Pair instability and pulsational pair instability supernovae and their remnants

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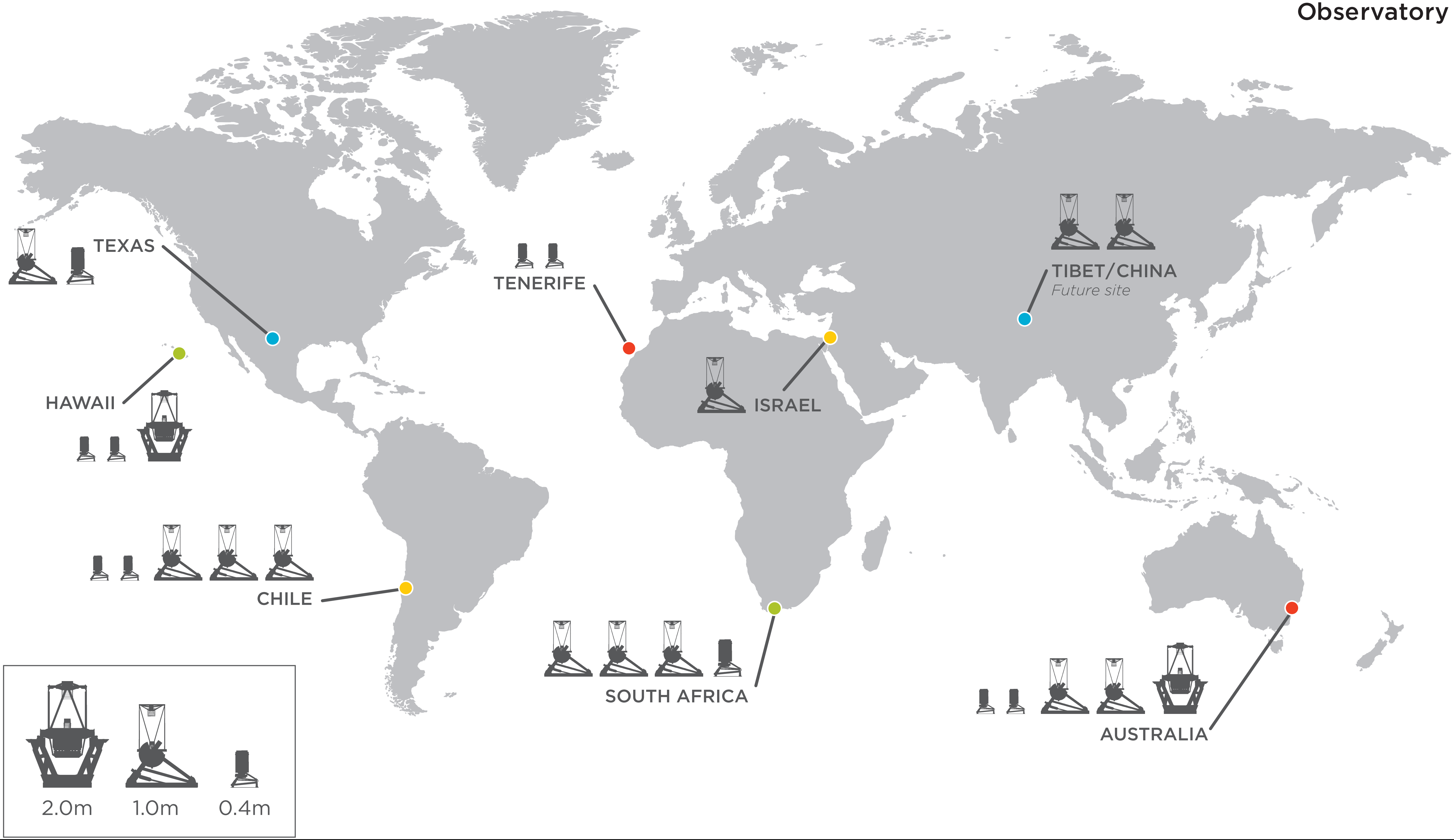
Based on:

- Arcavi, Howell et al. 2017, Nature, 551, 210
- Howell 2017 Superluminous SNe review in Handbook of Supernovae

GLOBAL TELESCOPE NETWORK

Las Cumbres Observatory



22 robotic telescopes with imagers

4 NRES high resolution (R~53,000) spectrographs (on 1ms)

Two low resolution (R~400) FLOYDS spectrographs (on 2ms)

Global Supernova Project

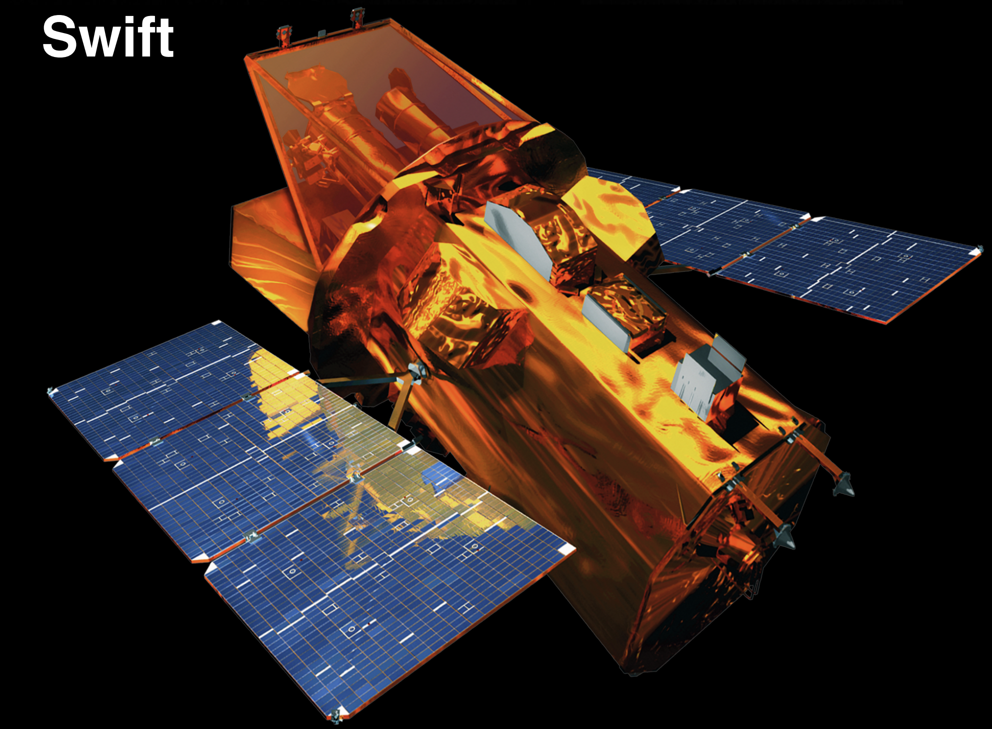
Led by LCO - PI: Howell

A large fraction of worldwide SN community (150+ members) working together. Members from every continent.

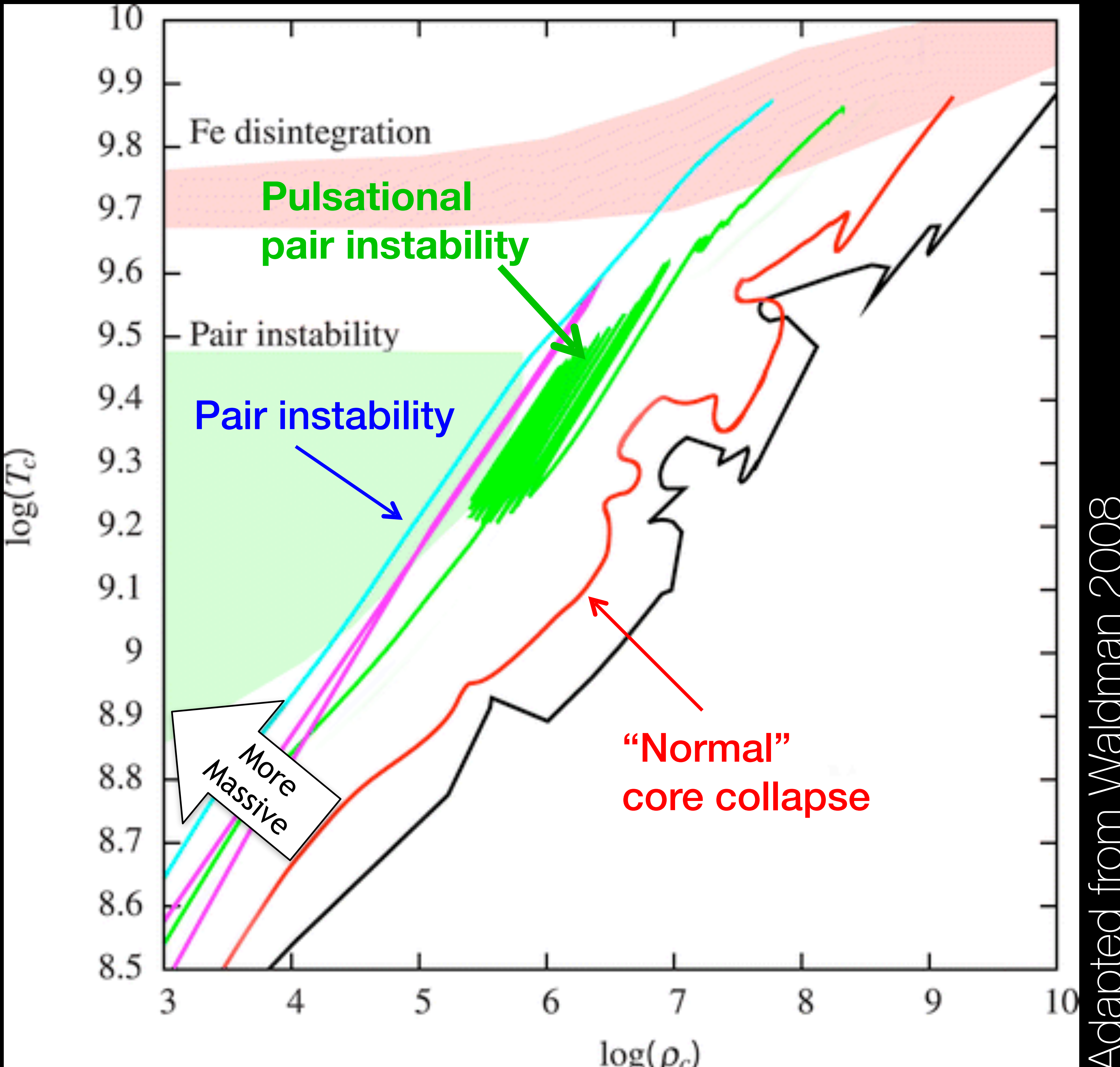
More than halfway to goal of getting unprecedented data on 900+ SNe with well sampled light curves and spectra from Las Cumbres over 6 years.

Creating tools and incentives for scientists to work together, share data.

Follow-up on, e.g….



Pulsational Pair Instability SN?



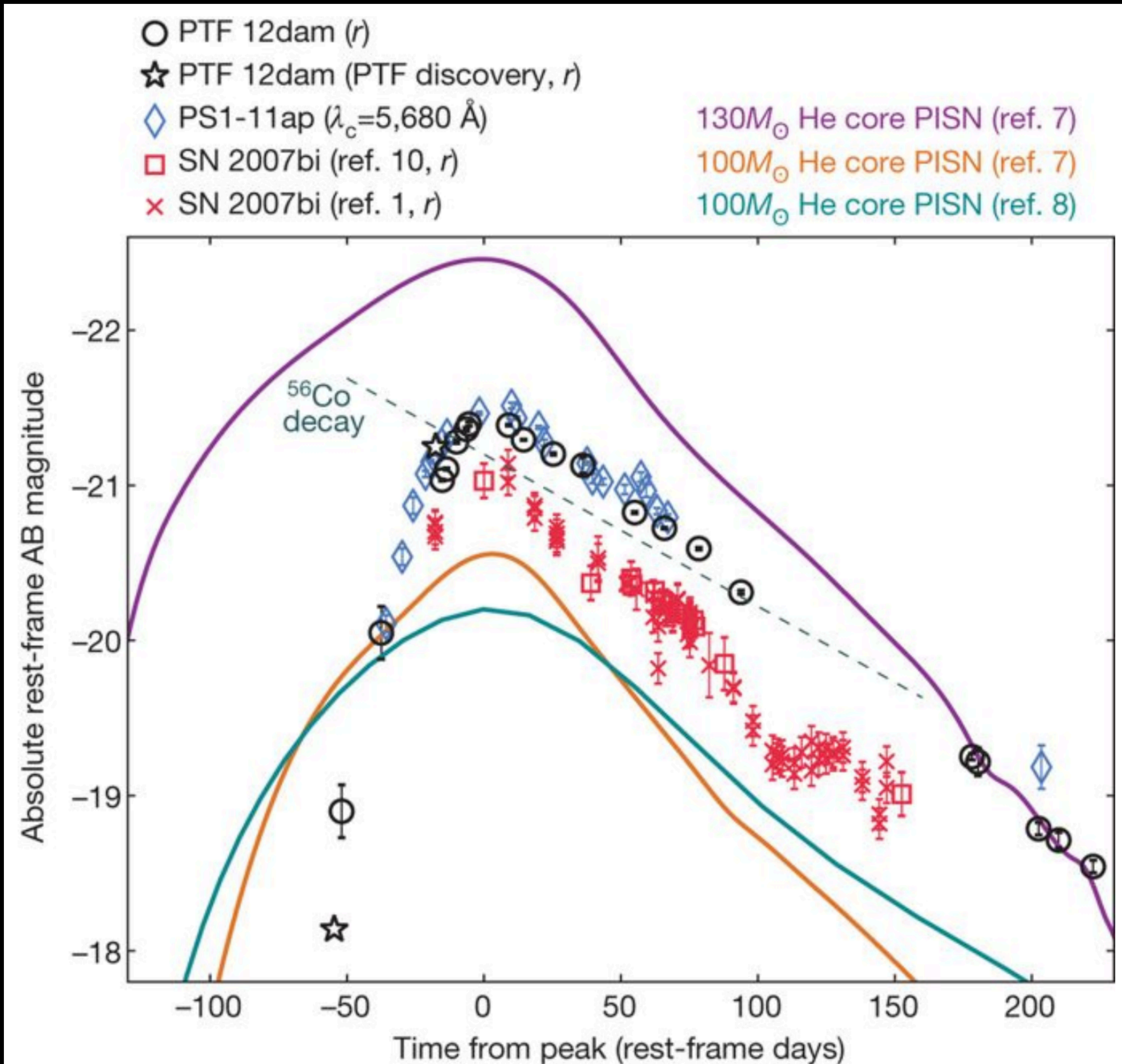
Pulsational pair instability supernovae (Woosley, Blinnikov, & Heger 2007; Woosley 2016) have been theorized as the endpoint of massive stars (~100 M☉) with massive He cores.

Regular pair instability SNe get so hot electron/positron pair production causes them to lose pressure support, eventually causes thermonuclear explosion.

For some ranges of parameter space, they can survive, keep evolving, and undergo multiple explosions over years.

For PPISNe, they can ultimately undergo a core-collapse to a black hole.

Pair Instability SNe

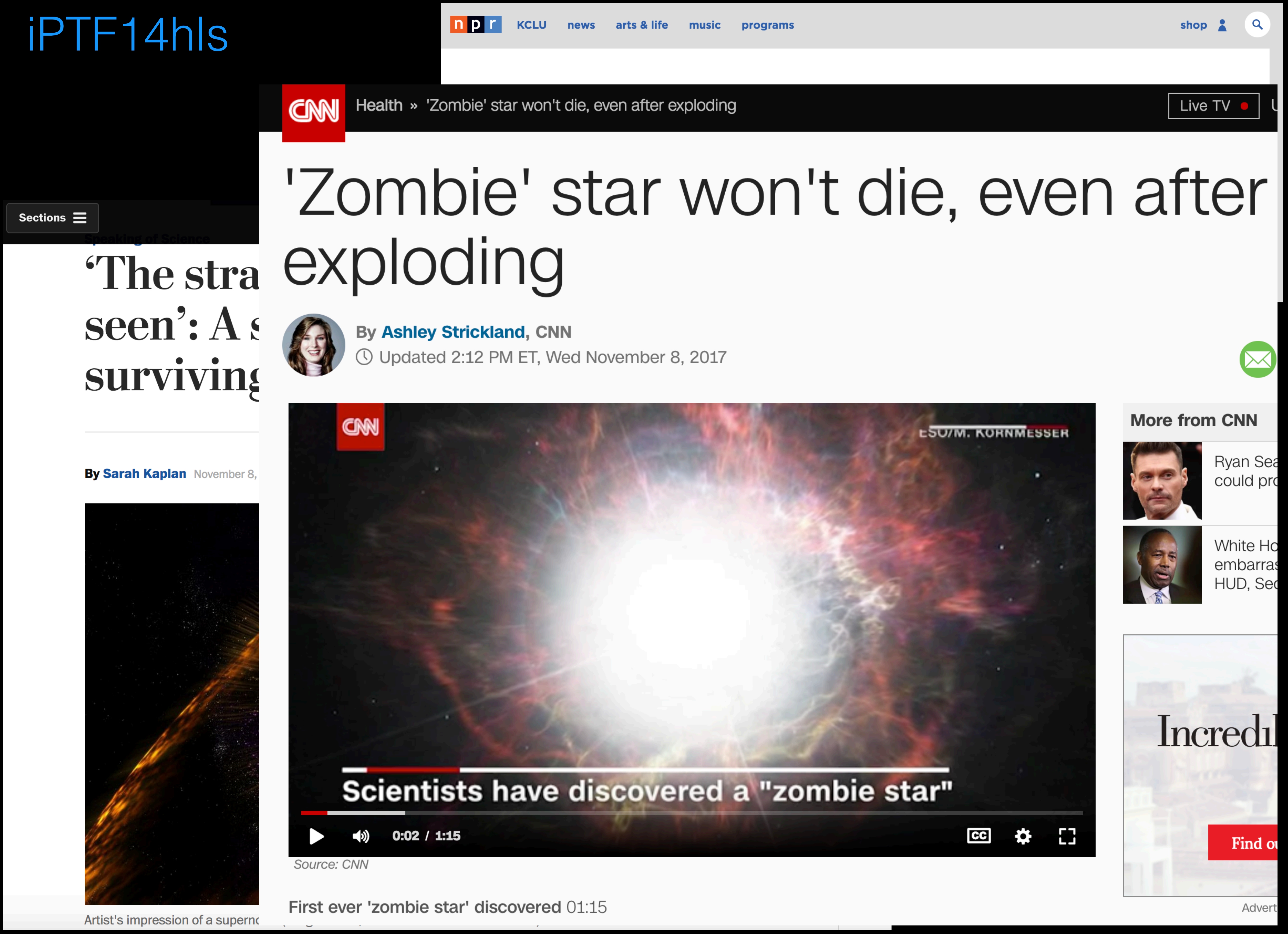


SN 2007bi was a super luminous supernova with a peak mag ~ -21.5, suggested to be a pair instability SN.

The rise time was not well constrained but should have been long, as it takes ~100d for light to diffuse out of ~100 $M_\odot$ of ejecta.

However, Nicholl et al. (+DAH), 2013 showed that the similar She PS1-11ap and PTF 12dam had a short rise time, ruling out the PISN model. The data are consistent with the luminosity being powered by magnetar spin-down.

iPTF14hls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'Zombie' star won't die, even after exploding
By Ashley Strickland, CNN
Updated 2:12 PM ET, Wed November 8, 2017
ESO/M. KORNMESSER
Scientists have discovered a "zombie star"
0:02 / 1:15
Source: CNN
First ever 'zombie star' discovered 01:15
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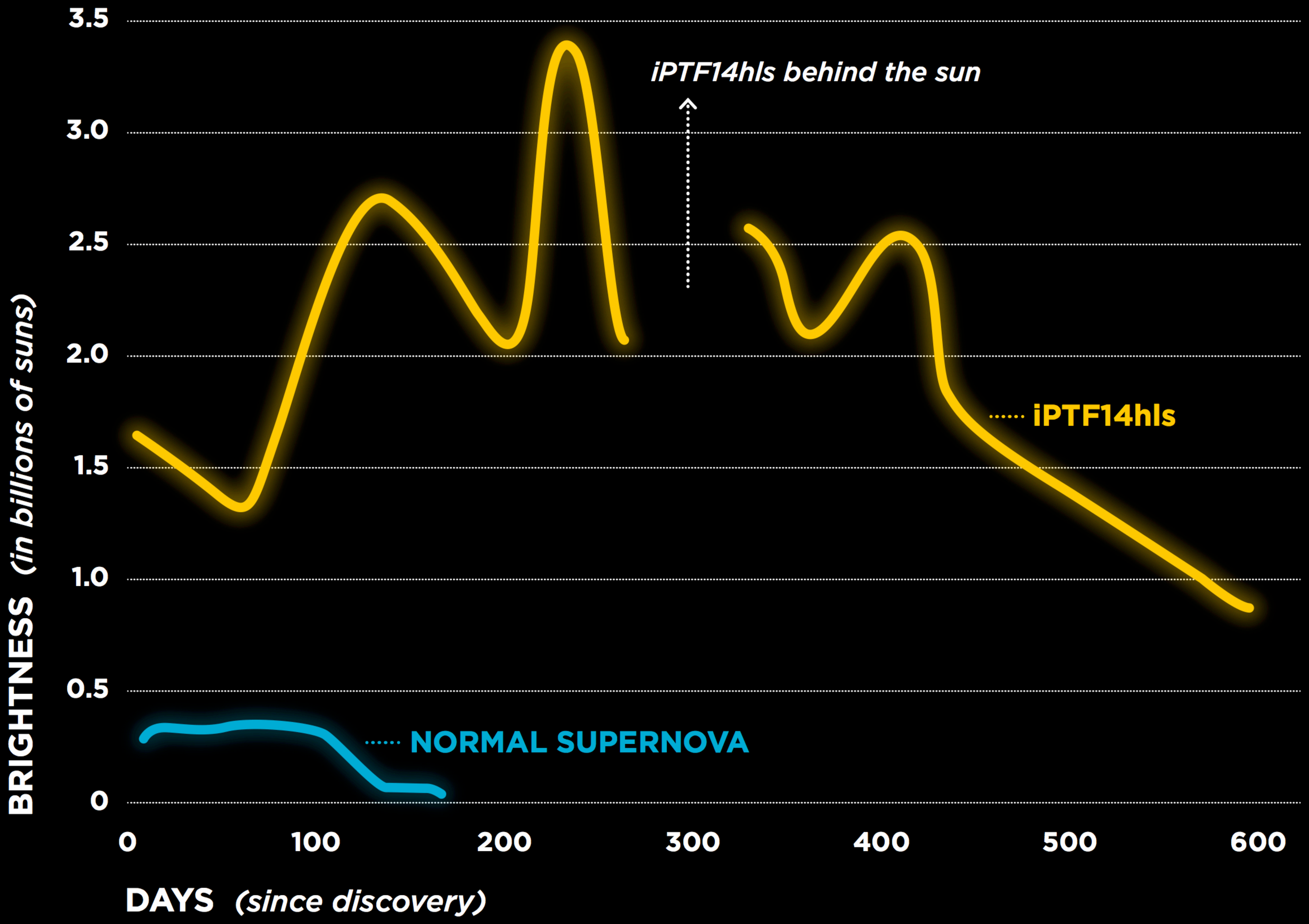
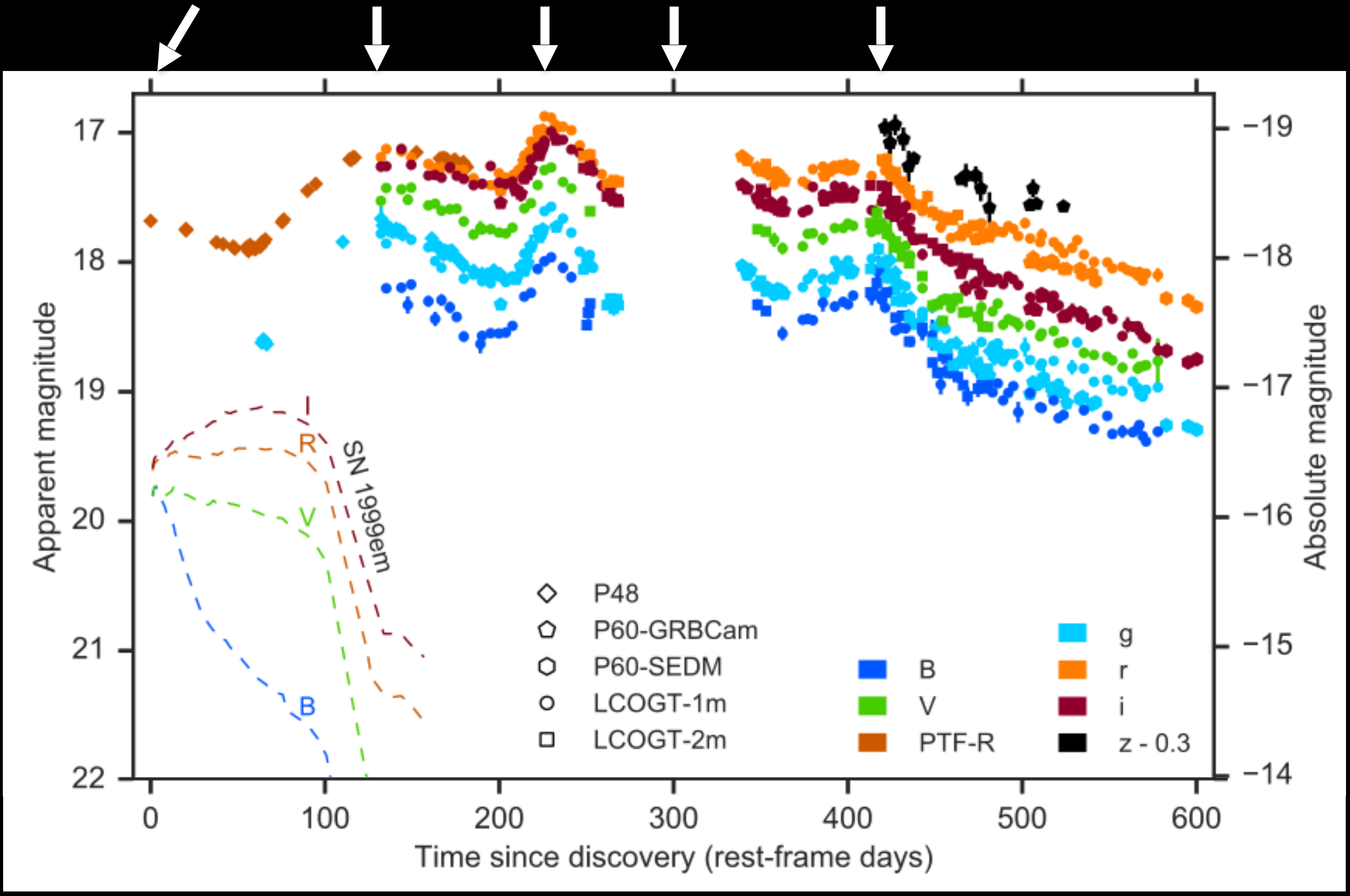
By Sarah Kaplan November 8,
Artist's impression of a superno

Luminosity ~few x 10^{42} erg/s for ~1-2 years

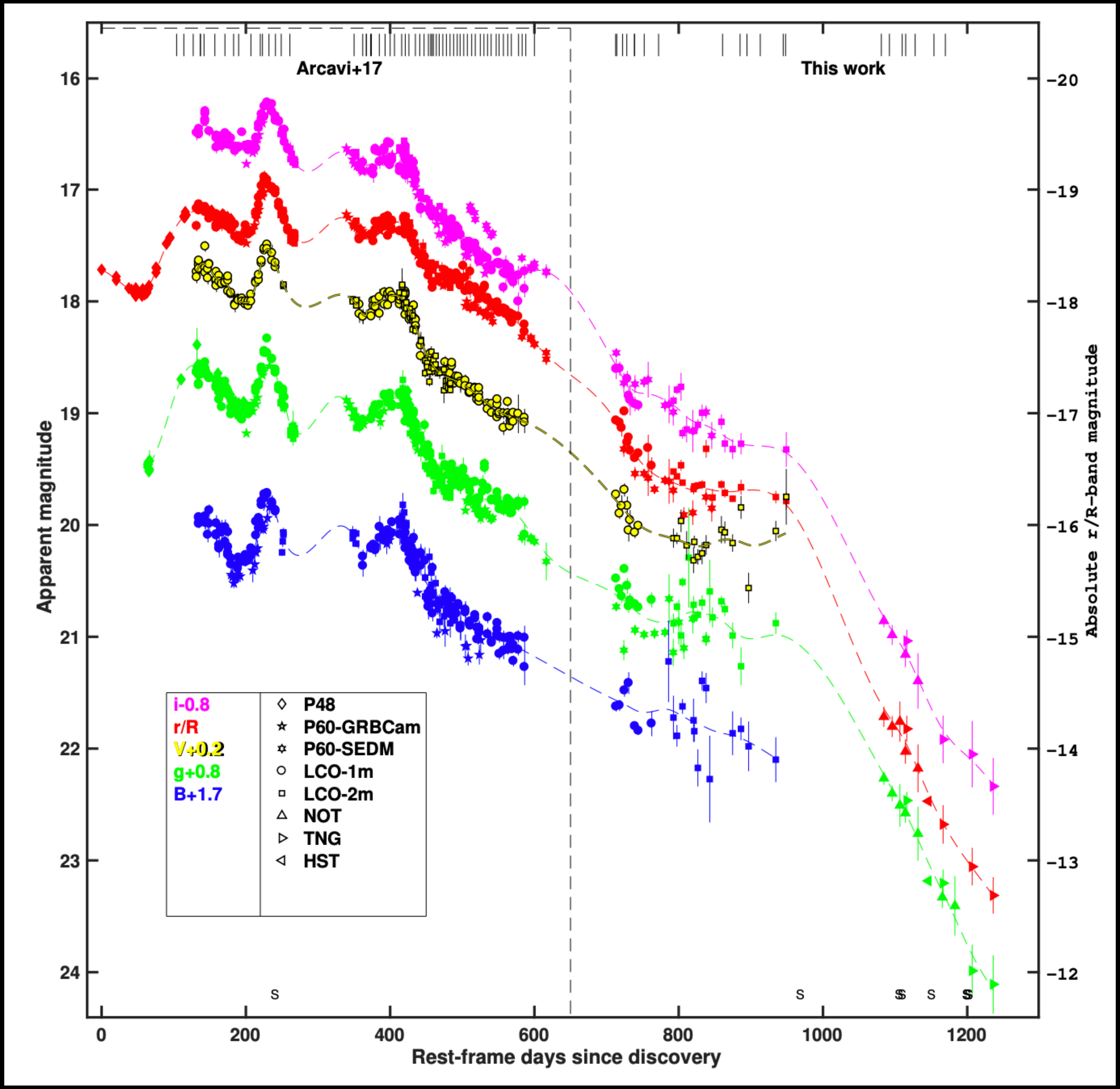


Long-Lived Multi-Peak Light Curve

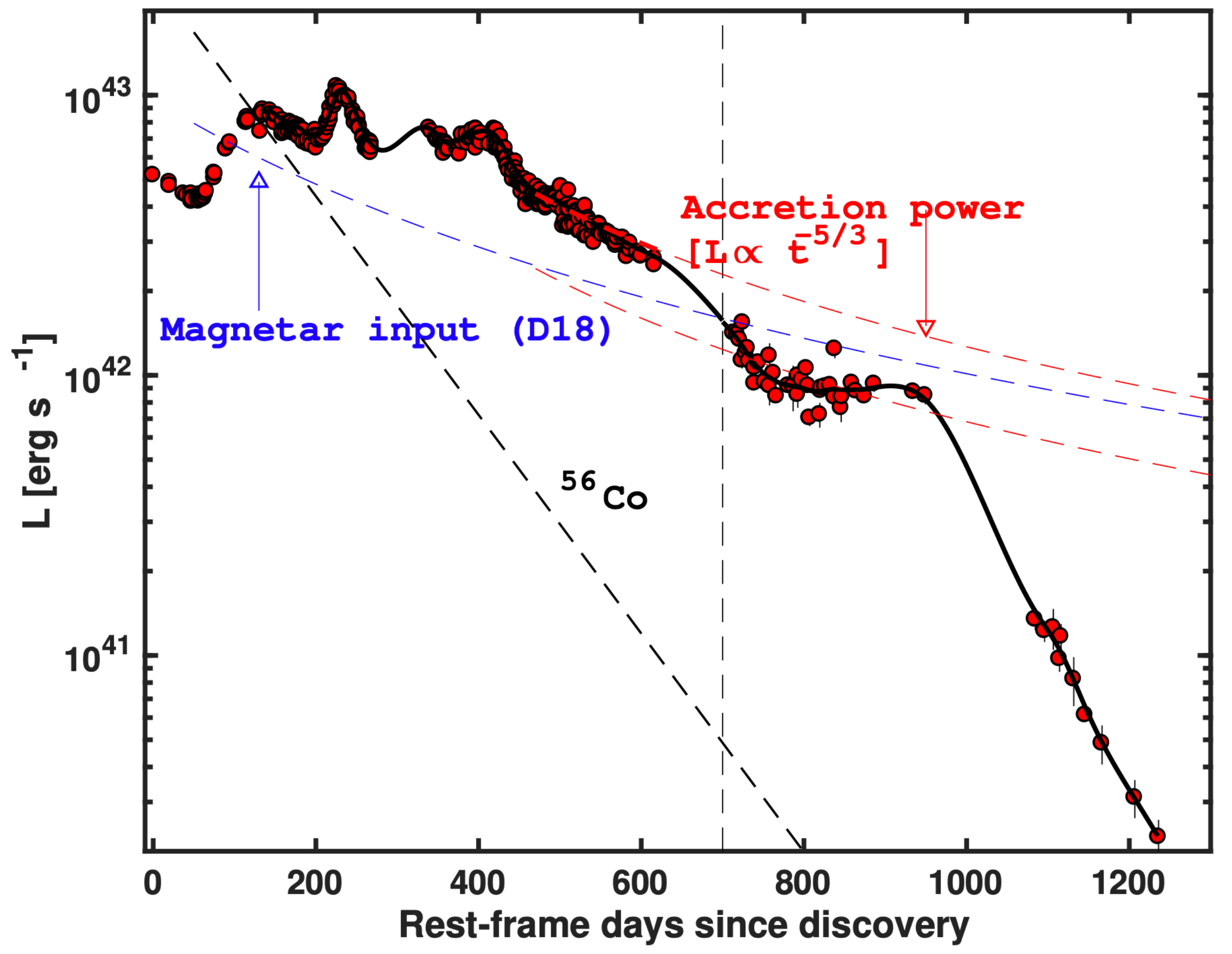


Last non-det is 140d before discovery

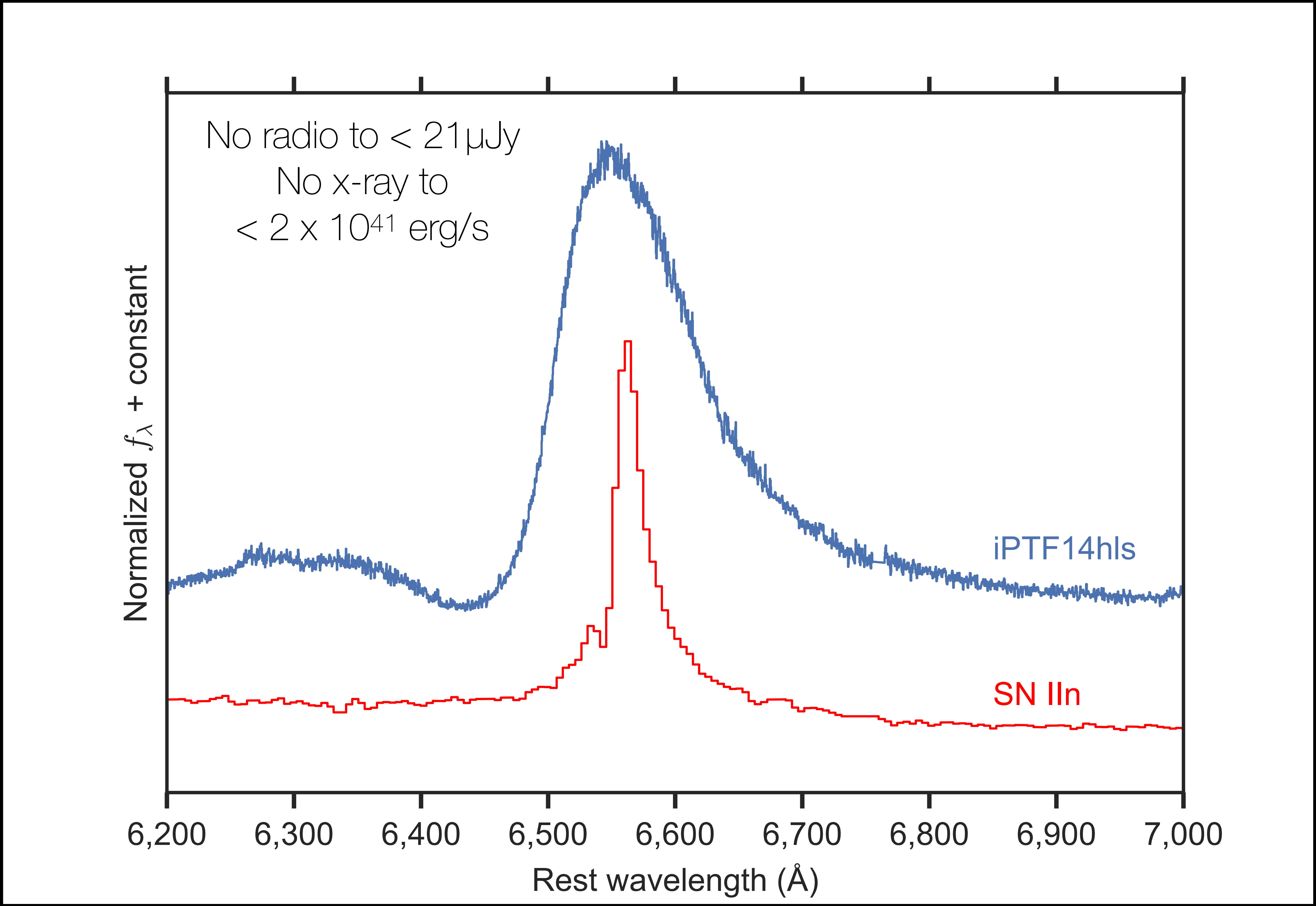
Long-Lived Multi-Peak Light Curve

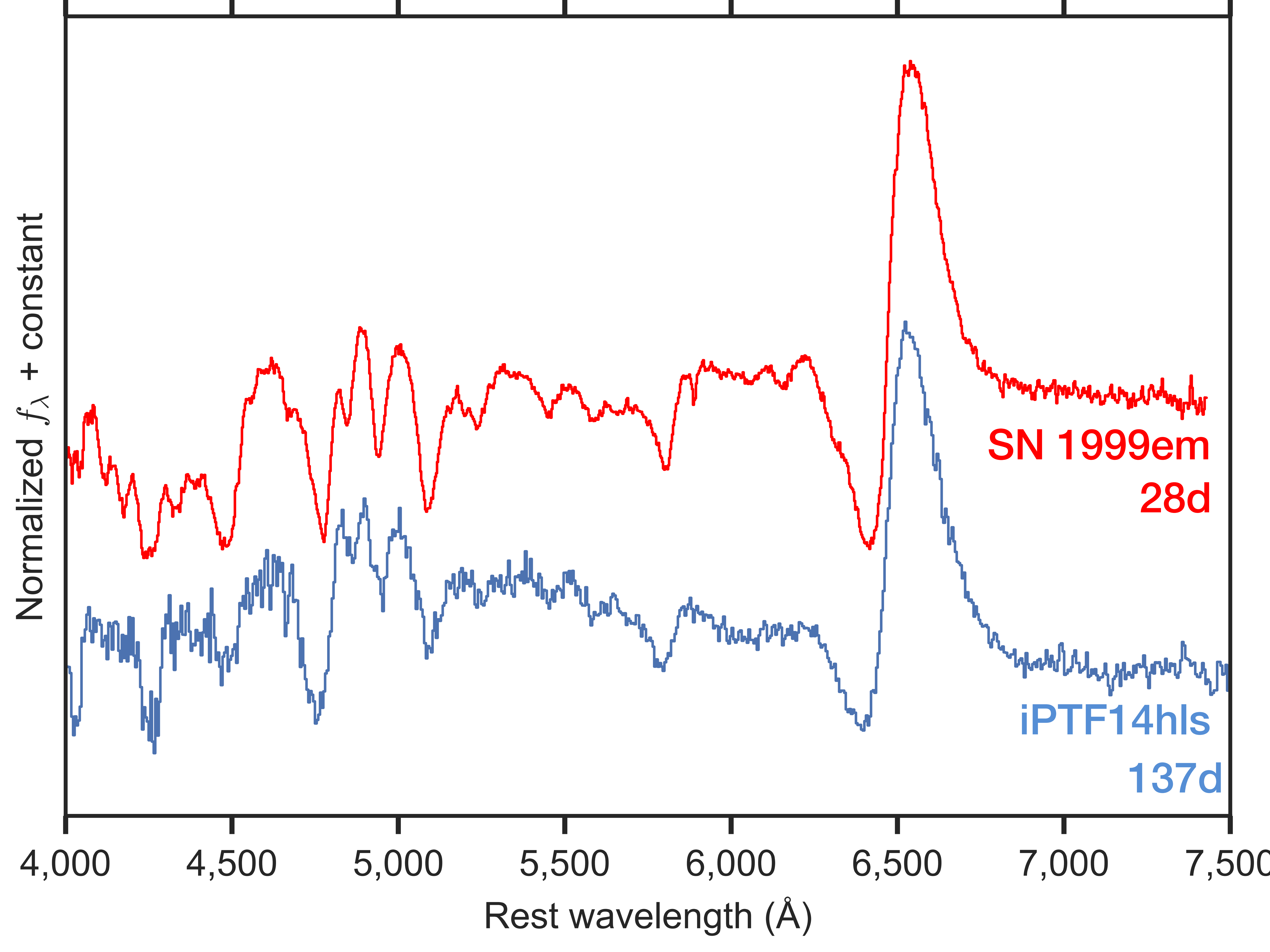


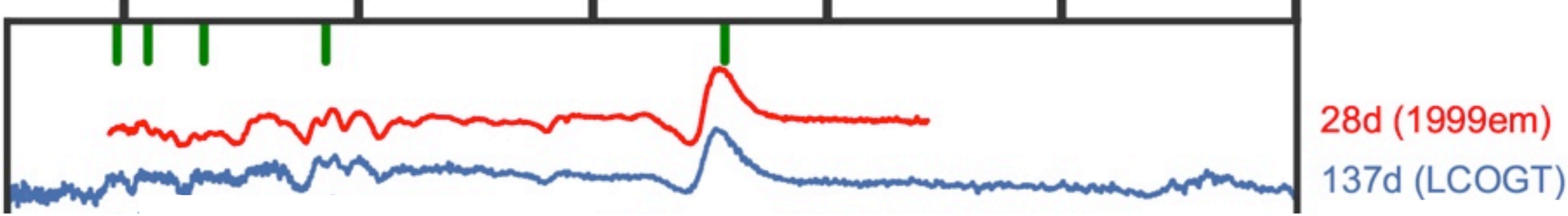
Late time data from Sollerman et al. (+IA, DAH) 2019



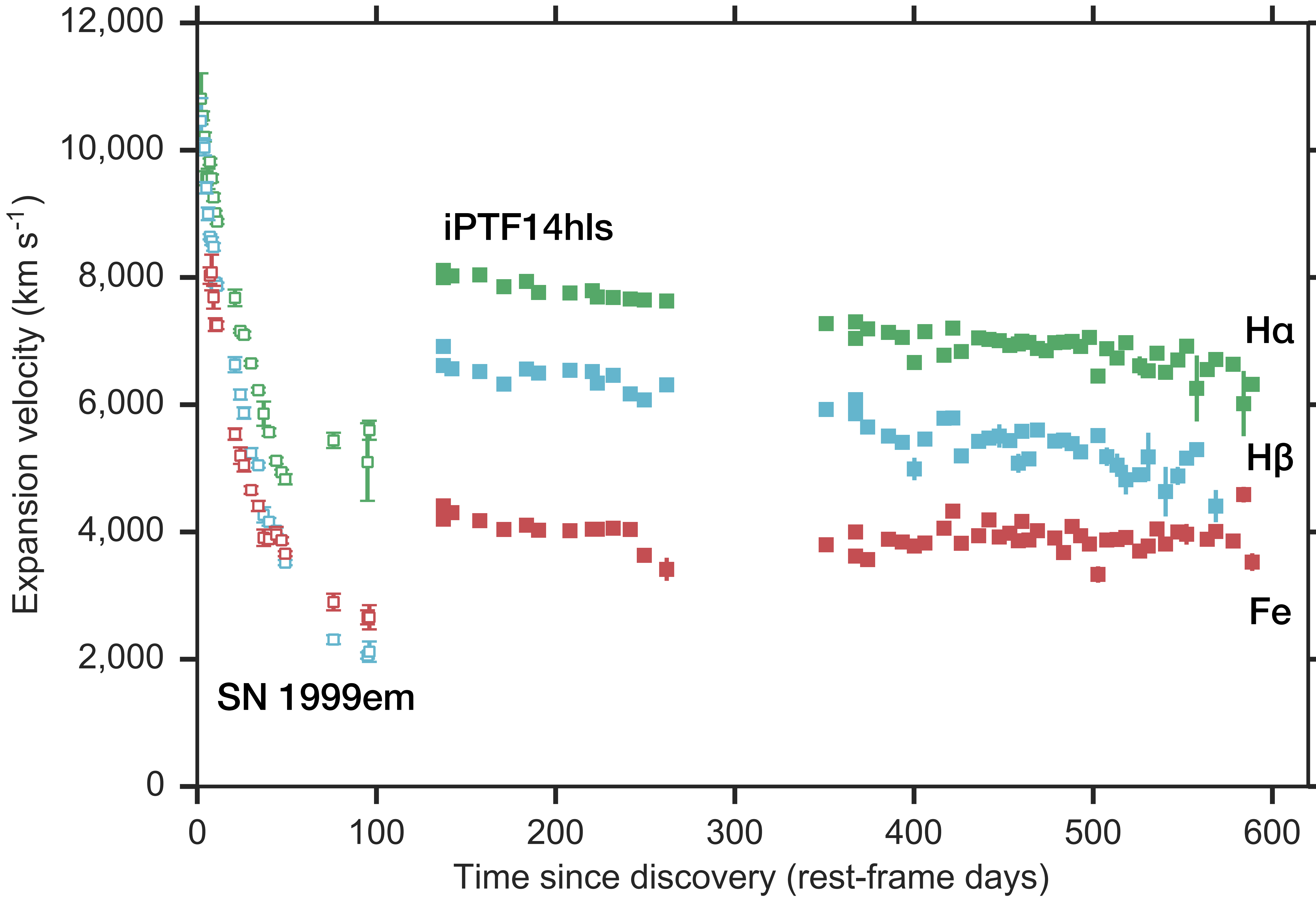
No Obvious Signs of Interaction



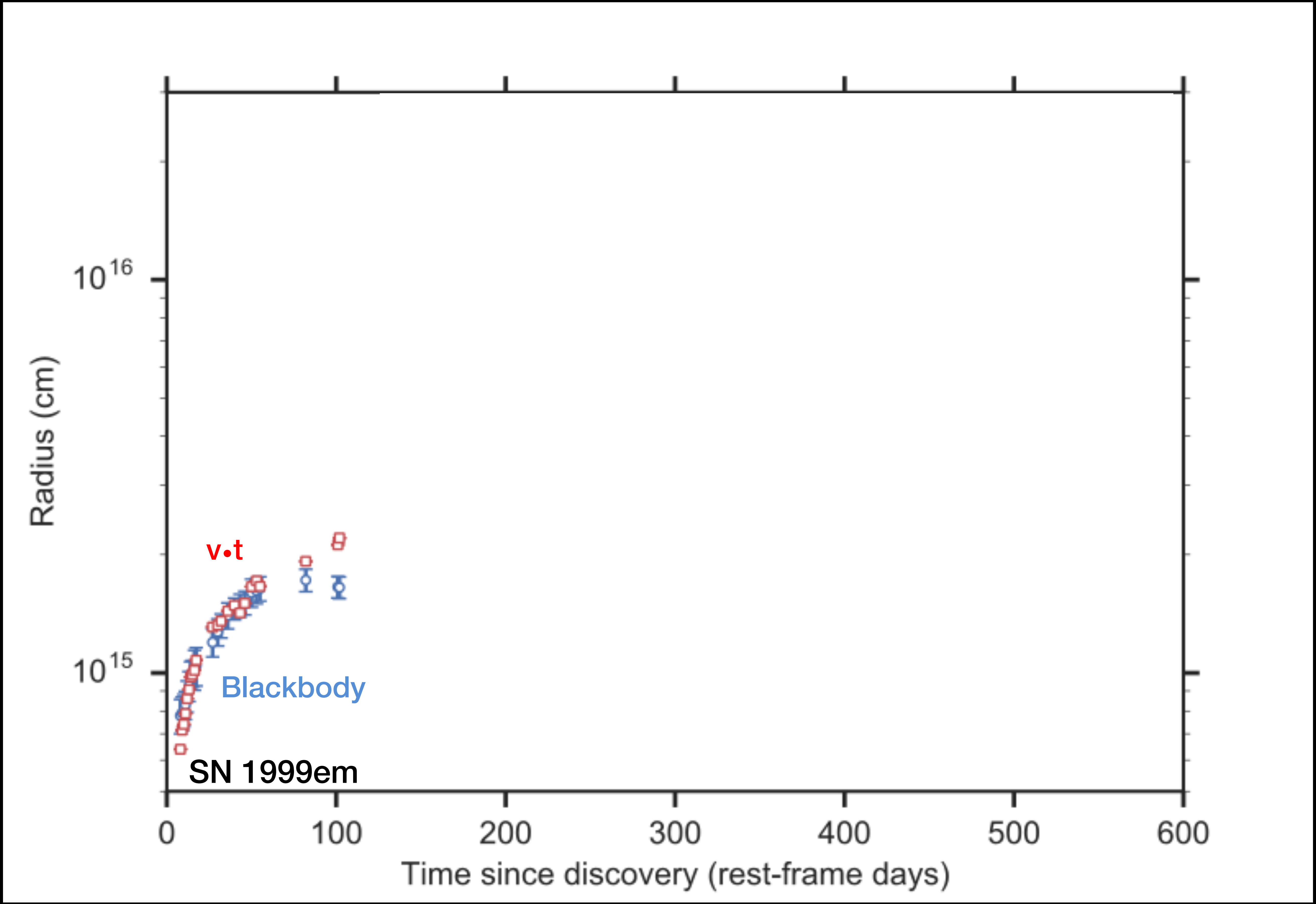

Normalized f_λ + constant
SN 1999em
28d
iPTF14hls
137d
4,000
4,500
5,000
5,500
6,000
6,500
7,000
7,500
Rest wavelength (Å)


28d (1999em)
137d (LCOGT)

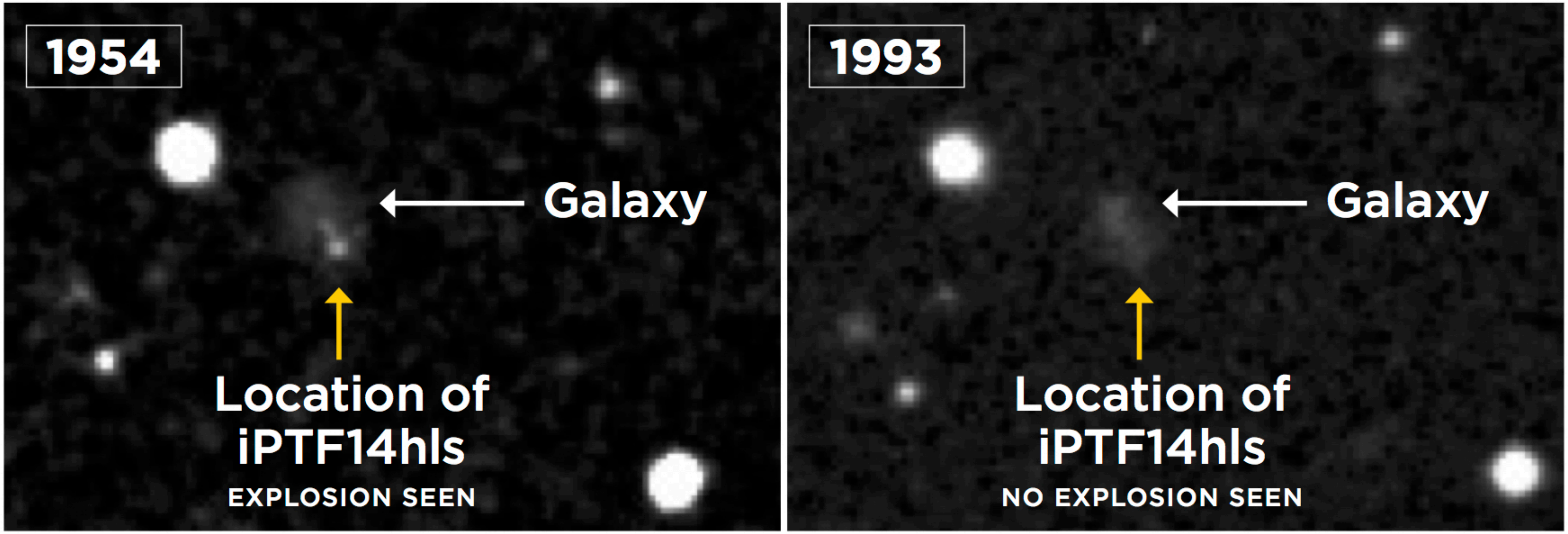
Slowly Evolving Velocities



Photosphere Radius Estimates Diverge

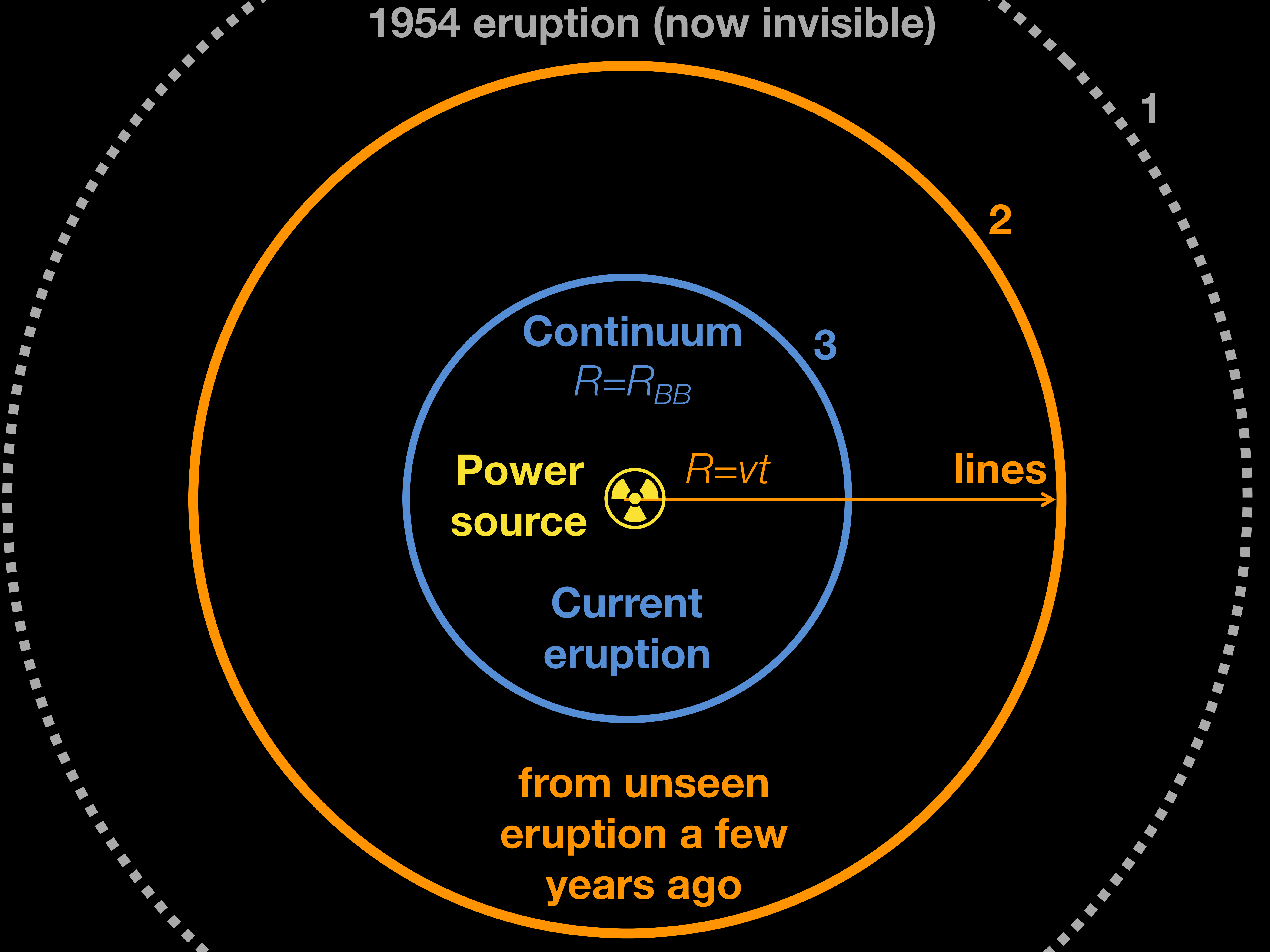


Prior eruption in 1954!



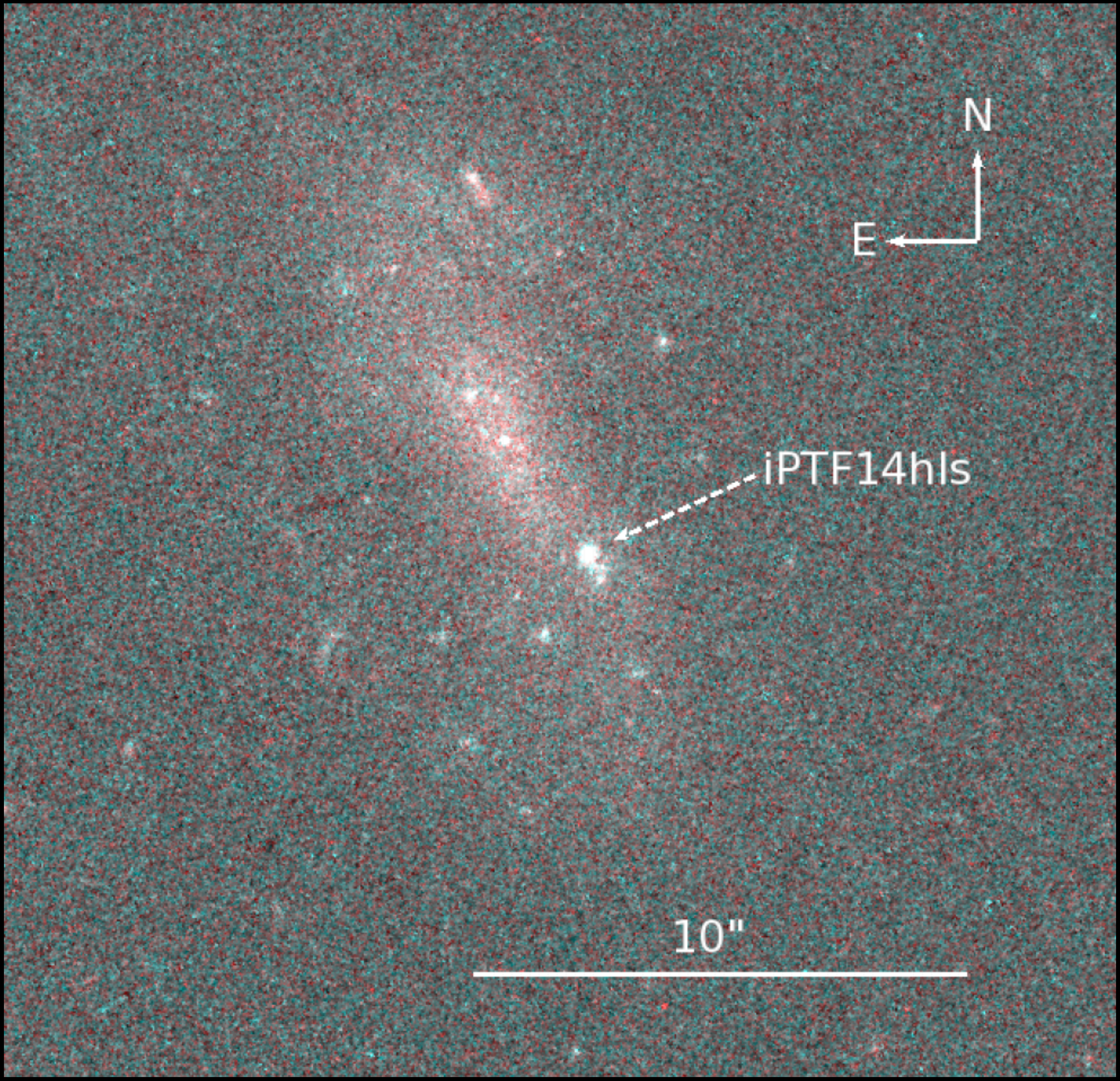
At least M_R=-15

Formally 2.2 sigma, though that is uncertain because they are photographic.



1954 eruption (now invisible)
1
2
3
Continuum
R=R_BB
Power
source
R=vt
lines
Current
eruption
from unseen
eruption a few
years ago

HST Images of Host Galaxy

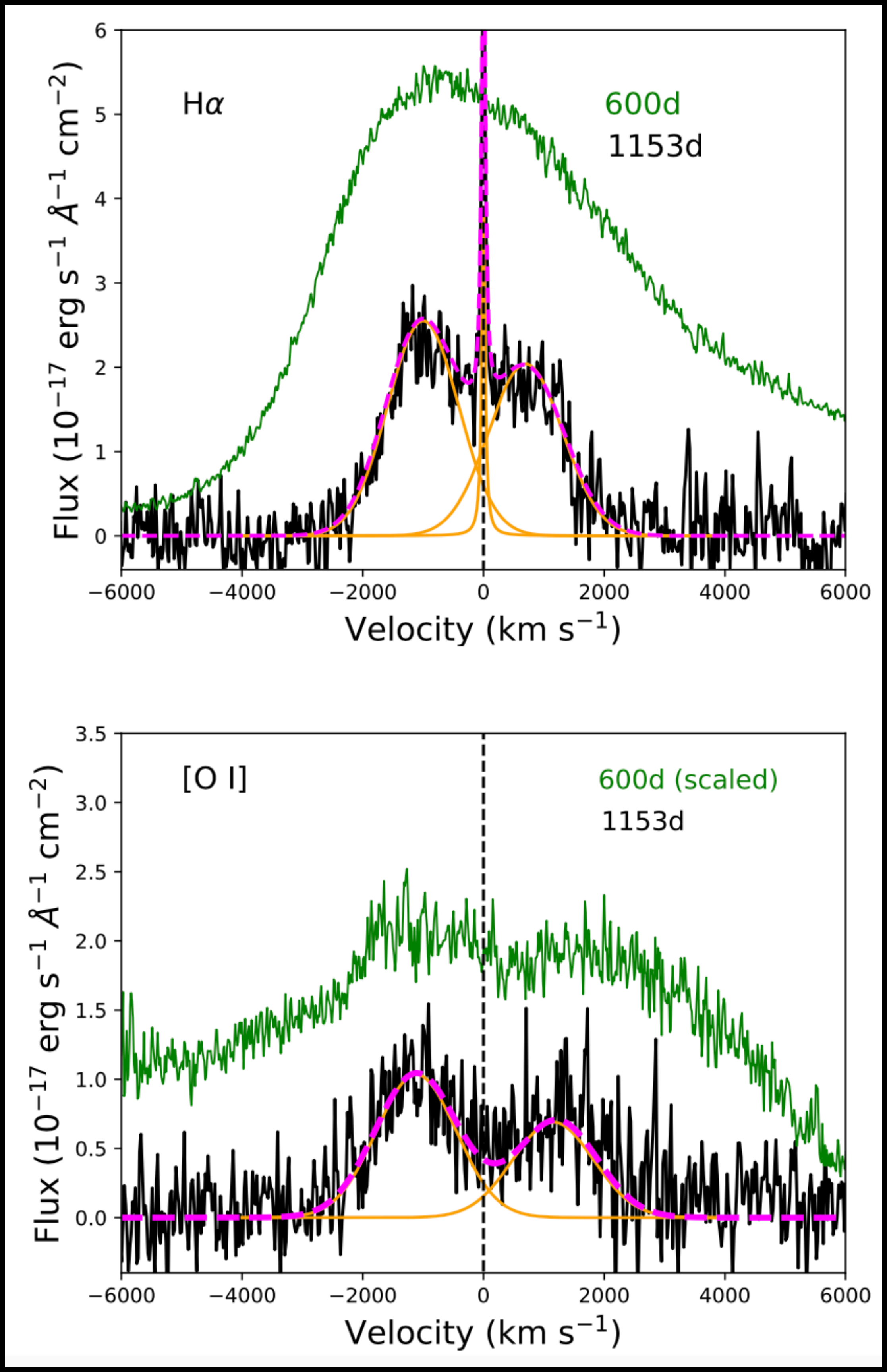


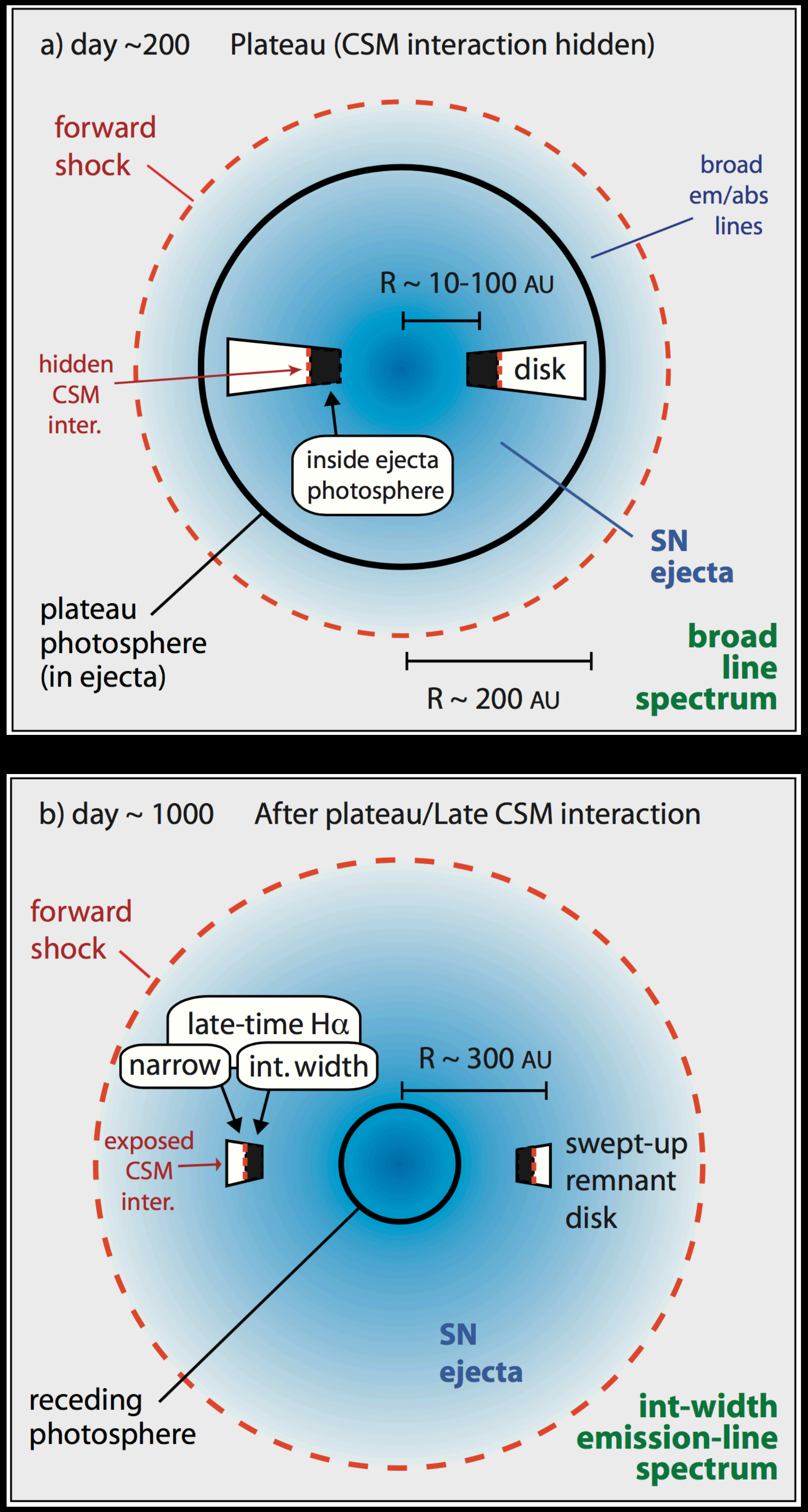
Sollerman et al. 2019

$M \sim 3\times10^8\ M_\odot$ (~SMC)

$Z \sim 0.4\text{-}0.9\ Z_\odot$

Andrews & Smith: CSM Interaction





Double hump: disk

Narrow line: circumstellar interaction

Woosley 2018: CSM / PPISN / Magnetar

All can explain the rough bolometric properties,
None can explain all the details

CSM explains light curve bumps but not H velocities

Magnetar explains velocities but not light curve bumps

PPISN models very sensitive, no one model does it all

Remnant could be NS, BH or star…

iPTF explanations

	LC Energetics	LC bumps	Velocity Evolution	1954 eruption
Soker & Gilkis (common env. + jets)	✔ ?	✔ ?	?	✔ ?
Andrews & Smith (CSM)	✔ ?	✔ ?	?	✔ ?
Dessart (Magnetar)	✔	✘	✔	✘
Woosley (CSM, PPISN, Magnetar)	✔	✔	?	✔

Different models

SN 2016iet

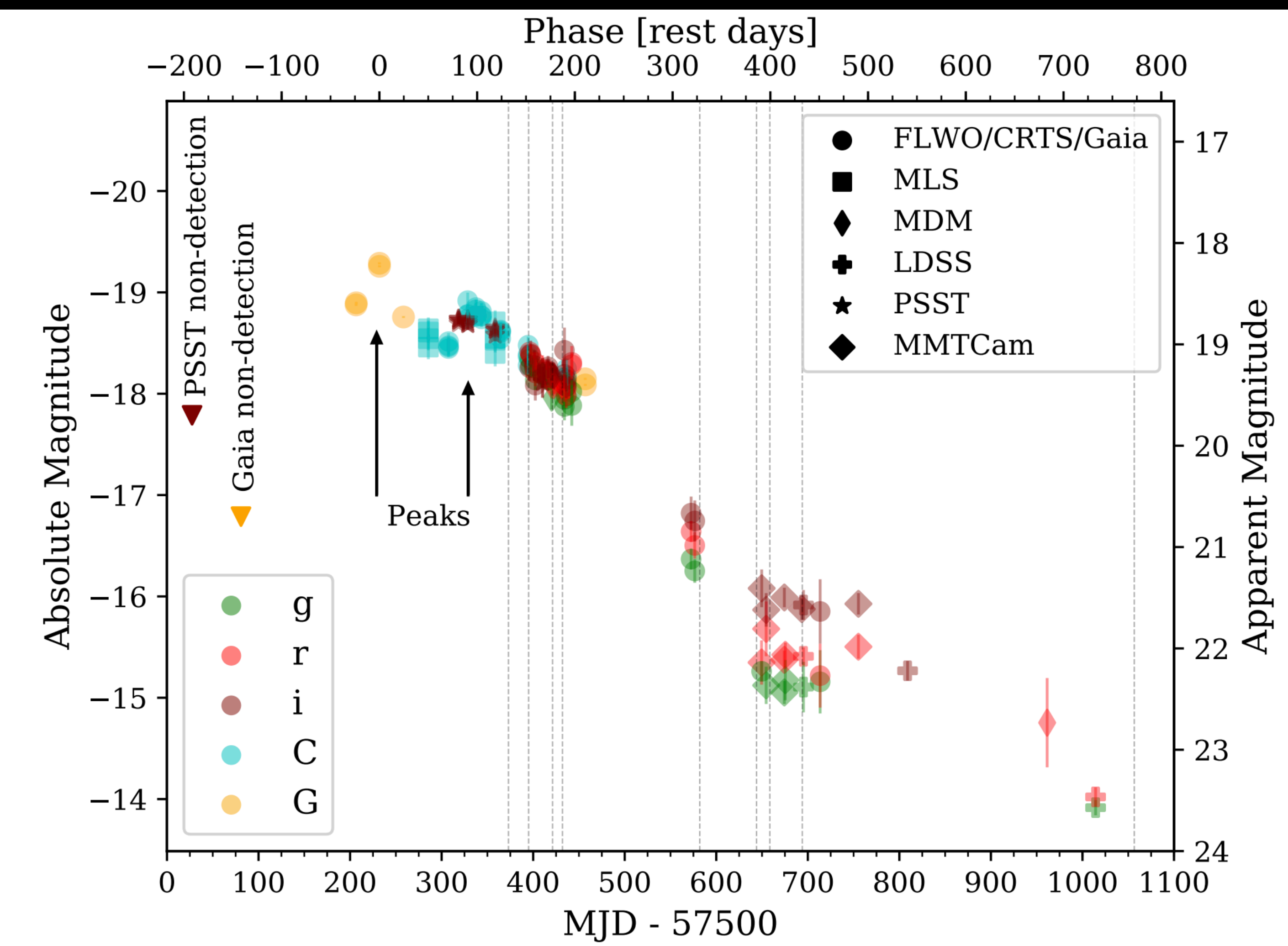
SN 2016iet: The Pulsational or Pair Instability Explosion of a Low Metallicity Massive CO Core Embedded in a Dense Hydrogen-Poor Circumstellar Medium

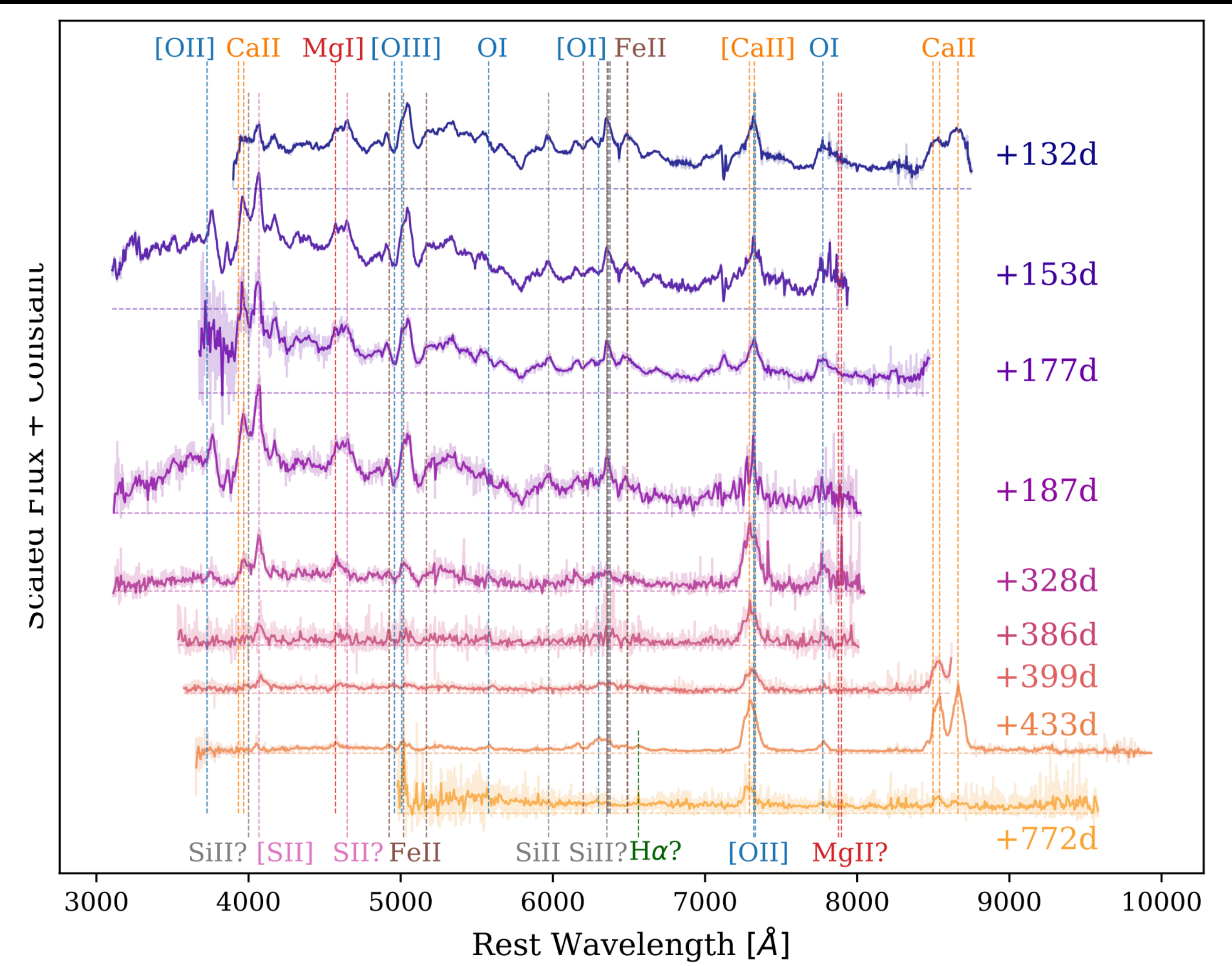
Sebastian Gomez,[1] Edo Berger,[1] Matt Nicholl,[2] Peter K. Blanchard,[1] V. Ashley Villar,[1] Locke Patton,[1] Ryan Chornock,[3] Joel Leja,[1] Griffin Hosseinzadeh,[1] and Philip S. Cowperthwaite[4]

Type I SN at z=0.0676 to equal brightness peaks at M~ -19, separated by ~100 days, slow decline over 450 days.

Tried fitting with models: radioactive decay, magnetar, fallback accretion, CSM interaction. All model fits indicate progenitor mass near end of life (CO core mass) is 55 $M_{\odot}$ - 120 $M_{\odot}$, within pair instability or pulsational pair instability range. PI & PPI models don't fully work.

16.5 kpc (~4 galaxy radii) from Z~0.1 $Z_{\odot}$ galaxy.





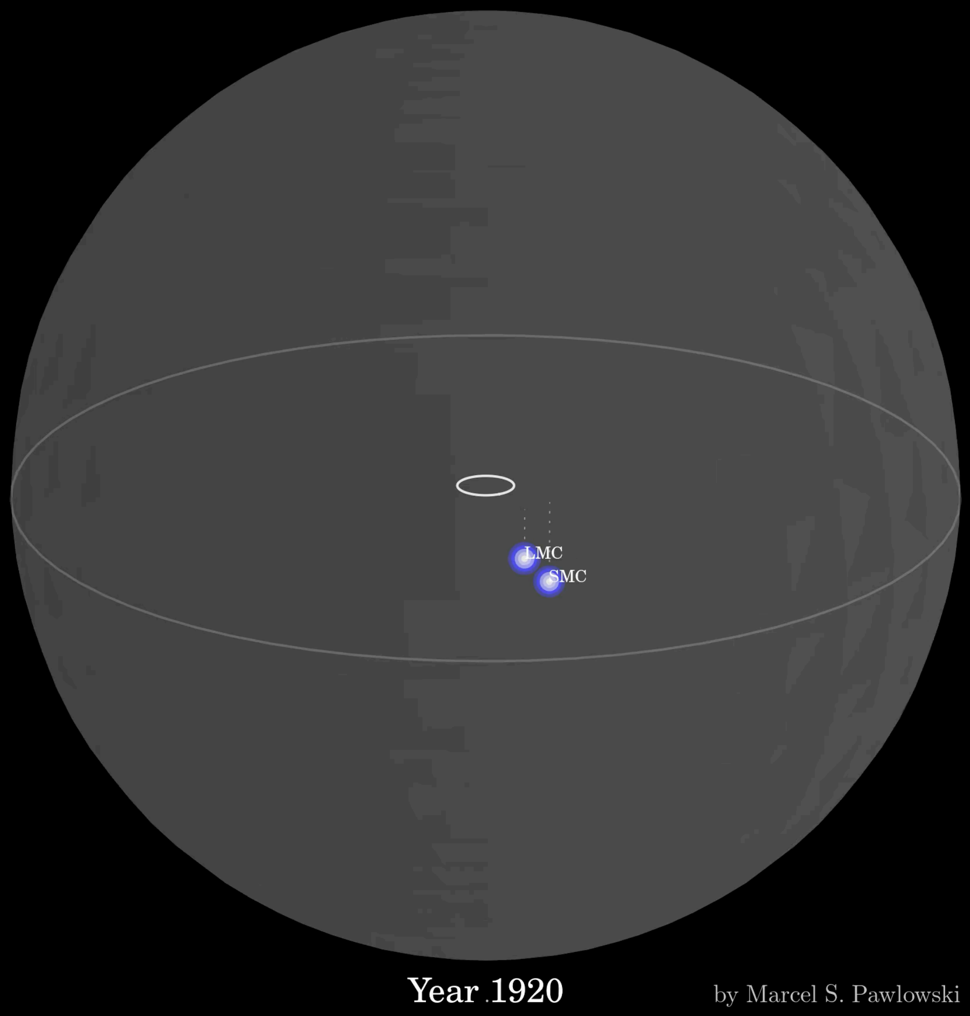
Remnants

There should be ~100 $M_\odot$ remnants out there, though they are rare at the present day.

They may have a multiple shell structure consistent with pulses of mass loss over 1-1000 years.

They should happen in low metallicity environments, e.g. dwarf galaxies.

We now know these galaxies are ubiquitous around larger galaxies. Perhaps these remnants are sheared into nontraditional remnant shapes.



Discovery of MW satellites vs time by Marcel Pawlowski.

Conclusions

iPTF14hls has a lightcurve with at least 5 peaks that lasts for several years. Spectra look like a SN IIP, with slowly evolving velocities. There is evidence for multiple shells / eruptions.

There are several SNe whose properties broadly (though not in detail) match the predictions of pair instability or pulsational pair instability supernovae.

Regardless of the theory, there should be remnants of ~100 $M_\odot$ SNe out there.