Progenitors of Type Ibc Supernovae

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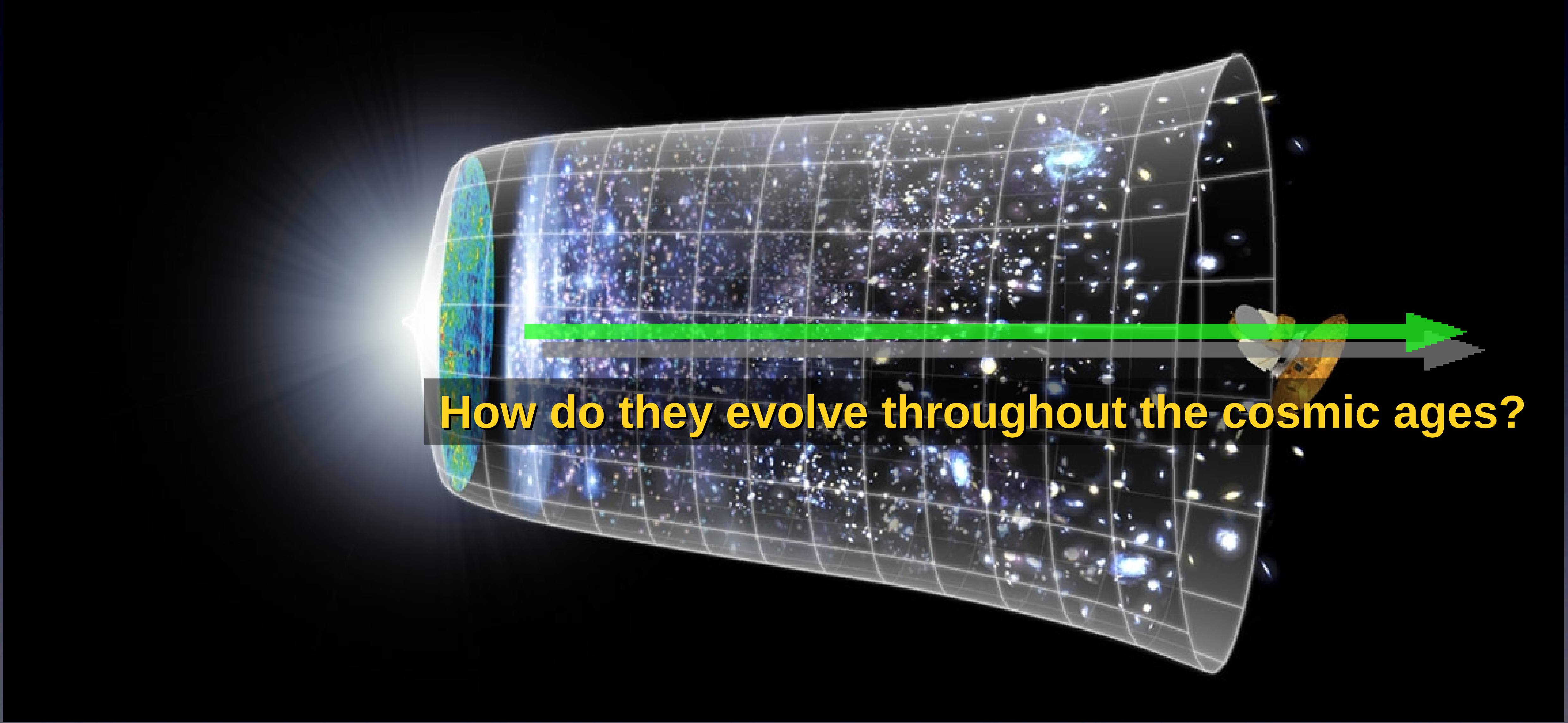
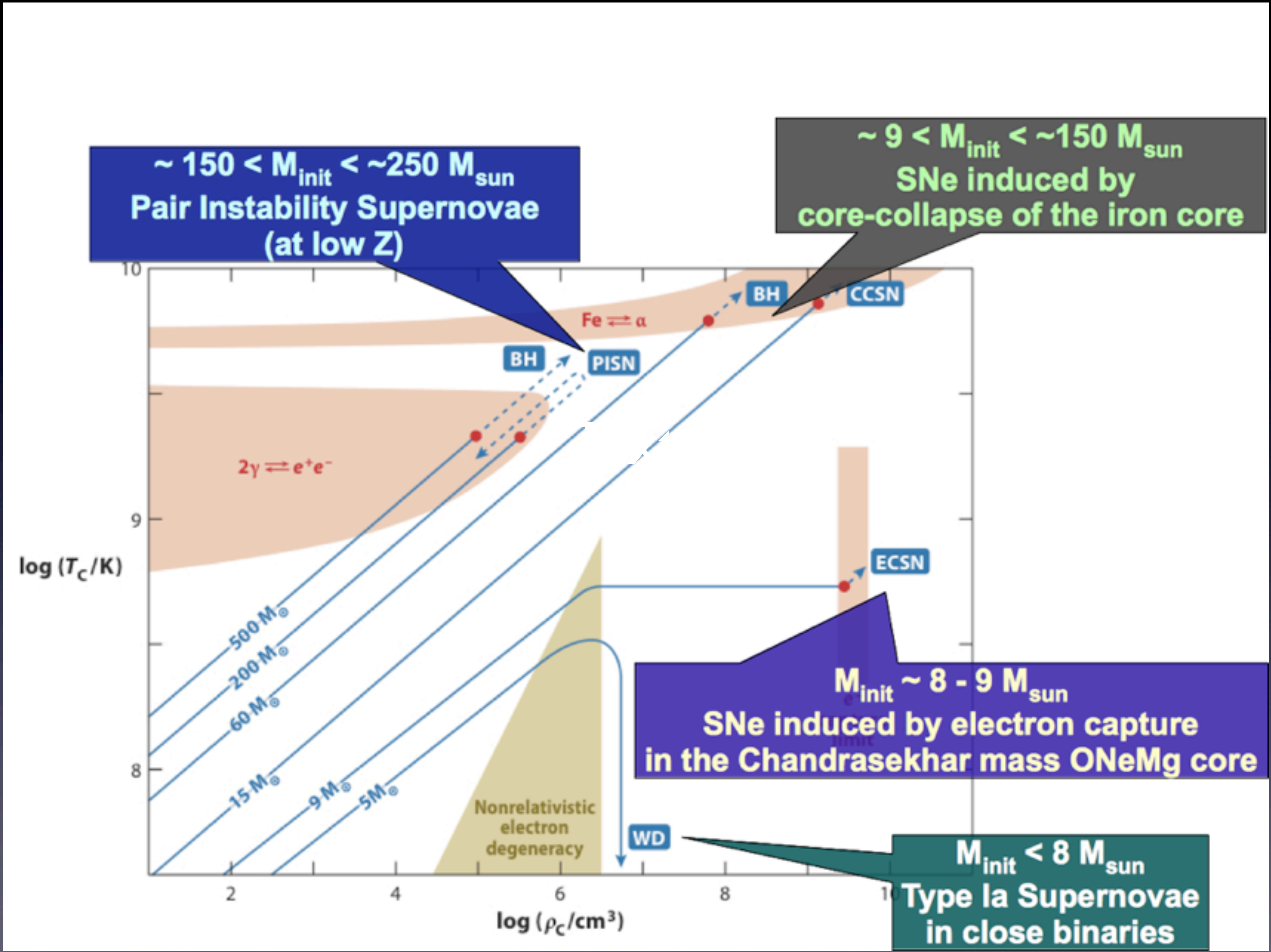
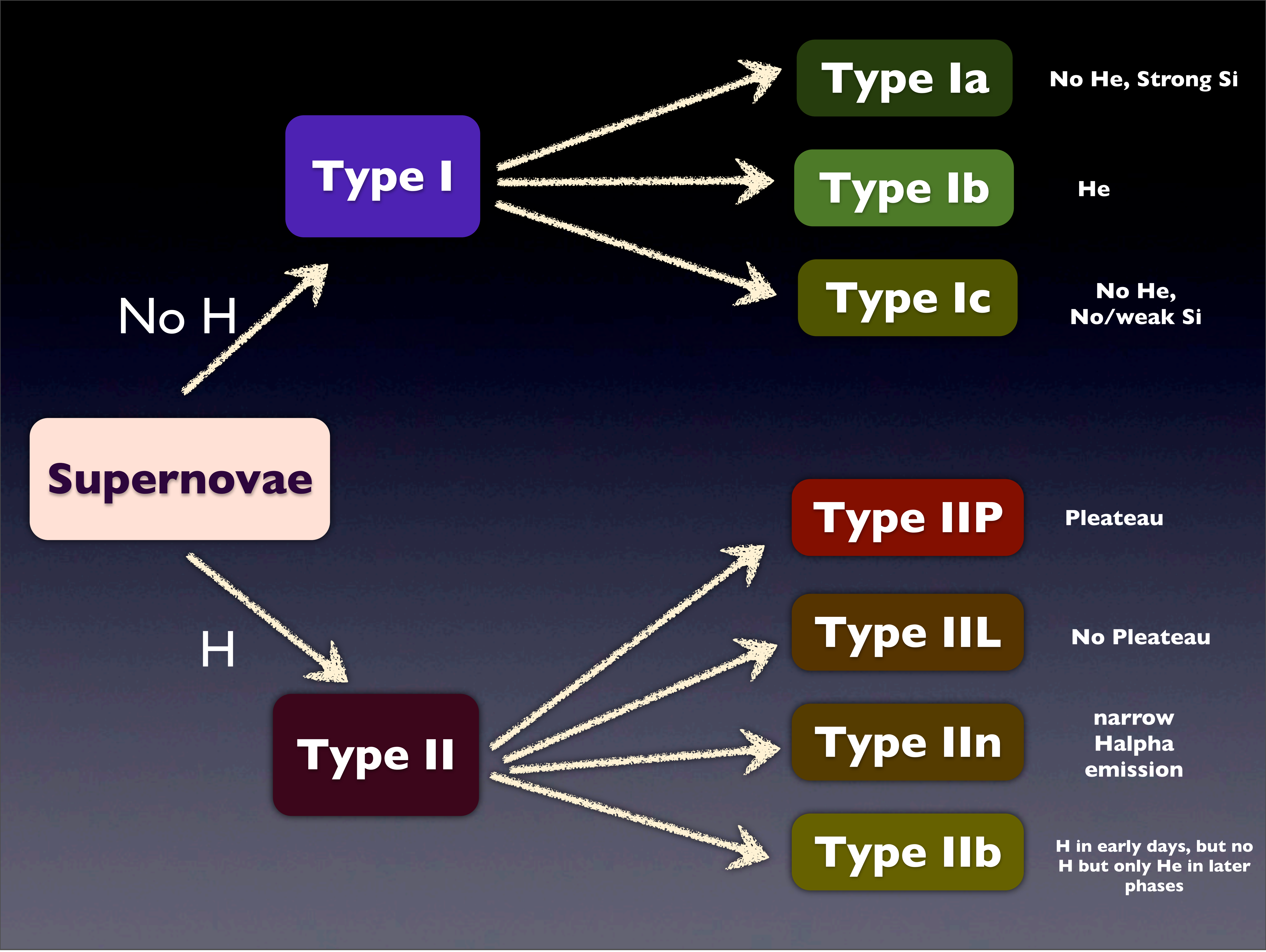
Kavli IPMU, June 26, 2013

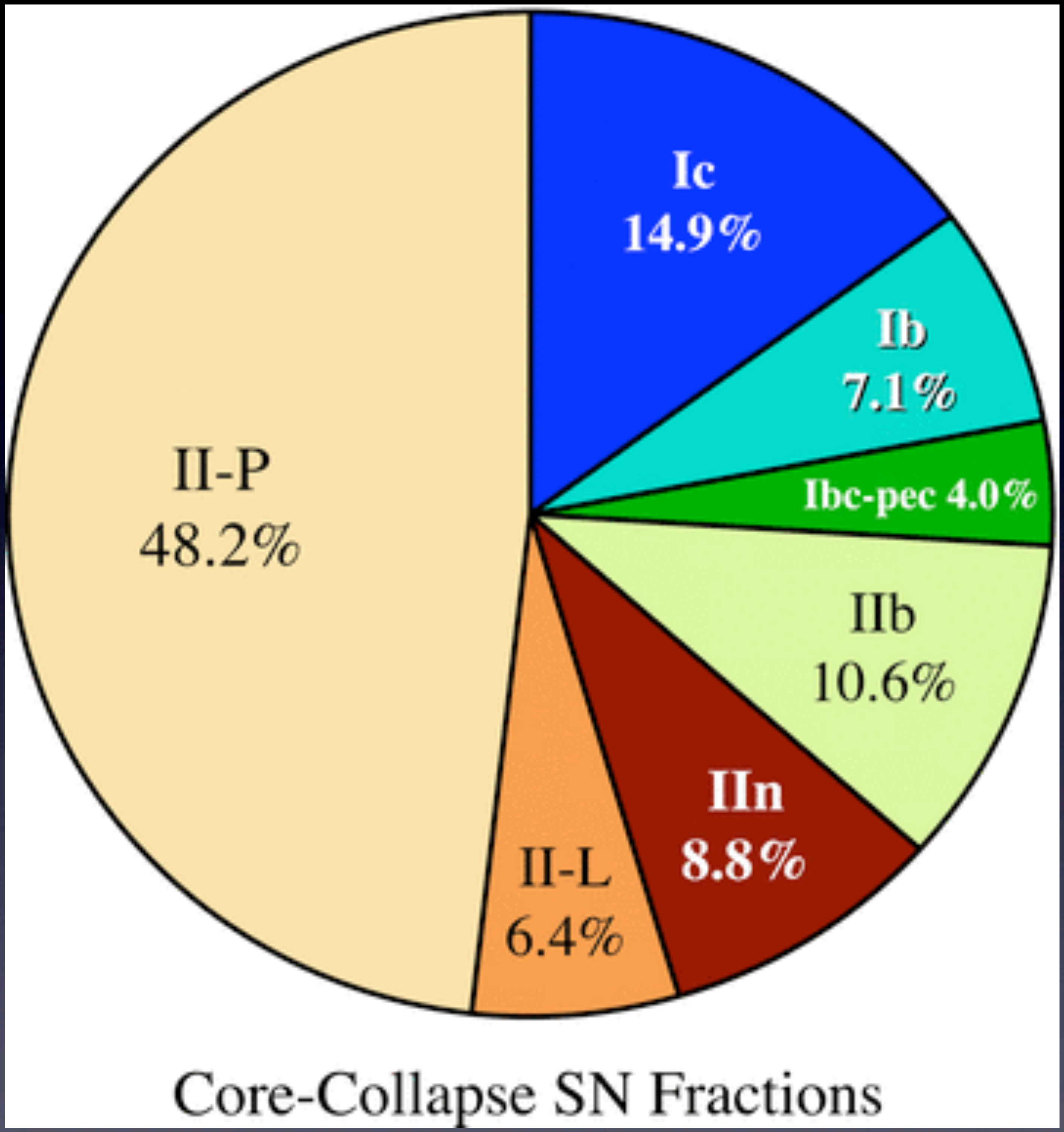
Progenitors of Supernovae & GRBs



Pre-SN Evolution of Massive Stars

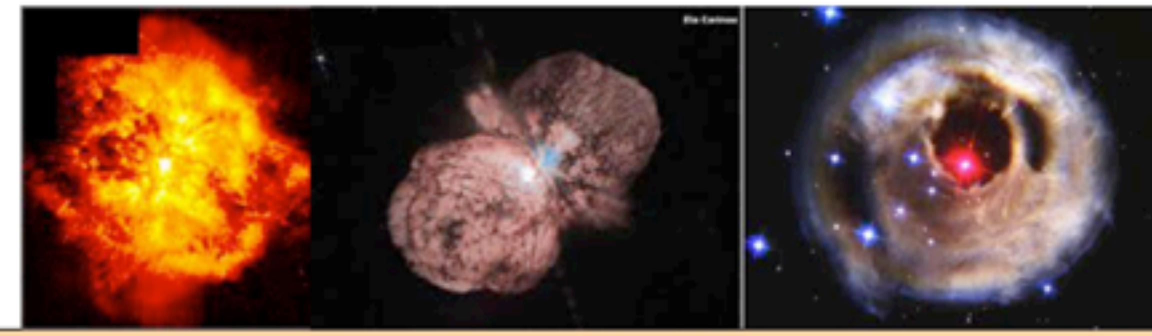



Type Ia
No He, Strong Si
Type I
Type Ib
He
Type Ic
No He,
No/weak Si
No H
Supernovae
Type IIP
Pleateau
H
Type IIL
No Pleateau
Type II
Type IIn
narrow
Halpha
emission
Type IIb
H in early days, but no
H but only He in later
phases



Smith et al. 2011

Pre-SN Evolution of Stars



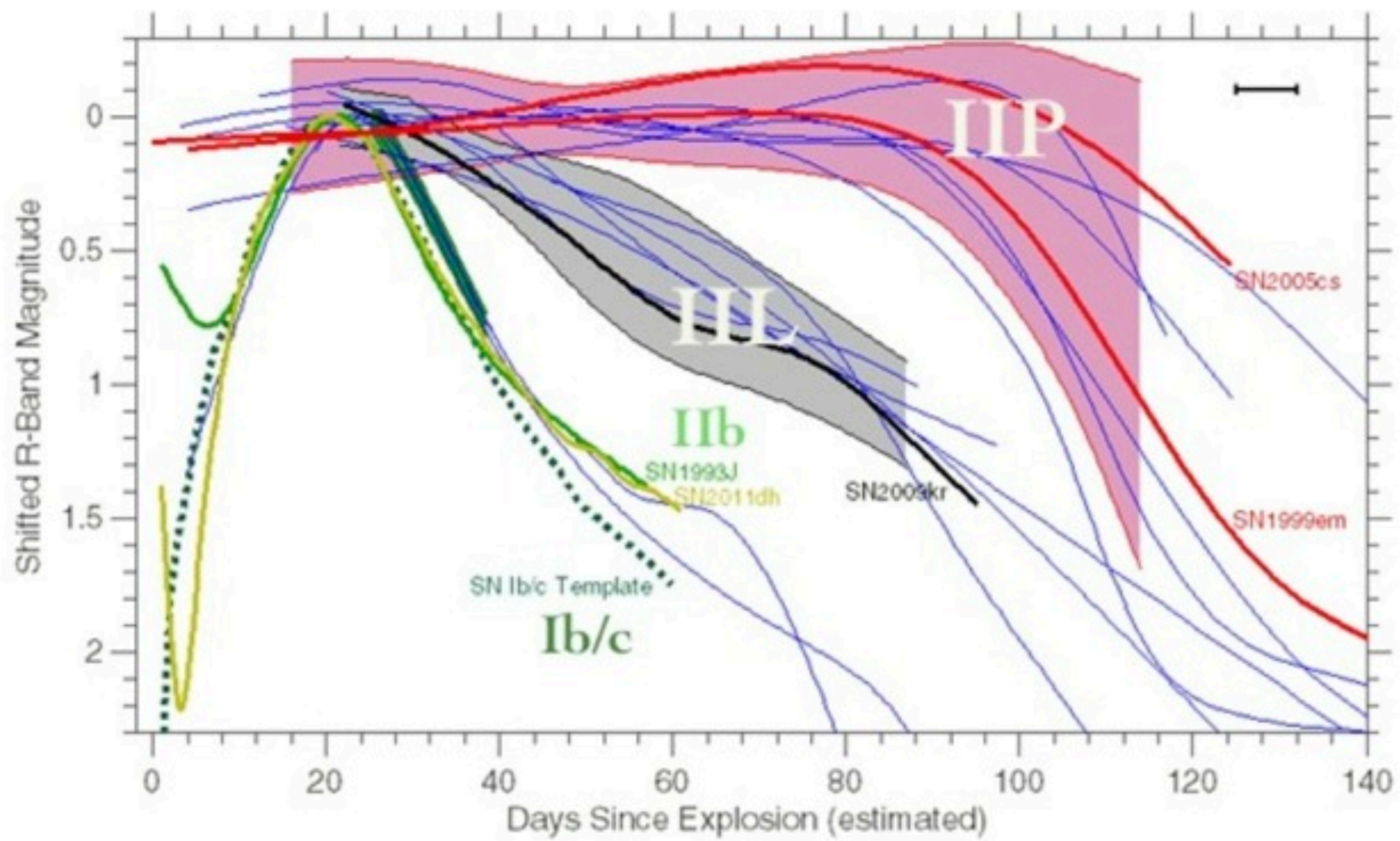
Metallicity → Mass & Angular Momentum Loss

Initial Mass → Mass & Angular Momentum Loss

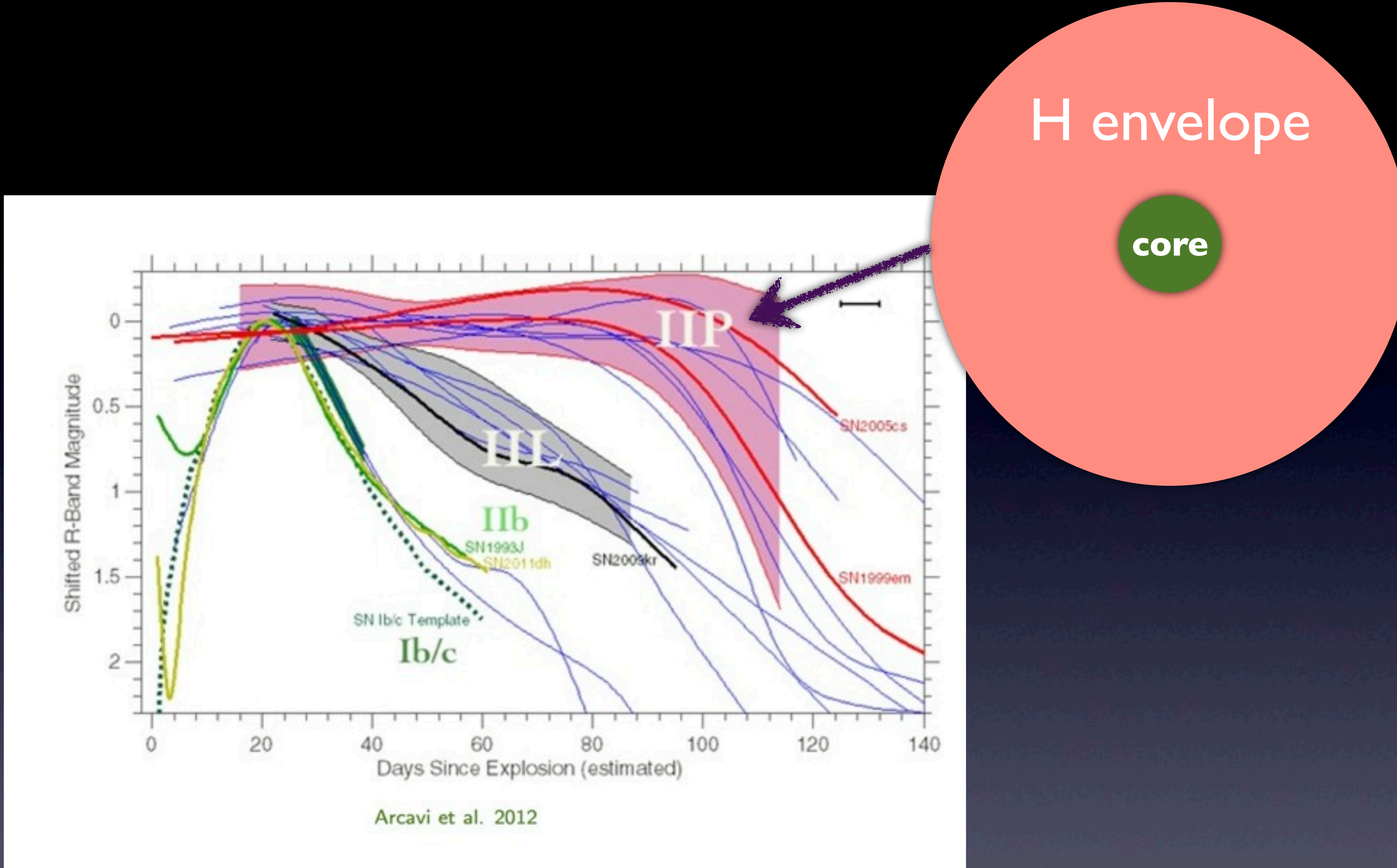
Initial Rotation → Mass & Angular Momentum Loss

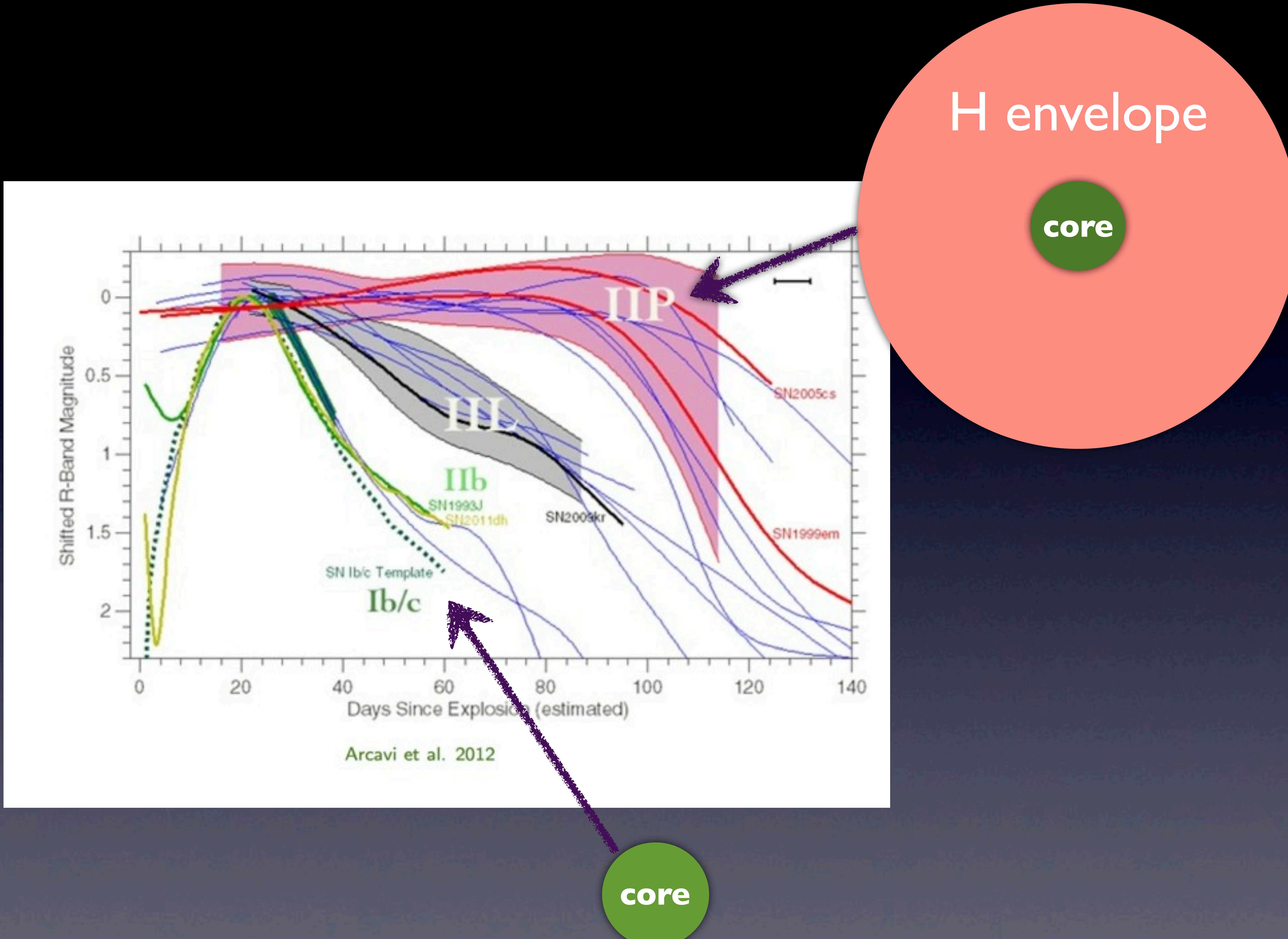
Diversity of Supernovae/GRB

Binarirty → Exchange of Mass & Angular Momentum



Arcavi et al. 2012


H envelope
core
IIP
IIL
IIb
Ib/c
SN2005cs
SN1999em
SN1993J
SN2011dh
SN2009kr
SN Ib/c Template
Shifted R-Band Magnitude
Days Since Explosion (estimated)
0
0.5
1
1.5
2
0
20
40
60
80
100
120
140
Arcavi et al. 2012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SN Ib/c Template
Shifted R-Band Magnitude
Days Since Explosion (estimated)
Arcavi et al. 2012
core

Evolutionary paths of massive stars to SNe Ibc

- Mass Loss from Single Stars (cf. Conti Scenario)
- Binary Interactions
- Chemically Homogeneous Evolution with rapid rotation (Maeder 87, Yoon & Langer 05, Yoon et al 06, 12, Woosley & Heger 06)

SNe Ibc progenitors are related to all the major factors of massive star evolution

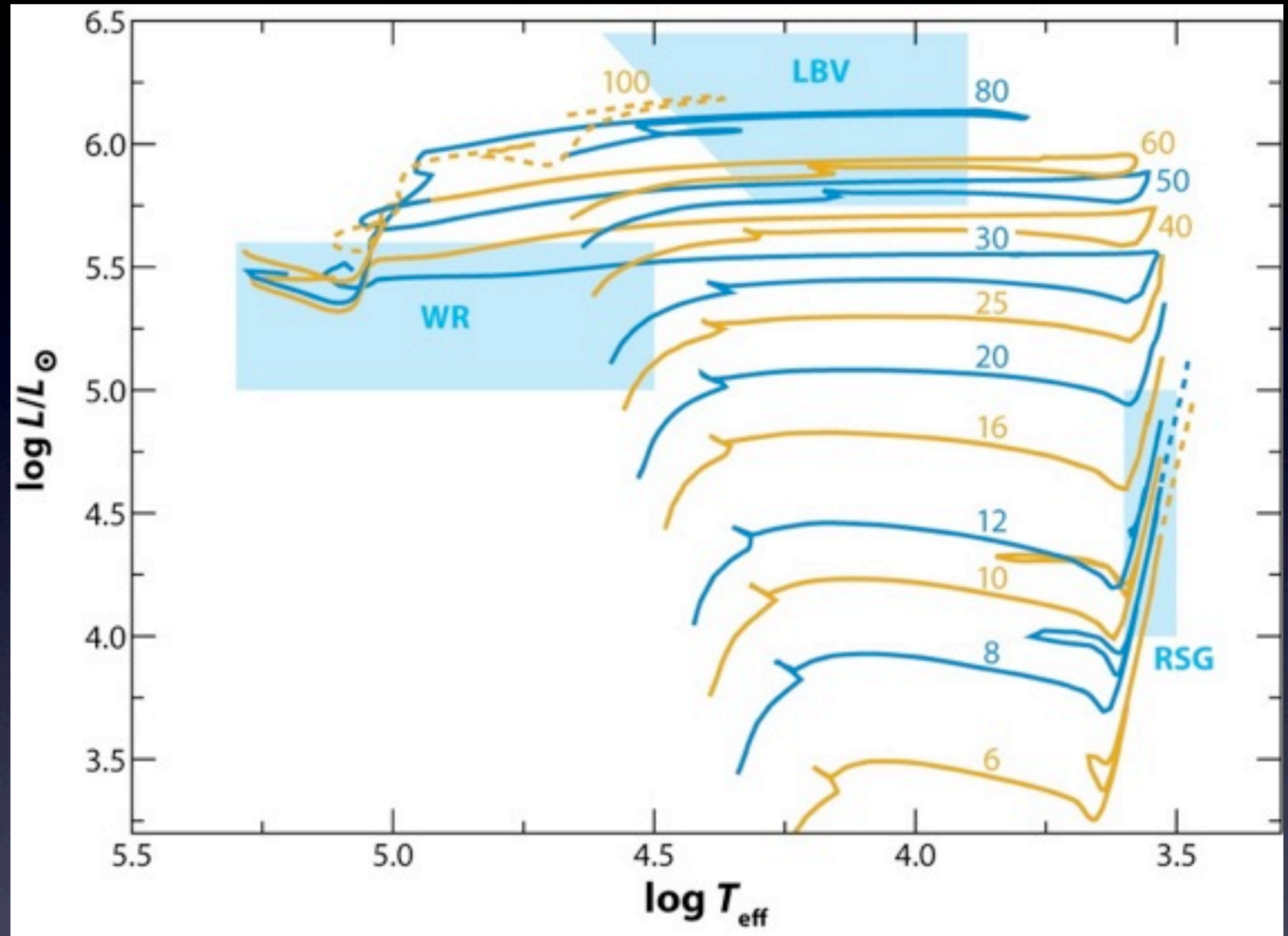
Importance of SNe Ibc in Astrophysics

- Their observational properties give us strong constraints on :
  - History of mass loss from massive stars
  - Binary star evolution
  - Evolution of massive stars at low metallicity and high redshift
  - Role of rotation, and connection to long gamma-ray bursts

Mass Loss
and
Type Ibc Supernovae

Mass loss from massive stars

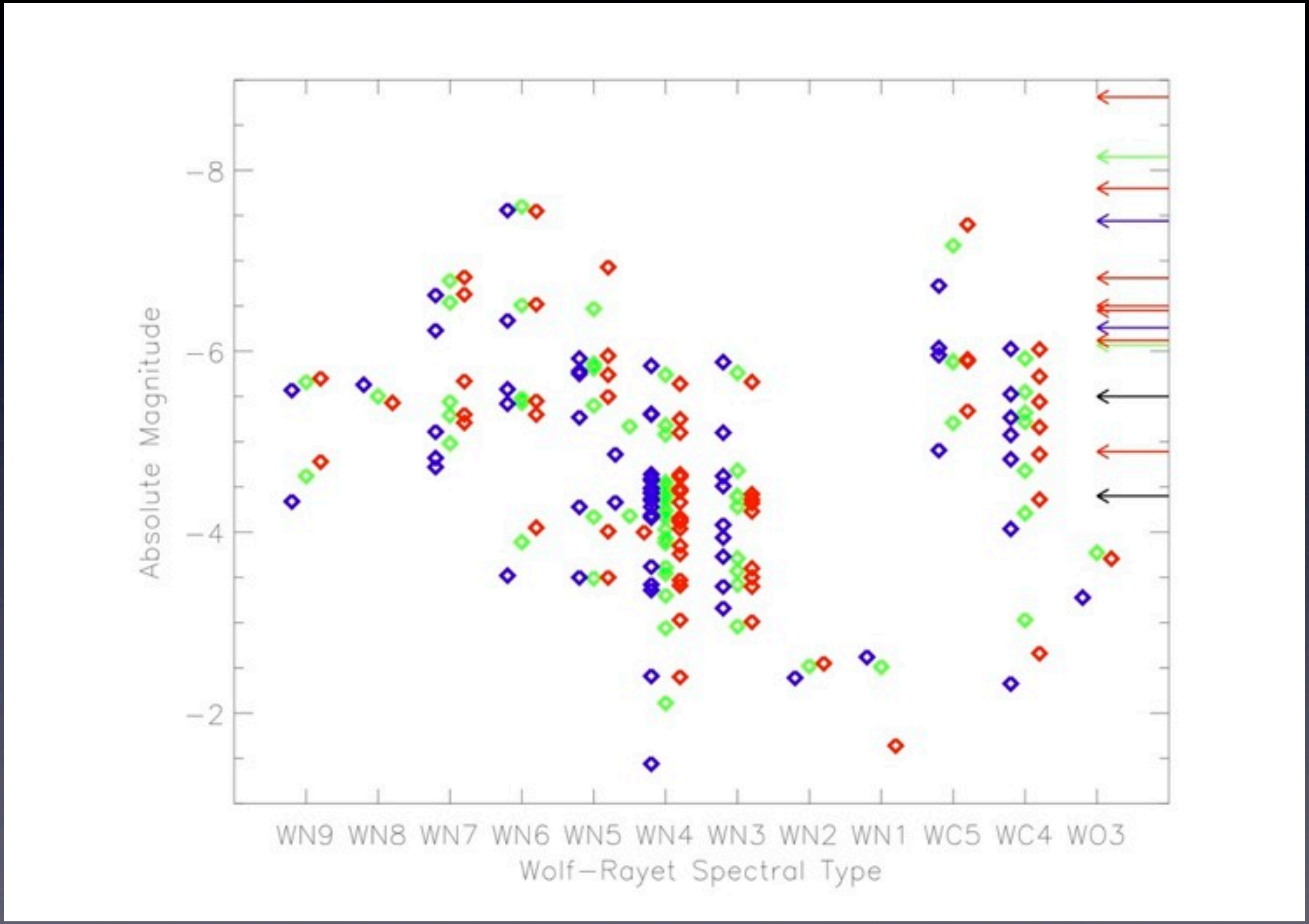
- Line driven winds: high-Z preferred.
- Pulsations
- Other instabilities



Smartt SJ. 2009.
Annu. Rev. Astron. Astrophys. 47:63–106

Evolution of stars more massive than about 30 Msun is dominated by mass loss.

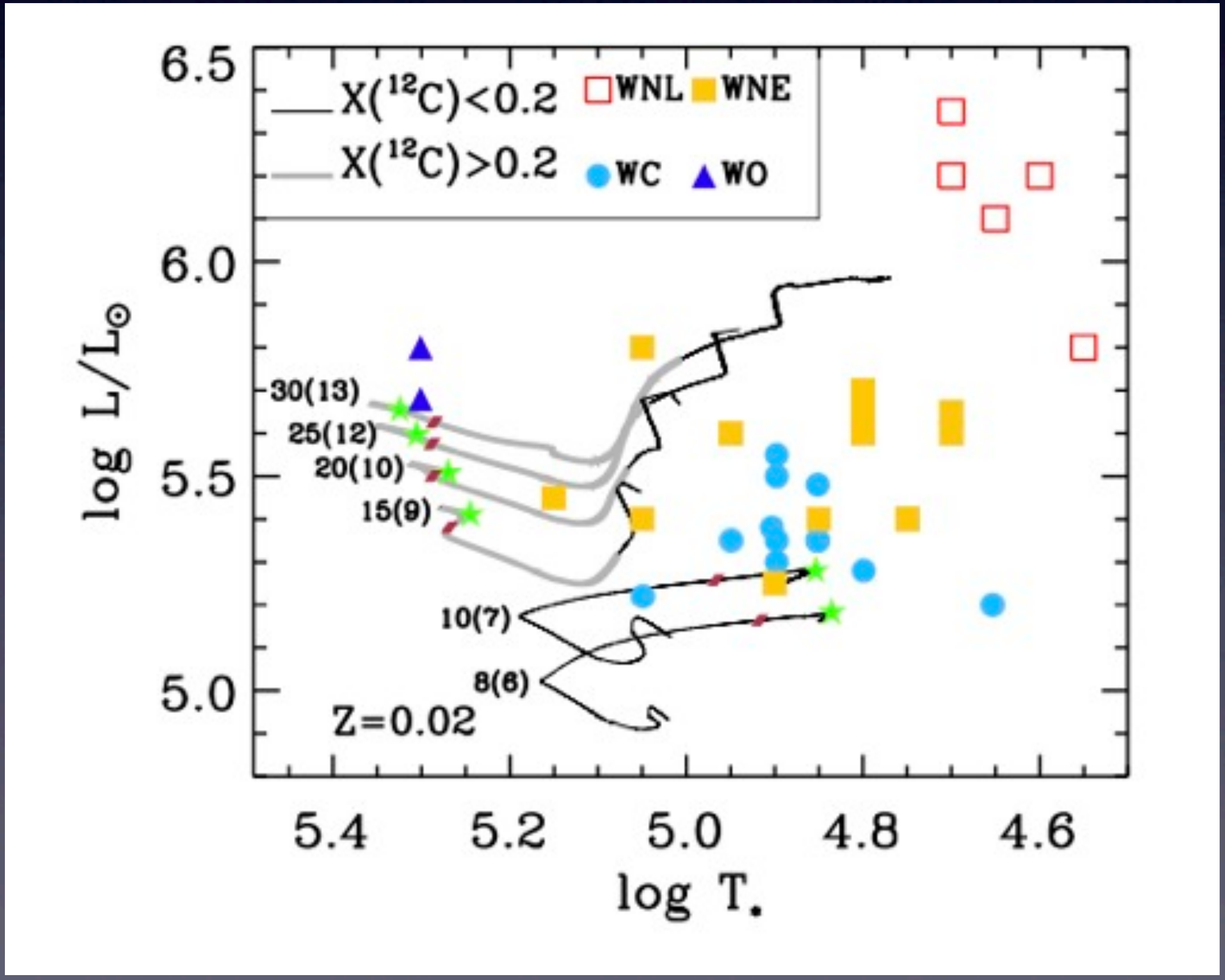
WR stars are generally very bright, but all attempts to directly identify them have failed so far.

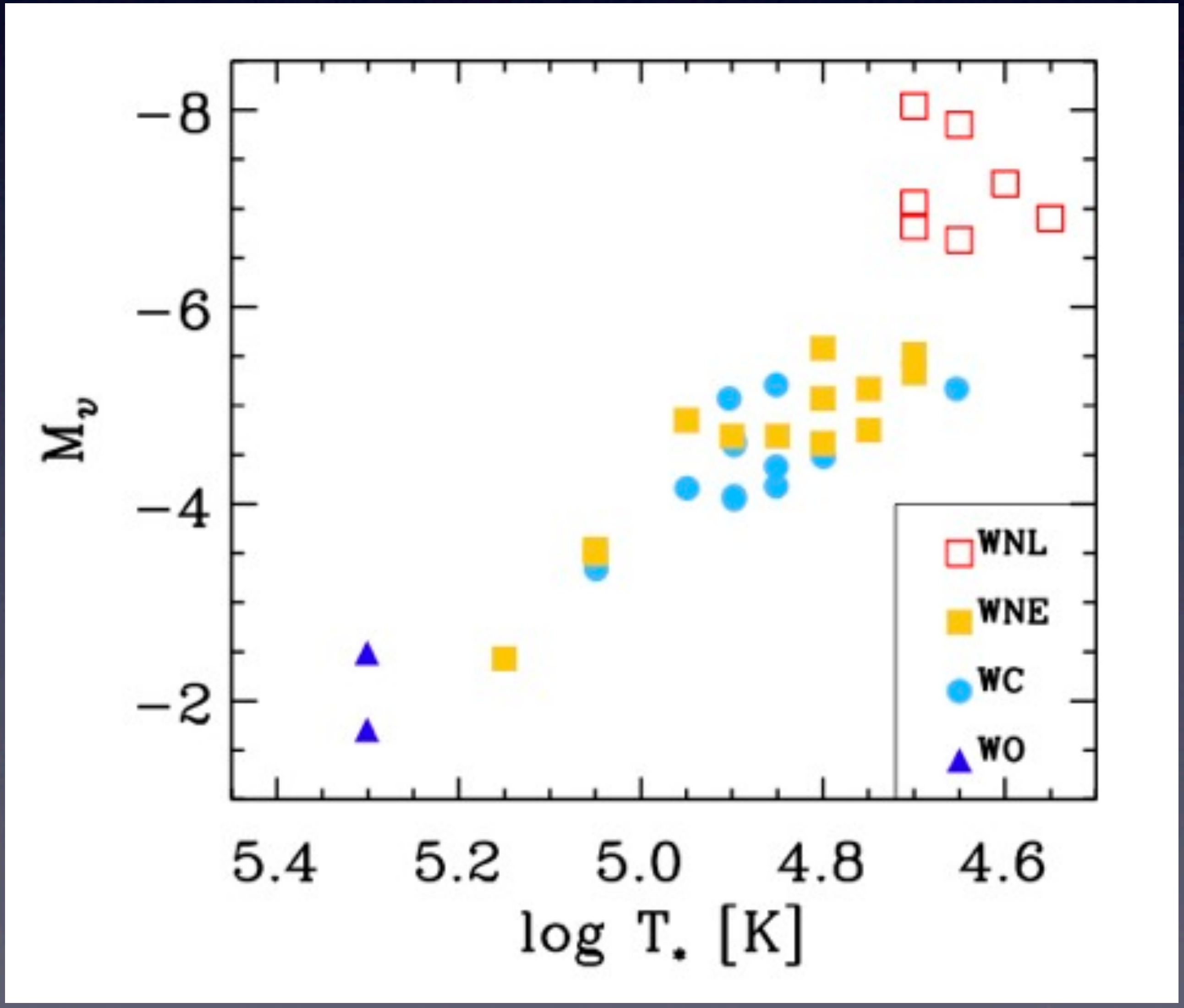


Smartt 09

In the mass-loss scenario, the final masses are higher than about 8 Msun, but the nature of SN Ibc progenitors at the pre-SN stage look very different from most of the observed WR stars:

They are very compact, hot, and optically faint like WO stars.



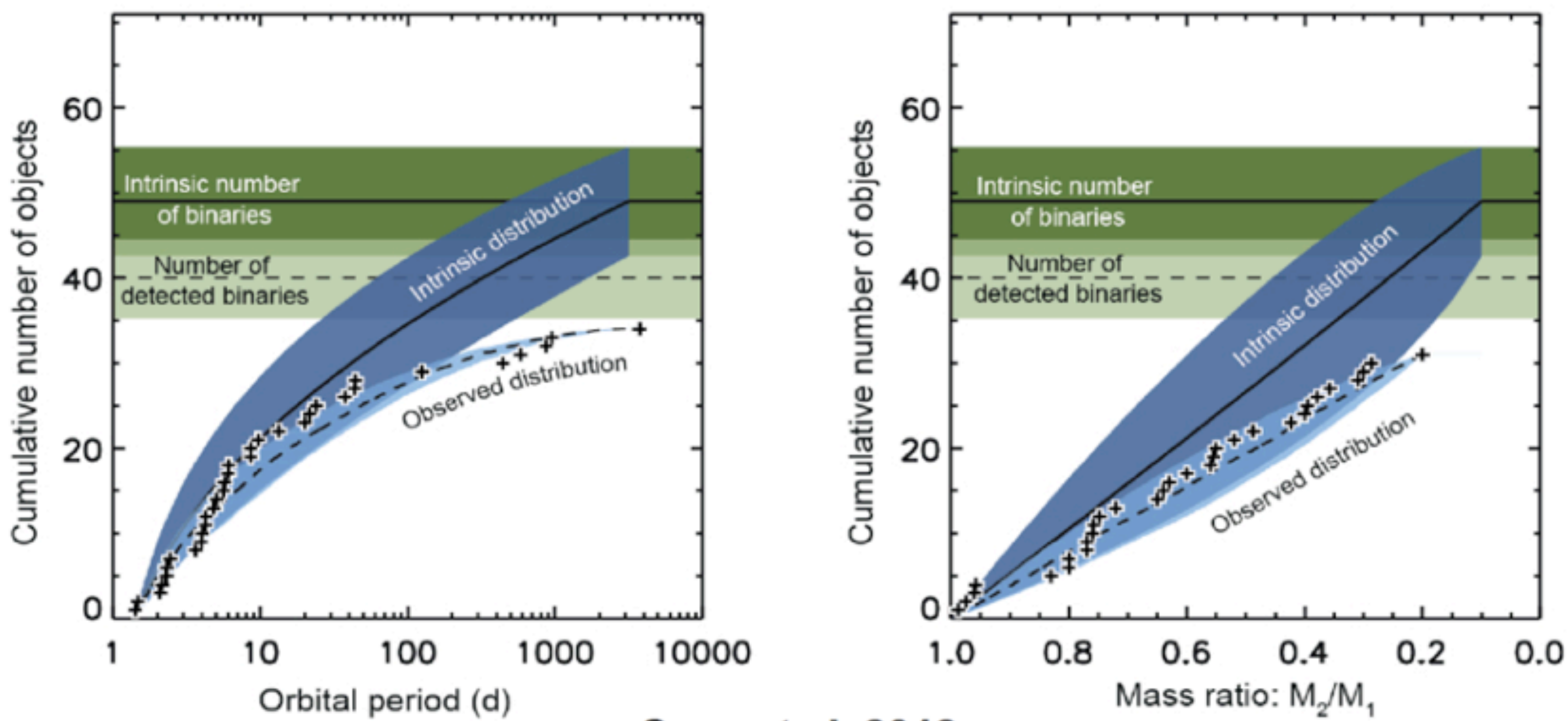


Yoon et al. 2012

13년 7월 2일 화요일

Binary Interactions
and
Type Ibc Supernovae

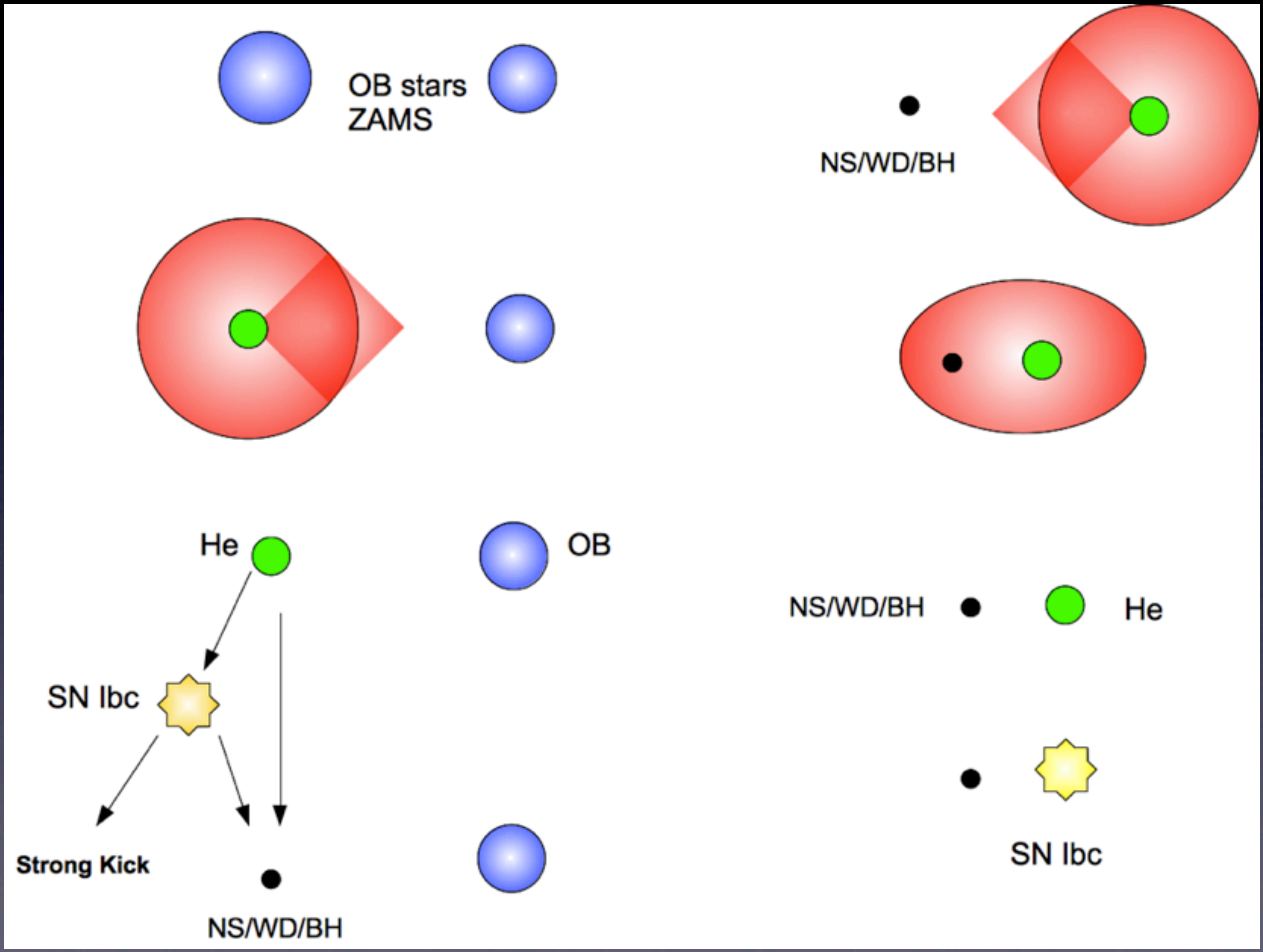
Observations indicate that more than 50% of massive stars are in close binary systems

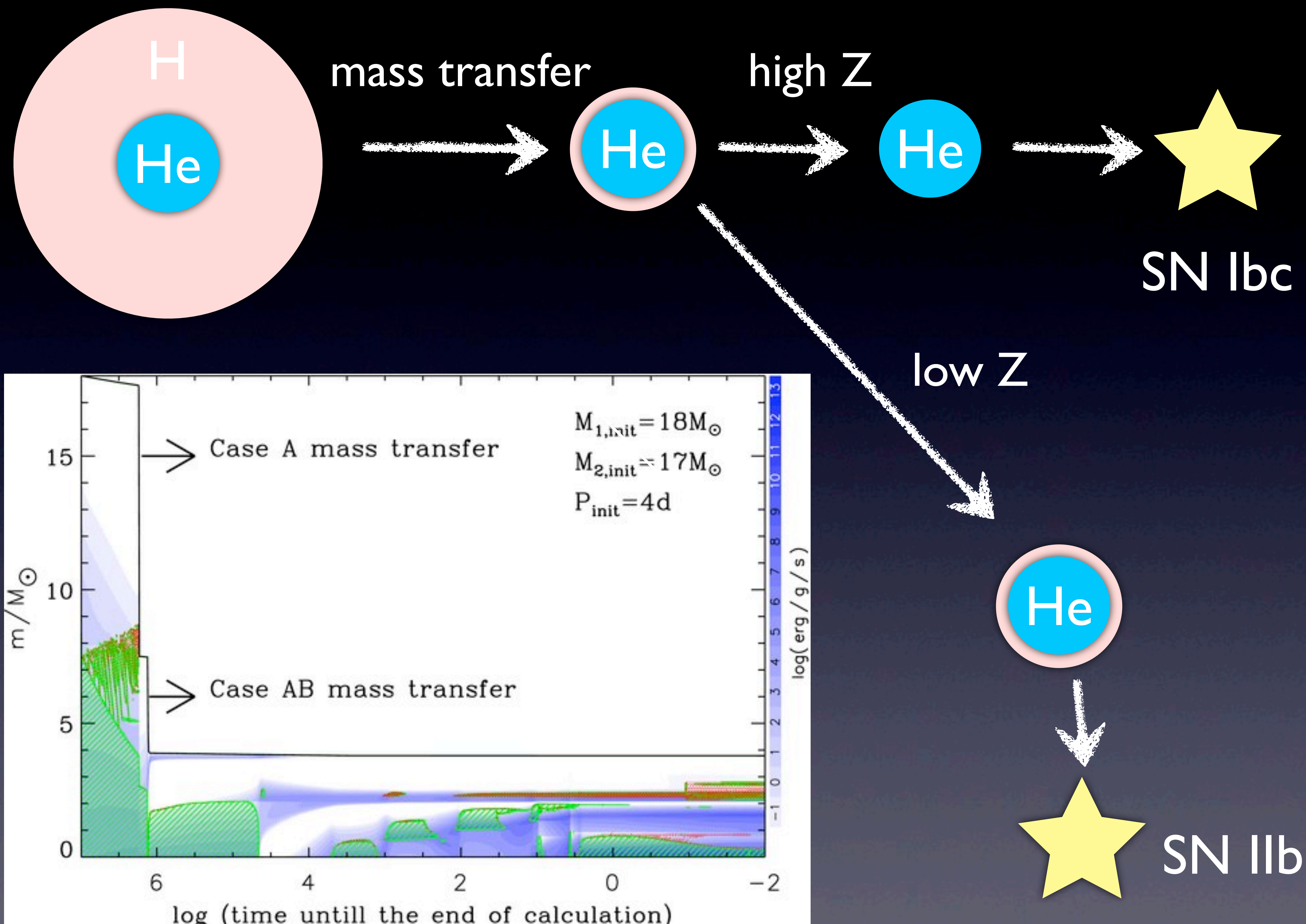


Sana et al. 2012

13년 7월 2일 화요일

Binary interactions can produce relatively low-mass He stars (2 < M < 10 Msun)

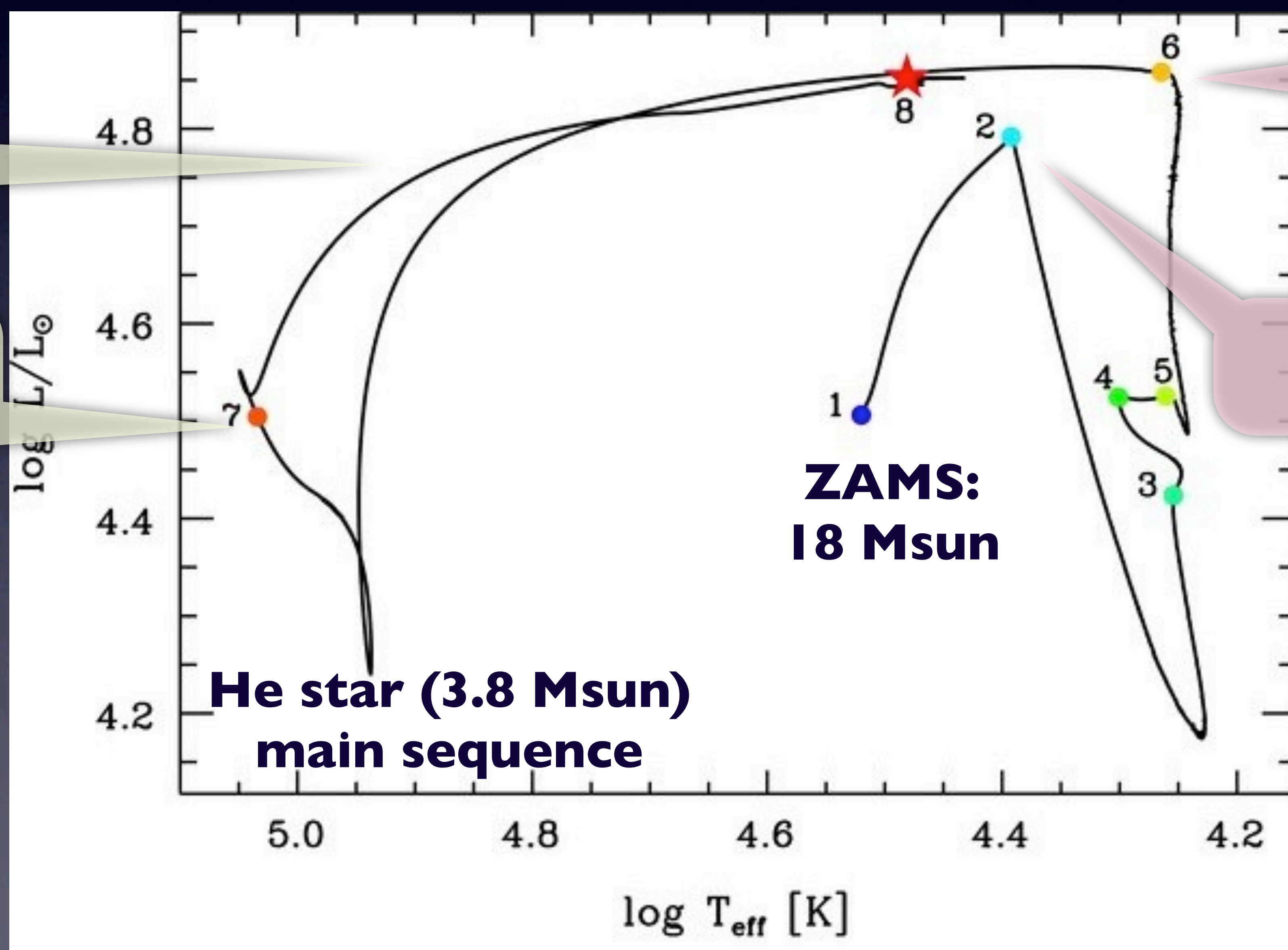




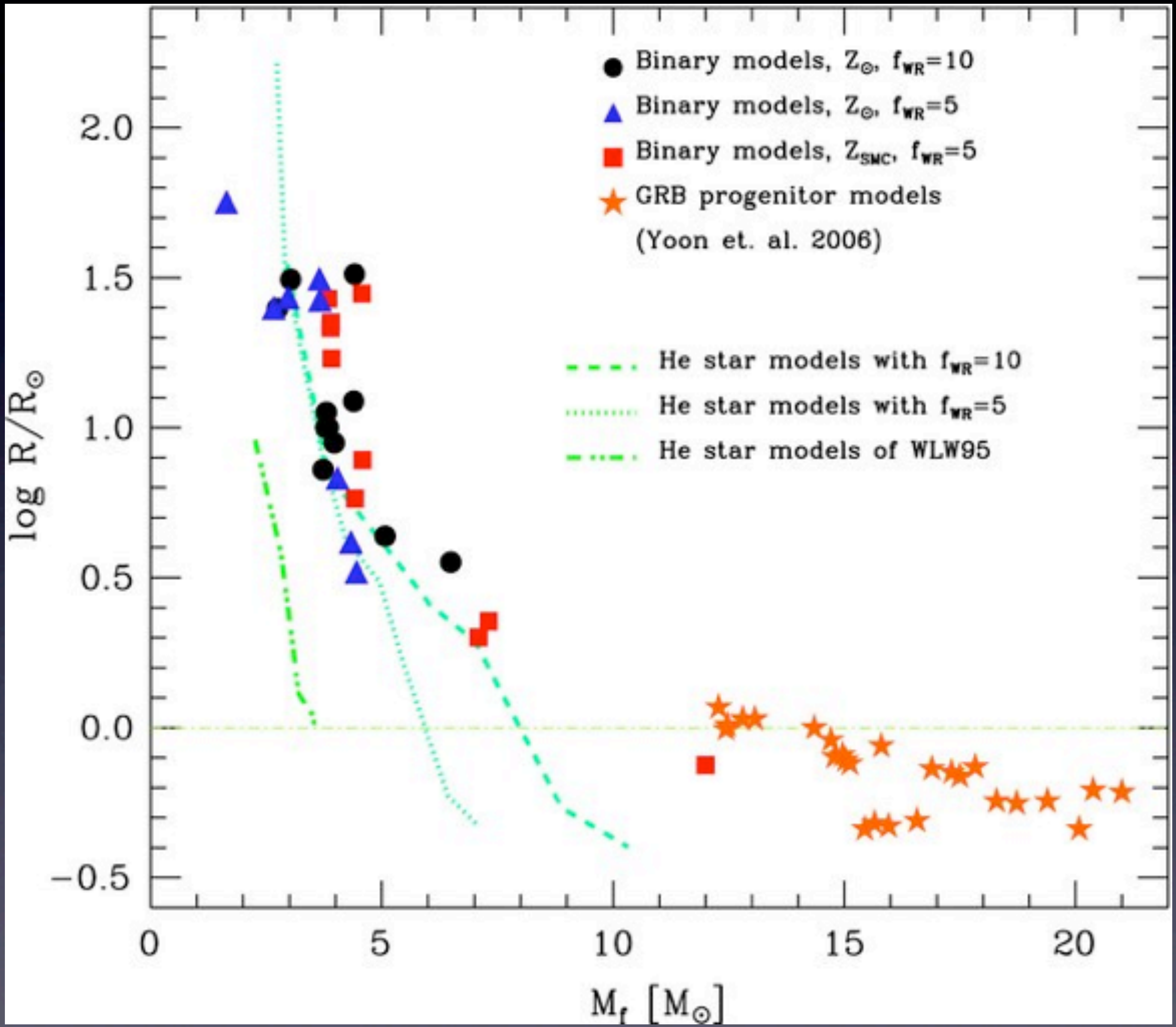
Yoon et al. 2010

The He envelopes of relatively low-mass SN Ibc progenitors expands rapidly during the final evolutionary phases.

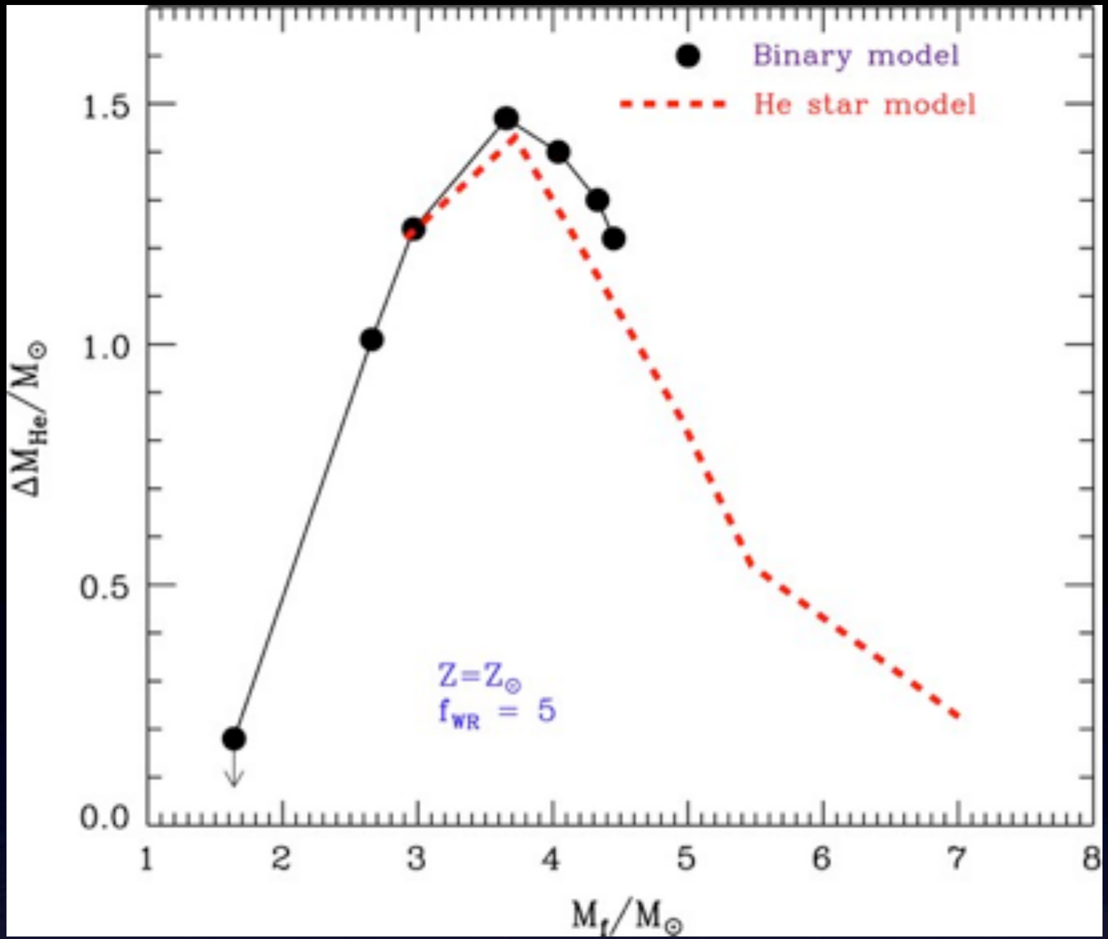
==> They should appear fairly luminous in optical bands at the pre-SN stage, despite their low masses (Yoon et al. 2012)

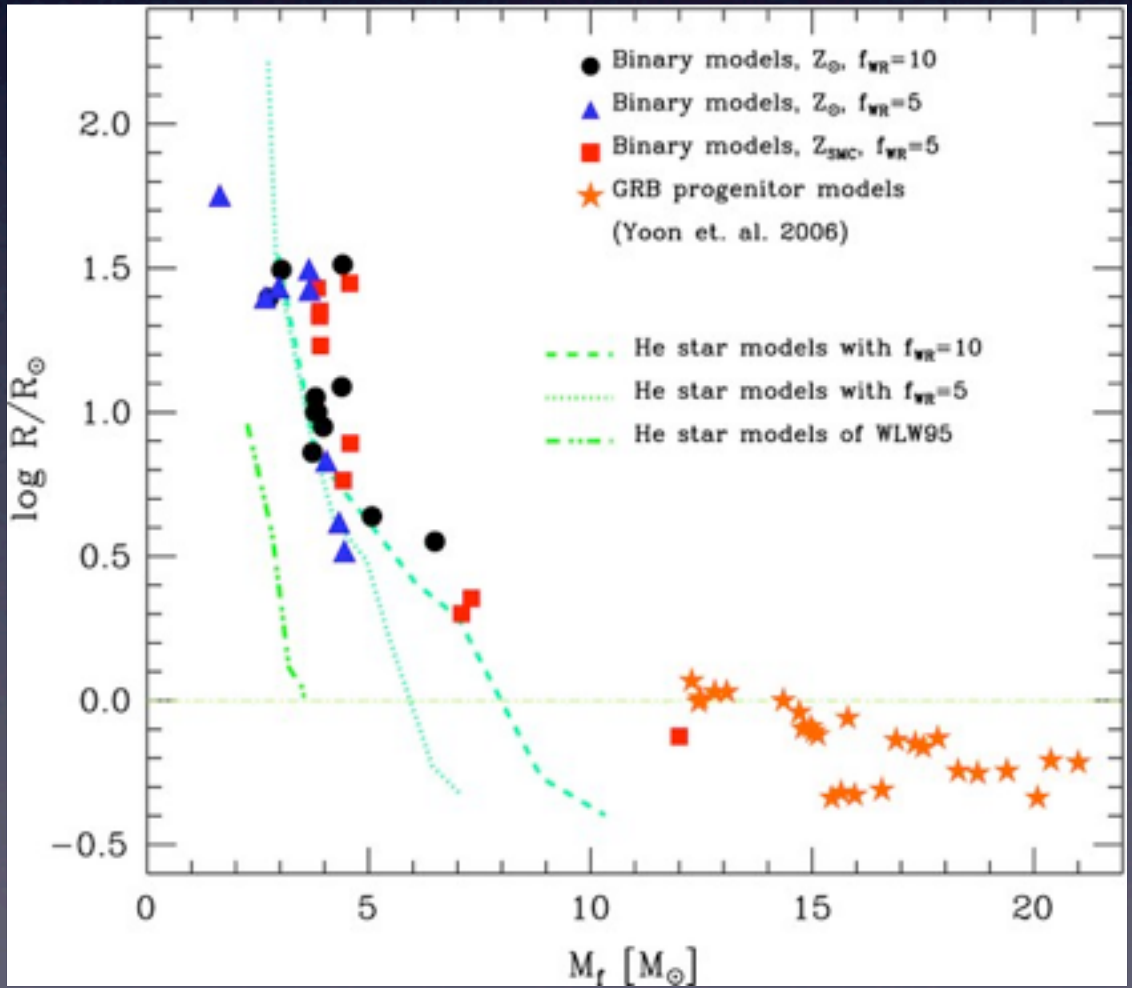


SN Ibc progenitors produced in binary systems have larger radii, than those of single stars



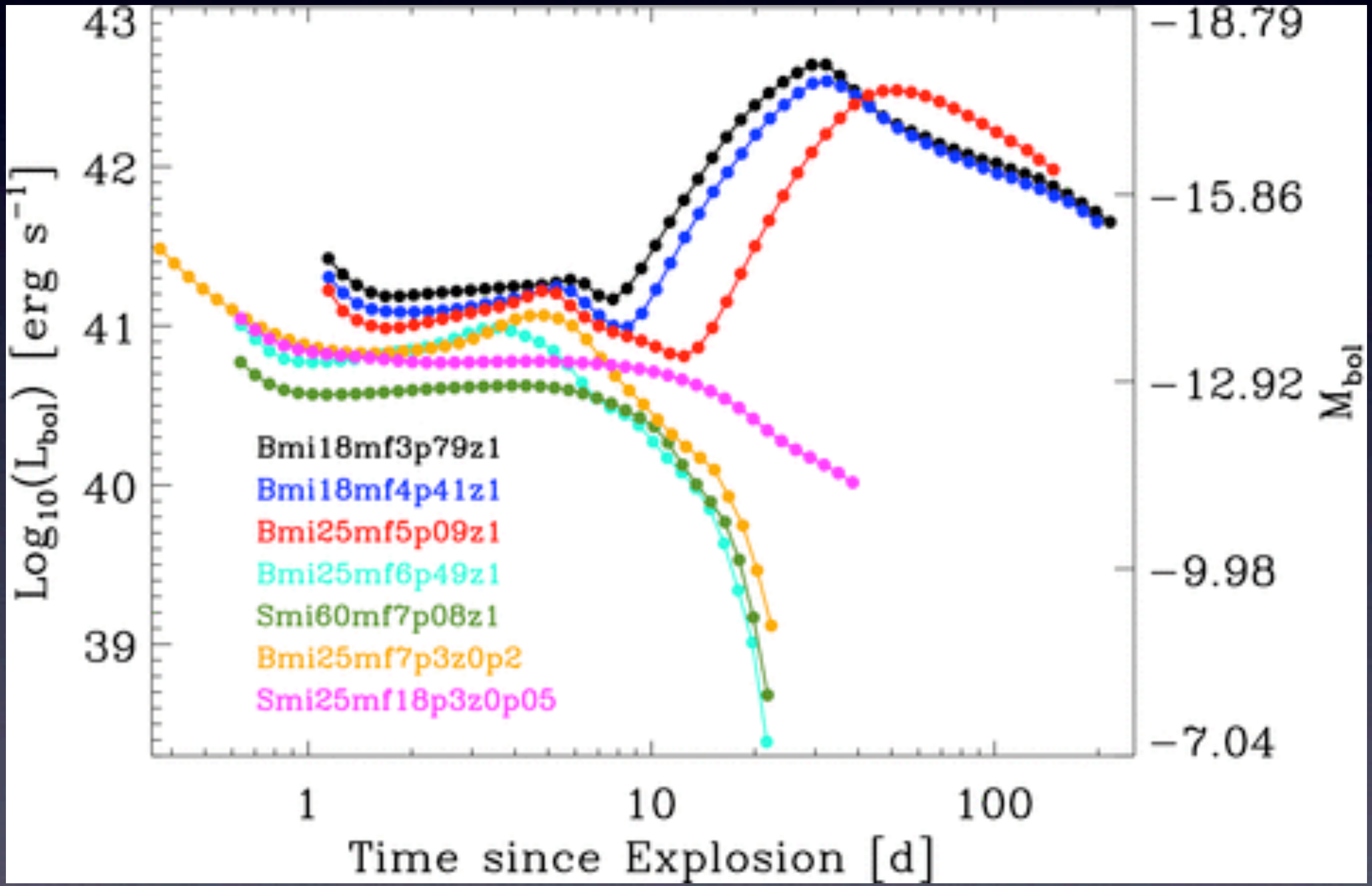
Yoon et al. 2012





Yoon et al. 2010

Fairly bright plateau in the early phase of SN Ibc, mostly due to He recombination.

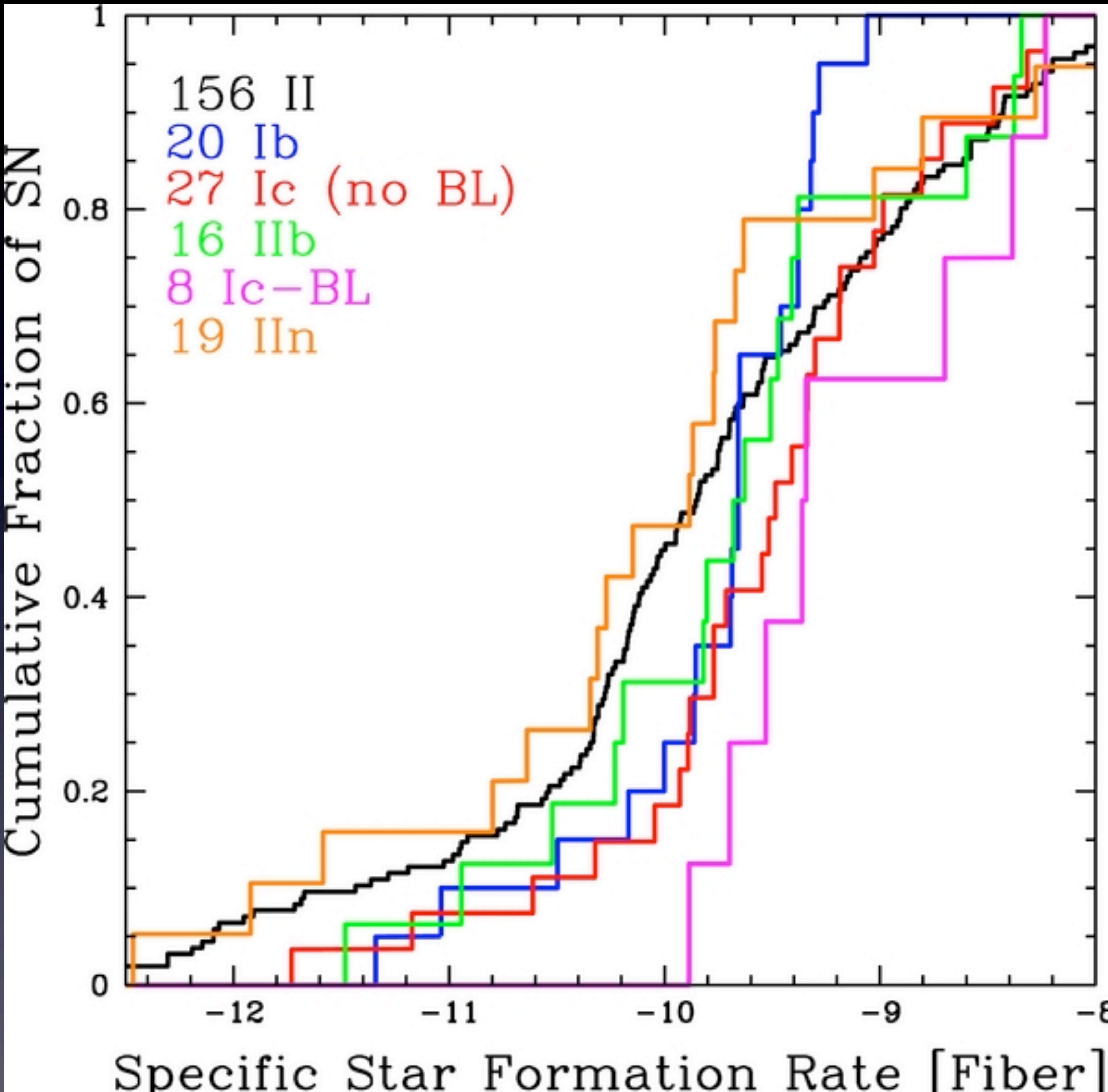


Dessart et al. 2011

Summary: Single v.s. Binary progenitors

	Single Star Progenitors	Binary Star Progenitors
Final mass	M/Msun> 8	1.4 < M/Msun < ~ 8
Radius	~ Rsun	Rsun < R < ~100 Rusn
Bolometric luminosity	log L/Lsun > 5	4 < log L/Lsun < 5
Optical magnitude	$M_V < -3$	$M_V = -4 \sim -5$
Shock Breakout	hard X-ray	soft X-ray
Early light curves, for a given energy	not that luminous	fairly luminous plateau

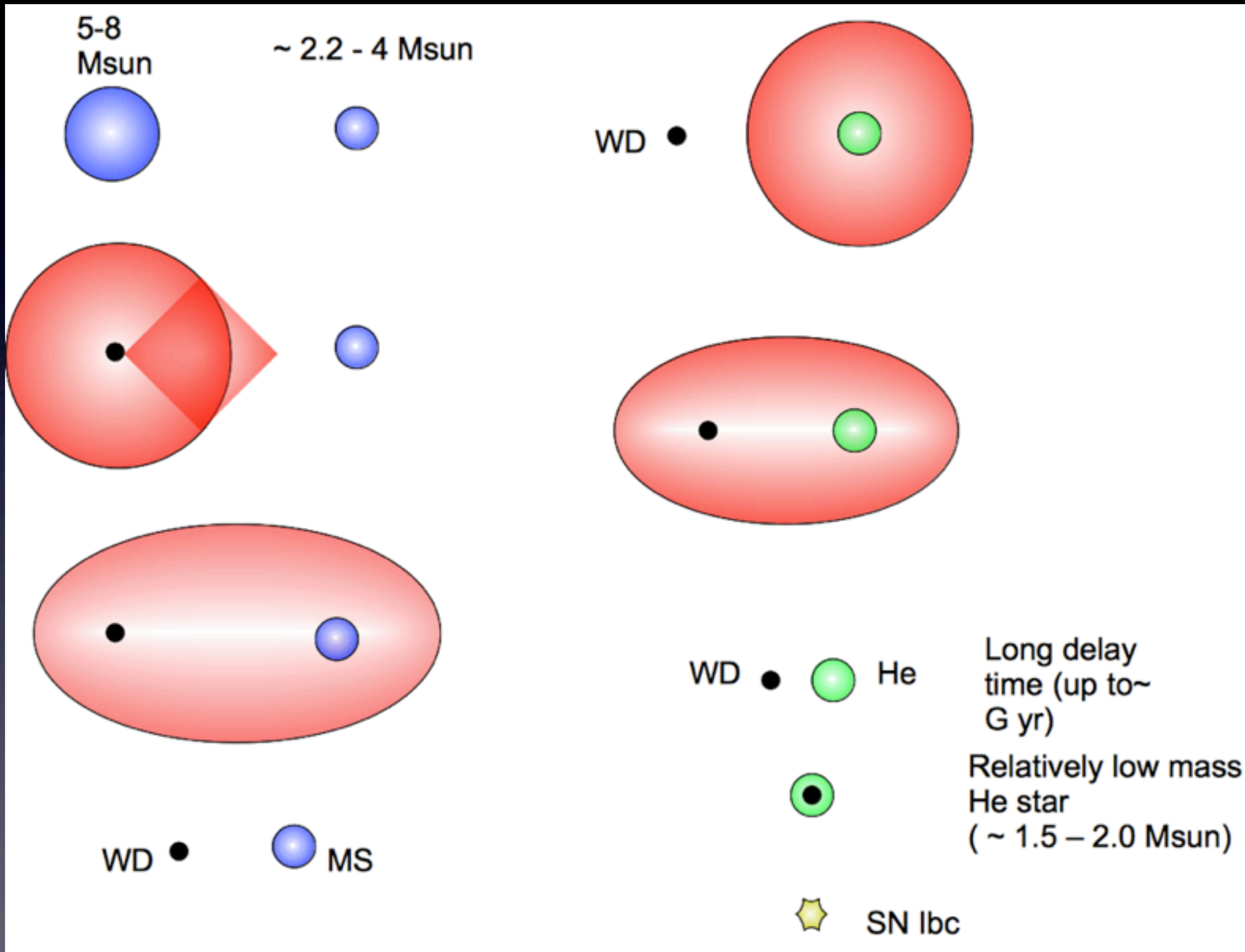
Population:
Can the binary models explain
the observed statistics of SNe Ibc?



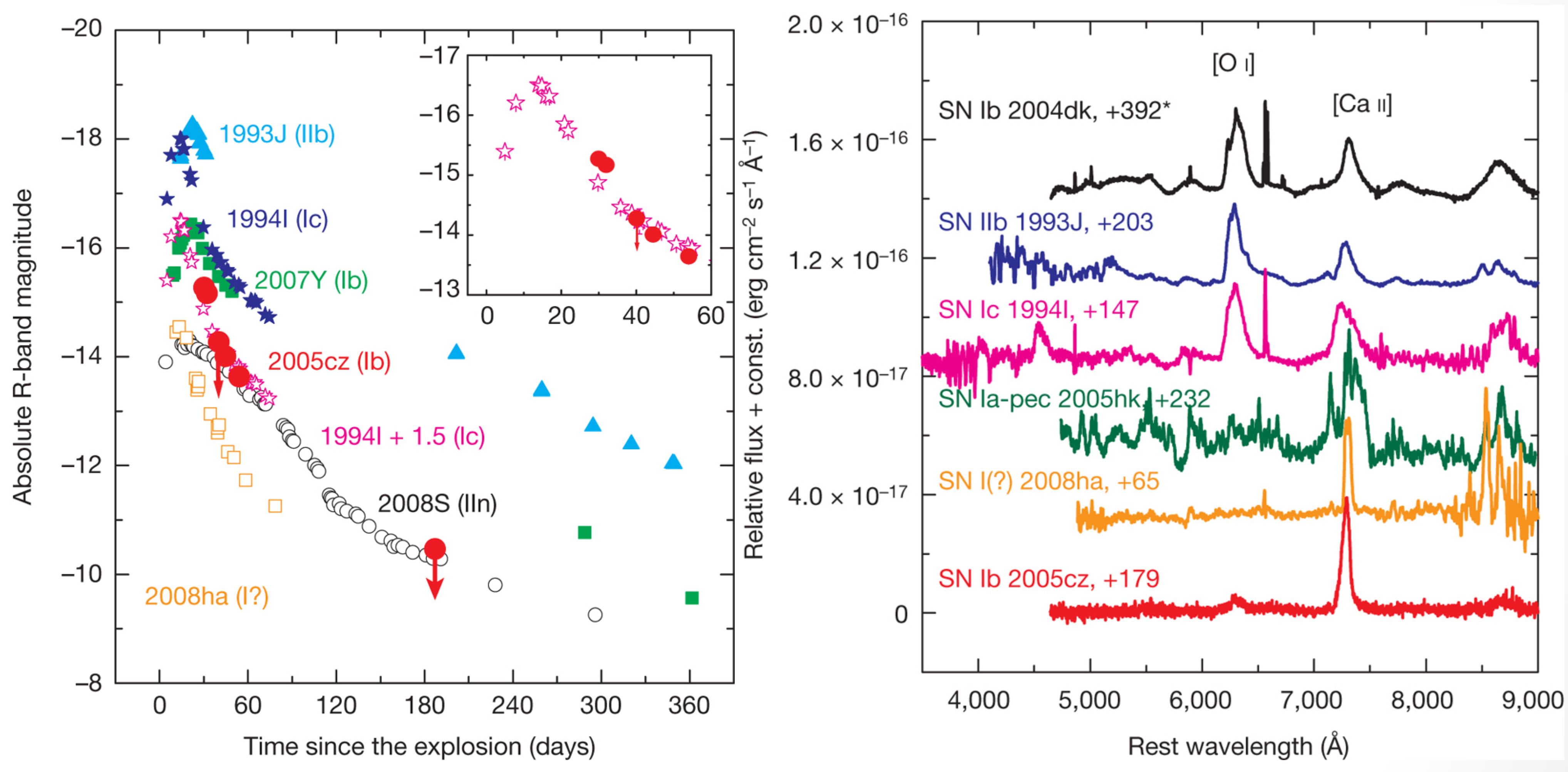
The progenitor masses increase in the following oder?
SNII => SN Ib => SN Ic

Kelly & Kirshner 2012

SN Ibc with long delay times

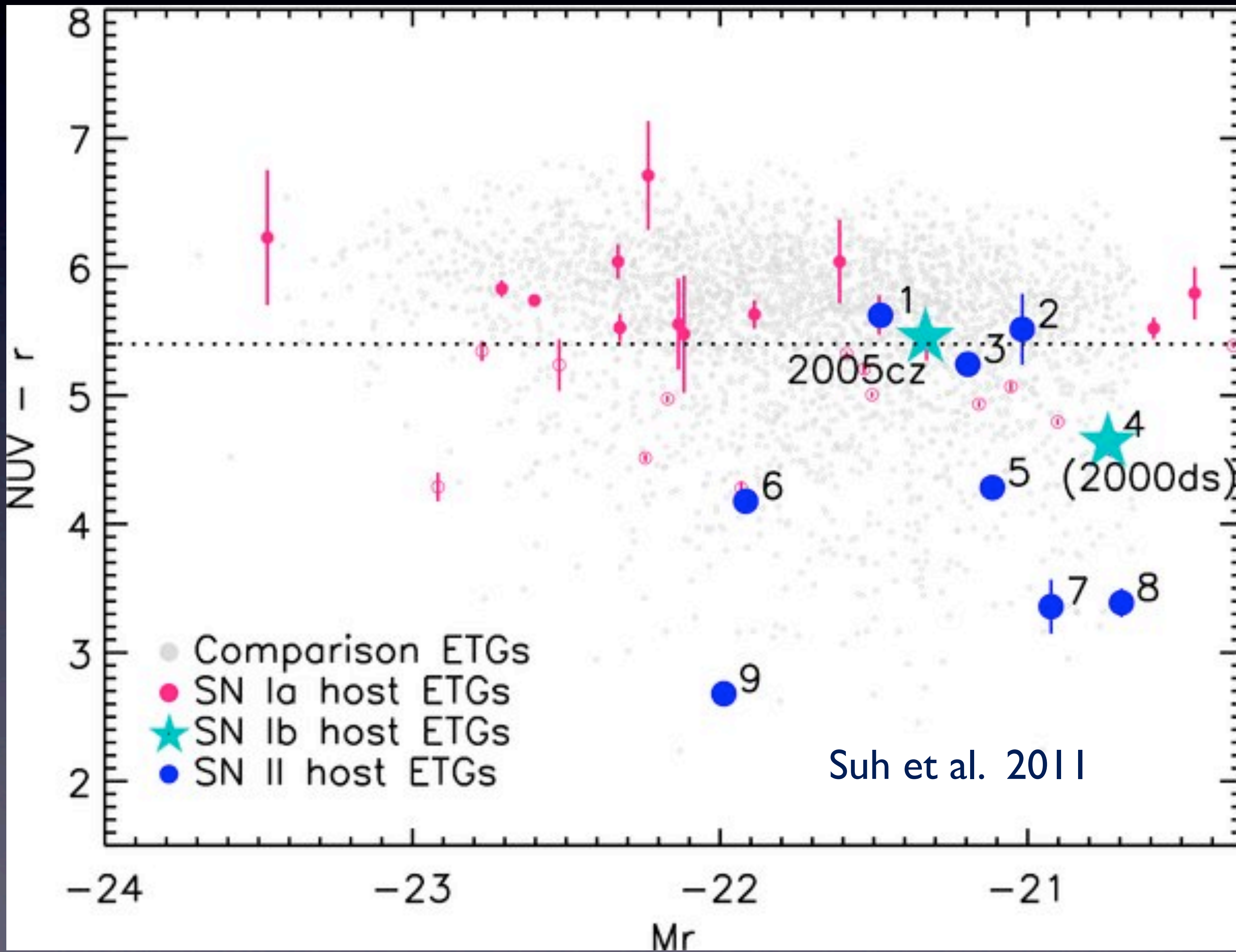


Faint, Ca-rich peculiar SNe Ib



2005cz: Kawabata et al. 2010

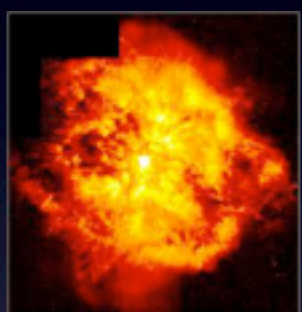
Binary evolution can explain SN IIP and SN Ib from early-type galaxies. They must have delay times of ~ 100 Myrs.

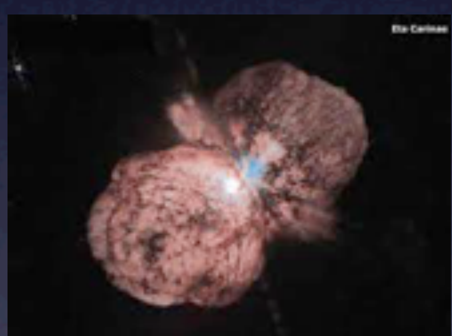


Can SNe Ibc occur in the Early Universe?

If so, what would they tell us about the evolution of the first stars?

How do Pop III stars evolve?



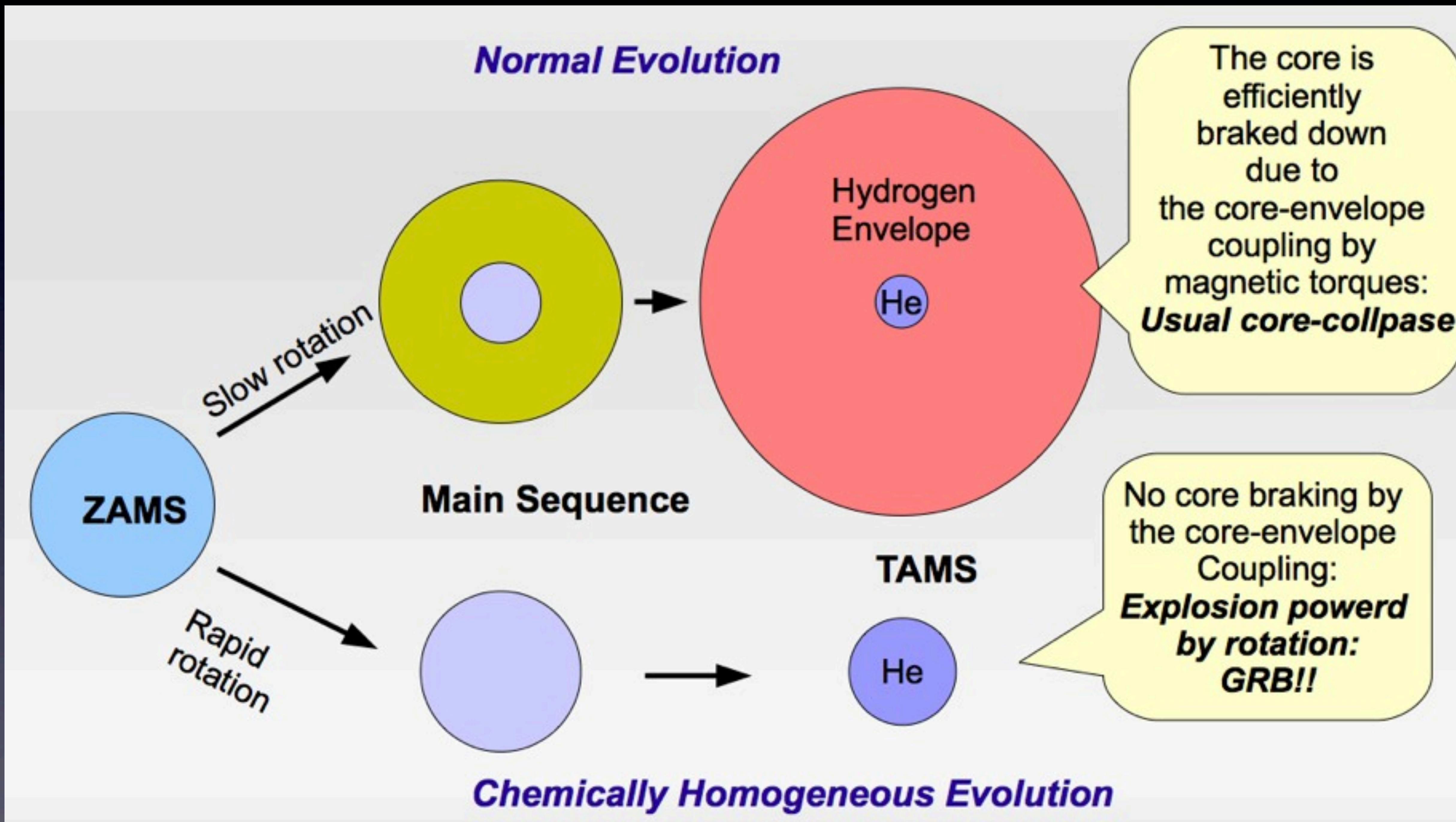


Z = Zsun	Z = 0
Strong winds resulting from metal lines	No line-driven winds (Krticka & Kubat 2006)
Unstable	Stable (Baraffe et al. 2001)
Strong mass loss	Not much mass loss
The evolution of very massive stars is dominated by "**mass loss**"	The evolution of massive Pop III stars is dominated by "**rotation**"

Role of Rotation in massive Pop III stars

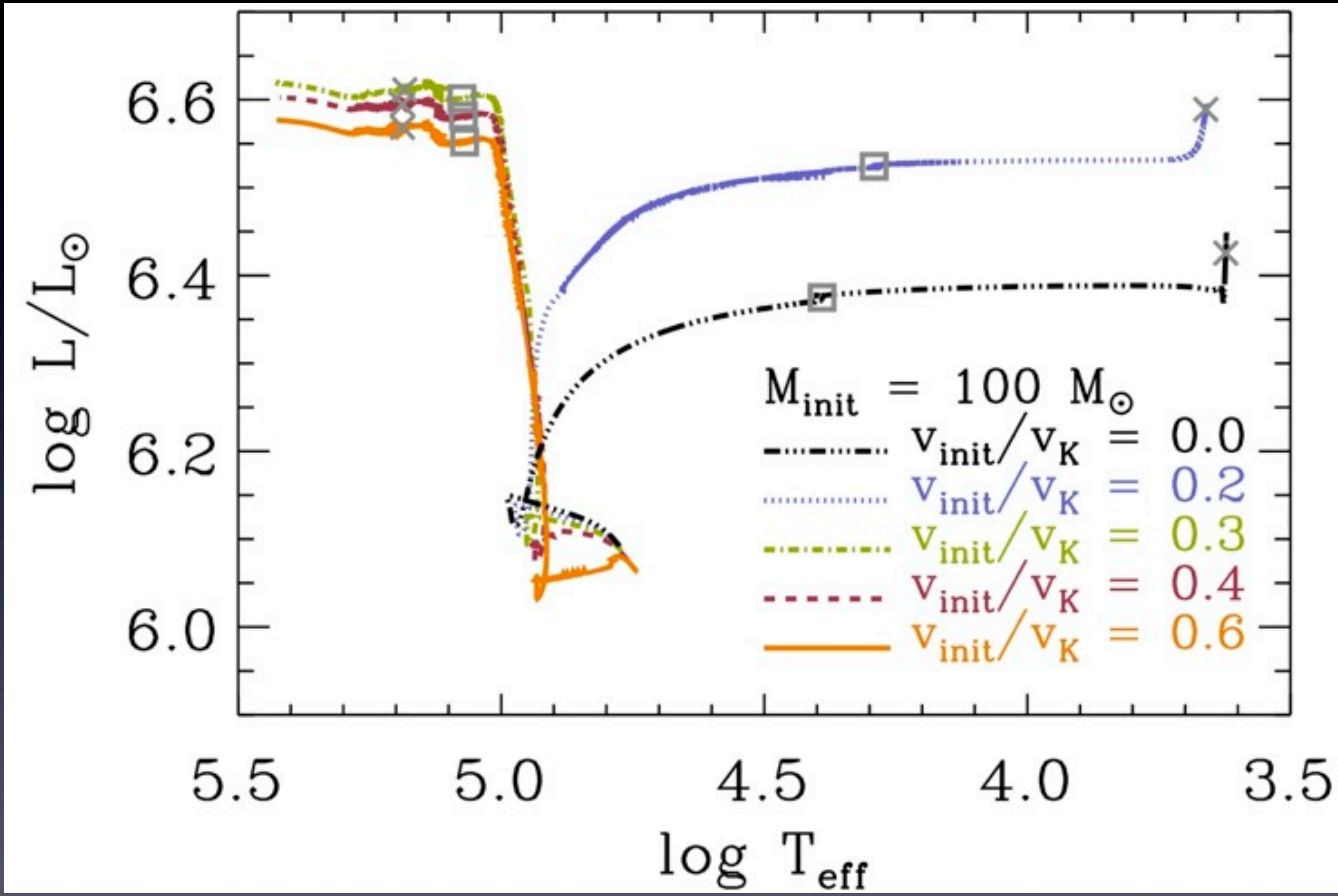
- Pop III protostars are supposed to have large amounts of angular momentum (Stacy et al. 2011).
- When the surface of a star reaches the critical rotation, mass shedding can occur (Marigo et al. 2003, Esktroem et al. 2008, Yoon et al. 2012).
- Chemical mixing induced by rotation can change the history of nucleosynthesis (Ekstroem et al. 2008, Yoon et al 2012), as well as the evolutionary paths (Yoon et al. 2012).

Bifurcation of massive star evolution at low-metallicity



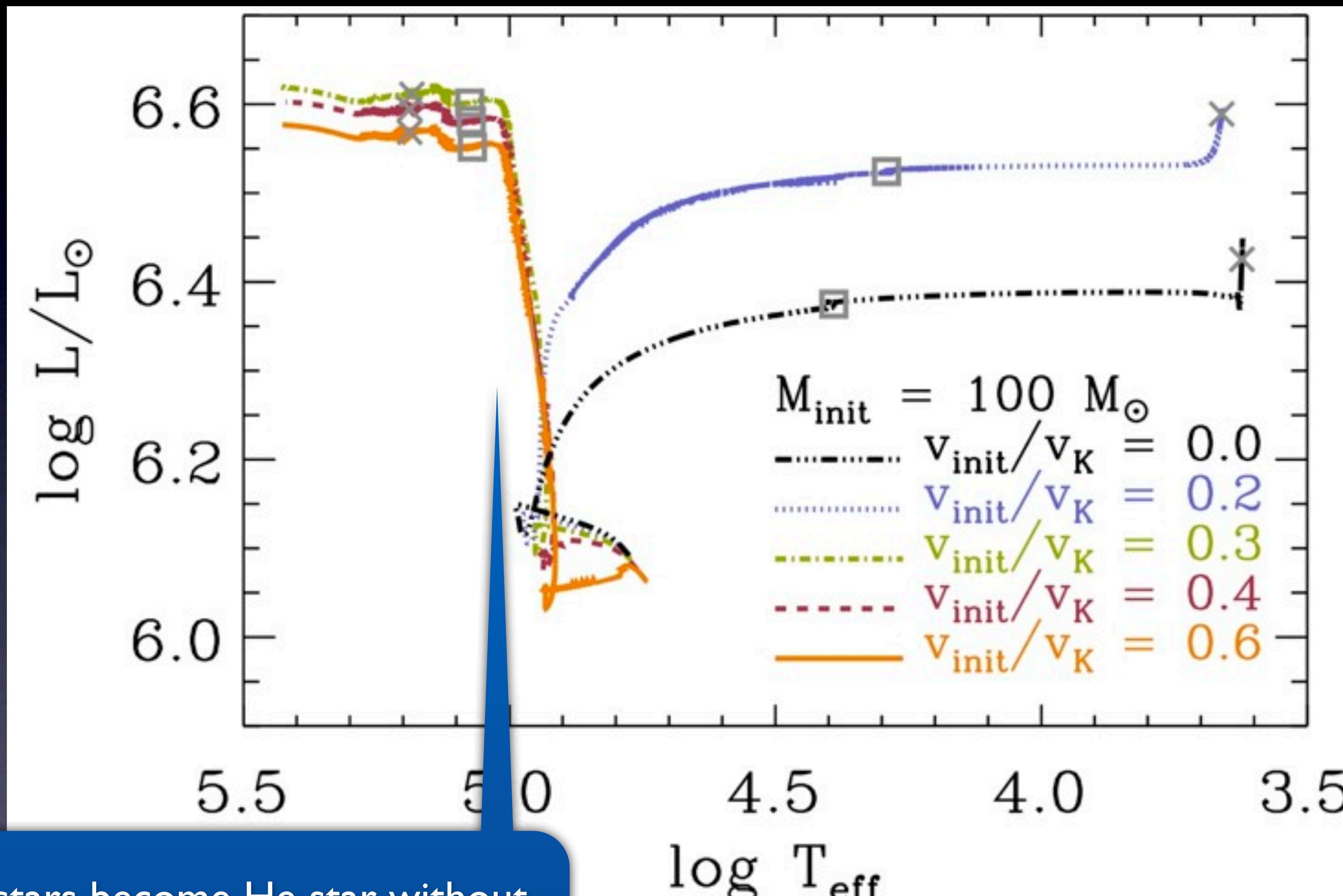
Yoon & Langer 05, Yoon et al. 06, Woosley & Heger 06, Yoon et al. 12

Bifurcation of massive star evolution at low-metallicity



Yoon et al. 2012

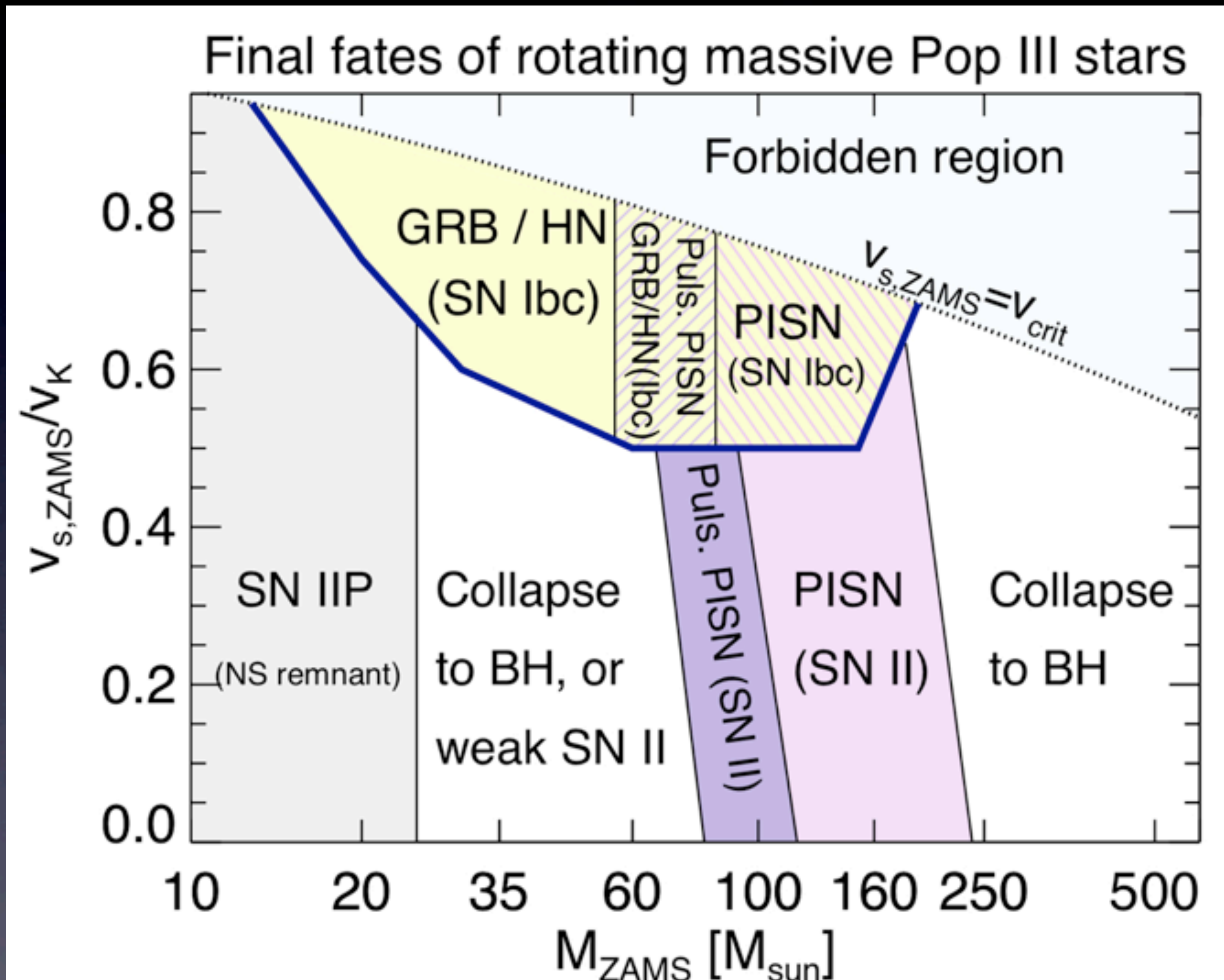
Bifurcation of massive star evolution at low-metallicity



These stars become He star without losing much mass.
They produce more ionizing photons.

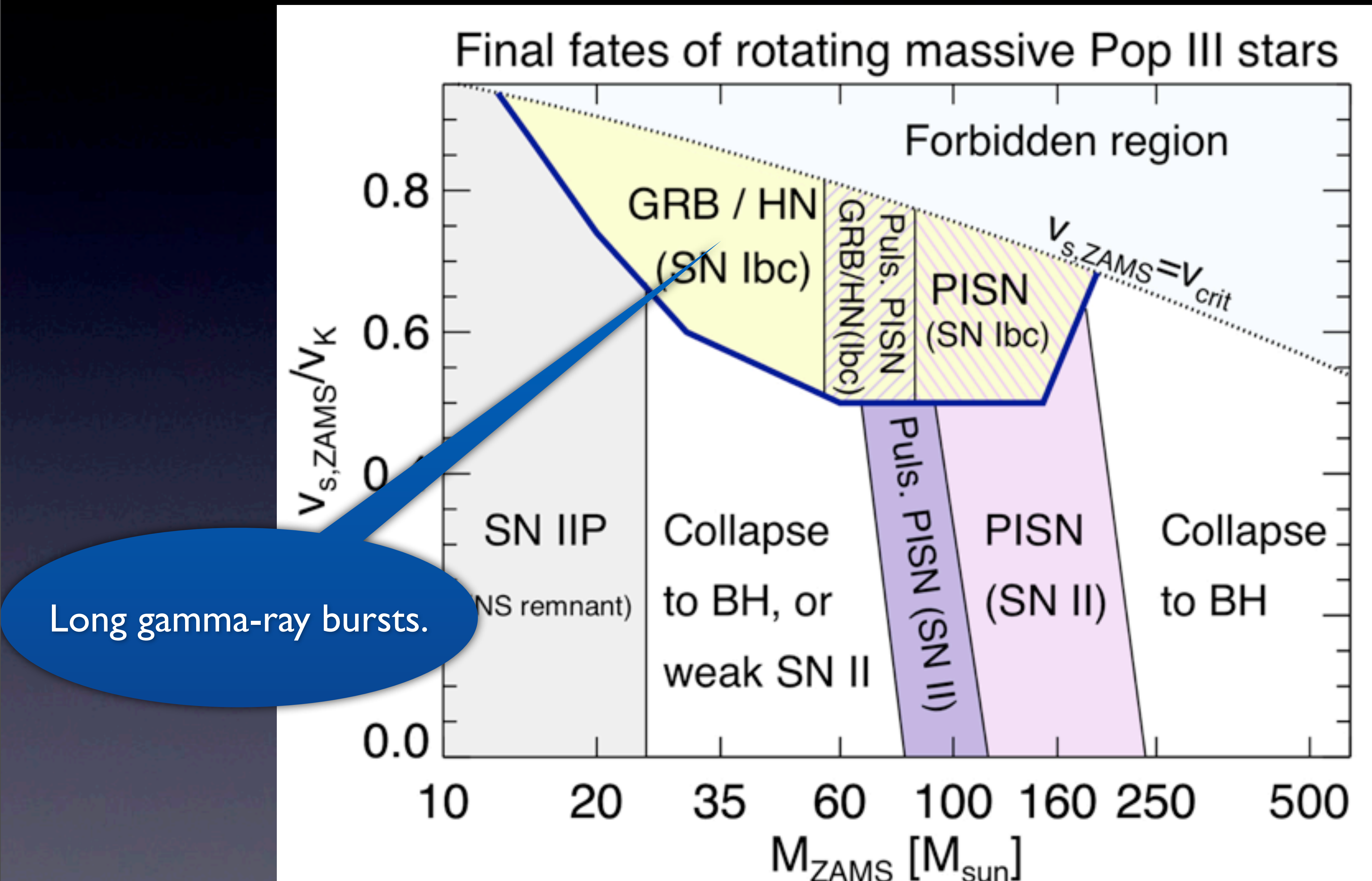
oon et al. 2012

Final fates of the first stars



Yoon et al. 2012

Final fates of the first stars



Yoon et al. 2012

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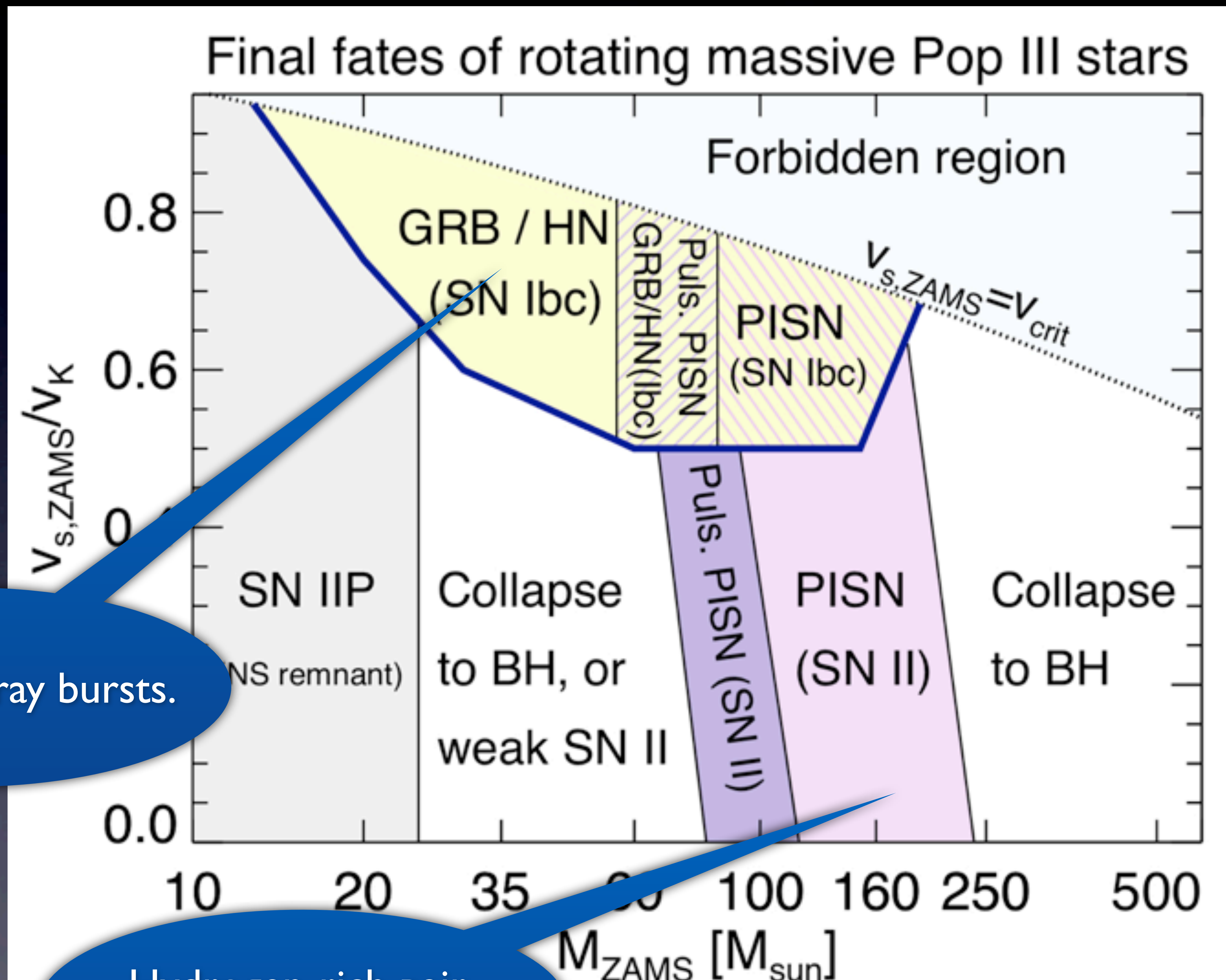
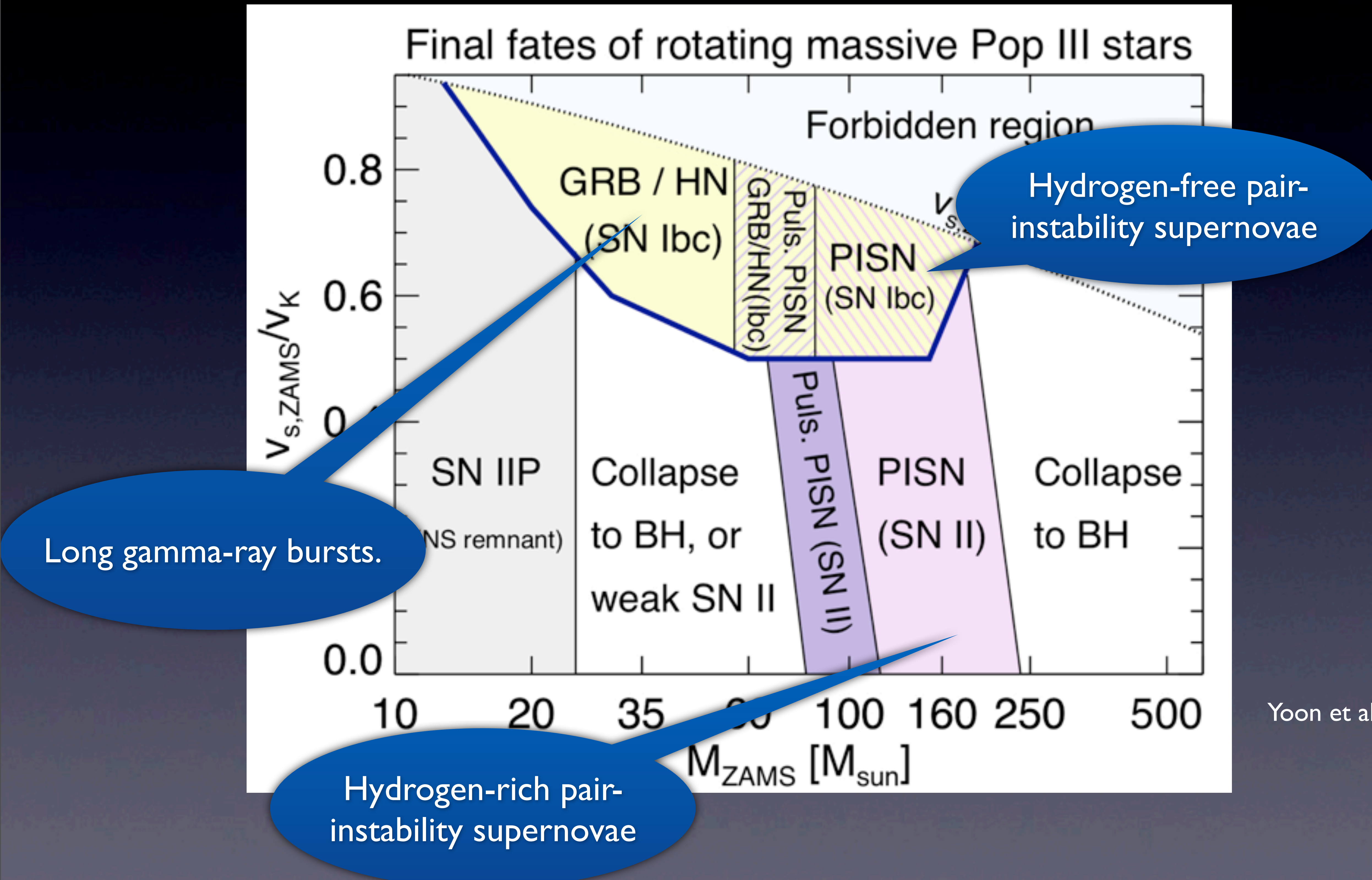


Long gamma-ray bursts.

Hydrogen-rich pair-instability supernovae

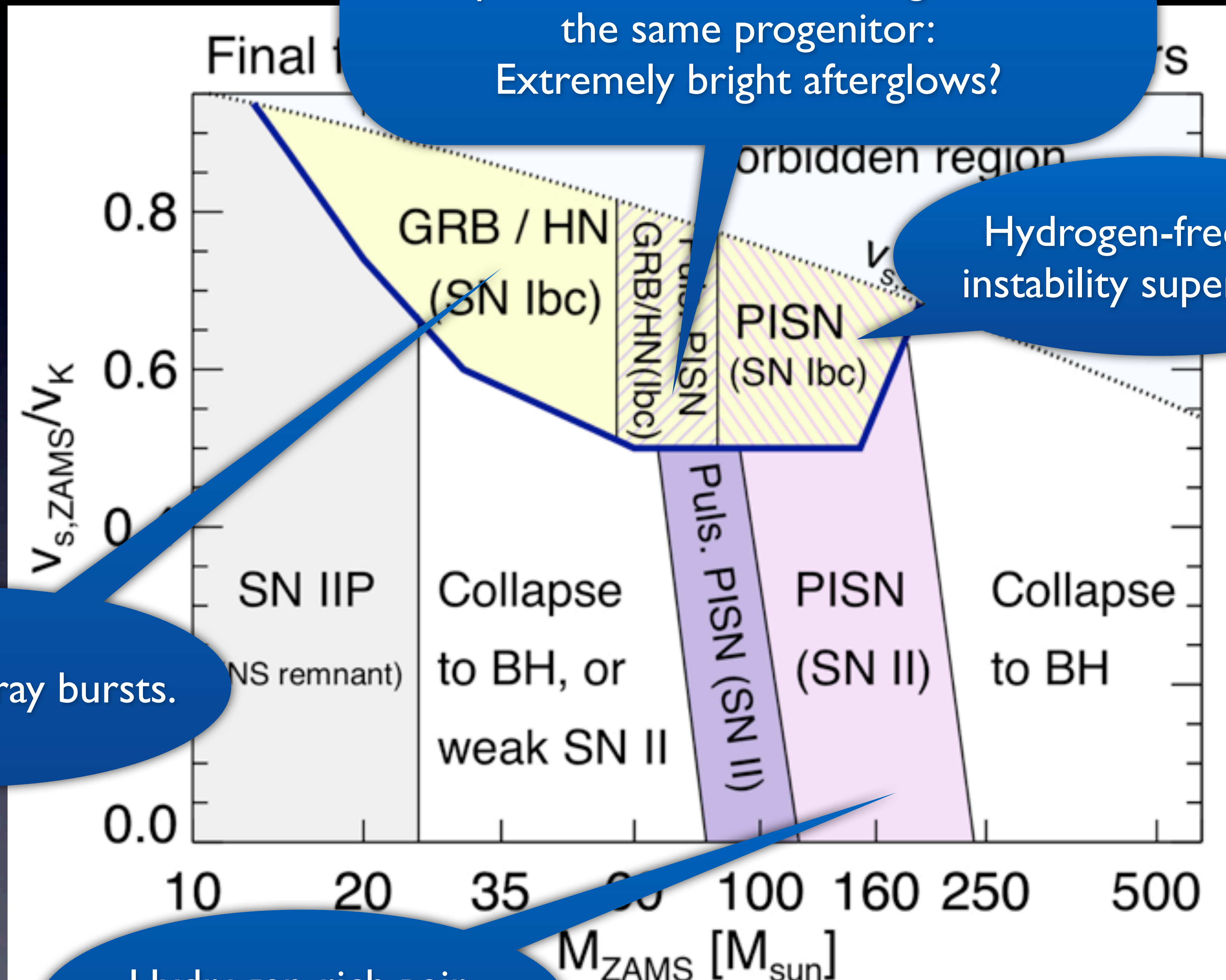
Yoon et al. 2012

Final fates of the first stars



Yoon et al. 2012

Final fates of the first stars



Both pulsational PISN and long GRB from the same progenitor: Extremely bright afterglows?

Hydrogen-free pair-instability supernovae

Long gamma-ray bursts.

Hydrogen-rich pair-instability supernovae

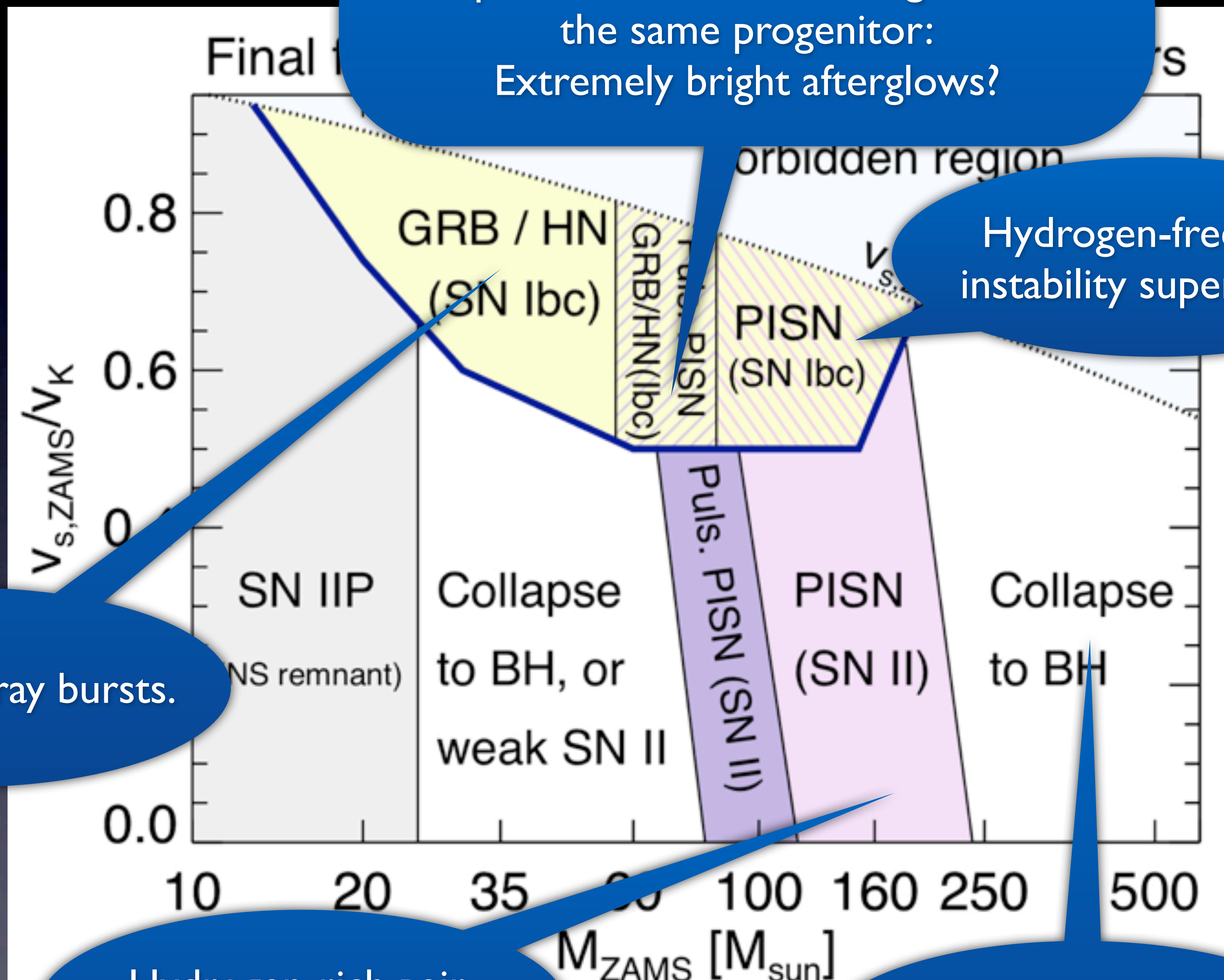
Yoon et al. 2012

Final fates of the first stars

Both pulsational PISN and long GRB from the same progenitor:
Extremely bright afterglows?

Hydrogen-free pair-instability supernovae

Long gamma-ray bursts.



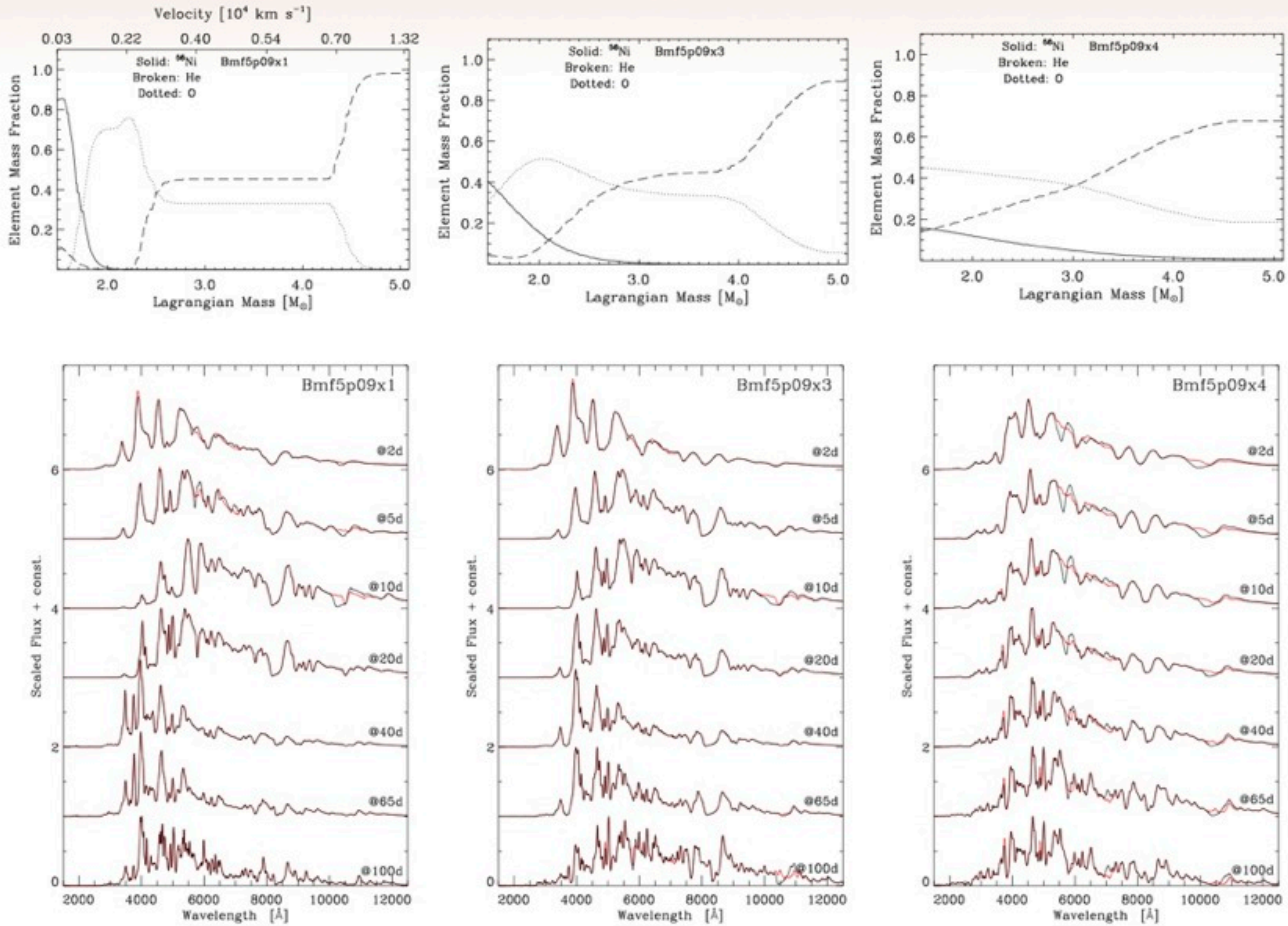
Yoon et al. 2012

Hydrogen-rich pair-instability supernovae

Super-collapsar is not likely to occur.

Final Remarks

- The nature of SN Ibc progenitors are "*different*" from that of most WR stars.
- To correctly interpret the observational data, you need "realistic" binary star models of SN Ibc progenitors.
- The diversity of SN Ibc can be very large: its progenitor masses can vary from 1.4 Msun to 100 Msun, and the delay time from a few Myr to Gyr.
- We still do not understand well what makes Ib and Ic different.
- We still do not know what makes the so-called broad-lined Ic supernovae.



Dessart et al. 2012; red line:He transition excluded, black line: full solution