Type Ibc & IIb supernova progenitors In massive binary systems

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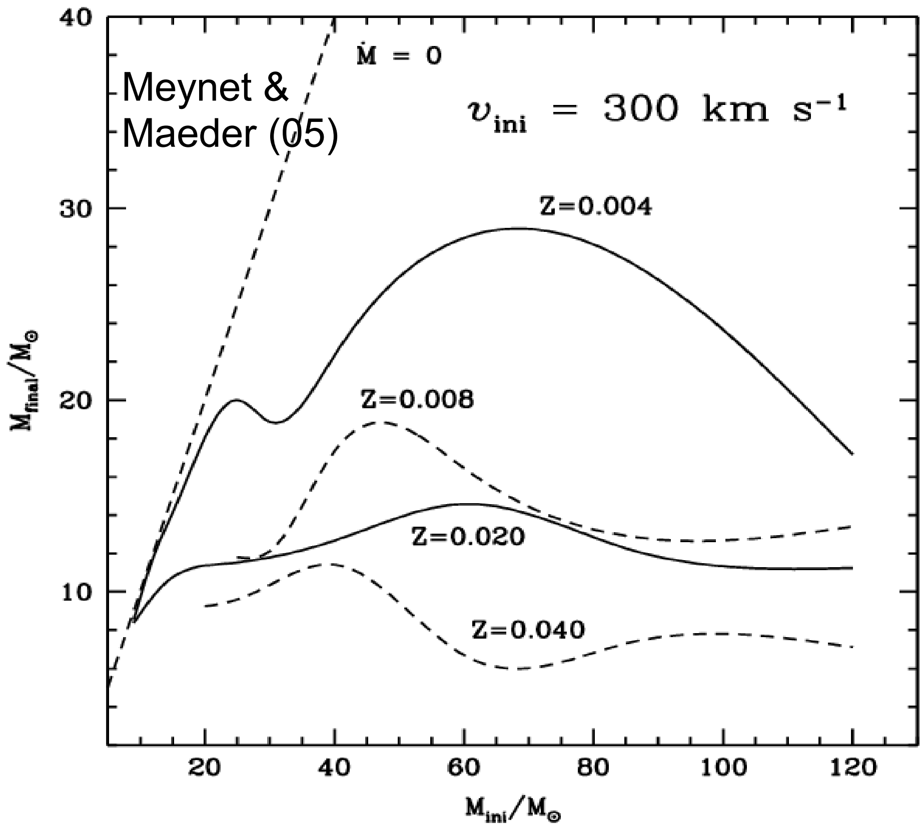
Type Ibc & IIb progenitors

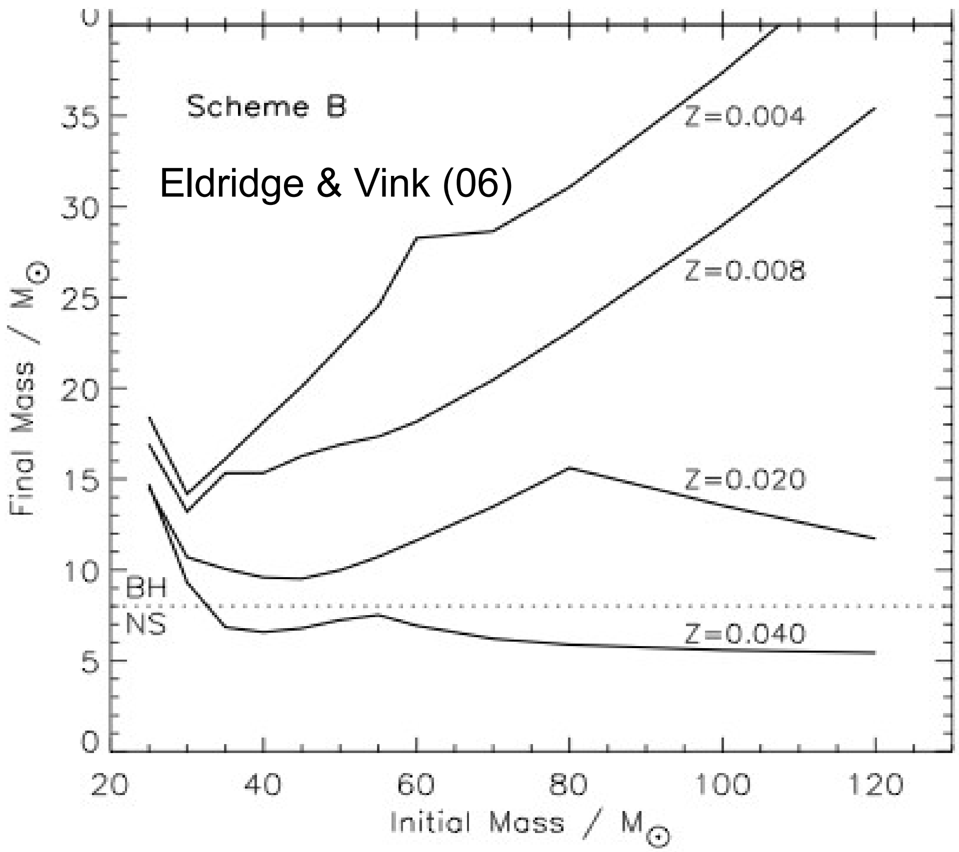
- Type Ib – no hydrogen, but helium lines
- Type Ic – no hydrogen, no helium lines
- Type IIb – appears as II in early times, but later as Ib
- Removal of a large fraction (or all) of hydrogen envelope is needed.
- ***Three ways to make hydrogen deficient stars***

1. Mass loss due to winds from massive single stars – **high Z** (talk by Cyril)
2. Complete mixing (chemically homogeneous evolution) with rapid rotation – **low Z** (long GRB progenitors; Yoon & Langer 05, 06, Woosley & Heger06)
3. ***Binary interaction – any Z***

Single Star Models

Recent work by Meynet & Maeder (05) and Eldridge & Vink (06)
considering the most up to date WR winds mass loss rate by Nugis & Lamers



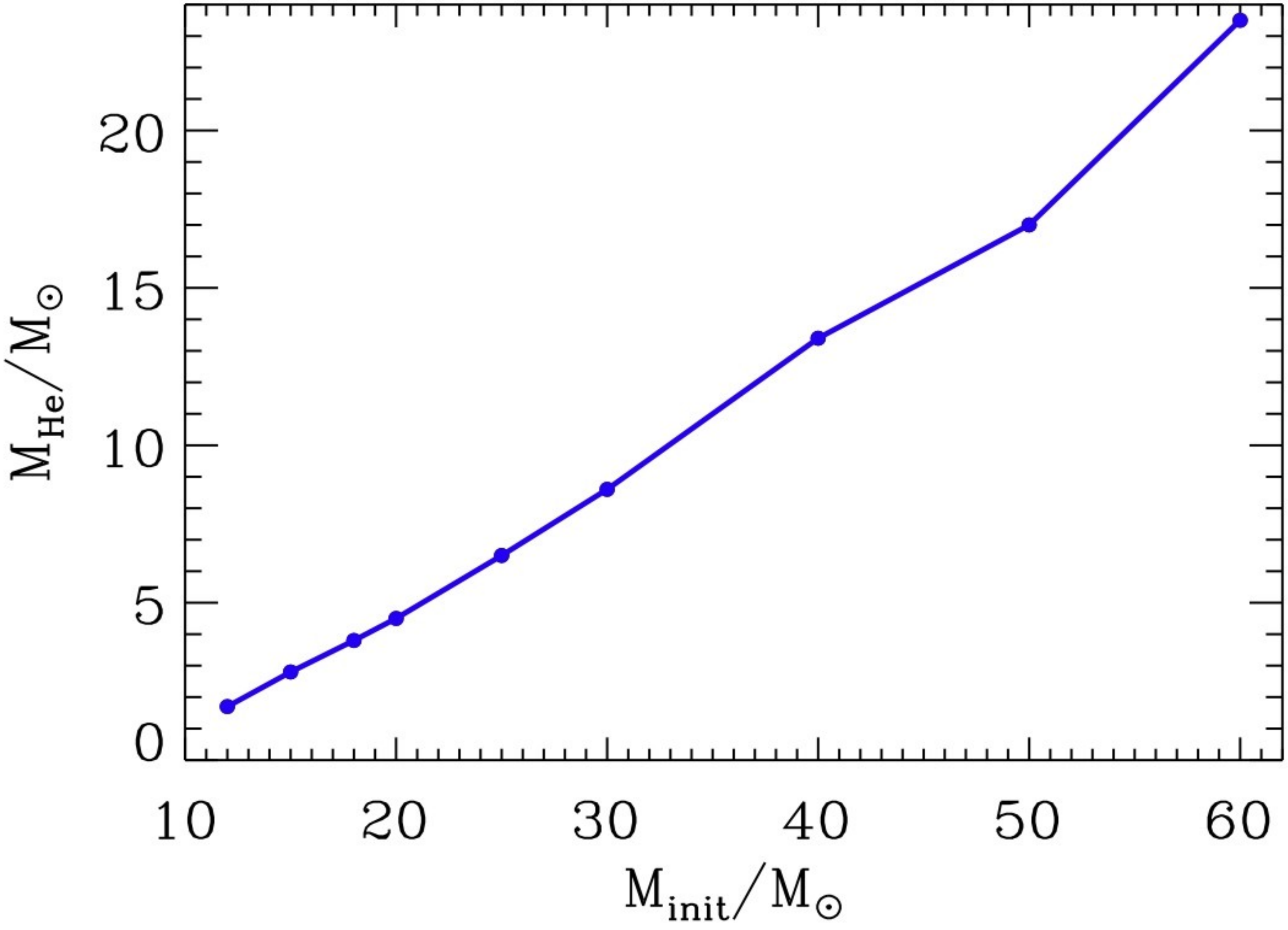


At Z ~ Zsun, single stars cannot produce helium stars with M < ~ 8 Msun.

Most normal SNe Ib/c are produced from binary stars ?

He Stars in Binary Systems

He stars of 2 ~ 20 Msun can be
made in binary systems as SN Ibc progenitors



Why New Models for Binary Stars?

- ***Not many detailed theoretical studies on the structure of SNIb/c progenitors in close binary systems exist.***
  - e.g. Woosley, Langer & Weaver (95), Wellstein & Langer (99) (see also Podsiadlowski et al. 1992)
  - **But they used too high WR mass loss rate (about 10 times higher than the Nugis-Lamers rate), and did not consider rotation.**
  - Some recent binary star models (Langer, Pols, de Mink, Petrovic, Yoon, Cantiello, Eldridge, Tout, Izzard, Vanbeveren...) overlooked the detailed nature of SNe Ib/c progenitors, rather focusing on stellar populations ,or GRBs progenitors.

Evolution of the primary star in a close binary system

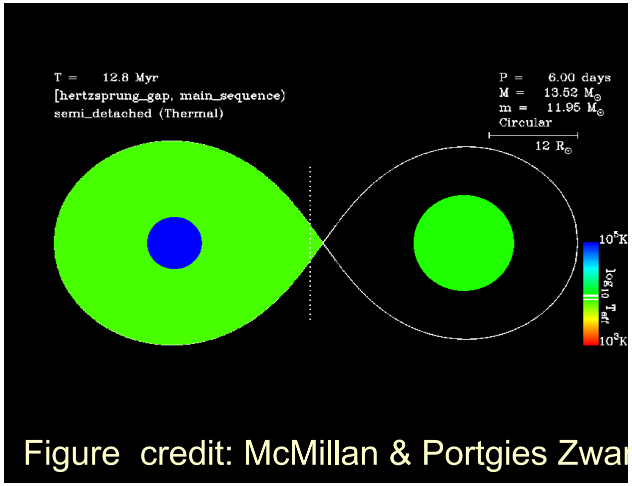
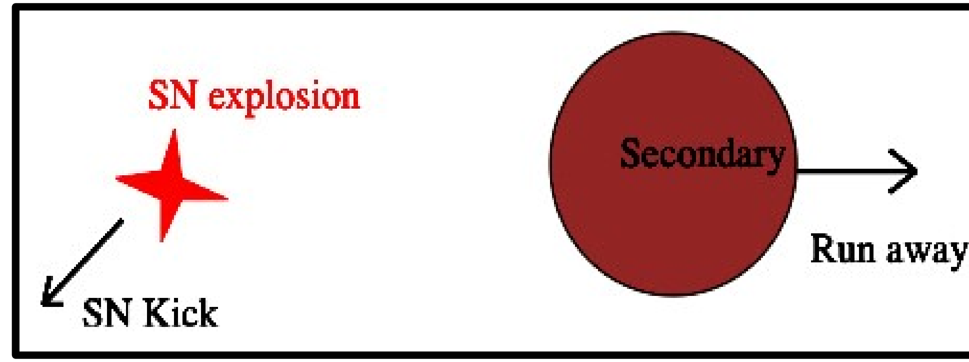
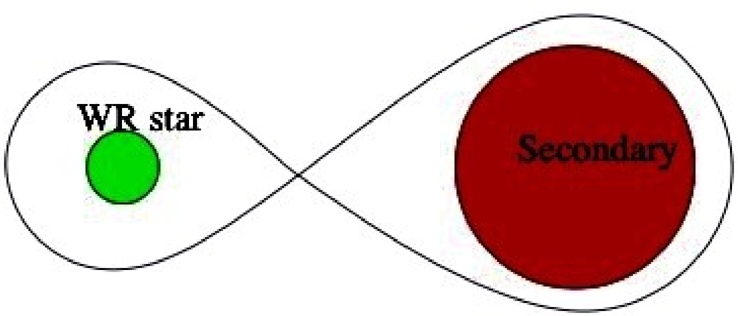


Figure credit: McMillan & Portgies Zwart

Mass transfer during He core contraction (Case B)

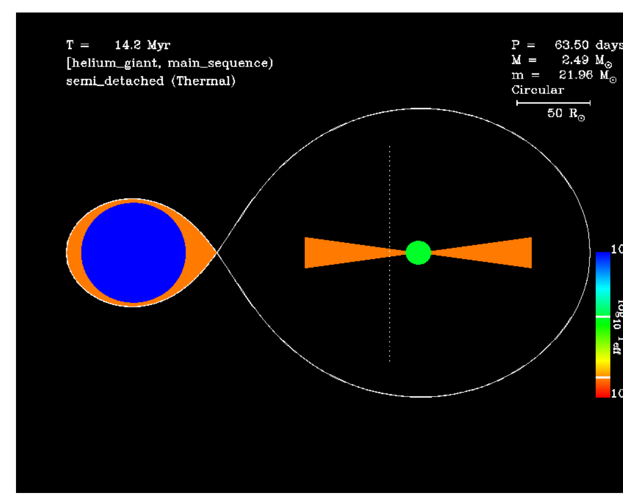


If M_{He} > ~ 3.5 Msun, or P is very large



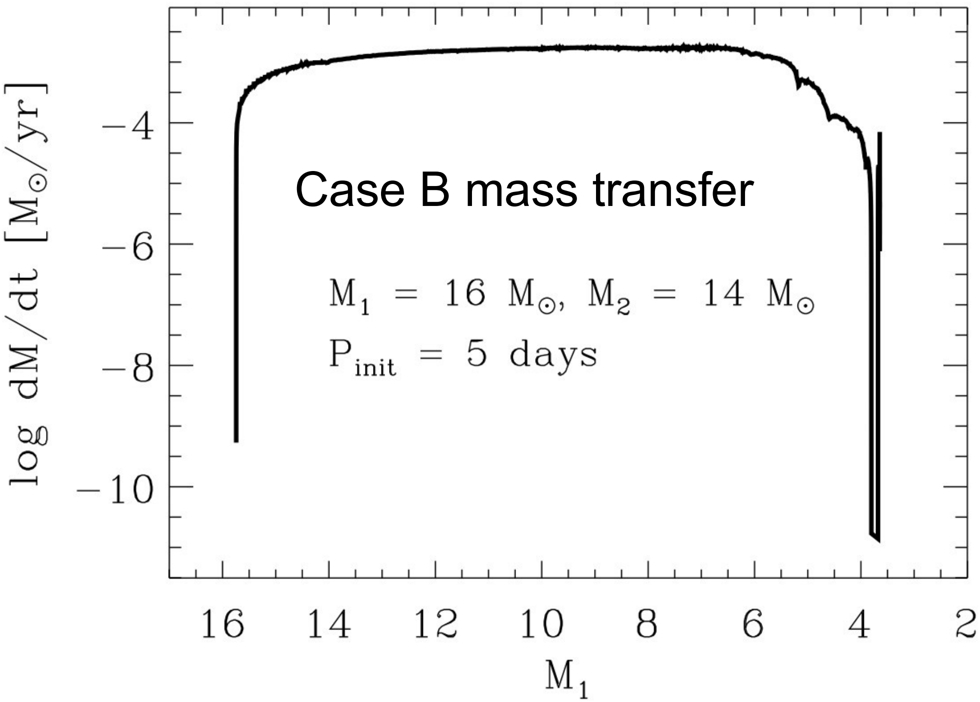
He star + MS star

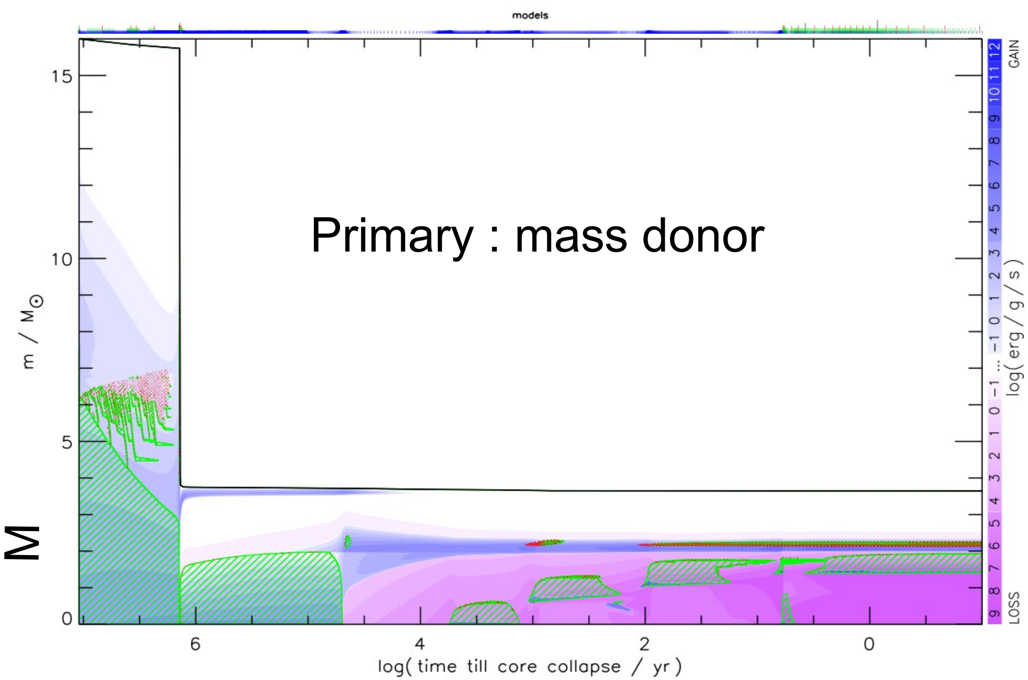
If M_{He} < ~ 3.5 Msun, & if P is small enough



Mass transfer from the helium star during/after CO core contraction (Case BB)

Mass Transfer Rate





Log (time until the core collapse)

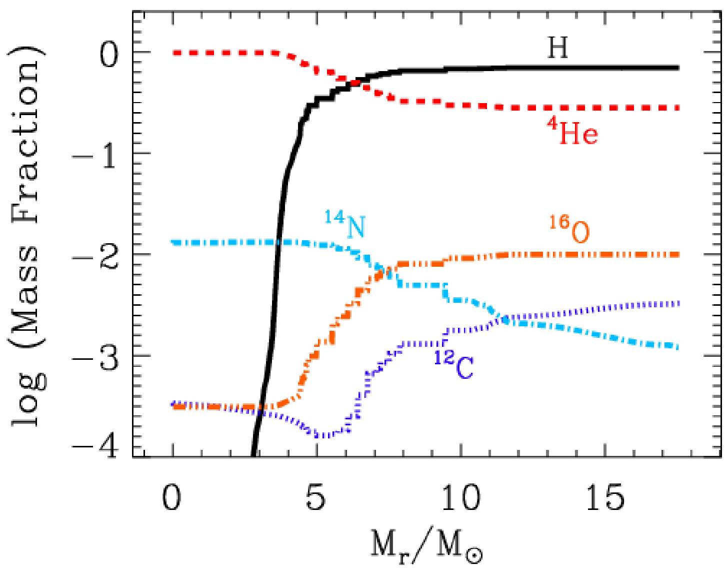
Evolution of the primary star

- Mass transfer during He core contraction (Case B) is most important for making He stars in close binaries.

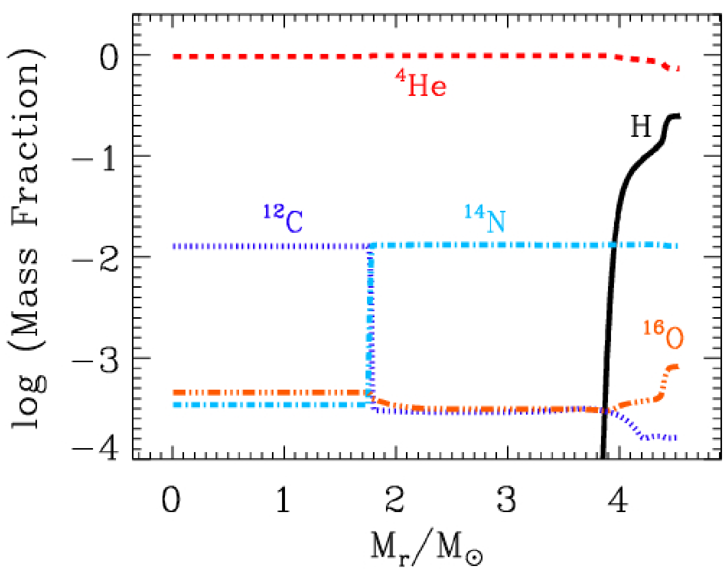
- If the helium core mass is less than about 3.5 Msun, Case BB mass transfer also can occur during/after the CO core contraction phase, as the helium envelope expand to a great extent

Evolution of the primary star

Before mass transfer



After mass transfer

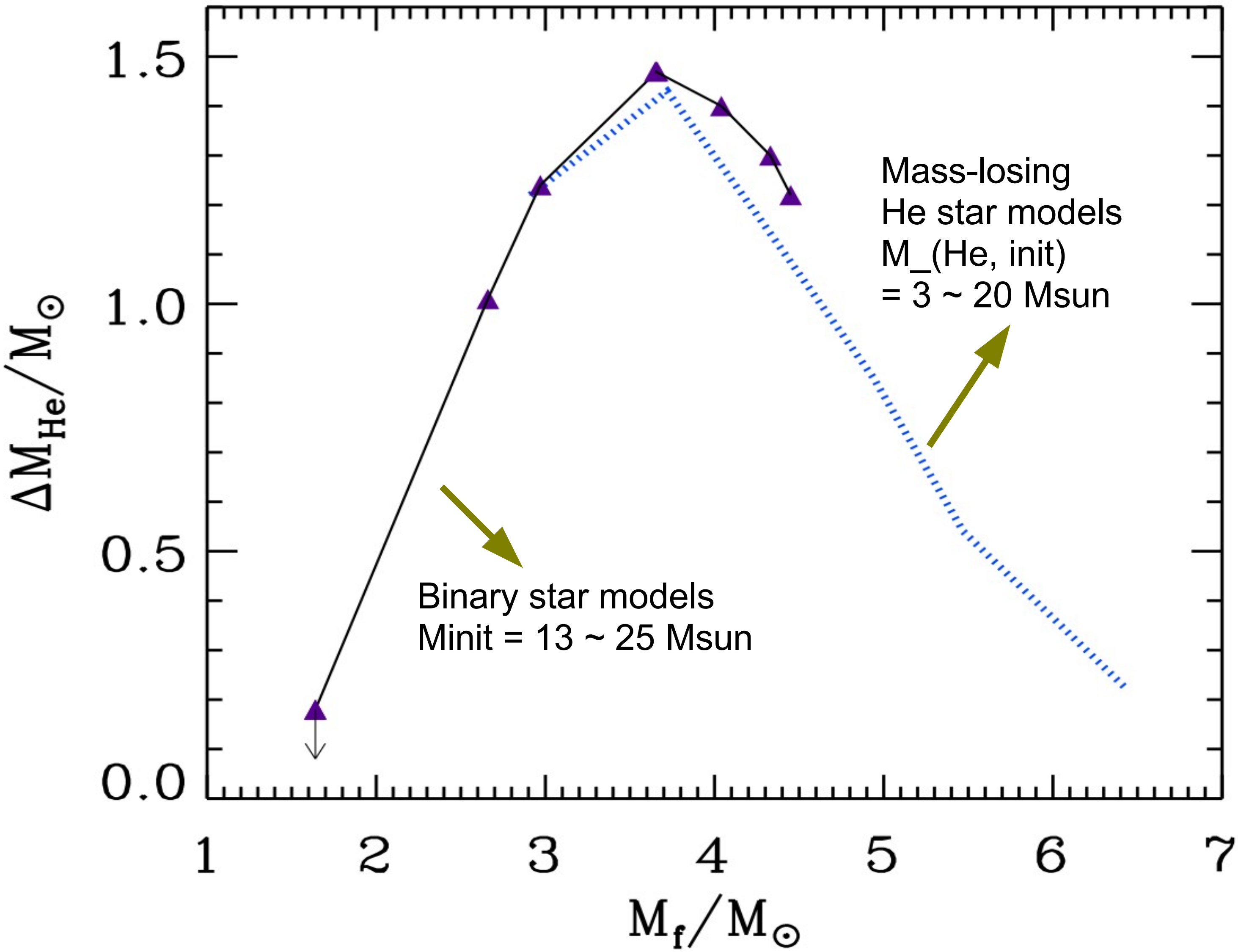


- Some hydrogen is left after the mass transfer during He core contraction (Case B)

- The final structure (hydrogen, helium, and the total mass) is determined by the WR mass loss rate,

AND, if M < ~ 3.5 Msun, by the another mass transfer during CO core contraction (Case BB)

Final mass – Helium mass



Which stars are progenitors of Type Ic ?

How much helium can be hidden in the spectra?

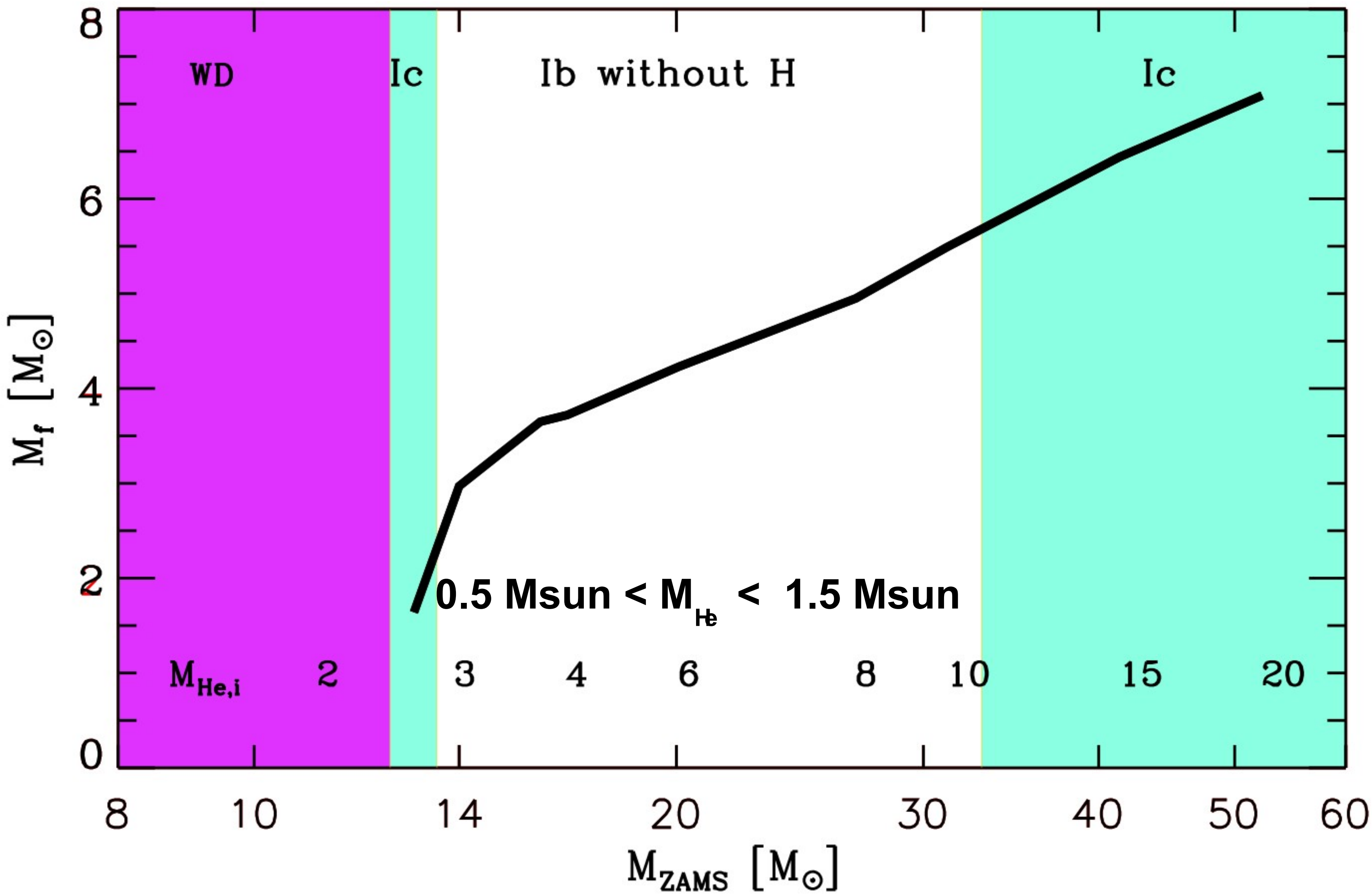
Most Ic's are made at super-solar metallicity?

RT instability-induced mixing of Ni into He rich layers may be important for helium lines.

Result at solar metallicity,
with a 5 times lower WR mass loss rate than the Hamman et al. Rate.
This is roughly 2 times higher than the Nugis & Lamers rate.

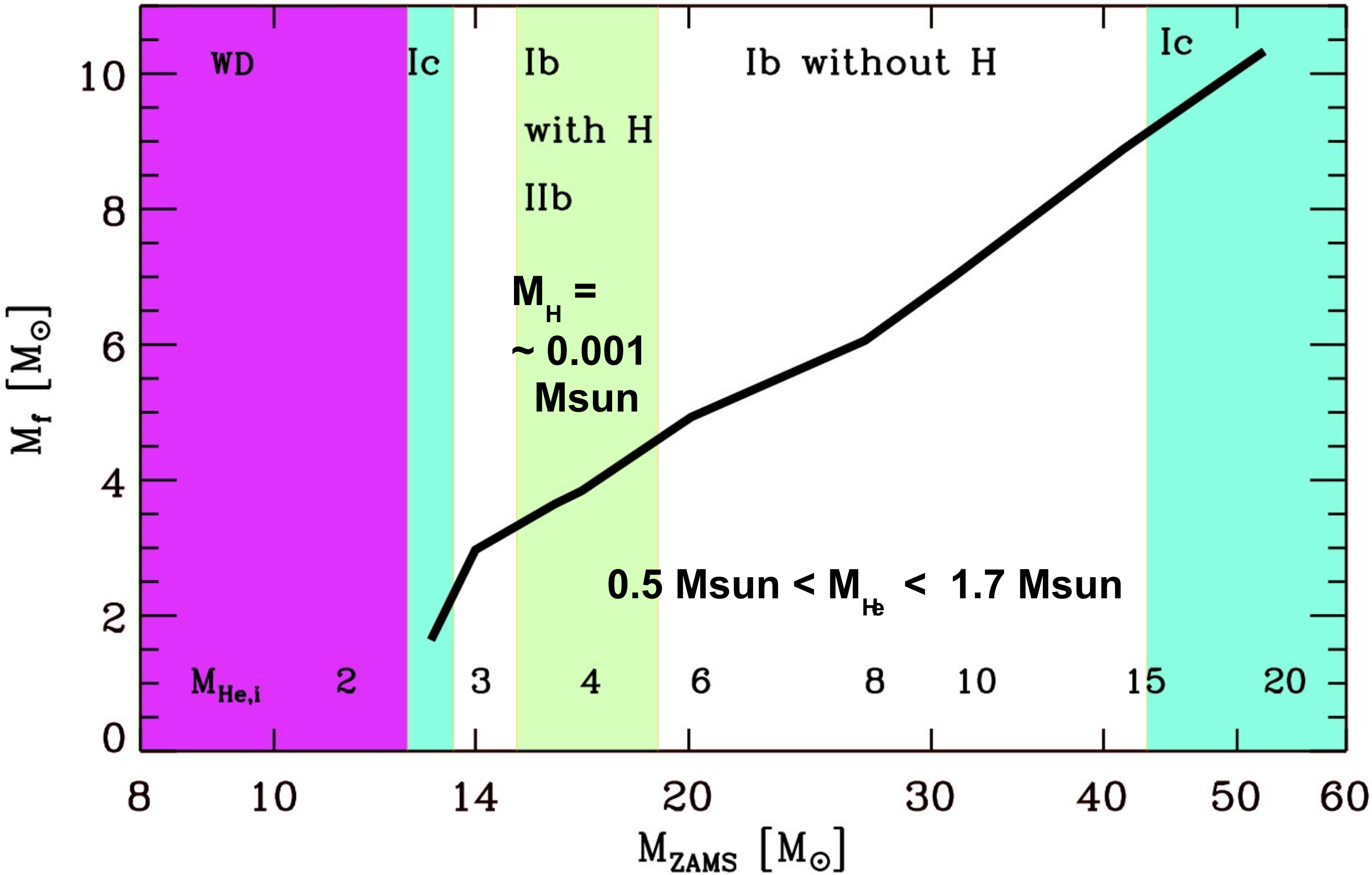
Initial mass – Final mass – SN type

Solar metallicity, Case B mass transfer, with $(dM/dt)_{WR}$ = Hamman/5 ~ 2*Nugis-Lamers-rate



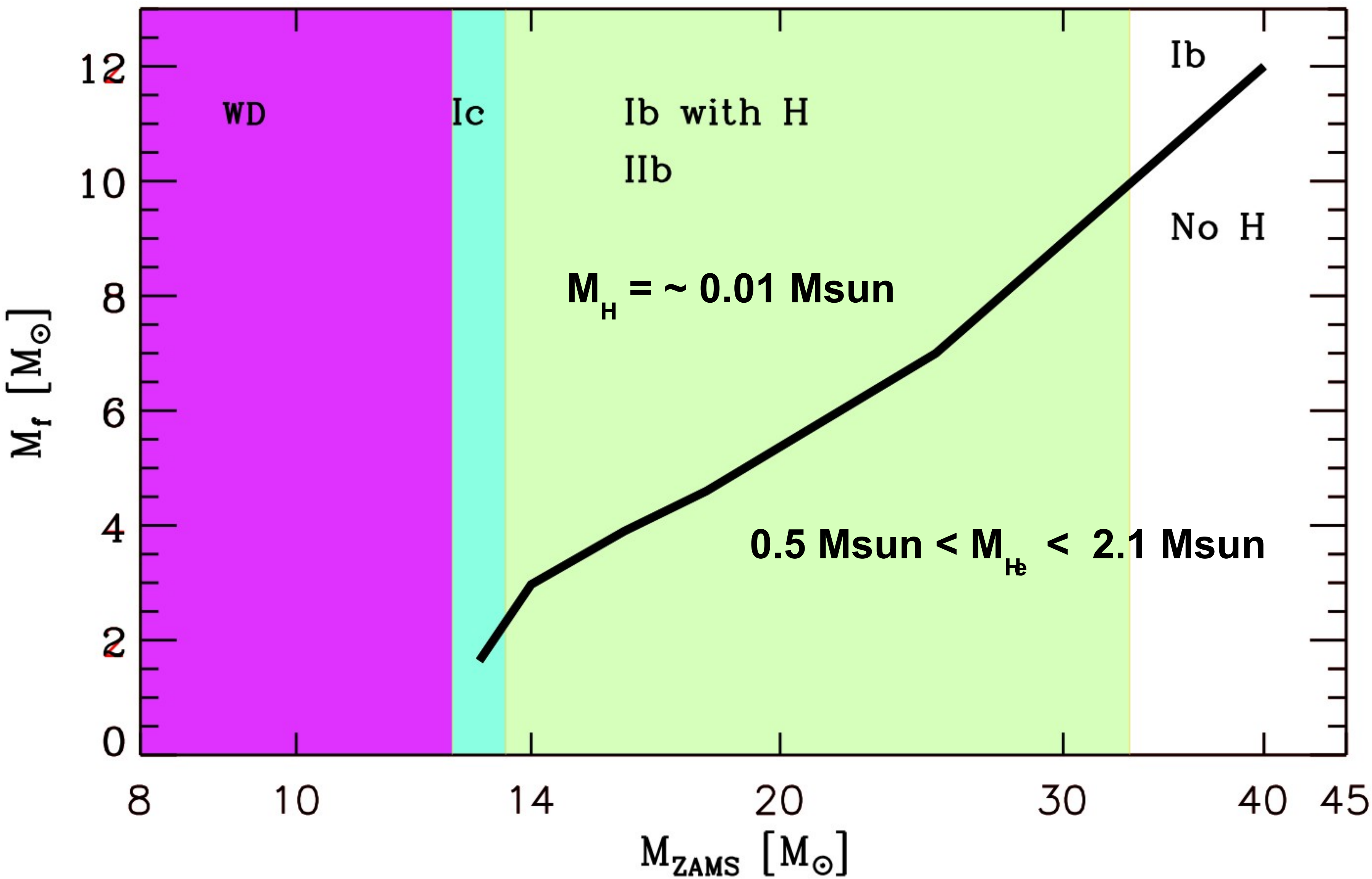
Initial mass – Final mass – SN type

Solar metallicity, Case B mass transfer, with $(dM/dt)_{WR}$ = Hamman/10 ~ Nugis-Lamers rate

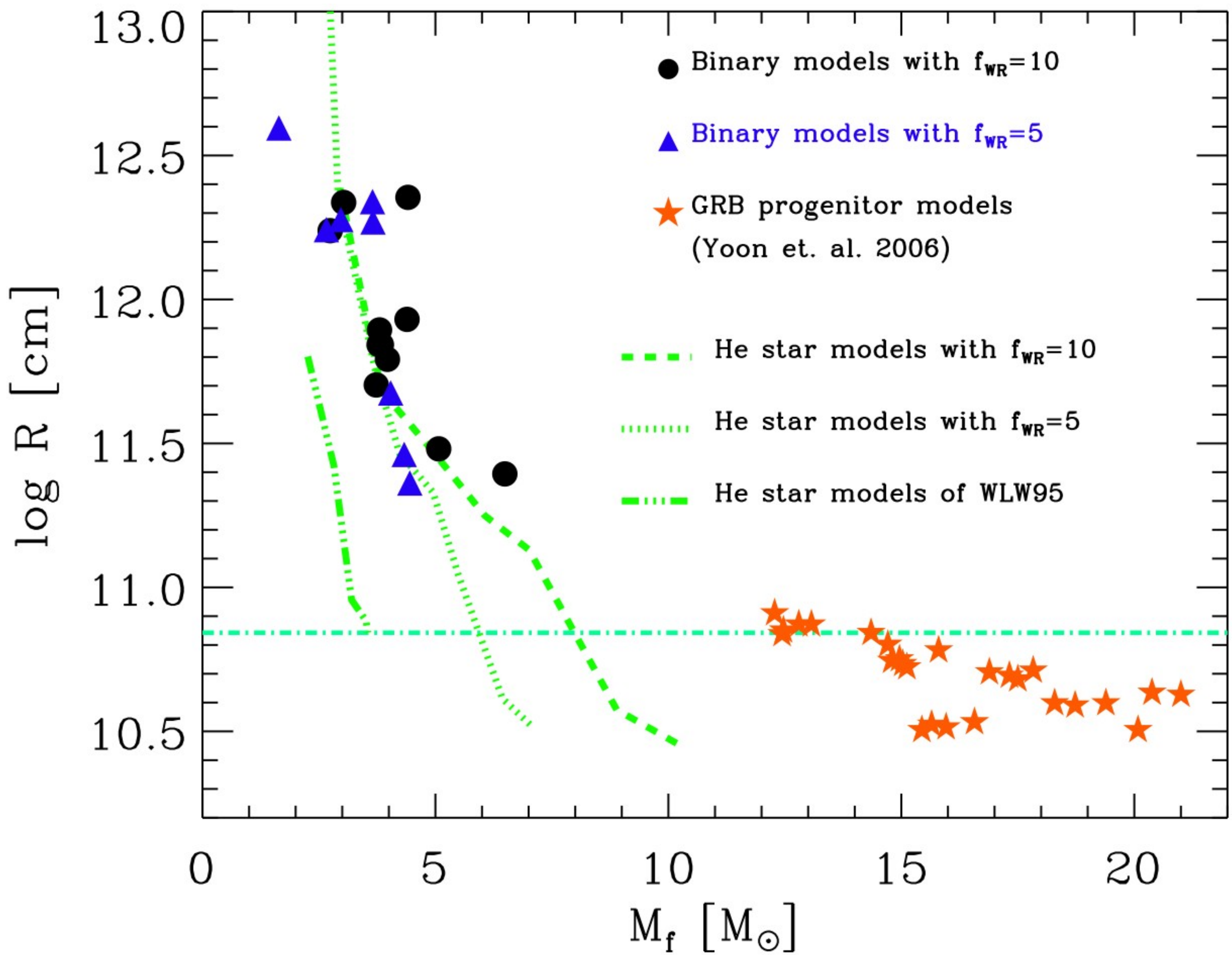


Initial mass – Final mass – SN type

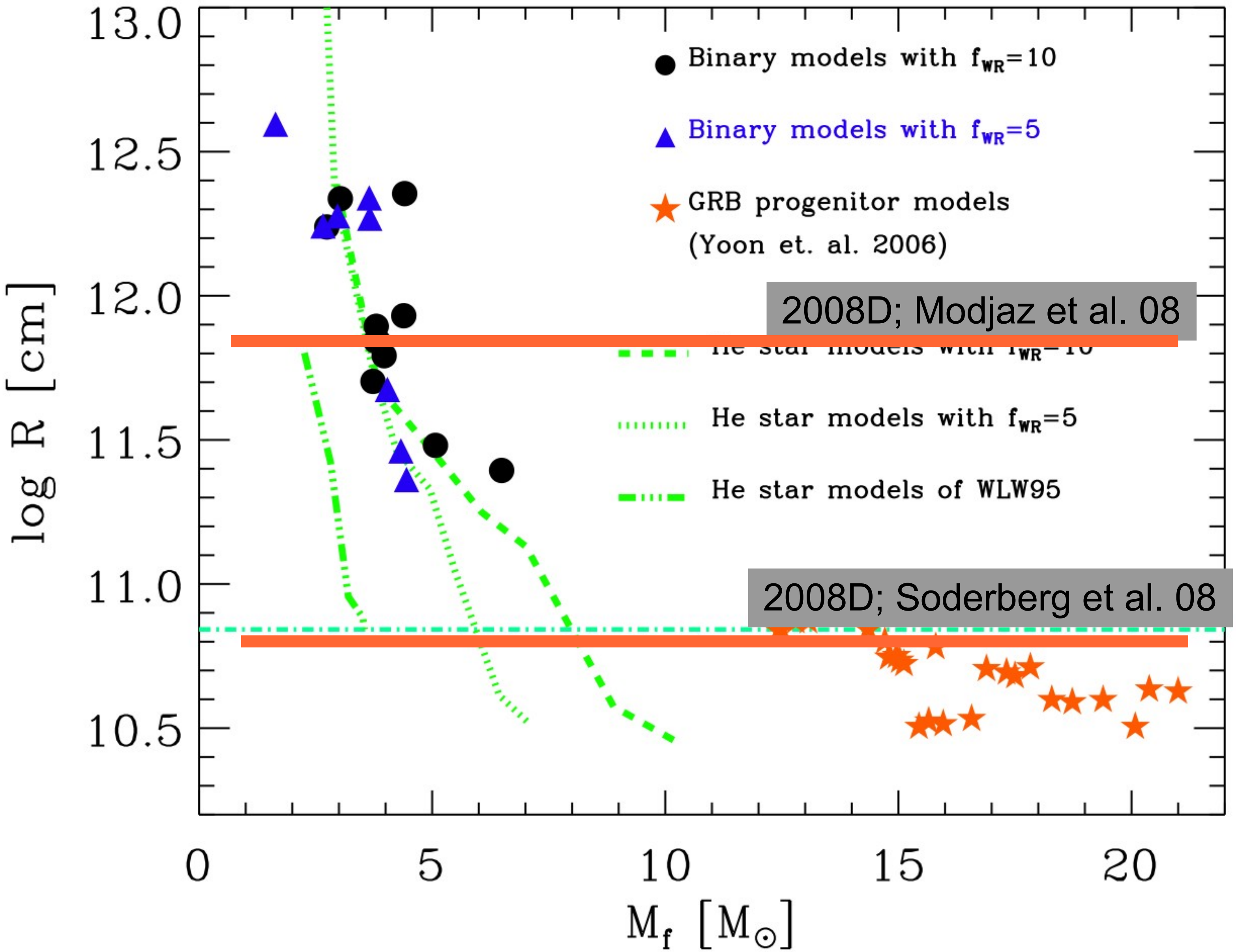
SMC metallicity, Case B mass transfer,



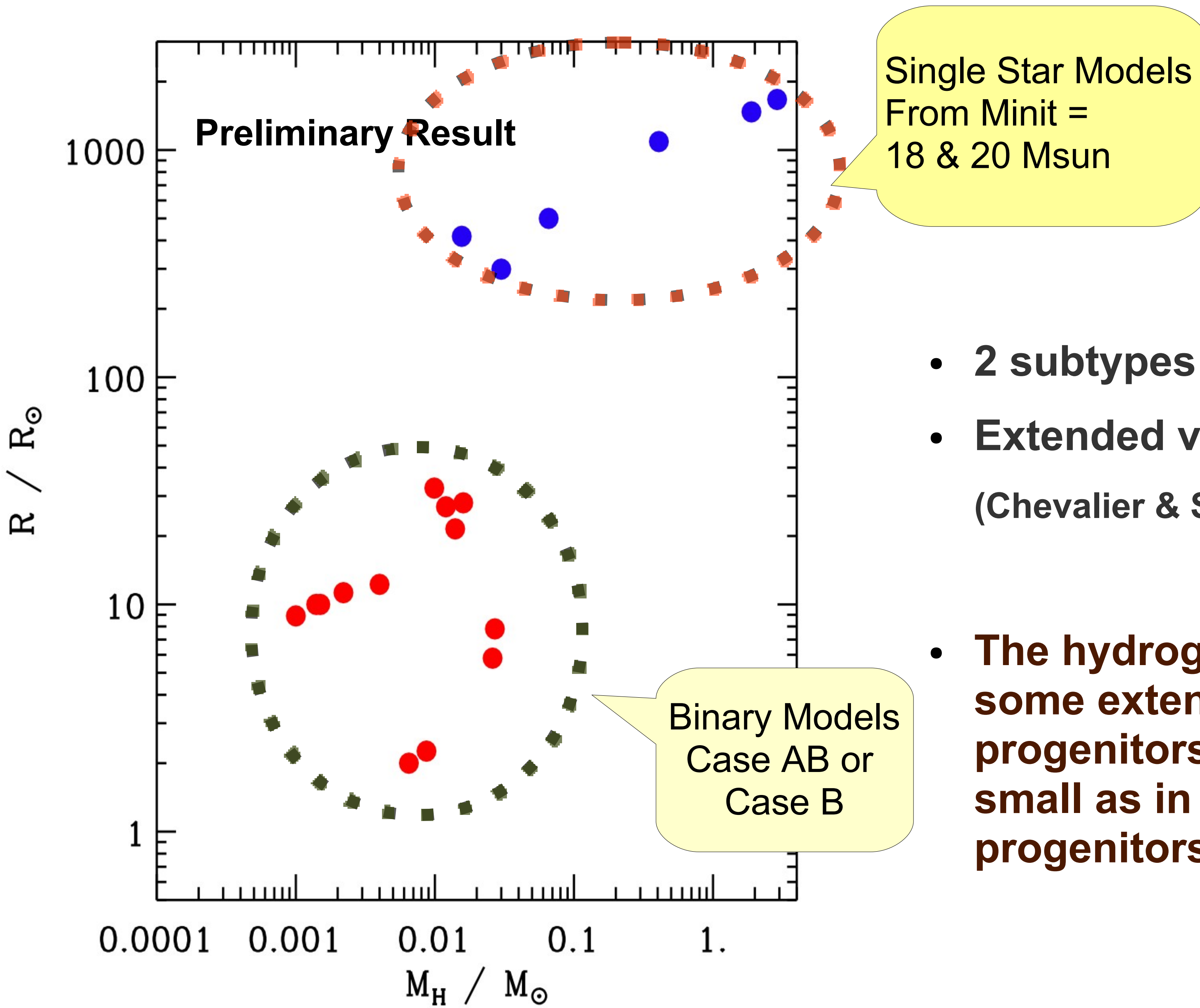
Final mass – Radius



Final mass – Radius



On the radii of Type IIb supernova progenitors



- **2 subtypes for IIb ?**
- **Extended v.s. Compact**

  (Chevalier & Soderberg 2010)

- **The hydrogen mass in some extended IIb progenitors might be as small as in compact IIb progenitors (~ 0.01 Msun)**

Conclusions

- A wide range of final mass is expected for SN Ib/c progenitors in binary systems (~ 2 – 10 Msun at Zsun), compared to the previous conconsions of "2 – 4 Msun at Zsun" by Woosley et al. 95, and Wellstein & Langer (1999)
- Thick helium layers (0.2 Msun – 2 Msun) : which stars are progenitors of SN Ic ? What's the critical limit for helium?
- Two classes for type Ic: low mass & high mass progenitors.
- Ic/Ib > 1 (talk by Smartt) is difficult to explain.
- In general, the radius of SN Ibc progenitors in binary systems is mass-dependent (larger for smaller final mass).
- A thin layer of hydrogen (0.001~ 0.01 Msun) for a limited range of the final mass (3.5 – 4.5 Msun at ~ Zsun, and 3.5 – 7 Msun at ~ Zsmc)
- Present of very small hydrogen (~ 0.01 Msun) could make a IIb progenitor star expand up to ~ 1000 Rsun, depending on the evolutionary history => the extended/compact type does not necessarily depends on the hydrogen mass.