Transients in the local universe with ZTF

Kishalay De

Caltech

With Andy Tzanidakis, Yuhan Yao, Mansi Kasliwal and the ZTF collaboration

Volume-limited Census of the Local Universe (CLU) experiment

A powerful complement to the flux-limited Bright Transient Survey

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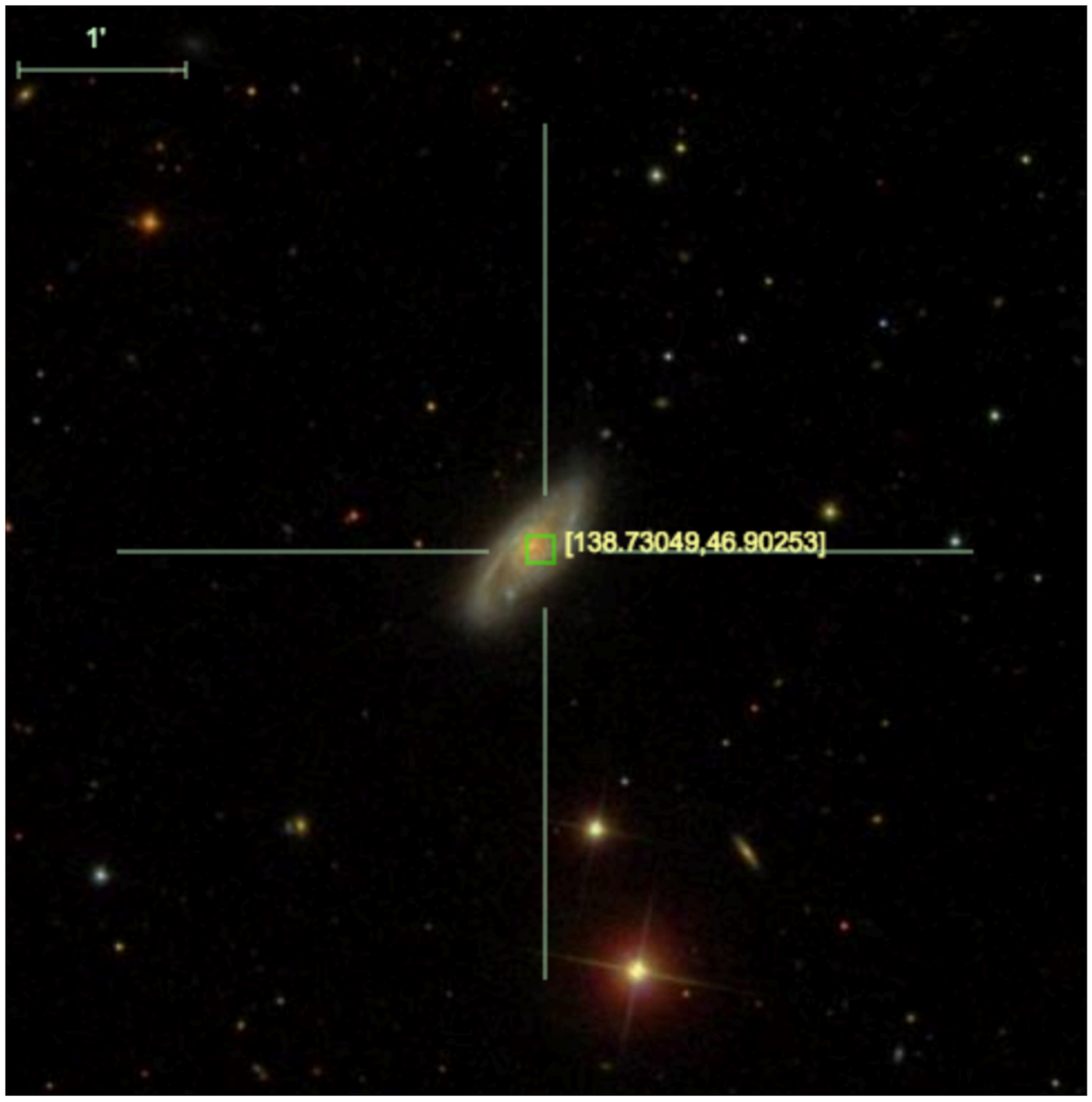

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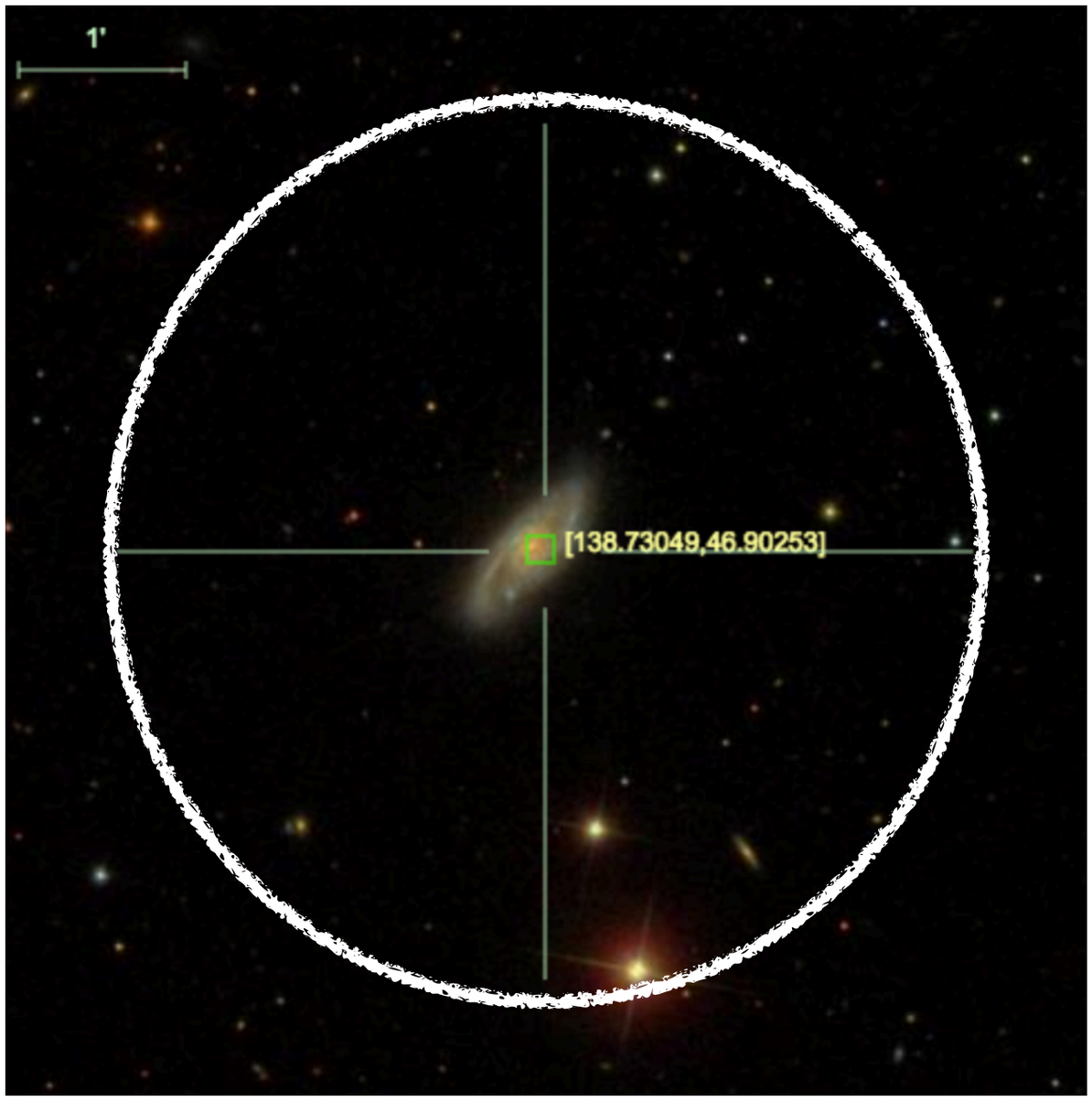
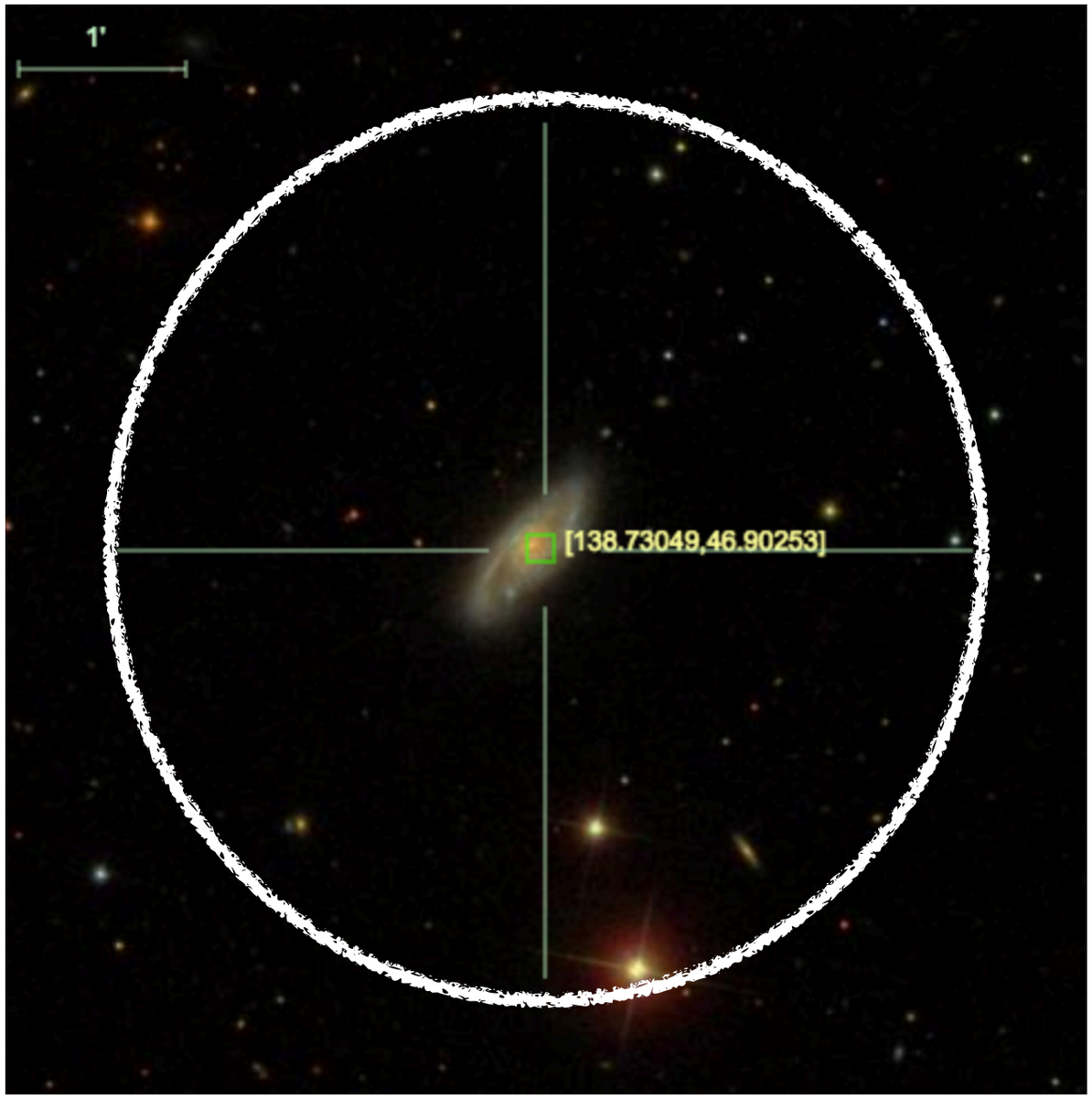


Transients announced immediately on the Transient Name Server

De+ 2020b

Volume-limited Census of the Local Universe (CLU) experiment

A powerful complement to the flux-limited Bright Transient Survey



Transients announced immediately on the Transient Name Server

Aim completeness of all transients brighter than M = -16.5 (< 200 Mpc) and M = -15 (< 100 Mpc)

De+ 2020b

Spectroscopic classification of all transients brighter than 20 mag, within 100” of host galaxy within 200 Mpc (Cook+ 2019)

P60 SEDM:
Brighter than 19 mag

P200 + DBSP:
Between 19-20 mag

Keck I + LRIS:
Follow-up

+ community effort + ZTF collaboration follow-up

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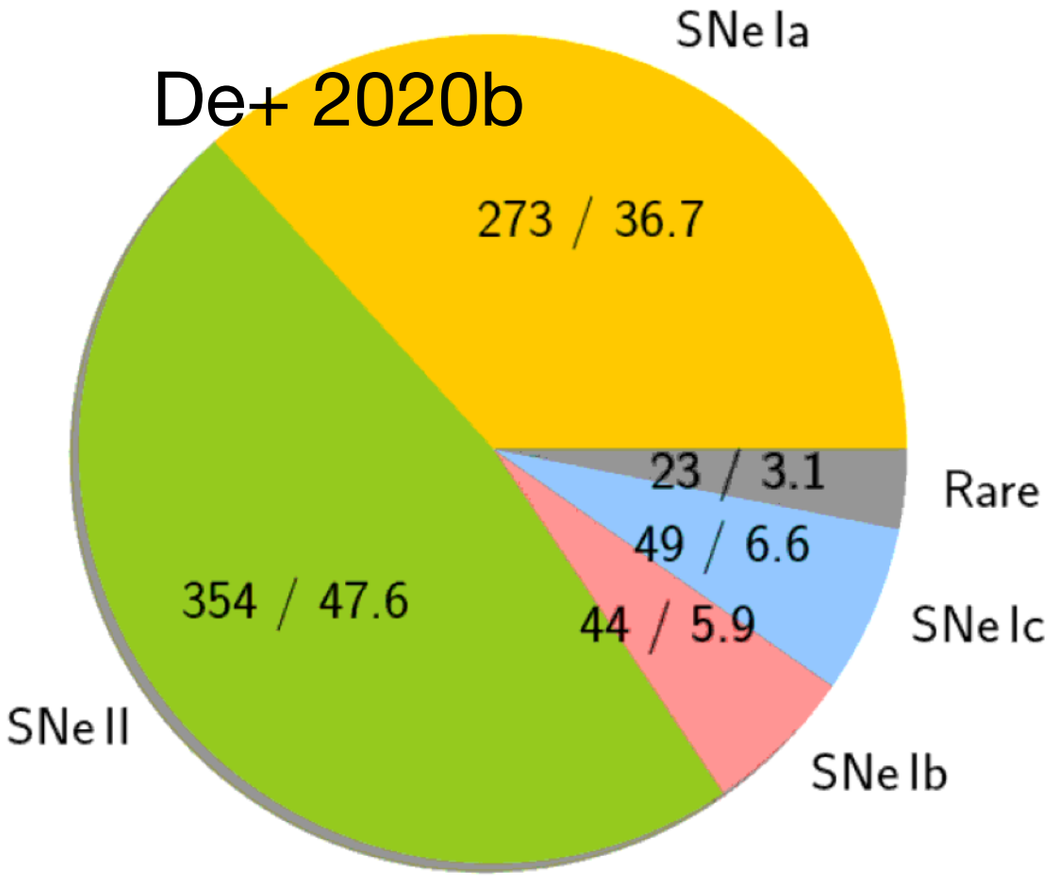
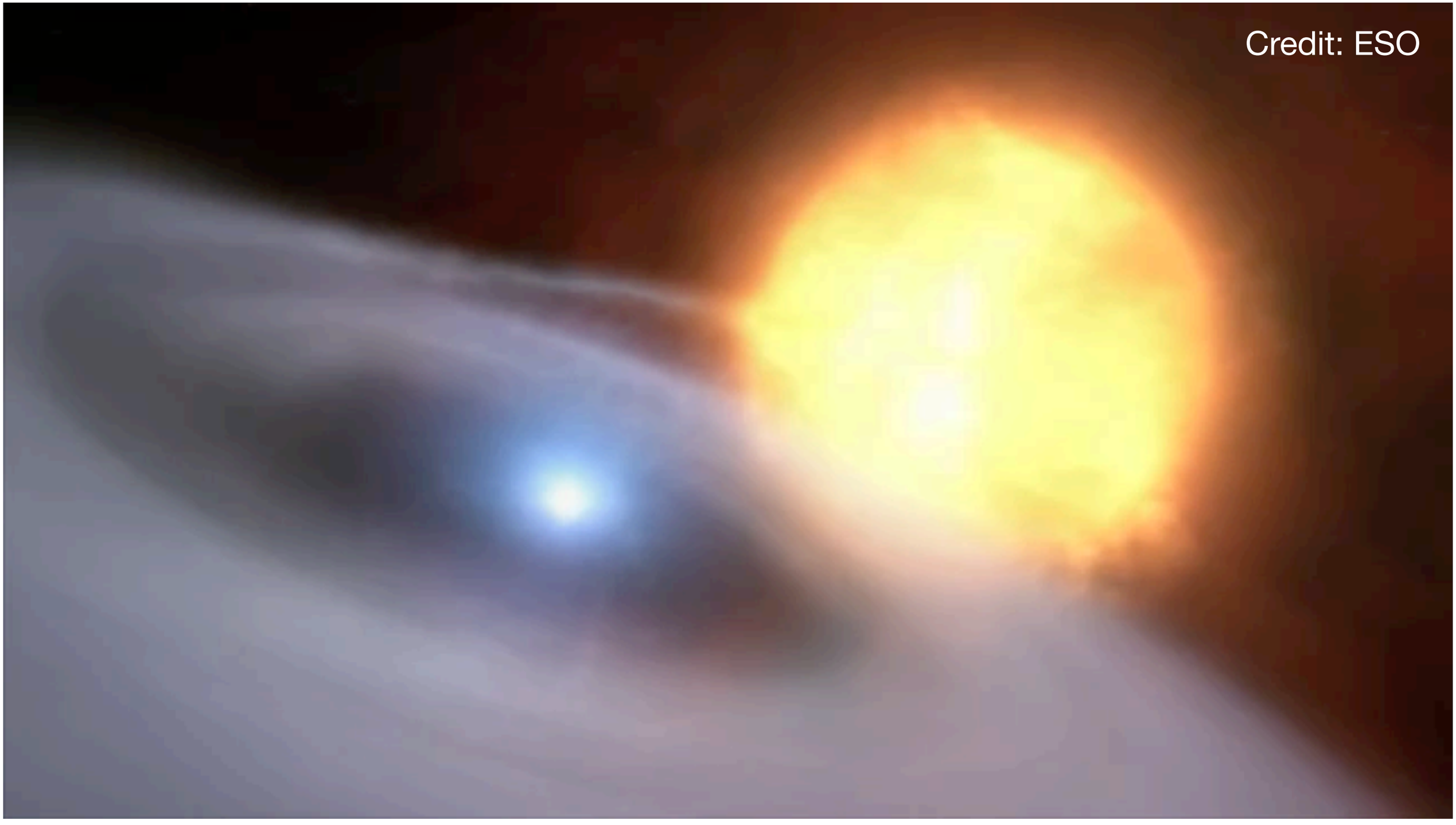
754 spectroscopically classified SNe in 16 months
(90% complete; ~ 1500 as of October 2020)
The largest volume-limited supernova sample till date



The faintest thermonuclear supernovae



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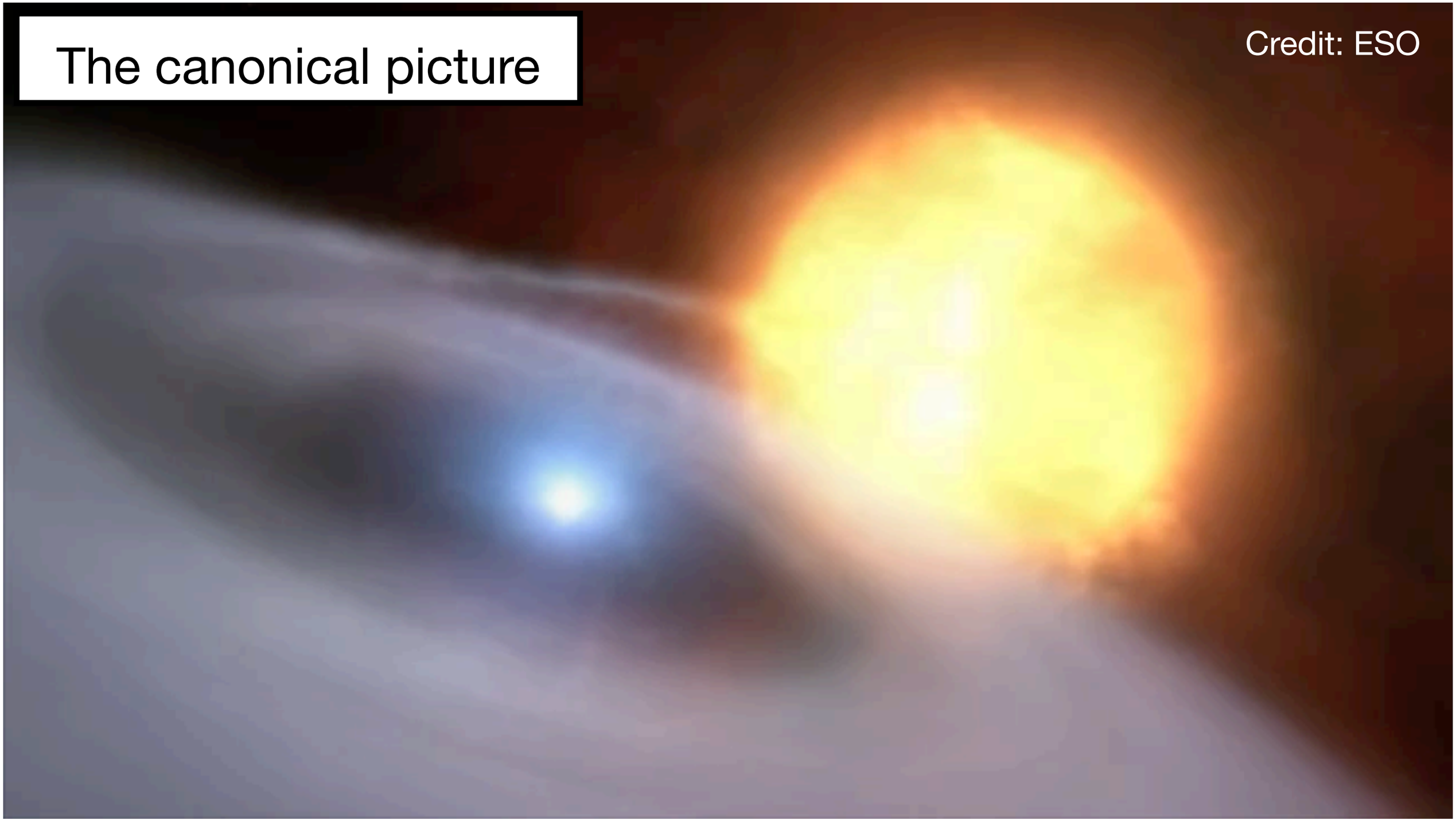

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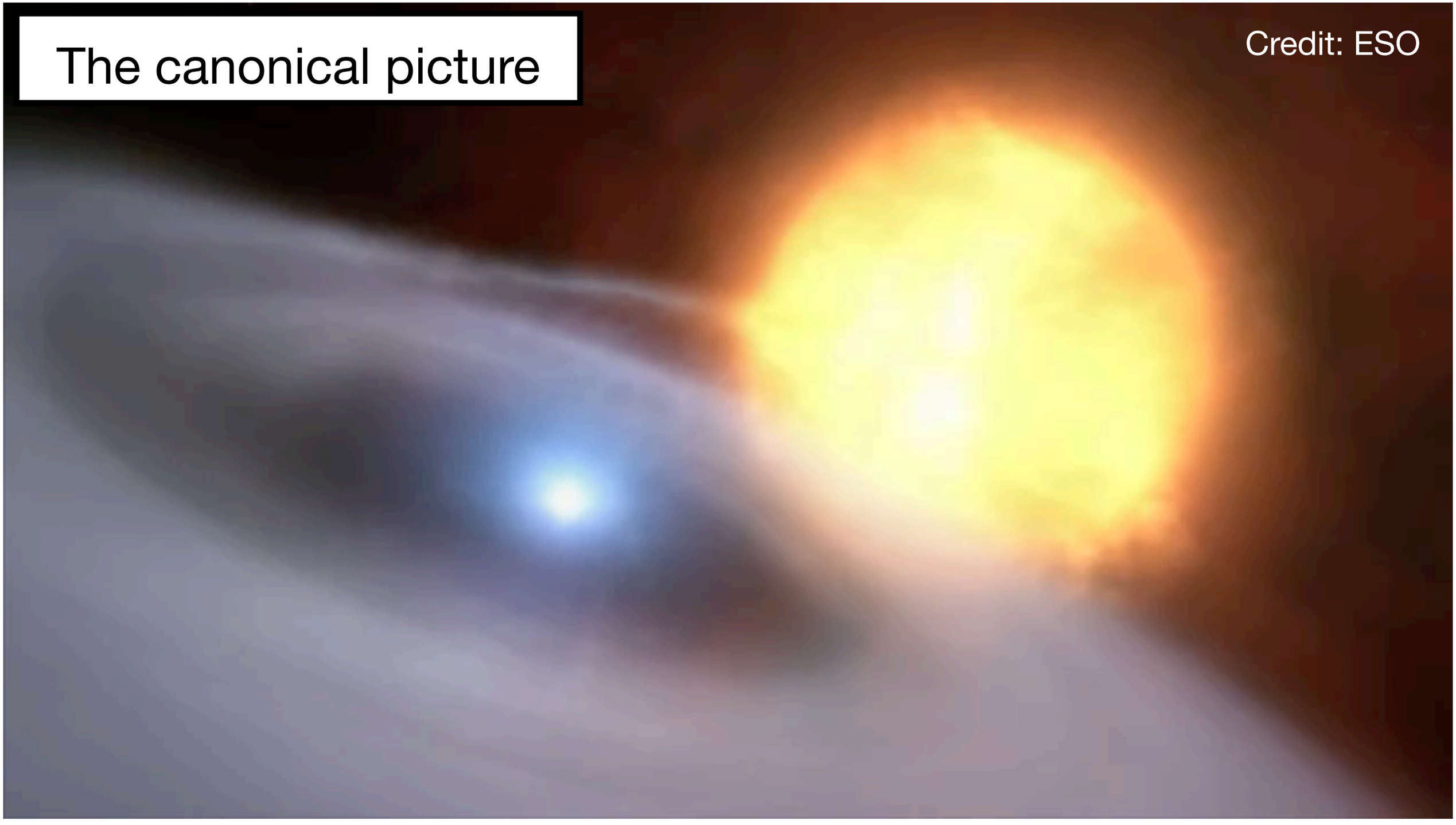

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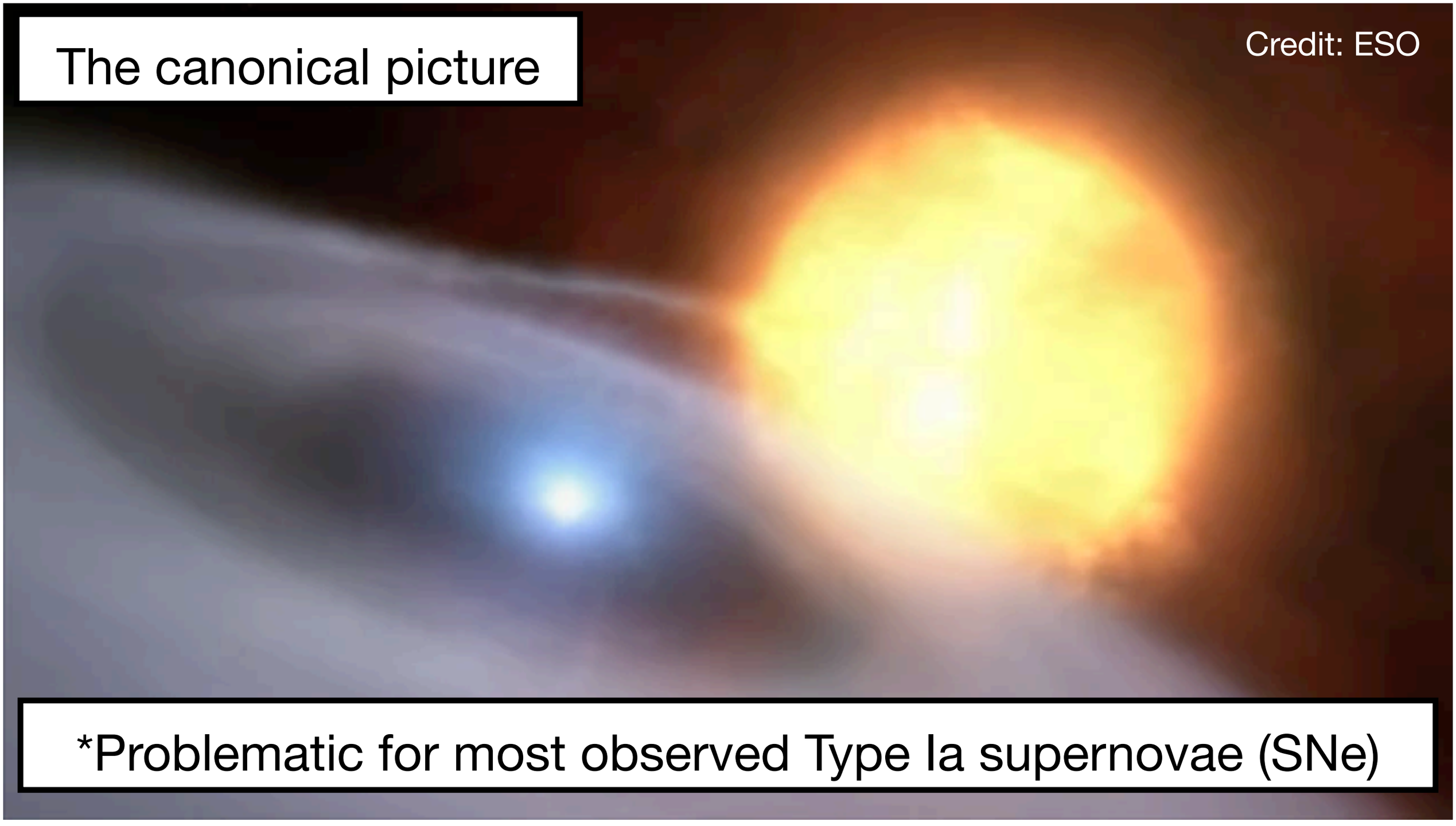
The canonical picture



*Problematic for most observed Type Ia supernovae (SNe)

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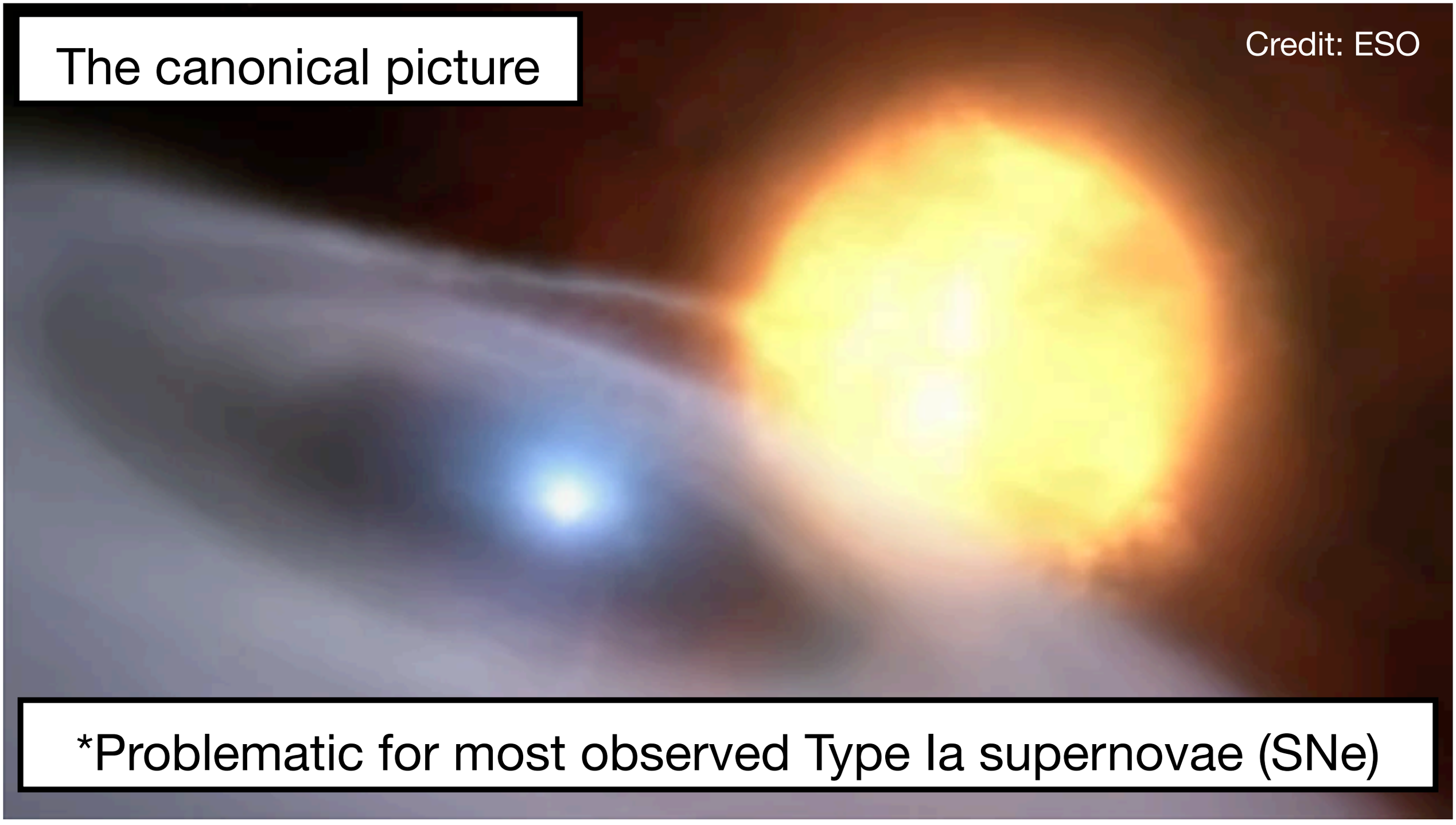

Single degenerate or double degenerate? Near-Chandrasekhar or sub-Chandrasekhar mass? What is the explosion trigger?

Pathways to sub-Chandrasekhar mass explosions

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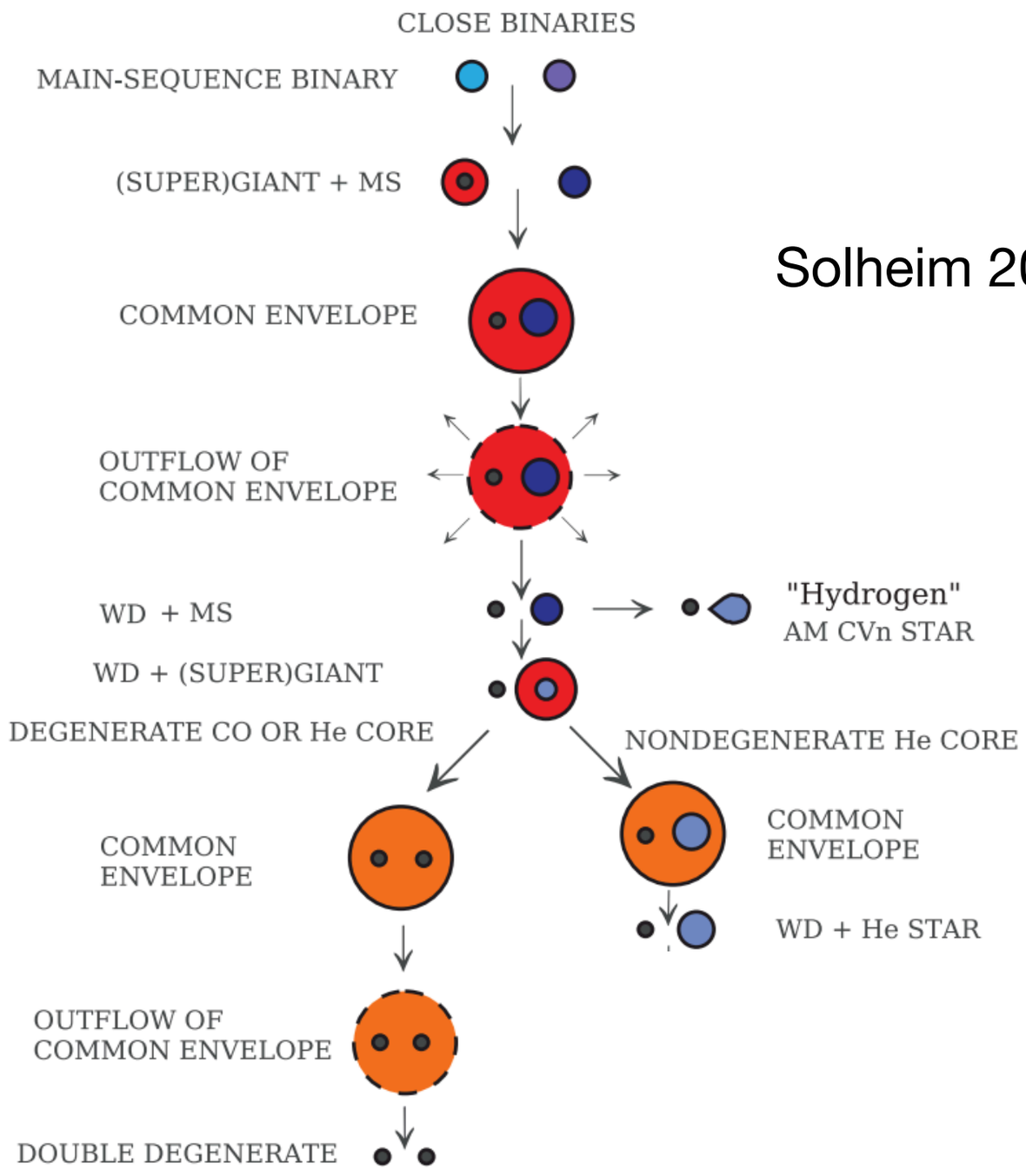
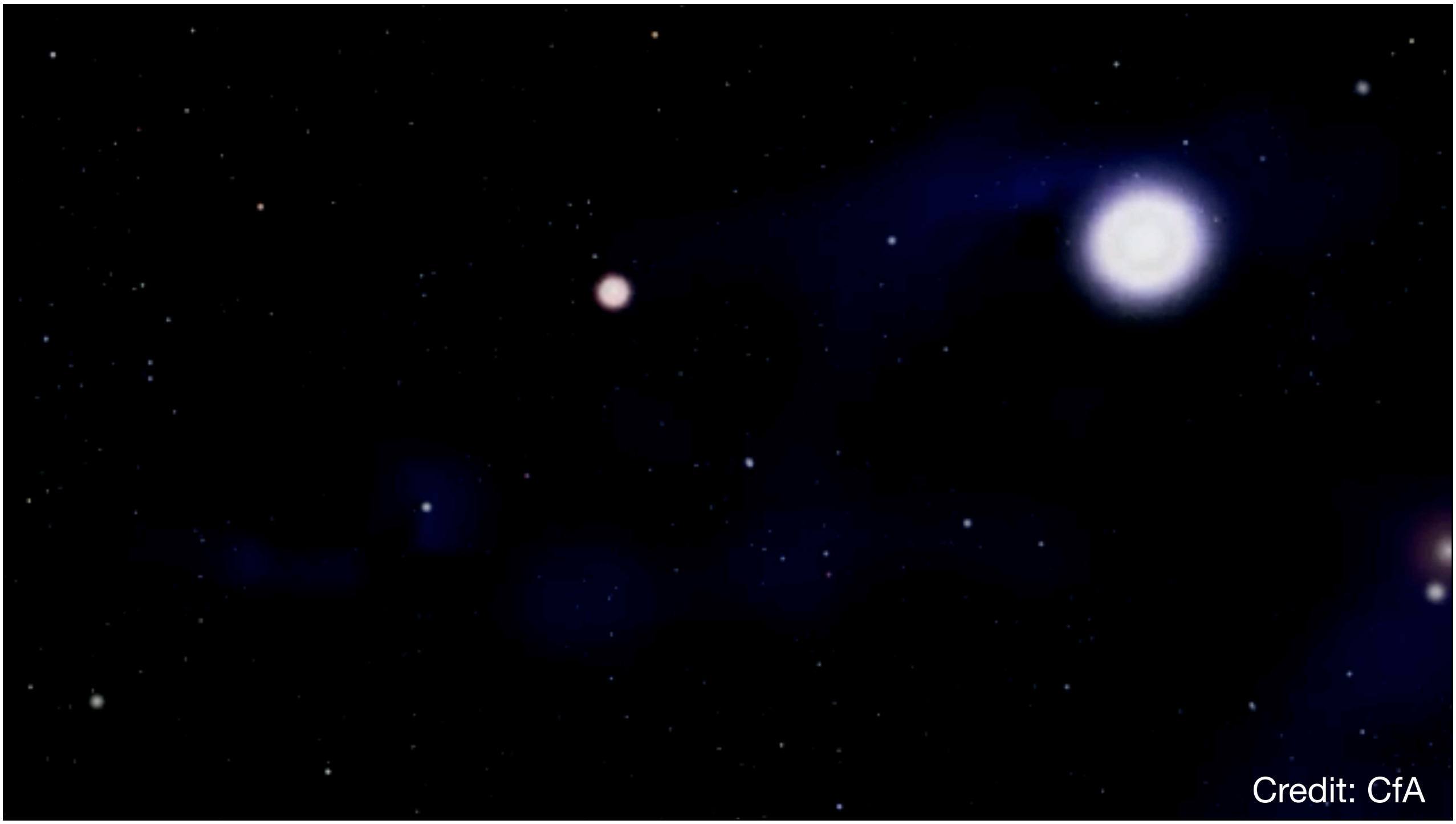


Solheim 2010, Yungelson+ 2008

Pathways to sub-Chandrasekhar mass explosions



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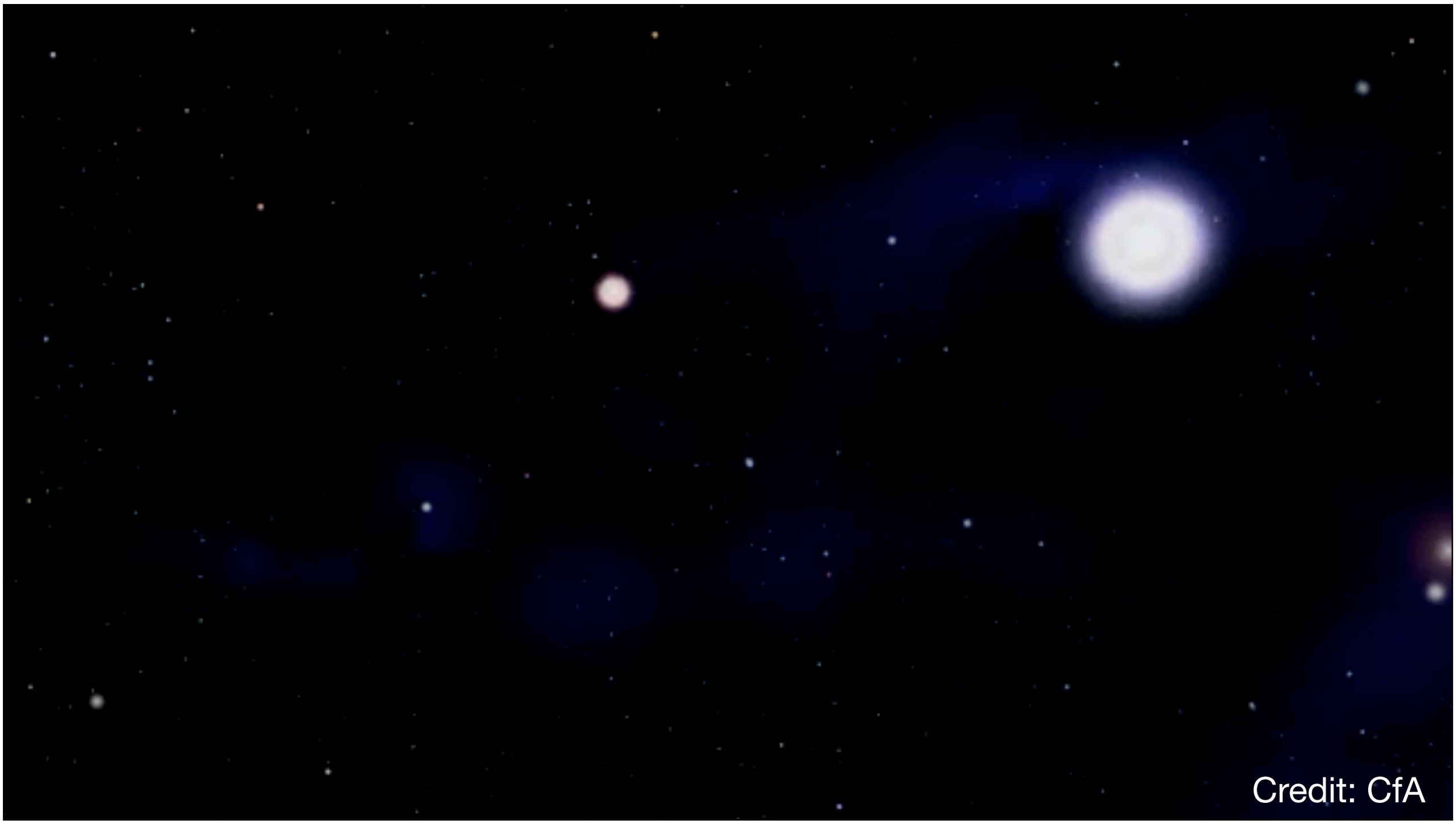

Next? Gravitational waves vs. Stellar physics

As Type Ia supernova progenitors: “Double detonation”

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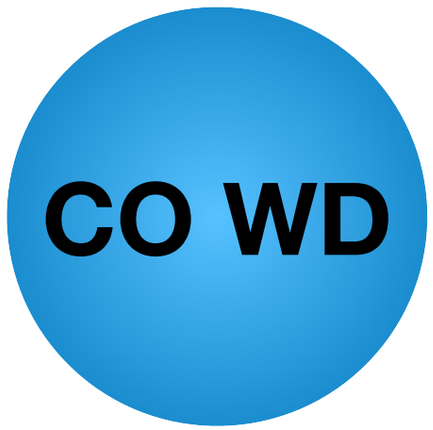

He shell

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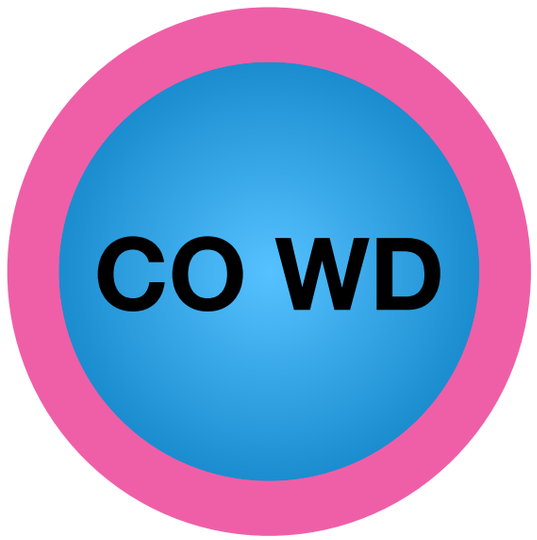

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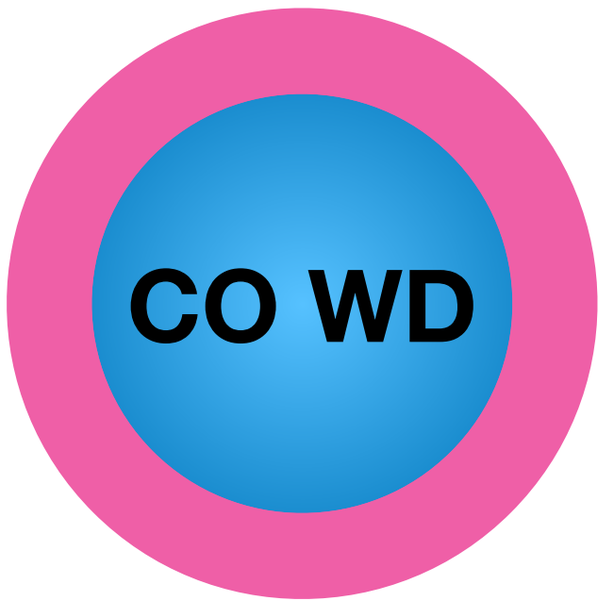

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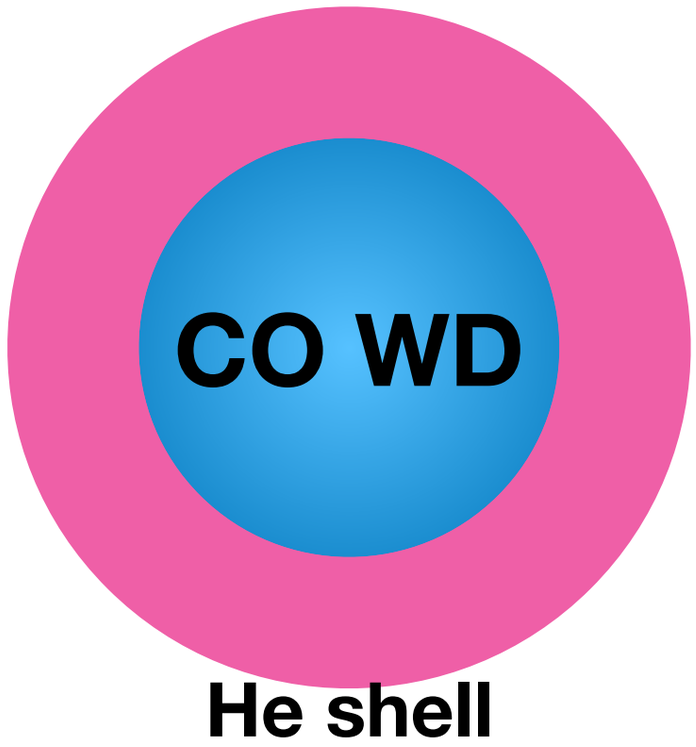

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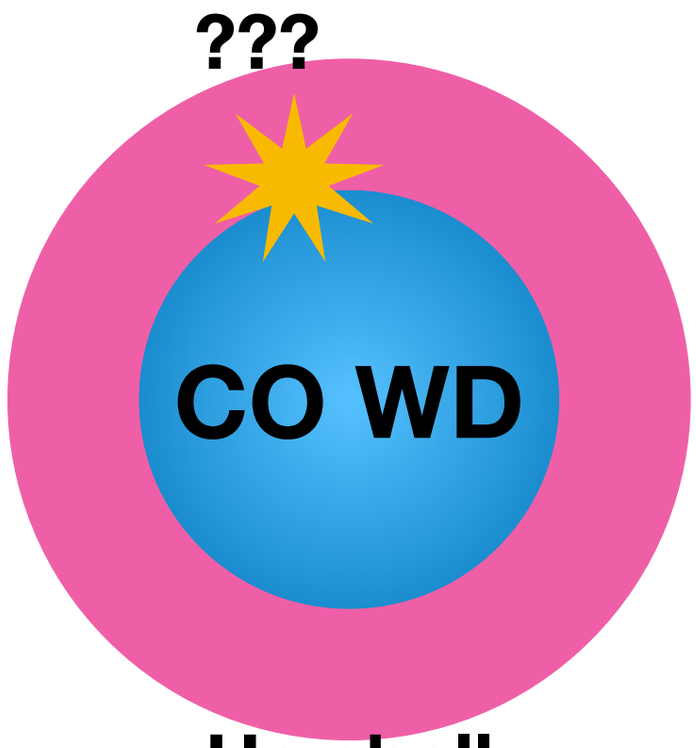

Helium nova? Type Ia supernova? .Ia supernova? Ca-rich transients?

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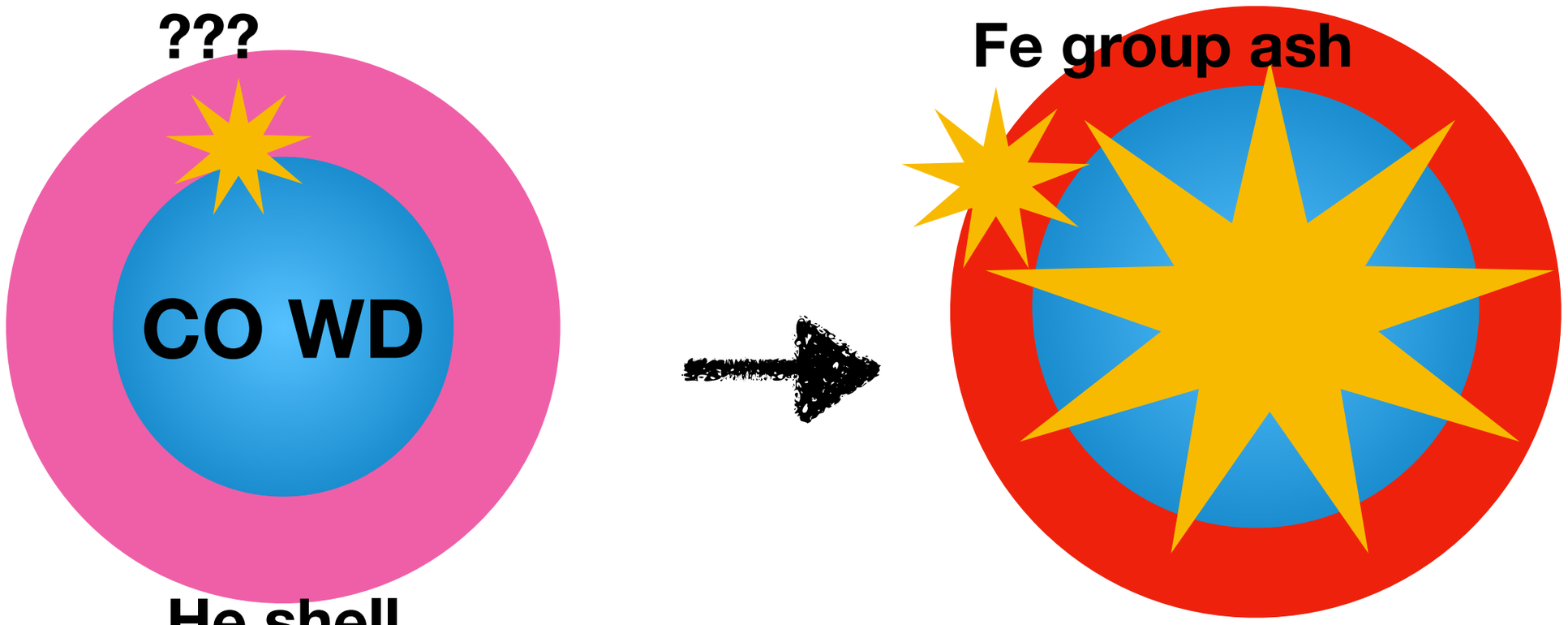

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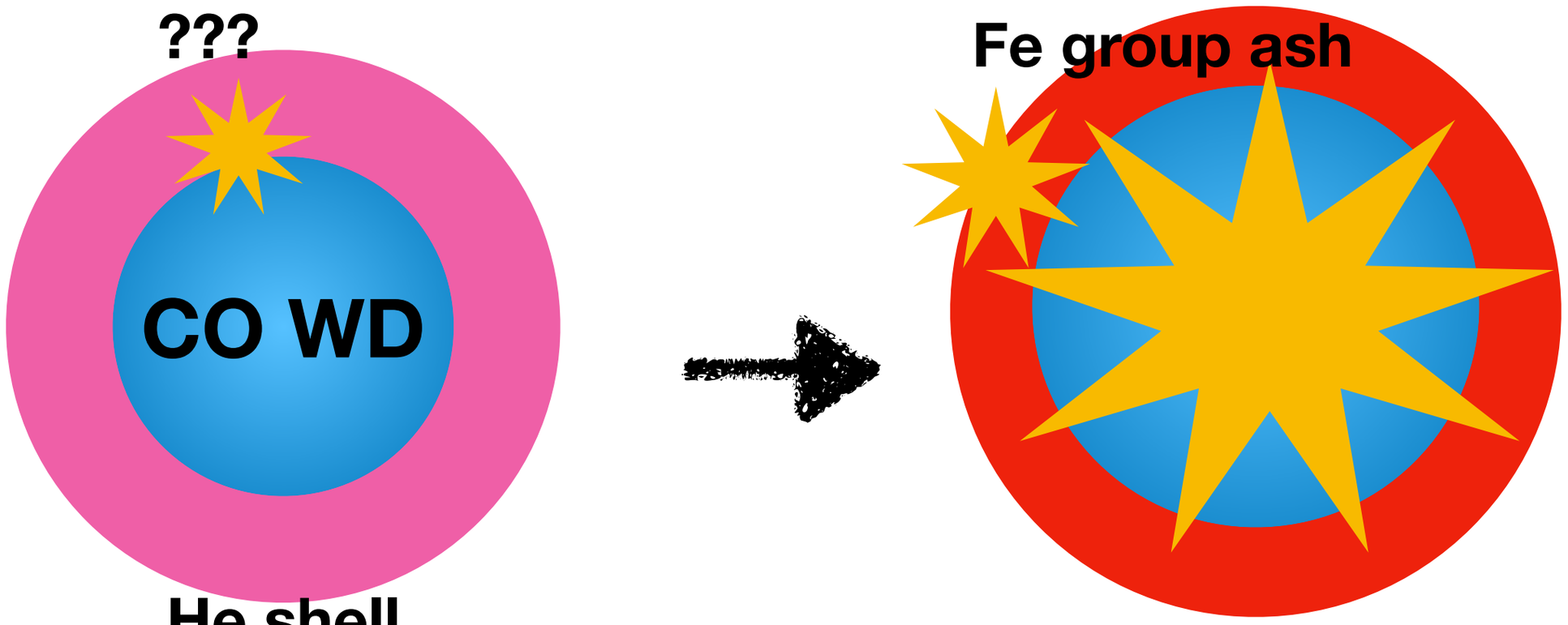

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Motivation: Fate of old low mass stars, accretion + explosion physics, gravitational wave sources, chemical nucleosynthesis

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Shallow radioactive material
= Early light curve excess

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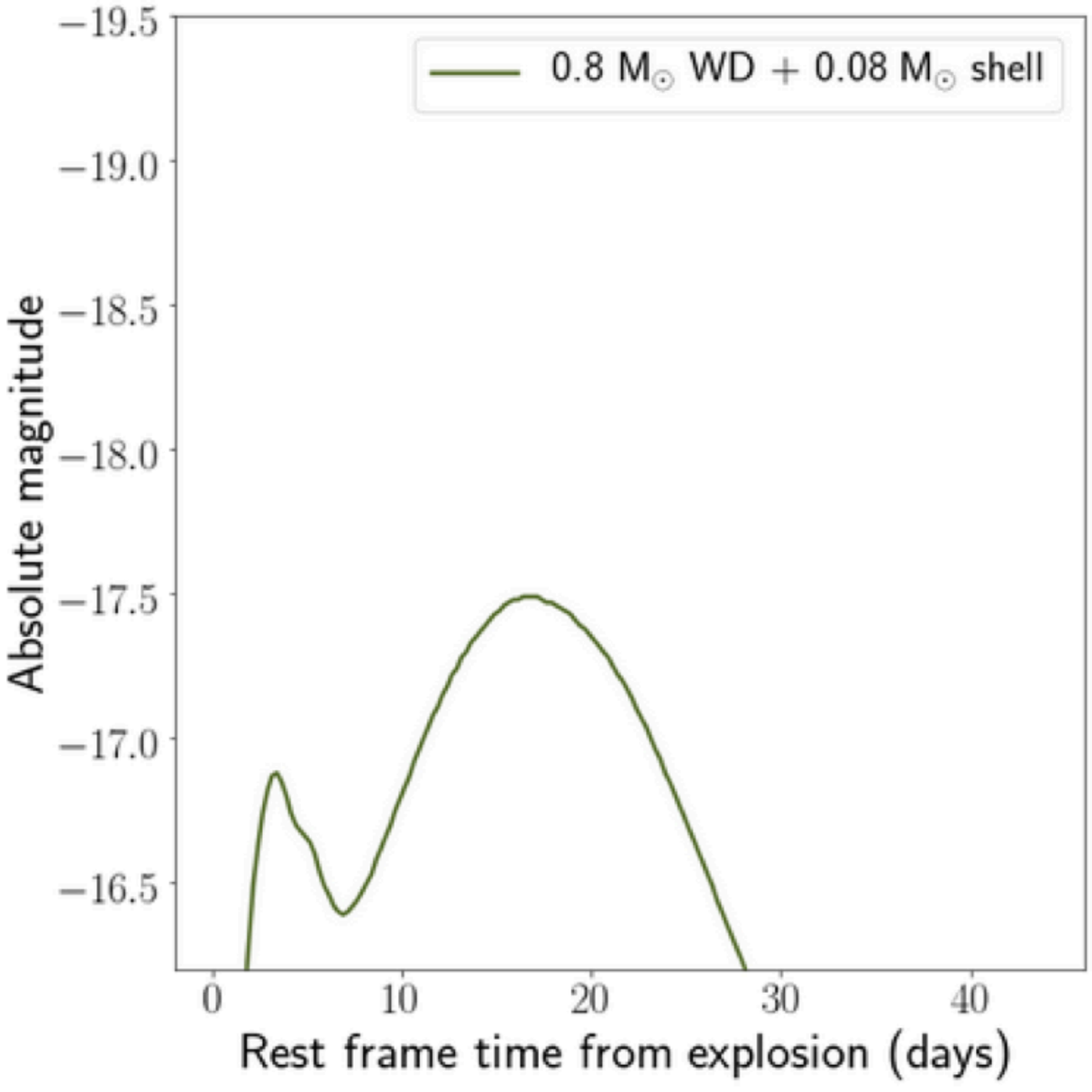

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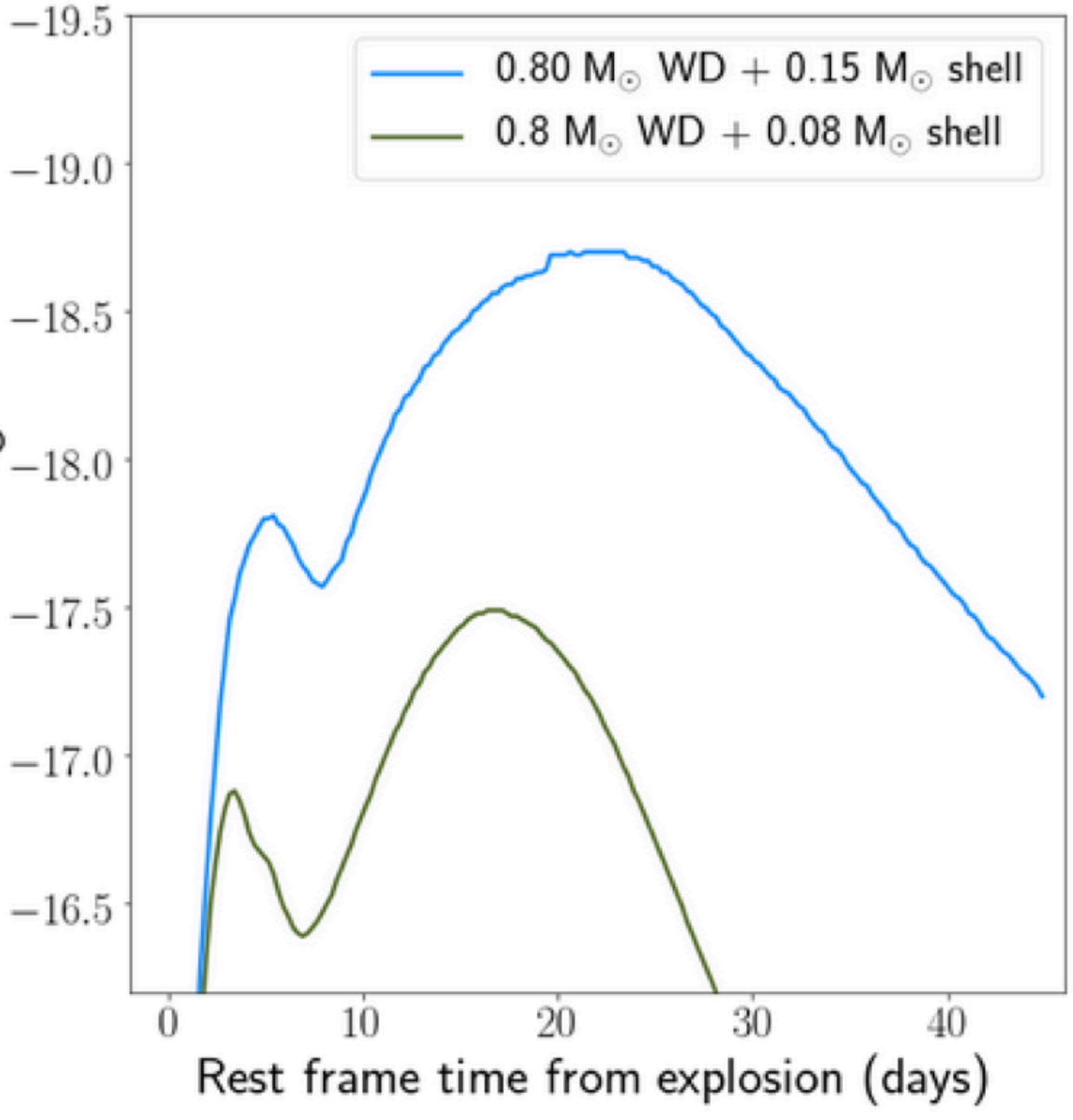

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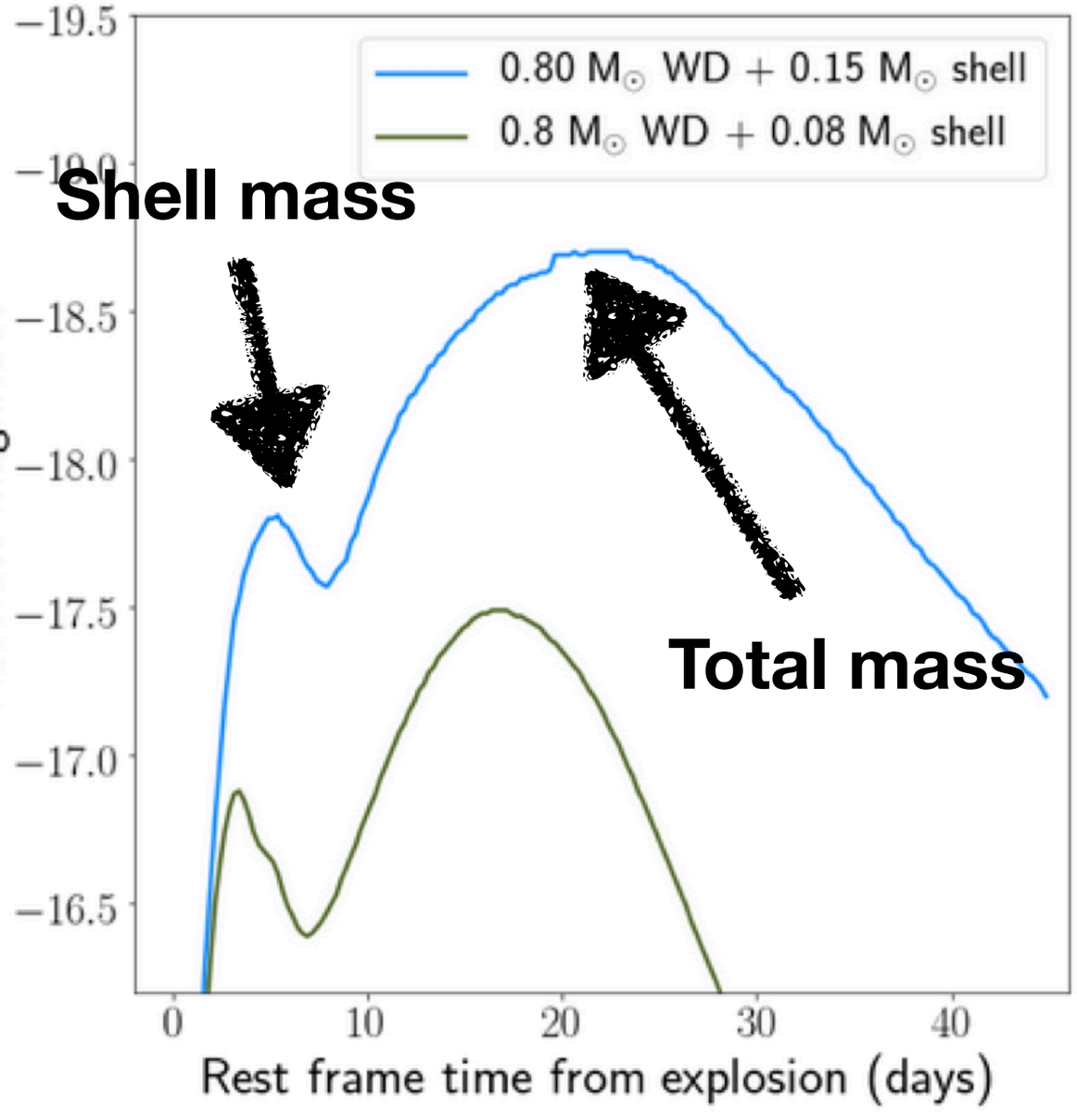

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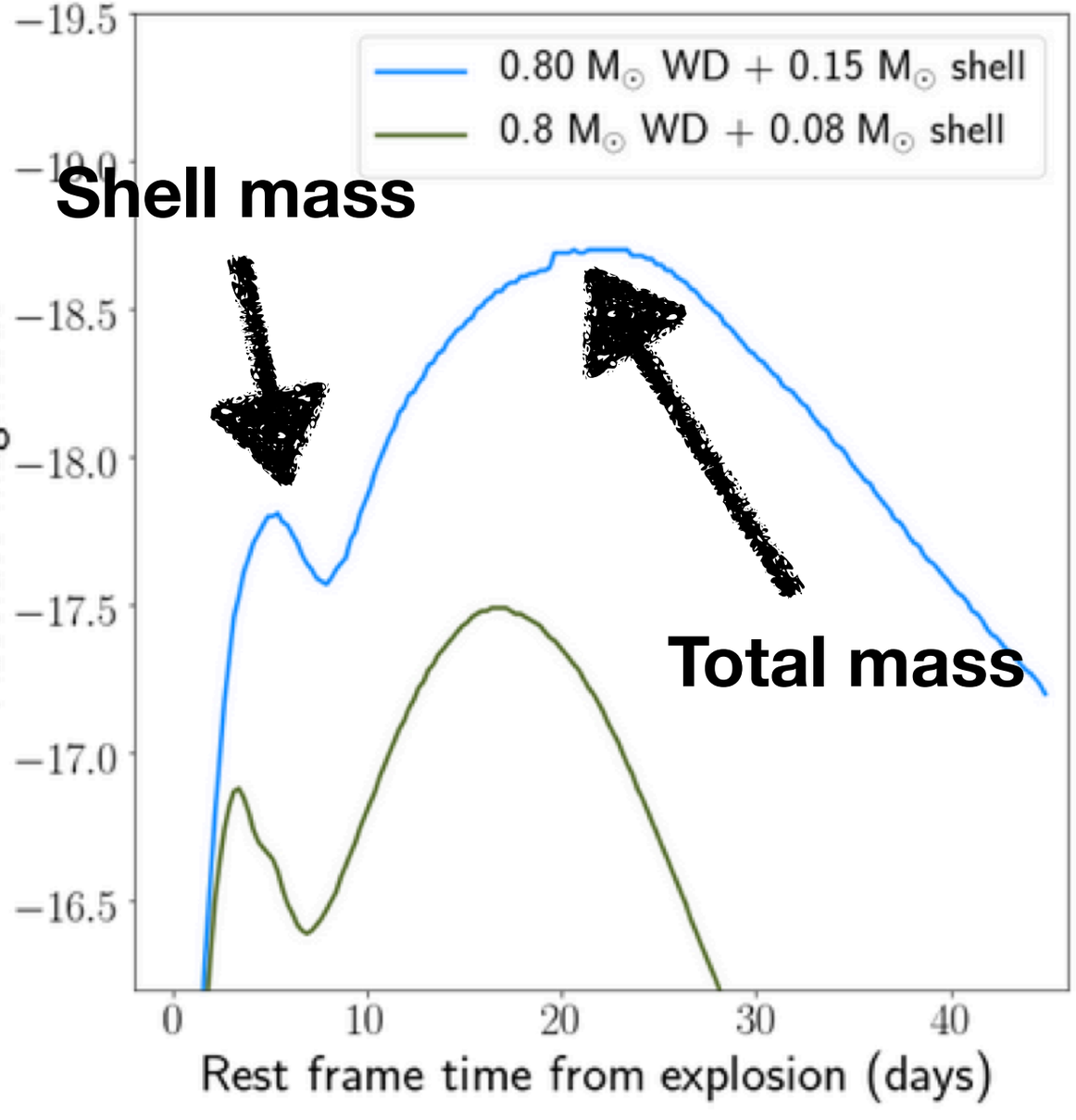

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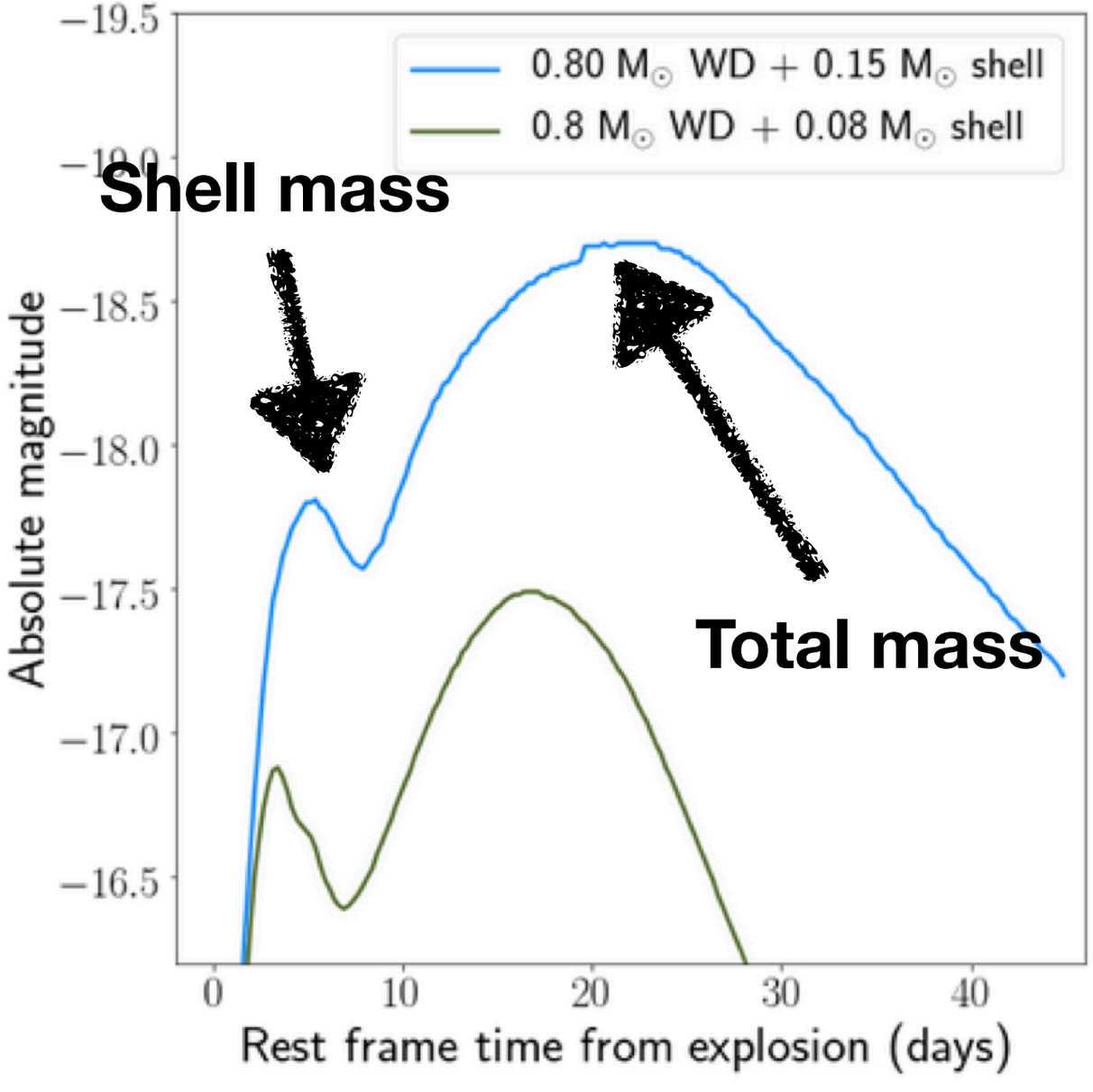

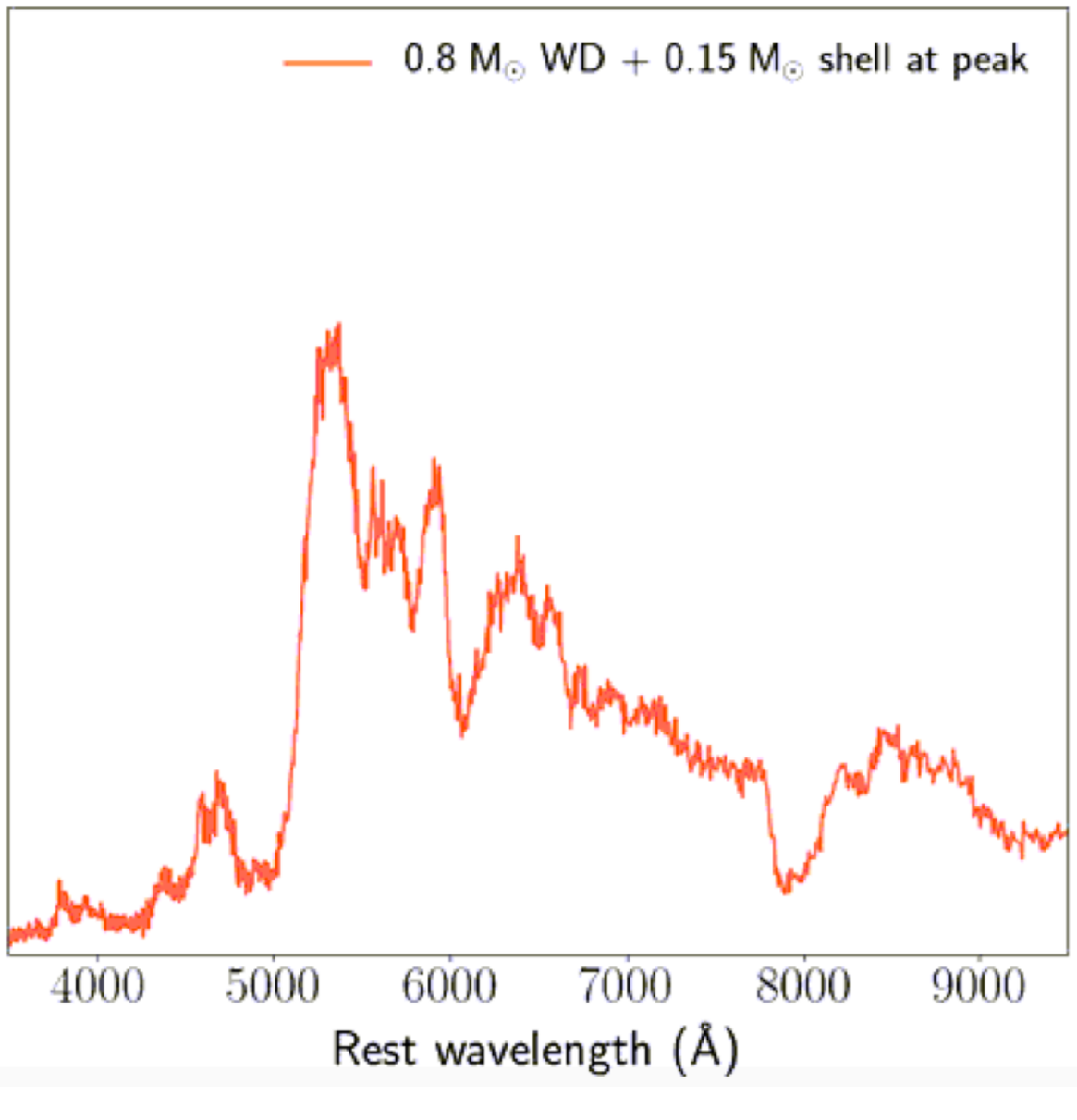

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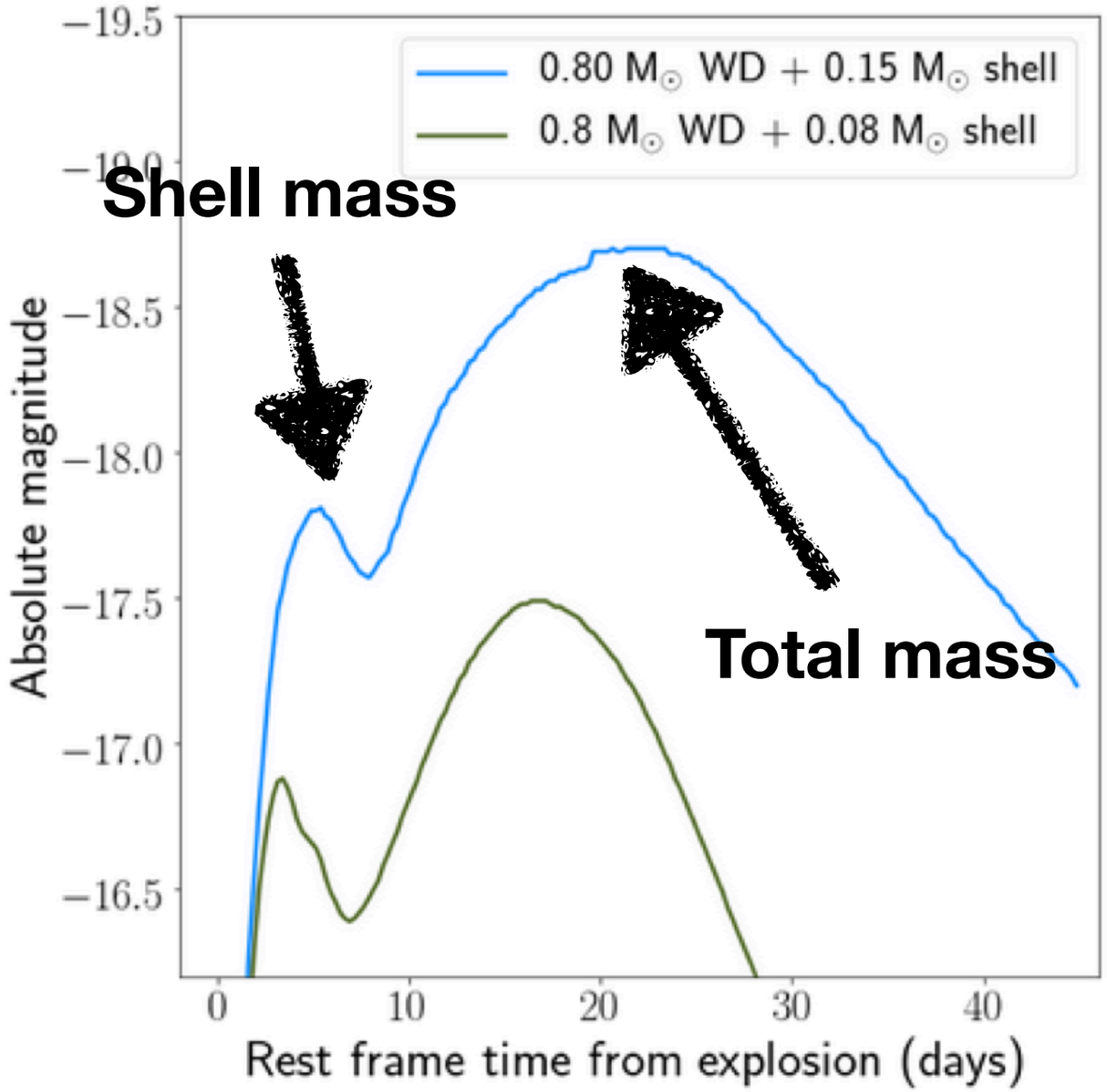

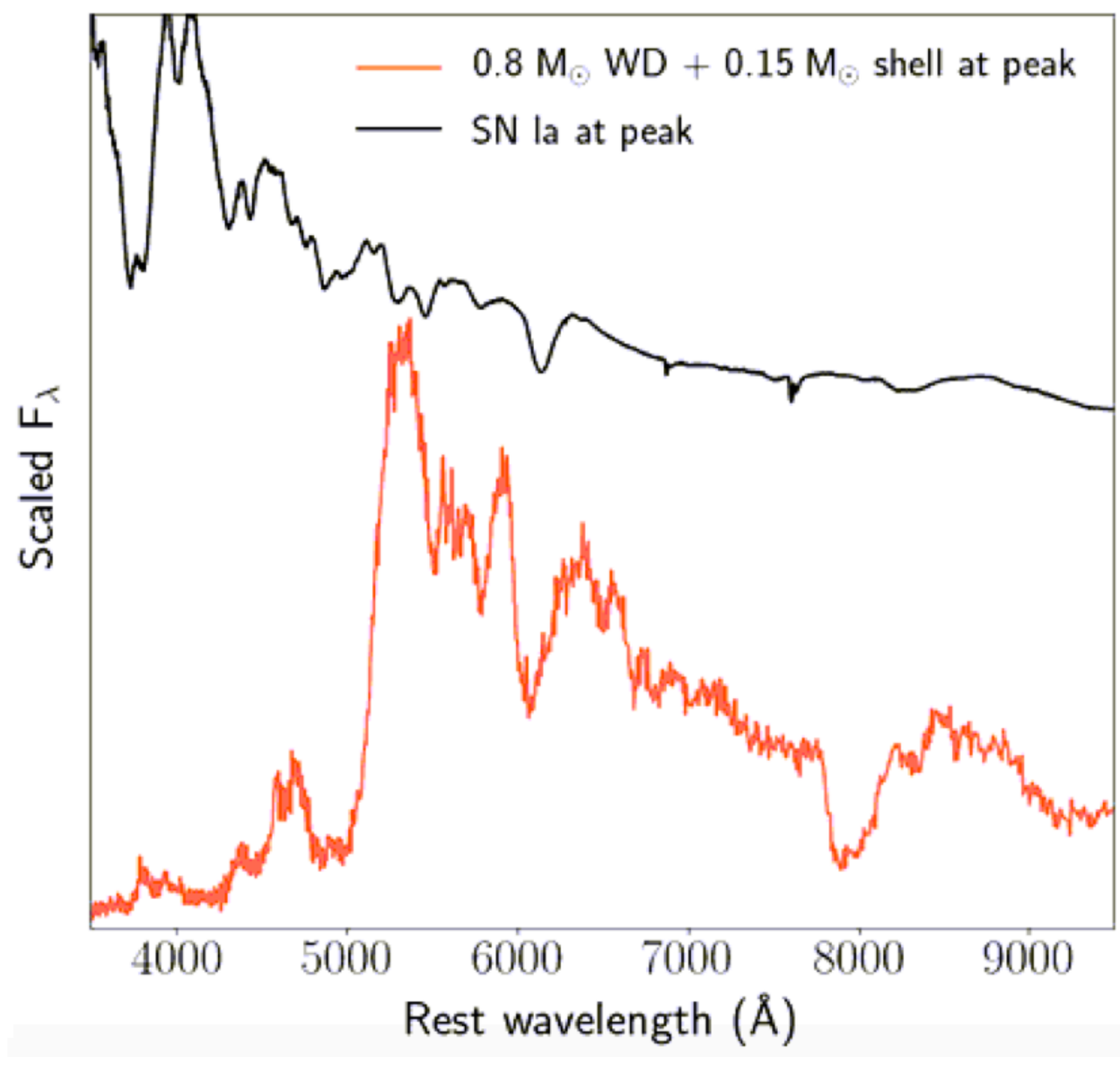

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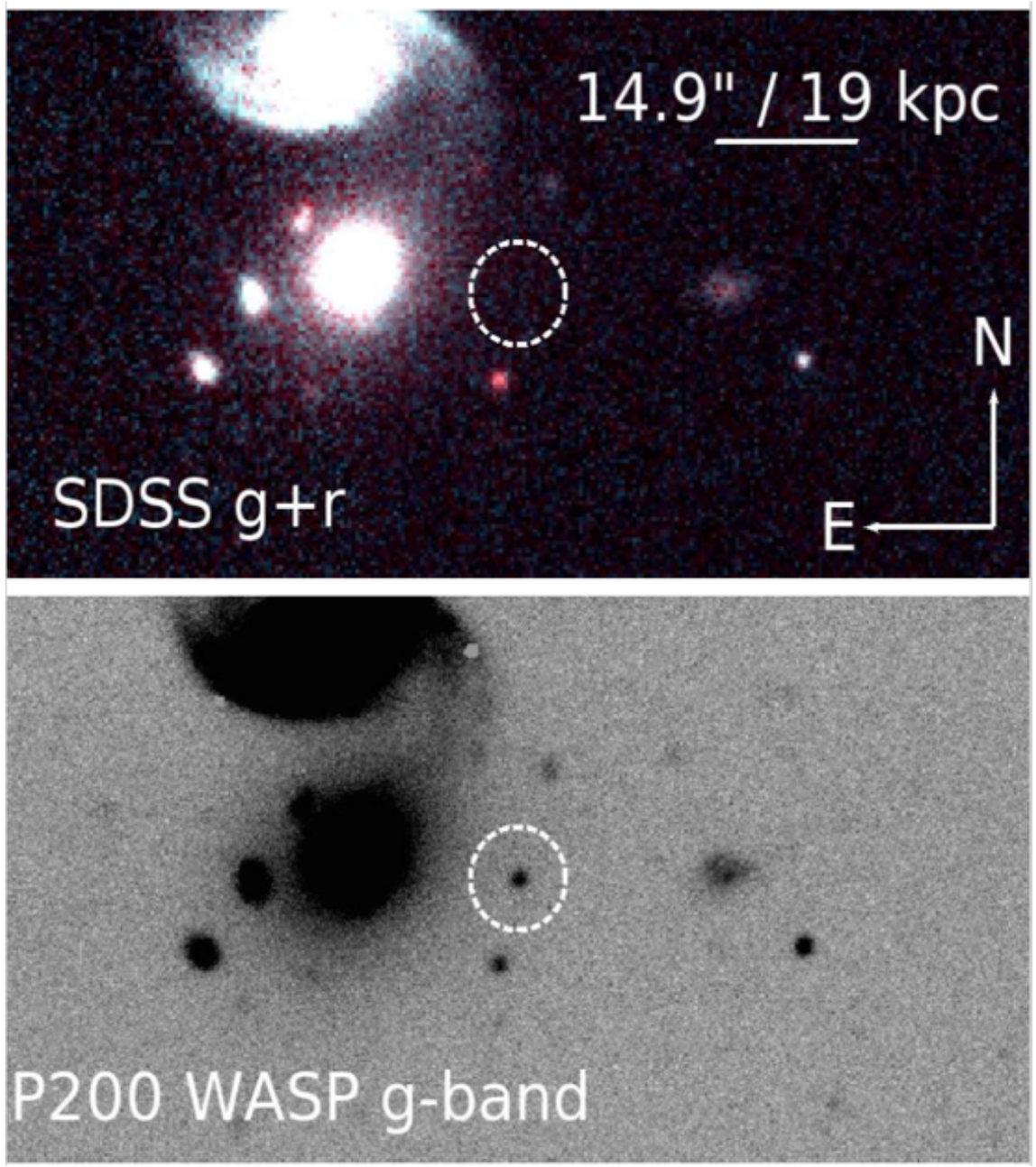

Discovered in nightly cadence survey with ZTF

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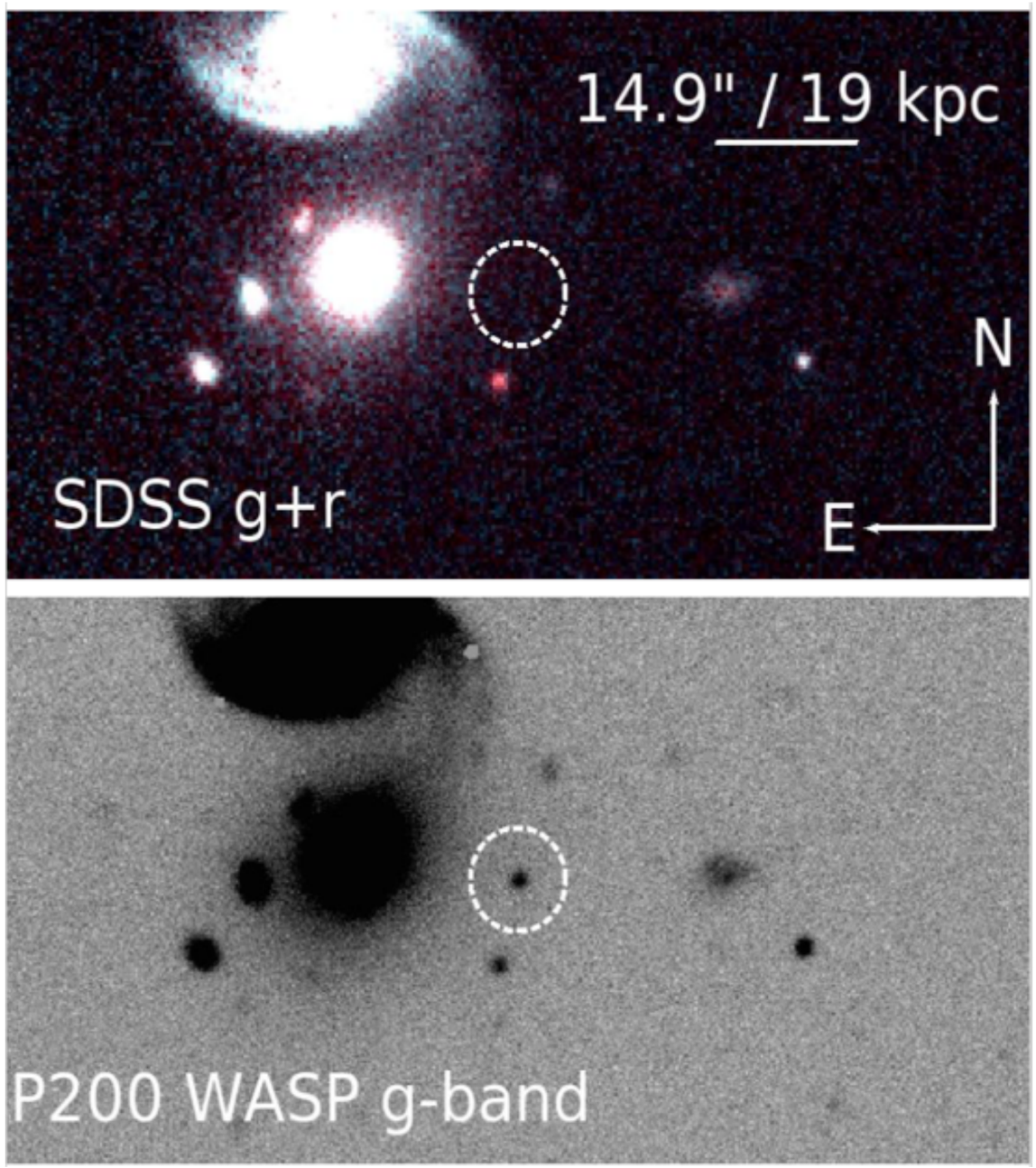

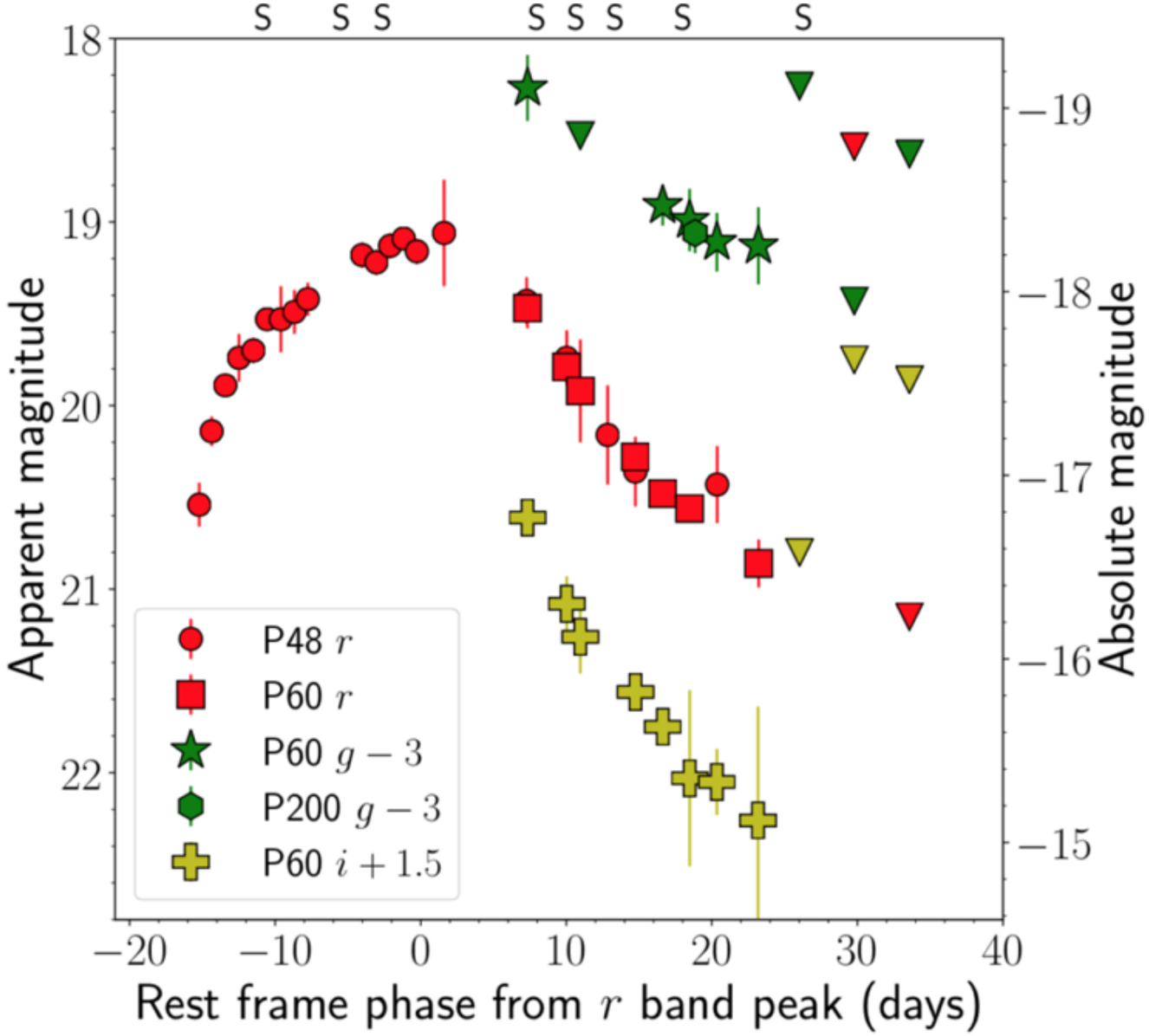

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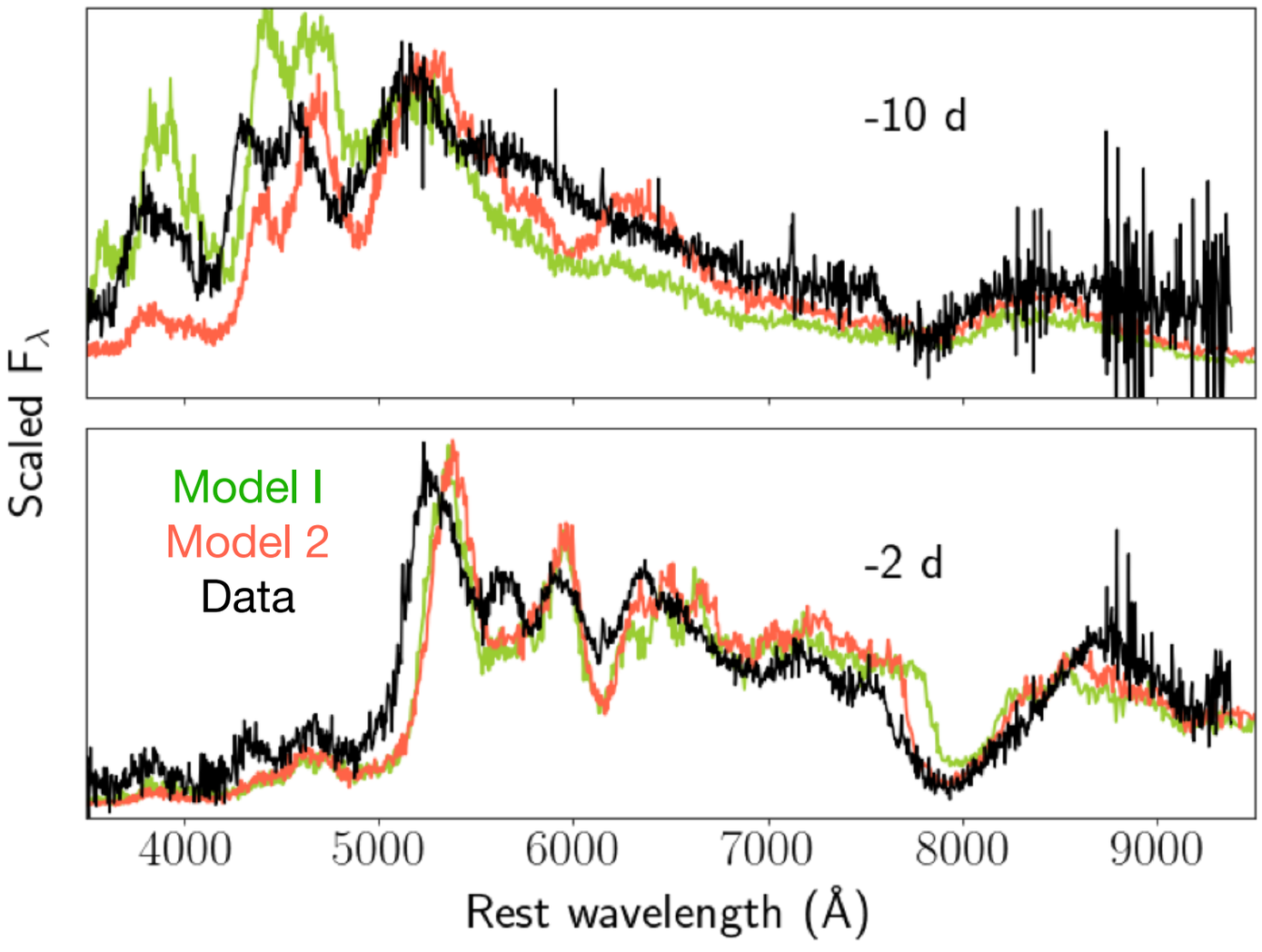
De+ 2019; Models from Polin+ 2019a



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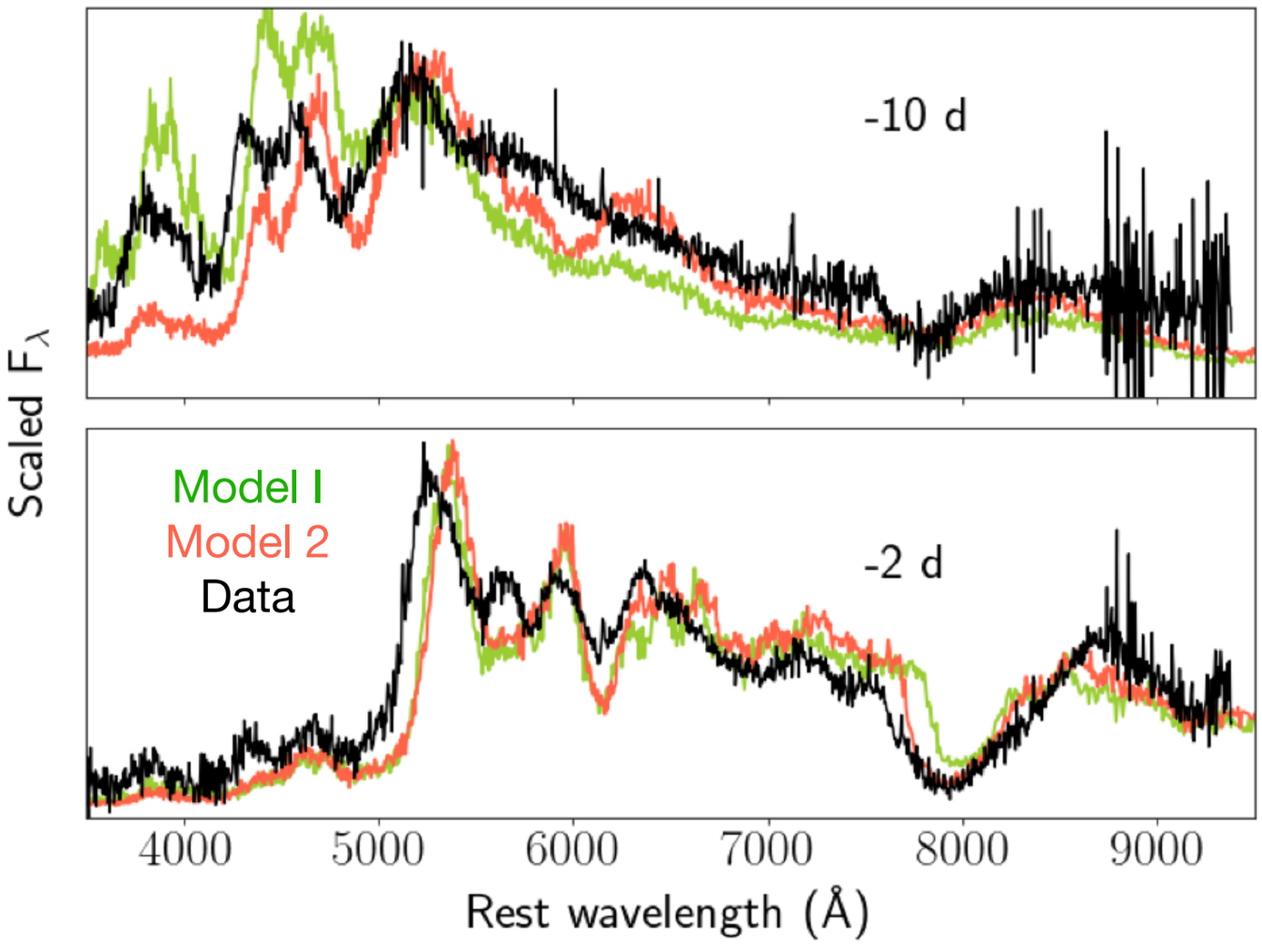

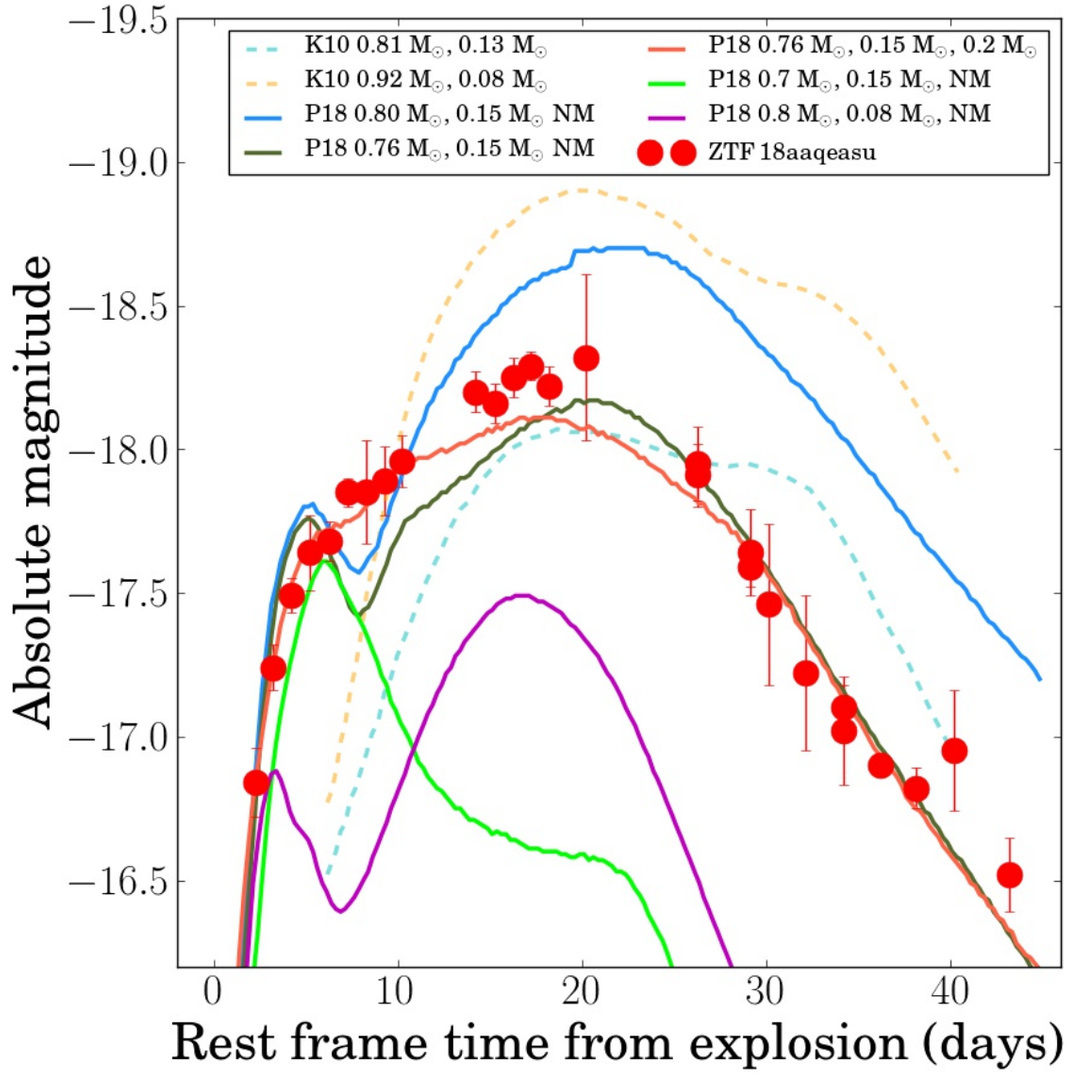

First unambiguous evidence of a He shell detonation

Fast rise + strong line blanketing = Smoking gun signature of a $0.15\,M_\odot$ shell detonation on a $0.75\,M_\odot$ white dwarf

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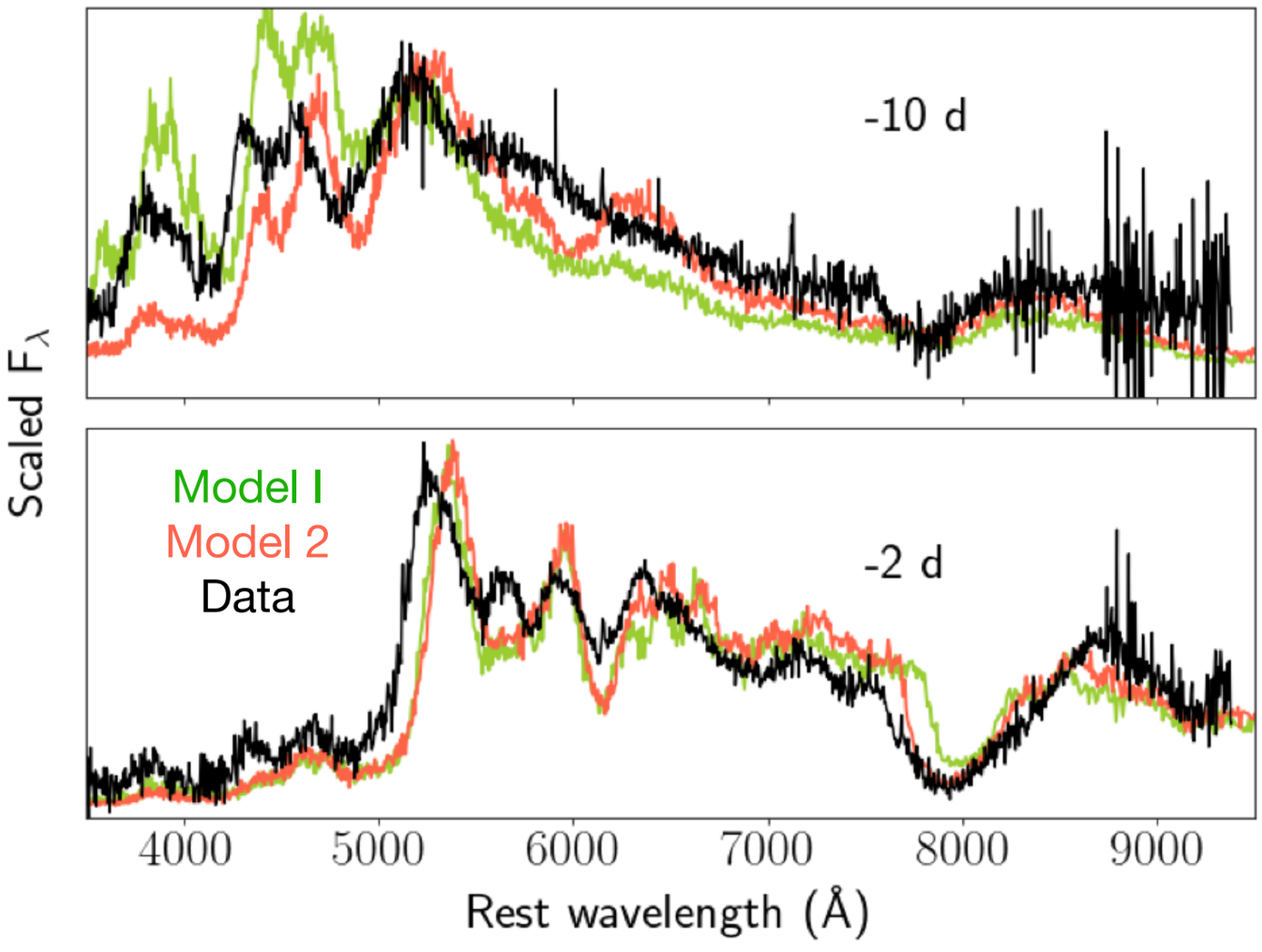

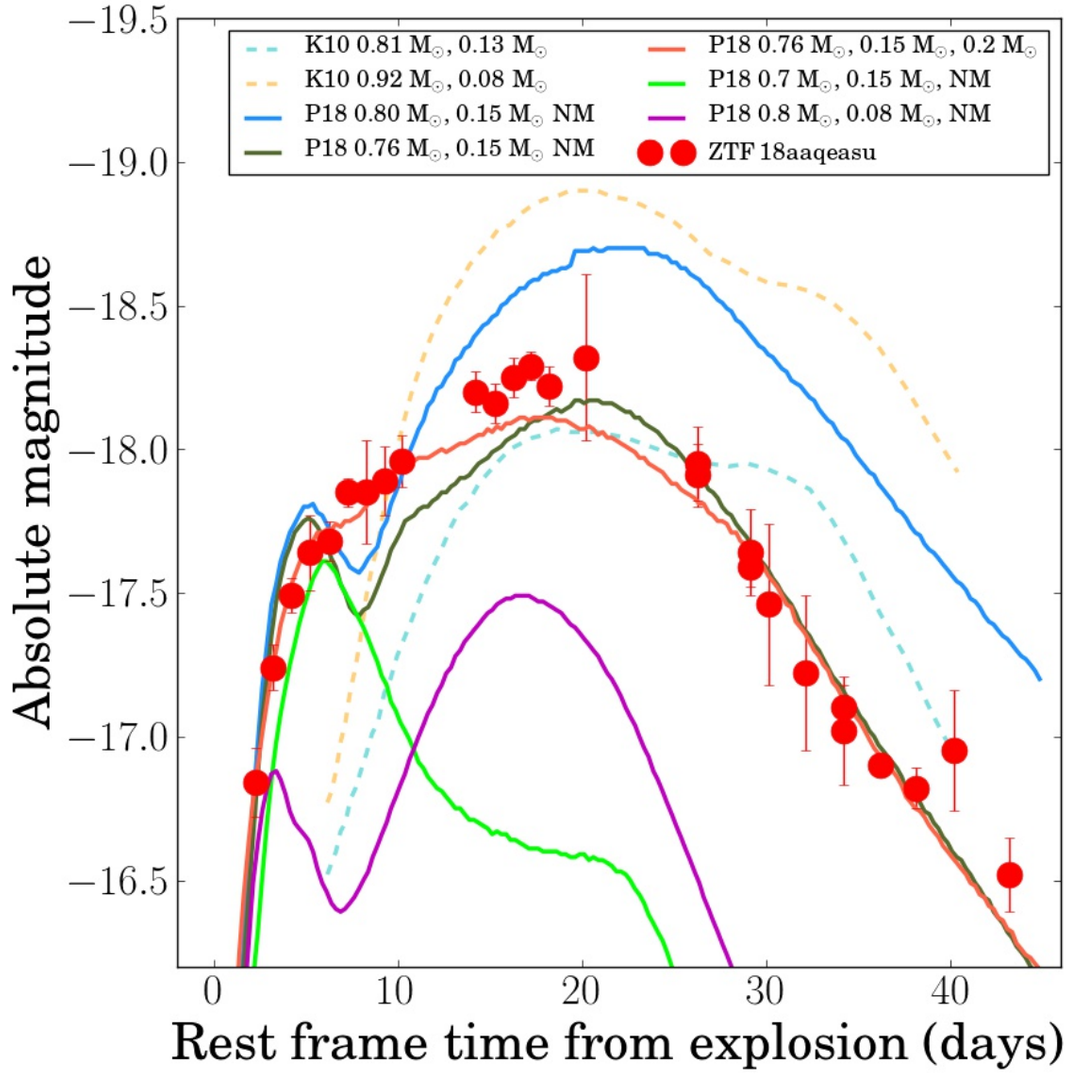

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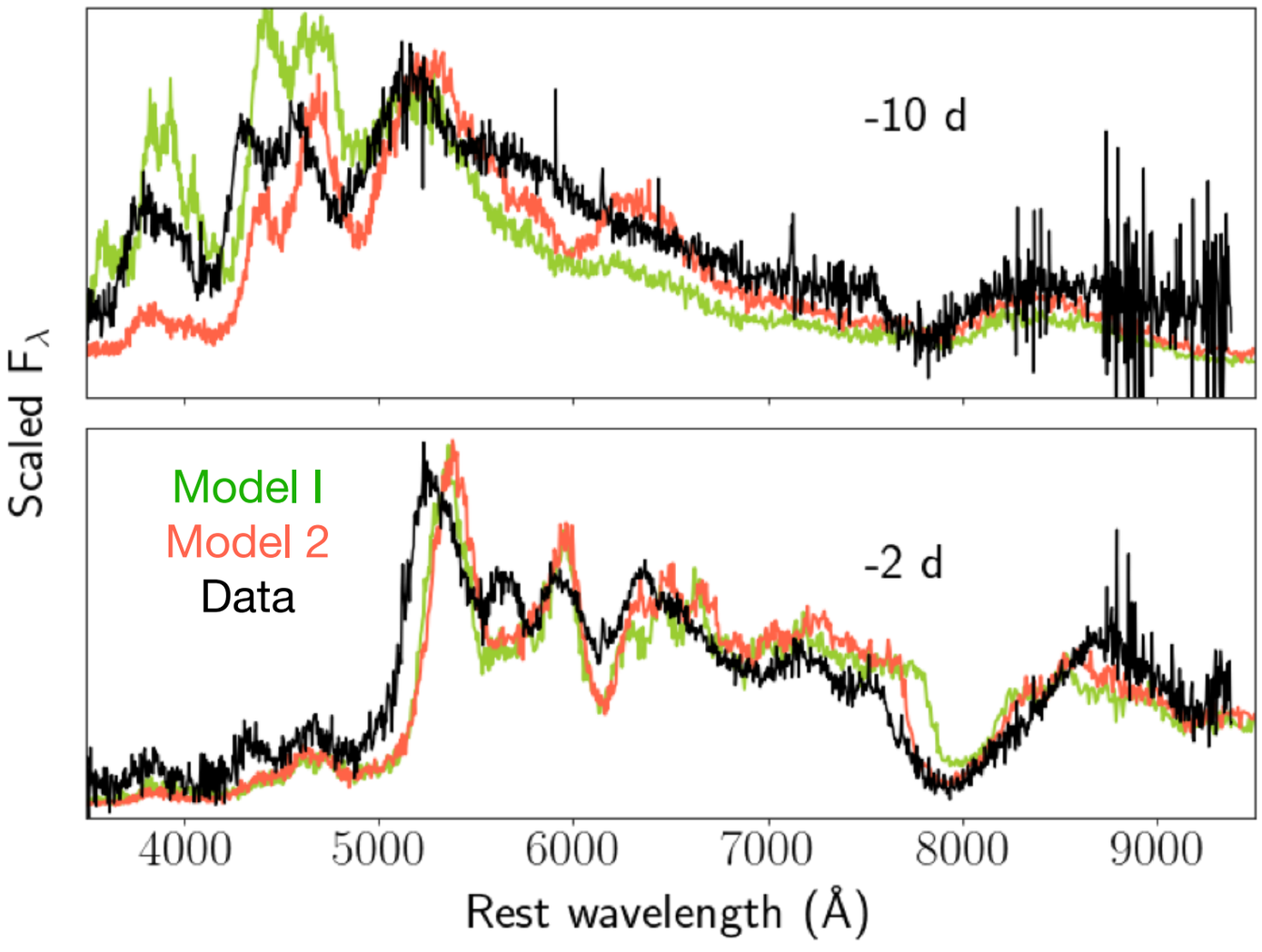

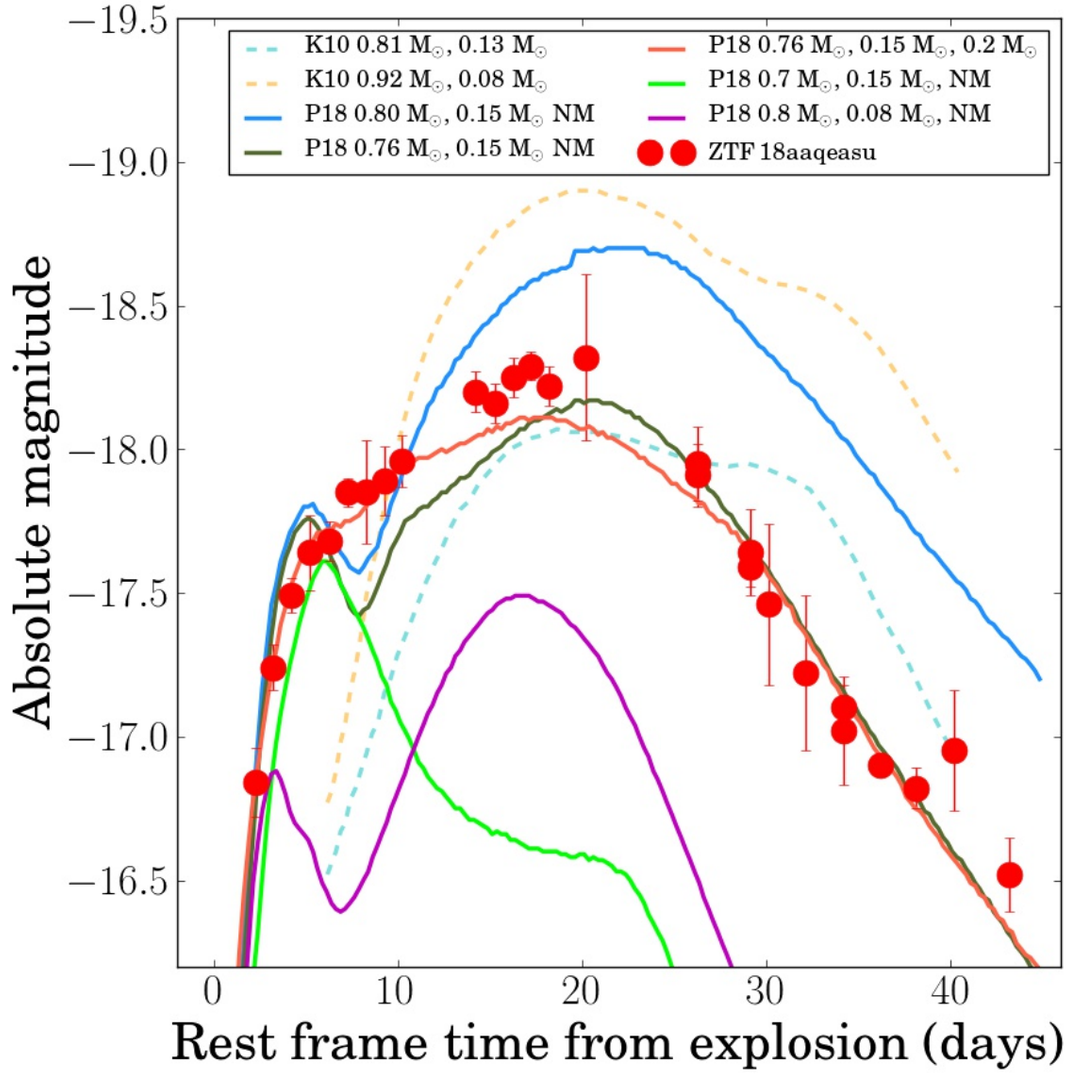

See also SN 2016hnk (Galbany+ 2019, Jacobson-Galan+ 2019), SN 2019yvq (Miller+ 2020, Siebert+ 2020, Tucker+ 2020)

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Shell detonations on massive white dwarfs exist but rare in the universe (~1% of SNe Ia)

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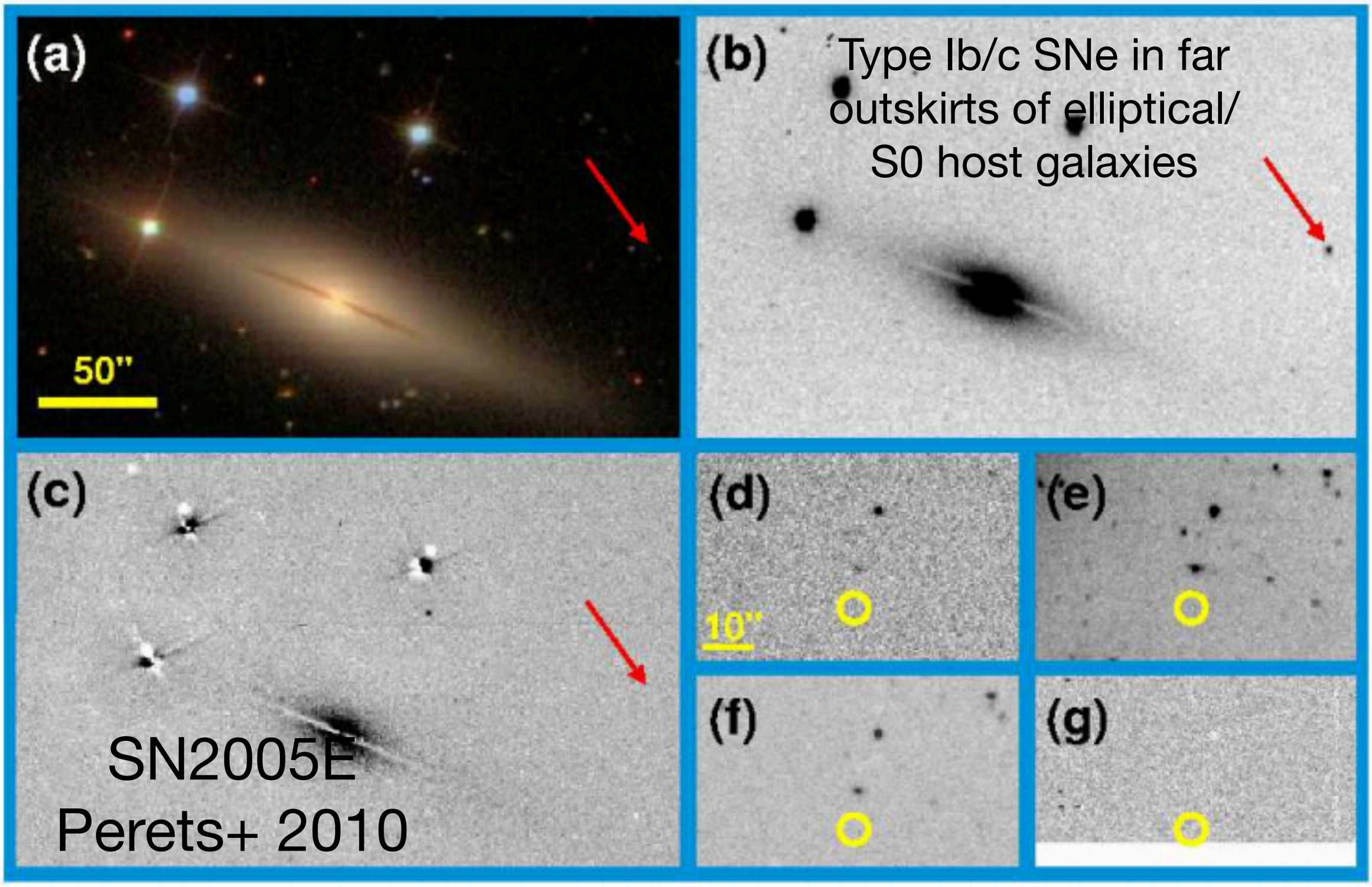
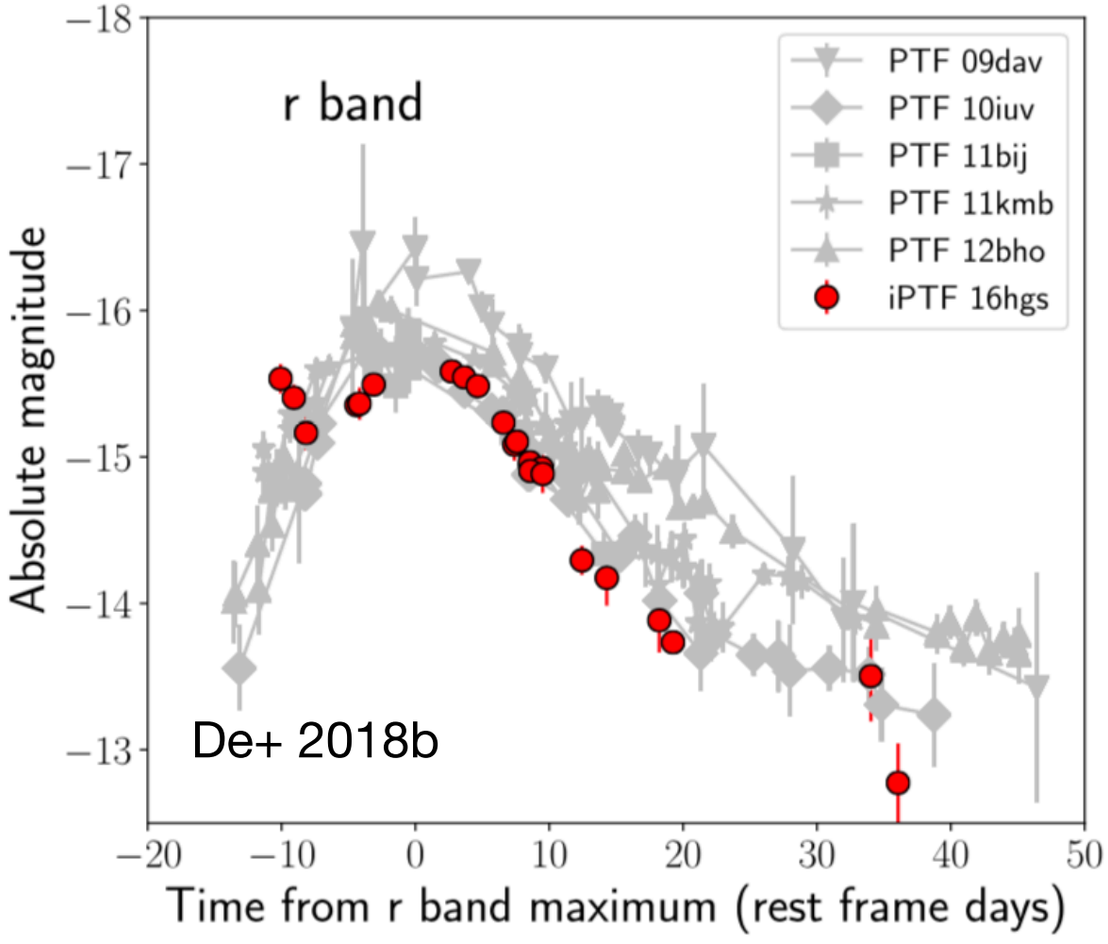
What about lower mass white dwarfs with He shells? Do they explode as fainter transients?

The elusive Ca-rich transients



Faint, fast evolving explosions

Fast timescales = low ejecta mass (~ $0.5\,M_{\odot}$)



Only 10 confirmed events published till date

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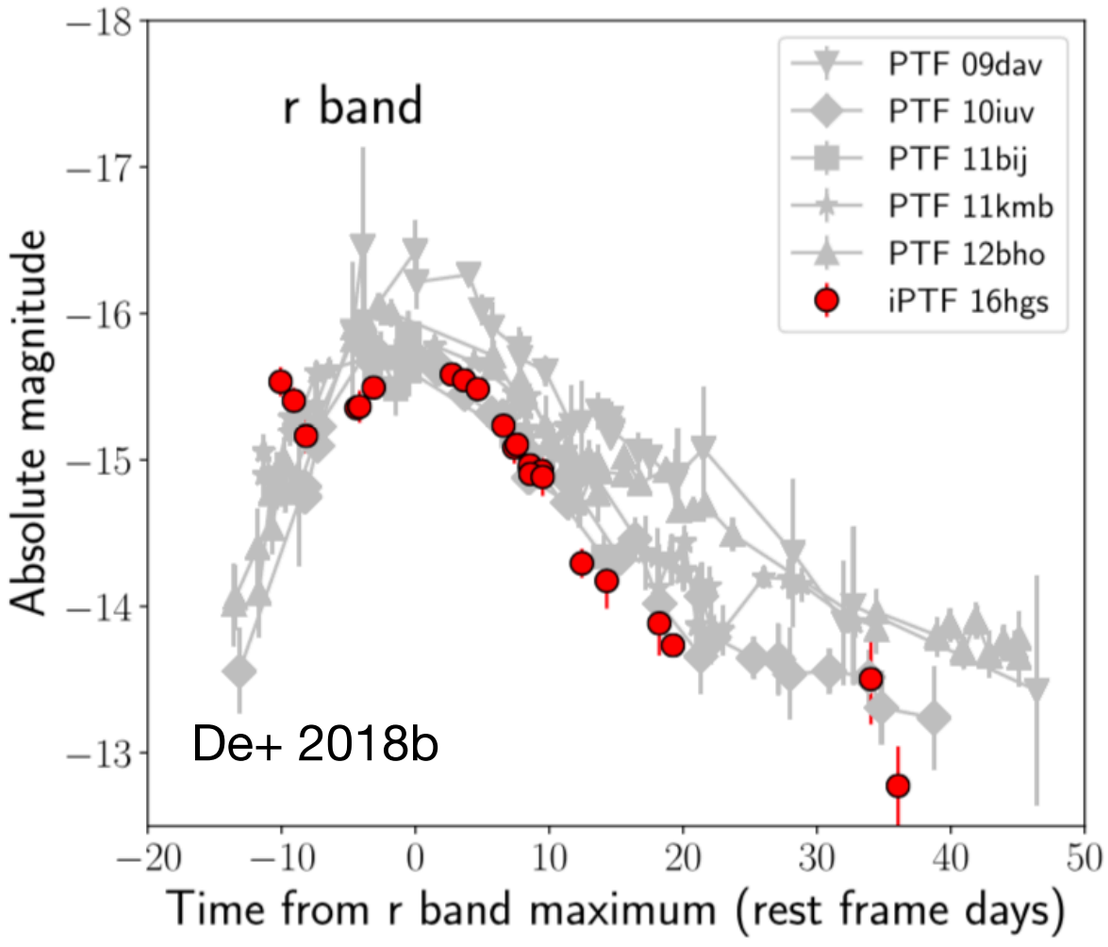
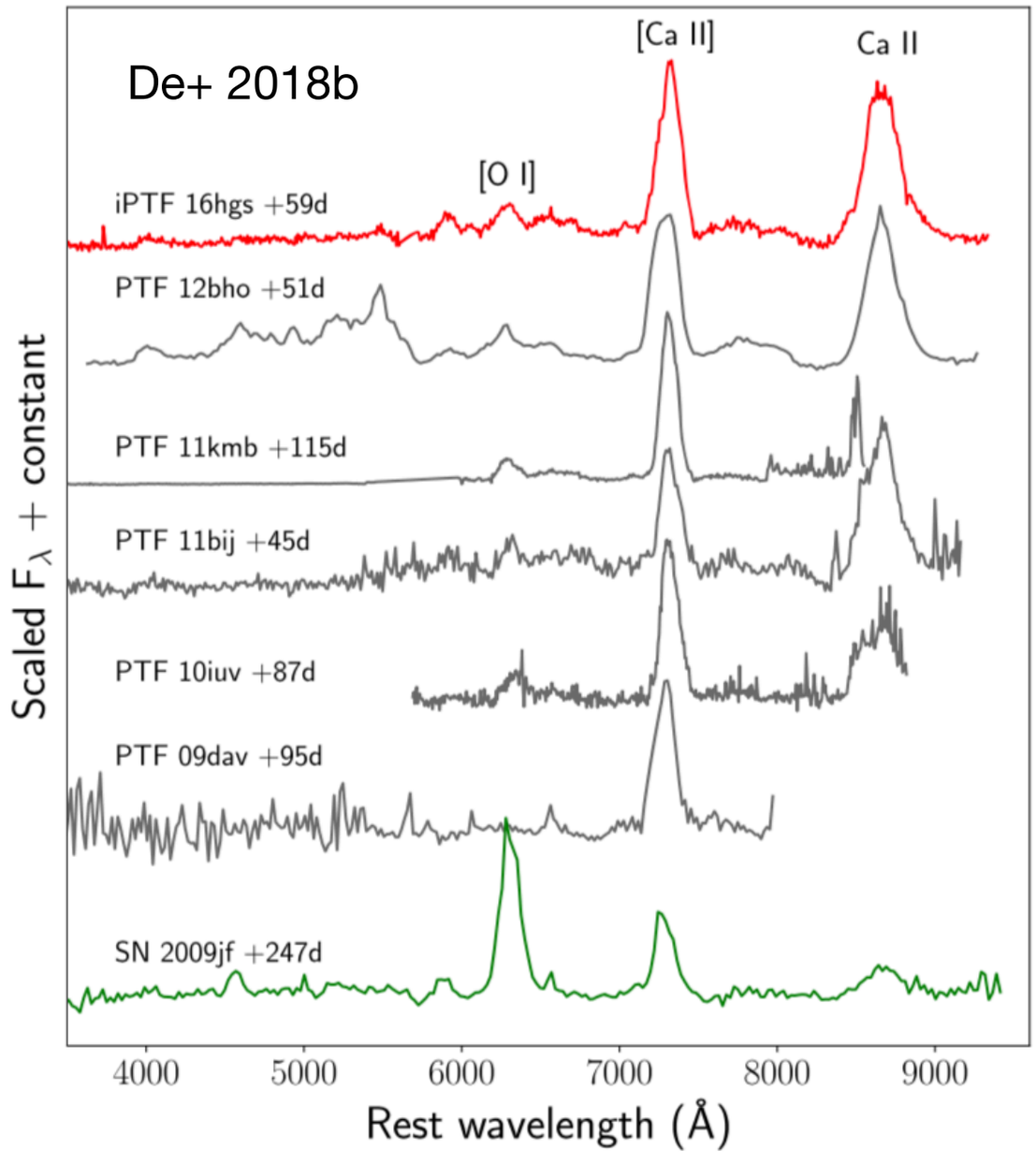


Strong [Ca II] (+ weak [O I]) emission in the nebular phase



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Sullivan+ 2009, Kasliwal+ 2012, Valenti+ 2014, Foley+ 2015, Lunnan+ 2017, Galbany+ 2019, Jacobson-Galan+ 2019

Search with ZTF: The largest homogeneous sample

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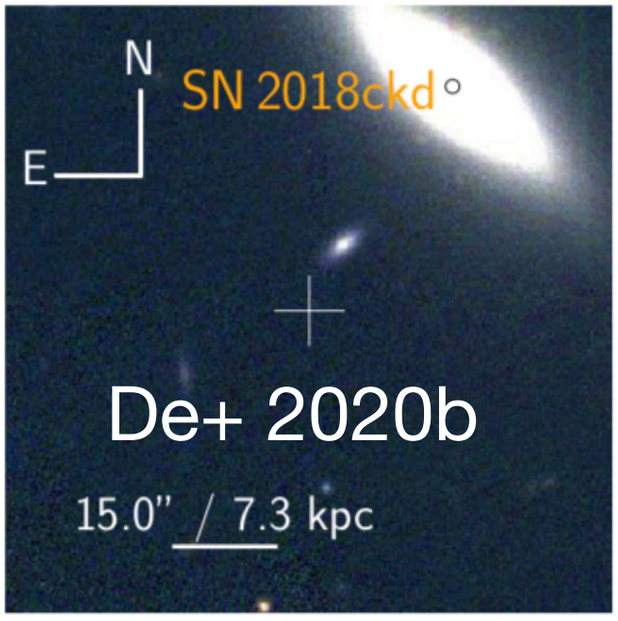
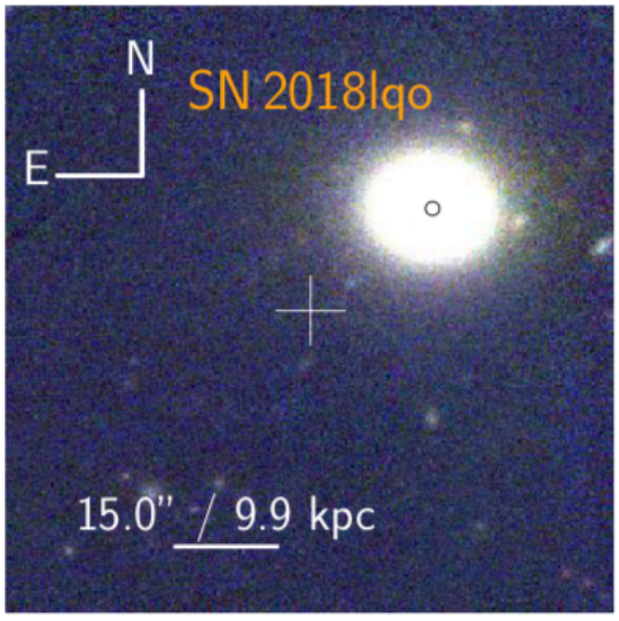
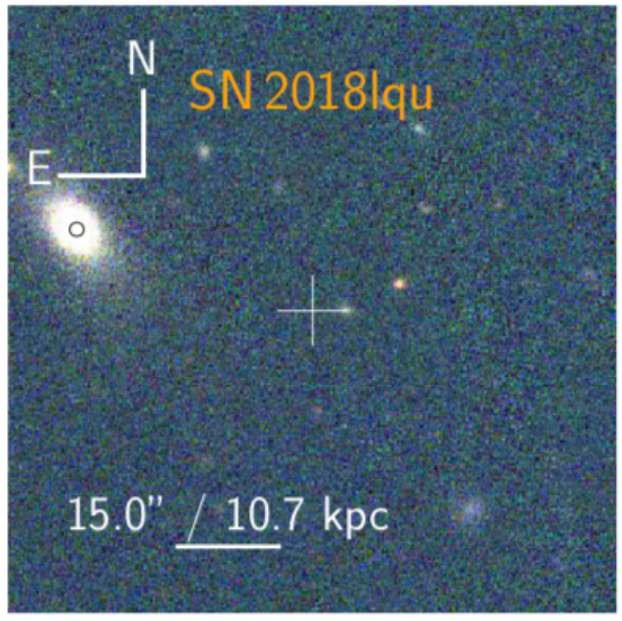
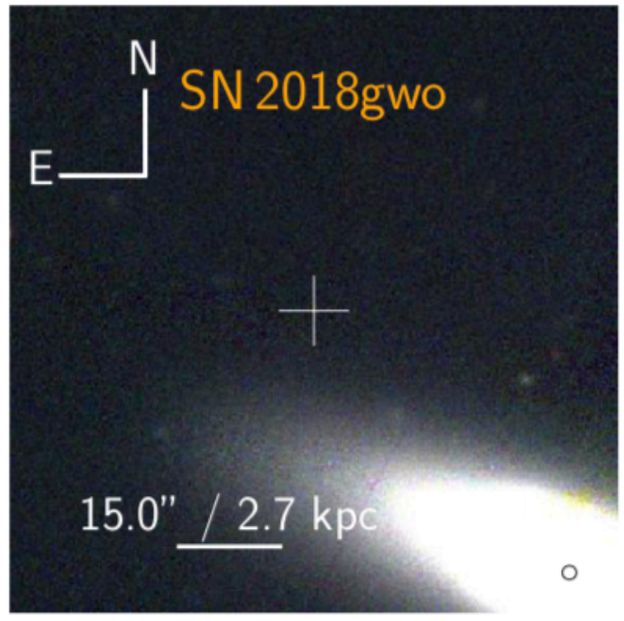
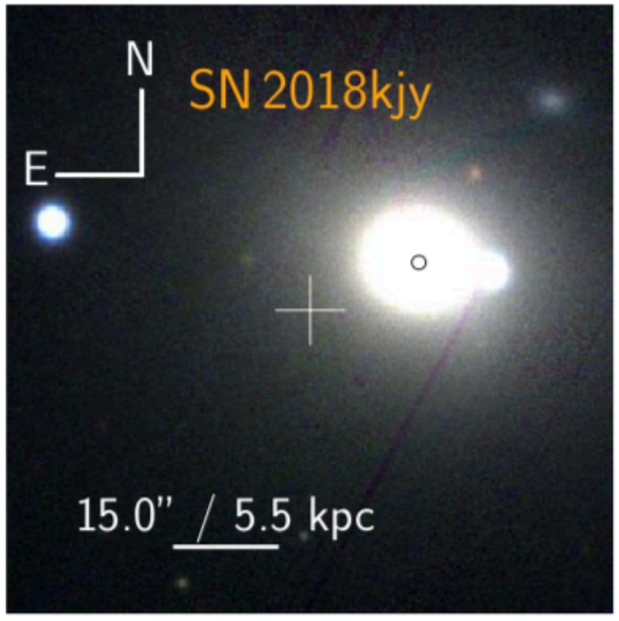
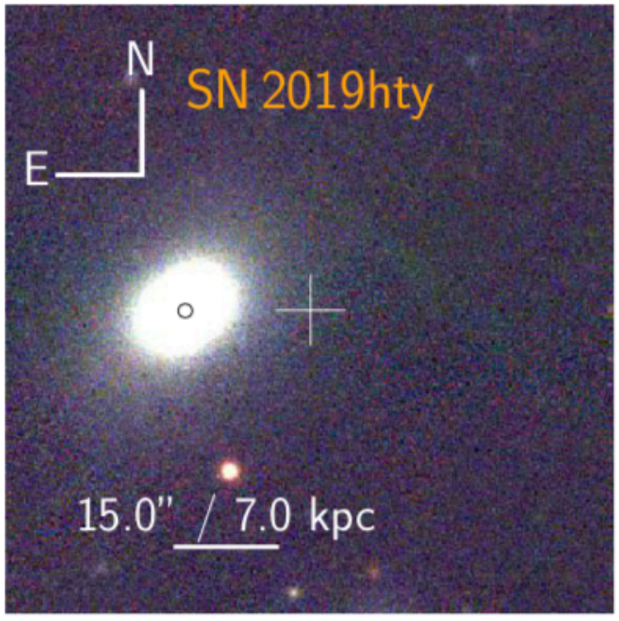


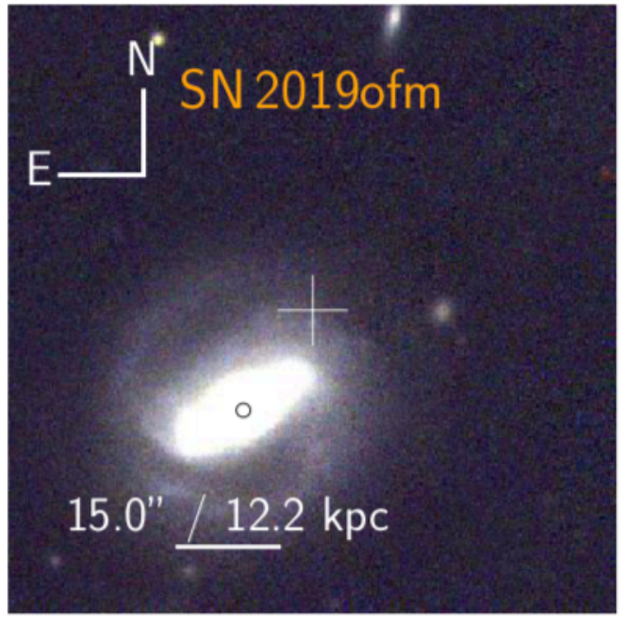


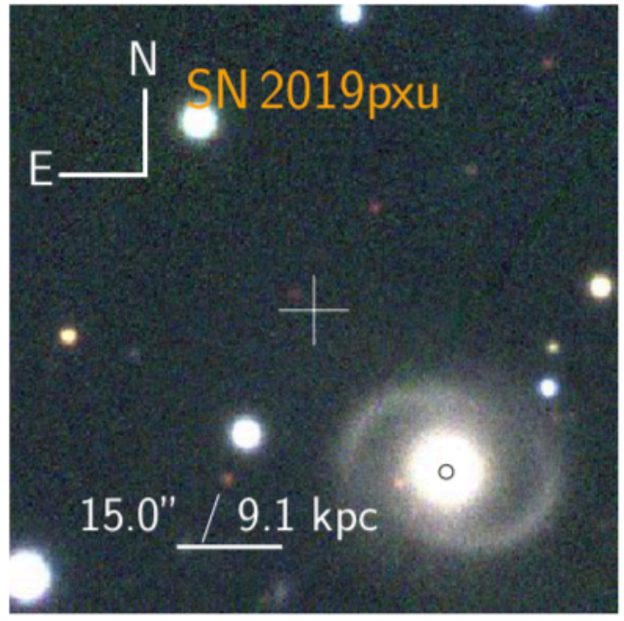




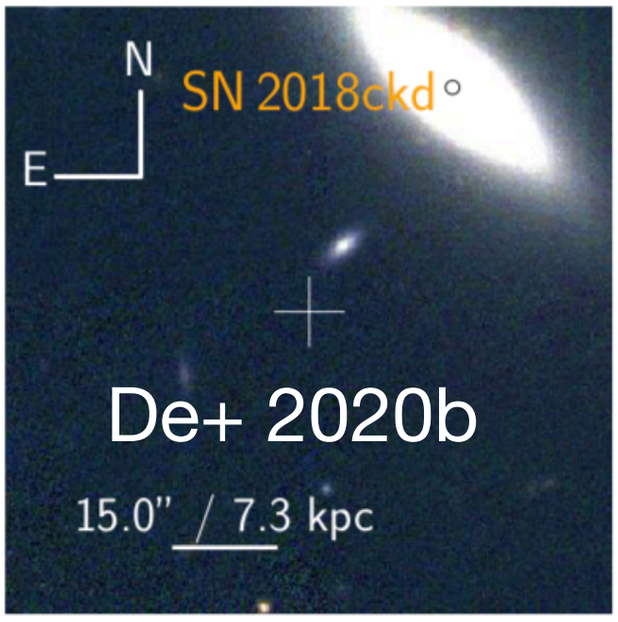


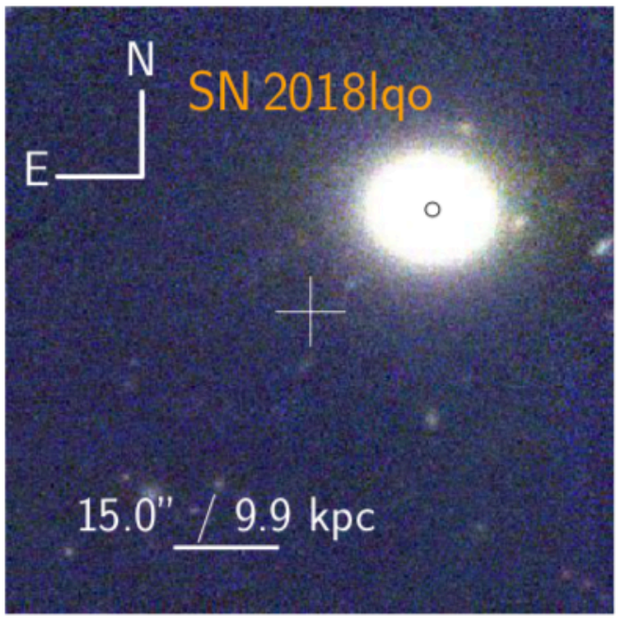


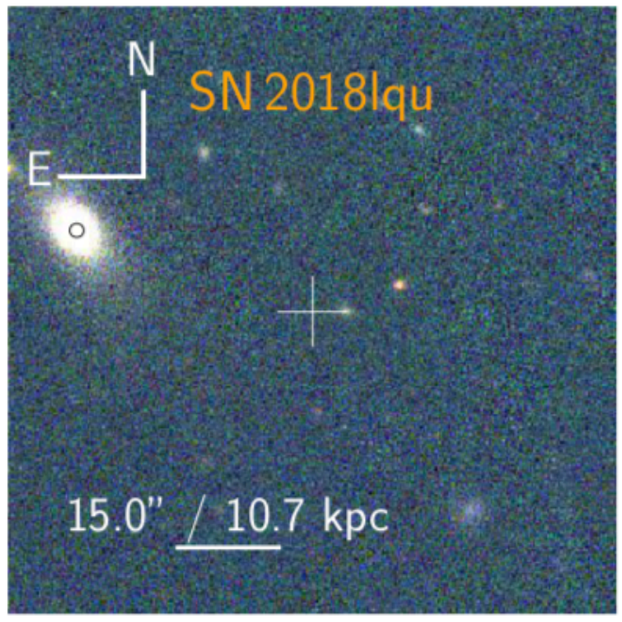


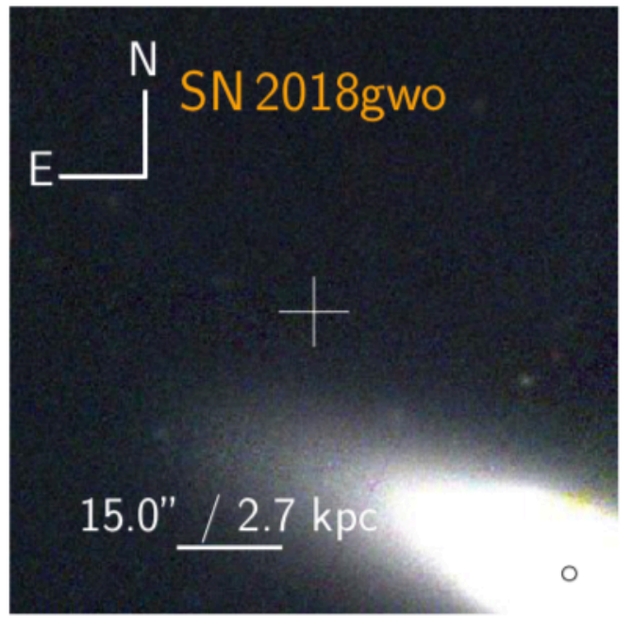


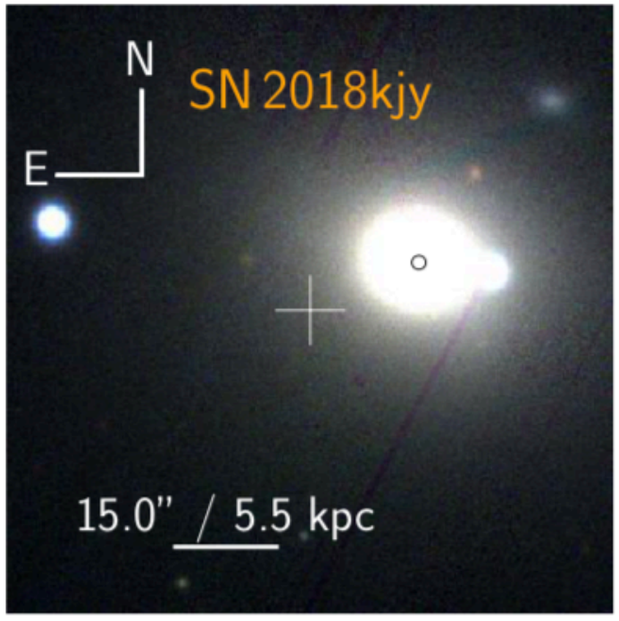
Search with ZTF: The largest homogeneous sample

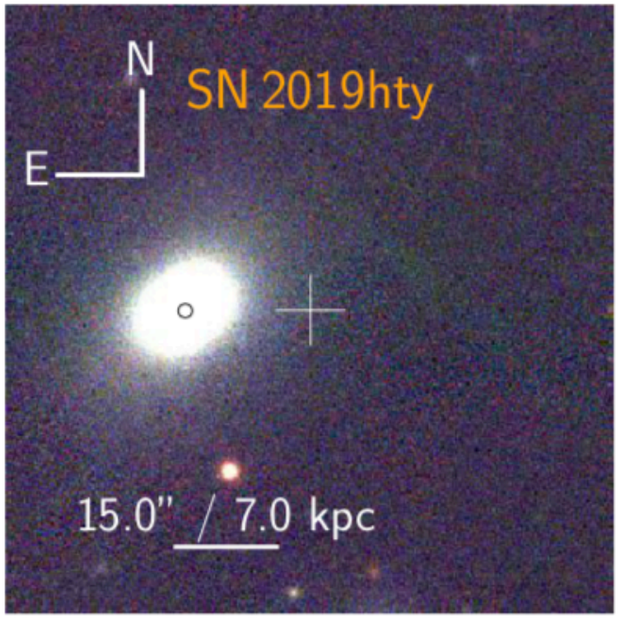


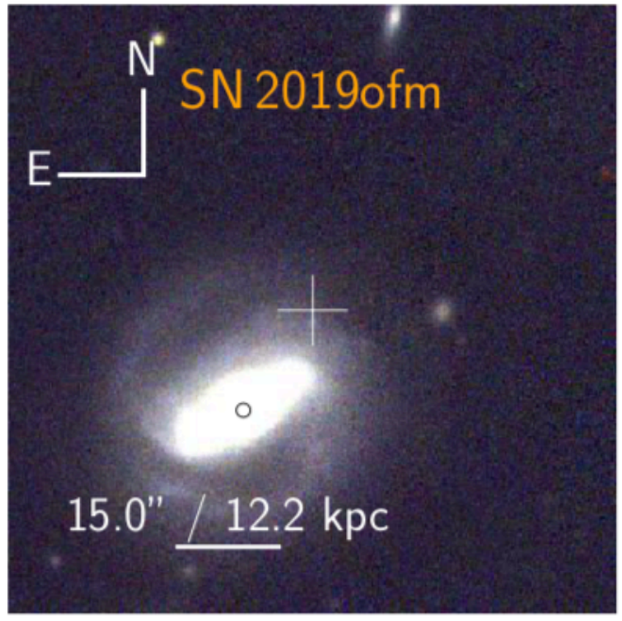


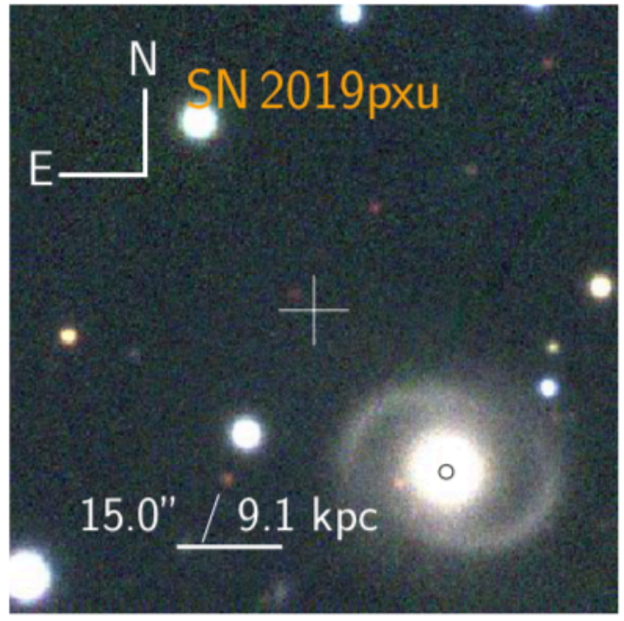






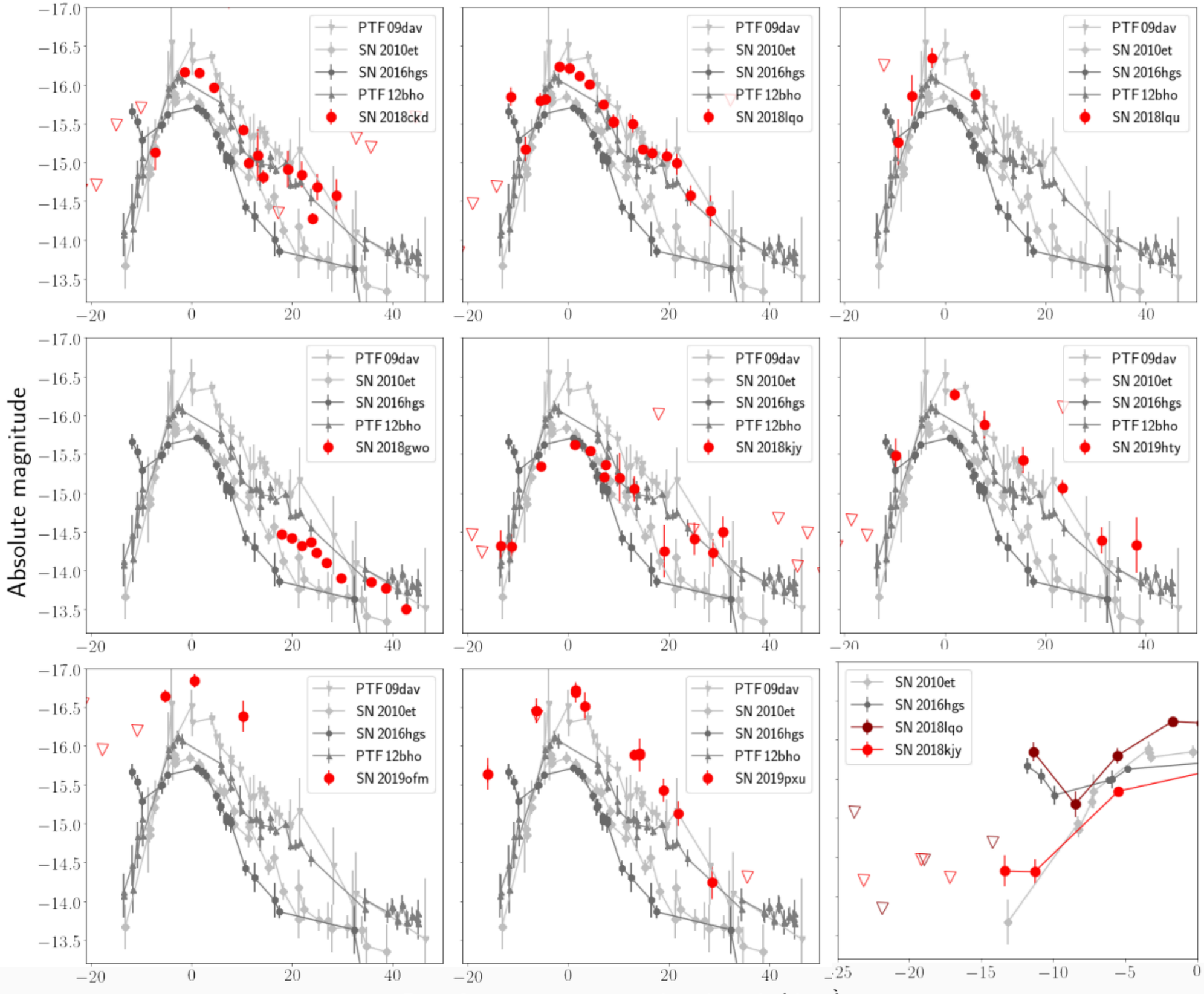




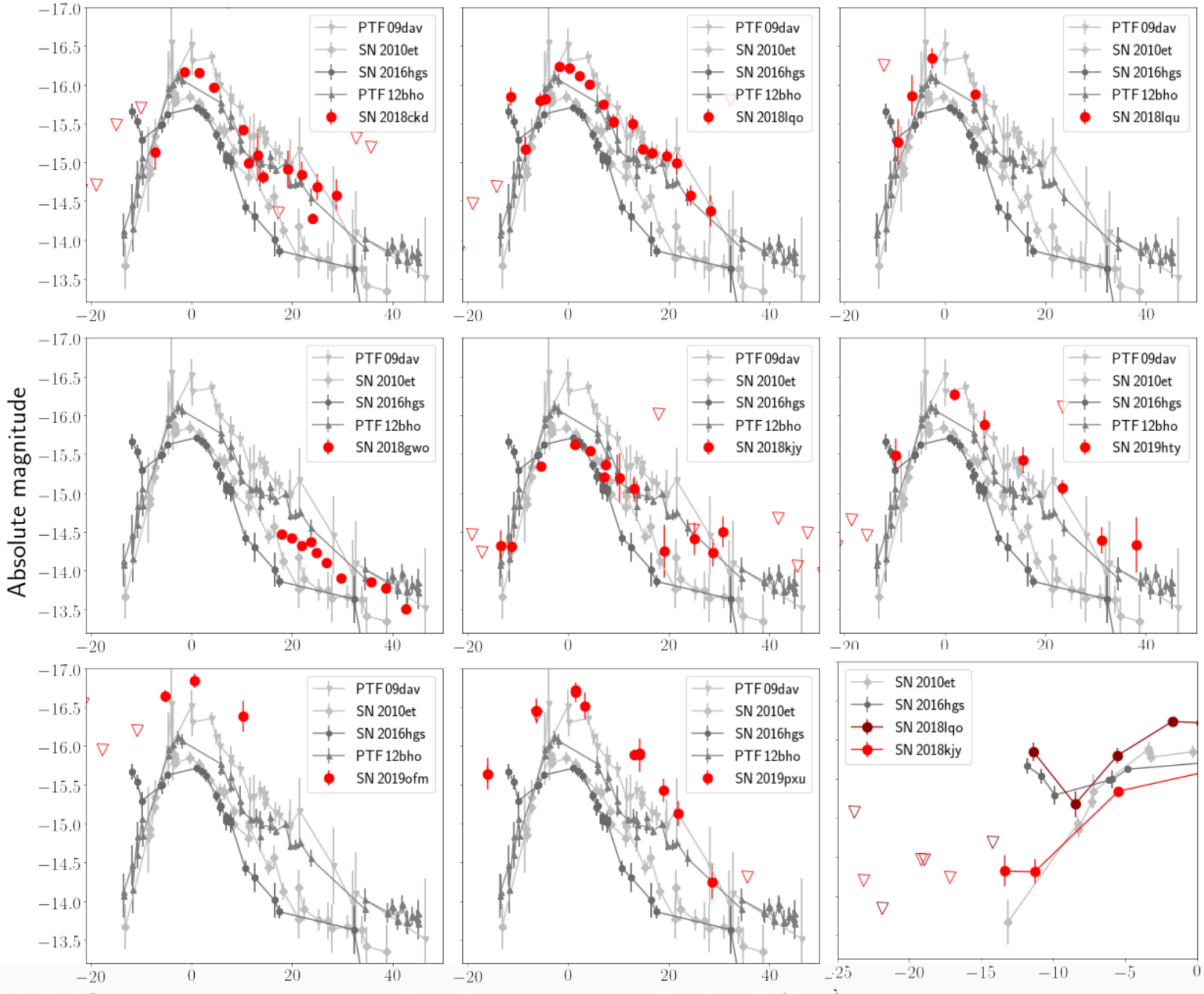


Consistently found in the outskirts of early type galaxies. Doubles the previously known population.

High cadence light curves

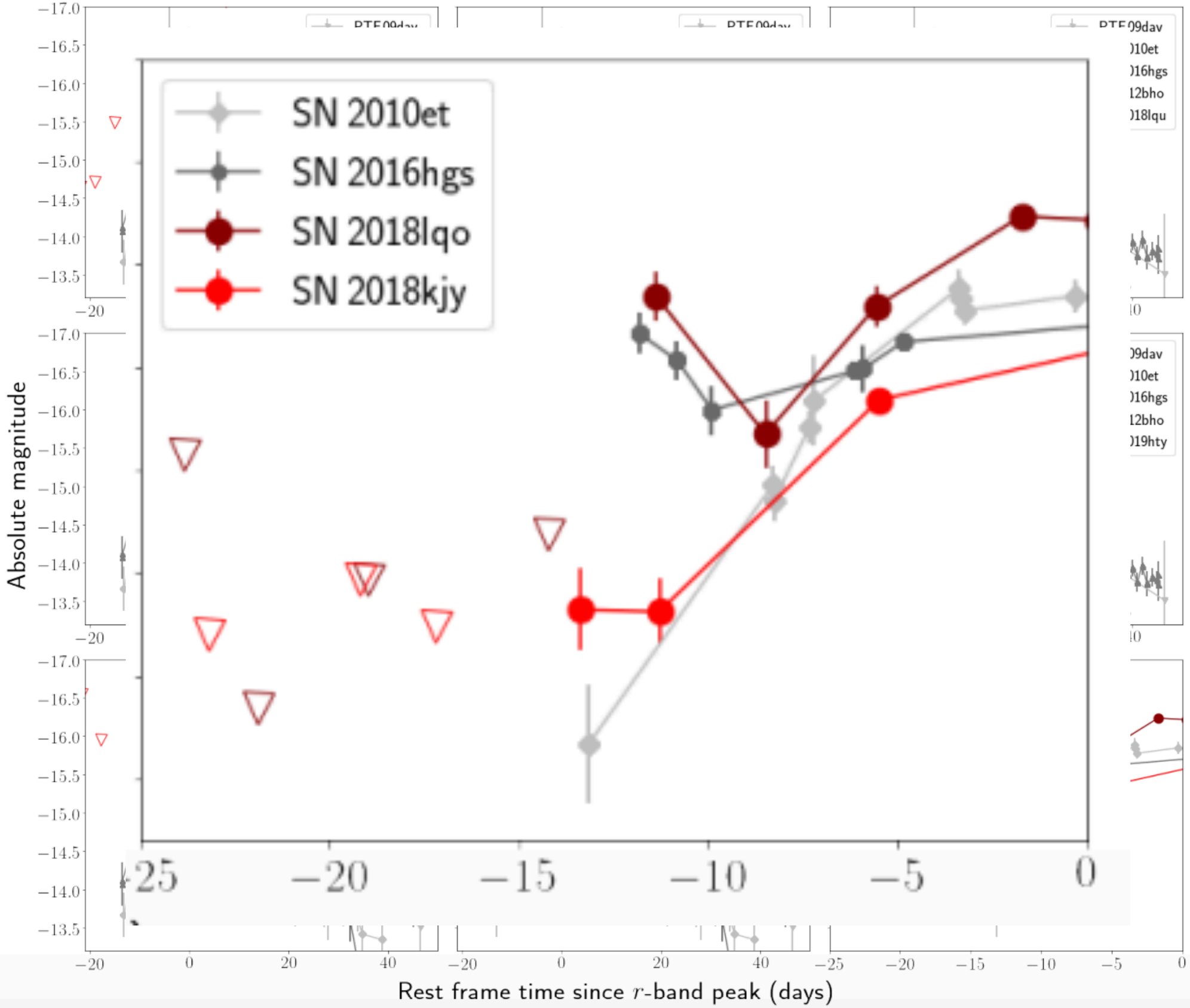


High cadence light curves

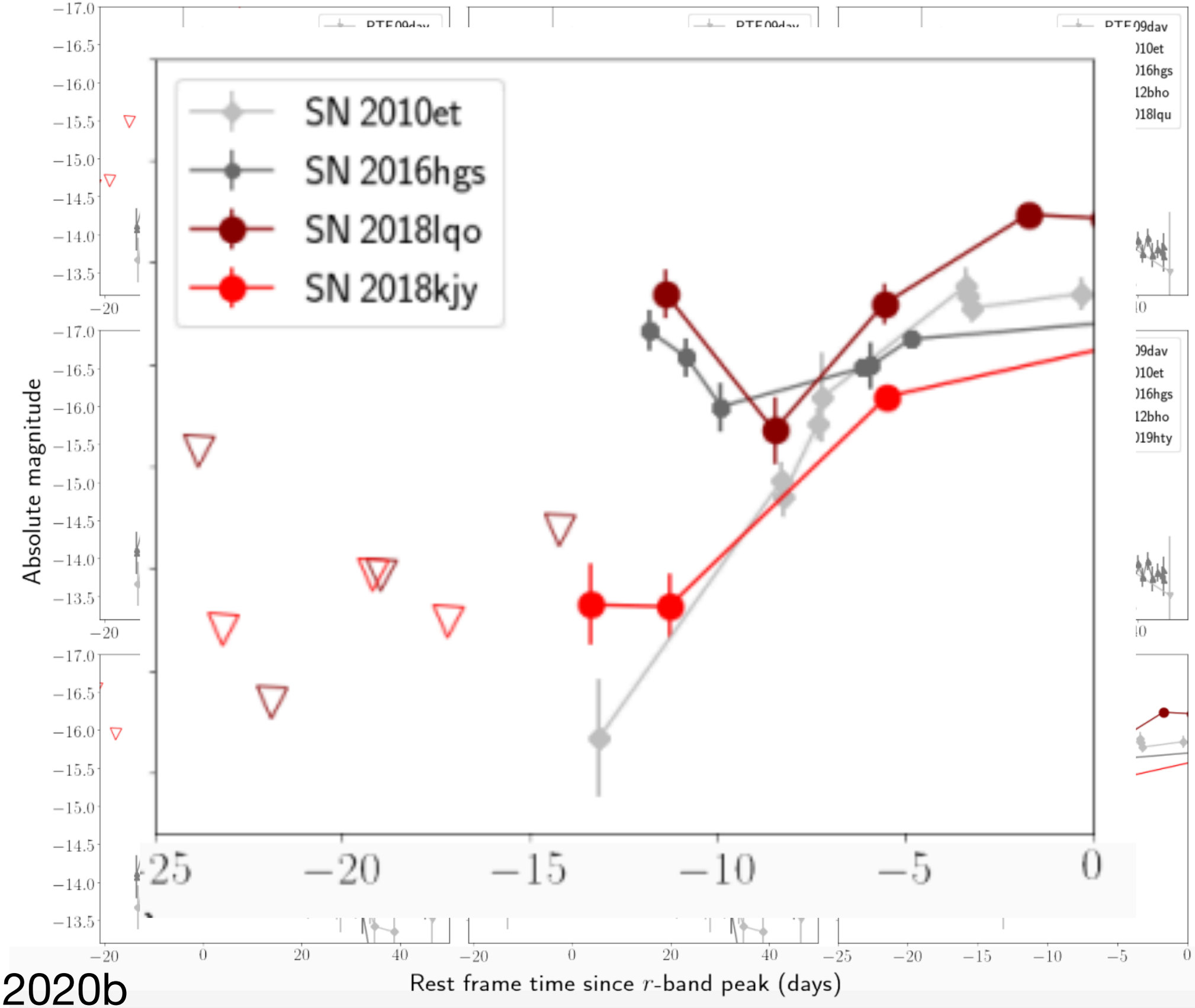


De+ 2020b

Evidence for the shell detonation?

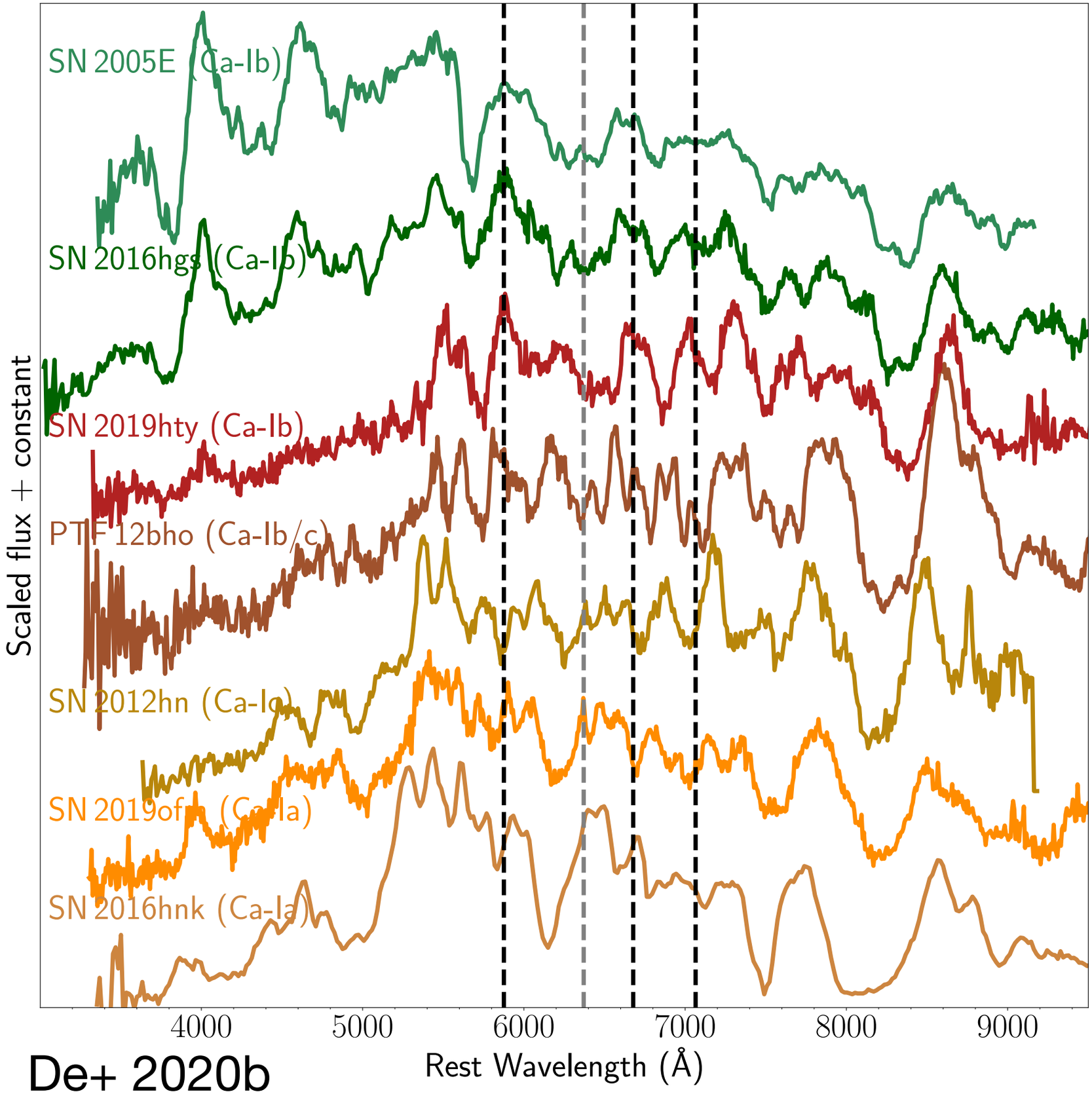


Evidence for the shell detonation?



De+ 2020b

A photometric + spectroscopic continuum



De+ 2020b

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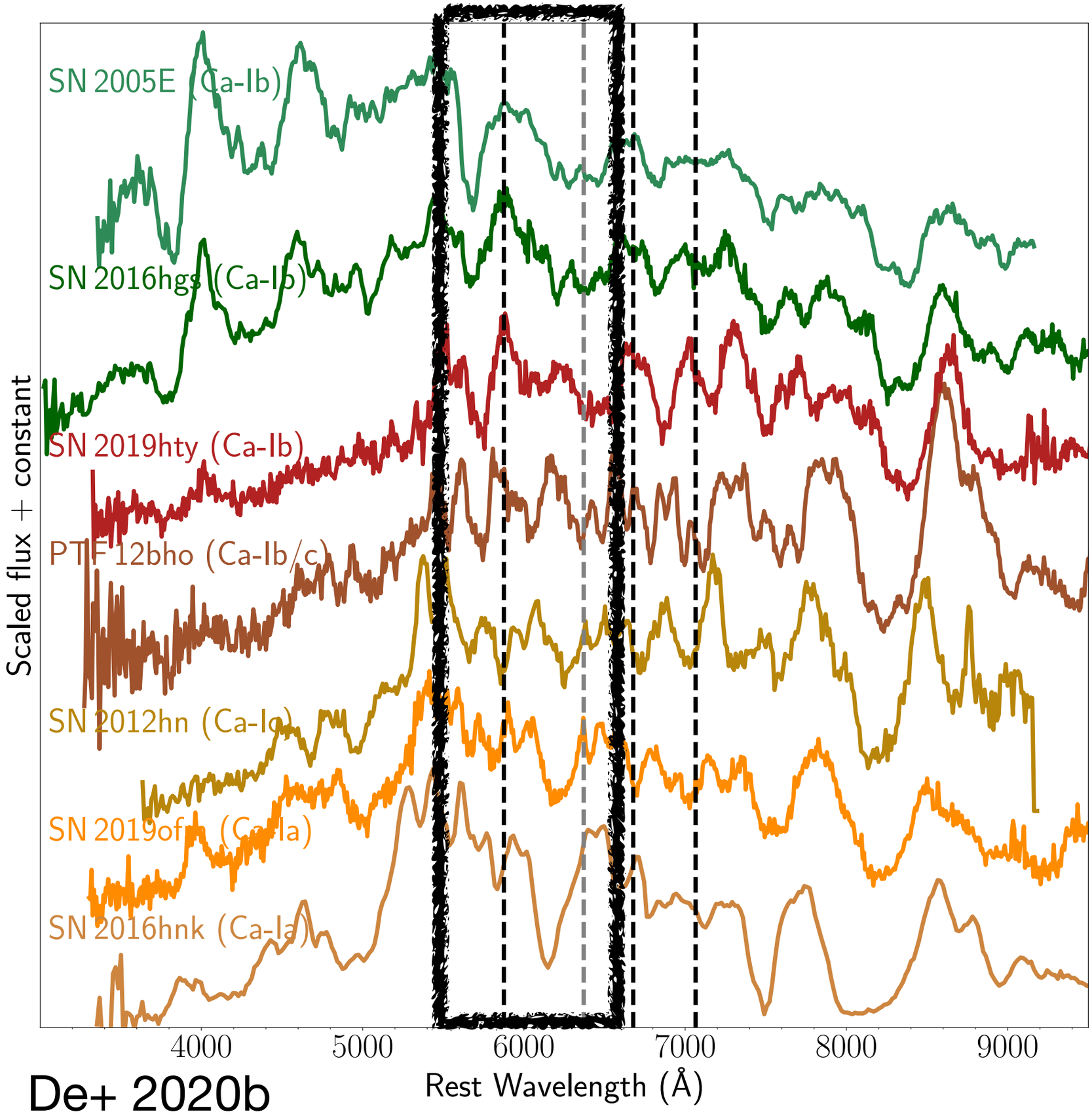

De+ 2020b

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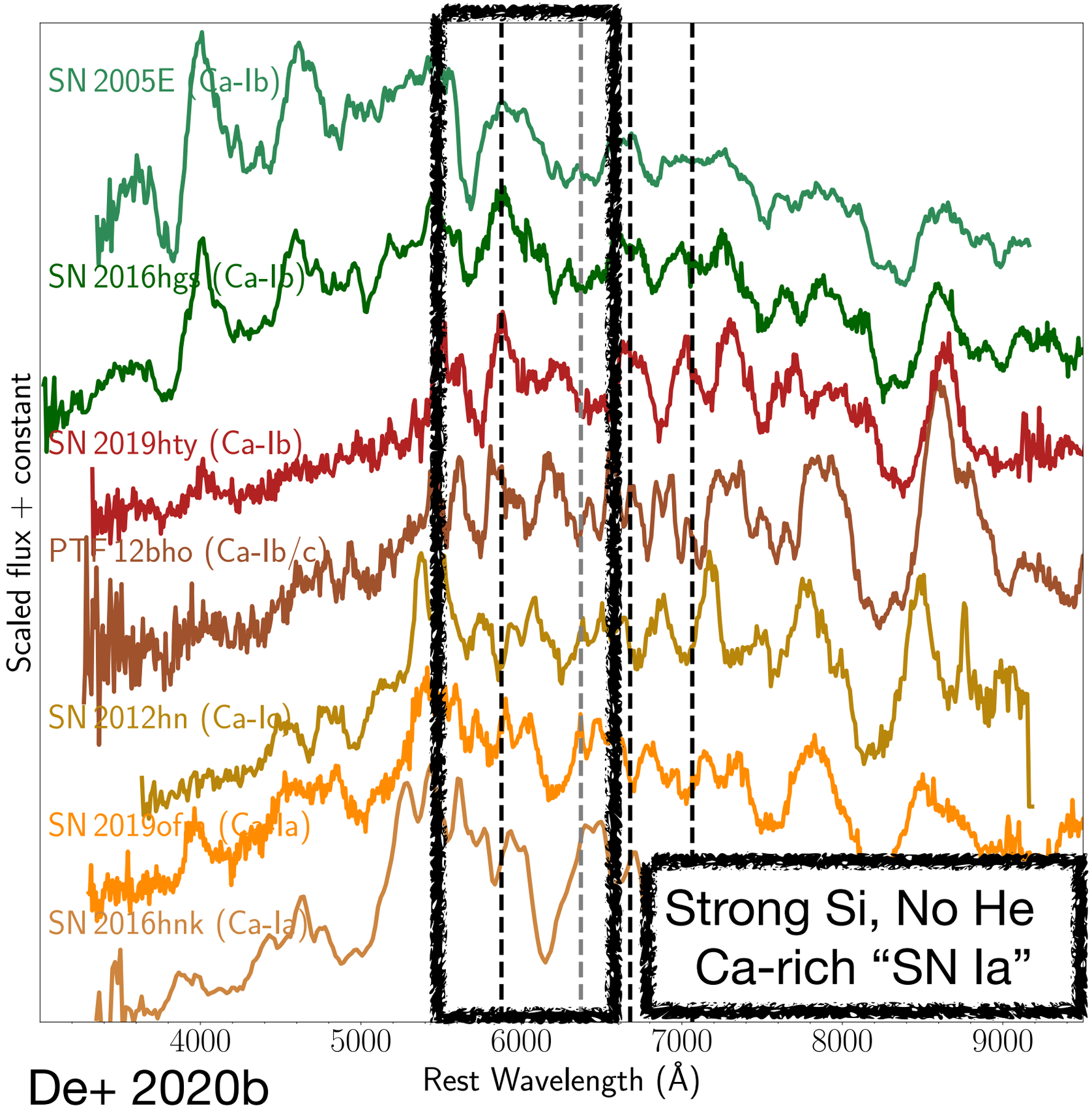

De+ 2020b

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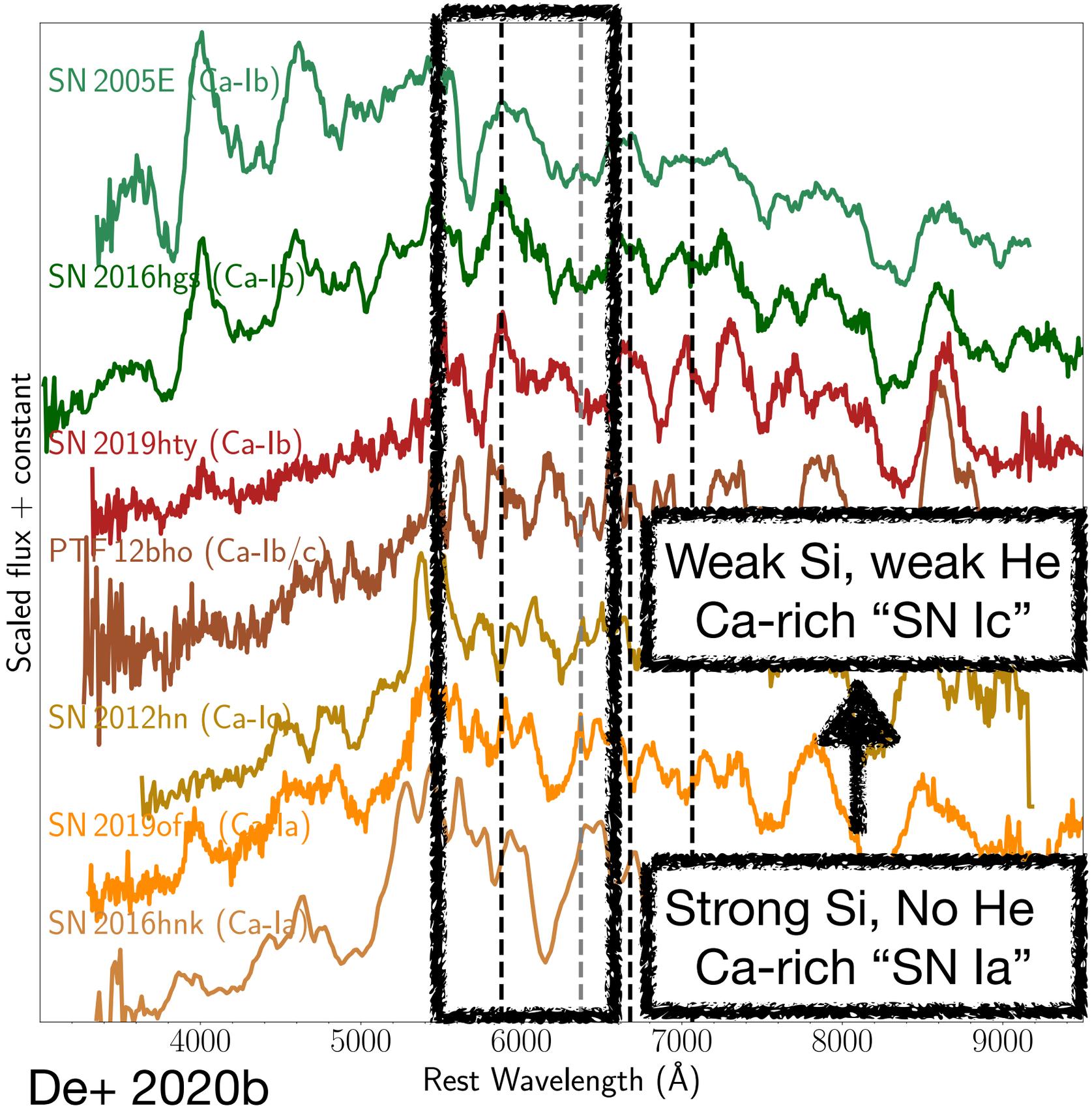

De+ 2020b

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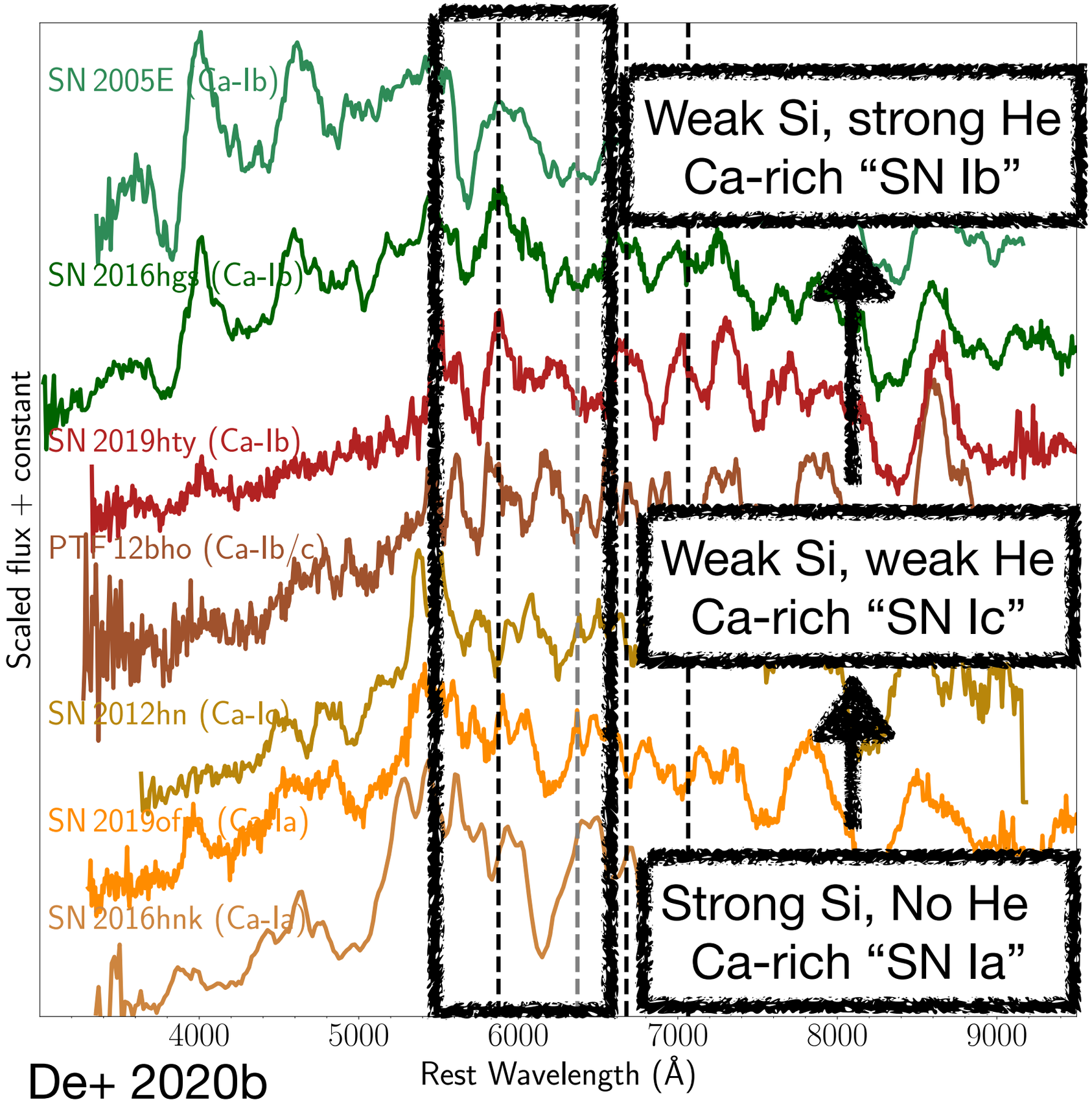
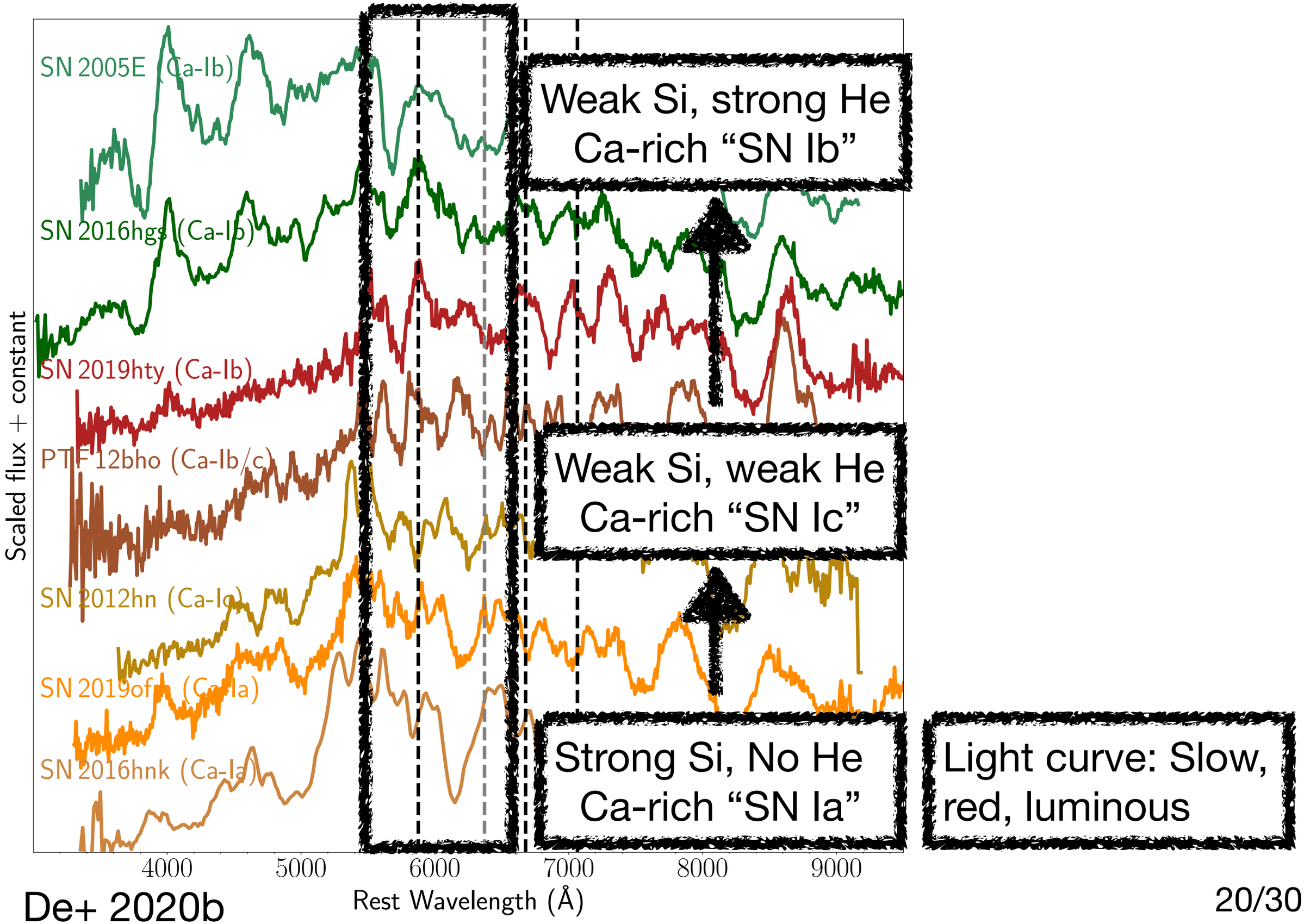


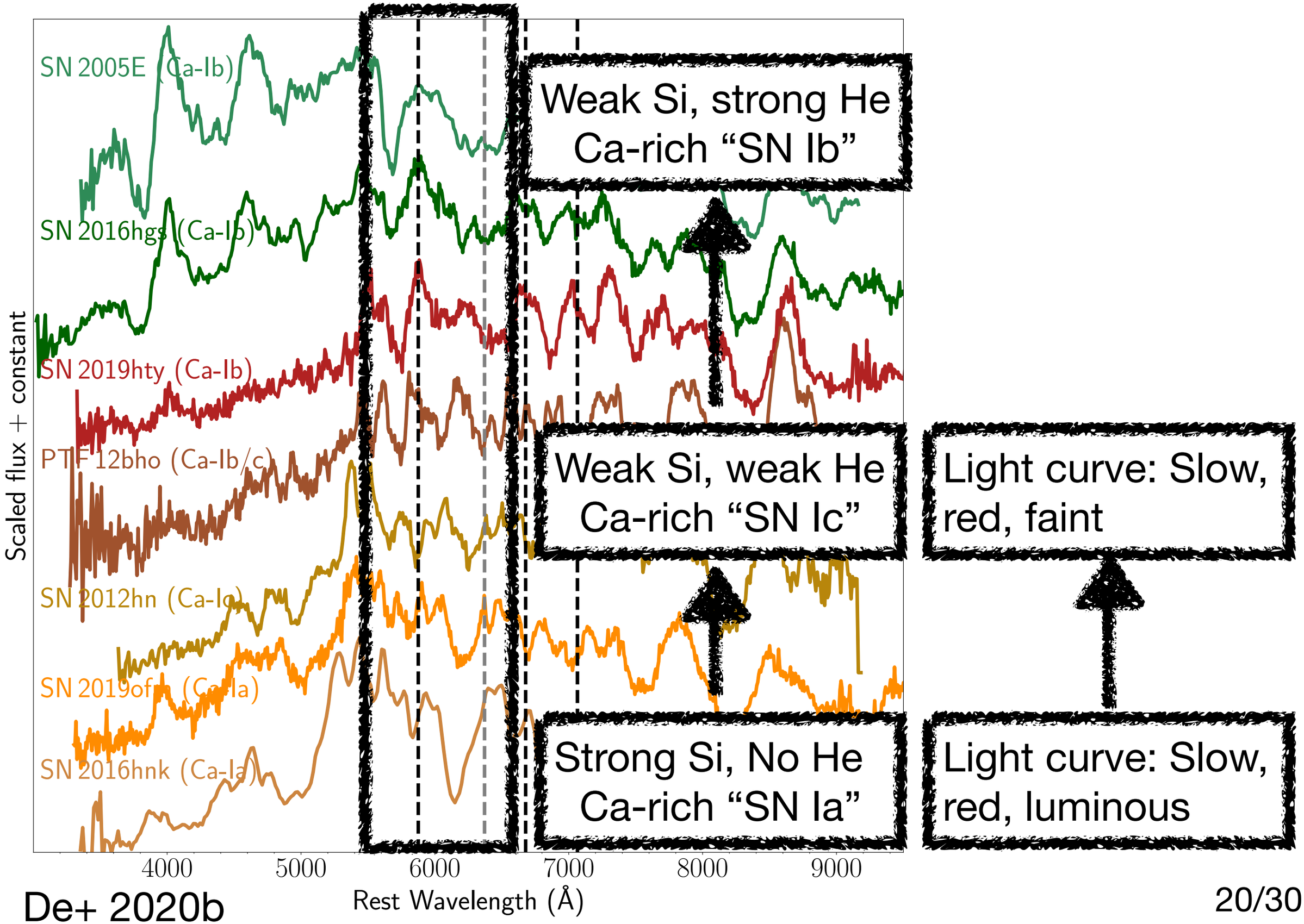
De+ 2020b

A photometric + spectroscopic continuum



De+ 2020b

A photometric + spectroscopic continuum



De+ 2020b

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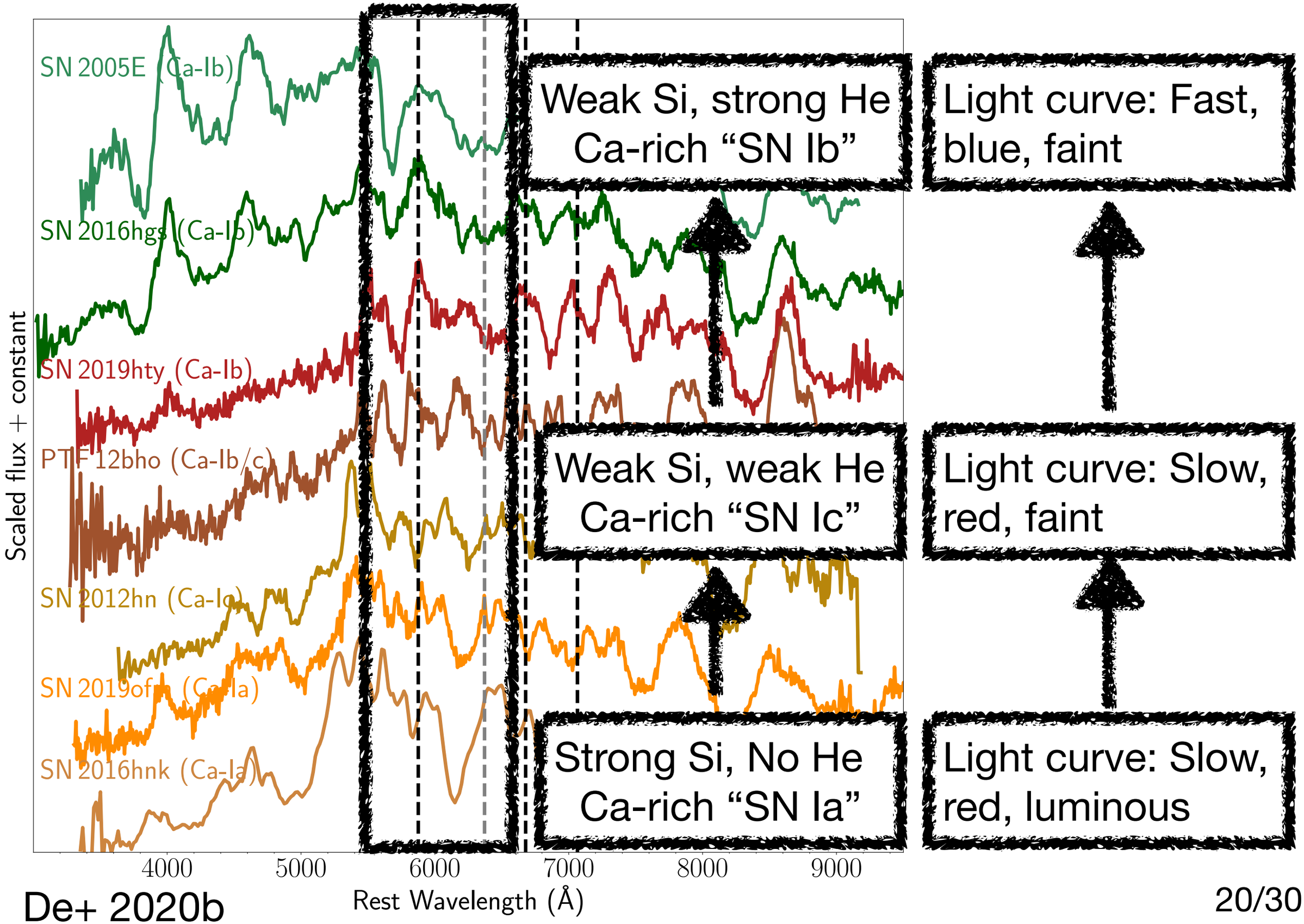

De+ 2020b

A continuum of He shell explosions from WDs?

De+ 2020b

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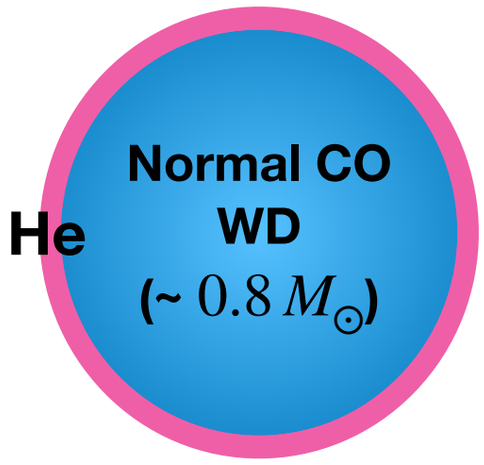
Ca-rich “SN Ia”



Double detonation?

Near complete shell burning

De+ 2020b

A continuum of He shell explosions from WDs?

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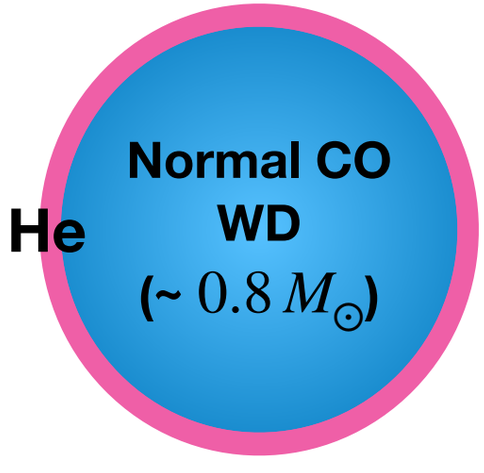
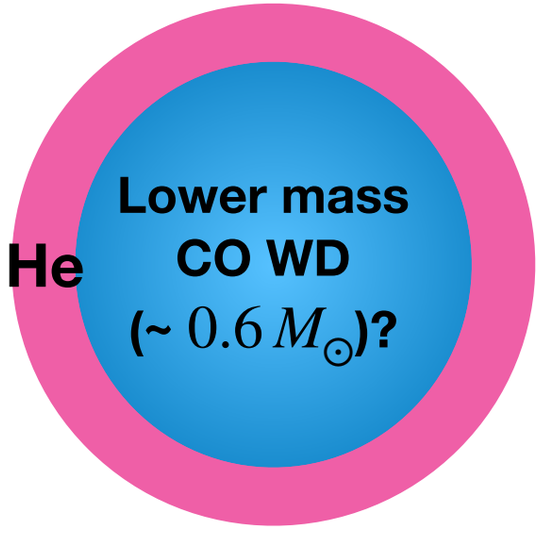


Double detonation?

Near complete shell burning

Ca-rich “SN Ic”



Double detonation?

Incomplete shell burning

De+ 2020b

A continuum of He shell explosions from WDs?

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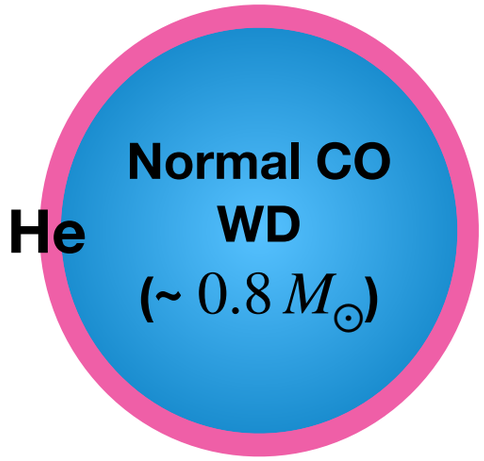
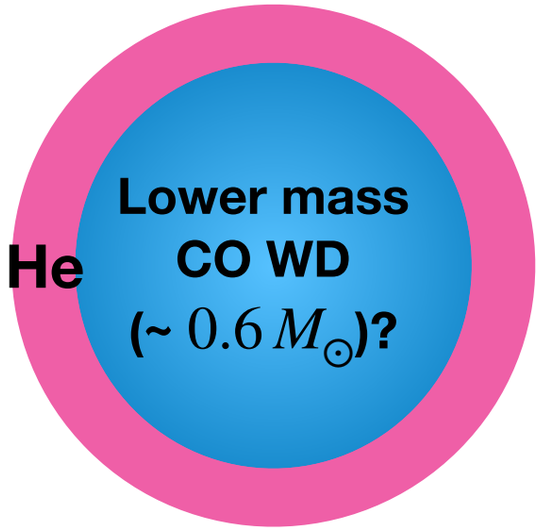


Double detonation?

Near complete shell burning

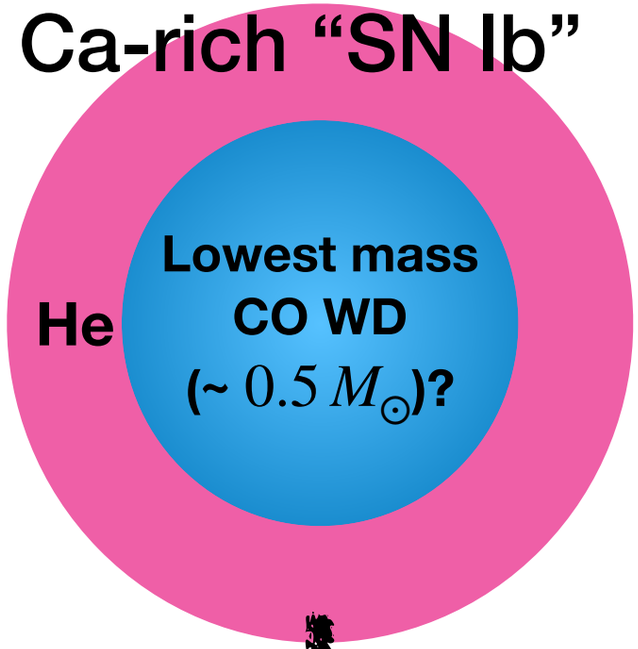
Ca-rich “SN Ic”



Double detonation?

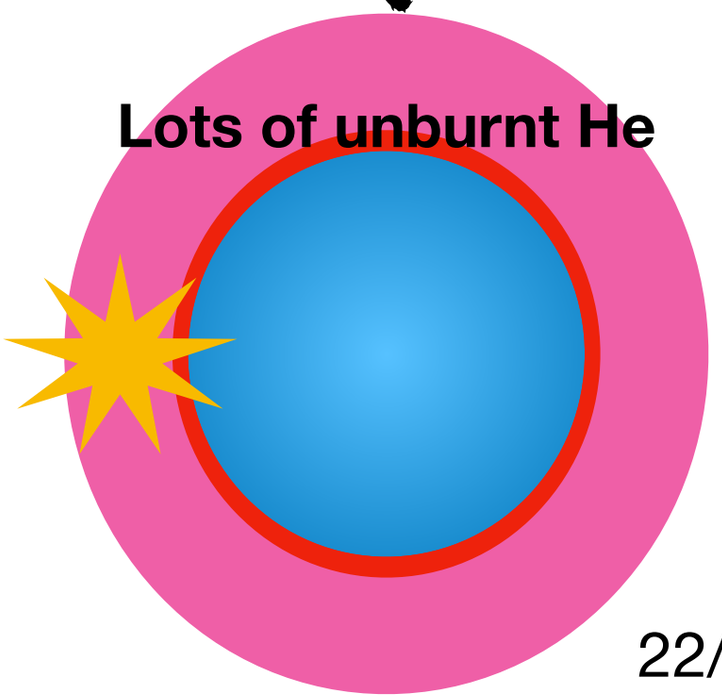
Incomplete shell burning

Ca-rich “SN Ib”



Shell-only detonation/ deflagration?

Very incomplete burning



De+ 2020b

False positives: Ca-rich SN 2019ehk from a core-collapse explosion of a hydrogen-rich progenitor

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Jacobson-Galan+ 2020, Nakaoka+ 2020

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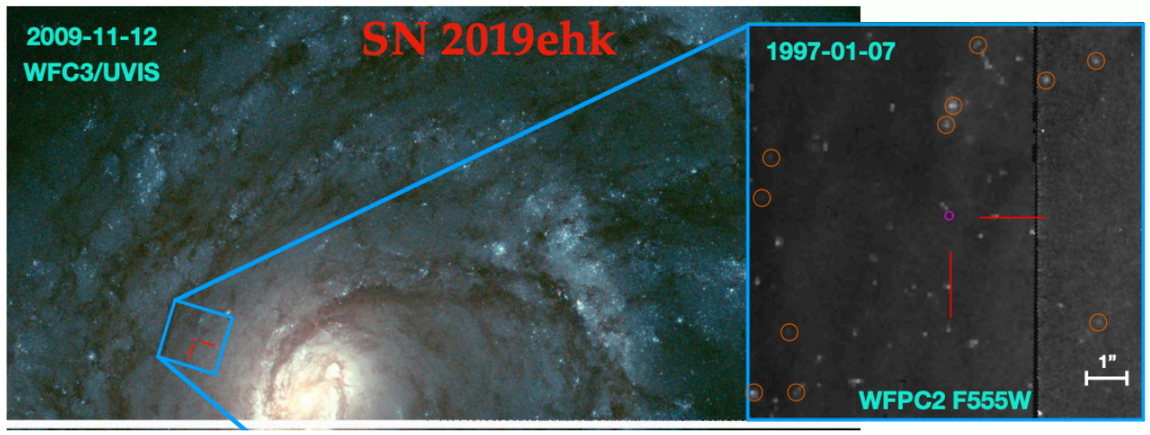
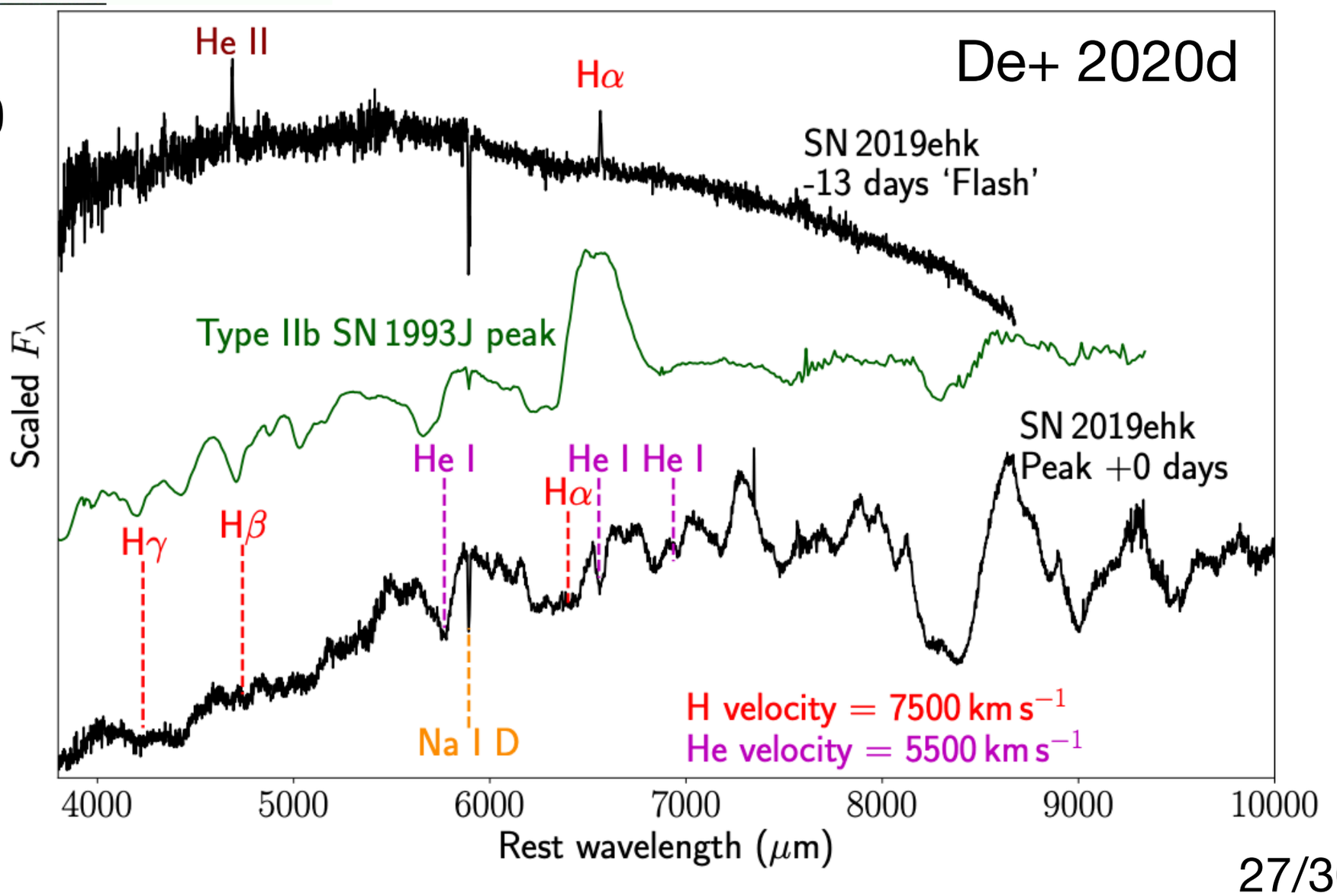
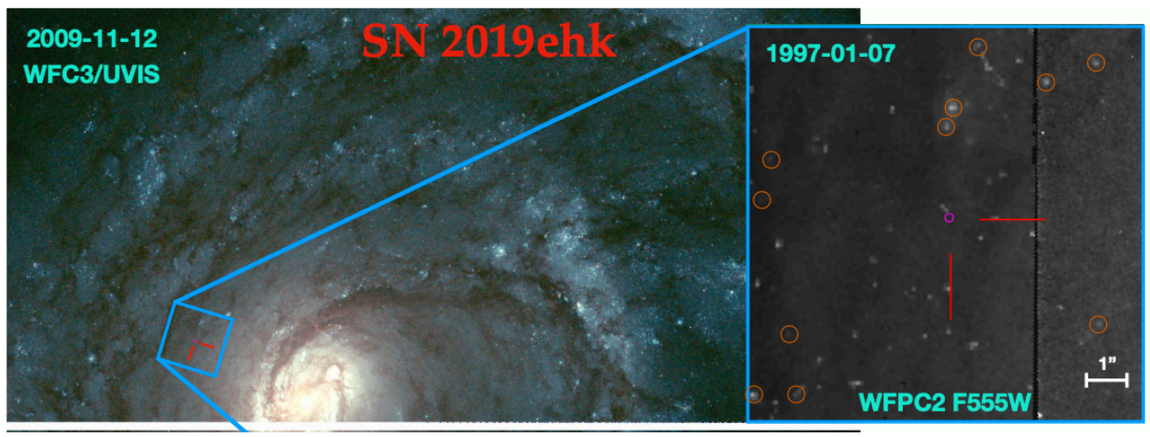


Jacobson-Galan+ 2020, Nakaoka+ 2020

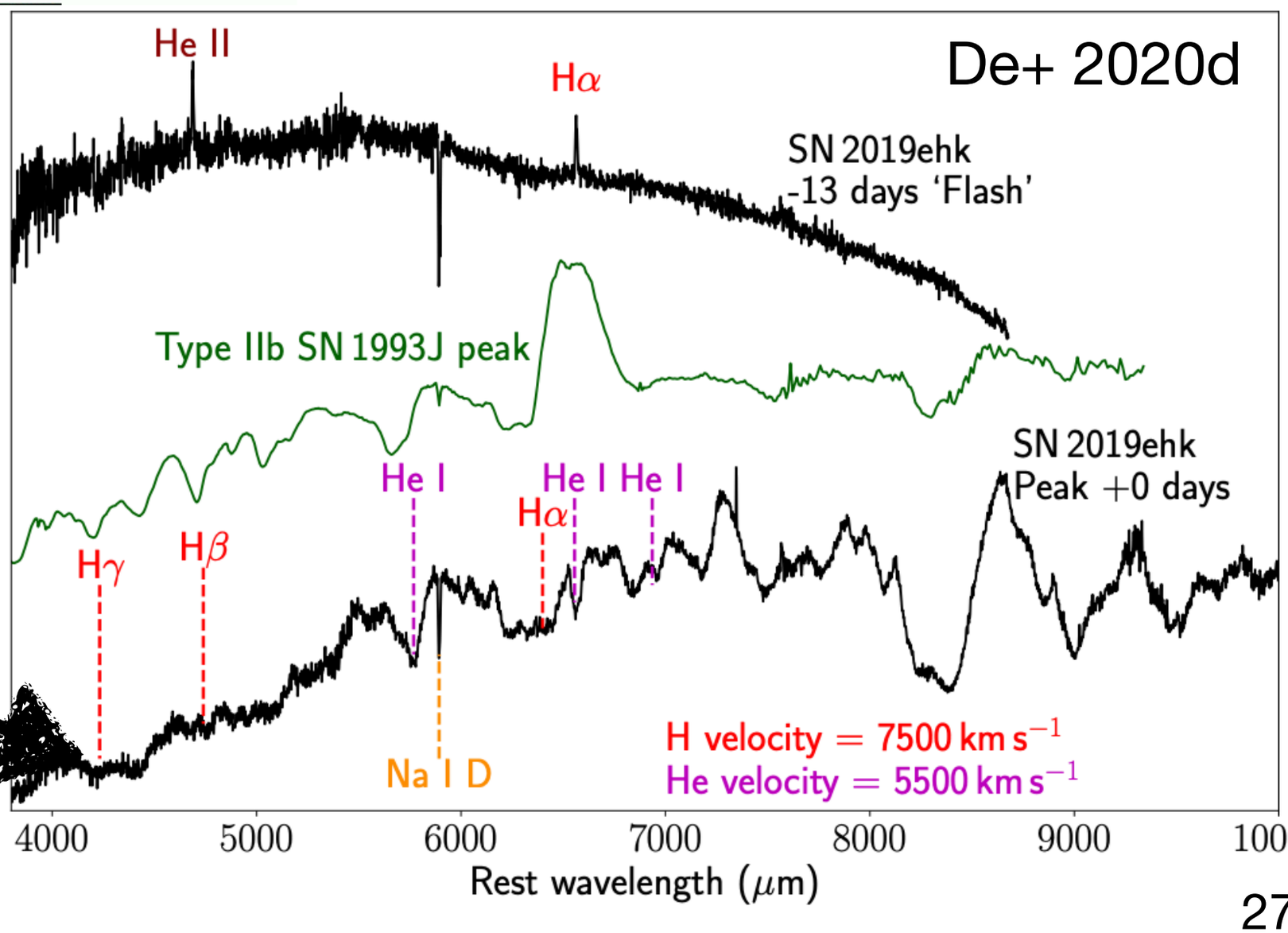


De+ 2020d

False positives: Ca-rich SN 2019ehk from a core-collapse explosion of a hydrogen-rich progenitor



Jacobson-Galan+ 2020, Nakaoka+ 2020



De+ 2020d

Photospheric hydrogen features

$M_H \gtrsim 0.02 M_\odot$

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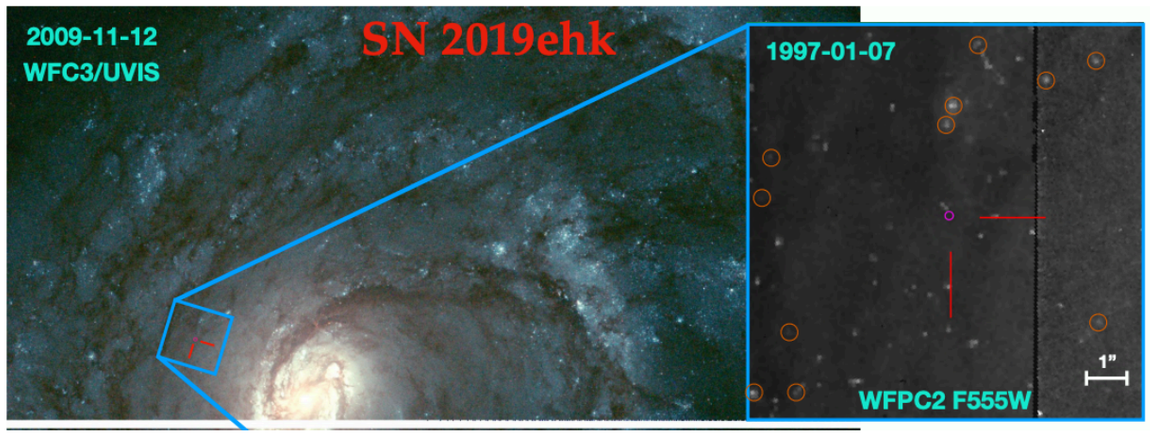

Jacobson-Galan+ 2020, Nakaoka+ 2020

Early ‘flash’ features indicate H-rich CSM with

$$M_H \sim 10^{-3} M_\odot$$

Photospheric hydrogen features

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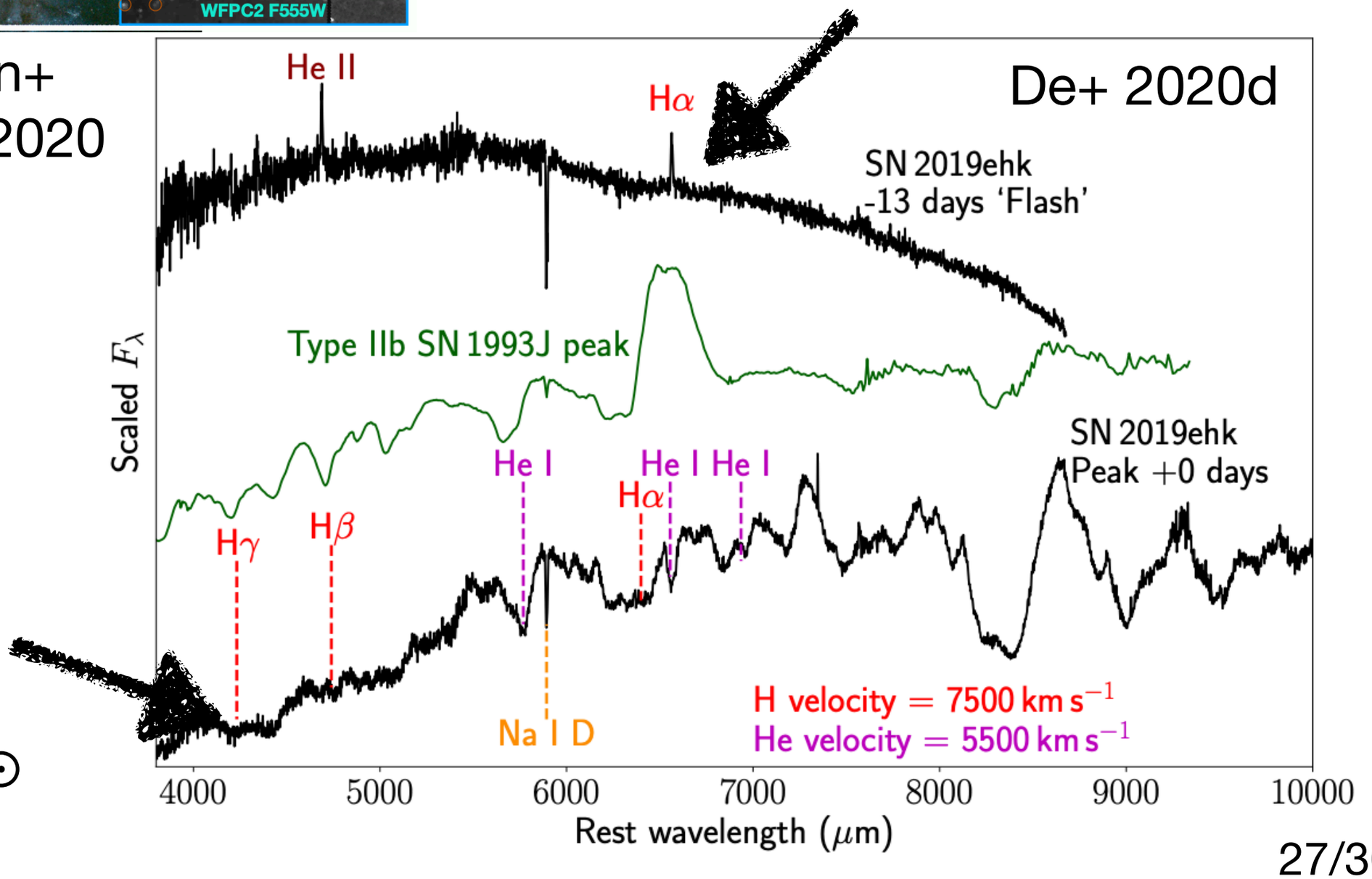

SN 2019ehk is not alone: A systematic exploration of the faintest “ultra-stripped” core-collapse supernovae

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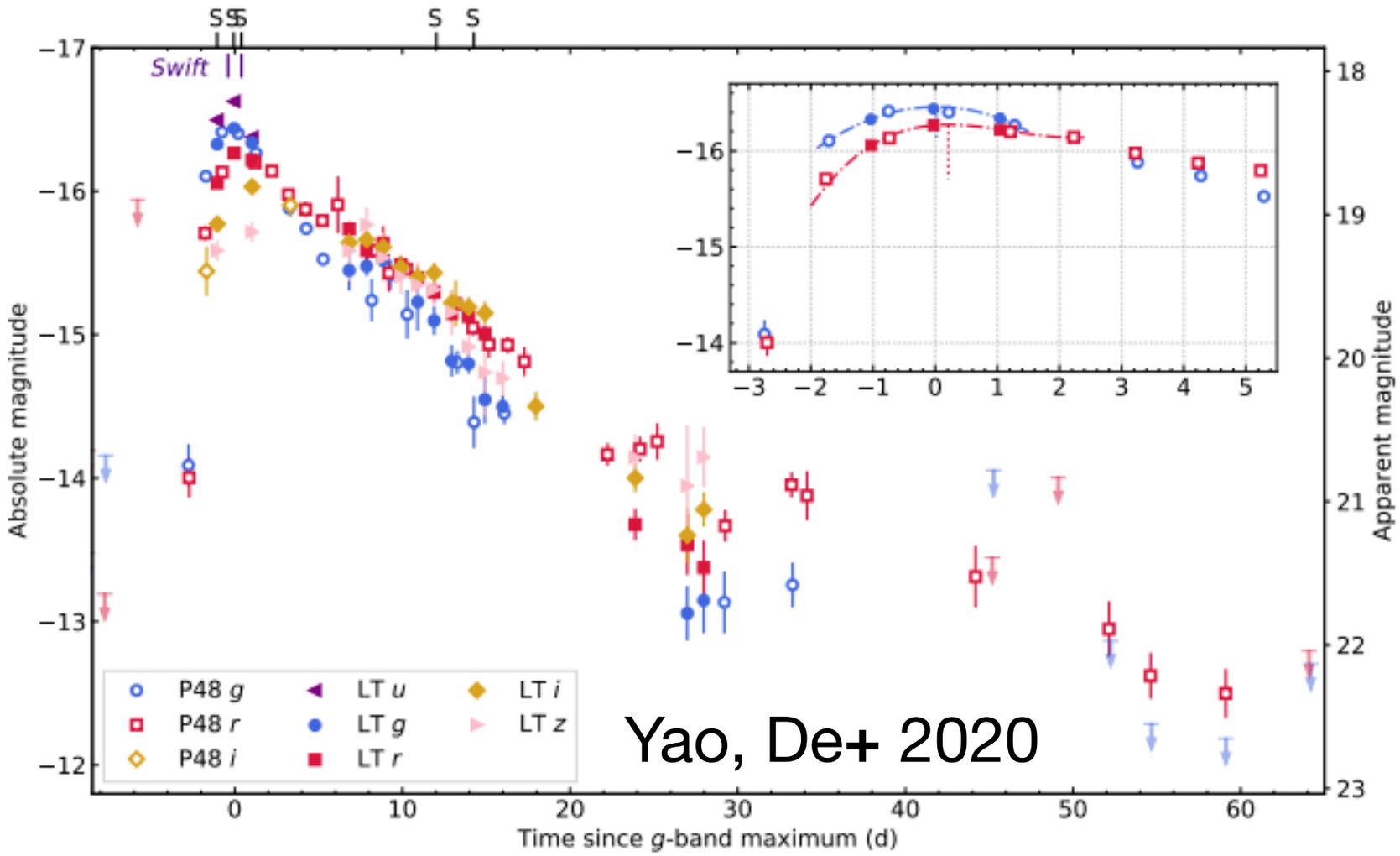

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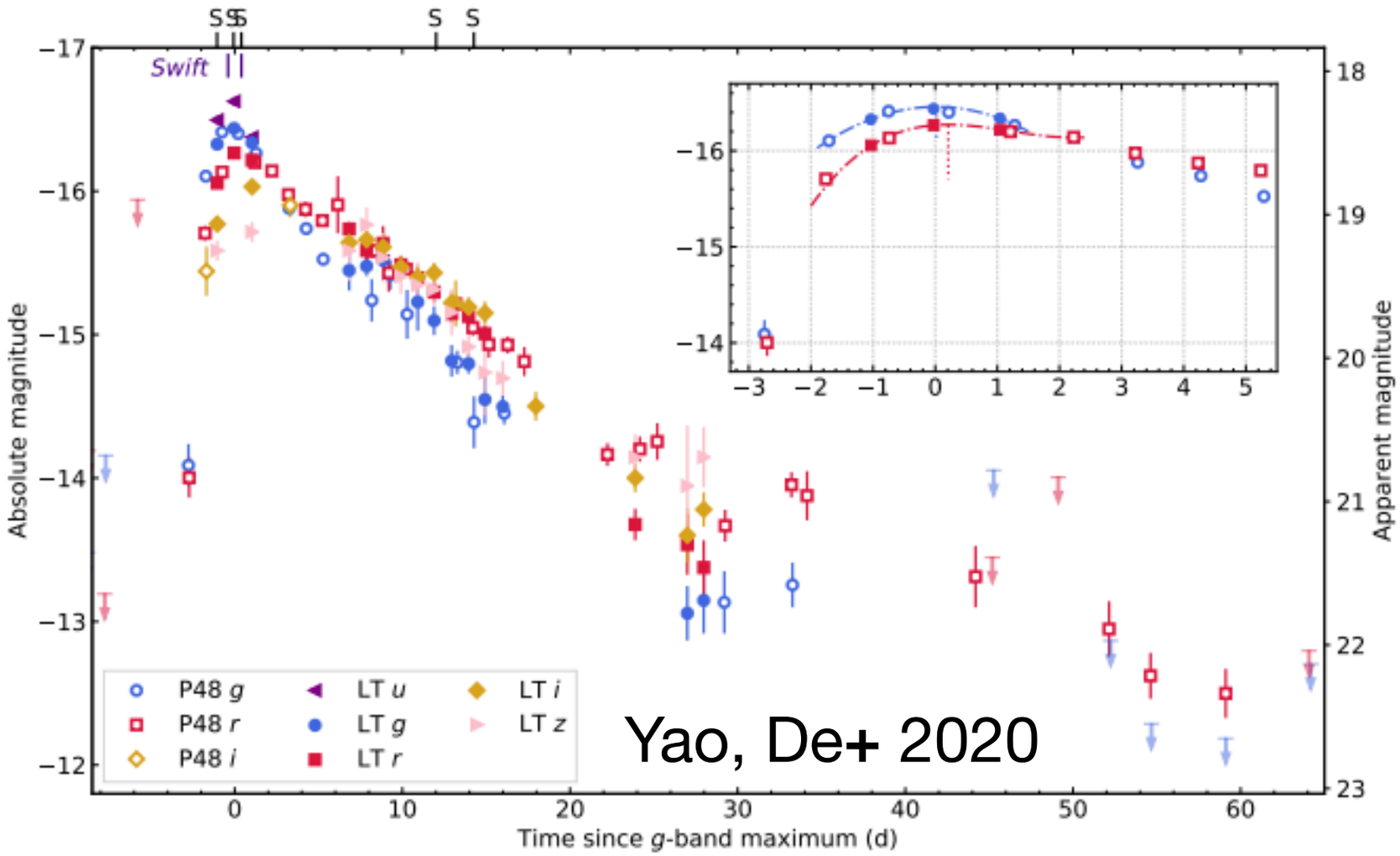
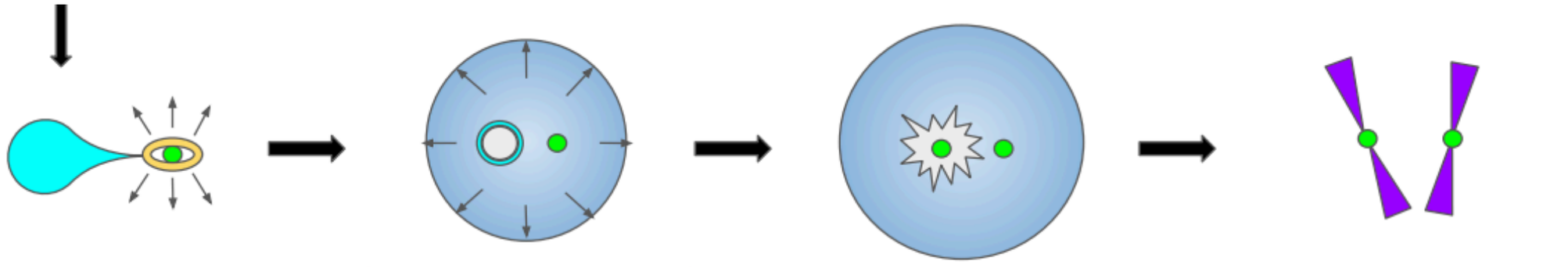


Yao, De+ 2020



He star (stable/unstable) RLO. Most He is ejected from the system

Stripped He star + NS **Intense mass loss leads to expanding envelope.**

iPTF 14gqr: Ultra-stripped SN inside He-rich envelope

Double NS system

De+ 2018a, De+ 2020d

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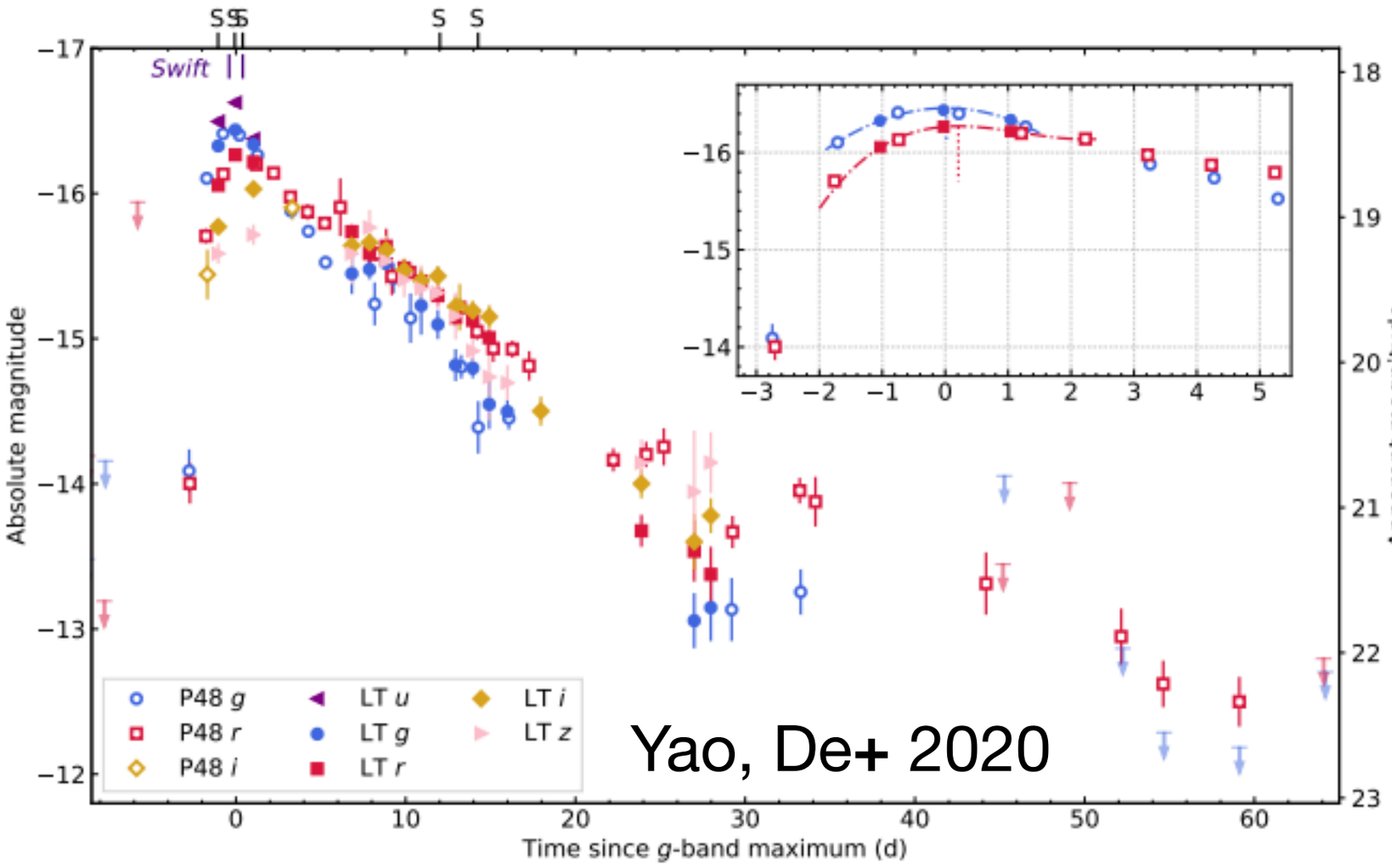
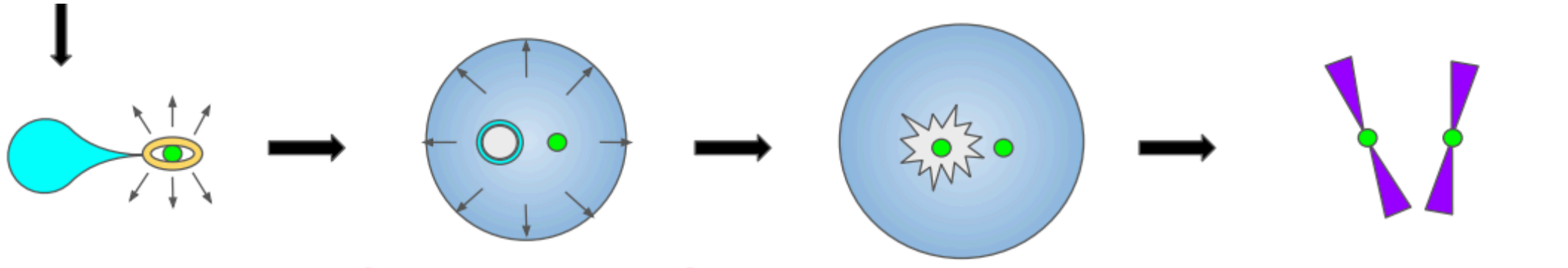


Yao, De+ 2020

ZTF constraints on volumetric rate: 2-12% of core-collapse supernovae



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Probing the faintest core-collapse supernovae

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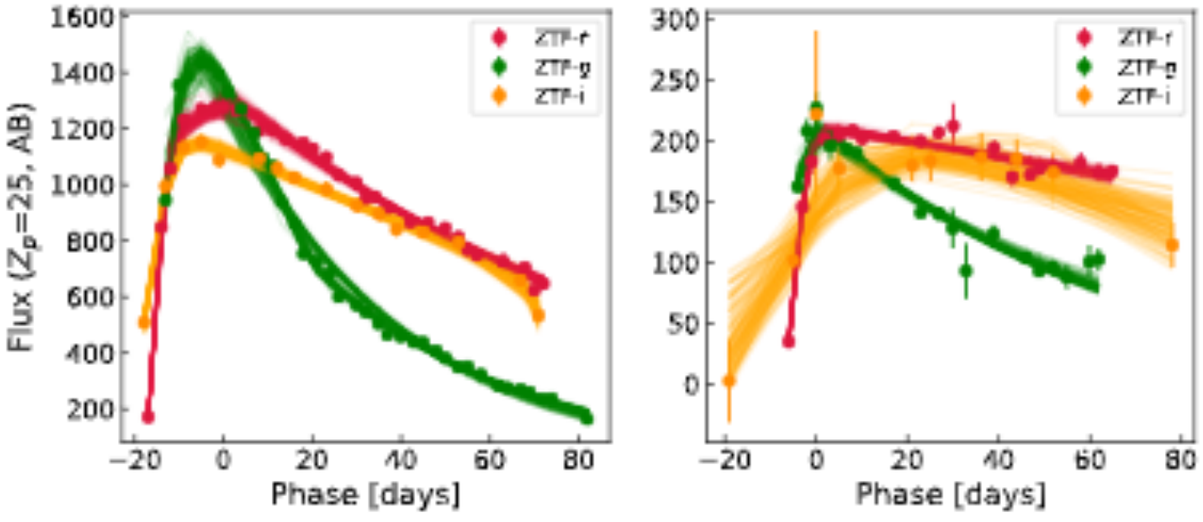
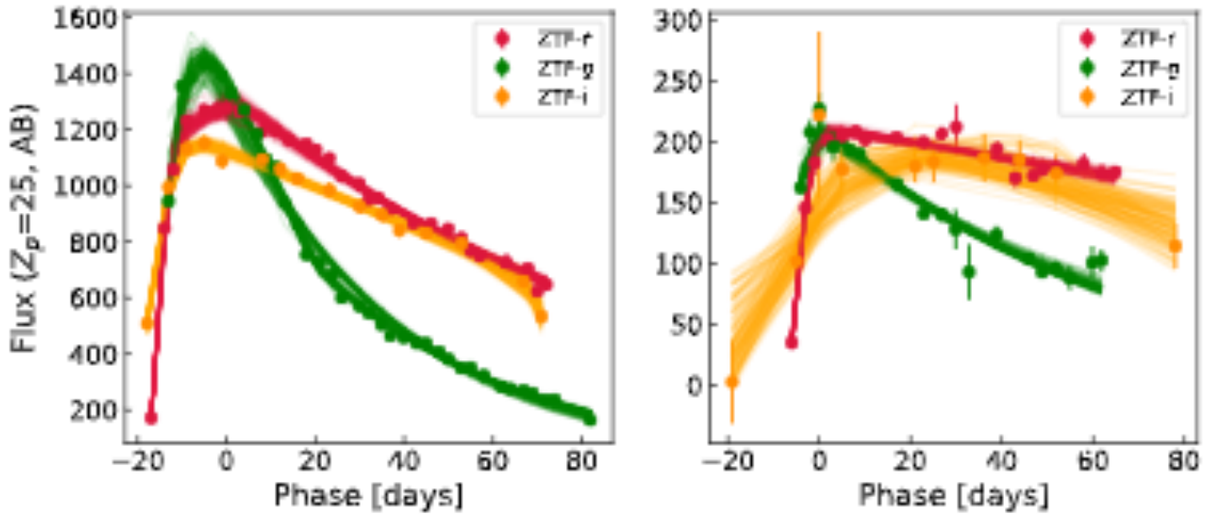


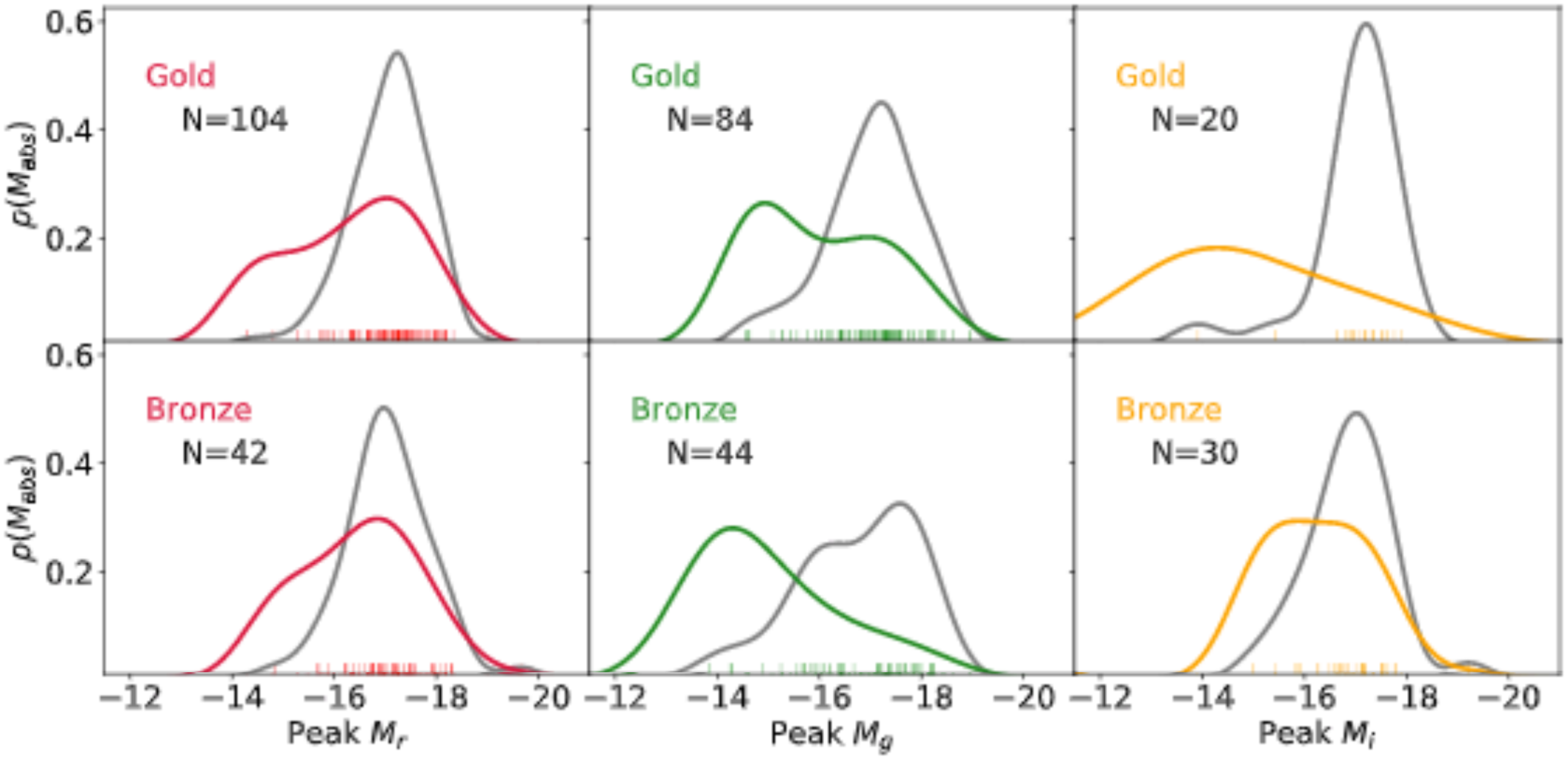
Luminosity function of ~300 Type II supernovae in 16 months of the CLU sample

Probing the faintest core-collapse supernovae



Luminosity function of ~300 Type II supernovae in 16 months of the CLU sample

Tzanidakis, De+ in prep



Summary of the ZTF CLU sample

- The largest volume-limited sample of extragalactic transients till date (De+ 20b)
- New insights into the explosive fates of helium accreting white dwarfs and progenitors of Type Ia supernovae (De+ 19, De+20b, De+ 18b)
- Ultra-stripped core-collapse supernovae and the formation of neutron stars in compact binaries (Yao, De+ 20; De+ 18a; De+ 20d)
- Evidence for a faint population of Type II supernovae in the local universe (Tzanidakis, De+ 20)

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