Progenitors of long gamma-ray bursts

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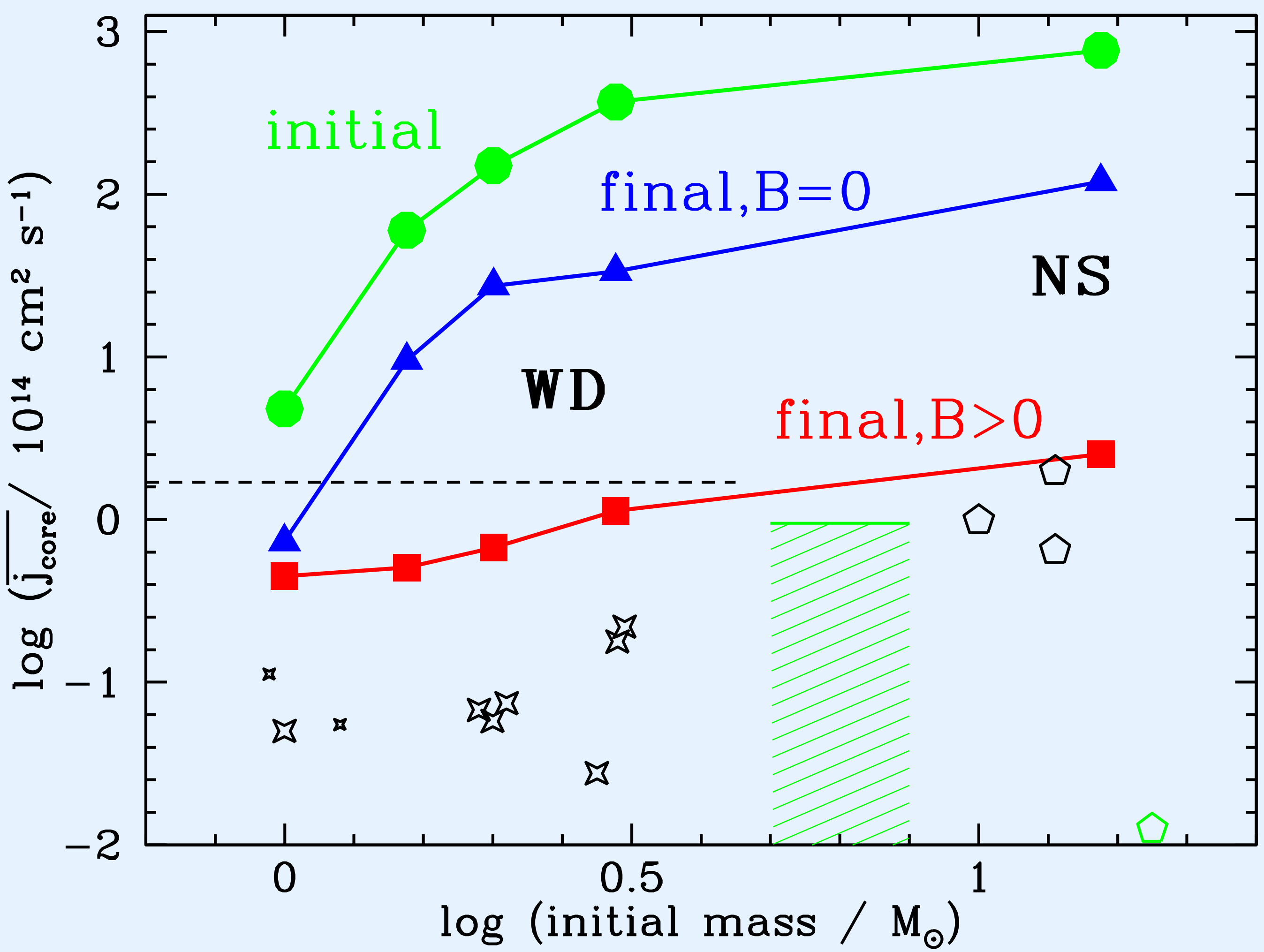
Rapidly spinning cores: how?

Just look at stellar evolution models with rotation!?

- no B-fields (Maeder et al. 2000; Heger et al. 2000)
  ⇒ cores largely decoupled
  ⇒ ALL cores rotate very fast!
  too many GRBs
  too fast young NSs, WDs
- with B-field (Heger et al. 2005, Petrovic et al. 2005)
  ⇒ core-envelope coupling ⇒ NO cores rotate very fast!
  no GRBs!
  NS, WD spins better!

Problem: stars produce slowly rotating



Suijs et al. 2008

Solution: chem. homogeneous evolution

- rapid rotation ⇒ internal mixing
  ⇒ chem. homogeneous evolution
  NO core spin-down (since no envelope)
  B-fields ok!

  Yoon & Langer 2005; Woosley & Heger 2006

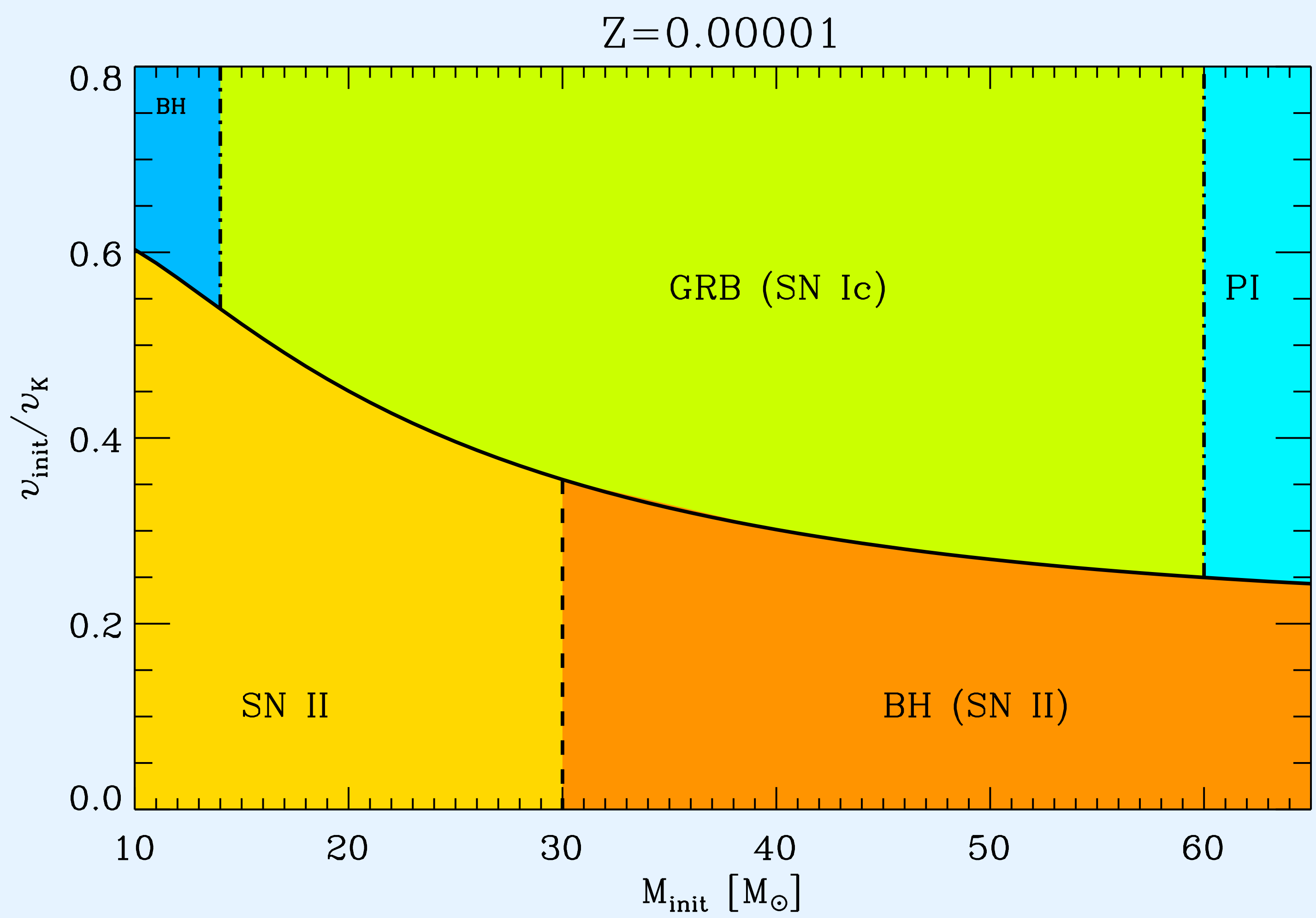
- for free: compact progenitor
  H-ZAMS → He-ZAMS: radius decreases!

chem. homogeneous: how often?

- initial rotation $v_{\rm rot}$:
  $v_{\rm rot} > v_{\rm crit}(M) \rightarrow$ hom. evol.
  mixing is easier for larger mass
- metallicity Z:
  $Z_\odot \rightarrow$ strong winds $\rightarrow$ spin-down $\rightarrow$ core-envelope structure
  $\Rightarrow Z < Z_{\rm crit}(M) \rightarrow$ hom. evol.

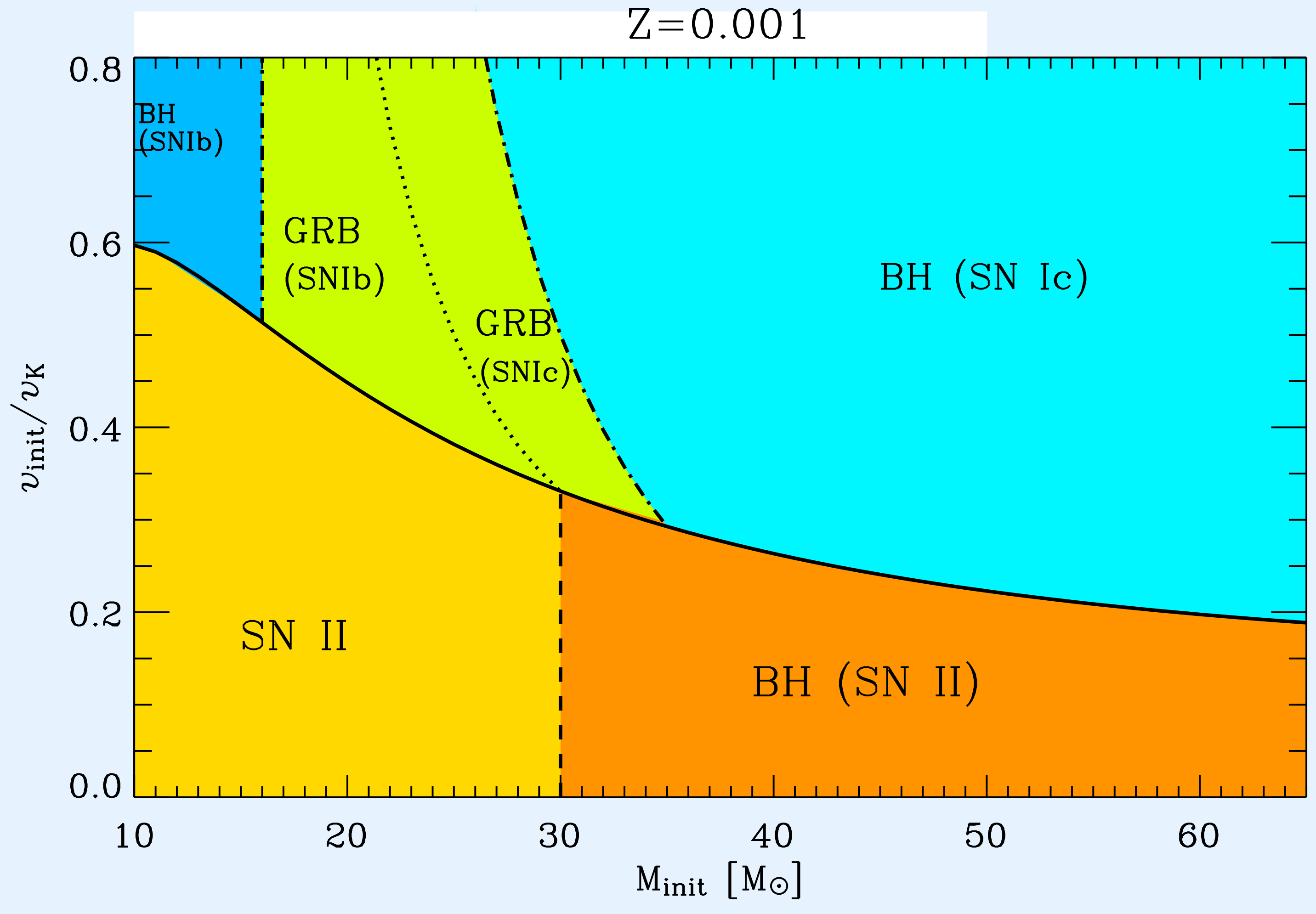
  Yoon et al. 2006

Models at $Z=10^{-5}$



Yoon, Langer & Norman, 2006

Models at $Z=10^{-3}$

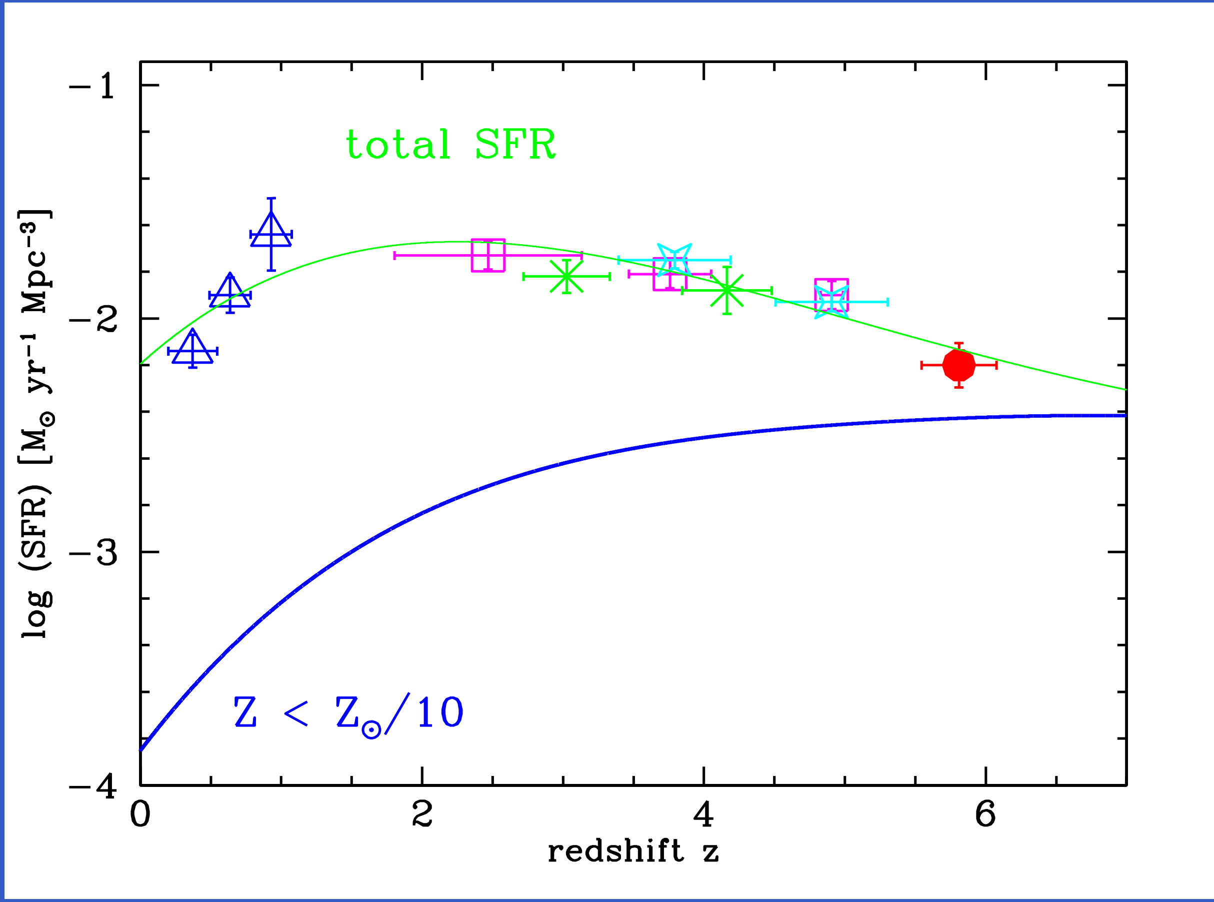


Yoon et al. 2006

How many massive low-Z stars?

$M_{\rm gal} - Z_{\rm gal}$–relation + cosmic Z-evolution:

$frac(Z < Z_0)(z)$



Langer & Norman 2006

GRB Metallicity bias $\rightarrow$ hom. evol.!

locally: 1 GRB / 1000 SNe

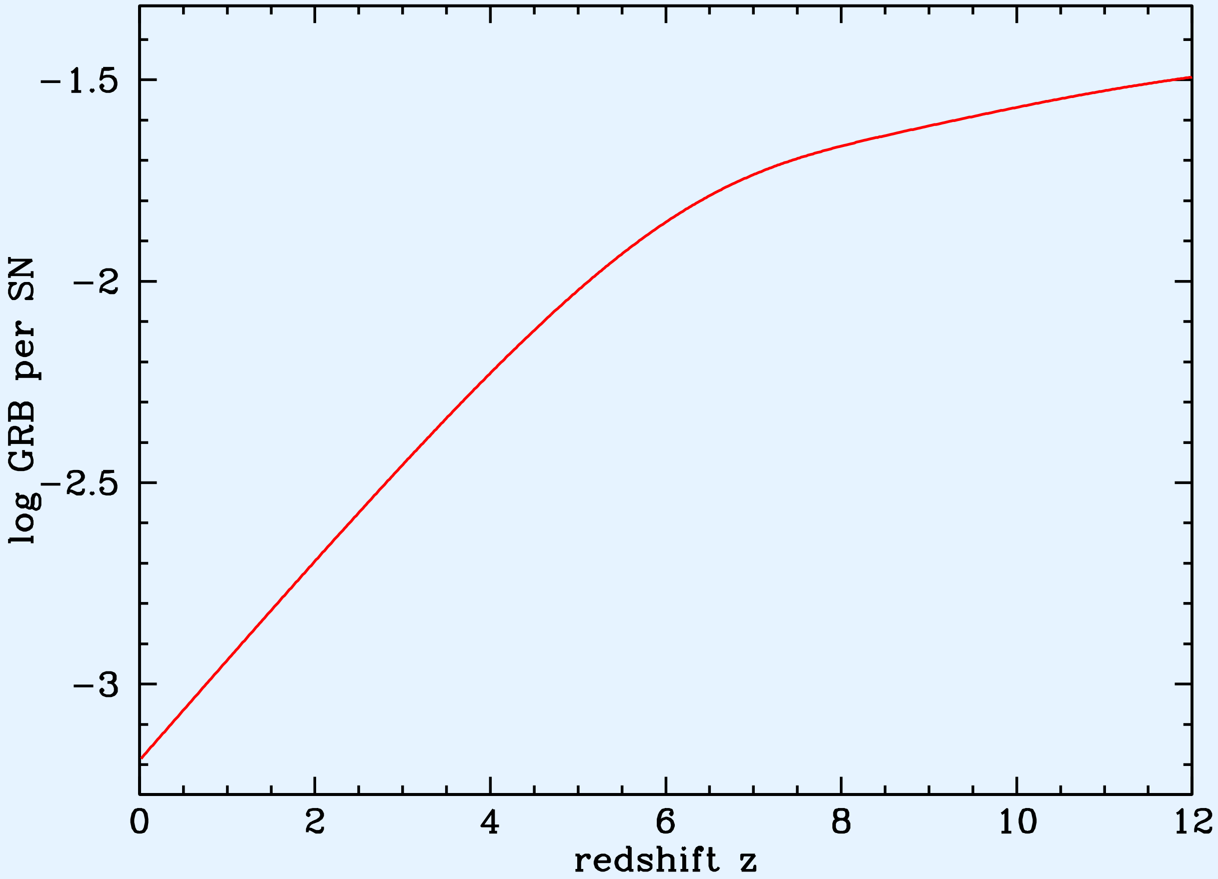
assume GRBs come from $Z < Z_{\odot}/10$

$$\longrightarrow \frac{\#SNe(Z<Z_{\odot}/10)}{\#SNe} \simeq \frac{1}{100}$$

also: $\frac{\#SNe \rightarrow BH}{\#SNe} \simeq \frac{1}{20}$

$\Rightarrow$ EVERY BH makes a GRB!

GRB/SN redshift dependence



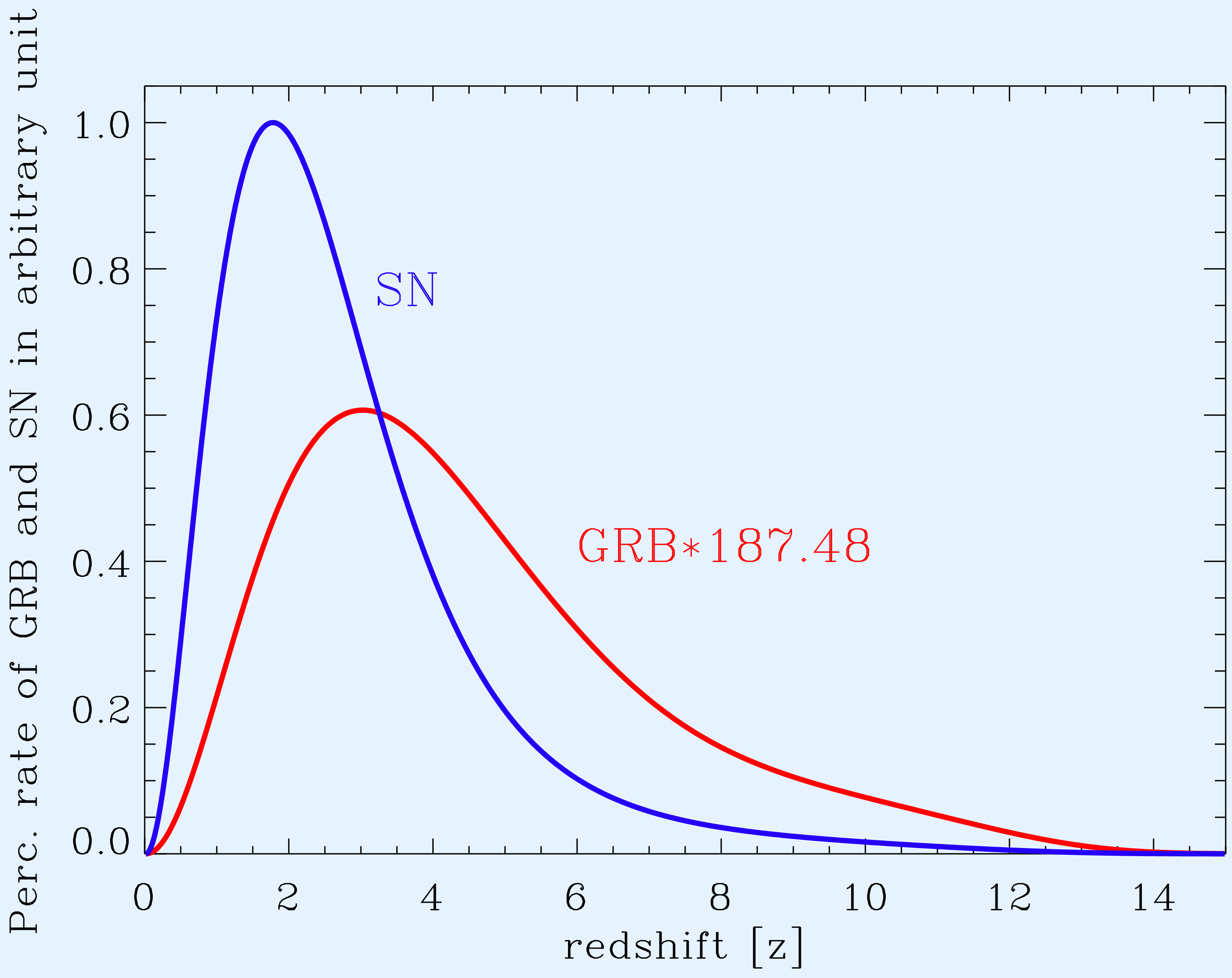
Yoon et al. 2006

Metallicity threshold

$Z_{\rm crit}$ is *absolute* threshold

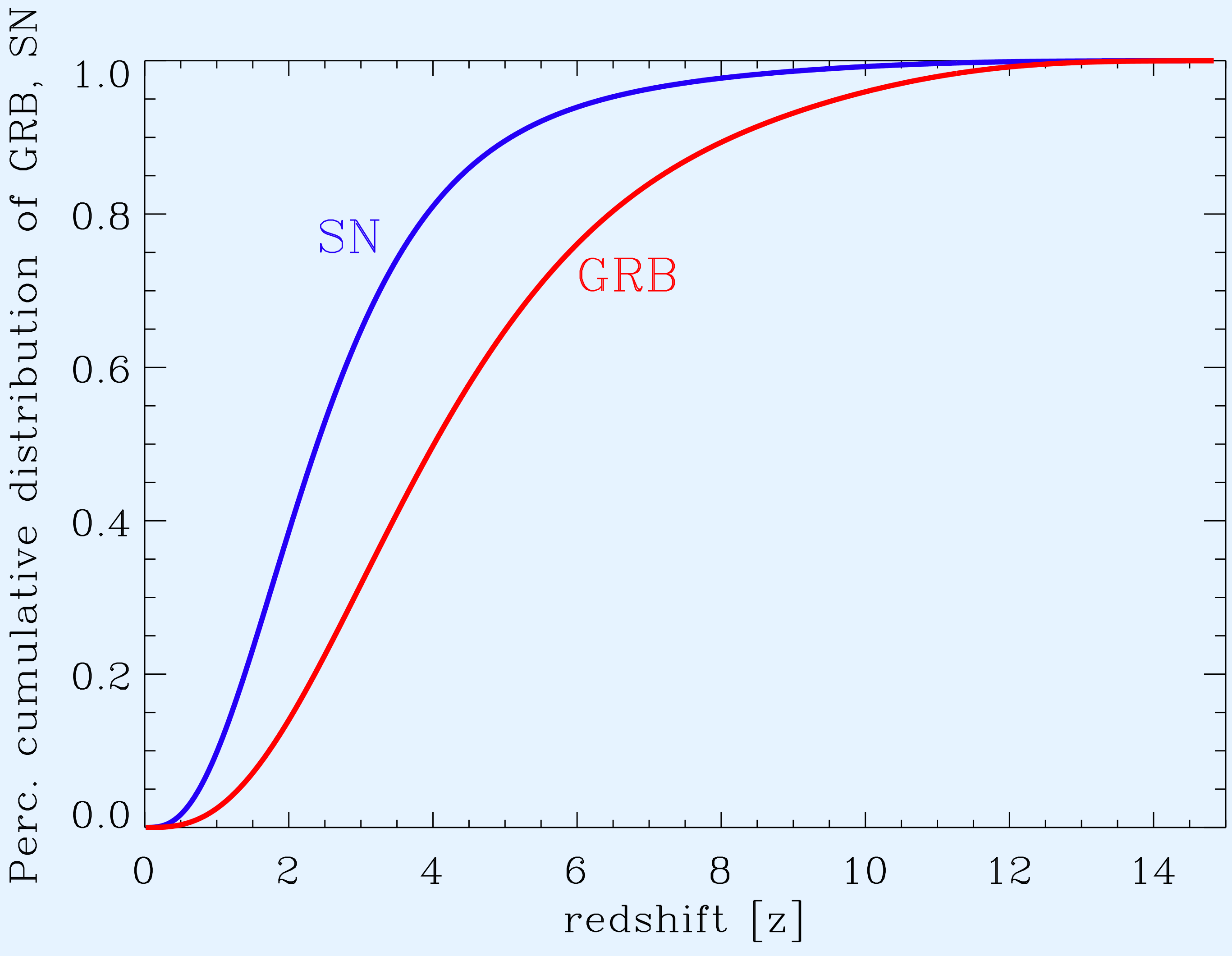
- locally
  most metal-poor galaxies produce GRBs
- at high z
  most-metal-rich DLAs may produce GRBs

GRB redshift distribution



Yoon et al. 2006

GRB redshift distribution



Yoon et al. 2006

Towards $Z = 0$

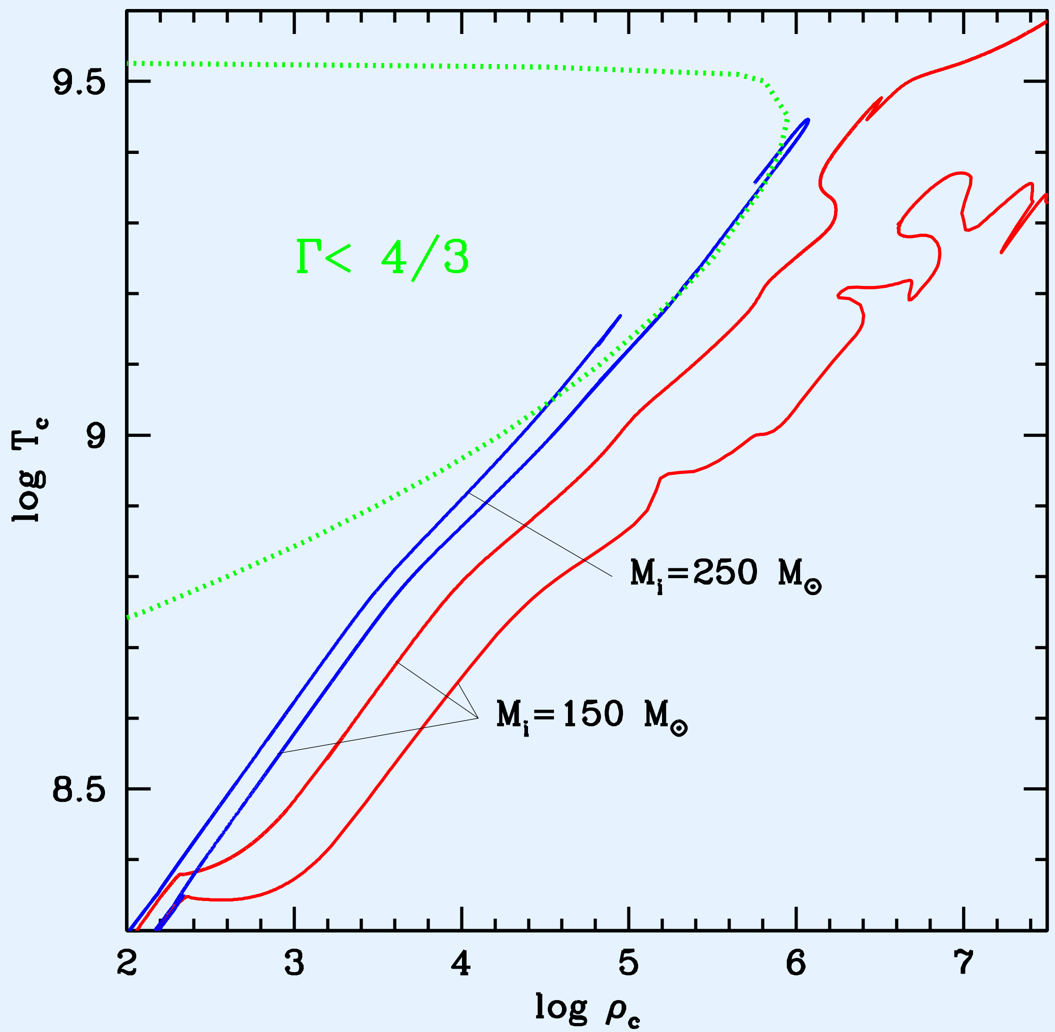
big difference is SF, not SE!

- chem. homogeneous models apply! fraction depends on $v_{\rm rot}$-distribution
- VMS: pair creation supernovae?

PCSNe

- only requirement: $M_{CO} > 50\,\mathrm{M}_\odot$
- $\dot{M} = 0 \Rightarrow M_{\mathrm{ZAMS}} > 100\,\mathrm{M}_\odot$
- $\dot{M} = f(Z) \Rightarrow Z_{\mathrm{crit}}$

PCSN progenitor evolution



Langer et al. 2007

PCSNe: slow rotation

- $Z_{\rm crit} \simeq Z_\odot/3$ Langer et al. 2007
- $\Rightarrow$ local PCSNe!
- $frac(Z < Z_\odot/3)(z = 0) \Rightarrow$ 1 PCSN/ 1000 SNe
- $\rightarrow$ SN 2006gy, ...
- $frac(Z < Z_\odot/3)(z = 5) \Rightarrow$ 1 PCSN/ 100 SNe
- those PCSNe make no GRBs

PCSNe: fast rotation

- envelope self-pollution
- $\Rightarrow Z_{\rm crit} \simeq Z_{\odot}/1000$ Langer et al. 2007
- $\rightarrow$ relevant only in early universe
- number depends on IMF
- GRB production possible

Summary

- if GRBs biased to low-Z
  $\Rightarrow$ no exotic progenitor channels!
- slow rotation in young NSs, WDs + non-exotic SE
  $\Rightarrow$ chemically homogeneous evolution
- chem. hom. SE + $frac(Z < Z_0)(z = 0)$
  $\Rightarrow$ 1 GRB/1000 SNe locally
- 50% of long GRBs at $z > 4$
- PCSNe local: < 1 per 1000 SNe (non-GRB)
- PCSNe at high z, $Z = 0$:
  core-collapse GRBs from chem. hom. evolution
  PCSN-GRBs from $M > 250\,M_\odot$