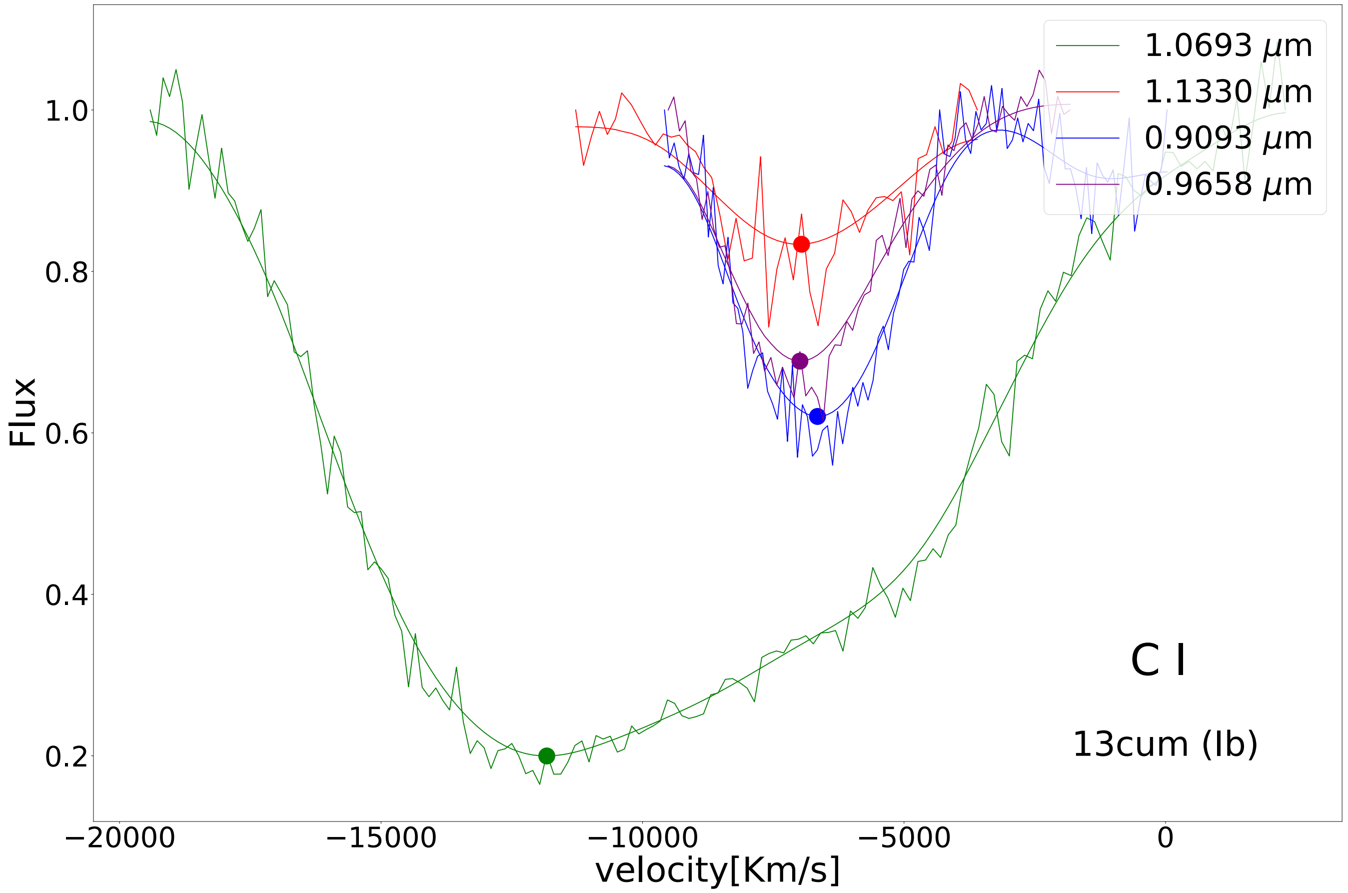


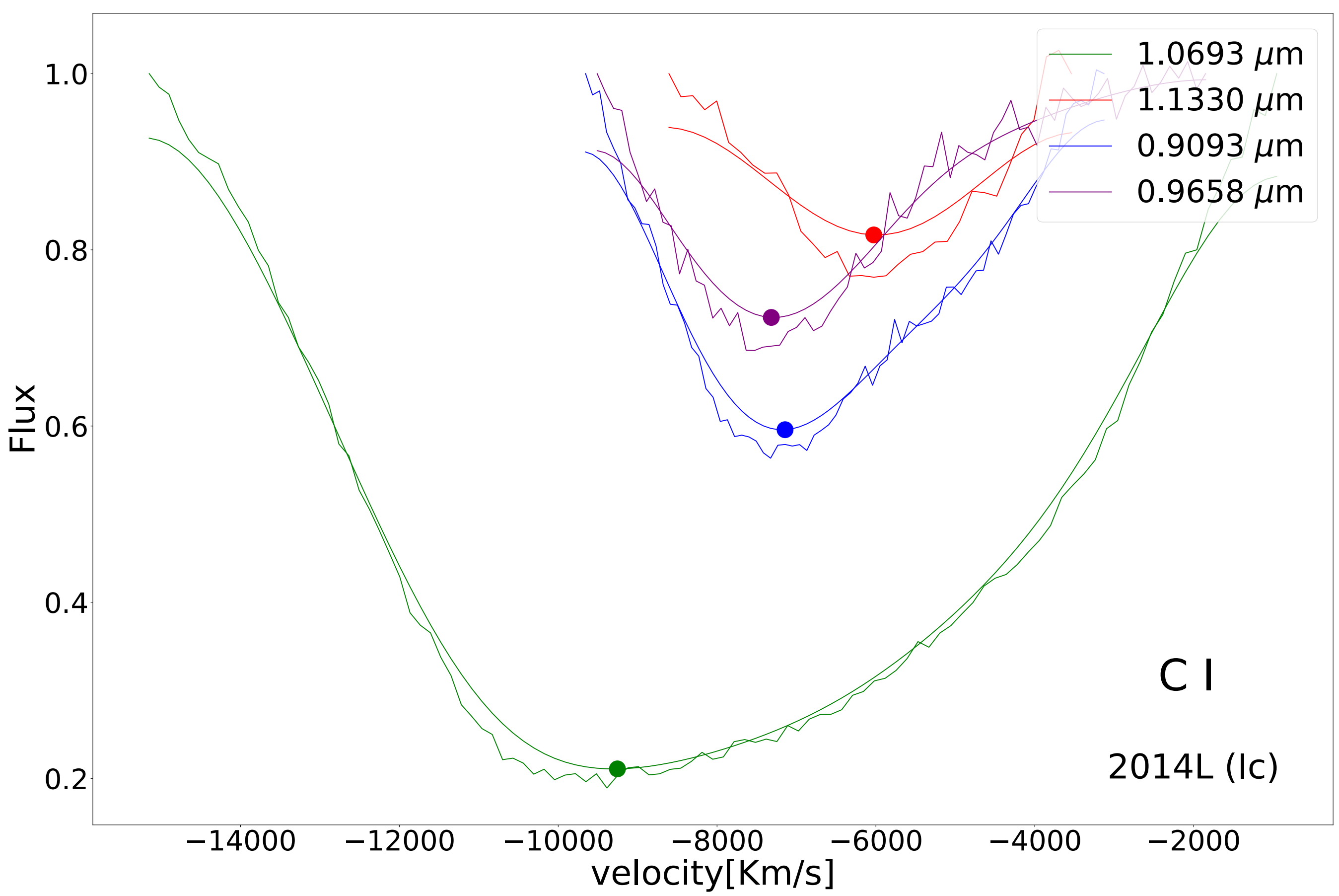

1.0830 μm
2.0581 μm
0.5876 μm
He I
13cum (Ib)
Flux
velocity[Km/s]

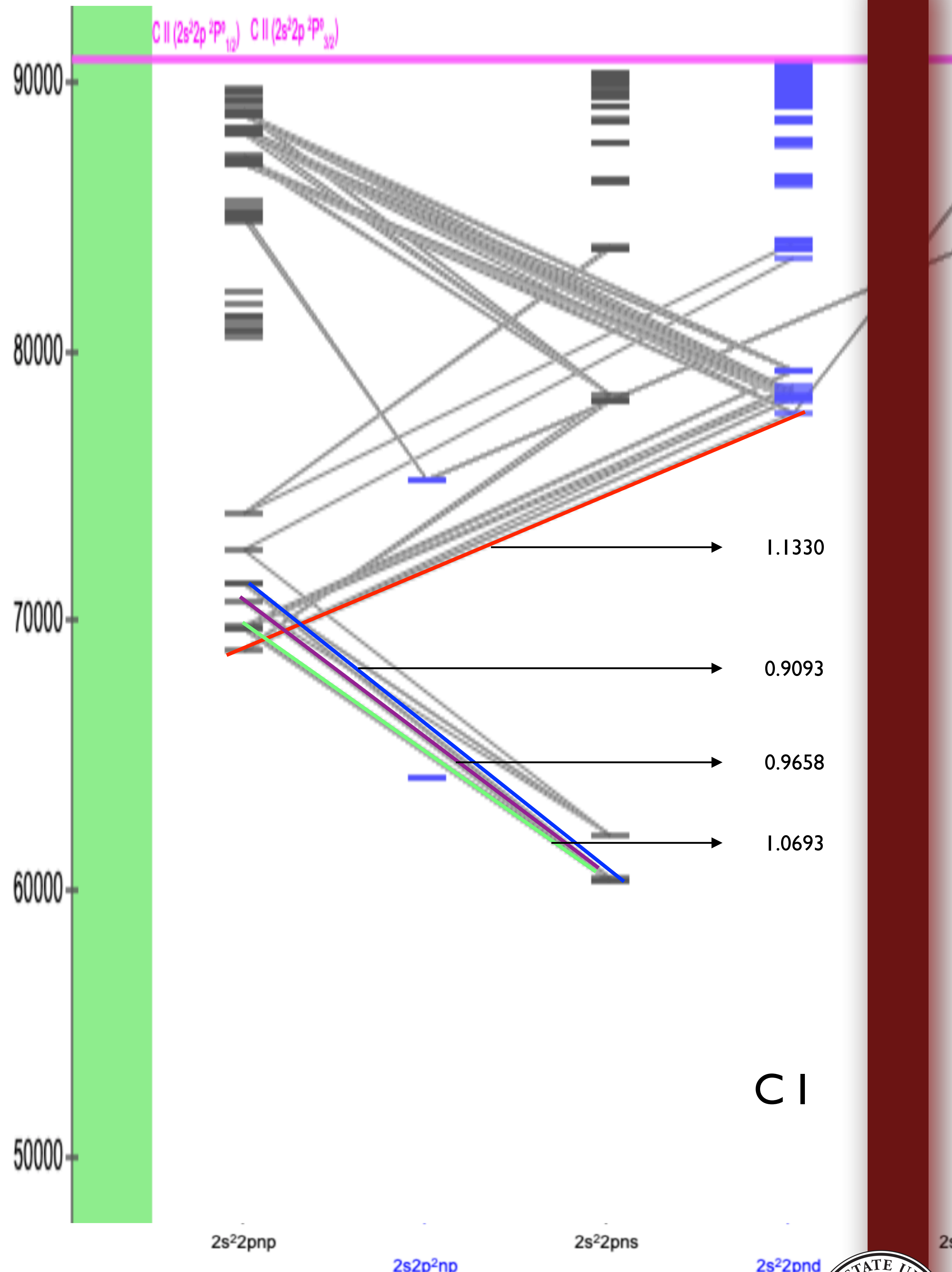

1.0830 μm
2.0581 μm
0.5876 μm
He I
2014L (Ic)
Flux
velocity[Km/s]


He I TRIPLETS
eV
10830
3187
3888
3732
3867
4120
4713
7065
3634
3705
3819
4026
4471
5875
200000
190000
180000
170000
160000
24.69
23.46
22.22
20.99
19.75


He I SINGLETS
eV
20581
5015
3613
3964
4168
4437
5047
7281
3926
4009
4143
4387
4921
6678
200000
190000
180000
170000
24.69
23.46
22.22
20.99


1.0693 μm
1.1330 μm
0.9093 μm
0.9658 μm
C I
13cum (Ib)
Flux
velocity[Km/s]

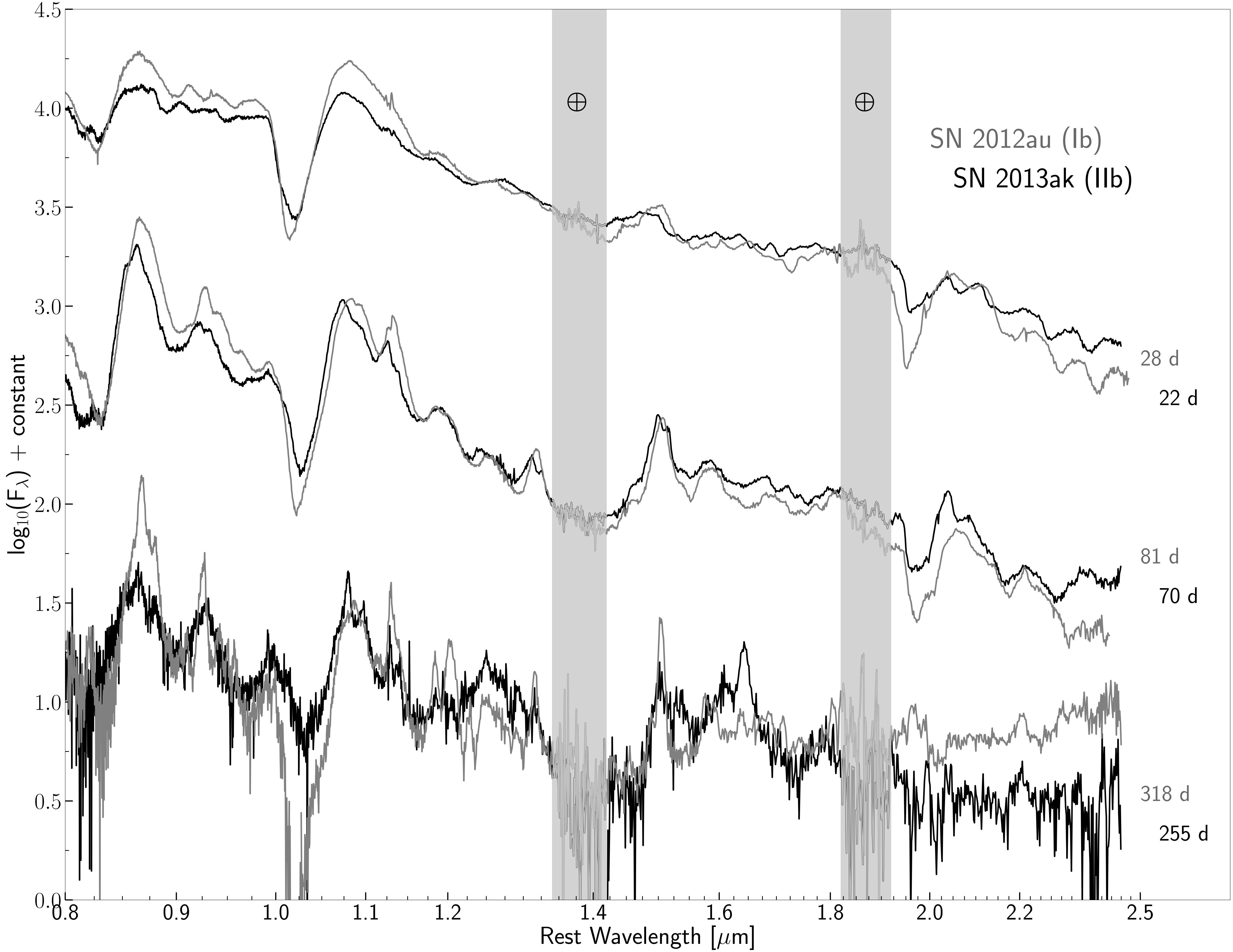

1.0693 μm
1.1330 μm
0.9093 μm
0.9658 μm
C I
2014L (Ic)
Flux
velocity[Km/s]


1.1330
0.9093
0.9658
1.0693
C I
2s²2pnp
2s2p²np
2s²2pns
2s²2pnd

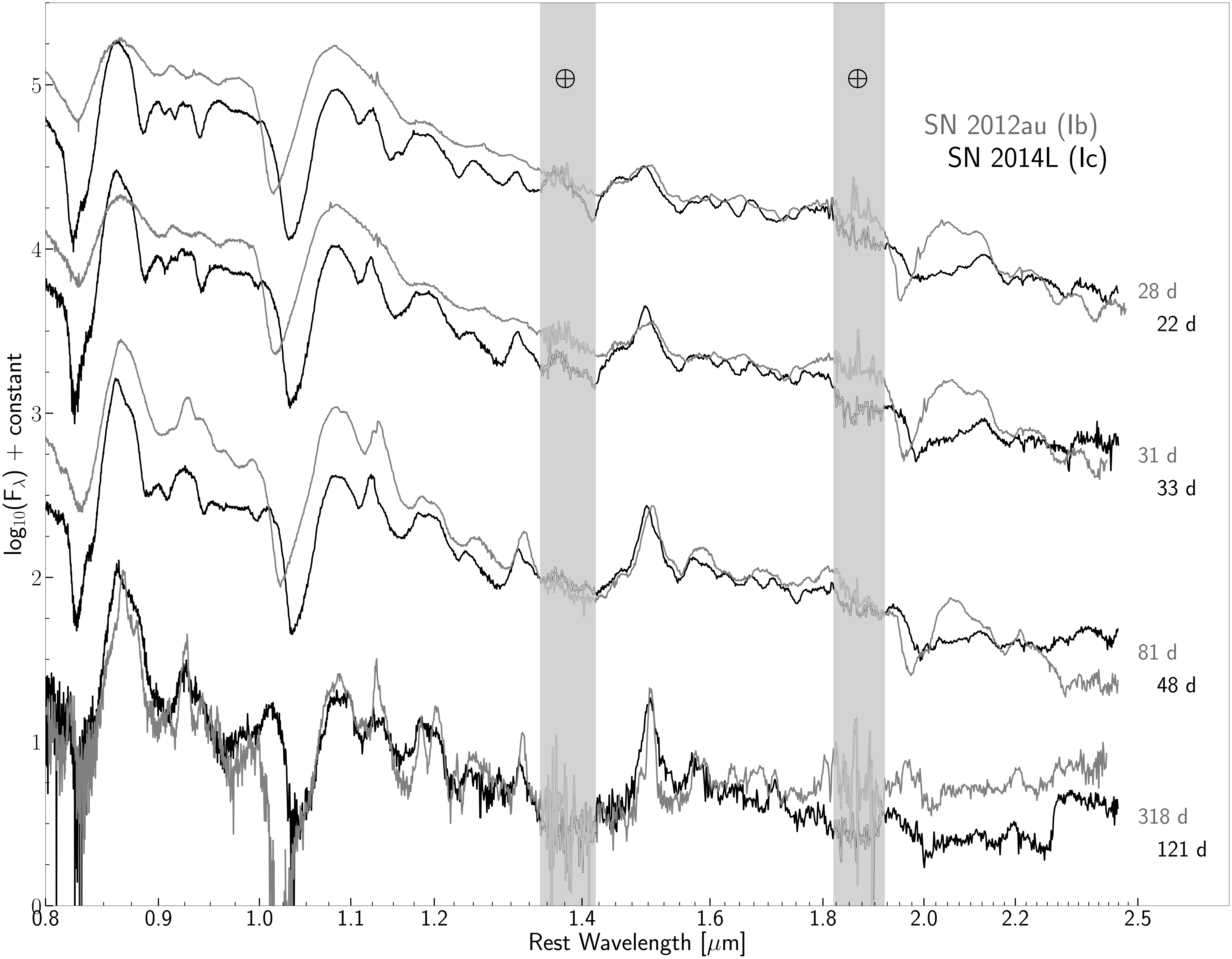
Method III

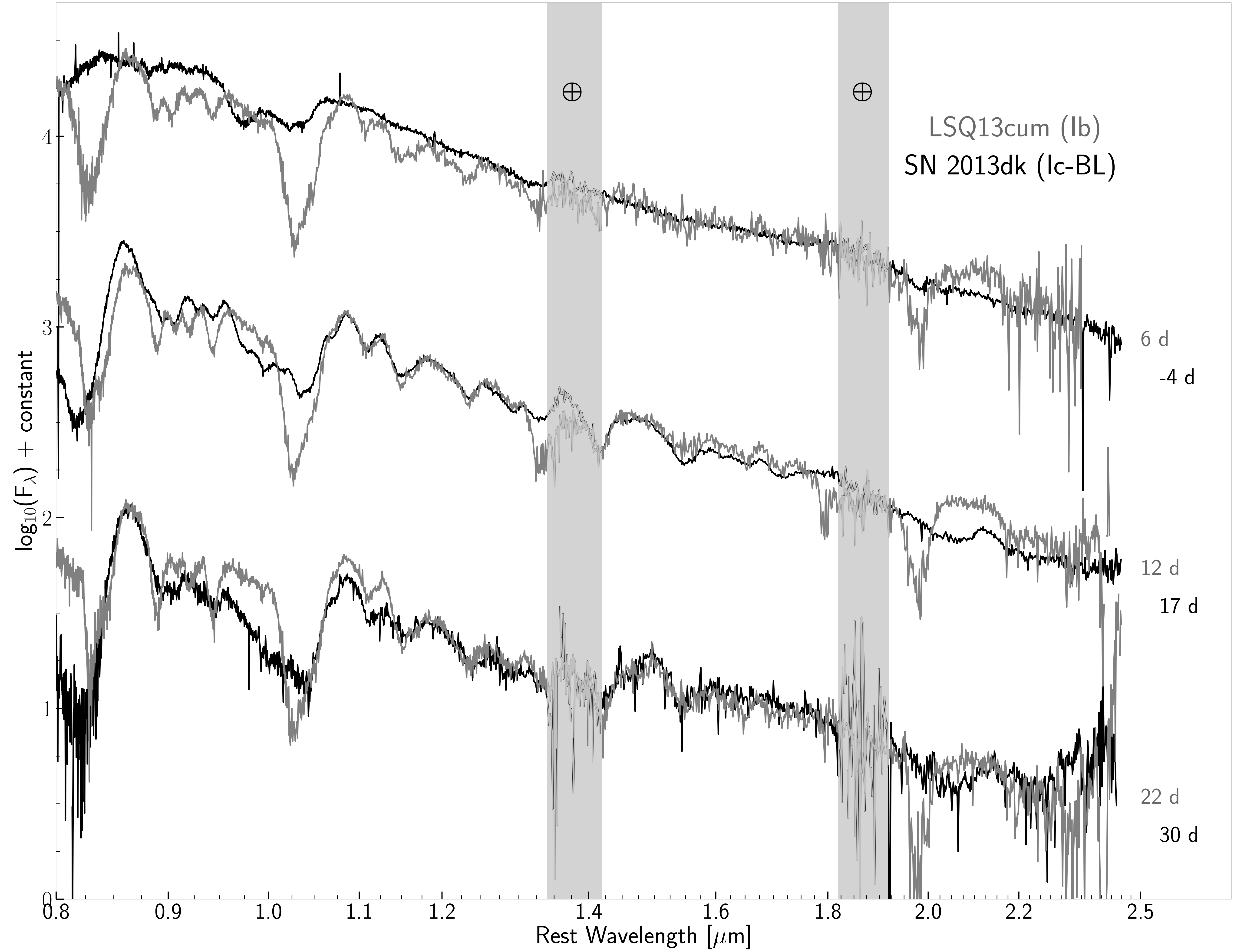
Using the line strength, gf values or intensity

- gf values (LTE assumption)
- Line strength $\propto$ [gf . exp (-ΔE/KT)]
  - He I λ 1.083 μm vs 2.058 μm
    - The strength of λ 2.058 μm should be roughly half of the strength of λ 1.083 μm



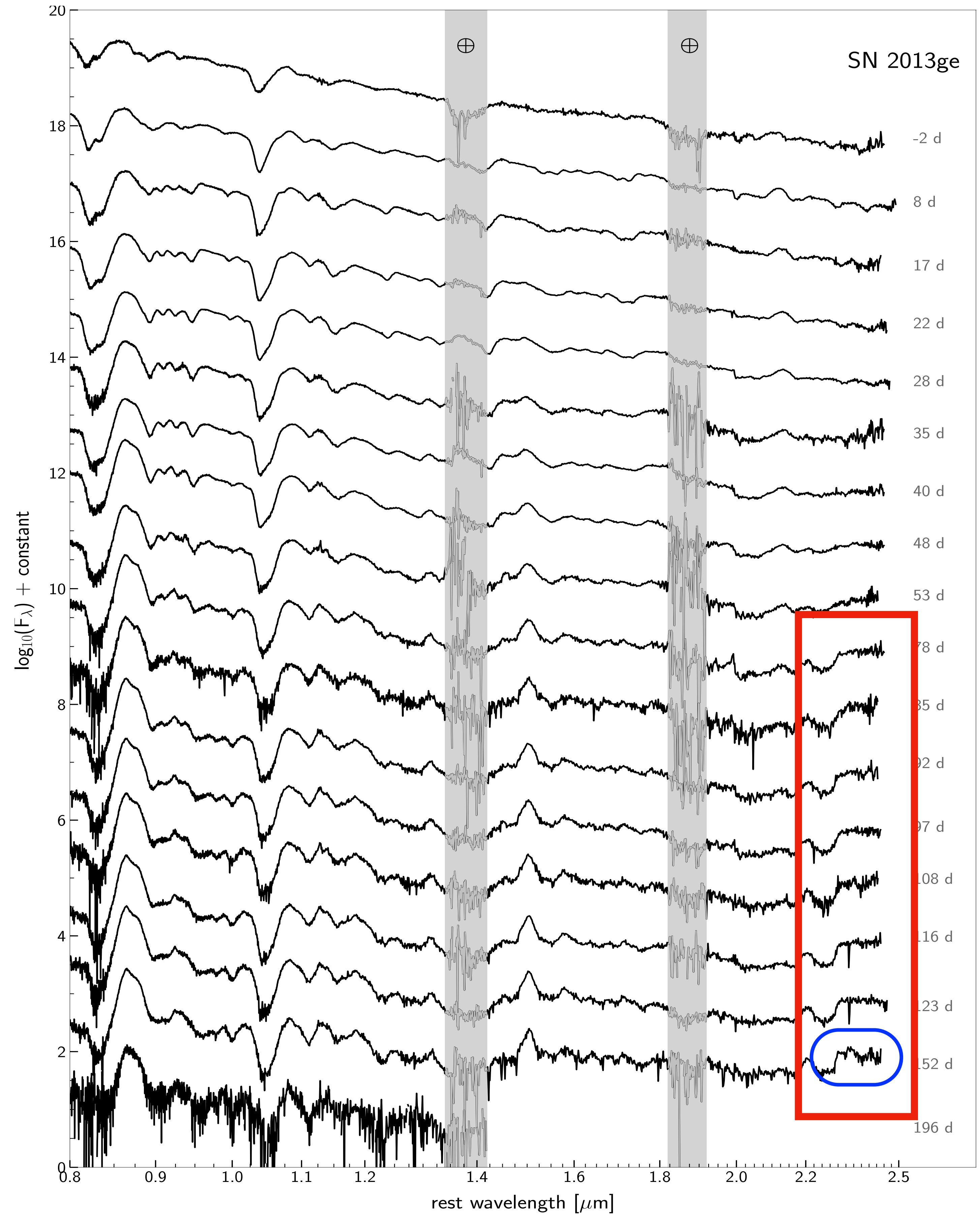
SN 2012au (Ib)
SN 2013ak (IIb)
28 d
22 d
81 d
70 d
318 d
255 d
log10(Fλ) + constant
Rest Wavelength [μm]
⊕
⊕


SN 2012au (Ib)
SN 2014L (Ic)
⊕
⊕
28 d
22 d
31 d
33 d
81 d
48 d
318 d
121 d
log10(Fλ) + constant
Rest Wavelength [μm]
0
1
2
3
4
5
0.8
0.9
1.0
1.1
1.2
1.4
1.6
1.8
2.0
2.2
2.5


LSQ13cum (Ib)
SN 2013dk (Ic-BL)
6 d
-4 d
12 d
17 d
22 d
30 d
log10(Fλ) + constant
Rest Wavelength [μm]
0
1
2
3
4
0.8
0.9
1.0
1.1
1.2
1.4
1.6
1.8
2.0
2.2
2.5

Carbon monoxide

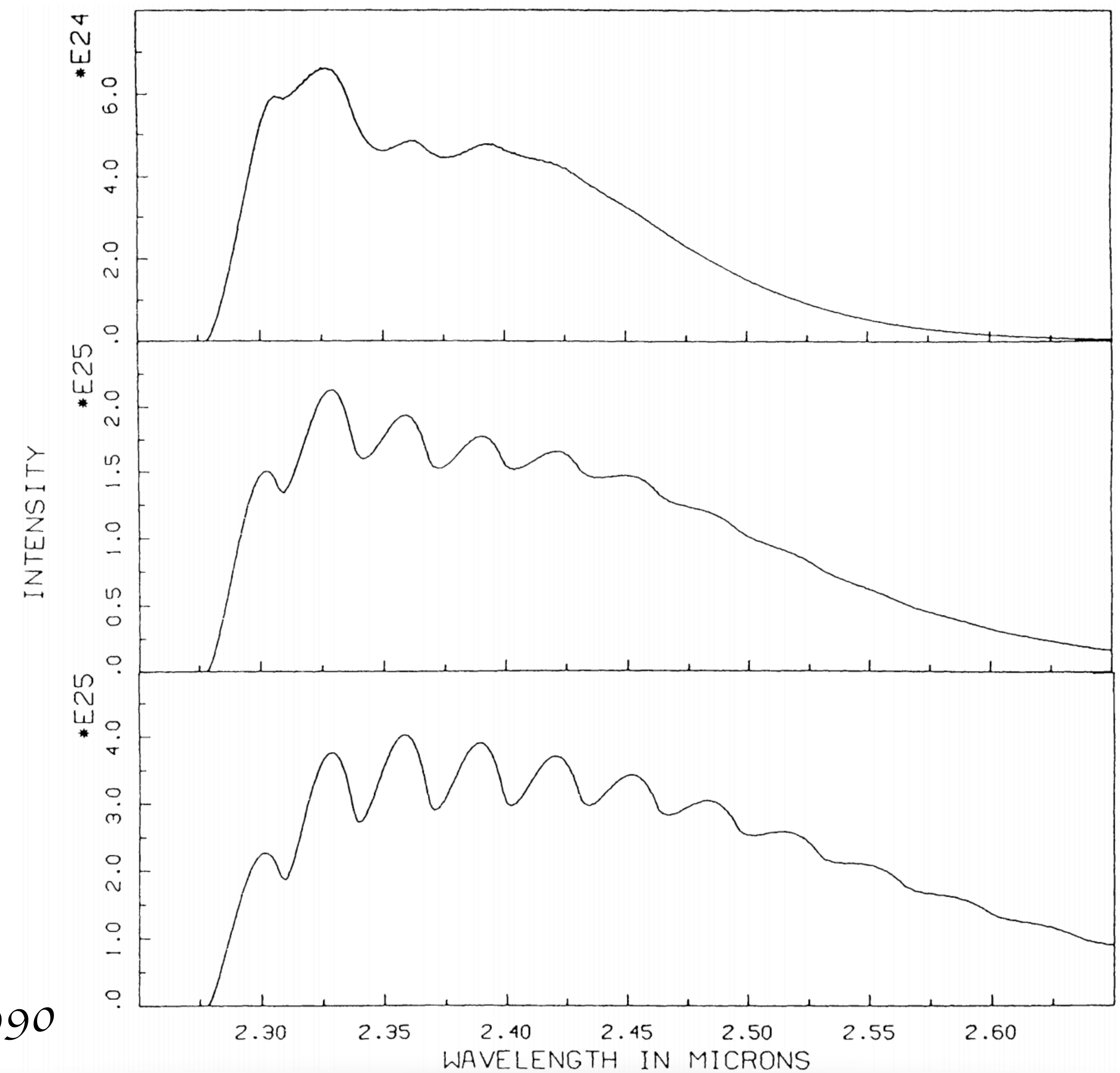
- Appears as early as 78 days
- Present in ~10 spectra



Why do we care about CO?

- CO formation timescale tells us where CO forms
  - Velocity
  - Local temperature and its time evolution
- Effective cooler >> Dust formation

How does CO profile change with temperature?



2000 K

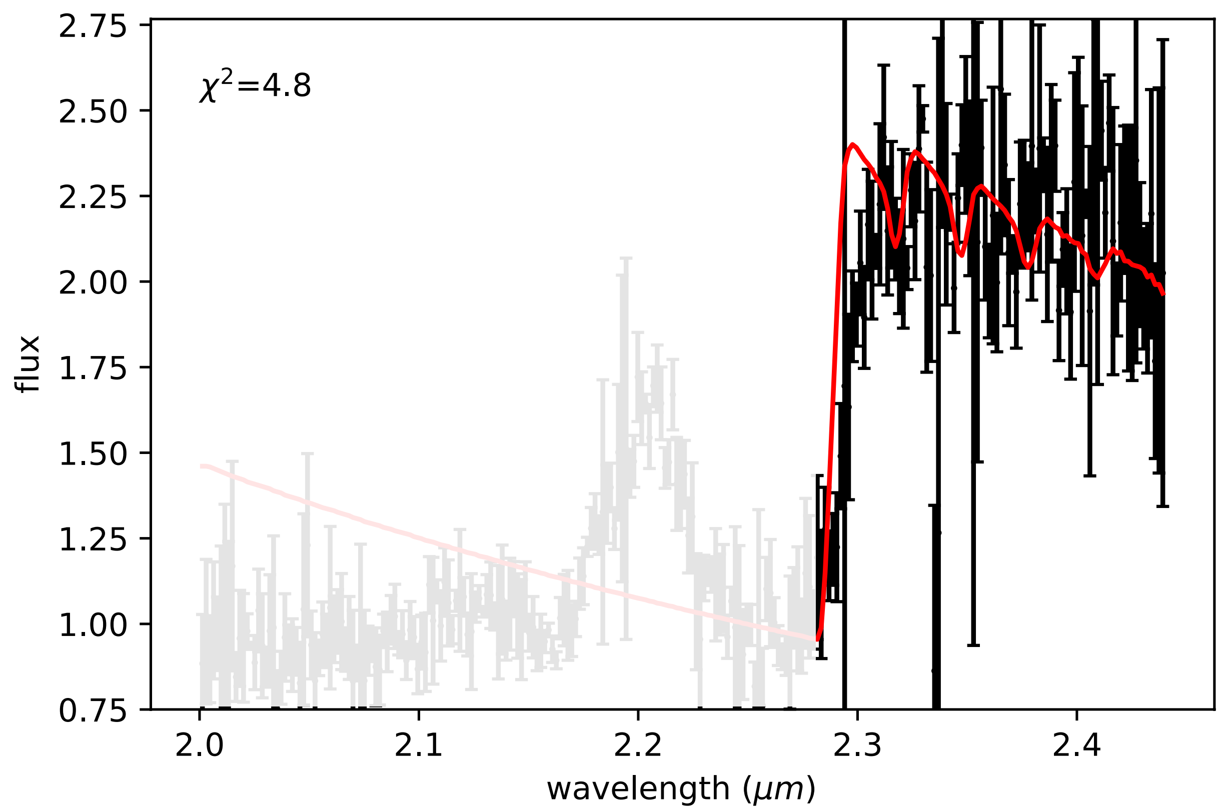
3000 K

4000 K

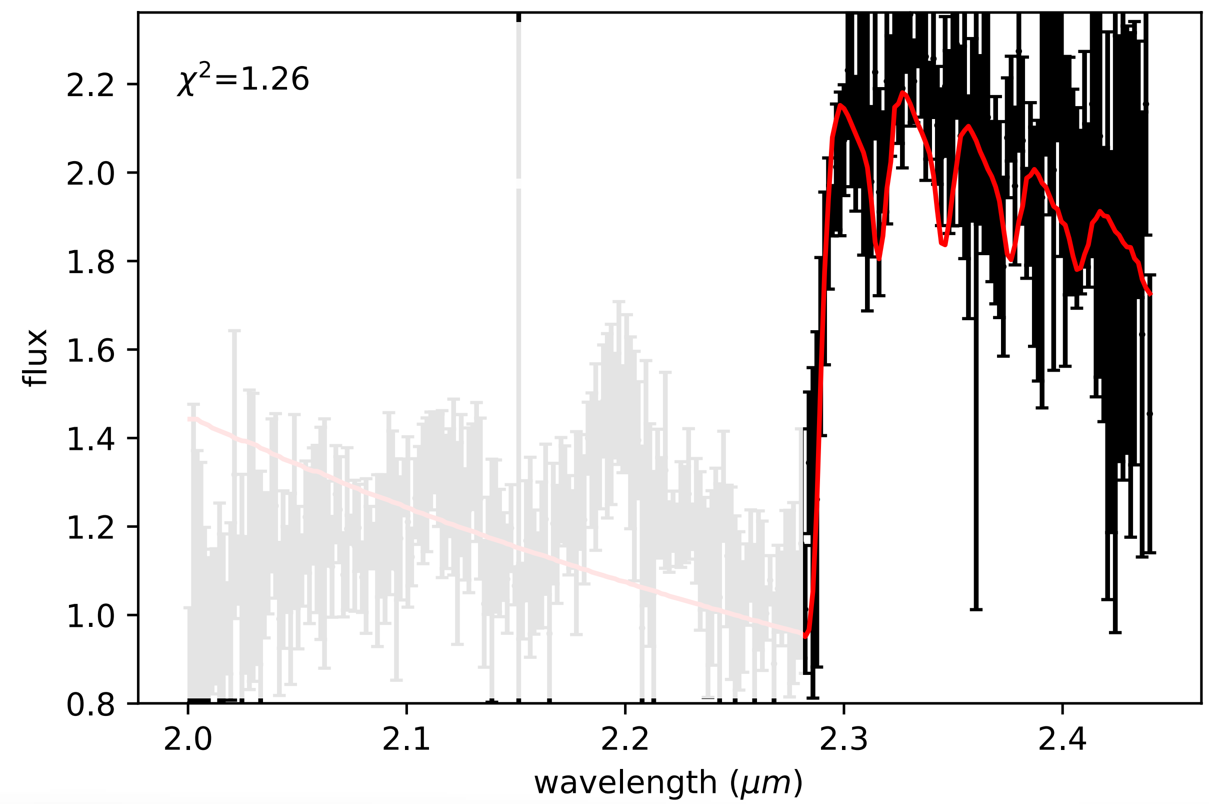
Sharp, Hoeflich 1990

Application to observations

- SN 2013ge
- Phase = 123 days
- T ~ 4000 K
- Radius ~ 10^{14} cm
- Density gradient (n) = 9 [$\rho \propto r^{-n}$]
- V~1000 Km/s



- SN 2014L
- Phase = 121 days
- T ~ 5000 K
- Radius ~ 10^{14} cm
- Density gradient (n) = 7 [$\rho \propto r^{-n}$]
- V~1000 Km/s



Preliminary Conclusion

- NIR spectra provided new insight into the nature of SE-SNe
- There is a strong P Cygni profile at ~λ1.08 μm present in all of the spectra of this dataset
- We combined 3 different constraints to identify the strongest profiles
- We find that SN Ib shows He rich layers whereas in SN Ic we see C/O
- We identify the C I lines as an effective way to potentially determine the C/O core mass in SE-SNe
- CO formation is common and can be used as diagnostics to lead dust formation studies.