A Unified Progenitor Model of SLSNe I, lGRBs, SNe Ic-BL and FBOTs

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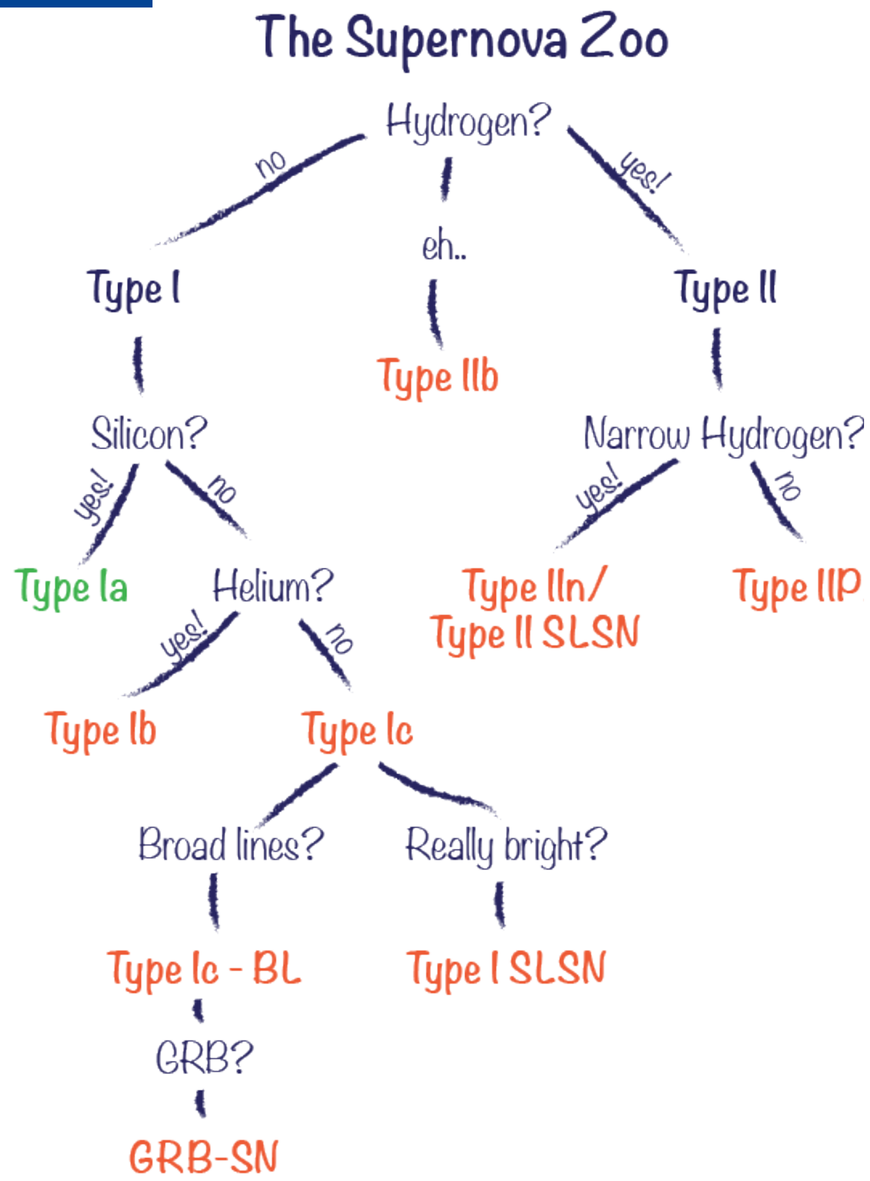
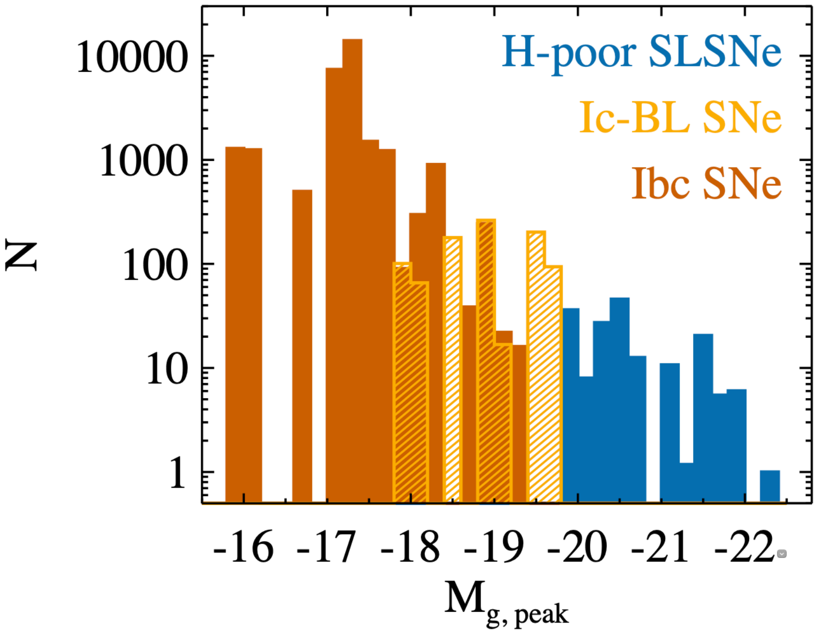
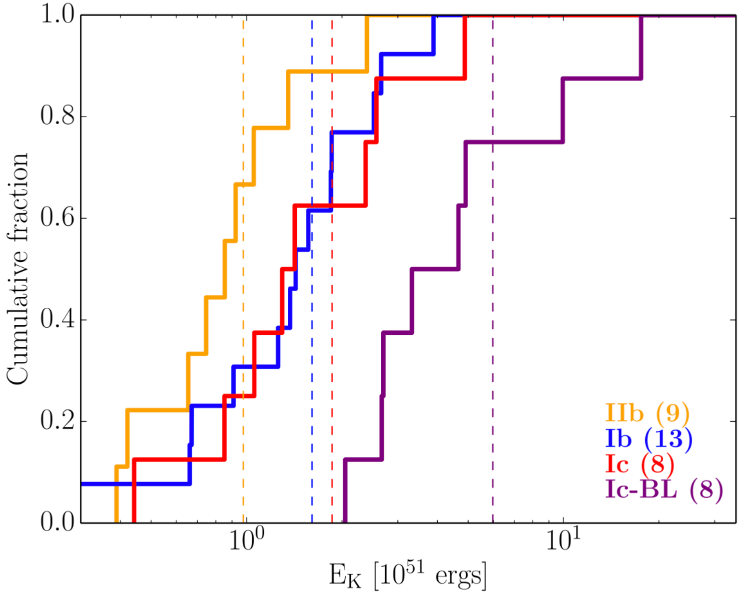
Introduction





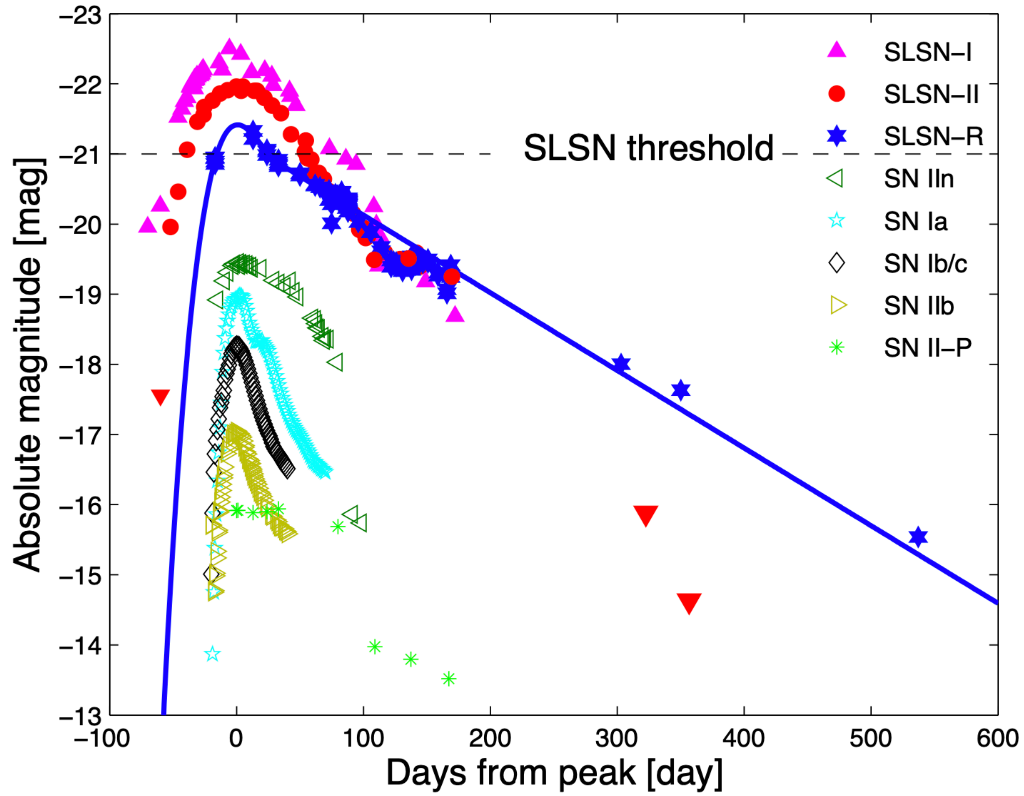
Peak absolute magnitude
De Cia et al. (2018)



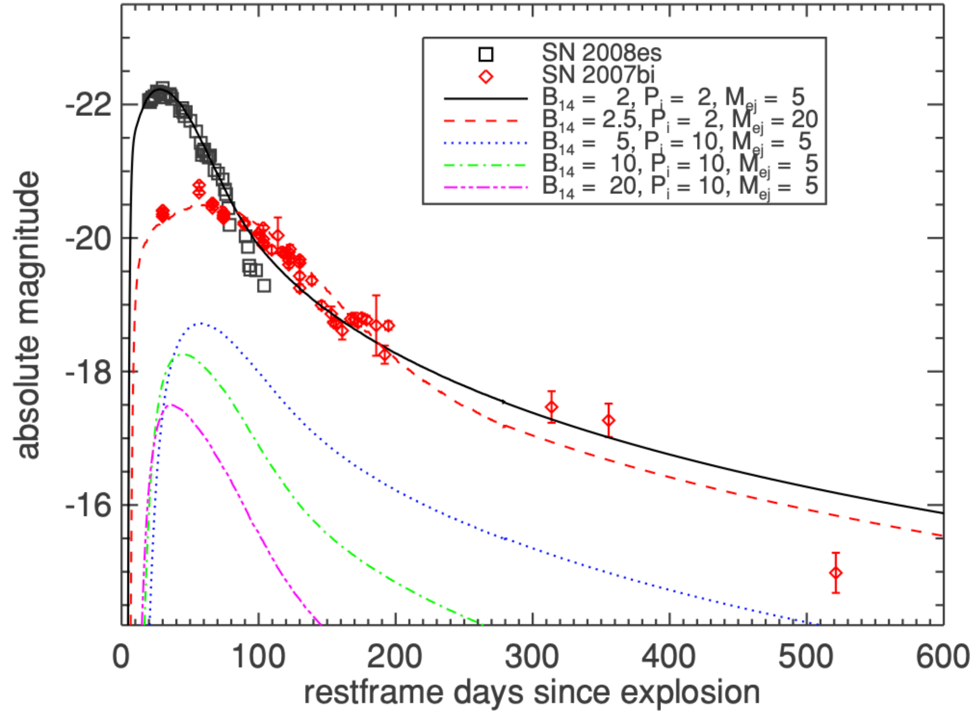
Explosion energy
Lyman et al. (2016)

- **SLSNe/GRB-SNe/SNe Ic-BL**
  - Brighter than normal SNe Ib/Ic
  - Broad-line properties in spectra
  - Explosion energy >> neutrino-powered energy
  - Star-forming dwarf galaxies

Introduction



Gal-Yam (2012)

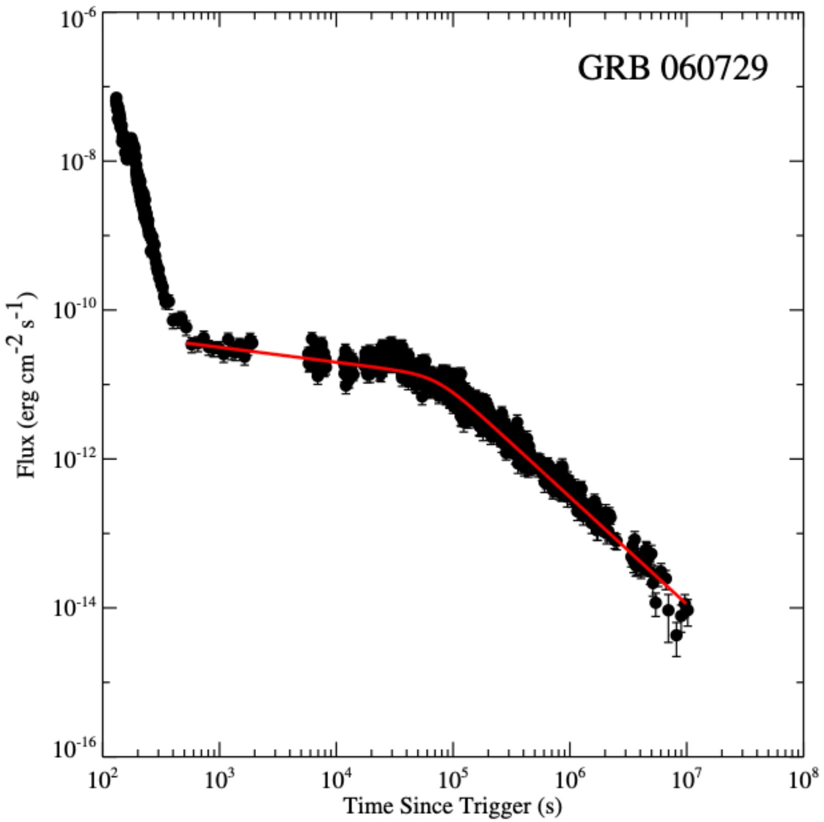


Kasen et al. (2010)

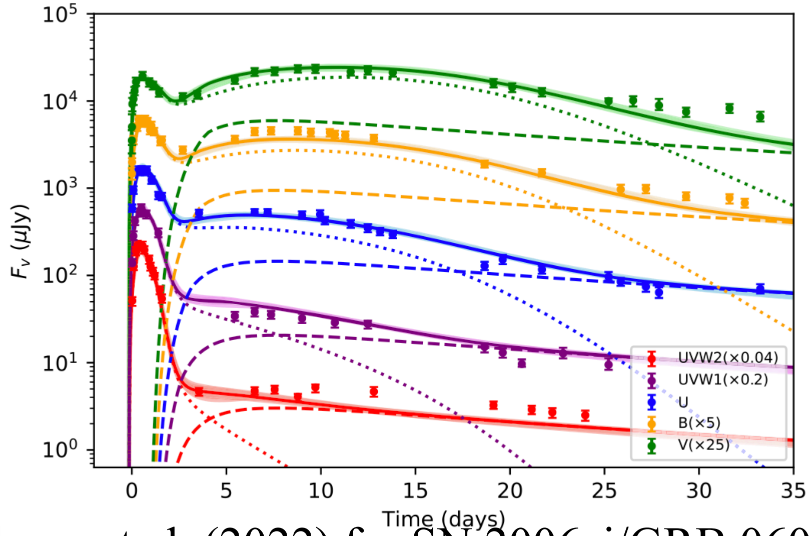
- **Millisecond Magnetar central engine**

$$L_{sd} = L_{sd,i}(1 + t/t_{sd})^{-2}$$

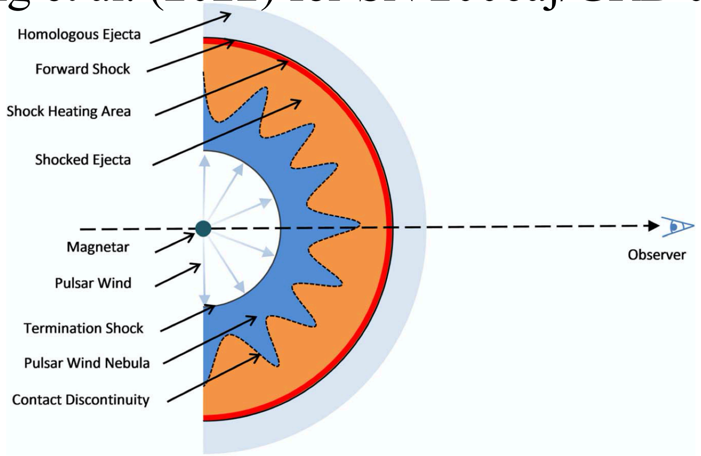
Introduction



Lv & Zhang. (2014)



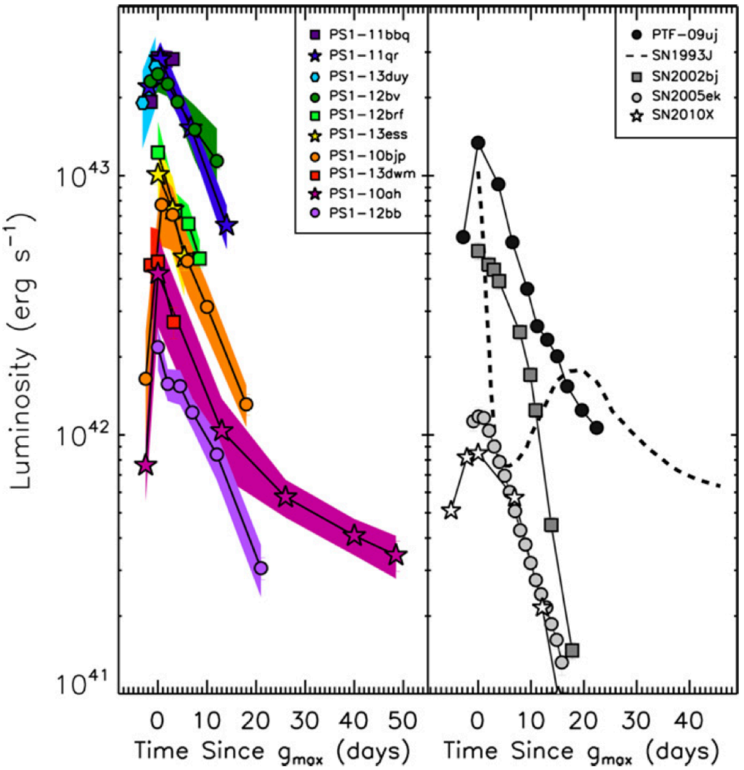
Zhang et al. (2022) for SN 2006aj/GRB 060218



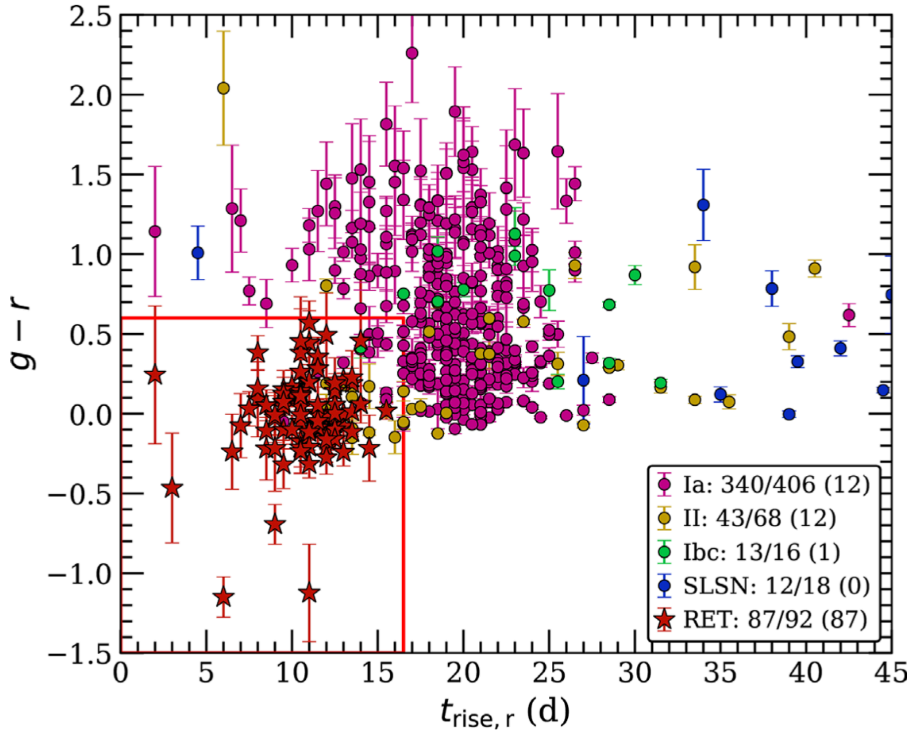
- **Internal plateau in X-ray afterglows**

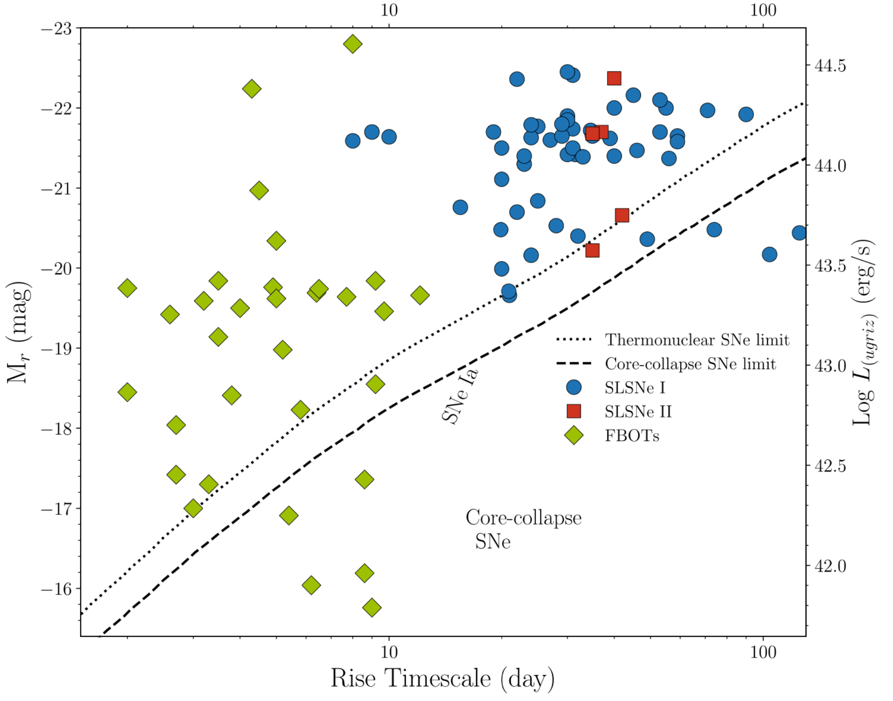
- **Magnetar shock breakout**

Introduction



Drout et al. (2014)

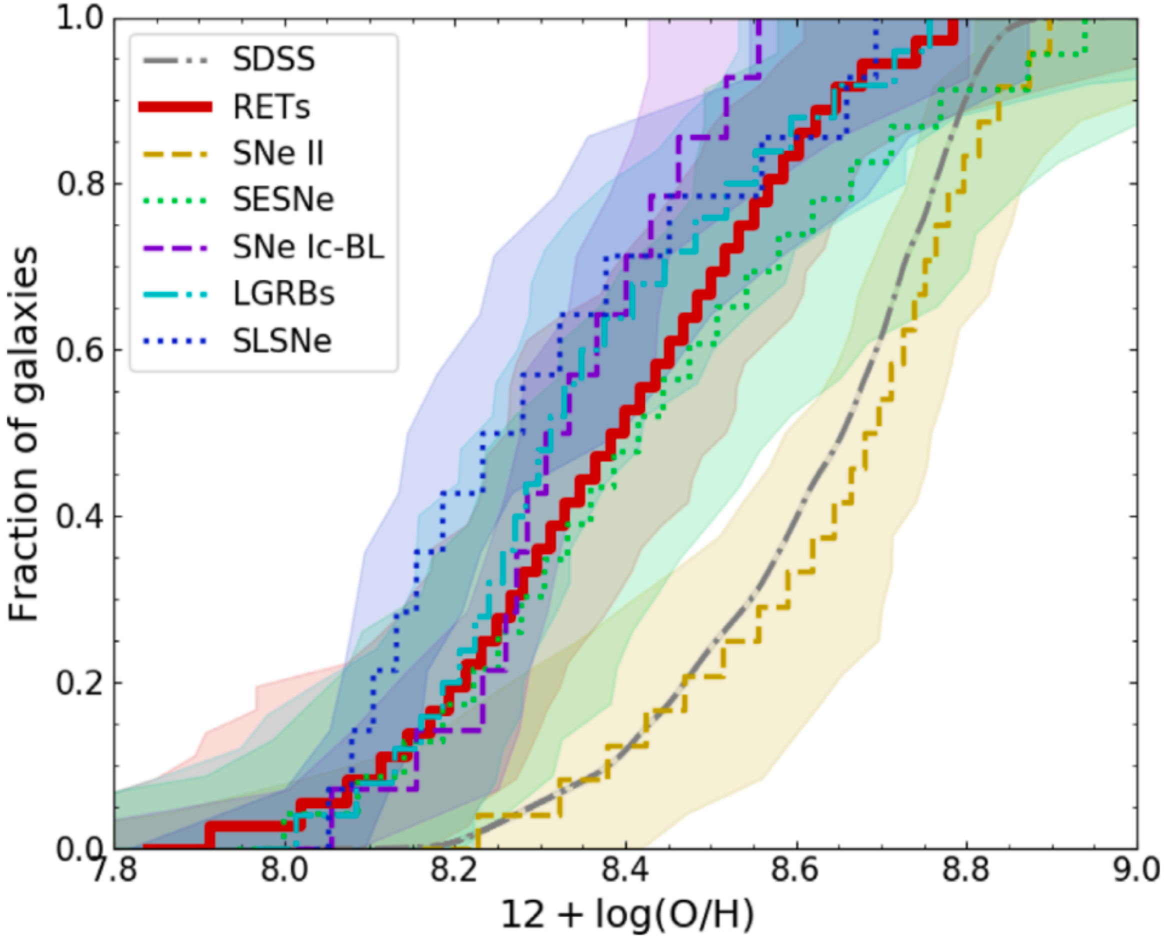




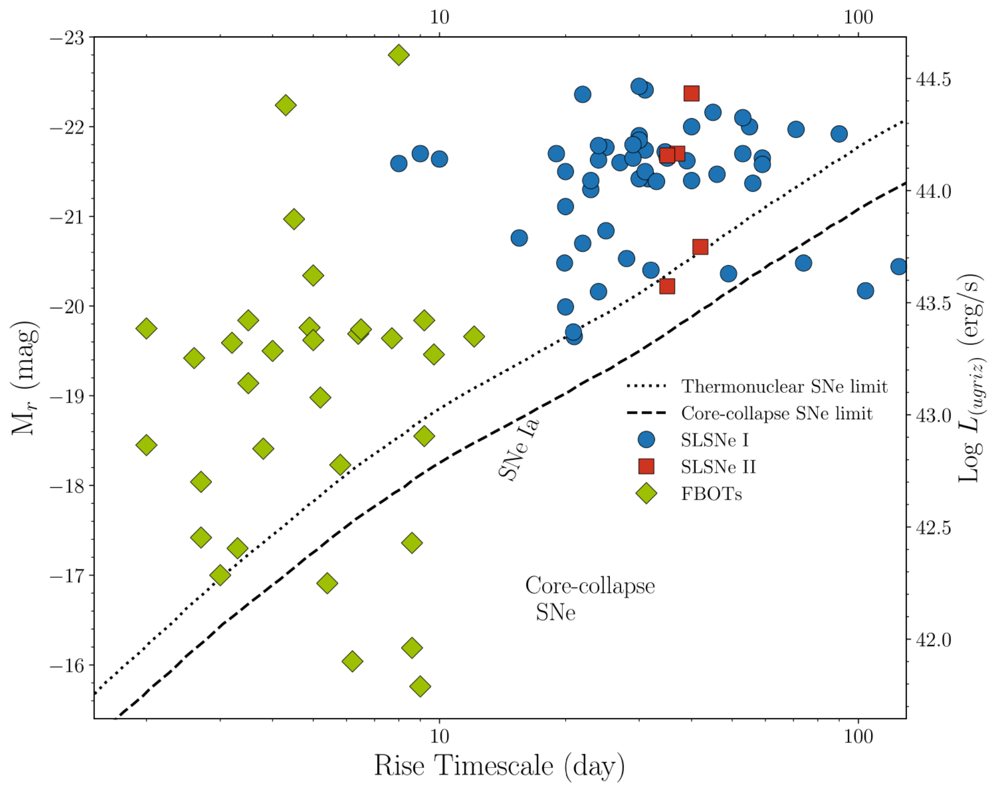
Inserra (2019)

Fast blue optical transients have fast-evolving and bright evolution and cannot be explained by pure ^{56}Ni-powered energy.

Introduction



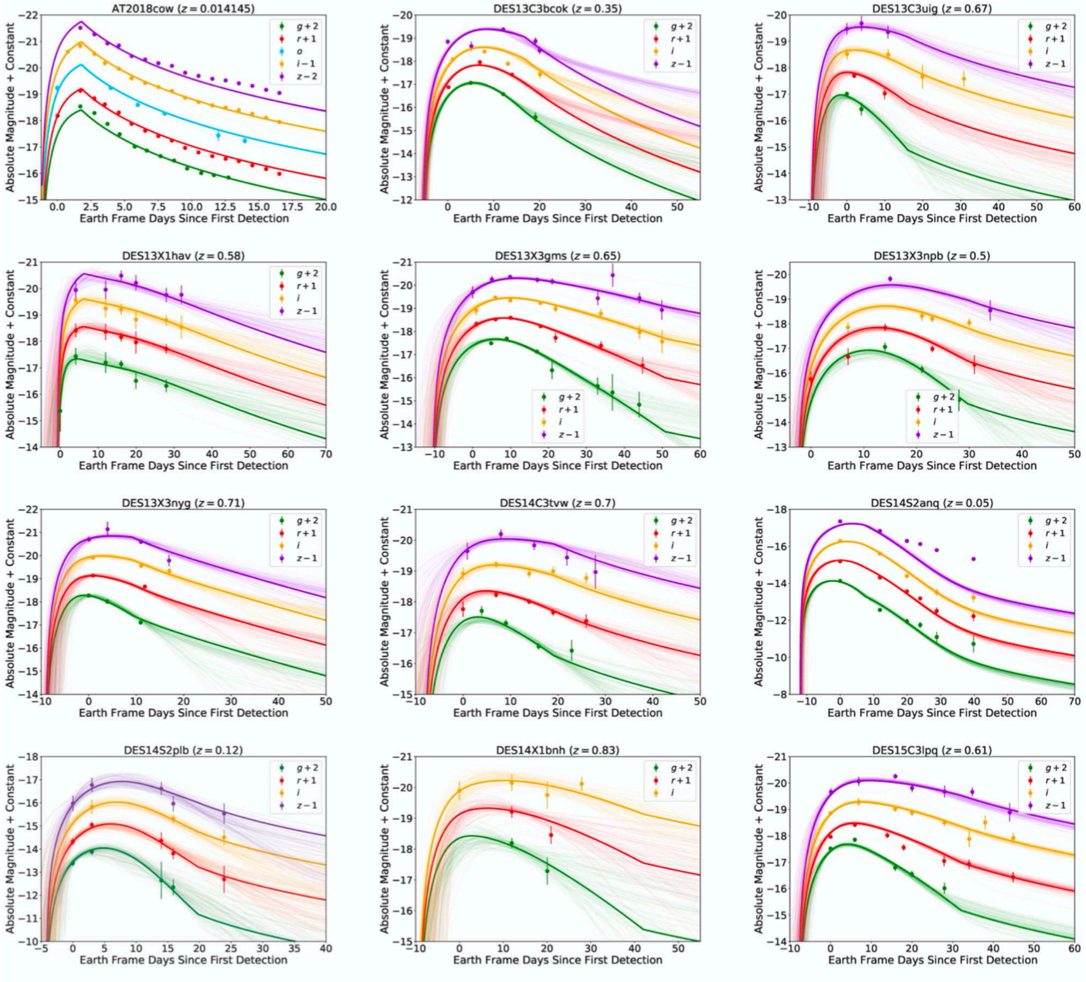
Wiseman et al. (2020)



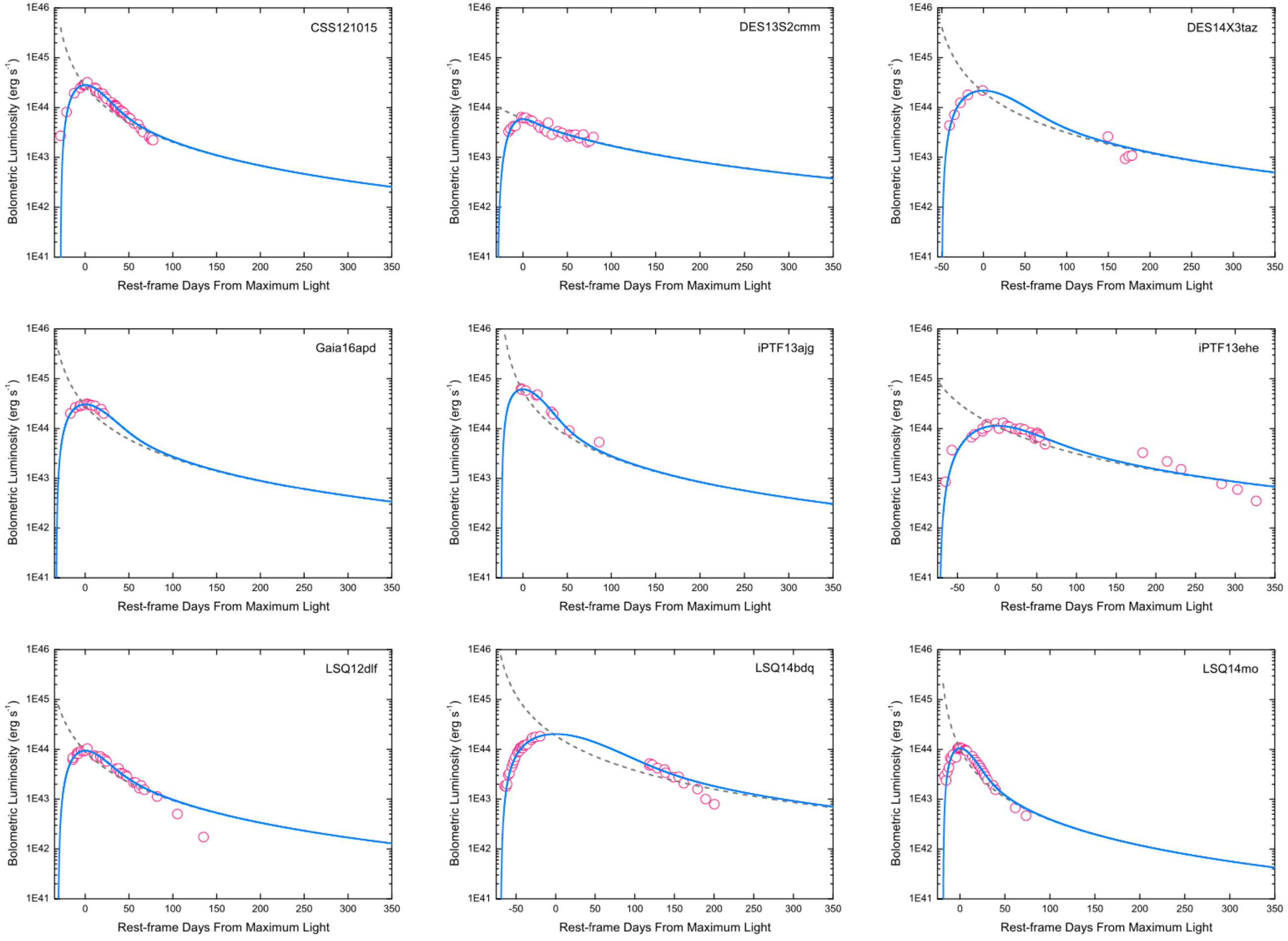
Inserra (2019)

FBOT hosts appear to show a lack of chemical enrichment, their metallicities akin to lGRB and SLSN host galaxies.

Fitting Results

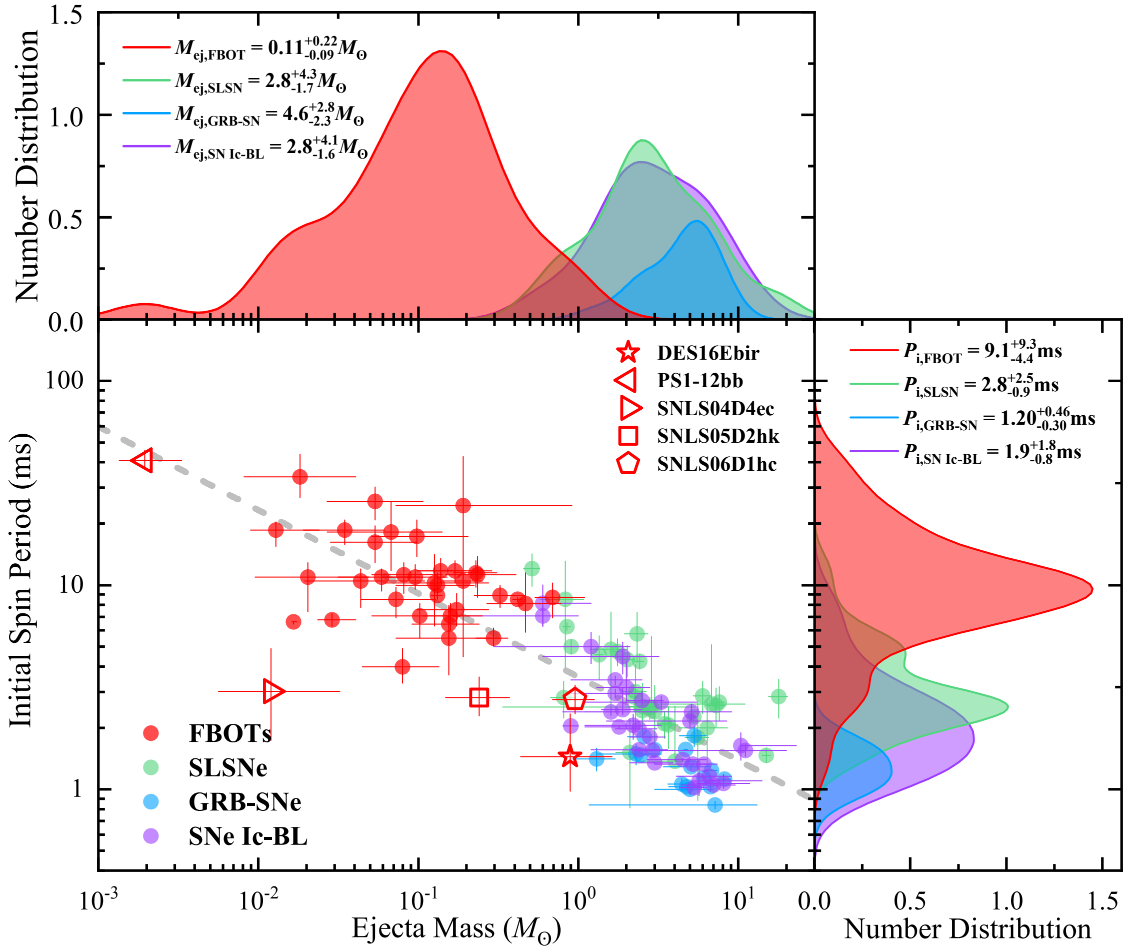


FBOT
Liu, Zhu et al. (2022)



SLSNe
Yu, Zhu et al. (2017)

A universal relationship: a common origin?

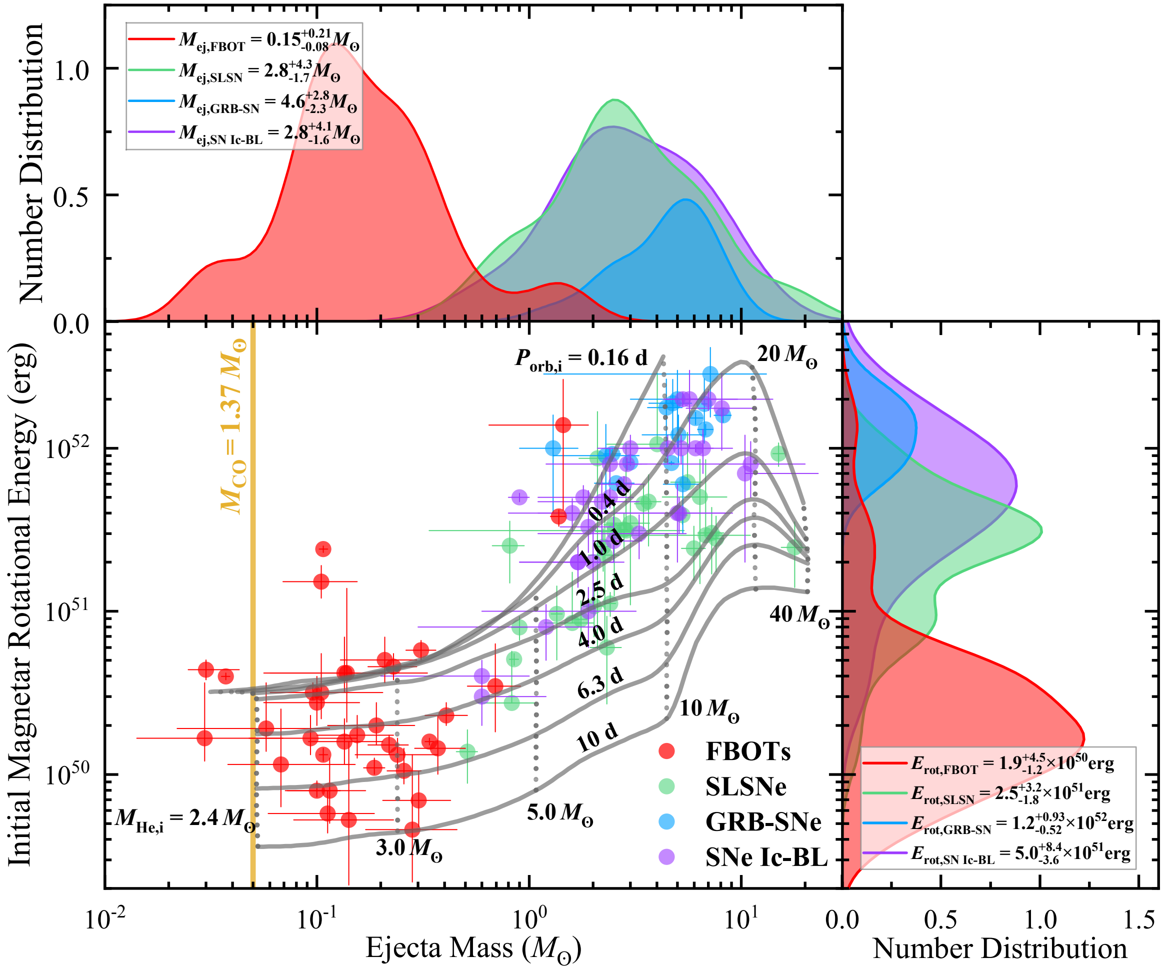


Liu, Zhu et al. (2022)

- Magnetar parameters of SLSNe and FBOTs are obtained by fitting lightcurves (Yu, Zhu et al. 2017; Liu, Zhu et al. 2022)
- Magnetar parameters of SNe Ic-BL and GRB-SNe are obtained following Arnett relationship (Lyman et al. 2016 ; Lv et al. 2017; Taddia et al. 2019)
- The boundary between FBOTs and other three types of transients is 1 $M_{\odot}$.
- GRB-SNe could have higher-mass progenitors

Strong universal relationship, indicating common origin for these magnetar-driven explosions

A universal relationship: a common binary origin!



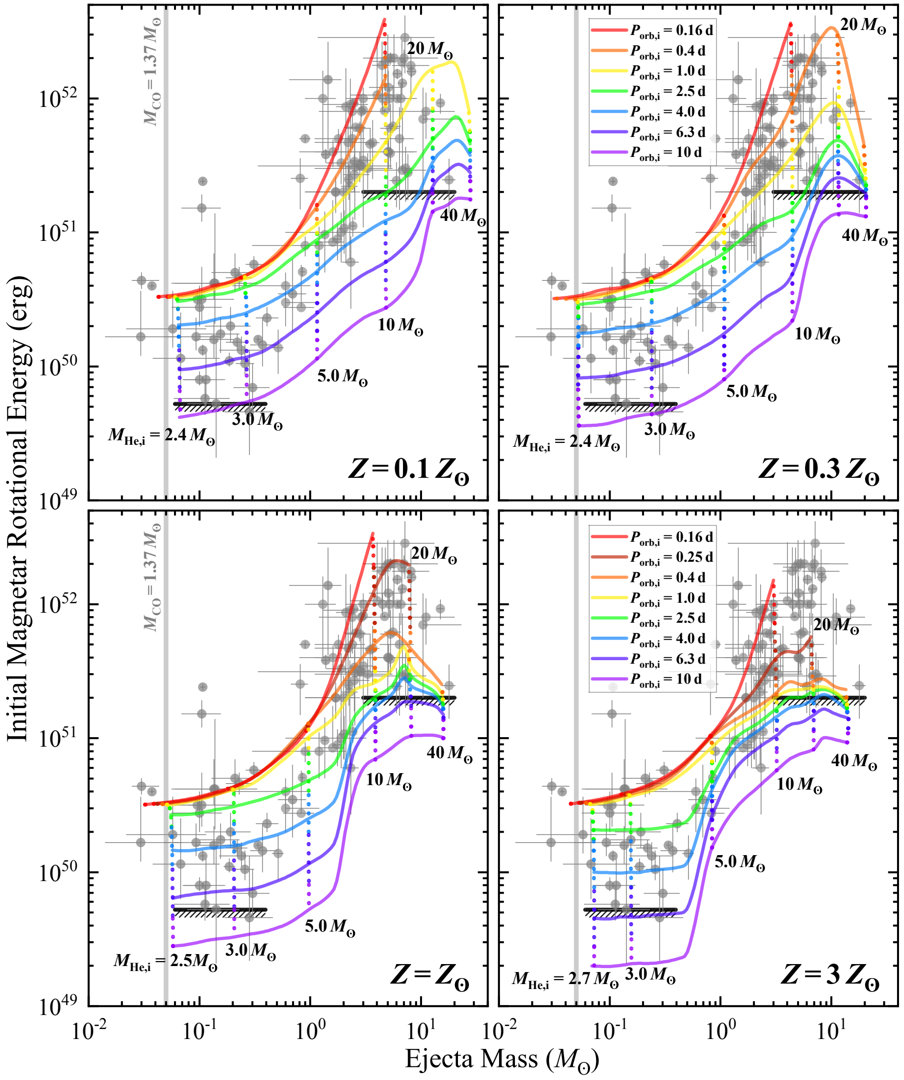
Hu, Zhu, Qin, Shao, Zhang et al. (2023)

● Evolve close-orbit Helium star binary

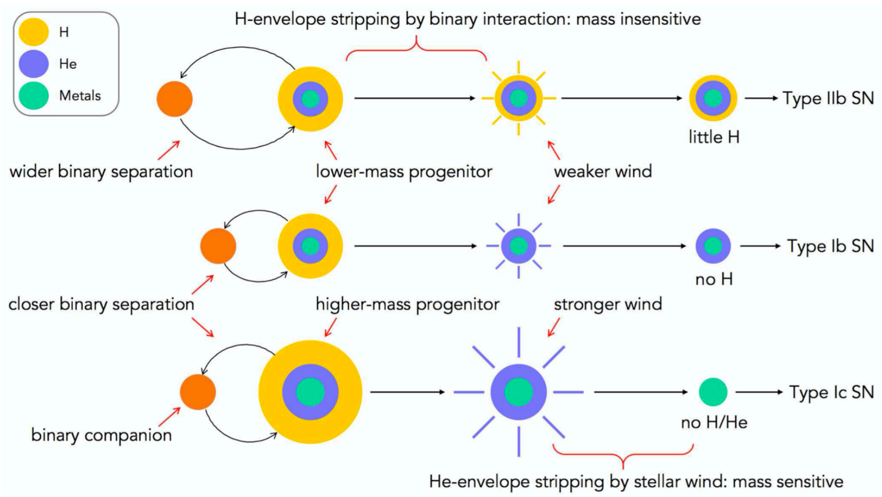
- SLSNe, GRB-SNe and SNe Ic-BL are originated from $M_{He,i} > 5\ M_\odot$ helium stars in binary systems with $P_{orb,i} < 2$ days.
- FBOTs are originated from $M_{He,i} < 5\ M_\odot$ ultra-stripped helium stars in binary systems with $P_{orb,i} <$ 10 days.

Tidal acceleration can explain the universal relationship of SLSNe, GRB-SNe, SNe Ic-BL and FBOTs!

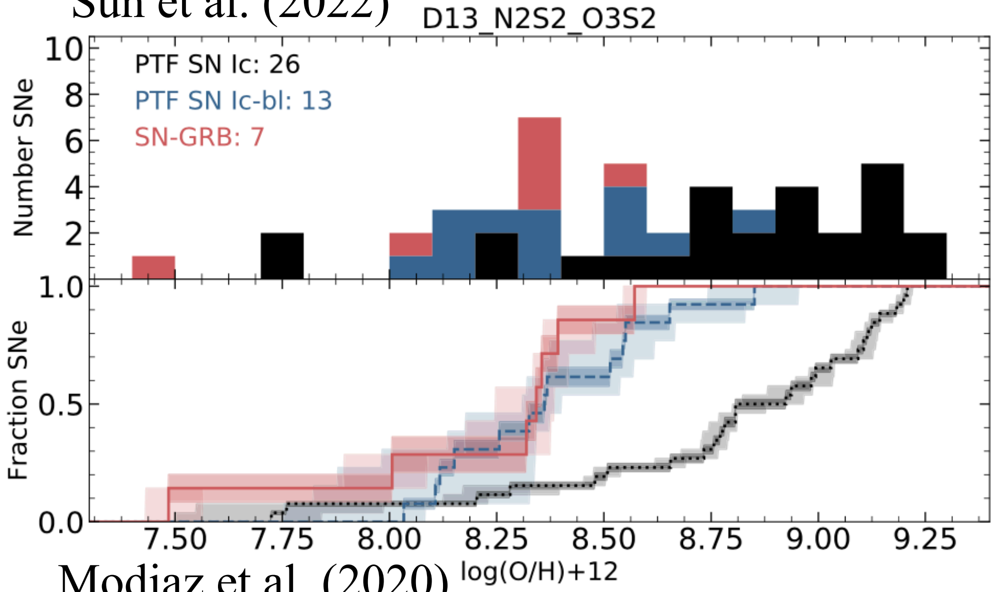
Normal SN Ic: close-binary at high-metallicity envirnoments



Hu, Zhu, Qin, Shao, Zhang et al. (2023)



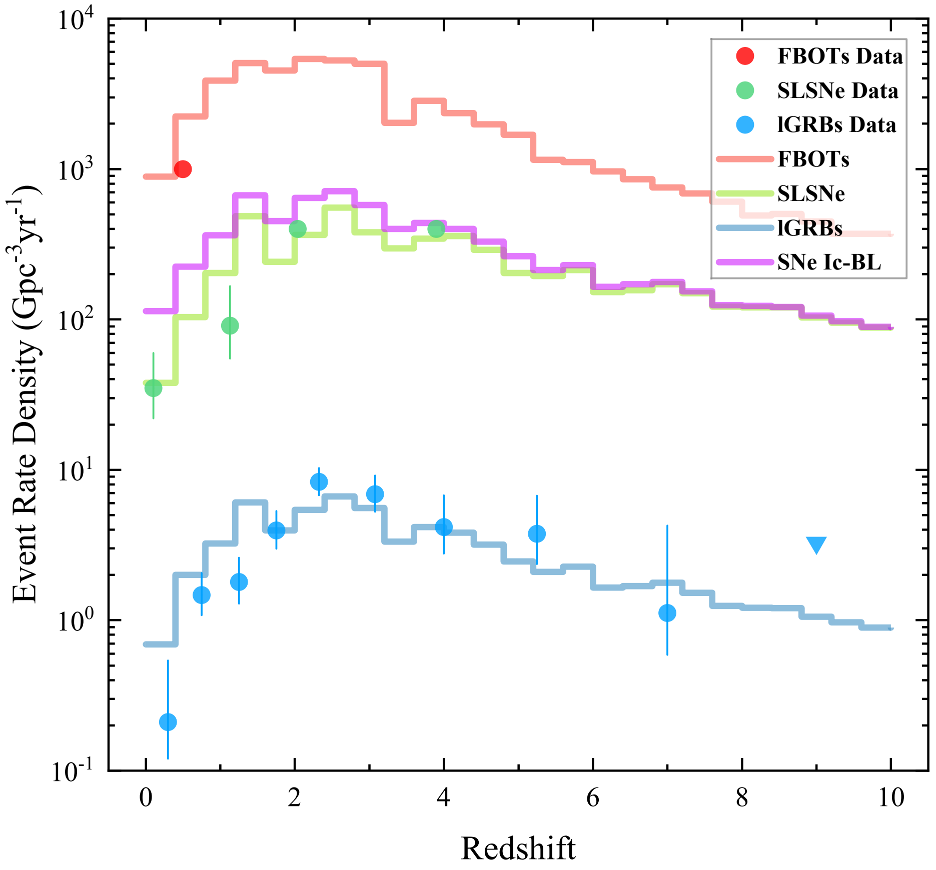
Sun et al. (2022)



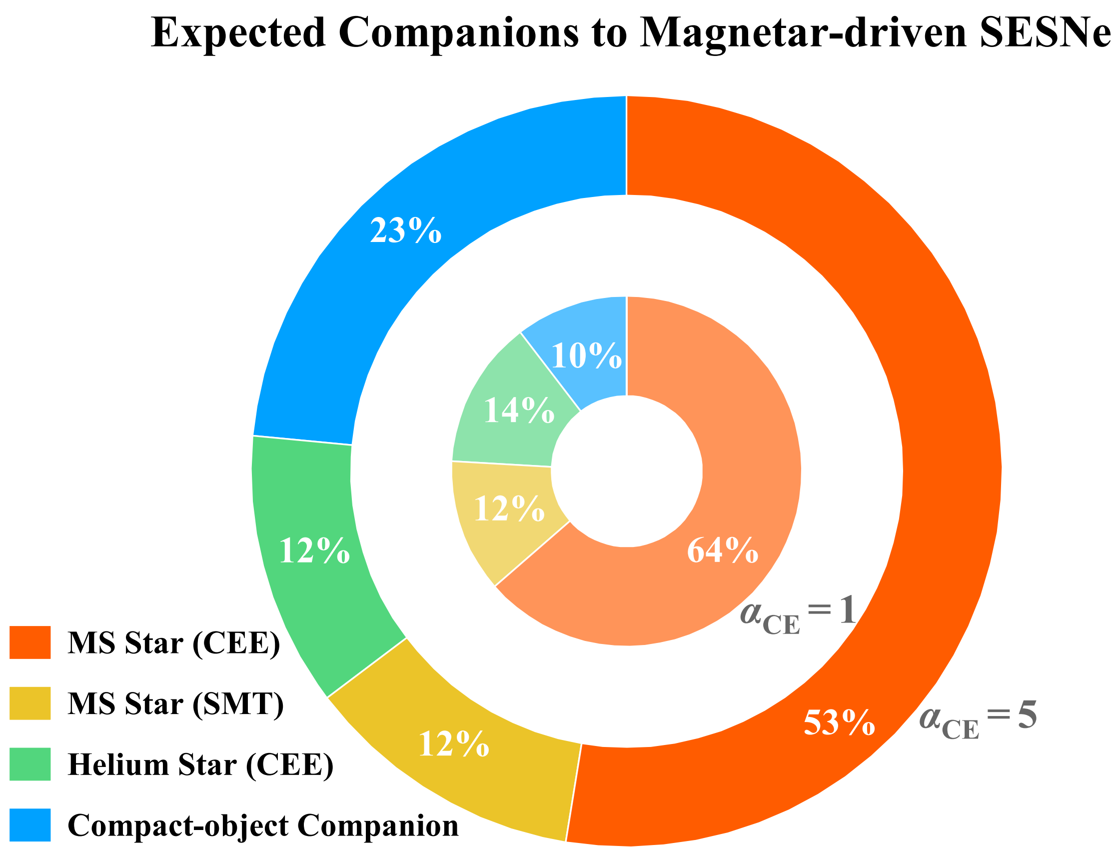
Modjaz et al. (2020)

SNe Ic could originate from massive stars in close binary at high-metallicity environments

Even rate densities are consistent



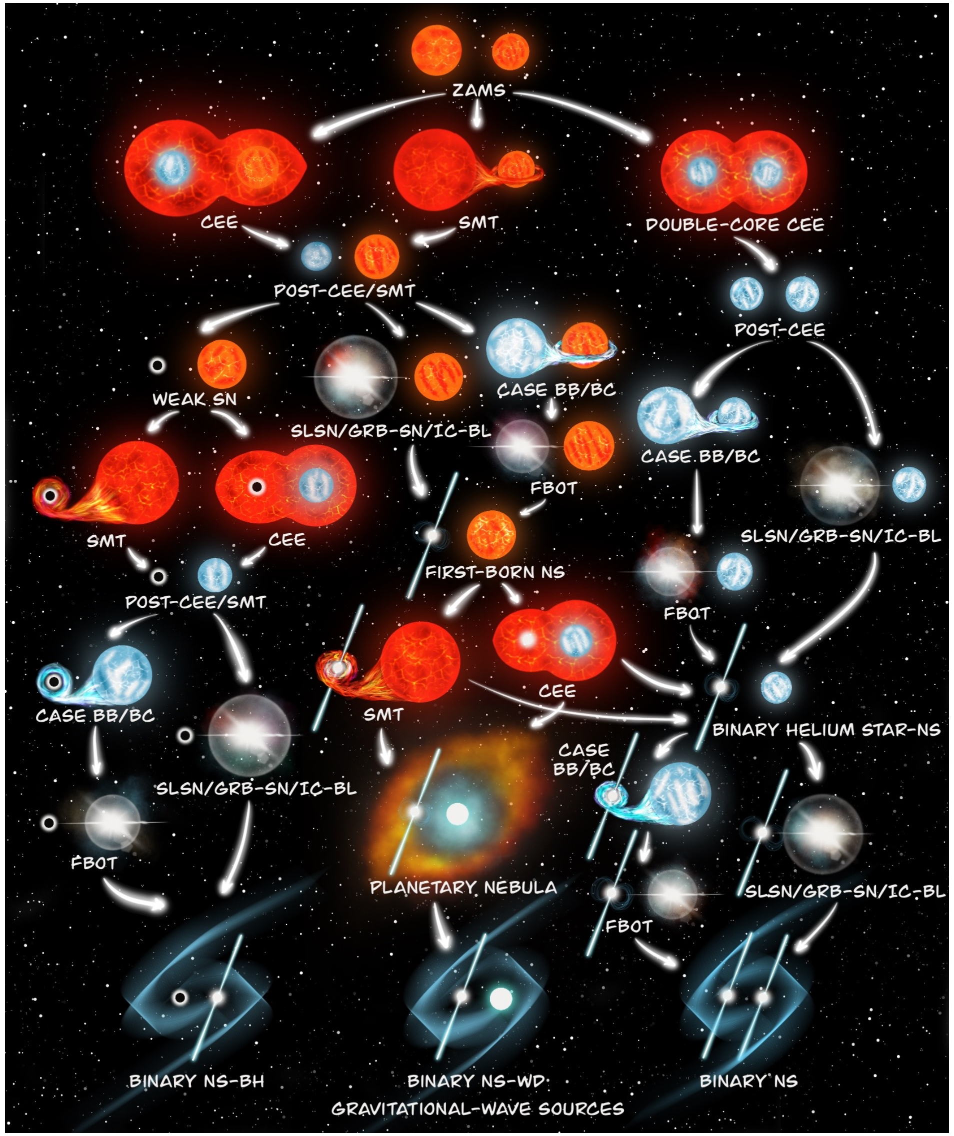
Population synthesis simulation results

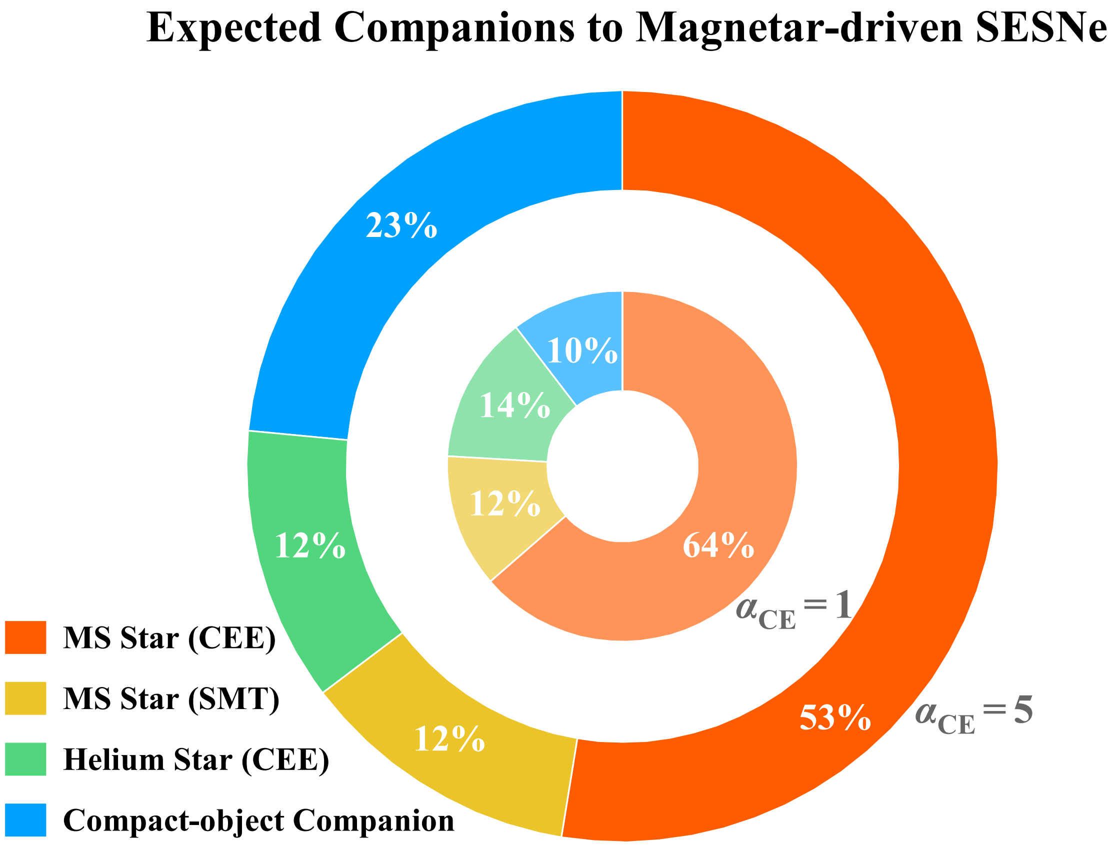


Expected companions to magnetar-driven SNe

Hu, Zhu, Qin, Shao, Zhang et al. (2023)

Formation pathway

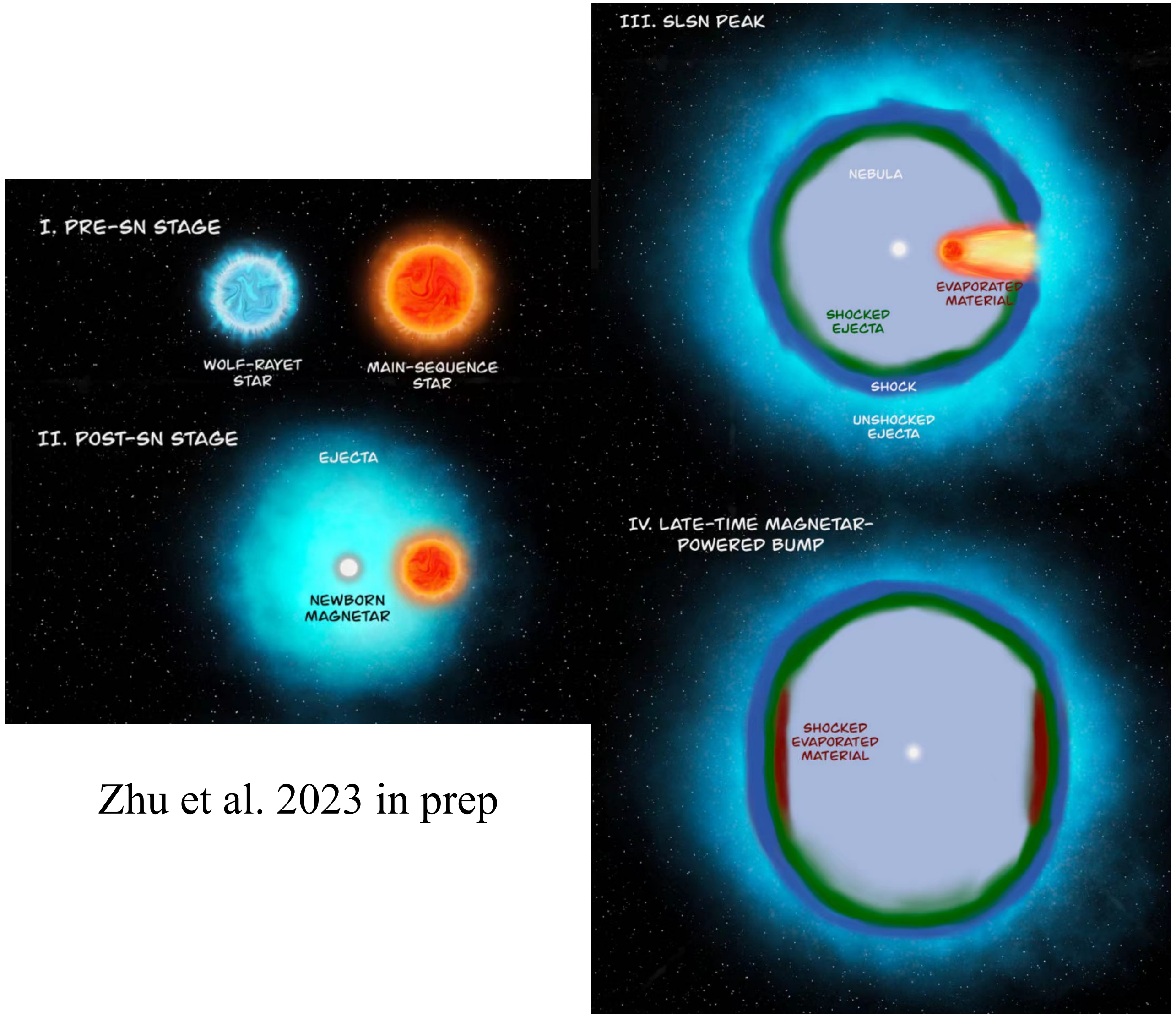




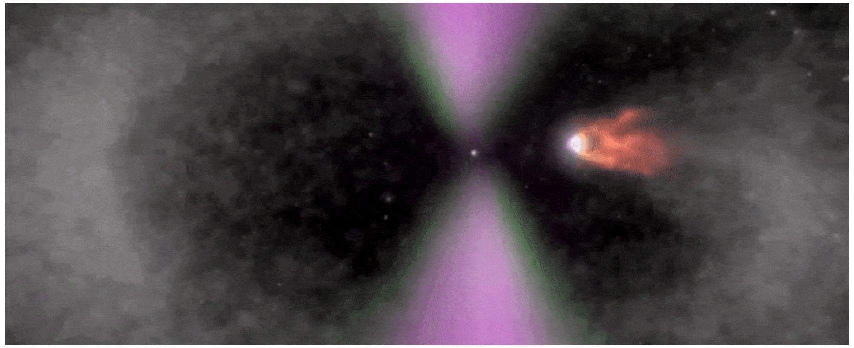
Expected companions to magnetar-driven SNe

Hu, Zhu, Qin, Shao, Zhang et al. (2023)

MS companion could result in SLSN bumps



Zhu et al. 2023 in prep



Black Widow Pulsar & Redback Pulsar

- Evaporated rate is

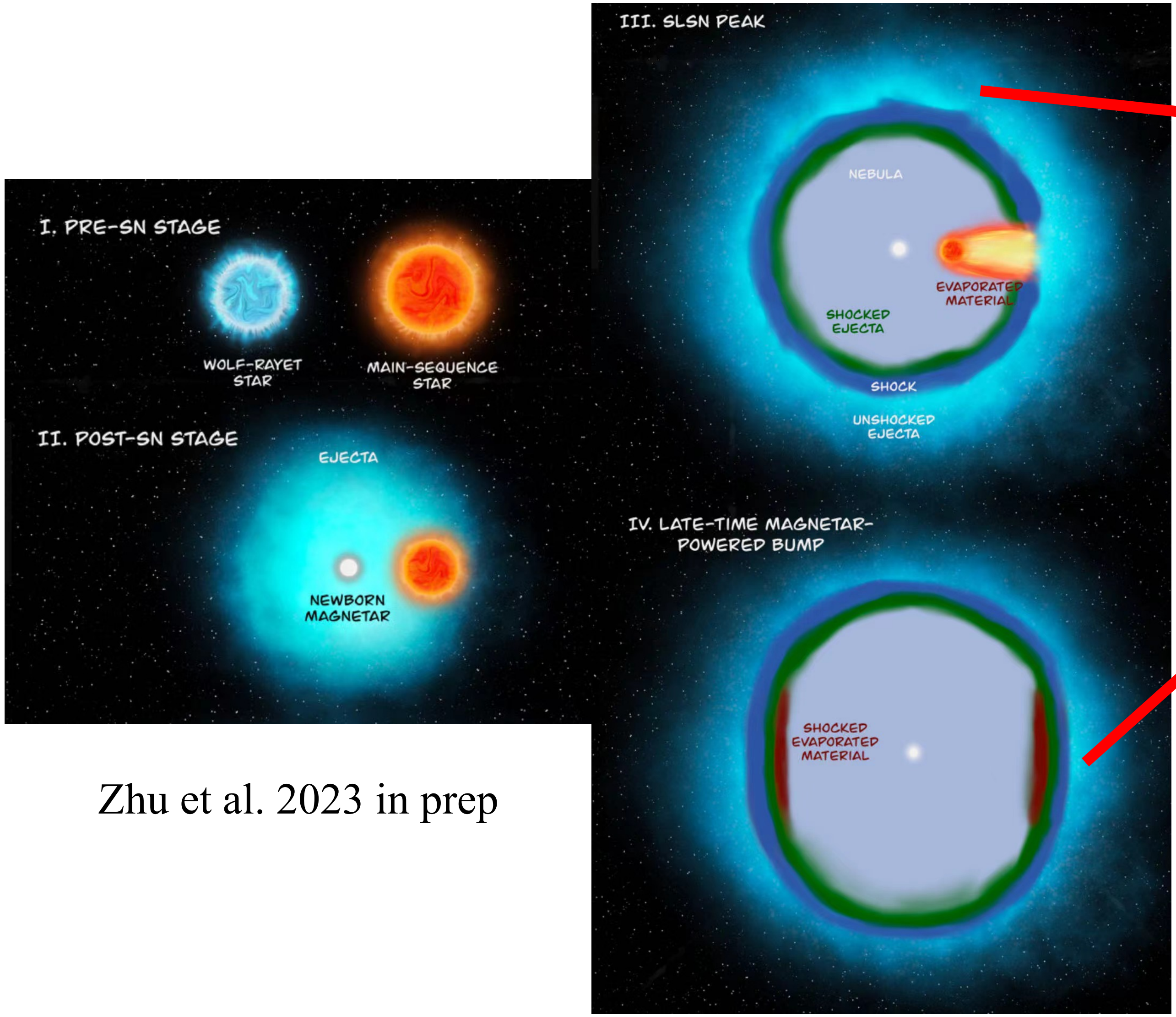
$$\dot{M}_{\rm ev} = f\left(\frac{R_\star}{a}\right)^2 \frac{L_{\rm sd}}{2v_{\rm esc}^2}$$
$$= 0.5\, f_{-1} M_{\star,4\odot}^{-1} R_{\star,3\odot}^{3} a_{5\odot}^{-2} L_{\rm sd,i,45.5}\, M_\odot\, {\rm d}^{-1}$$

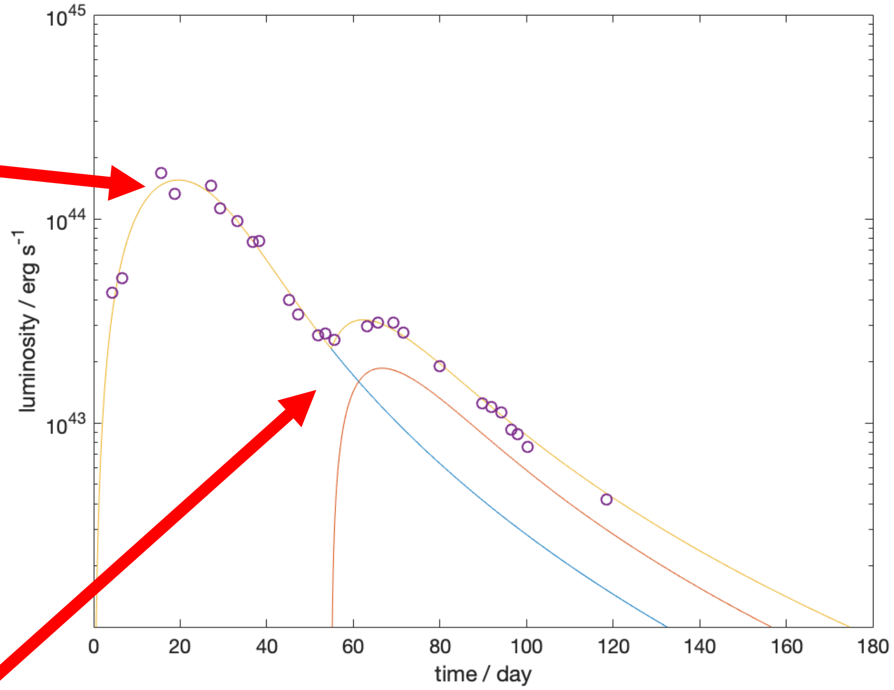
- The time for completely evaporating the MS by the pulsar wind is

$$t_{\rm ev} = \frac{M_\star}{\dot{M}_{\rm ev}} = 8\, f_{-1}^{-1} M_{\star,4\odot}^{2} R_{\star,3\odot}^{-3} a_{5,\odot}^{2} L_{\rm sd,i,45.5}^{-1}\, {\rm d}$$

MS star can be completely evaporated within magnetar spin-down timescale.

MS companion could result in SLSN bumps

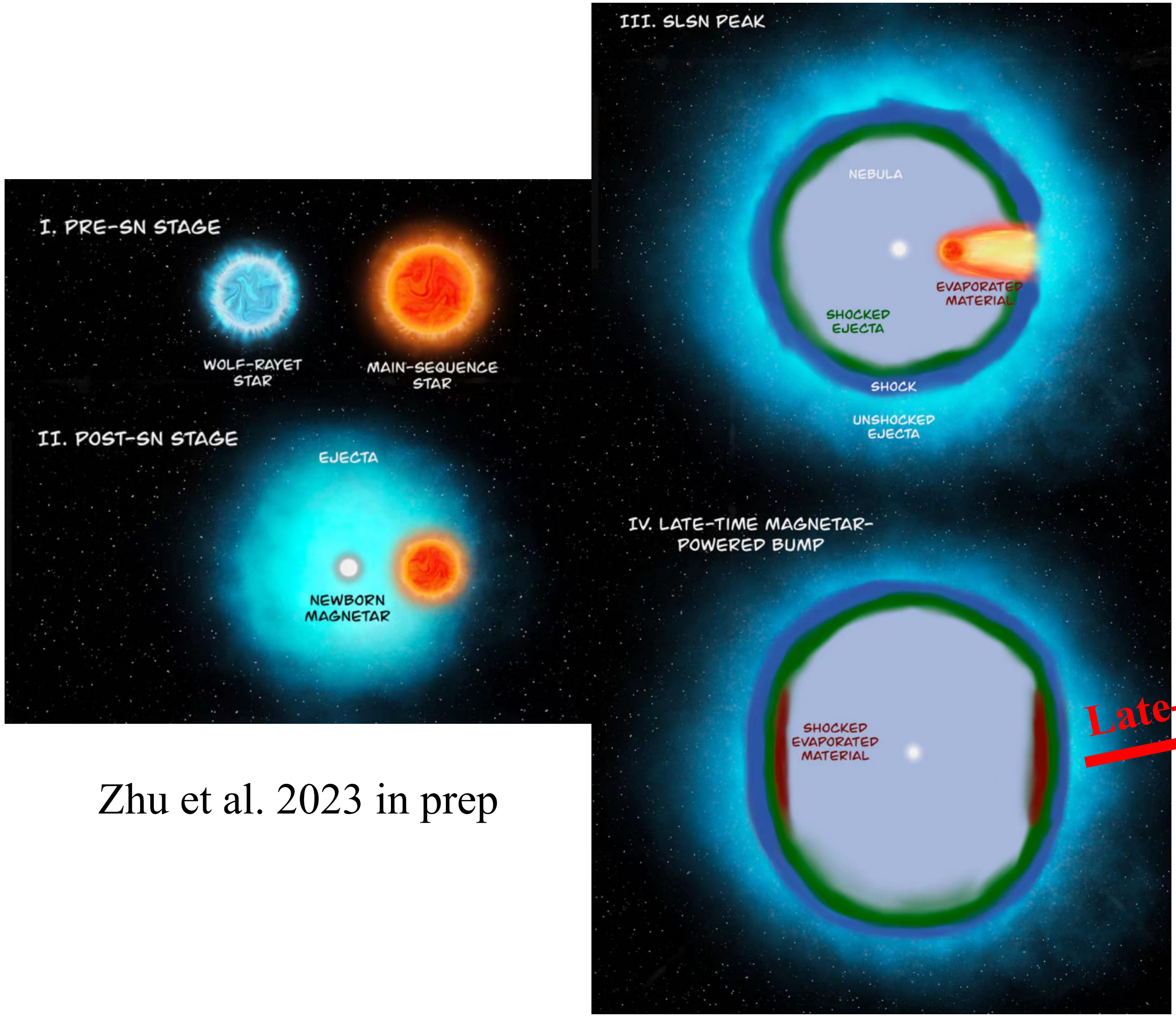




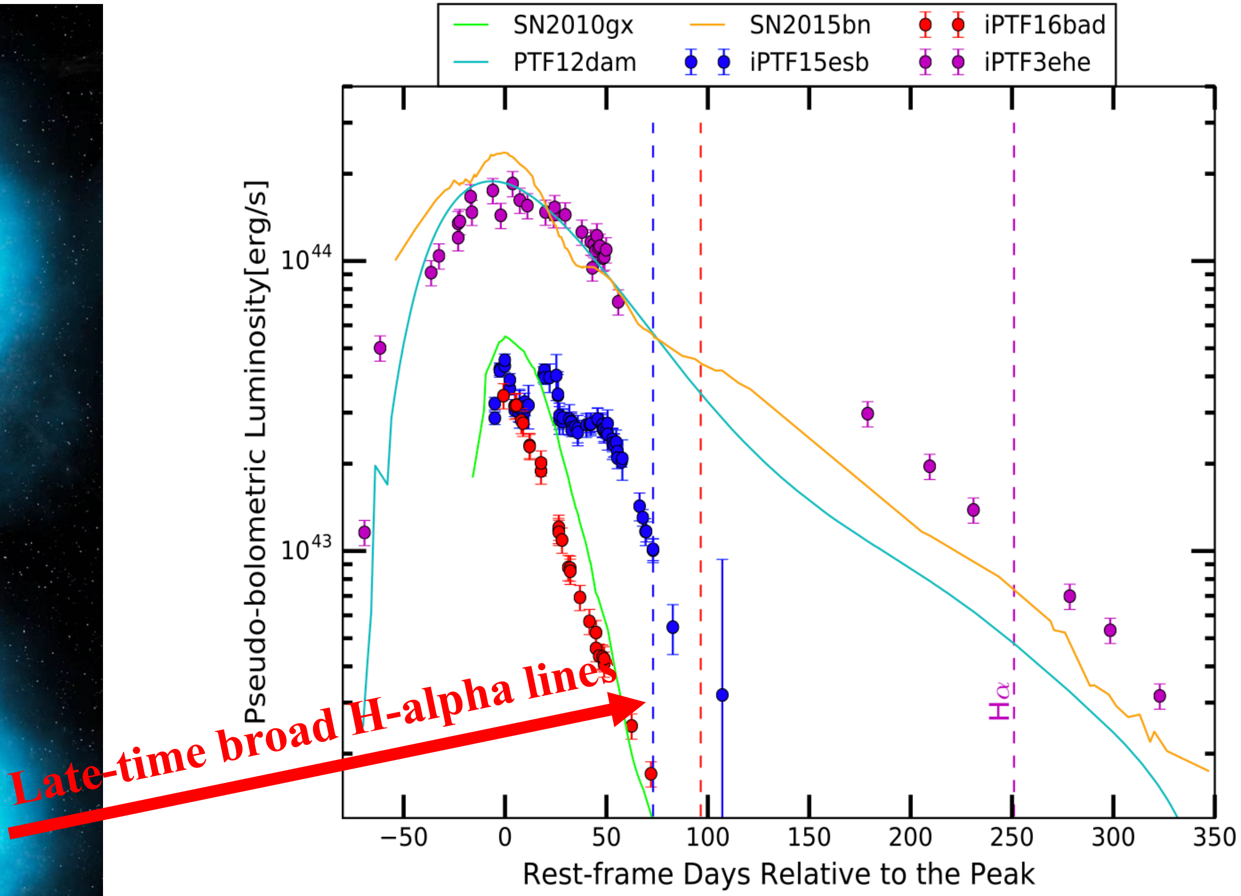
Zhu et al. 2023 in prep

- Main peak: PW heats the ejecta
- Late-time bump: PW heats the evaporated materials and ejecta

MS companion could result in SLSN bumps



Zhu et al. 2023 in prep



Yan et al. (2015, 2017)

Summary

In our unified model, we can conclude

- FBOTs: magnetar-powered ultra-stripped supernovae
- SLSNe, SNe Ic-BL, and GRB-SNe: core-collaspse $M_{\rm He,i} > 5\ M_{\odot}$ helium stars in close binary systems formed through common-envelope evolution and stable mass transfer channel. GRB-SNe progenitors could be more massive.
- We can explain the origin of bumpy SLSNe and late-time broad H-alpha lines.
- These supernovae could be progenitors of NS mergers.

Open question:

Why are SLSNe, SNe Ic-BL, and GRB-SNe different?