Hydrogen-rich gap transients in the optical and infrared

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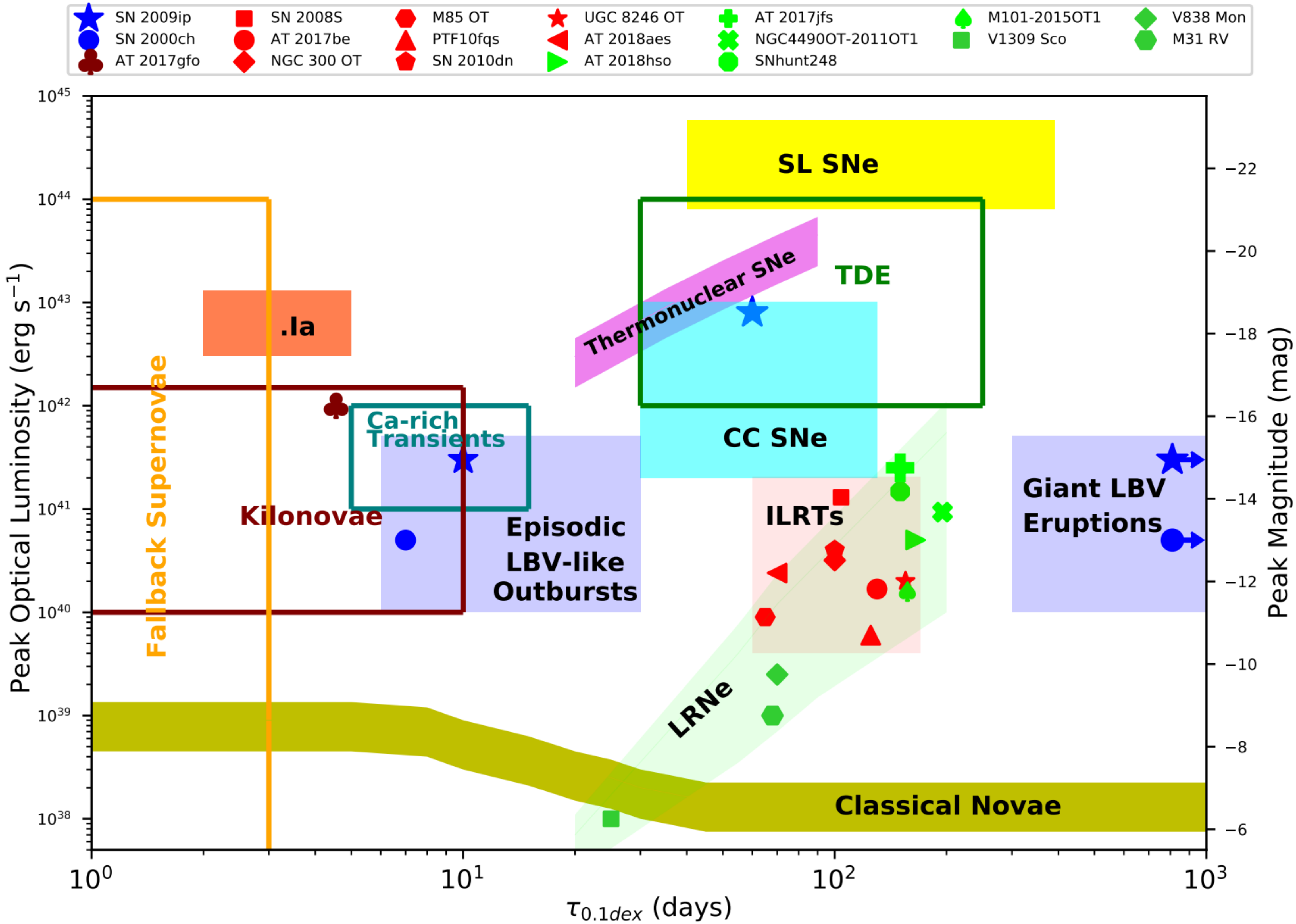
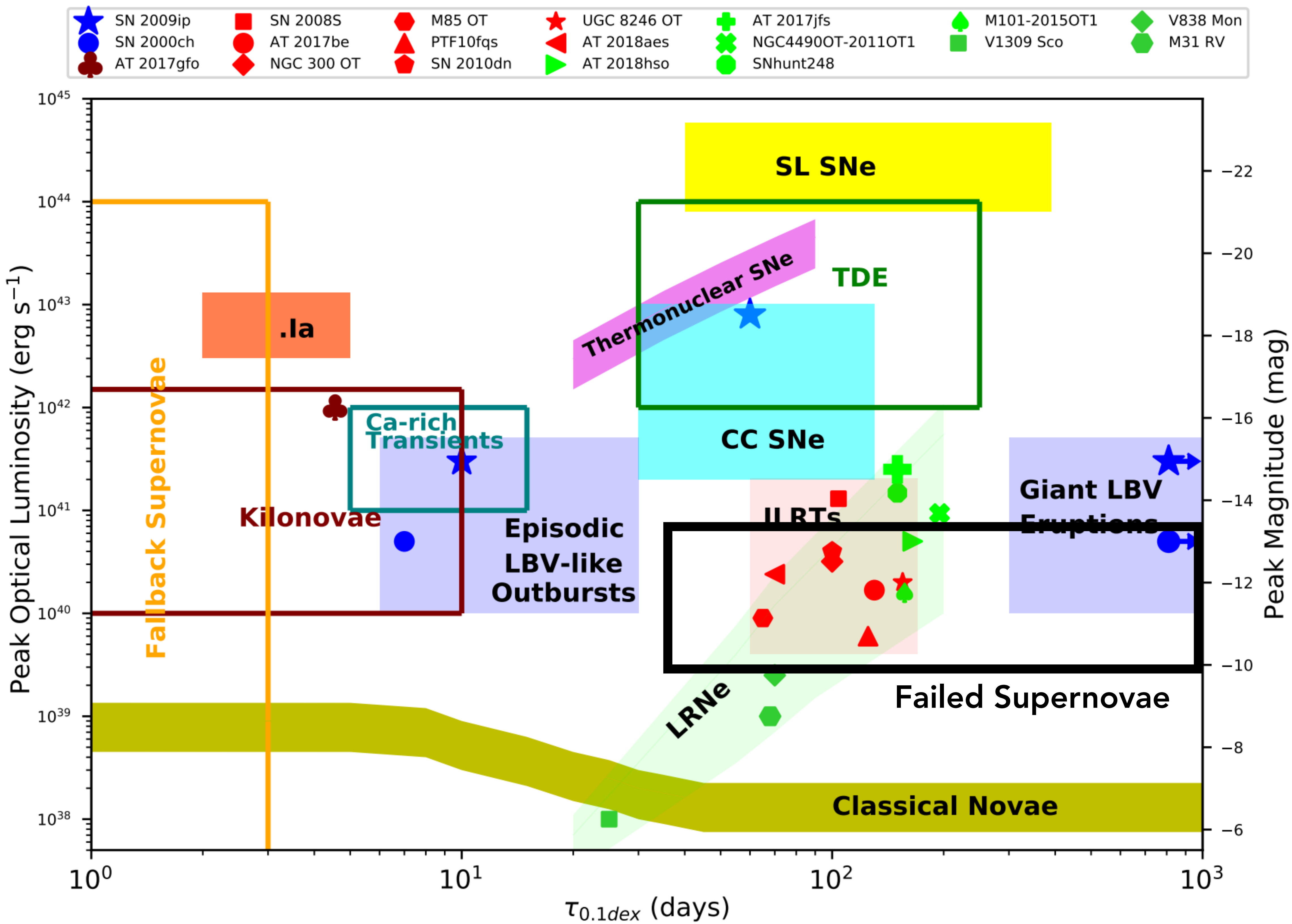
RAPID Response: Hot-wiring the Next Generation of Time-Domain Science
CalTech, March 23-27, 2026



Adapted from Cai et al. (2022)



Adapted from Cai et al. (2022)

Hydrogen-rich gap transients

Luminous red novae

Intermediate luminosity red transients

Failed supernovae

Double-Peaked Optical Light curves

Blue first peak:

~a month

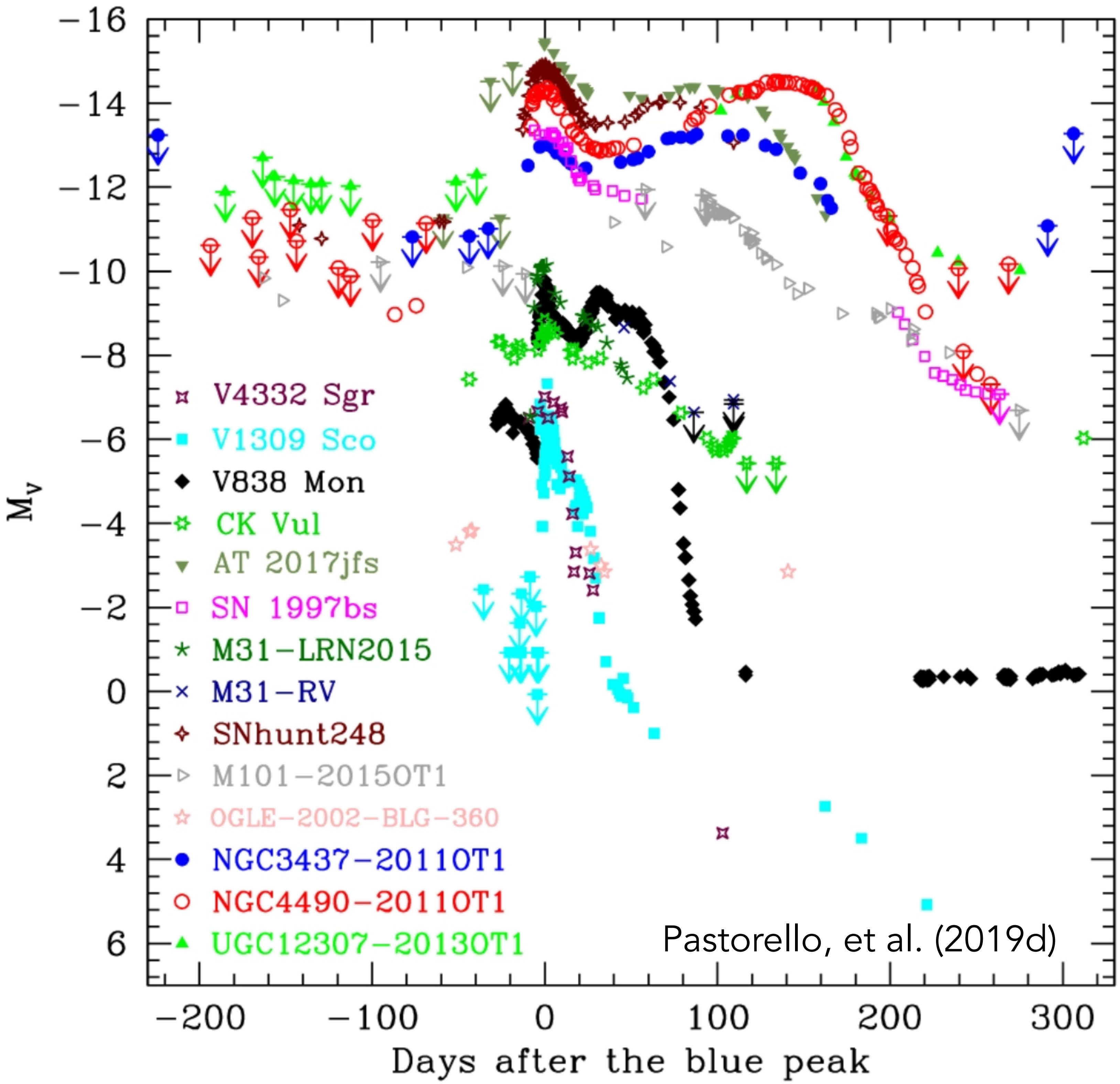
Prominent H, Fe emission lines

Hα FWHM ~100s -1000 km/s

Redder second peak/plateau:

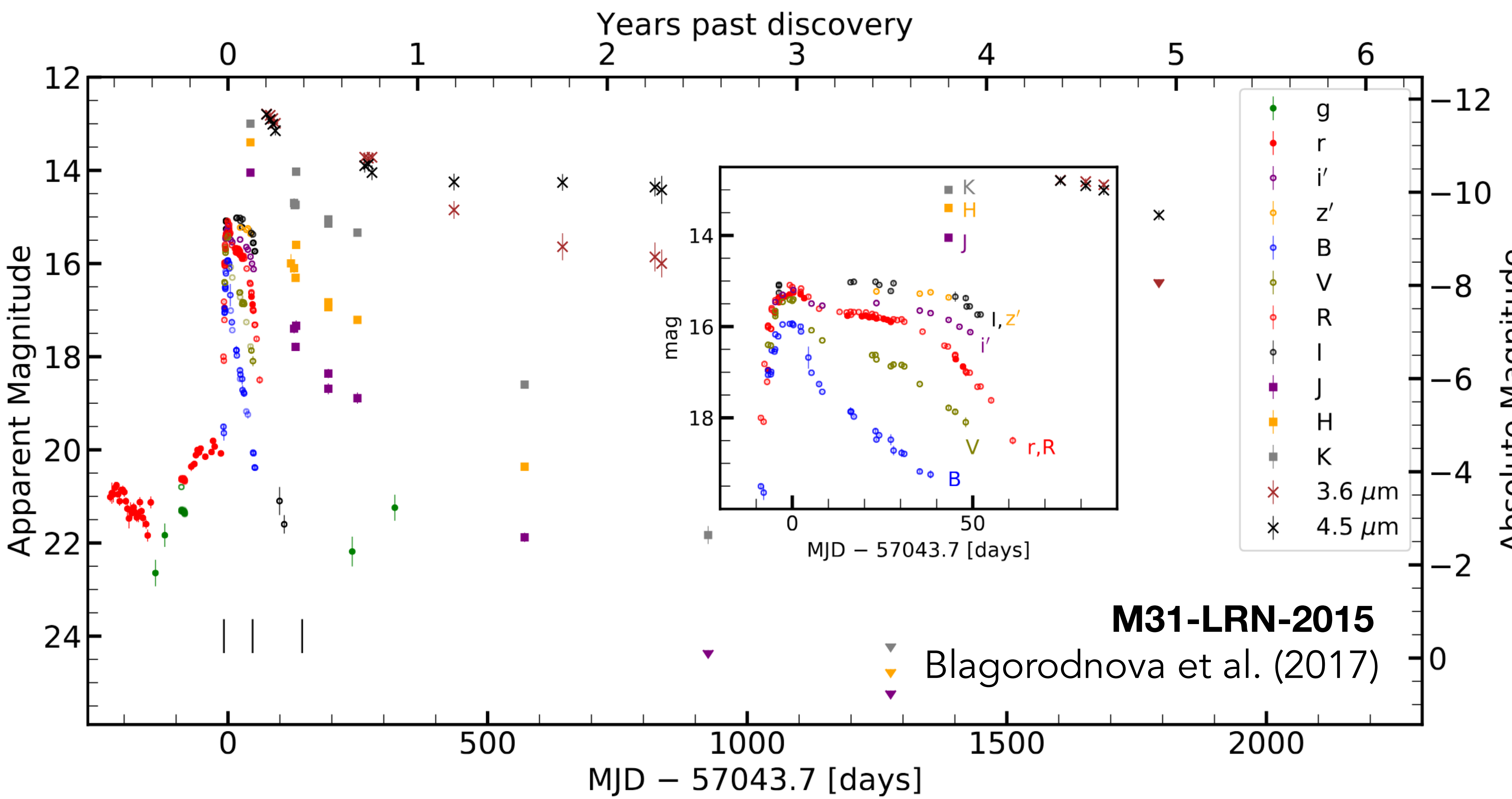
~50 -200 days

Weaker Balmer lines, forest of metal absorption lines



Evolve from blue to red to infrared

- become dusty
- bright in infrared for years

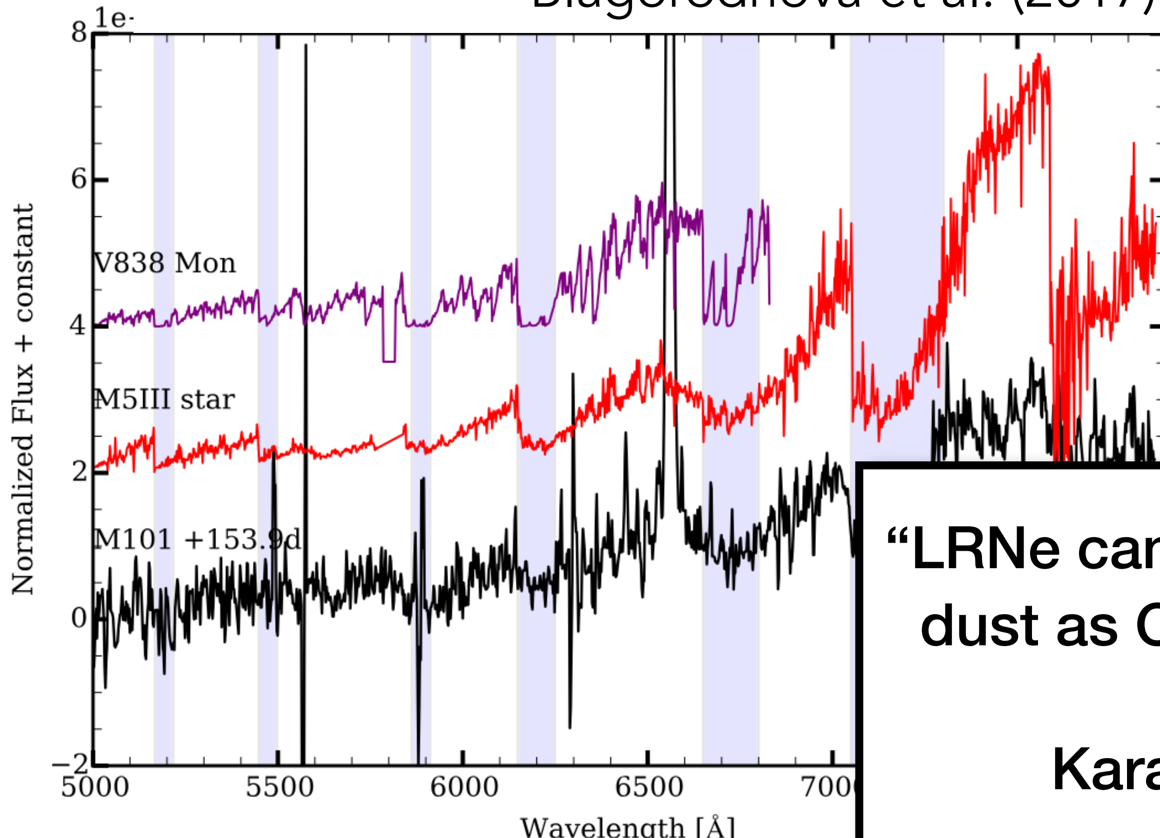


Late times - O-rich molecules & Silicate Dust

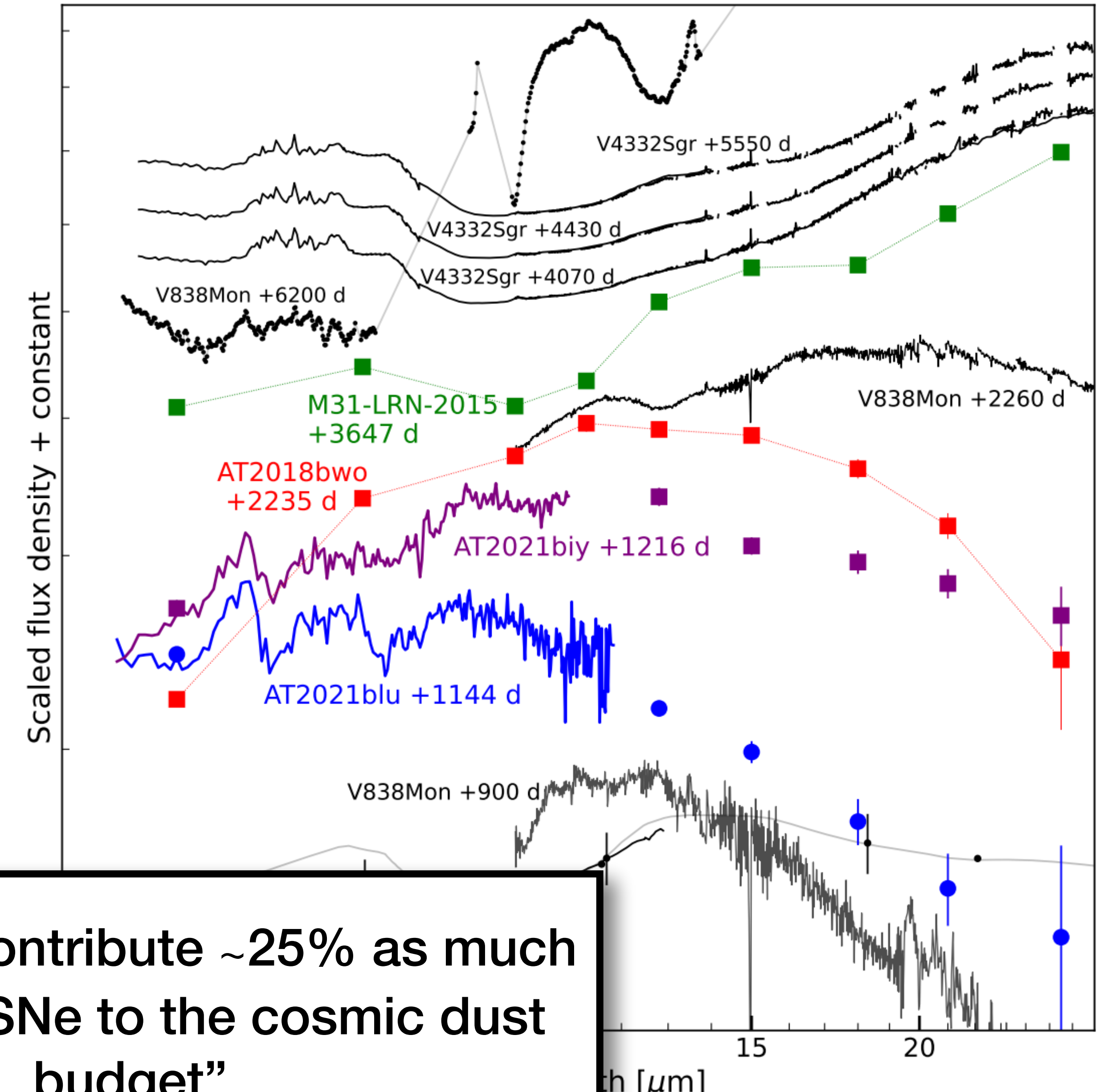
After second peak:

- Very red (like M star)
- Prominent Hα emission
- Strong molecular absorption (TiO, VO)

Blagorodnova et al. (2017)



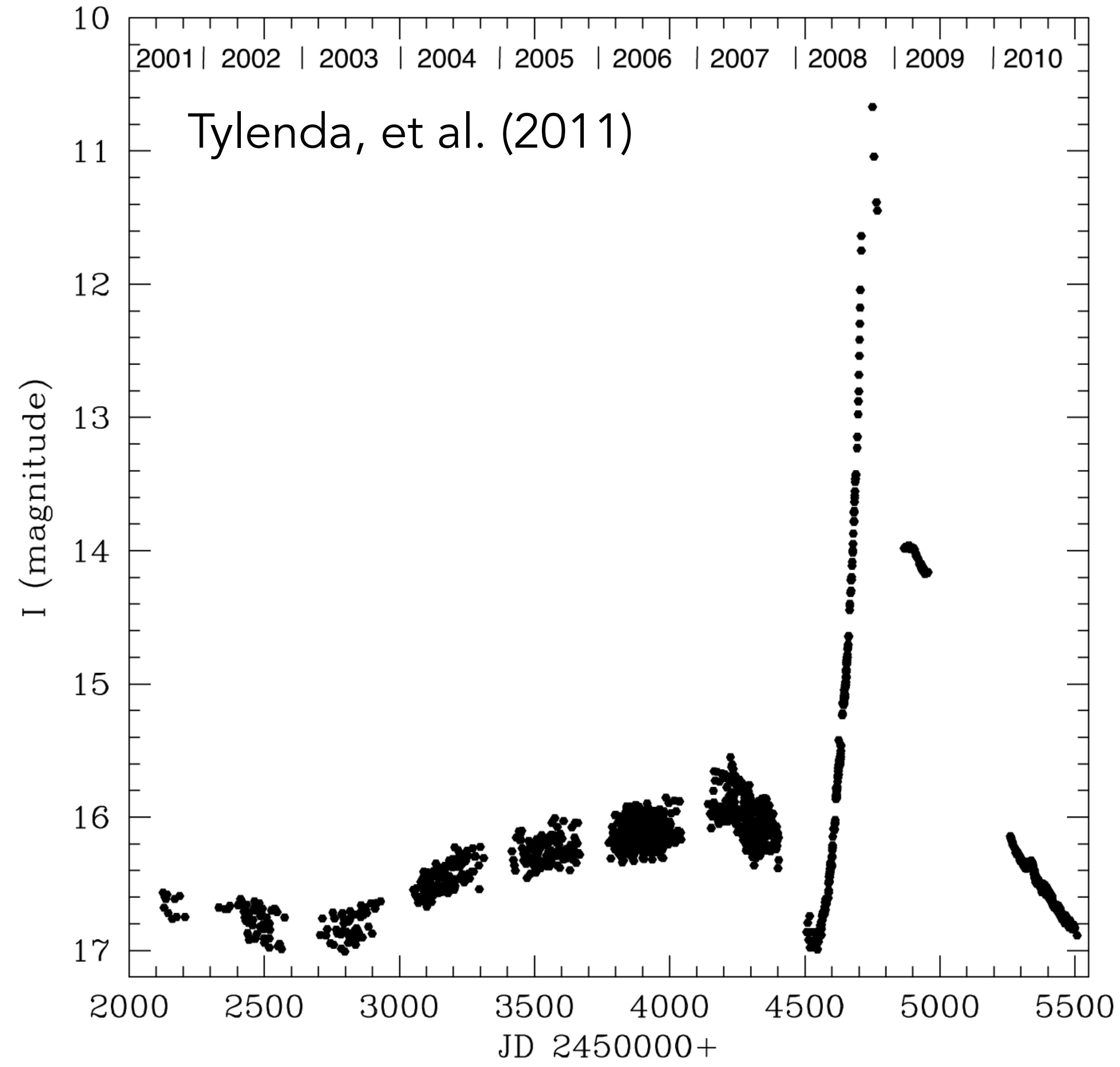
JWST, Karambelkar et al. (2026)



“LRNe can contribute ~25% as much dust as CCSNe to the cosmic dust budget”
Karambelkar et al. (2026)

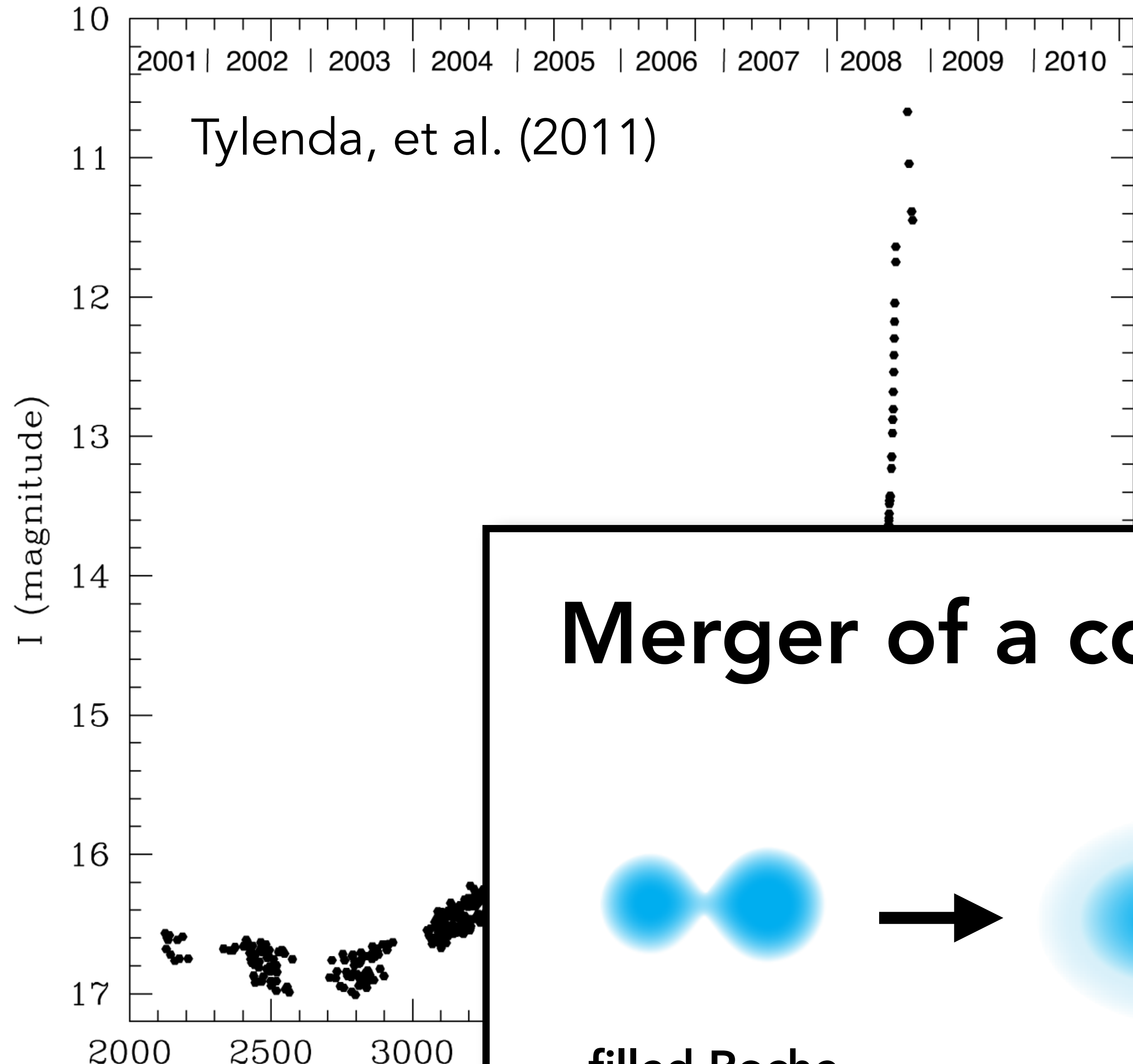
, e.g, Yongzhi Cai et al. (2022), Reguitti, Pastorello, and Valerin (2026)

V1309 Sco (2008): merger of a contact binary



- system observed with OGLE since 2001
- contact binary on ~1.4 day orbit period
- orbital period decayed towards merger ending in the 2008 eruption

V1309 Sco (2008) - confirmed merger hypothesis



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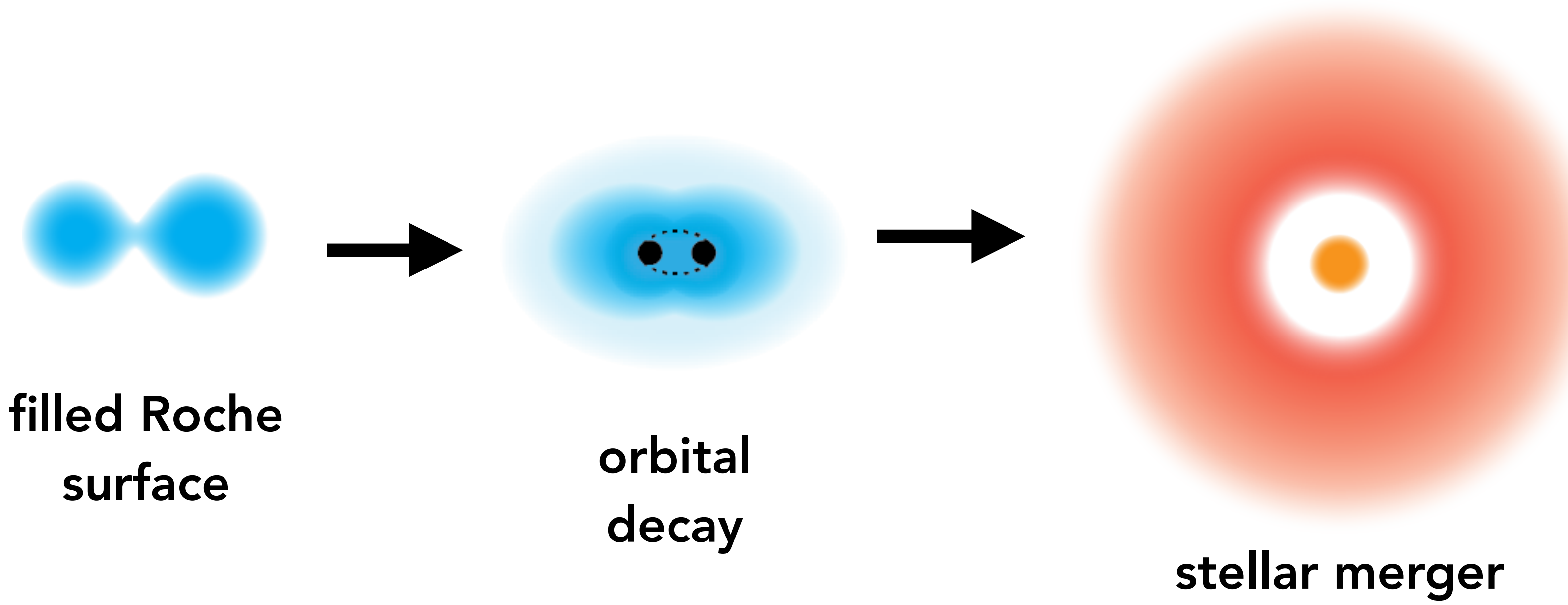
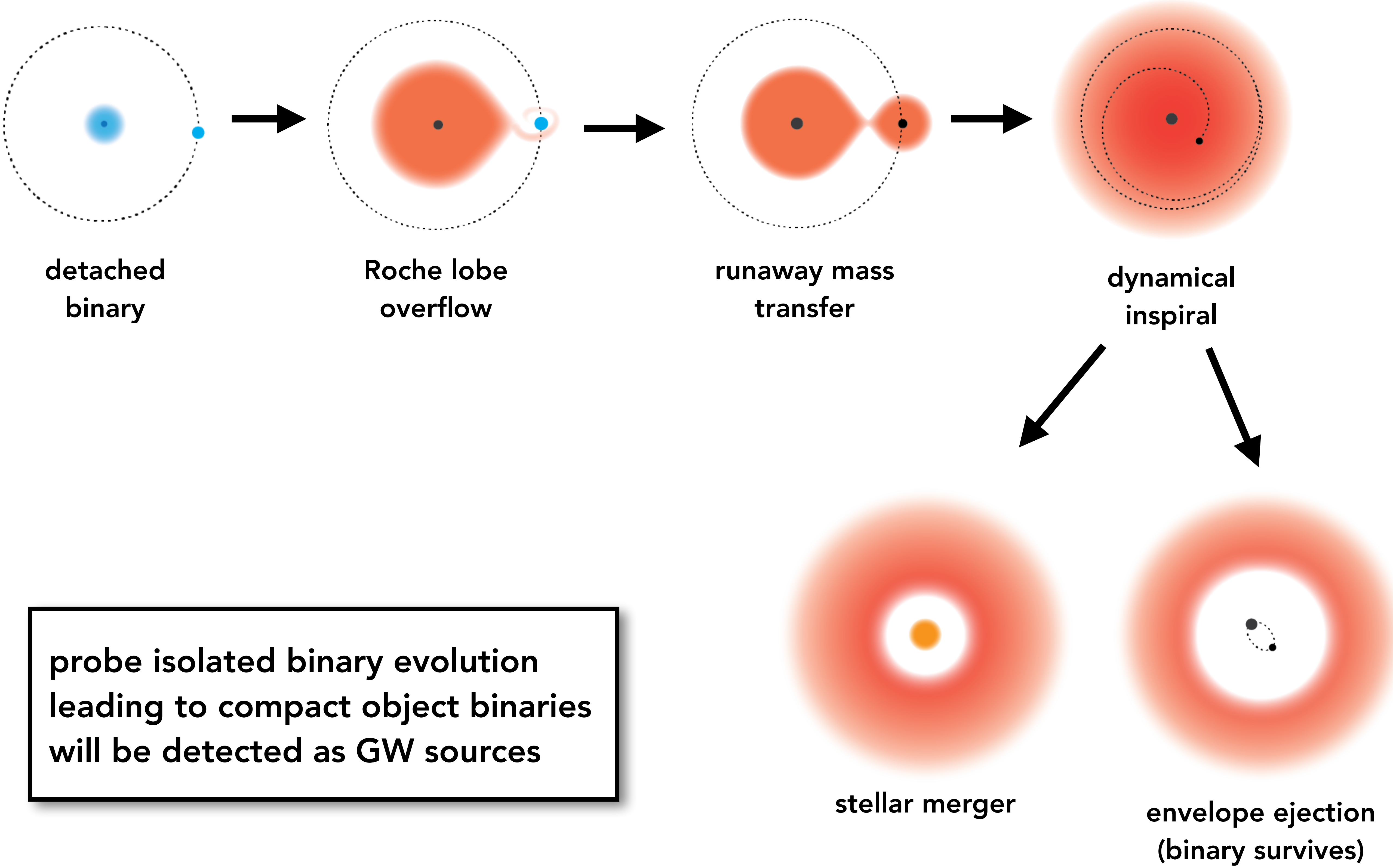
Merger of a contact binary



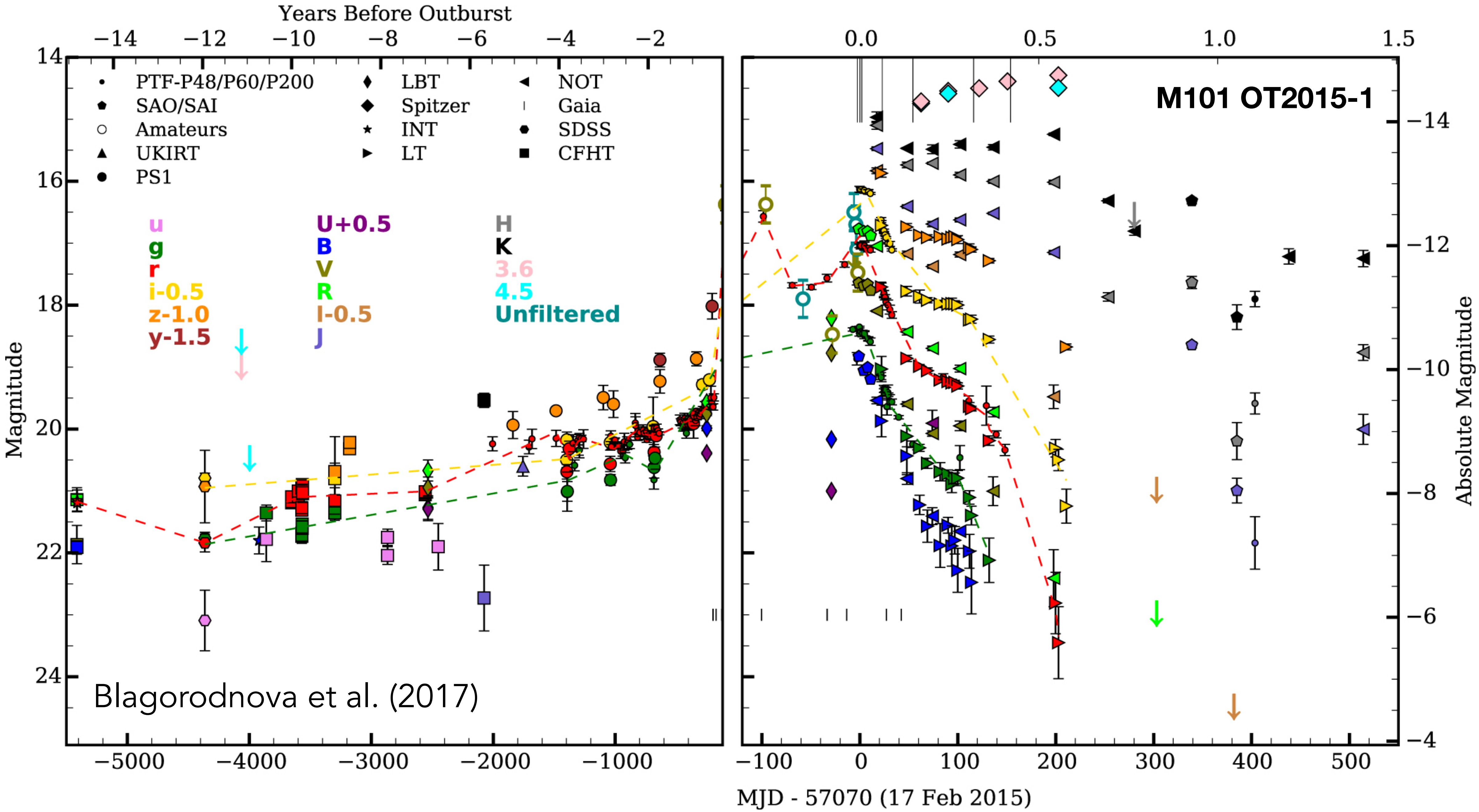
Unstable mass transfer leading to common envelope



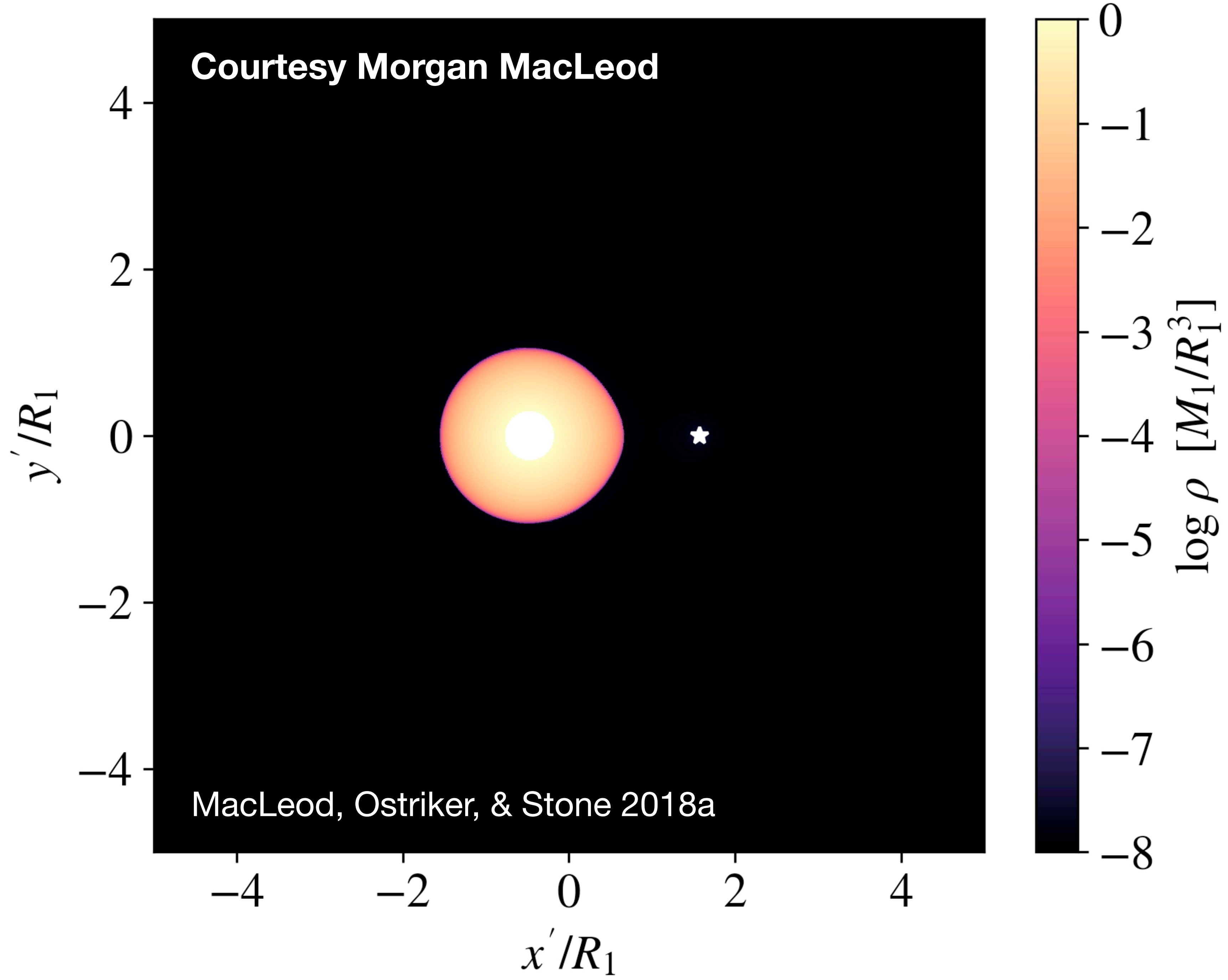
probe isolated binary evolution leading to compact object binaries will be detected as GW sources

Slow brightening for years before the LRN

—> onset of mass transfer in the binary (Roche lobe overflow)

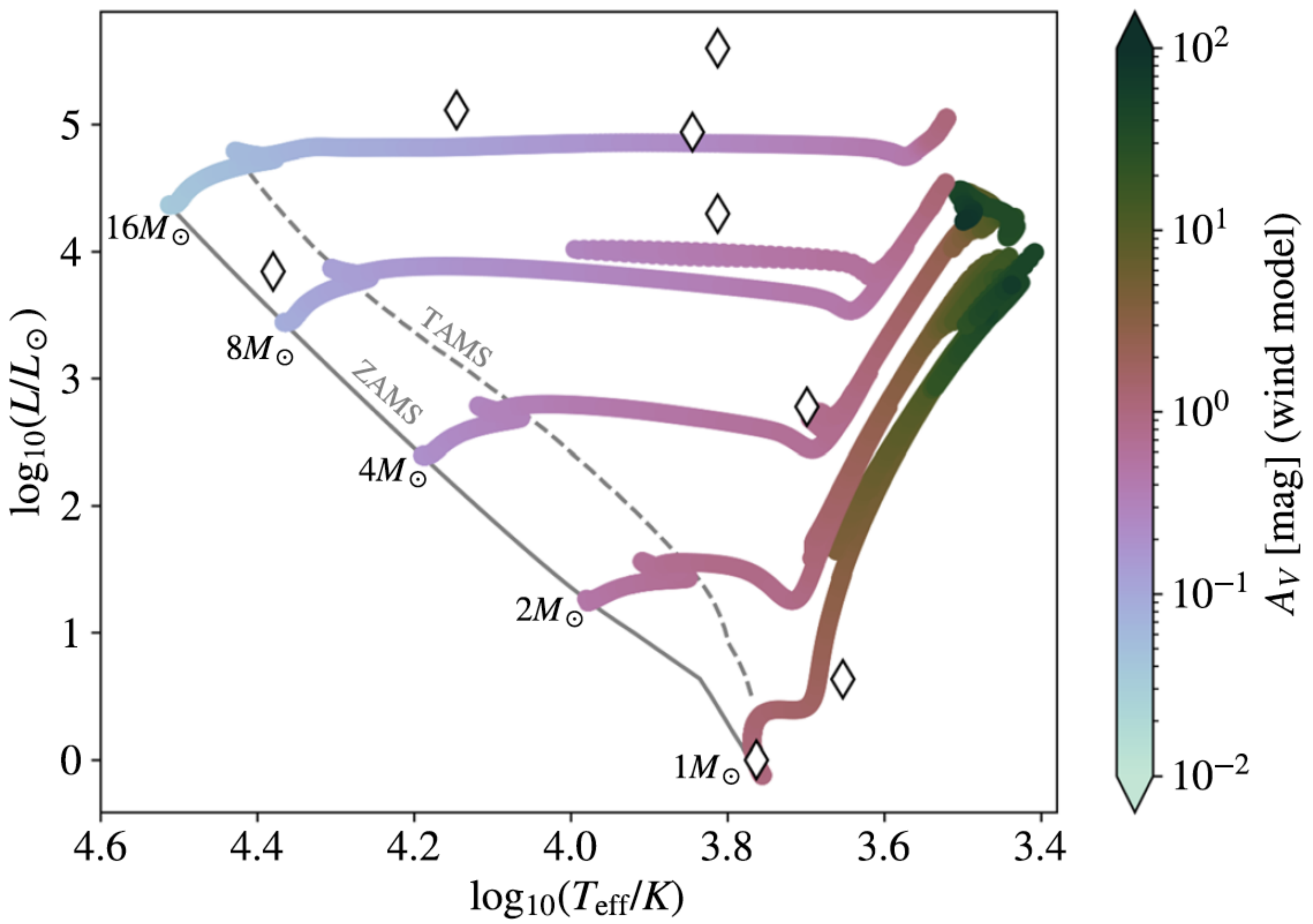


Roche lobe overflow



Low mass red giant donor: very dust-enshrouded luminous red nova

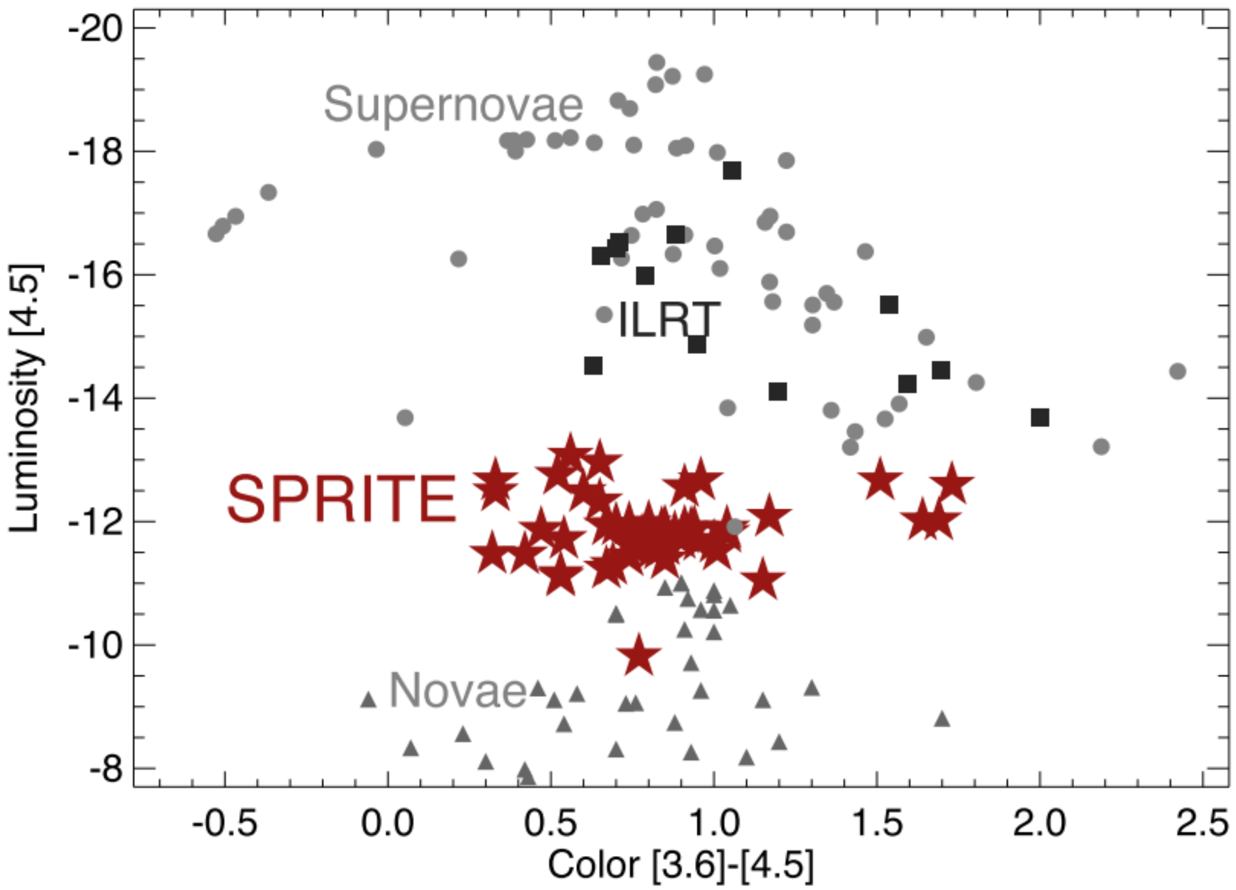
MacLeod, De, & Loeb (2022)



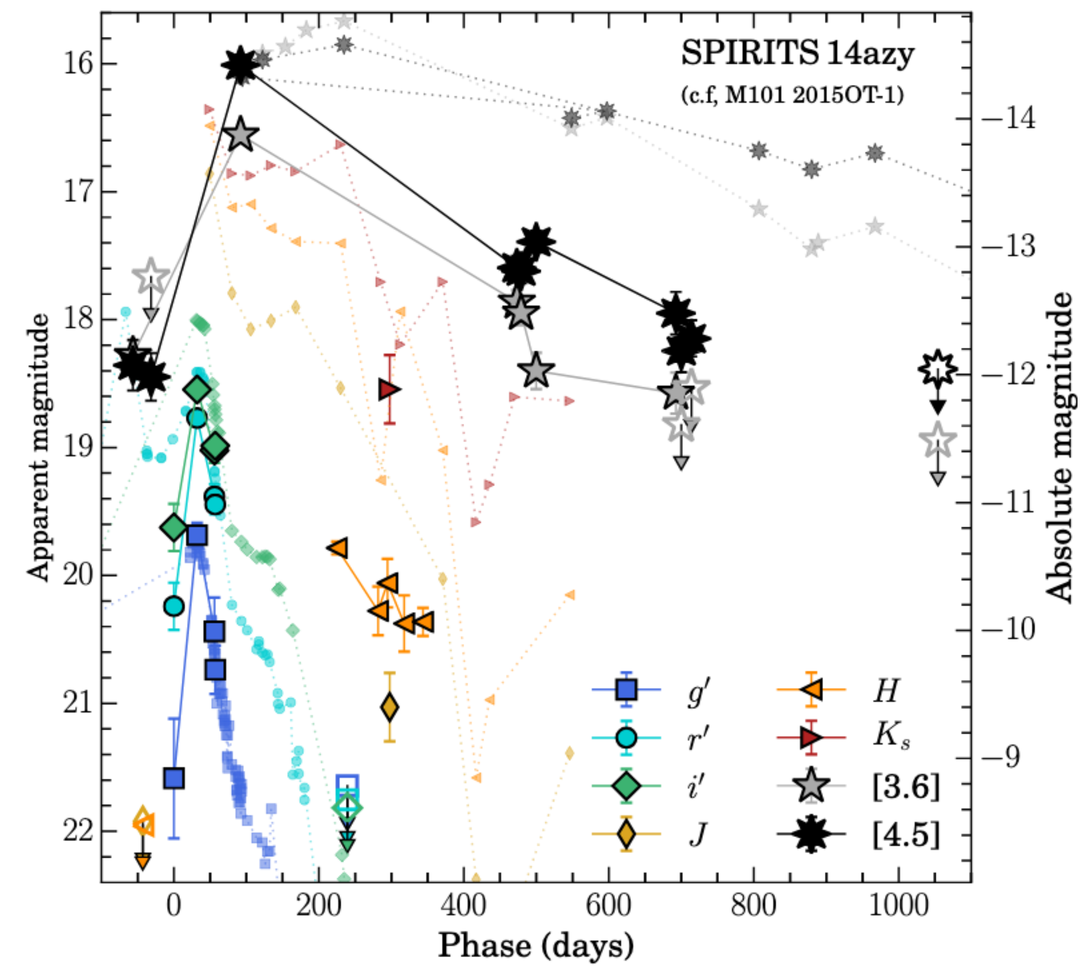
Heavily dust-obscured transients

SPRITEs (eSPecially Red Intermediate-luminosity Transient Events)

Kasliwal et al. (2017)



Jencson et al. (2019)



Hydrogen-rich gap transients

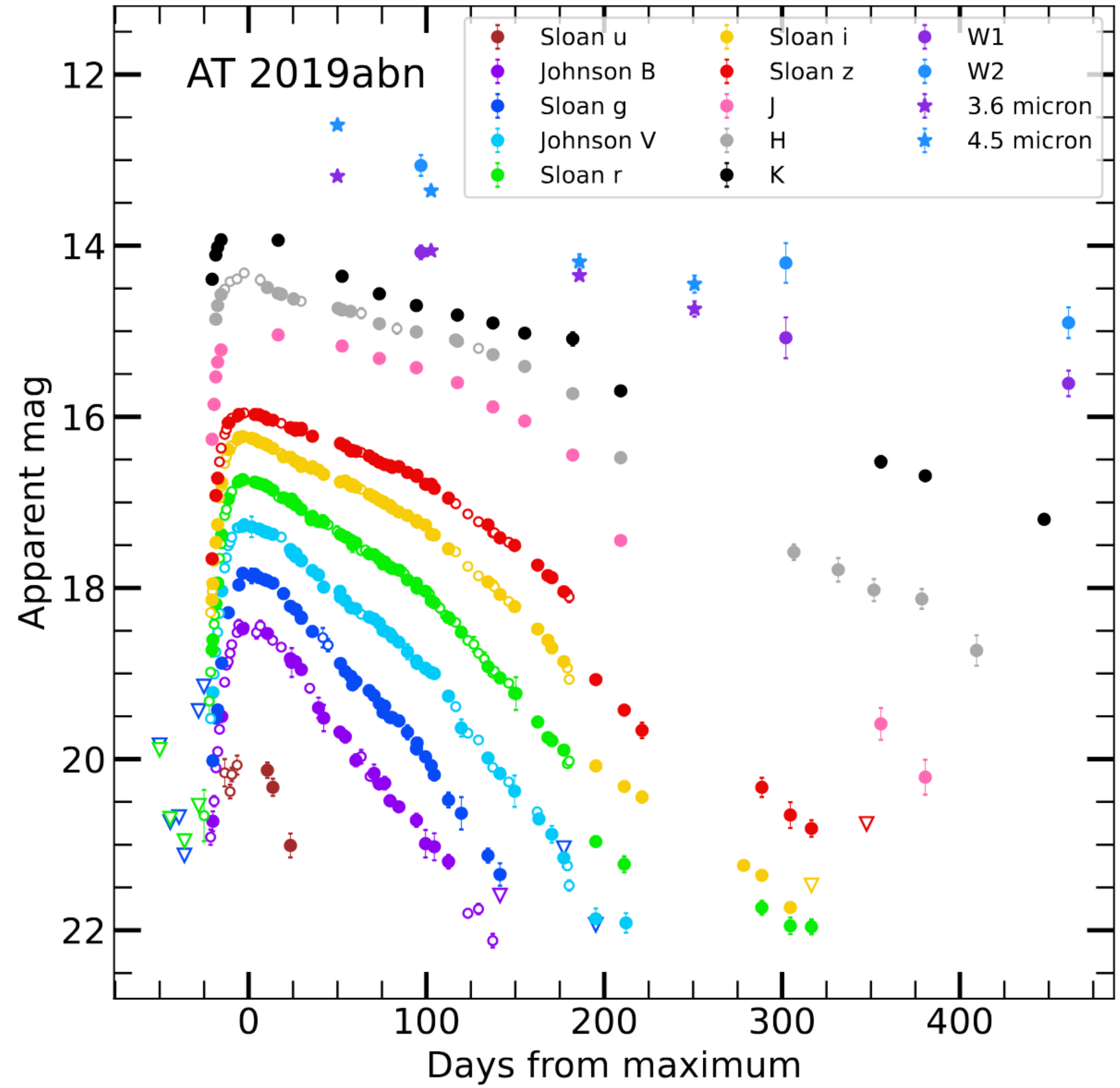
Luminous red novae

Intermediate luminosity red transients

Failed supernovae

Single-peaked light curves

- linear decline from peak
- blue to red evolution
- become very dusty;
  bright in infrared for years



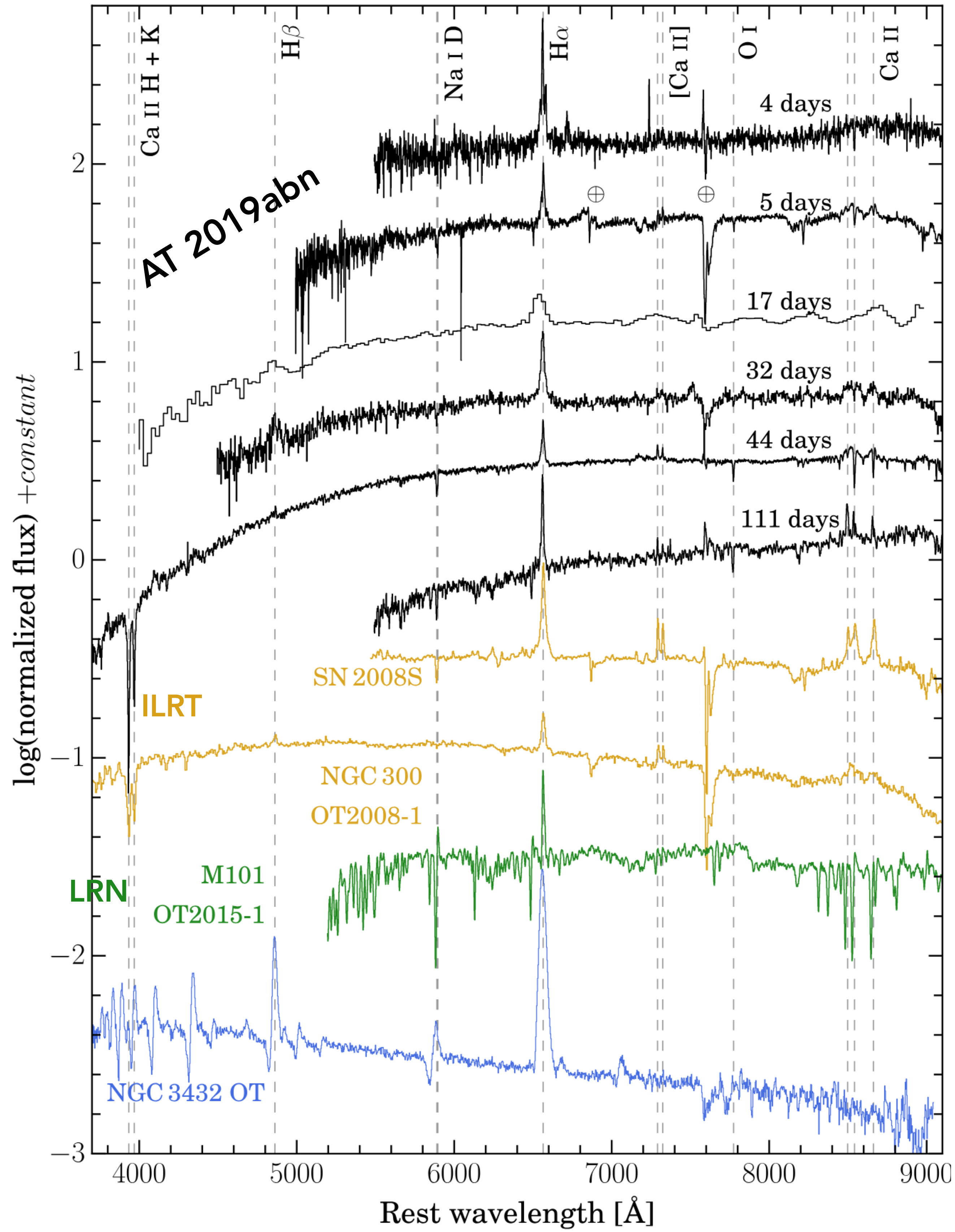
Also see Kochanek 2011, Karambelkar et al. 2023.

Valerin at al. 2025 (including data from Jencson et al. 2019 discovery paper and Williams et al. 2020); see Rose et al. 2025 for JWST data.

Narrow Hα and [Ca II] emission

~600 - 1000 km/s

Jencson, et al. (2019)



See also Thompson et al. 2009,
Smith et al. 2009, Berger et al. 2009

Nature of the transient

- LBV-like giant eruption (non-terminal, e.g. eta Car)?
- Low energy supernova (terminal event)?

Considerations:

- no wide / P-Cygni features (as are seen in LBV giant eruptions
- Progenitor detected in the mid-IR (obscured in optical, near-IR)
  - Dust-enshrouded, intermediate mass stars ($\sim 6 - 10 M_{\odot}$), at the faint end of RSG

=> ILRTs: electron capture supernovae of super AGB stars

Prieto (2008), Prieto et al. (2008b) , Berger, at al. (2009b), Thompson et al. (2009), Botticella et al. (2009), Cai et al. (2012), Jencson et al. (2019)

Uncertain transition region in single stellar evolution

$\sim 6 - 8 M_\odot$? $\sim 10 - 12 M_\odot$?

Initial Stellar Mass

Low Mass Stars

- asymptotic giant branch (AGB)
- no explosion
- white dwarf

Uncertain Outcomes

- Go through **super-AGB** phase
- Form ONe core

- no explosion
- ONe white dwarf

- **electron-capture supernova**
- **neutron star**

High Mass Stars

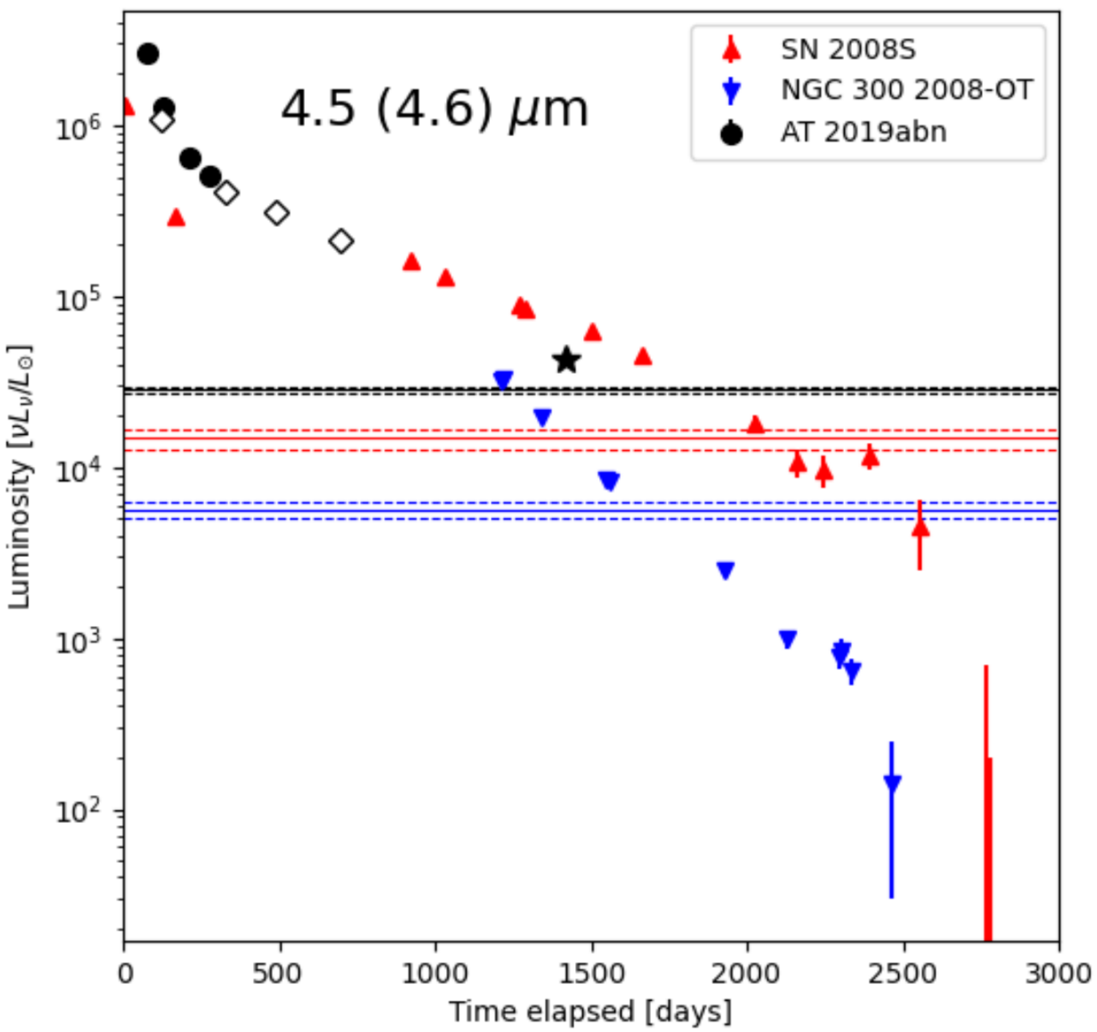
- red supergiant phase
- Form Fe core
- **core collapse supernova**

Das et al. 2025:
Low-luminosity Type IIP supernovae

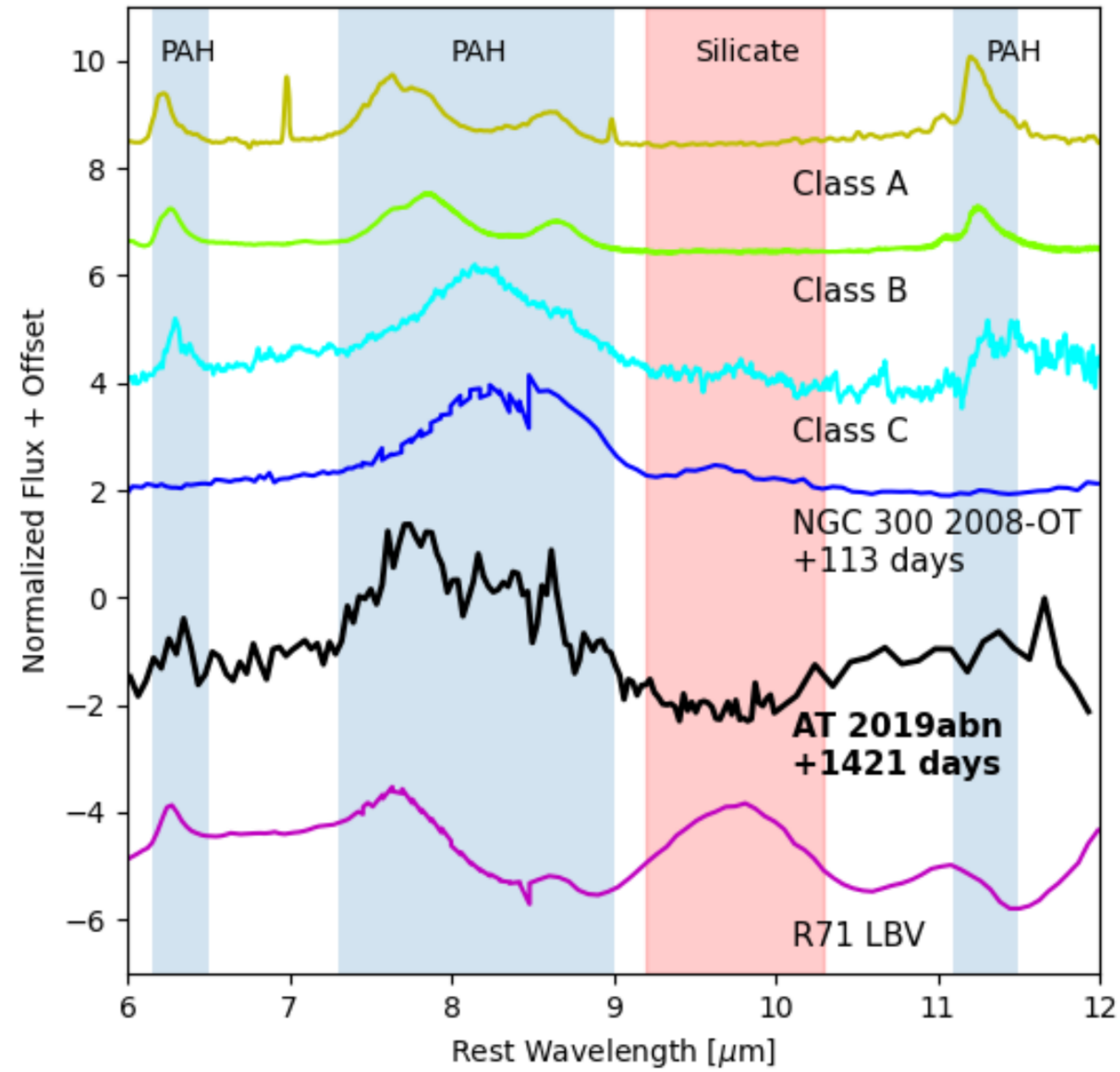
e.g. Doherty et al. (2017)

JWST - Carbon rich dust / PAH feature

Rose et al. (2025)



AT 2019abn



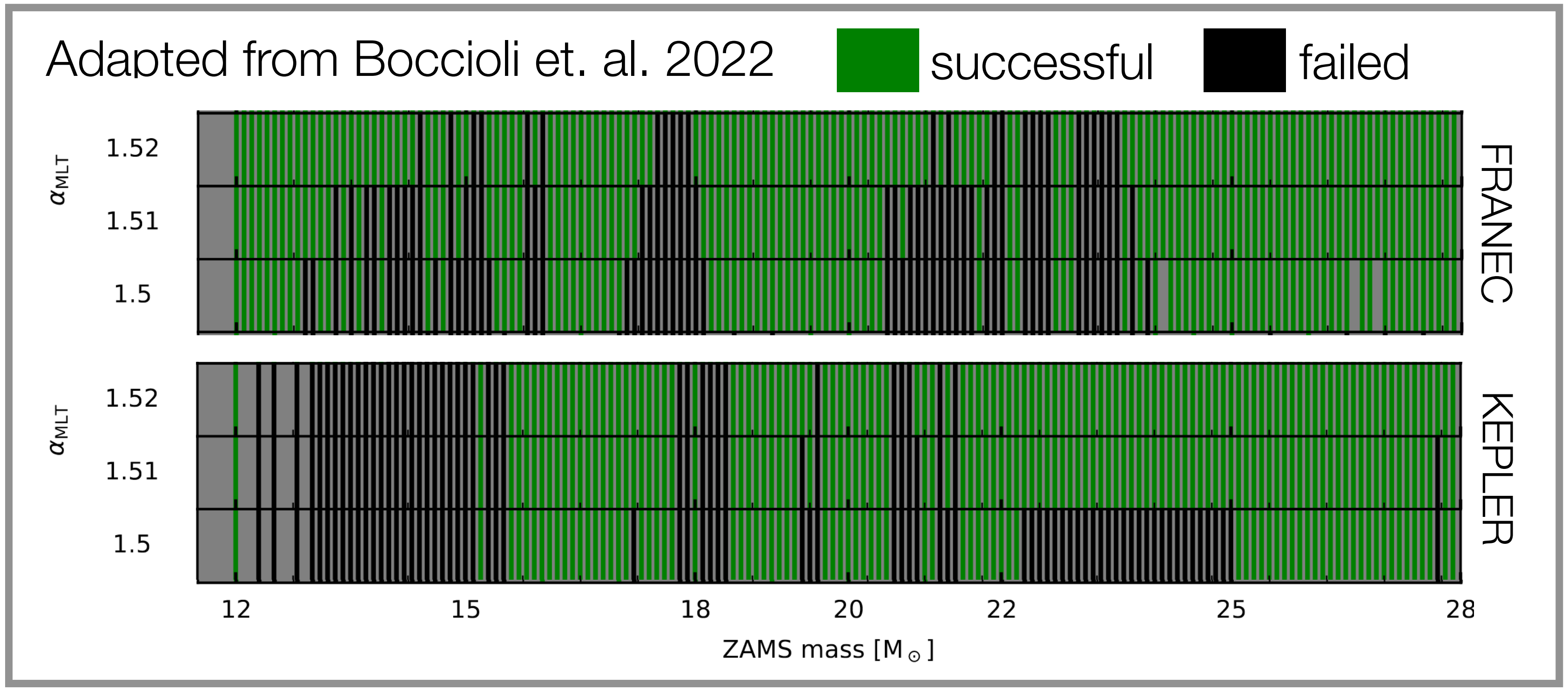
Hydrogen-rich gap transients

Luminous red novae

Intermediate luminosity red transients

Failed supernovae

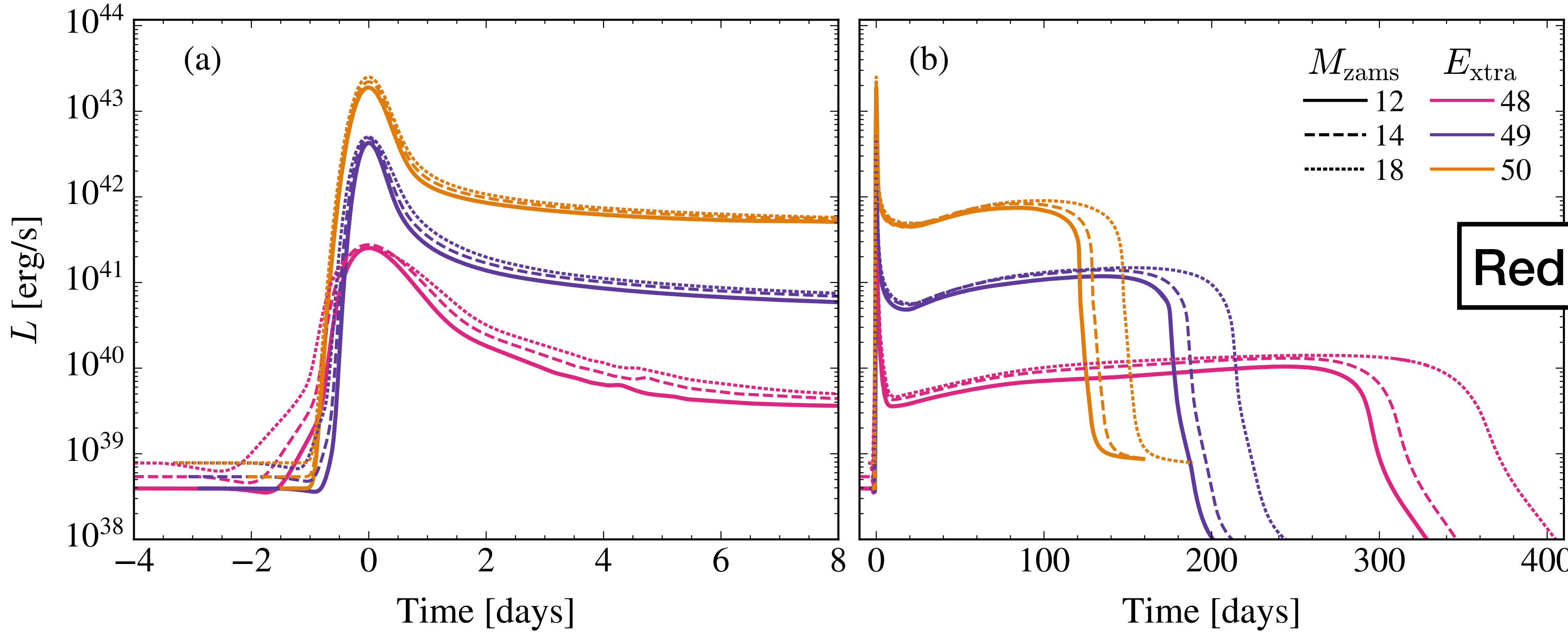
The supernova fails in an uncertain fraction of core-collapse deaths



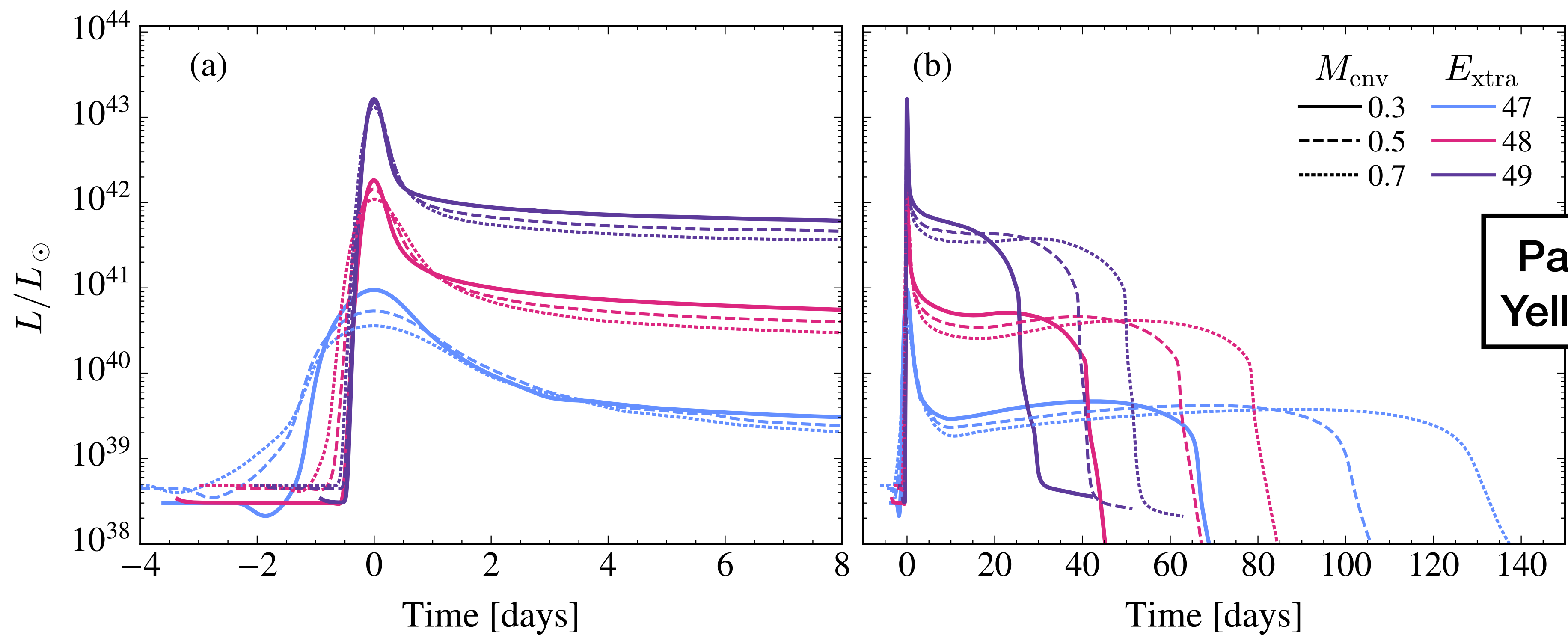
Red and Yellow Supergiant Progenitors:
still get a $\sim 10^{46} - 10^{49}$ **erg explosion**

Nadyozhin (1980), Lovegrove & Woosley (2013), Piro (2013), Fernandez et al. (2018), Ivanov & Fernandez (2021), Schneider & O'Connor (2022), **Antoni** & Quataert (2022,2023)

Low energy explosions of red and yellow supergiants: scaled down Type IIP SNe w/o a radioactive tail



Red Supergiants

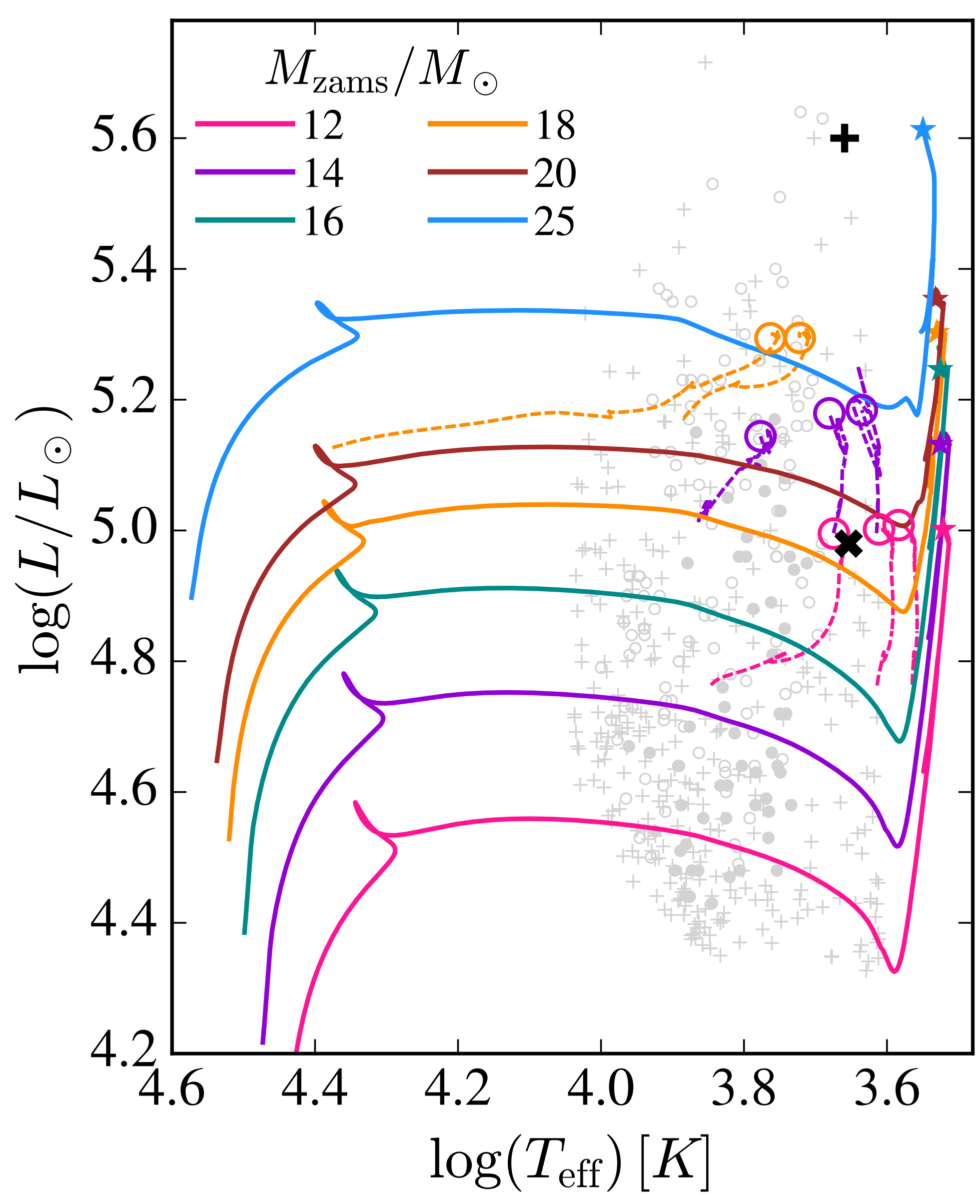


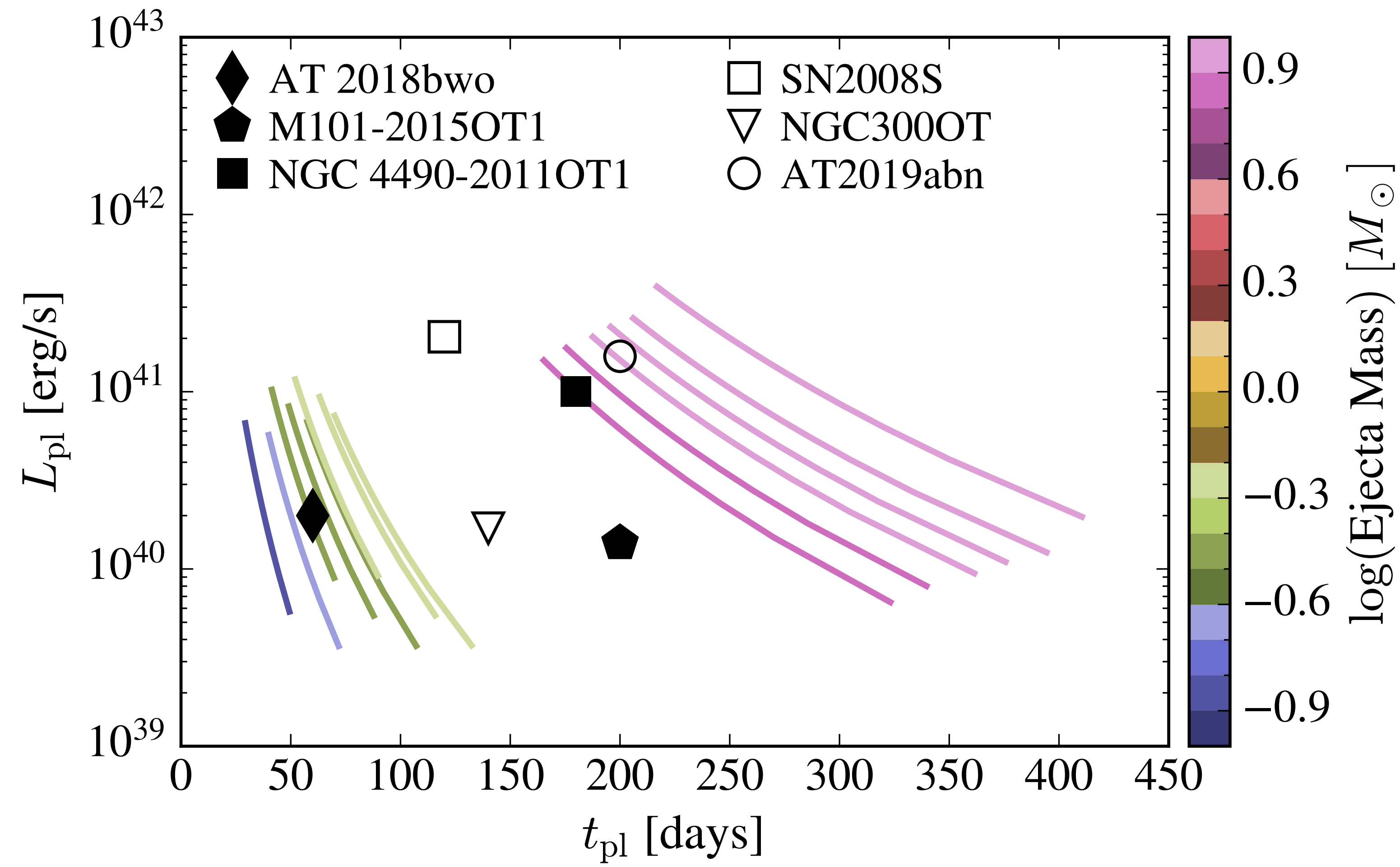
Partially-Stripped Yellow Supergiants

A. Antoni, Y.-F. Jiang, & E. Quataert (2025)

Failed SNe of RSGs/YSGs fall in the gap

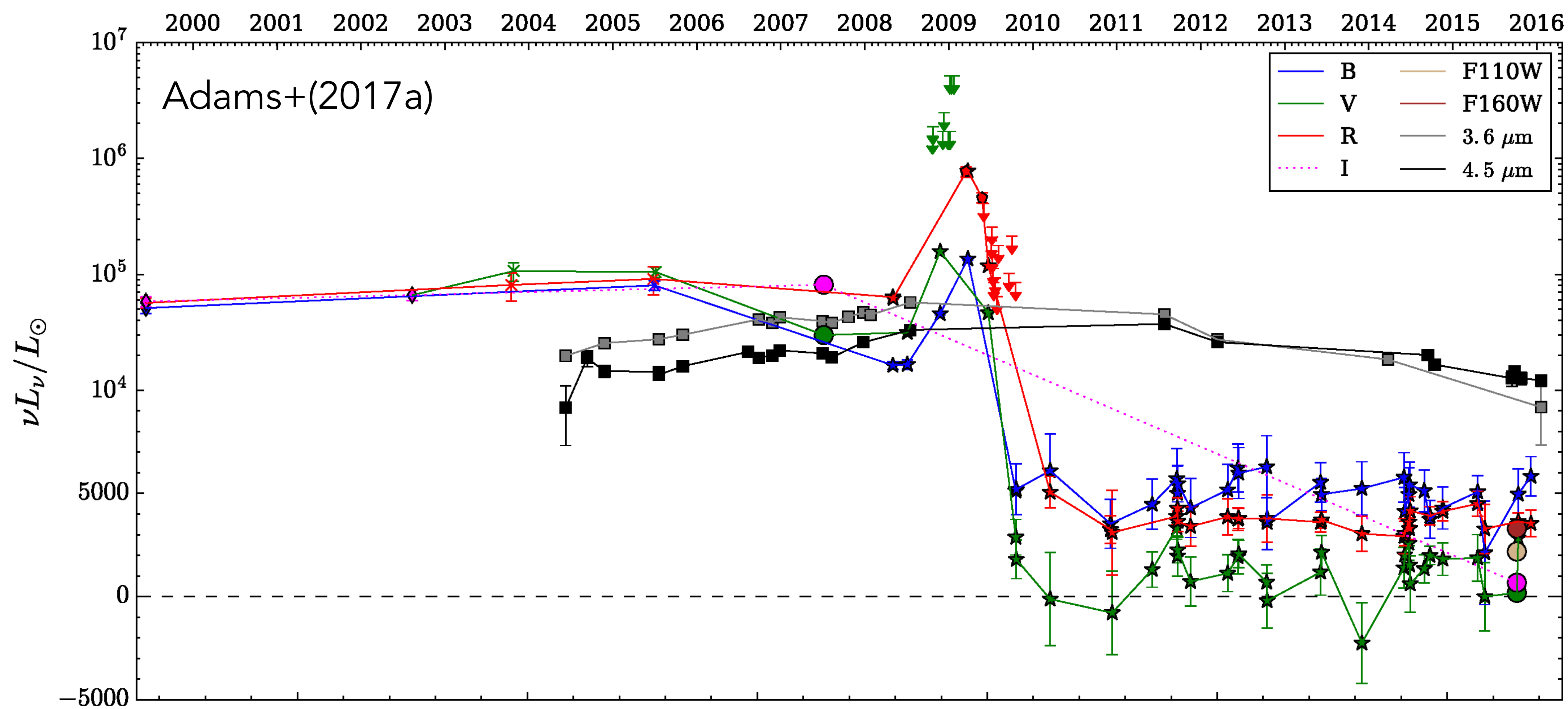
Scalings from **A. Antoni**, Y.-F. Jiang, & E. Quataert (2025)





NGC 6946-BH1

Kochanek+2008, Gerke+2015, Adams+2017a,2017b, Basinger+2021, Neustadt+2021, Beasor+2024, Kochanek+2024



Progenitor (2007)

$\log(L_\star/L_\odot) \approx 5.63$

$T_{\rm eff} \approx 3600$ K (Adams 2017)

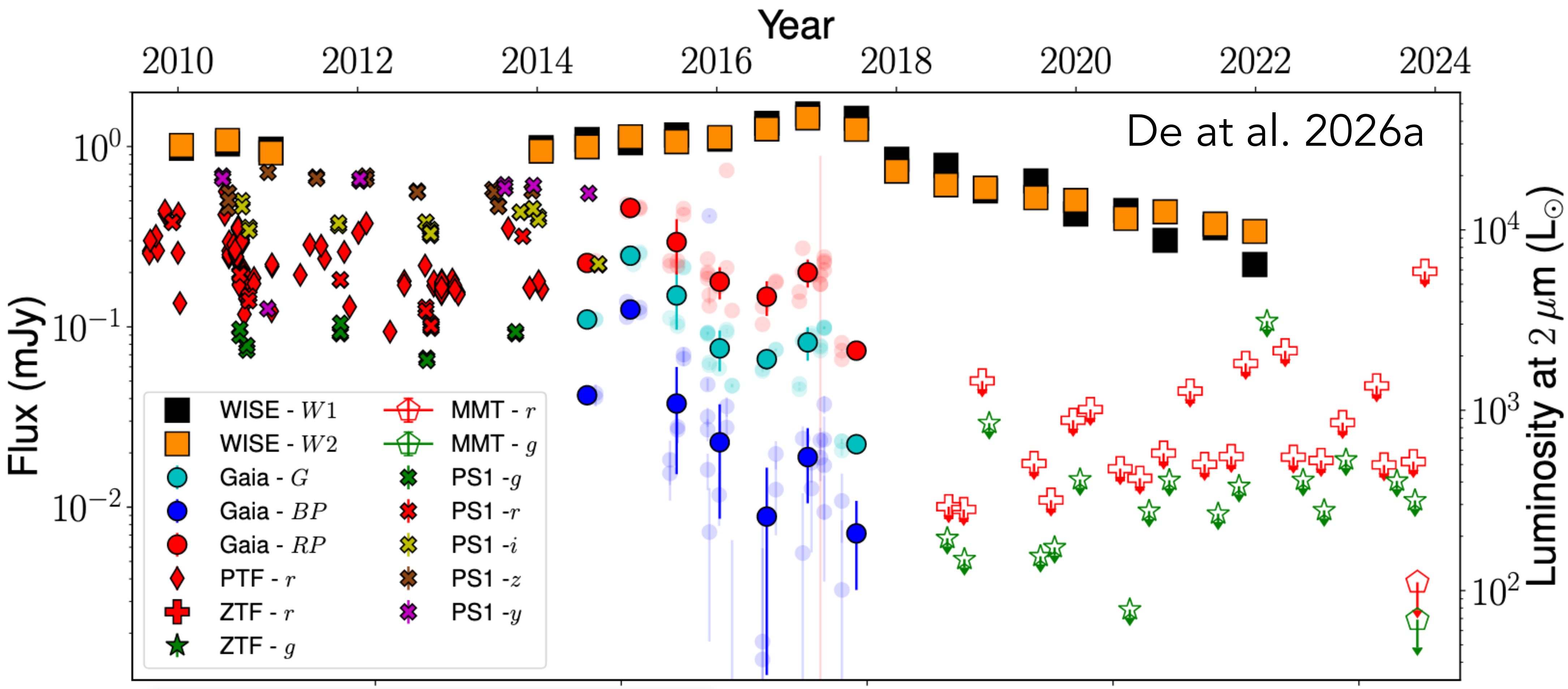
Remnant (2024)

$L \approx 0.1 - 0.15 L_\star$

(including JWST)

M31-2014-DS1 - infrared discovery

K. De, et al. (2026a,b)



Progenitor (2012)

$\log(L_\star/L_\odot) = 4.98$

$T_{\rm eff} = 4504$ K

Remnant (2024)

$L \approx 0.1 L_\star$

(including JWST)

Also see Beasor et al. (2026).

Hydrogen-rich gap transients

Luminous Red Novae

stellar mergers / binary inspirals

probe isolated binary evolution leading to binary BH/NS (GW sources)

Intermediate Luminosity Red Transients

electron capture SNe

probe the lowest energy massive star explosions that leave behind a NS (rather than a WD)

Failed Supernovae

Fe core collapse without a SN

probe the births of stellar mass black holes

Hydrogen-rich gap transients

Very dusty!!!!

Luminous Red Novae	Intermediate Luminosity Red Transients	Failed Supernovae
stellar mergers / binary inspirals	electron capture SNe	Fe core collapse without a SN
✓ late times	✓ late times	✓ late times
	✓ progenitor	
✓ transient (sometimes)		

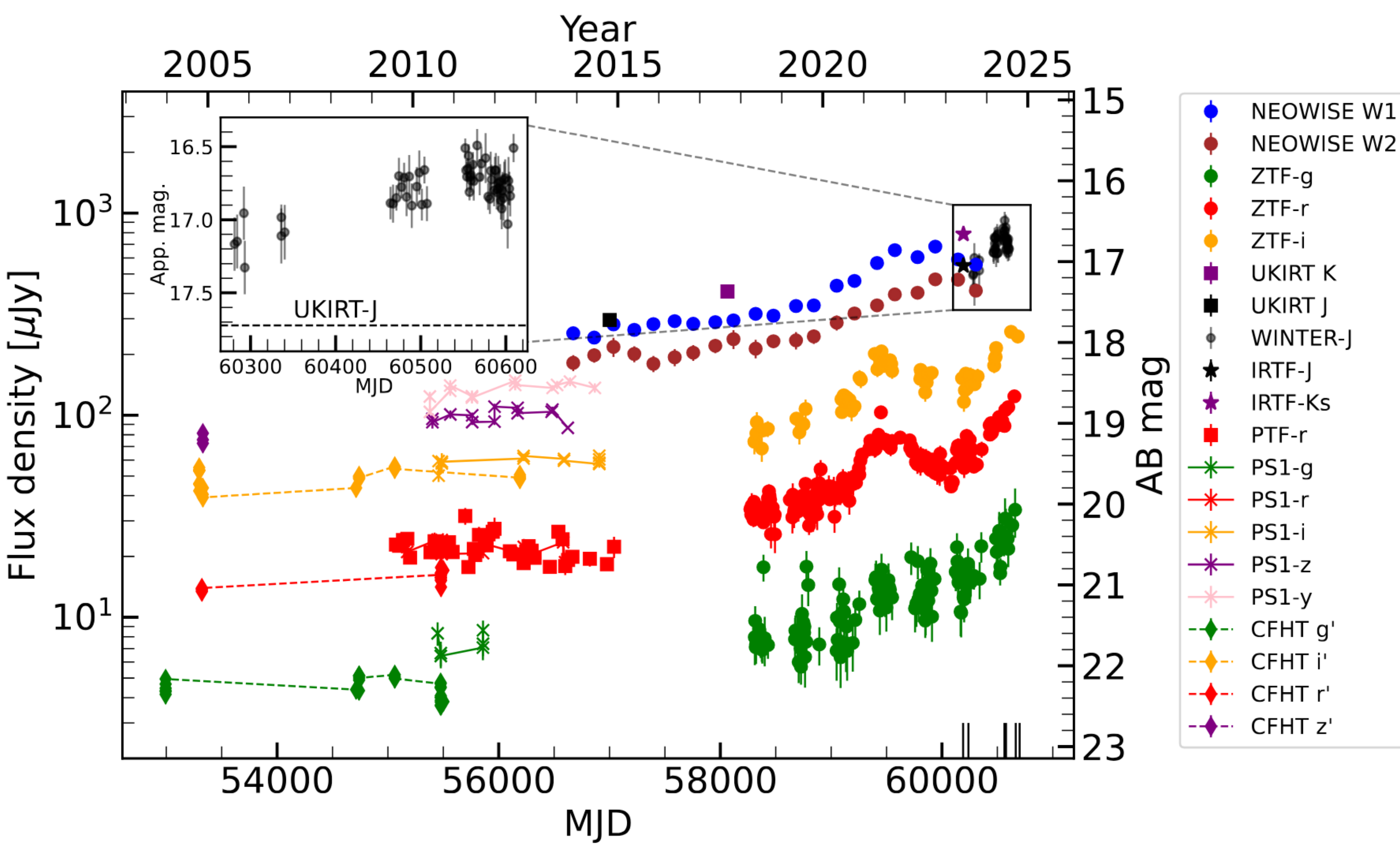
Transient discovery in the infrared

WINTER (Wide-field Infrared Transient Explorer)

(Lourie et al. 2020, Frostig et al. 2024)

Karambelkar et al. (2025)

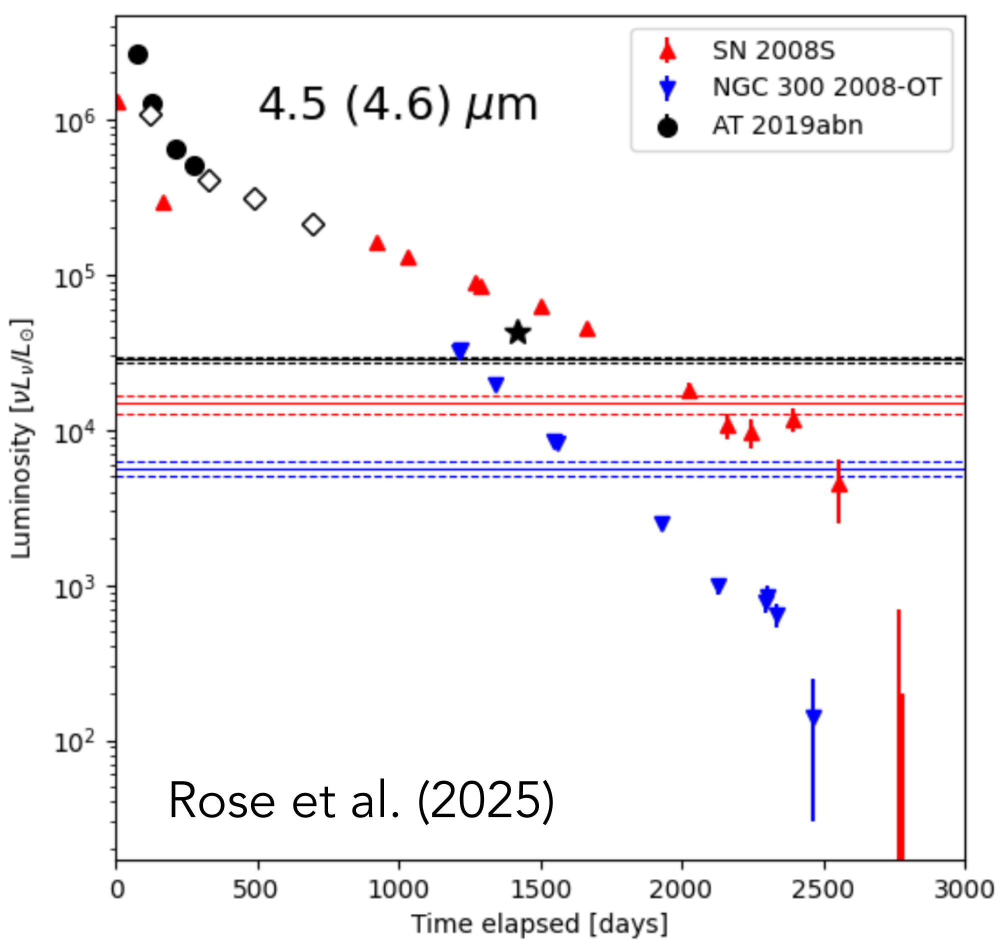
The Brightening of WNTR23bzdiq/WTP19aalzlk: Possible Onset of Common Envelope Evolution in an Asymptotic Giant Branch Star?



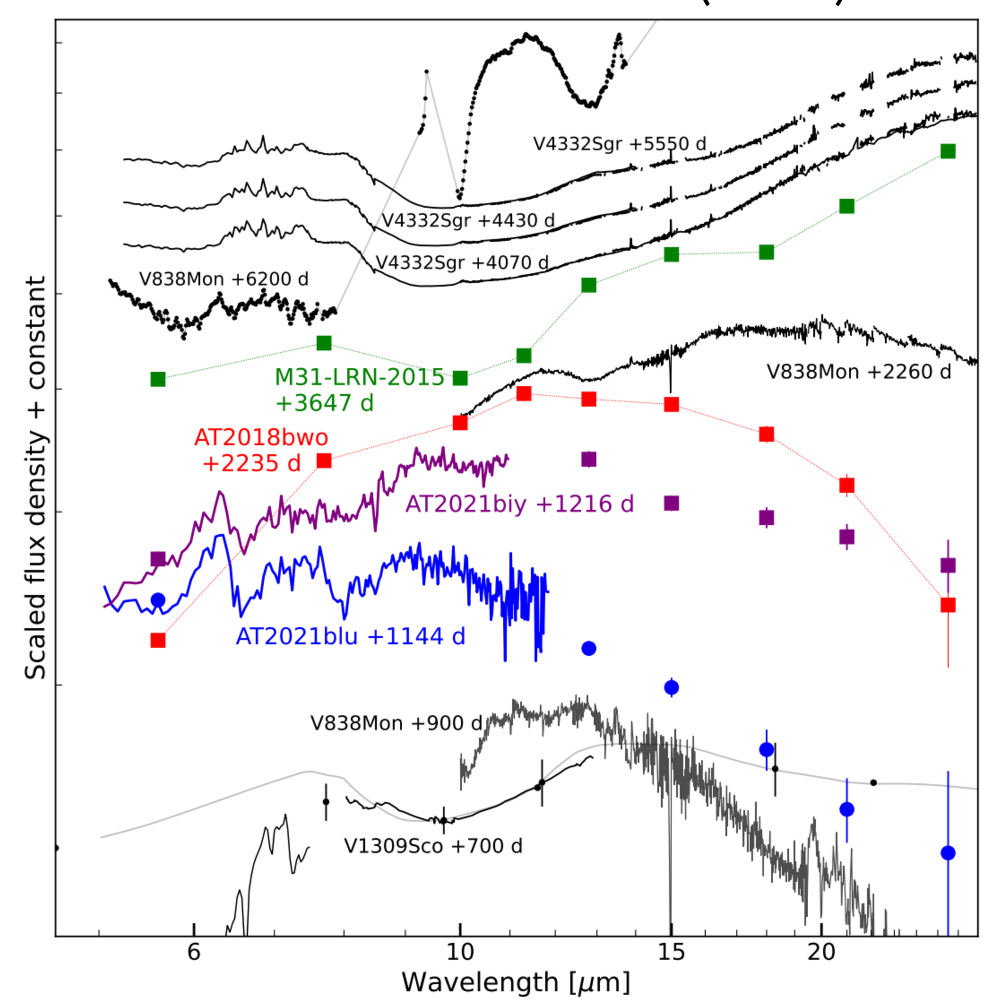
Andrea Antoni

Discussion question

What synergies between WINTER, Rubin, and Roman (and SPHEREx/JWST?) are being exploited to catch and characterize dusty transients (with initial peak durations of ~10s of days to a month and bright in the IR for months to years)?

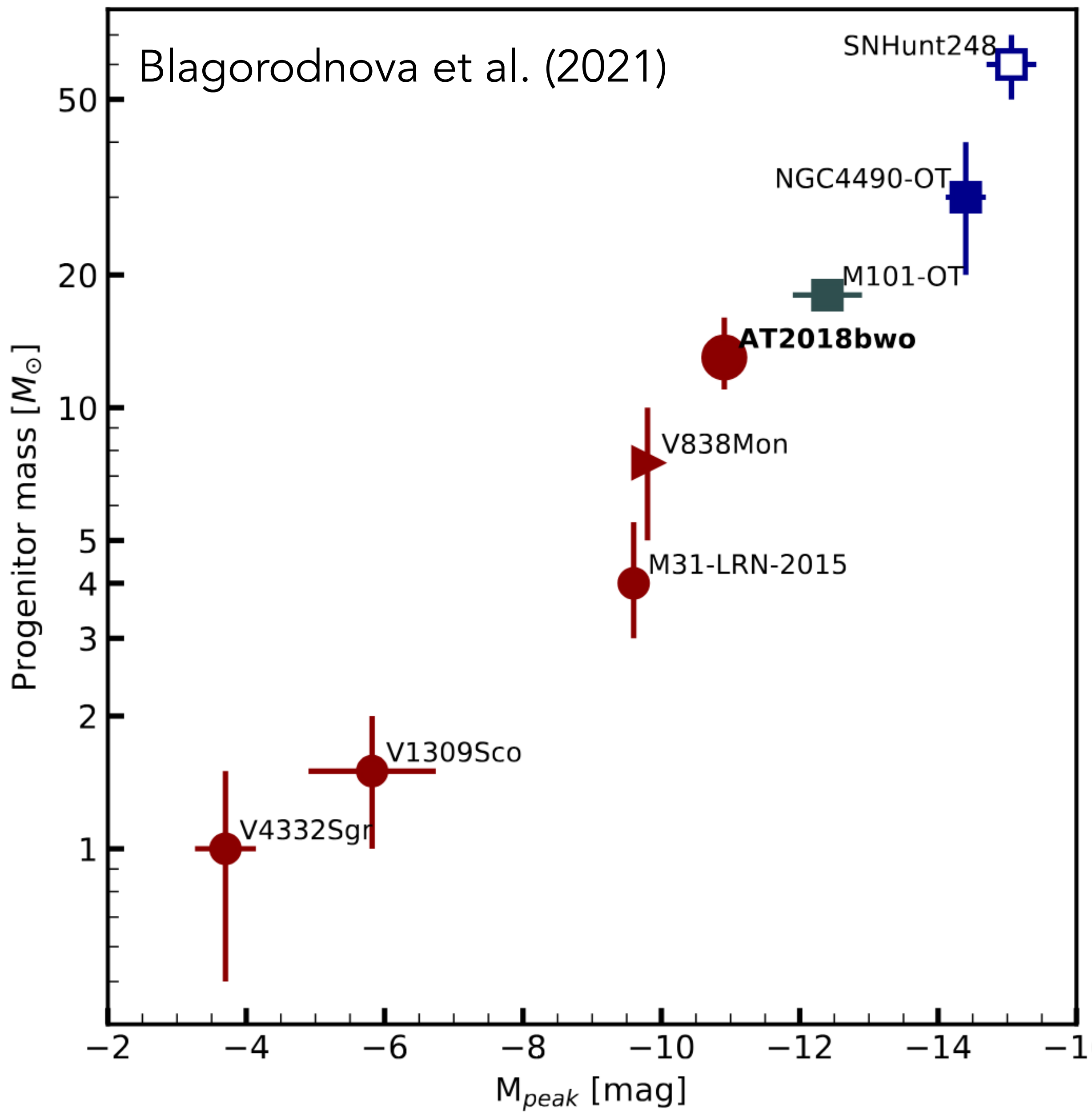


Karambelkar et al. (2026)



Backup Slides

More massive progenitor —> brighter LRN



Also see Kochanek, Adams and Belcynski (2014) , Smith et al. (2016), Pastorello et al. (2019) and others.

Spectral evolution

First peak:

- Blue continuum
- Prominent H, Fe emission lines
- Ha FWHM ~100s -1000 km/s

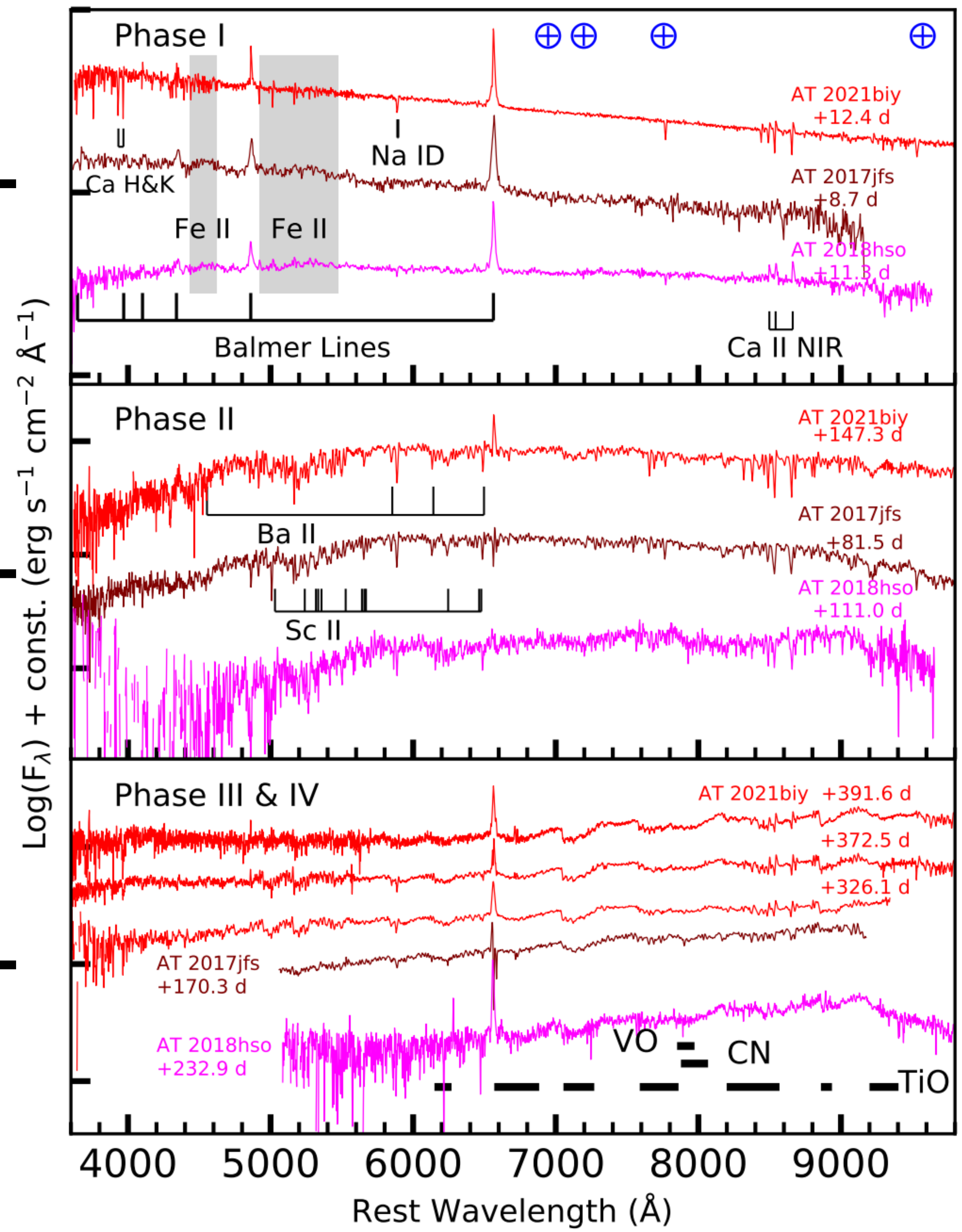
Second peak / plateau:

- Like G/K star
- Weaker Balmer lines, forest of metal absorption lines

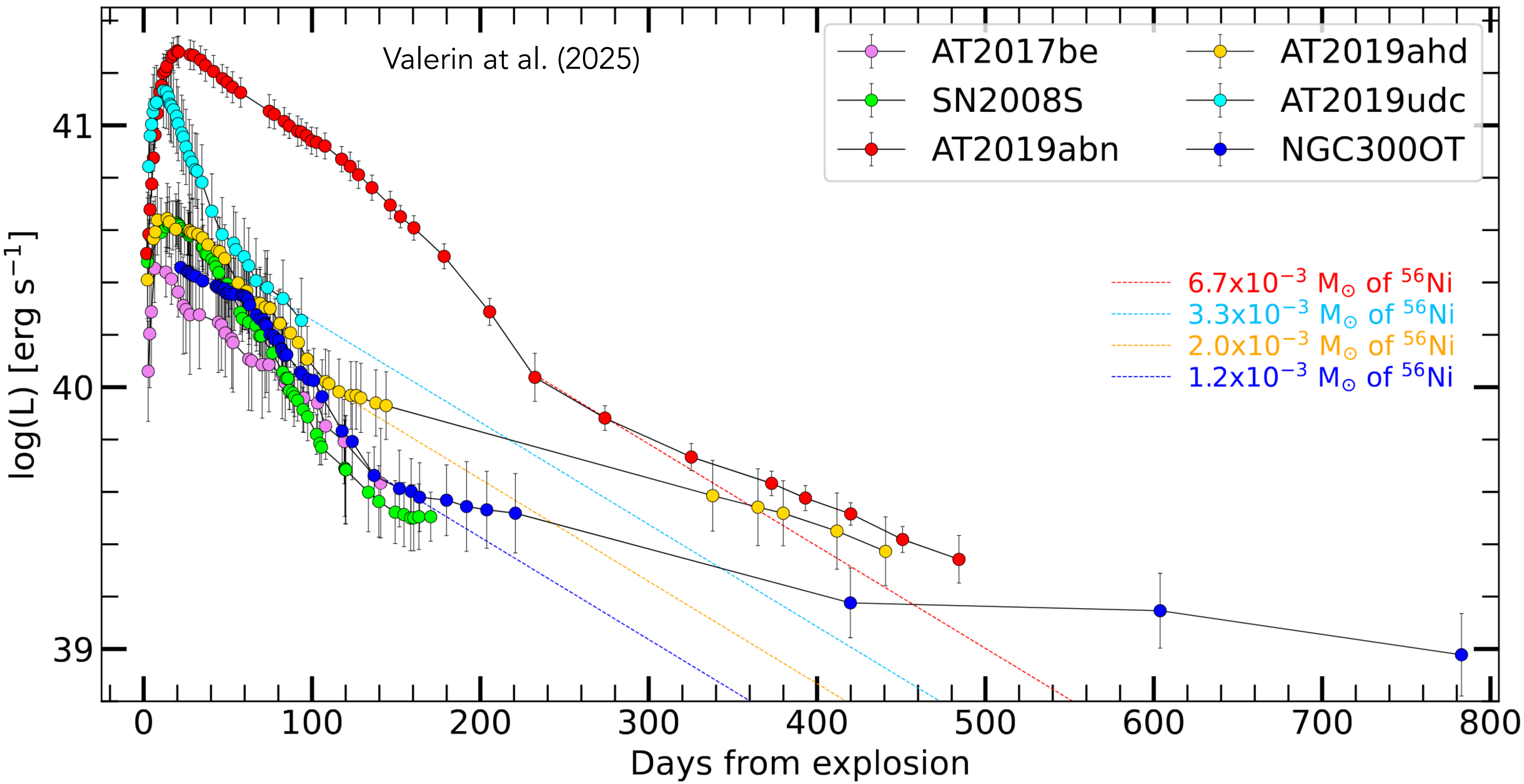
Late times (after second peak)

- Very red (like M star)
- Prominent Ha
- Strong molecular absorption (TiO, VO)

Yongzhi Cai et al. (2022)



Radioactive tail?



Neutrino mass loss during proto-neutron star phase leads to a weak shock in the envelope

Nadyozhin (1980), Lovegrove & Woosley (2013), Piro (2013), Fernandez et al. (2018), Ivanov & Fernandez (2021), Schneider & O'Connor (2022)

Red supergiants:

Eject $\lesssim$ few $M_\odot$ of H envelope

$L \sim 10^{39-40}$ erg/s, for ~year

(contribution of hydrogen recombination energy a large uncertainty)

Convective envelope carries too much angular momentum to accrete quiescently onto the black hole

Gilkis & Soker (2014, 2016), Quataert et al. (2019),

Antoni & Quataert (2022,2023)

Accrete ~1% of envelope, unbind the rest in a $\sim 10^{47} - 10^{49}$ erg explosion