

# Superluminous Supernovae



SAN DIEGO STATE  
UNIVERSITY

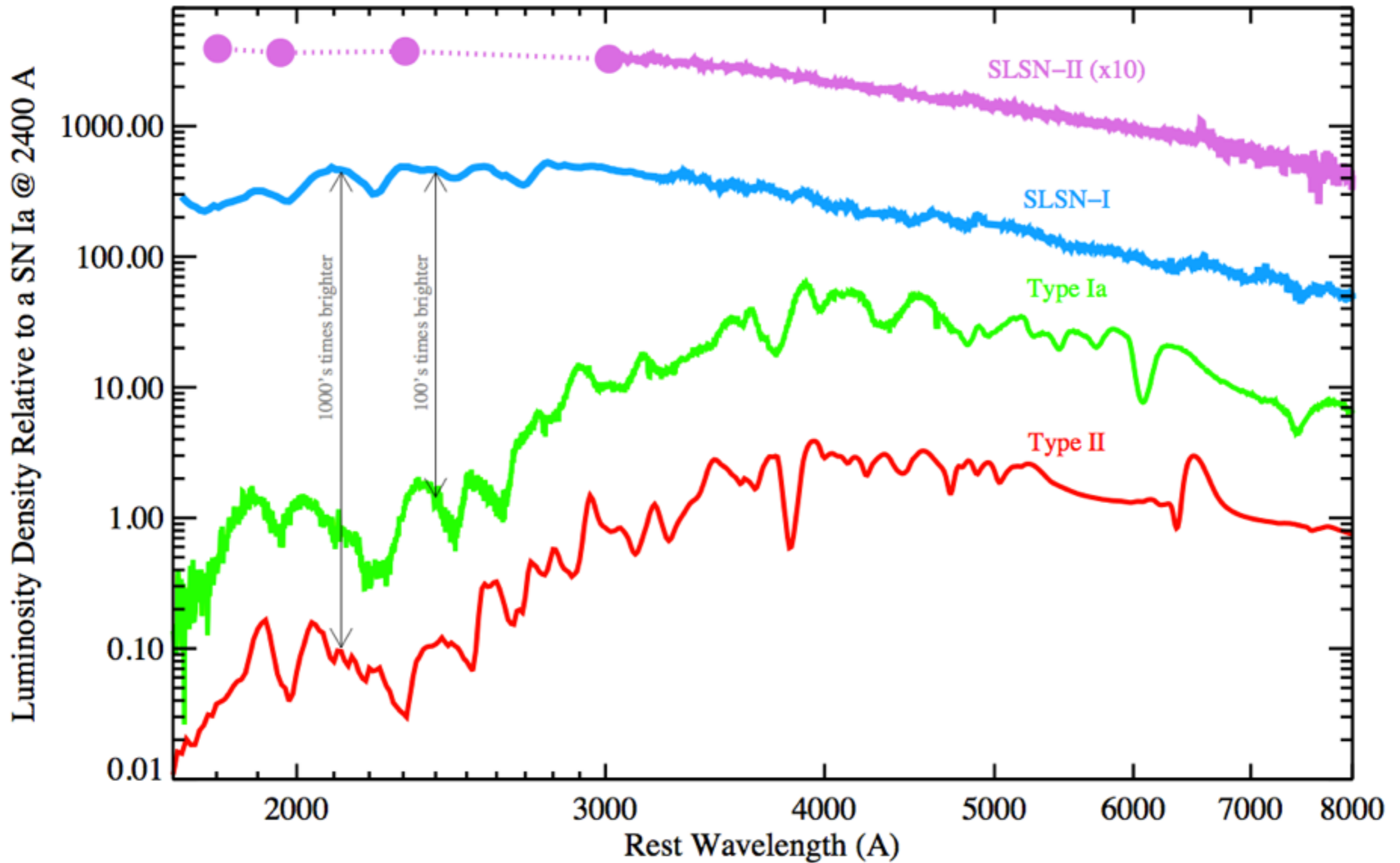


**Robert Quimby**

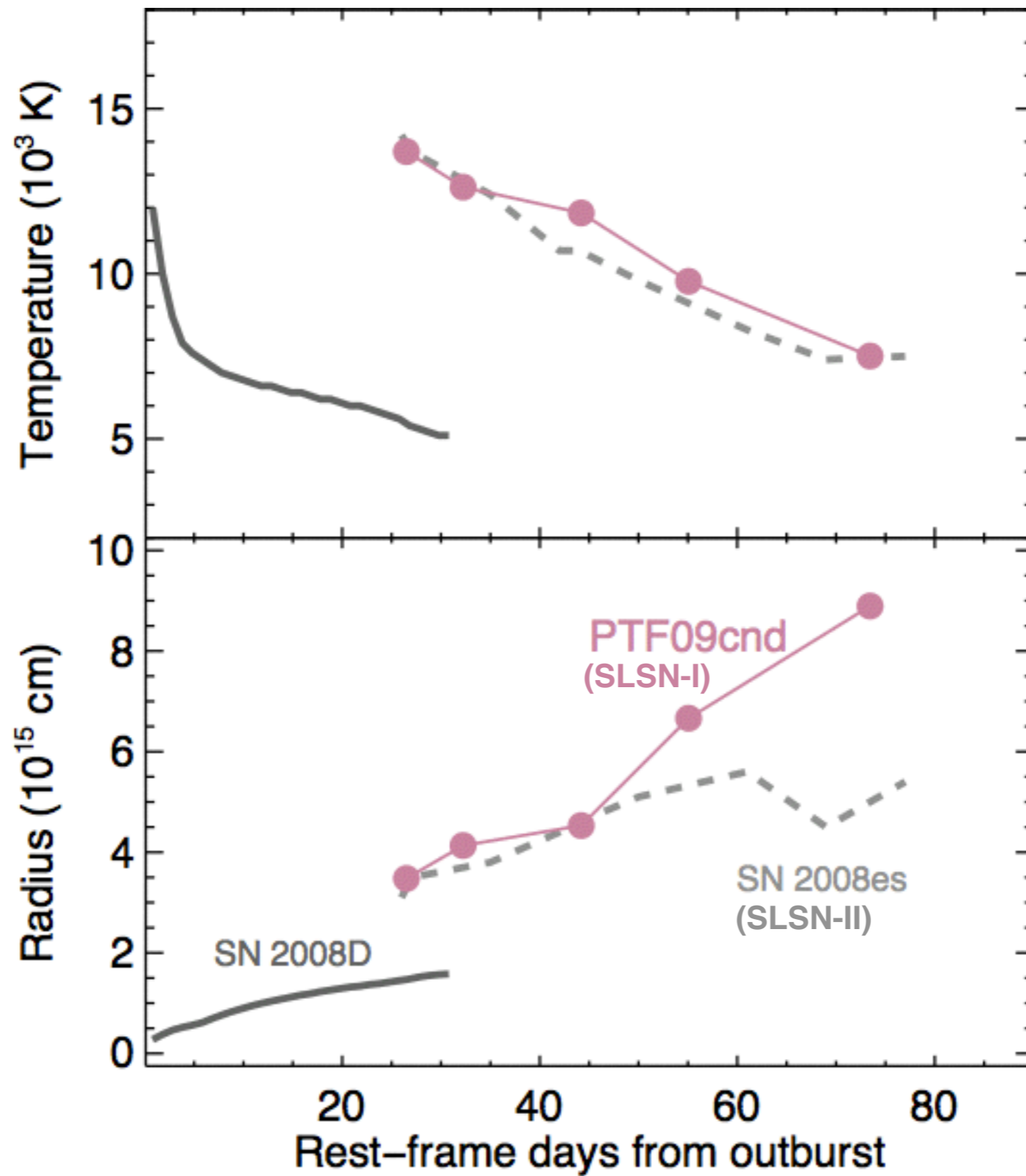
May 2016



# SLSN Spectra

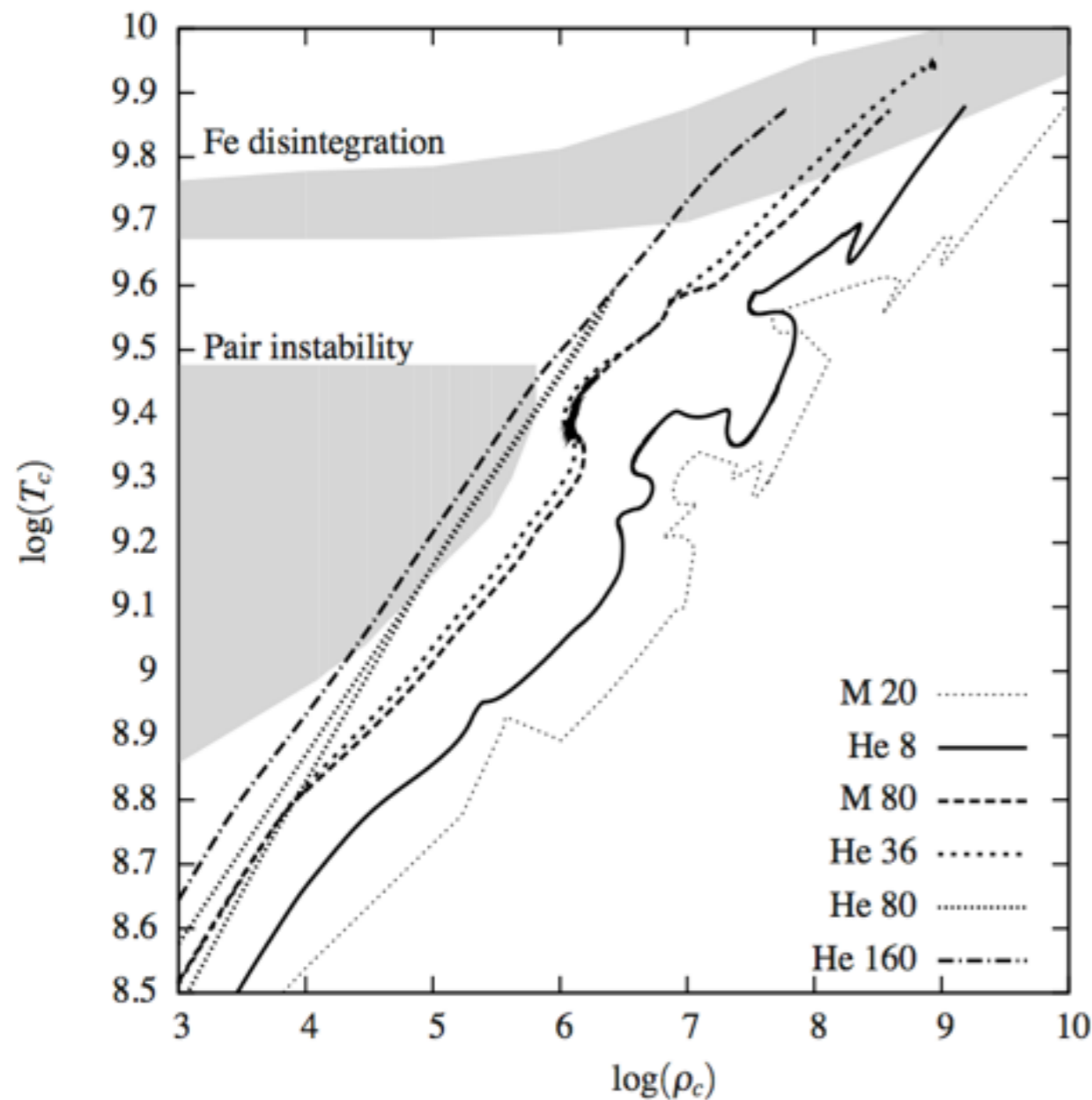


# SLSN Stay Hot Longer



RQ et al. 2011

# Are SLSNe: I) Pair-Instability SNe?

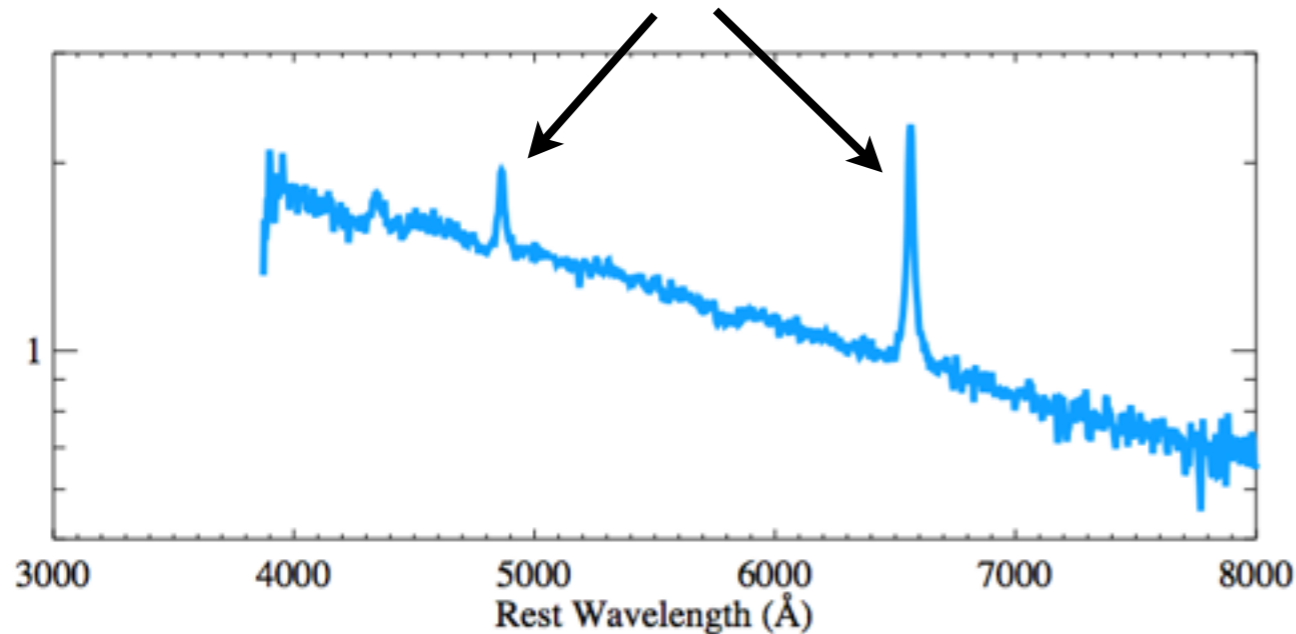


Waldman 2008

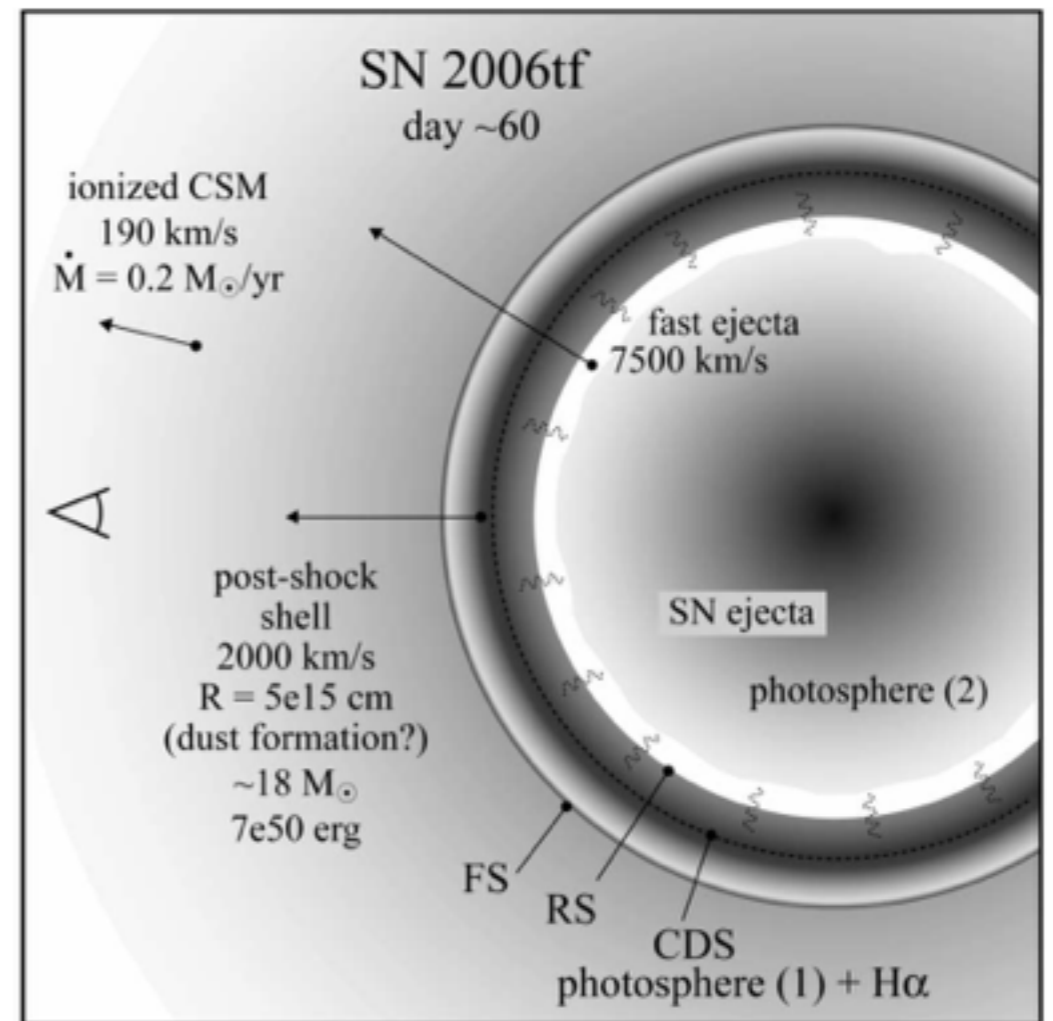
- First Proposed in the 1960's (Rakavy et al. 1967; Barkat et al. 1967)
- Massive stars are supported by radiation pressure
- At high temperatures, photons are created with  $E > e^+e^-$
- Losses to pair production soften the EOS, and lead to instability
- Expected fate of the first (low metal, high mass) stars

# 2) Interaction Power?

Narrow emission lines indicate ejecta/wind interaction



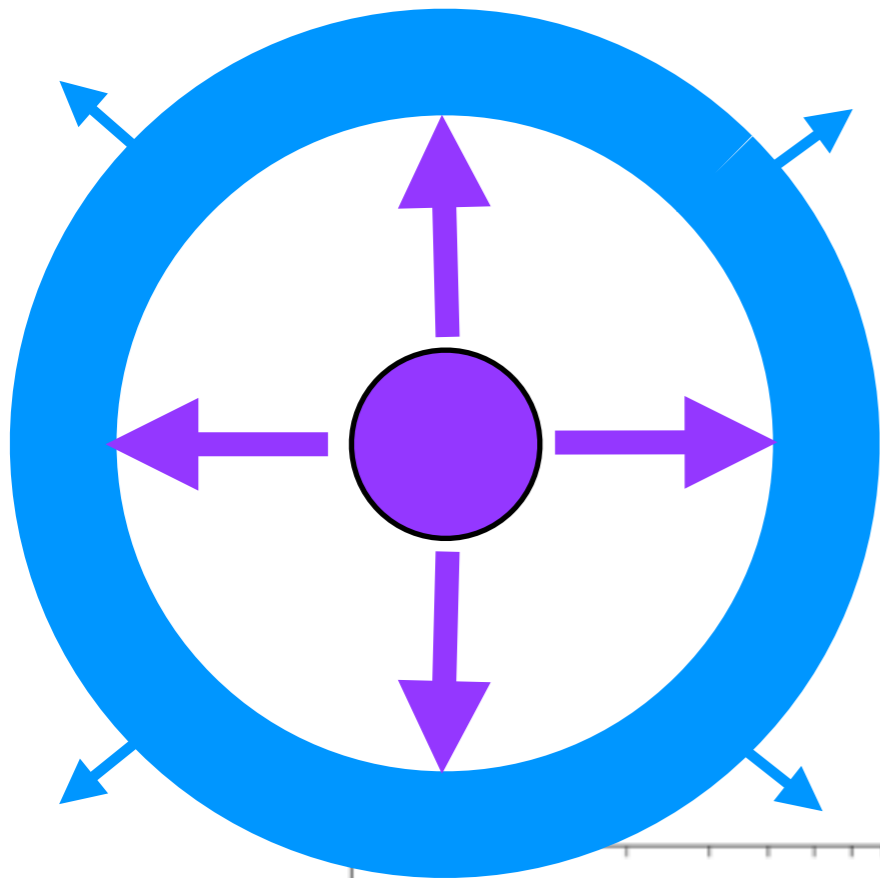
Ejecta run into surrounding material (progenitor wind, shells, etc.) and convert kinetic energy into luminosity



Smith et al. 2008

see also Smith & McCray 2007,  
Chevalier & Irwin 2011

# 3) Central Engine Power?

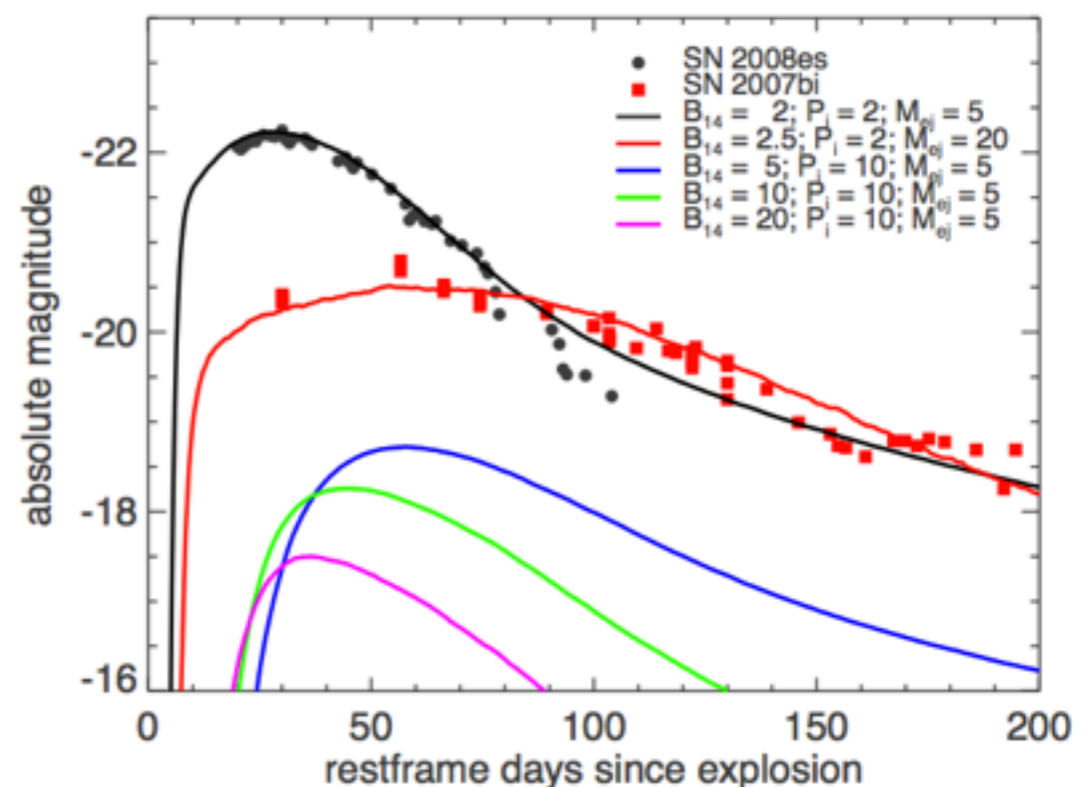
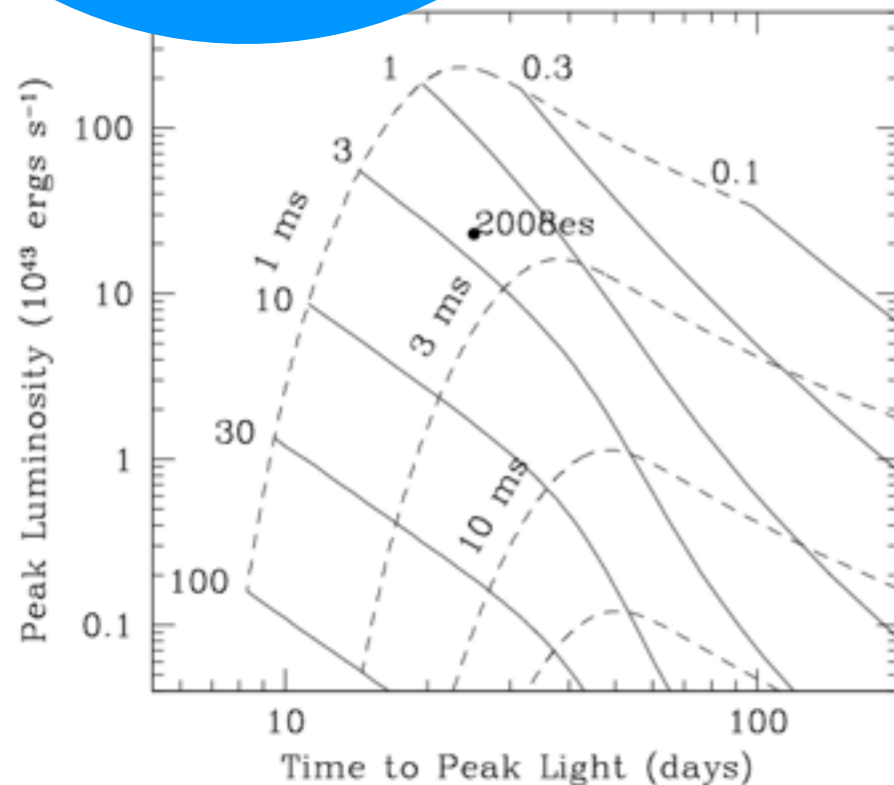


$$E_p = \frac{I_{\text{ns}} \Omega_i^2}{2} = 2 \times 10^{50} P_{10}^{-2} \text{ ergs},$$

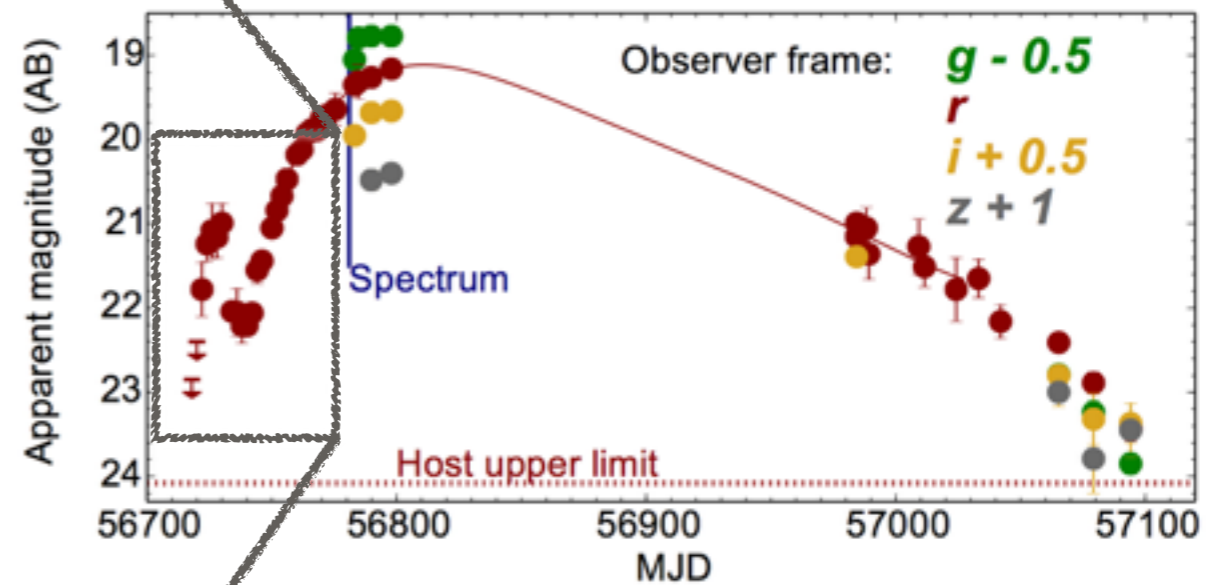
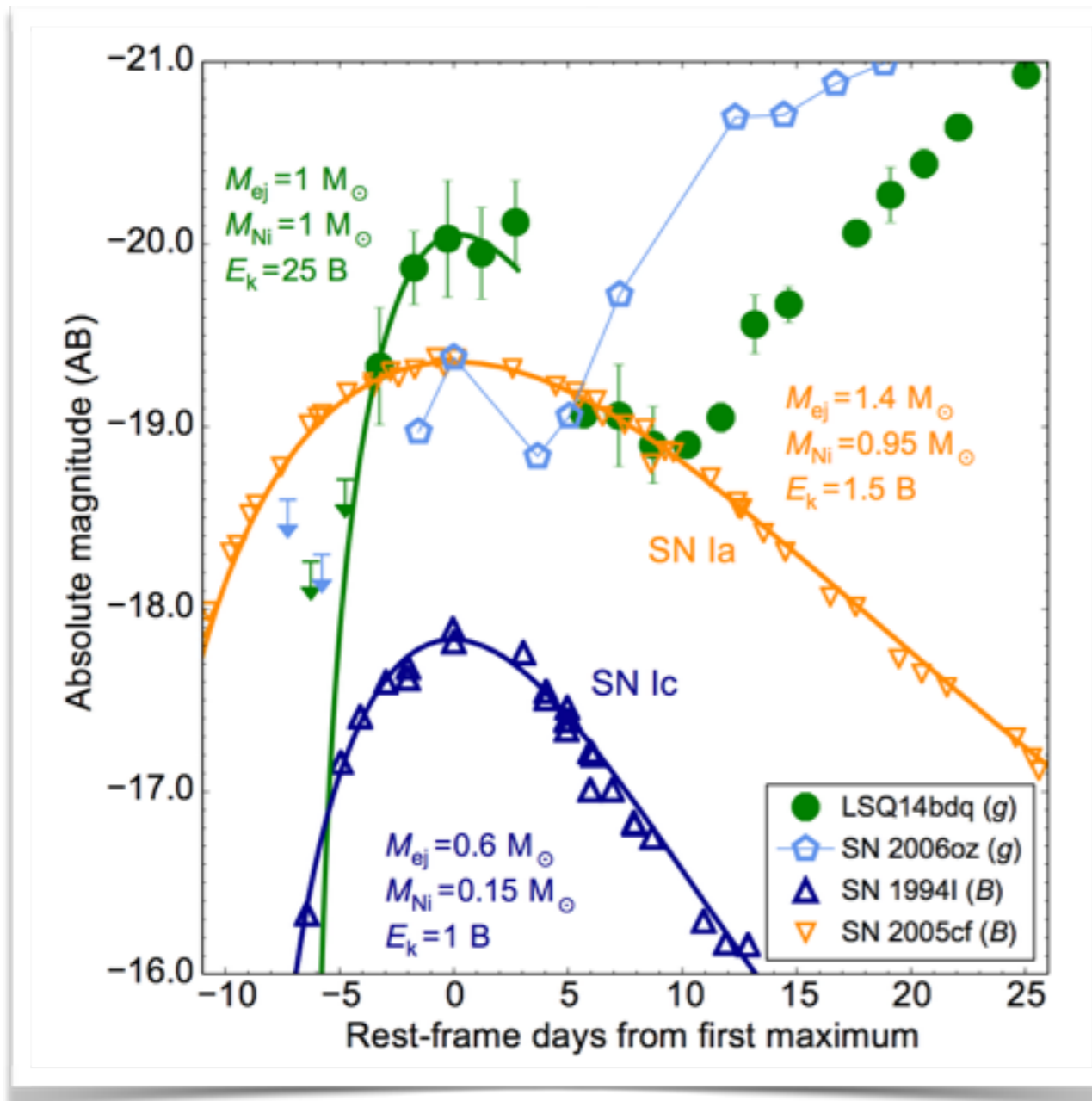
$$t_p = \frac{6 I_{\text{ns}} c^3}{B^2 R_{\text{ns}}^6 \Omega_i^2} = 1.3 B_{14}^{-2} P_{10}^2 \text{ yr},$$

$$L_{\text{peak}} \sim \frac{E_p t_p}{t_d^2} \sim 5 \times 10^{43} B_{14}^{-2} \kappa_{\text{es}}^{-1} M_5^{-3/2} E_{51}^{1/2} \text{ erg s}^{-1}$$

Kasen & Bildsten 2010; see also Woosley 2010



# Double Peaked SLSN-I



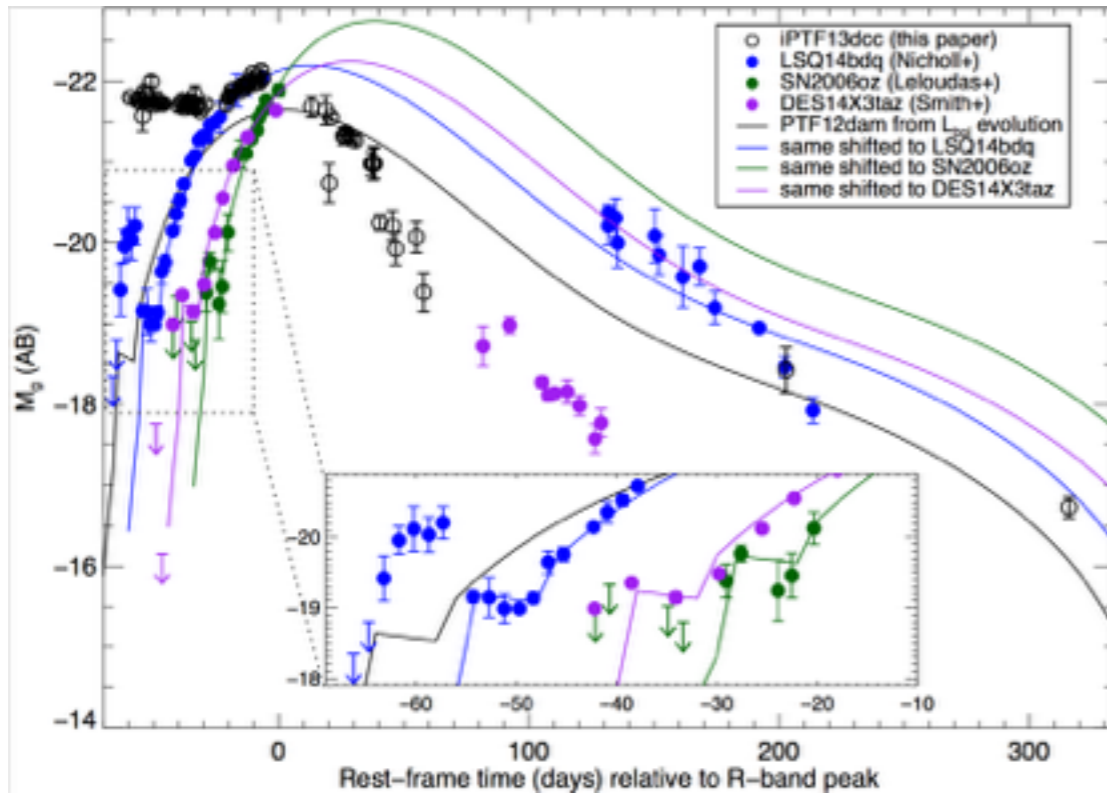
Nicholl et al. (2015)

See also Leloudas et al. 2012

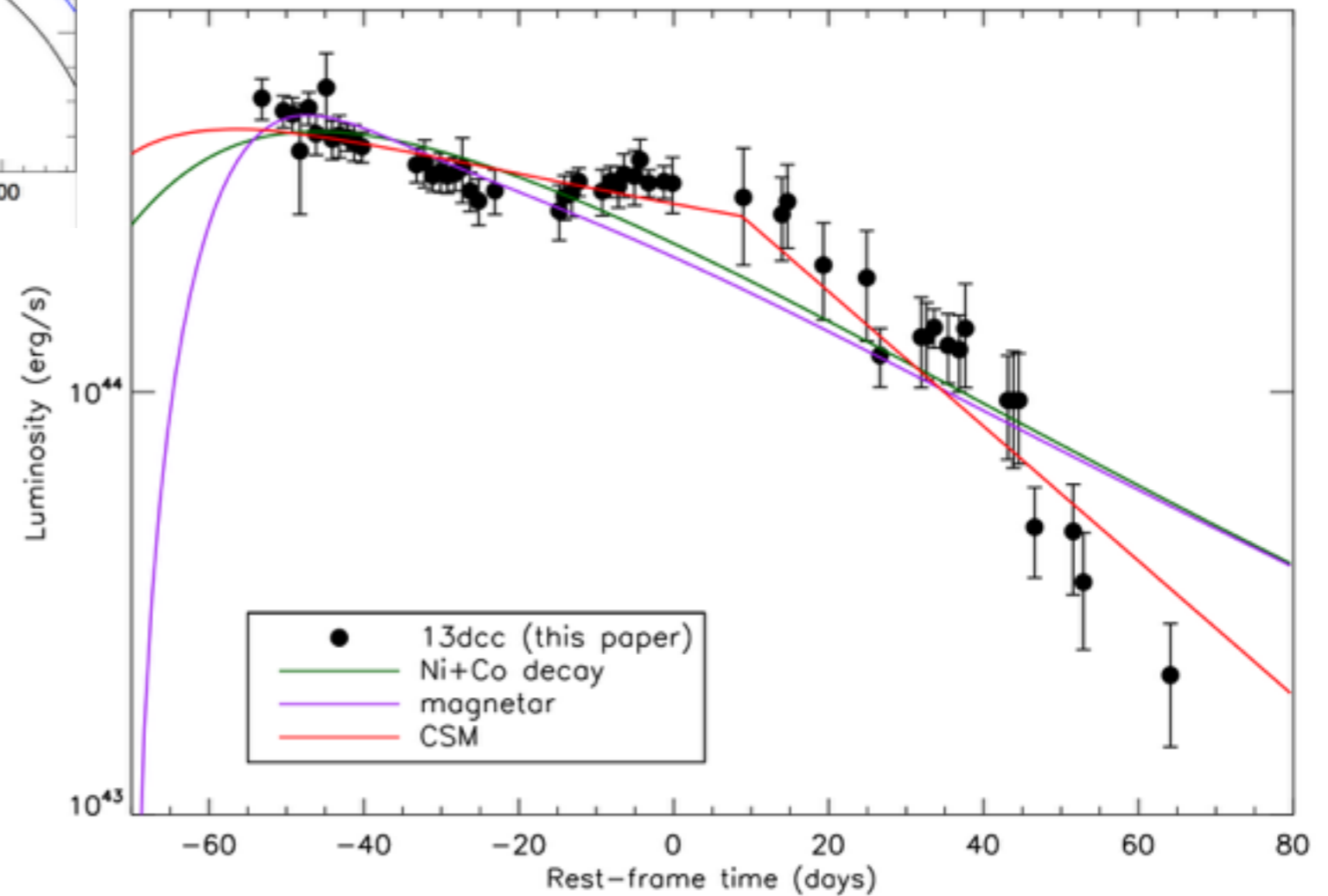
Nicholl & Smartt 2016

Kasen et al. 2016

# PTF 13dcc



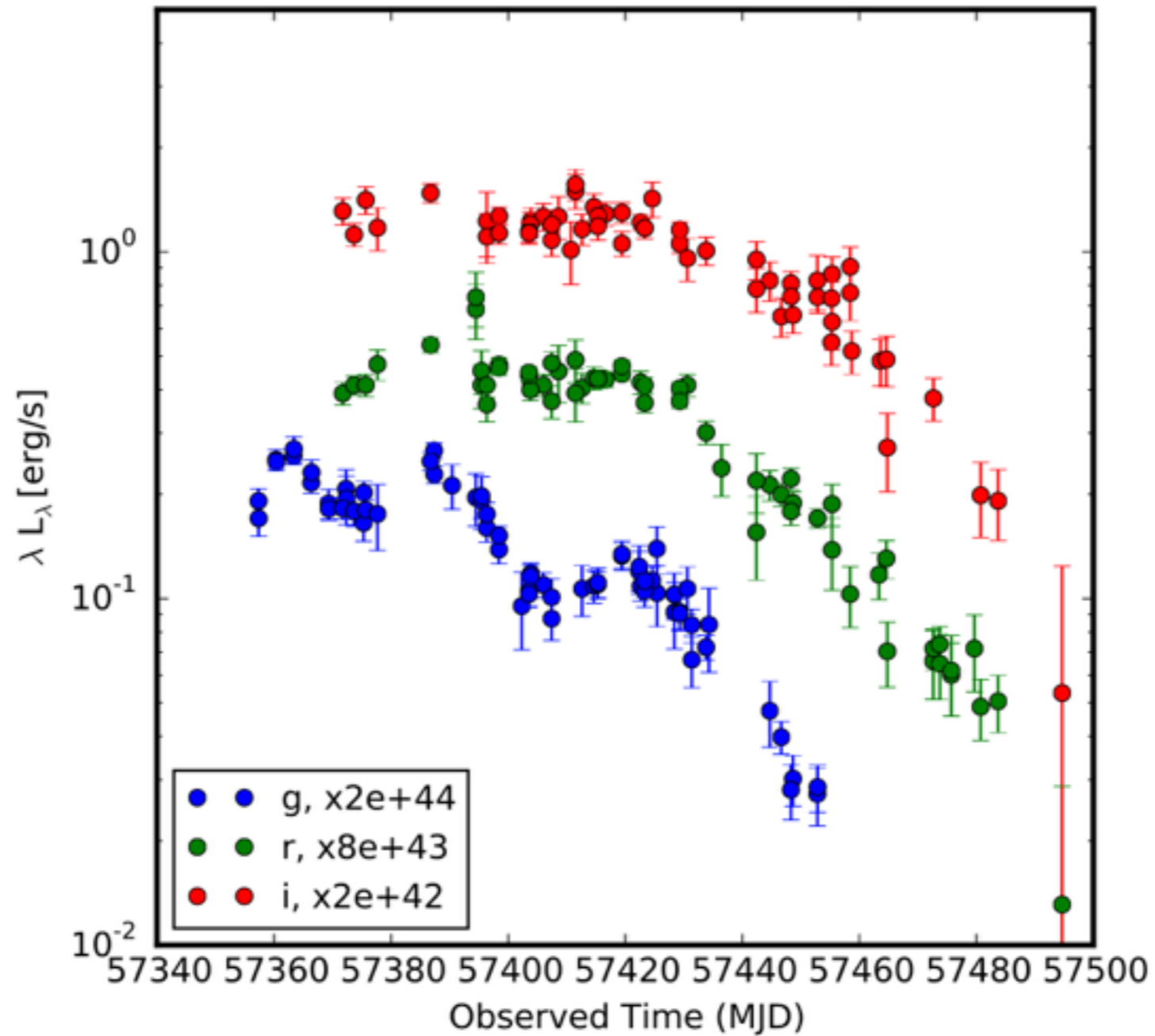
Vreeswijk et al. (in prep)



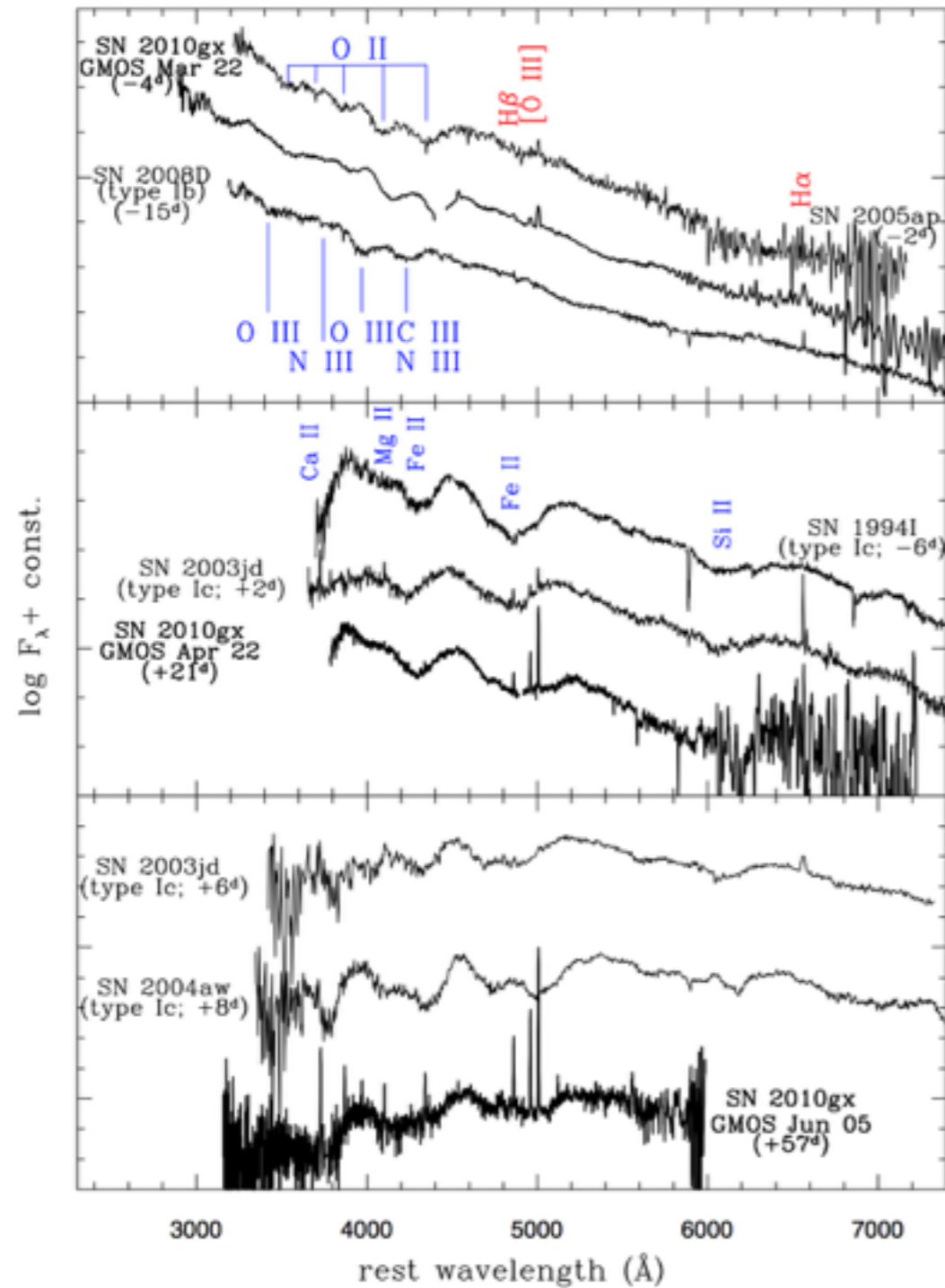


# PTF 15esb

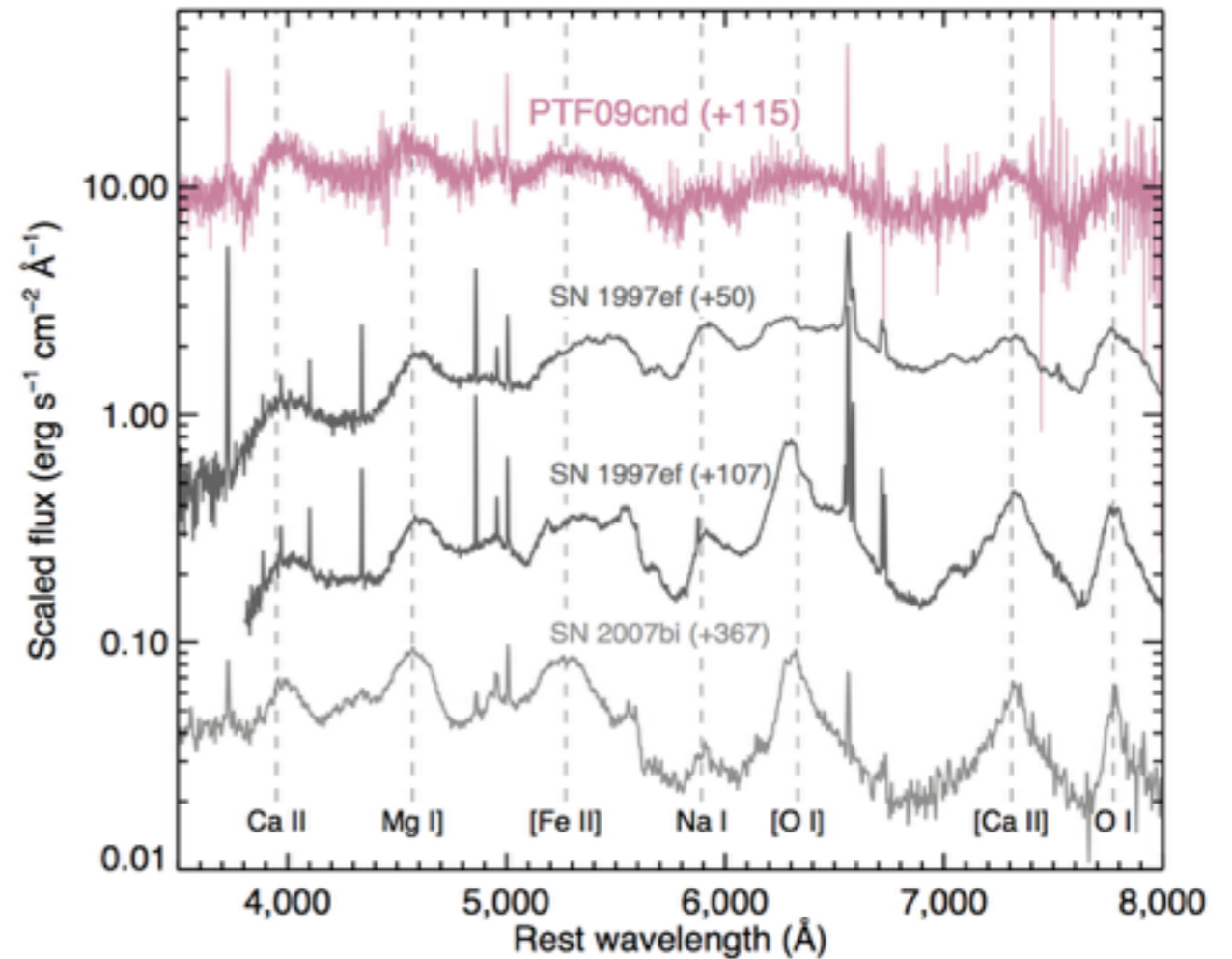
Yan et al. (in prep)



# SLSN-I / SNIc “Connection”



Pastorello et al. 2010



RQ et al. 2011

# Superfit

Howell et al. 2006

supergraph

Input file:

Supernova	S	z	gal	Av	cc	ff	gfrac	sfrac
smooth/PTF/snPTF12dam,u0002.dat	0.094	0.100	Sc	-0.1153	0.7730	0.1069	0.115	
smooth/PTF/snPTF12dam,u0001.dat	0.107	0.100	Sc	-0.0641	0.6783	0.0762	0.082	
smooth/SLSN-I/snPTF12dam,w0014.dat	0.108	0.100	Sc	0.1795	1.0268	0.1064	0.114	
smooth/SLSN-I/snPTF12dam,w0023.dat	0.113	0.100	Sc	-0.3084	0.5450	0.1945	0.209	
smooth/SLSN-I/sn2005ap,p0004.dat	0.119	0.110	Sc	0.4187	2.0364	0.0000	0.000	
smooth/PTF/snPTF09cwl,u0000.dat	0.122	0.100	Sc	-0.4277	0.6755	0.1855	0.199	
smooth/SLSN-I/sn2010gx,w0004.dat	0.128	0.110	Sc	-0.1241	0.8426	0.0893	0.098	
smooth/PTF/snPTF10aagc,u0002.dat	0.128	0.090	Sc	-0.0365	0.6098	0.1481	0.156	
smooth/PTF/snPTF09cnd,u0033.dat	0.129	0.090	Sc	-0.3734	0.7325	0.0674	0.071	
smooth/SNIc-bl/sn2006aj,w0006.dat	0.134	0.130	Sc	-1.3458	0.2046	0.0936	0.108	
smooth/PTF/snPTF09cnd,u0010.dat	0.135	0.100	Sc	-0.4721	0.5612	0.1808	0.194	
smooth/PTF/snPTF10cwr,u0000.dat	0.139	0.120	Sc	-0.5157	0.5533	0.1823	0.205	
smooth/SLSN-I/snPTF12dam,w0021.dat	0.139	0.100	Sc	0.3296	1.3613	0.0263	0.028	

Type: Agreement: 0 of the top 0. Epoch (weighted average): -99.0 +/- 2.0

Plots: check to show, enter offset in box:

Obs-gal:  Orig. Obs:  Temp:  Sm. 0-6:  Swth. Obs:  Gal:

Smoothing parameters: Npix:  Degree:

begin:  end:  z:  Bin (Å):

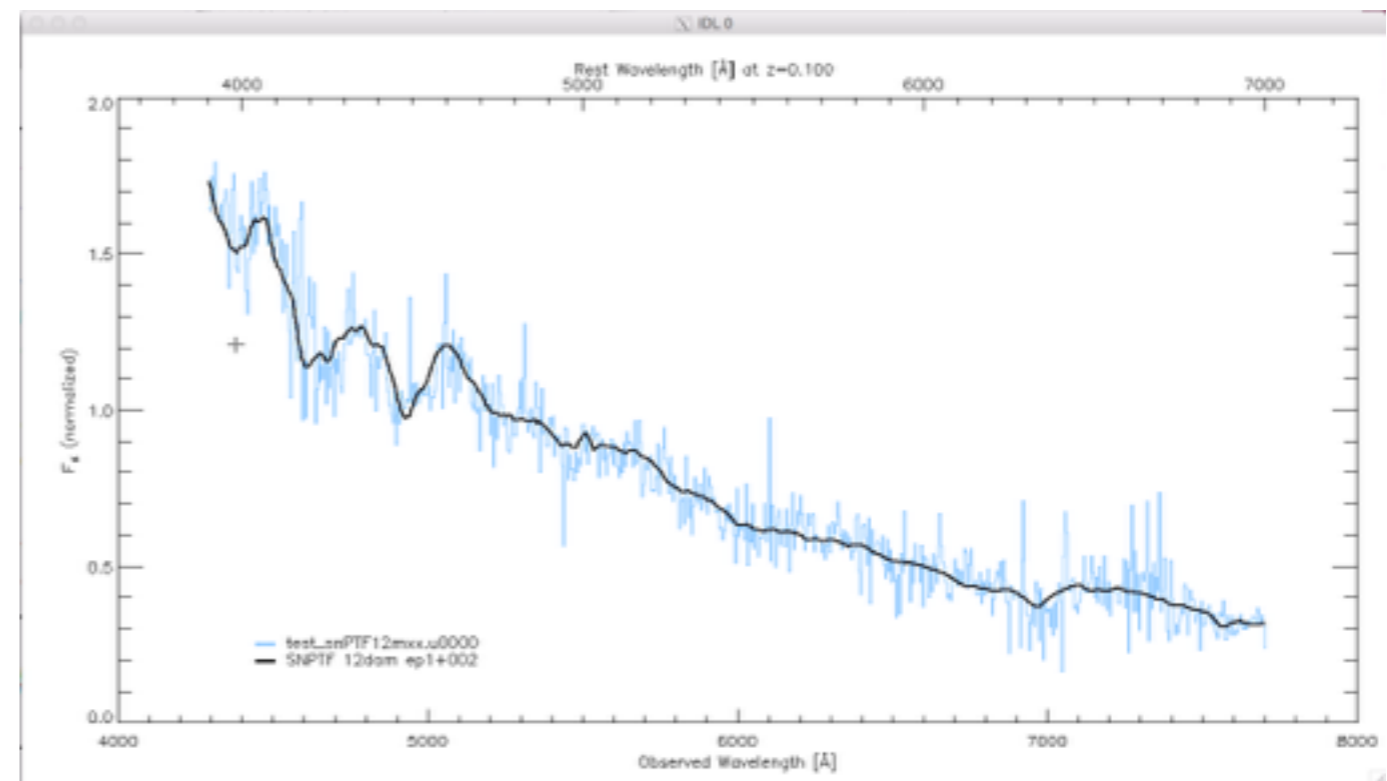
Rv:  Av:  SN scale:  Gal. scale:

X min:  X max:  Y min:  Y max:

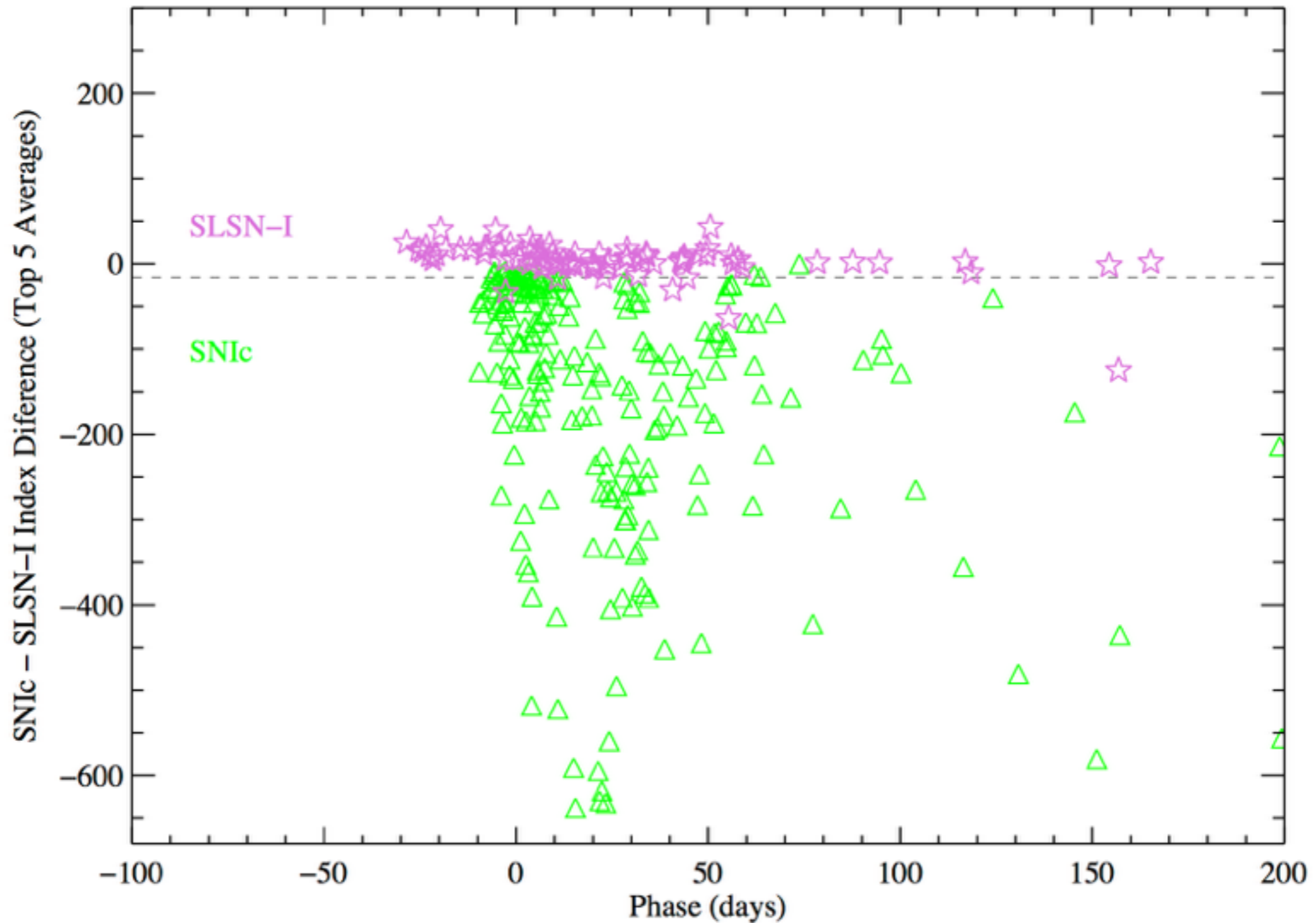
O str:  T str:  0X:  Y:

PS file:

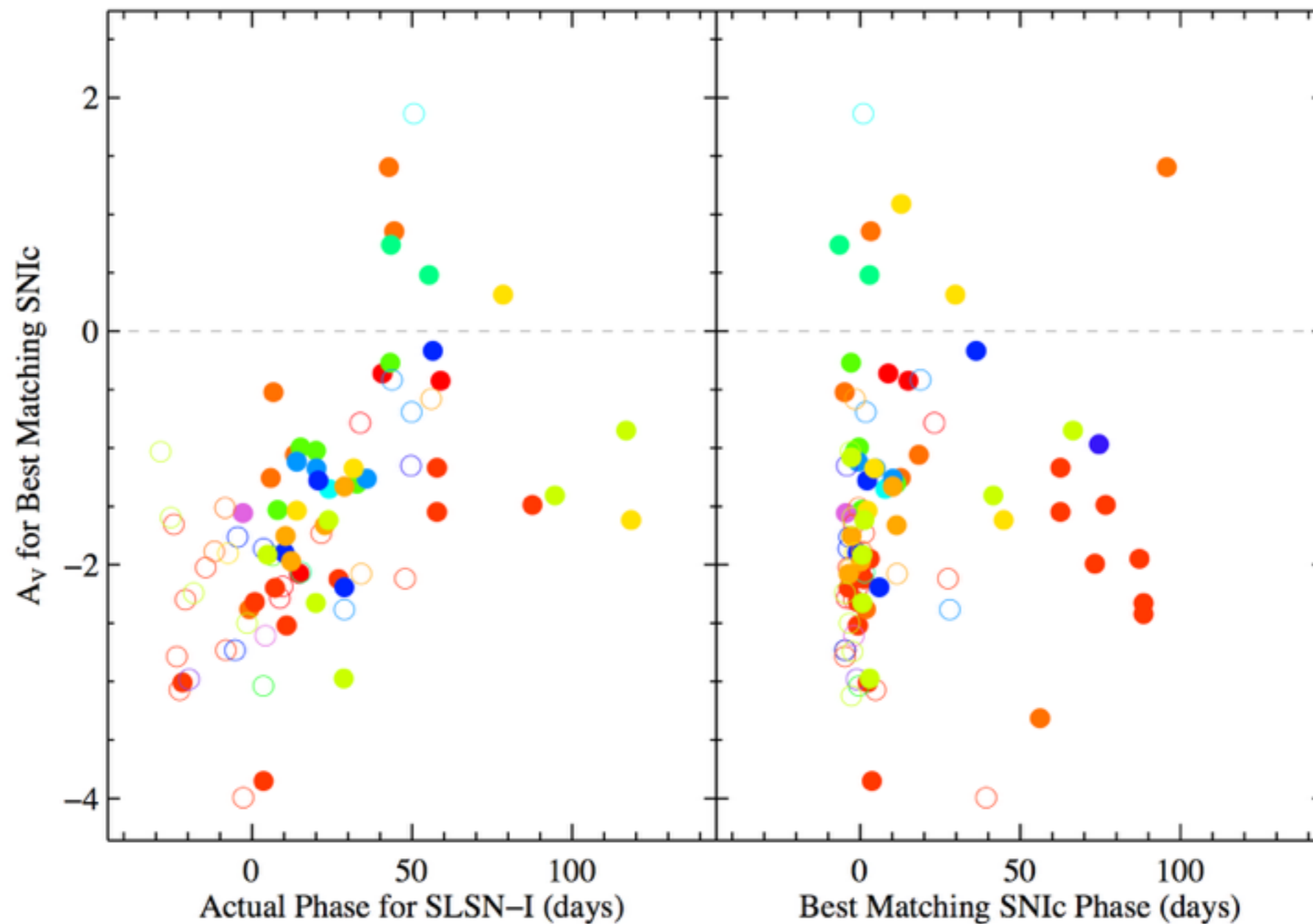
Done   Obs. Å / pix blue:  Obs. Å / pix red:



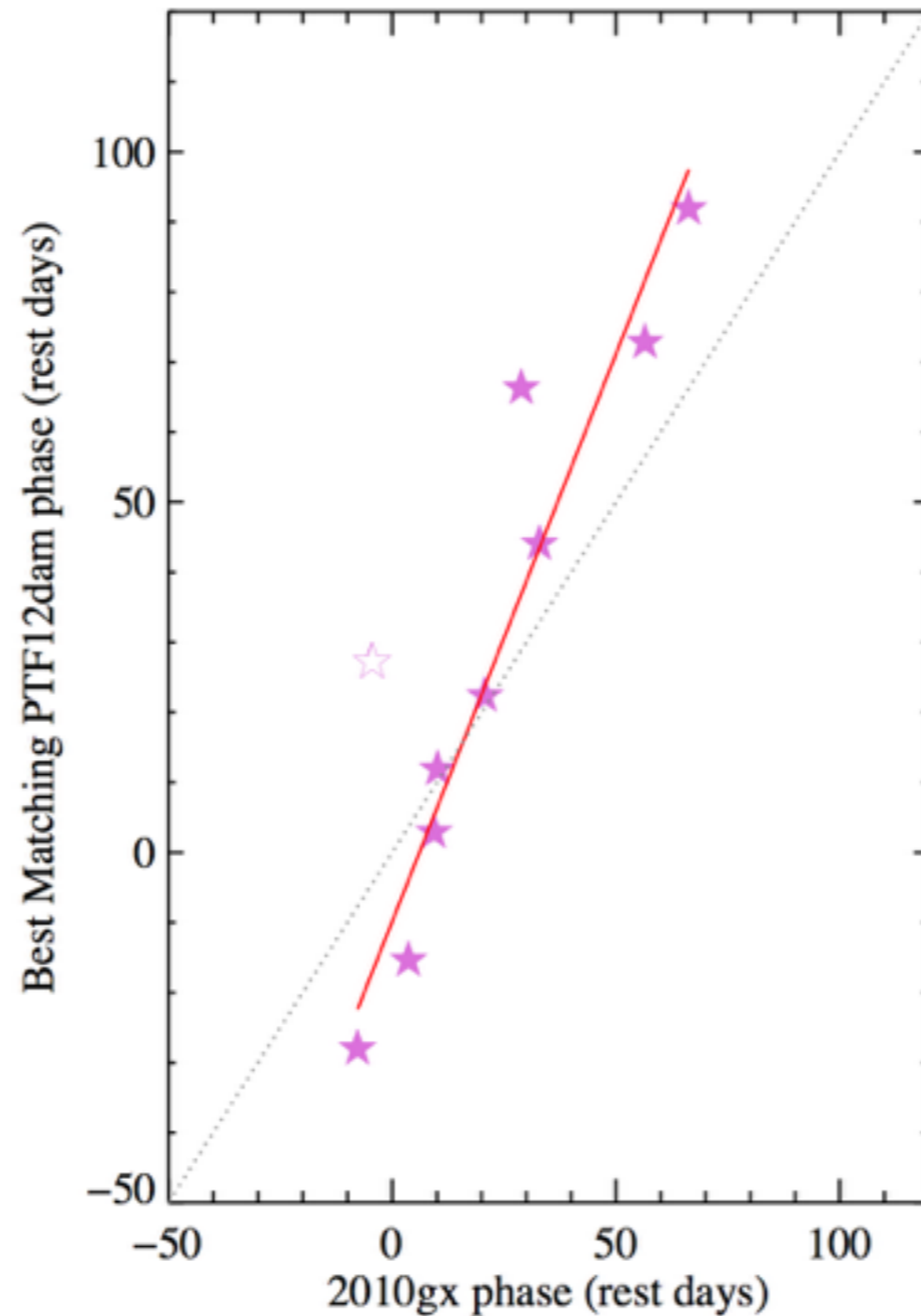
# Are SLSN-I and SNIc Spectra The same?



# SLSN-I are Bluer than SNIc

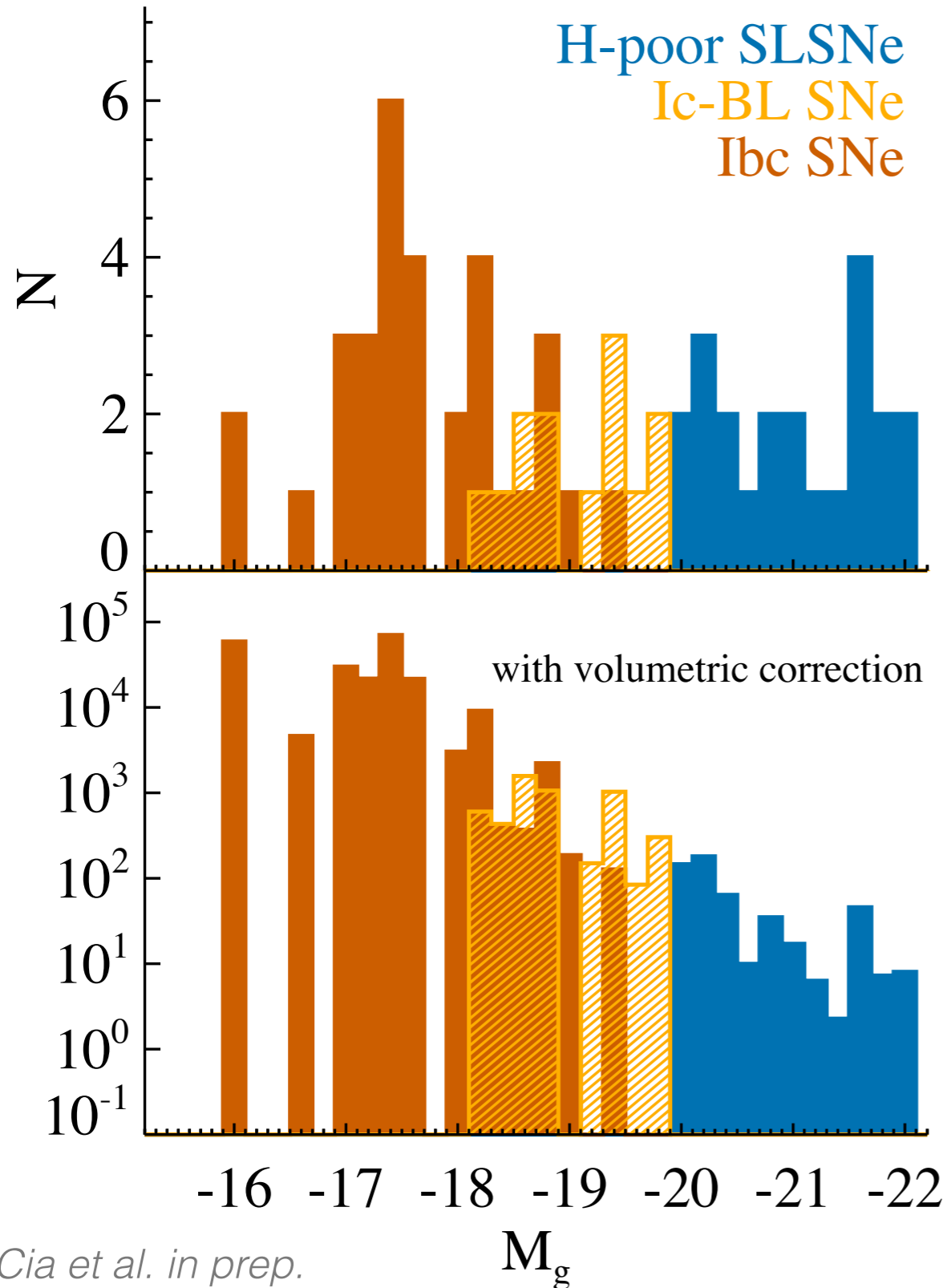


# Some SLSN-I Evolve Faster (spectroscopically)

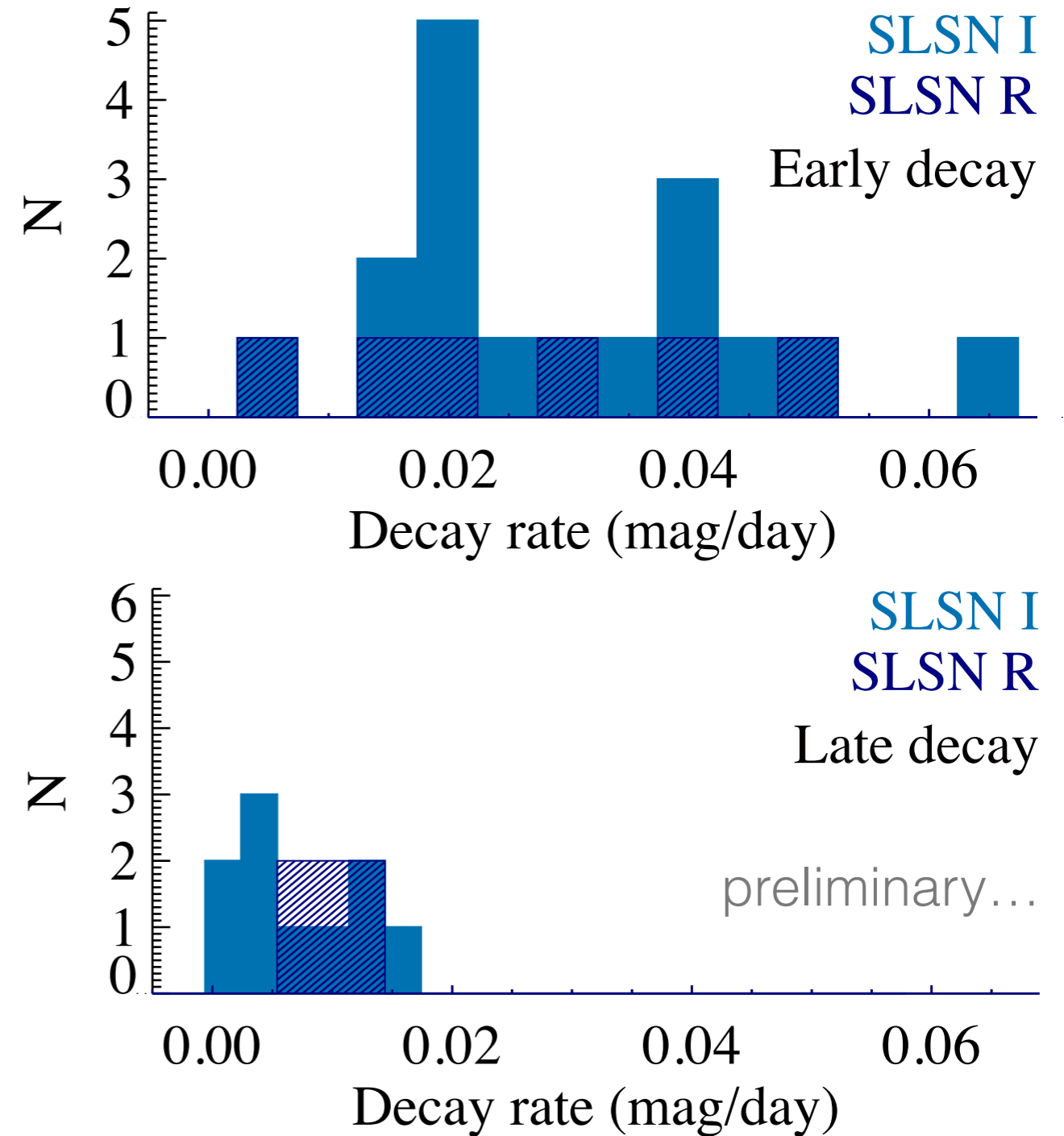


# H-poor SLSNe and Ib/c SNe in PTF - light curve properties

## PEAK MAG



## DECAY RATE

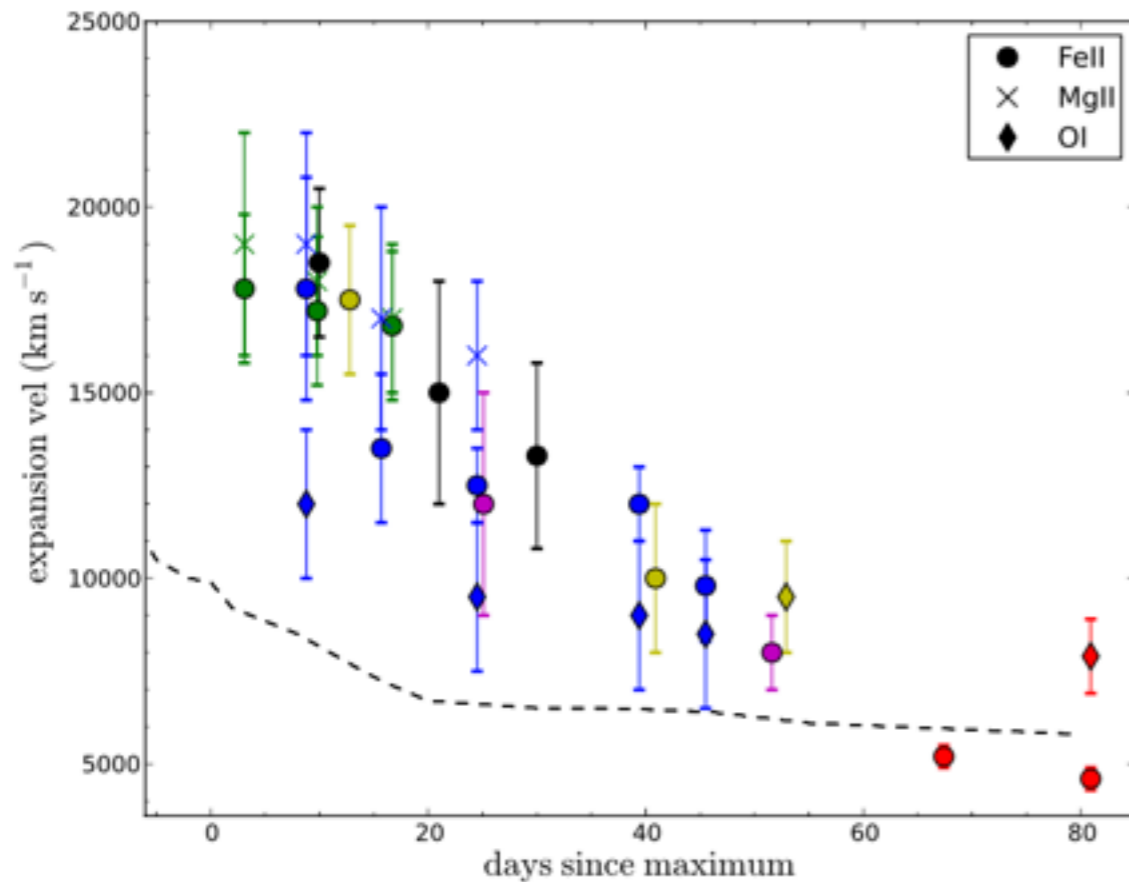


# SLSN-I Spectroscopic Sequence

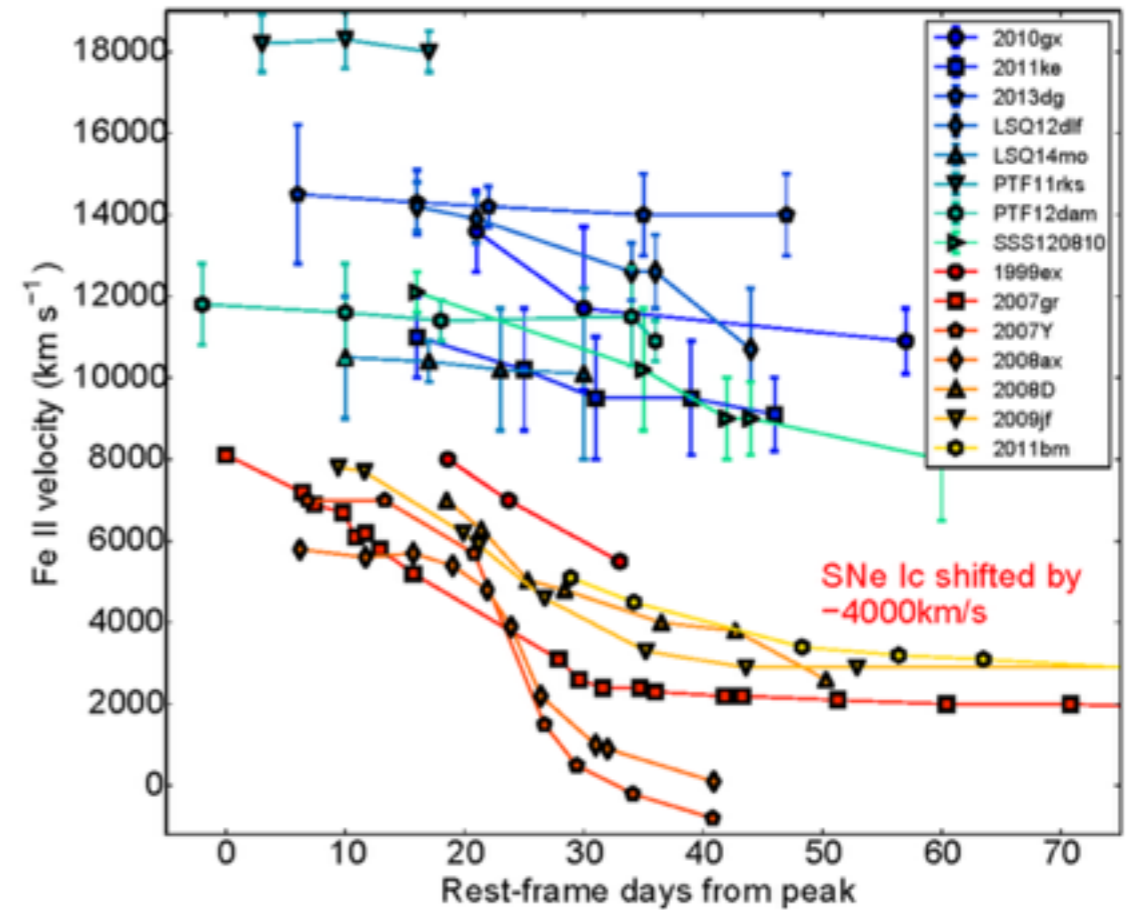


# Line Velocities

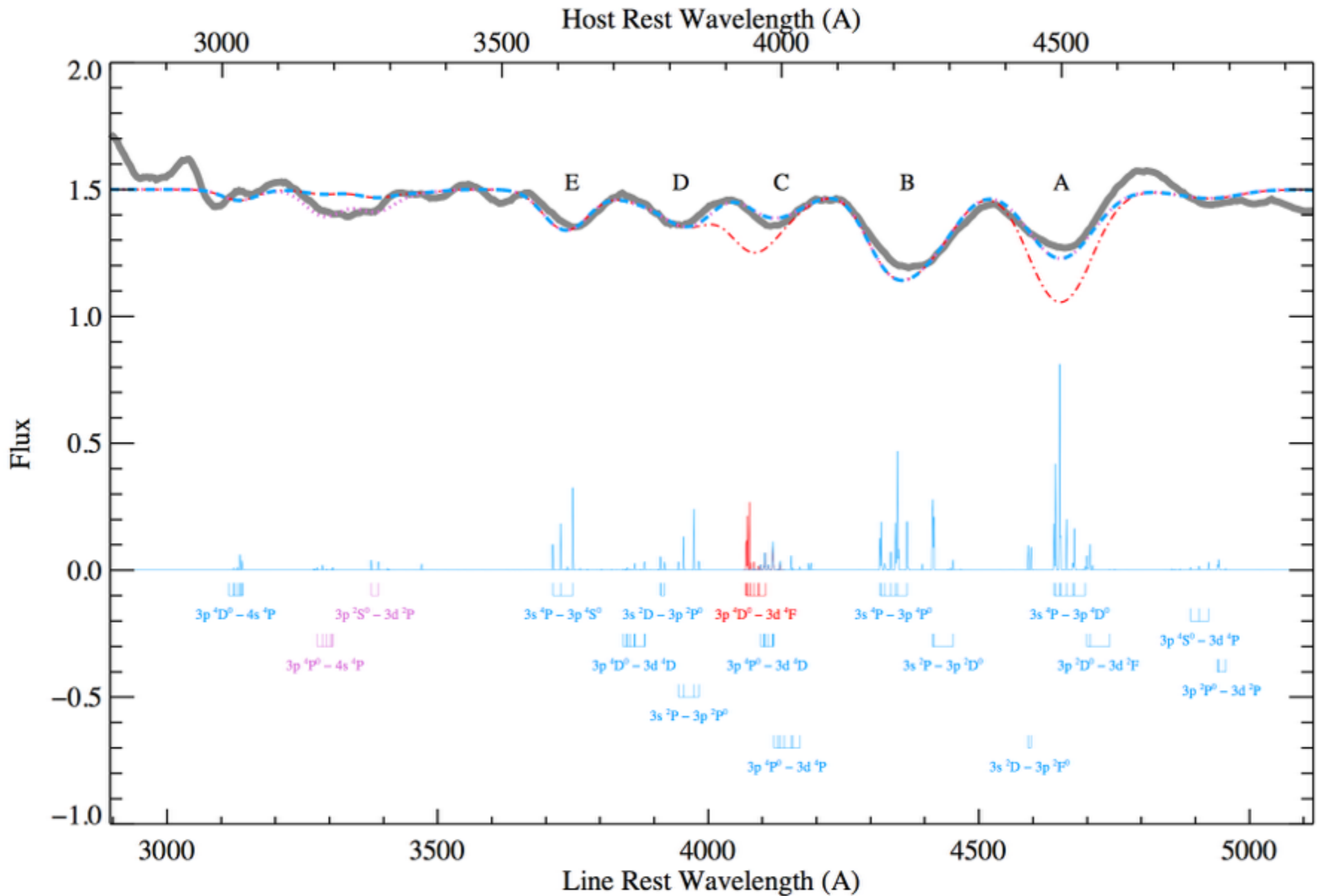
Inserra et al. 2013



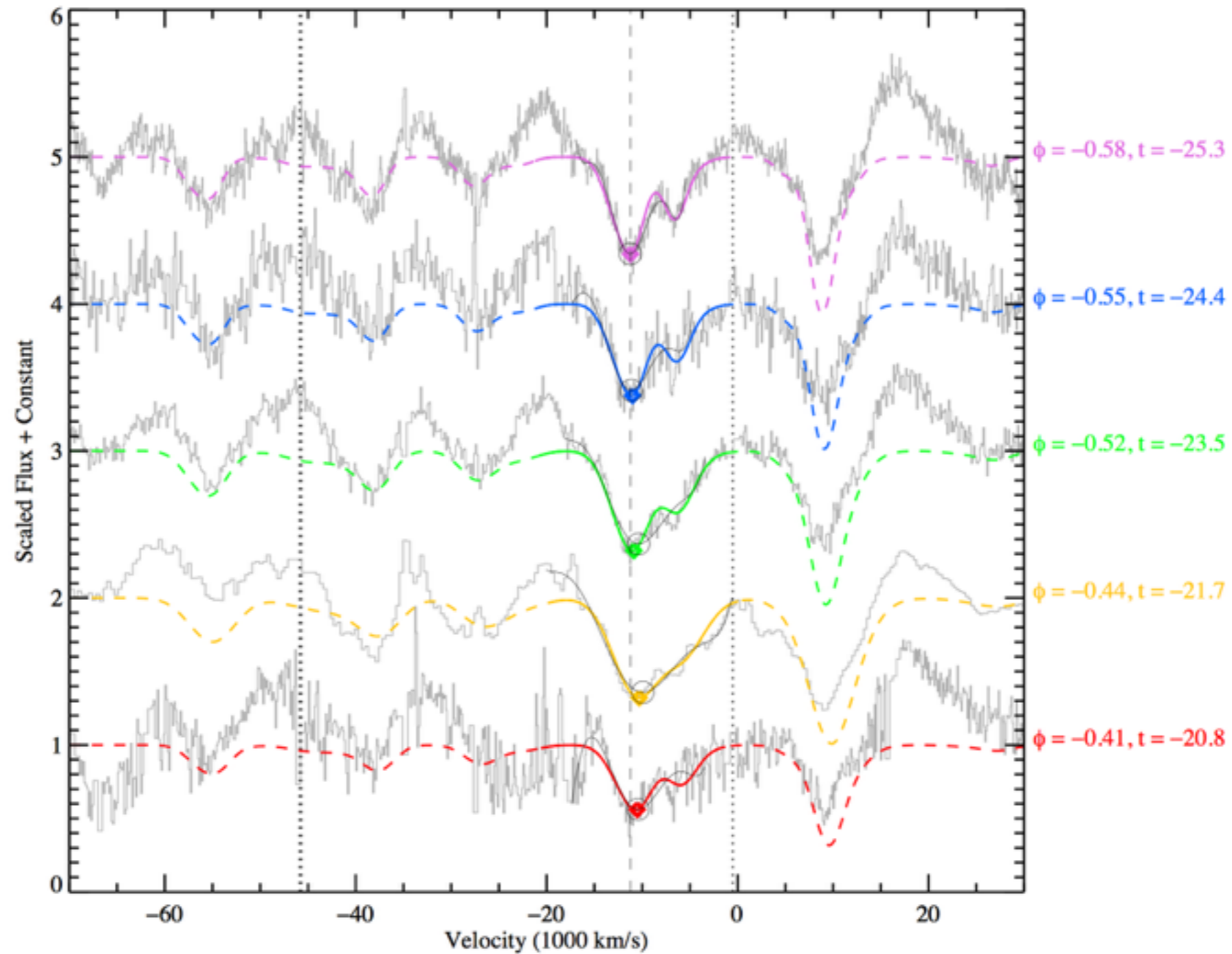
Nicholl et al. 2015



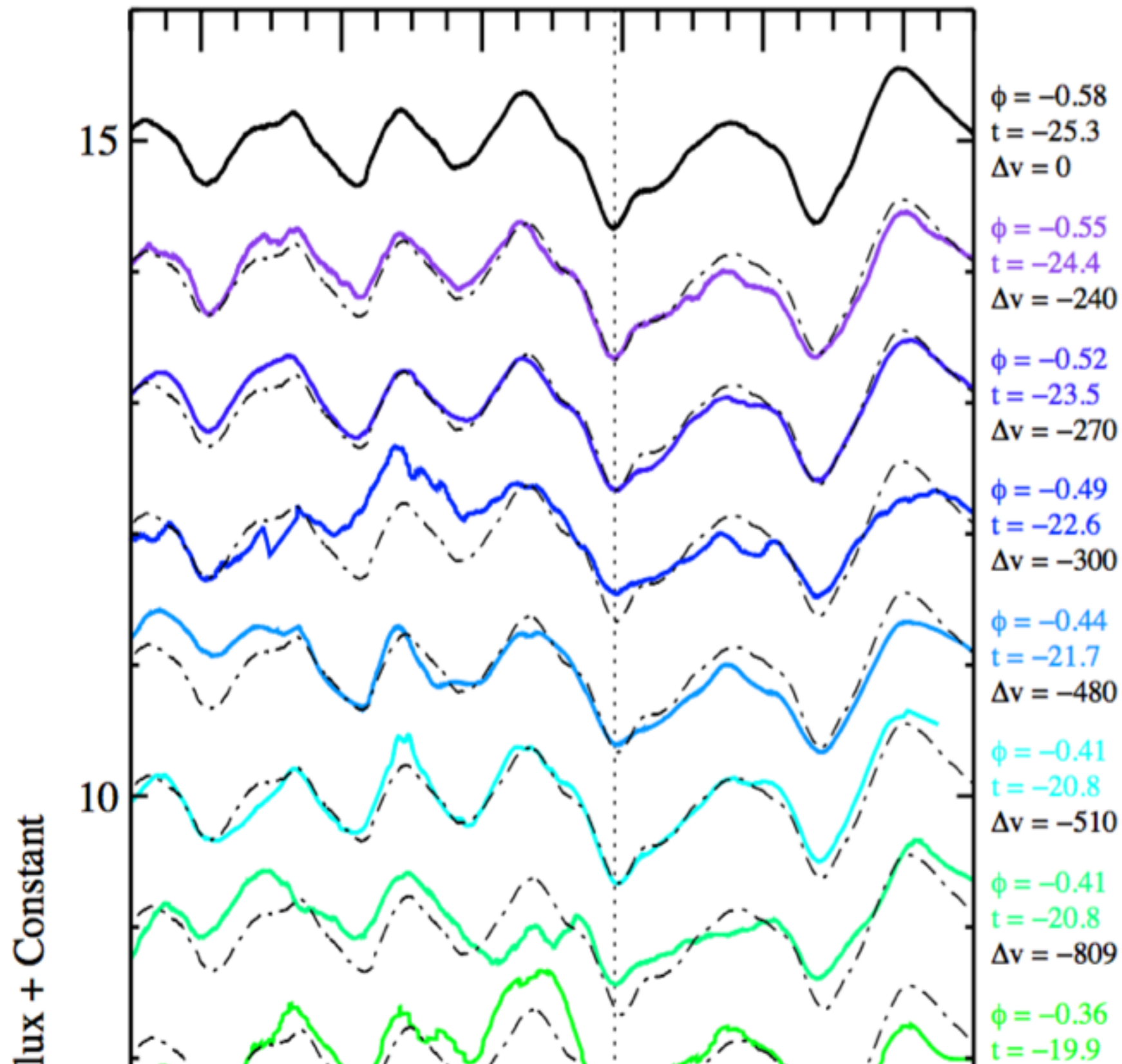
# Oxygen Lines (OII)



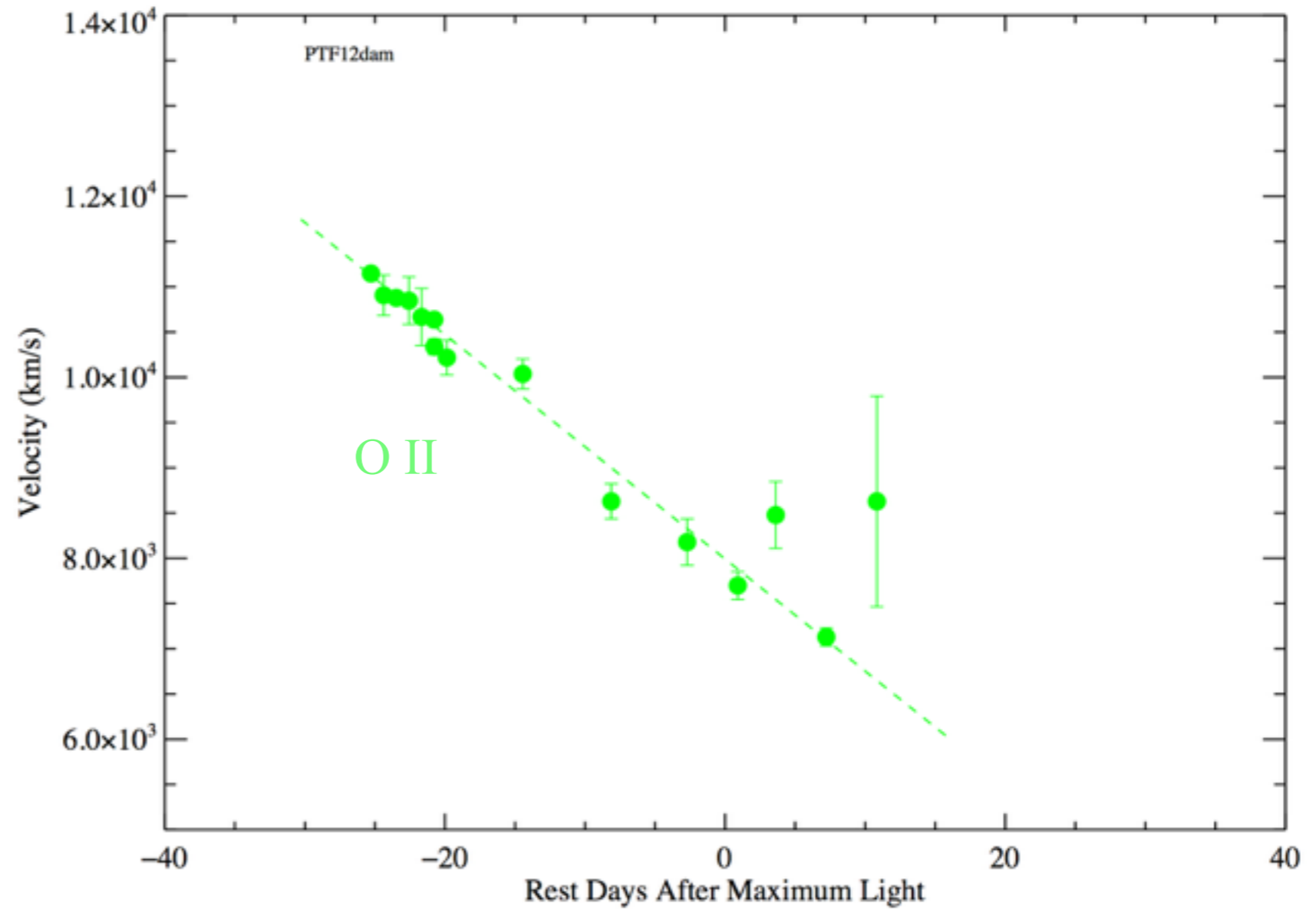
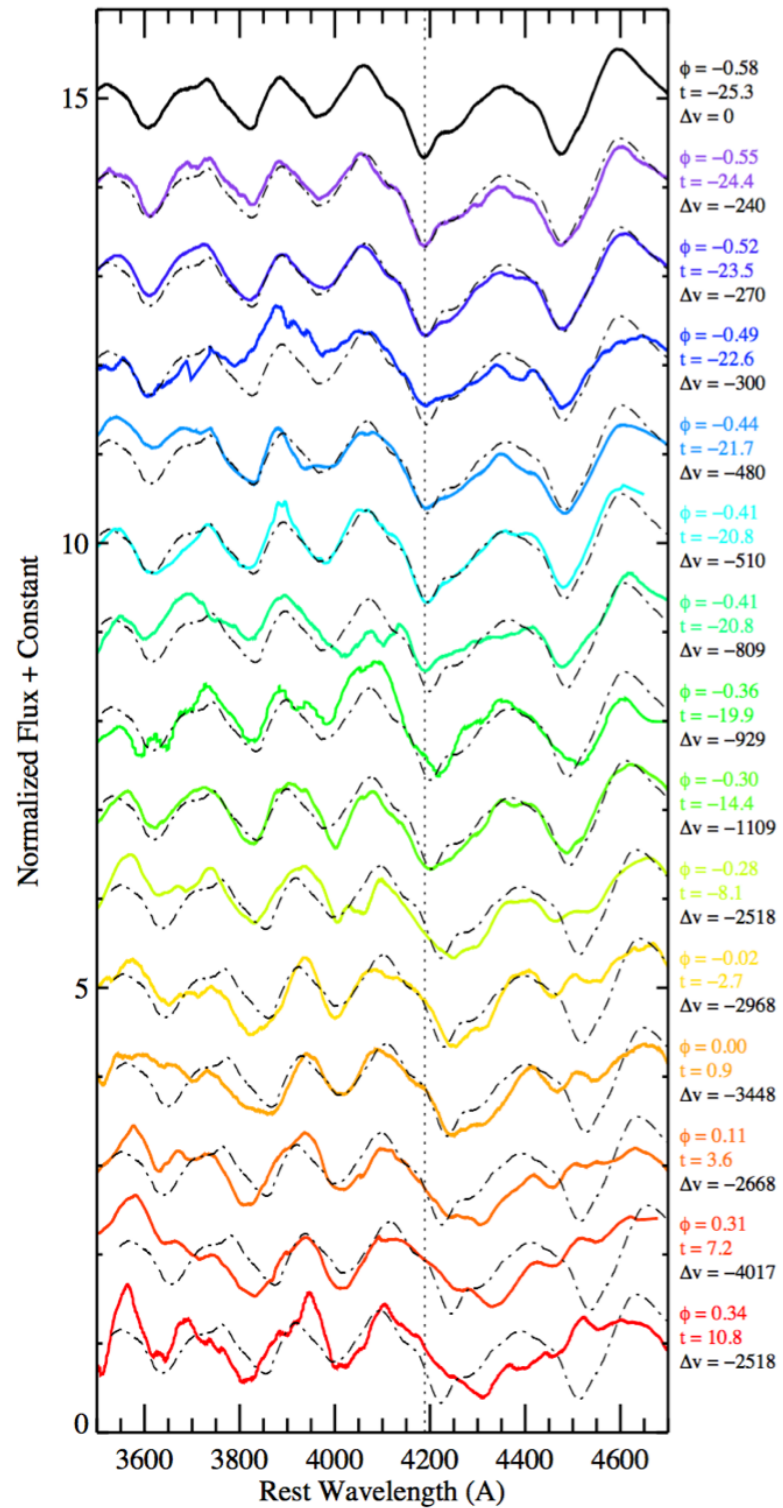
# PTF I 2dam (O II)



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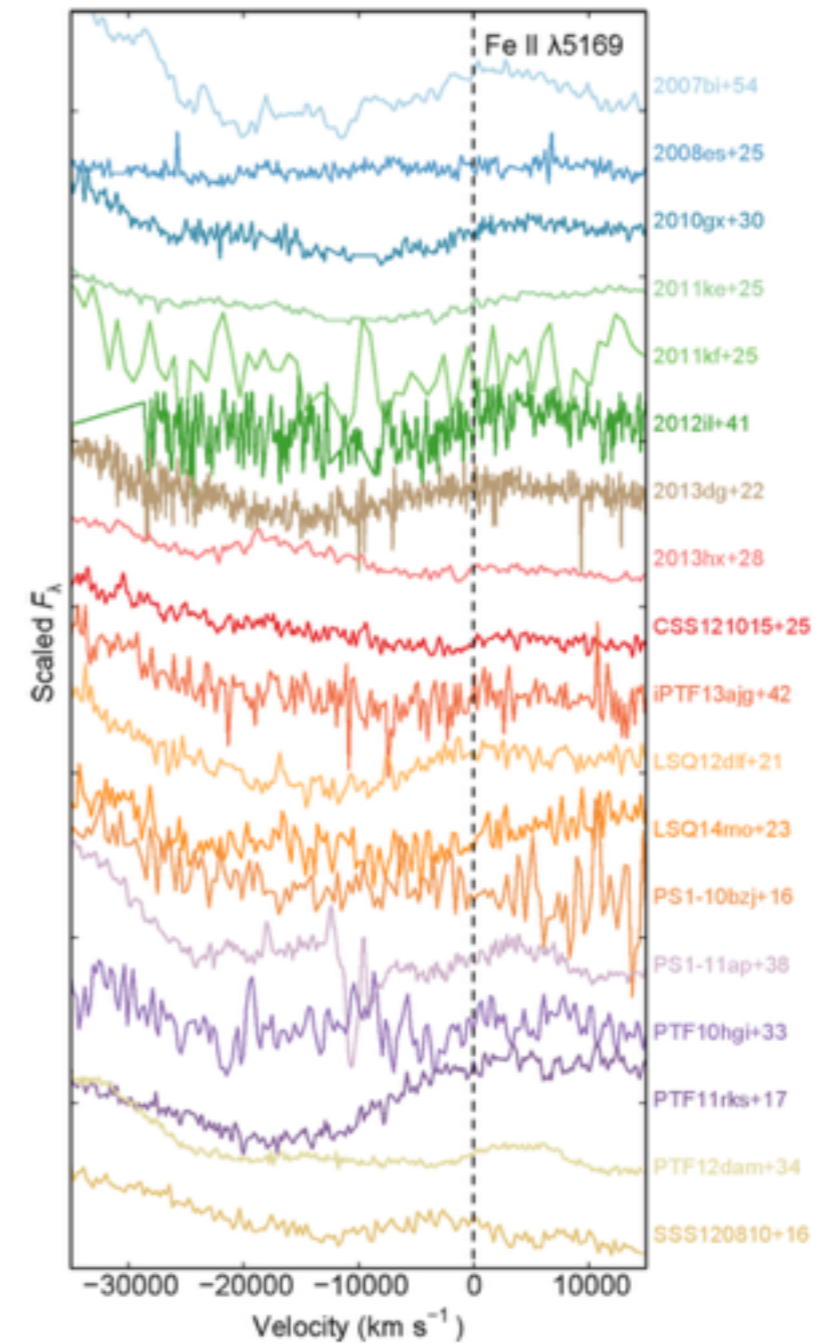
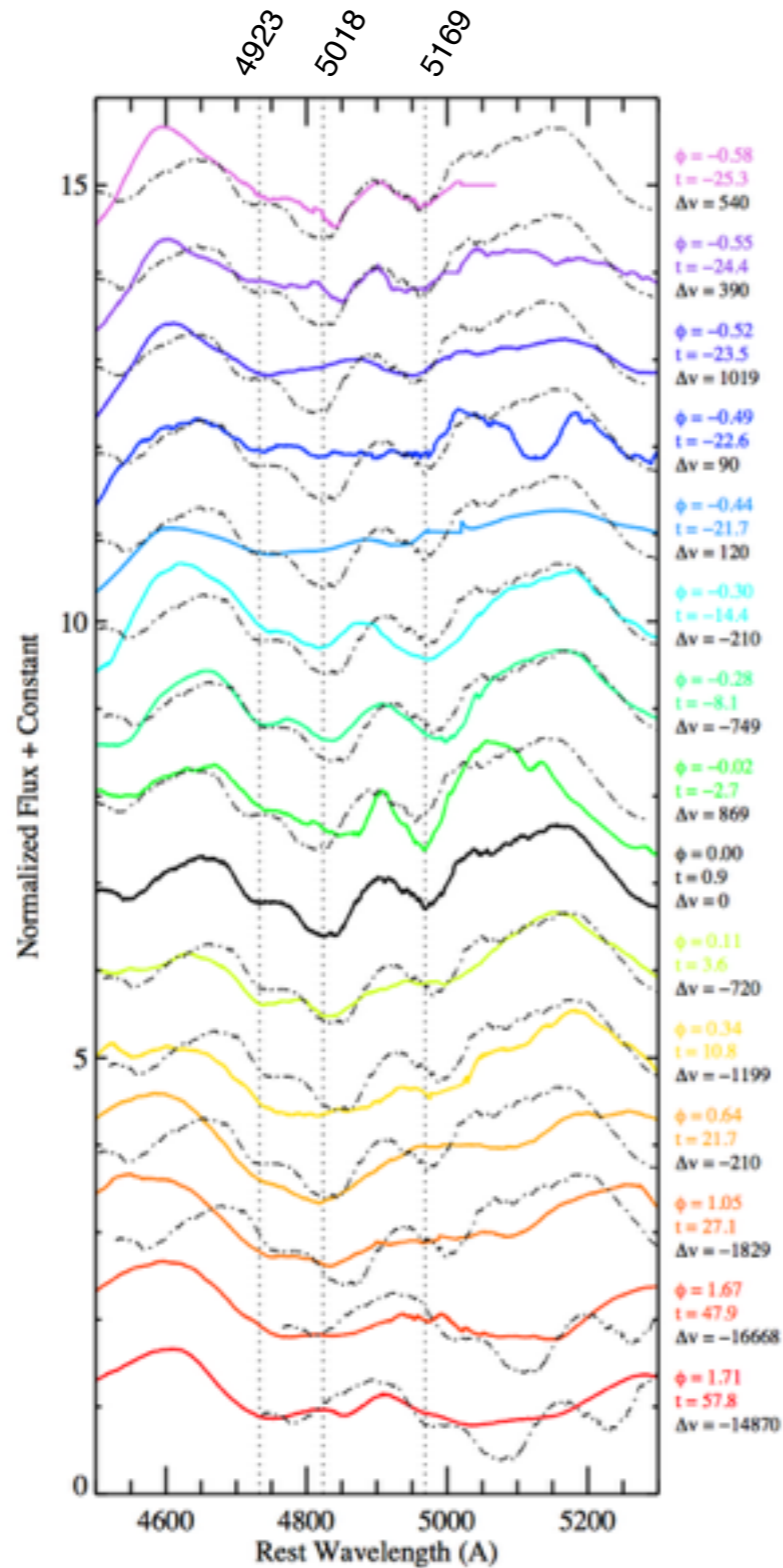


# PTF 12dam (O II)

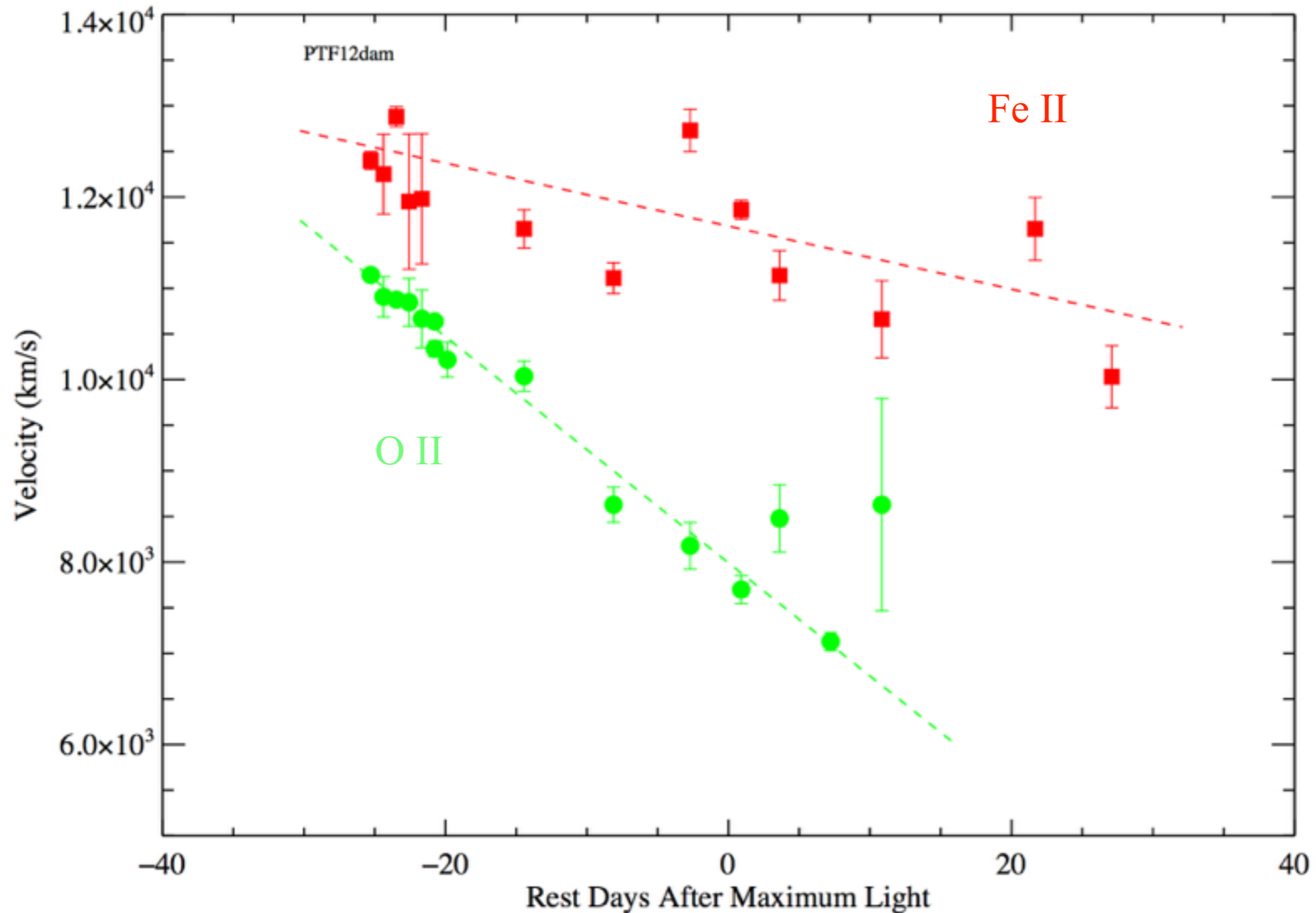


# Fe II is Tough

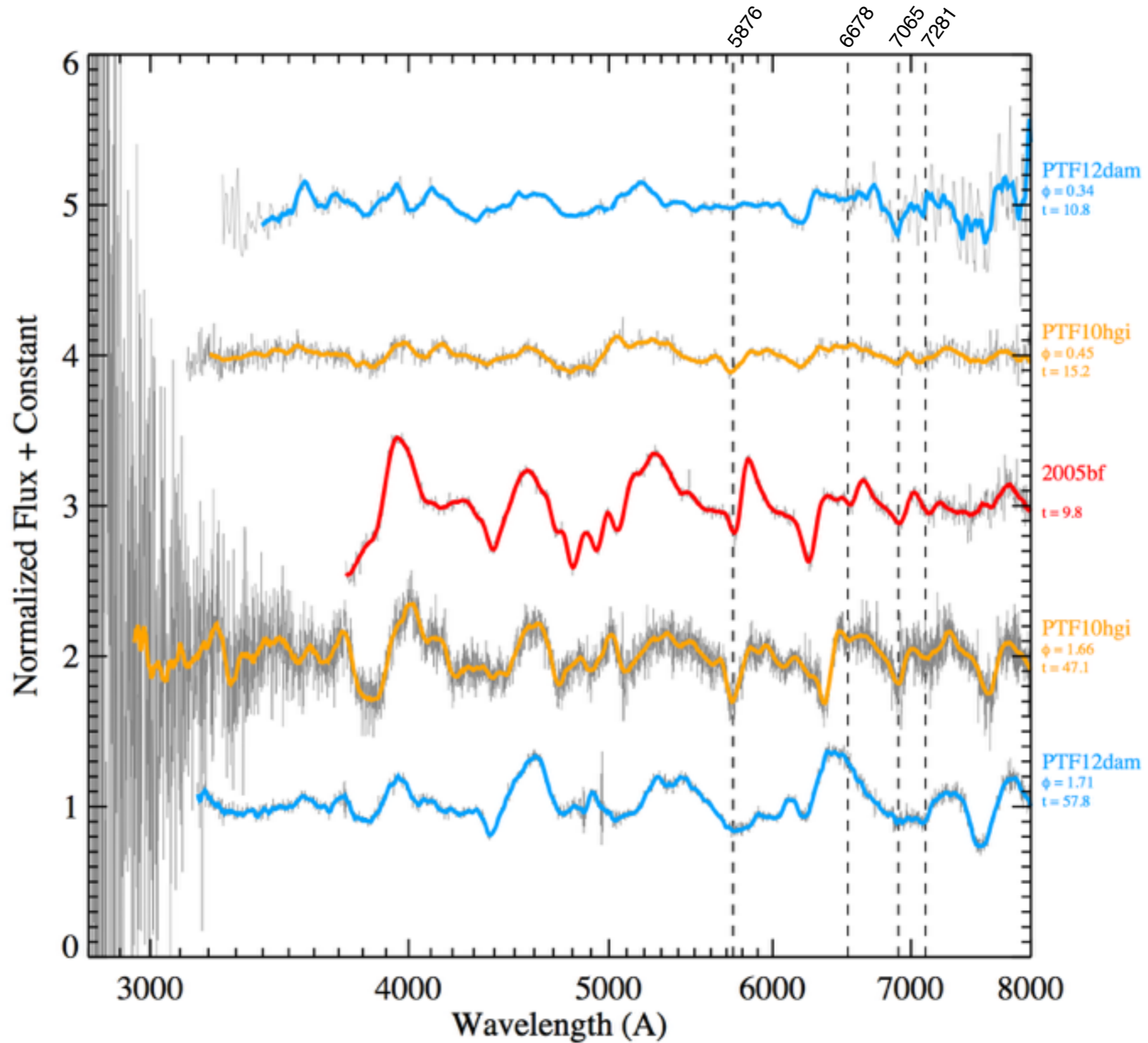
Nicholl et al. 2015



# PTF12dam Line Velocities



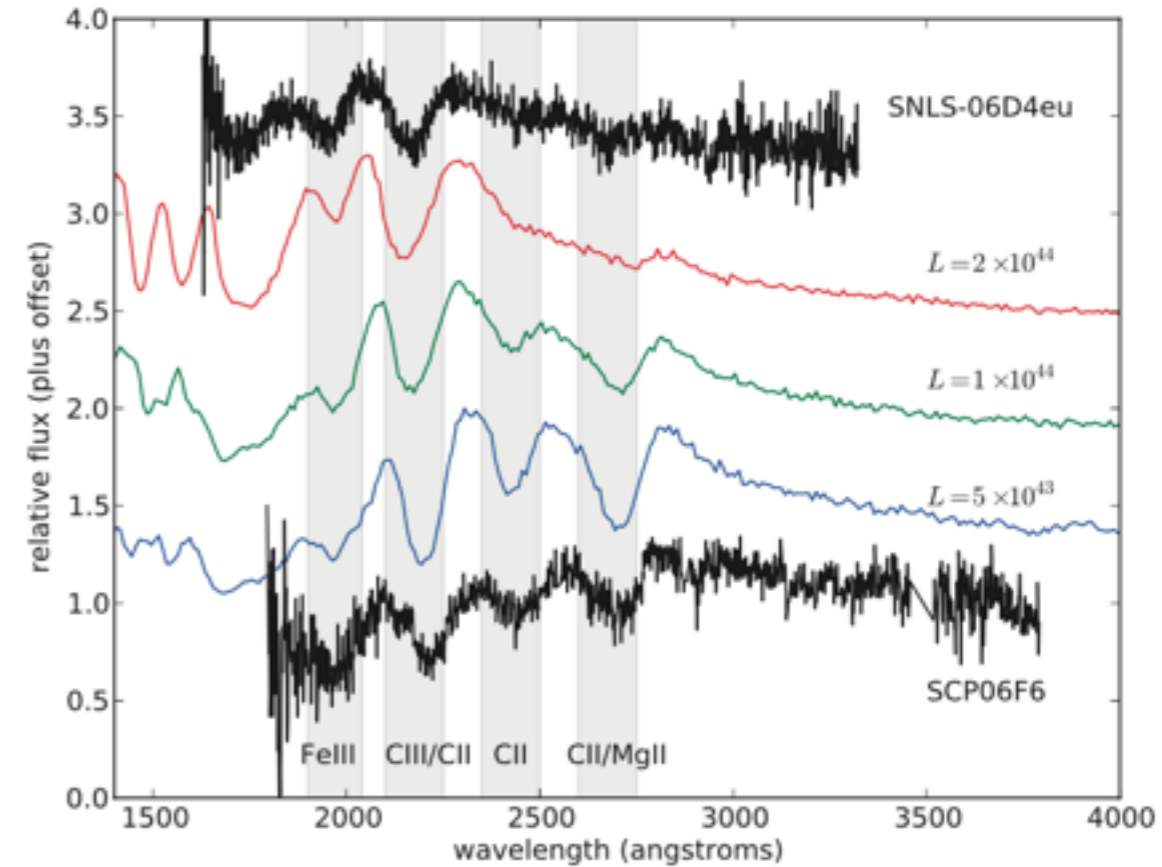
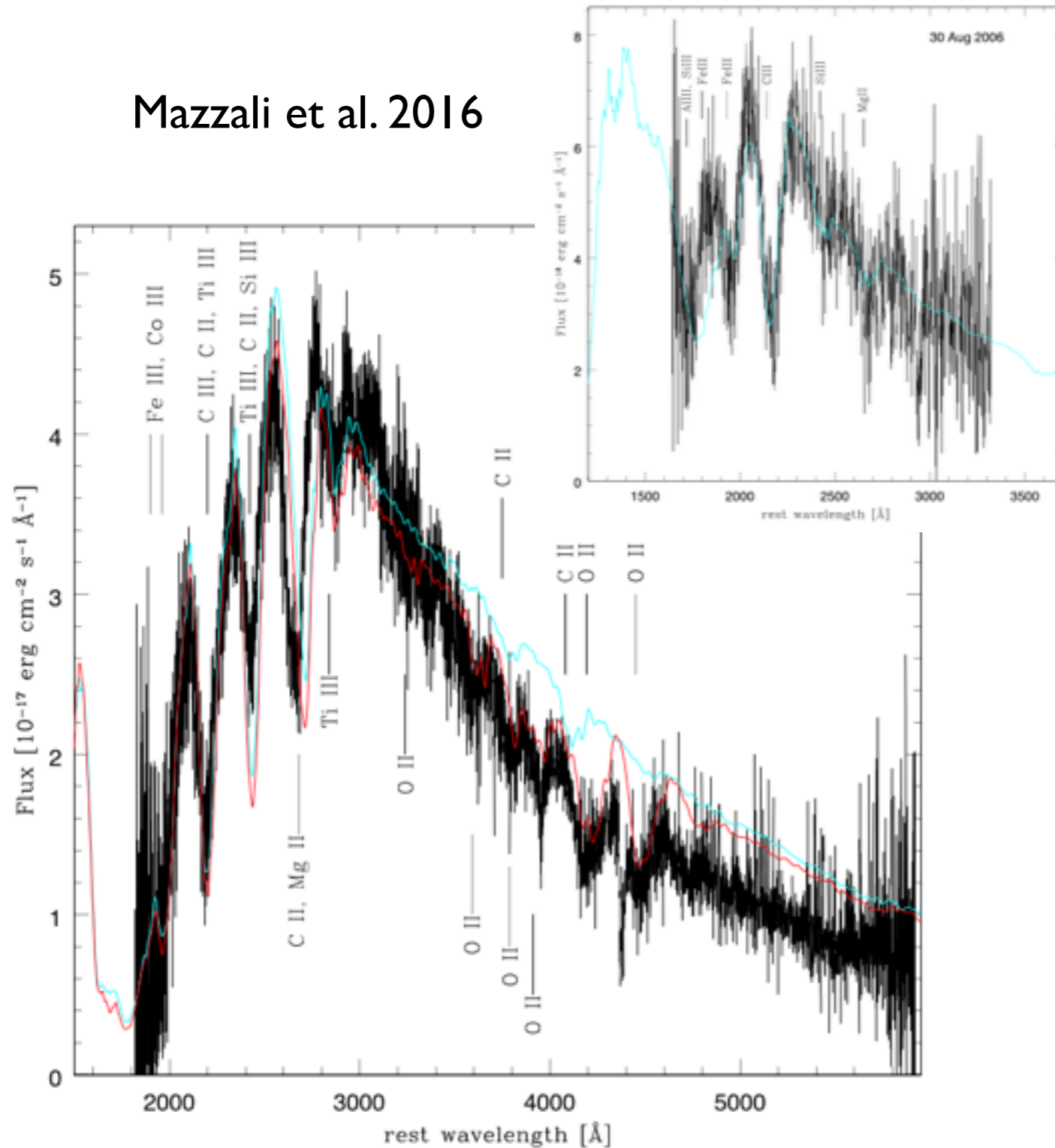
# Helium?





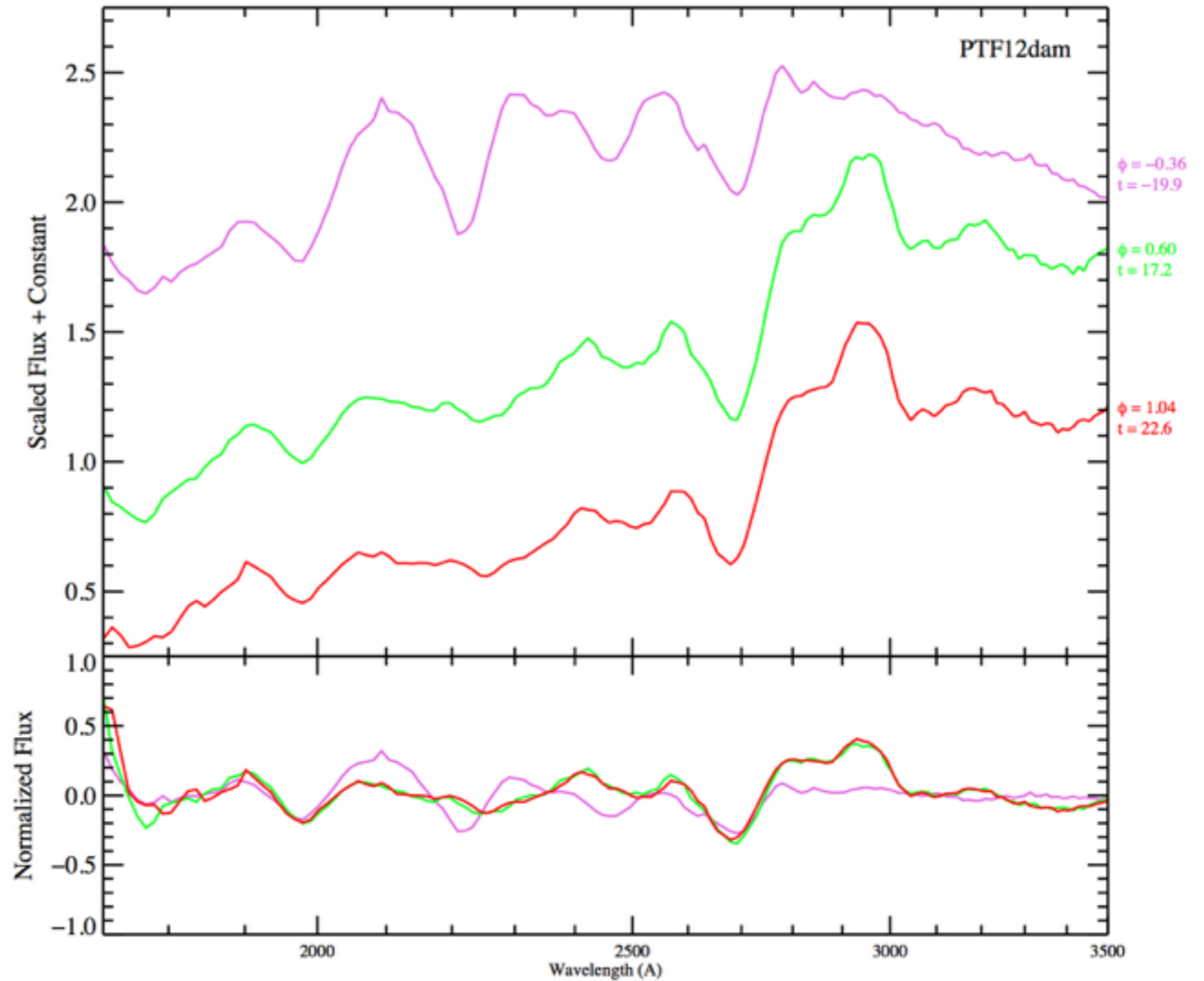
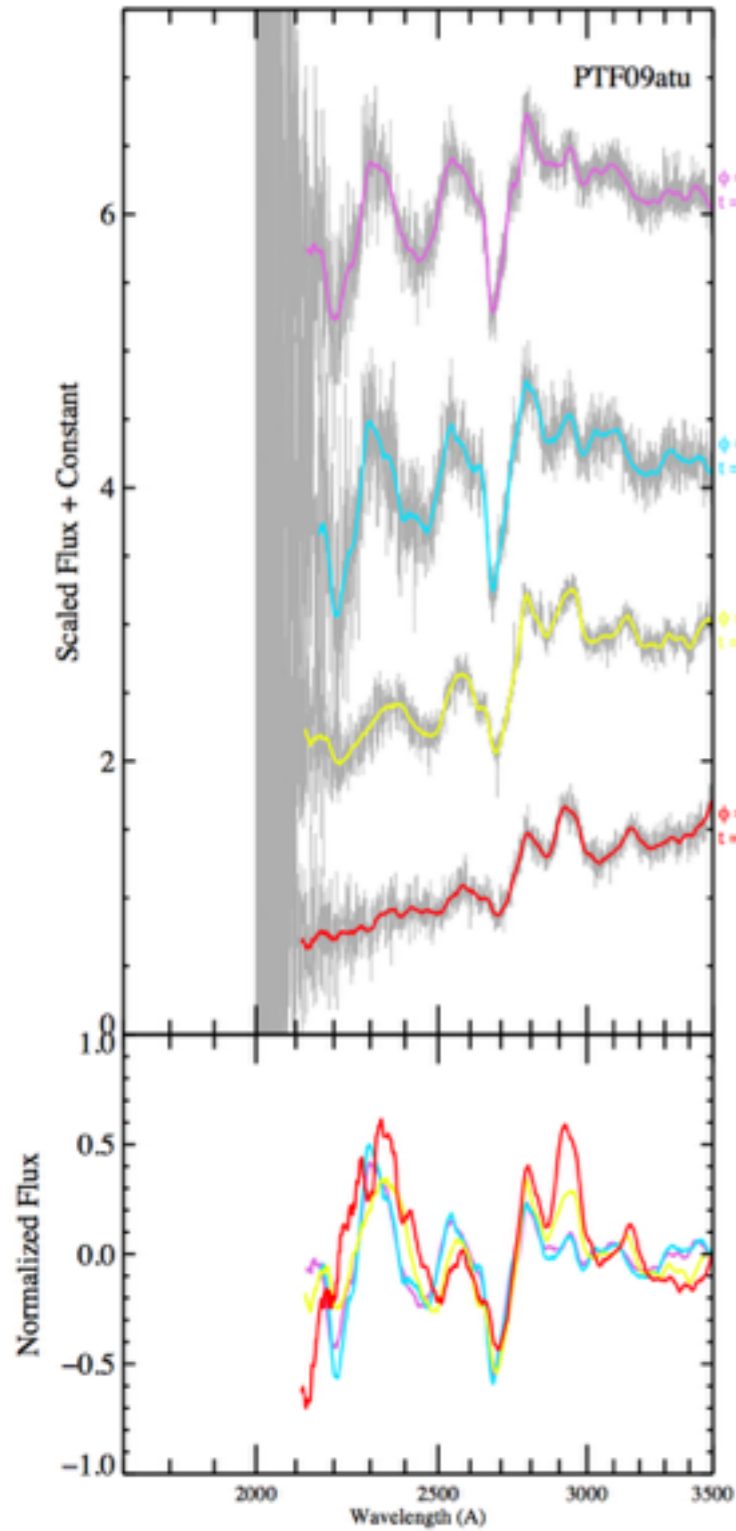
# Line Identifications

Mazzali et al. 2016



Howell et al. 2013

# UV Features



# Synow Identifications

