Wide-Field SN Surveys: New Regimes of Transient Science

Maria R. Drout
University of Toronto; Carnegie Observatories

Image Credit: Robin Dienel/Carnegie Observatories

Wide-Field Transient Searches

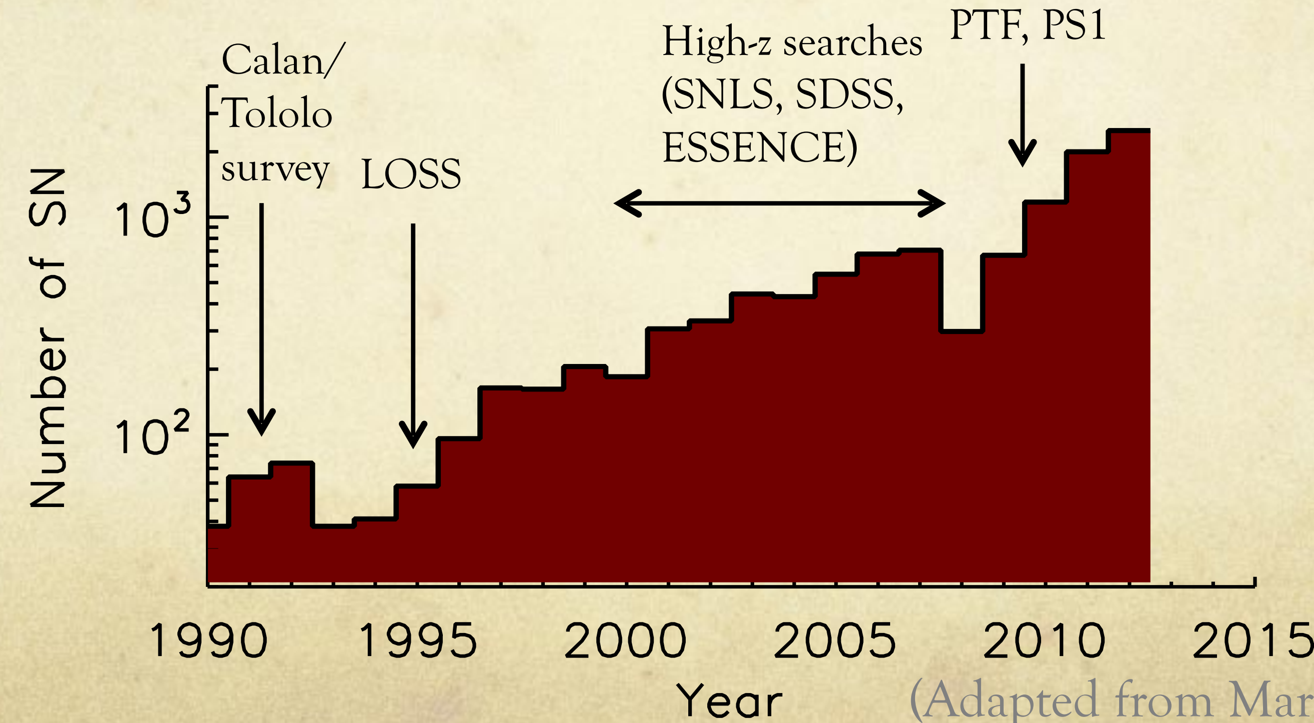
SNLS SuperNova Legacy Survey

PALOMAR TRANSIENT FACTORY

Pan-STARRS

CATALINA SKY SURVEY

ASAS-SN

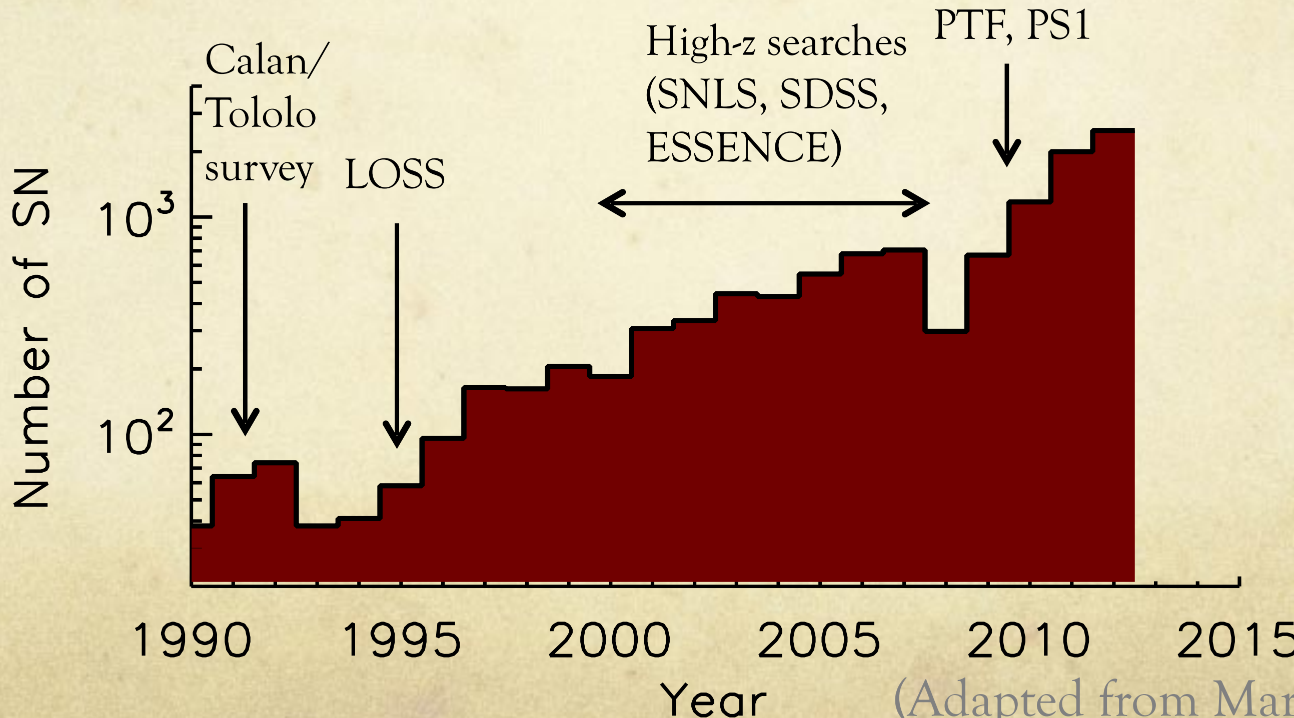


(Adapted from Mark Sullivan)

Supernova and Transients

Three pillars of wide-field surveys

1. Identification of Large Samples of Known Classes of SN
2. Discovery of Intrinsically Rare Transients
3. Opening of New Regimes for Transients



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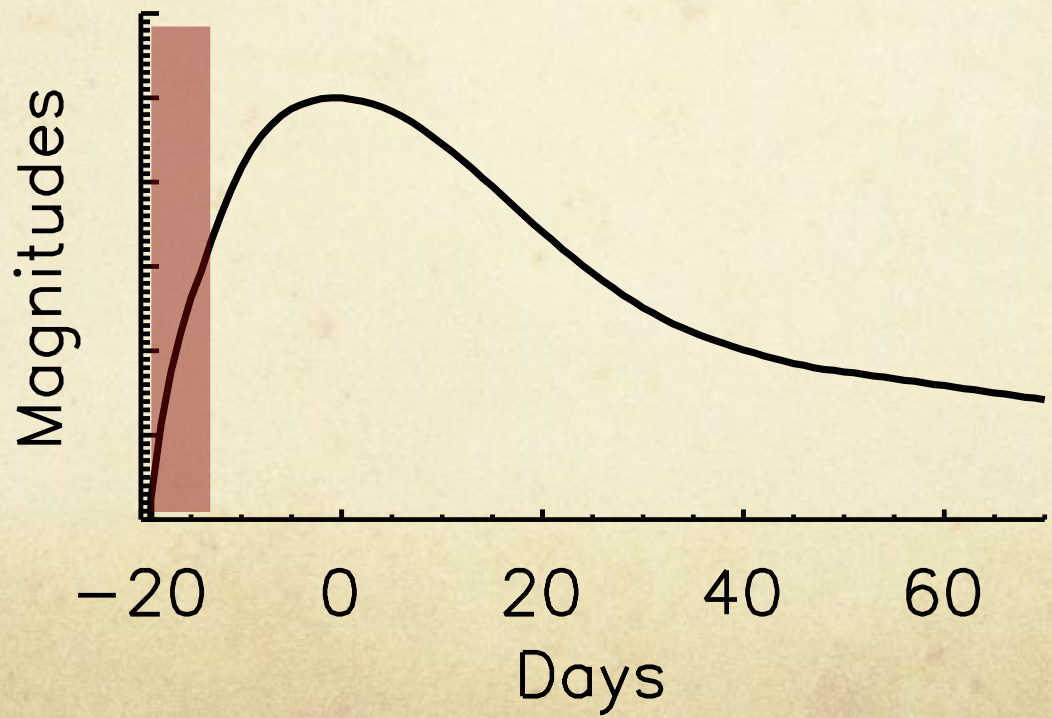

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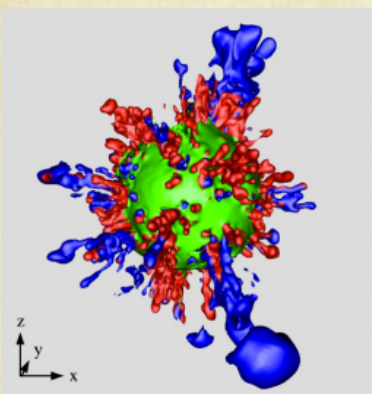
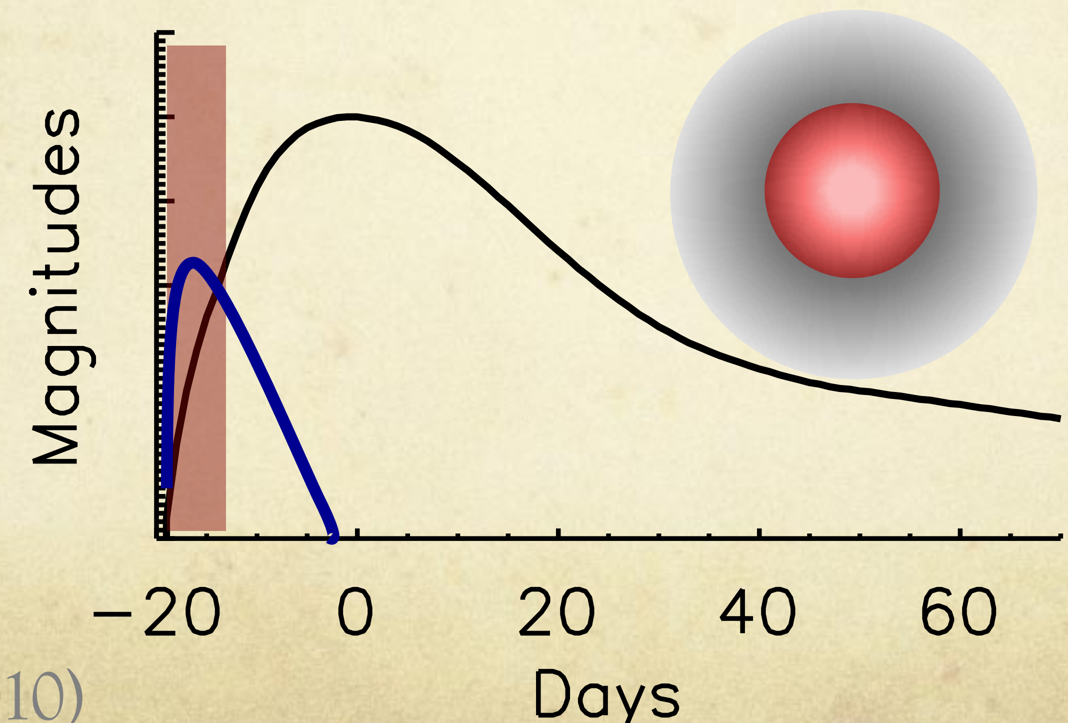
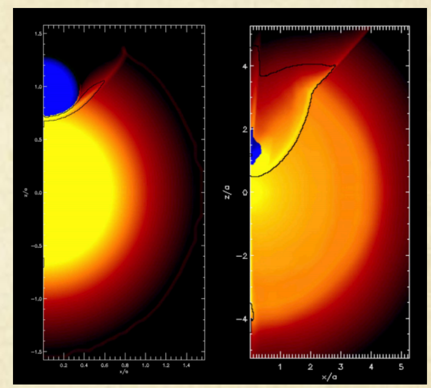


Hammer+ (2010)





Kasen (2010)

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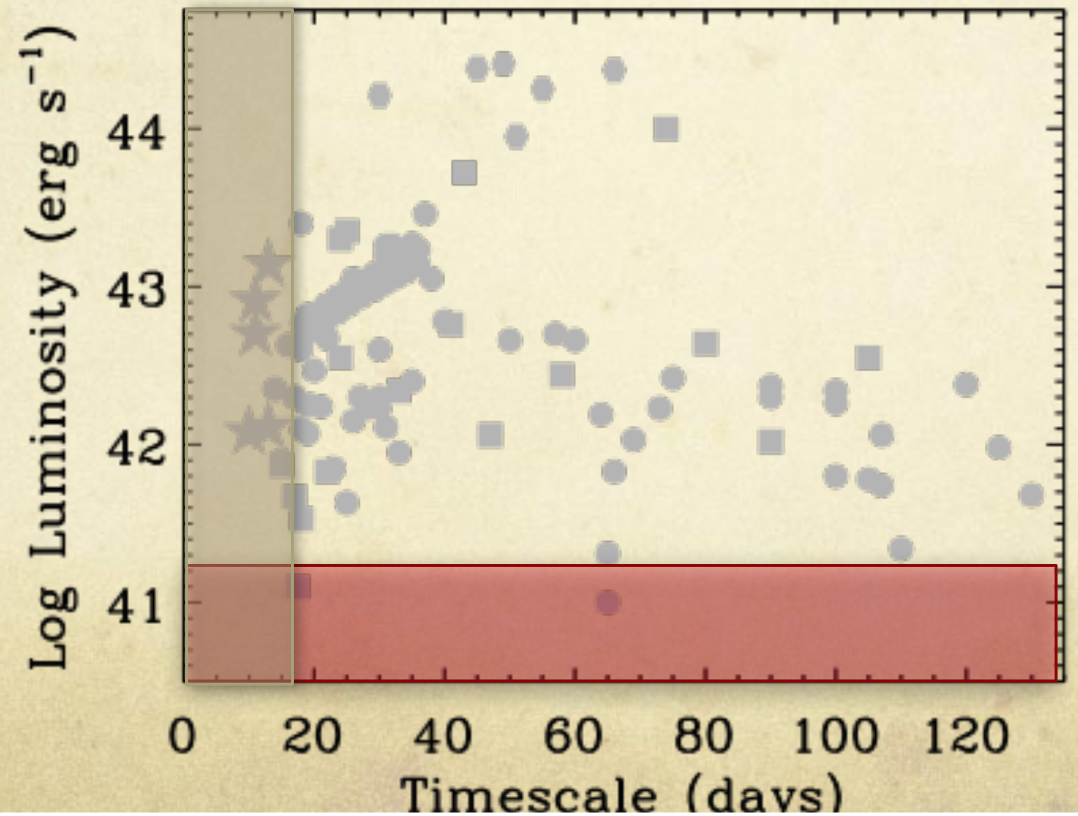

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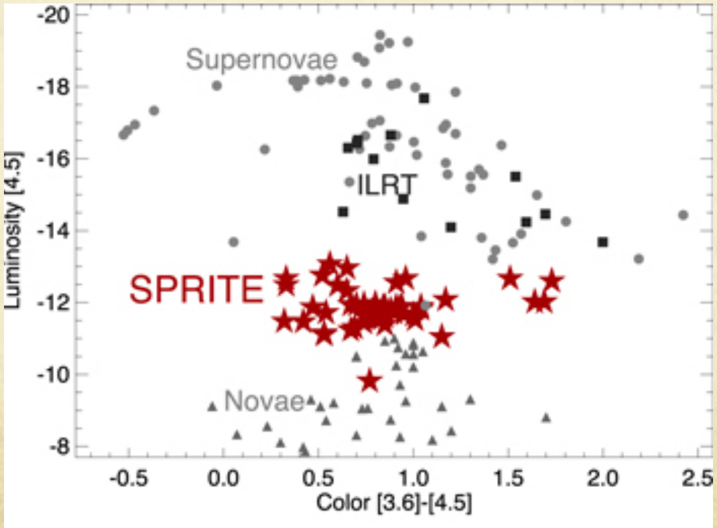
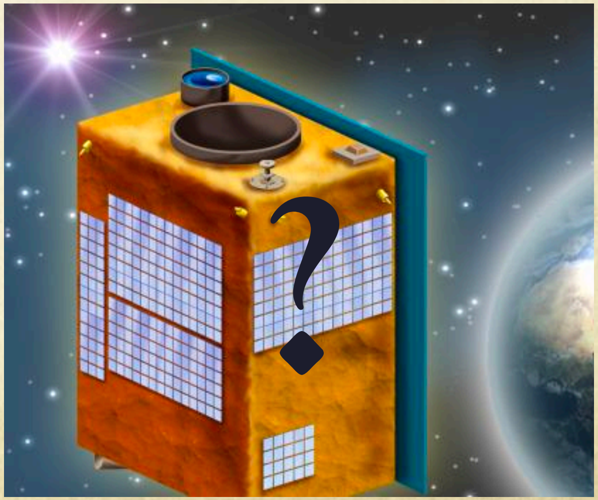
Radio



Infrared (Kasliwal+2017)



Ultra-violet…

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Current/Upcoming Surveys

Wide-Field/All Sky

ASAS-SN
PS1
Dark Energy Survey
ATLAS
ZTF
BlackGEM*
LSST*

Boutique/Specialized Science

DLT40
KMTNet SN Survey
HiTs
Deeper, Wider, Faster
K2/TESS
Survey for Nothing

Supernova and Transients

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Key Question 1:

What are the observed populations, intrinsic rates, and nature of "peculiar" explosive transients present in the universe?

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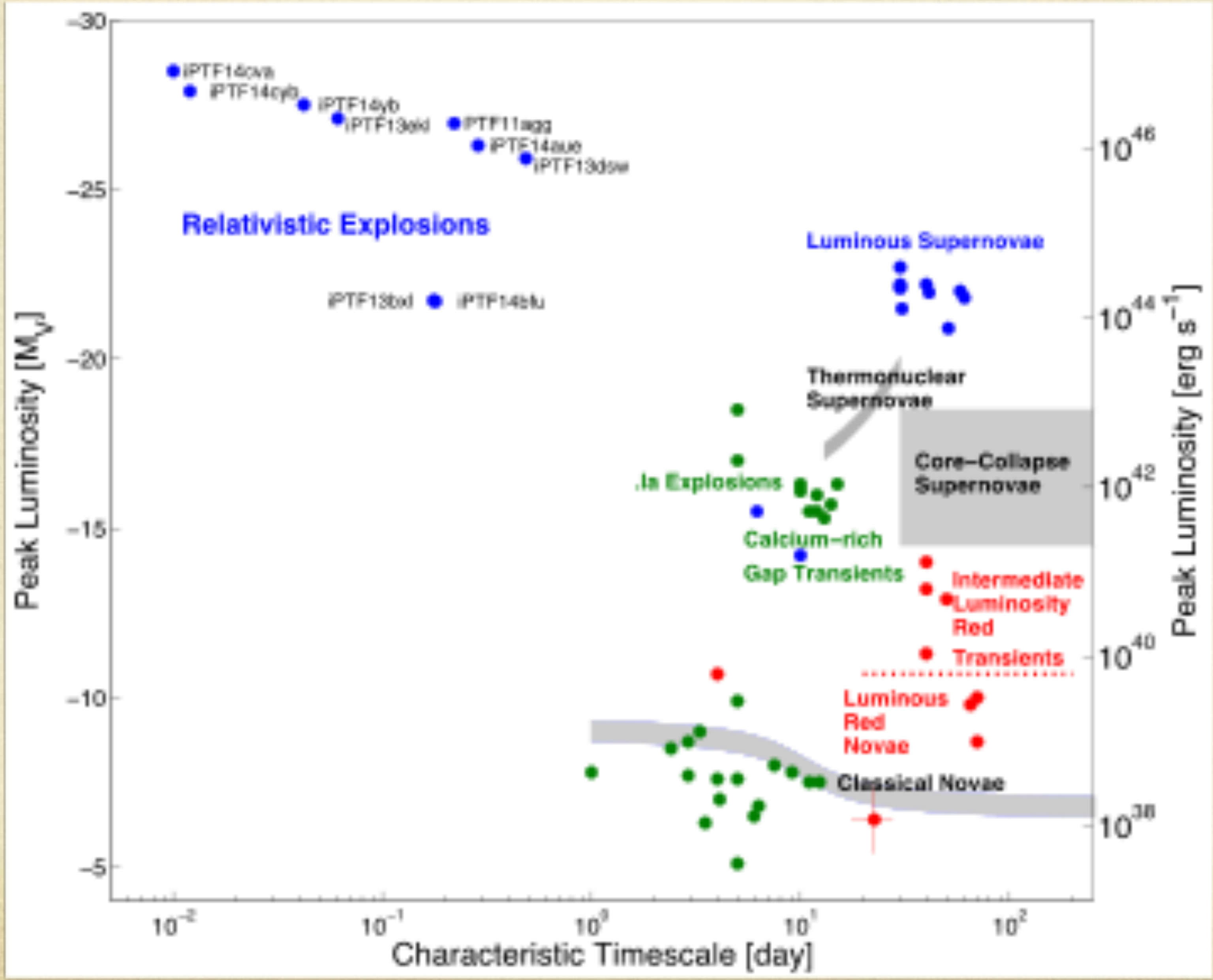
"Peculiar" Transients



LSST Observing Strategy White Paper (adapted from Kasliwal 2011)

“Peculiar” Transients: Observations

Observed Transient	Why “peculiar”
Super-luminous SN	Intrinsically rare; prefer low-mass hosts
Nuclear flares	rare, image subtraction
Luminous Blue Transients	rapid
Type Iax SN	faint, somewhat rapid
Calcium-rich Transients	faint, somewhat rapid
Rapidly Declining Type I SN	faint, rapid
Intermediate luminosity optical transients (ILOTs)	very faint
Luminous red novae	very faint
Long-lived Type II	Rare. Bias?

Peculiar Transients

Probe different regimes of progenitor systems and explosion mechanisms. Unique means to study uncertain stages of stellar evolution and channels for stellar death.

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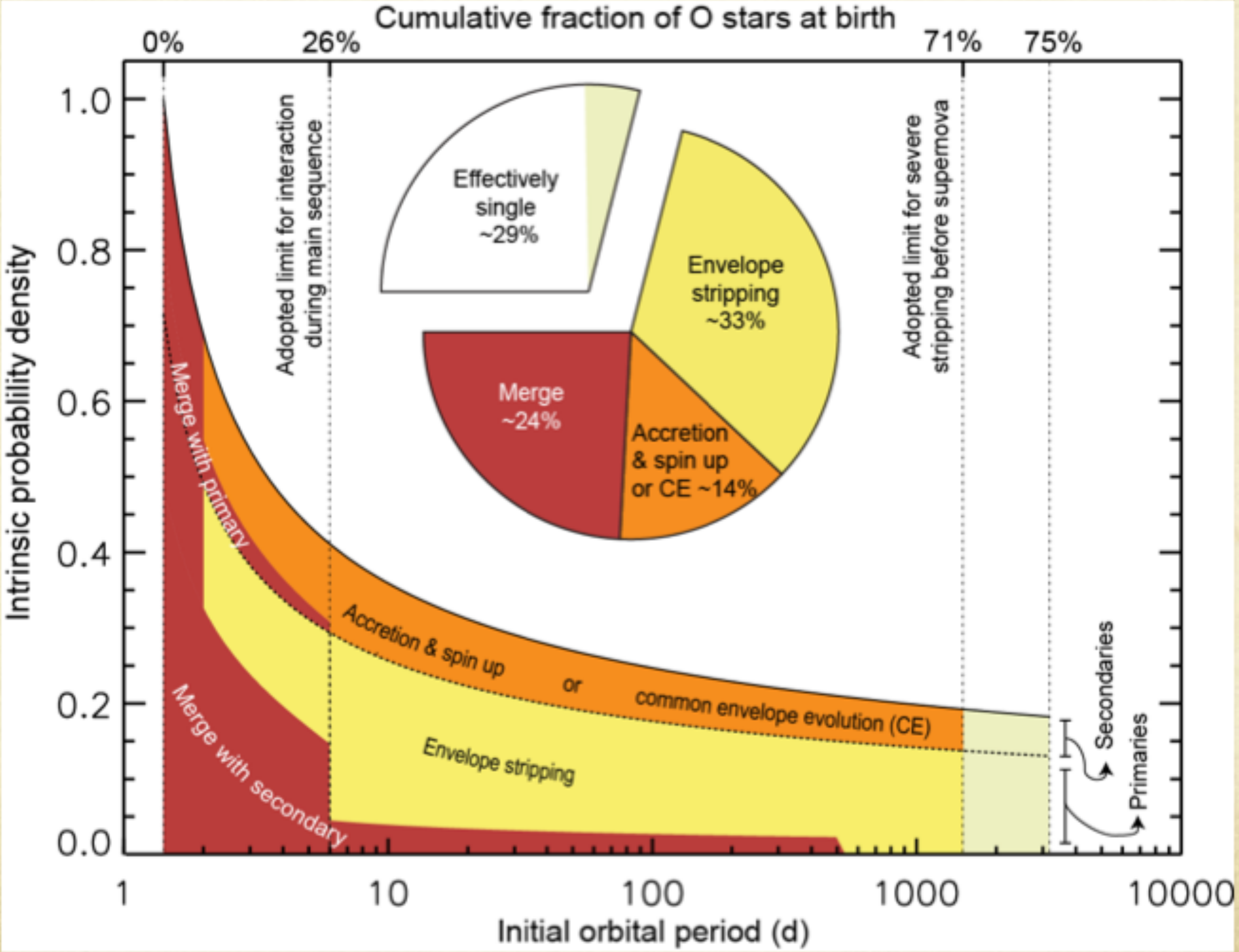

Sana, de Mink, et al. (2012)

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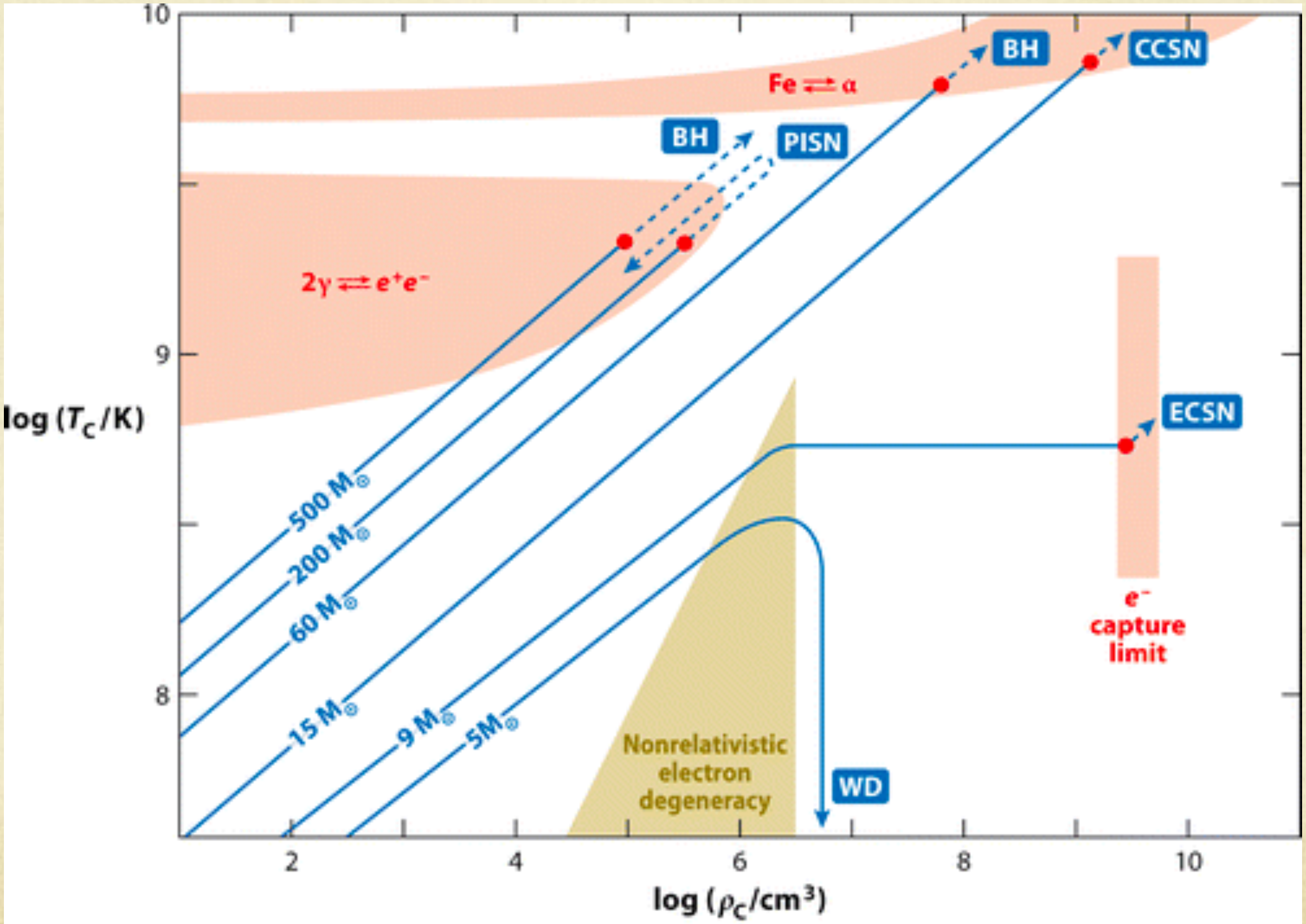

Langer N. 2012.
Annu. Rev. Astron. Astrophys. 50:107–64

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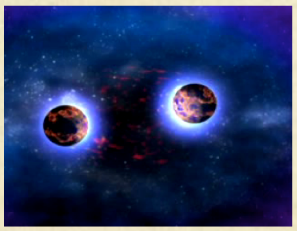

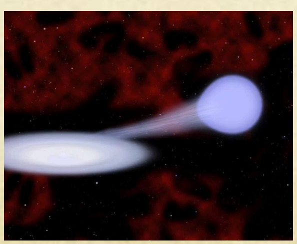

<table>
<tr><th>Binary system</th><th>Outcomes with deflagration-detonation-transition</th><th>Outcomes without deflagration-detonation-transition</th></tr>
<tr><td>He-rich WD
+ C/O WD < 0.8 Msol</td><td colspan="2">Shell detonation
. Ia supernova (?)</td></tr>
<tr><td>He-rich WD
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SN Ia</td></tr>
<tr><td>Low-mass He-burning star
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<tr><td>High-mass He-burning star
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<tr><td>High-mass He-burning star
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SN Ia</td><td>Core deflagration
SN Iax</td></tr>
</table>

Table Courtesy of Ken Shen

Peculiar Transients: Theory

Theoretical Transients	Science Case(s)
Tidal Disruption Events	quiescent SMBHs; jet physics
Kilonovae	Gravitational waves; r-process
Off-axis GRB afterglows	Rates, energy scale; jet structure
Accretion Induced Collapse	WD physics
Helium shell detonation (.Ia)	WD accretion, nuclear physics
Failed supernovae	BH formation; feedback
Ejection of a stellar envelope	Mass loss; common-envelope
Mergers	Merger rates; common-envelop efficiency
Pair instability SN	Explosion mechanism
…	

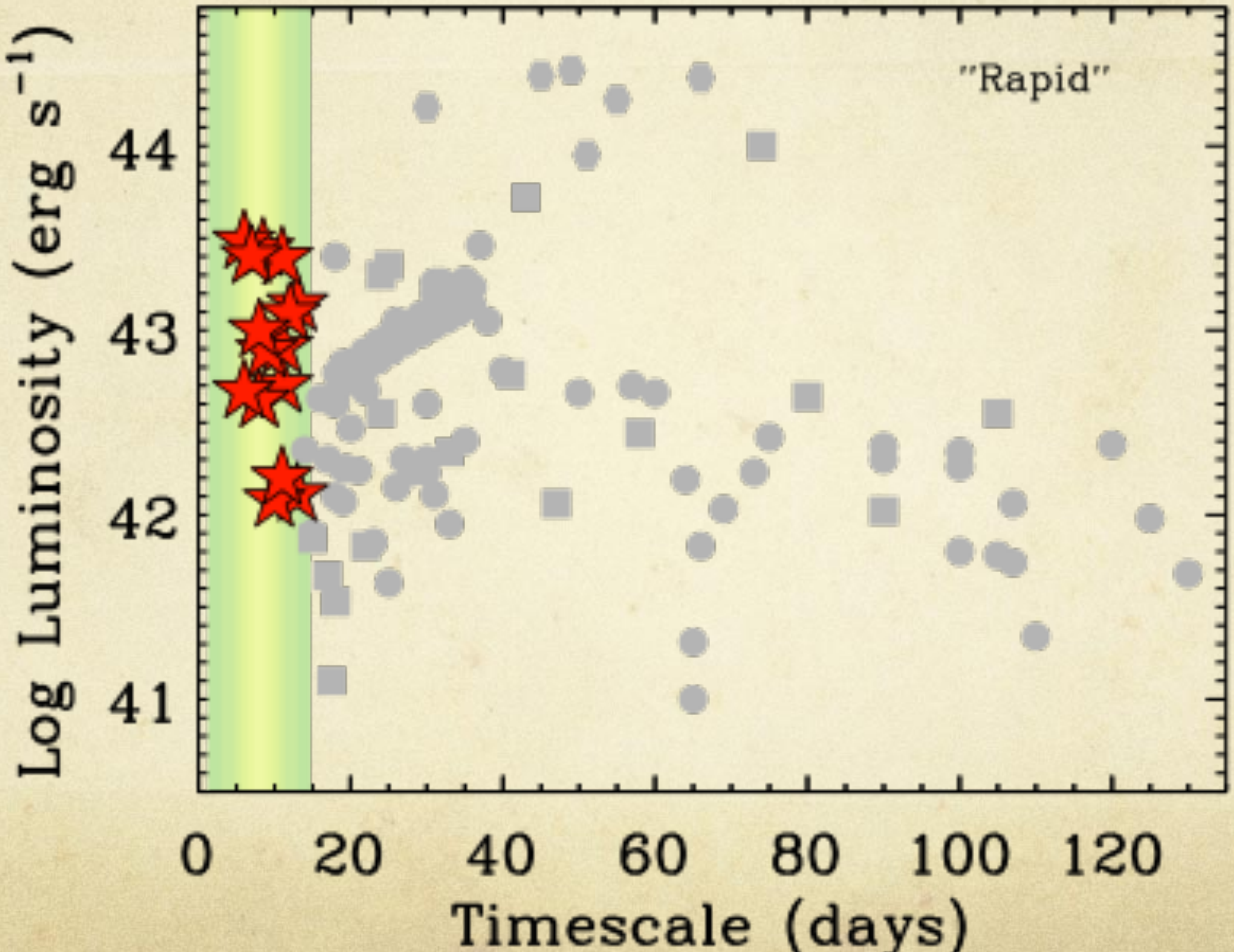
Peculiar Transients

- What are the **observed** populations?
- What is their nature?
- What are their **intrinsic** rates?

What are the implications?

- Stellar evolution, binary interactions, mass loss, ...
- Physics of compact objects, stellar explosions, ...

SN Phase Space



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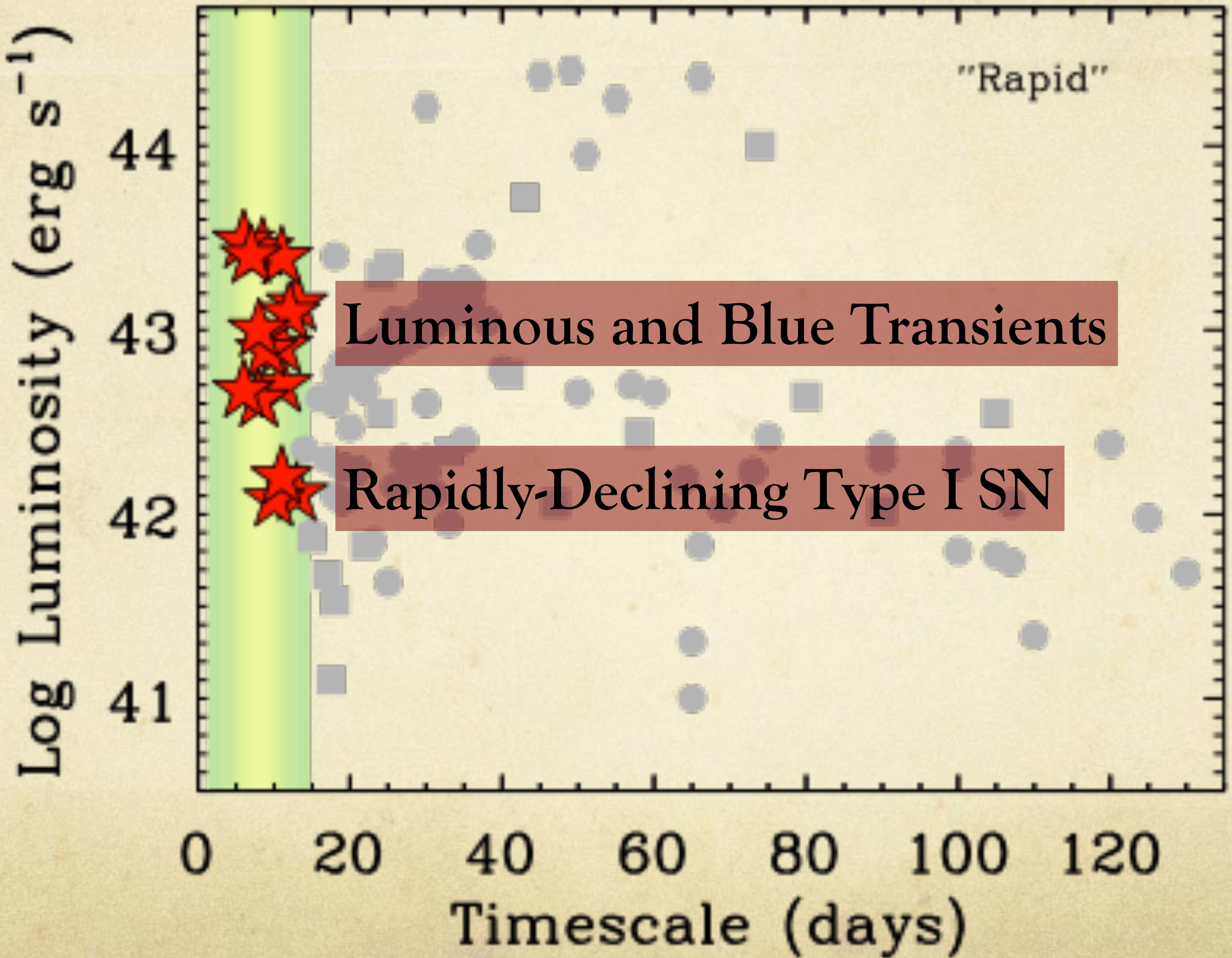
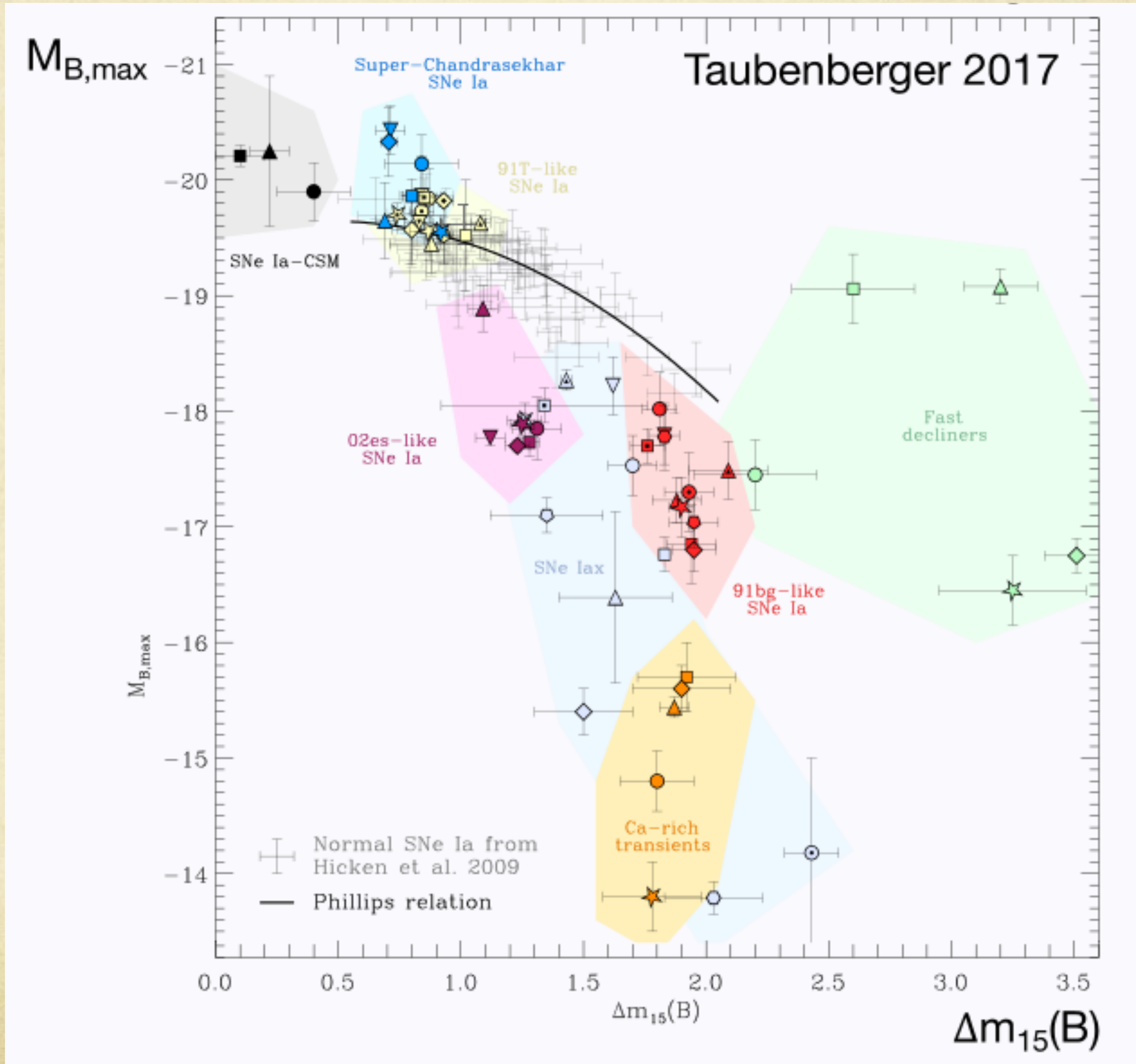


Rapidly-Declining Type I SN



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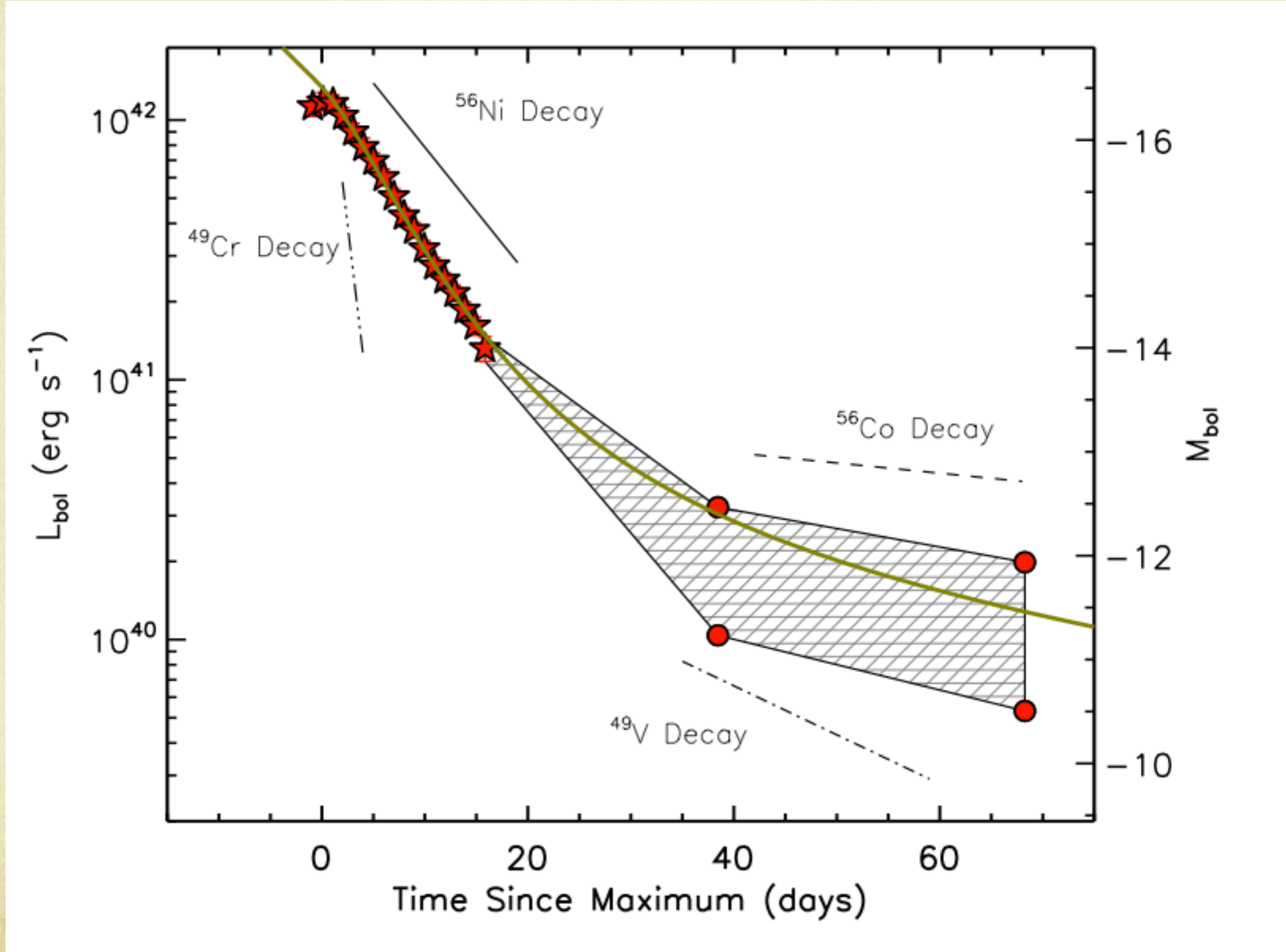
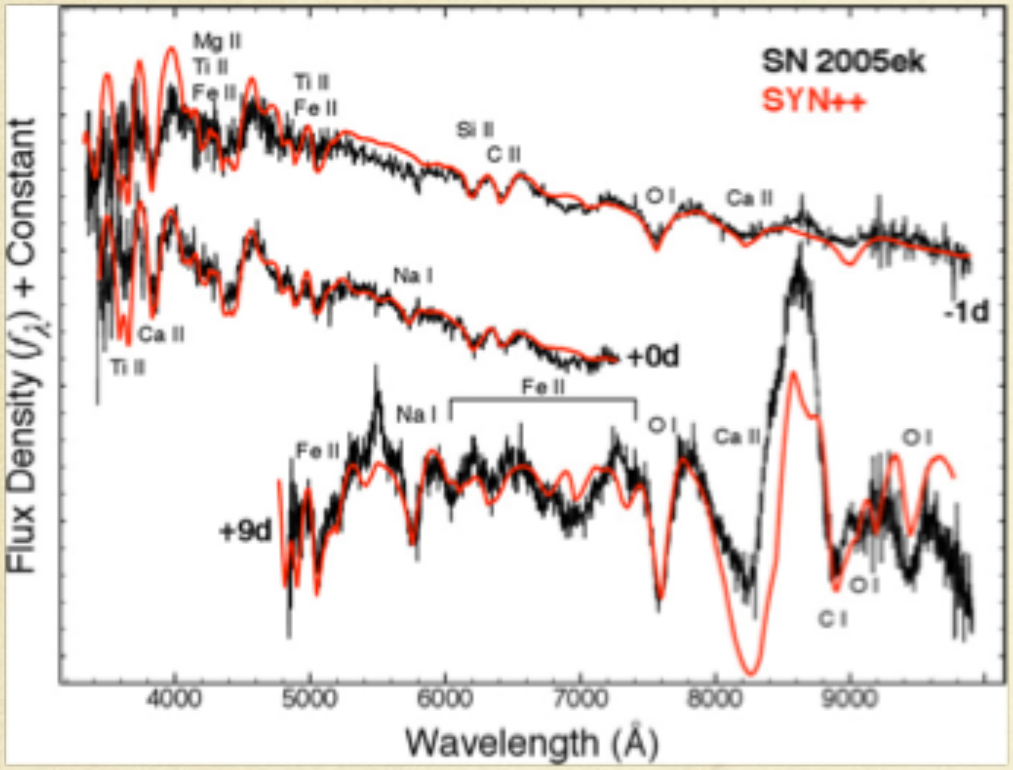


Drout et al. (2013)

Rapidly-Declining Type I SN

SN2005ek, SN2010X



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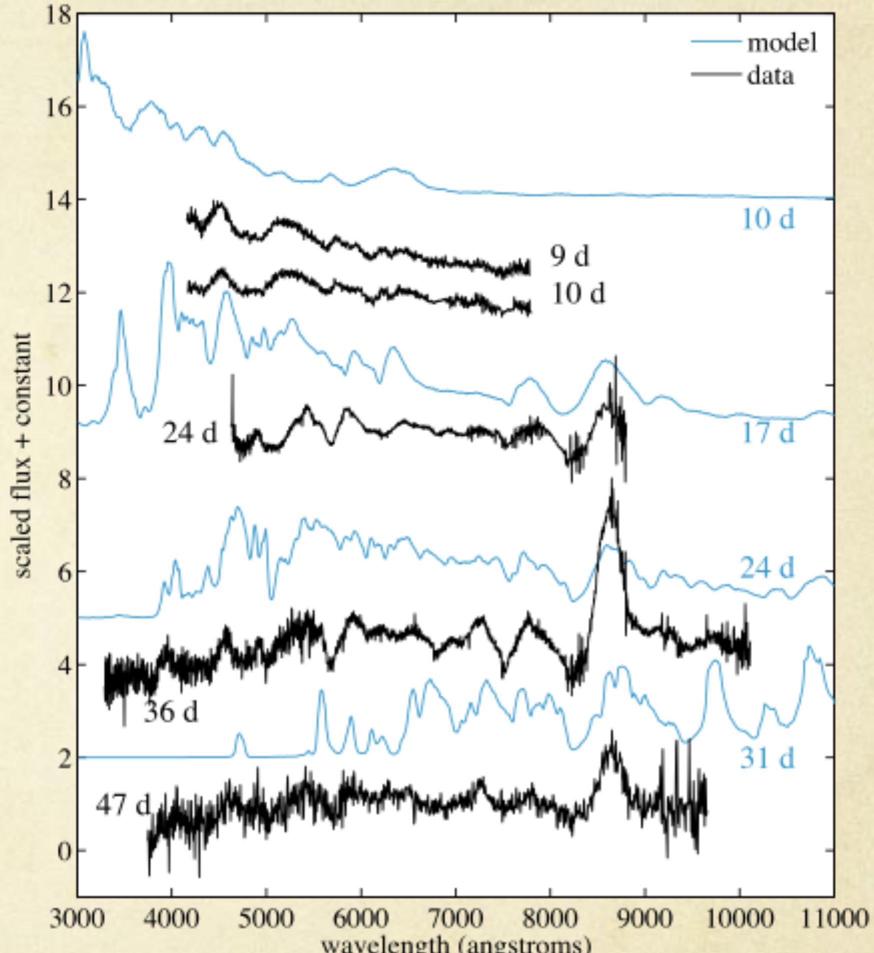

Kleiser & Kasen (2014)

Spectroscopic modeling finds an ejecta dominated by oxygen.
(Drout et al. 2013, Tauris et al. 2013, Kleiser et al. 2014)

Rapidly-Declining Type I SN

Possibility 1. An Ultra-stripped SN

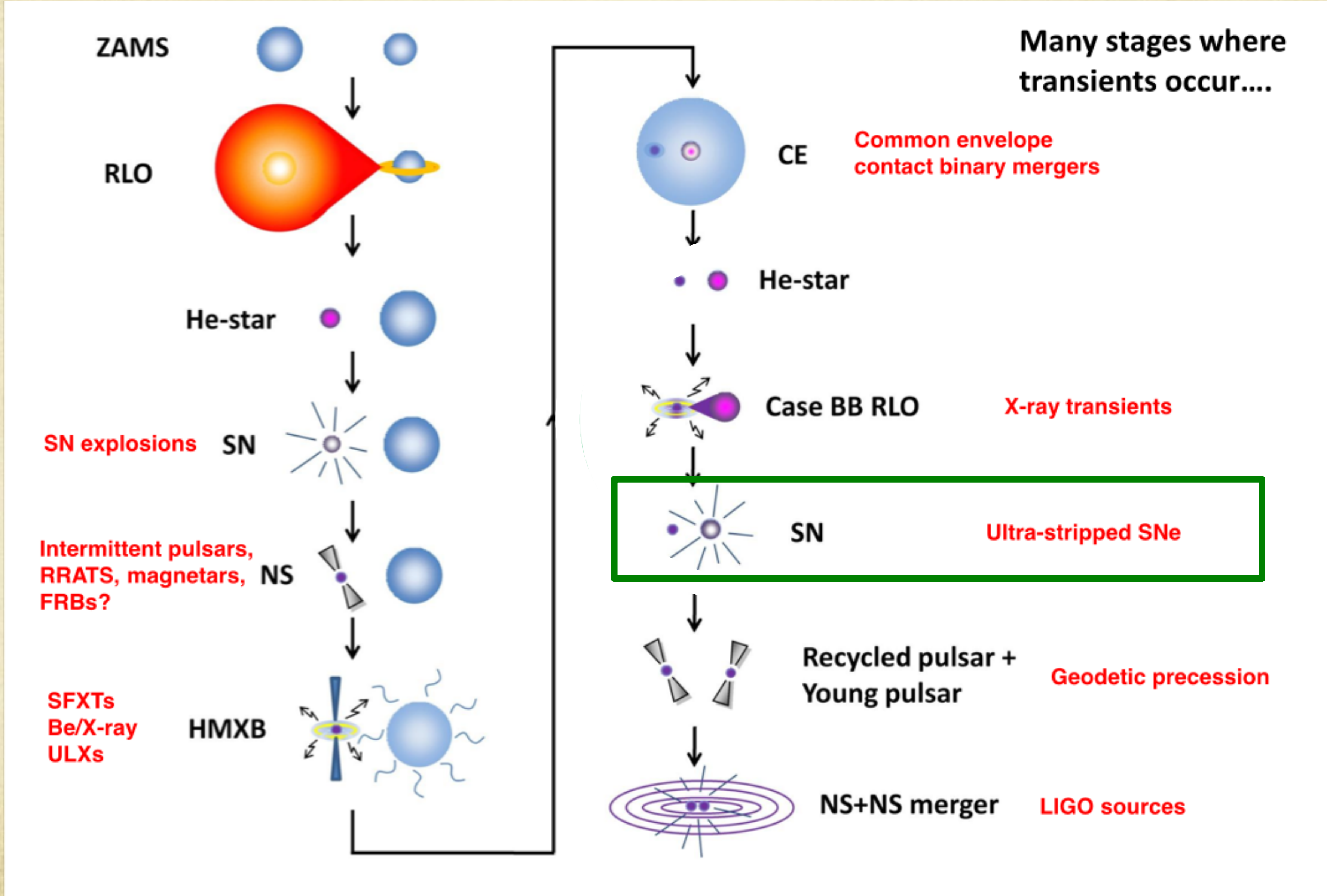

Image courtesy of T. Tauris

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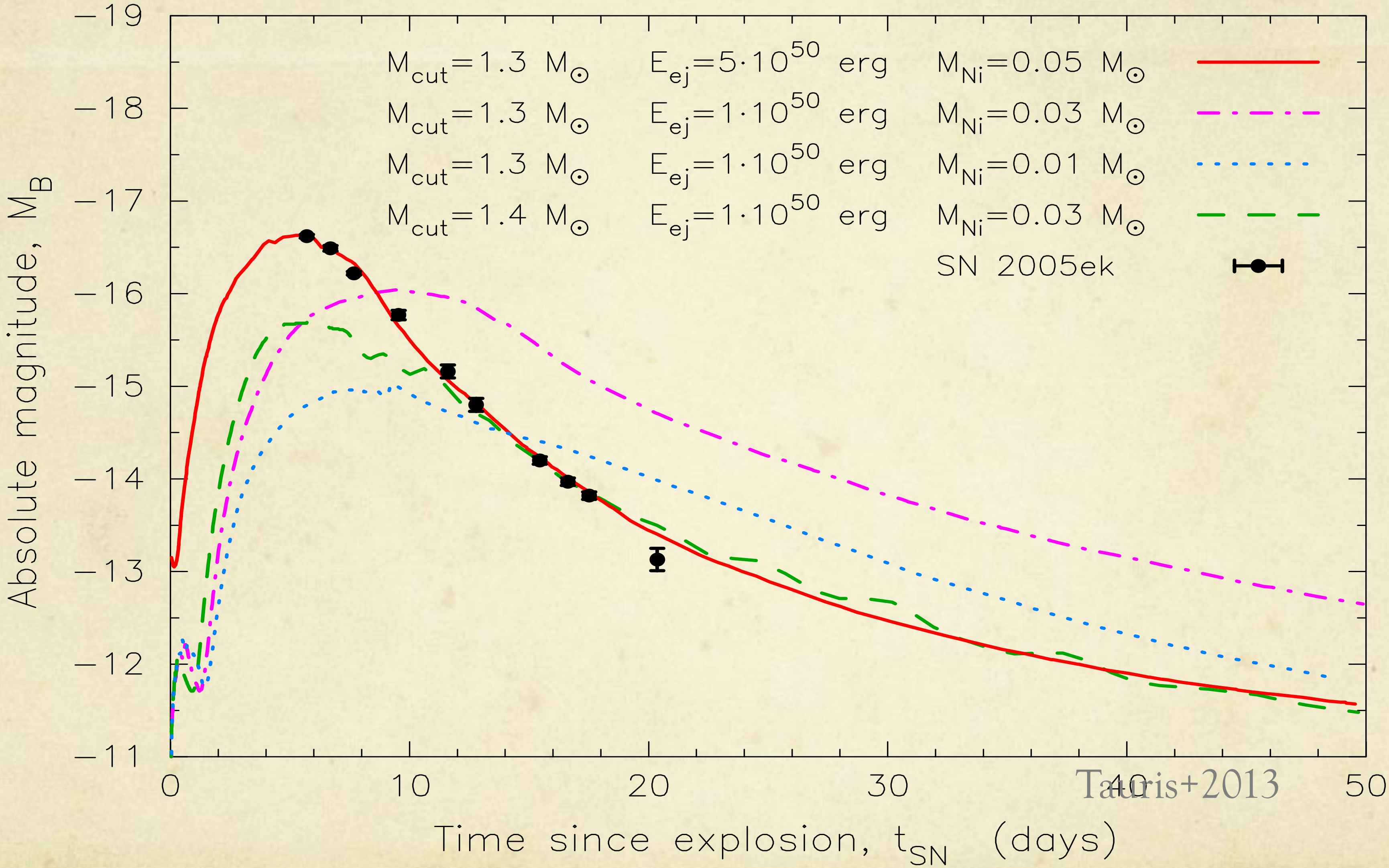
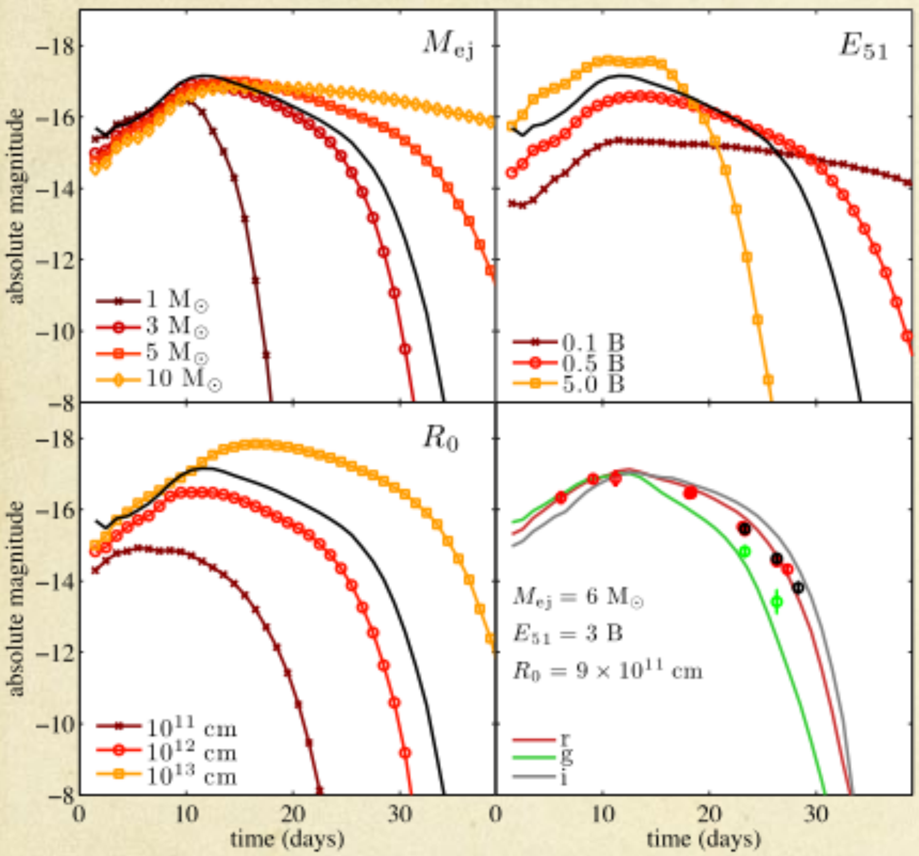
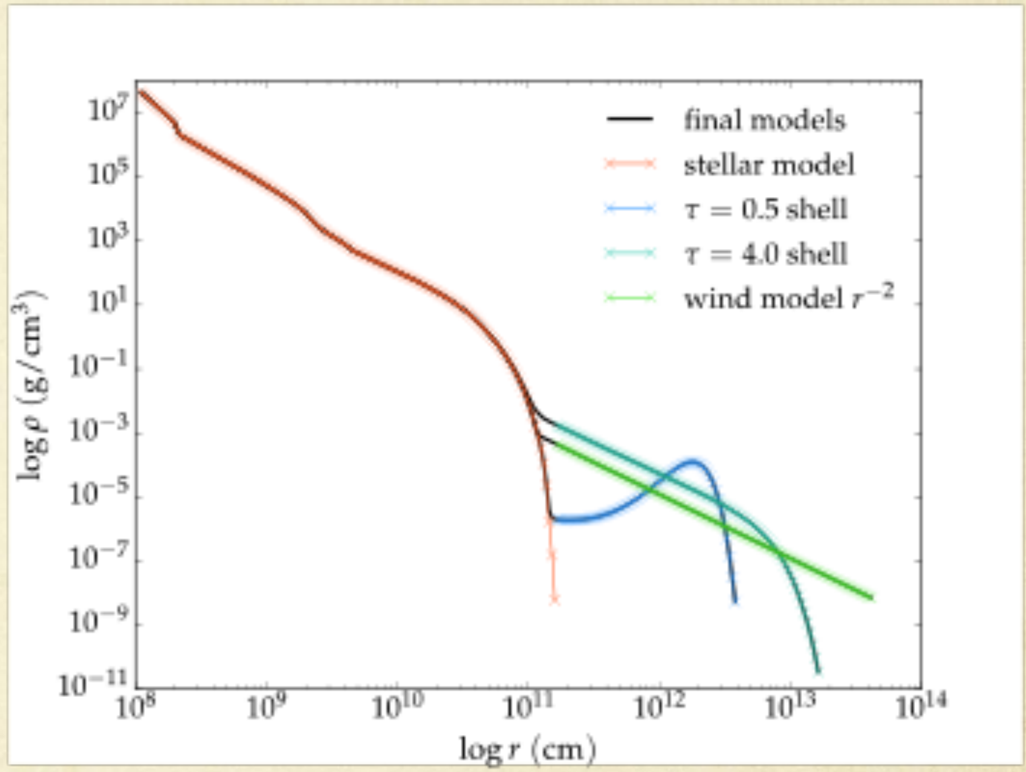


Secondary explosion leading to a compact binary can be ultra-stripped.
(Tauris+2013, Tauris+2015, Suwa+2015, Moriya+2017, ...)

Rapidly-Declining Type I SN

Possibility 2. Explosions of helium giants lacking ^{56}Ni





Kleiser & Kasen 2014; Kleiser et al. 2018a,b

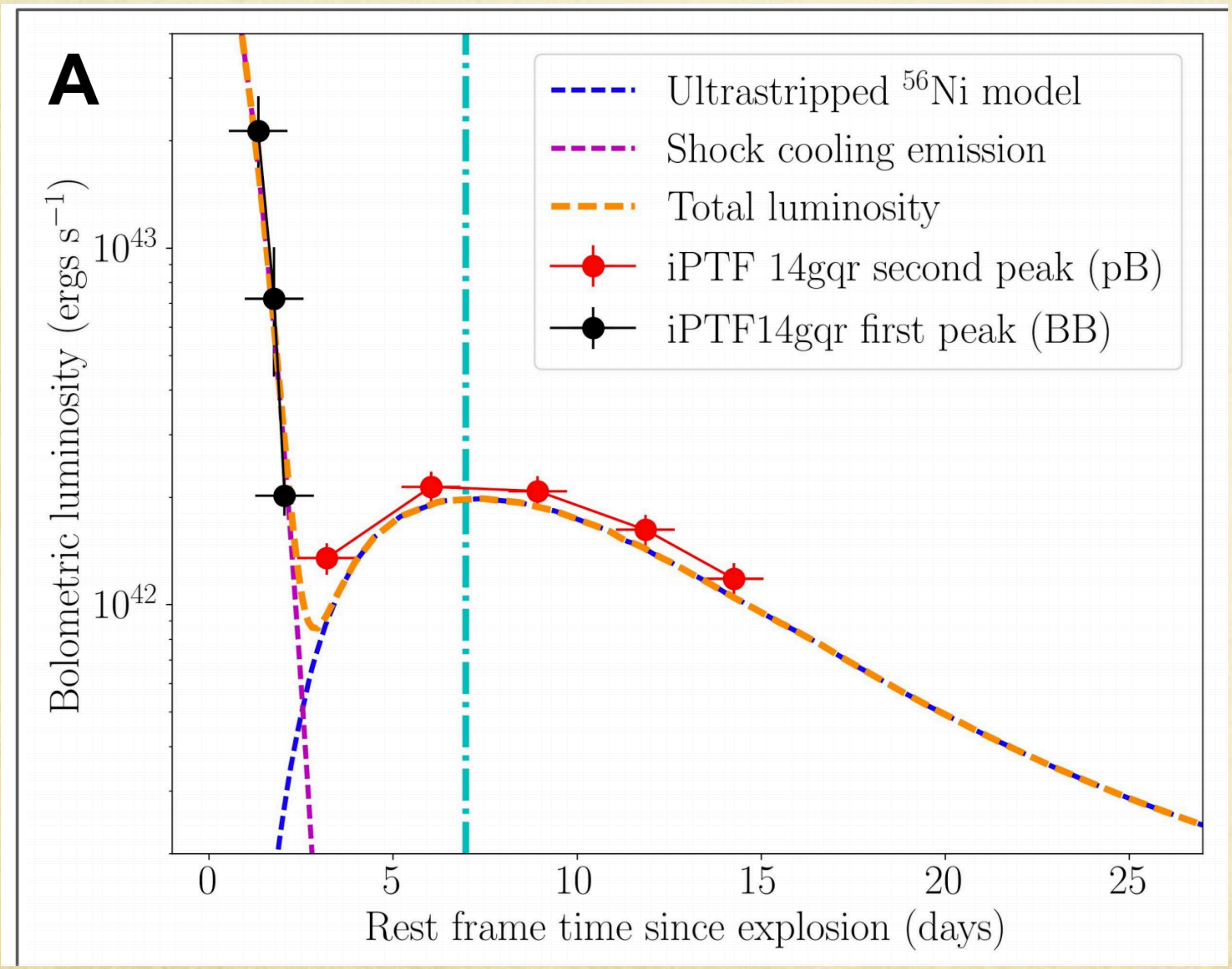
Rapidly-Declining Type I SN

General Lack of Observational Information

- 2-3 known events
- Rates very uncertain (1% of Type Ia rate?)
- Almost no late-time or pre-peak data.

Rapidly-Declining Type I SN

New Observations: iPTF14gqr



De et al. 2018

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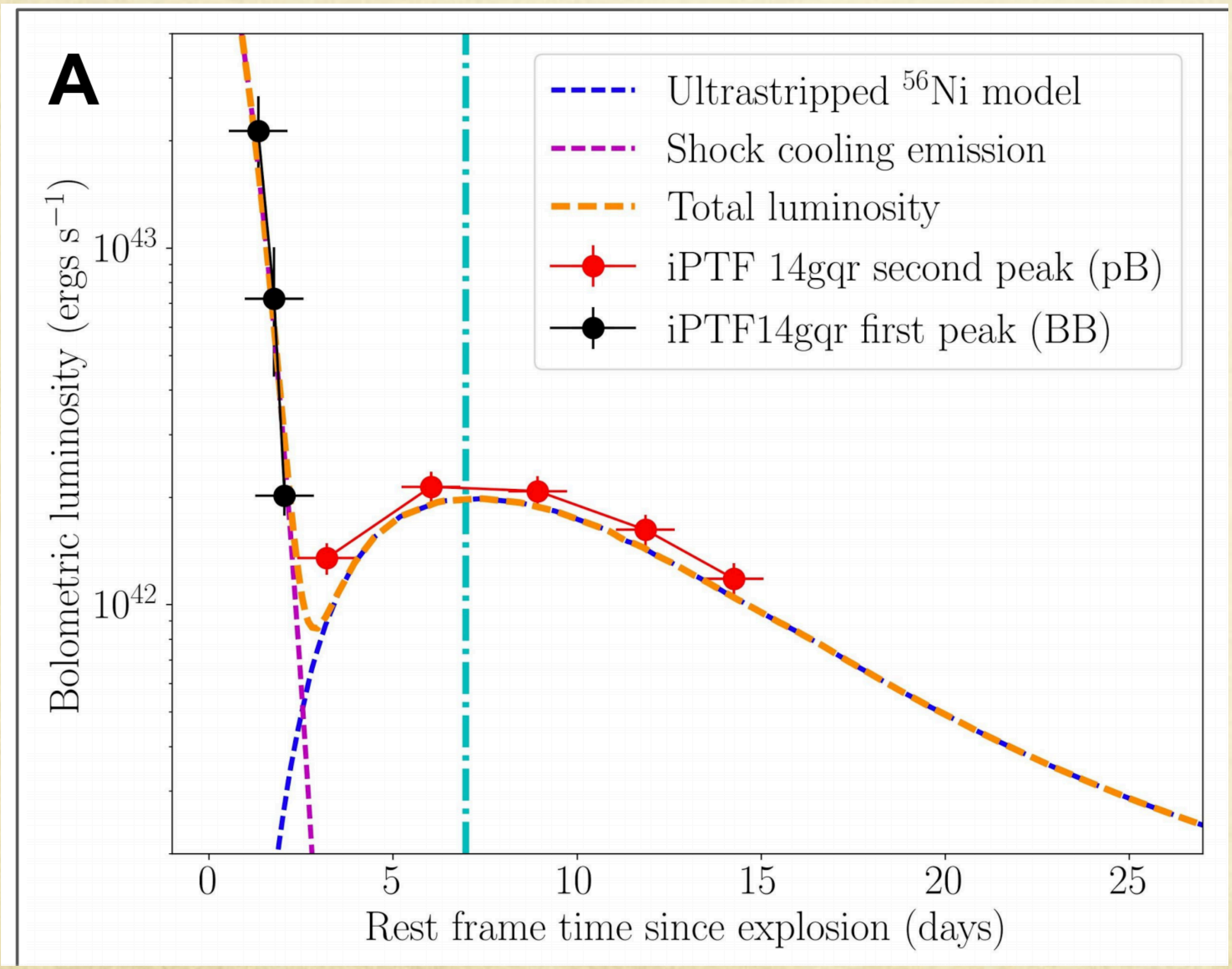

Mej = 0.2 Msun

Ek = $2x10^{50}$ erg

<u>Extended envelope:</u>

0.01 Msun

500 Rsun

De et al. 2018

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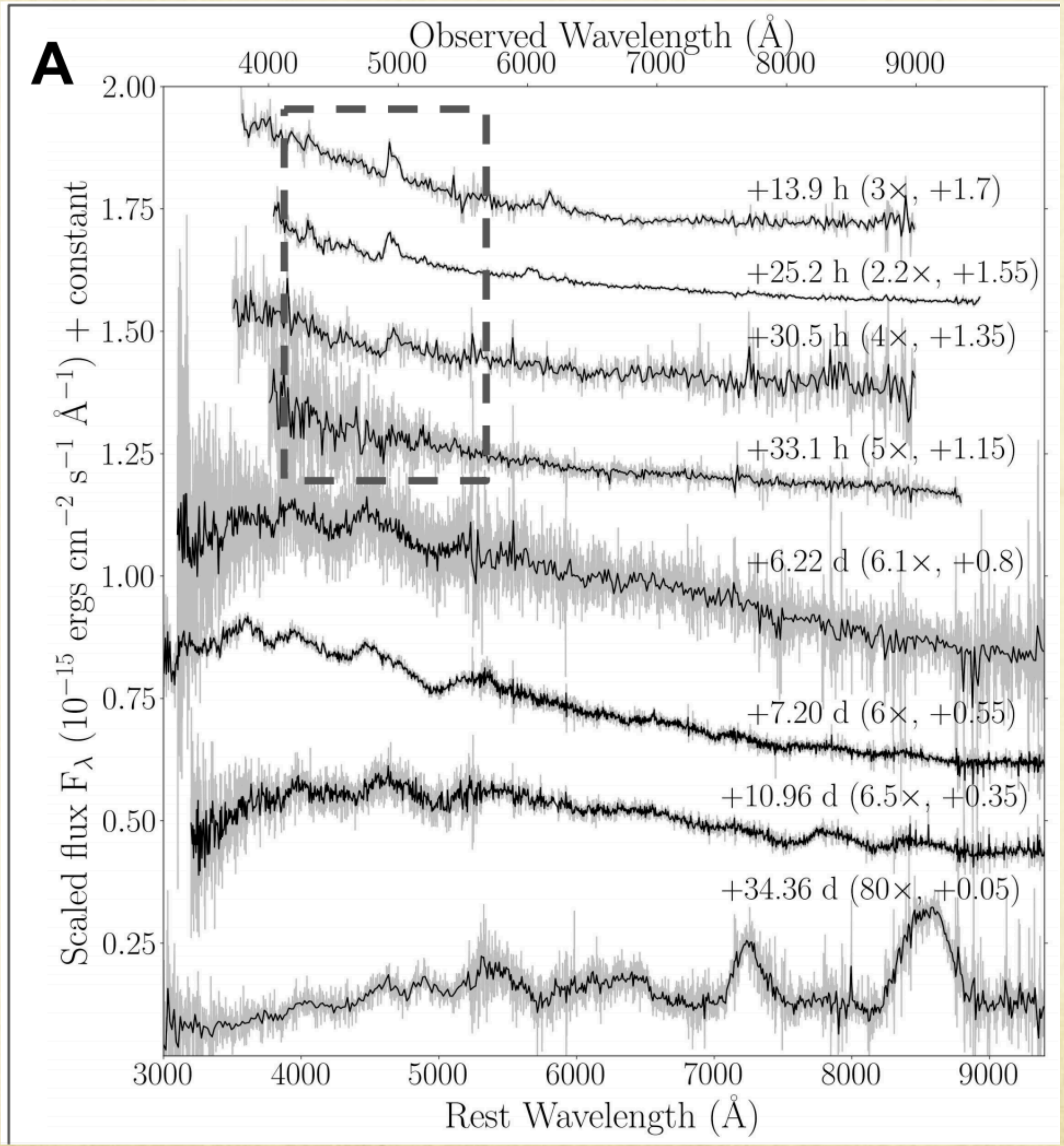

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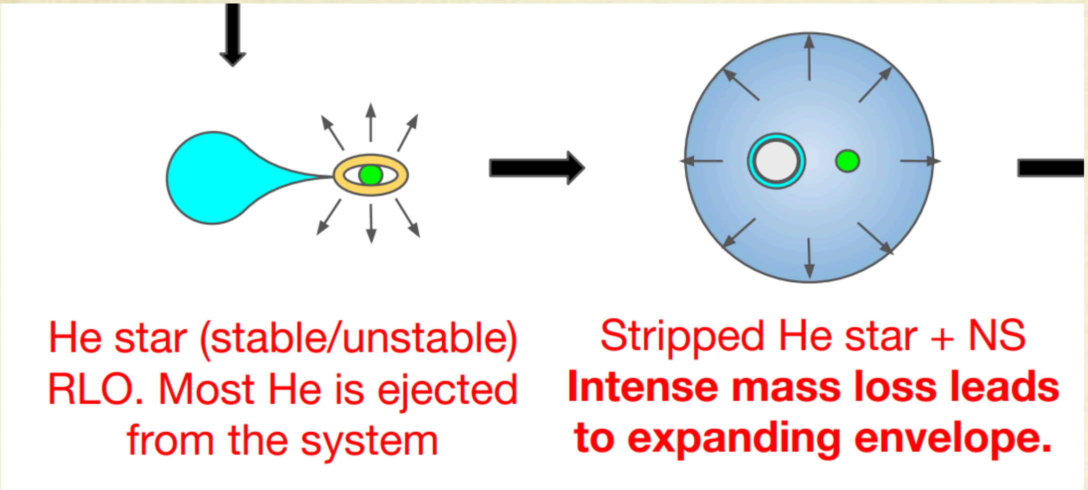

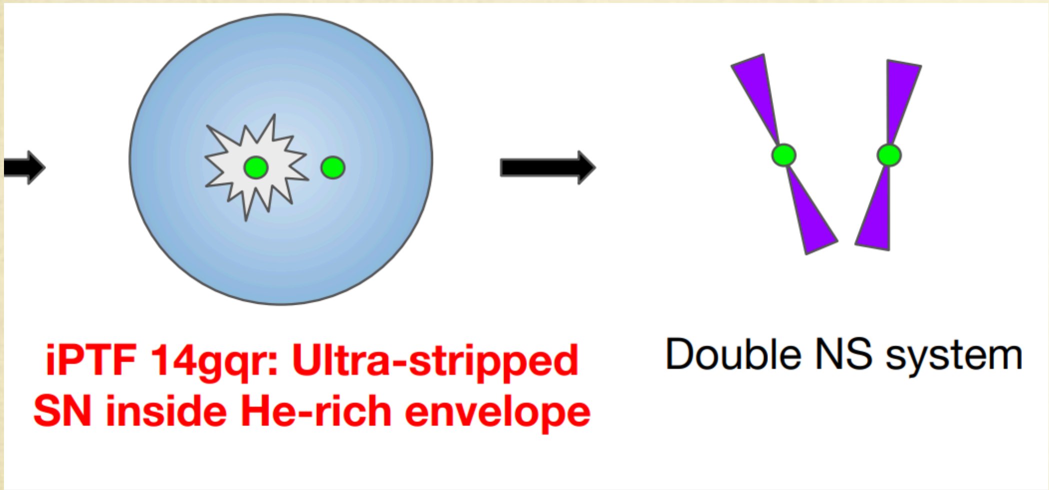

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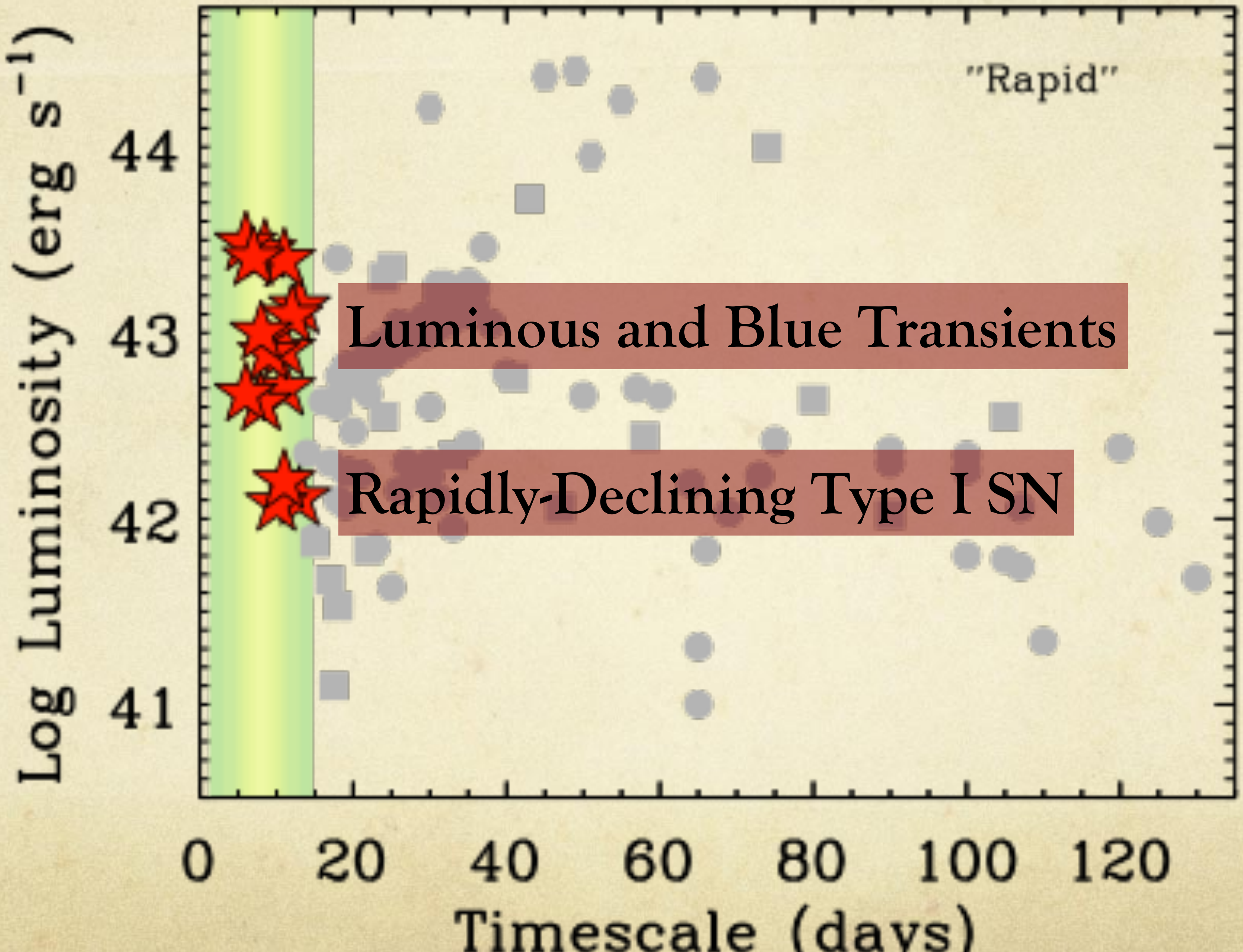
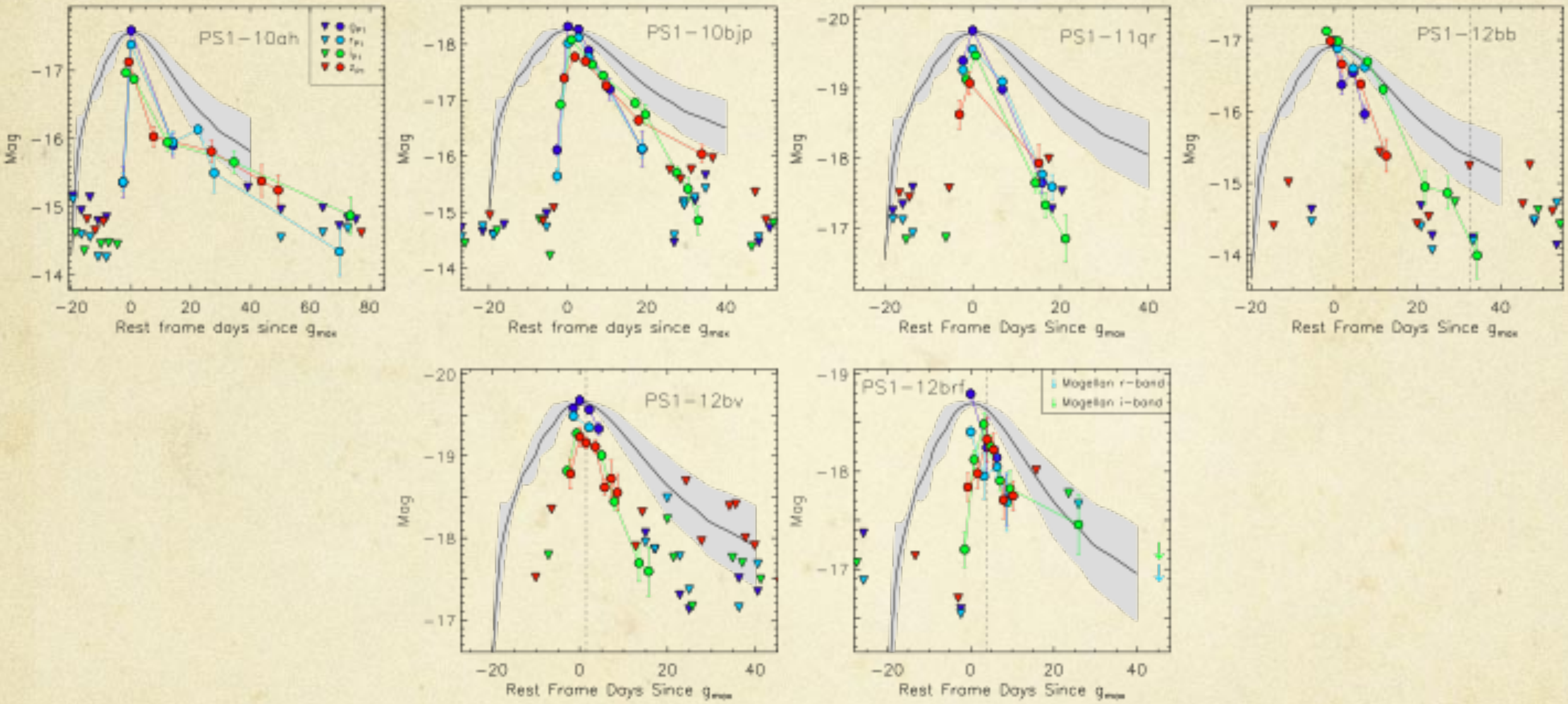


Luminous and Blue Transients

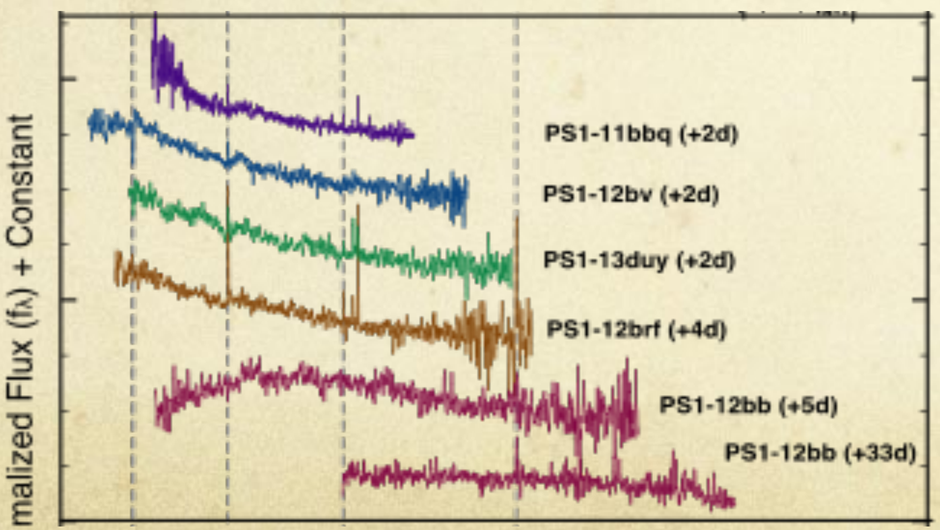


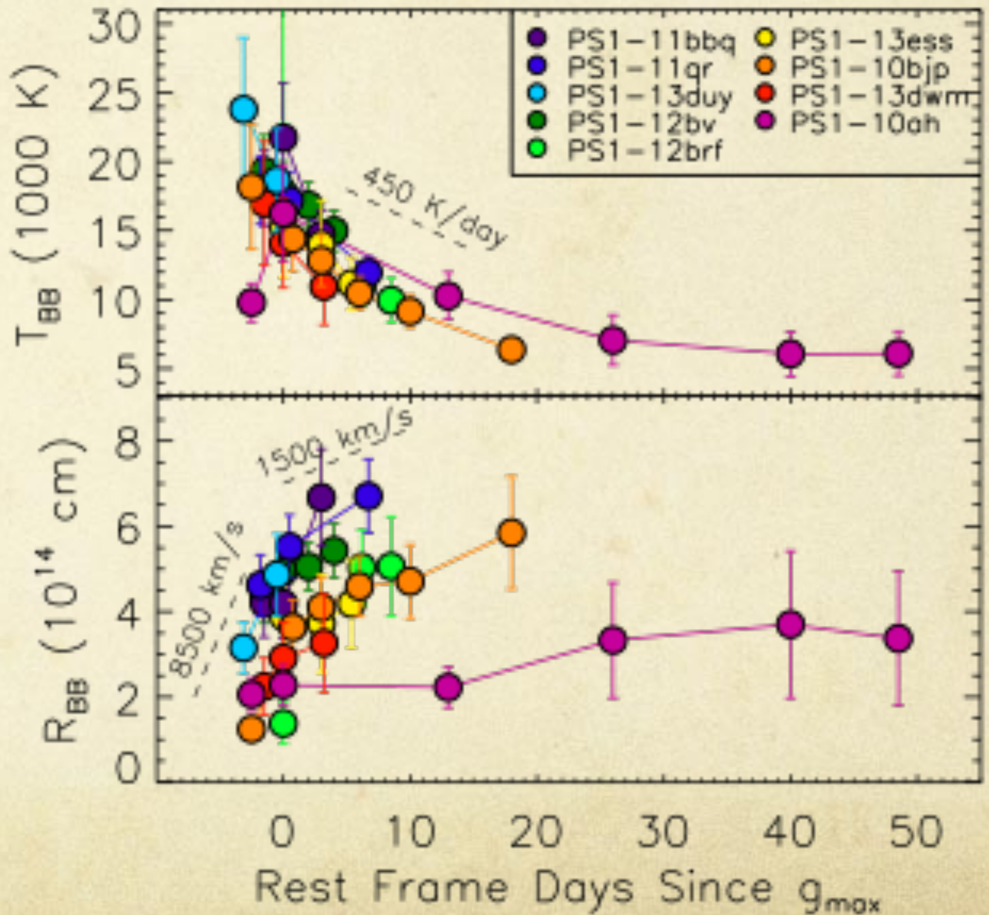
Drout, M. R. et al. (2014)

Luminous and Blue Transients

Sample Properties:

- Luminous
- Blue Colors
- Expanding & Cooling Photosphere
- Spectra Dominated by Continua
- Star forming host galaxies





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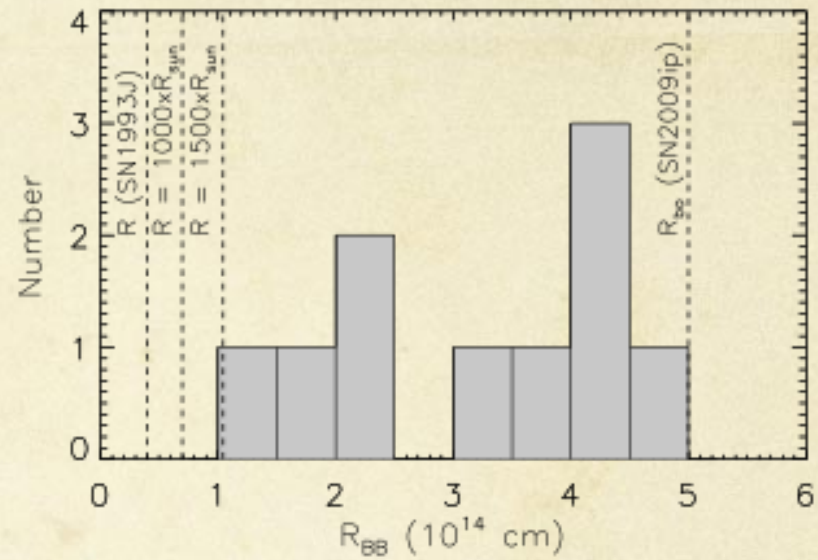
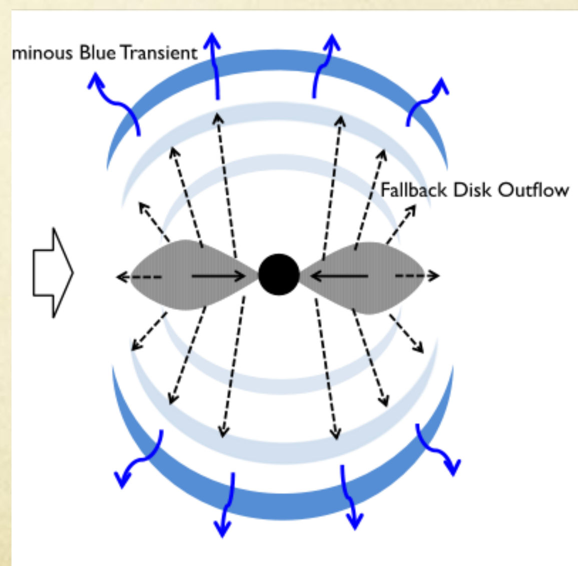
Implications/Progenitors:

- Shock break out/cooling from extended stellar envelope or dense wind
- Winds/outflows from compact objects (e.g. Kashiyama & Quataert 2015)





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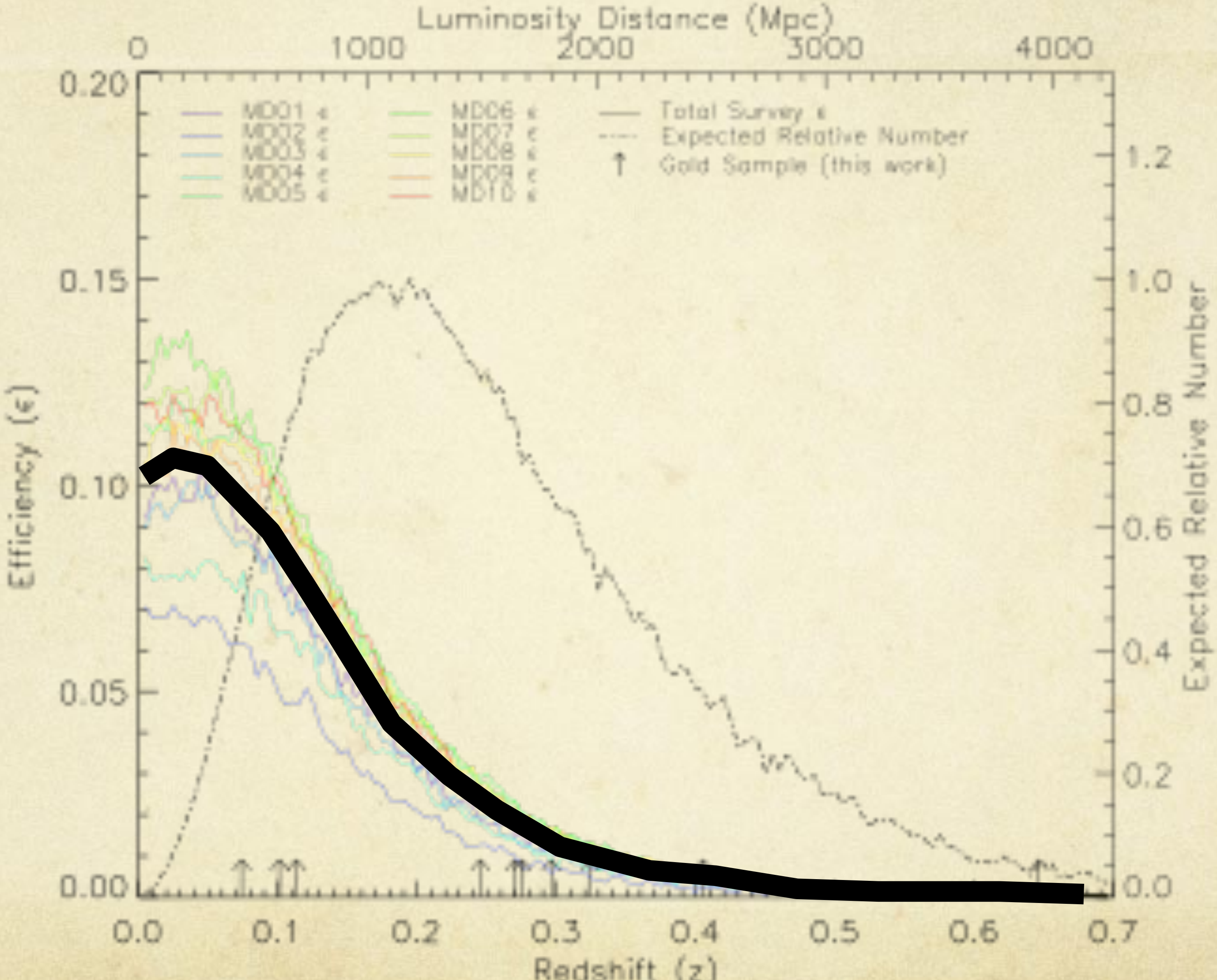
Luminous and Blue Transients

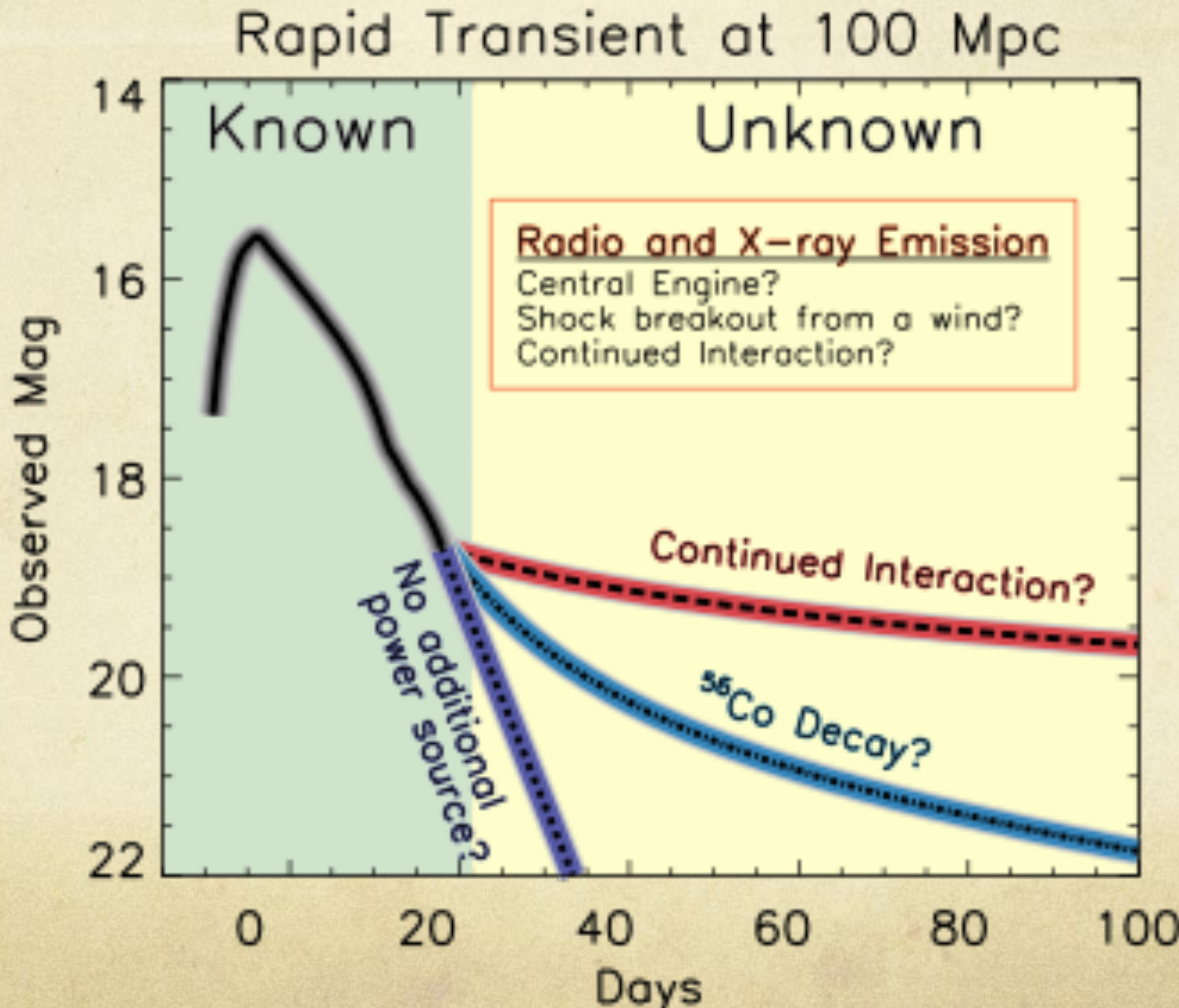
Detection Efficiency & Intrinsic Rates



Rate of blue, luminous events are 4-7% of the core-collapse rate at z=0.2

Drout, M. R. et al. (2014)

Luminous and Blue Transients



“New” and “Related” Transients

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9. HiTSs transient, CSS transient, LSQ transient, ZTF object
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Mass Loss/Interaction

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SN/Engines

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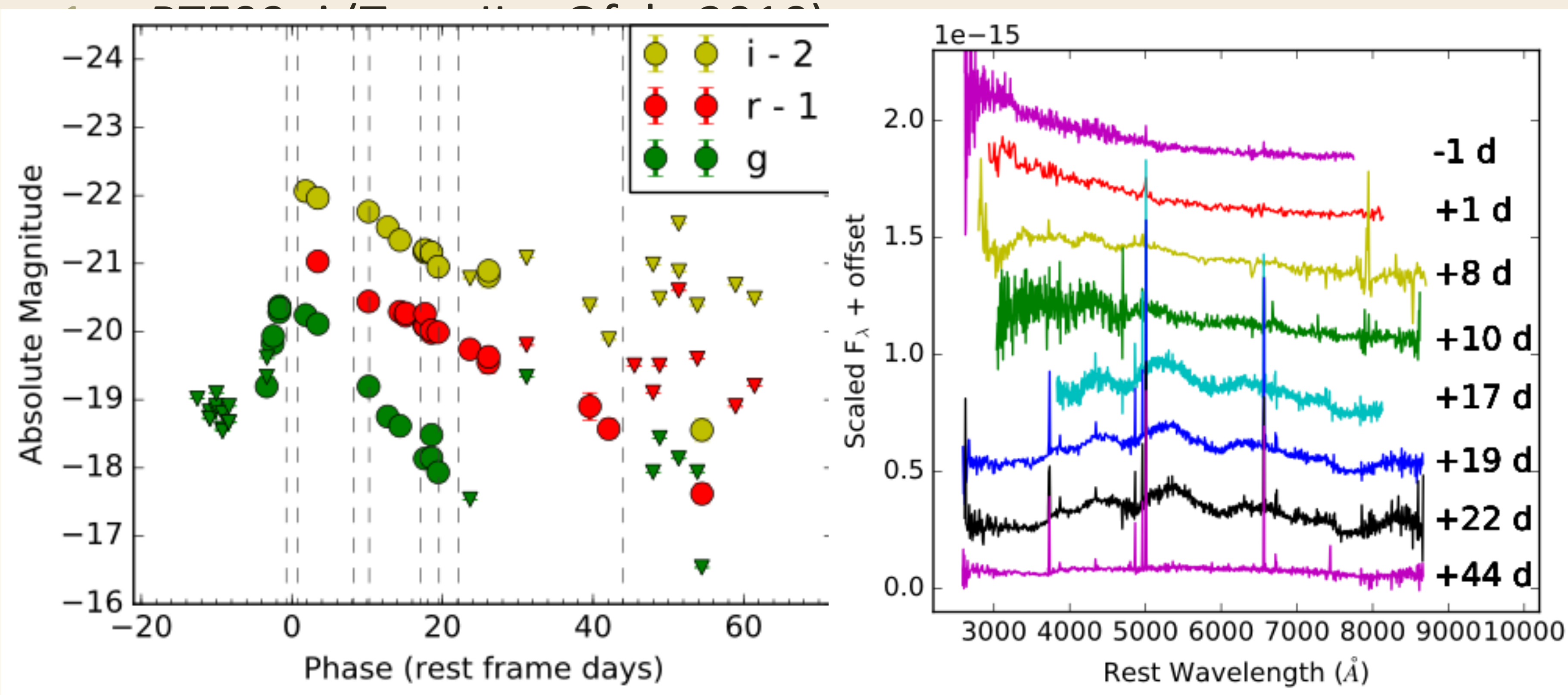

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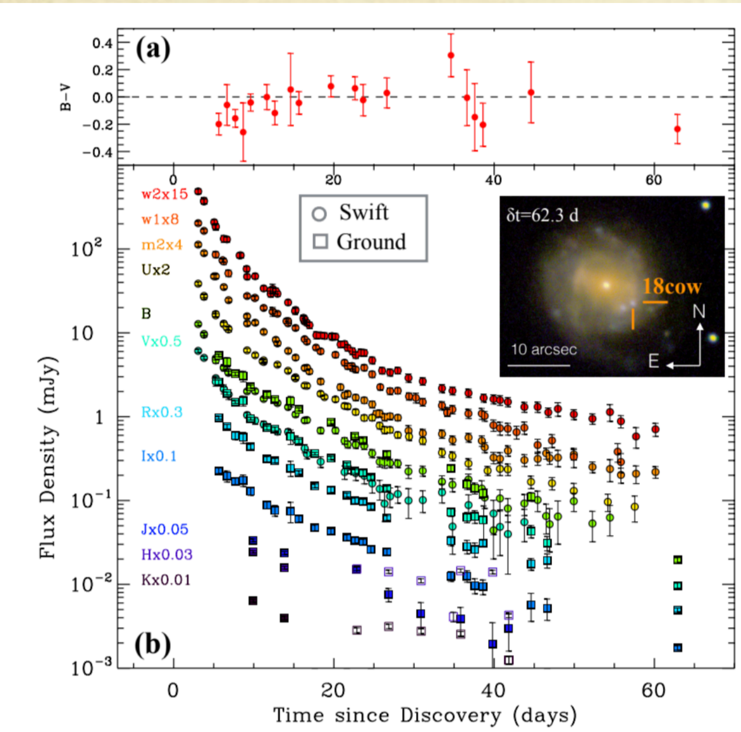
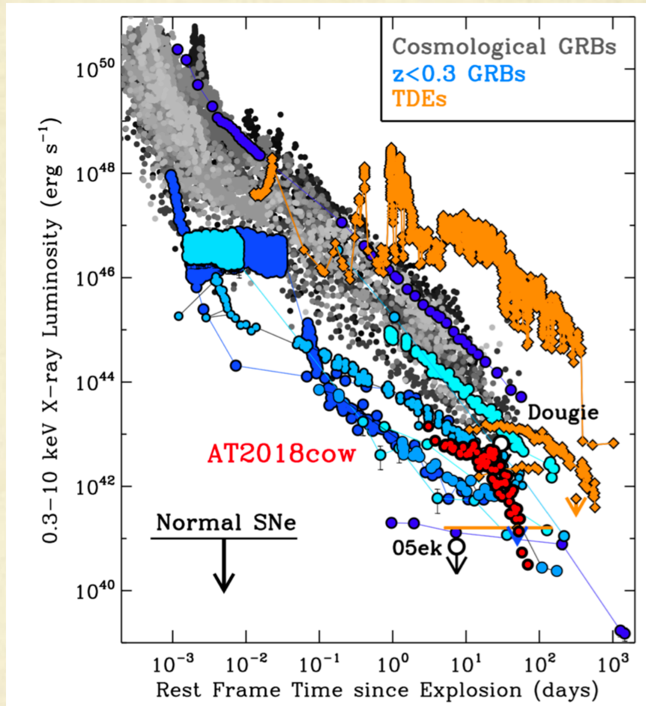
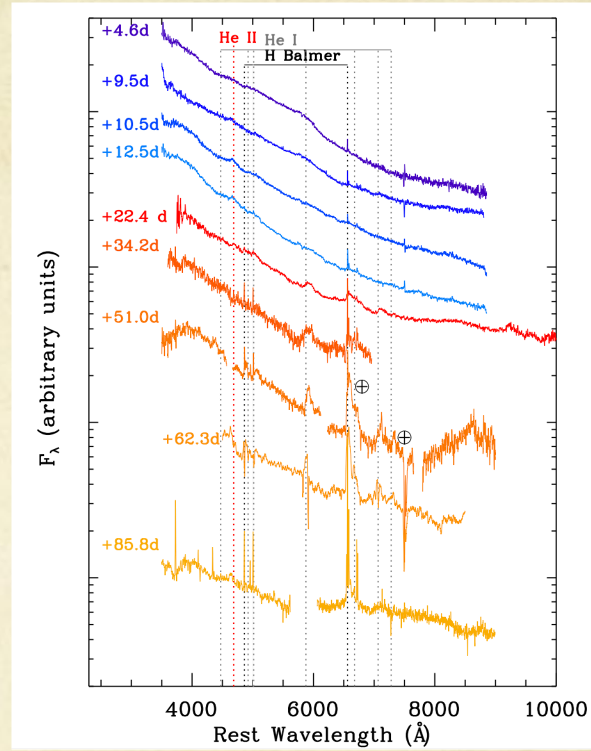
AT2018cow

The Best Observed Case



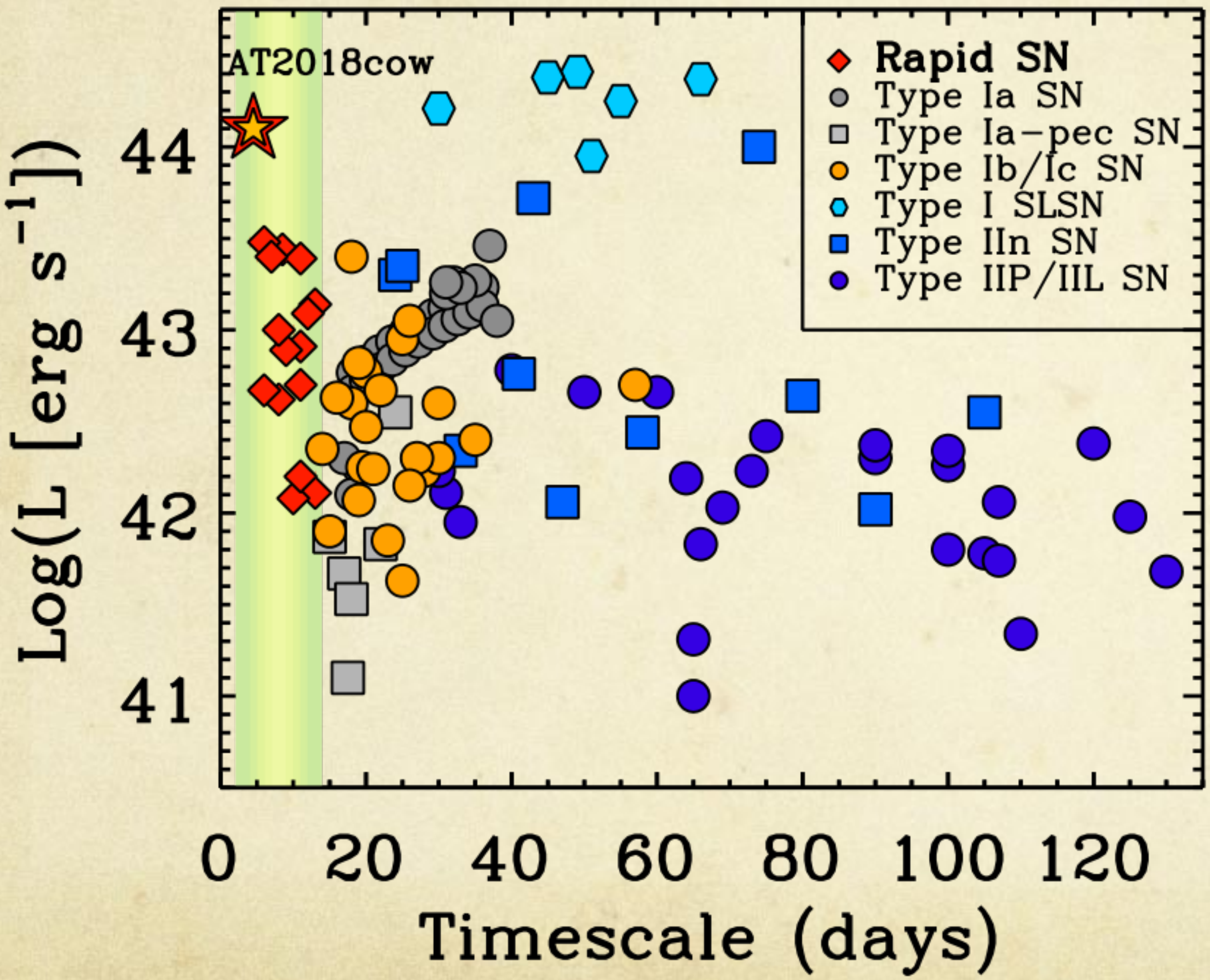


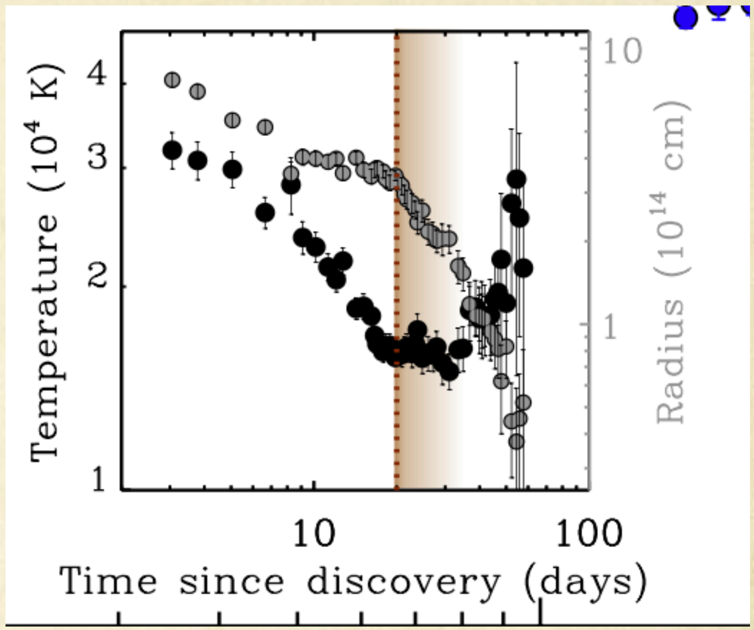


Margutti+2018

AT2018cow

The Best Observed Case





AT2018cow

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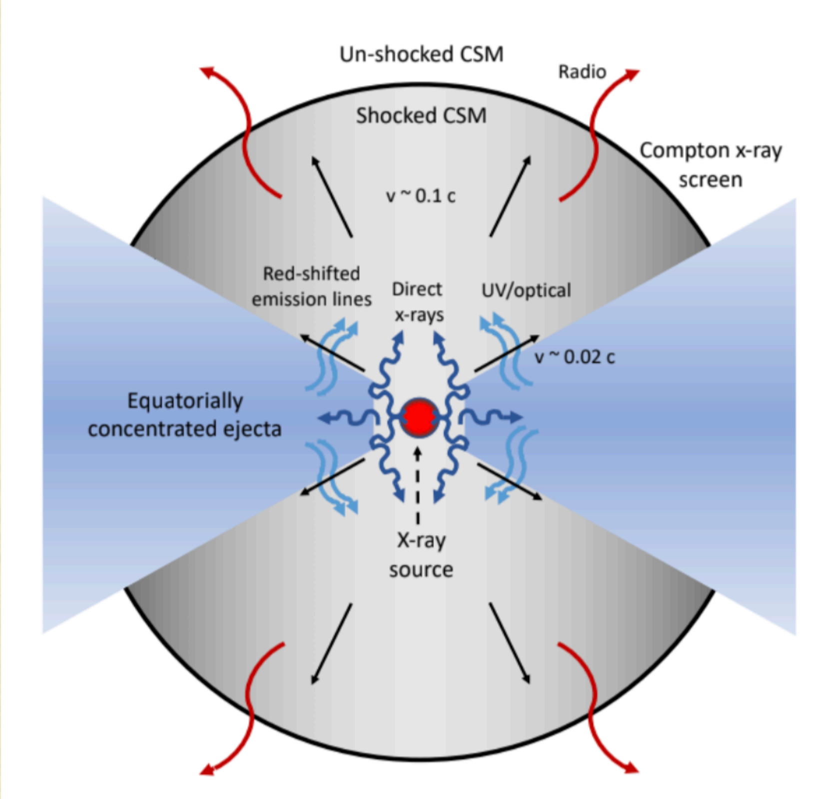

- Engine
- CSM
- Hydrogen/helium
- Low M_{Ni}, M_{ej}

Table 2. Central X-ray "Engine" Models for AT 2018cow

Model	Ejecta Mass/Velocity	Engine Timescale	CSM?	He?	H?	Reference
NS-NS Merger Magnetar	X	✓	X	X	X	1
WD-NS Merger	✓	✓	X	X	X	2
IMBH TDE	✓	Maybe†	X	✓	✓	3
Stripped-Envelope SN + Magnetar/BH	✓	✓	✓	Maybe	X	4
Electron Capture SN + Magnetar	✓	✓	✓	✓	✓	5
Blue Supergiant Failed SN + BH	✓	✓	✓	✓	✓	6
SN + Embedded CSM Interaction	✓	✓	✓	✓	✓	7

“New” and “Related” Transients

1. PTF09uj (Type IIn; Ofek+2010)
2. SN1999cq (Type Ibn; Matheson+2000)
3. SN2015U (Type Ibn; Shivvers+2016)
4. LSQ15ccw (Type Ibn; Pastorello+2015)
5. Rapidly-Rising Transients in the SN-SLSN gap (Arcavi+2016)
6. Rapidly-Rising Transients from Subaru Hyper Suprime-Cam (Tanaka+2016)
7. iPTF16asu (Type Ic-BL; Whitesides+2017)
8. Kepler transient KSN2015K (Rest et al. 2018)
9. HiTSs transient, CSS transient, LSQ transient, ZTF object
10. DES Sample (Pursiainen et al. 2018)
11. AT2018cow (everyone…2018)

Supernova and Transients

Three pillars of wide-field surveys

1. Identification of Large Samples of Known Classes of SN
2. Discovery of Intrinsically Rare Transients
3. Opening of New Regimes for Transients

Key Question 1:

What are the observed populations, intrinsic rates, and nature of "peculiar" explosive transients present in the universe?

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Key Question 2:

What is the behavior of massive stars immediately preceding core-collapse?

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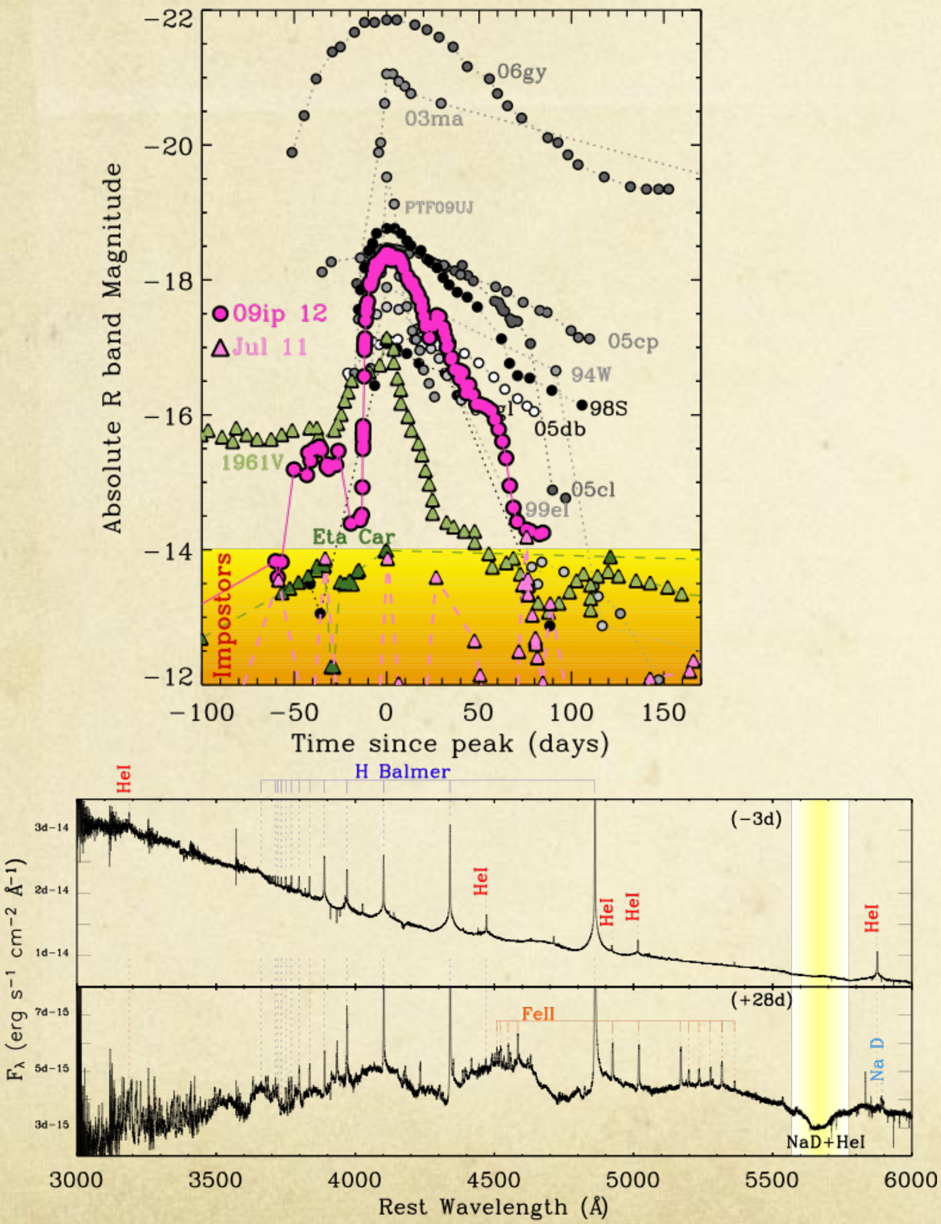
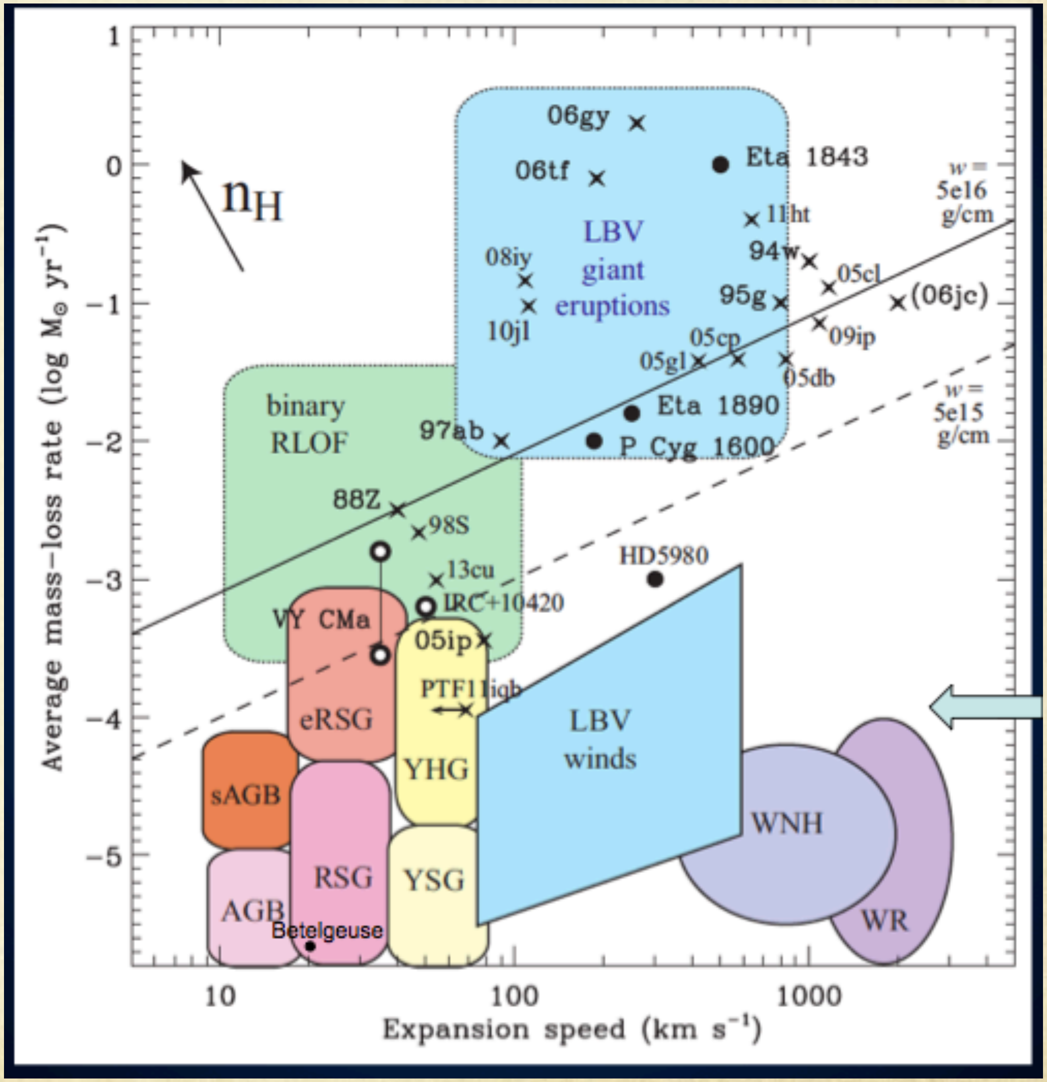
Pre-Supernova Mass Loss



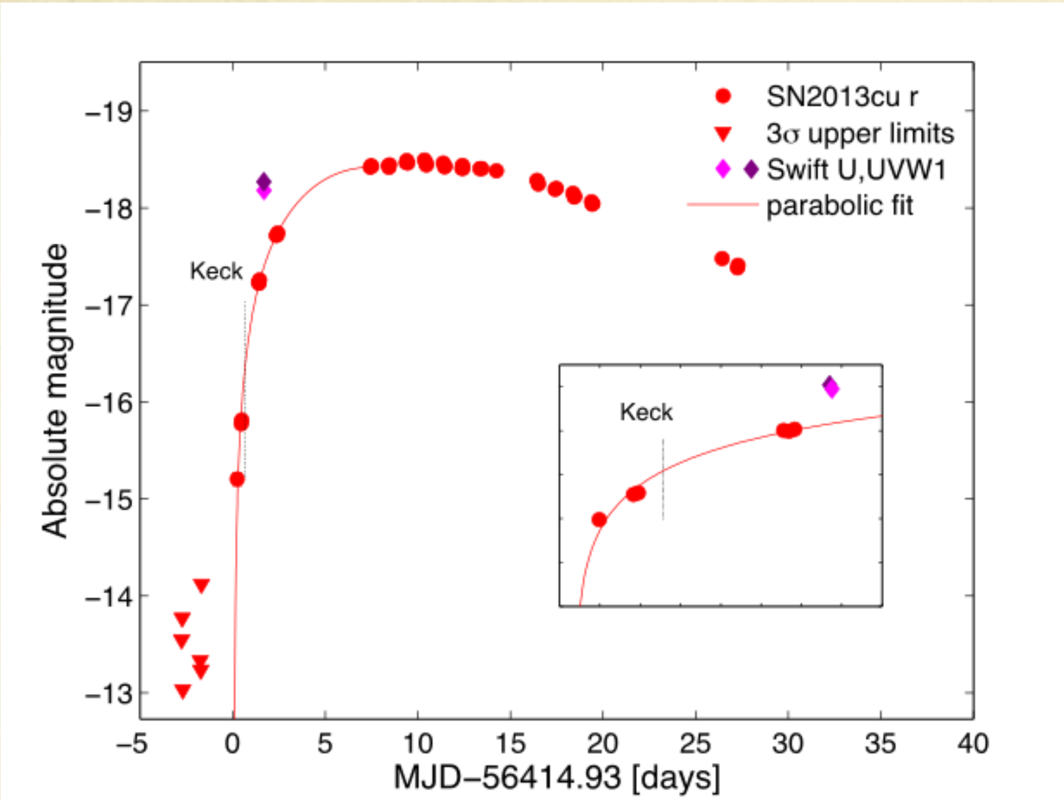
Margutti et al. (2014)

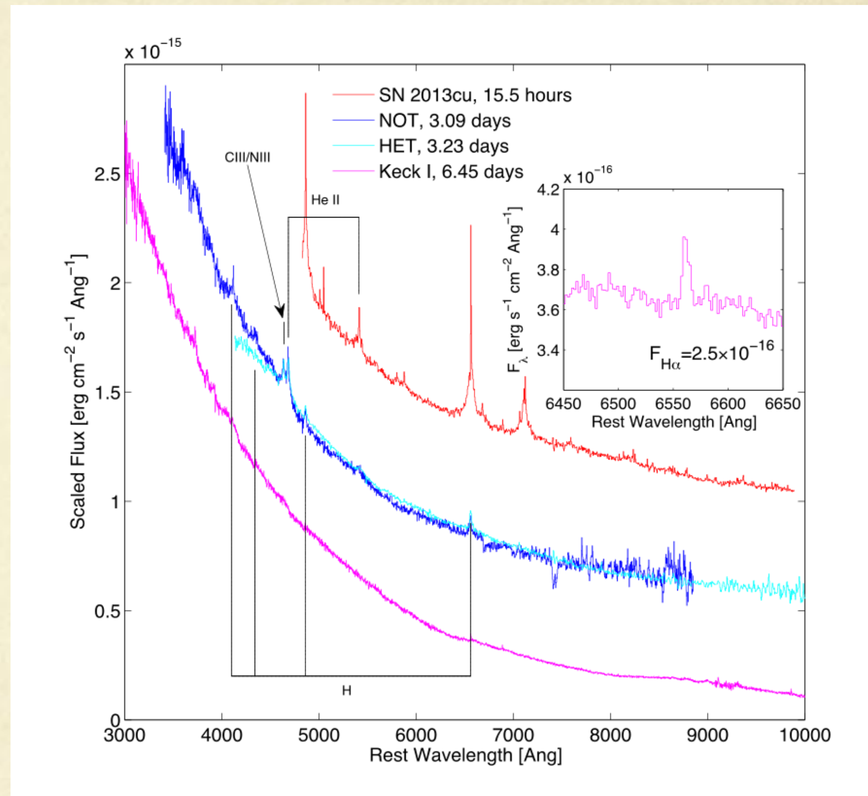


[Nathan Smith 2016, Supernova Handbook]

Enhanced Mass Loss in "Normal SN"

Flash Spectroscopy

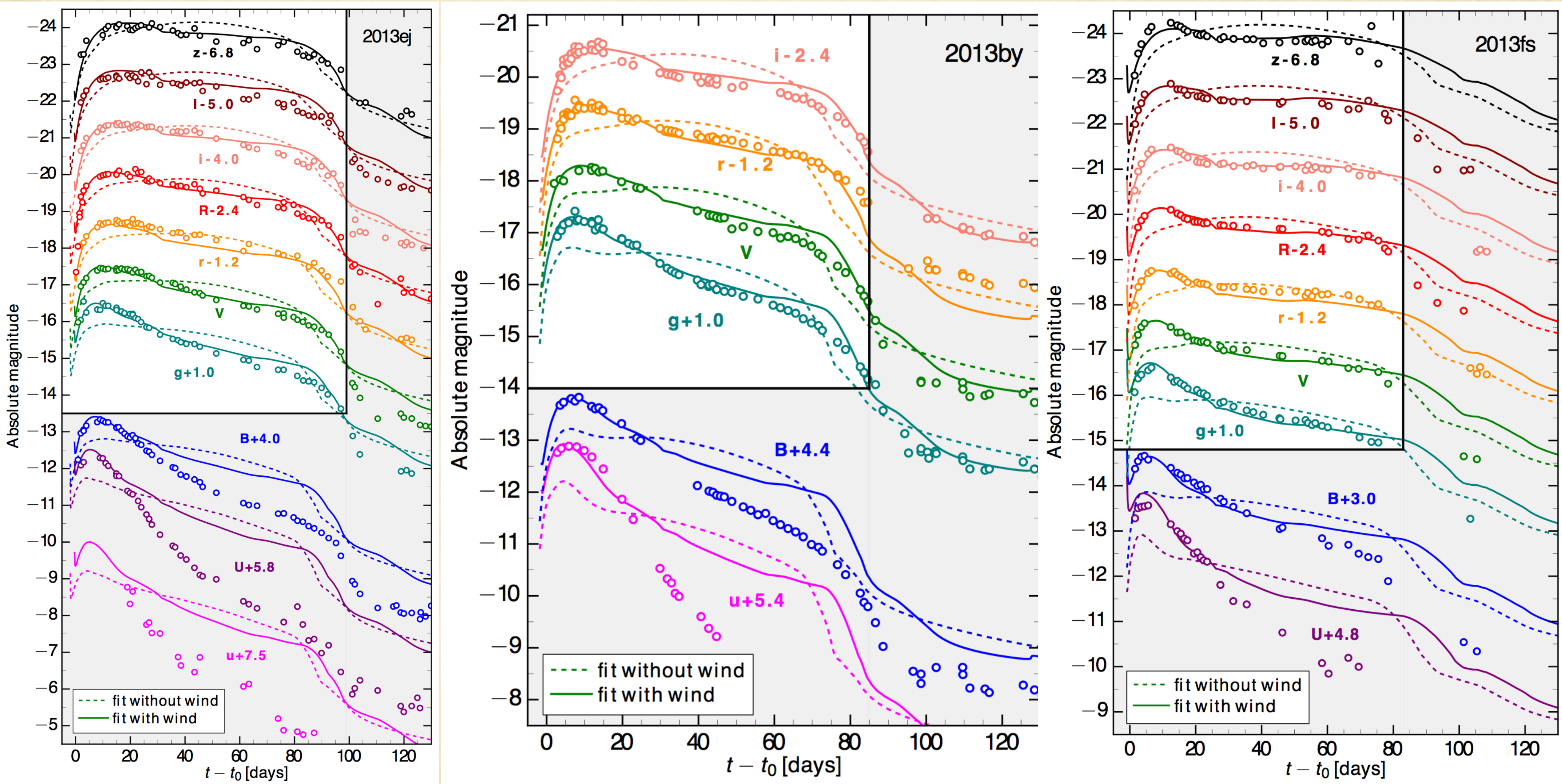




Gal-Yam et al. 2014.

Enhanced Mass Loss in “Normal SN”

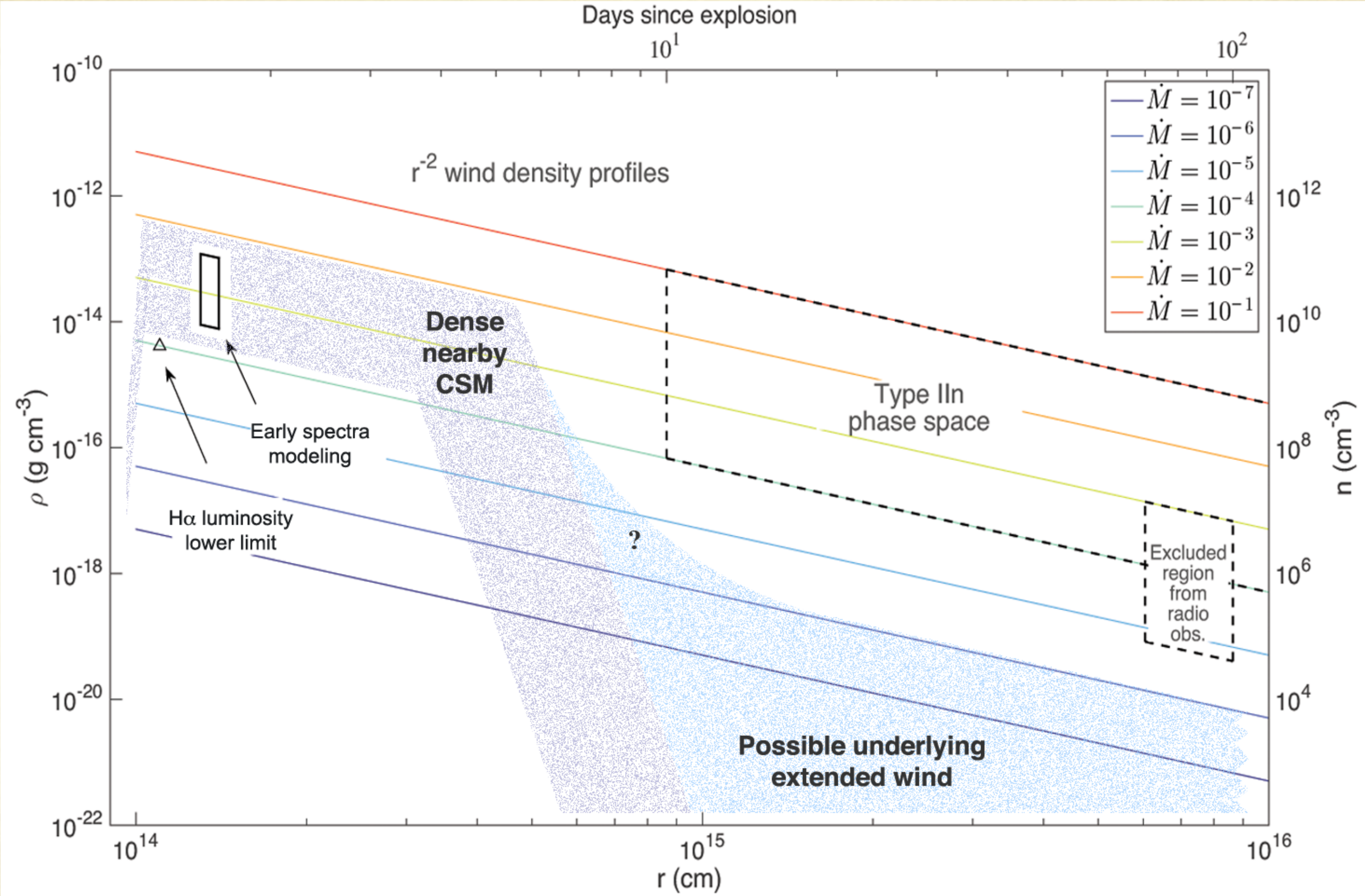
Early Light Curves



Morozova, Piro, & Valenti 2017, 2018

Enhanced Mass Loss in "Normal SN"

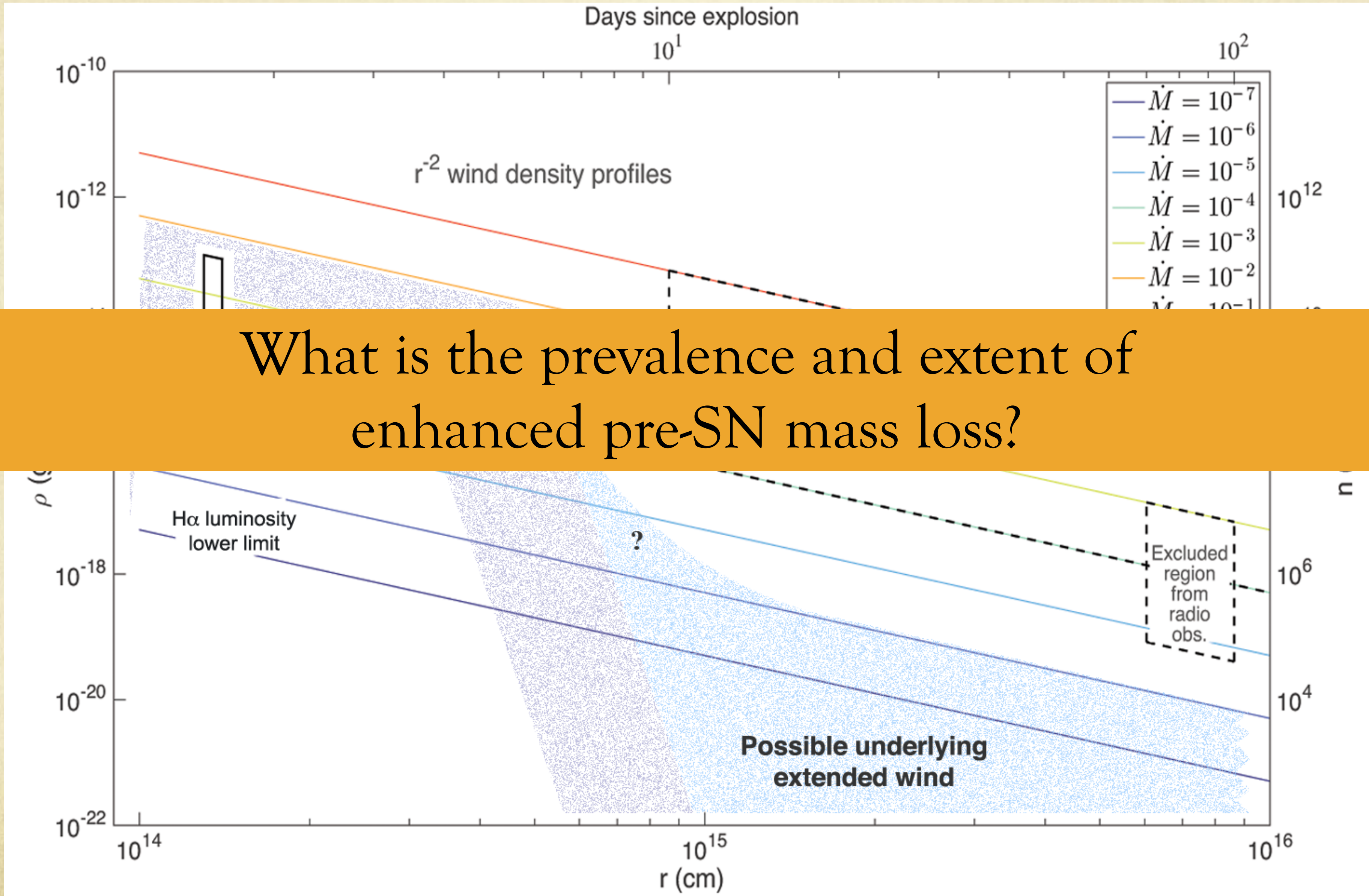
Early Observations couple with radio/X-ray



Yaron et al. 2017.

Enhanced Mass Loss in "Normal SN"

Early Observations couple with radio/X-ray

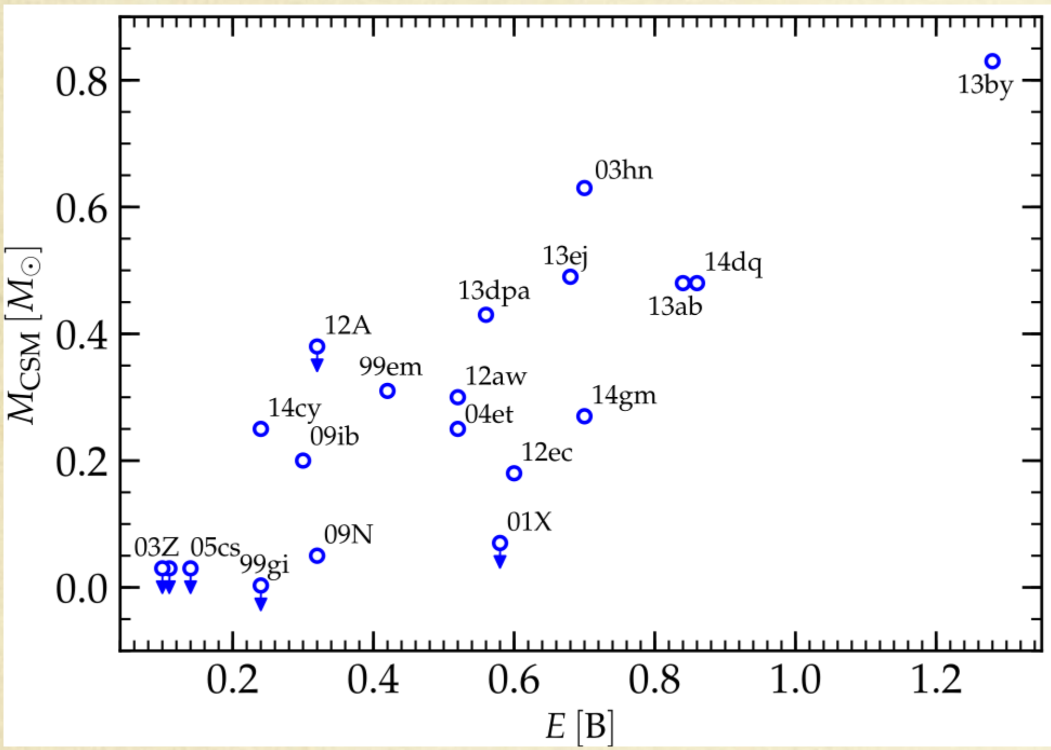


What is the prevalence and extent of enhanced pre-SN mass loss?

Yaron et al. 2017.

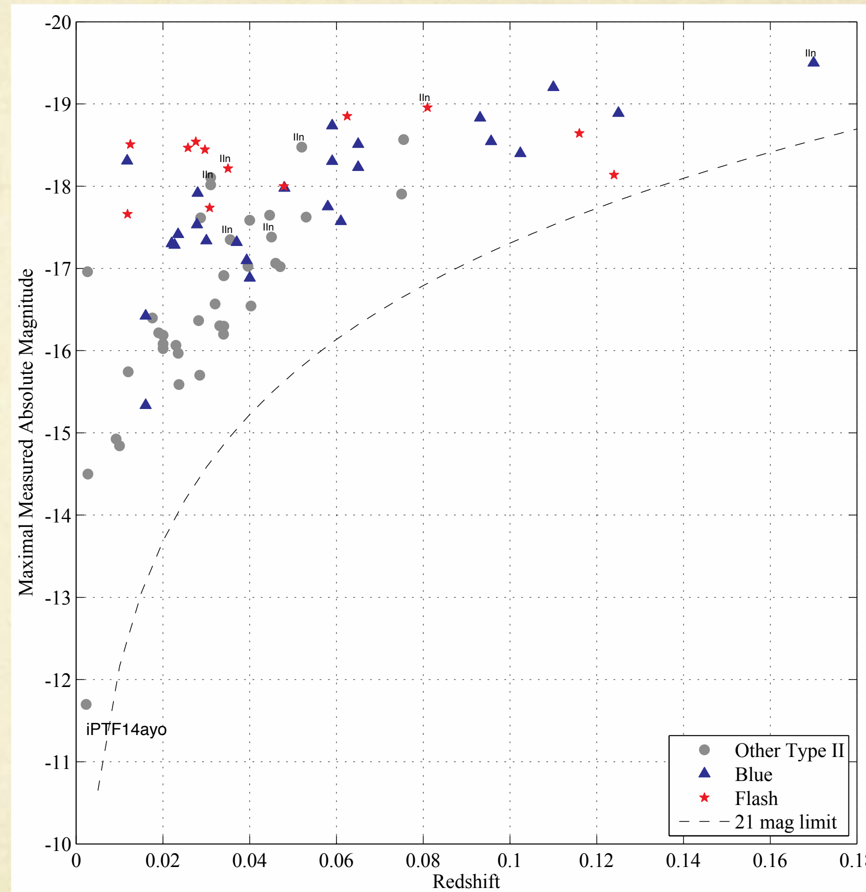
How Ubiquitous?

Light Curve Modeling:



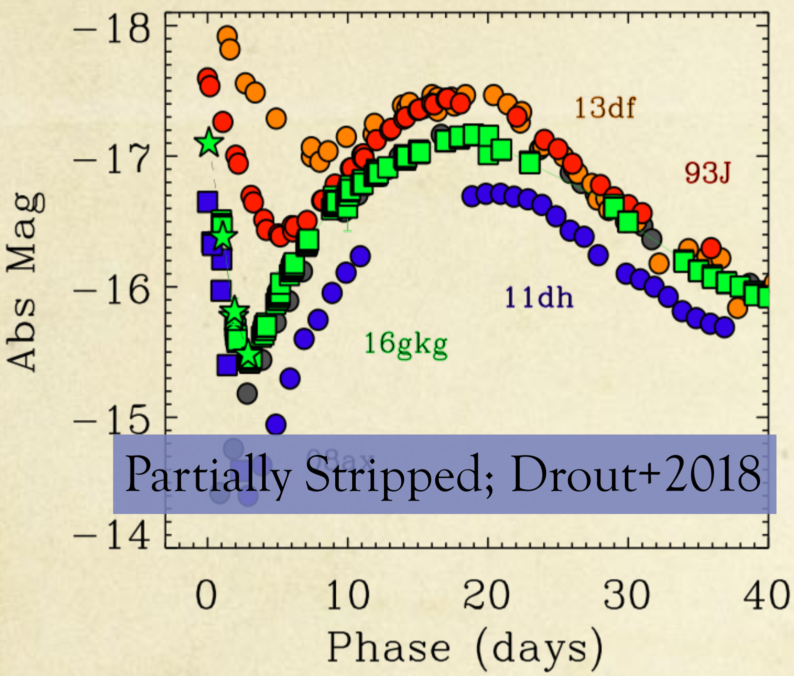
Morozova, Piro, & Valenti 2018
see also Asfari, Drout et al., 2018

Flash Spectroscopy:

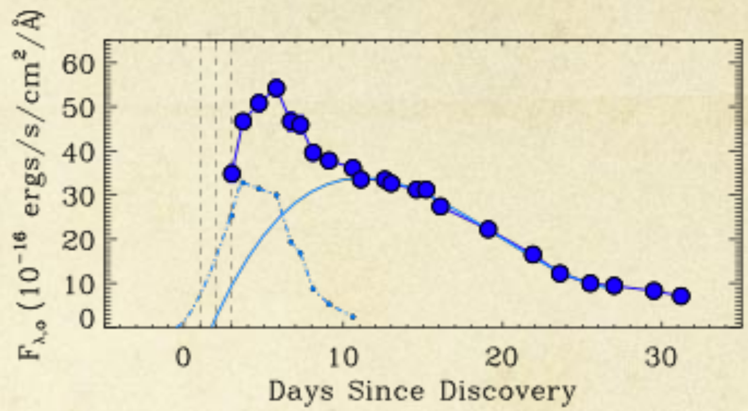


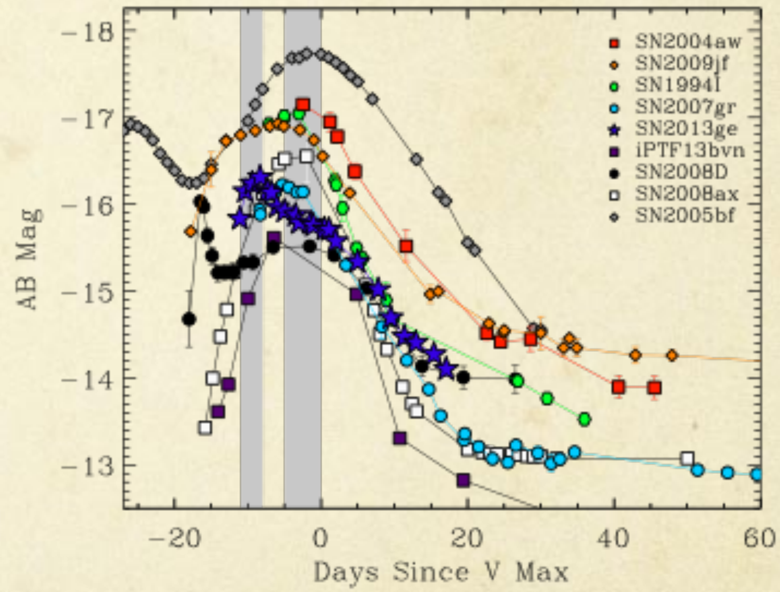
Kazov et al. 2016
see also Hozzeinzadeh et al. 2018

Plethora of SN Types

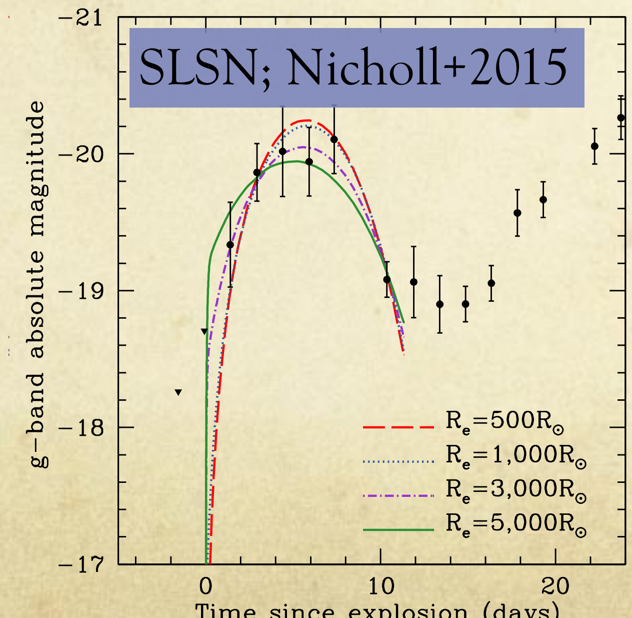


Partially Stripped; Drout+2018





Fully Stripped; Drout+2016



SLSN; Nicholl+2015

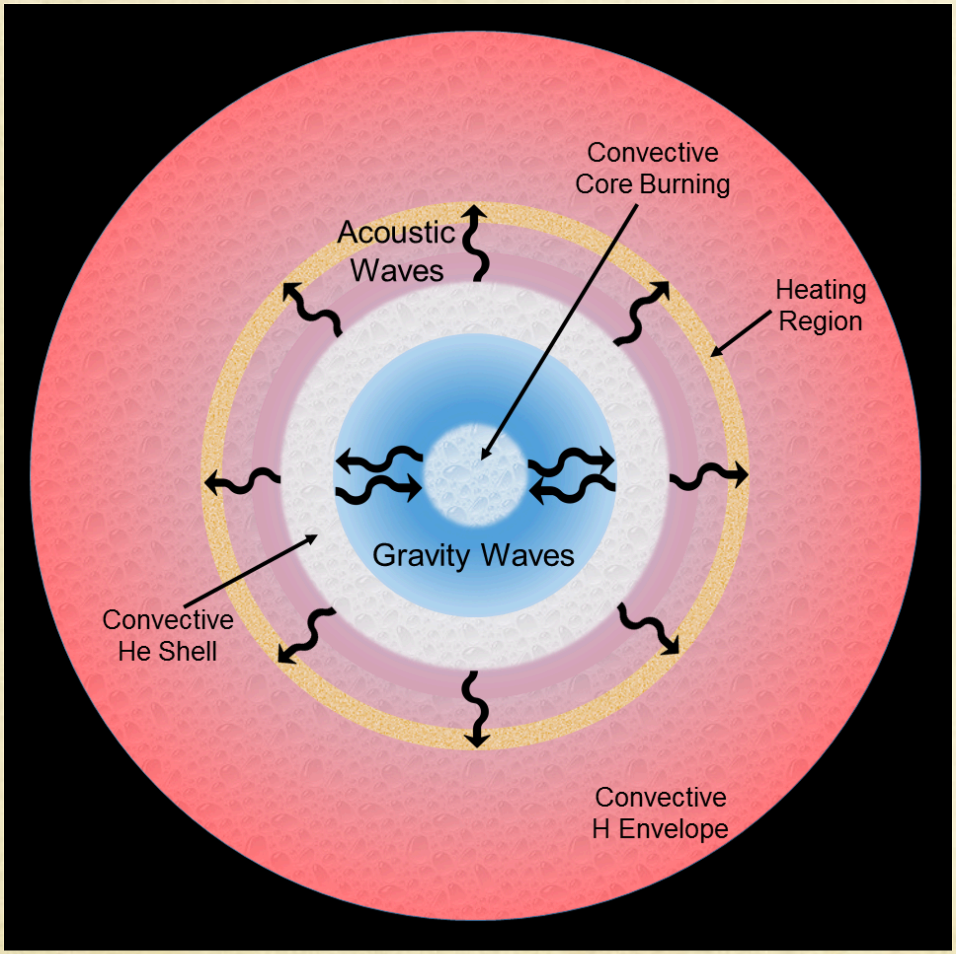
Long-GRBs; Type Ibn…

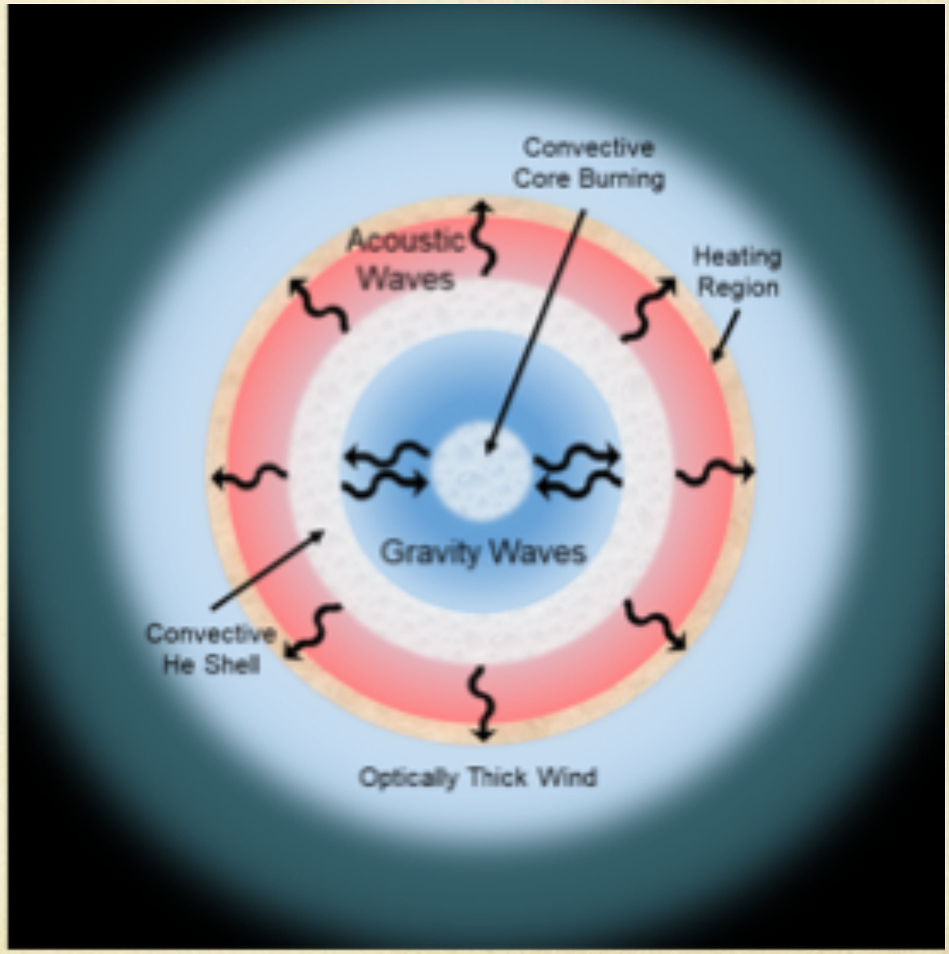
Tangential/Technical Open Question:

How well do we understand early SN light curves?
How accurately can we pull information from them?

Why does this matter?

Pre-explosion structure of the star
Pre-explosion spin rate of the stellar core





Quataert & Shiode 2012; Shiode & Quataert 2014; Smith & Arnett 2014; Fuller et al. 2015; Fuller 2017, Fuller & Ro 2018

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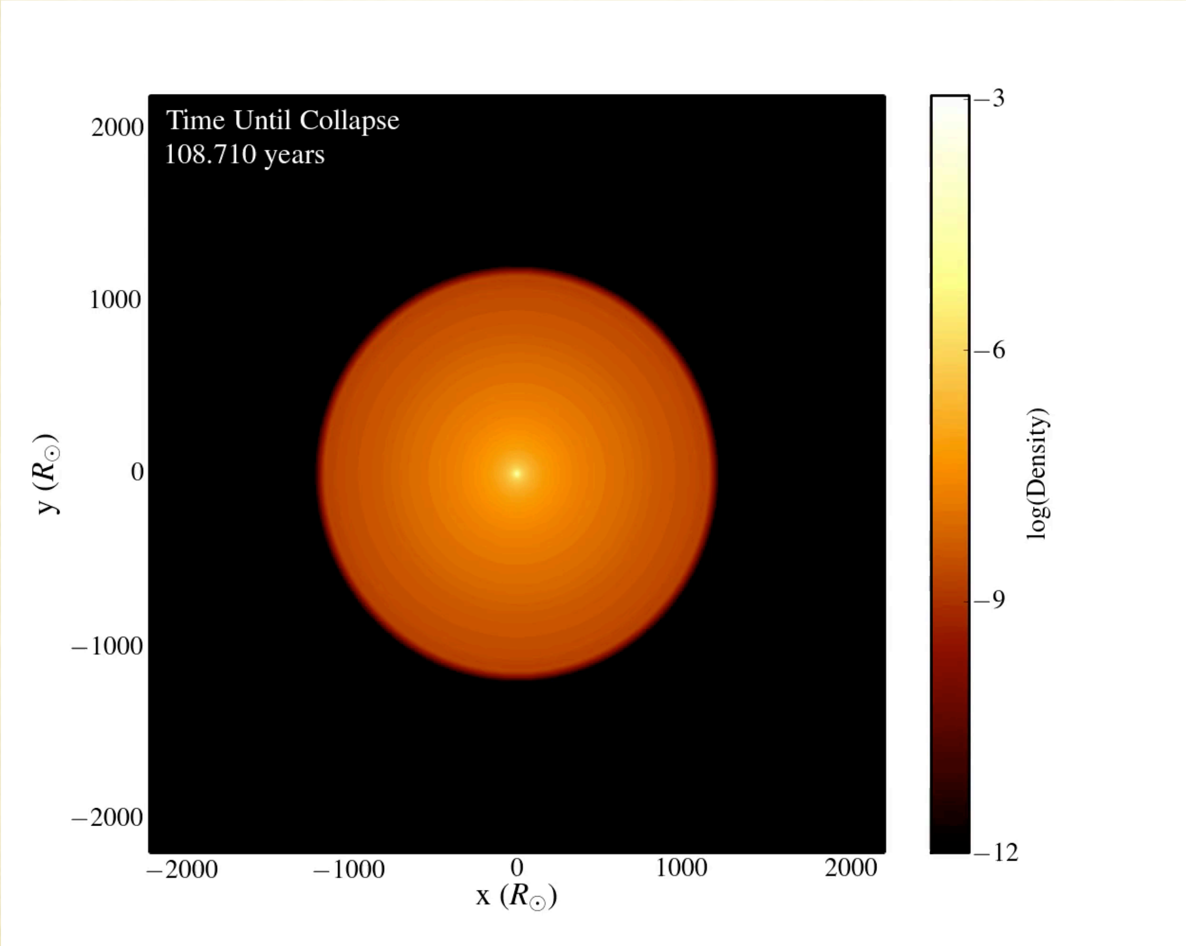

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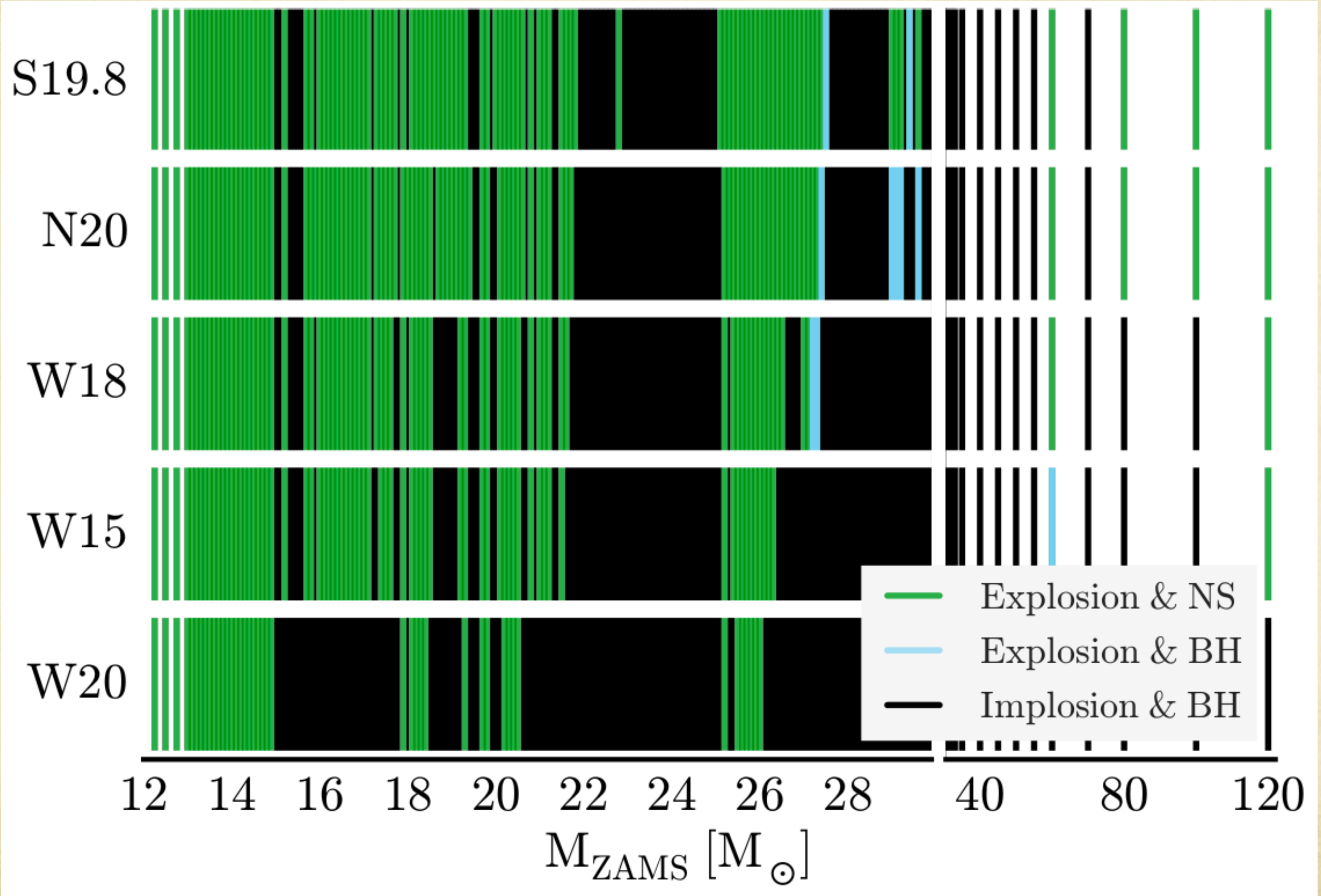
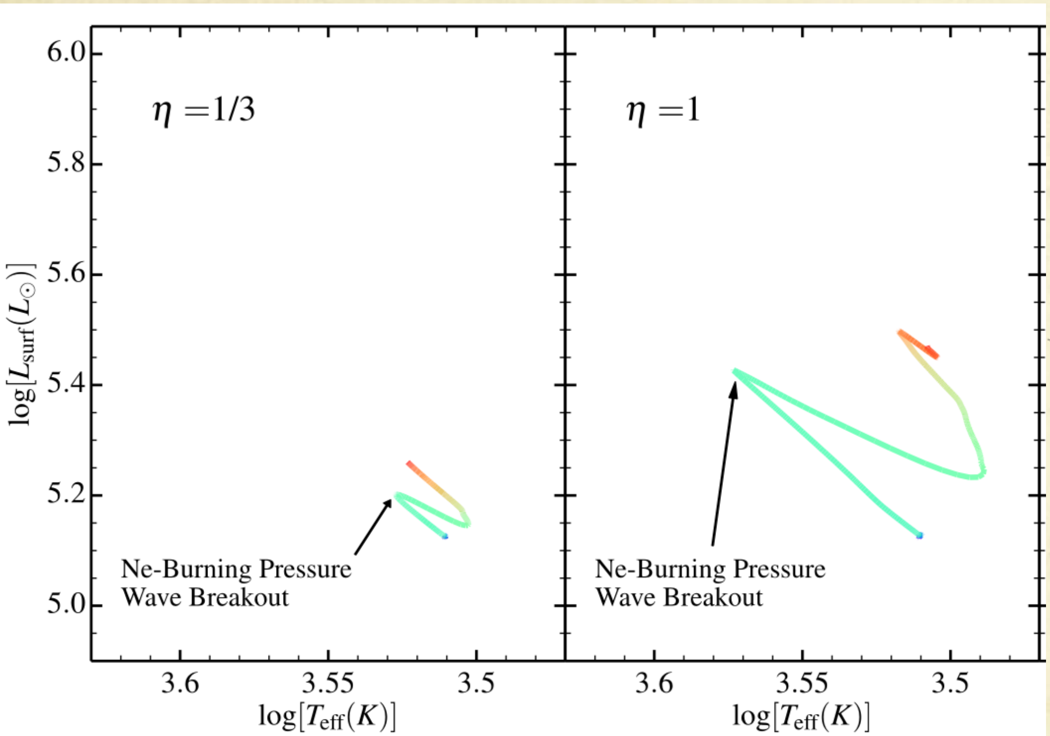
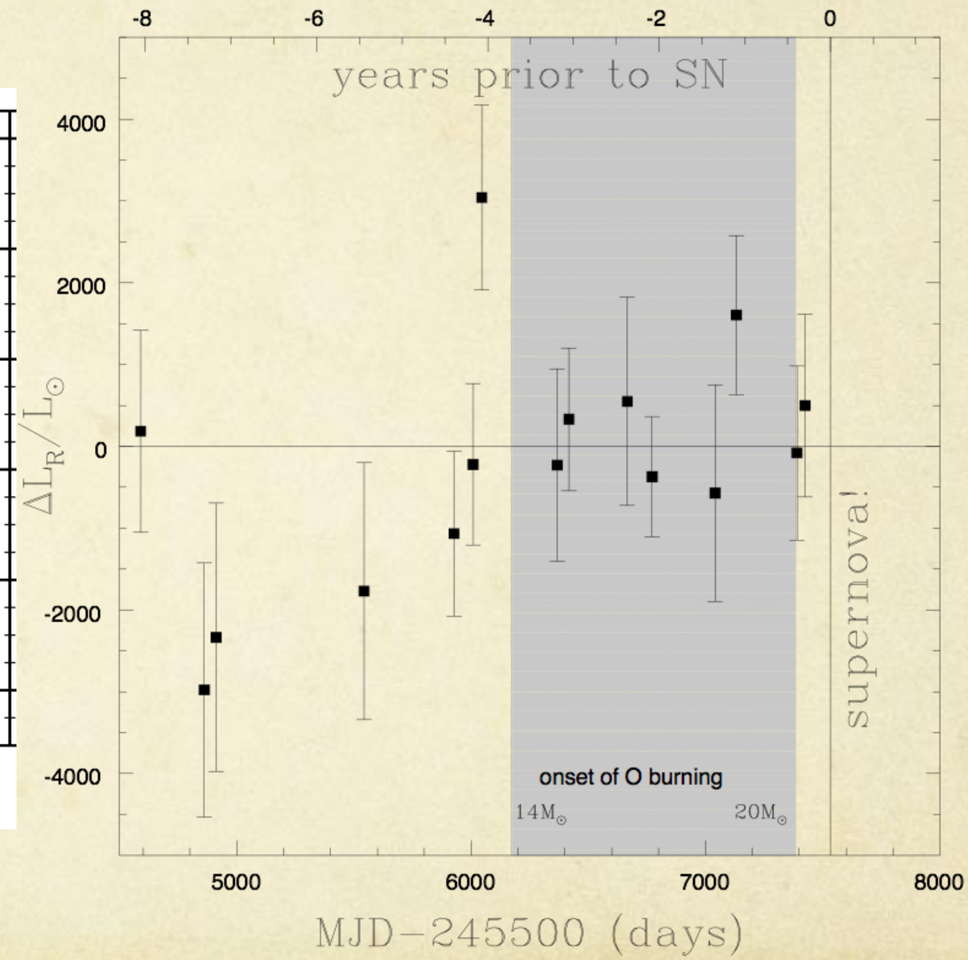


T. Sukhbold et al.

Testable Predictions



Fuller (2017)



Kochanek et al. (2017)

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<u>Key Question(s) 3:</u>

What stars explode (or not) as supernova?
How does this, and their explosion properties, change with environment?

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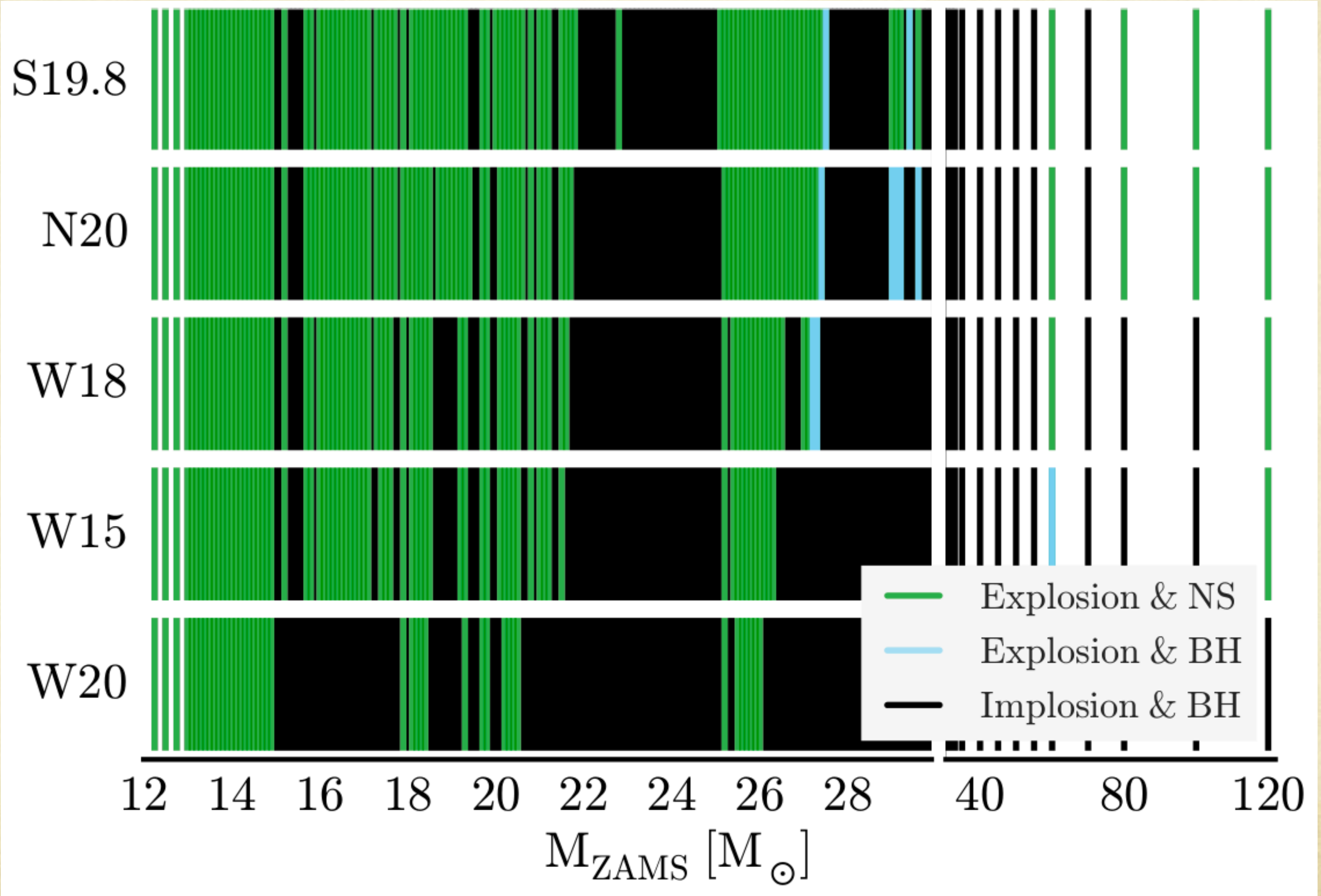
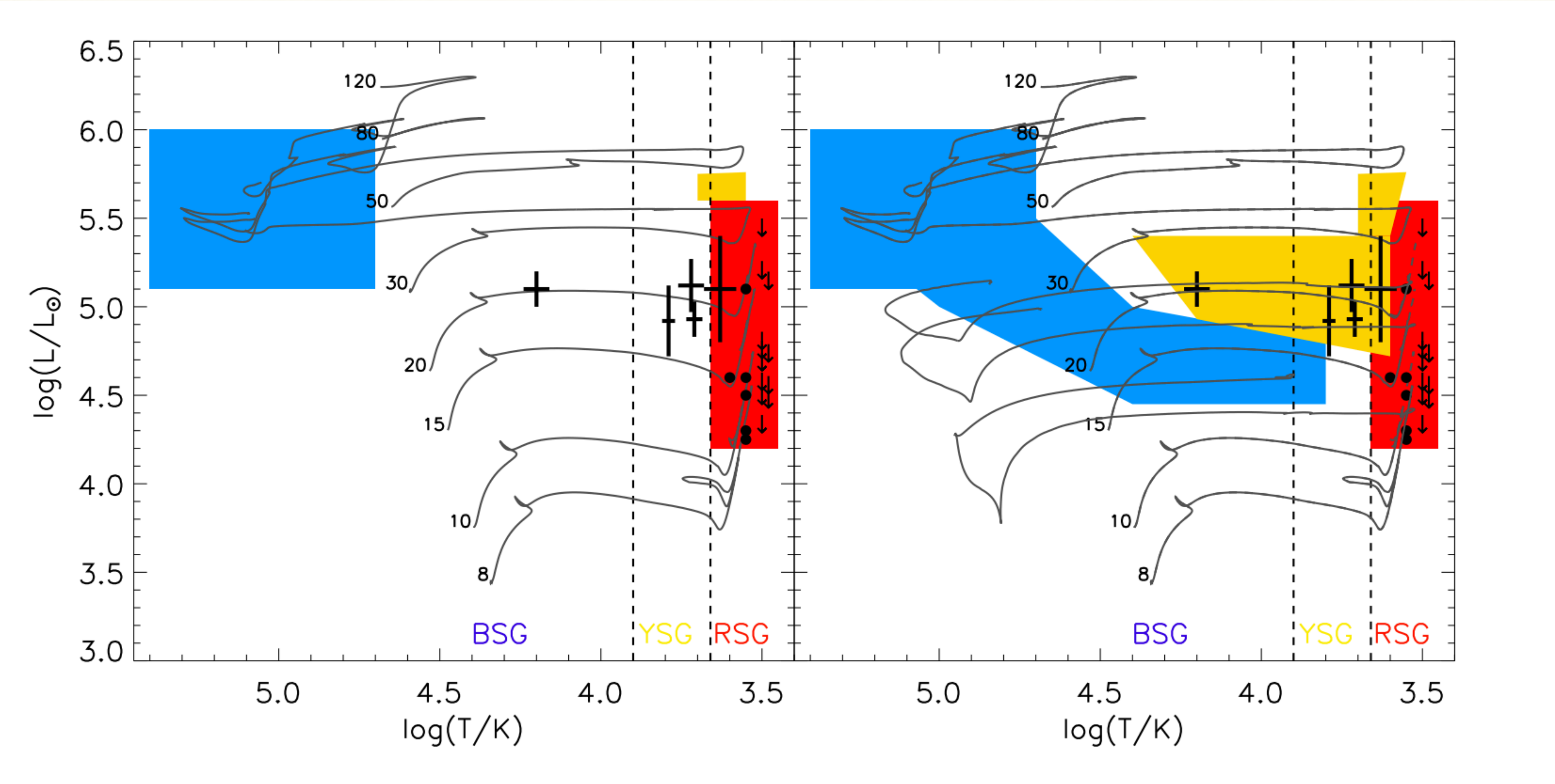
Progenitor -> Compact Object?



T. Sukhbold et al.

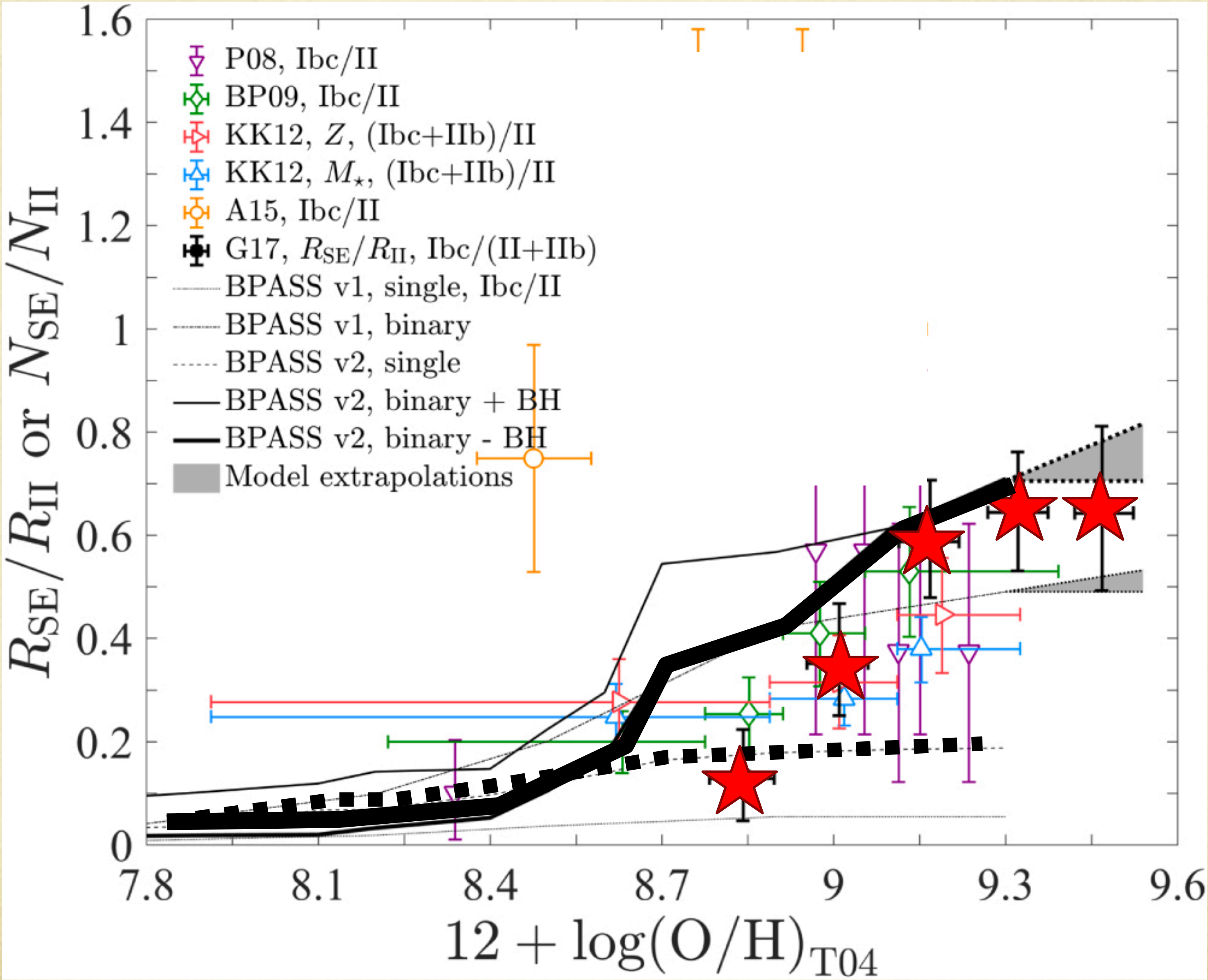
Observational Lack of High Mass Progenitors



Eldridge, et al. (2013)

Bulk Statistics

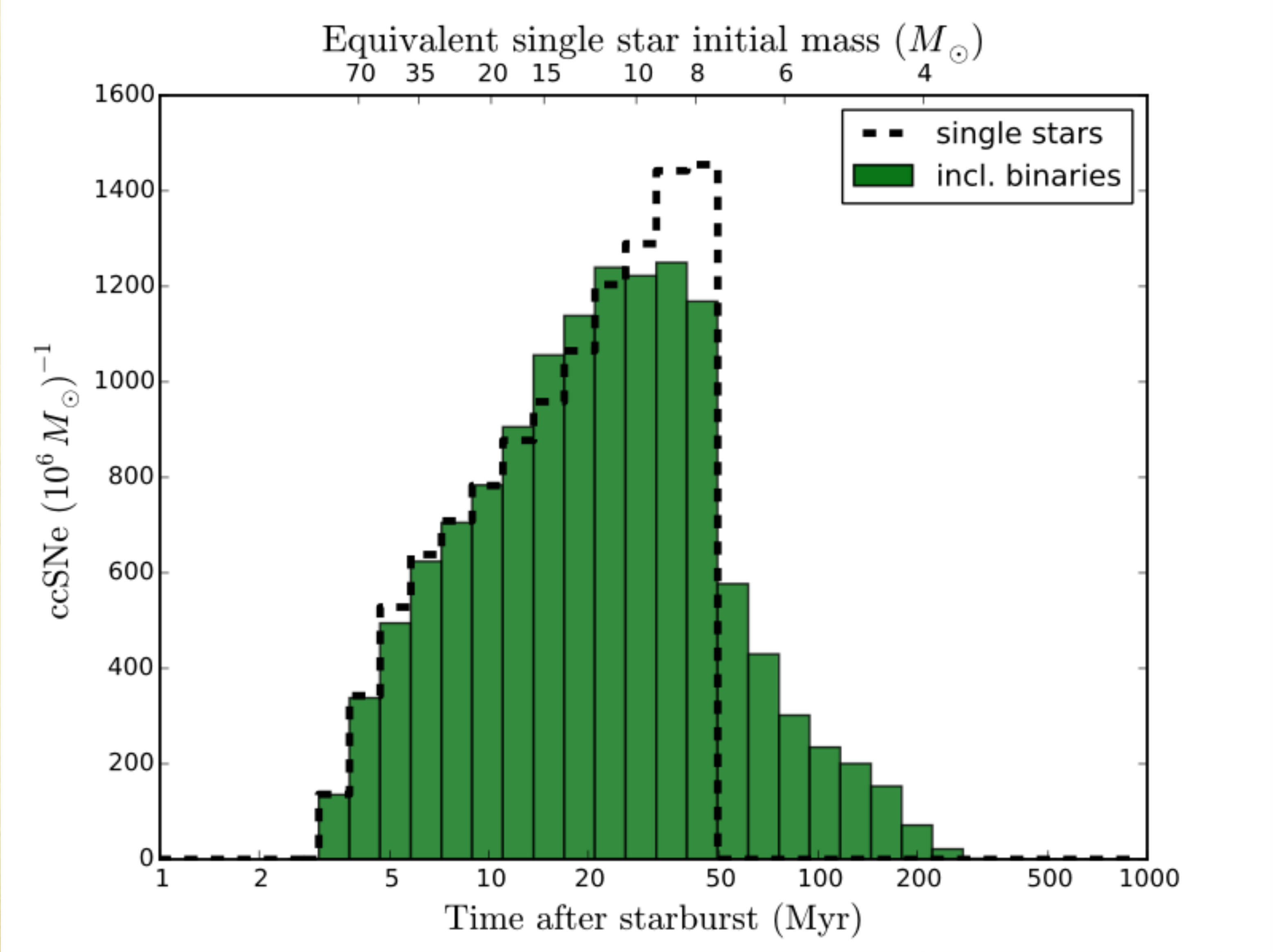
Probes of the Underlying Stellar Population



Graur et al. (2017)

Bulk Statistics

Delay – Time Distribution



Zapartas et al. (2017)

Unsolved Problems
In Time Domain Astronomy

What are the observed populations of "peculiar" explosive transients present in the universe?

What is the behavior of massive stars immediately preceding core-collapse?

What stars explode (or not) as supernova?