The progenitors of supernovae at various metallicities

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Outline

What single star models tell us about the progenitors of SNe at various metallicities?

- The progenitor type as a function of $M_{\rm ini}$ and Z
  - Remnant mass
  - Chemical composition of the ejecta
- Supernova type
  - as a function of $M_{\rm ini}$ and Z
  - SN type ratio vs Z

Stellar models

Grid used: 27 rotating stellar models (*Meynet & Maeder 2003, 2005*)

- masses from 12 to 120 $M_\odot$
- 4 metallicities: $Z = 0.004$ ($\sim$ SMC), $Z = 0.008$ ($\sim$ LMC), $Z = 0.020$ ($\sim$ solar) and $Z = 0.040$
- mean MS velocity: $v_{eq} \sim 200\,\mathrm{km\,s^{-1}}$ (*Huang & Gies 2006*)
- metallicity-dependent stellar winds (*Vink et al. 2000,2001, de Jager et al. 1988, Nugis & Lamer 2000*)
- followed up to the end of central He-burning

WR classification

Depends on the surface property of the star !

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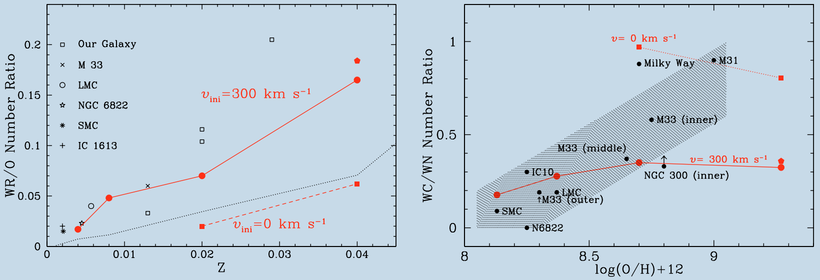
Star with $\log(T_{\text{eff}}) > 4$ and $X_{\text{S}} < 0.4 \Rightarrow$ WR

- If $X_{\text{S}} > 0 \Rightarrow$ WNL
- If $X_{\text{S}} = 0$ and $X_{\text{N}} > X_{\text{C}} \Rightarrow$ WNE
- If $X_{\text{S}} = 0$, $X_{\text{N}} < X_{\text{C}}$ and $\frac{\text{C+O}}{\text{He}} < 1 \Rightarrow$ WC
- If $X_{\text{S}} = 0$, $X_{\text{N}} < X_{\text{C}}$ and $\frac{\text{C+O}}{\text{He}} > 1 \Rightarrow$ WO

WR classification

WR population (*Meynet & Maeder 2005*)

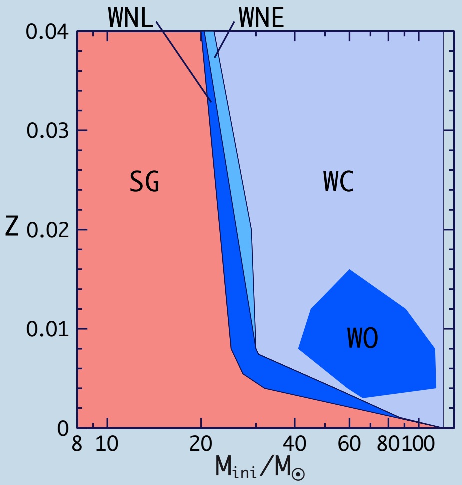


- Reproduces quite well the WR / O star ratio in the covered metallicity range, as well as the fraction of WR star at the transition between WN → WC;
- Reproduces the WN / WC ratio at low metallicity, but not at solar and super-solar metallicity (importance of LBV phase?)

SN progenitor

- WR mass range increases with Z

SN progenitors (*Georgy et al. 2009*)



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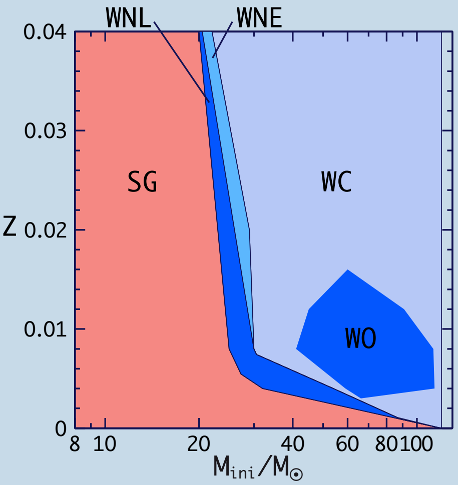

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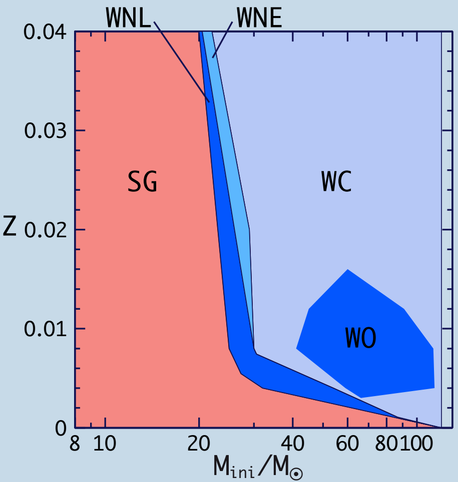

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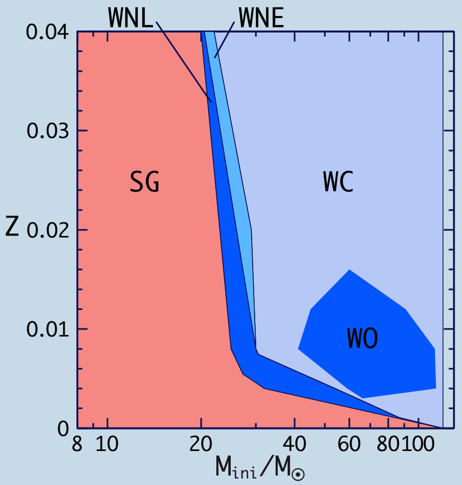

SN progenitor

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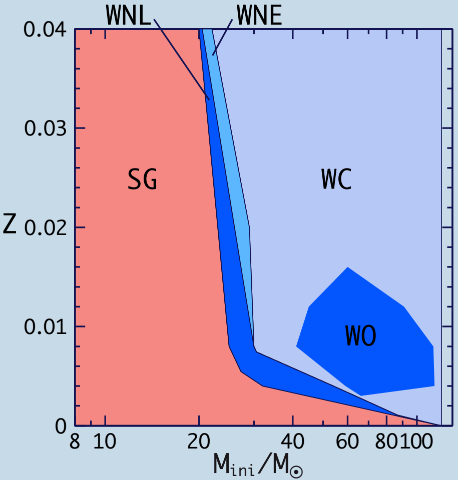
- WO only in a small mass and metallicity domain
- WO only at low metallicity (6 among 8 observed WO stars have $Z < 0.9\,Z_{\odot}$.)

SN progenitors (*Georgy et al. 2009*)



SN remnant

Remnant mass from *Hirschi et al. (2005)*. Assuming $M_{\max,\mathrm{NS}} = 2.7\,\mathrm{M}_\odot$ (*Freire et al. 2008*):

- Up to $Z \sim 0.01$: all WR$\Rightarrow$ BH

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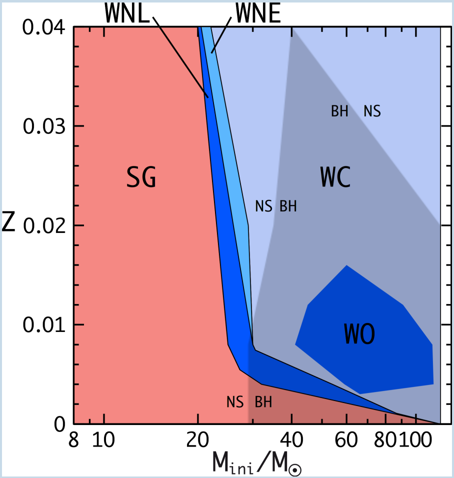

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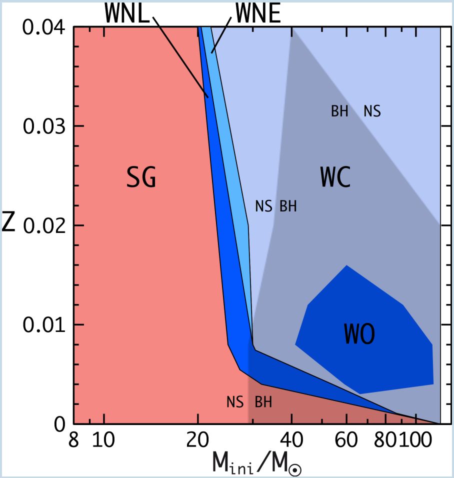

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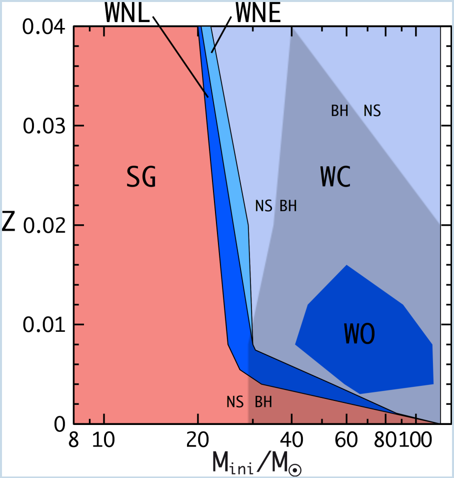

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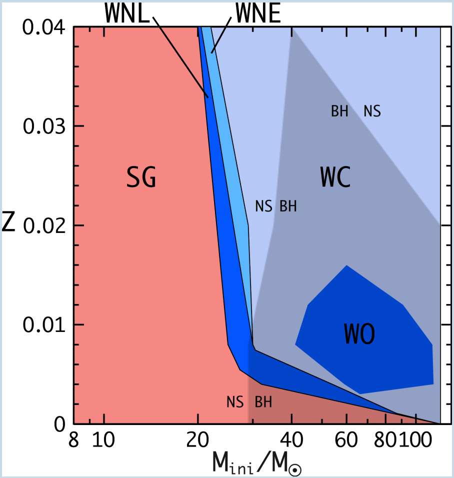
- Inferior mass limit for BH increases with Z
- From $Z \sim Z_\odot$, upper mass limit for BH, decreasing with Z (winds)
- At $Z \sim 2Z_\odot$ and above: no more BH

SN progenitors (*Georgy et al. 2009*)



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- For WN: H $<$ 1 $M_\odot$, He $>$ 1 $M_\odot$, 3/4 heavy elements, more C and O than SG
- For WC/WO: heavy elements $>$ 90%
- No models completely without He ! At least $\sim$ 0.3 $M_\odot$ (cf. *Eldridge & Tout 2004*)

SN type criterion

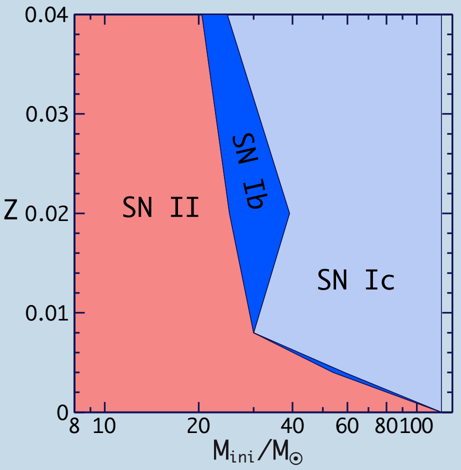
type	m_H	m_{He}
SN II	> 0	-
SN Ib	0	$> 0.6\,M_\odot$
SN Ic	0	$< 0.6\,M_\odot$

The choice of the helium mass limit between SN Ib and Ic only slightly affects the results.

SN type as a function of M_{ini} and Z

- At low Z: only SN II (low mass loss rate)

SN type (*Georgy et al. 2009*)



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- SN Ib recovers WNE / WNL area, and the lower range of mass of WC stars

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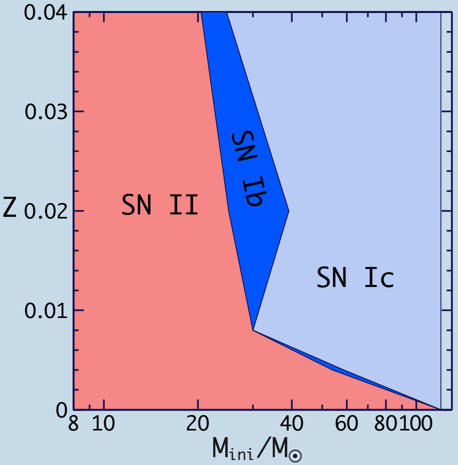
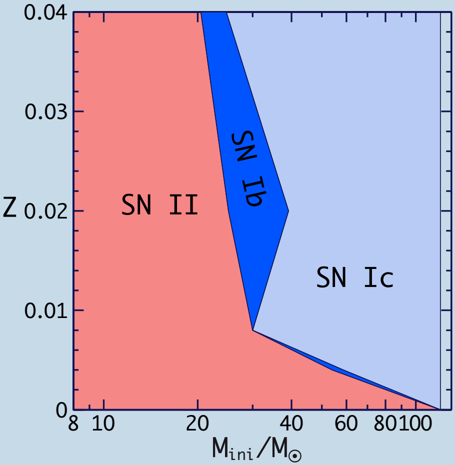


SN type as a function of M_{ini} and Z

- At low Z: only SN II (low mass loss rate)
- SN Ib recovers WNE / WNL area, and the lower range of mass of WC stars
- SN Ic have always a WC or a WO progenitors

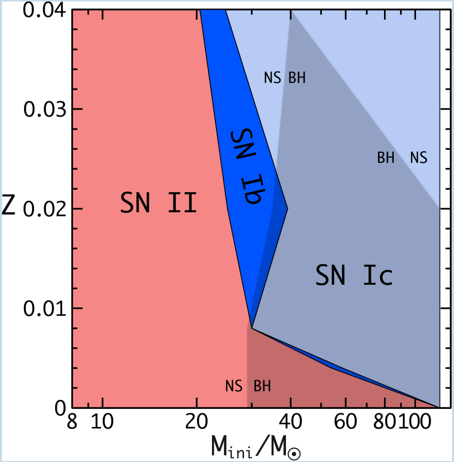
SN type (*Georgy et al. 2009*)



SN type as a function of M_{ini} and Z

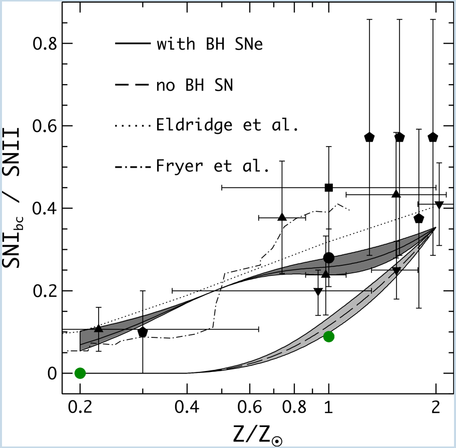
- No SN Ibc at low metallicity !

SN type (*Georgy et al. 2009*)



SN Ibc ratio vs Z

SN Ibc / SN II vs Z (*Georgy et al. 2009*)



⬟: *Prieto et al. 2008* ■: *Smartt et al. 2009* ●: *Cappellaro et al. 1999*

▲: *Prantzos & Boissier 2003* ▼: *Boissier & Prantzos 2009*

With BH-SNe:

- Increase with Z
- General trend reproduced

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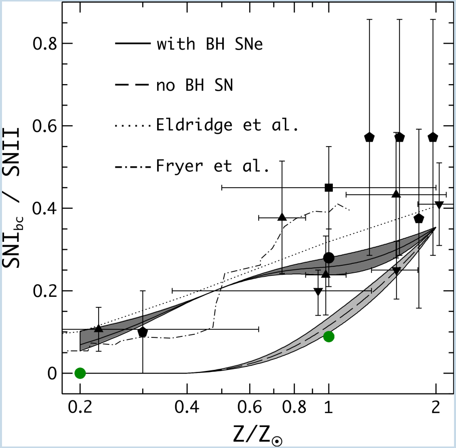

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With BH-SNe:

- Increase with Z
- General trend reproduced

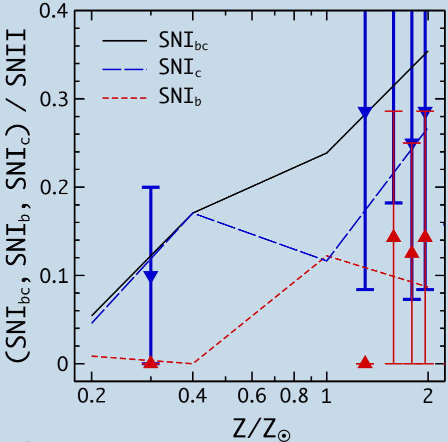
No BH-SNe:

- Over-solar Z : OK
- Sub-solar Z: Not enough (or not at all) SN Ibc

SN Ib and Ic ratio vs Z

SN Ib and Ic / SN II vs Z

(*Georgy et al. 2009*)

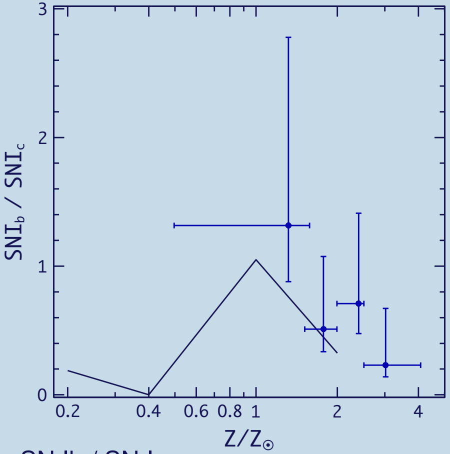


▼ : SN Ic (*Prieto et al. 2008*) ▲: SN Ib (*Prieto et al. 2008*)

- SN Ib / SN II peaks at $Z_{\odot}$
- general trend: increase of SN Ic , decrease of SN Ib above $Z_{\odot}$

SN Ib and Ic ratio vs Z

SN Ib and Ic / SN II vs Z



● : SN Ib / SN Ic (*Boissier & Prantzos 2009*)

- Confirms the increase of type Ic SNe with respect to type Ib's at high Z.
- Trend reproduced by the models.

Conclusions

- Rotation plays a key role to determine the fate of single massive stars
- What is the contribution of single stars to the number of SNe Ibc vs binary channel ?
- Key point: what happens to the SN when a BH is formed ?
- If all massive stars produce a SN, single star models should contributes significantly to the total number of SNe Ibc. Moreover, the general trends with respect to Z are well reproduced.
- If the BH formation prevents a visible SN to appear, need of other channels, particularly at sub-solar metallicity.

Final vs initial mass

Final vs initial mass (*Meynet & Maeder 2005*)