



Observations of Type Ia Supernovae Strongly Interacting with Their Circumstellar Medium

Jeffrey M. Silverman

NSF Astronomy & Astrophysics Postdoctoral Fellow
University of Texas at Austin



FOE, Raleigh, NC
4 June 2015





PTF11kx and the ia-csm Objects

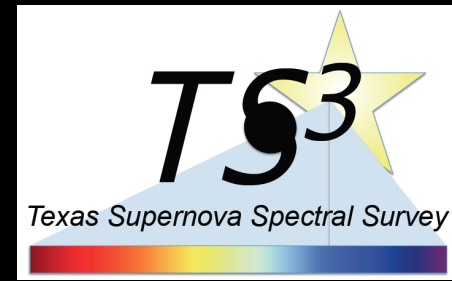
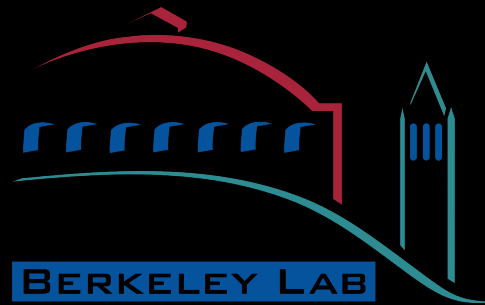
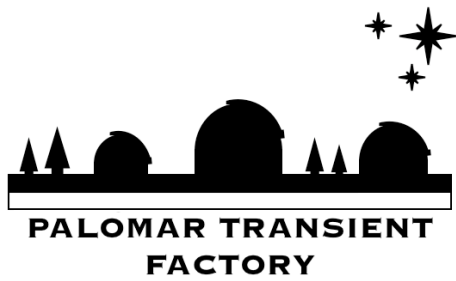
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with P. E. Nugent, A. Gal-Yam,
M. Sullivan, D. A. Howell,
A. V. Filippenko, M. Graham,
O. Fox, & C. Harris

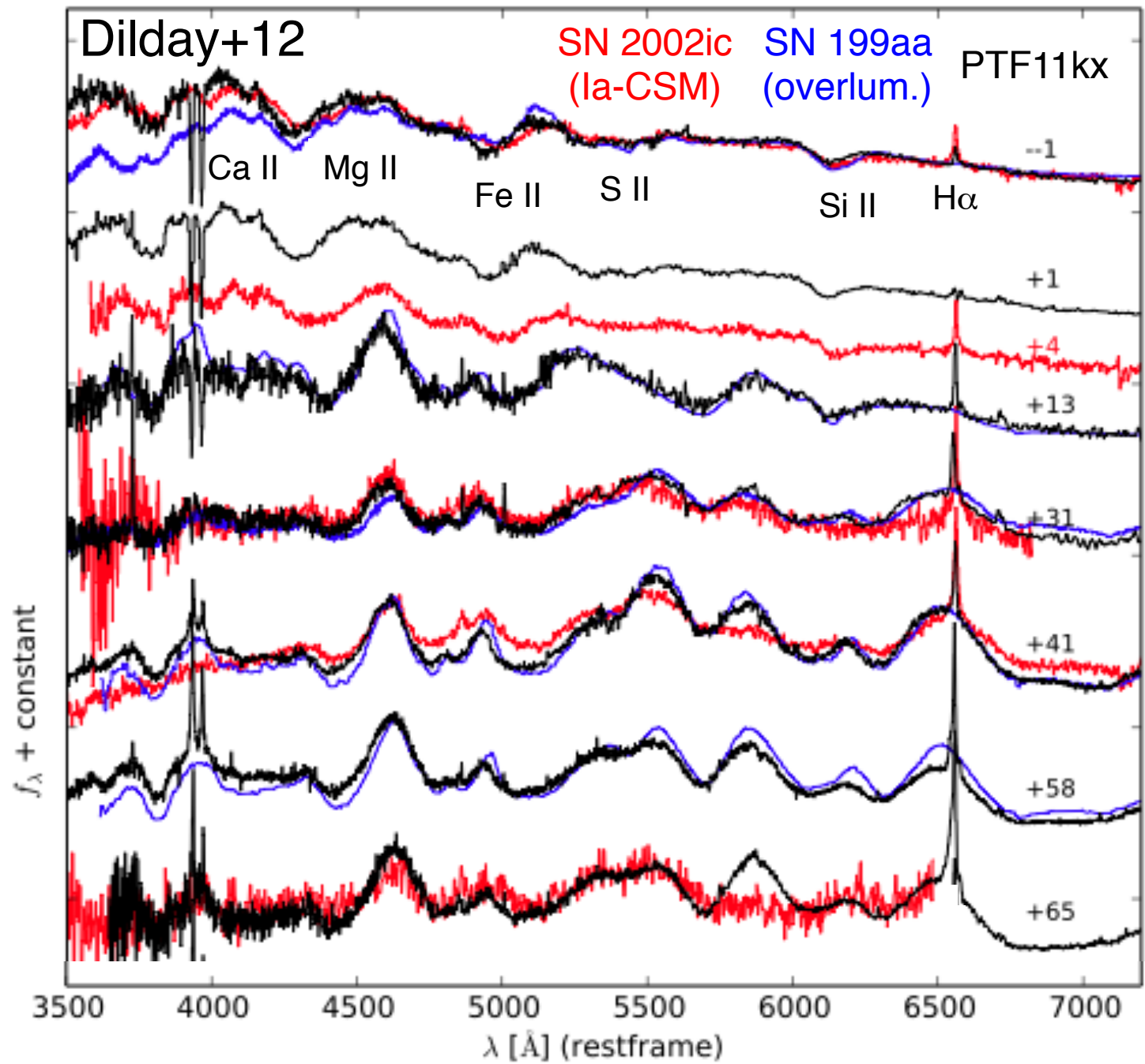
and the Palomar Transient Factory,
the UC Berkeley SN group,
the Lawrence Berkeley National Lab
& the Texas Supernova Spectral Survey

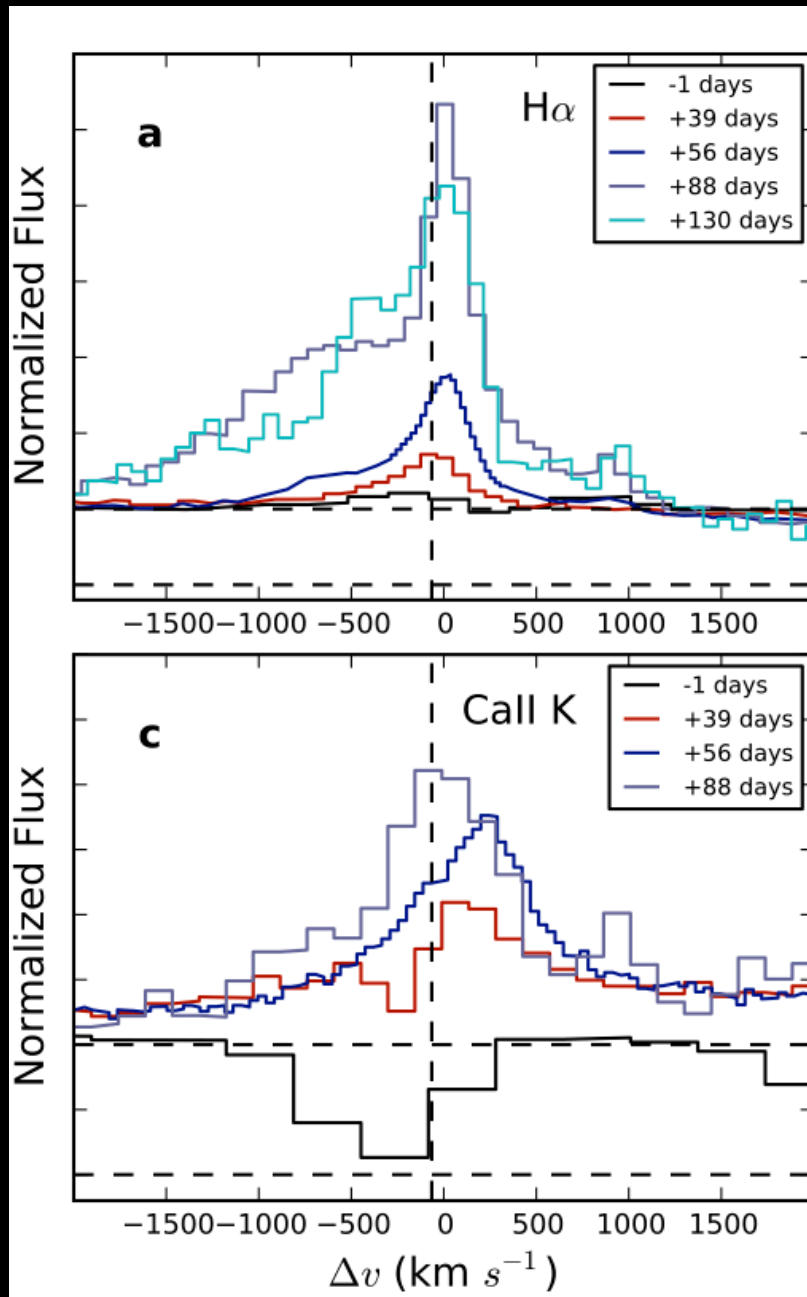
PTF11kx

(early-time data, $t < 100$ d)

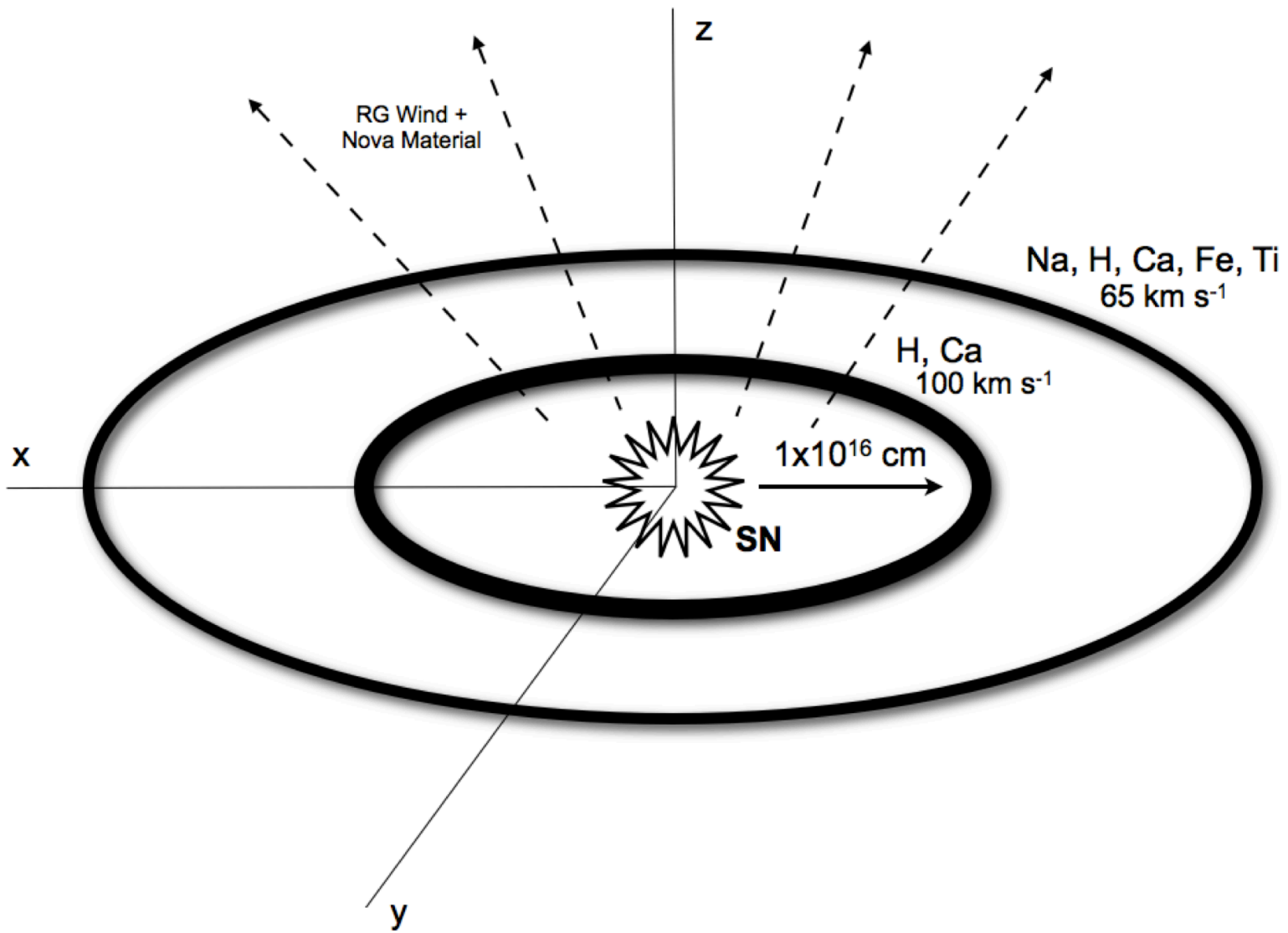
[Dilday+12]

- Resembled a somewhat overluminous SN Ia (99aa/91T-like)
- Initially “crazy deep” Ca II H&K absorption
- Ca II H&K became emission w/ time
- $H\alpha$ emission appeared and increased w/ time





Dilday+12



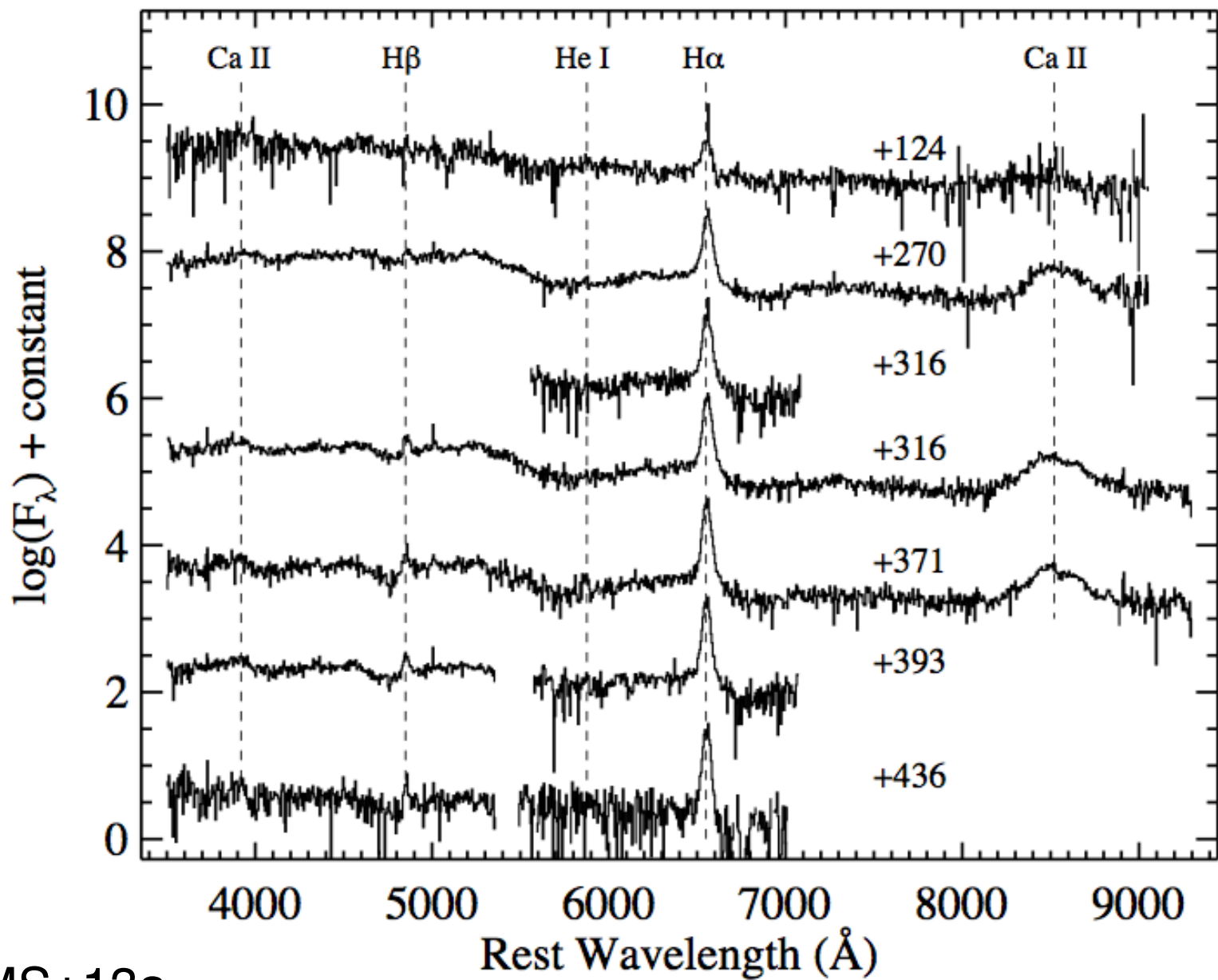
Dilday+12

PTF11kx

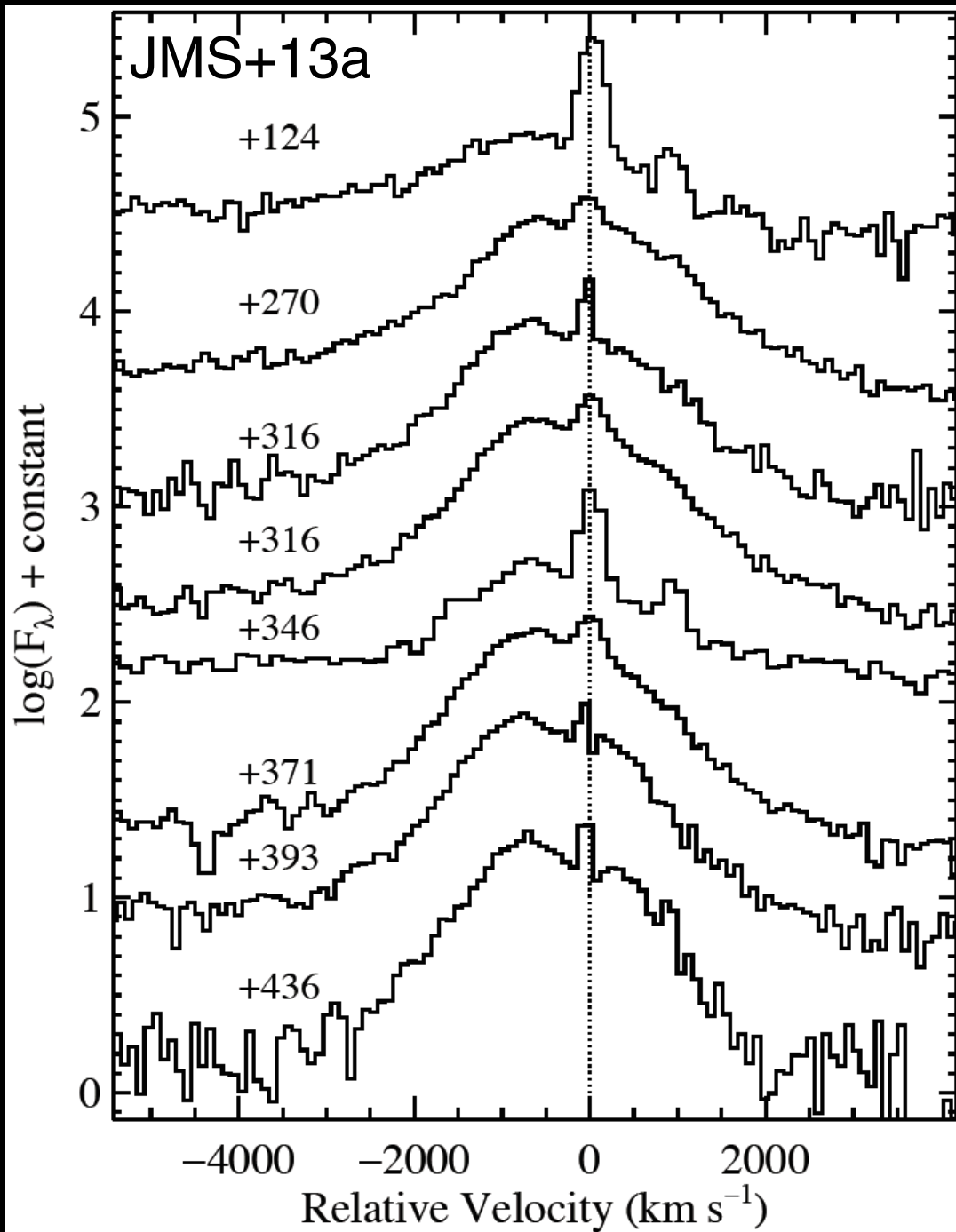
(late-time data, $100 < t < 440$ d)

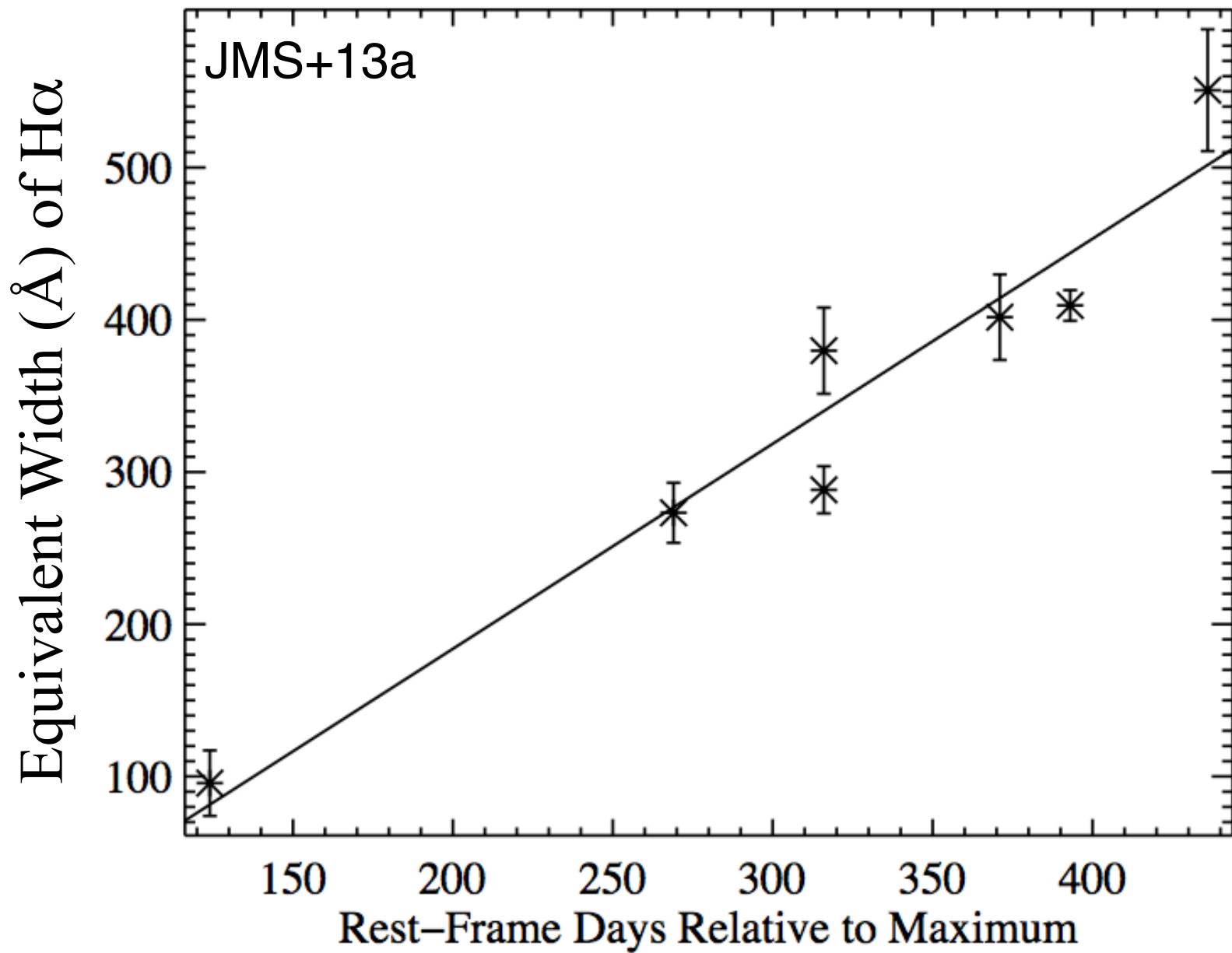
[JMS+13a]

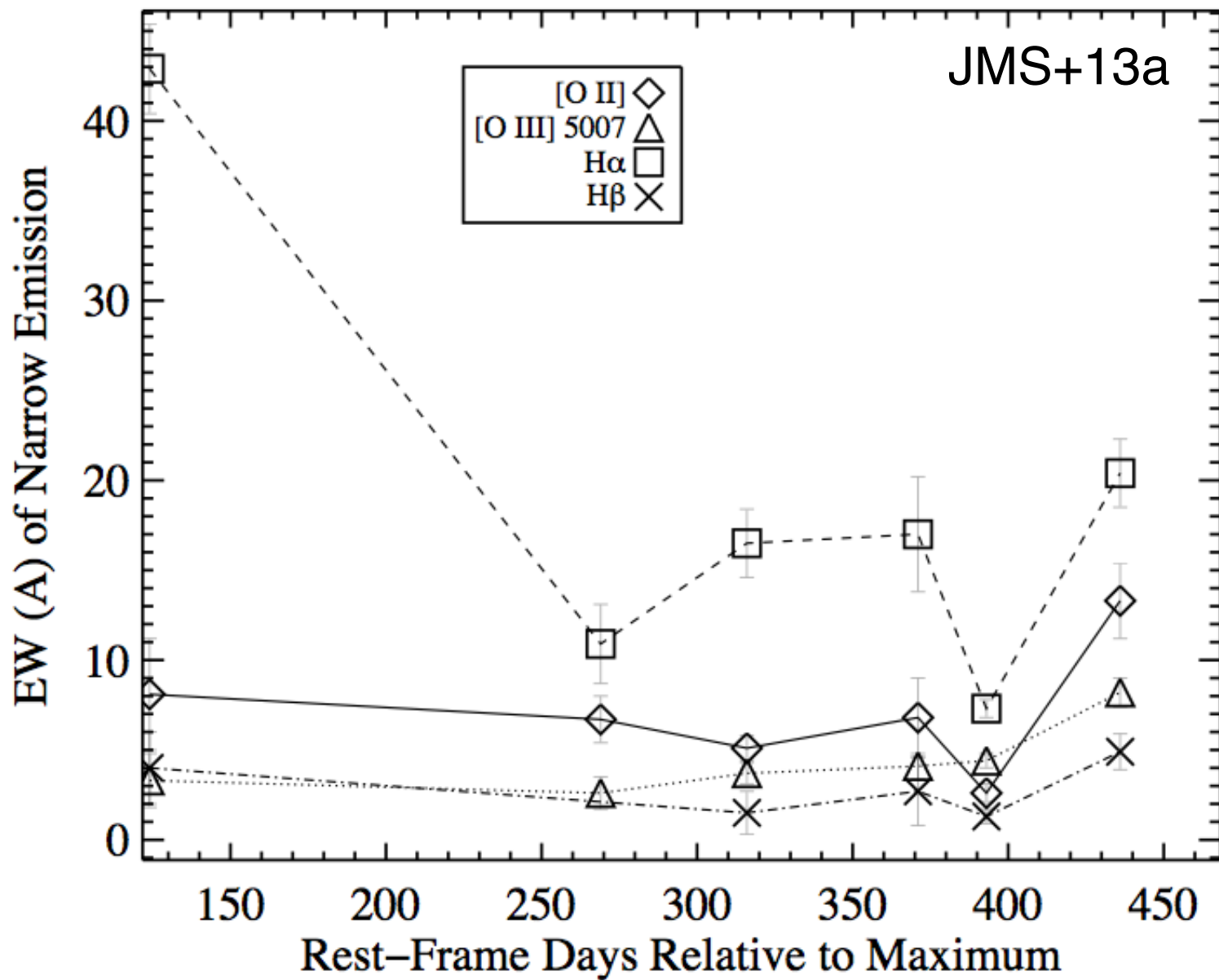
- Not much spectral evolution for ~ 1 yr
- Very strong $H\alpha$ emission (width ~ 2000 km/s)
 - $H\alpha$ emission increases w/ time
- Strong broad ($\sim 10,000$ km/s) Ca II NIR triplet emission

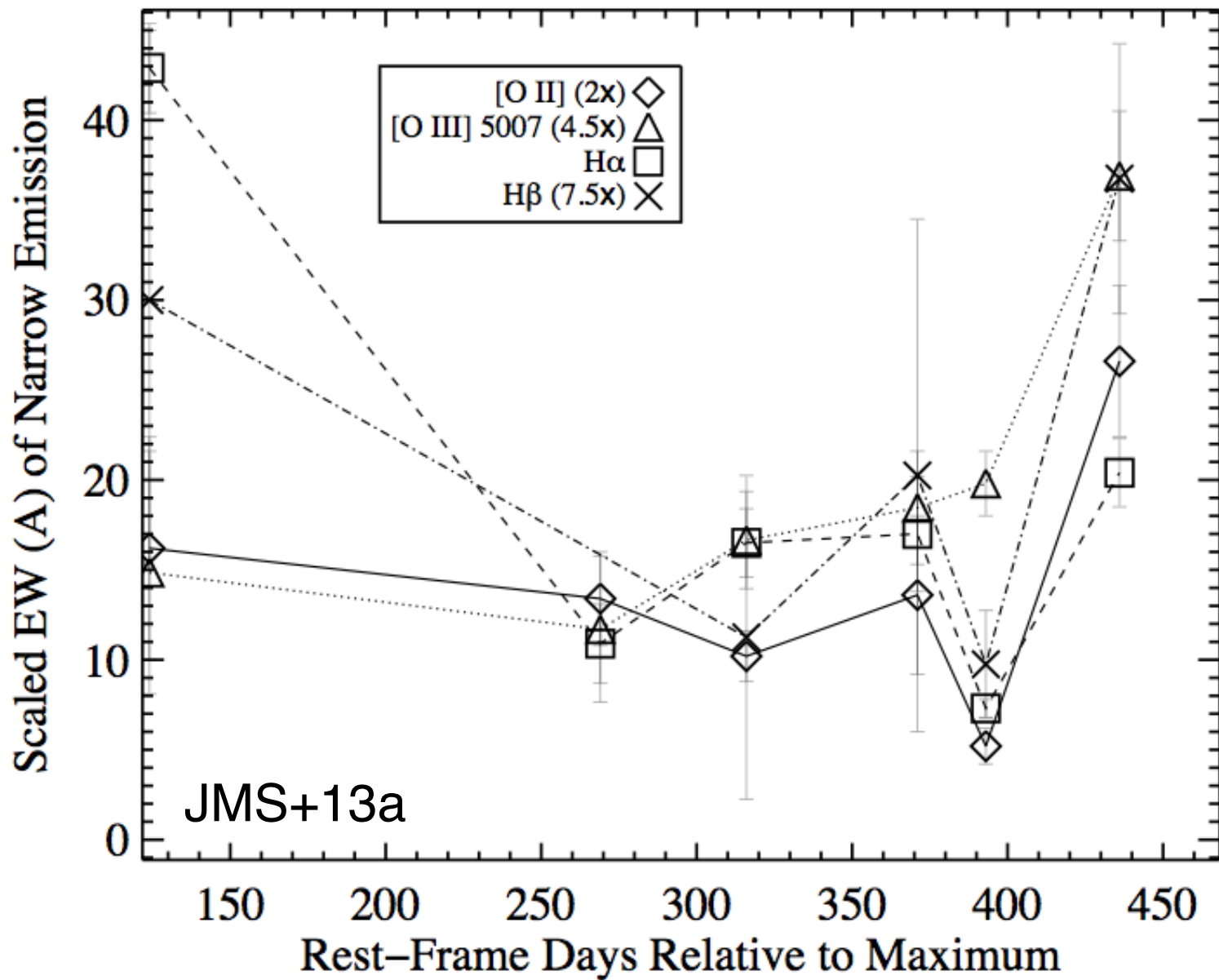


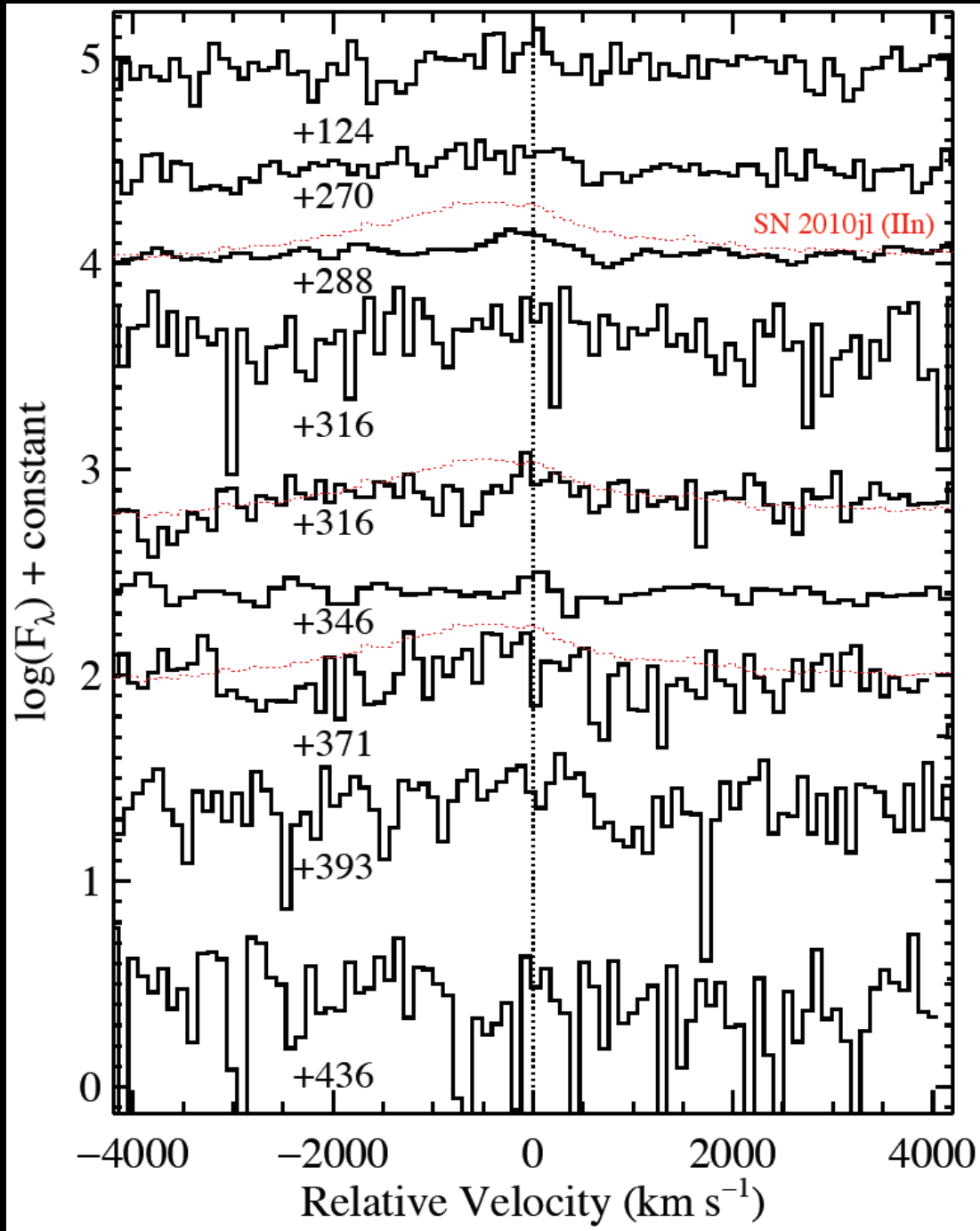
JMS+13a









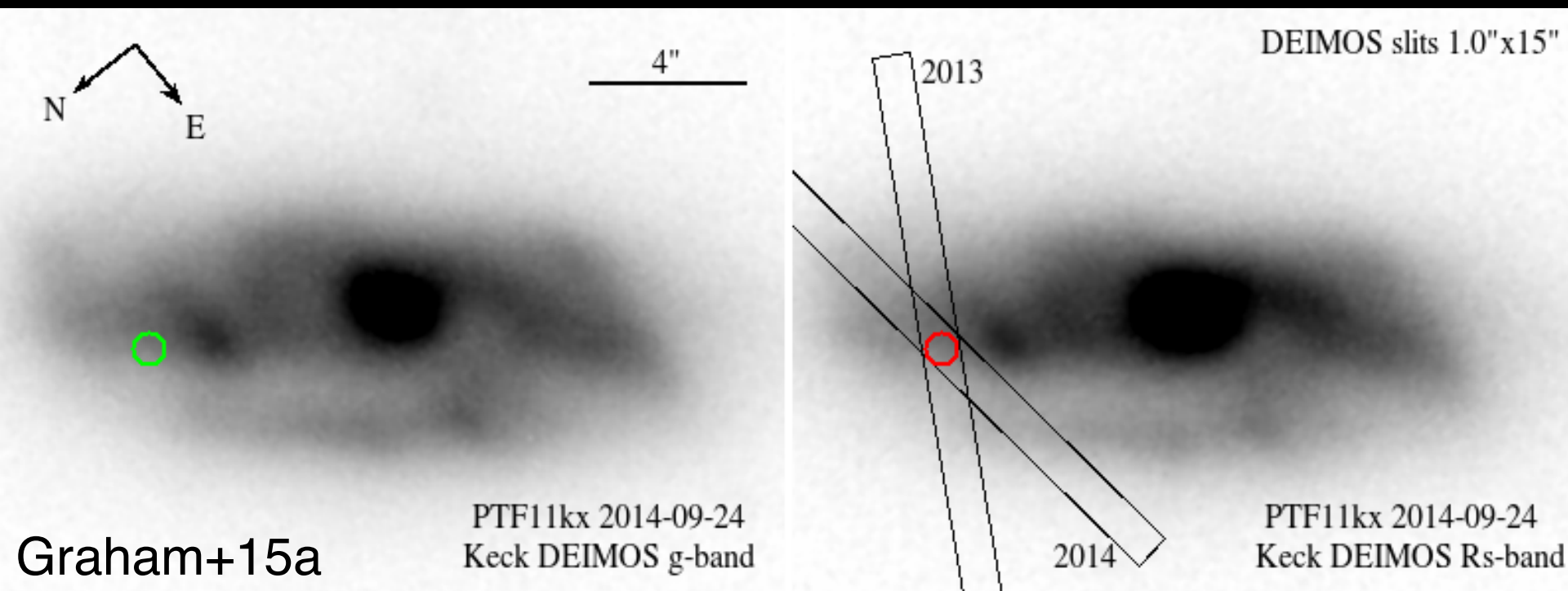


PTF11kx

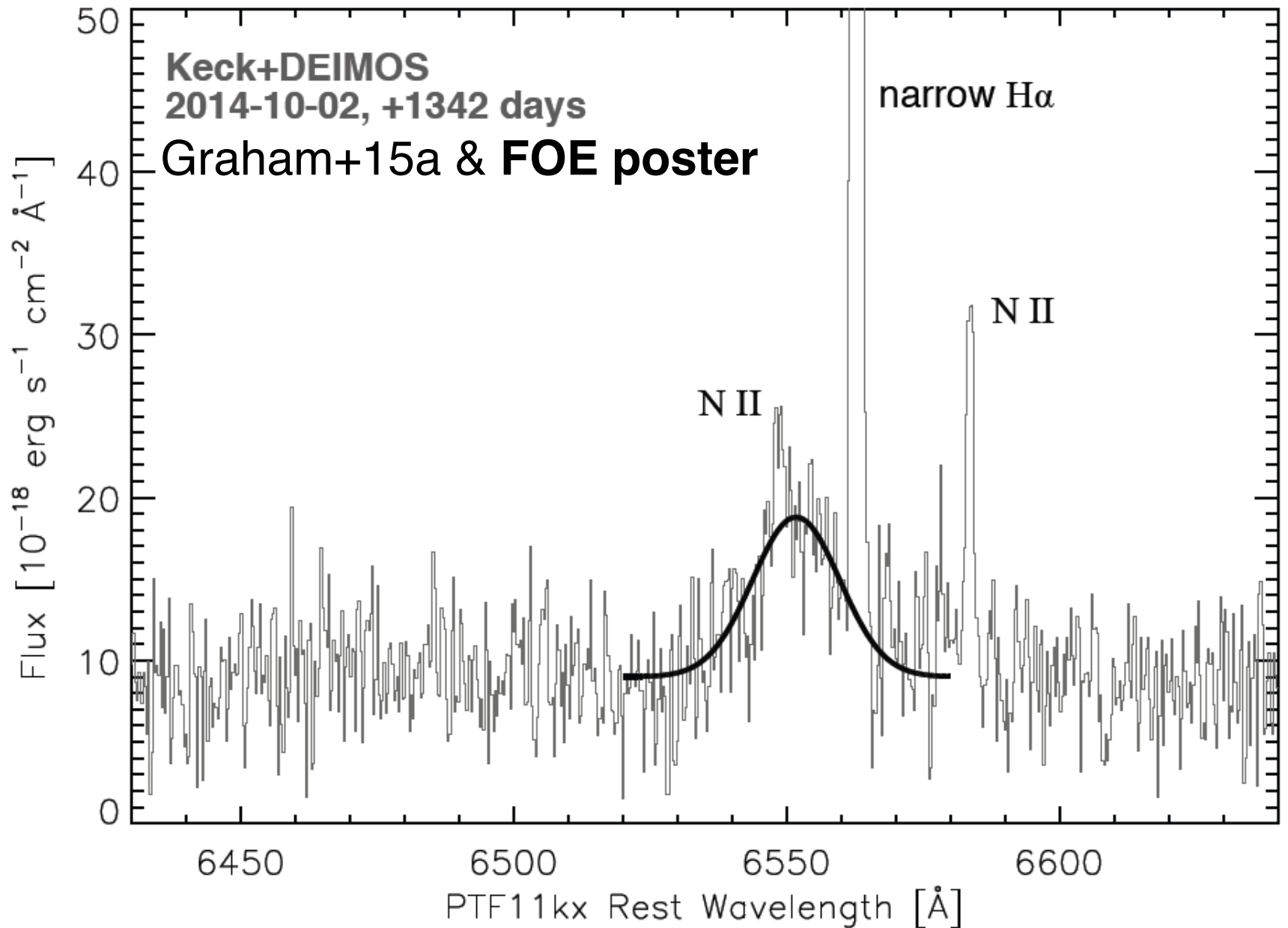
(very late-time data, $t \sim 1340$ d)

[Graham+15a & FOE poster]

Not detected in g- or R_s -band DEIMOS images



...but H α emission from PTF11kx persists!!!



Other SNe Ia Strongly Interacting w/ CSM

(Ia-CSM, ~~Ian~~, ~~Ia~~, ~~IIna~~, ~~hybrid SNe~~)

- PTF11kx looked like a SN Ia at first
- After ~1 month, PTF11kx looked kinda like a SN IIn
- There are others like it: **Ia-CSM objects**
- *Ia-CSM objects are the thermonuclear explosion of a WD that strongly interacts with a H-rich CSM.*

But by definition,



SNe Ia don't have H in their spectra...

Other SNe Ia Strongly Interacting w/ CSM

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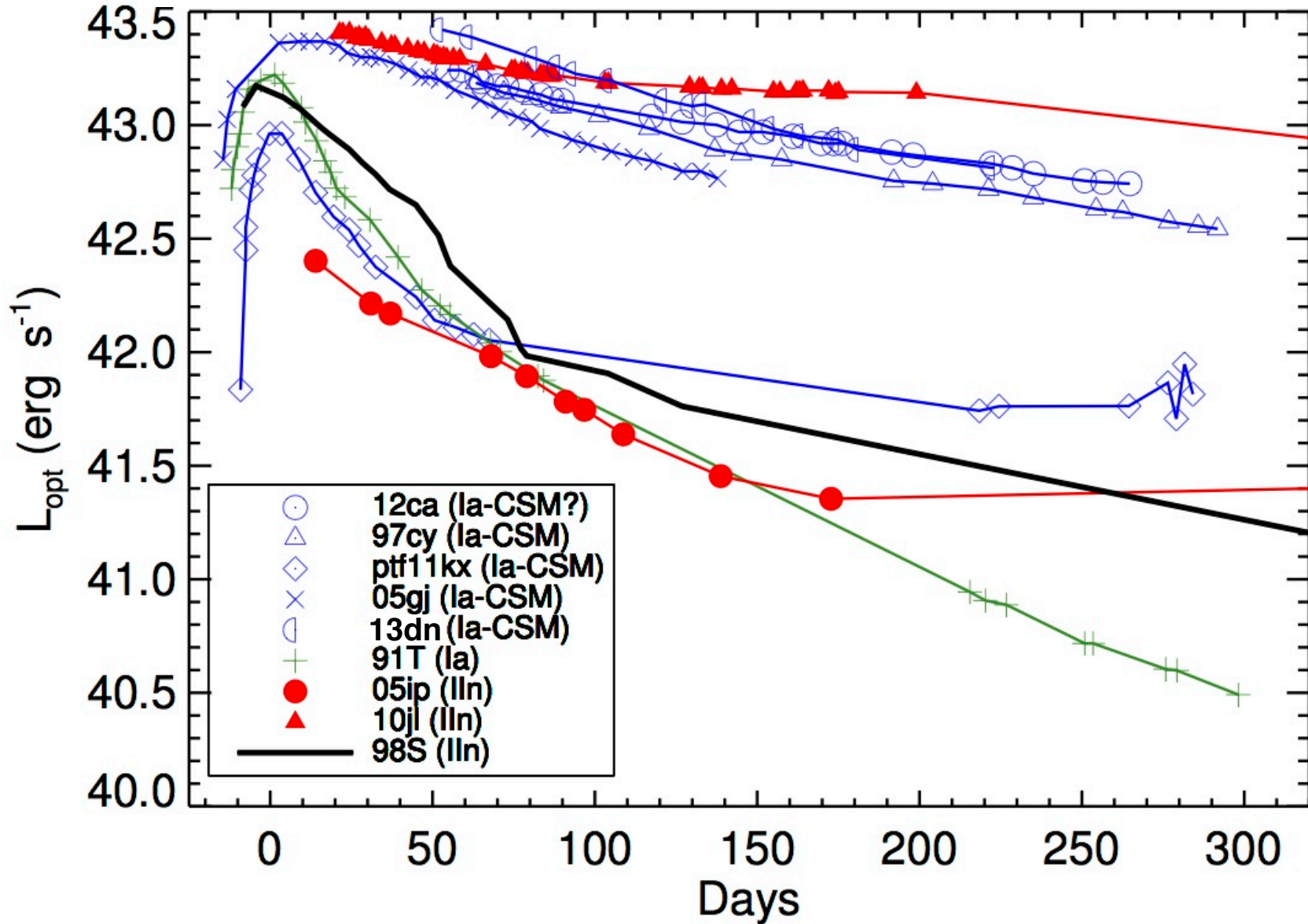
Older Ia-CSM Objects

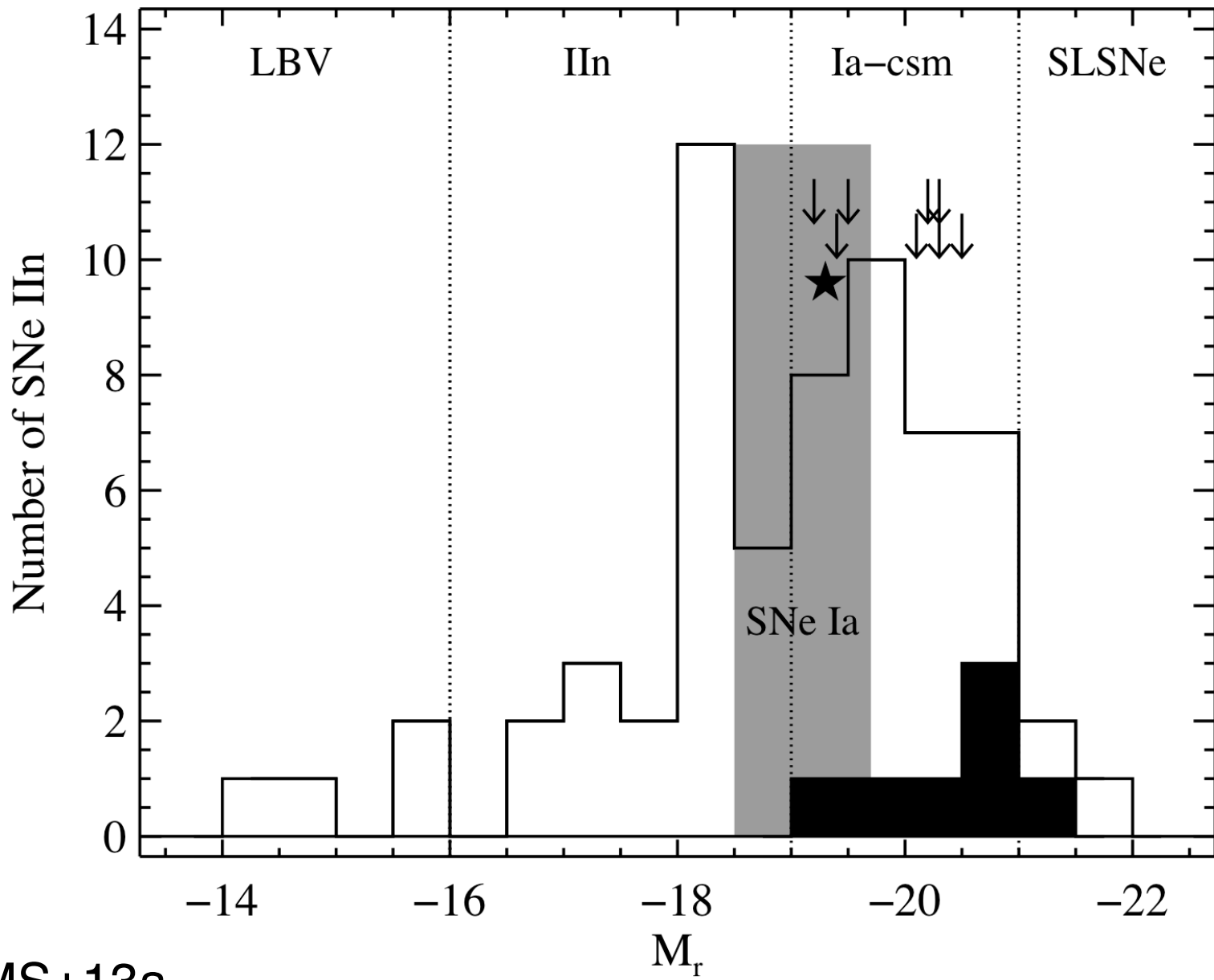
- SN 1997cy (Turatto+2000; Germany+2000)
- SN 1999E (Rigon+2003)
- SN 2002ic (Hamuy+2003; Deng+2004; Kotak+2004; Wang+2004; Wood-Vasey+2004)
- SN 2005gj (Aldering+2006; Prieto+2007)
- SN 2008J (Taddia+2012)
- SN 2008cg, SN 2011jb,
CSS120327:110520-015205
(only unrefereed CBETs)

Newer Ia-CSM Objects

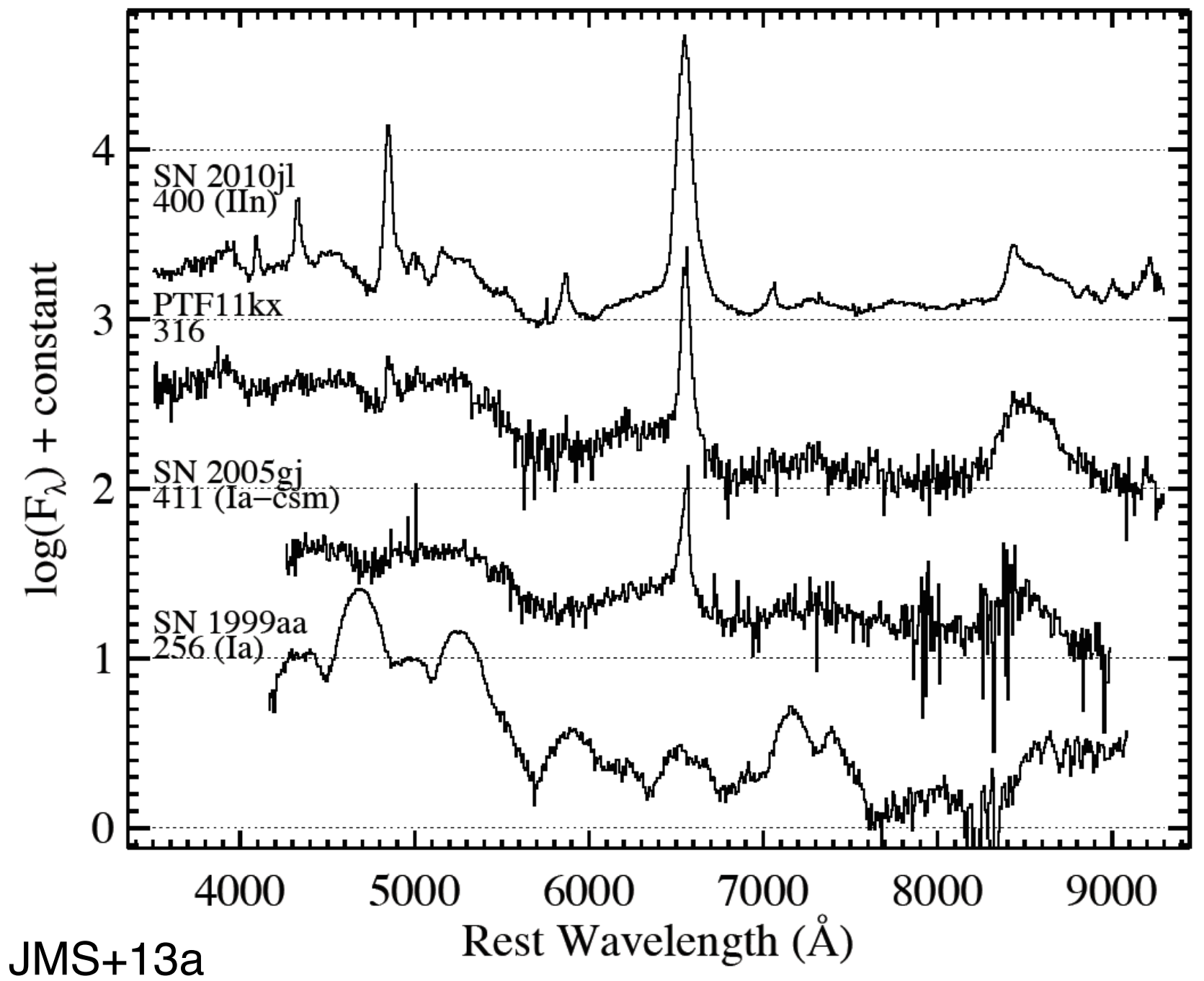
- PTF11kx (Dilday+2012; JMS+13a; Graham+15a)
 - 7 more PTF objects (JMS+13b)
 - SN 2012ca (Fox+2014...but see also Inserra+2013)
 - SN 2013dn (Fox+2014)
 - 2—3 more objects announced in ATELS
- ~20 (or 1) Ia-CSM objects

Optical Photometry Compiled by Fox+14

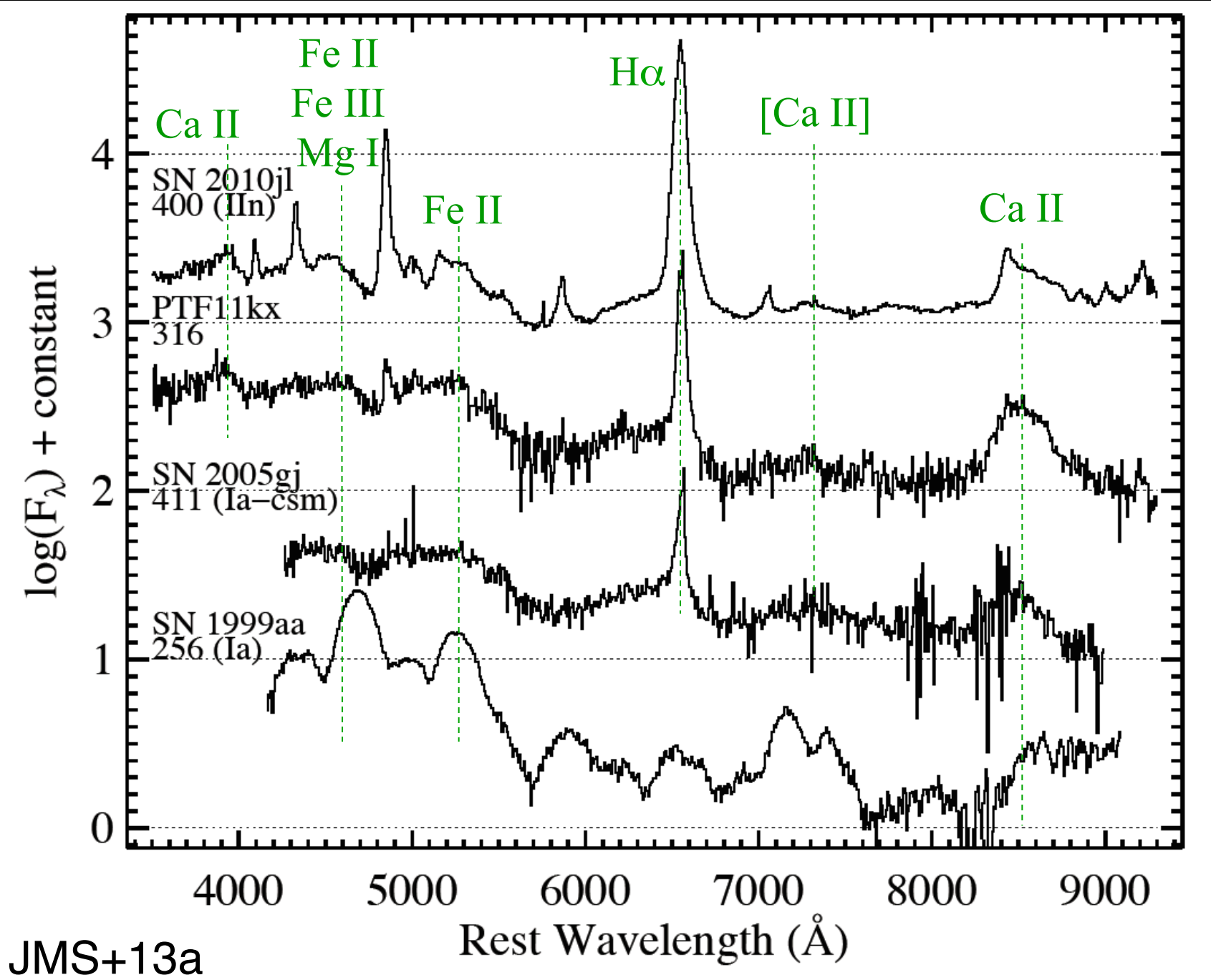




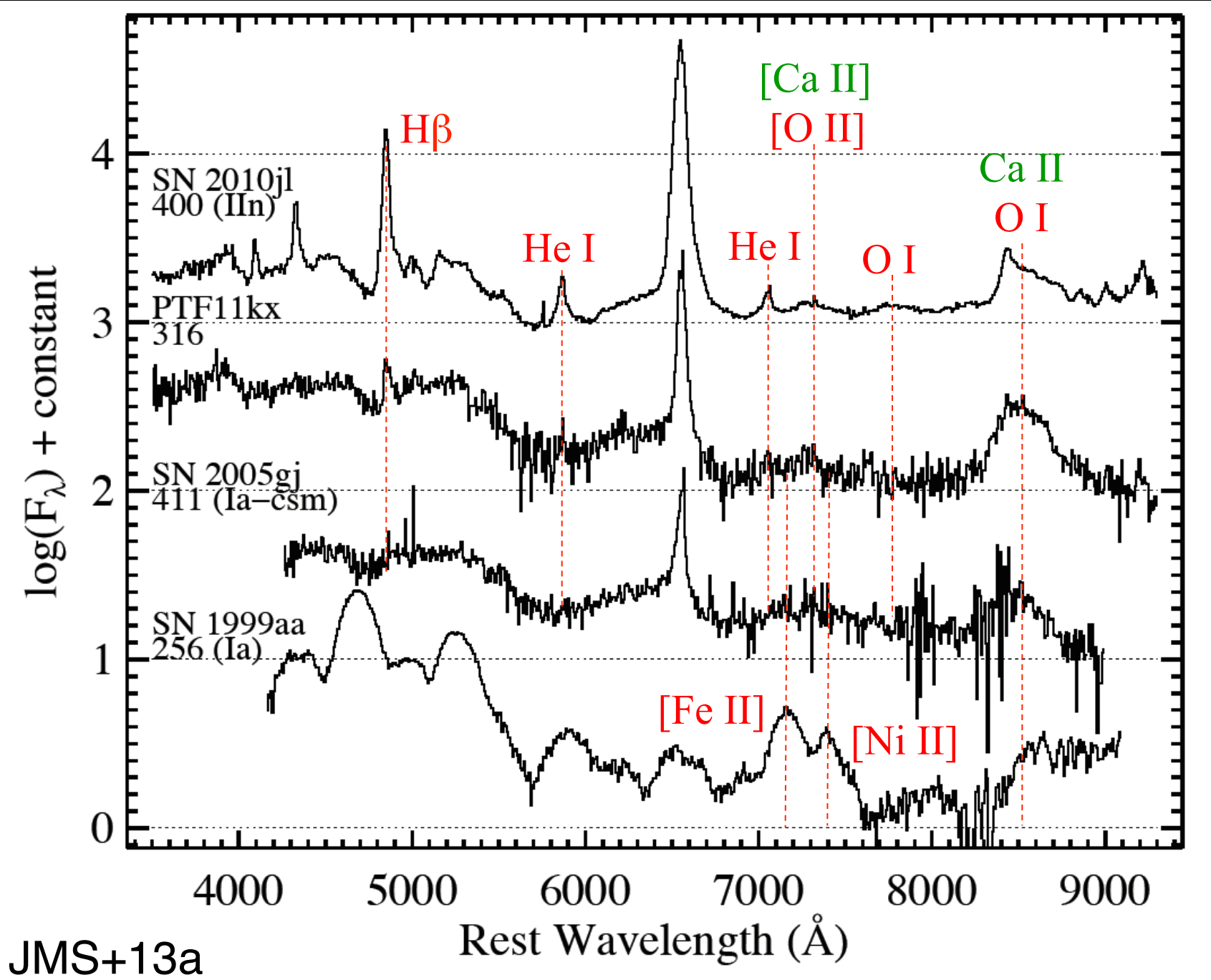
JMS+13a

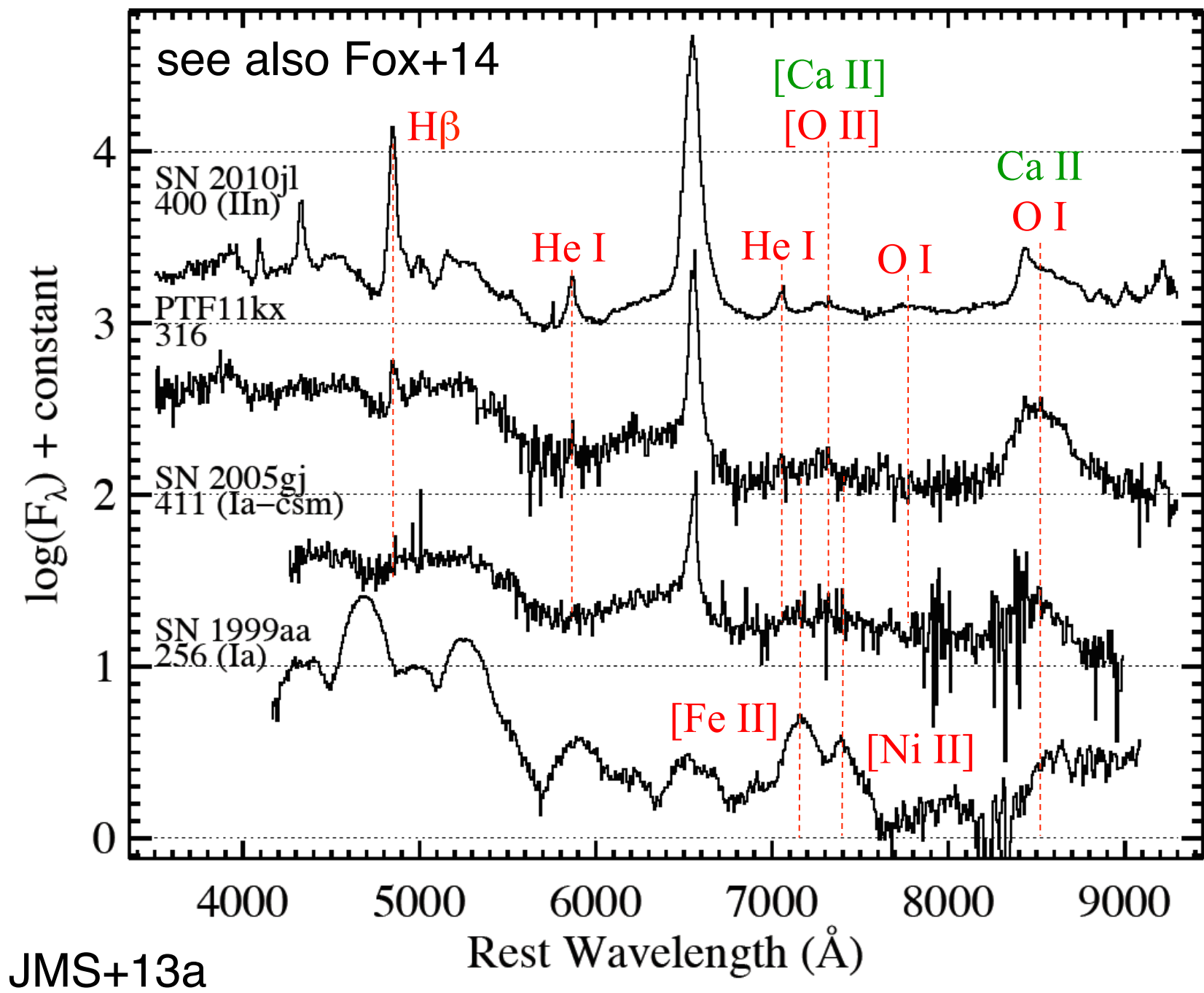


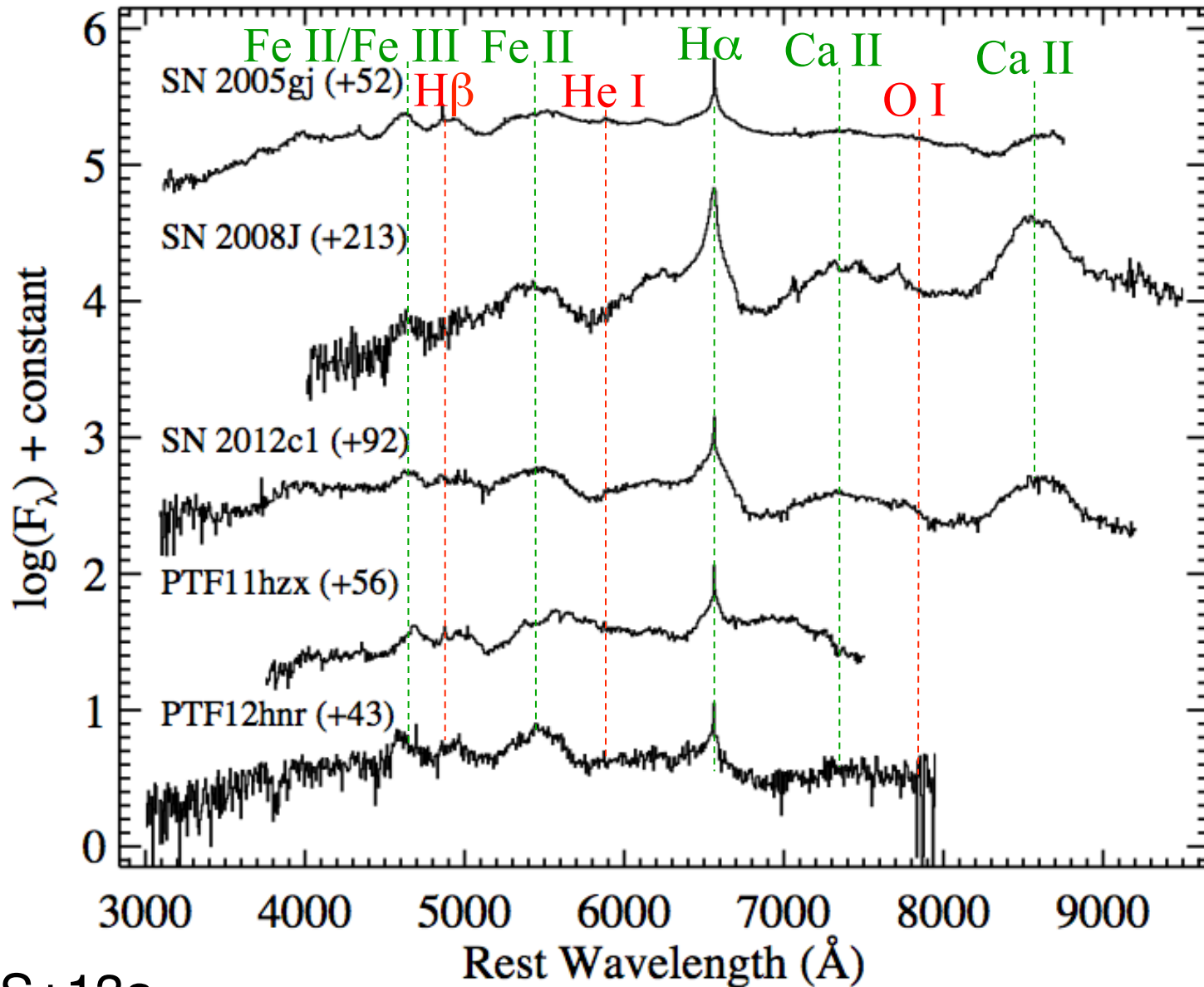
JMS+13a



JMS+13a

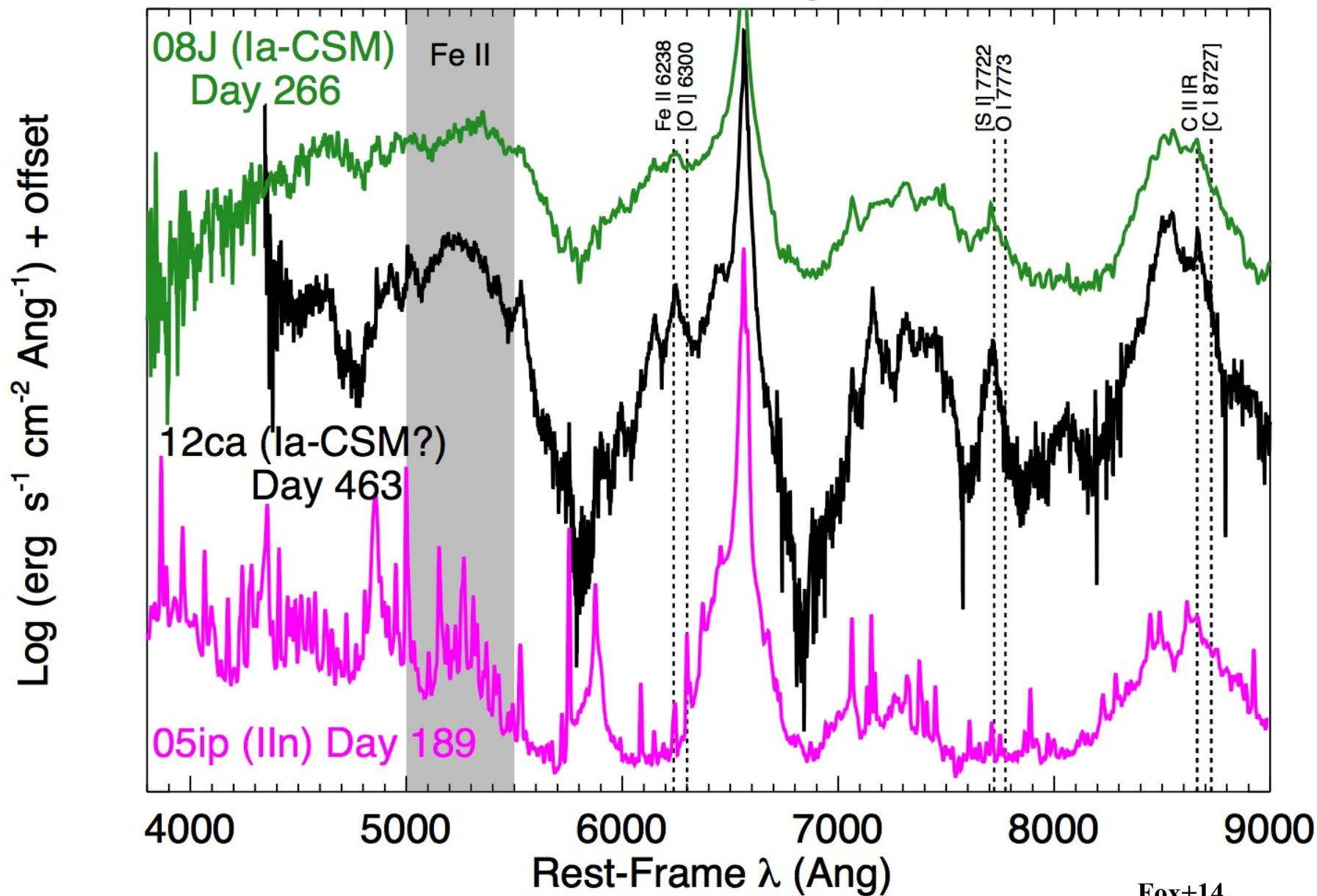


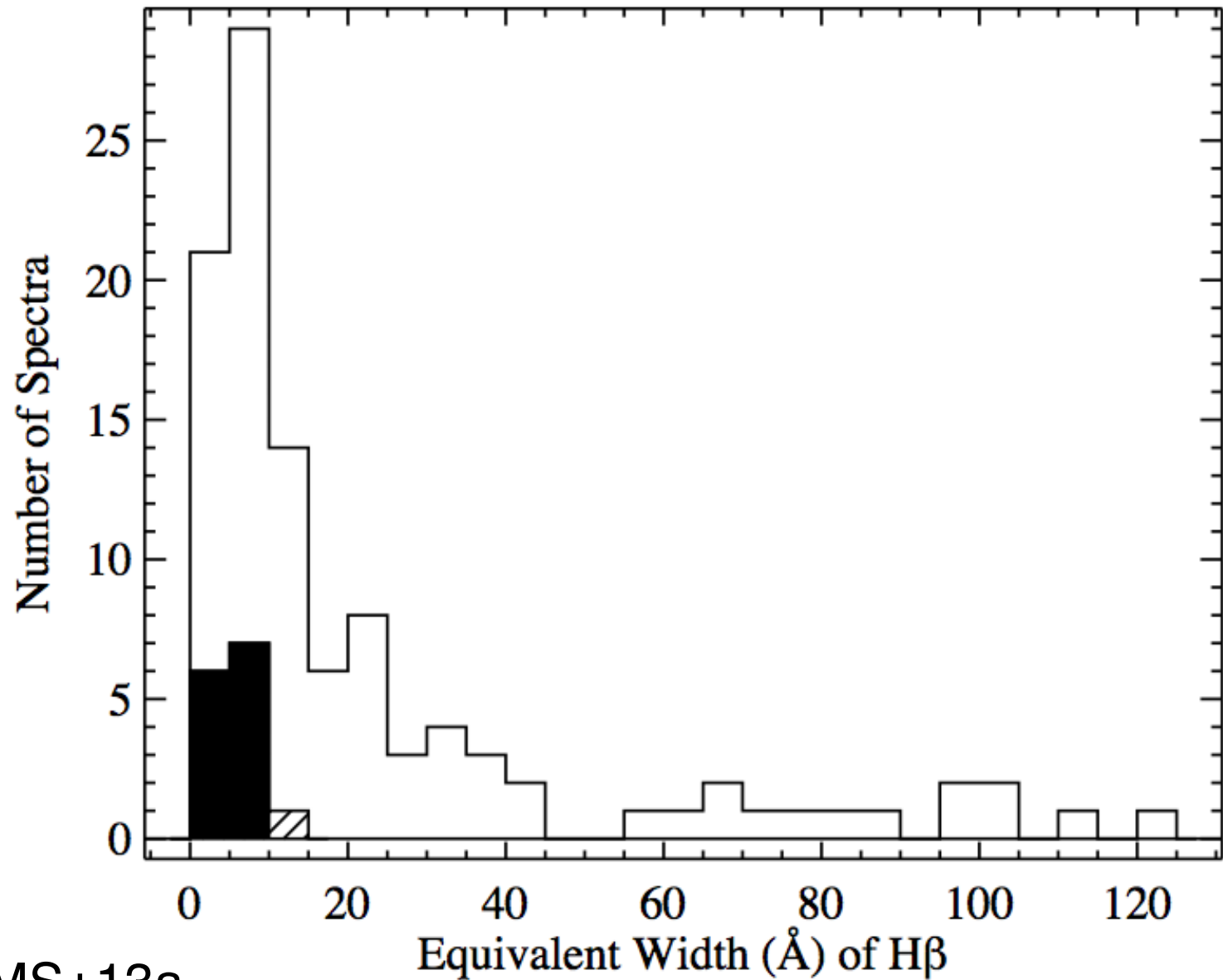




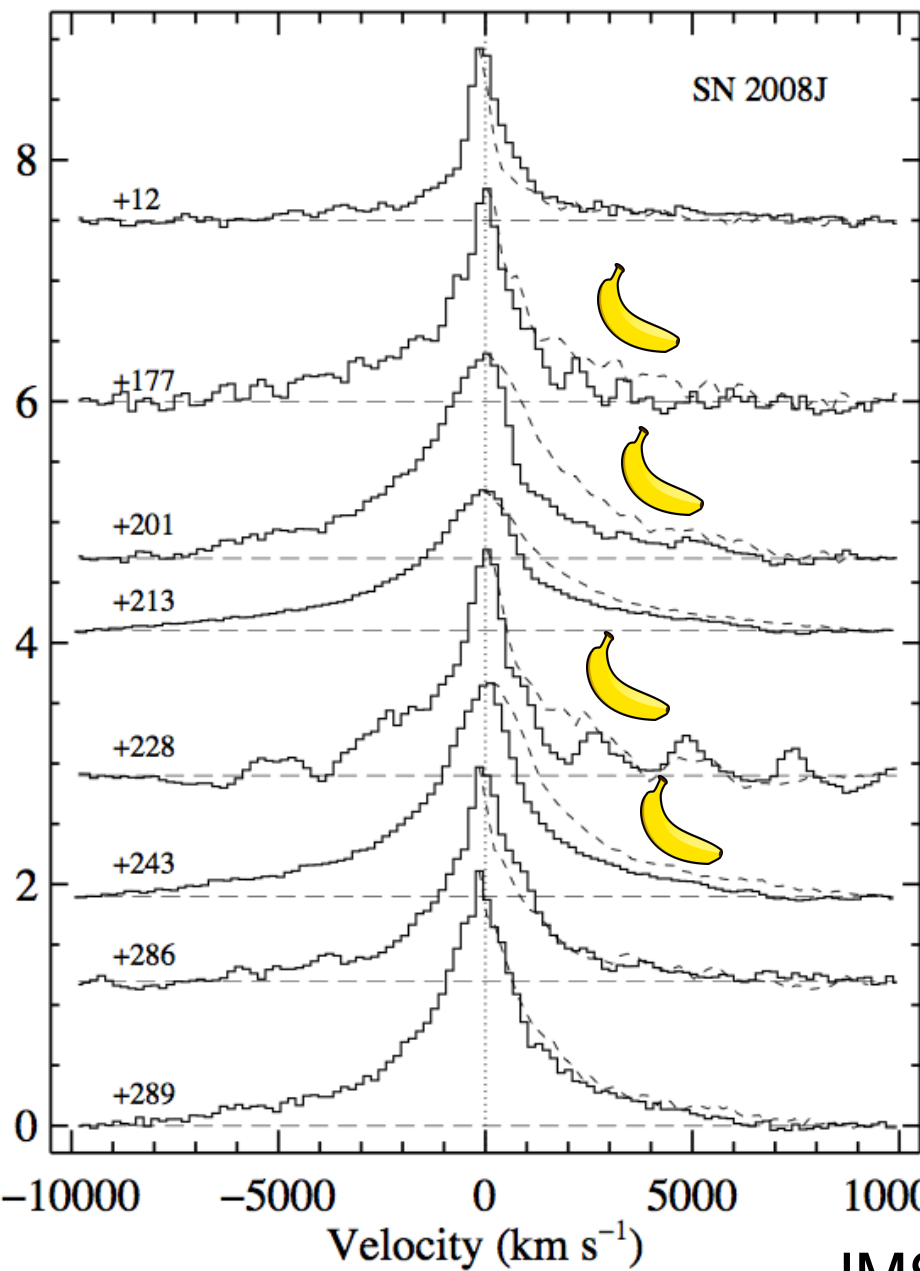
JMS+13a

Optical Ambiguity

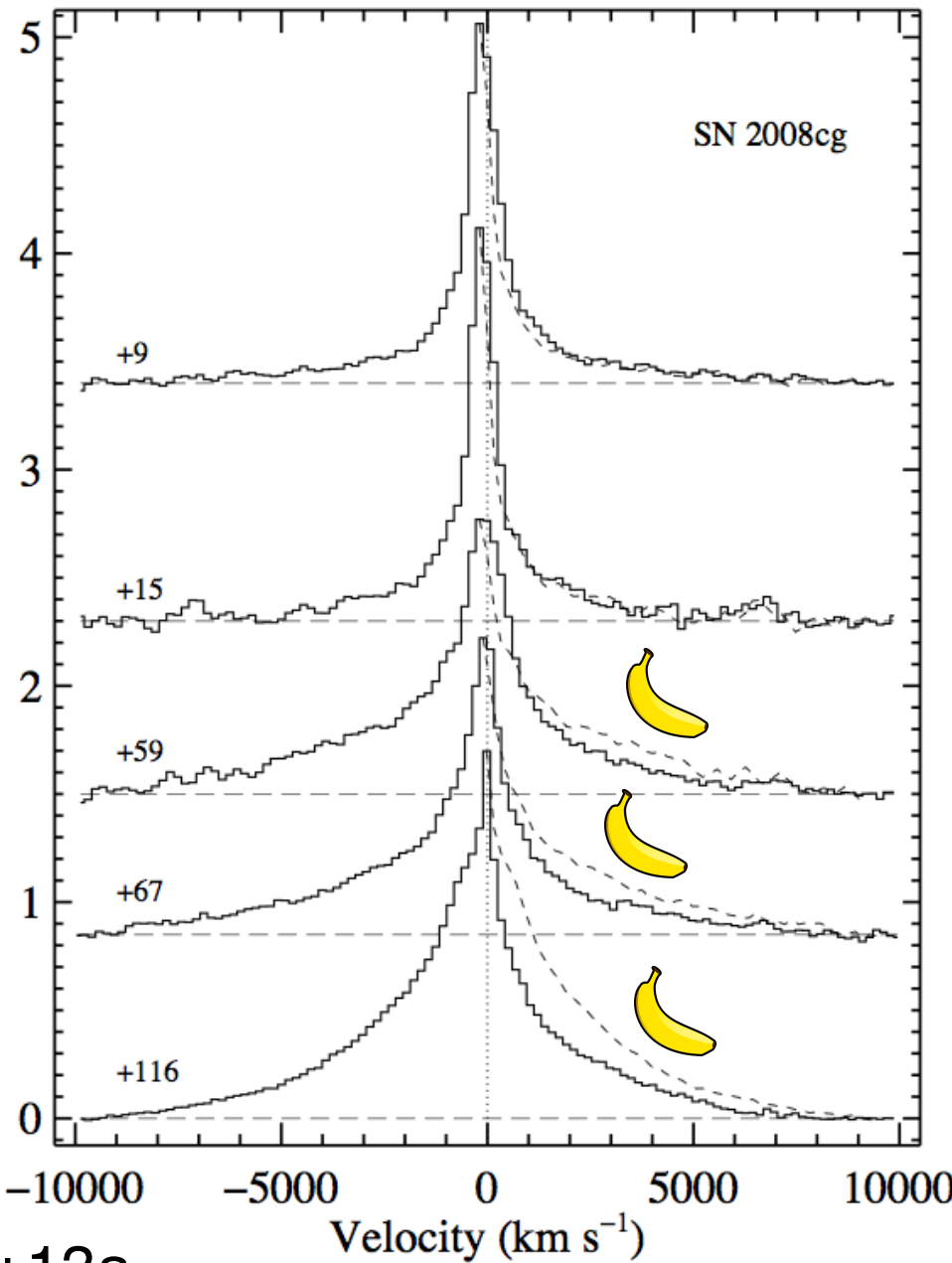




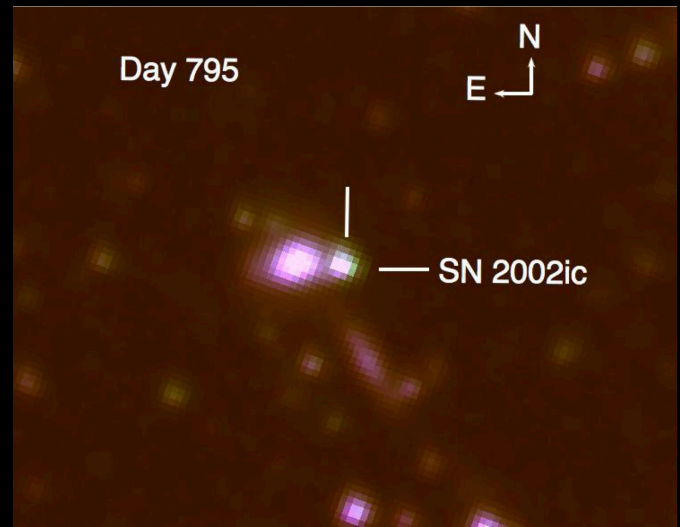
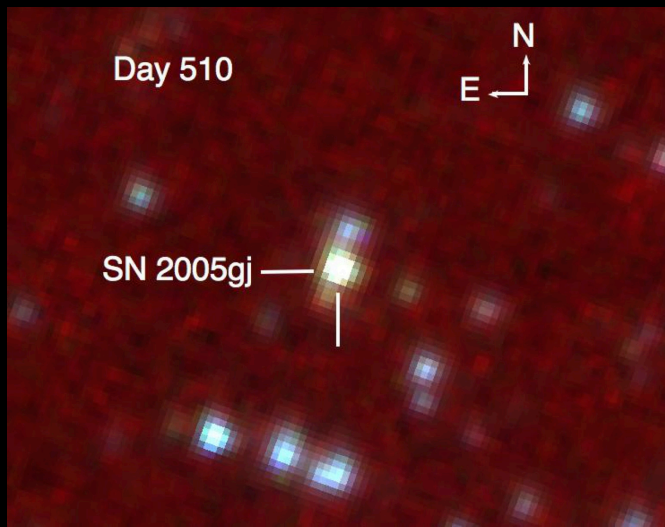
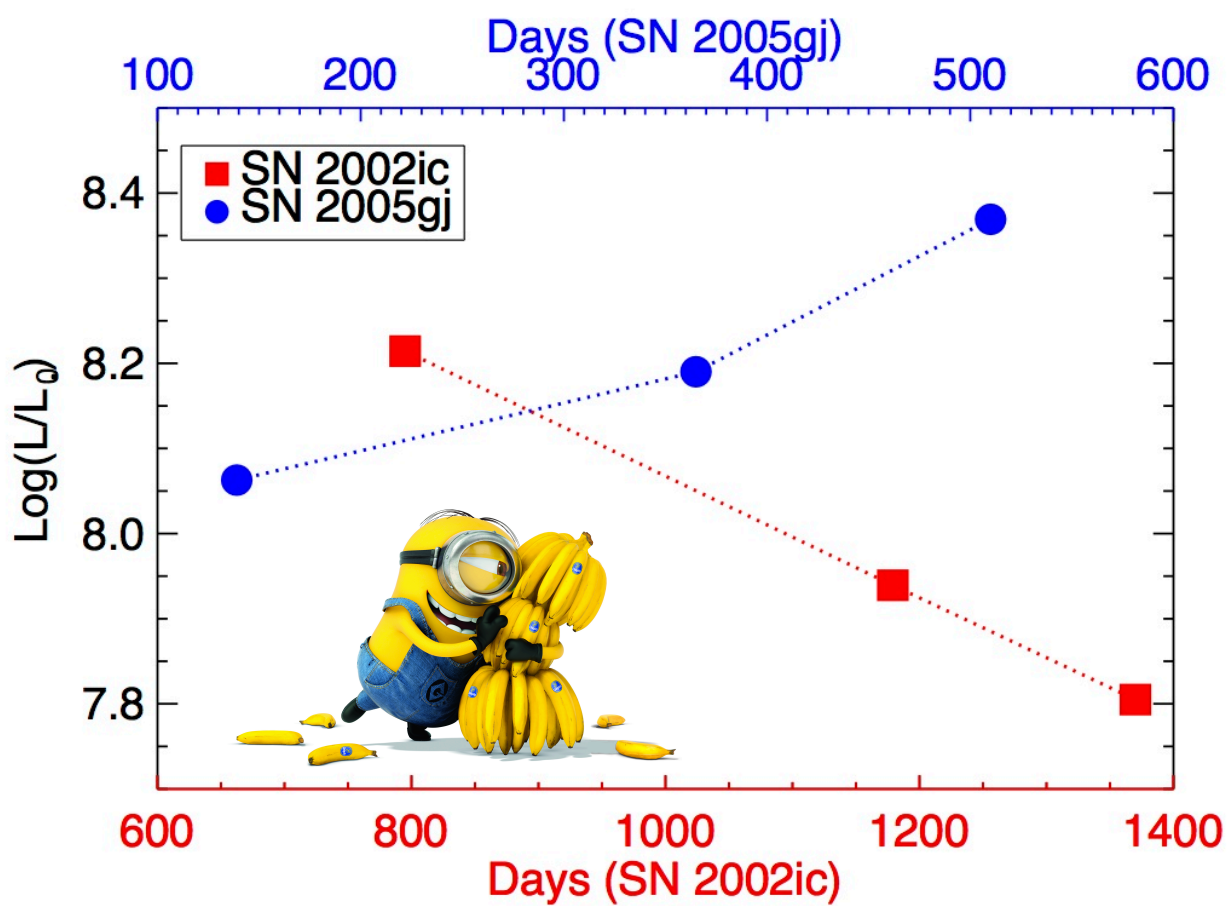
JMS+13a



JMS+13a



Fox & Filippenko 2013

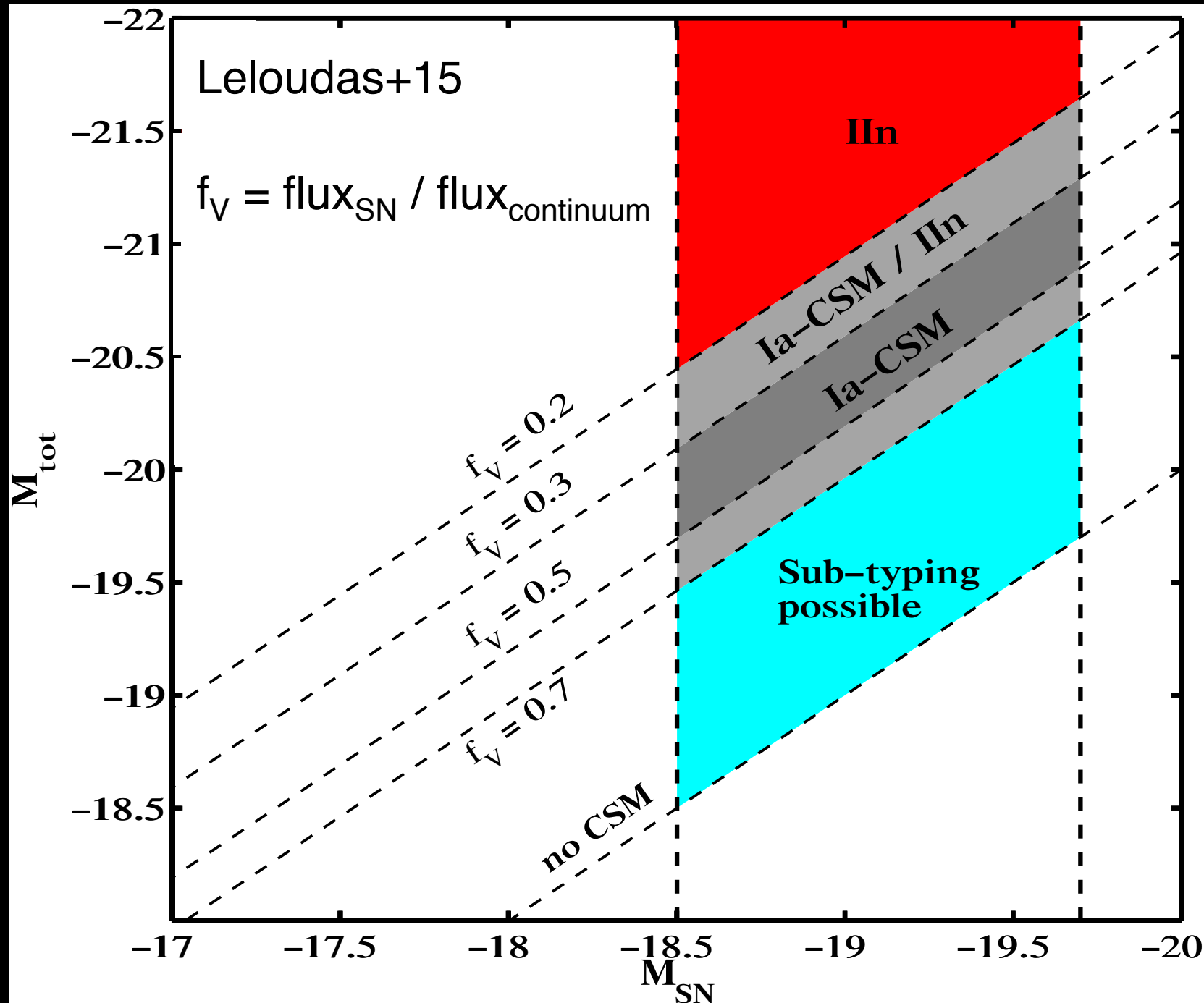


**Spitzer
False Color
(3.6, 4.5,
5.8 μm)**

How much is too much?

[Leloudas+15]

- Generated >800 spectra with differing amounts of circumstellar interaction
- 10 co-authors each classified a random subset (by eye, SNID, Superfit, GELTAO)
- Main factor affecting spectral classification is $f_V = \text{flux}_{\text{SN}} / \text{flux}_{\text{continuum}}$
- S/N, extinction, and strength of narrow emission lines didn't affect classifications



PTF 11kx Summary

[Dilday+12; JMS+13a; Graham+15a]

- SN Ia w/ symbiotic nova progenitor
- Possible evidence for single degenerate (RG)
- Weird and rare, but it does have brethren (though it's an extreme/weak Ia-CSM object)
- Directly links Ia-CSM objects to SNe Ia and WDs


Ia-CSM Objects Summary

[JMS+13b; Fox+13; Fox+14; Leloudas+15]

- Luminous ($-21 \leq M_{R,\text{peak}} \leq -19$) & slow LCs
- Strong $H\alpha$ and Ca II near-IR triplet emission
- Weak $H\beta$, He I, and O emission
- Collisionally excited H?
- Spectra are Ia-91T/99aa + continuum (up to 3x the SN Ia flux) + narrow H emission
- $L_{H\alpha} \approx 10^{40-41}$ erg/s

Ia-CSM Objects Summary

[JMS+13b; Fox+13; Fox+14; Leloudas+15]

- Strong, early-time UV emission
- No early time XR or radio emission
- Red wing of $H\alpha$ decreases w/ time and strong, late-time NIR/mid-IR emission
- Evidence of dust formation 
- Strong Na I D absorption from host ISM
- Late-type (or dwarf irregular) host galaxies

Other SNe Ia w/ CSM interaction?

- Ia-CSM objects have a lot (11kx has slightly less than others)
- Strong late-time limits on H emission (e.g., Mattila+05; Leonard07; Shappee+13; Taubenberger+14; Lundqvist+15; Graham+15b; Maguire+15)
- Variable and/or blueshifted Na I D absorption (e.g., Patat+07; Blondin+09; Simon+09; Sternberg+11; Foley+12; Maguire+13)
- Should other SNe Ia with H-rich CSM show H emission?
- Viewing angle effect??

Are kinda luminous SNe IIn actually Ia-CSM?

- Maybe...if CSM interaction starts right after explosion?
- Maybe...if there's more or denser CSM than around (what I call) Ia-CSM objects?
- Spectra are classified as SNe IIn if the continuum flux is $\gtrsim 3x$ the SN Ia flux (Leloudas+15)
- Perhaps some (or all) moderately luminous SNe IIn are actually Ia-CSM objects?

Can we distinguish between Ia-CSM objects and SNe IIn?

- Ia-CSM objects have observational characteristics (some necessary, but none obviously sufficient)
- Many SNe IIn share most (but not all) Ia-CSM signatures (e.g., JMS+13a; Fox+14)
- Is there a continuous/overlapping range of observables connecting Ia-CSM objects to (at least some) SNe IIn?

How common are Ia-CSM objects?

- Observed Ia-CSM rate is >0.1 – 1% of SN Ia rate (Dilday+12, based on SDSS-II and PTF)
- Theoretical fraction of SNe Ia from symbiotic nova progenitors is 1 – 30% (e.g., Han+04, Lu+09, Chiotellis+12)
- Can host properties, environments, or stellar ages tell us something?

Thanks!

