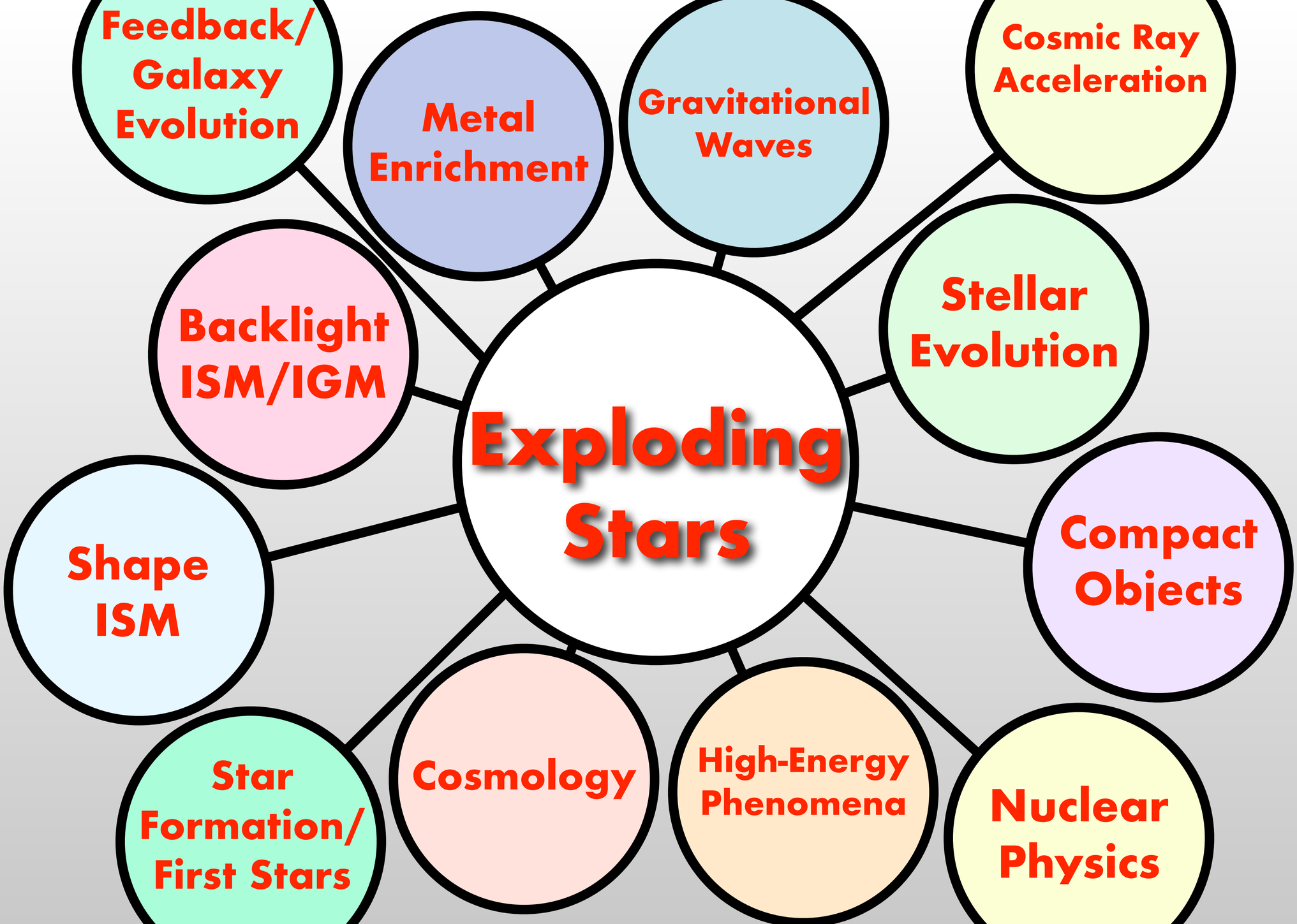
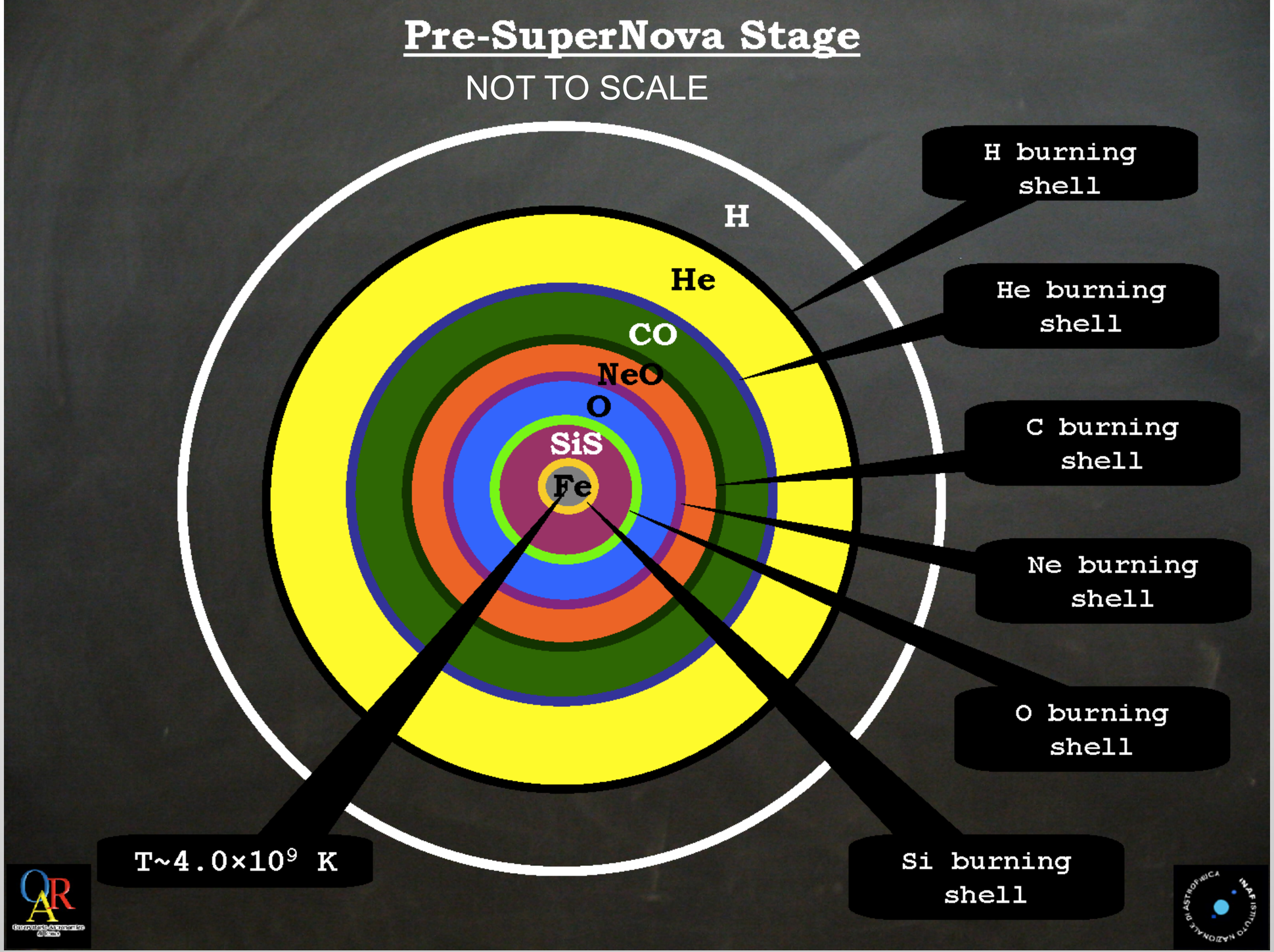
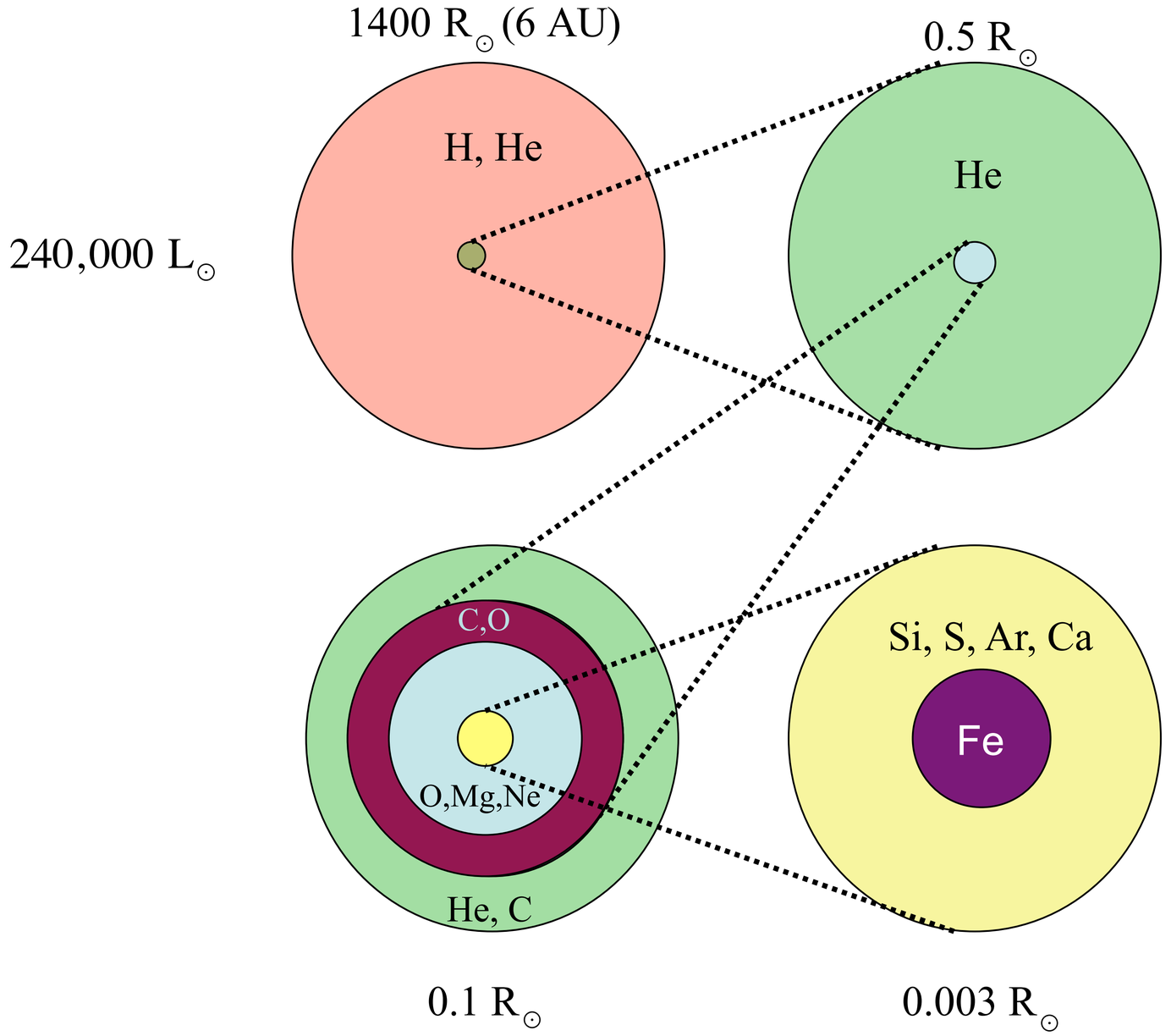
Supernovae!

Ryan Foley (UC Santa Cruz)


Exploding Stars
Feedback/ Galaxy Evolution
Metal Enrichment
Gravitational Waves
Cosmic Ray Acceleration
Backlight ISM/IGM
Stellar Evolution
Shape ISM
Compact Objects
Star Formation/ First Stars
Cosmology
High-Energy Phenomena
Nuclear Physics

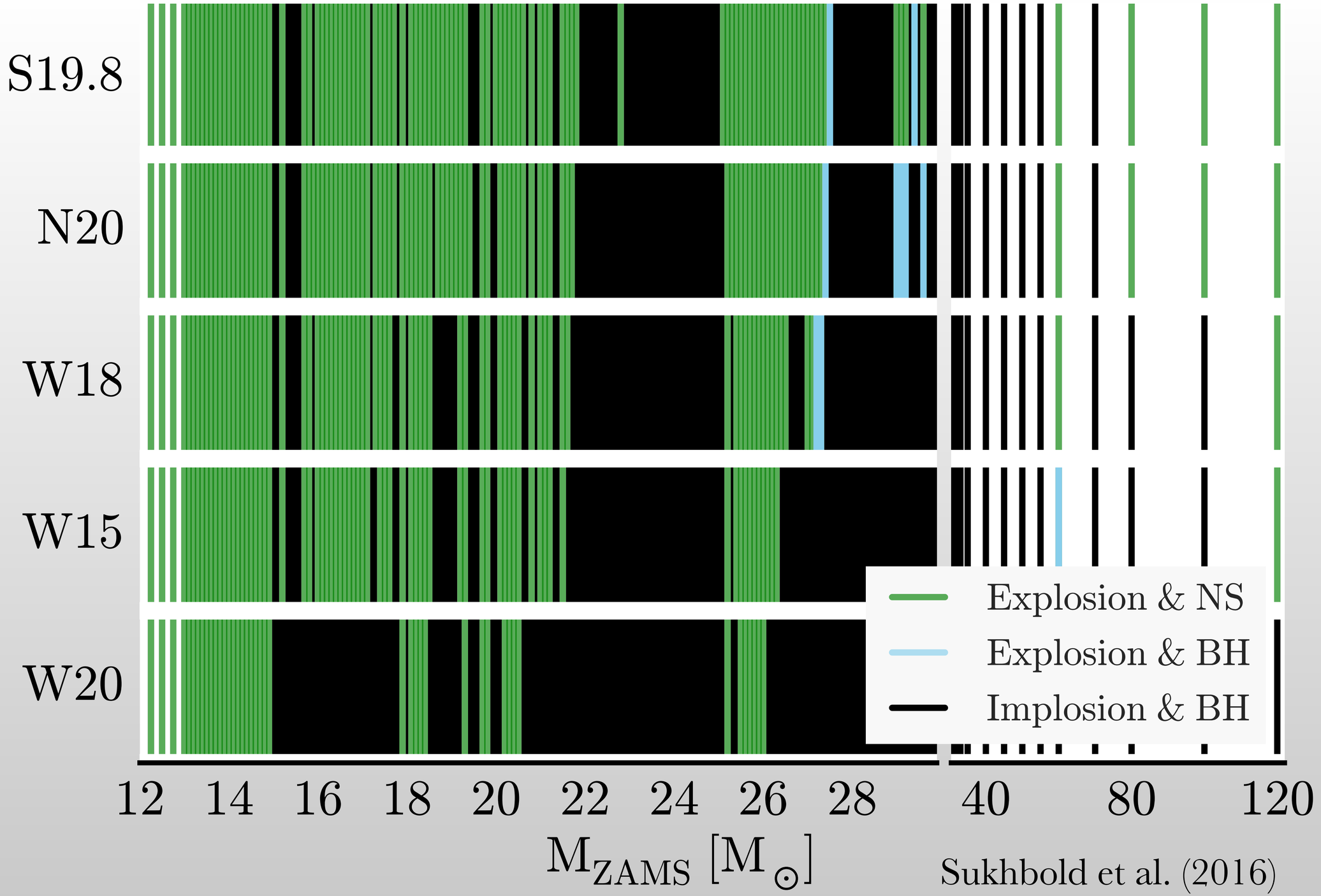

Pre-SuperNova Stage
NOT TO SCALE
H
He
CO
NeO
O
SiS
Fe
H burning shell
He burning shell
C burning shell
Ne burning shell
O burning shell
Si burning shell
T~4.0×10⁹ K

25 $M_\odot$ Presupernova Star (typical for 9 - 130 $M_\odot$)

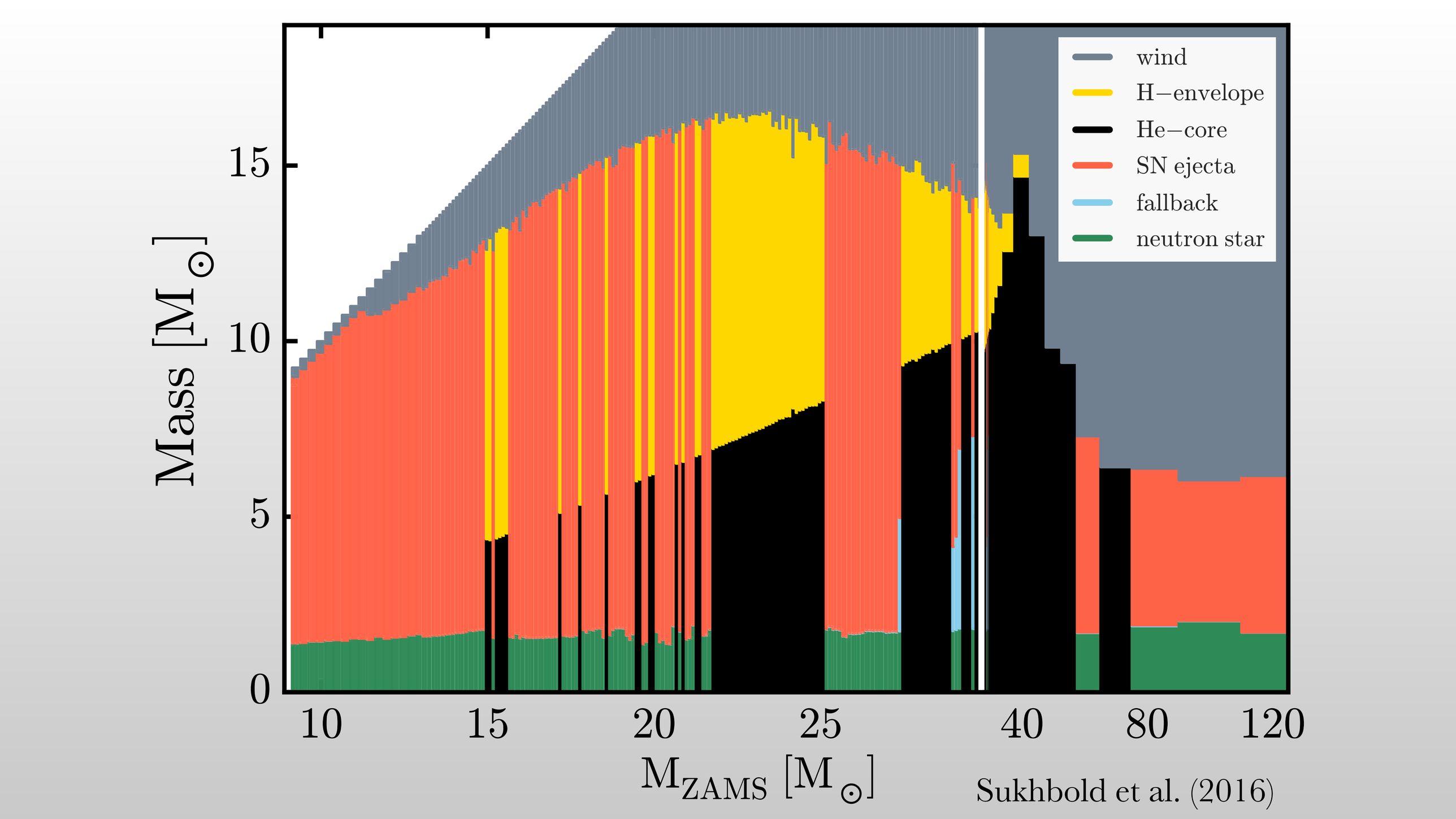


Actual – to scale

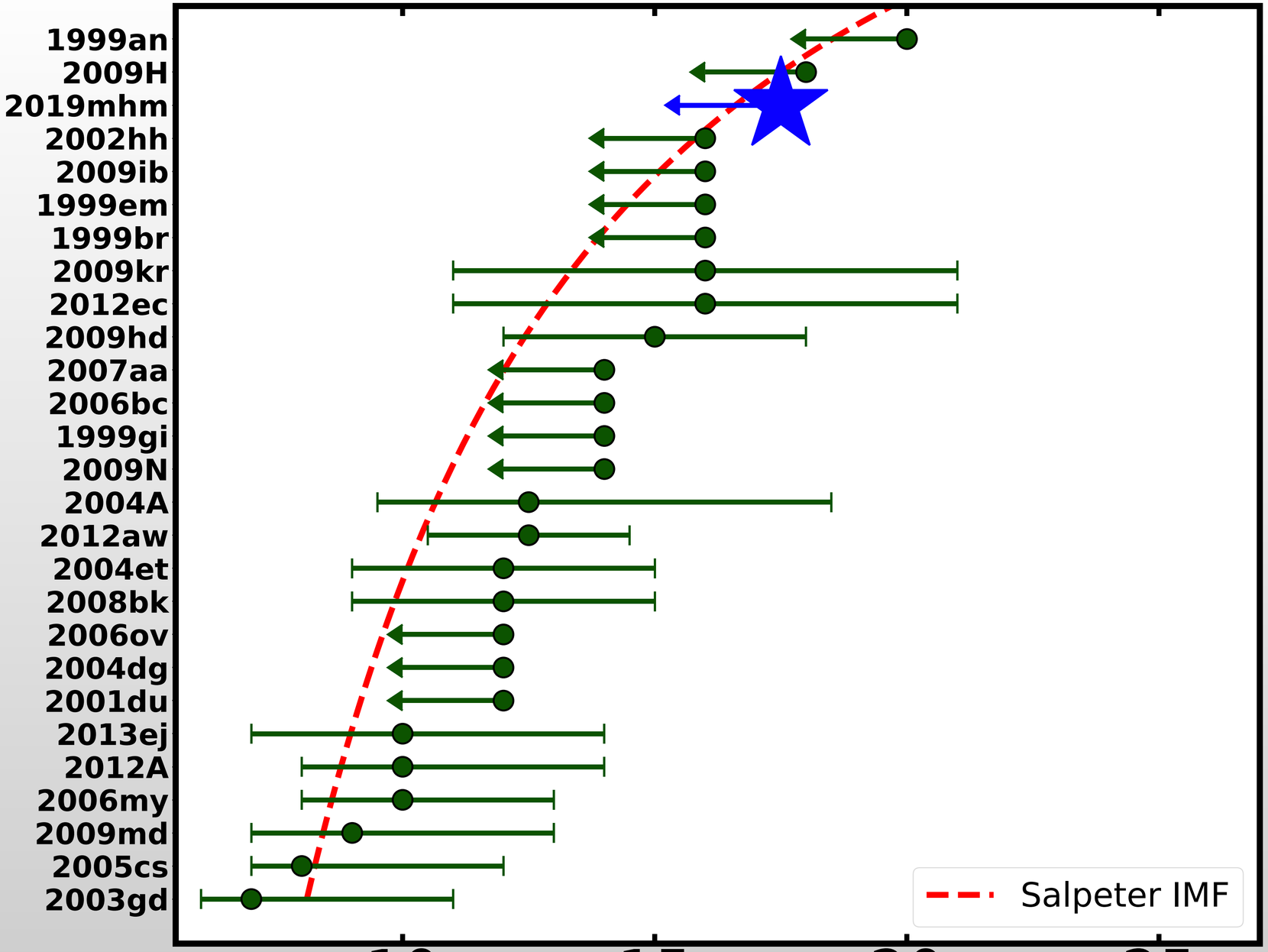
Burrows et al. (2020)



Sukhbold et al. (2016)



Sukhbold et al. (2016)



Salpeter IMF

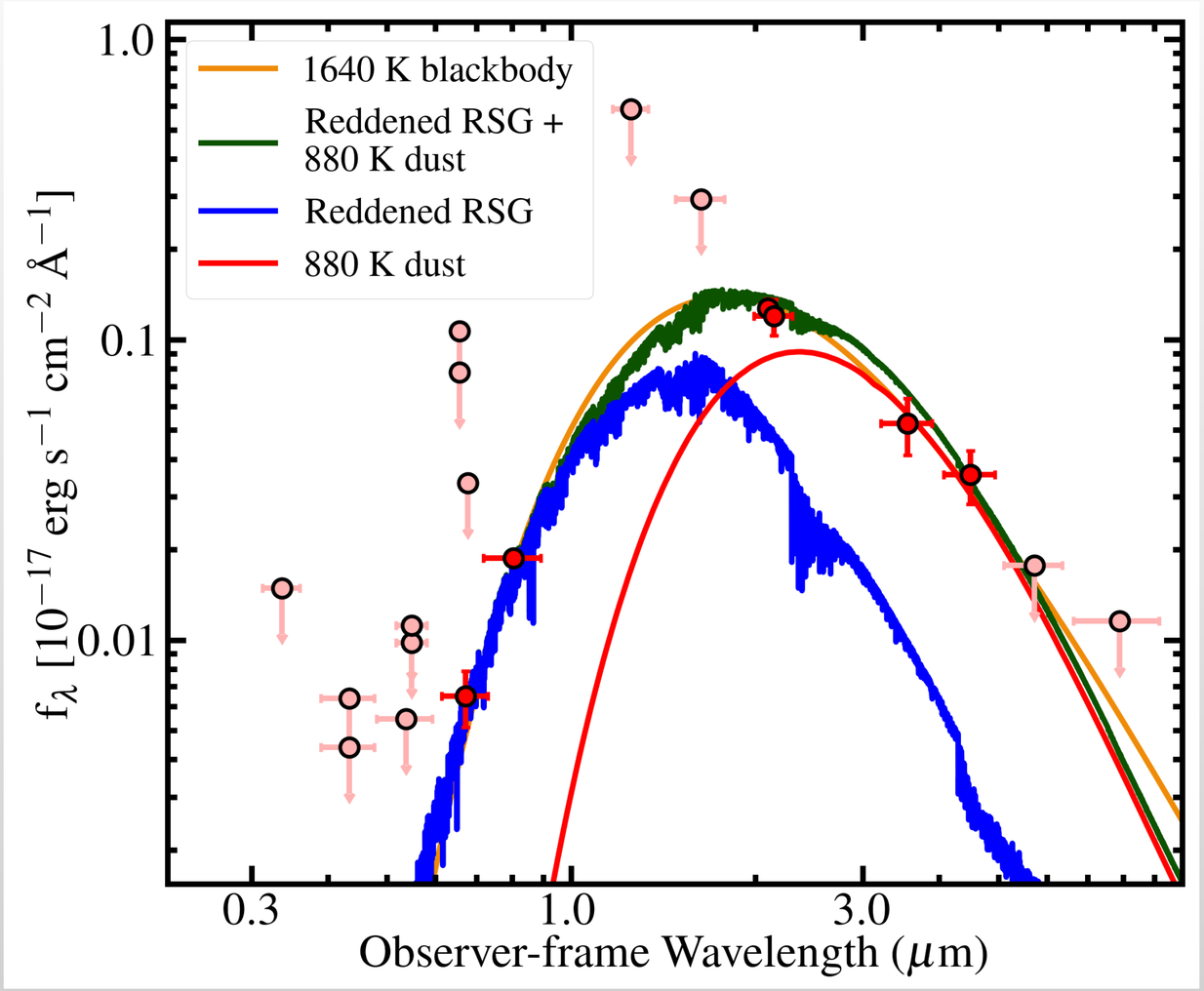
$M_{\rm low} = 8 M_\odot$

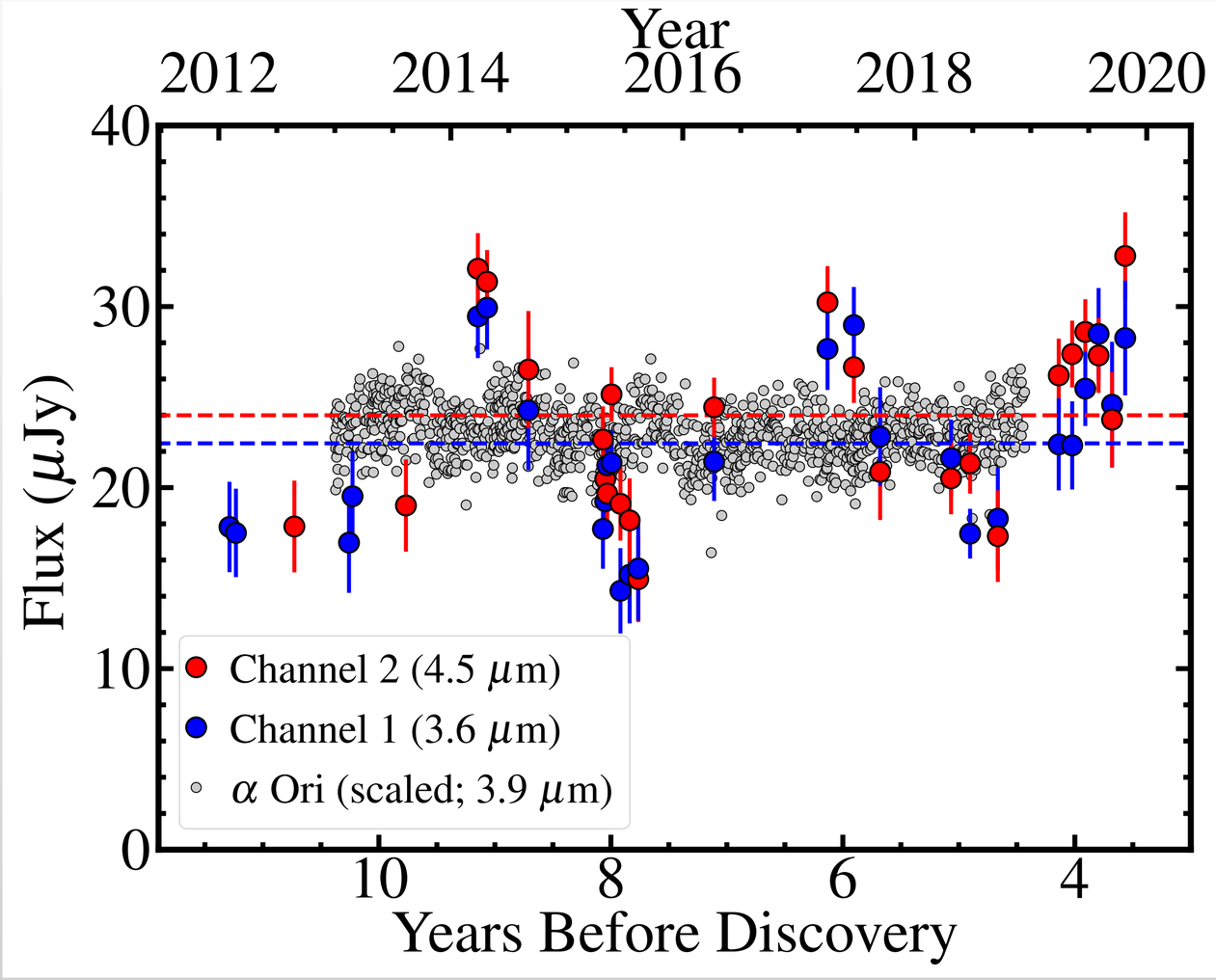
$M_{\rm high} = 24 M_\odot$

Vazquez et al. (2023)

see also Smartt (2015)
Davies & Beasor (2020)
many others

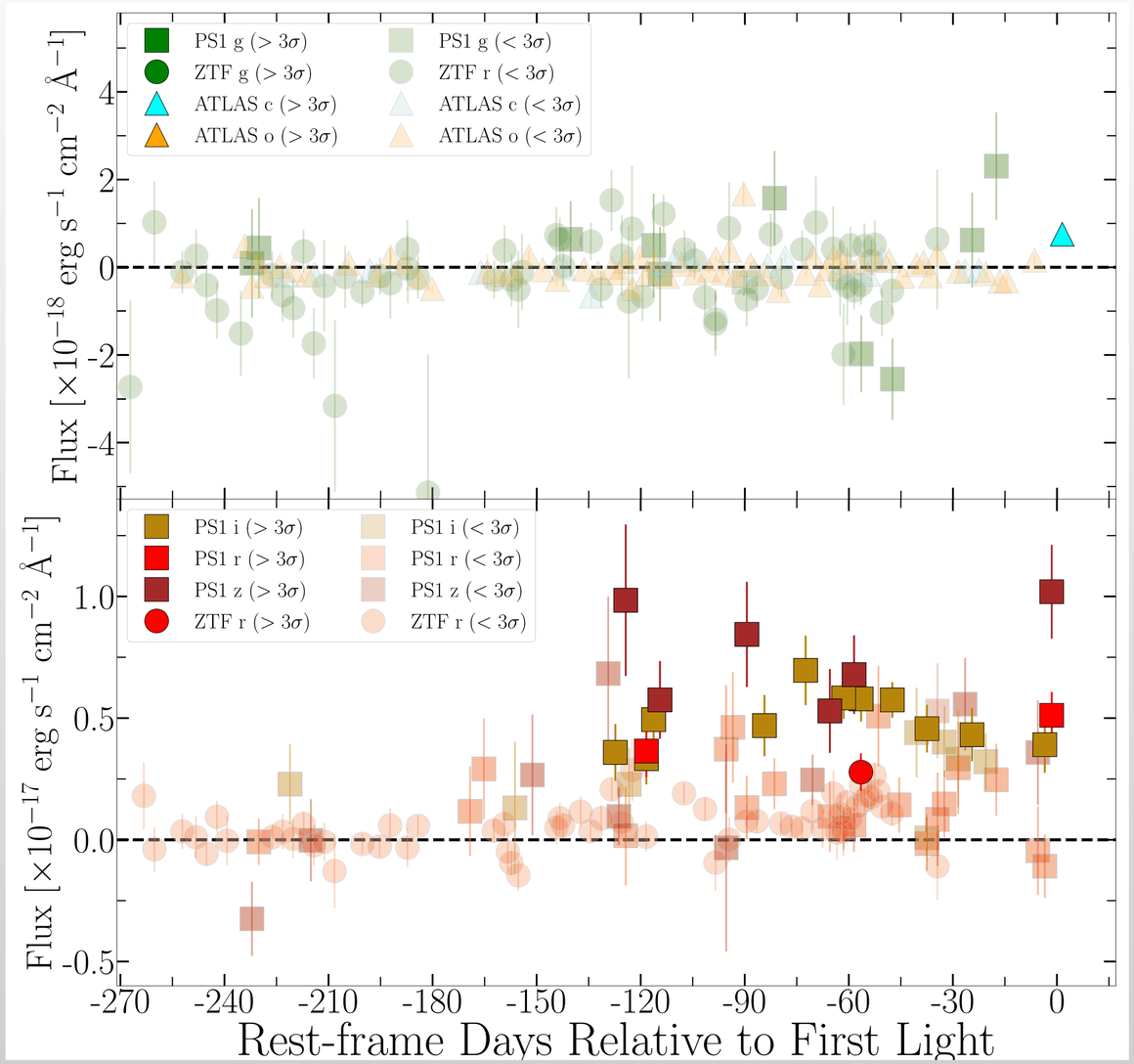
SN 2023ixf in M101

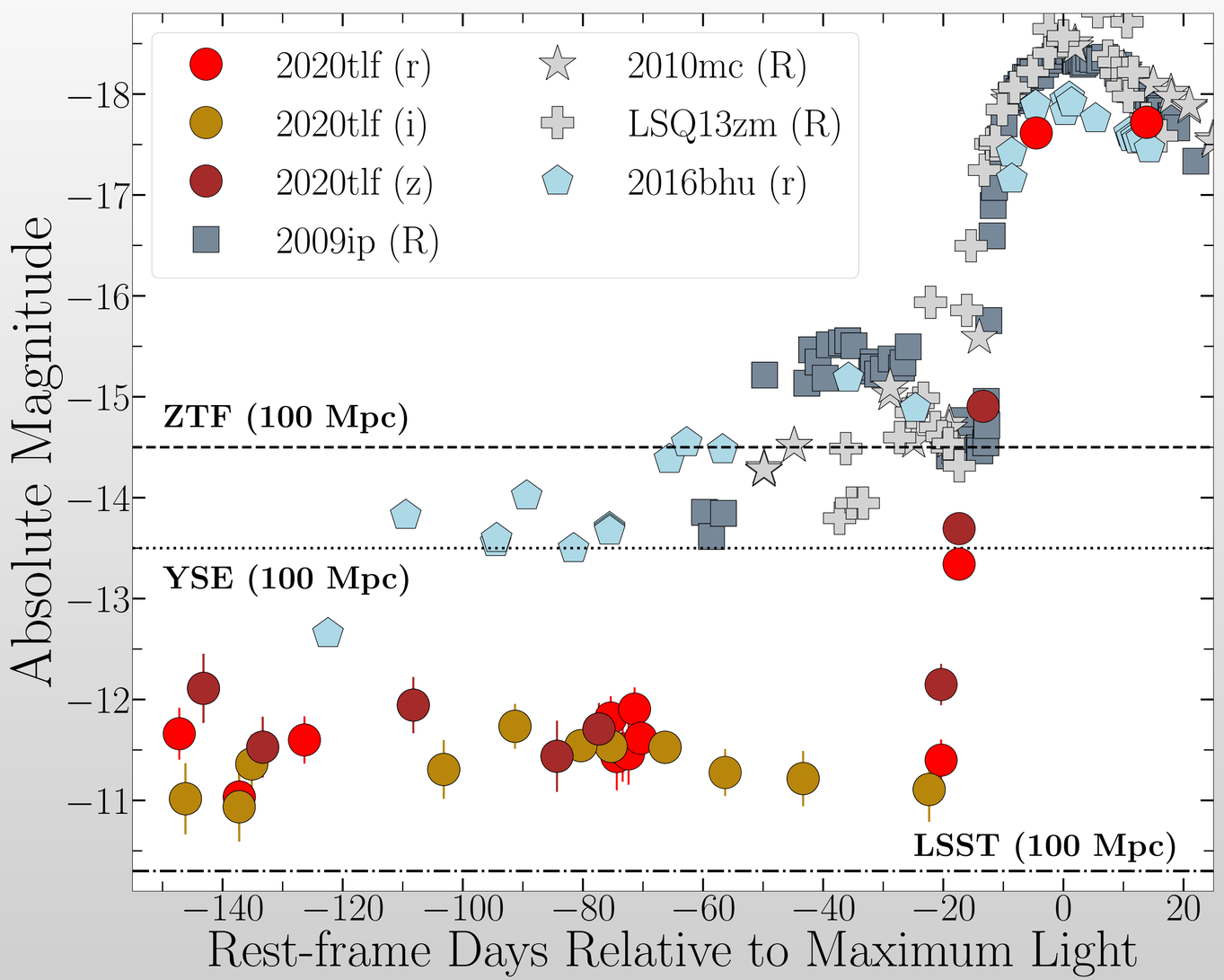




Kilpatrick et al. (2023)
see also Jencson et al. (2023)
Kilpatrick & Foley (2018)

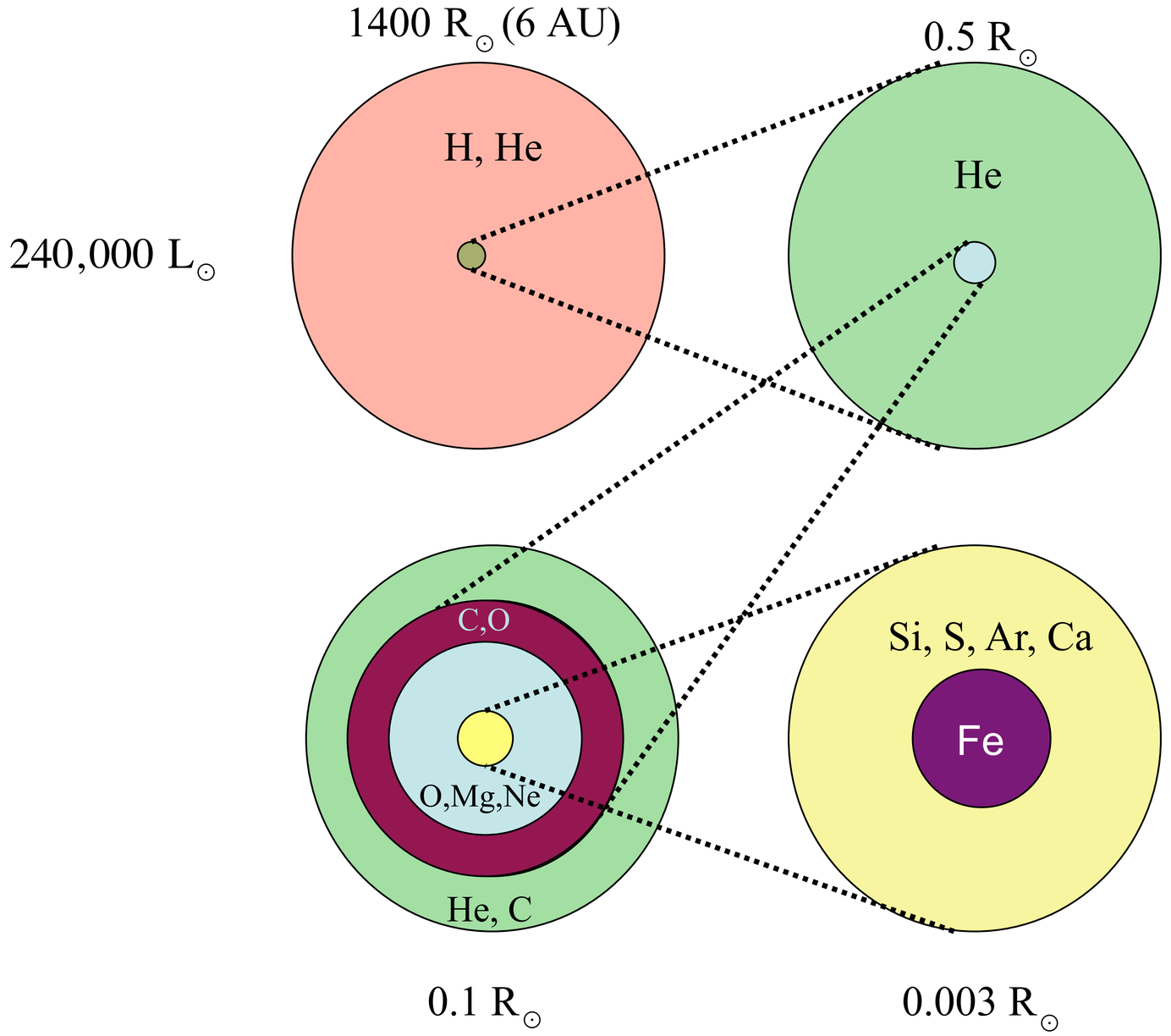
Pre-Explosion Activity in SN 2020tlf





Jacobson-Galán et al. (2022)

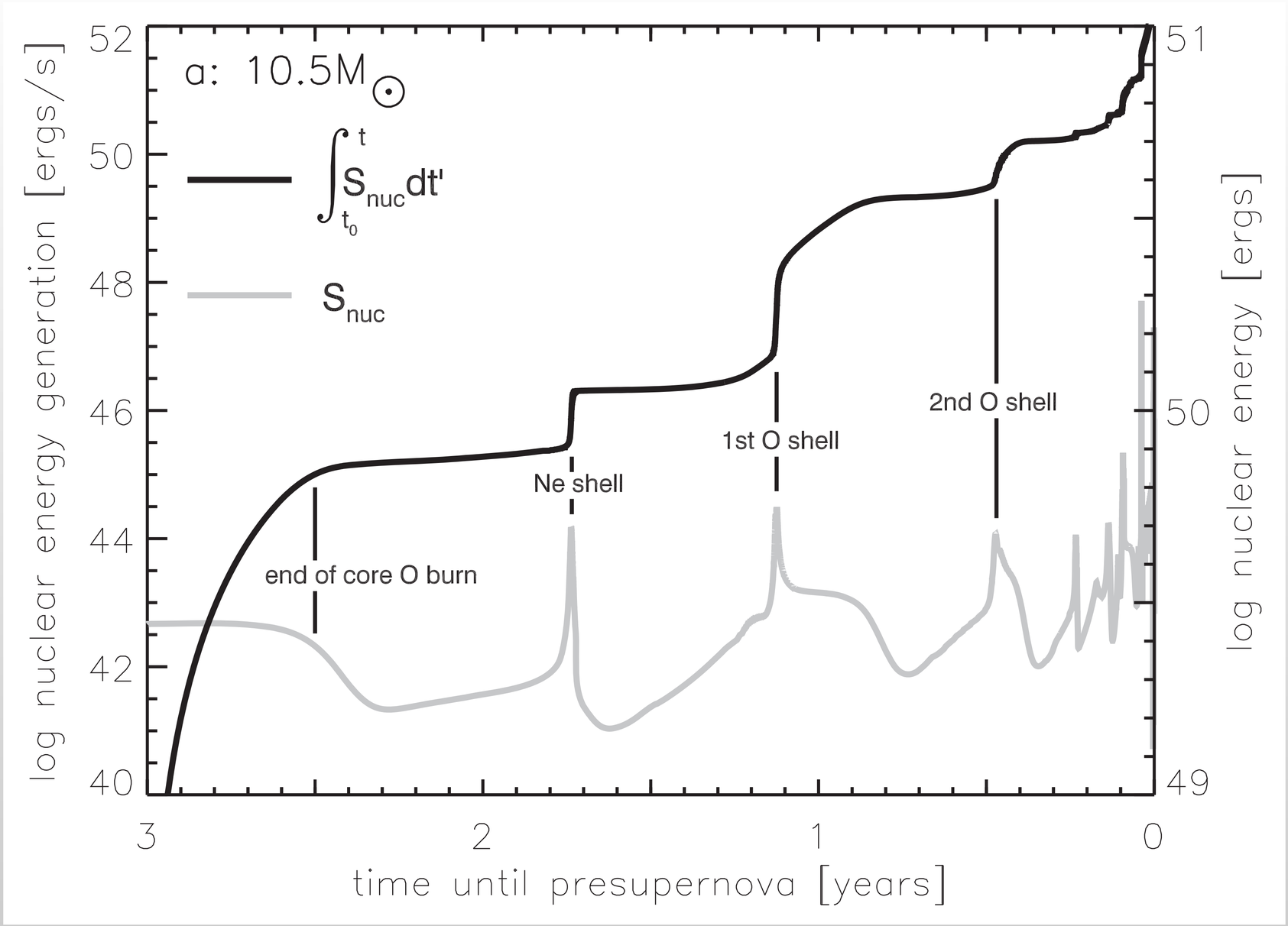
25 $M_\odot$ Presupernova Star (typical for 9 - 130 $M_\odot$)



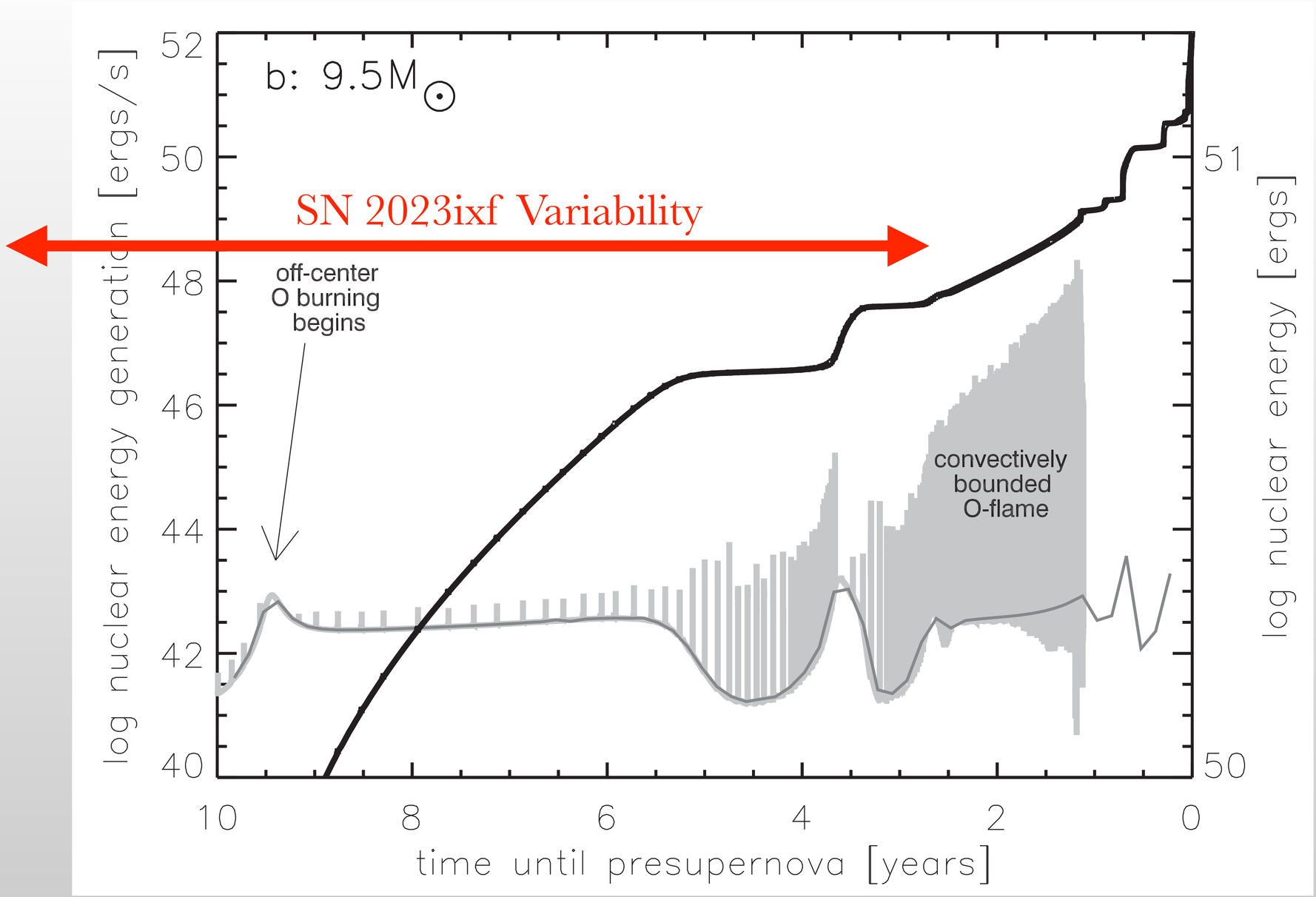
Actual – to scale

Burning Timescales

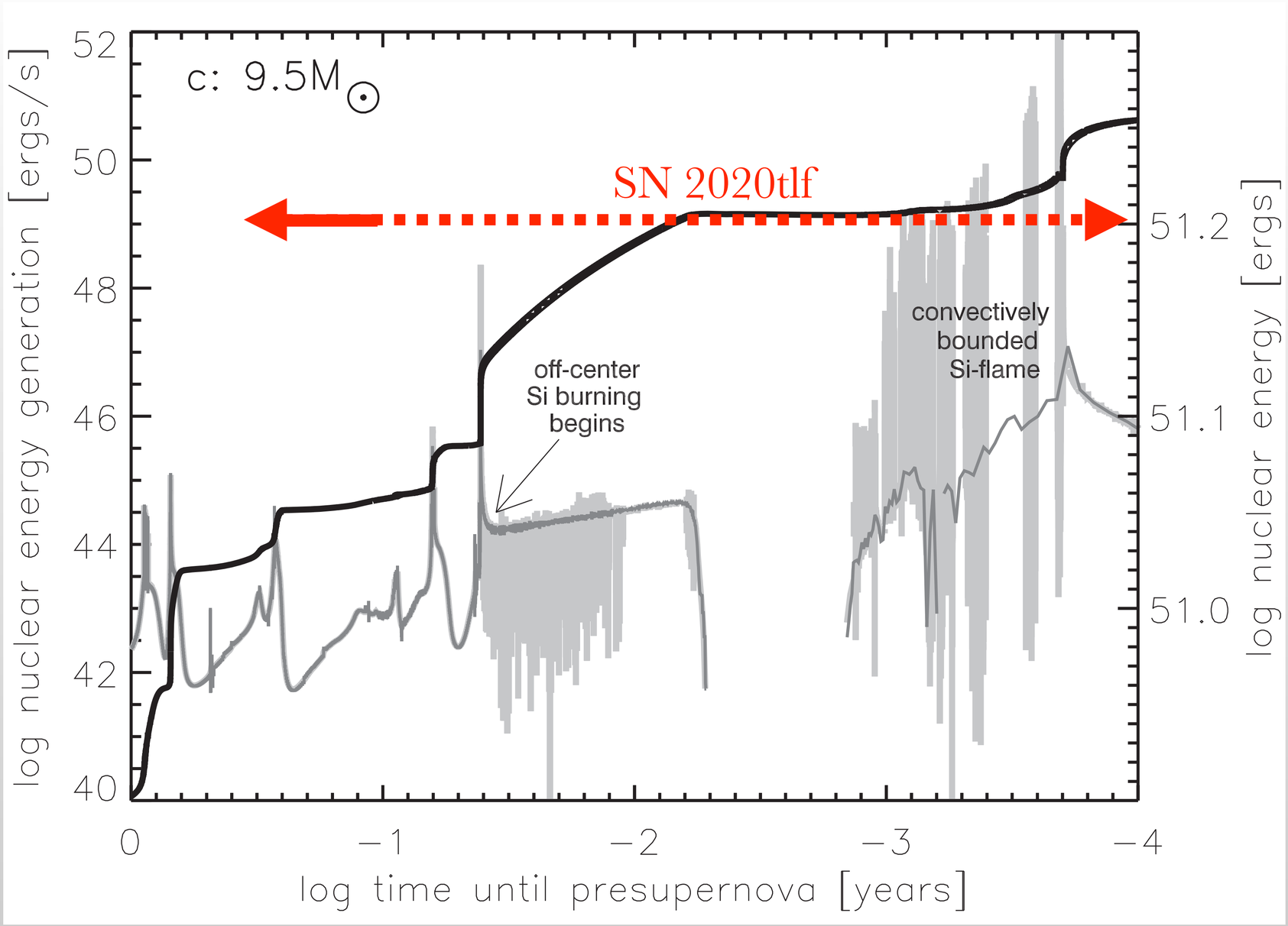
Element	Time (15 $M_\odot$)	Time (25 $M_\odot$)
C	6000 years	170 years
Ne	7 years	1.2 years
O	1.7 years	6 months
Si	1 week	1 day



Woosley & Heger (2015)

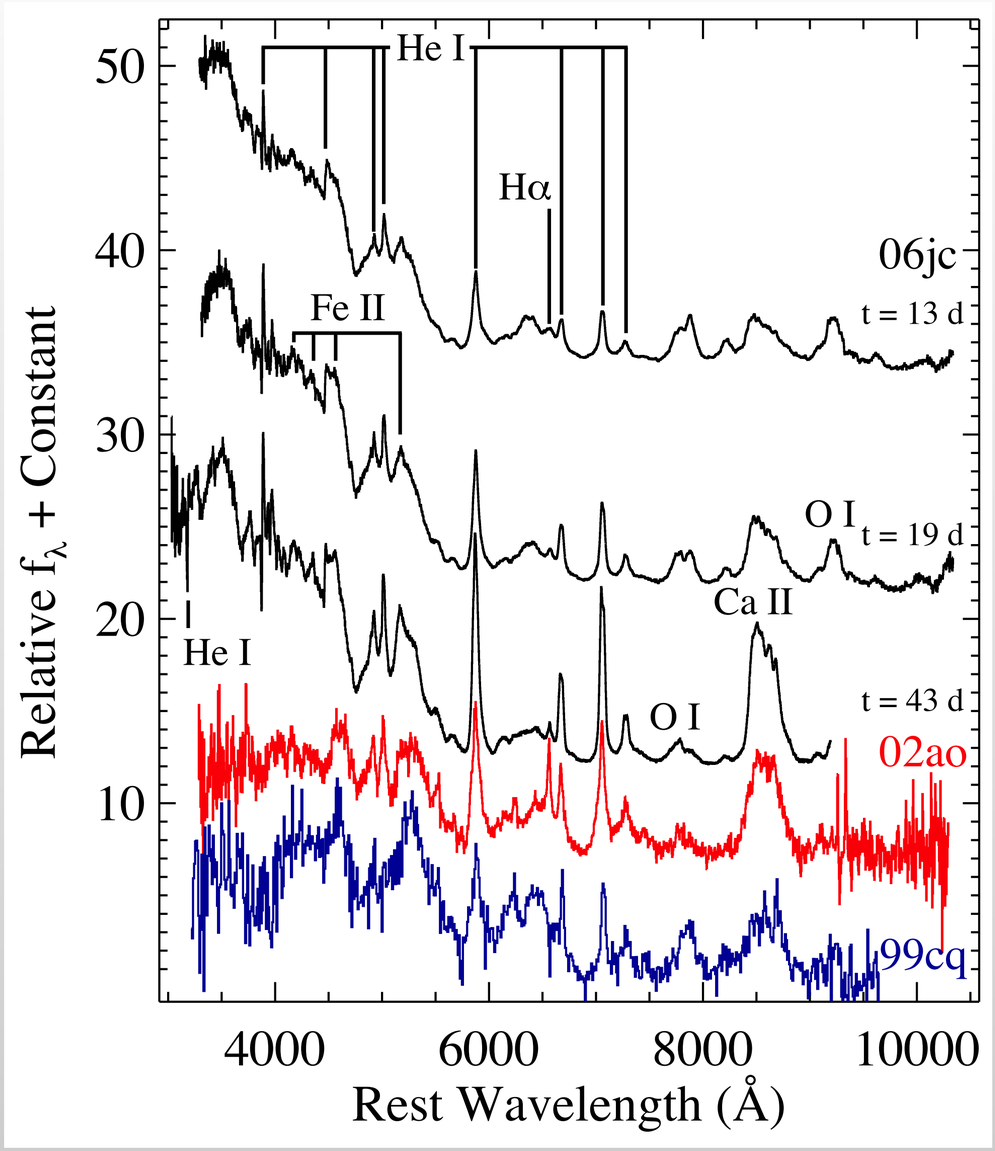


Woosley & Heger (2015)

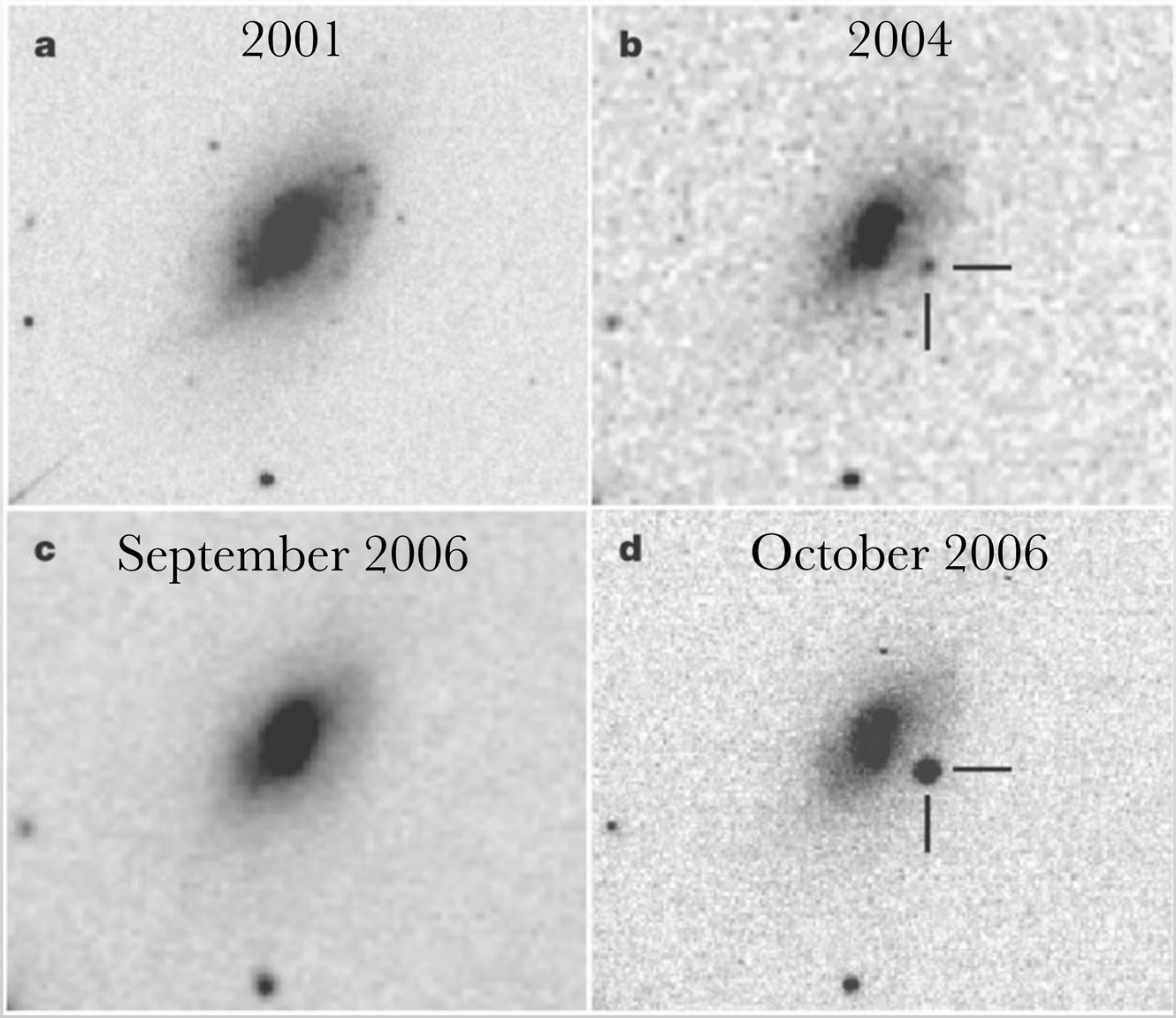


Woosley & Heger (2015)

SN 2006jc: Outburst, SN, CSM Interaction

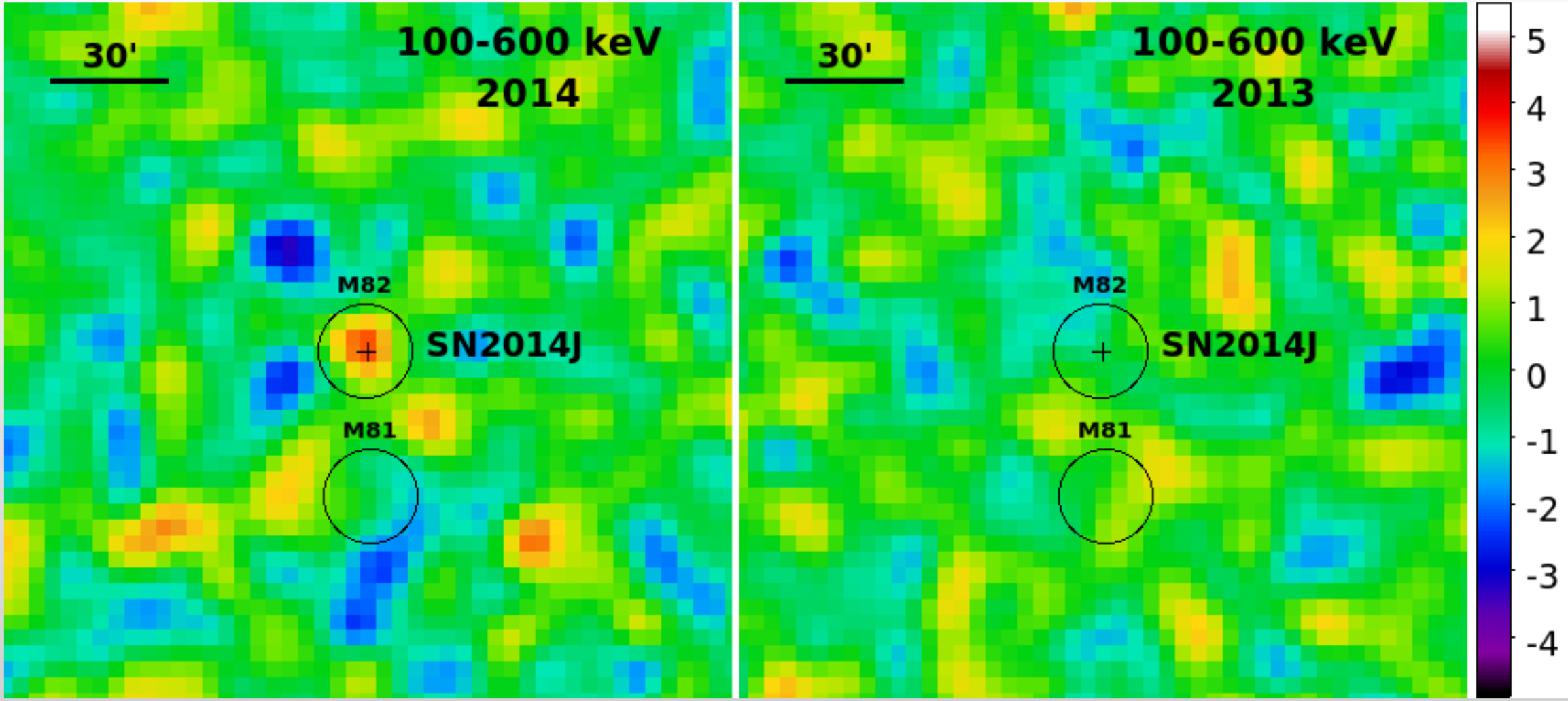


Foley et al. (2007)



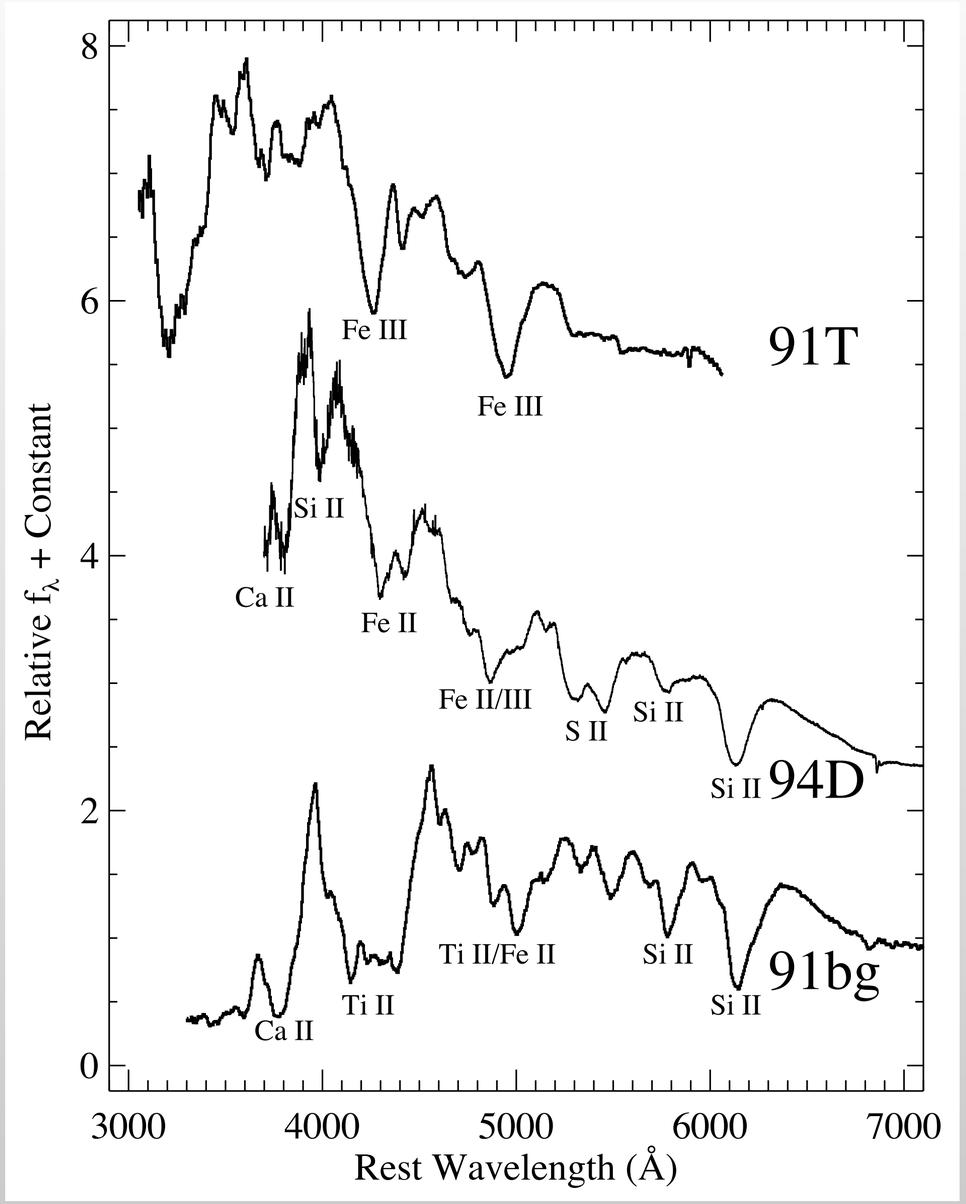
Pastorello et al. (2007) – see talk by Kyle Davis

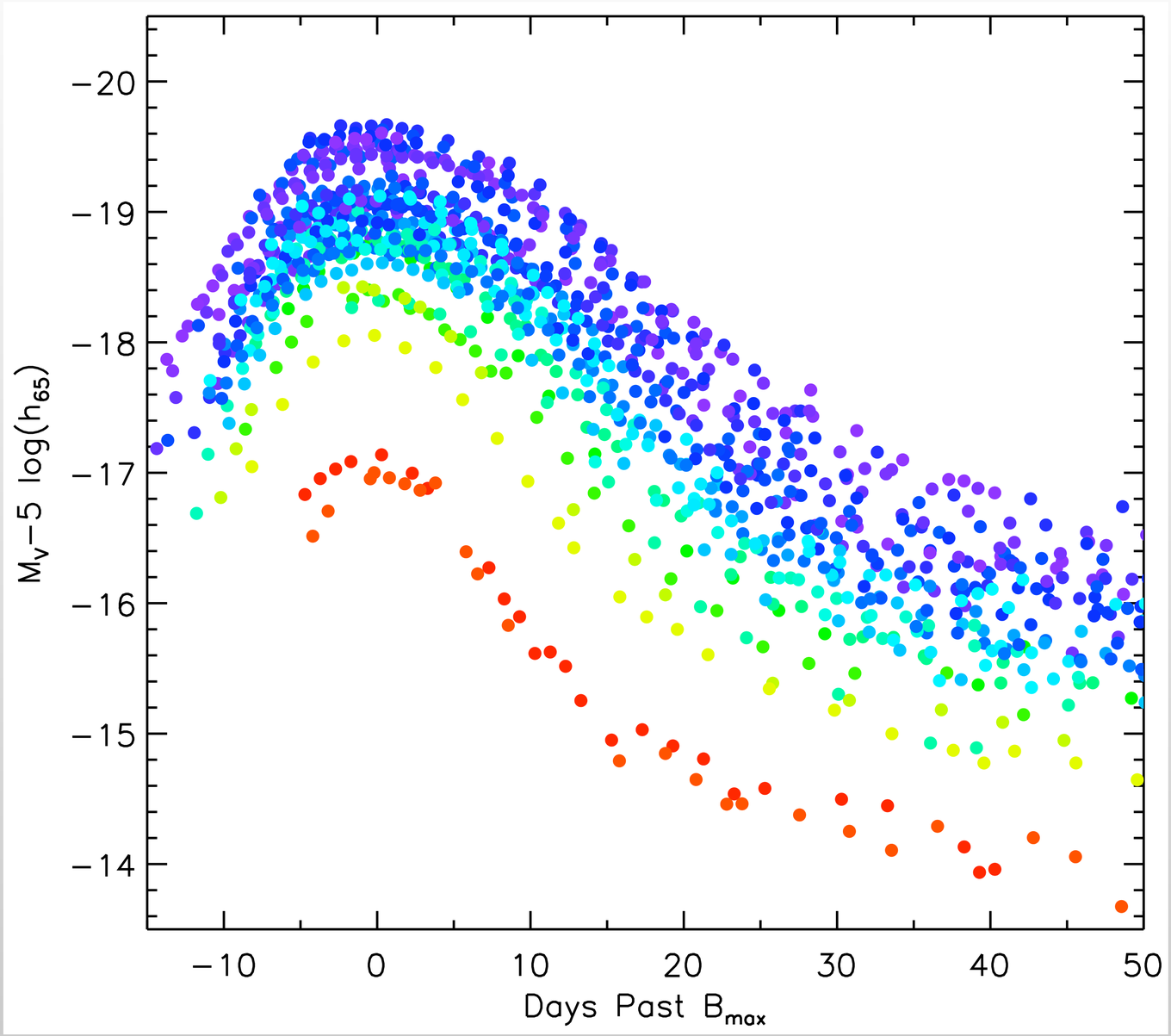
~0.6 M⊙ ^{56}Ni Directly from γ-rays in SN 2014J



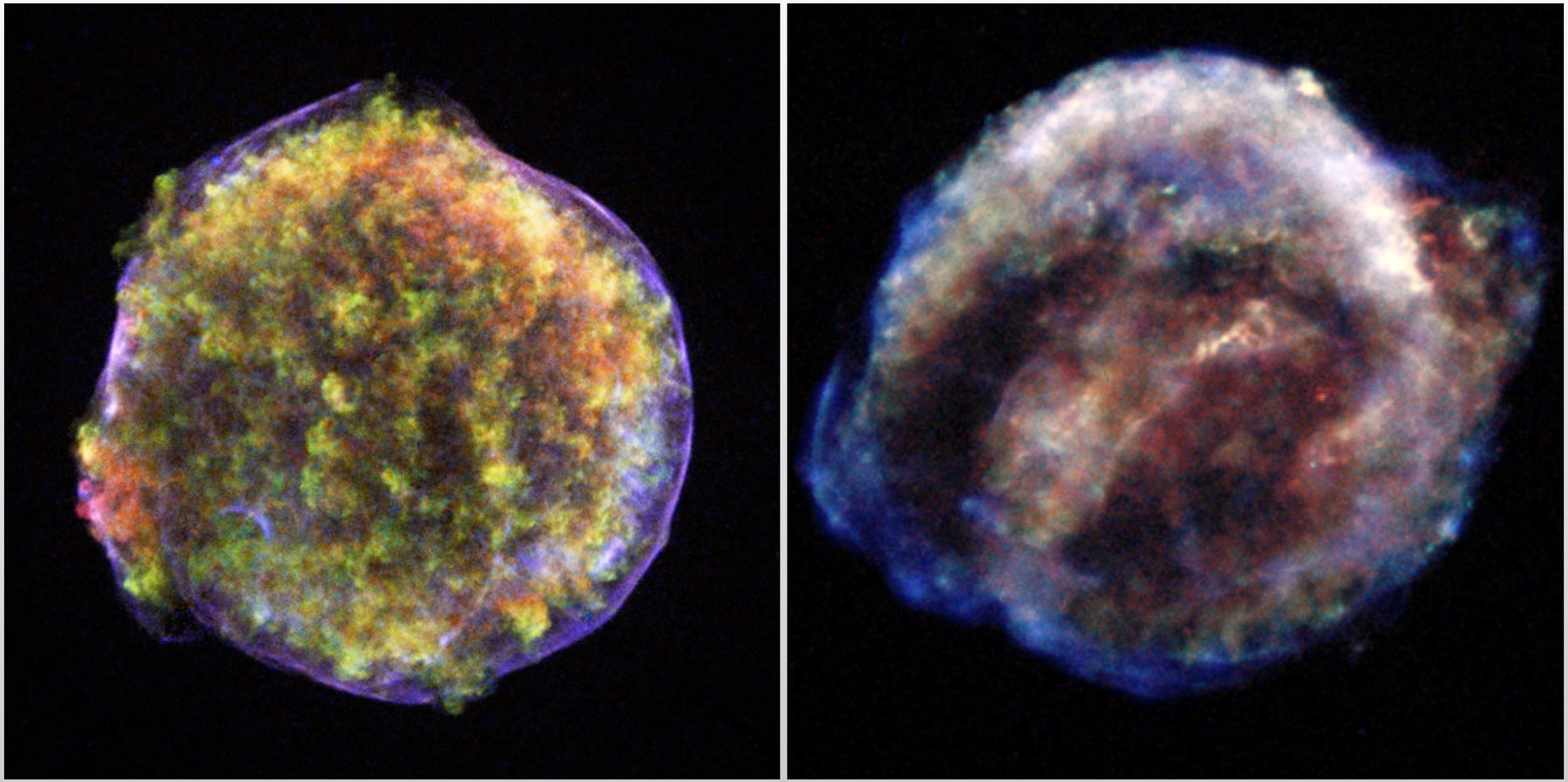
Churazov et al. (2014)

Type Ia Supernova Diversity (^{56}Ni Mostly)

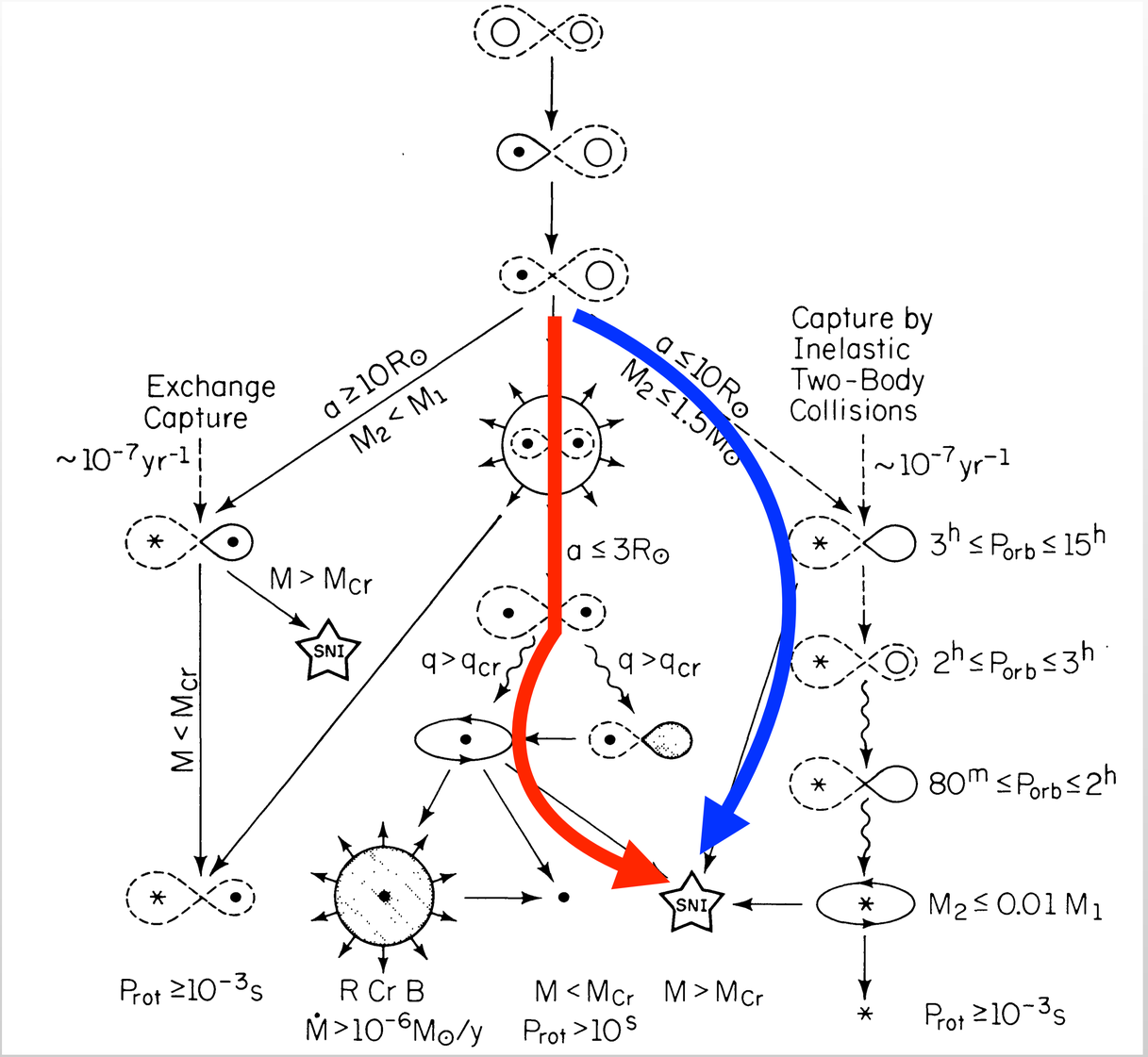




Different Explosions? Different Progenitors?



Potential SN Ia Progenitor Channels



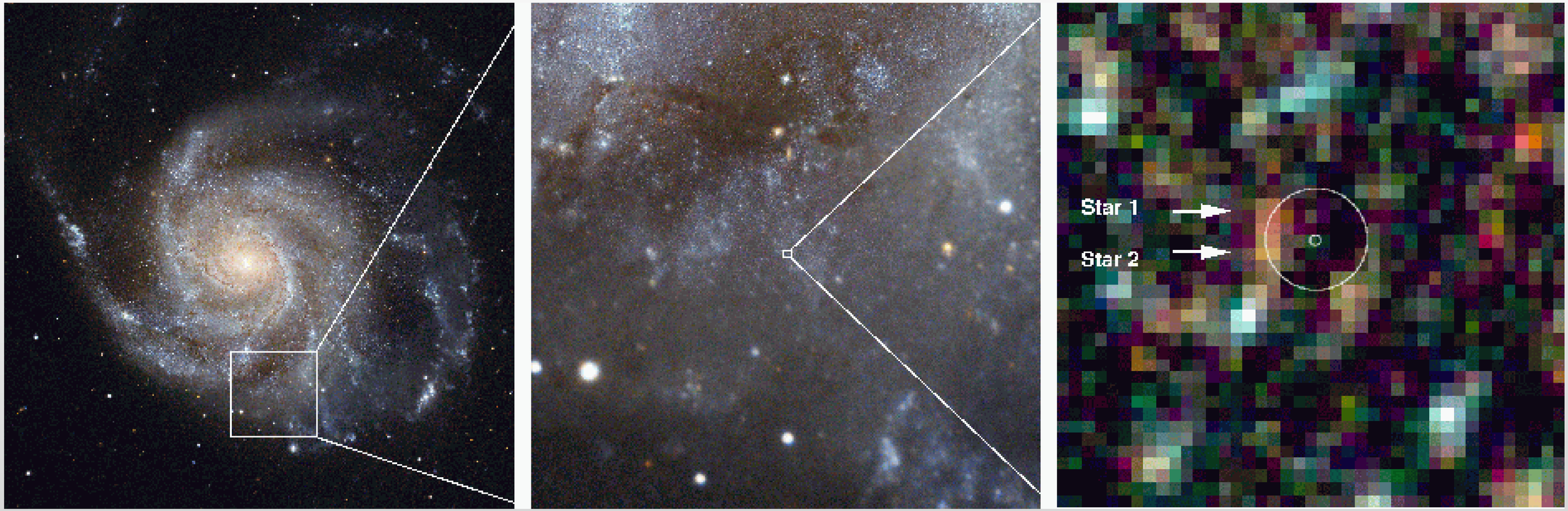
Single Degenerate:
1 White Dwarf

Double Degenerate:
2 White Dwarfs

Iben & Tutukov (1984)
see also Webbink (1984)

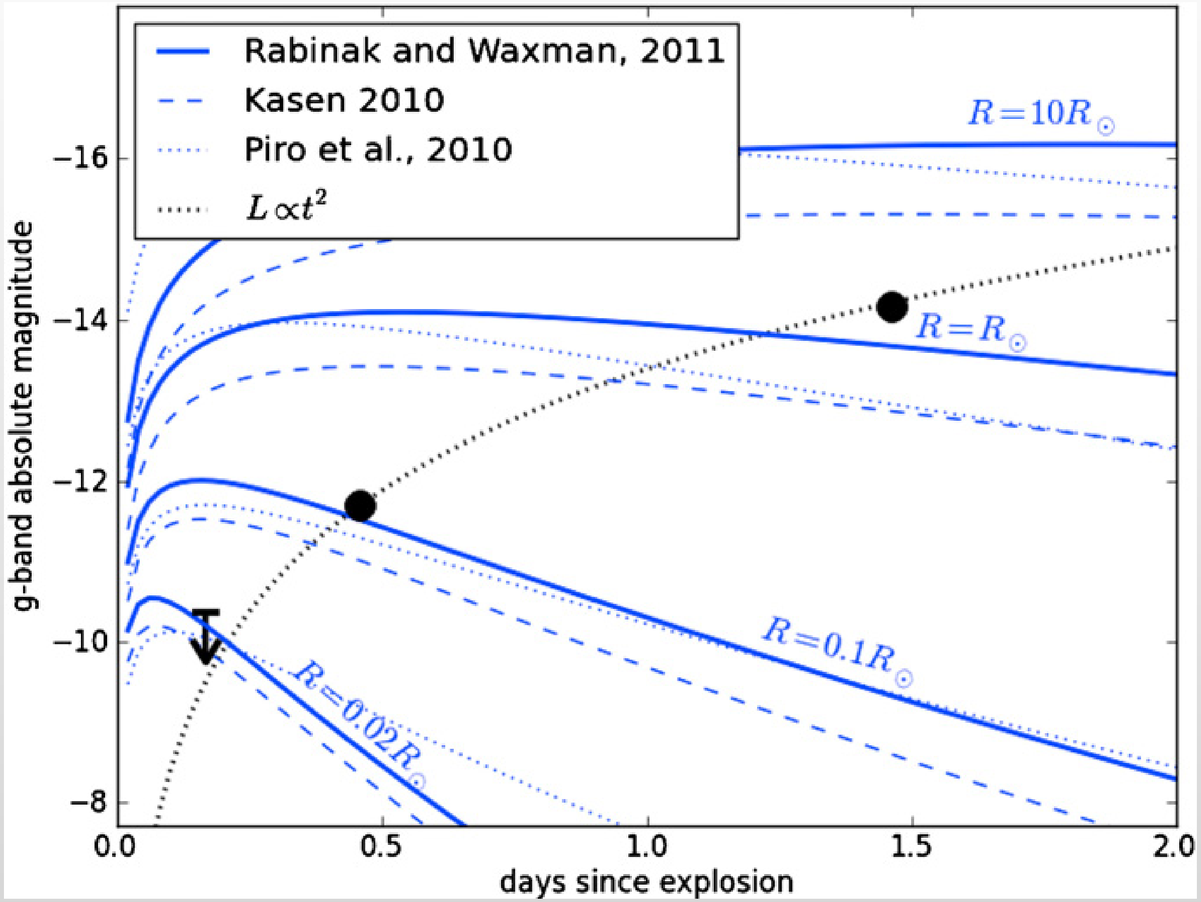
White D nerate)

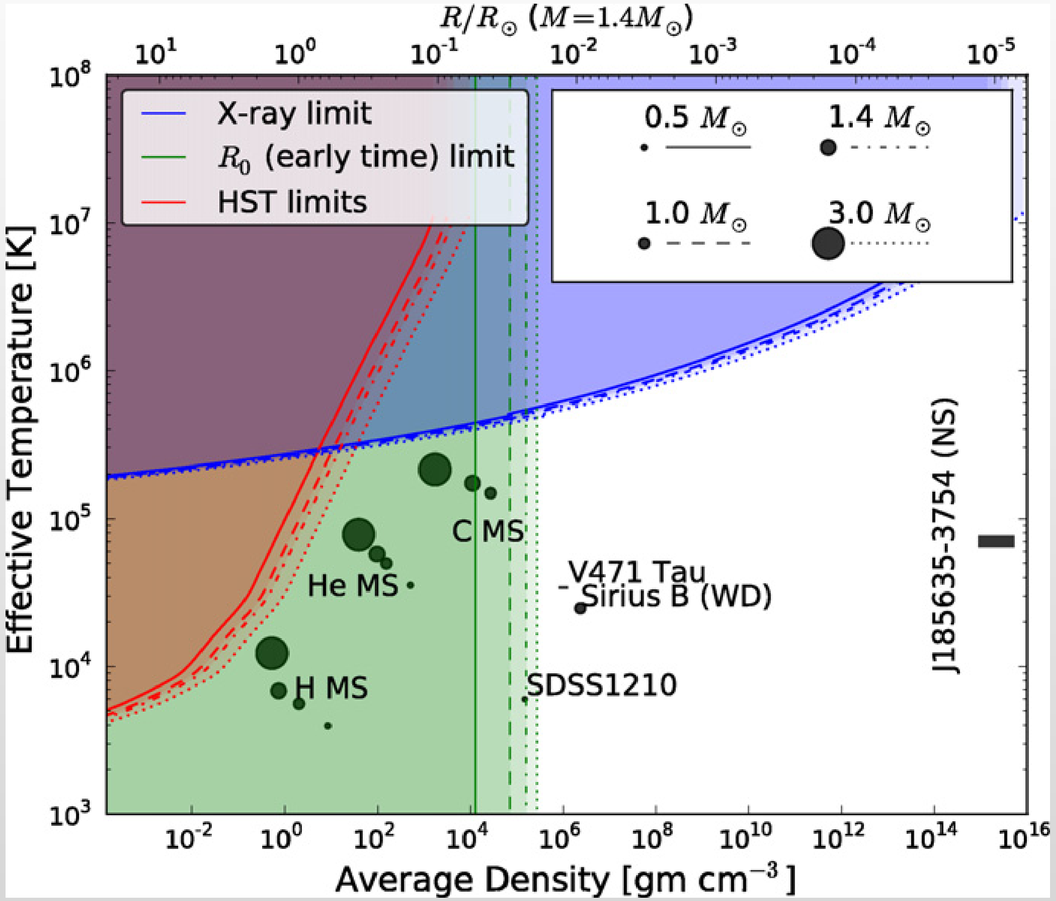
Double Degenerate Likely for Several SNe Ia



Li et al. 2011

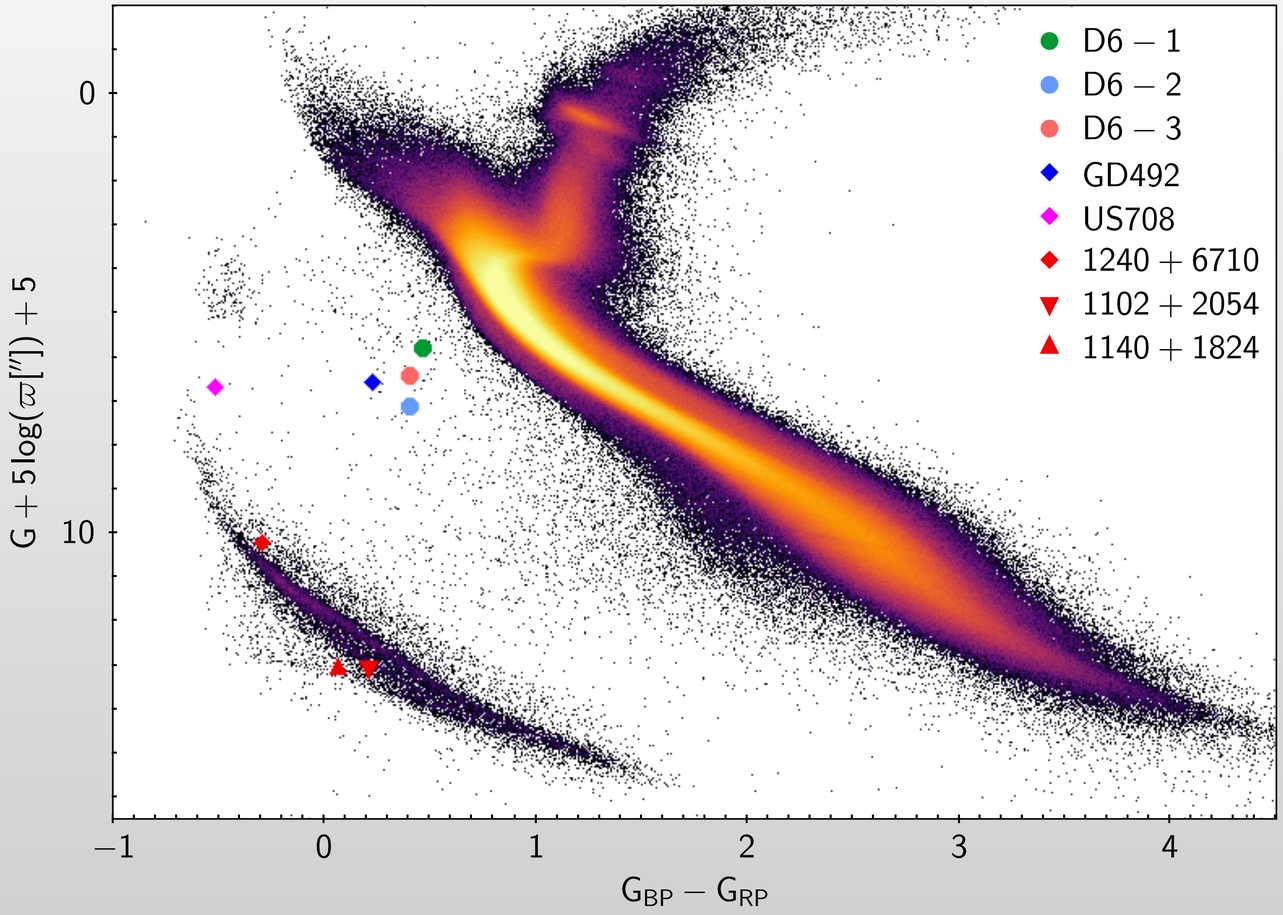
SNe Ia (2011fe) Have Degenerate Progenitors

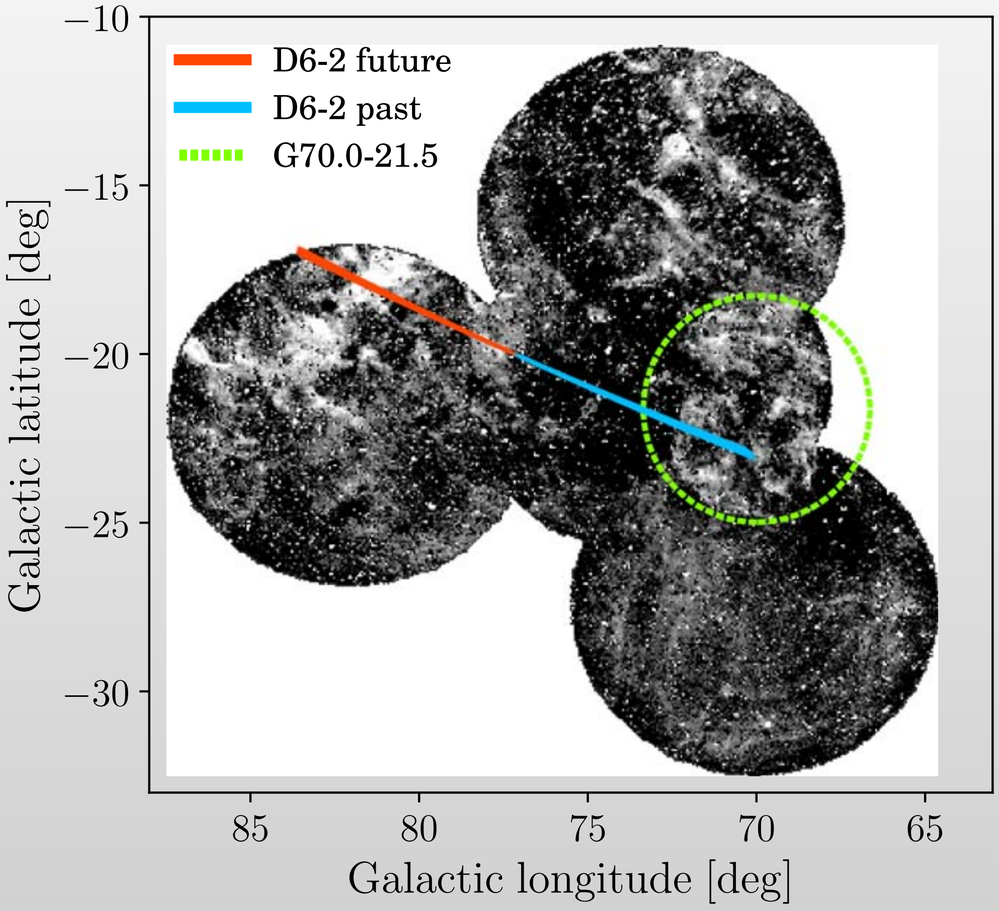




Bloom et al. (2012)

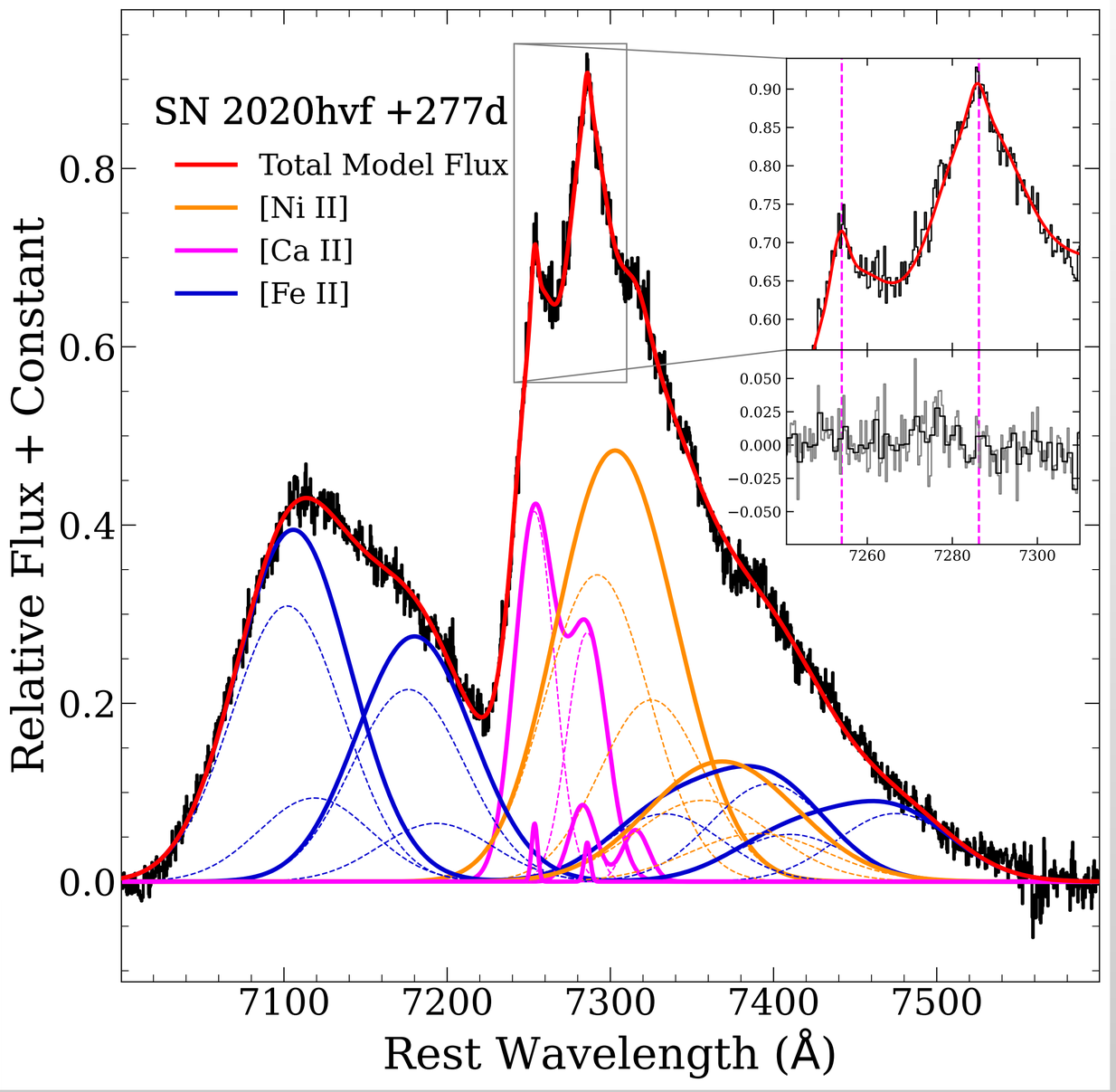
Surviving WD Companions





Shen et al. (2018)

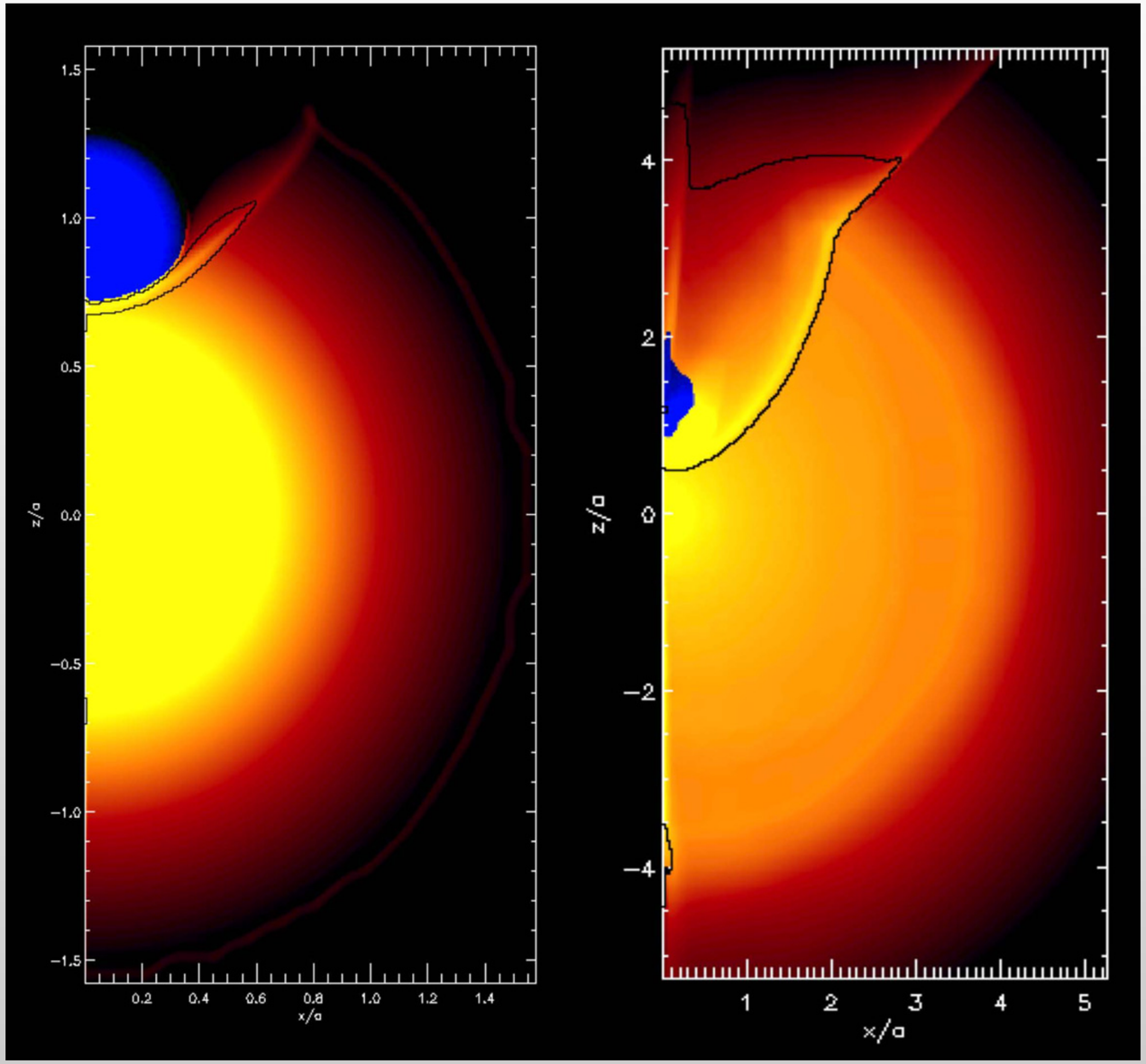
Surviving WD Companions

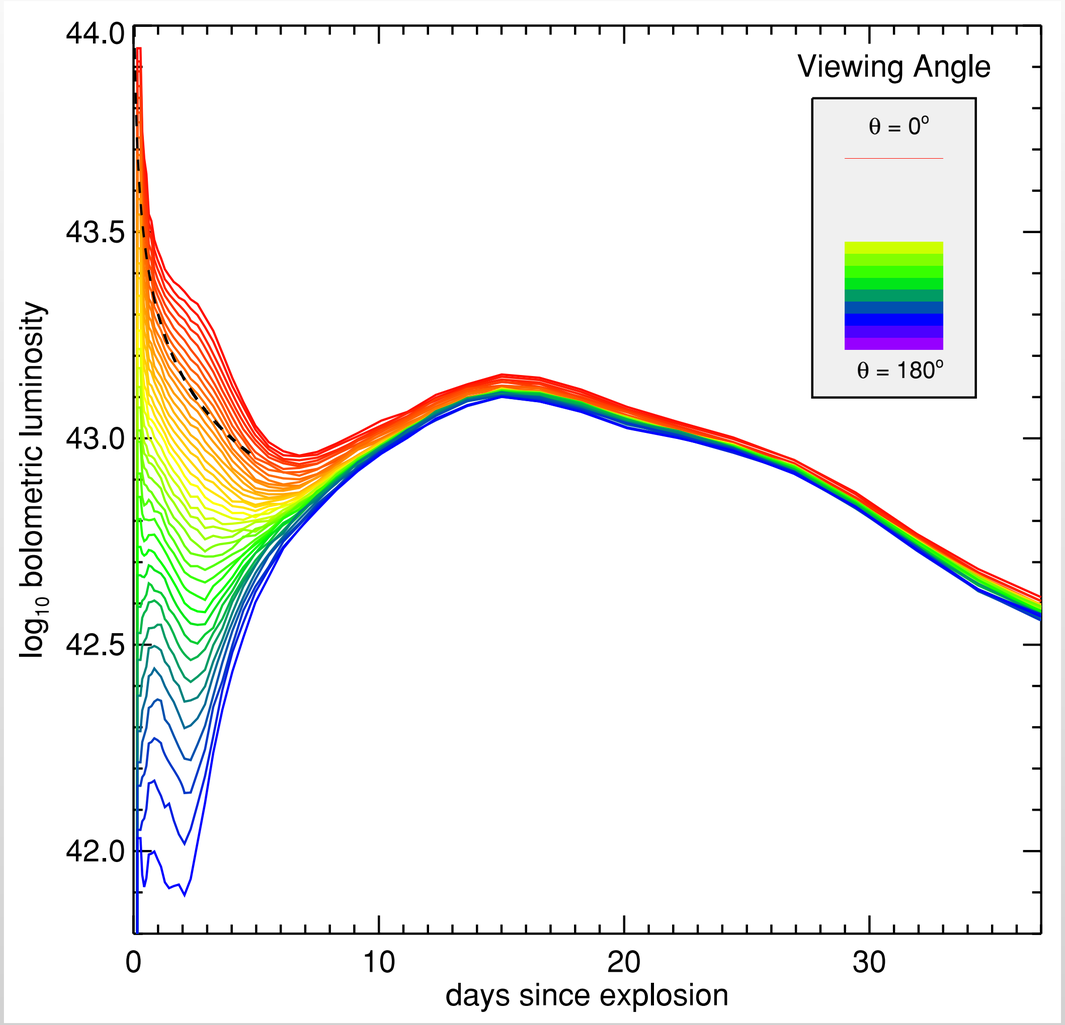


Siebert et al. (2023)
See talk tomorrow!

erate

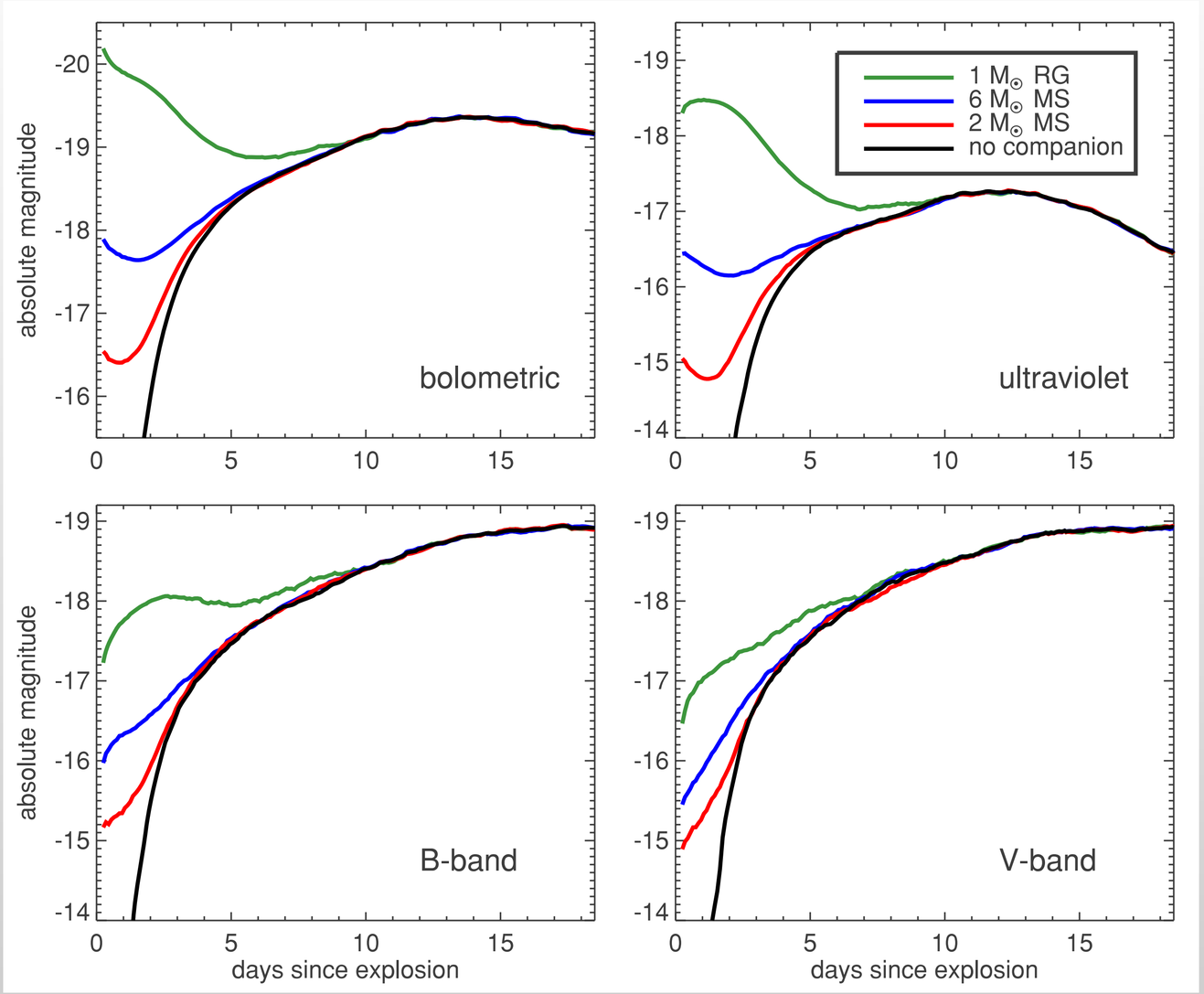
1 WD: Companion Interaction?





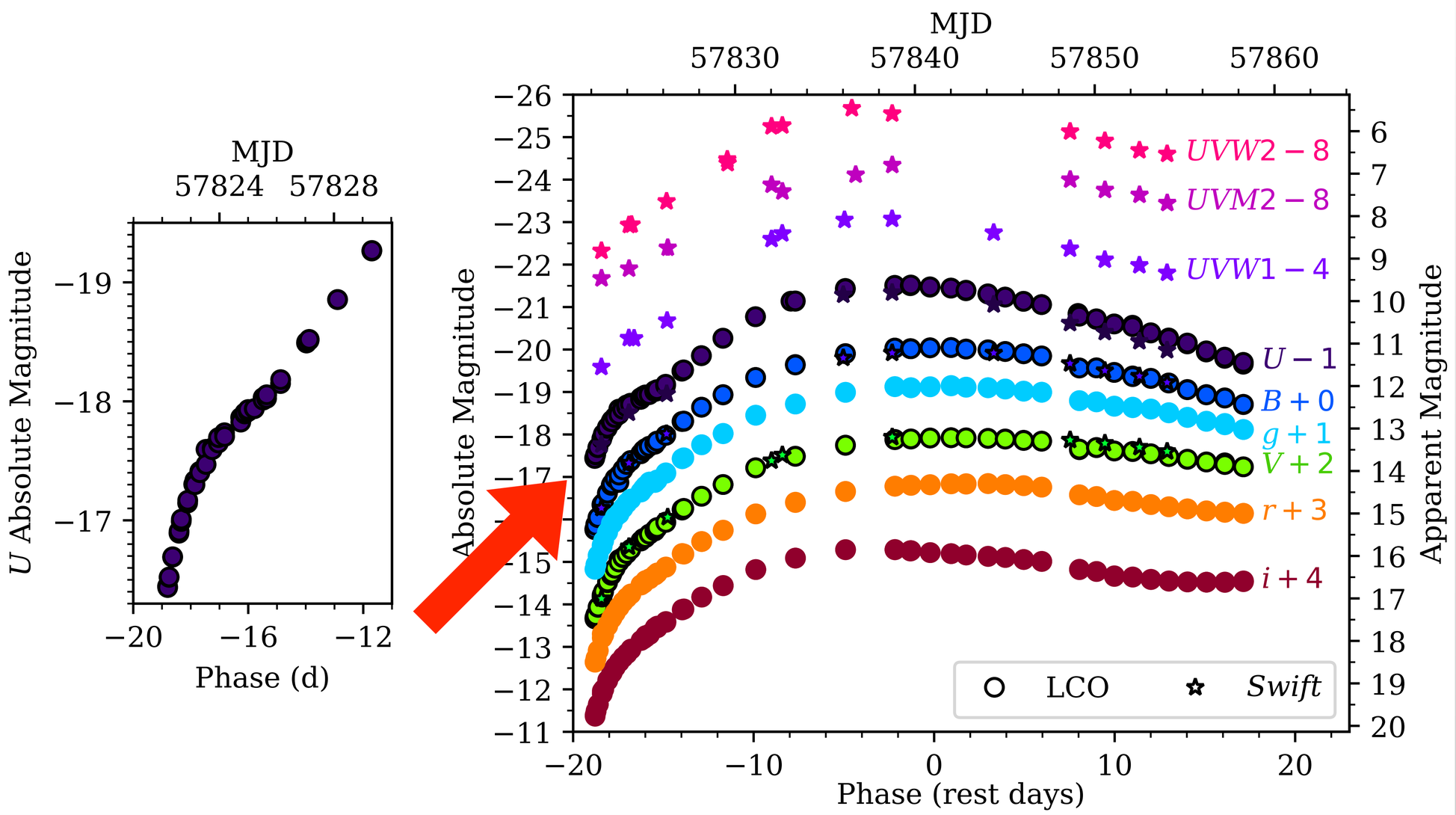
Kasen et al. (2010)

1 WD: Companion Interaction?



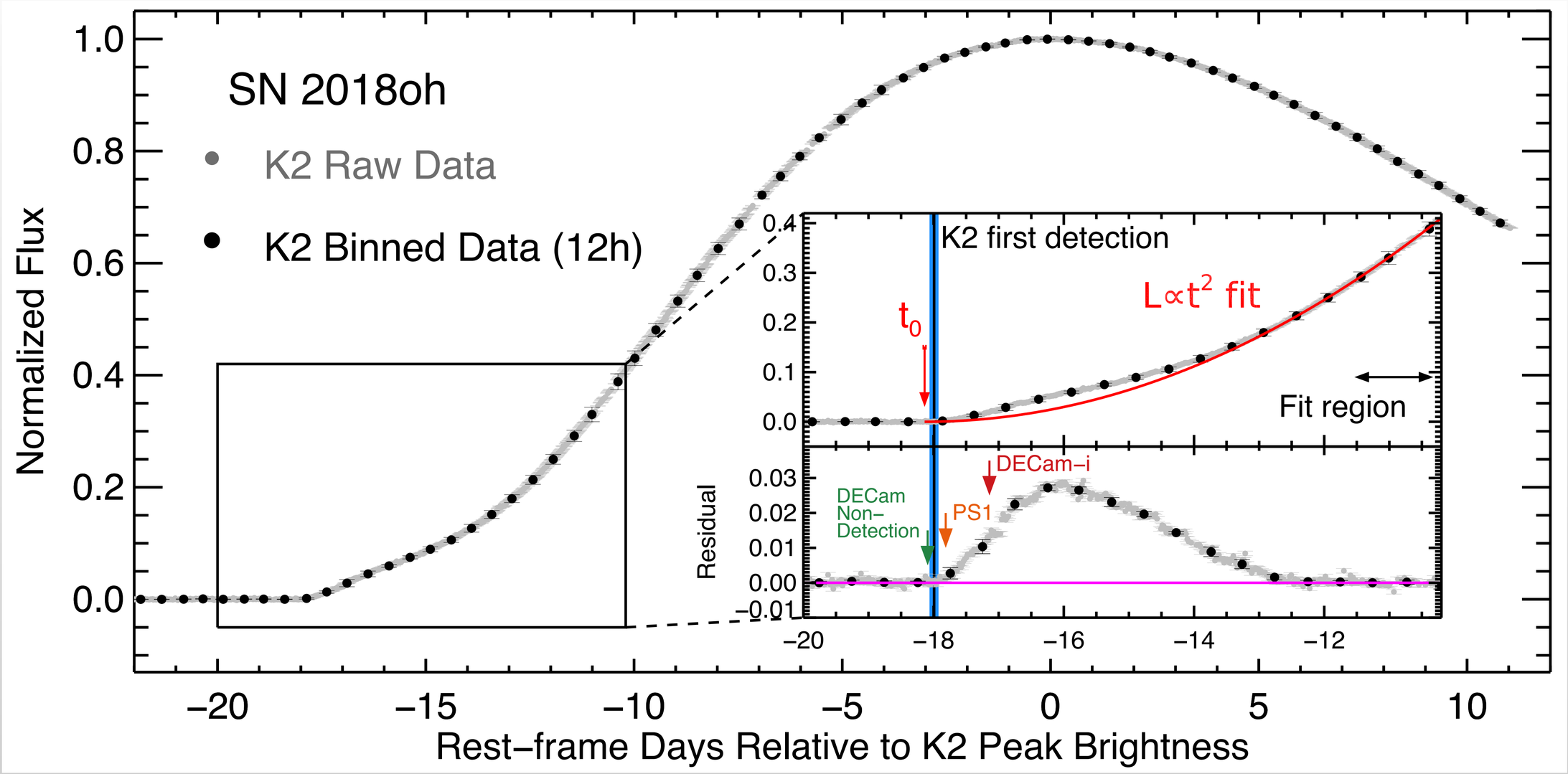
Kasen et al. (2010)

Early Flux Excess: Best Evidence for Companion

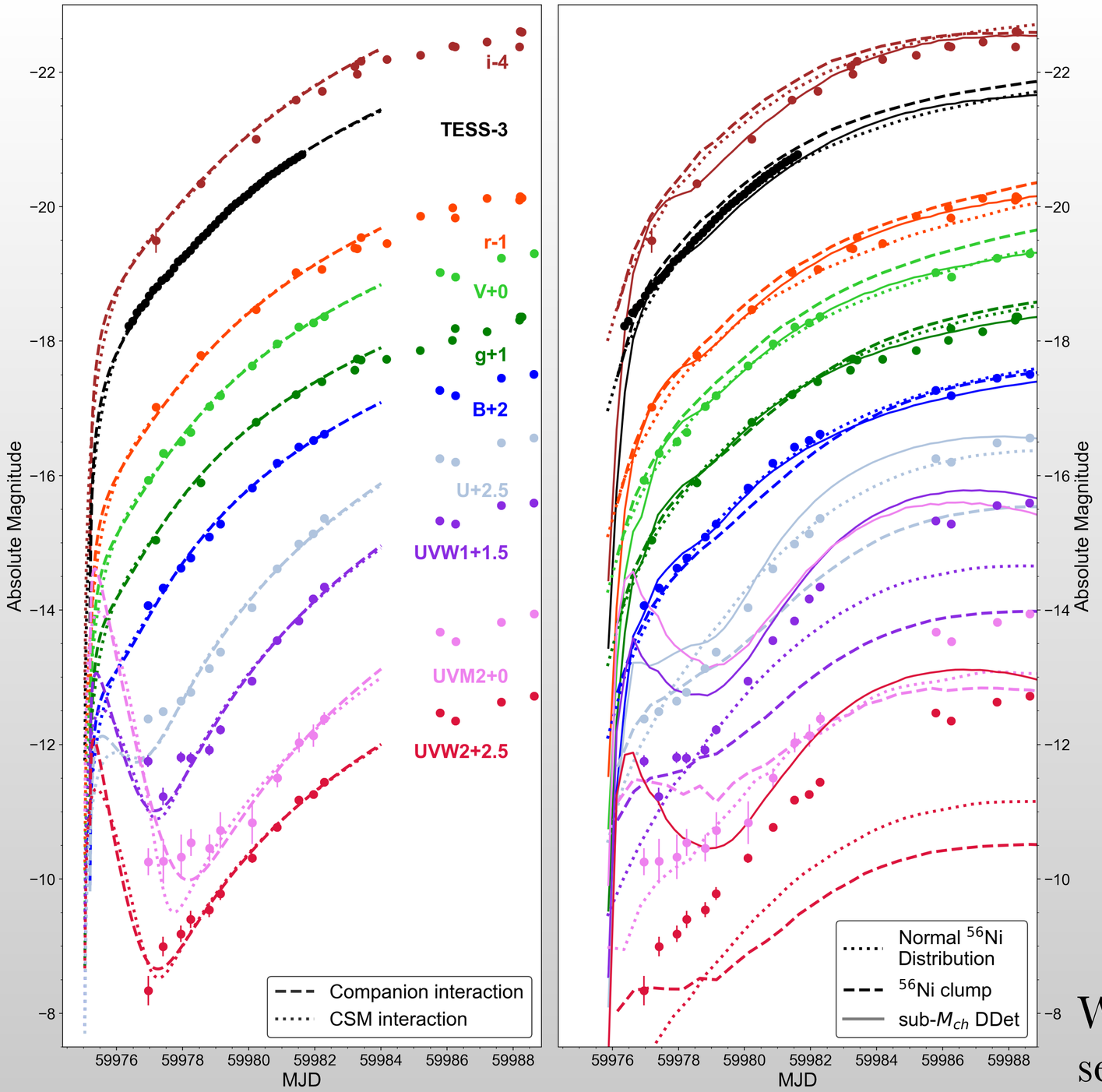


Hosseinzadeh et al. (2017)

Excess Early Flux for SN 2018oh



Dimitriadis et al. (2019)
see also Shappee et al. (2019), Ni talk!

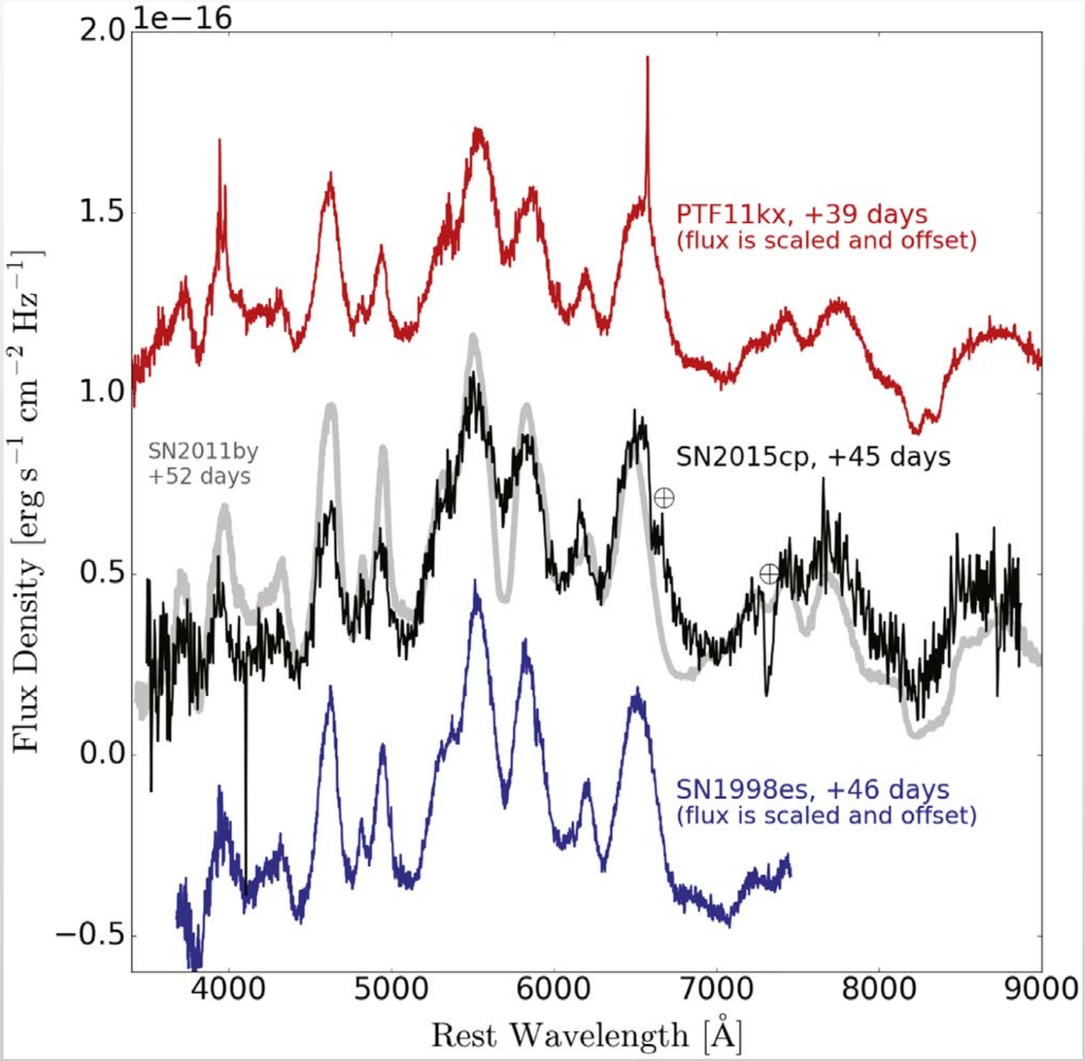


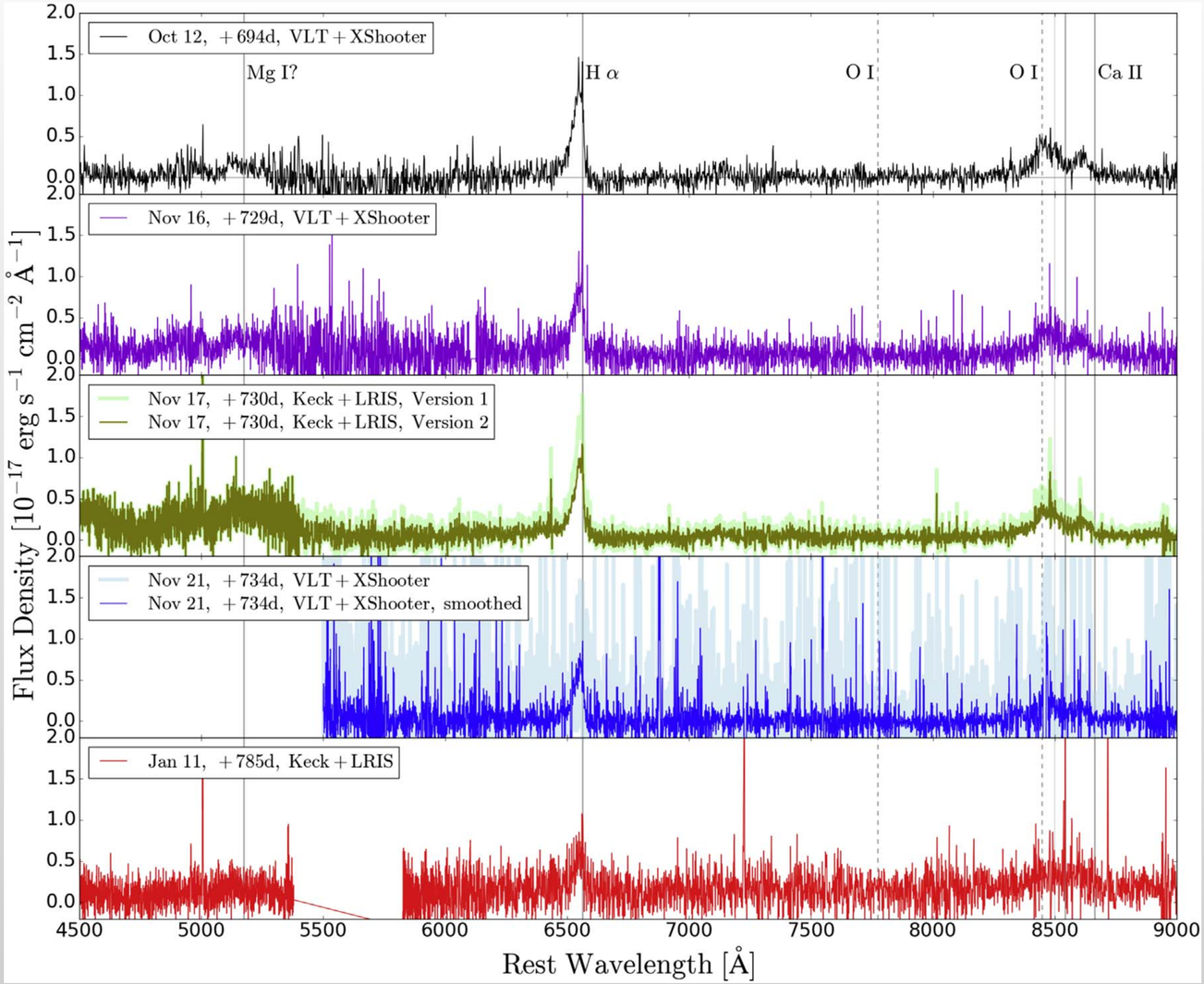
No model fits!

Other observations also rule out models

Wang et al. (2023)
see also Hosseinzadeh et al. (2023)

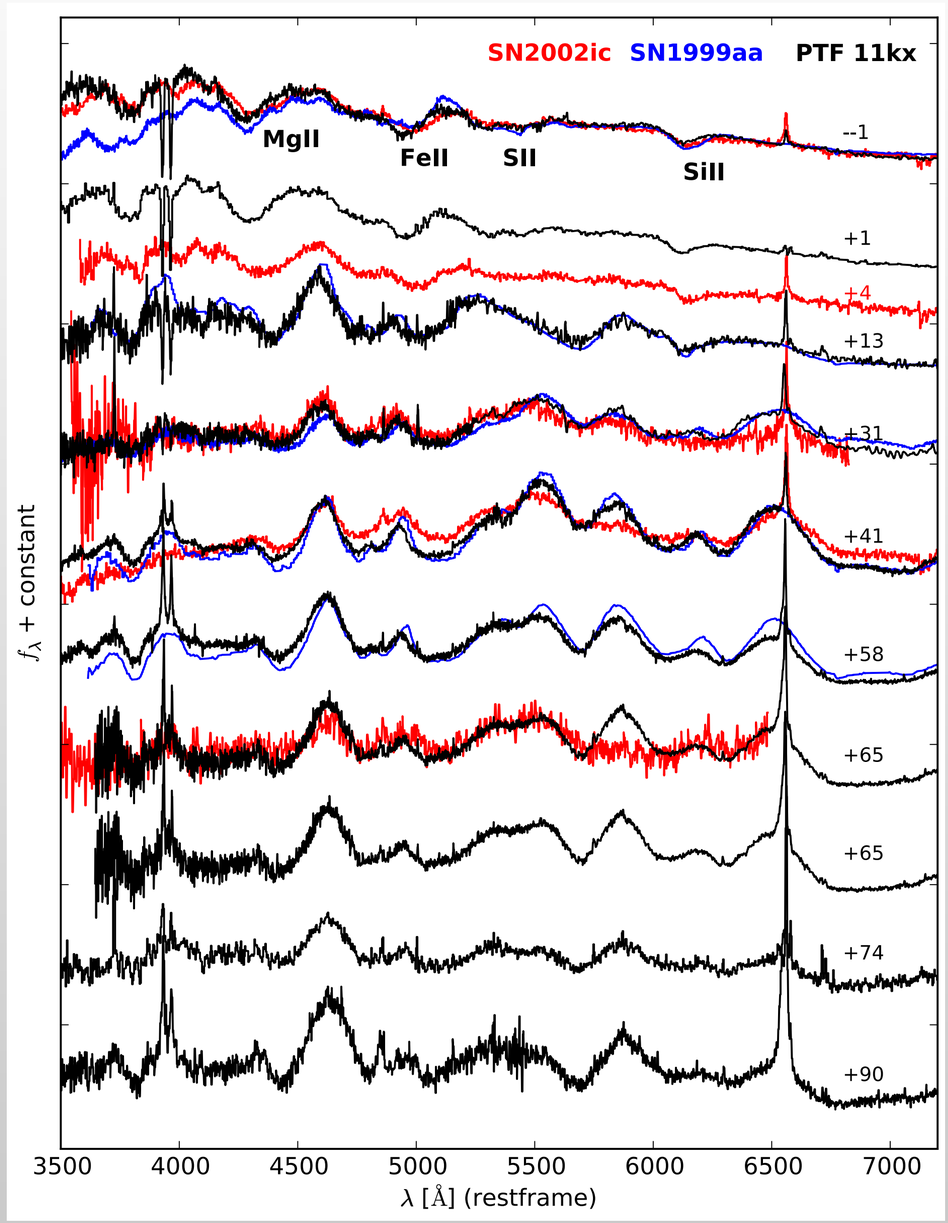
Delayed H Interaction (r > 7000 AU)

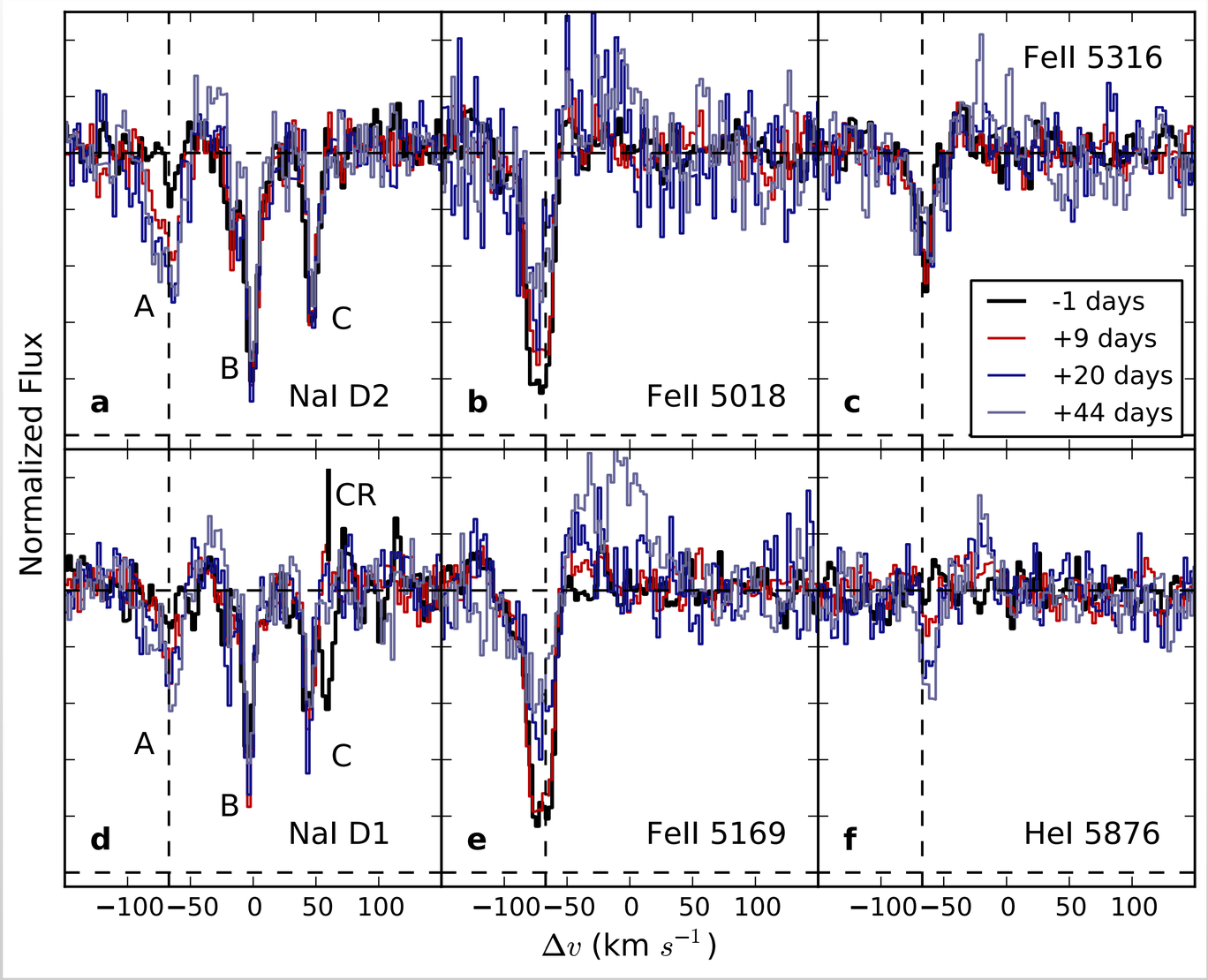




Graham et al. (2019)

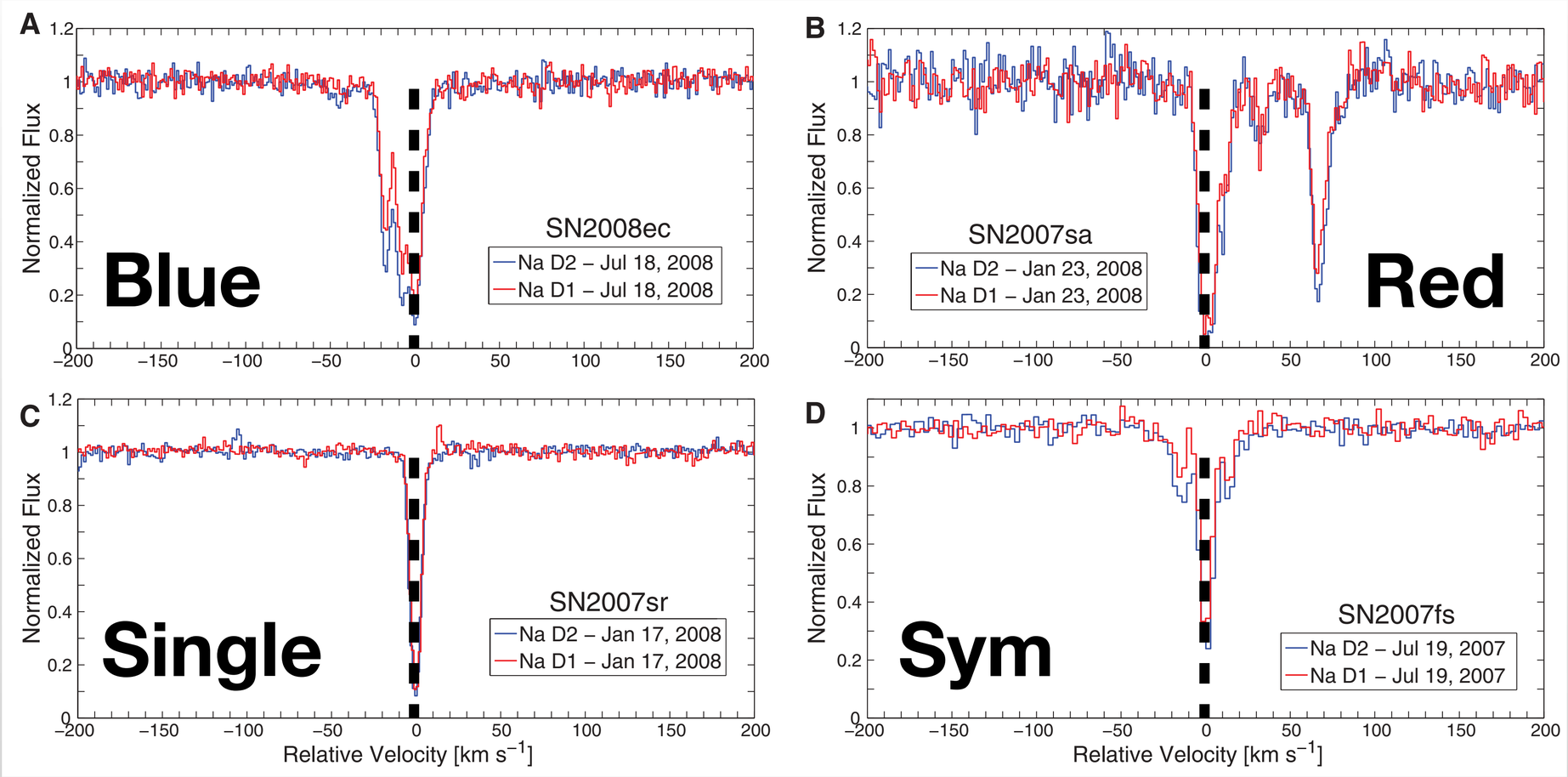
SNe Ia-CSM H Interaction (r ~ 700 AU)





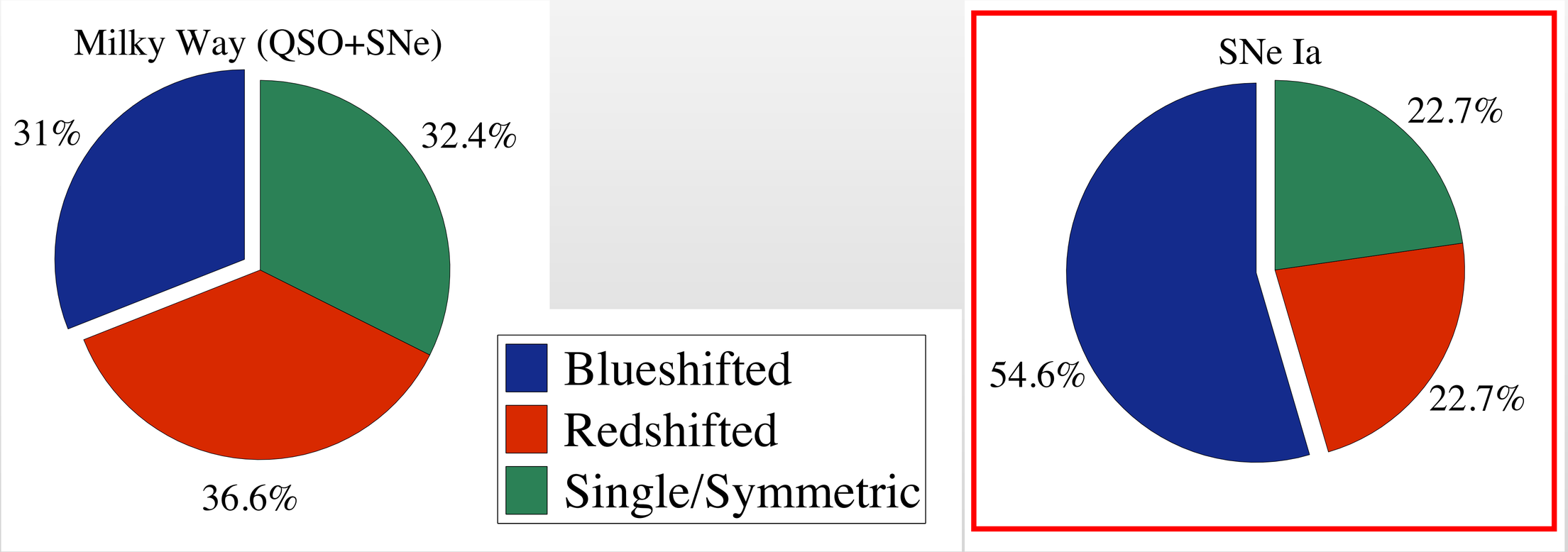
Dilday et al. (2012)

High-Resolution Spectra Probe CSM



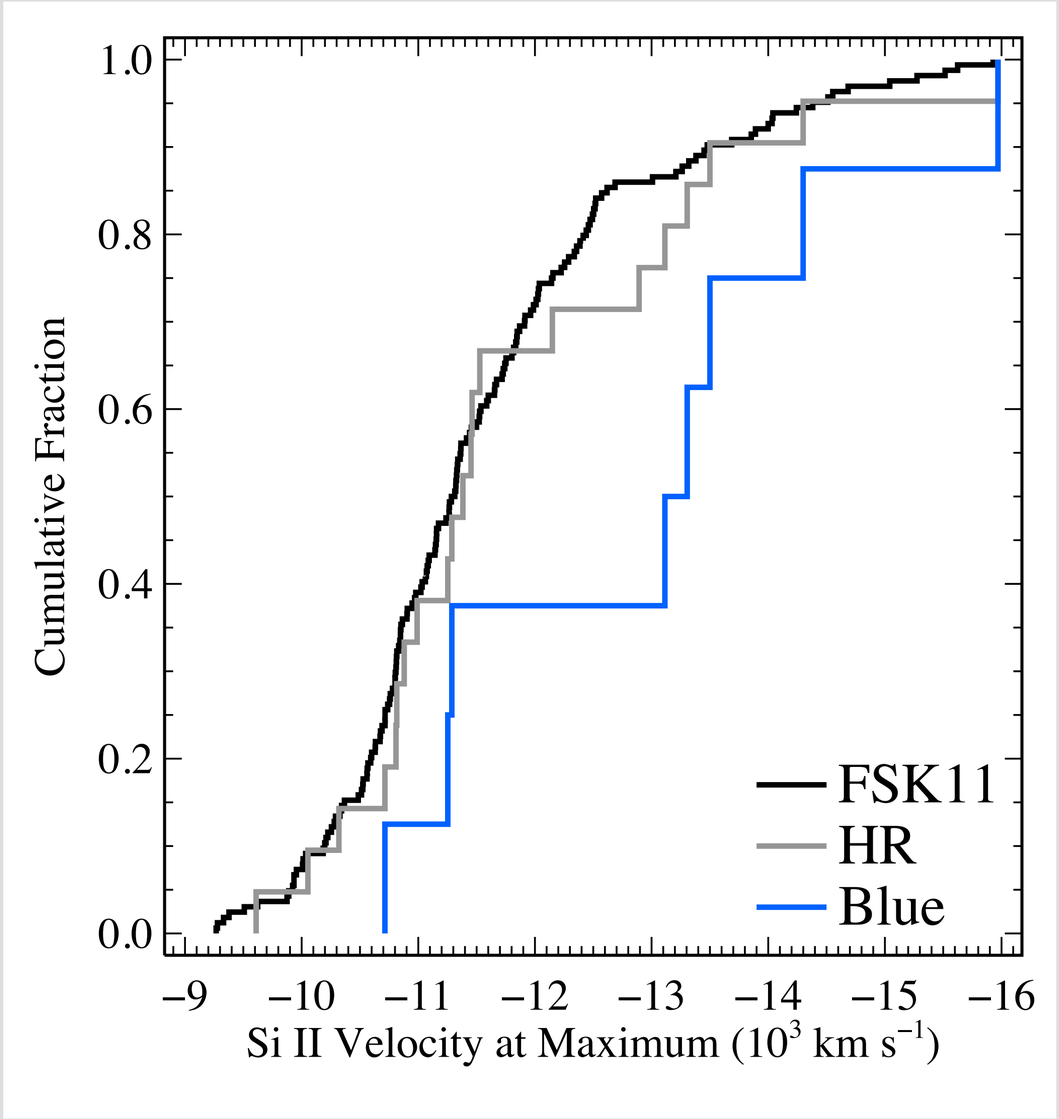
Sternberg et al. (2011)

(Some) SN Ia Progenitor Systems Have Outflows



Sternberg et al. (2011)

SN Ia Explosions Linked to Environment



Full SN Ia Sample

High-Res Sample

Blueshifted Na

Foley et al. (2012)

Type Ia Supernovae

1. Relatively Standard Luminosity
2. Relatively Standard Velocity
3. Usually no H or He in Spectra
4. C/O Burning
5. Stratified Ejecta
6. Variety of Hosts/Environments
7. Pretty Spherical Explosion
8. No Companion Directly Detected
9. Indications of CSM/Companions in some SNe Ia
10. No X-ray/Radio Emission
11. Gamma-rays Detected (^{56}Ni Powered)
12. Roughly 1 SN Ia / MW / century
13. Delay Time Distribution ~t^{-1}

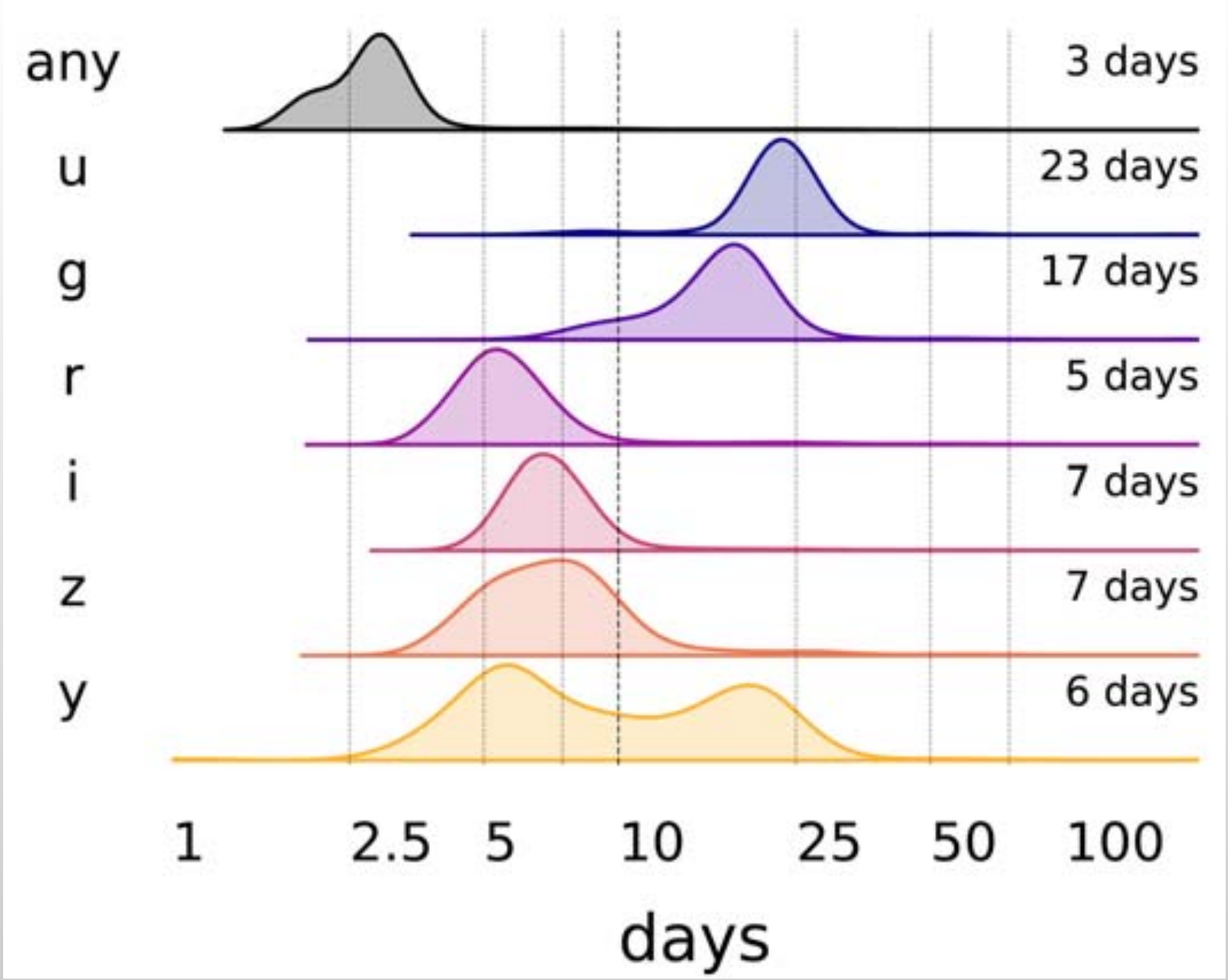
A C/O White Dwarf that accretes matter from a Binary Companion, resulting in an explosion. The Explosion Disrupts the White Dwarf.

The Nature of the Companion is *Still* an Open Question.
Current Data Points to *Multiple* Progenitor Channels.

What now?

How do we make progress?

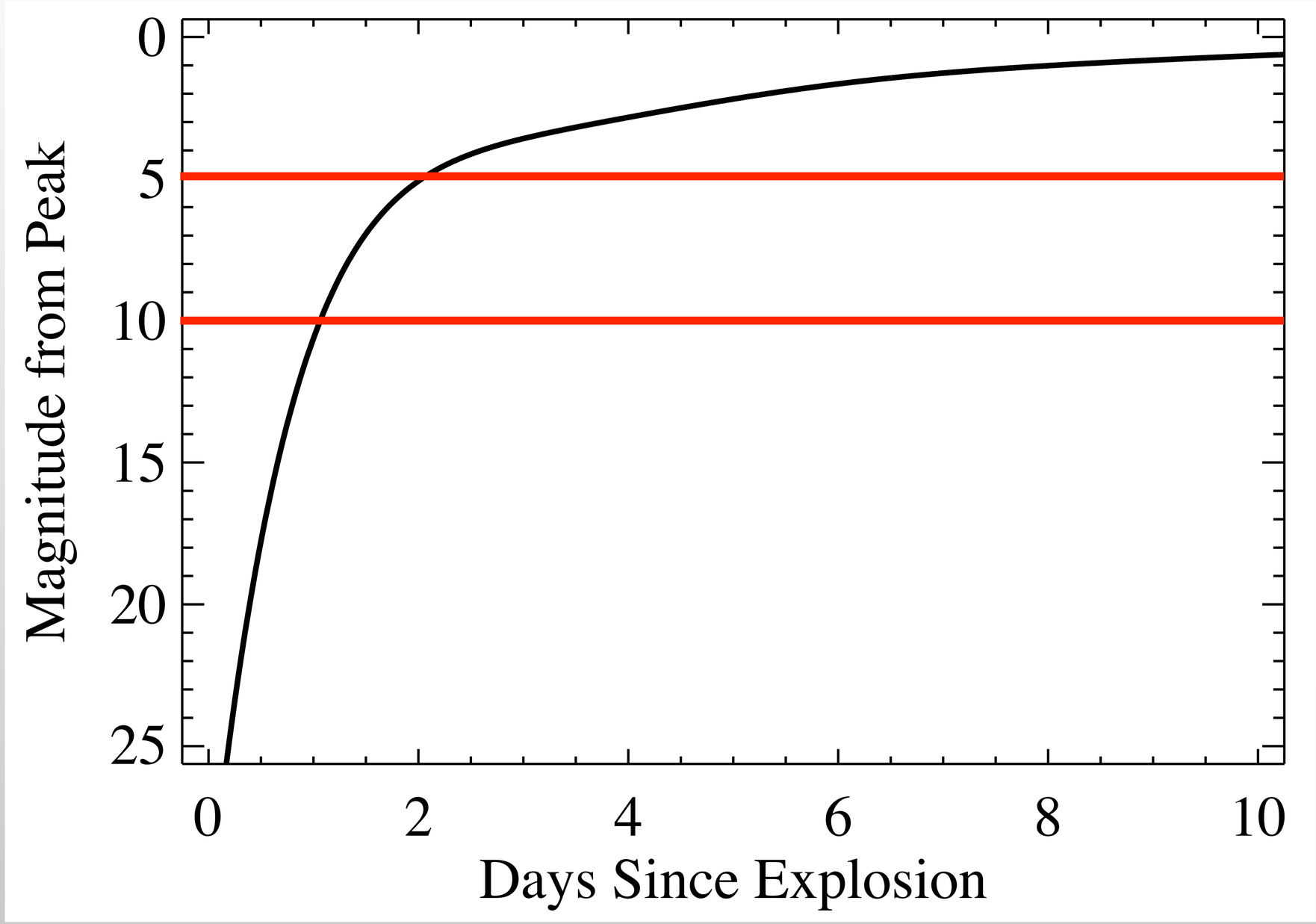
Rubin/LSST will *not* (alone) save us



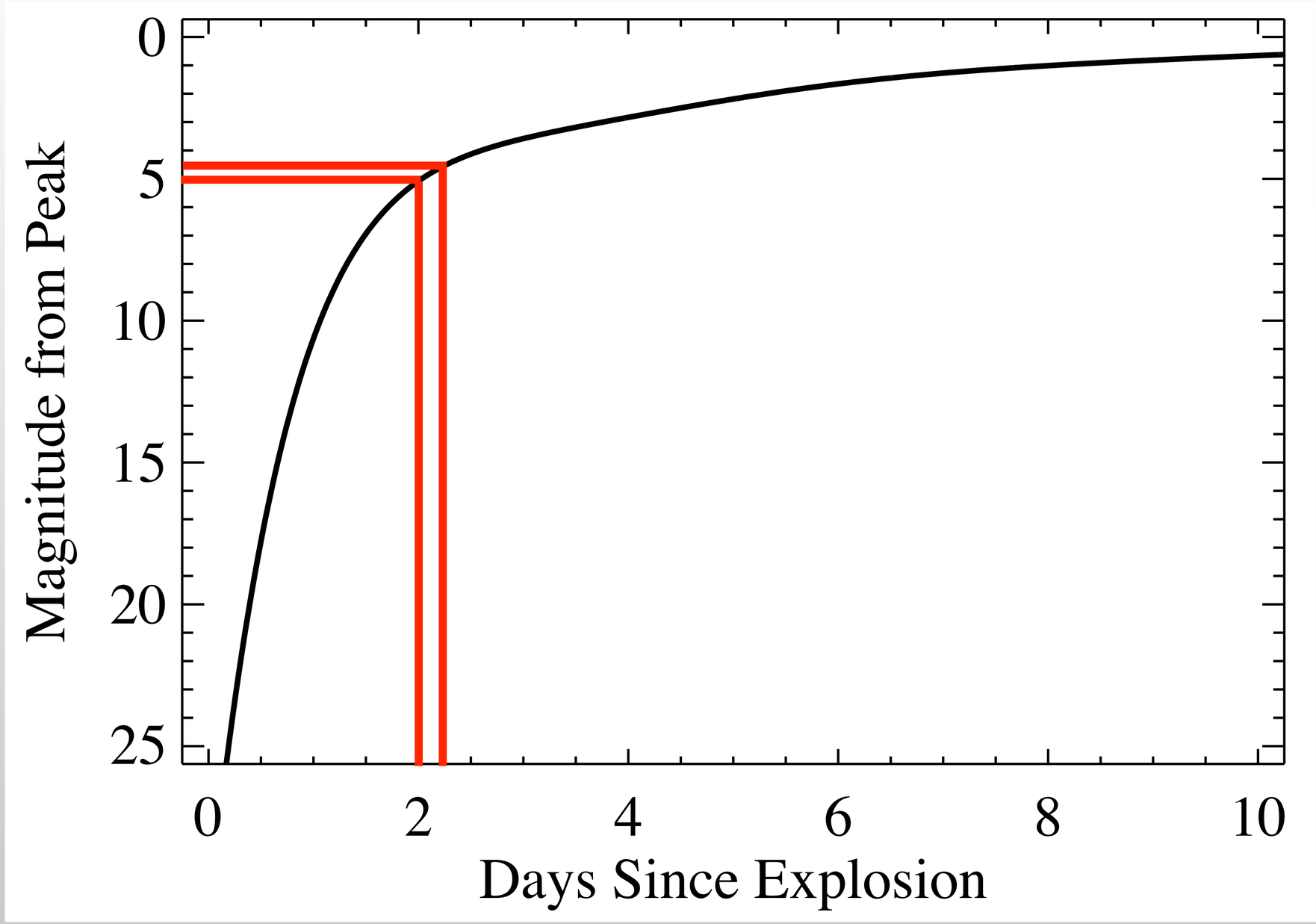
Bianco et al. (2022)

Technology is great, but we need ideas

Cadence, not Depth

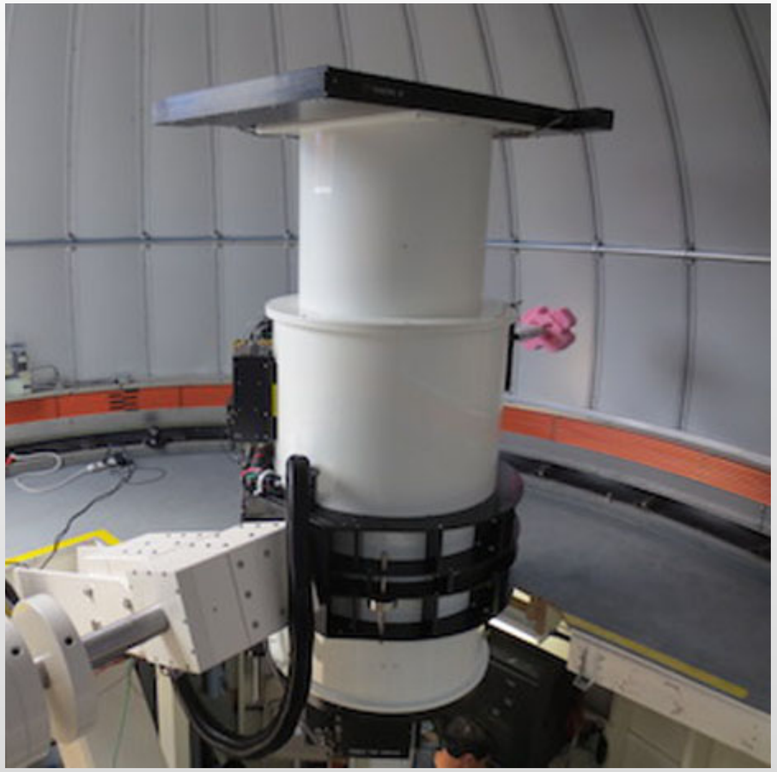


Identification, not Numbers



Several Public “All Sky” Surveys

ASASSN



ATLAS

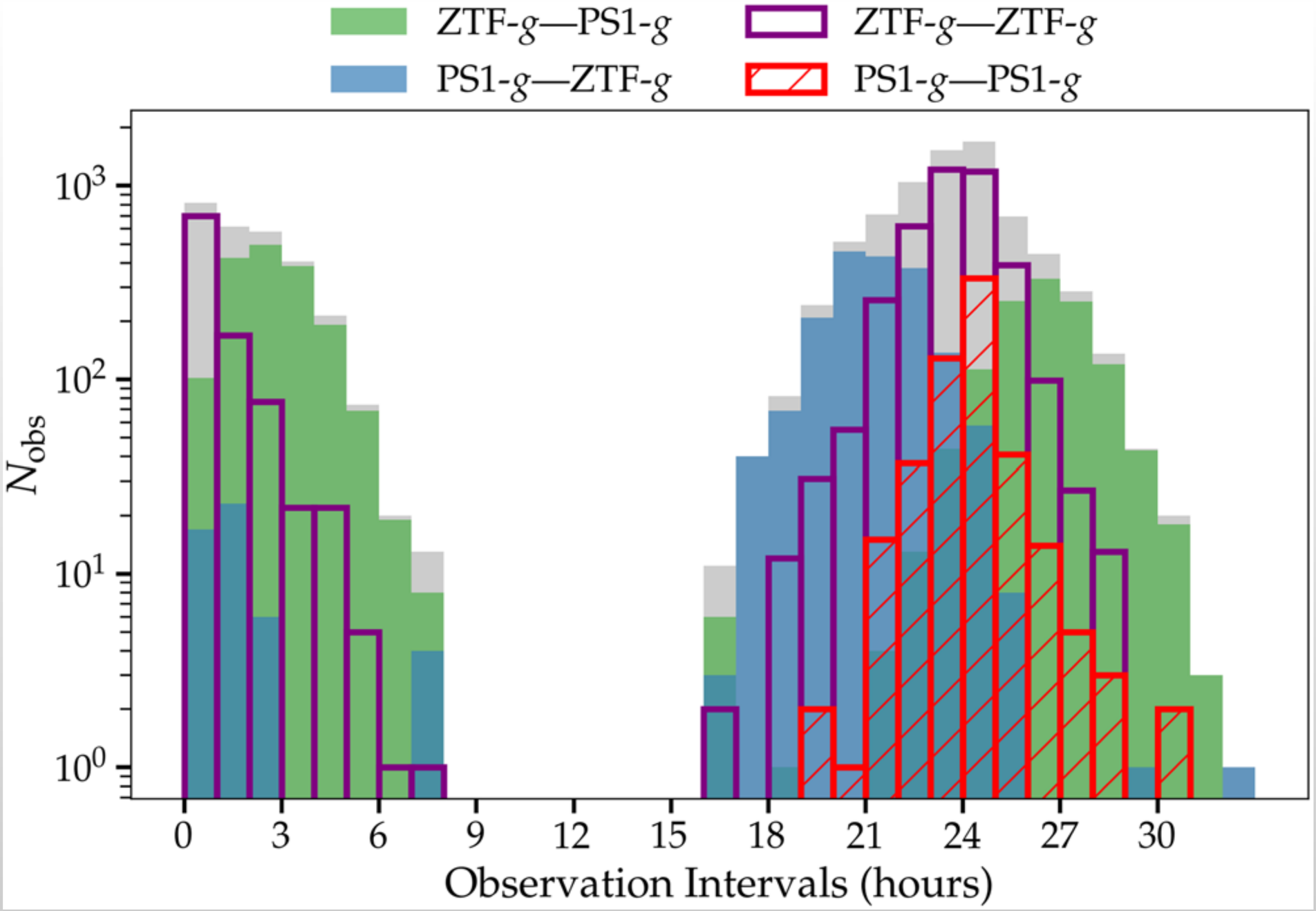
ZTF

Young Supernova Experiment

- Use PS1/PS2/DECam
- Observe ~1500 deg2
- Compare to other survey transient streams
- Identify young transients
- Immediately get spectra

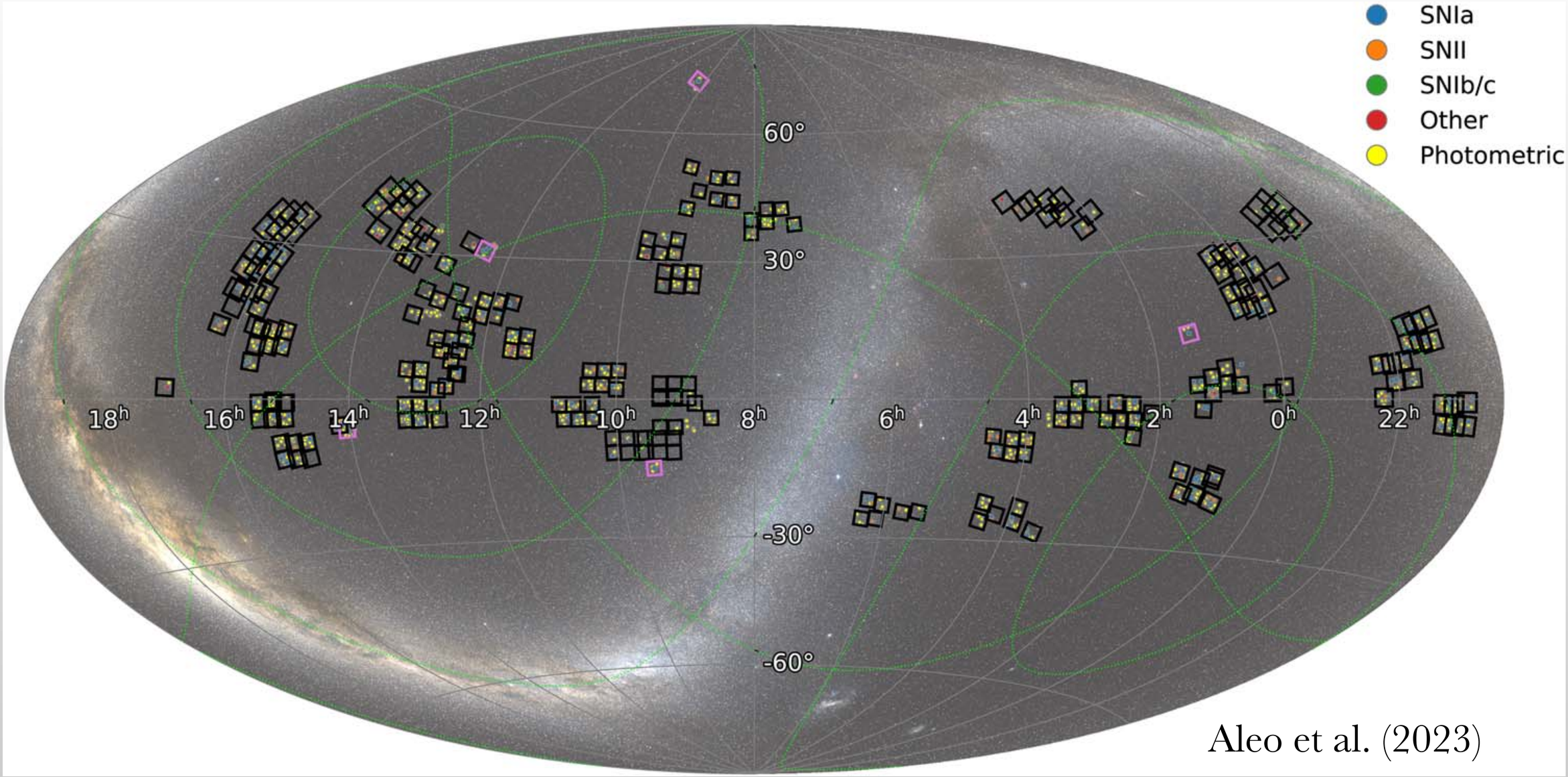
Also get griz light curves of >15,000 SNe

DECam	Chile	22,5	0 Hours
PS1	Hawaii	21,5	6 Hours
ZTF	California	20,5	27 Hours
ATLAS	Hawaii	19,5	30 Hours



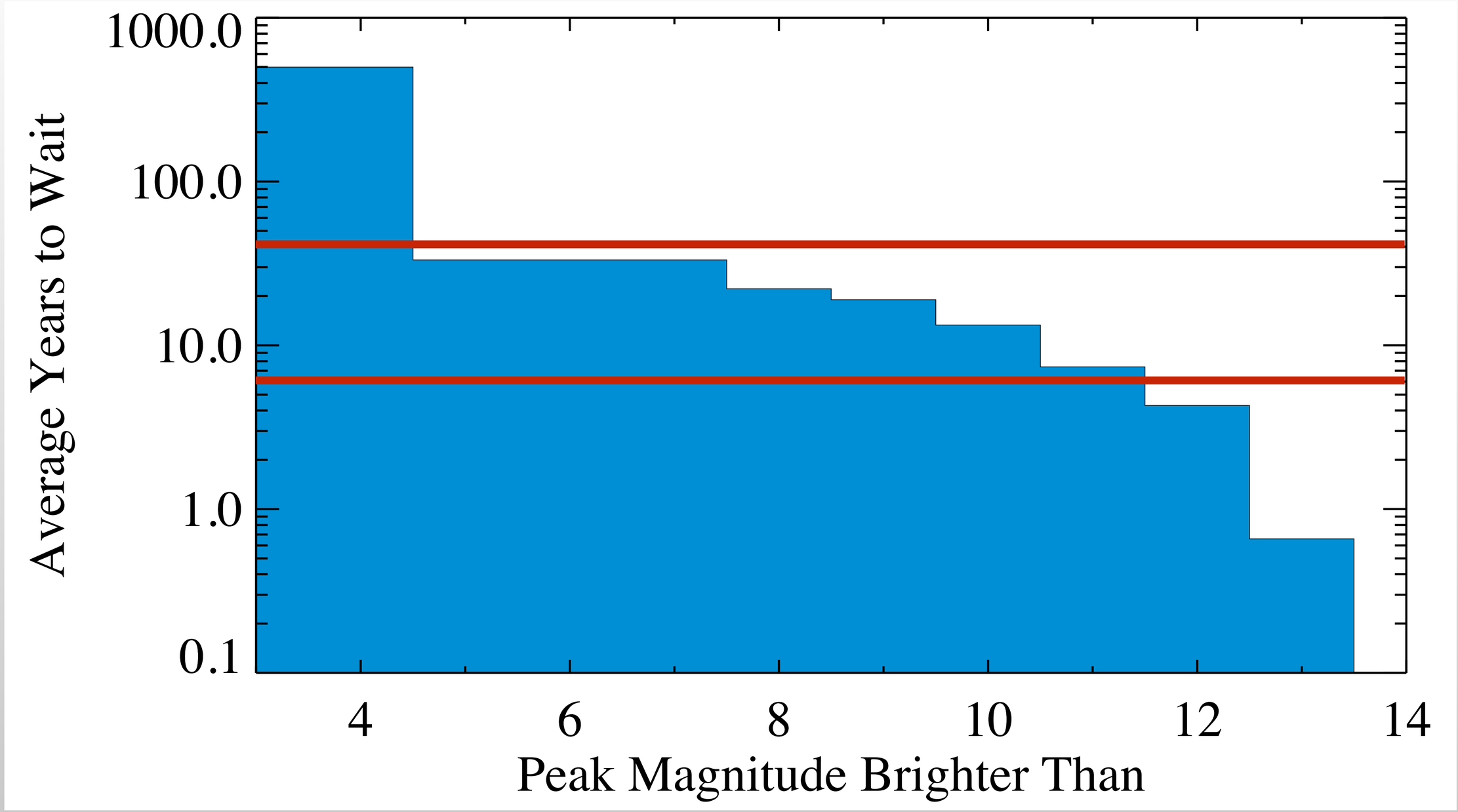
Aleo et al. (2023)

YSE DR1 (2000 Transients)



Aleo et al. (2023)

Alternatively, wait…




Wake up !
Life is transient
Swiftly passi
Be aware
The great matte
Don't waste
time