Supernova SN 1987A: From progenitor to explosion

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BinCosmos

MoCA
Monash Centre for Astrophysics

The first surprise: the progenitor, Sanduleak -69° 202

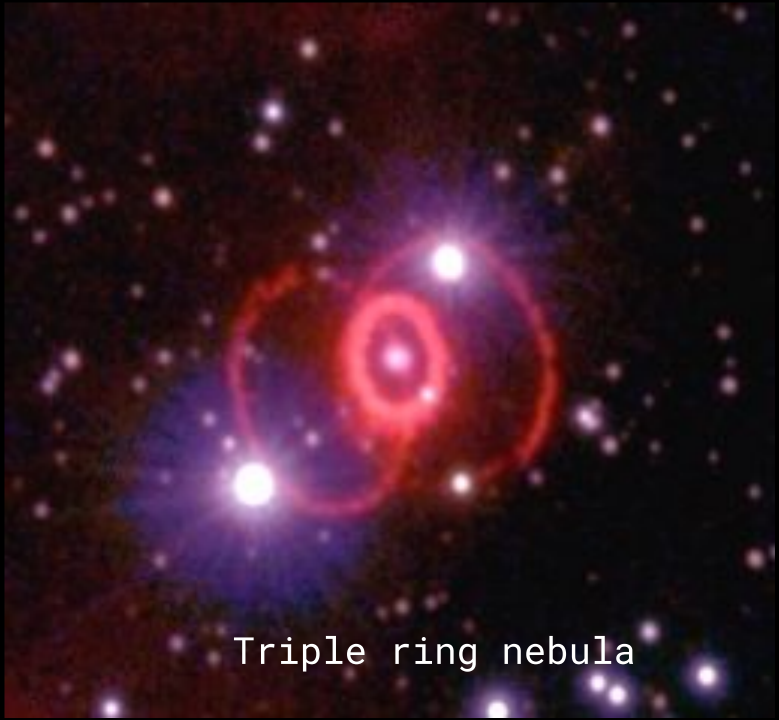
SN 1987A: the most well-observed Type II SN

Location: Large Magellanic Cloud

Progenitor:

Hot, compact, blue supergiant of 30-50 Rsun.

The progenitor, Sanduleak -69° 202

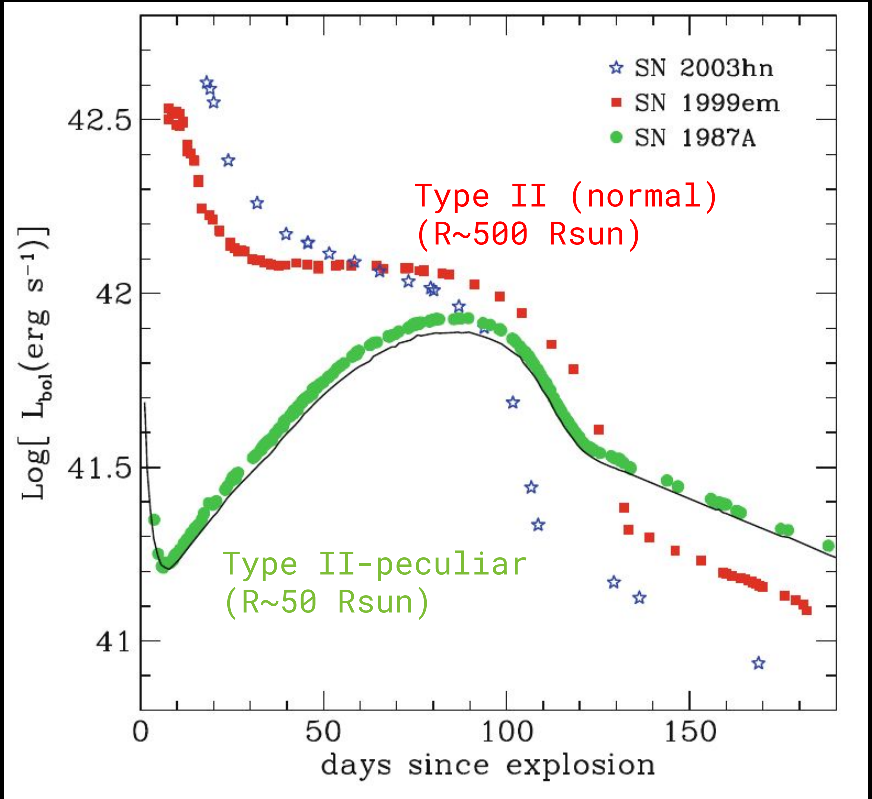


Rings ejected by progenitor 20,000 years before explosion
→ rotating star

Signs of CNO processing (Hydrogen burning): N/O, N/C and He/H ratios in rings

Image: Hubble space telescope

The second surprise: Light curve



Origin of SN 1987A: **Single star approach**

- ‘Force’ a massive star to explode as a blue star→ fine-tuned parameters

- Explosion of BSG single-star models does not reproduce observed light curve

- Single stars of LMC metallicity do not by themselves end their lives as BSGs (Schootemeijer, 2019)

Origin of SN 1987A: **Merger of binary stars**

- Over 50% of massive stars are in binary systems
- Binary merger scenario for progenitor proposed by Joss+ 1989, Podsiadlowski+ 1990, 1992
- 3D simulations of merger (Ivanova et al. 2002, 2003)
- Under what circumstances, can a merger produce a BSG for 87A?
- Can its explosion reproduce the light curve?

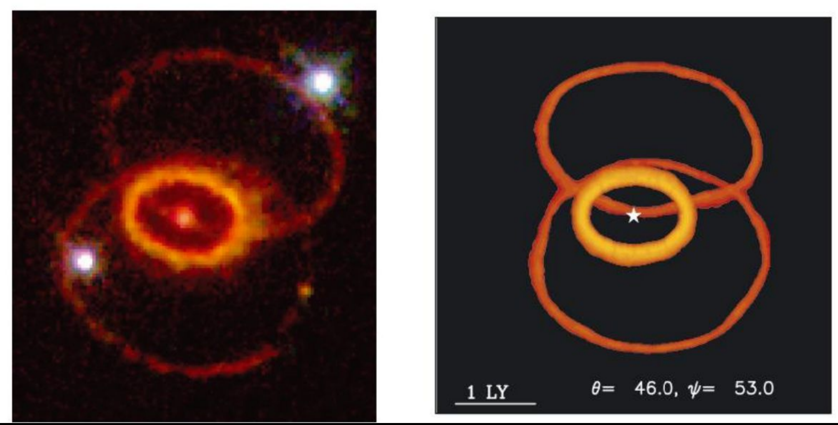
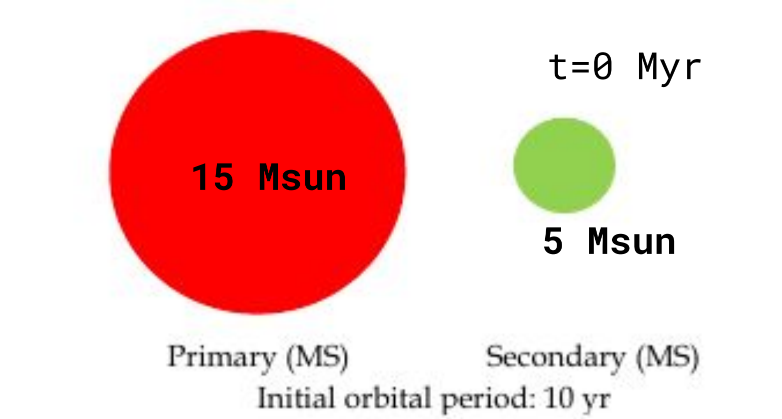


Image from Hubble space telescope (left) and from 3D hydrodynamic simulation of Morris & Podsiadlowski (2009) (right)

A late binary merger scenario



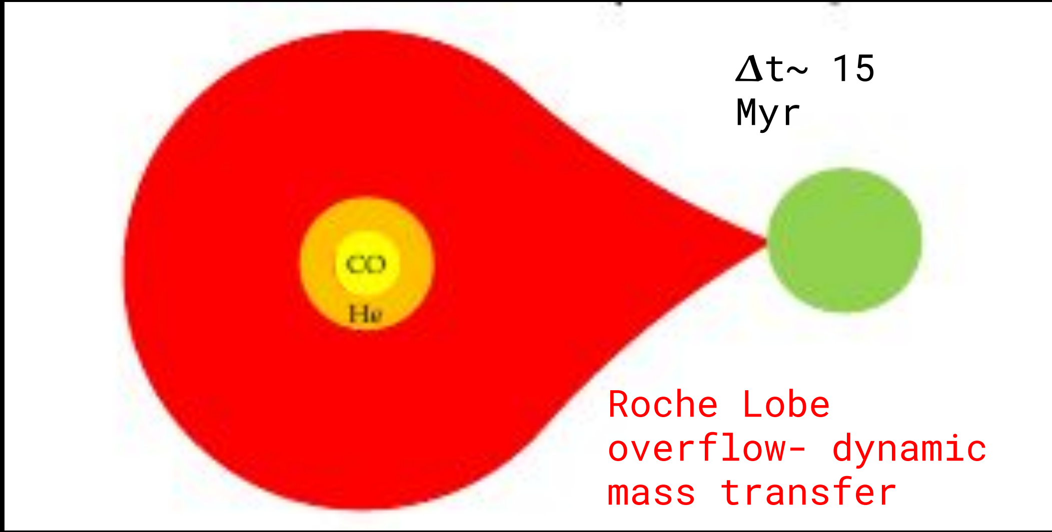
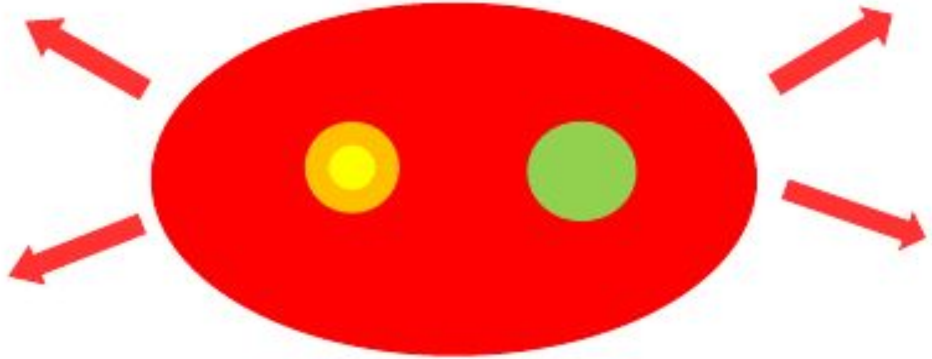


Figure from Menon, PhD thesis
Based on Podsiadlowski 1992
and Podsiadlowski 2007

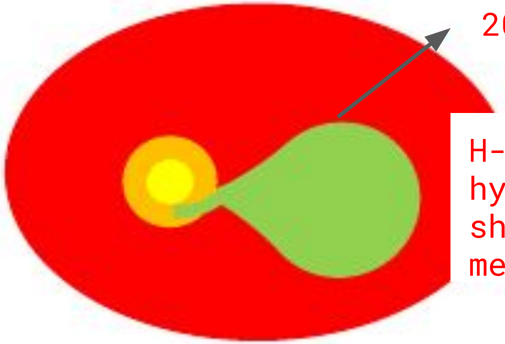


Common envelope phase
Partial ejection of envelope

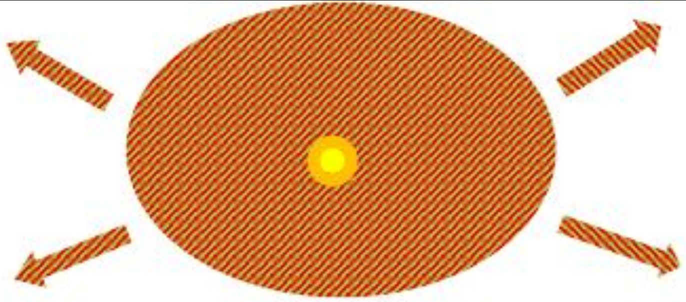
Mixing of H-rich material into He/CO core (Ivanova et al. 2003)

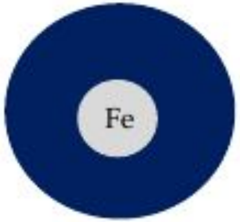
Merger!

Δt=100 yr



H-free core: where no hydrogen is present→ shrinks in mass after merger





Structure contracts and explodes as a **blue supergiant**

1 D model of merger and post-merger evolution

Initial parameters

-M1: 15,16,17,18 Msun (rotating at 30% critical rate)

-M2: 2,3,…, 8 Msun

- fc: fraction of He core-dredged up

Stellar evolution code

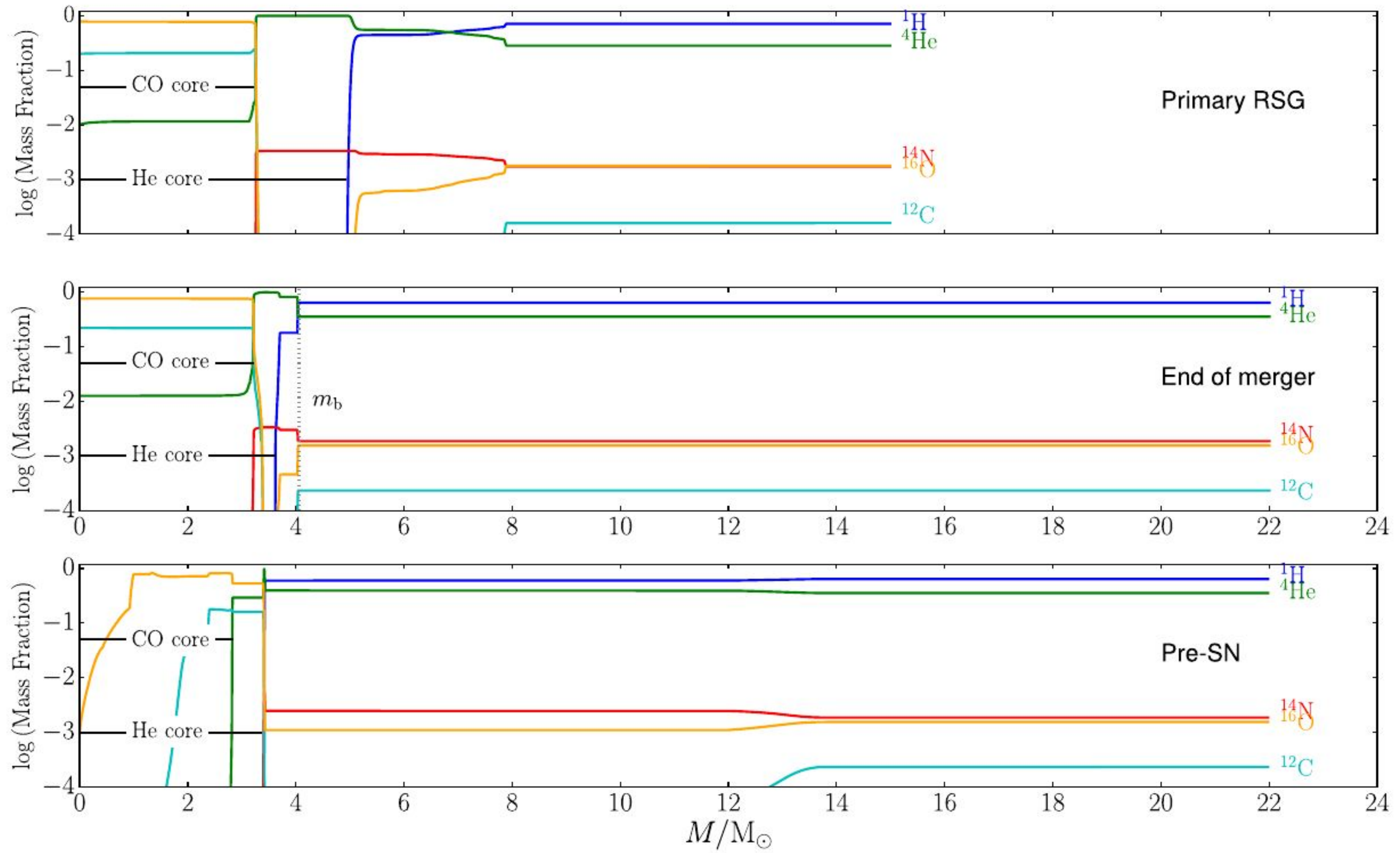
KEPLER (1D stellar evolution code

Heger et al. 2002
Woosley et al. 2002
Woosley & Heger 2007)

Explosion

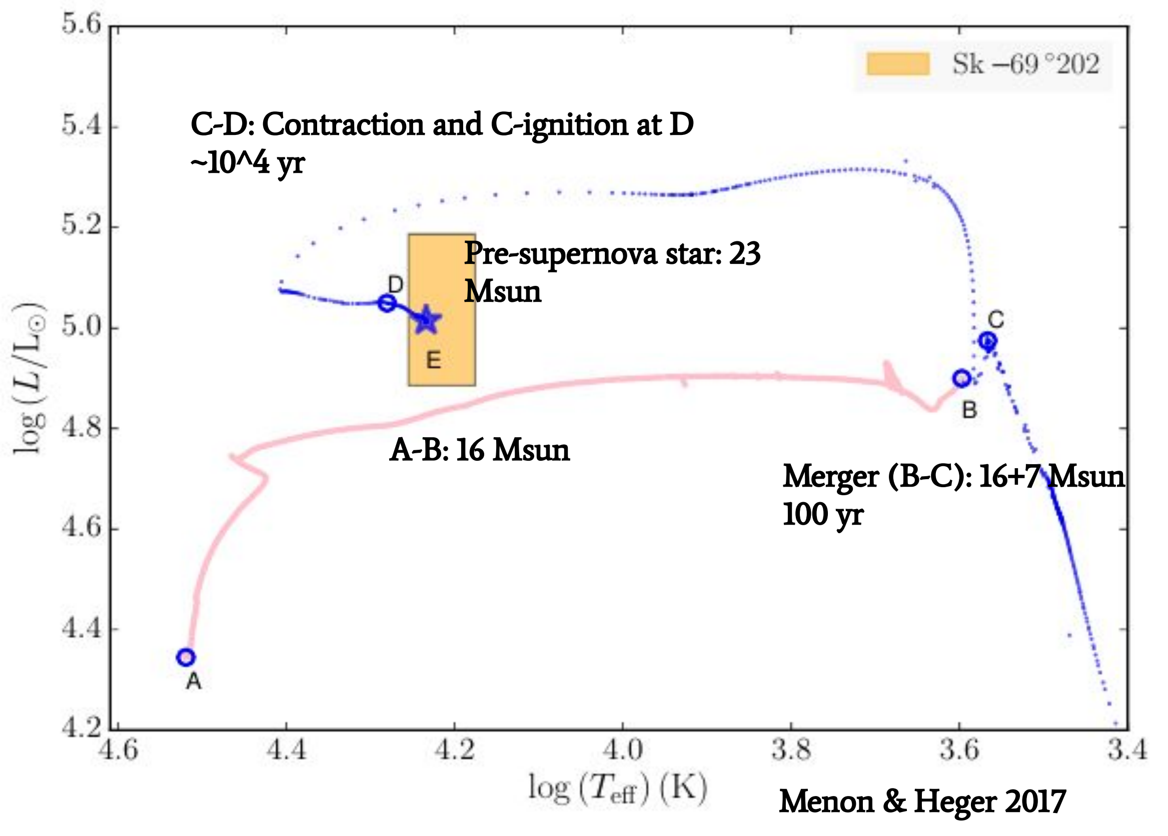
- 1D radiative hydrodynamics code, (Utrobin 2004, 2007)

- 3D hydrodynamic simulations, (Utrobin, Wongwathanarat, Janka et al. in prep)



Primary RSG
End of merger
Pre-SN
log (Mass Fraction)
CO core
He core
m_b
^{1}H
^{4}He
^{14}N
^{16}O
^{12}C
$M/M_\odot$

Stellar evolution of a 16+7 Msun system



Checks for the progenitor model :

- HRD position
- Lifetime of BSG phase: 15,000-50,000 years
- Nuclear abundances in rings

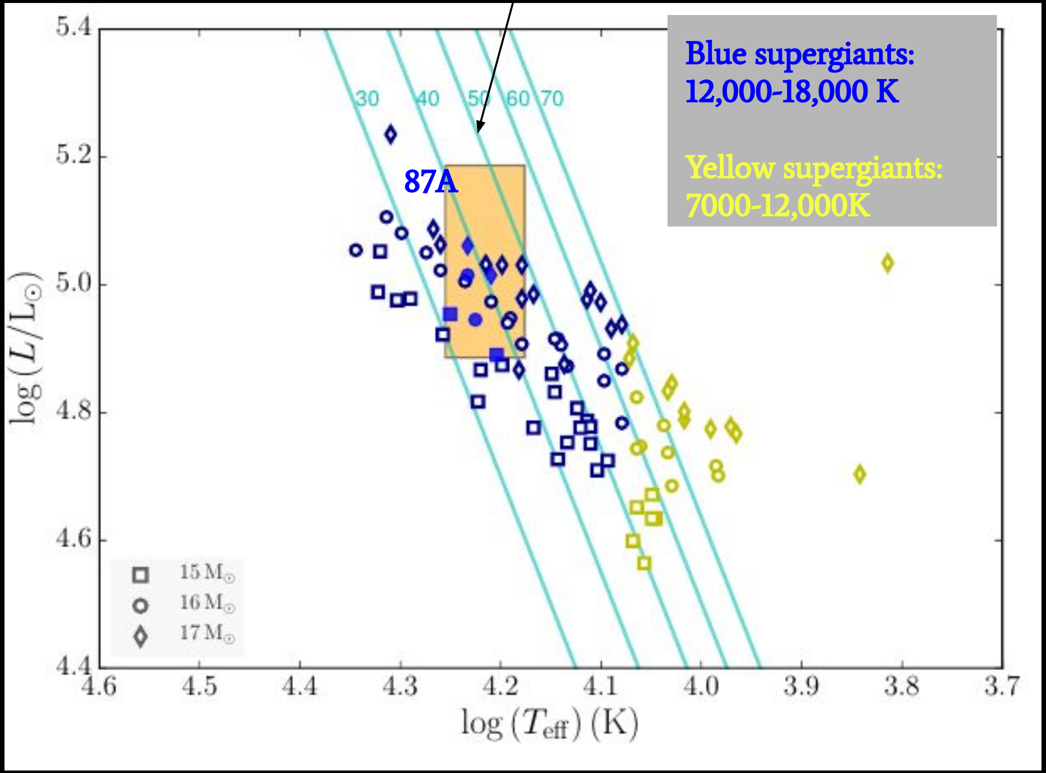
Pre-supernova models from mergers

- BSGs Type II progenitors are very likely from binary mergers

- Of the 84 models computed, 56 were blue supergiants;

  6 matched the progenitor of '87A (filled blue symbols)

- No red supergiants from our grid!



Menon & Heger 2017

Light curves

Observational constraints for explosion

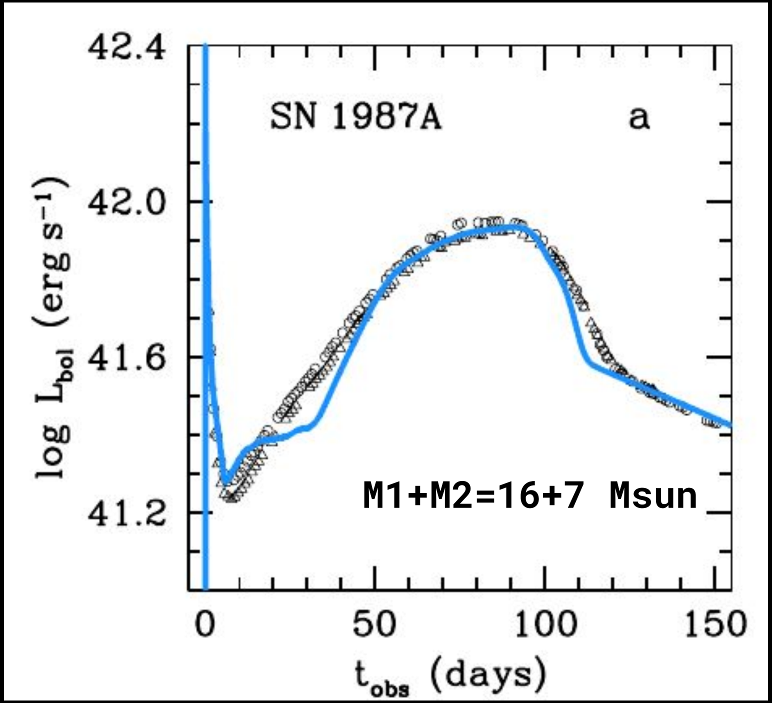
-56Ni mass is 0.075MSun

-Maximum velocity of the bulk of 56Ni reaches 3100 km/s

-Mass of hydrogen mixed within 2000 km/s is 2.2Msun

-Oxygen mass in the SN ejecta is between 0.7 to 2.0MSun

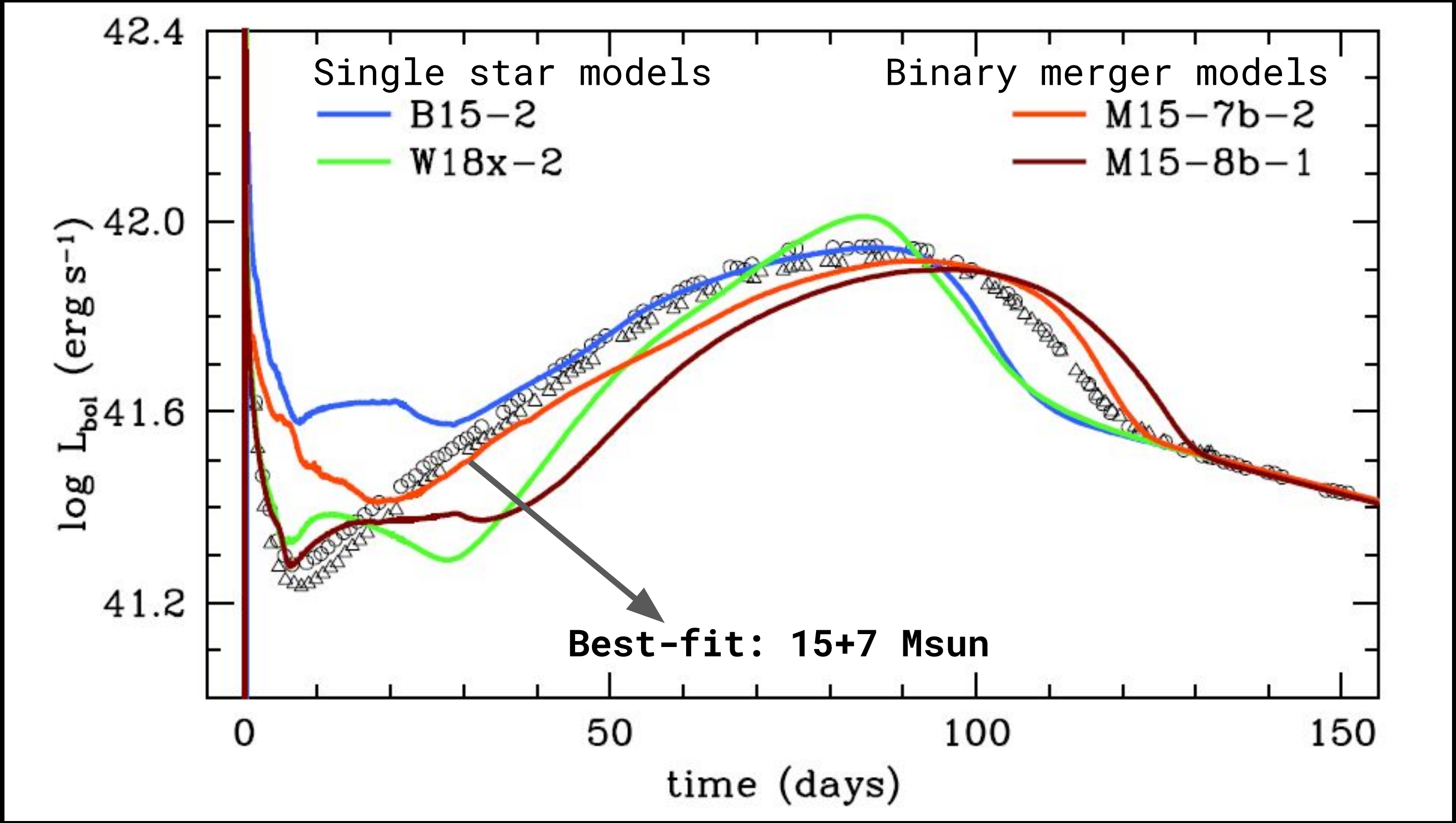
1D explosion of binary merger progenitor (Menon, Utrobin, Heger 2019)



- 1D radiative hydrodynamics (piston) code

- Set mixing requirements
- Set Ni mass
- Set explosion energy

3D + 1D explosions for 87A
(Utrobin, Wongwathanarat, Janka et al. in prep)



Final thoughts

- First progenitor + light curve models from a binary merger for SN 1987A
- Most likely progenitor for SN 1987A:
  15+7 Msun, with R=30Rsun,
  E= 1.4 foe,NS mass= 1.5Msun
- More refined progenitor models considering angular momentum evolution
- Follow up studies:
  MPA, Garching: 3D explosions
  MPA, Garching: Gamma-ray & X-ray emission
  NCSU: Nuclear yields (Frohlich+ submitted)