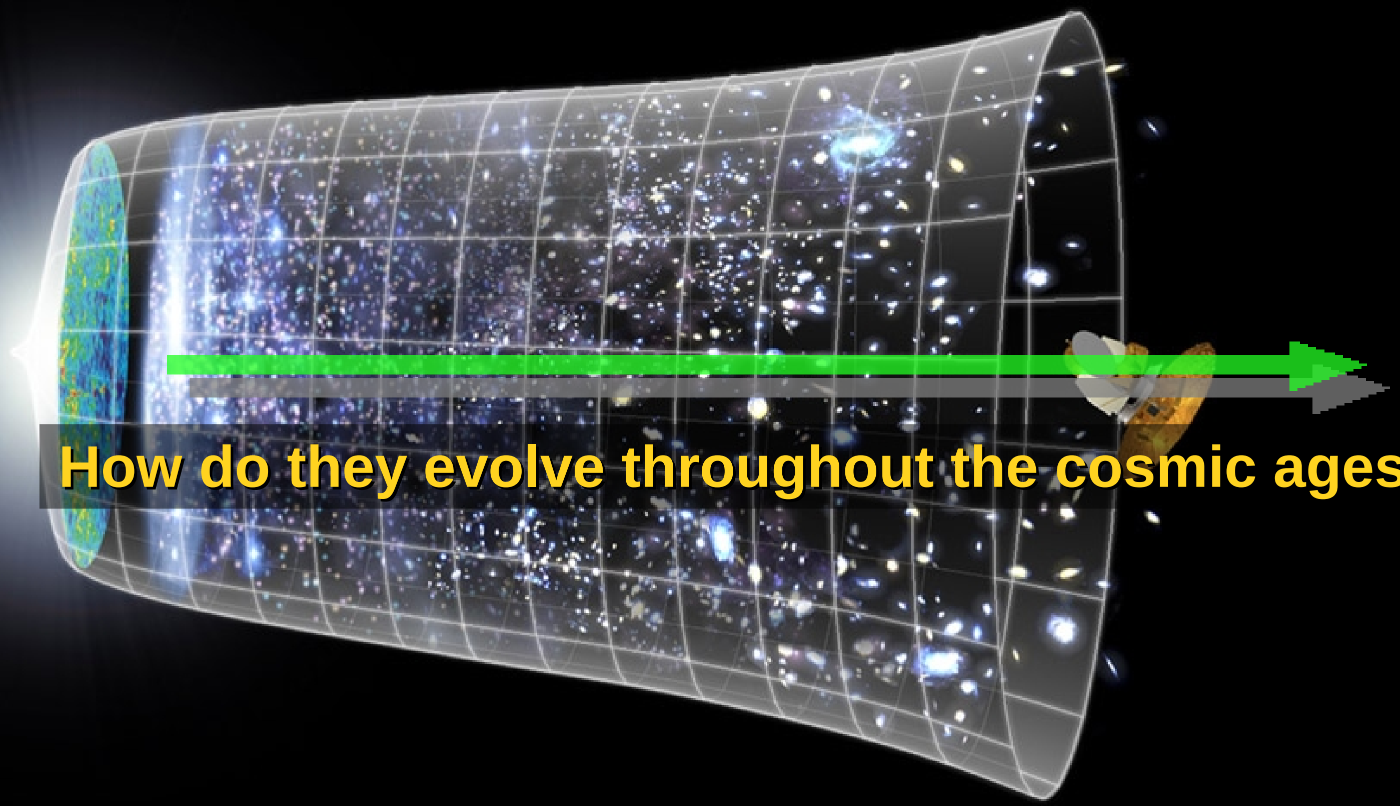
Progenitors of Supernovae & GRBs



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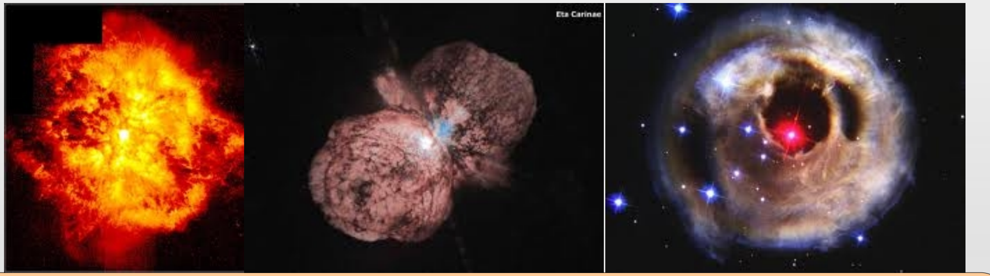
Realtime Astroparticle Physics
4-6 February 2013, Universitaet Bonn

NASA/WMAP Science Team

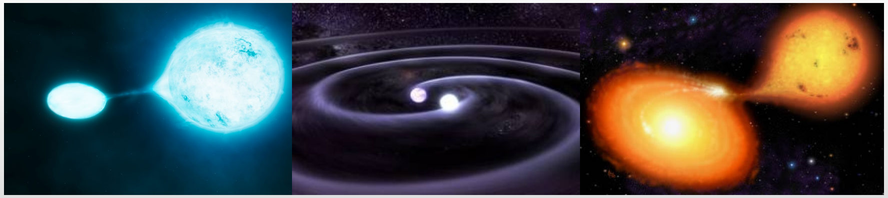
Pre-SN Evolution of Stars



- **Metallicity** → **Mass & Angular Momentum Loss**
- **Initial Mass** → **Mass & Angular Momentum Loss**
- **Initial Rotation** → **Mass & Angular Momentum Loss**

Diversity of Supernovae/GRB

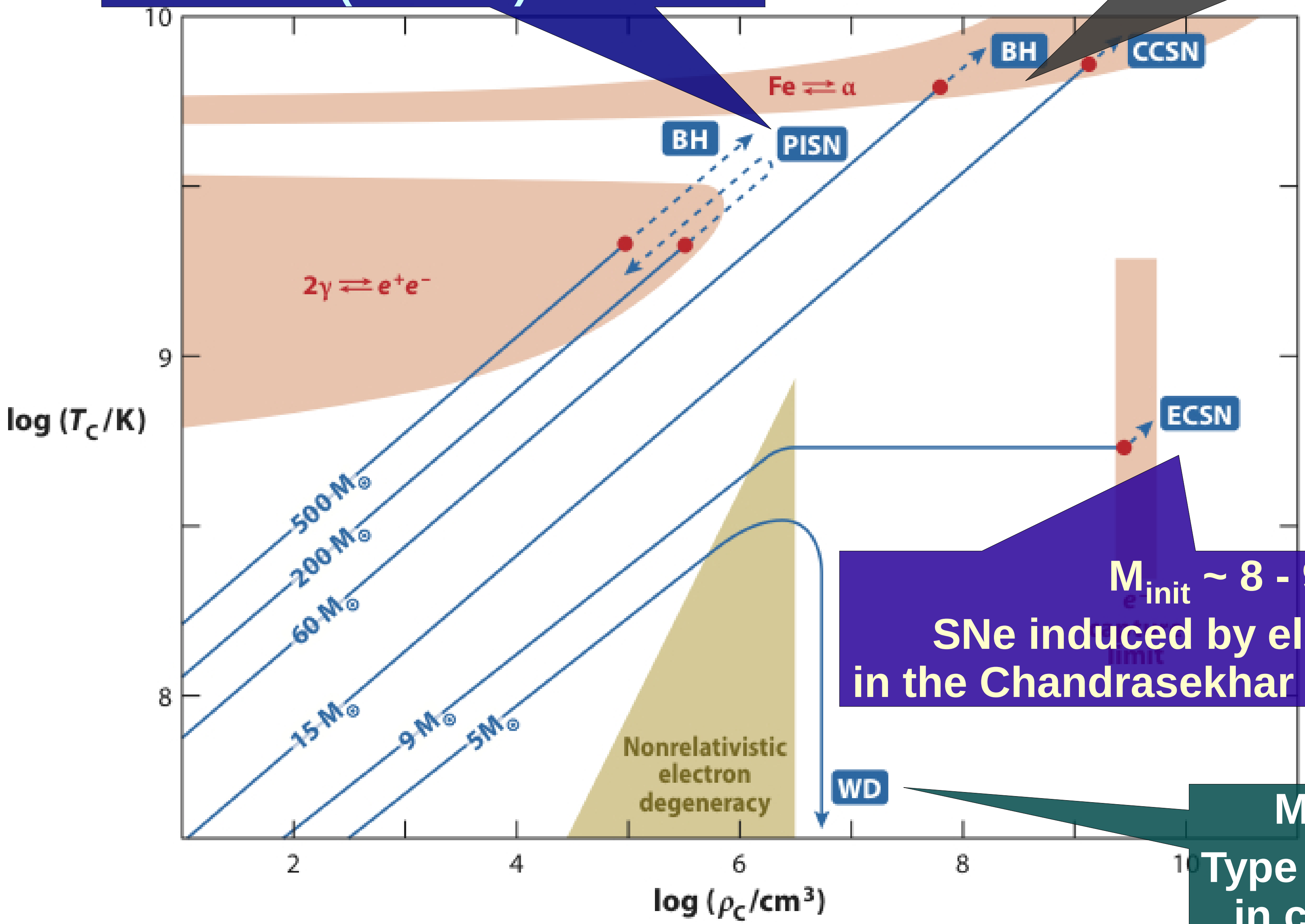
- **Binarirty** → **Exchange of Mass & Angular Momentum**



Initial Mass v.s. SN Types

~ 150 < M_{init} < ~250 M_{sun}
Pair Instability Supernovae
(at low Z)

~ 9 < M_{init} < ~150 M_{sun}
SNe induced by
core-collapse of the iron core



M_{init} ~ 8 - 9 M_{sun}
SNe induced by electron capture
in the Chandrasekhar mass ONeMg core

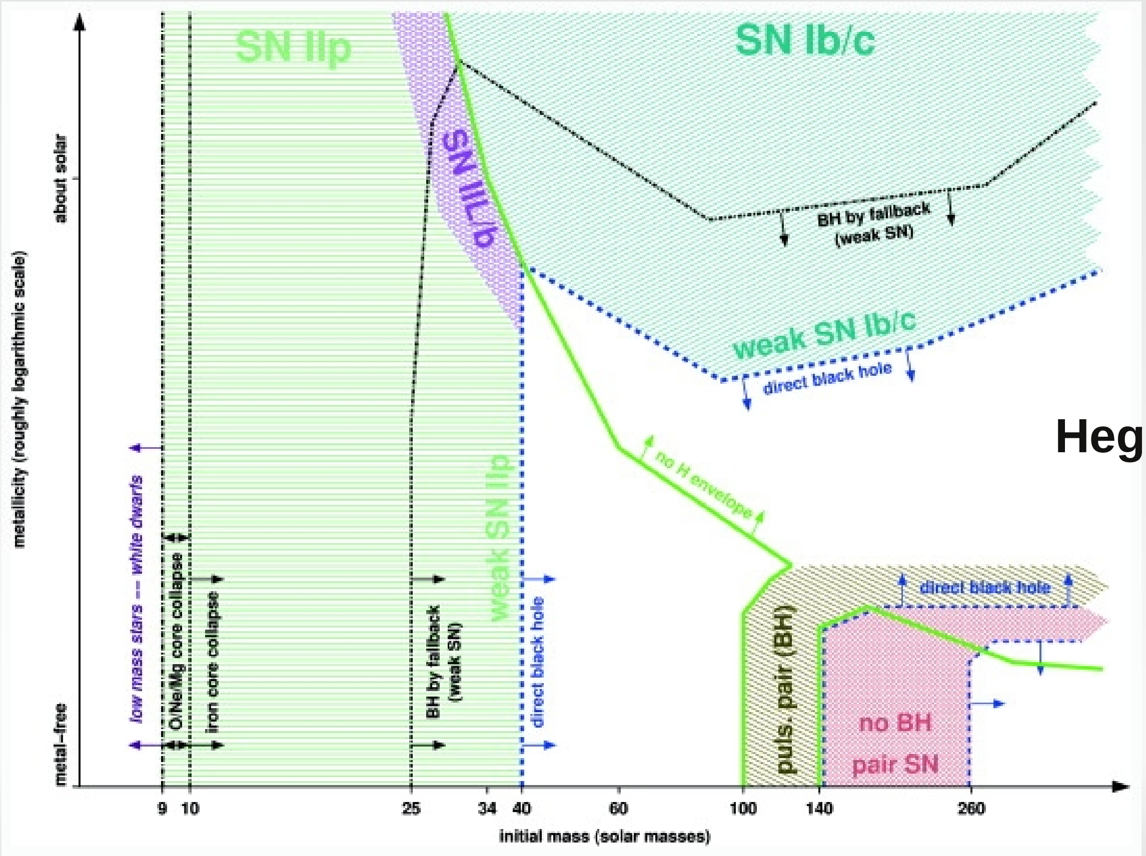
M_{init} < 8 M_{sun}
Type Ia Supernovae
in close binaries

Winds and Mass & Metallicity

Stars lose more mass with higher mass and metallicity.

- Radiation pressure becomes higher in more massive stars.
- Hot star winds are mainly driven by metal lines. In particular, iron lines play the most important role.

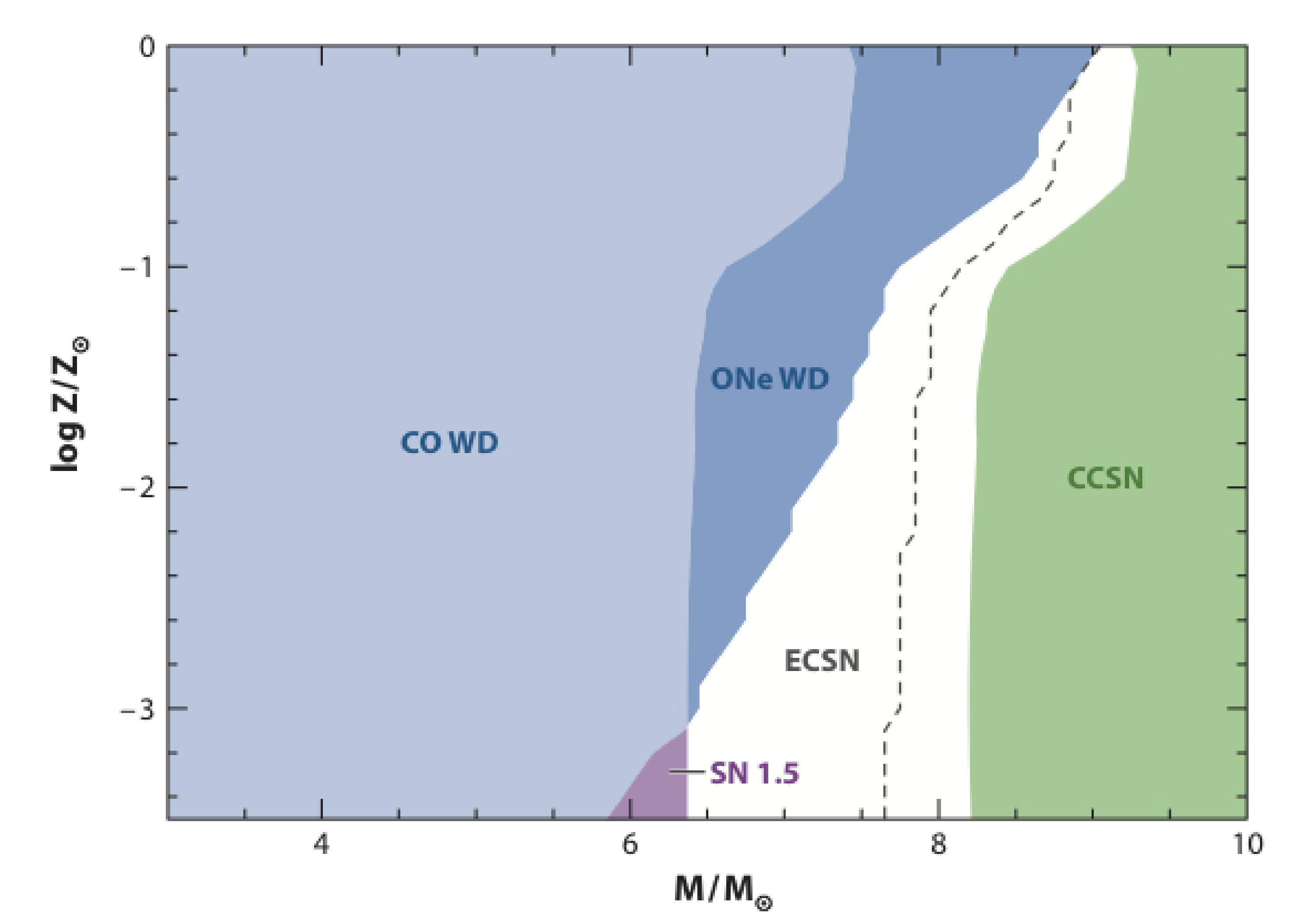
Metallicity



Heger et al 2003

Intitial Mass

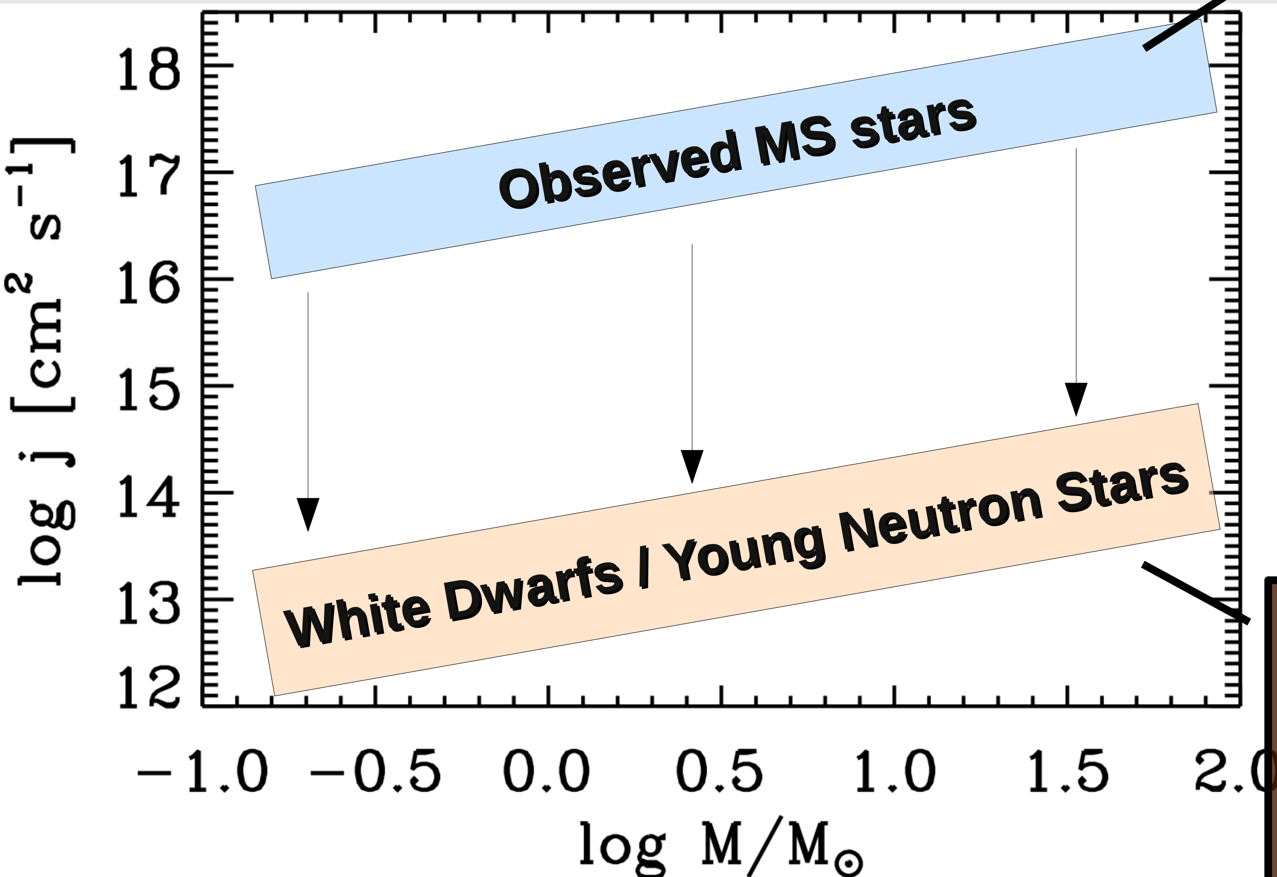
Winds and Mass & Metallicity



Poelarends 2007, Langer 2012

Rotation

Massive stars are rapid rotators.



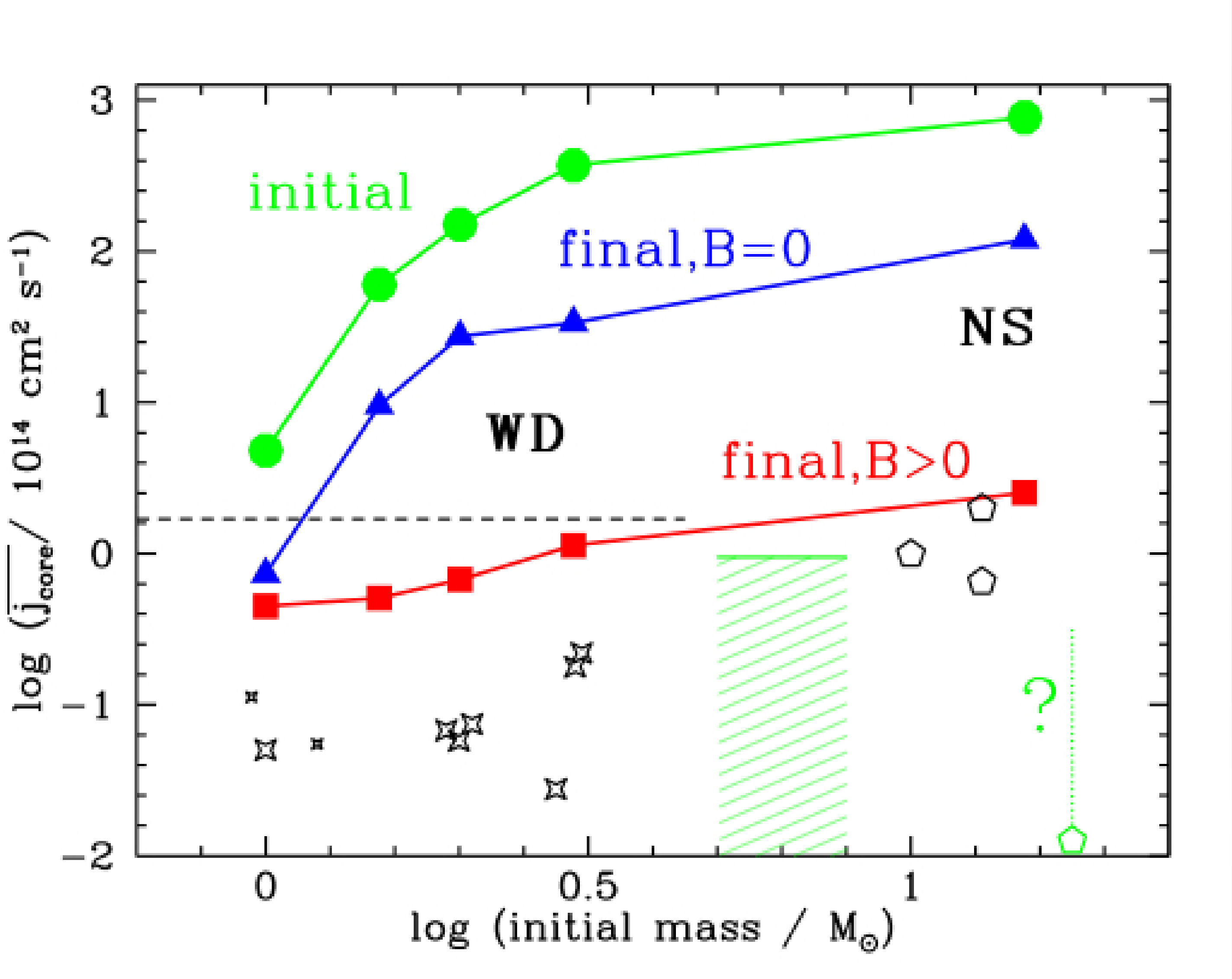
Almost all massive stars are born with enough angular momentum to make a rotation-powered explosion, like GRB.

But, young neutron stars retain only j ~ 10^{14} cm^2/s, implying efficient core-braking in stars:

Most of the massive stars may not make a rotationally induced explosion.

See Suijs et al. 2008

Rotation



Suijs et al. 2008

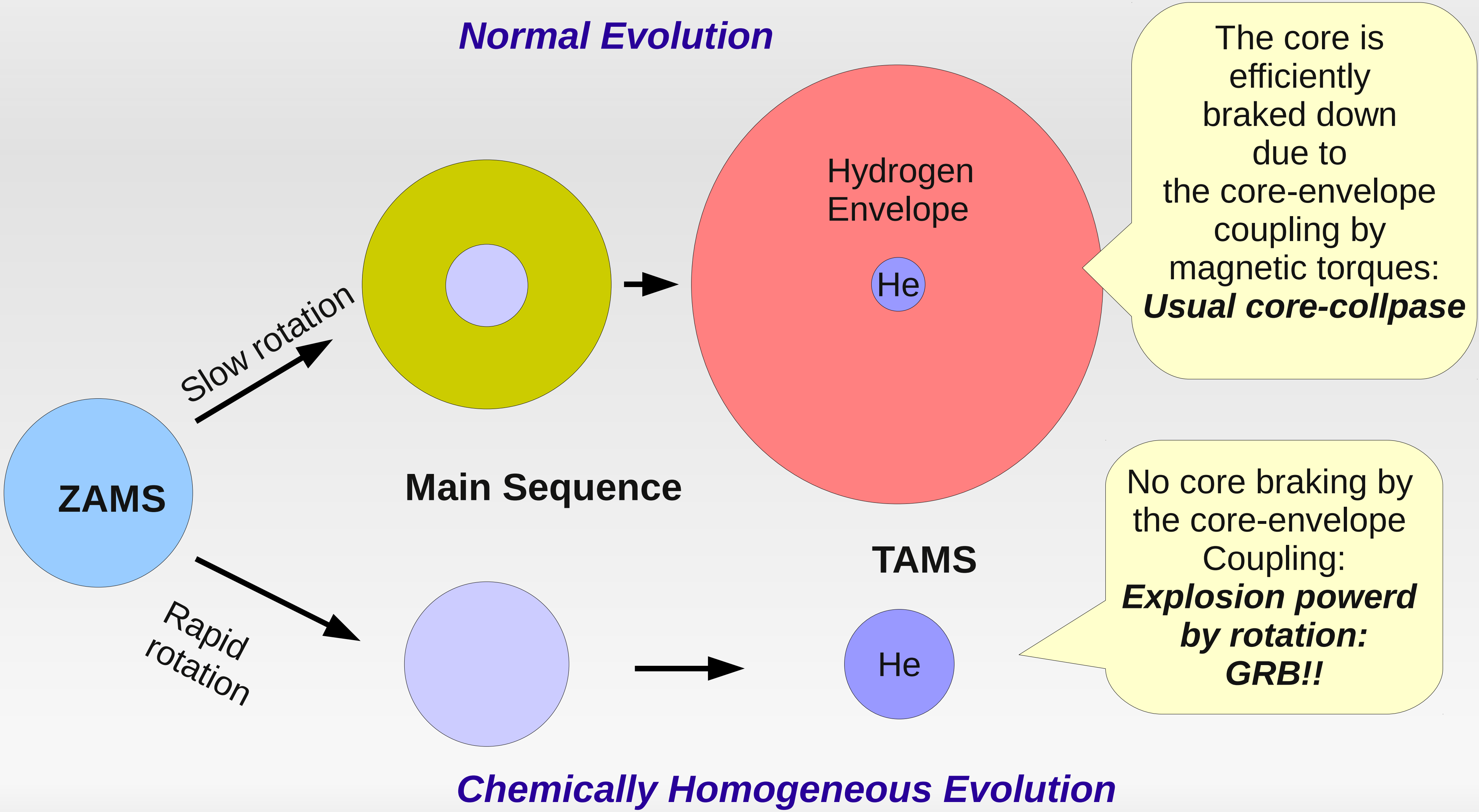
Which stars are GRB progenitors?

Three necessary conditions for GRB progenitors

- **High angular momentum in the core to power relativistic jets**
  - Difficult to achieve in most stars due to the core braking
- **Removal of hydrogen envelope**
  - Difficult for metal poor stars since they do not have strong winds
- **Massive core to form a black hole**

Rotation

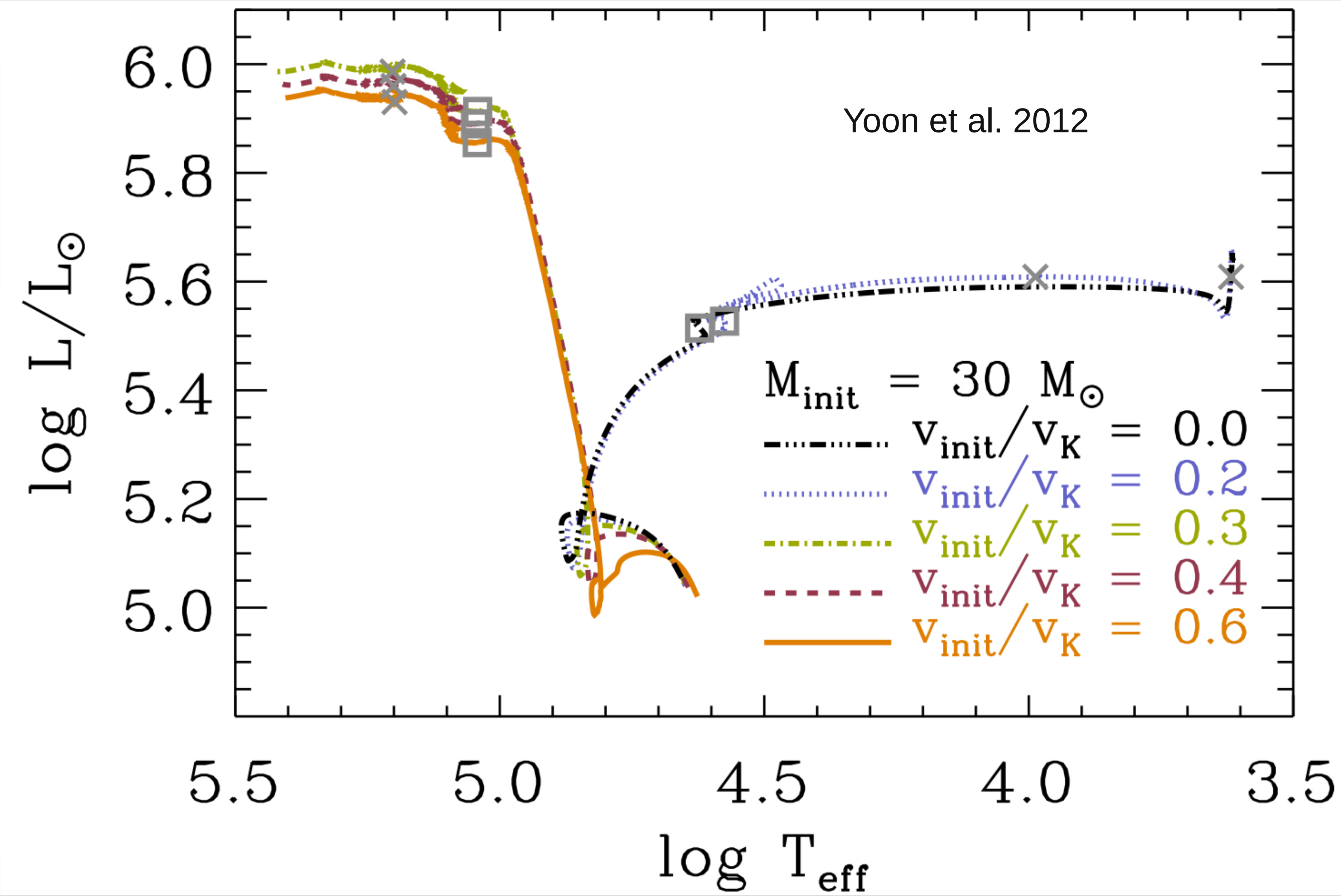
Bifurcation according to initial rotation



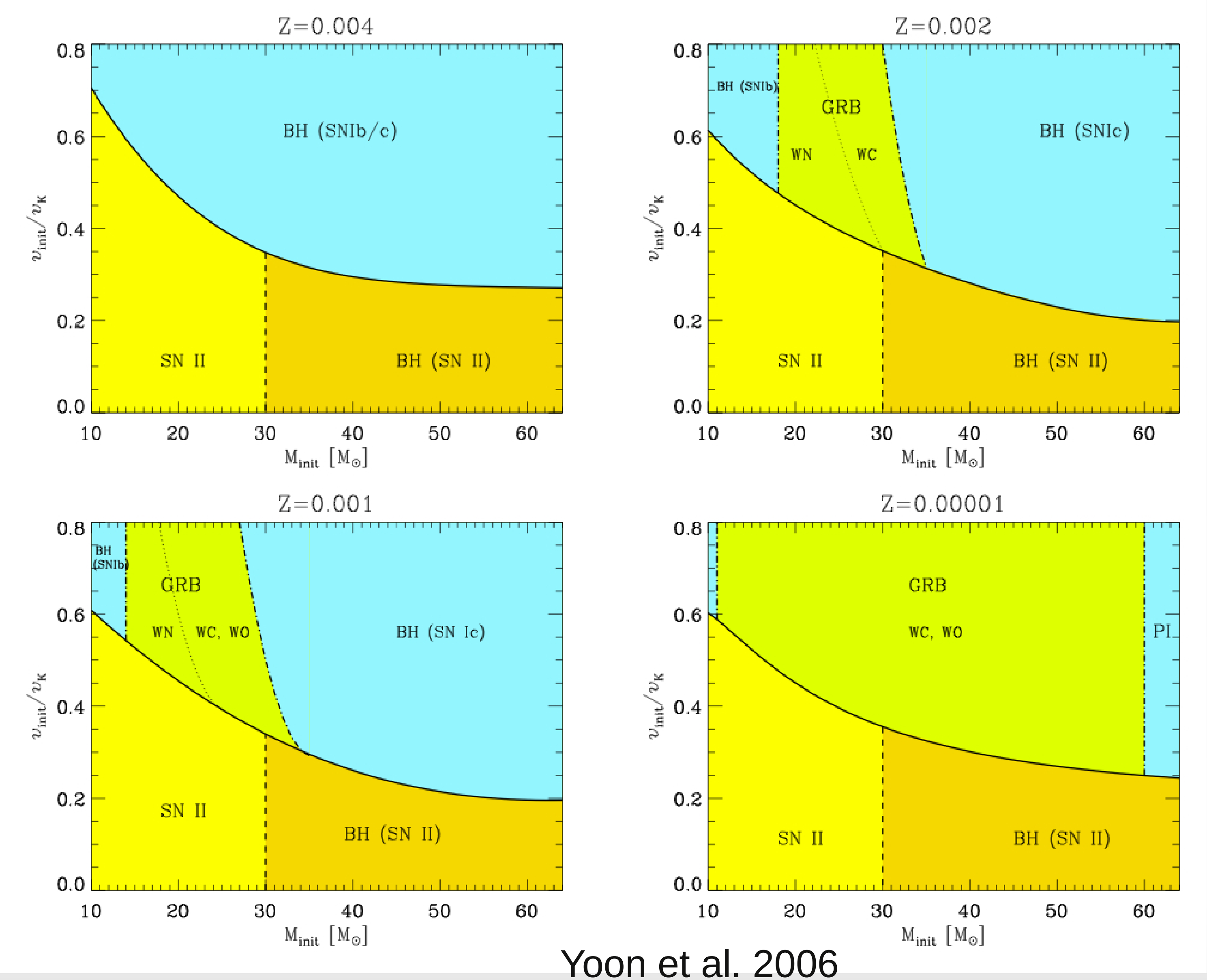
cf. Maeder 1987, Yoon et al. 2006, 2012

Evolution of the First Stars

Bifurcation according to initial rotation

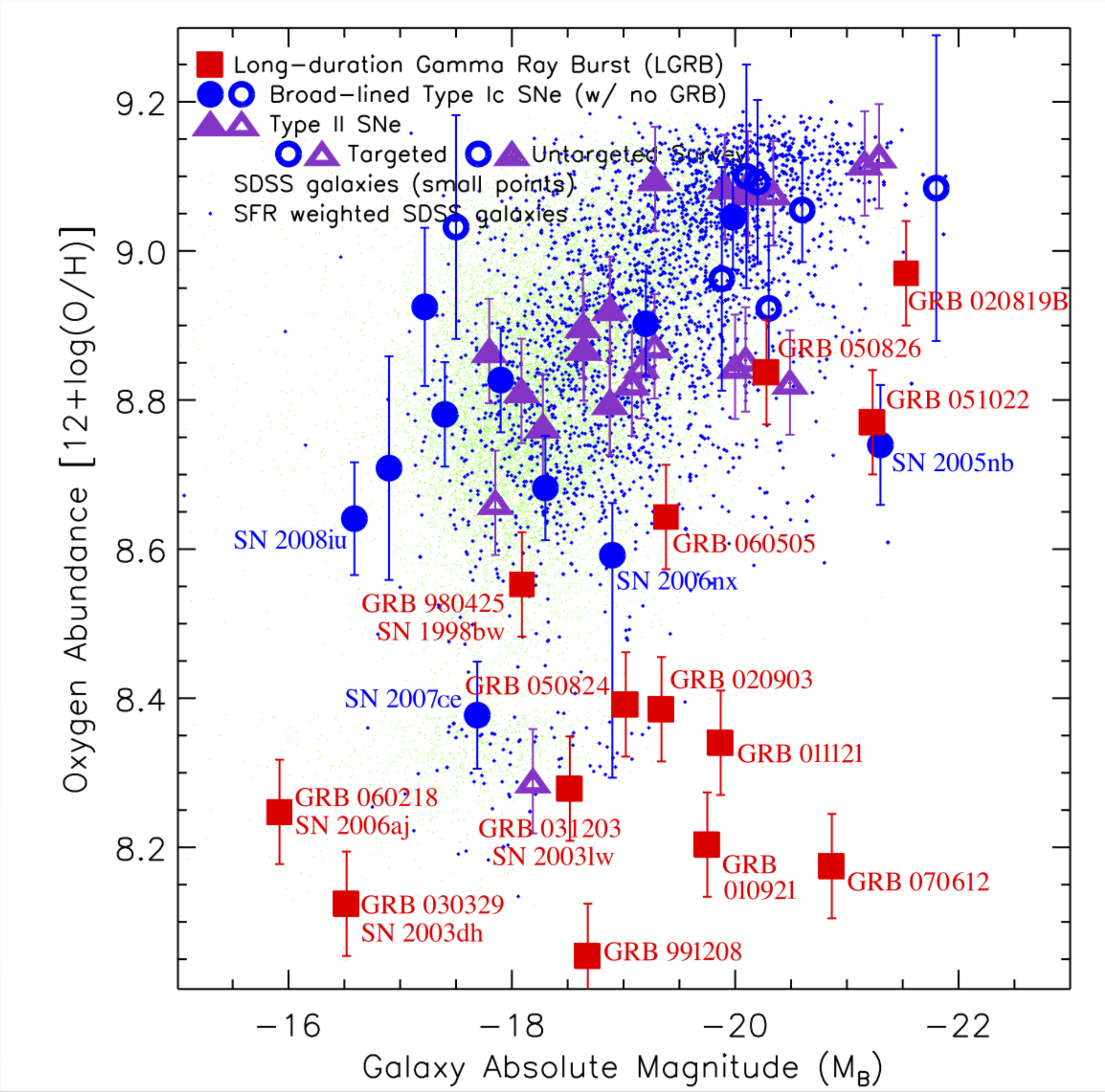


Final fates of rotating massive single stars



Yoon et al. 2006

Low-Z preference for long GRBs?

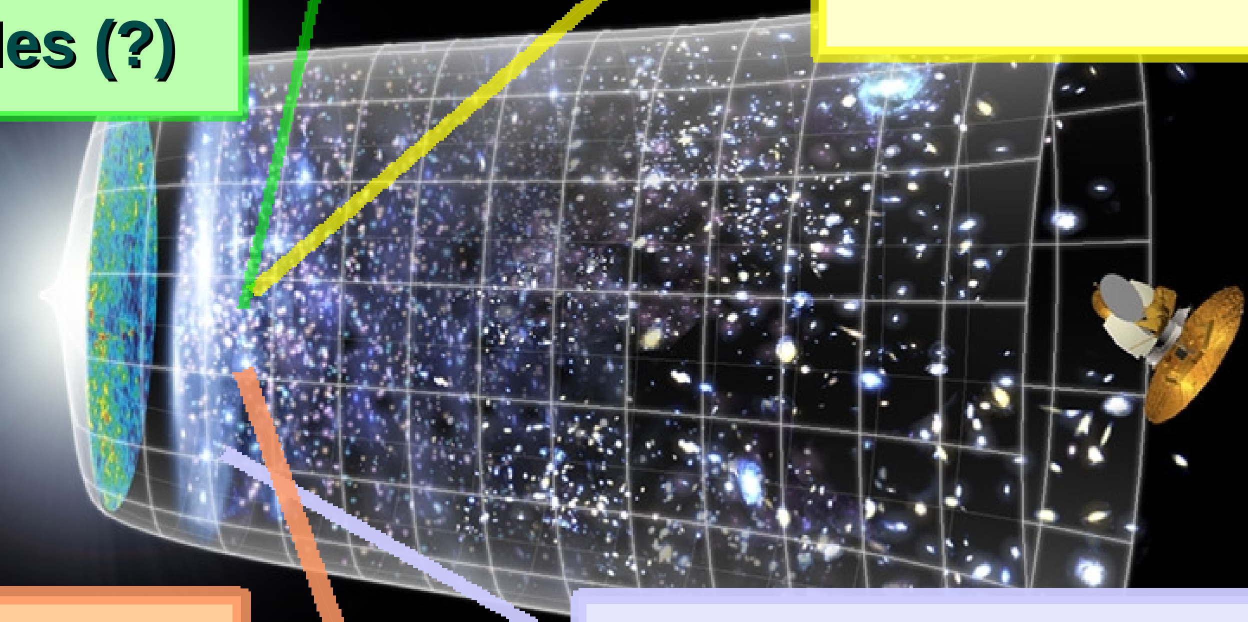


Graham & Fruchter 2013

What about the first stars or very metal poor stars at high redshift?

Seeds for super-massive black holes (?)

Sources of the ionizing photons



Production of heavy elements

Supernovae/GRBs:
-Probe of the early universe
-Tracers of star-formation

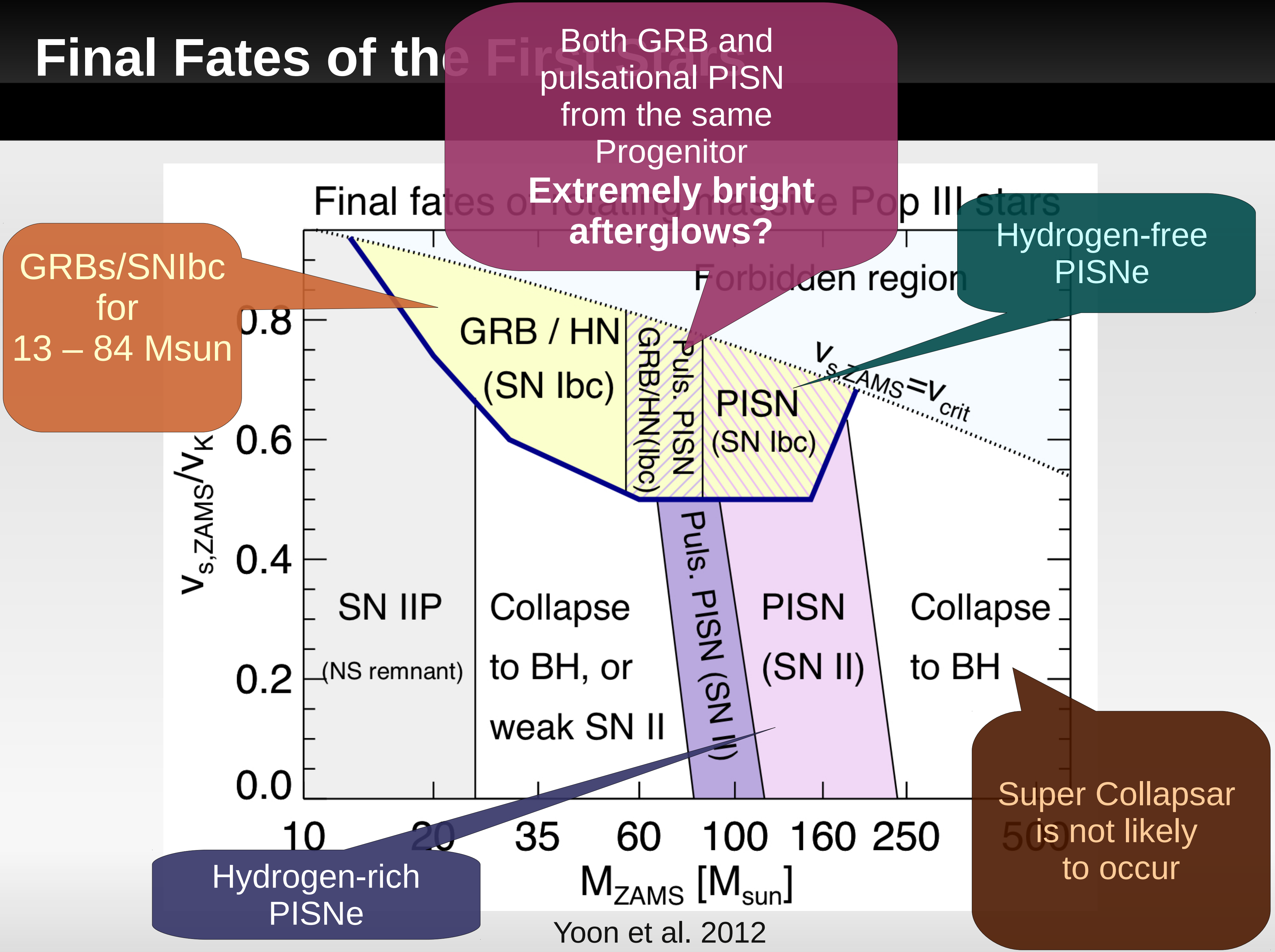
NASA/WMAP Science Team

Evolution of the First Stars

- Line driven winds due to H and He are negligible (Krticka & Kubat 2006).
- The increase of the mass loss rate due to the surface enrichment of the CNO elements by mixing is small (Krticka & Kubat 2009, Muijers et al. 2011)
  - In particular, the CNO elements are too much ionized to drive winds, when T > 50000 K.
- Pop III stars are usually stable against pulsation (Baraffe et al. 2001).

- **Therefore, no significant mass loss is expected, in contrast to the case of massive stars in our Galaxy.**
- ***Effects of rotation must be crucial.***

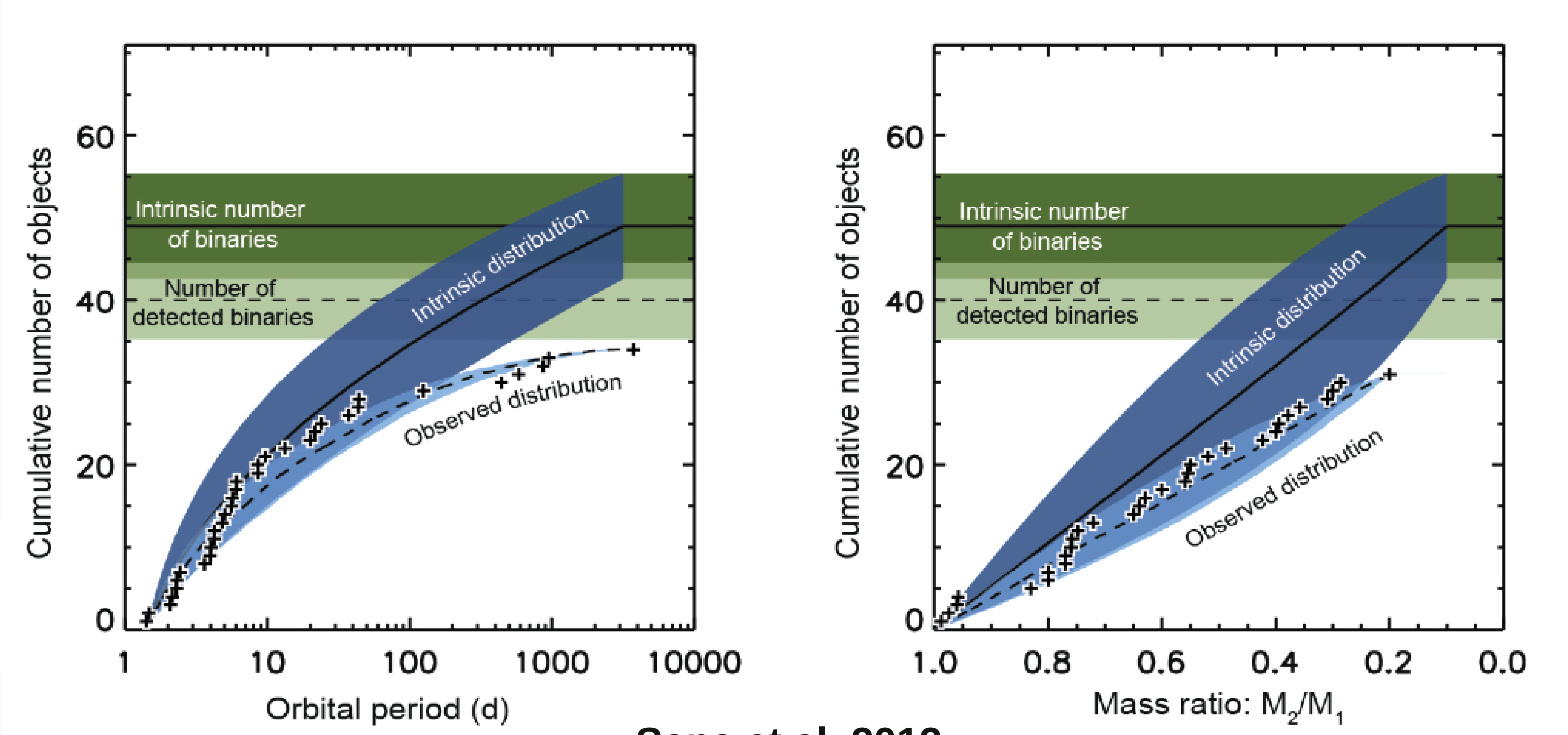
Final Fates of the First Stars



Yoon et al. 2012

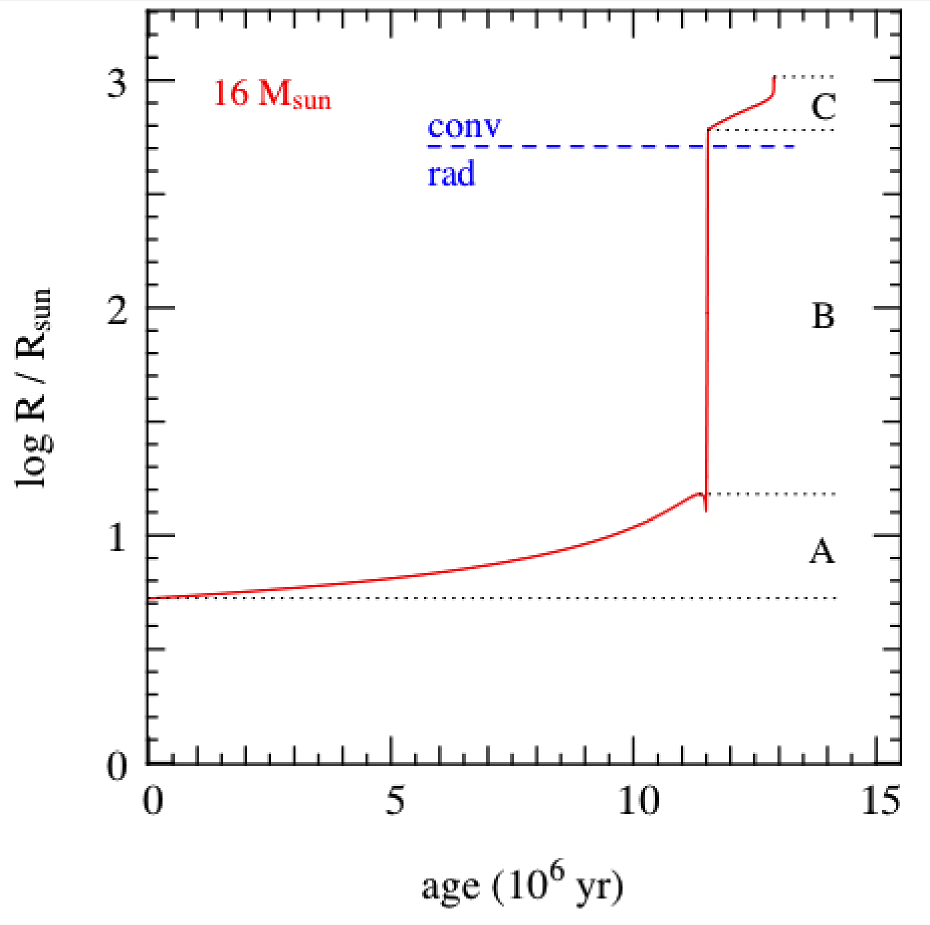
Binary Stars

Observations indicate that more than 50% of massive stars are in close binary systems



Sana et al. 2012

Evolution of Binary Stars



- **Case A mass transfer:**

  Mass transfer during core hydrogen burning

- **Case B mass transfer:**

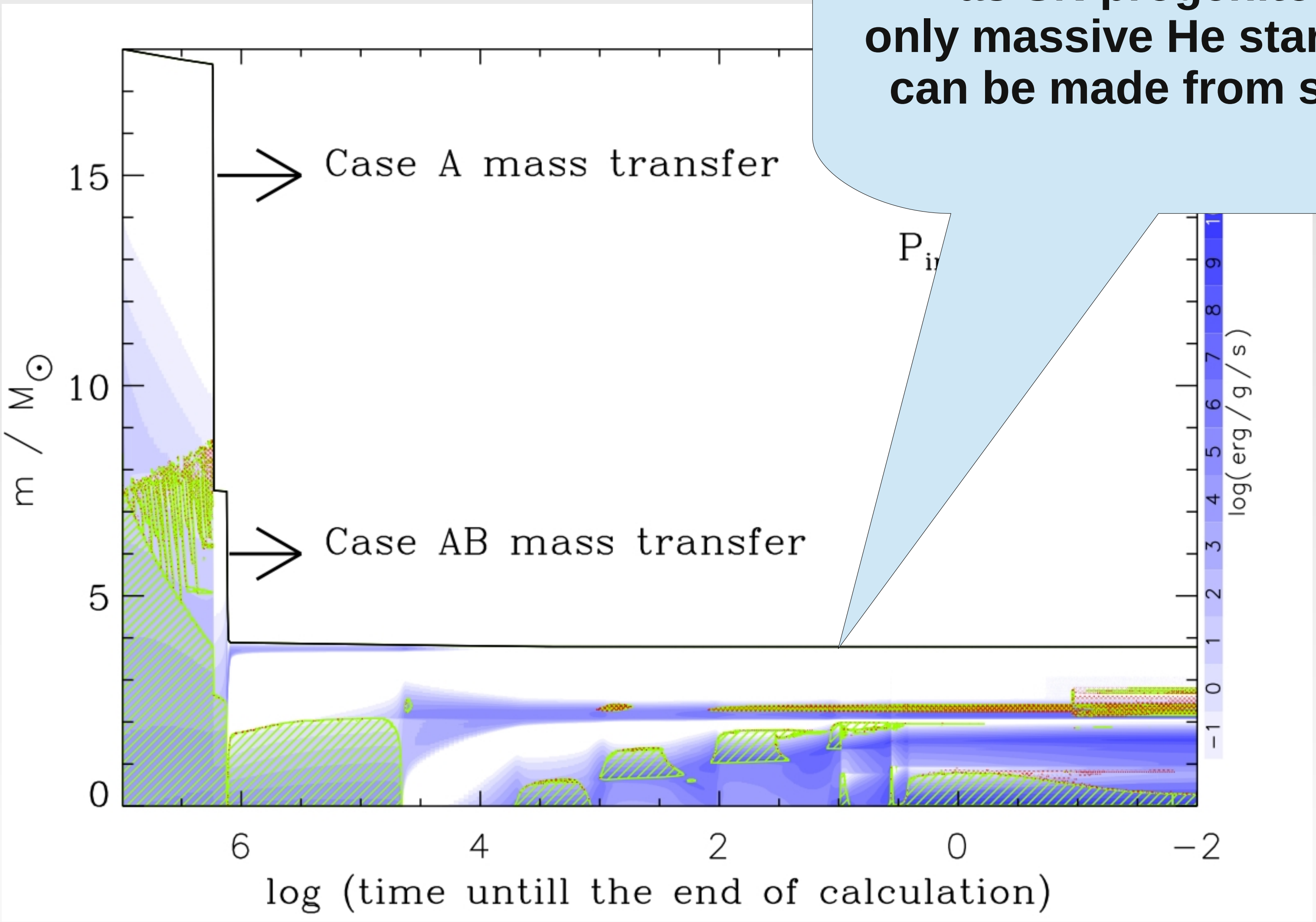
  Mass transfer during helium core contraction, or during the beginning of core helium burning

- **Case C mass transfer:**

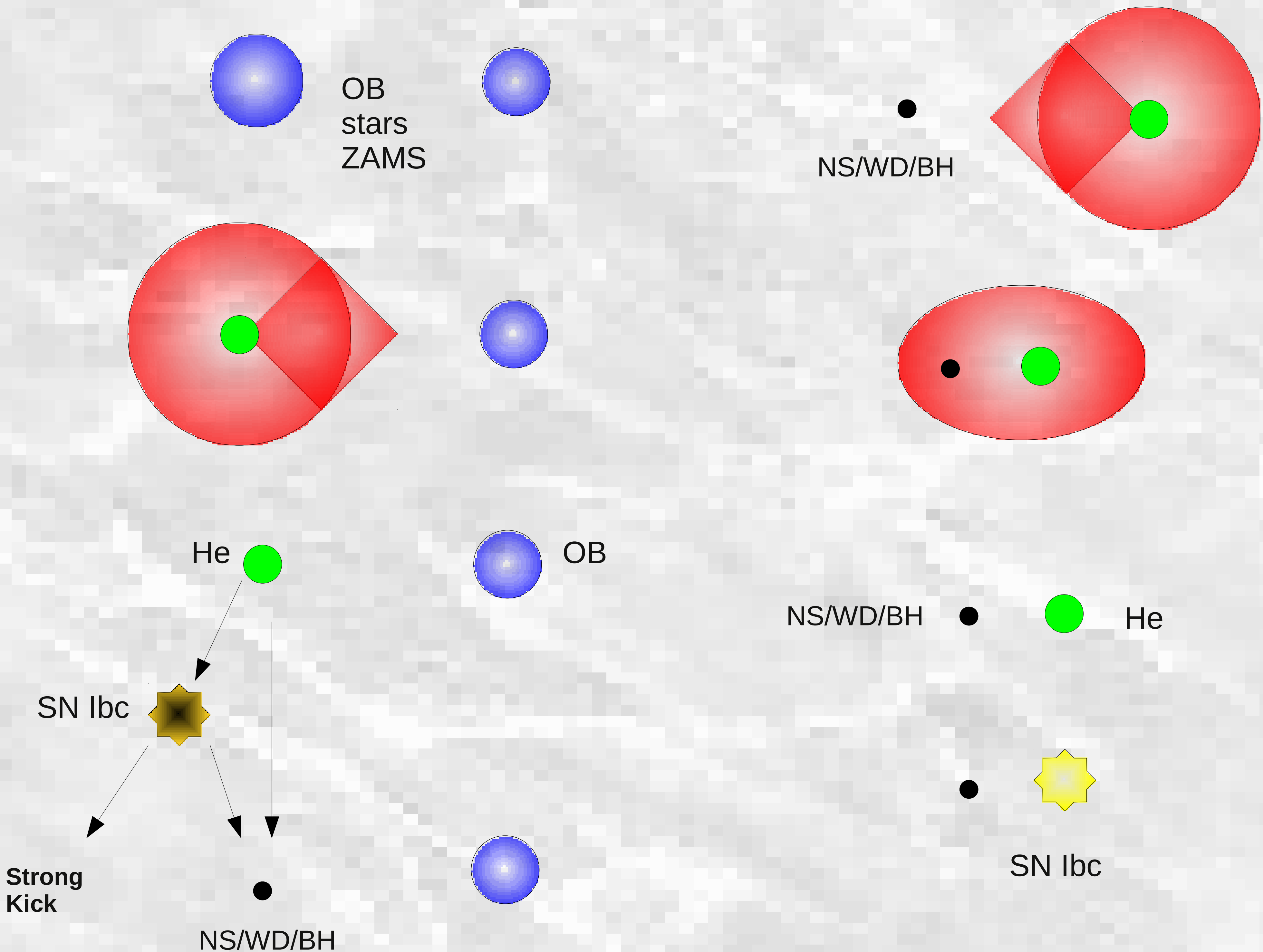
  Mass transfer during the later stages.

Example

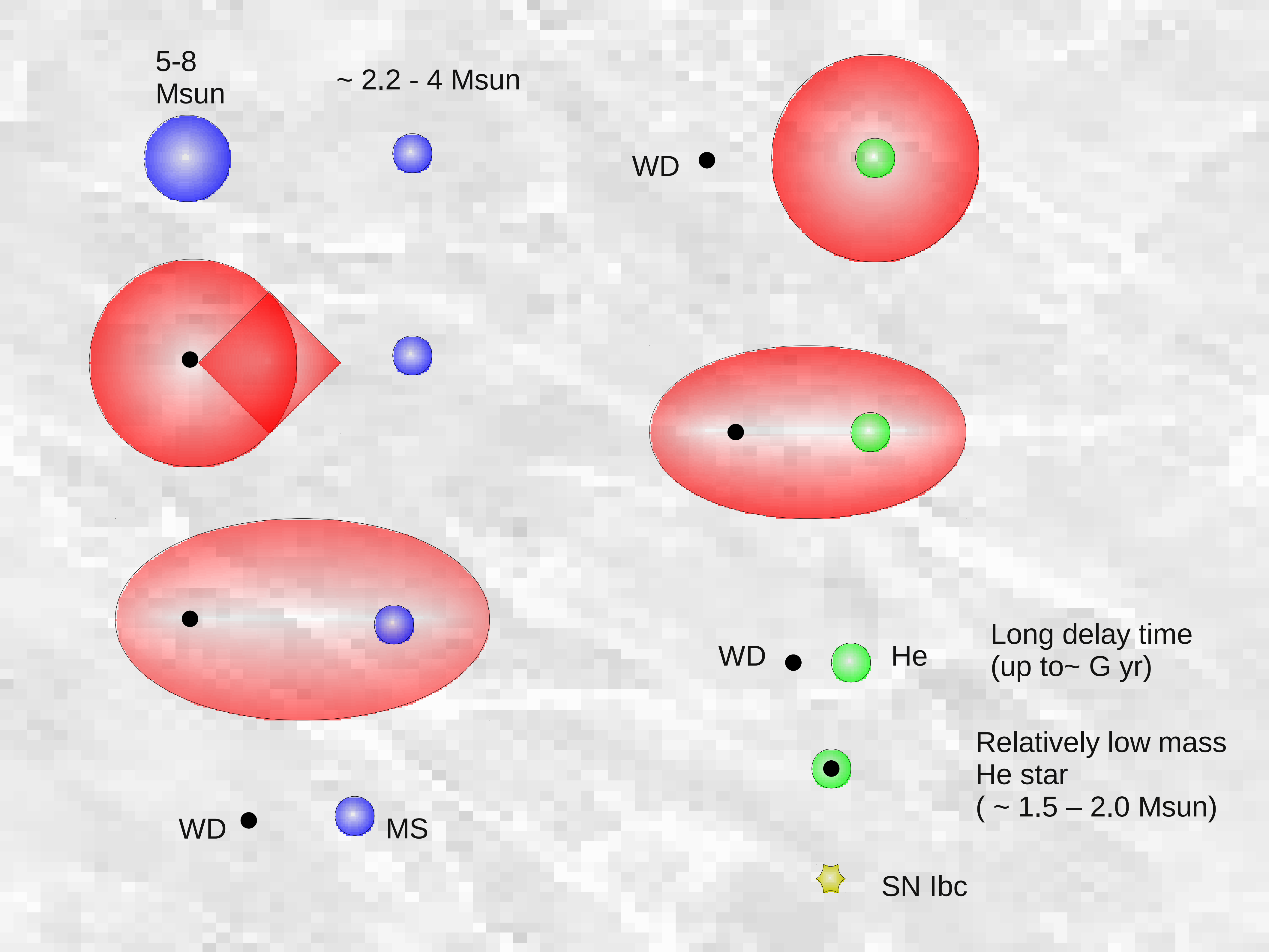
Binary stars can produce relatively low-mass He stars (2~ 7 Msun) as SN progenitors, while only massive He stars (> 7 Msun) can be made from single stars.



Yoon et al. 2010

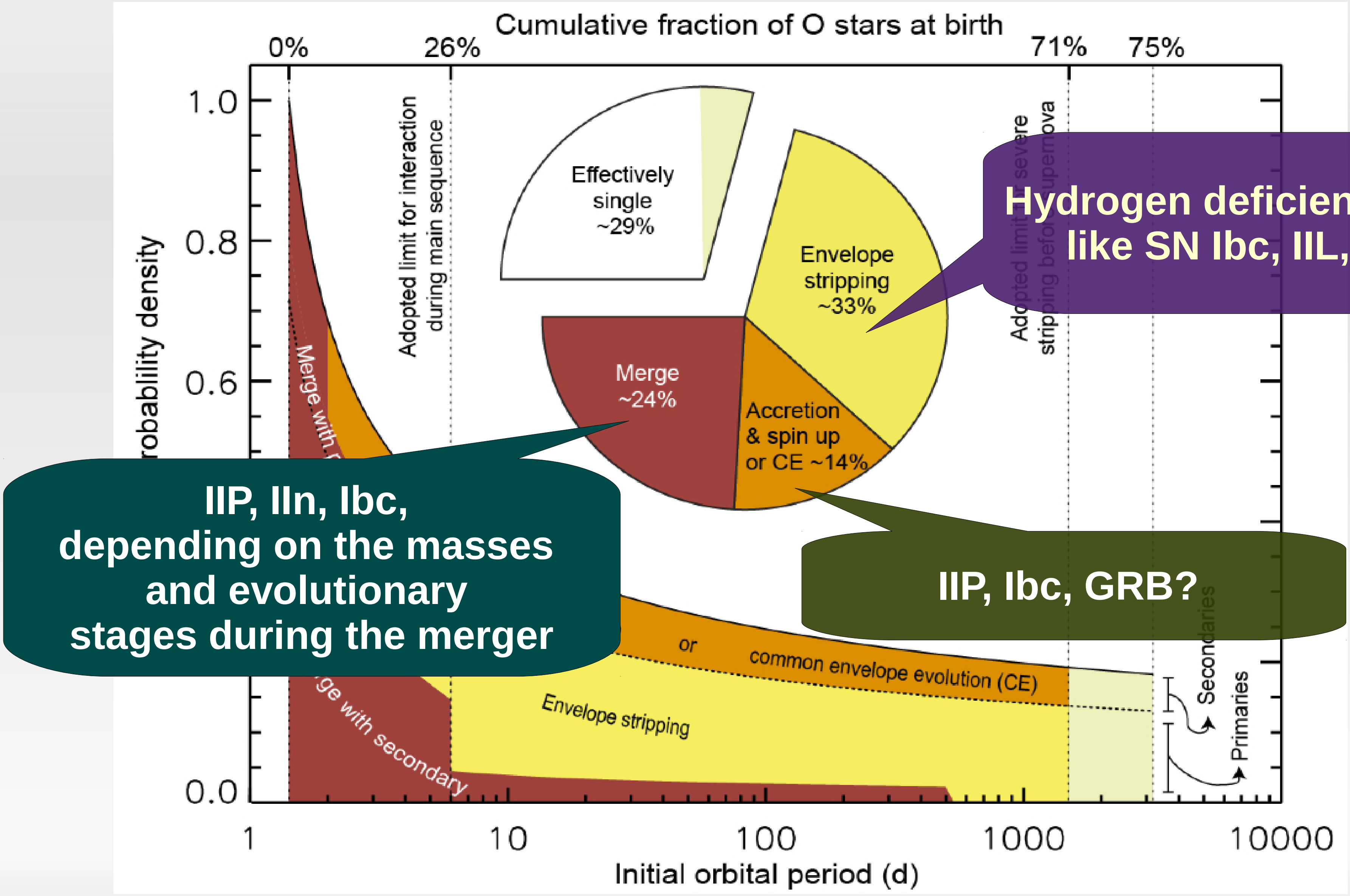


OB
stars
ZAMS
NS/WD/BH
He
OB
NS/WD/BH
He
SN Ibc
Strong
Kick
NS/WD/BH
SN Ibc



5-8
Msun
~ 2.2 - 4 Msun
WD
WD
He
Long delay time
(up to~ G yr)
WD
MS
Relatively low mass
He star
(~ 1.5 – 2.0 Msun)
SN Ibc

Binary Stars



Sana et al. 2012

Final Remarks

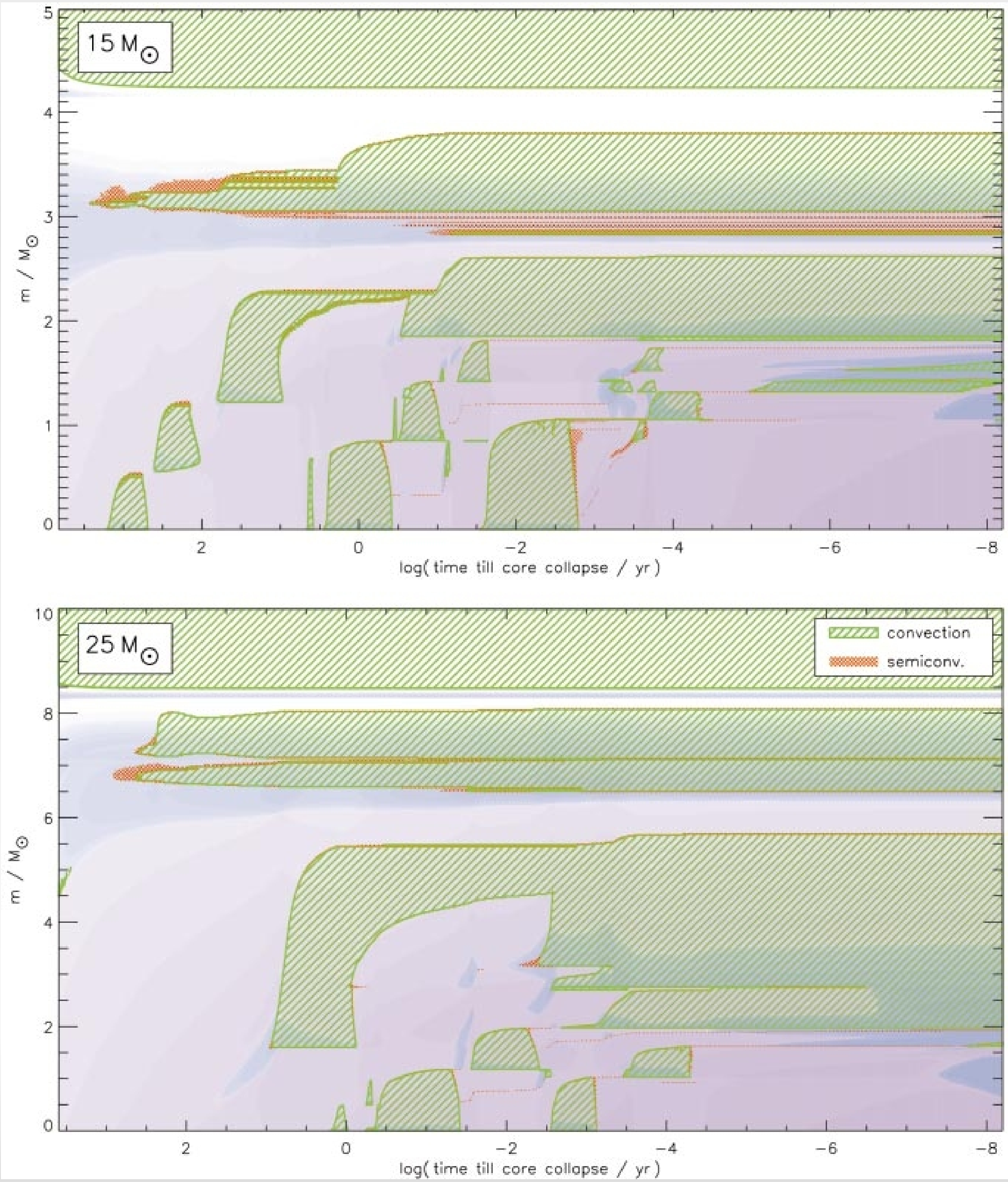
- Stellar winds, metallicity, rotation and binary interactions may expain the observational diversity of SNe, in principle.
- However, there still exist many unsolved problems:
  - Progenitors for SN IIn or other types of interaction supernovae (e.g., Quimby-type SNe): why some stars experience mass eruptions shortly before their death?
  - Progenitors of broad-lined SN Ic?
  - Progenitors of Ca-rich SN Ib?
  - Progenitors SN IIL?

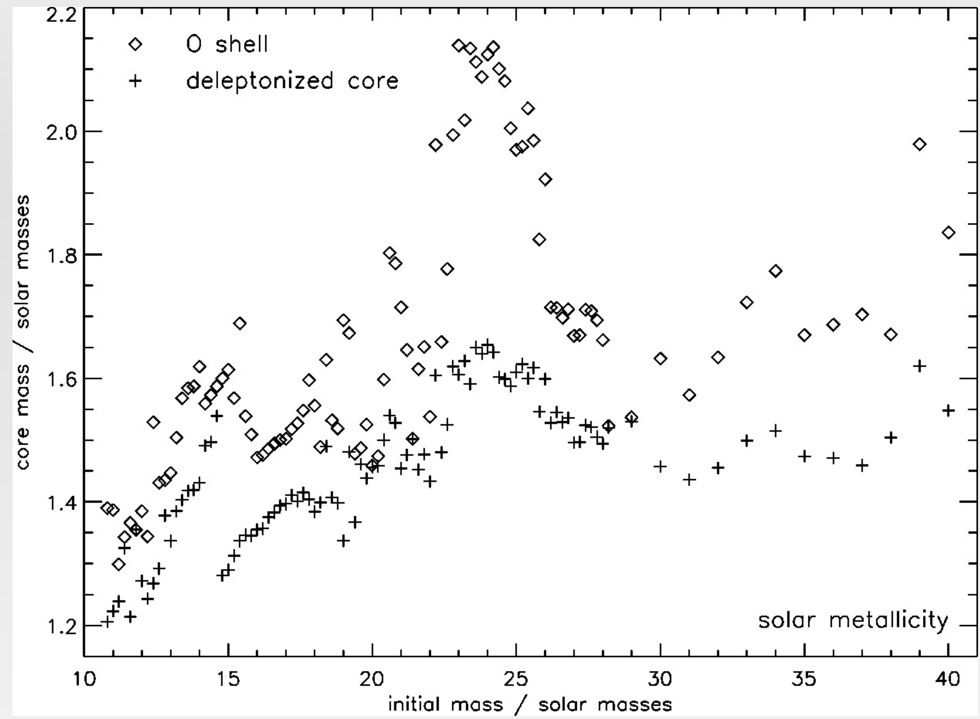
Final Remarks

- We still have not explored the full parameter space, in particular for binary stars (e.g., Cantiello et al. 2007; Yoon et al. 2010).

- There also exist many other physical processes that should be studied in future: e.g. magnetic fields, multi-D effects of convection & semi-convection, etc.

Example: uncertainty of stellar models due to the treatment of convection





Woosley & Heger 2002