A binary progenitor for the Type Ib Supernova iPTF 13bvn

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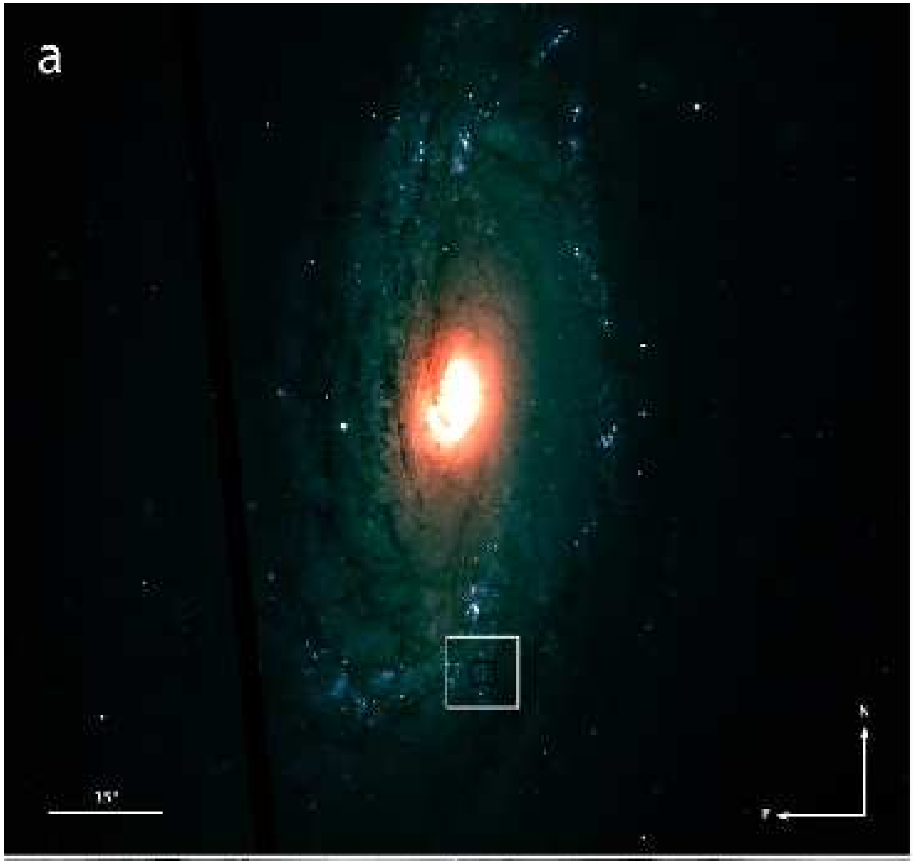
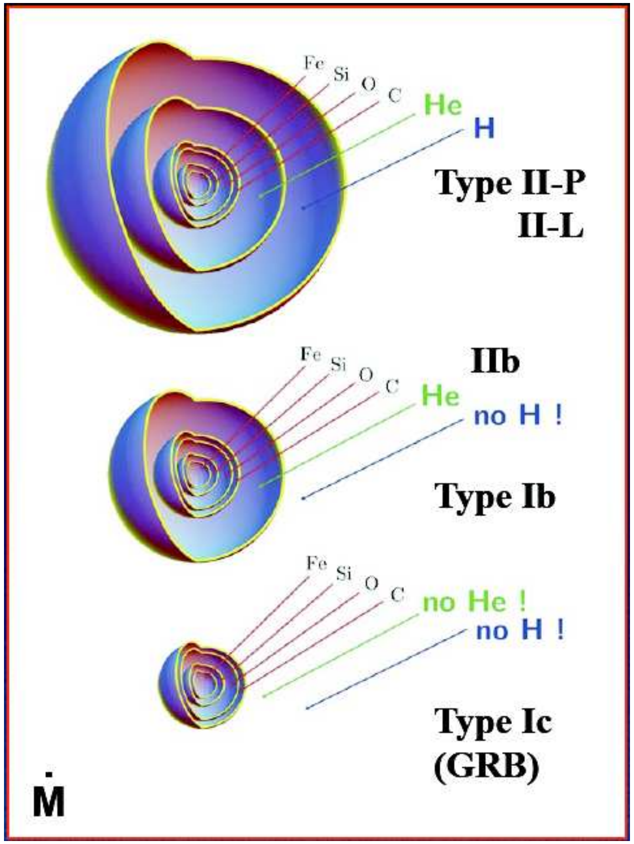


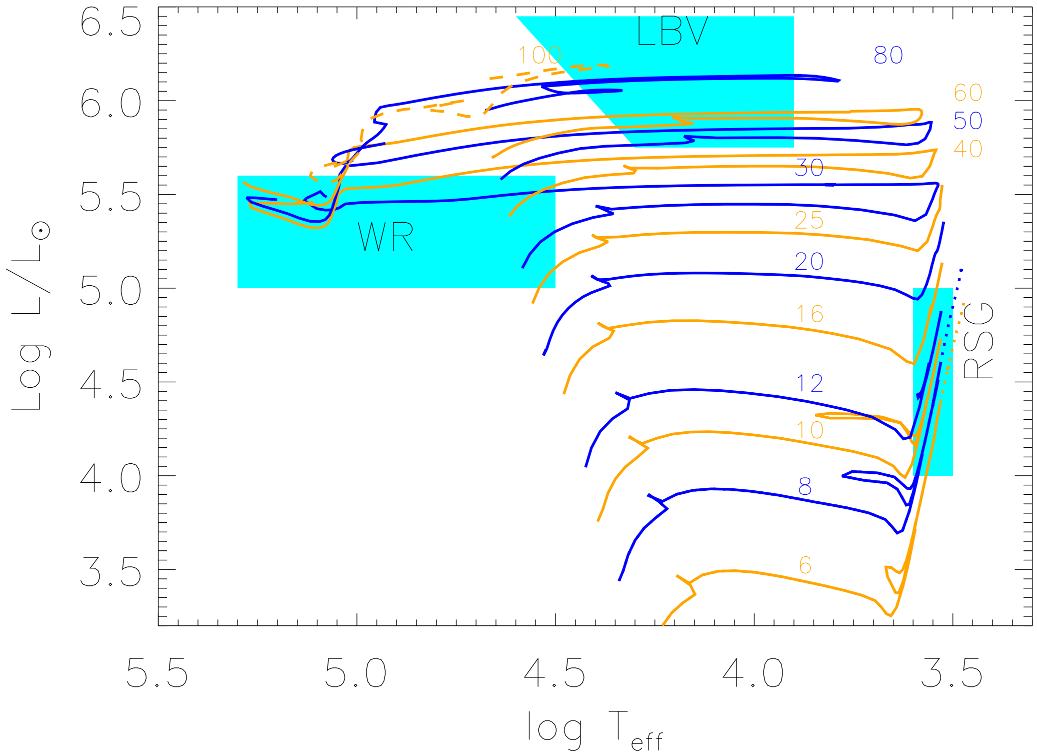
Cao+13

Normal Core-Collapse Supernovae

- End of massive stars ($M_0 \gtrsim 8 M_\odot$)
- Which type of progenitors correspond to each type of SN?
- Isolated stars or interacting binary systems?



Credit: Modjaz

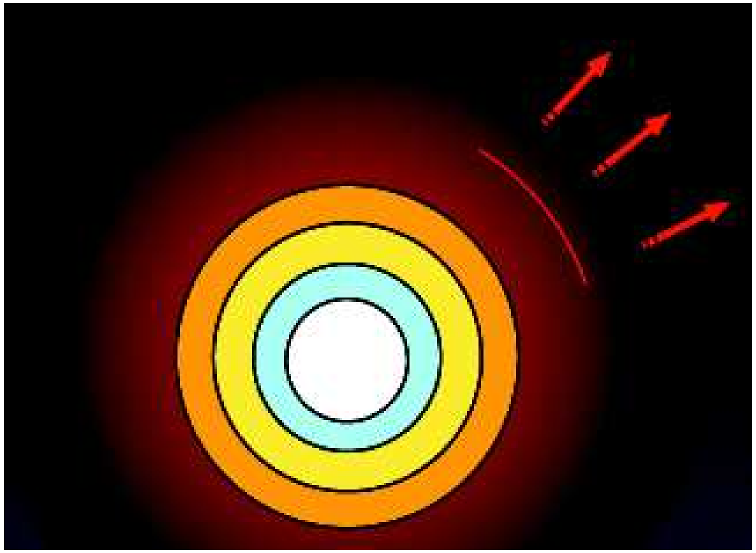


Smartt et al. (2009)

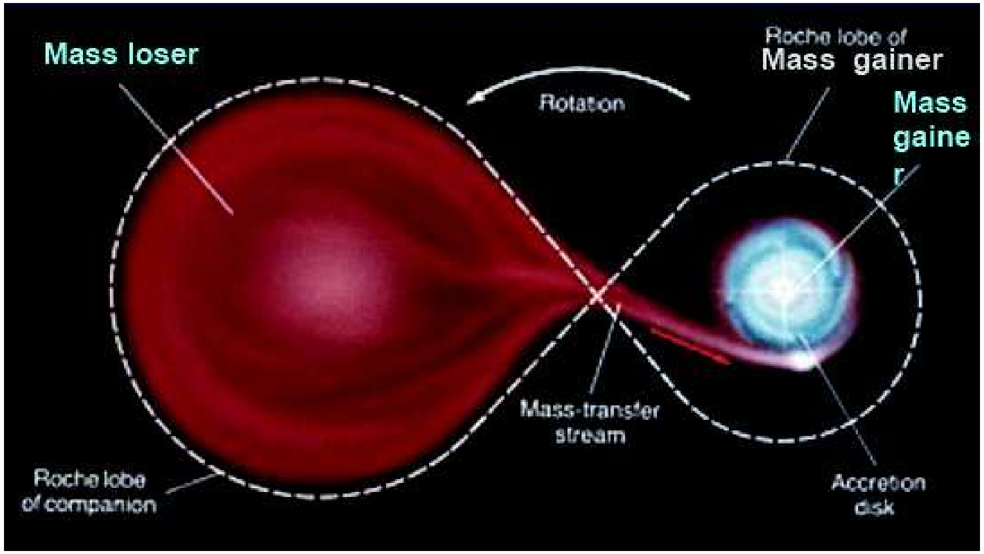
Mass-loss Mechanism

- Single, massive ($\gtrsim 25\ M_\odot$) Wolf-Rayet stars with strong winds
  $\Longrightarrow$ He core mass $\gtrsim 8\ M_\odot$
- Interacting binaries can make lower-mass stars lose their envelopes

Single-star mass-loss

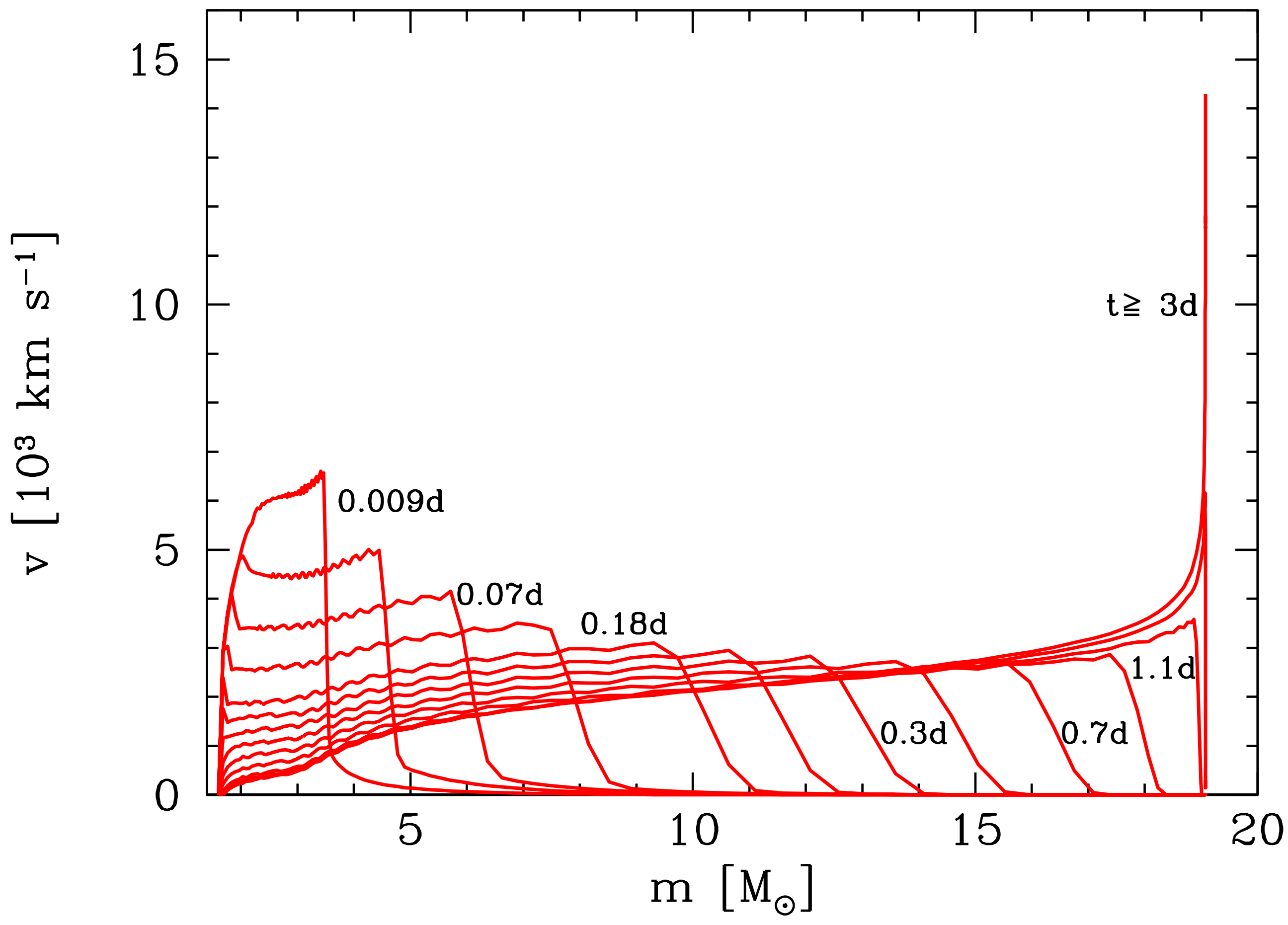


Binary-star mass-transfer



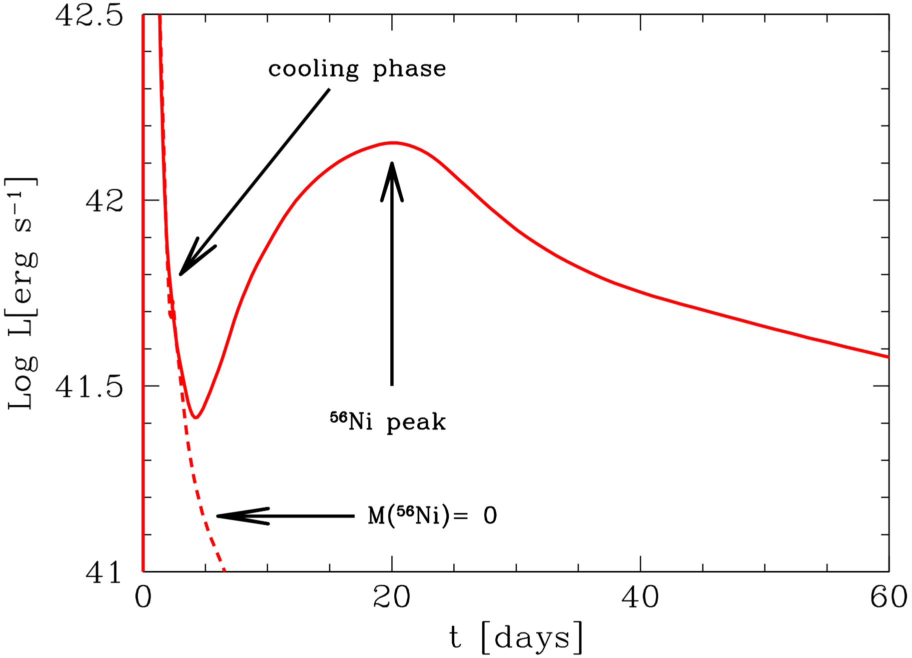
Light curve models

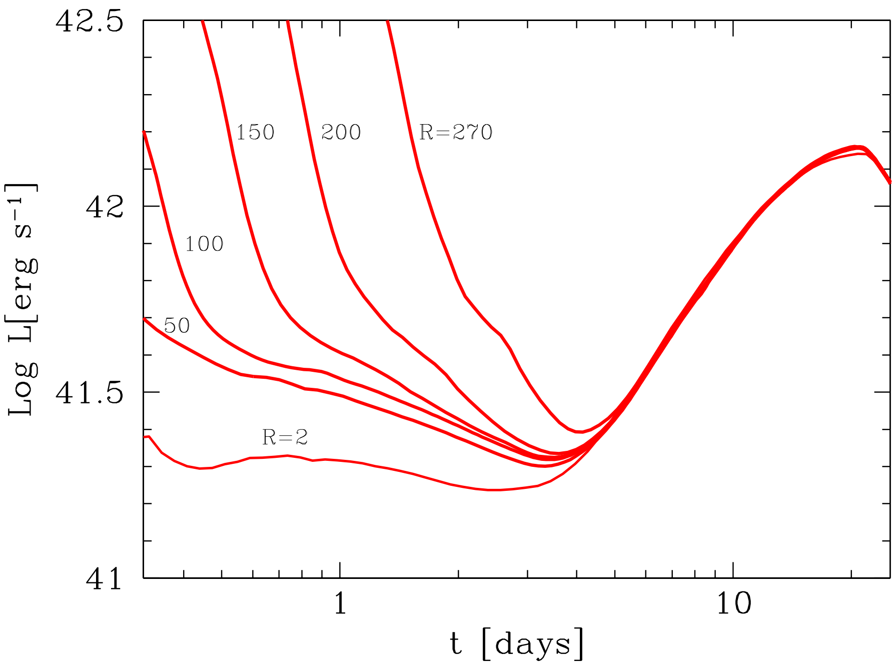
- One-dimensional Lagrangian code with flux-limited radiation diffusion and gray transfer for gamma-rays (Bersten et al 2011)
- Pre-SN model from single stellar evolution



Light curve models

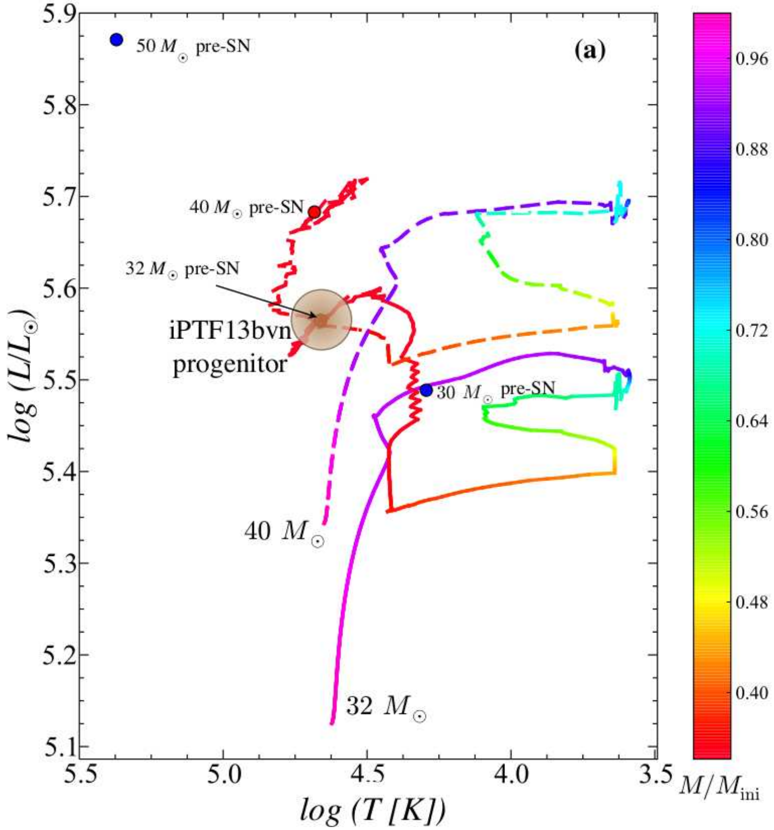
- One-dimensional Lagrangian code with flux-limited radiation diffusion and gray transfer for gamma-rays (Bersten et al 2011)
- Pre-SN model from single stellar evolution: $M_{\mathrm{ZAMS}} = 13,\ 15,\ 18,\ 25\,M_{\odot}$
  $\Longrightarrow$ He stars with masses of $3.3,\ 4,\ 5,\ 8\,M_{\odot}$ (Nomoto et al.)





The Type Ib iPFT13bvn

- Discovered very soon after explosion (NGC 5806, $d \sim 25.54$ Mpc)
- Possible progenitor identified in HST pre-SN images (Cao+13)
- Non-rotating WN star of $M_{\rm ZAMS} \approx 32 M_\odot$ fits the photometry (Groh+13)



- Very hot and luminous star ($\log(L/L_\odot) = 5.55$, $T_{\rm eff} = 40,000$ K)
- $M_{\rm pre-SN} \approx 10.9 M_\odot$
- Traces of H ($X_H \sim 10^{-5}$) crucial to reproduce the pre-SN photometry

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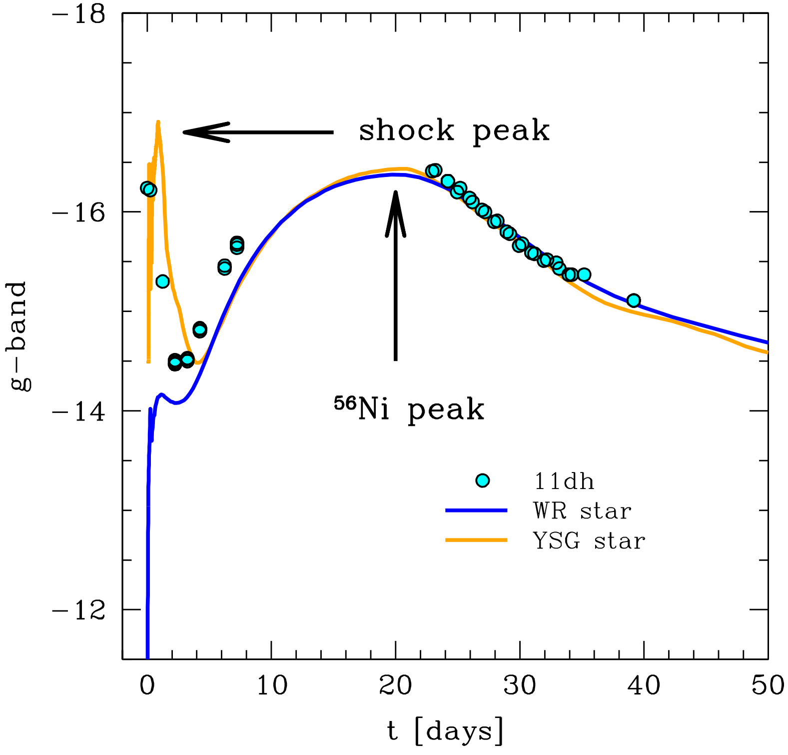
(1) Is such large mass consistent with the SN photometry?

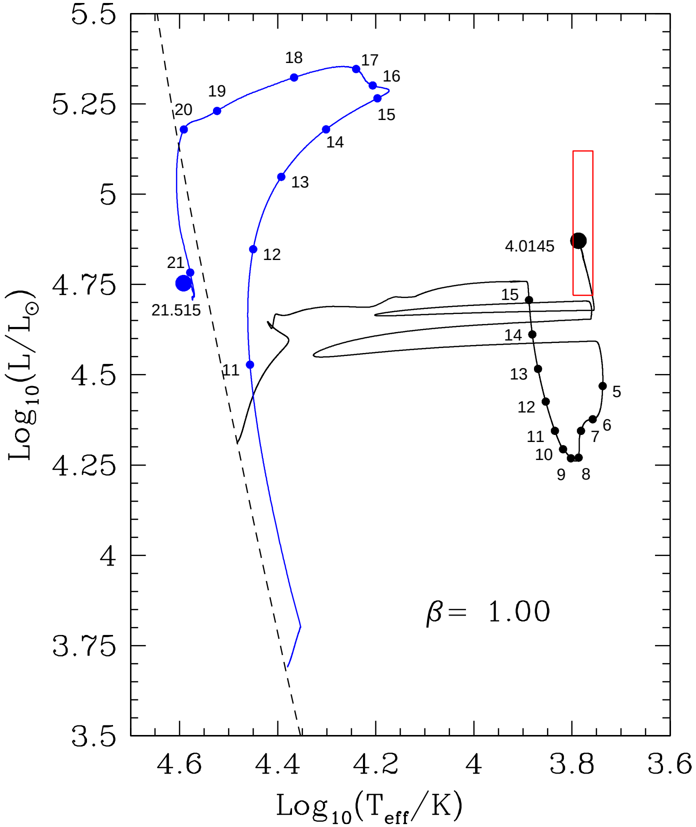
(2) Can lower mass progenitors explain pre-explosion photometry?

(3) iPFT13bvn represents the first direct detection of a SN Ib progenitor?

SN 2011dh

- The first evidence that a yellow supergiant star became a supernova
  - Self-consistent model of explosion and binary evolution
  - Confirmed by disappearance of the YSG (Van Dyk+13, Ergon+14)
  - HST time granted to search for the predicted companion star

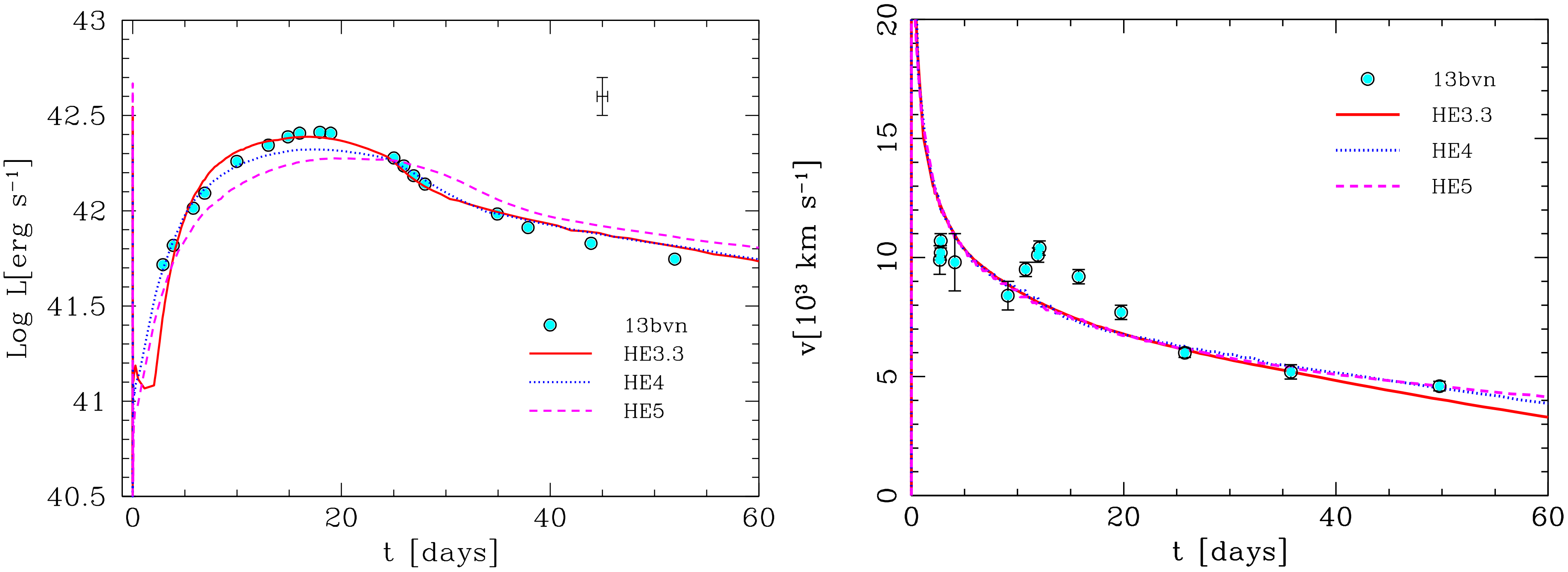




Bersten+12, Benvenuto+13

Hydro model of iPTF13bvn

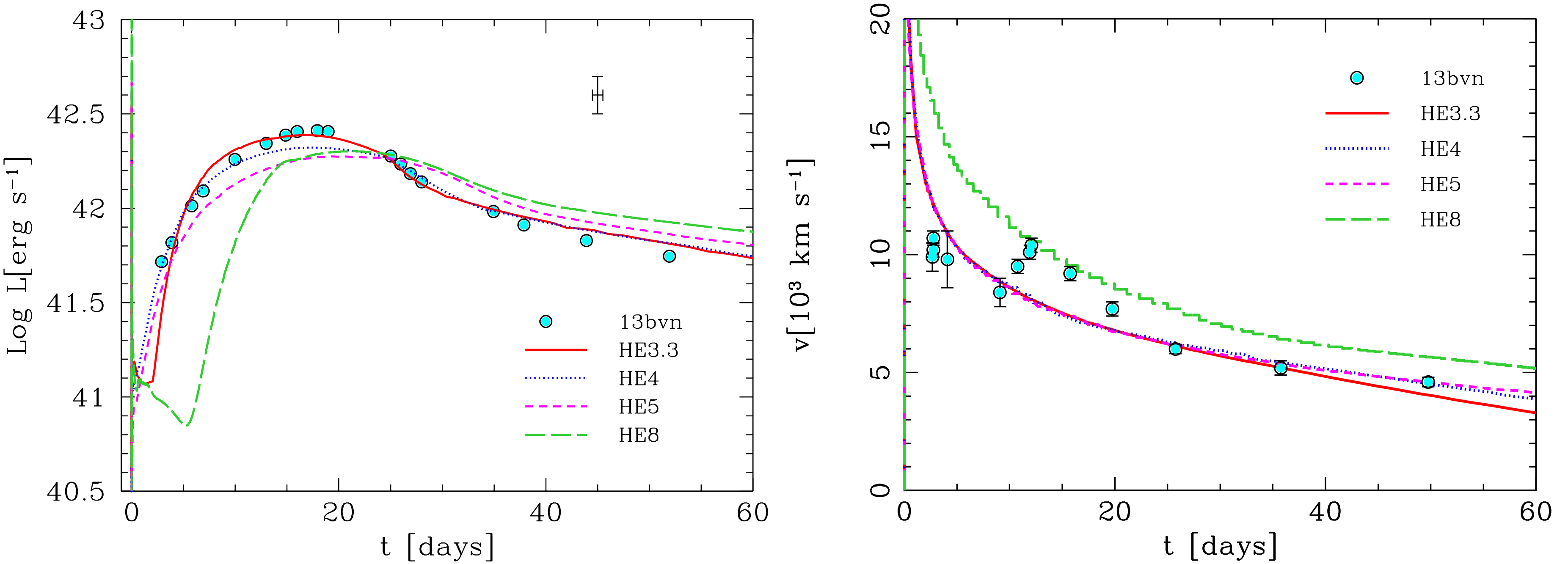
- He core mass $\approx$ 3.5 $M_\odot$ ($M_0 = 12 - 15 M_\odot$) (see also Fremling+14), $E_{\rm exp} = 7 \times 10^{50}$ erg and $M_{\rm Ni} = 0.1\ M_\odot$



Bersten et al subm.

Hydro model of iPTF13bvn

- He core mass $\approx$ 3.5 $M_\odot$ ($M_0 = 12 - 15 M_\odot$), $E_{\rm exp} = 7 \times 10^{50}$ erg and $M_{\rm Ni} = 0.1\ M_\odot$
- He8 ruled out $\Longrightarrow$ $M_{\rm ZAMS} < 25\ M_\odot$ $\Longrightarrow$ suggests a binary progenitor



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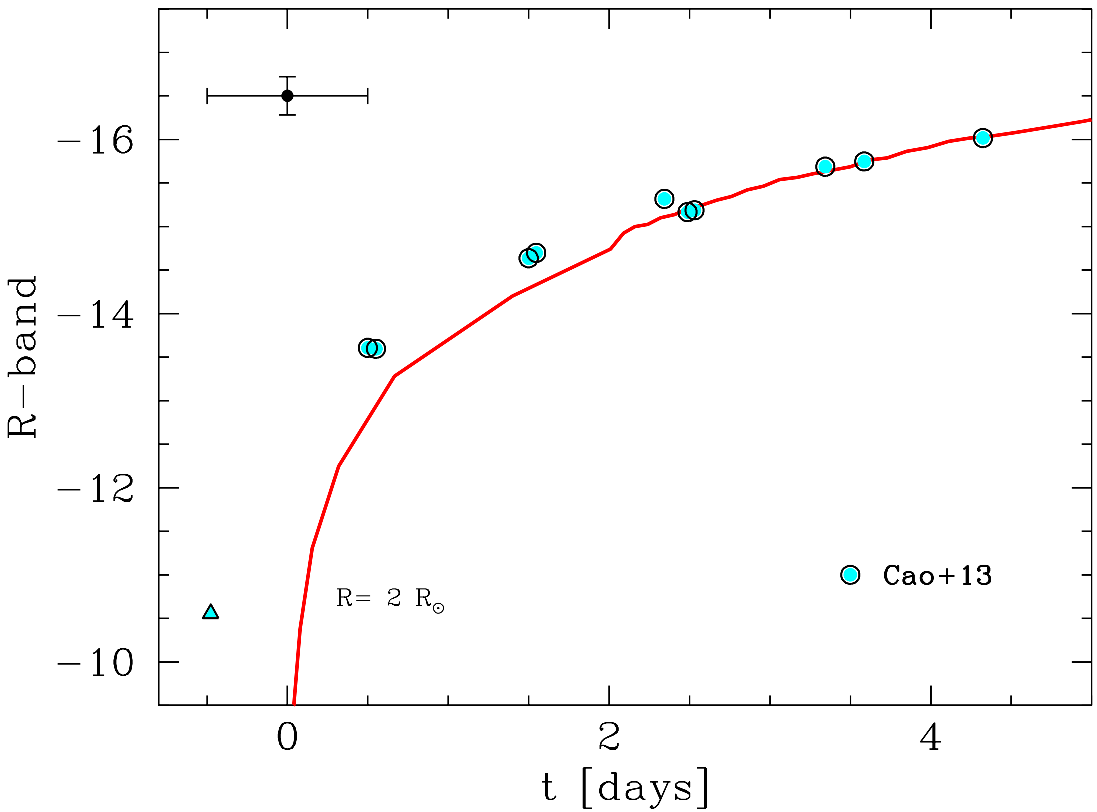
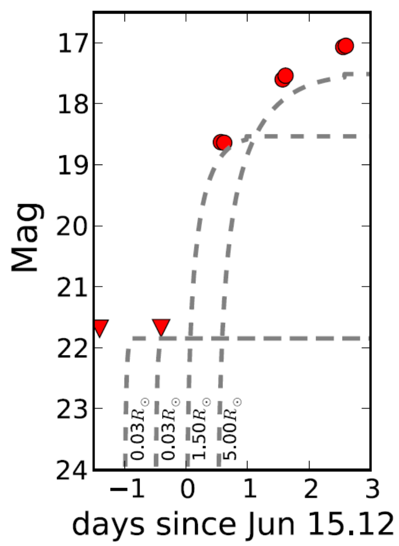
Progenitor Radius

- No evidence of shock cooling $\Longrightarrow R \approx$ a few $R_{\odot}$?





Cao+13

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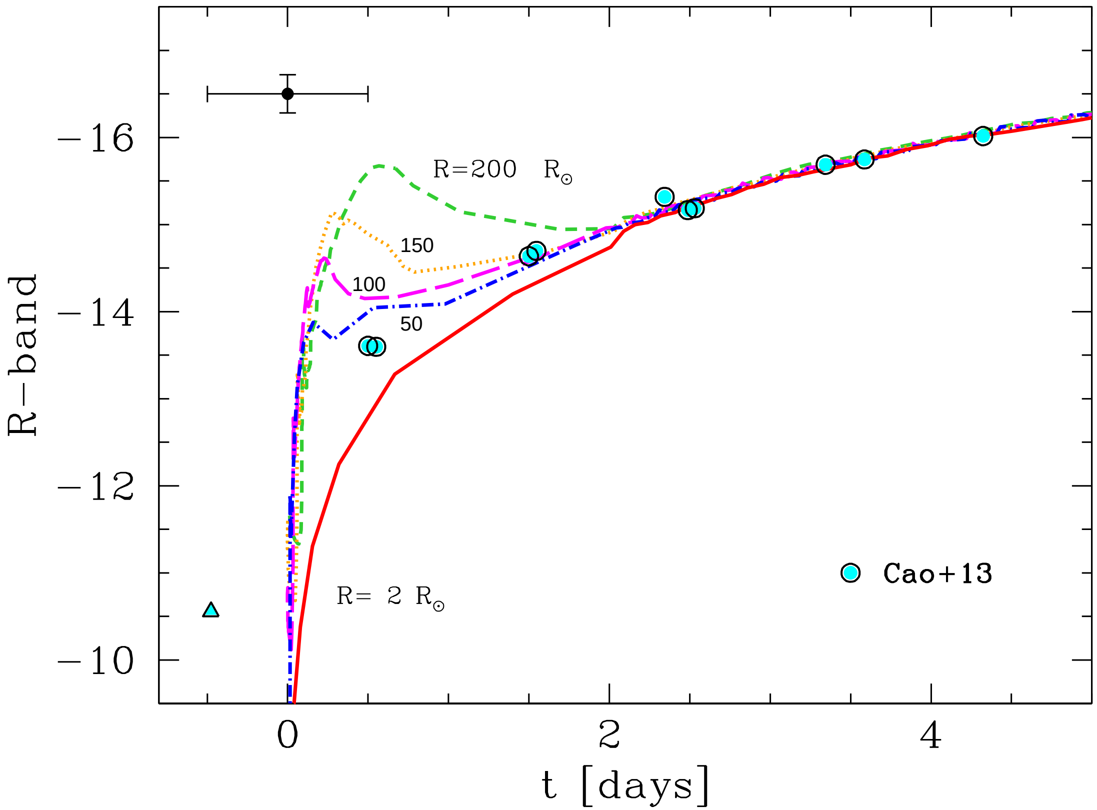
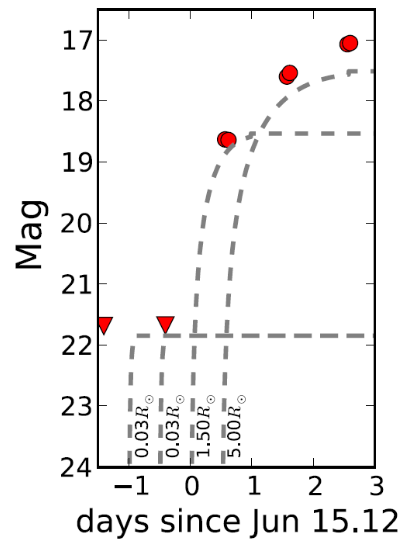
Progenitor Radius

- We tested envelopes of different radii attached to the He4 model
- Progenitors with $R < 150 R_\odot$ are possible
- Even with $t_{\rm exp}$ known to ≈1 day, $R_\odot$ is not well constrained
  $\Longrightarrow$ several observations per night are necessary



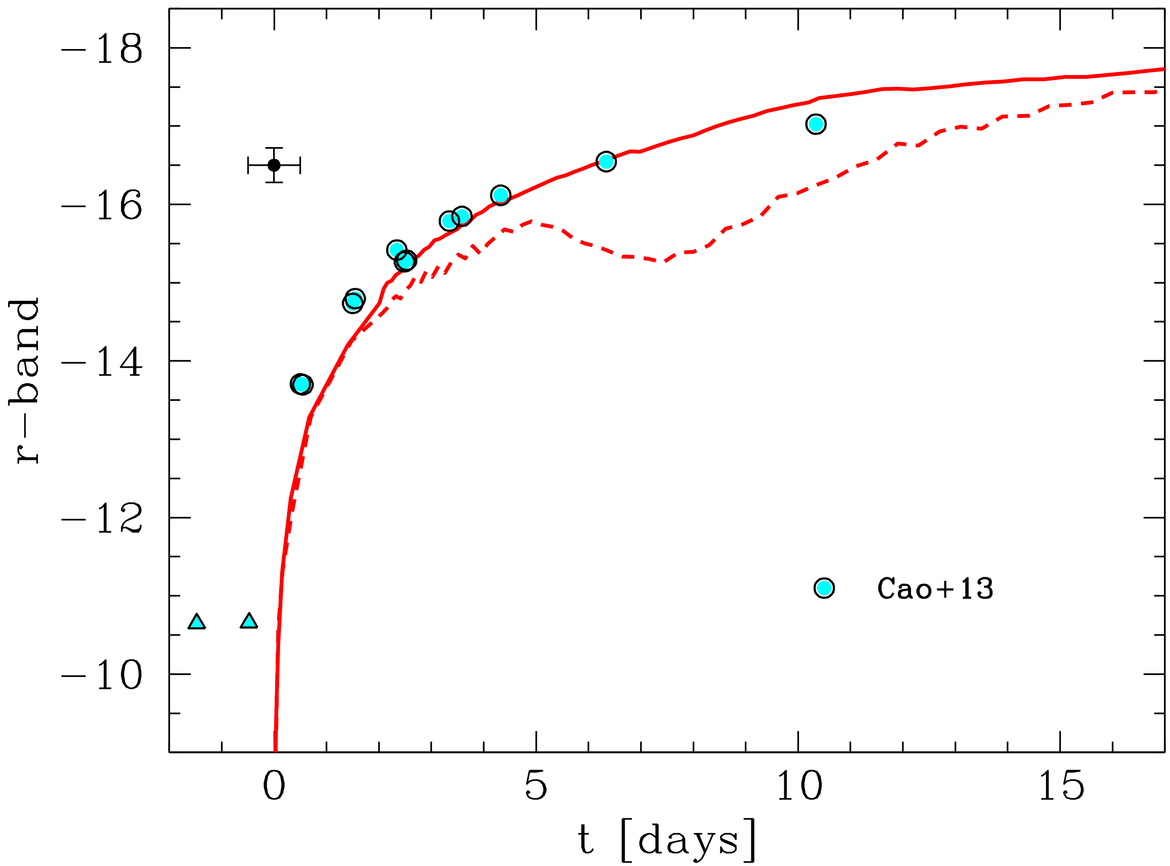
Bersten et al subm.



Cao+13

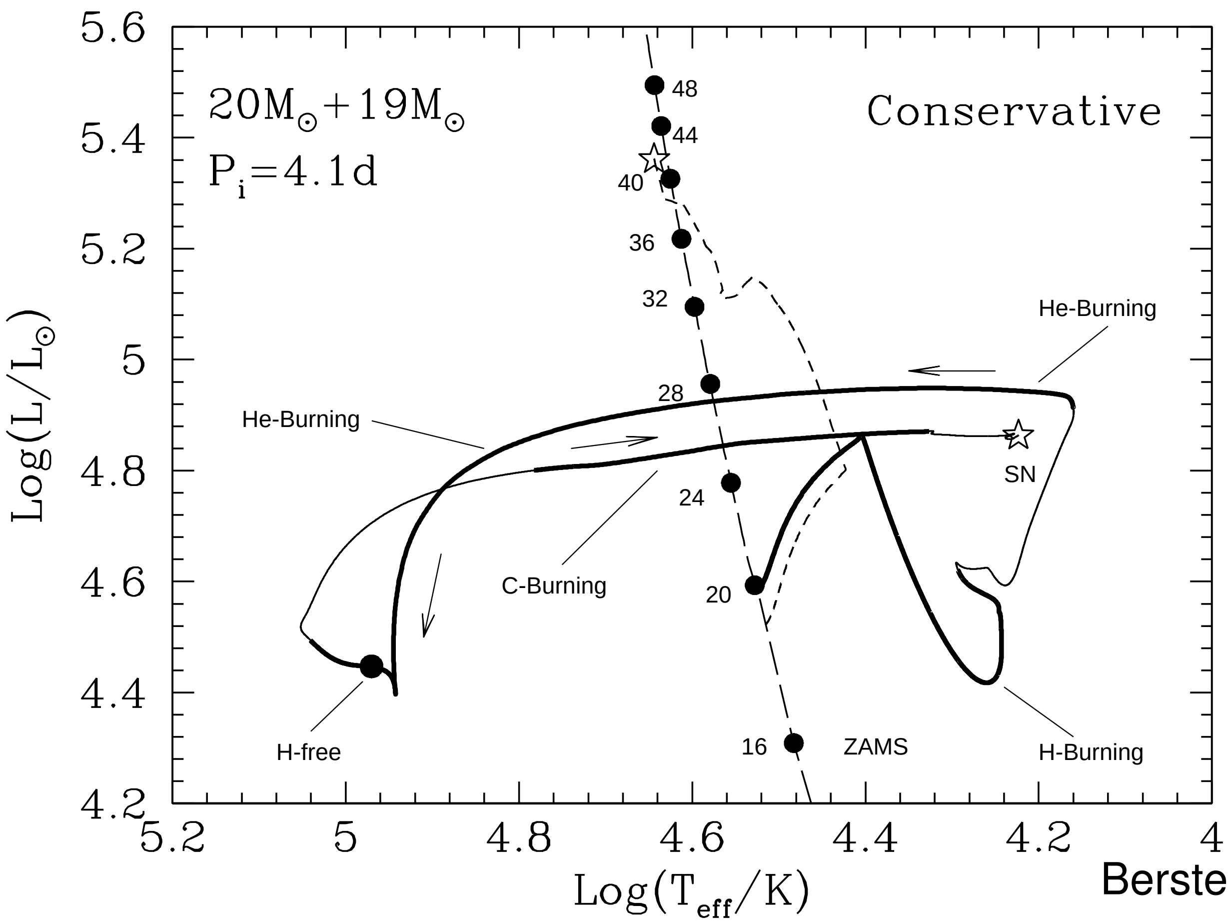
Progenitor Radius

- R-band LC sensitive to ^{56}Ni mixing:
  - Extreme ^{56}Ni mixing model gives a smooth LC
  - Less ^{56}Ni mixing shows an “initial peak”



iPTF13bvn: Binary Evolution

- Primary (donor) star ends with He core mass: $\approx 3.7\ M_\odot$, $R \approx 32\ R_\odot$ and H-free
- Companion star is an over-luminous main-sequence star



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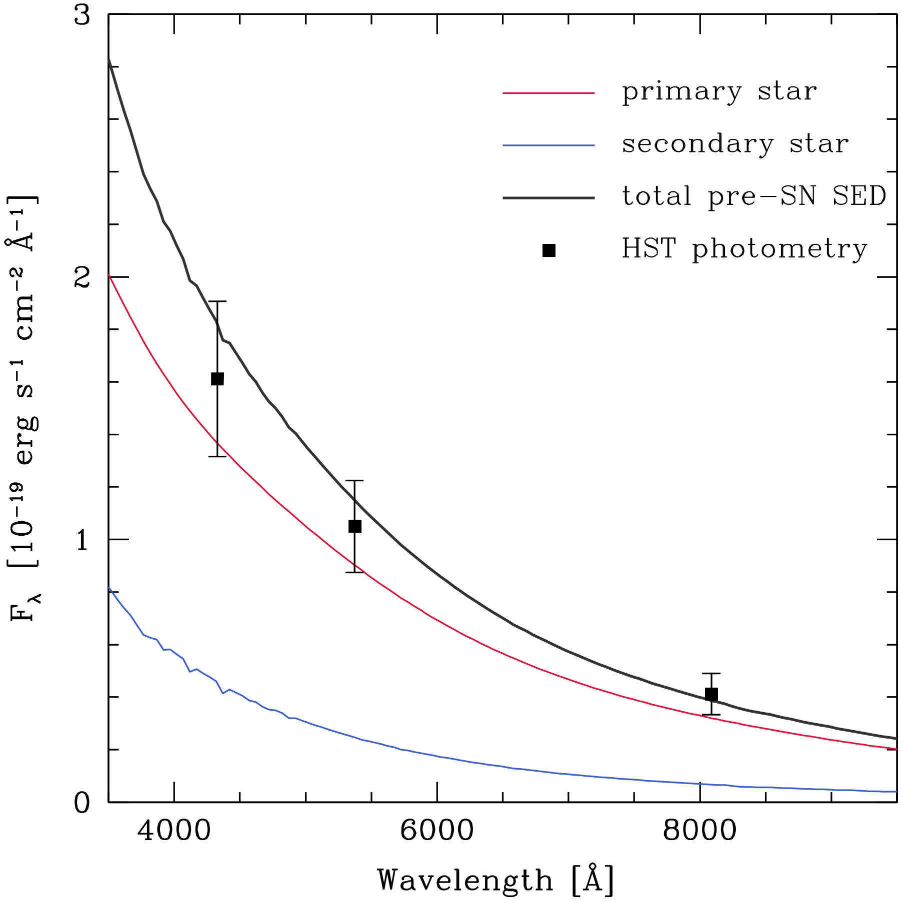
Comparison with pre-SN Photometry

- Our binary configuration is compatible with the HST observations
- Primary star dominates the flux in the optical regime
- Very hot (optically faint) companion star remains



Companion is close to ZAMS and with

$4.6 \lesssim \mathrm{Log}(L_2^{\mathrm{f}}/L_\odot) \lesssim 5.6$

Bersten et al subm.

Summary

- Hydrodynamical models of iPTF 13bvn
  - Models with He core mass of $\approx 3.5 M_\odot$, $E_{\rm exp} = 7 \times 10^{50}$ erg and $M_{\rm Ni} = 0.1 M_\odot$ reproduce very well the observations
  - Extended progenitors ($R < 150 R_\odot$) are consistent with the early light curve $\Longrightarrow$ several observations per night required to distinguish between compact and extended structures
  - He core mass $\gtrsim$ 8 $M_\odot$ ($M_0 \gtrsim$ 25 $M_\odot$) ruled out $\Longrightarrow$ single-star progenitor unlikely
- Binary evolution models of iPTF 13bvn
  - Explain the pre-SN photometry as well as the observed SN properties
  - Predicts the existence of a very hot companion star
- iPTF 13bvn could represent the first robust identification of a H-free SN progenitor.

Initial Density Profile