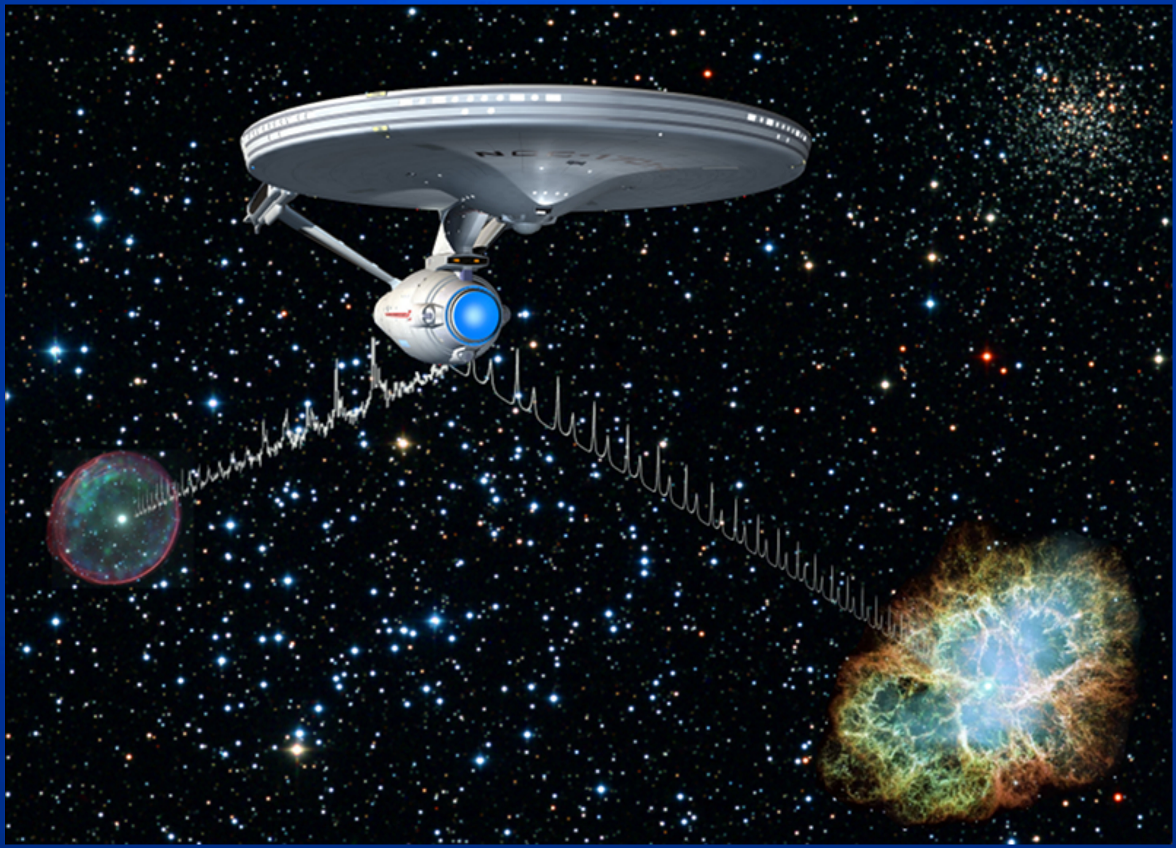
Supernovae flash spectroscopy: a new window into stellar death



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FSG, Toronto 2015

Realtime Time-Domain Science

Based on manuscripts

Gal-Yam et al. 2014, Nature

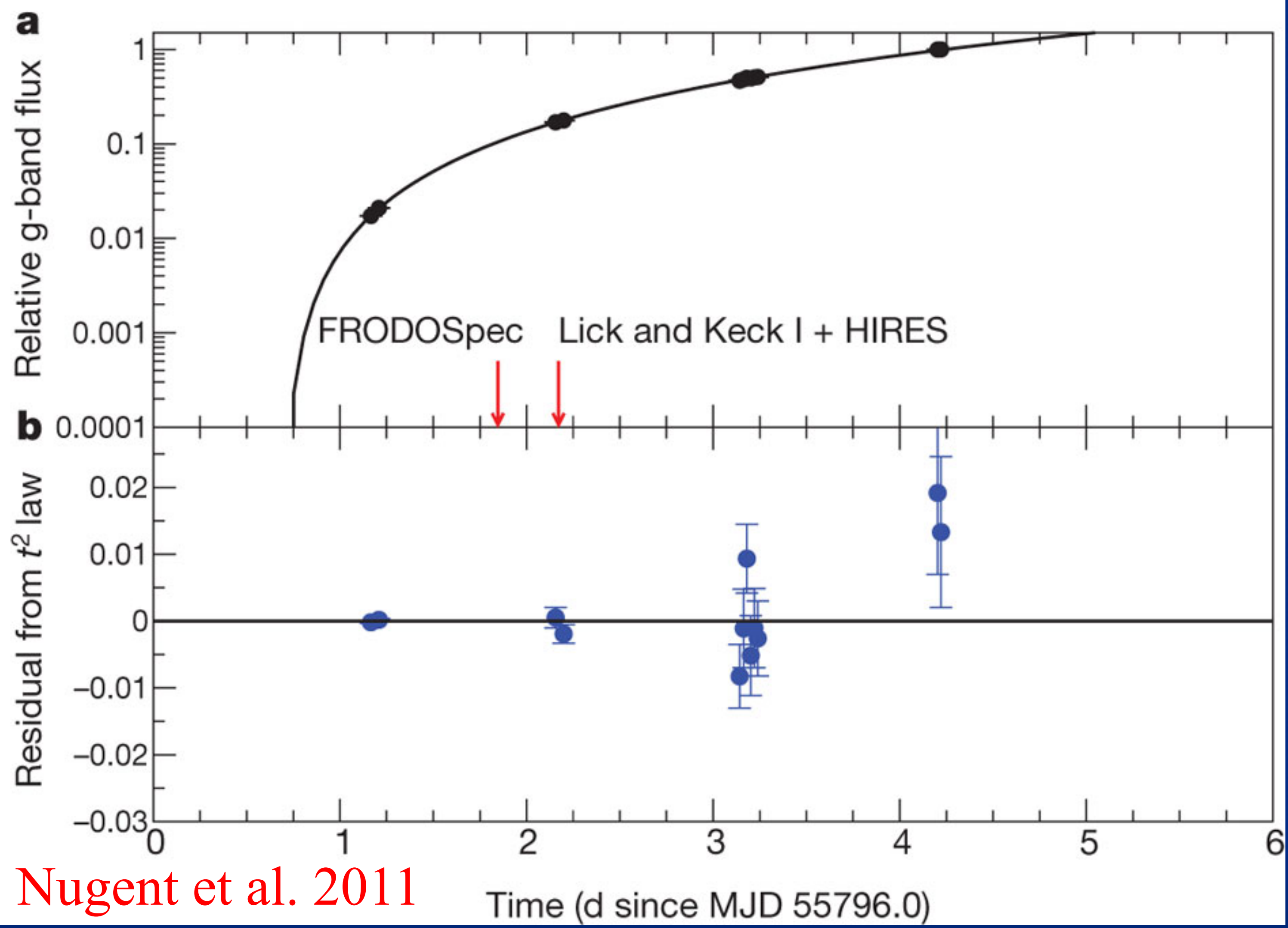
Yaron, Perley et al. 2015; Ganot et al. 2015; Rubin et al. 2015

Now

It is now prime time to think about science at day 1

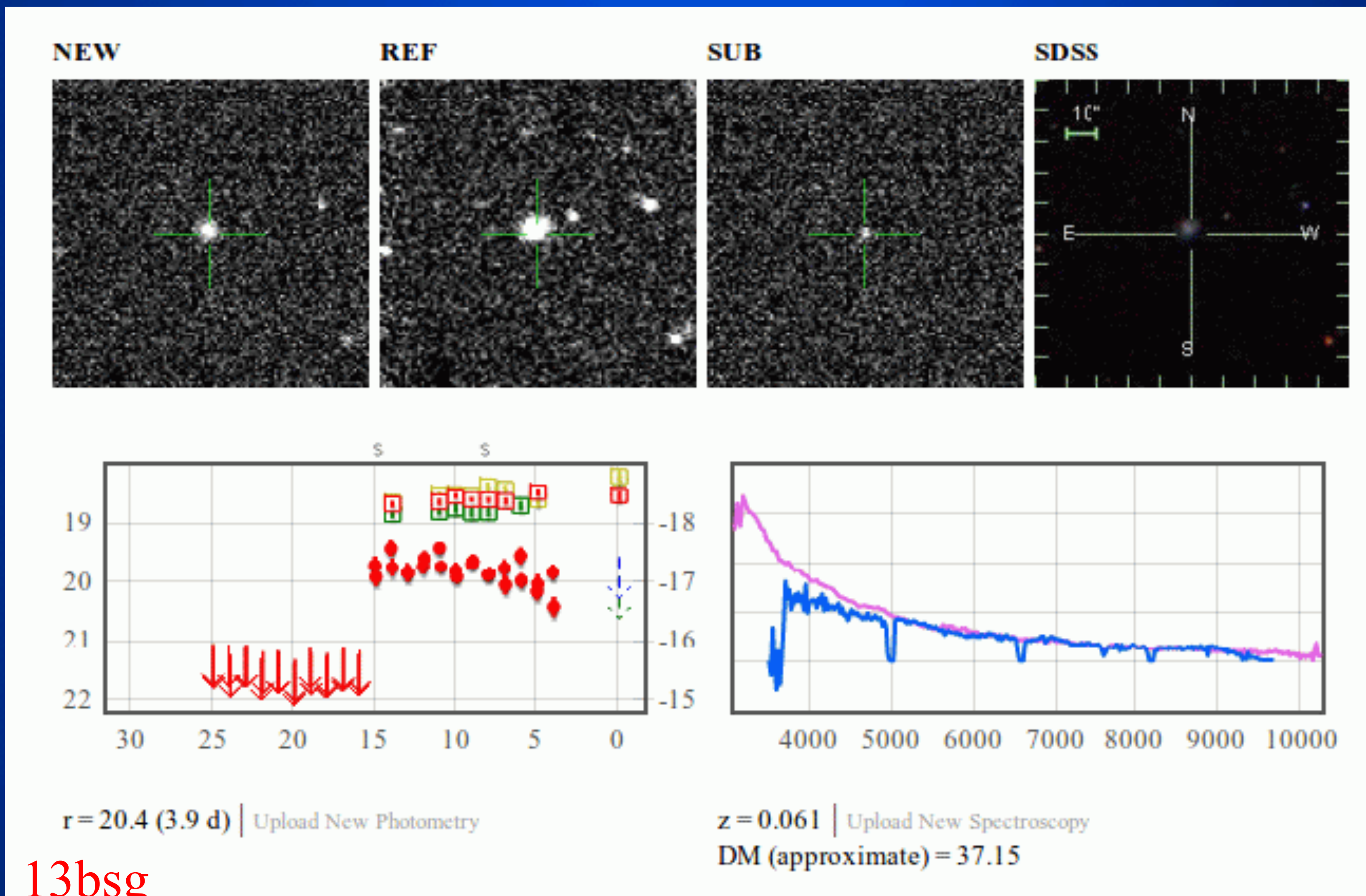
- Shock breakout
- Multiwavelength
- World networks
- Neutrino and GW coincidence
- Flash spectroscopy
- …

The Palomar Transient Factory (PTF) found some SNe very early



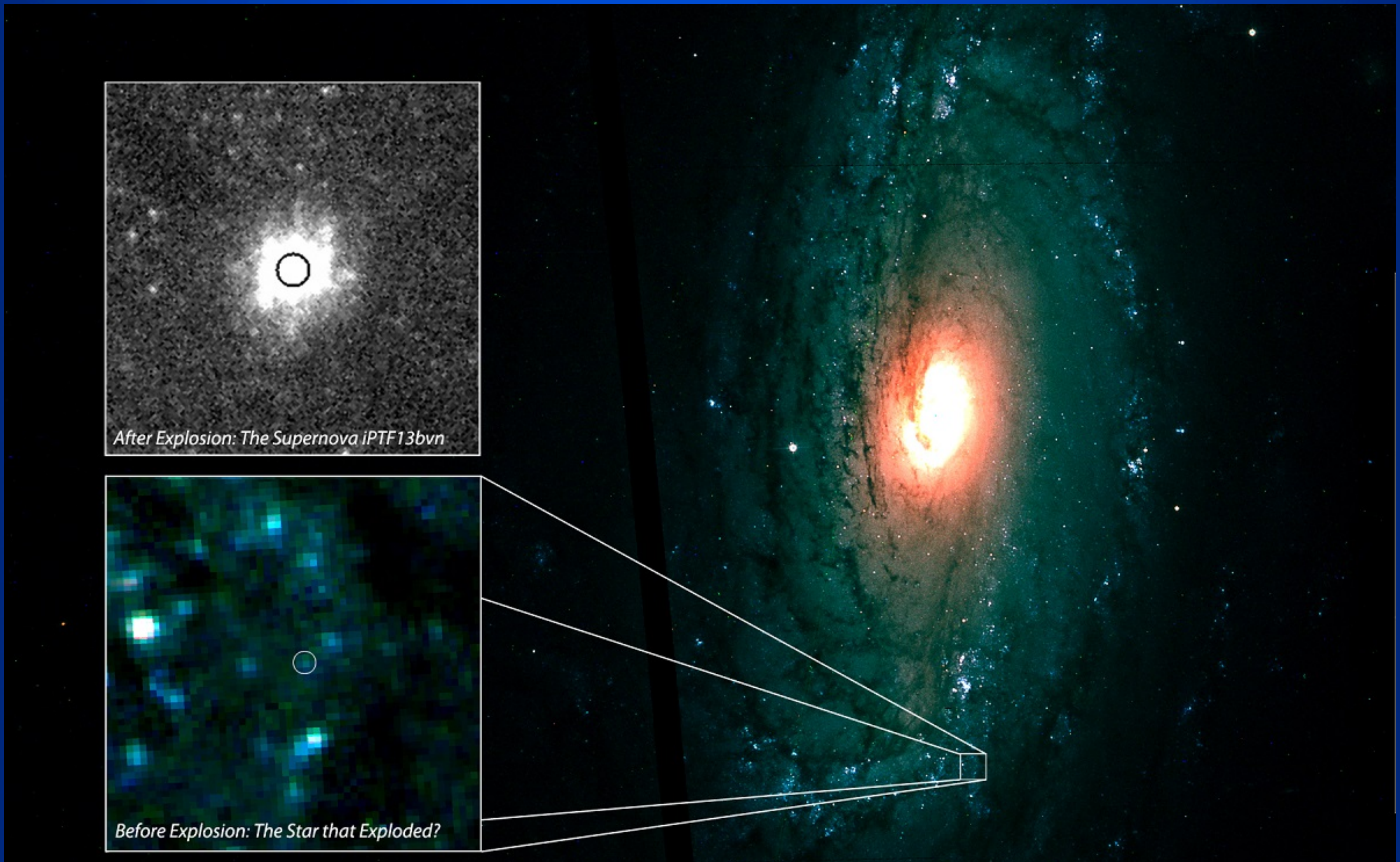
Nugent et al. 2011

iPTF can find optical transoients as they happen!



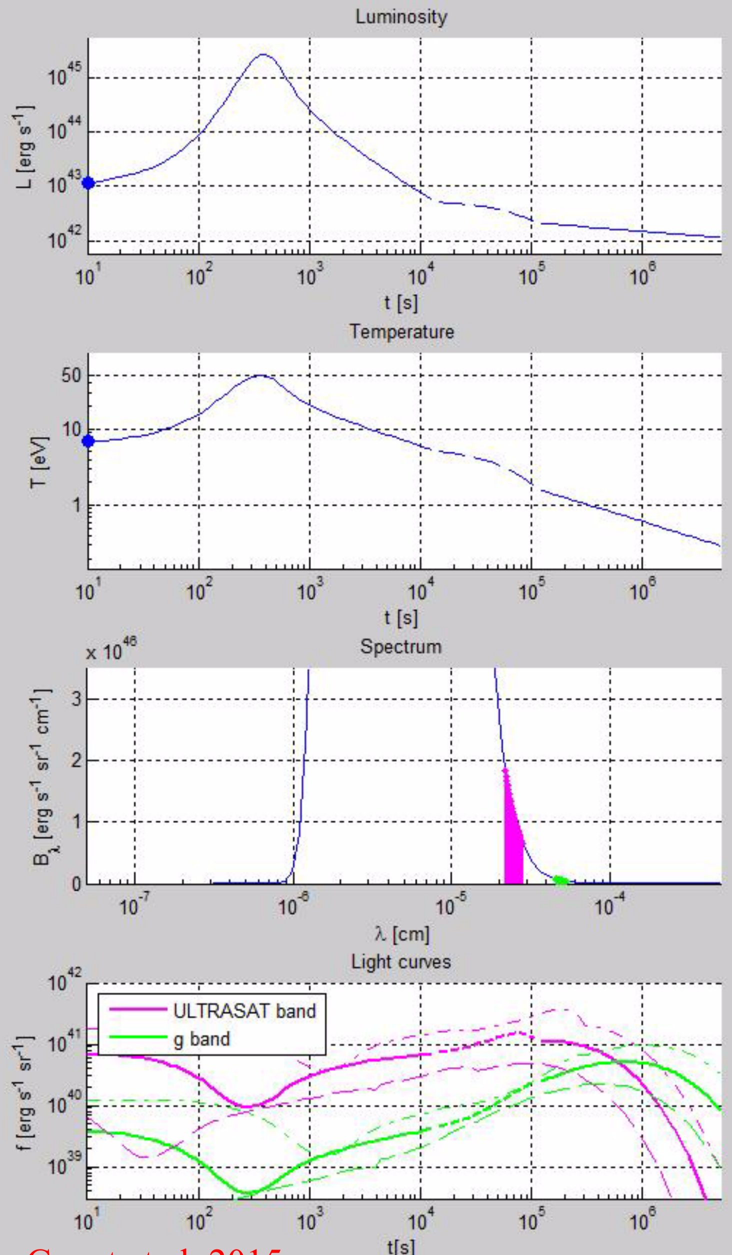
13bsg

iPTF is even better!

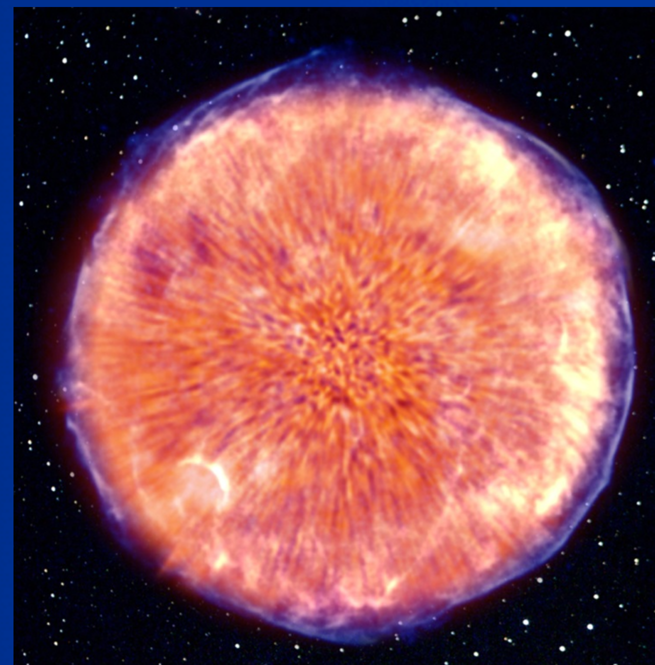


Cao et al. 2013; Fremling et al. 2014

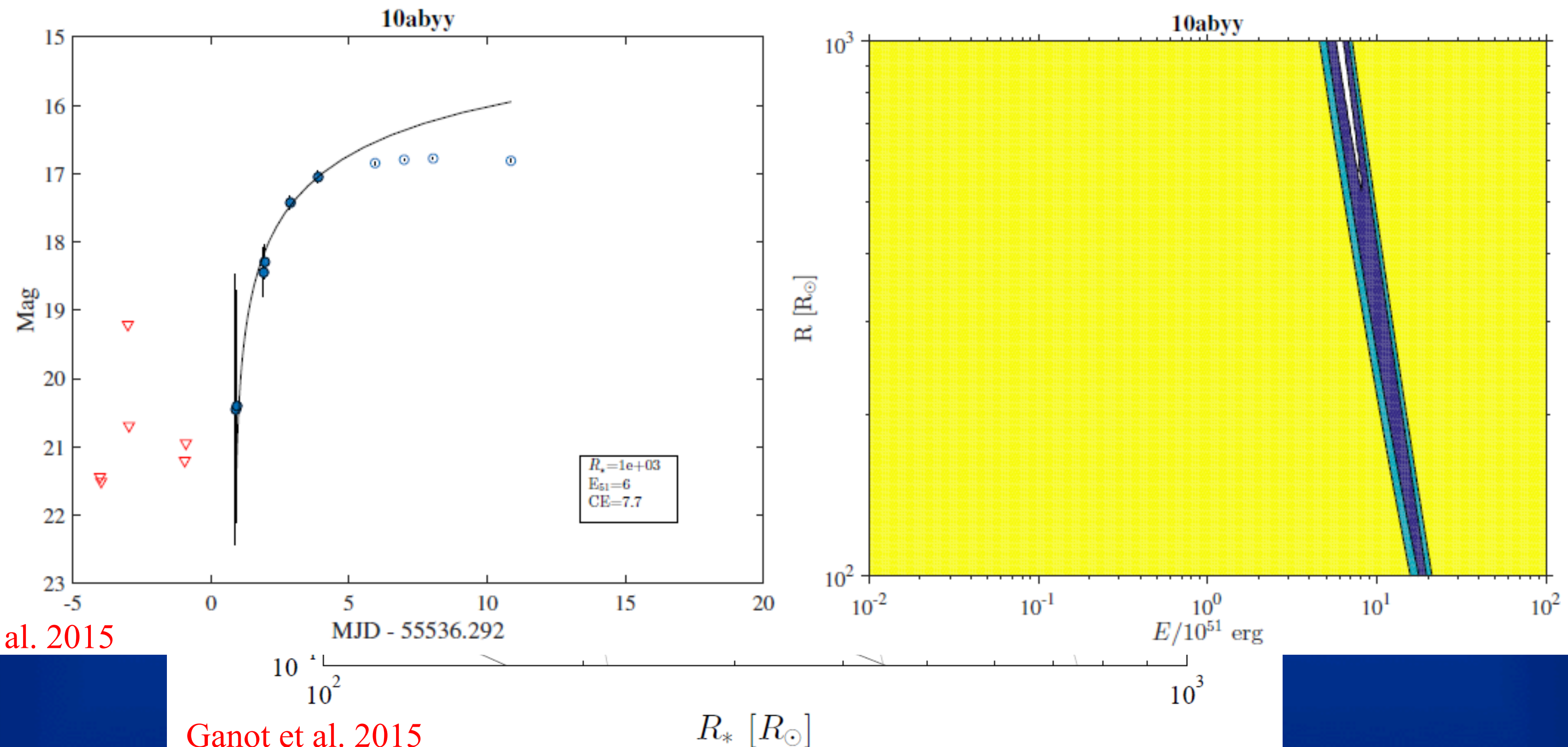
What will we see?



Ganot et al. 2015



Early UV data can directly constrain progenitor and explosion properties

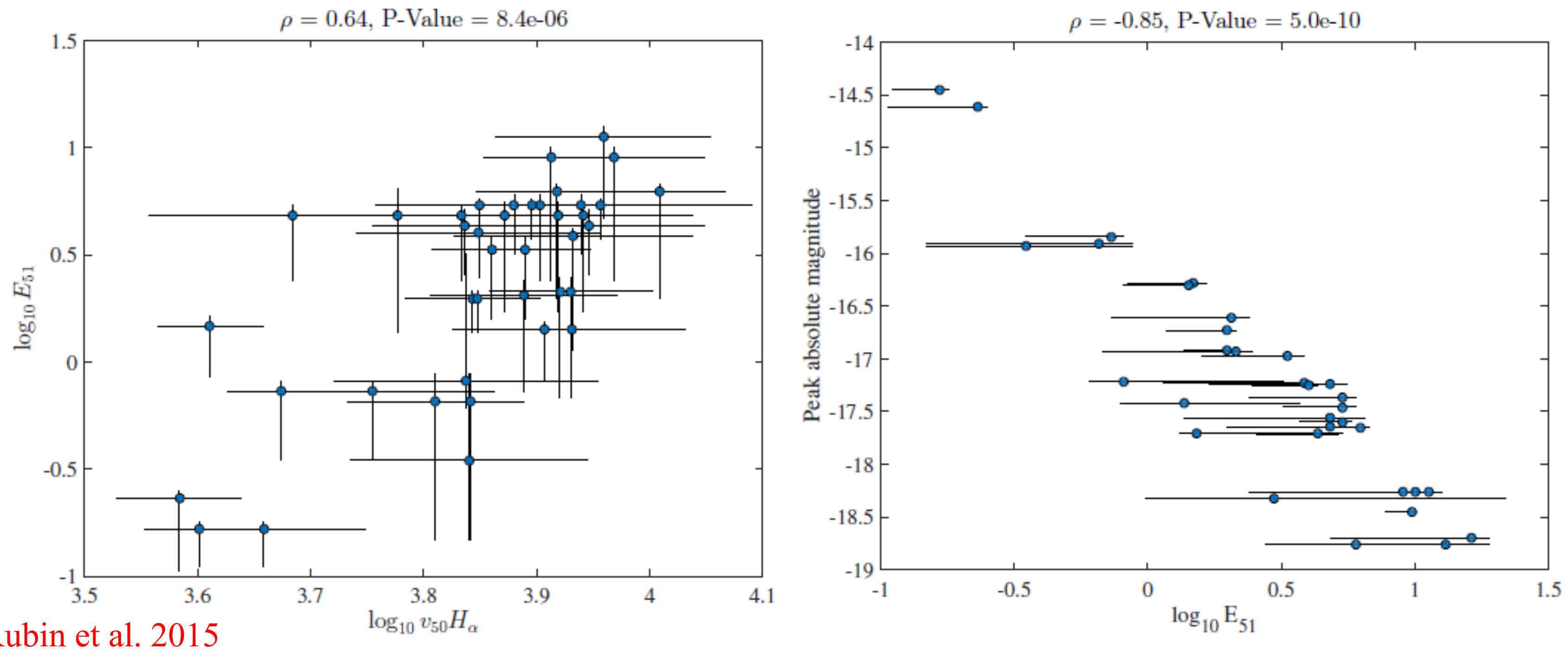


Rubin et al. 2015

Ganot et al. 2015

We can recover the pre-explosion radius R* and explosion energy per unit mass from observations: UV risetime and peak mag

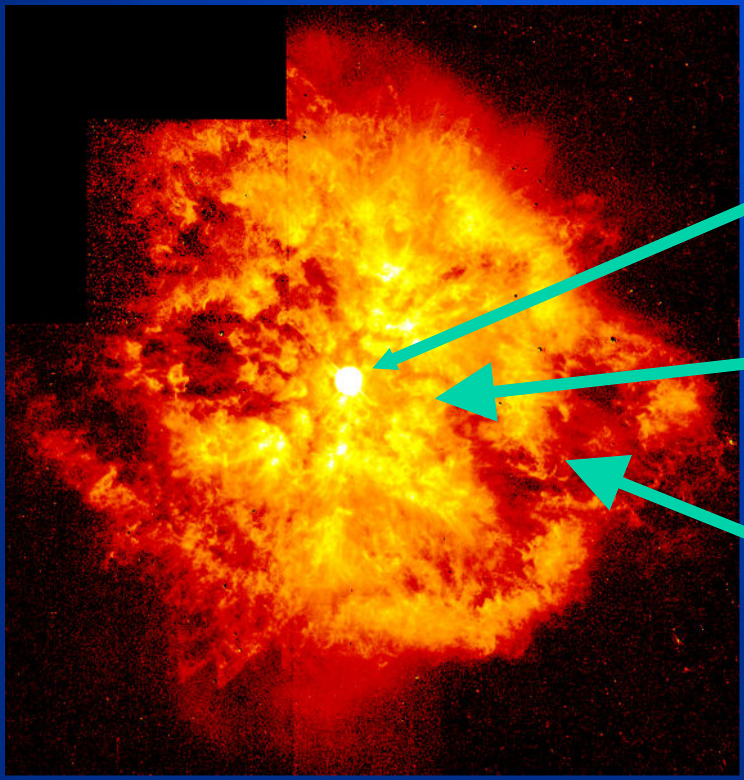
Early optical data: useful



Rubin et al. 2015

Flash spectroscopy

W-R star (example)



Hydrostatic surface ($<10^{12}$cm)

Opaque (optically thick) wind

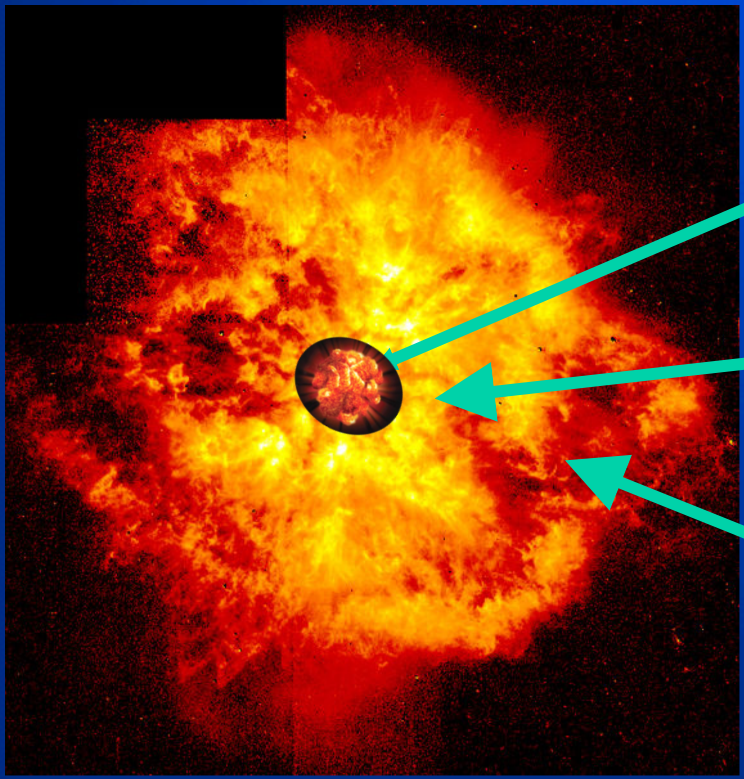
(up to $\sim 10^{13}$cm)

Optically thin wind

W-R emission lines

Flash spectroscopy (2)

W-R star explosion (example)



Infant supernova, orders of magnitude brighter

Opaque (optically thick) wind

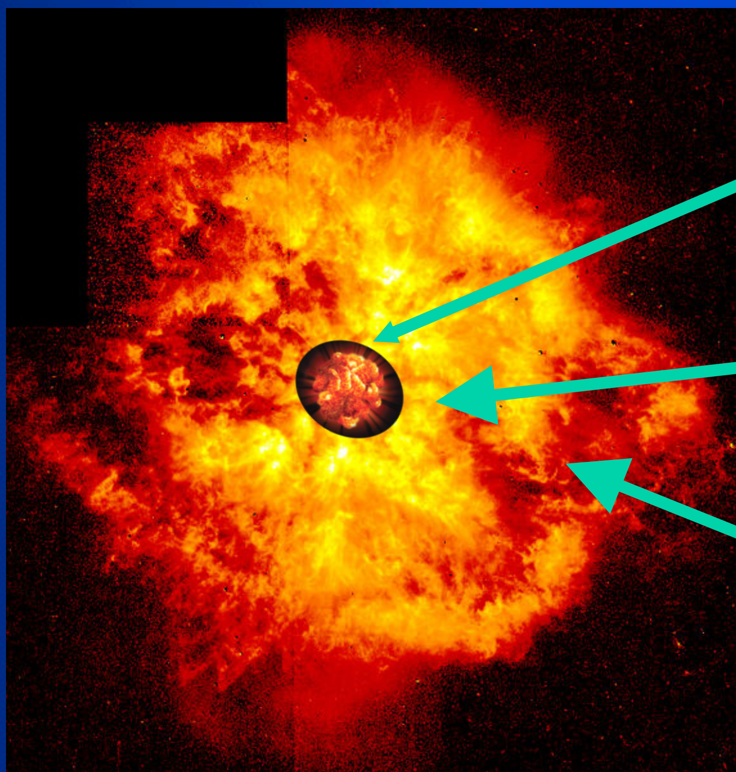
(up to ~10^{13}cm; wind breakout; Ofek et al. 2010 …)

Optically thin wind

W-R-like emission lines

Timescales

Massive star explosion (example)

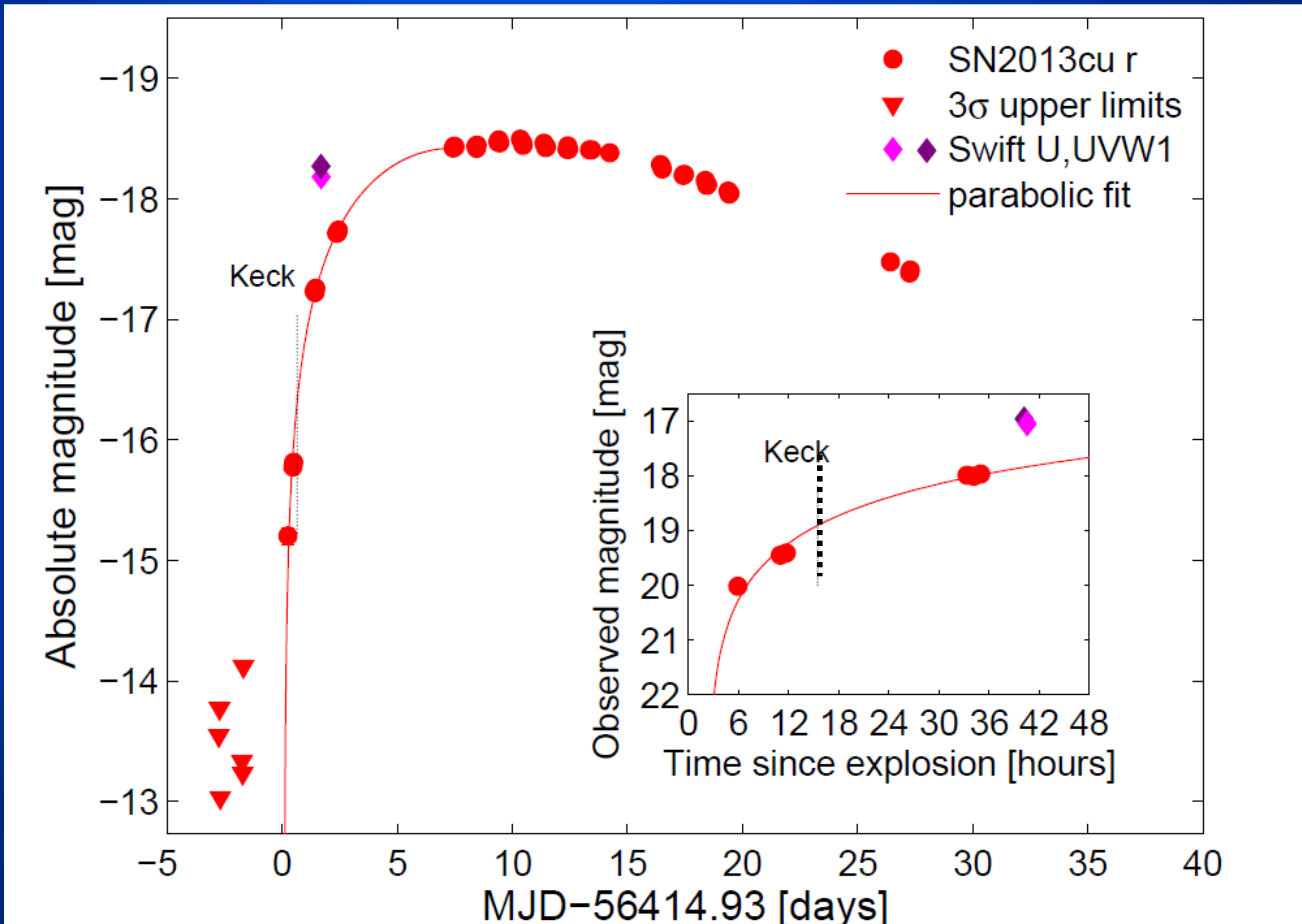


Shock breakout flash: minutes to hours

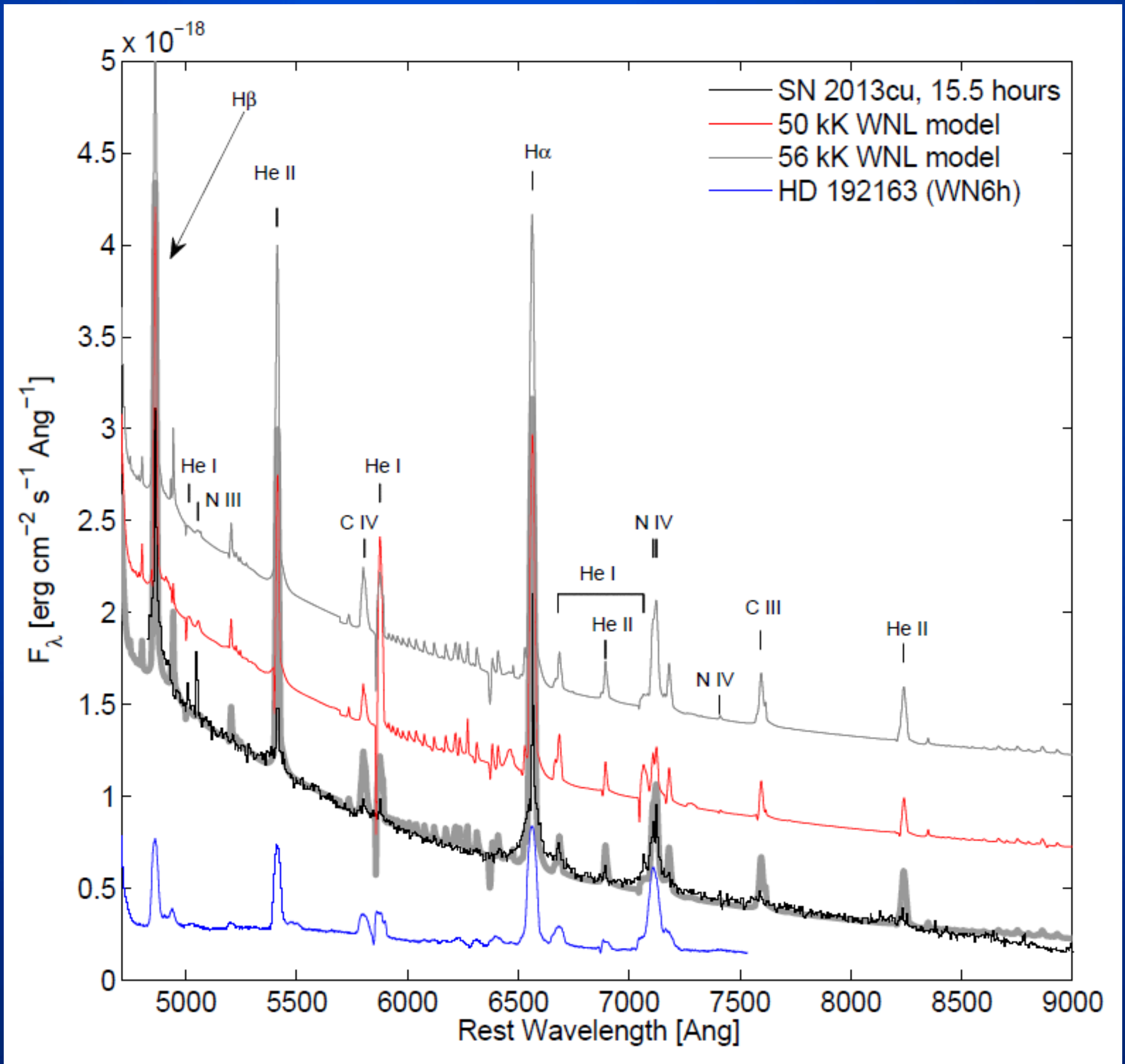
Recombination time: minutes. Wind reacts to SN spectrum instantly. Light-crossing time of wind (hours) may smear spectral evolution.

Moving at 10000 km/s, SN ejecta reach ~5×10^{13} cm in a day, flash spectrum gone within days of explosion.

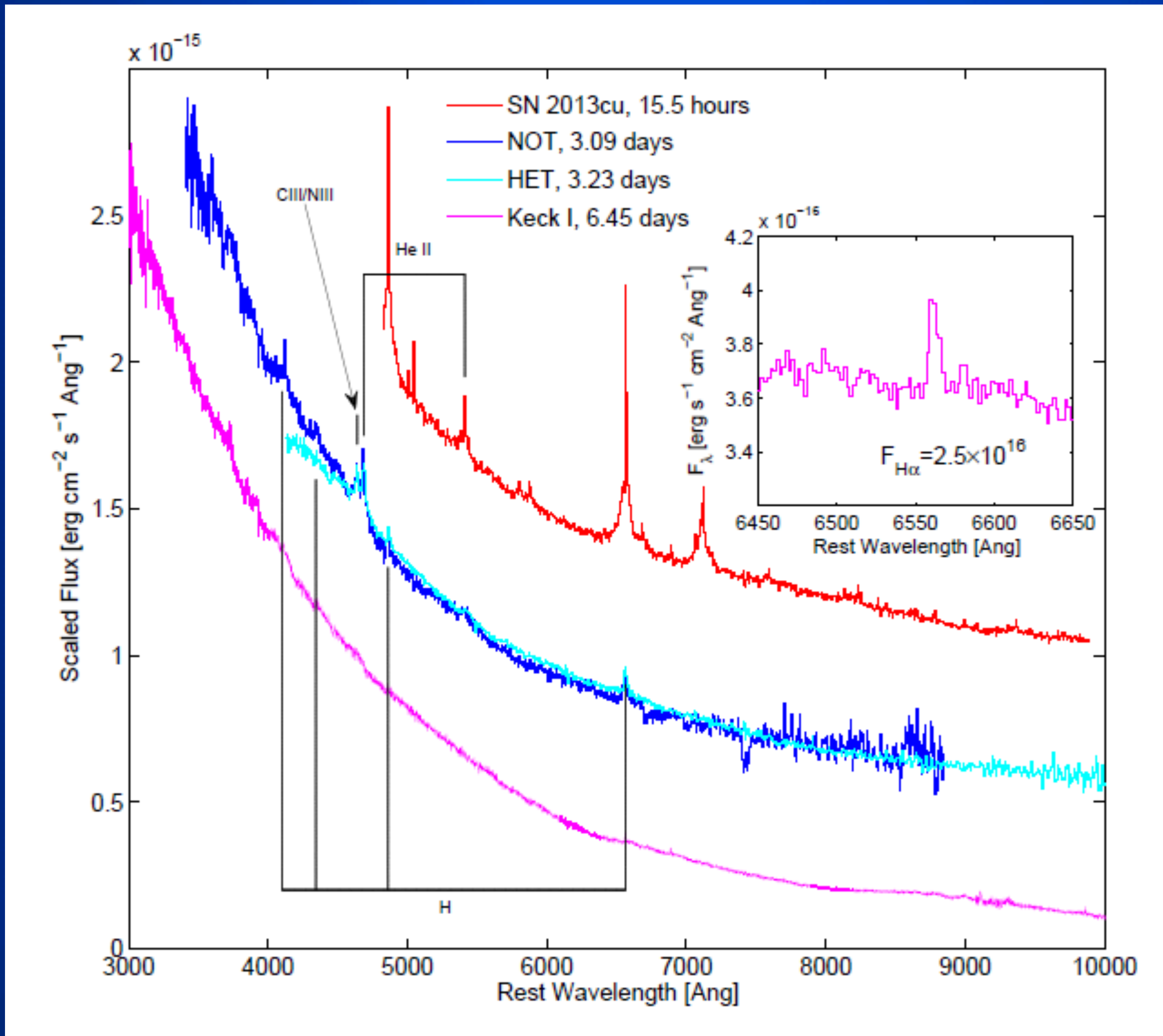
Example: iPTF13ast



iPTF13ast: WN(h) wind



iPTF13ast: wind properties



Hα line:

R>2 10^{14}cm

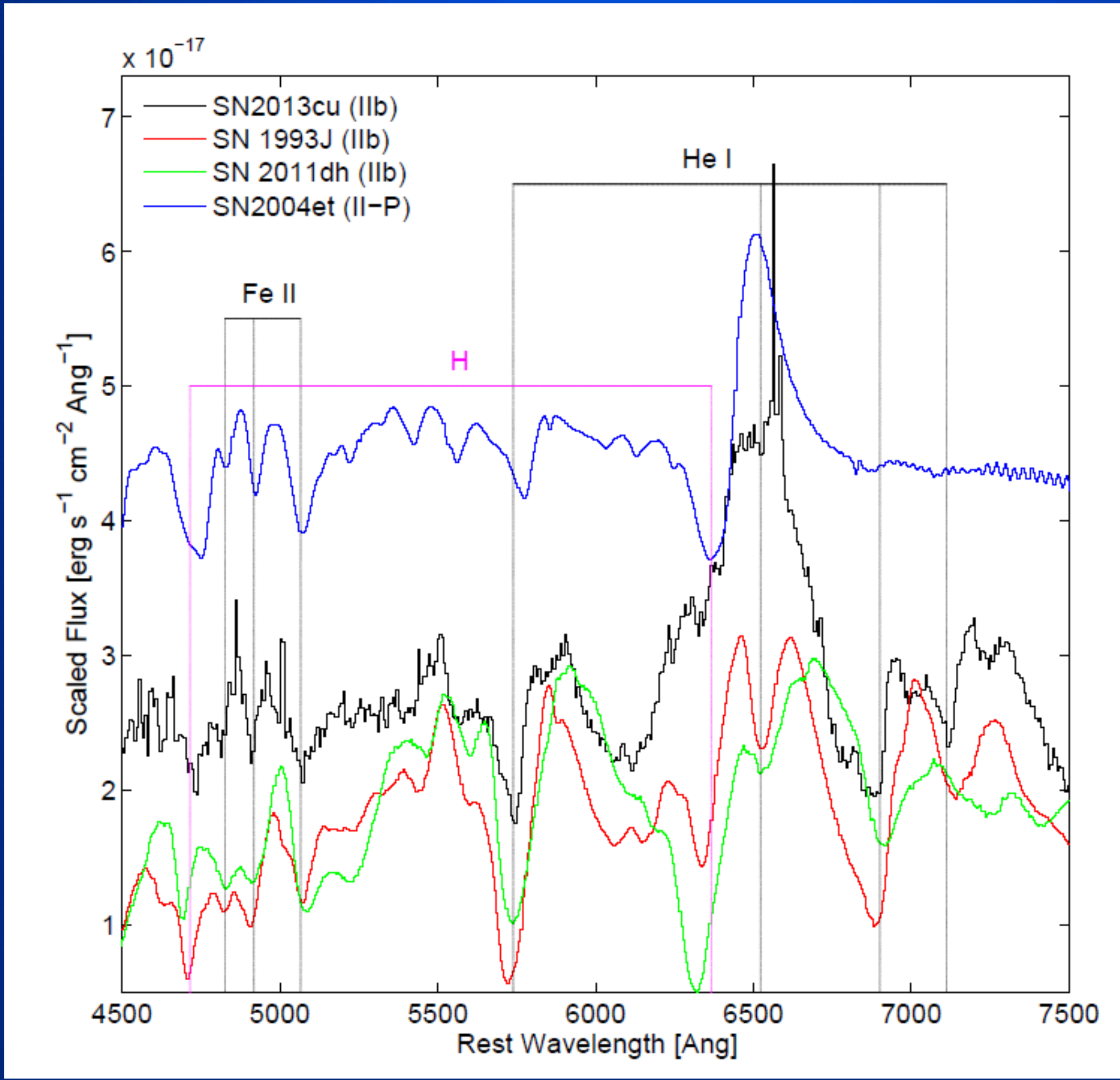
Line evolution:

R<7 10^{14}cm

Mass loss>0.03 solar mass/year

Total mass<0.01 solar

iPTF13ast: WN(h)-like progenitor of a SN IIb



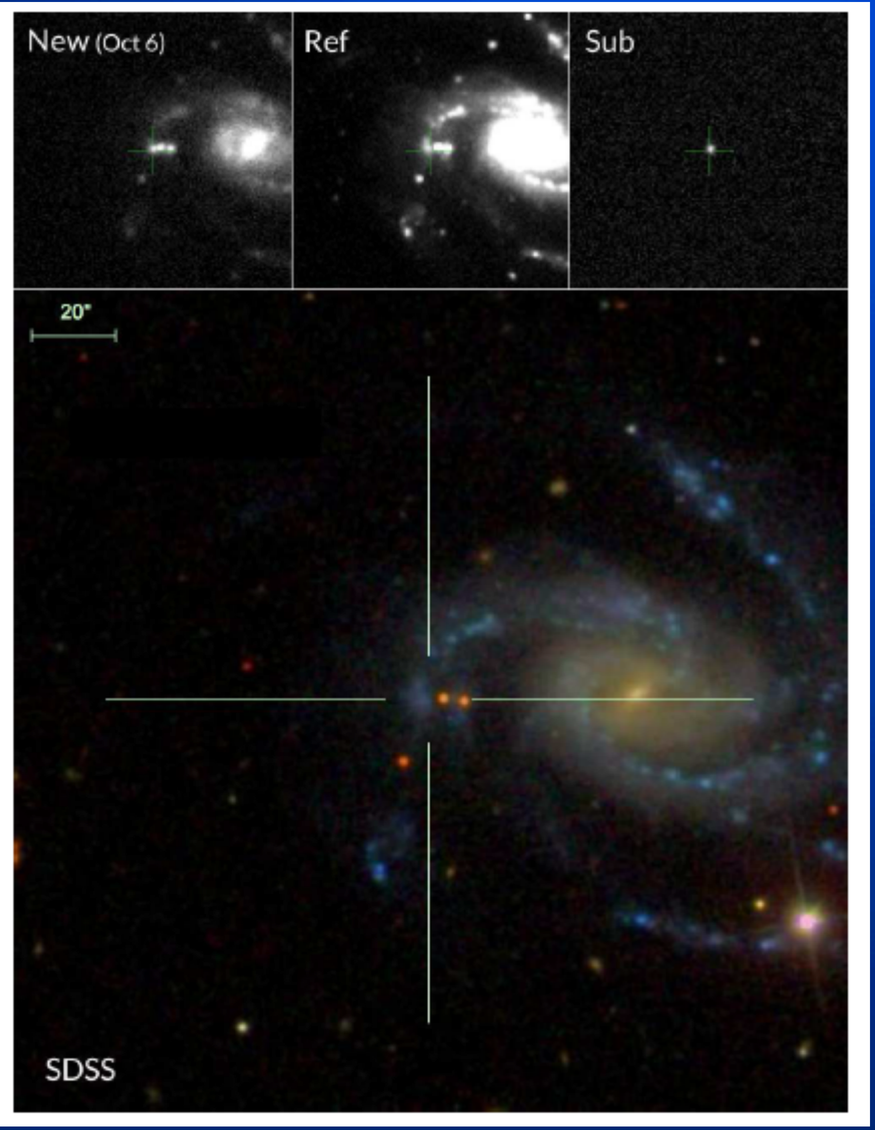
ID of a SN progenitor (via surface composition) at 108 Mpc

WN(h)-like composition for an SN IIb consistent with other data (SN 2008ax) and what you'd expect (<0.1 solar total H mass)

What does WN(h)-like mean?

- Flash spectroscopy constrains the progenitor wind composition, and by association its surface composition
- Line profile analysis may be able to also probe wind velocity and hence escape velocity and progenitor radius
- For iPTF13ast, the composition is similar to a WN(h) star, but with an optically thick shell at 10^{14} cm, it will no look like a compact WR star. Indeed, line profiles suggest slow wind and hence supergiant (and cool) rather than compact progenitor (Shivvers et al.; Groh et al.)
- Indications for recent and enhanced mass loss may suggest a compact WR star that expands prior to explosion (fits some recent predictions)

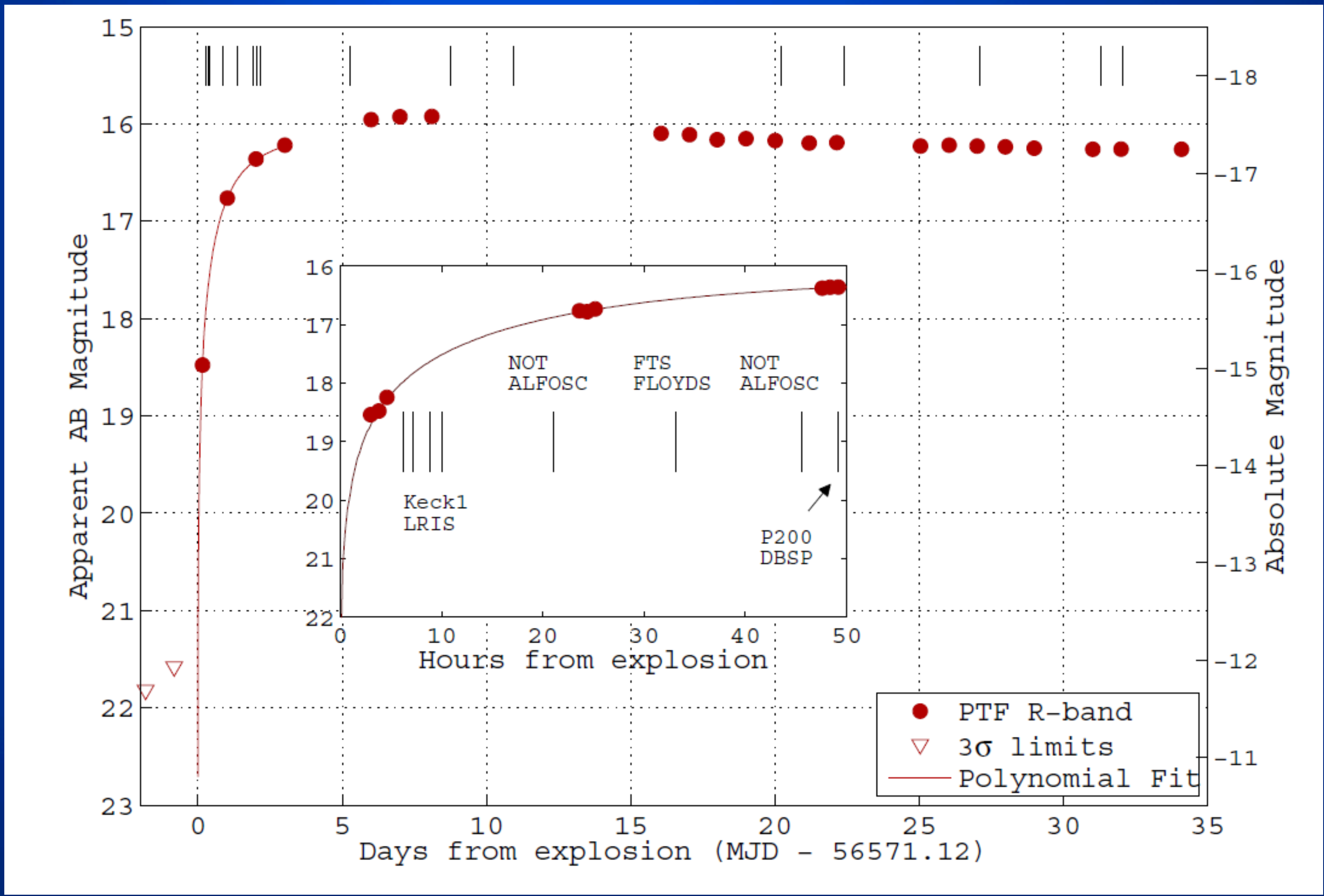
iPTF13dqy: a second nearby event



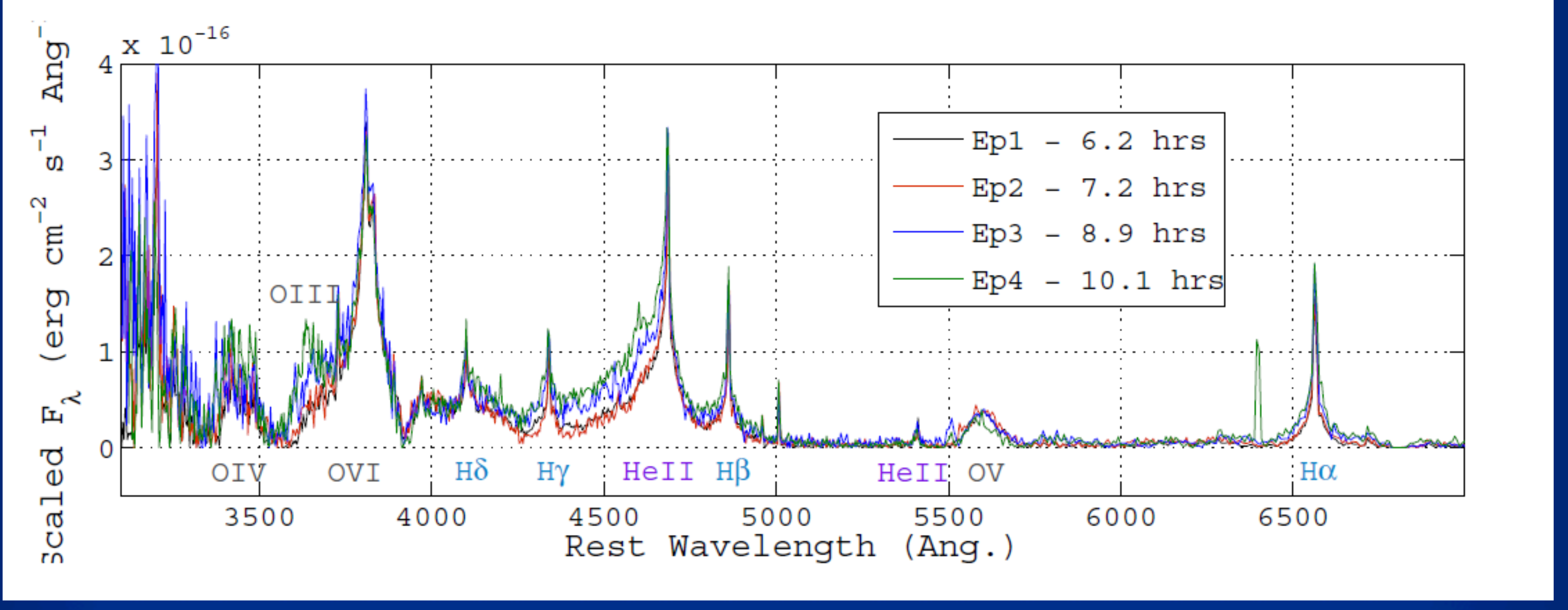
Type II SN in NGC 7610

(50 Mpc)

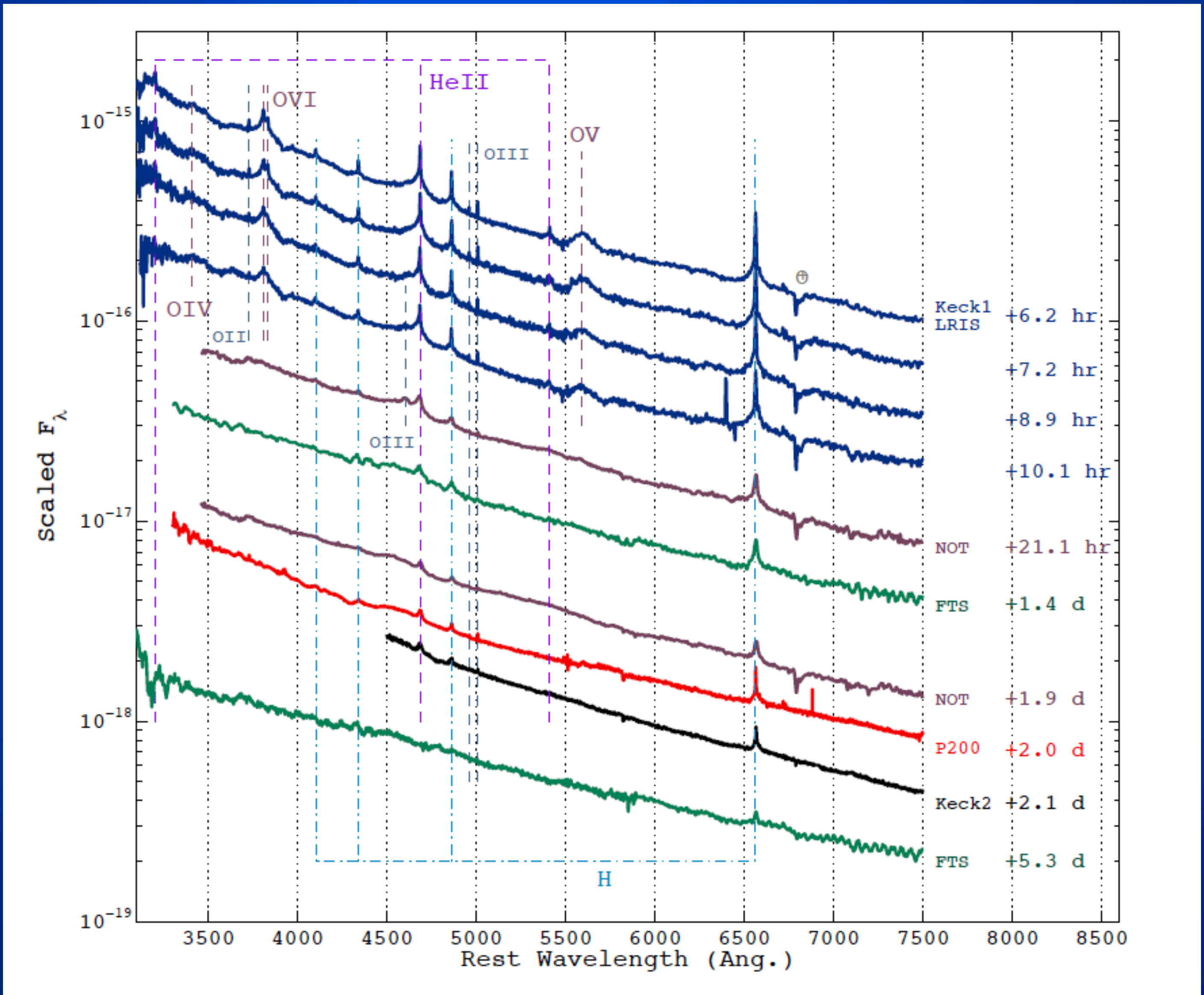
Redefining “good coverage”



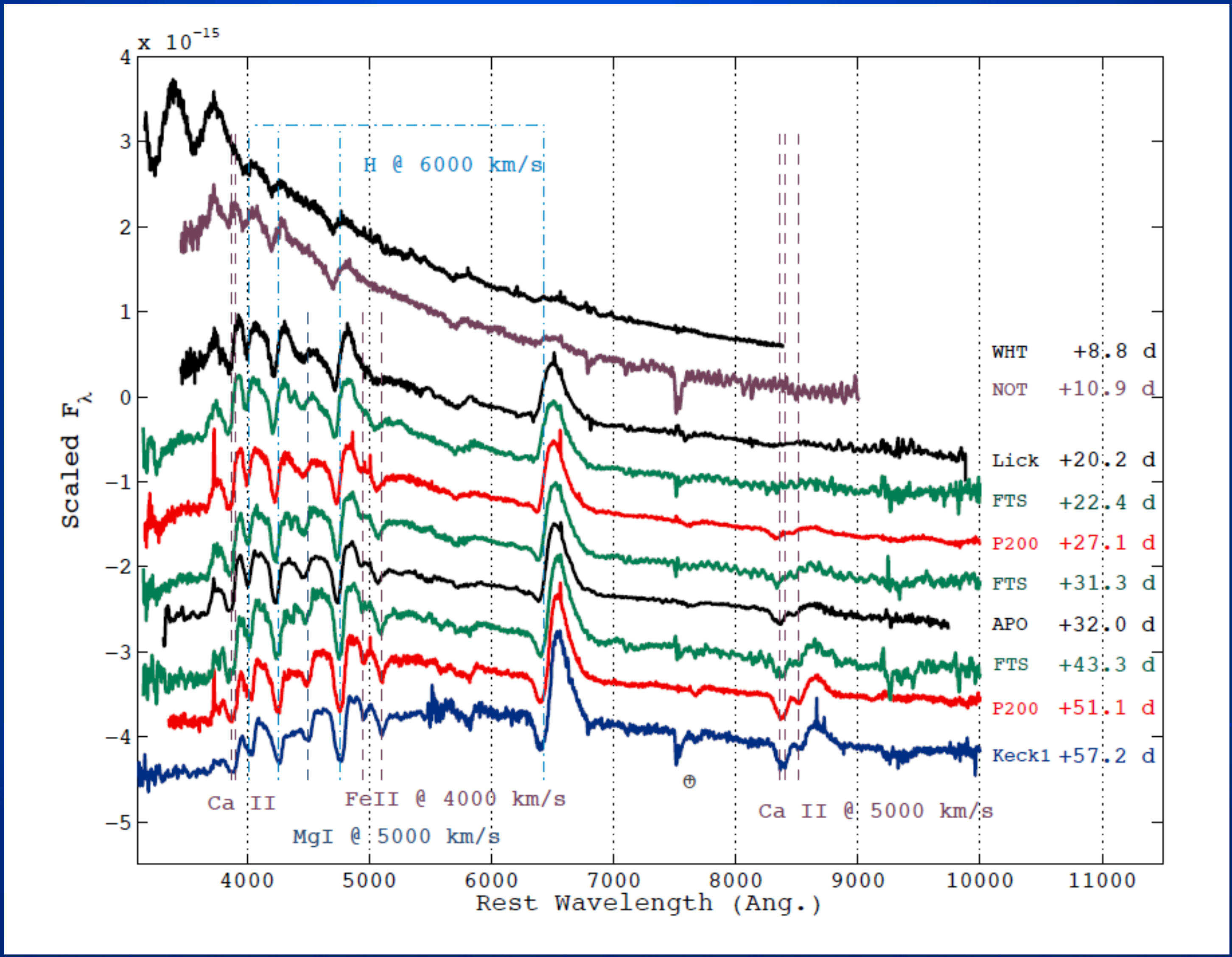
iPTF13dqy: early spectral evolution



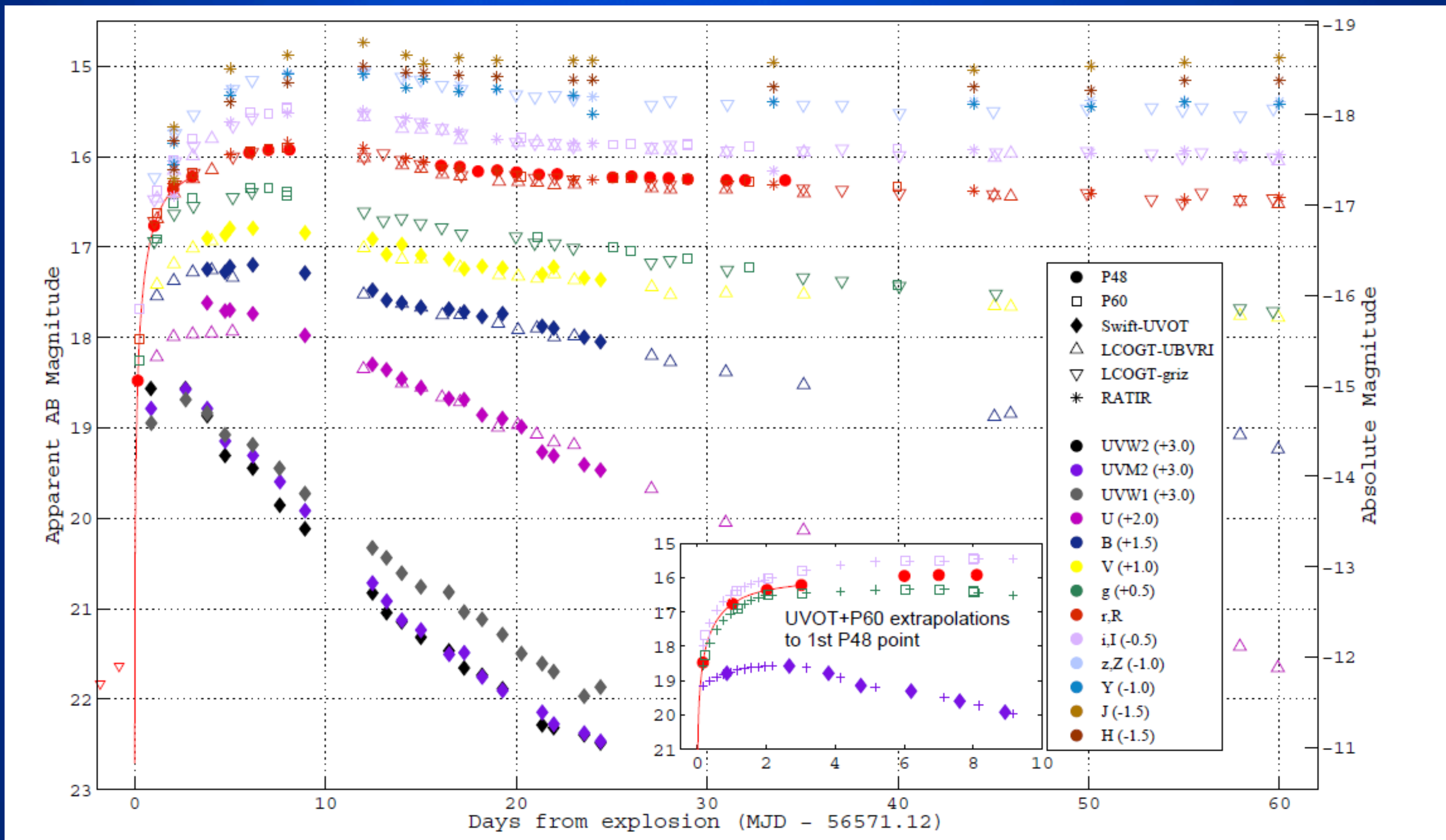
iPTF13dqy: later spectral evolution



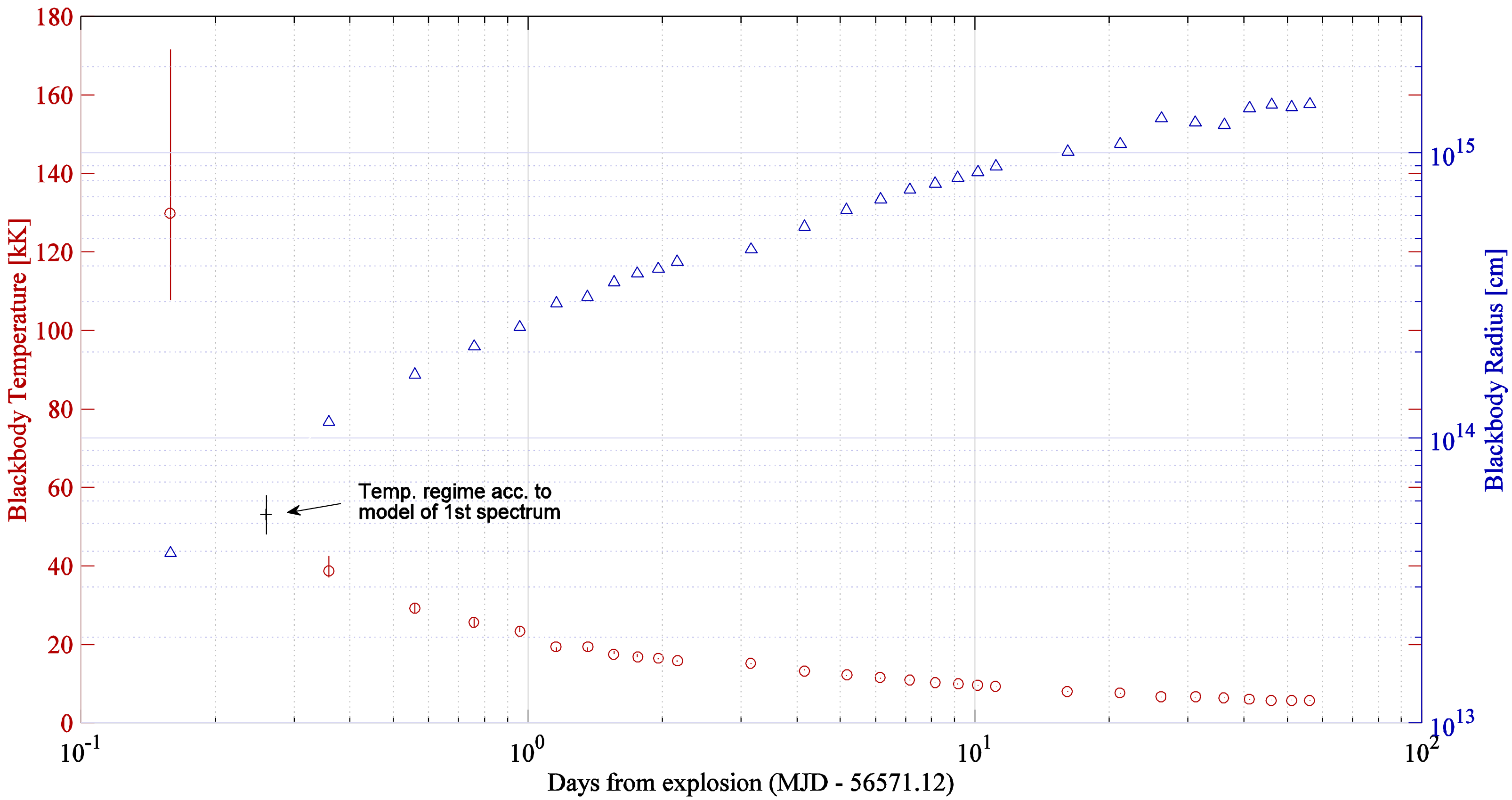
iPTF13dqy: SN II-P



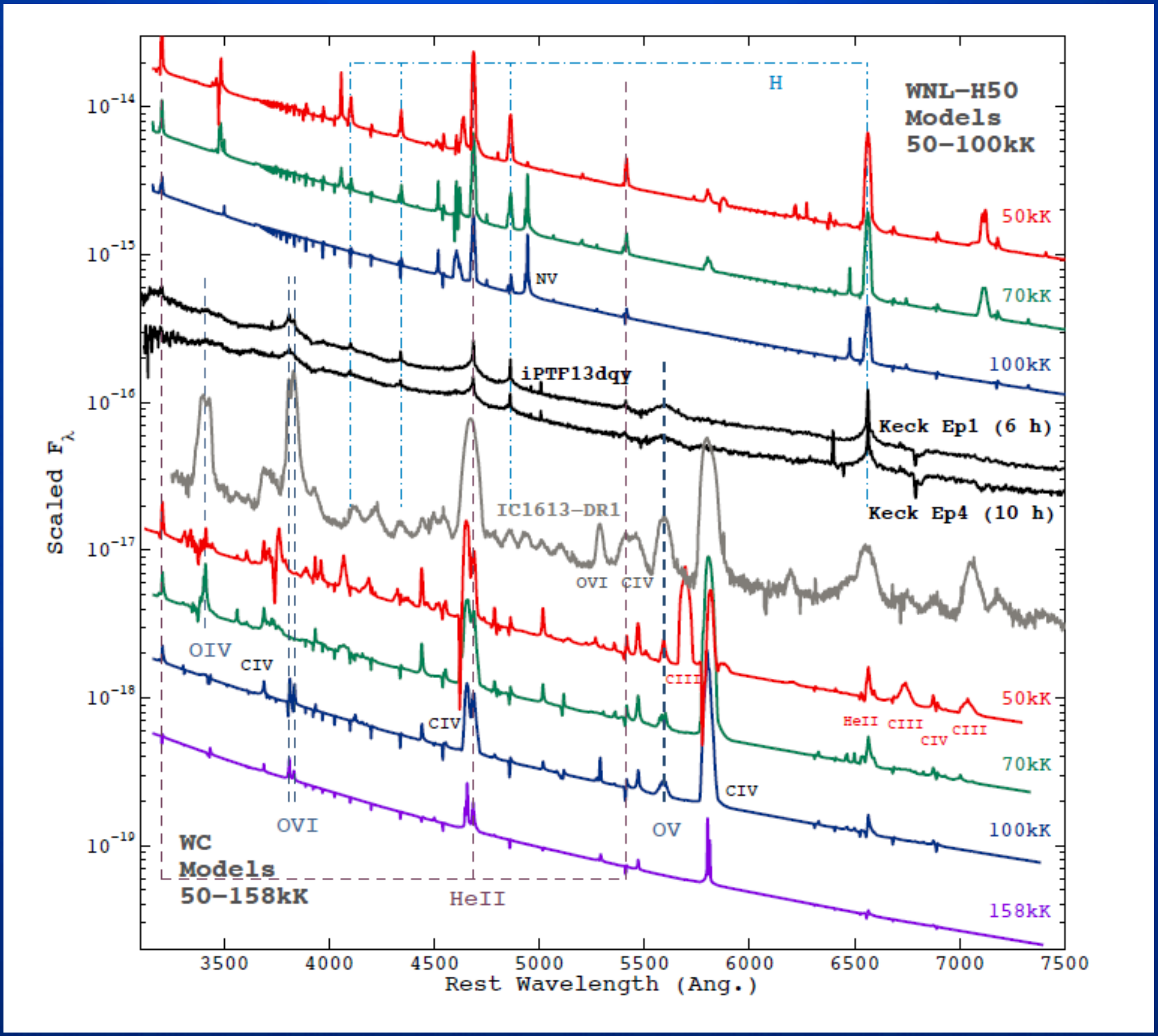
iPTF13dqy: multicolor photometry



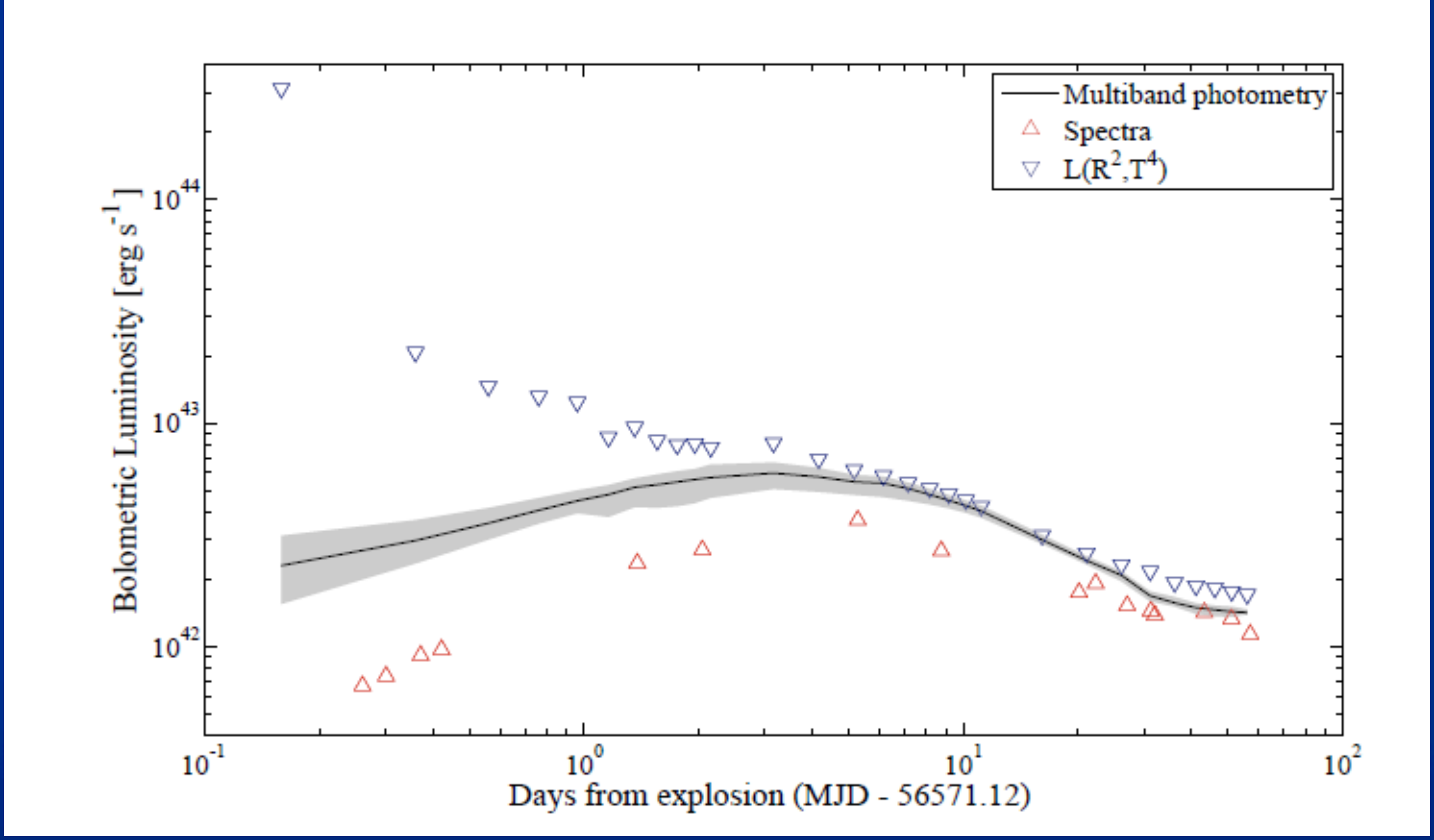
iPTF13dqy: starting hot



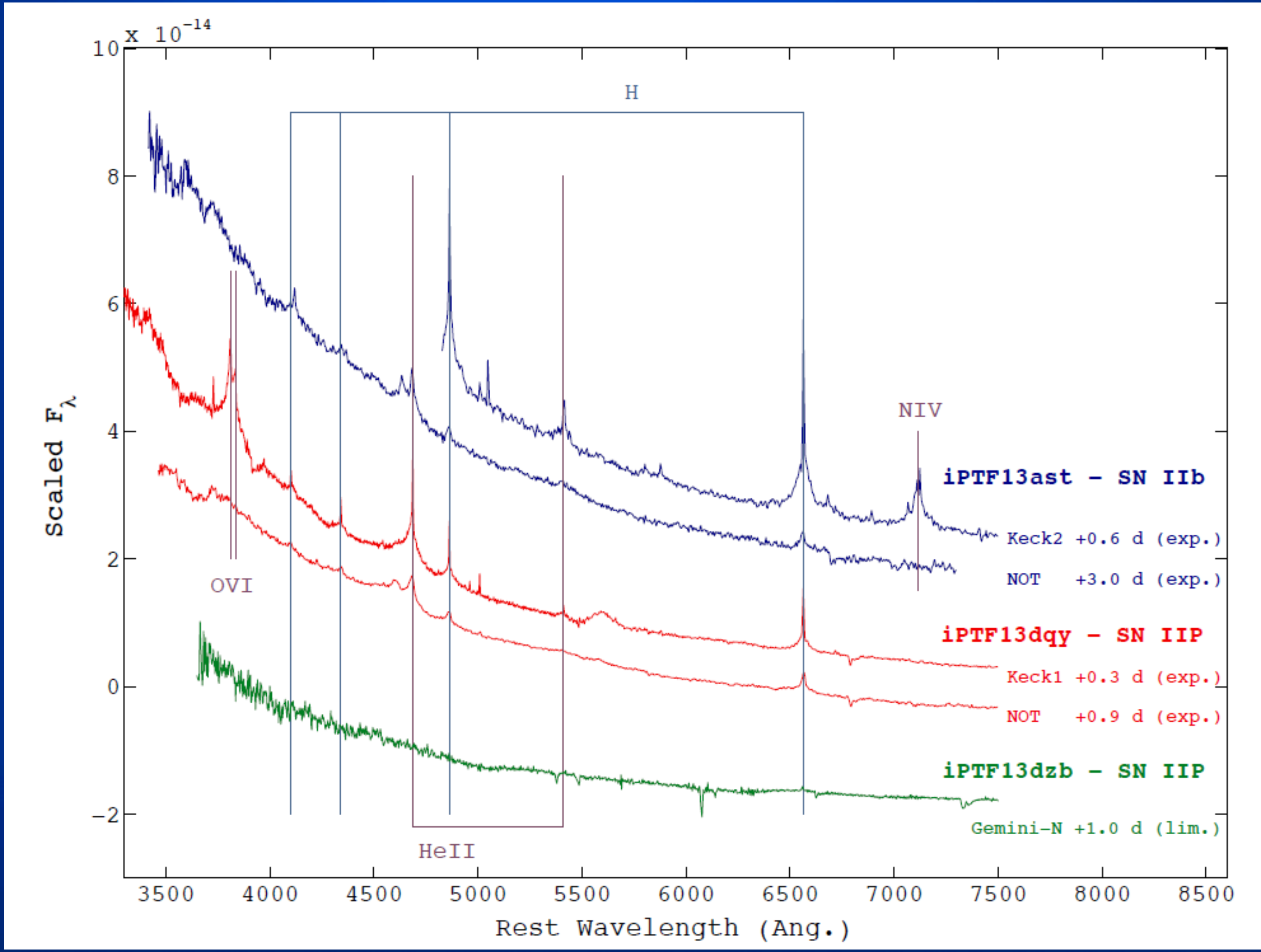
iPTF13dqy: starting hot



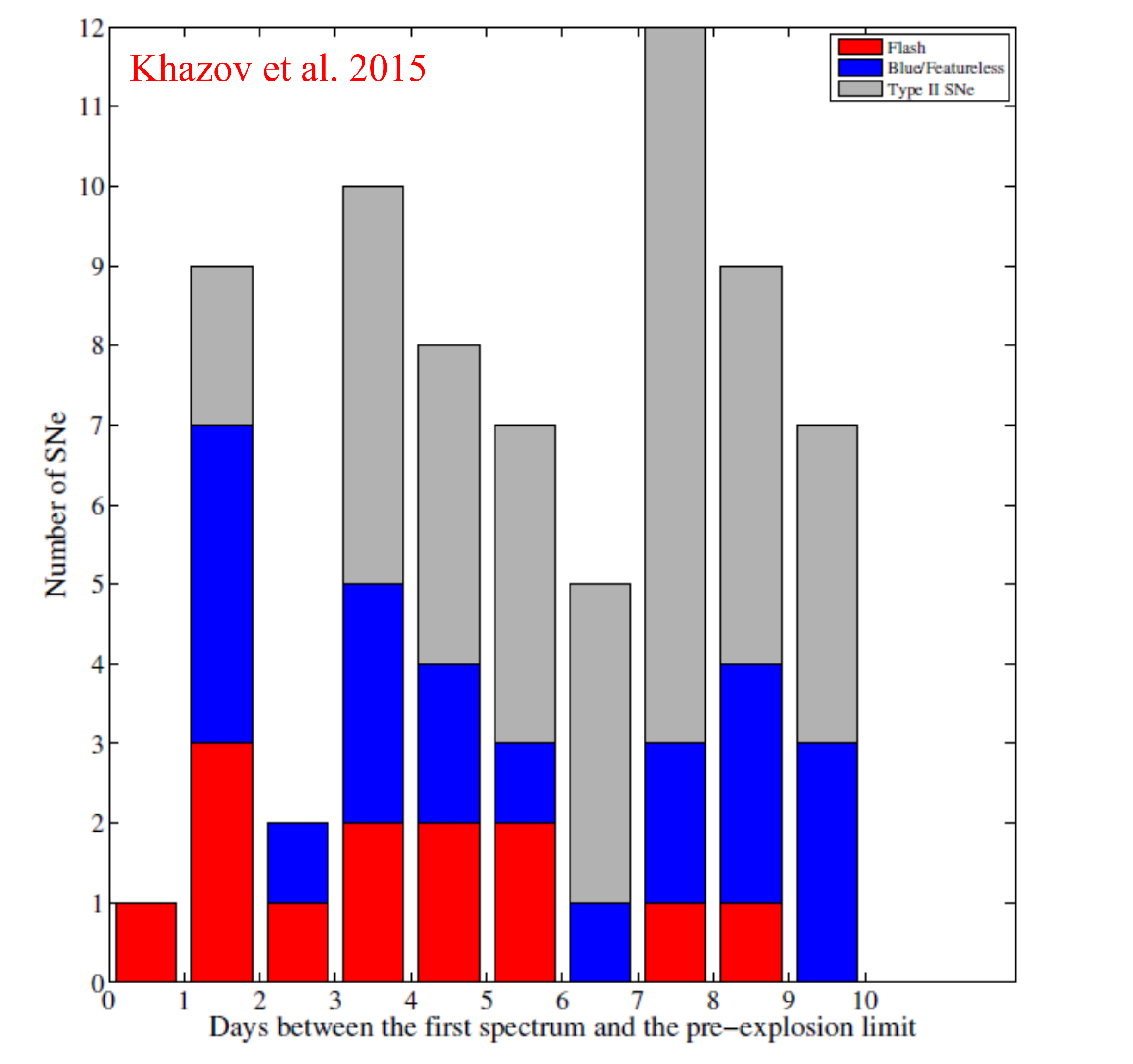
iPTF13dqy: bolometrics



Not all SNe show flash spectra



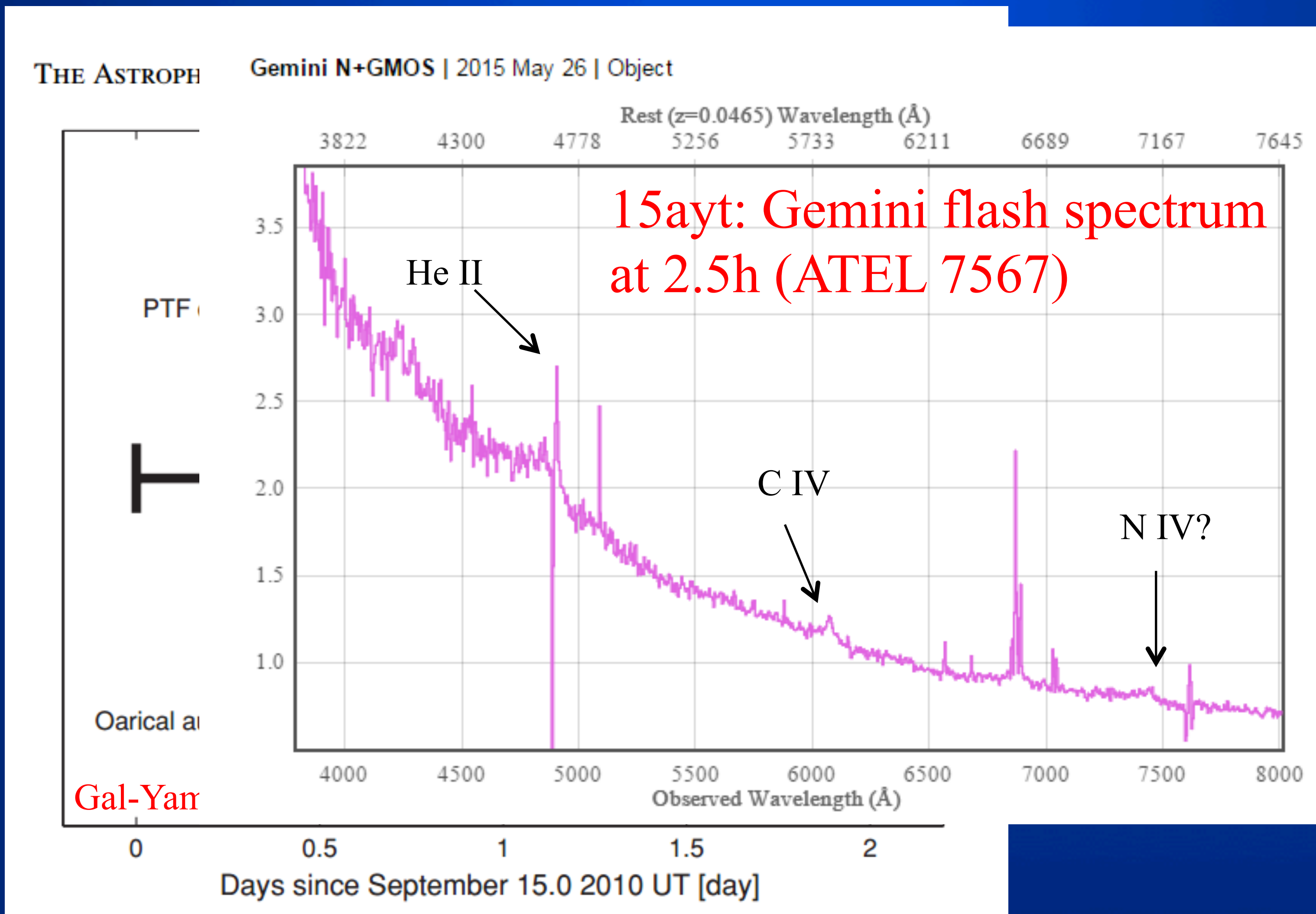
But many do … these are not atypical stars



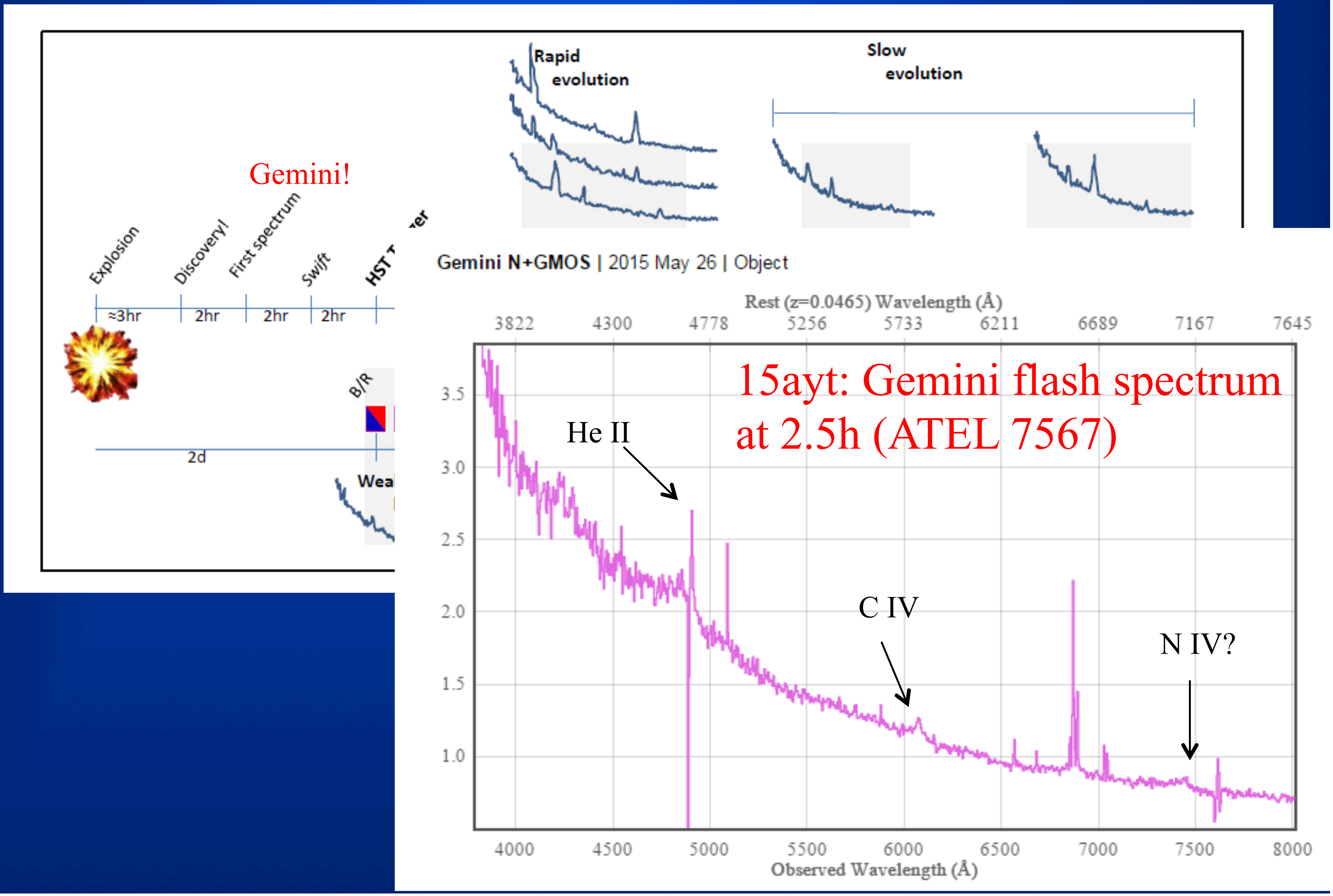
Implications

- iPTF13ast: IIb with WNh-like progenitor
- In general: classify W-R explosions (or any SN progenitor with CSM)
- Easily done to >100 Mpc, potential is >100 SN/y
- (Many? Some?) massive stars have increased mass loss during their terminal year
- Core instability (Shiode & Quataert)?

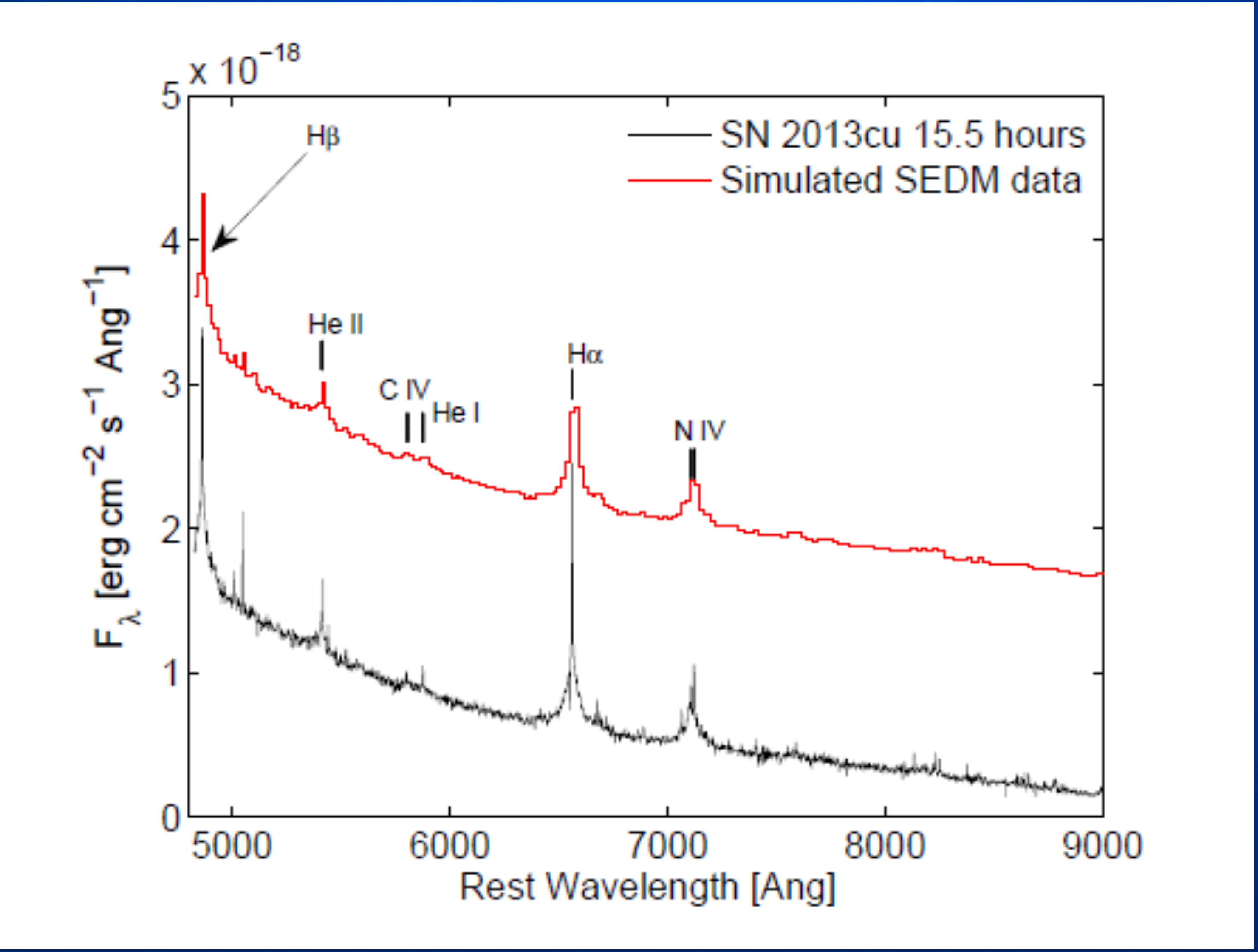
The Gemini impact



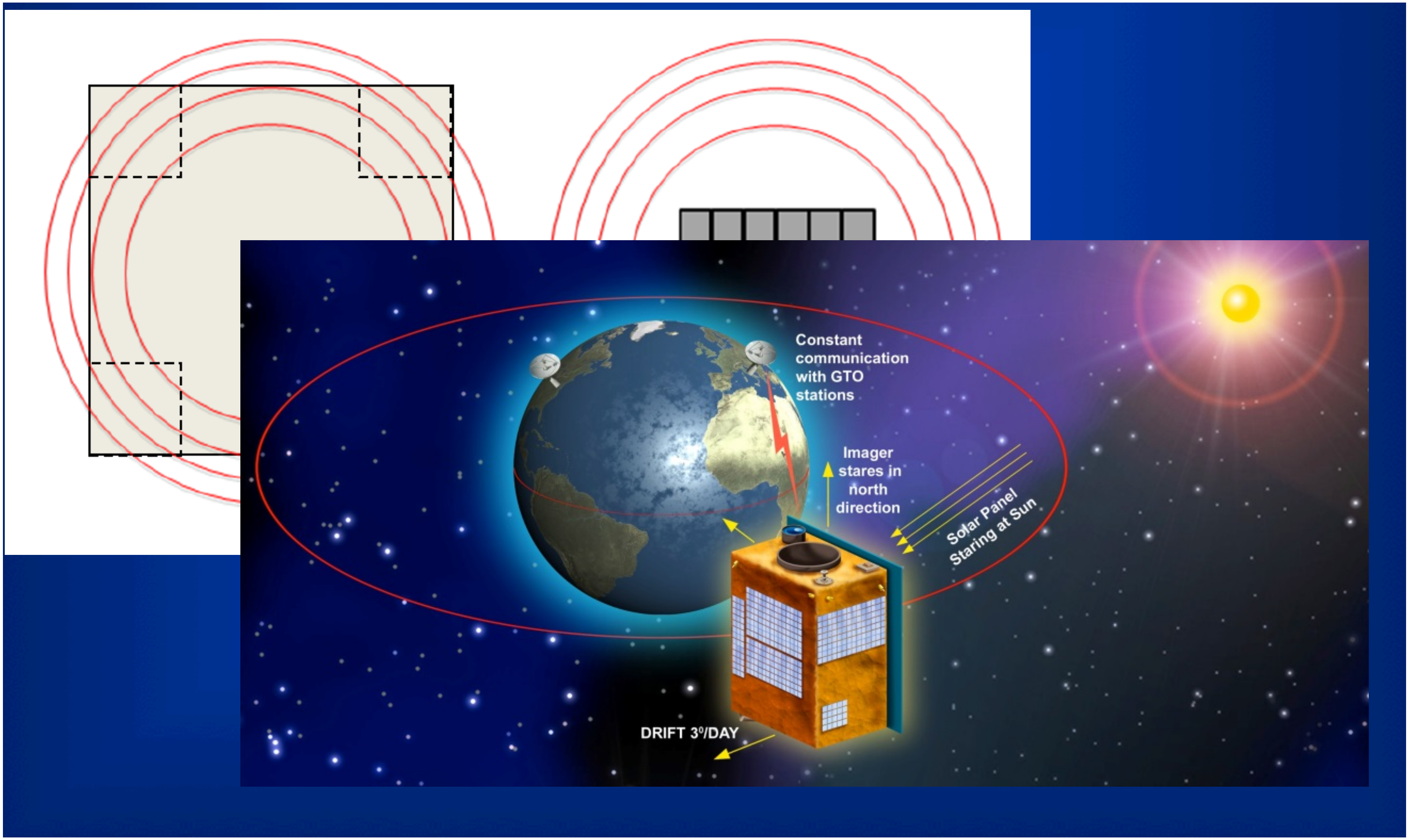
The UV is a very attractive place to go to



SEDM: flash spectroscopy machine: getting the smaller W-R stars



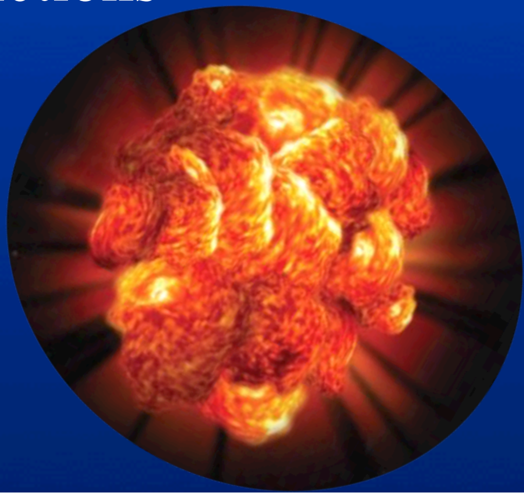
Future: ZTF and ULTRASAT



Take home message

First-day SN observations will:

- Provide new information about massive stars,as they explode
- Define a new set of initial conditions for computational massive star explosion models, and
- Provide a definite observational benchmark to test model predictions



Thanks

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