Early-time spectroscopic properties of core-collapse supernovae and impostors

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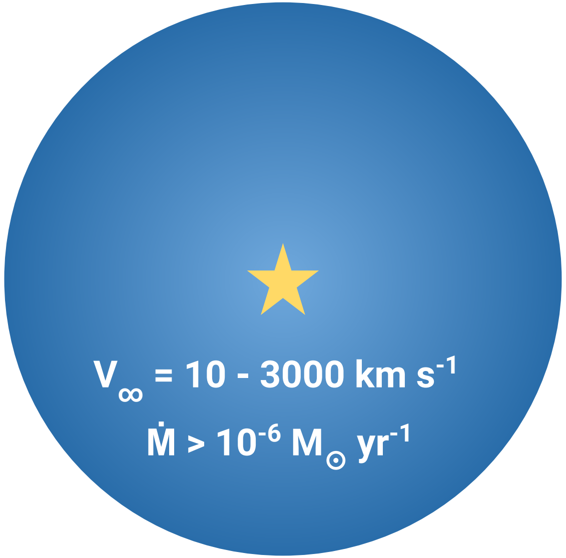
Boian & Groh 2019
Boian & Groh 2018

Overview

I. Supernovae interacting with their progenitors
II. Radiative transfer using CMFGEN
III. Diversity of early-time spectra of supernovae
IV. The progenitor of SN 2015bh
V. Summary and conclusions

Supernovae interacting with their progenitors

- Massive stars exhibit strong mass-loss, forming a dense circumstellar material (CSM)



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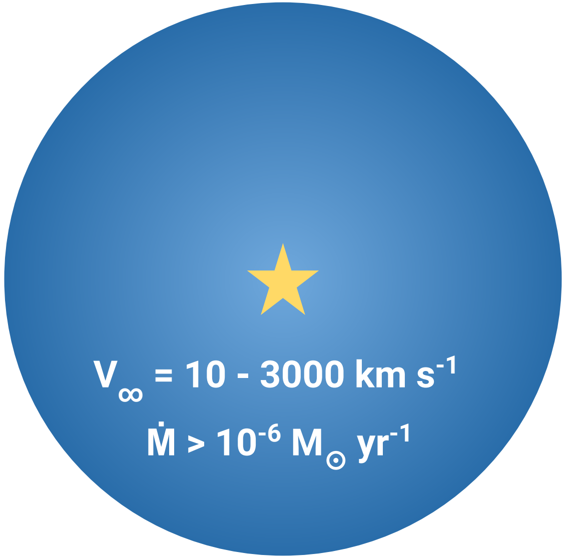
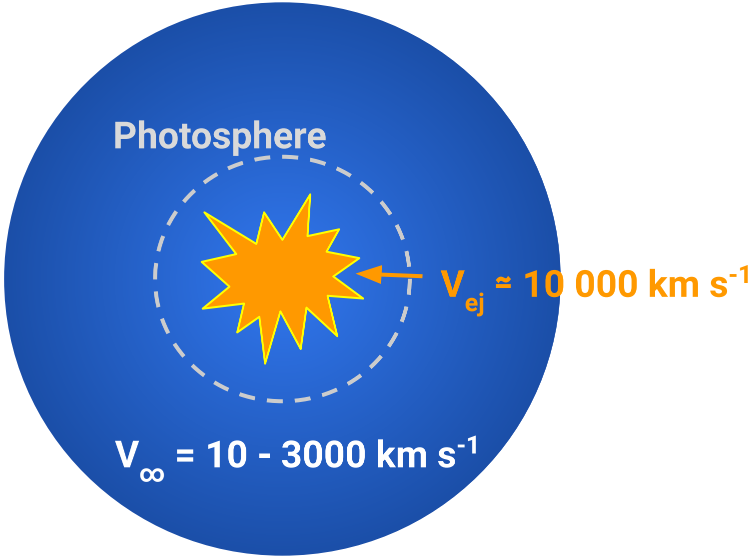


- The SN ejecta crashes into the CSM and the kinetic energy is converted to radiation, which ionises the CSM



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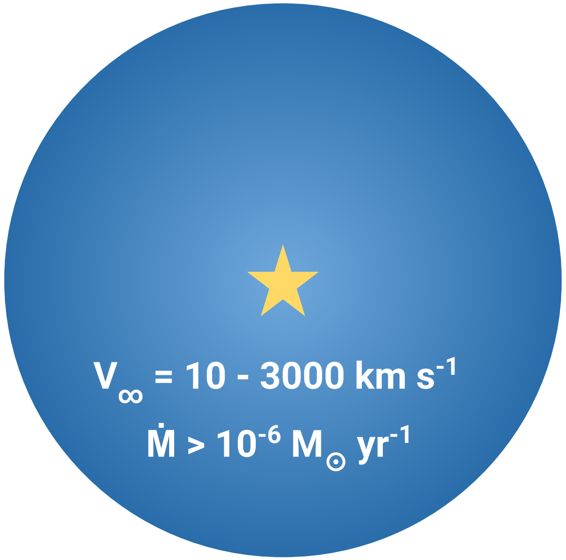

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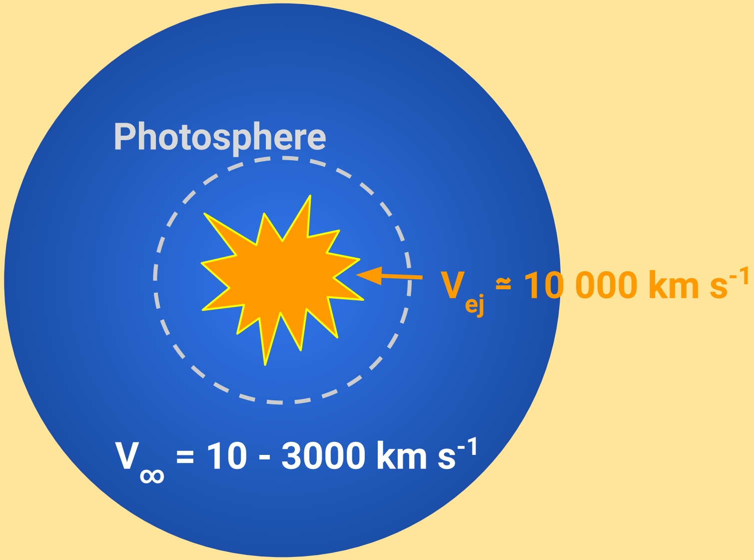
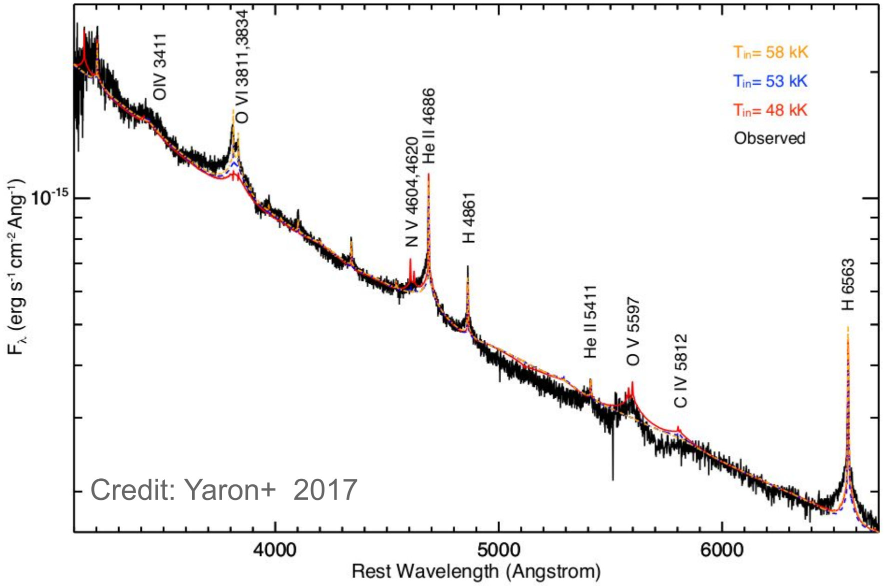


Supernovae interacting with their progenitors

- SN2013fs (Yaron 2017)
- Spectrum 6h after explosion
- Interaction signatures lasted 2 days
- Regular SN II-P after



- Many observed events and more to come with the advent of new facilities such as the Zwicky Transient Facility (ZTF; Bellm & Kulkari 2018; +Avishay's talk) and the Large Synoptic Survey Telescope (LSST; Abell+ 2009)

Radiative Transfer Using CMFGEN

Assumptions:

- Spherical symmetry
- Stationary wind
- Non-LTE

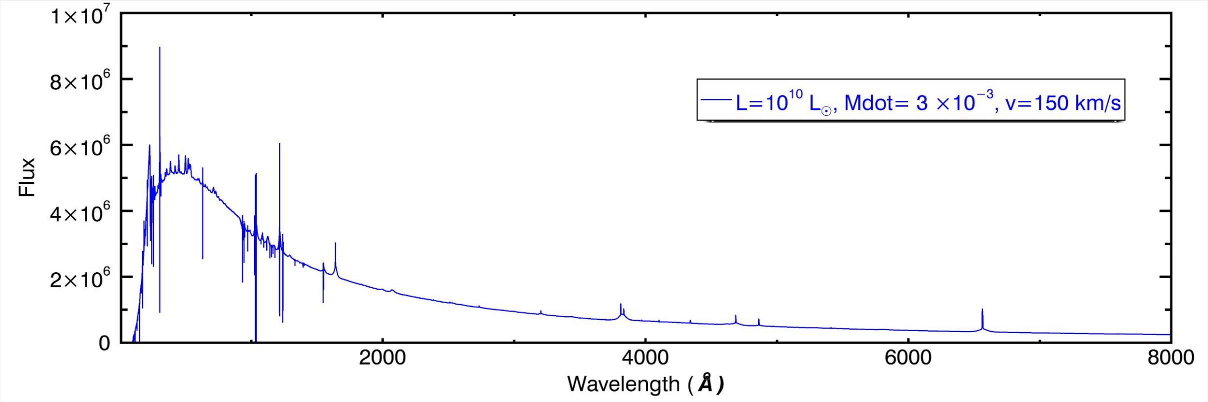
Inputs:

- SN bolometric luminosity
- SN radius
- Progenitor mass-loss rate
- Progenitor wind velocity
- Progenitor surface abundances

Equations:

- Radiative transfer
- Statistical equilibrium

Output:

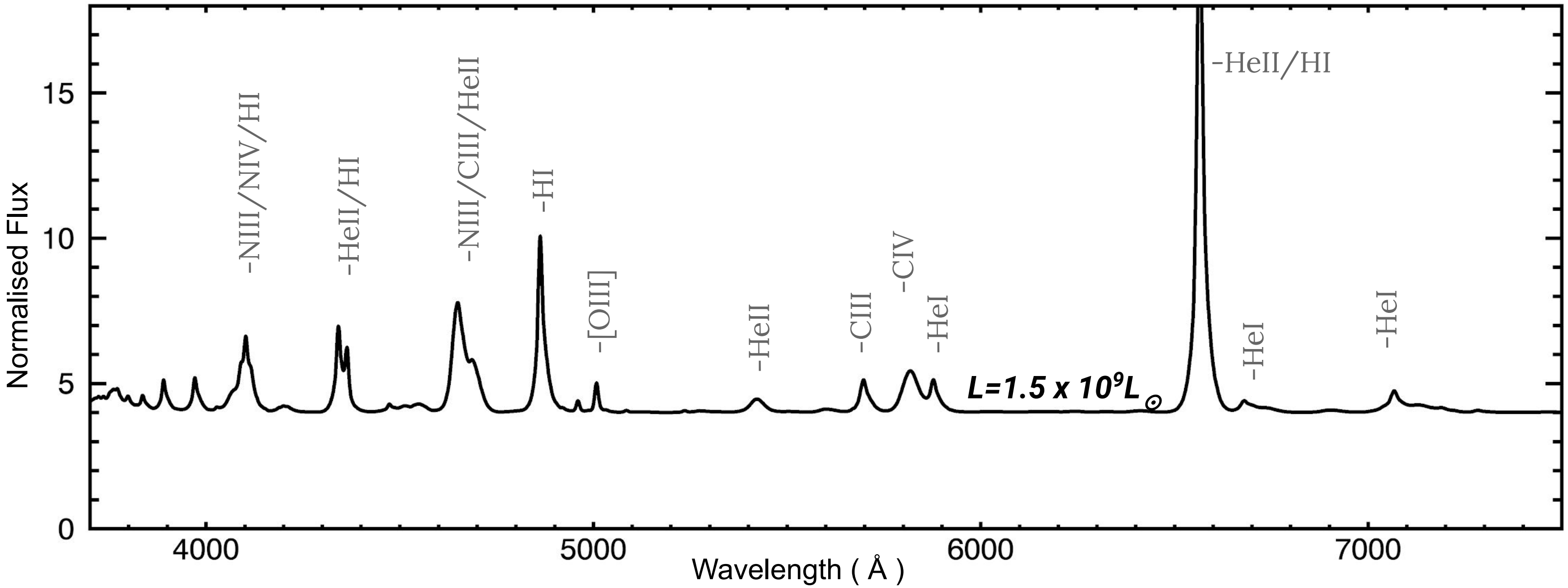


Interacting supernovae models at 1 day

- Large range of explosion luminosities: 10^8 - 10^{10} $L_\odot$
- Large range of progenitor mass-loss rates: 5×10^{-4} - 10^{-2} $M_\odot yr^{-1}$
- Diversity of progenitor surface abundances: solar, CNO-processed, He-rich (80% He), which can be mapped to different progenitors
- Constant wind terminal velocity of 150 km s^{-1}
- All spectra are publicly available

Diversity of Interacting Supernovae: Luminosities

- Synthetic SN spectrum with $L = 1.5 \times 10^9 L_\odot$, from a star with solar surface abundances, $\dot{M} = 10^{-2} M_\odot yr^{-1}$, v_∞ = 150 km s^{-1}, resolving power R = 1000, 1 day after explosion



Medium ionisation

Diversity of Interacting Supernovae: Luminosities

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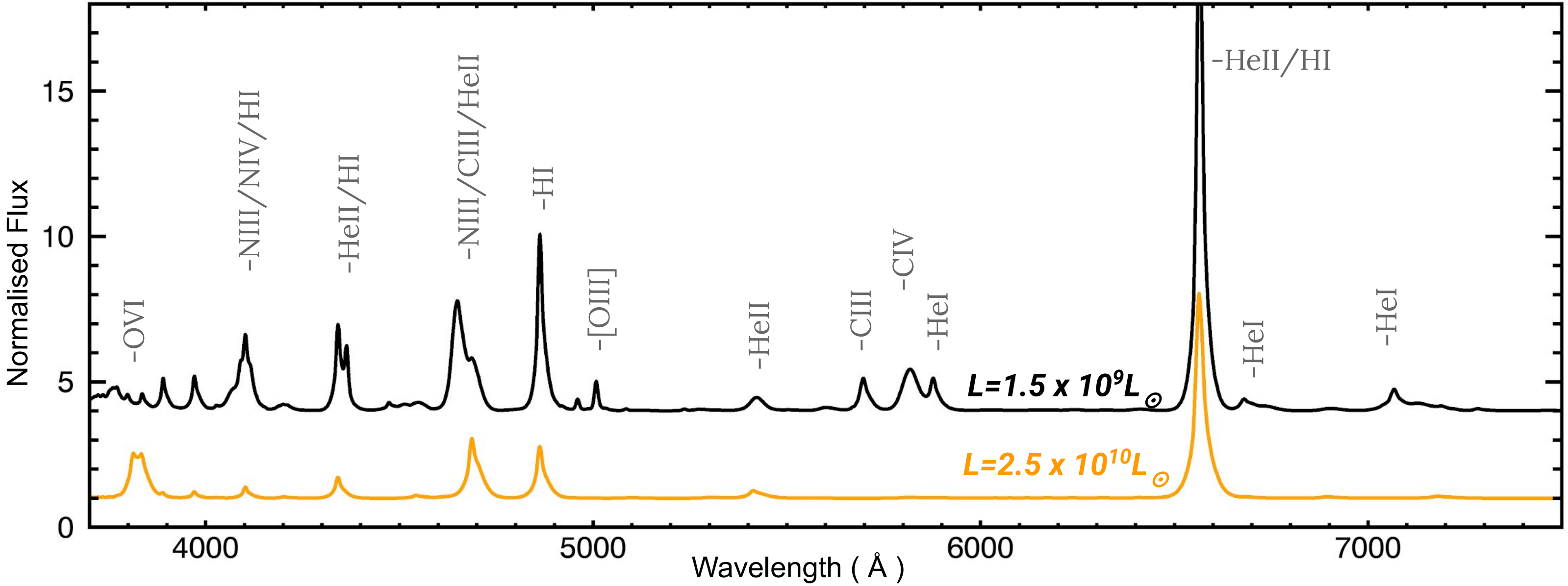

Medium ionisation
High ion.

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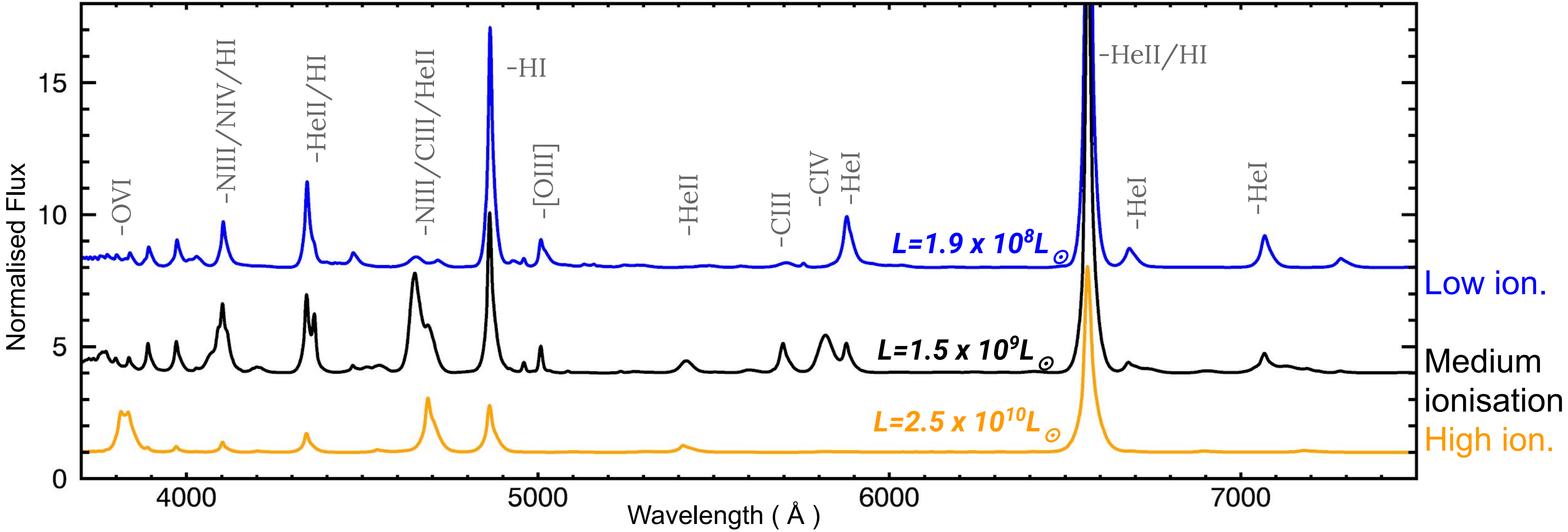
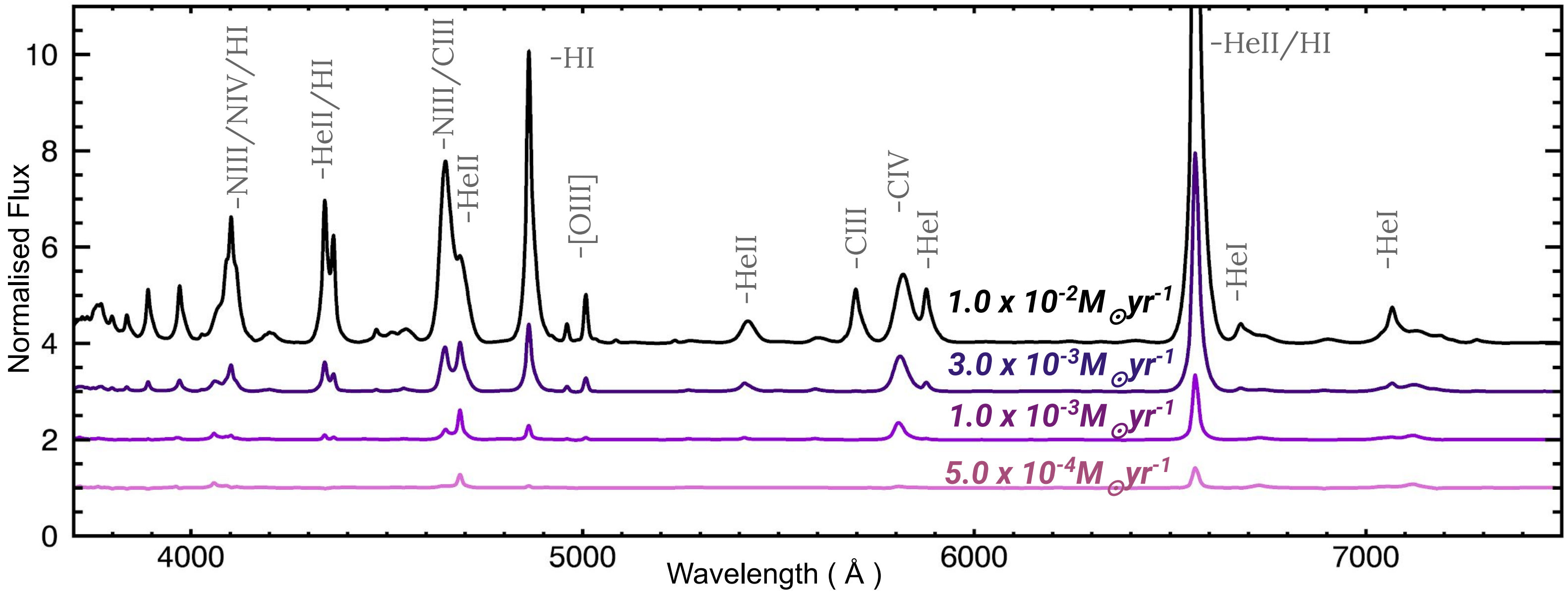


- Different morphologies arise from different explosion properties of otherwise identical progenitors

Diversity of Interacting Supernovae: Mass-loss rates

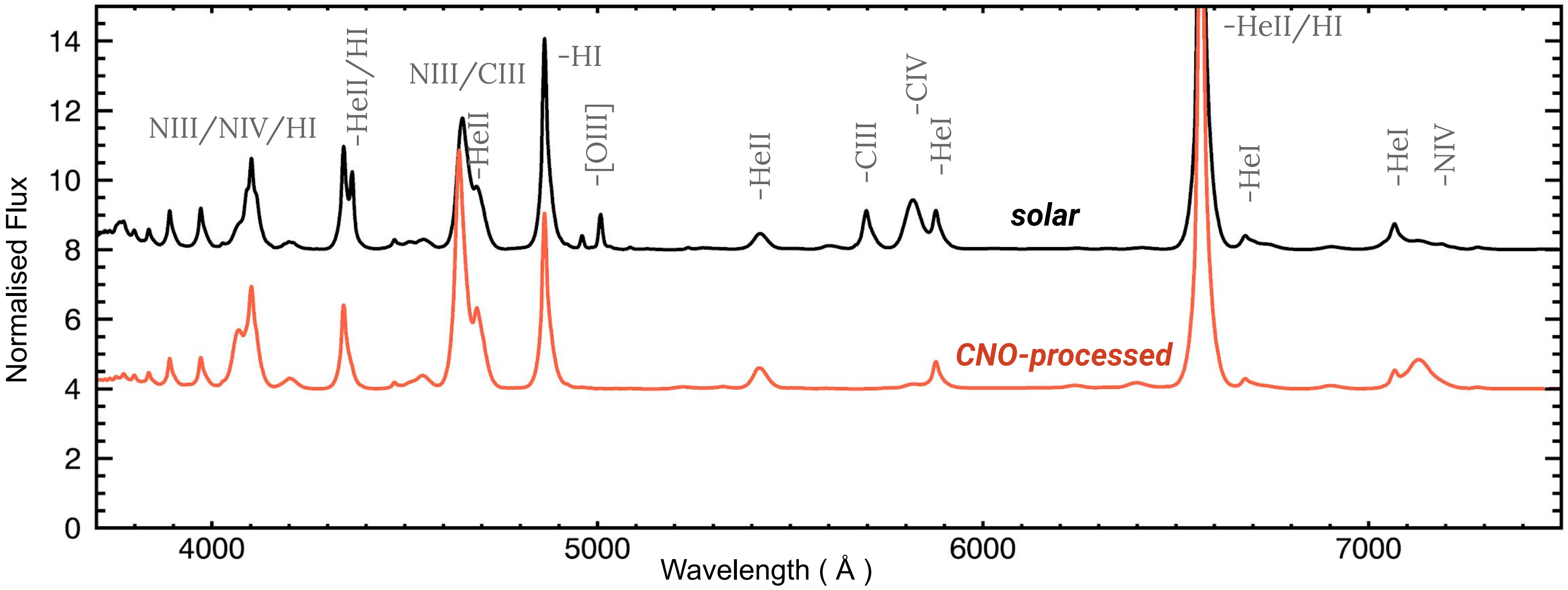
- Synthetic spectra of supernovae with a luminosity of $1.5 \times 10^9\ L_\odot$, from progenitors with solar surface abundances, and wind velocity of 150 km s^{-1}, resolving power R=1000, 1 day after explosion



- No detectable emission lines below $5 \times 10^{-4}\ M_\odot yr^{-1} (v_\infty / 150\ \mathrm{km\ s^{-1}})$

Diversity of Interacting Supernovae: Abundances

- Synthetic spectra of supernovae with luminosity 1.5 x 10^9 $L_\odot$, from stars with mass-loss rate of 10^{-2} $M_\odot yr^{-1}$, wind velocity of 150 km s^{-1}, resolving power R=1000, 1 day after explosion



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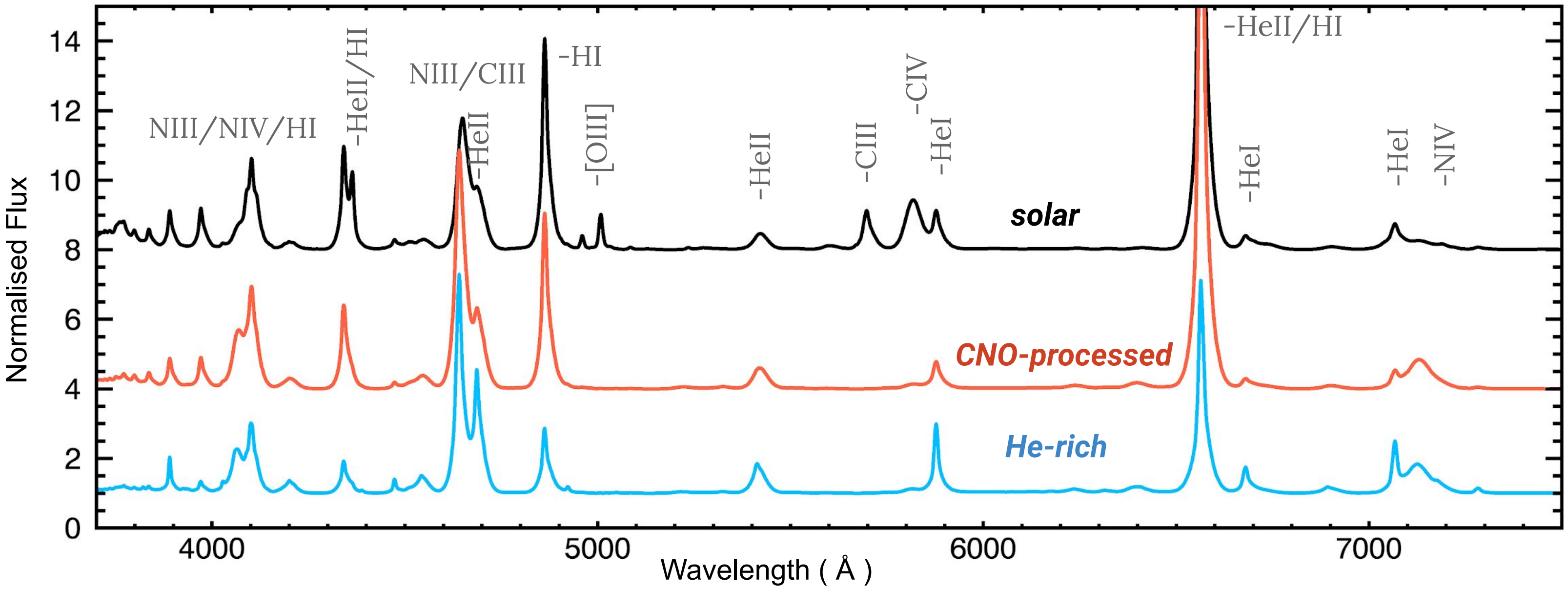

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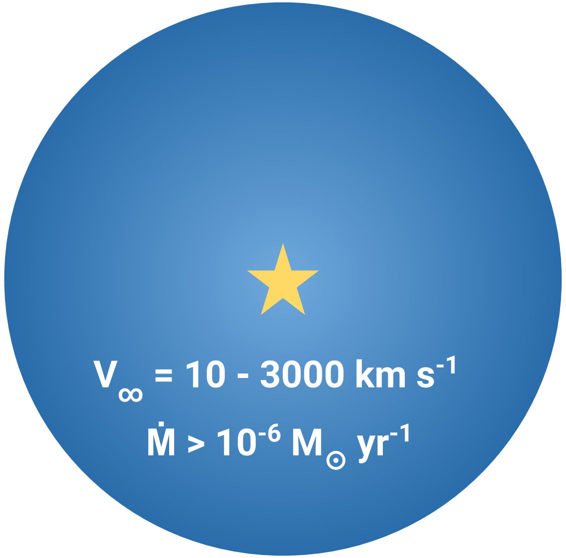

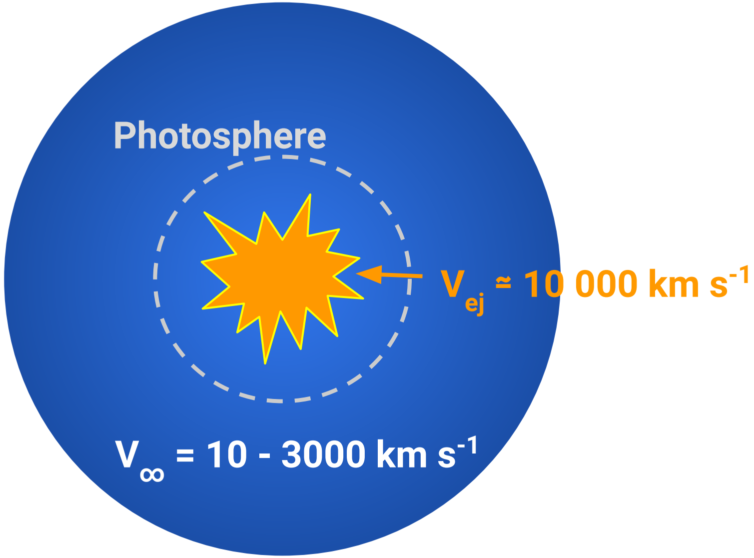

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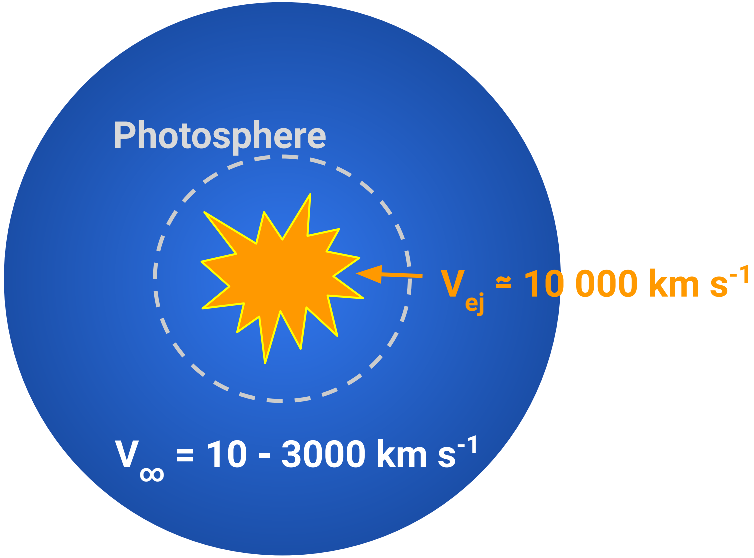
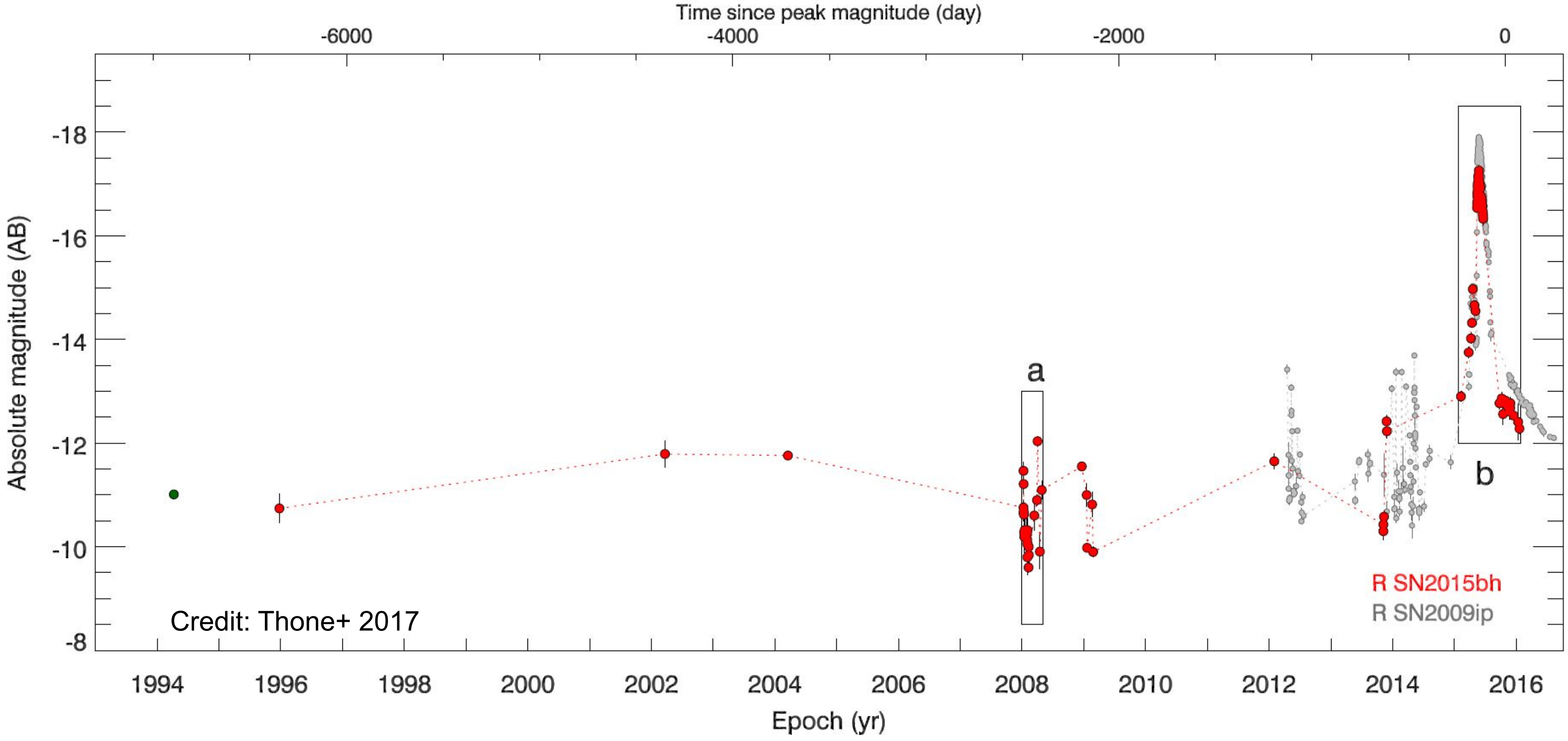


The Progenitor of SN 2015bh



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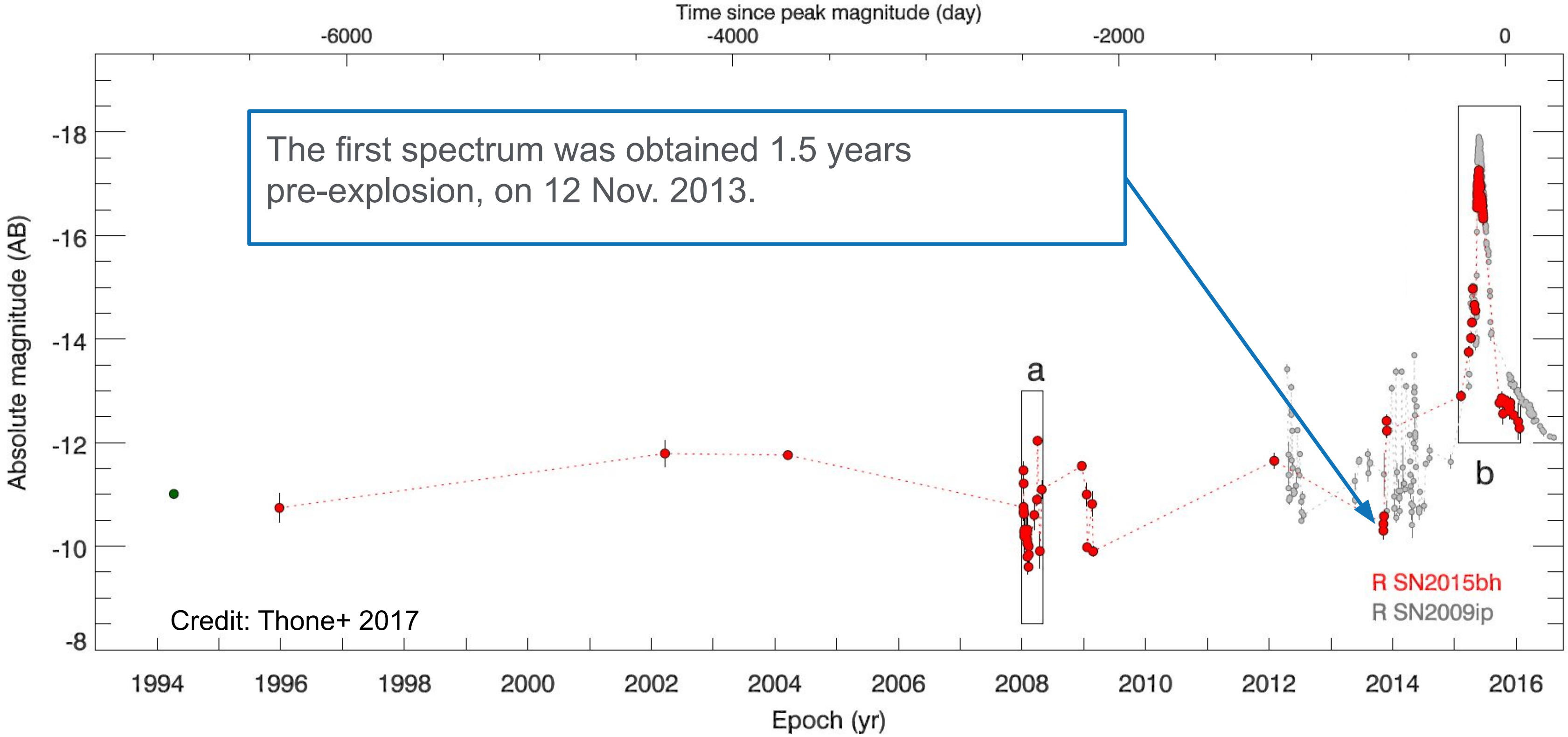


The first spectrum was obtained 1.5 years pre-explosion, on 12 Nov. 2013.

The Progenitor of SN 2015bh

- The models suggest:

$L_\star = 1.8 - 4.7 \times 10^6\ L_\odot$

$T_\star = 13\,000 - 19\,500$ K

$T_{eff} = 8\,700 - 10\,000$ K

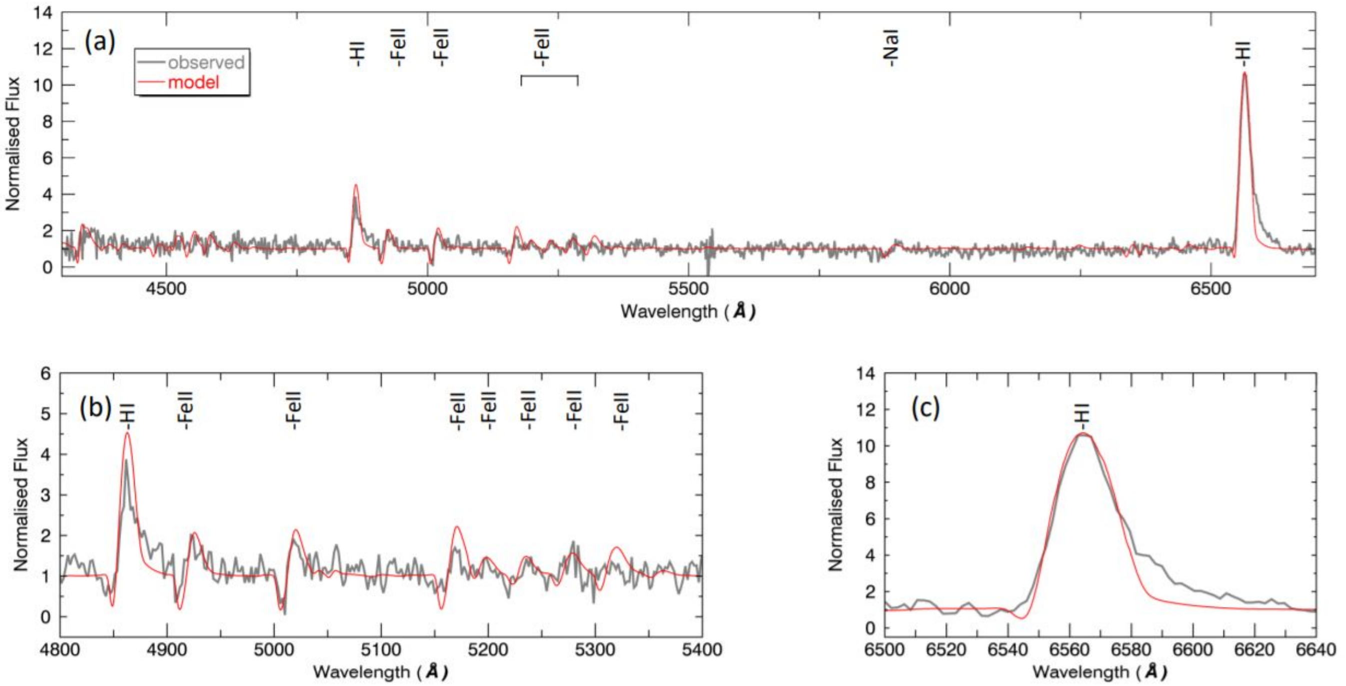
$\dot{M} = 0.6 - 1.5 \times 10^{-3}\ M_\odot yr^{-1}$

$V_\infty = 1\,000$ km s^{-1}

$M_{CSM} > 5 \times 10^{-5}\ M_\odot$

$R_{CSM} > 2.5 \times 10^{14}$ cm

Half-solar Fe abundance



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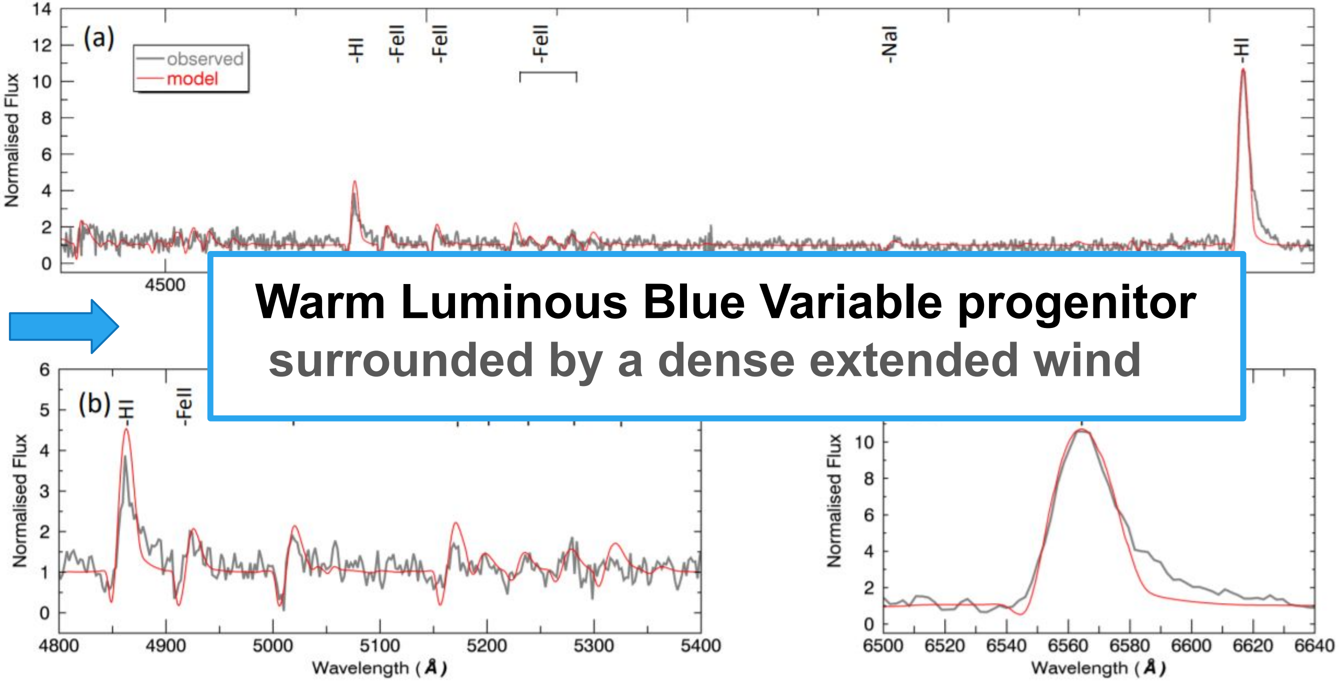

Warm Luminous Blue Variable progenitor surrounded by a dense extended wind

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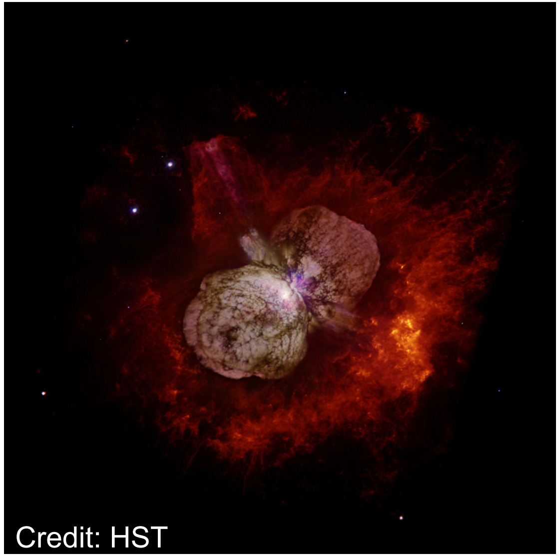
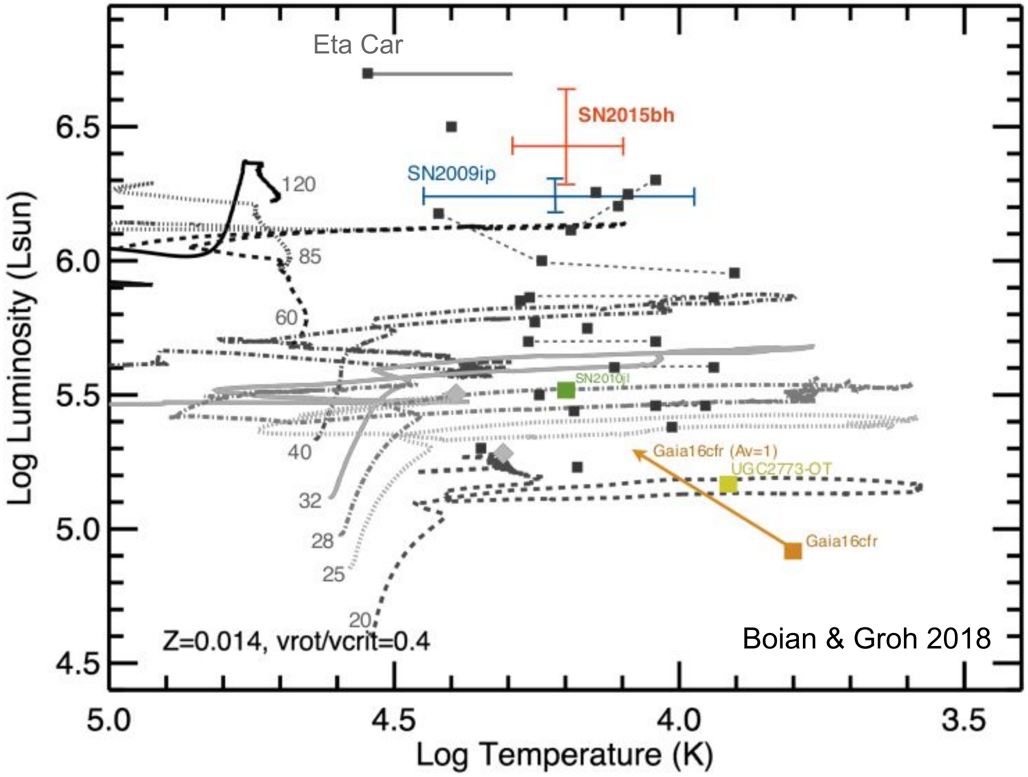


Credit: HST



Summary and Conclusions

- Extensive library of synthetic spectra of supernovae interacting with progenitors wind shortly after explosion.
- Progenitor properties matter: different progenitor masses lead to differences in the surface abundances which reflect strongly in post-explosion spectra.
- Explosion properties matter: the strength of the SN radiation manifests itself in the ionisation species present in the spectra, showing either low-ionisation (HI, HeI), medium-ionisation (CIII, NIII), or high-ionisation (HeII, NV,OV/VI).
- SN 2015bh: the unique pre-explosion spectrum of the progenitor of SN 2015bh reveals a Luminous Blue Variable with an extended wind