Rare? types of massive star explosions

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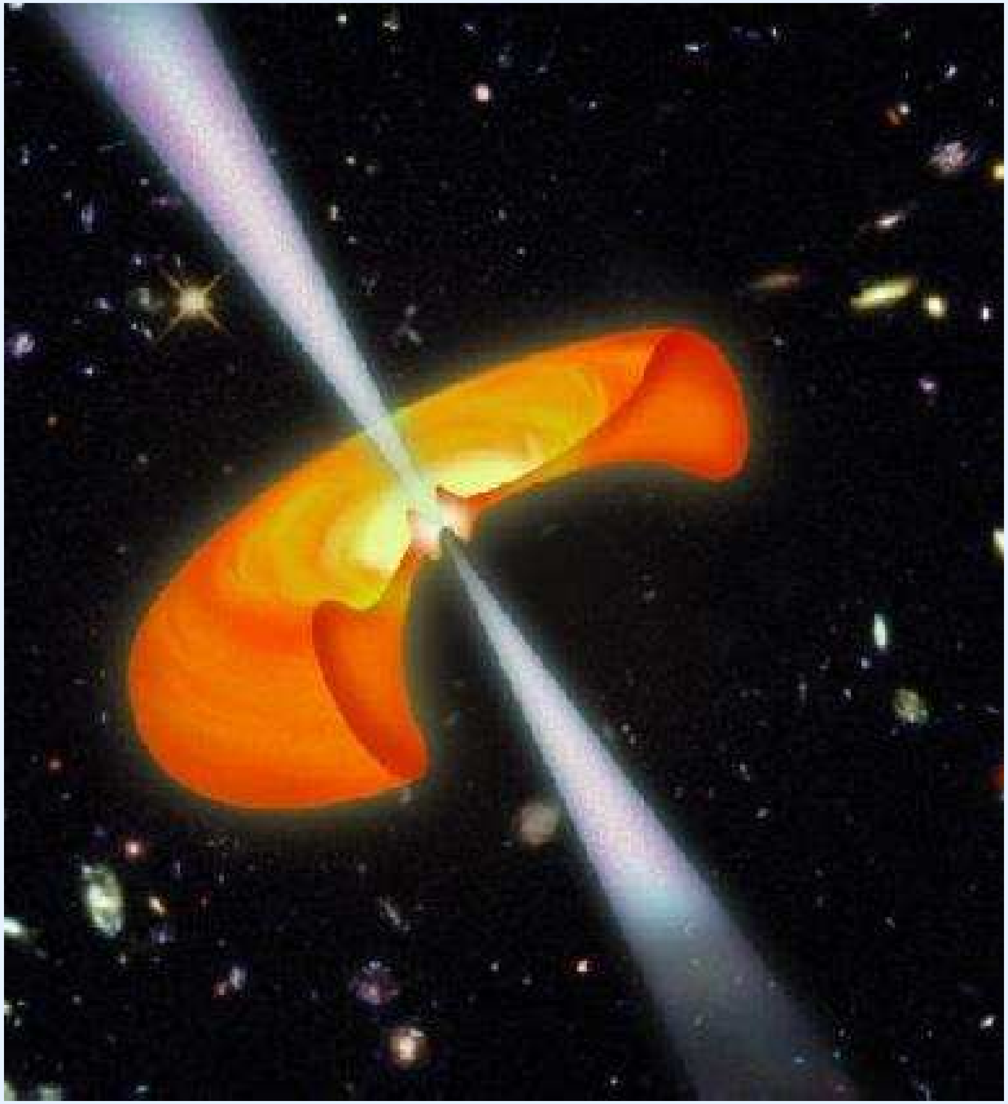
- Falk Herwig (Victoria)
- Selma de Mink (Baltimore)
- Colin Norman (Baltimore)
- Stan Woosley (Santa Cruz)

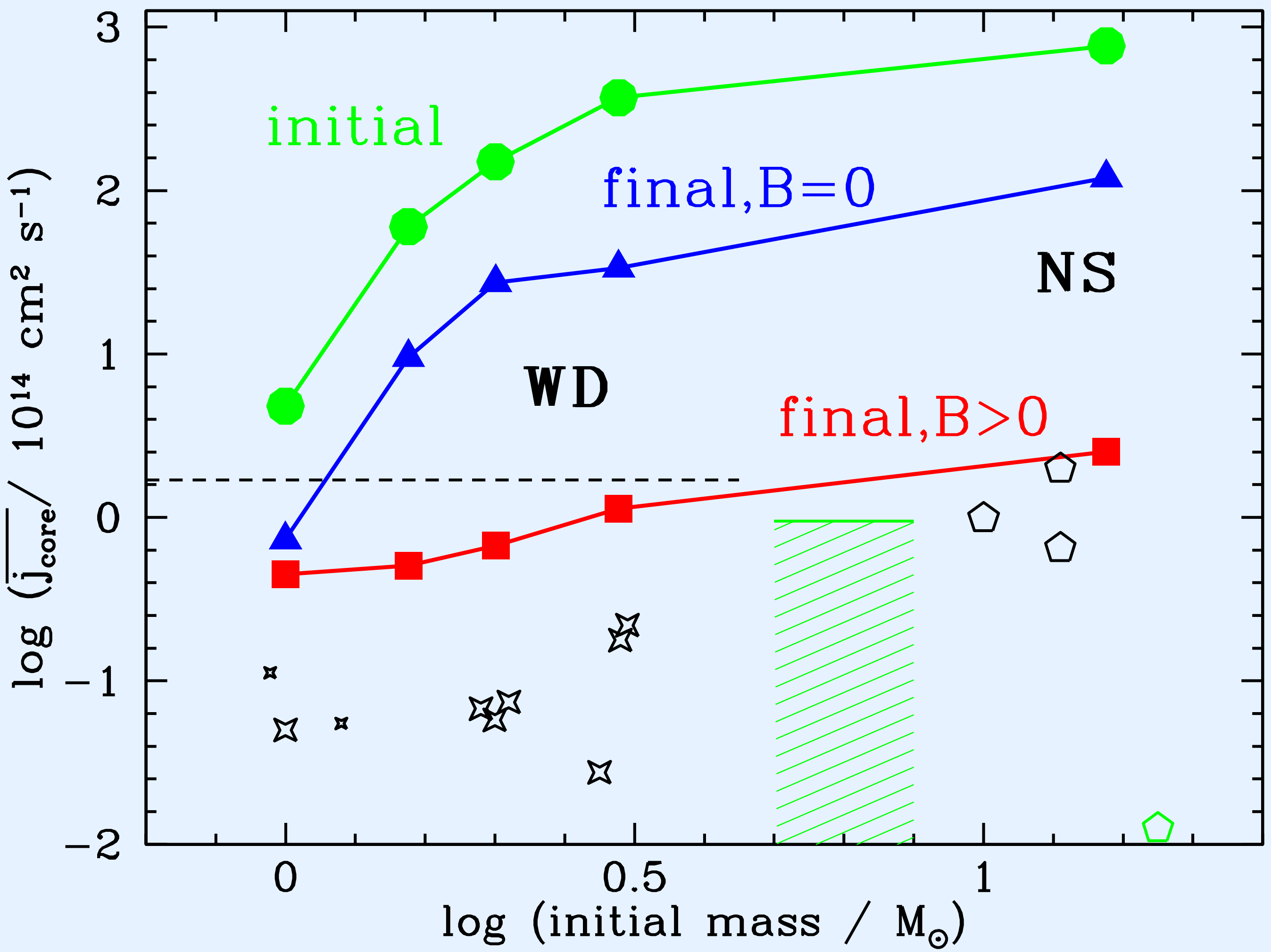
long GRBs



Collapsars (Stan Woosley)

- massive core $\Rightarrow$ black hole
- compact size $\Rightarrow$ $\frac{R_*}{c} \simeq \tau_{engine}$
- rapid rotation $\Rightarrow$ centrifugal barrier $\Rightarrow$ $j \simeq 10^{16}\,\mathrm{cm}^2\mathrm{s}^{-1}$

Stars favour slowly rotating cores

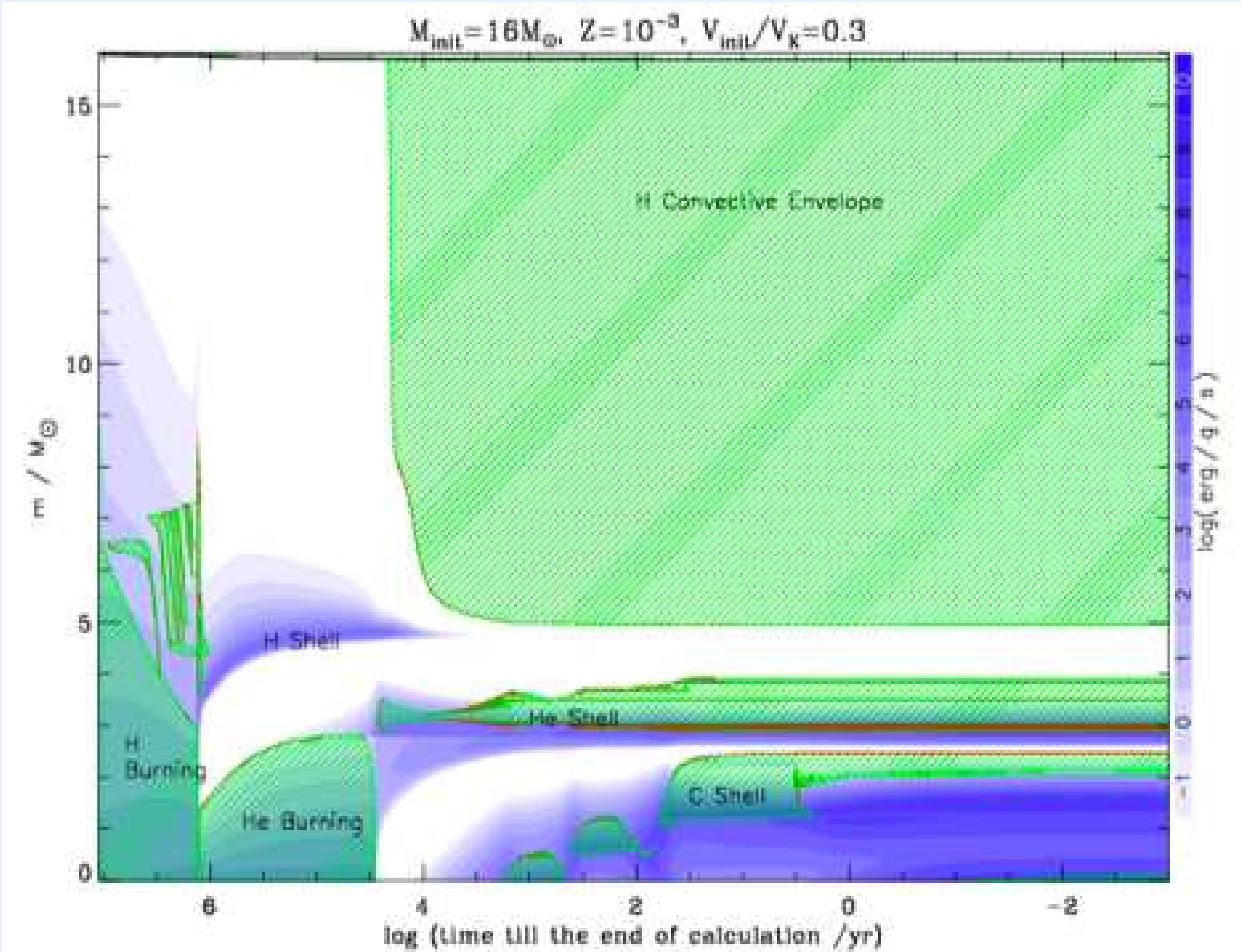


Suijs et al. 2008

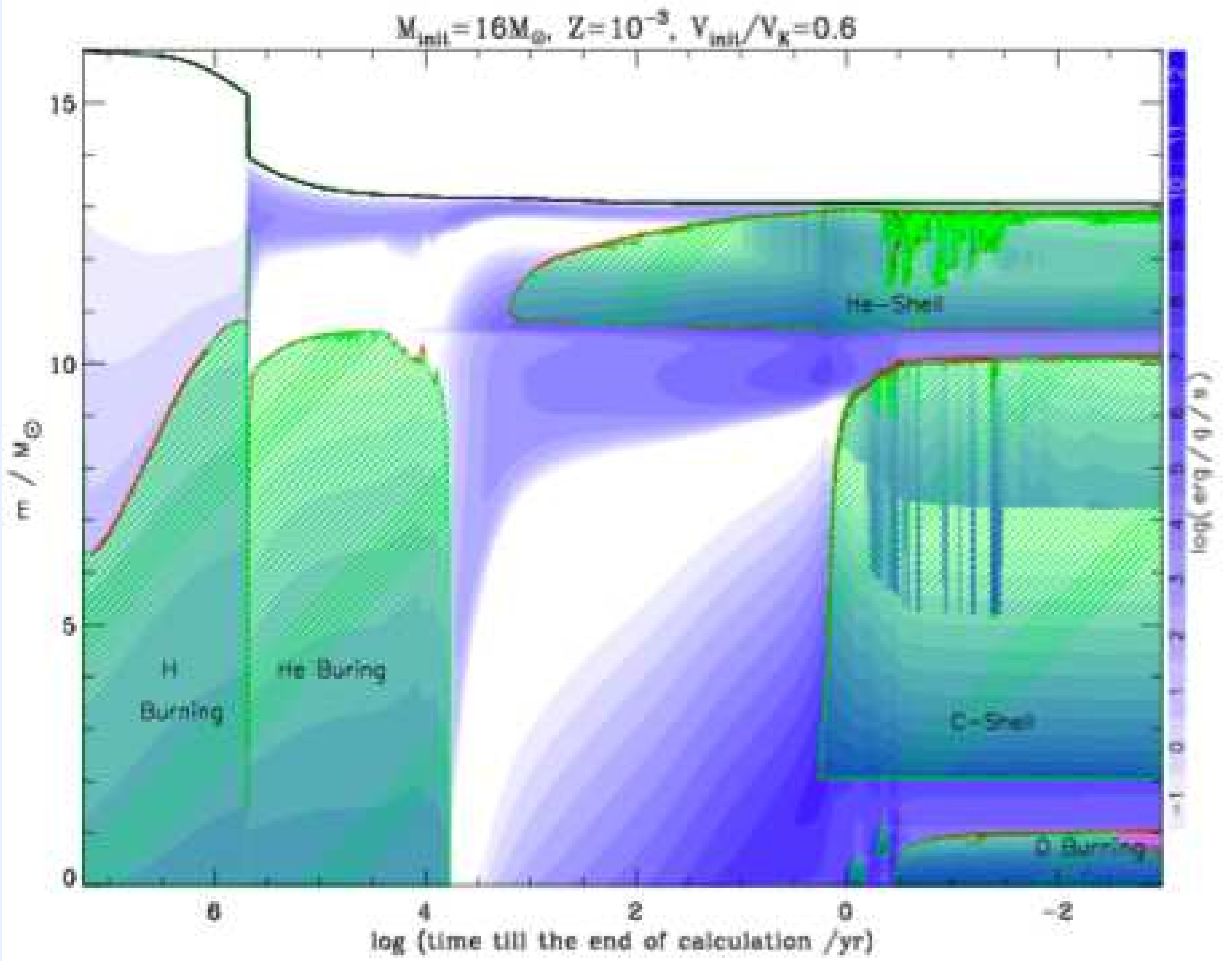
Stars without envelope

- Stellar cores spin down due to core-envelope coupling
- $\Rightarrow$ need stars without envelope
- also required by collapsar picture:
  $\frac{R_*}{c} \simeq \tau_{engine}$
- but: loss of envelope induces spin-down

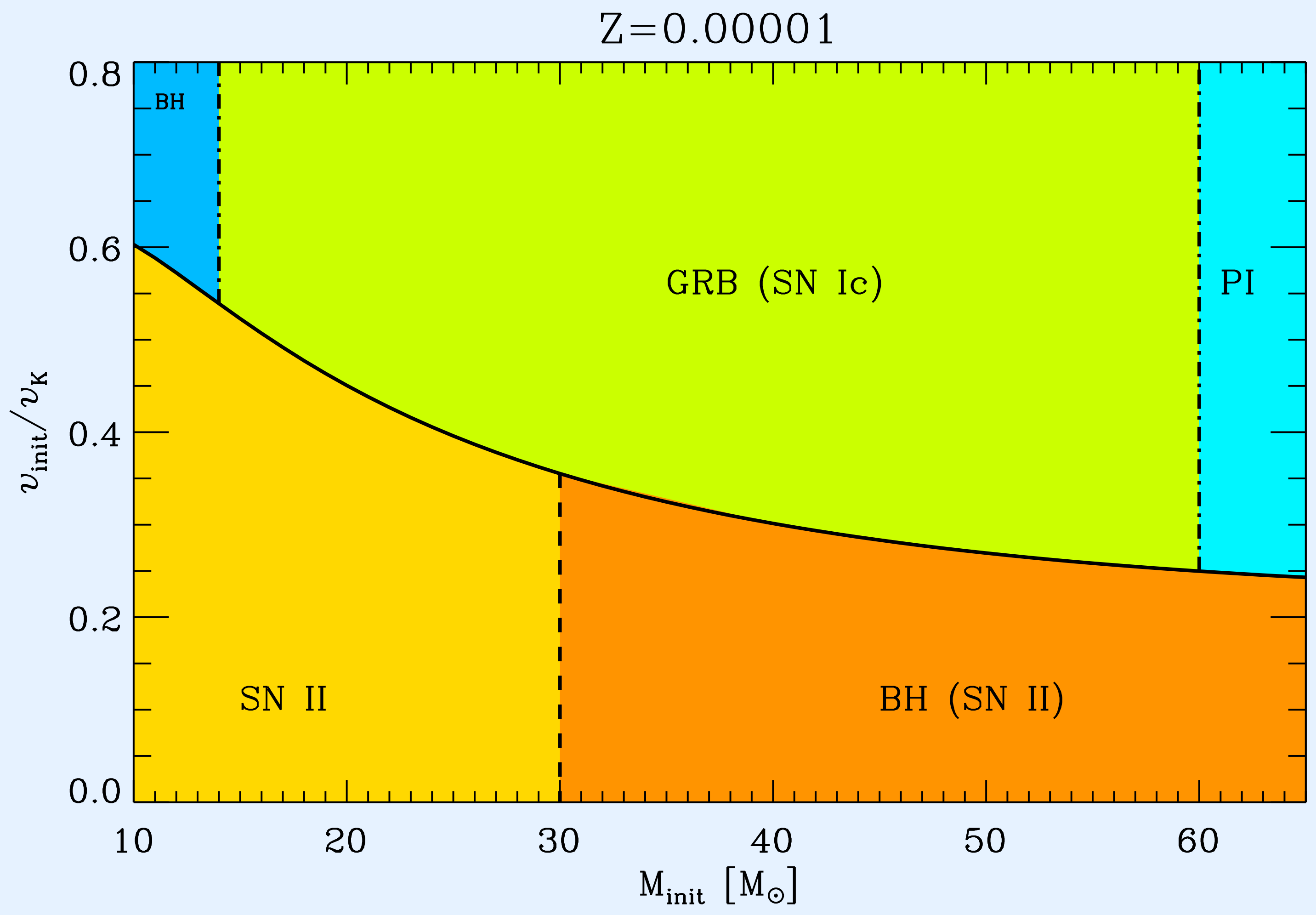
Slow rotator



Fast rotator: chem. homogeneous

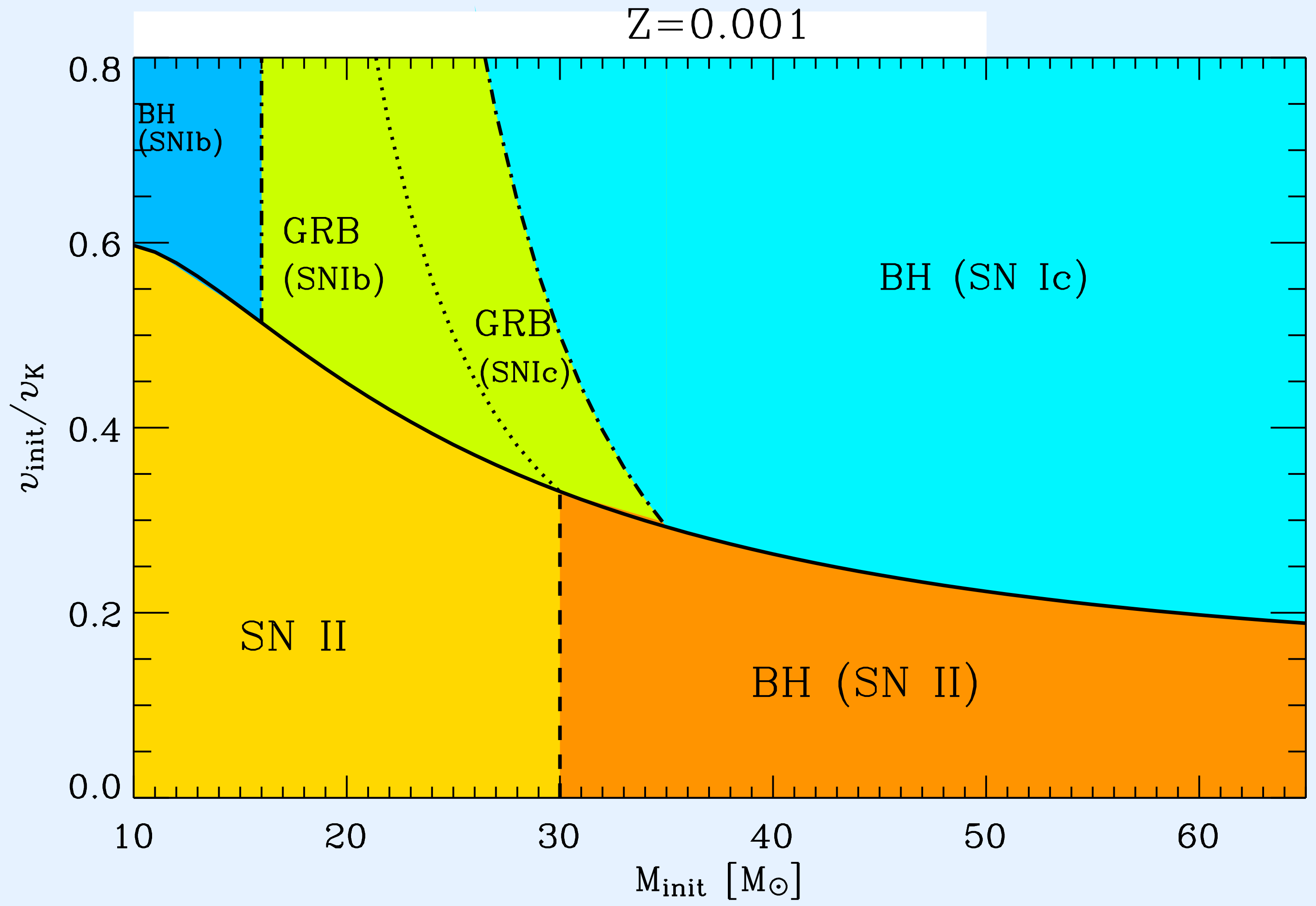


Models at $Z=10^{-5}$



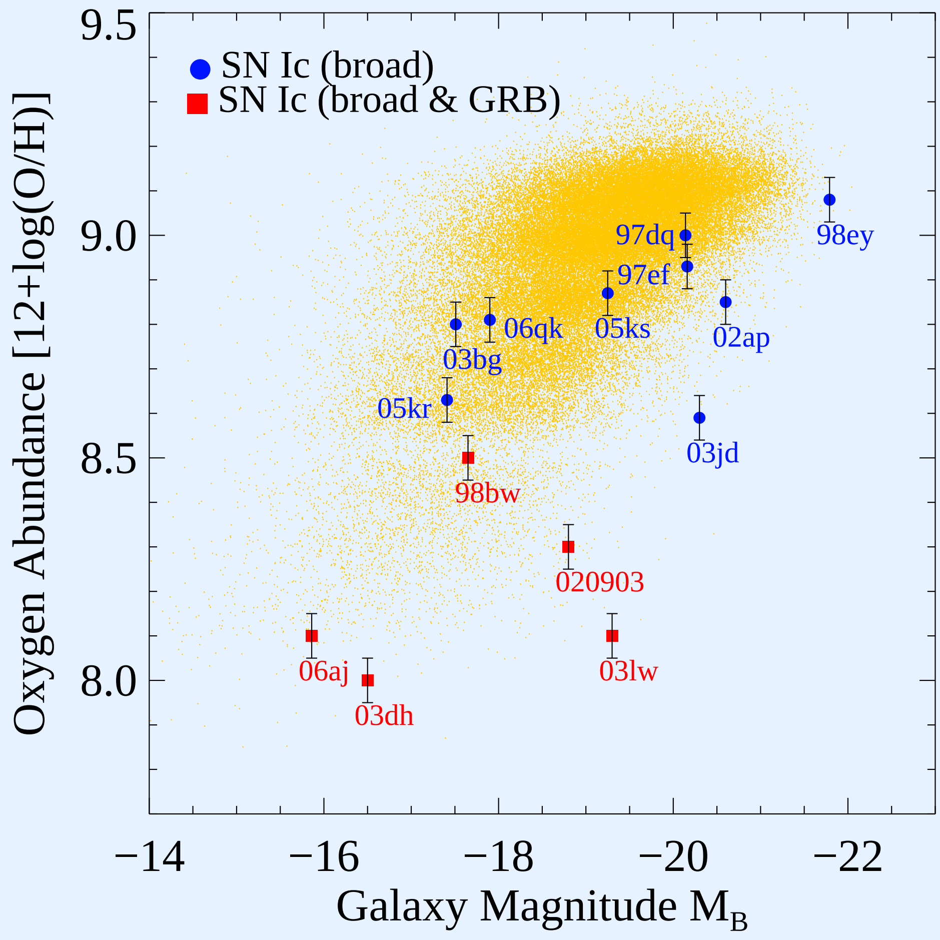
Yoon, Langer & Norman, 2006

Models at Z=10^{-3}



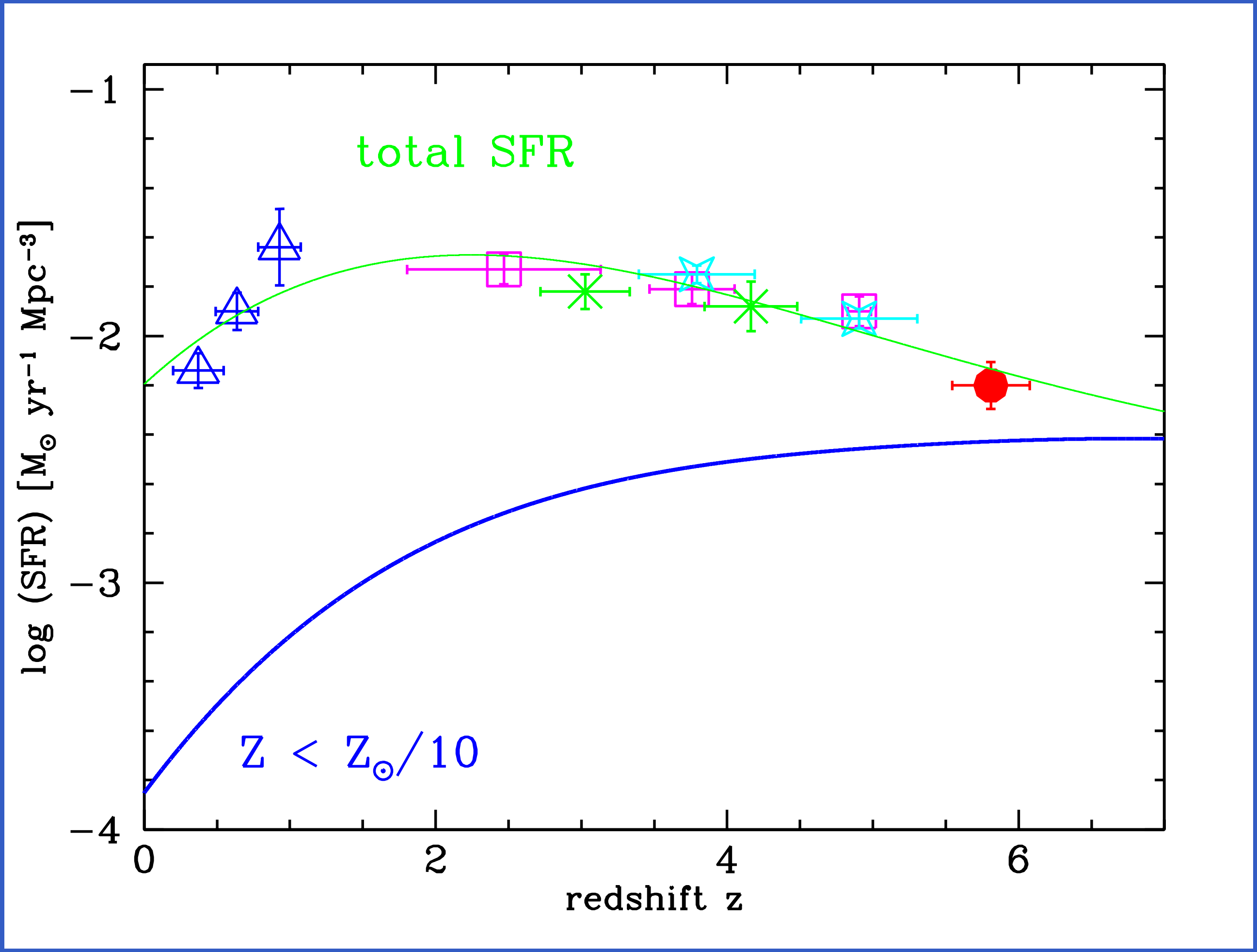
Yoon et al. 2006

GRB metallicity bias!



Modjaz et al. 2007

Metallicity bias



Langer & Norman 2006

GRBs are NOT rare everywhere ...

- local GRB/SN ratio: 1/1000
- but: low metal content rare locally
- $\Rightarrow$ at low metal content:
  GRB/SN ratio $\simeq 1$?

GRB Metalicity bias $\rightarrow$ single stars

locally: 1 GRB / 1000 SNe

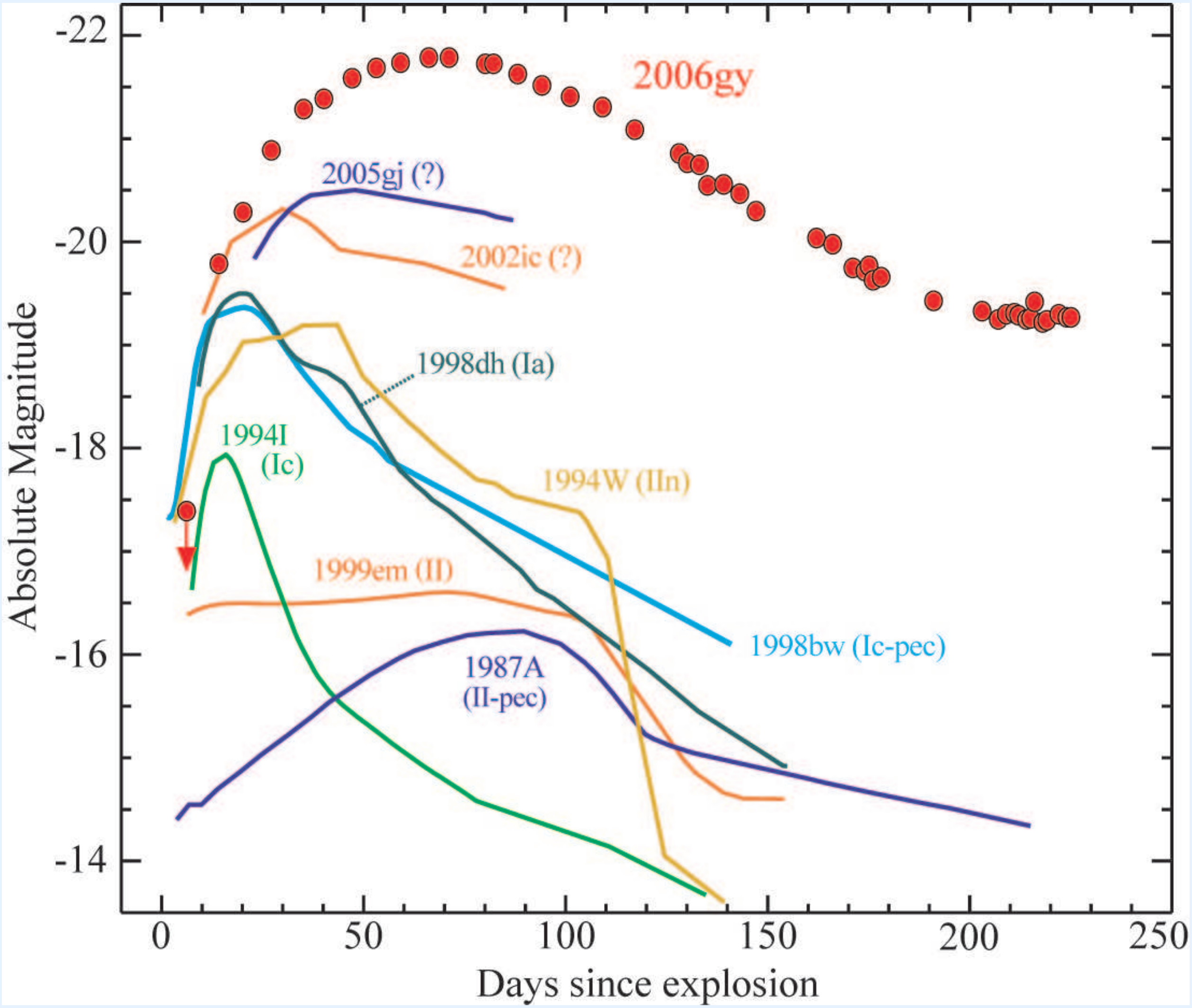
assume GRBs come from $Z < Z_\odot/10$

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

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

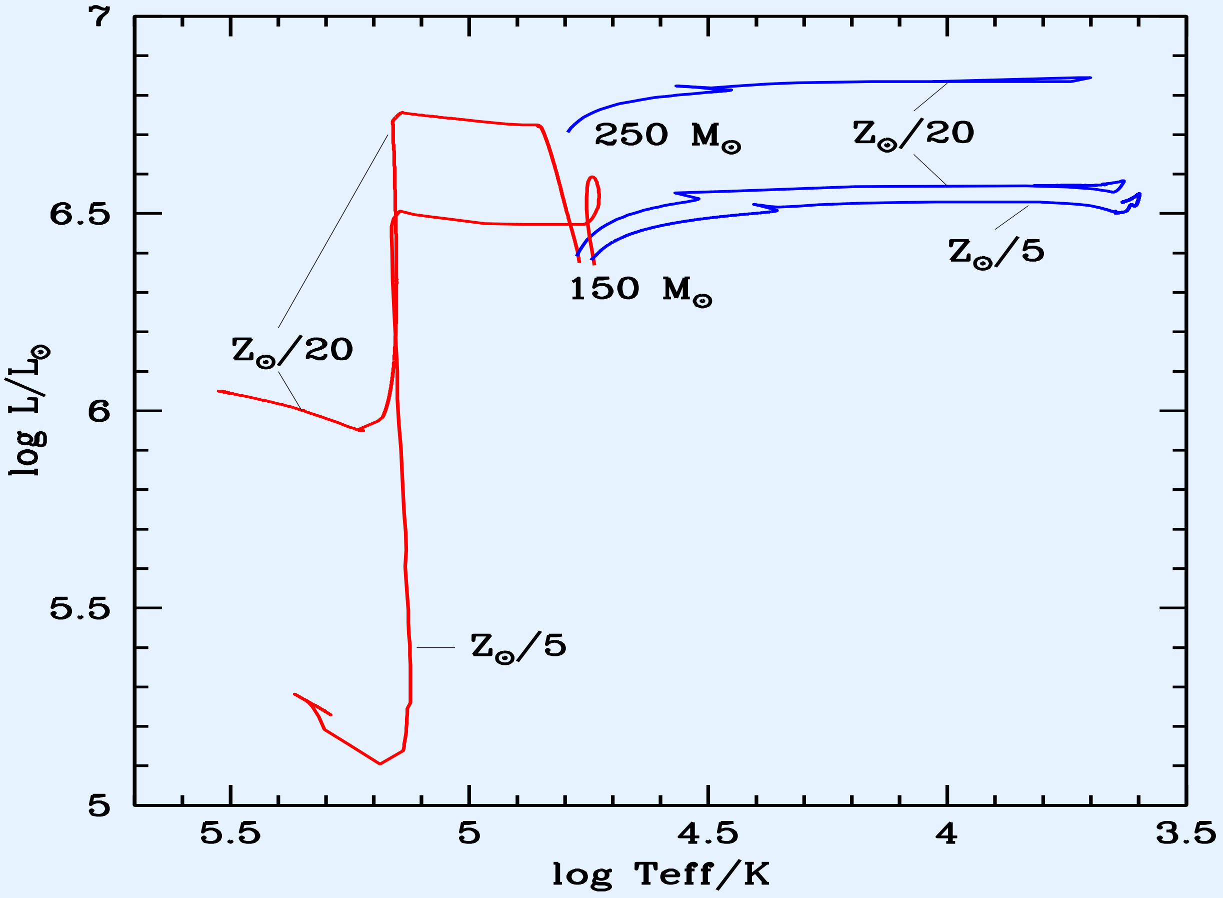
$\Rightarrow$ EVERY BH makes a GRB!

Was SN 2006gy a PCSN?



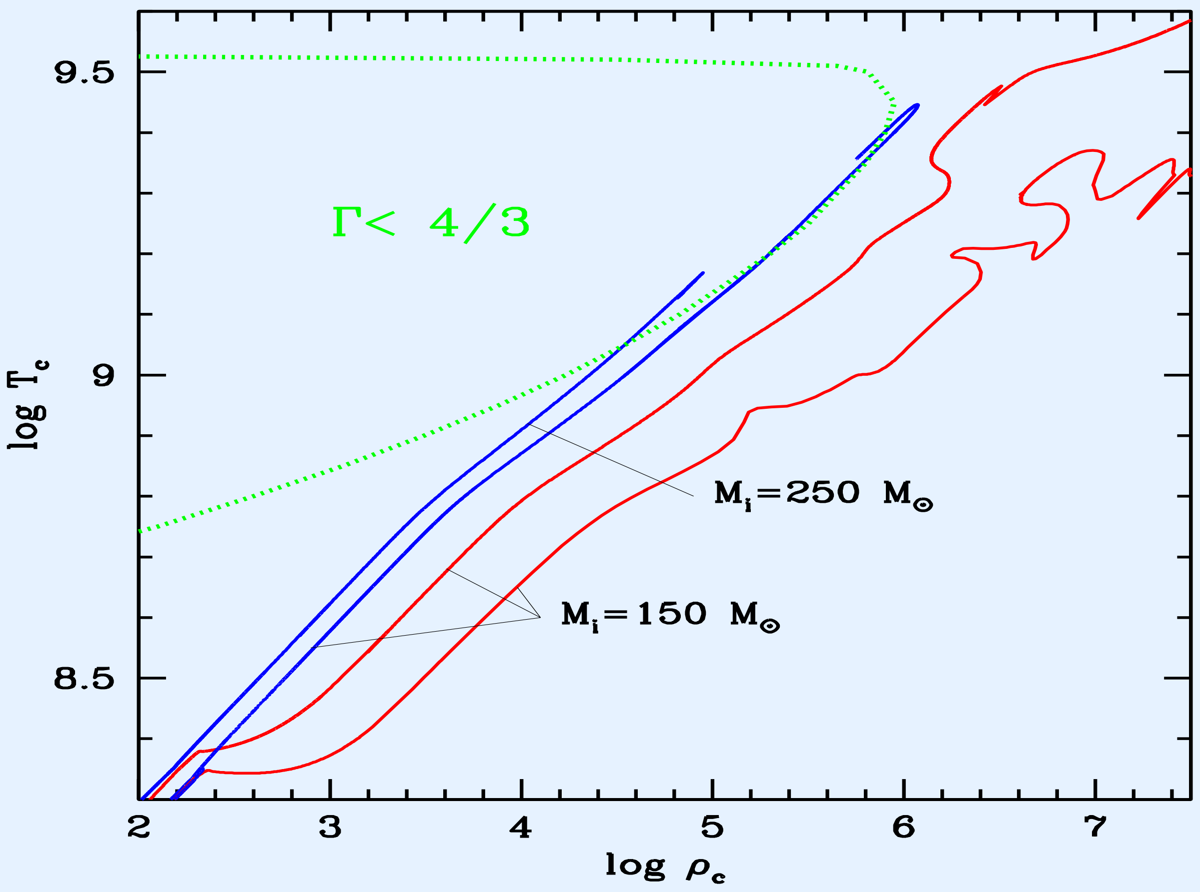
Smith et al. 2007

Local PCSNe possible?



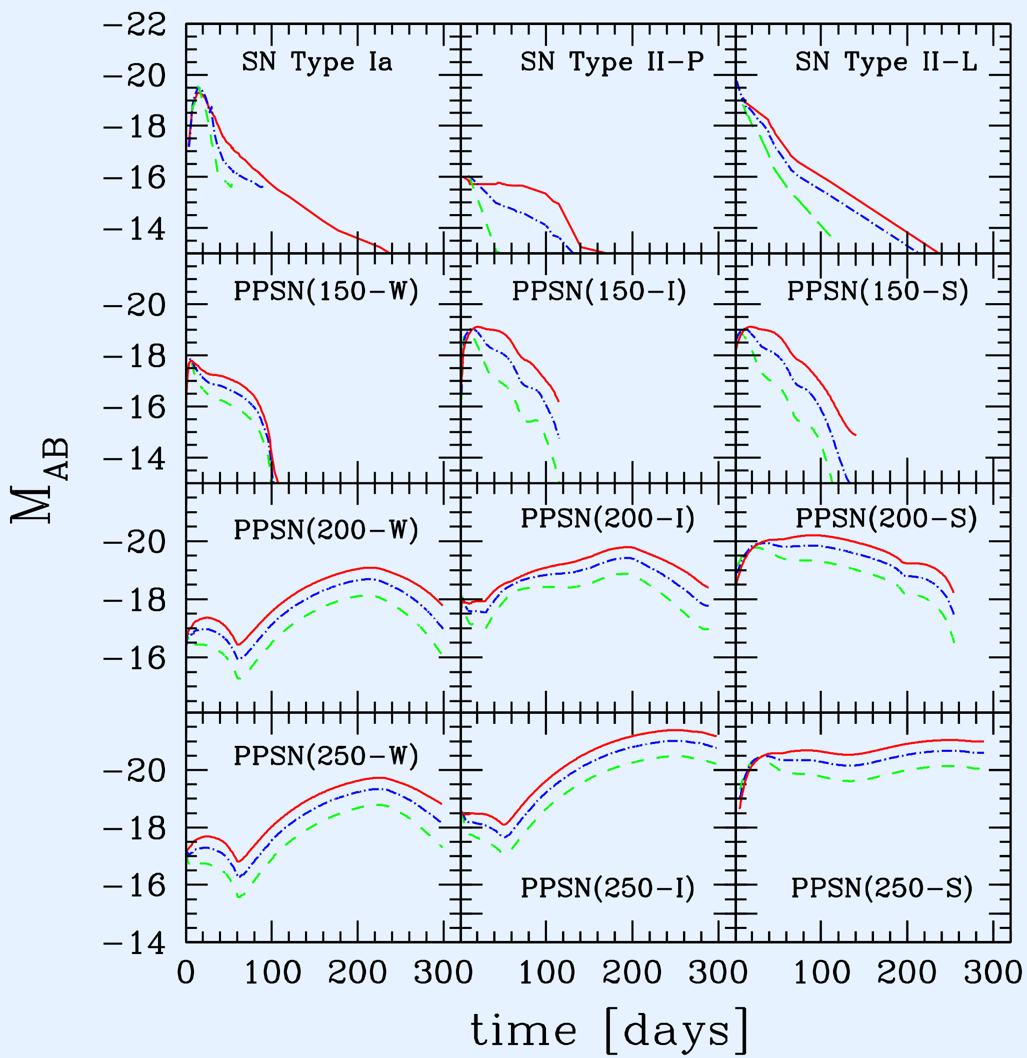
Langer et al. 2007

$T_c - \rho_c$-plane



Langer et al. 2007

Pop III PCSN light curves



Local PCSN rate

assume PCSNe come from $Z < Z_\odot/3$

$$\longrightarrow \frac{\#SNe(Z{<}Z_\odot/3)}{\#SNe} \simeq \frac{1}{10}$$ (Langer & Norman 2006)

also: $$\frac{\#stars{>}150\,\mathrm{M}_\odot}{\#stars 10...150\,\mathrm{M}_\odot} \simeq \frac{1}{100}$$??

$\Rightarrow$ 1 PCSN / 1000 SNe

PCSN nucleosynthesis!

measured chemical yields in SN 2007bi:

O: $> 10\,\mathrm{M}_\odot$

Ne: $4 \pm 0.2\,\mathrm{M}_\odot$

Si: $22 \pm 3\,\mathrm{M}_\odot$

S: $10 \pm 1\,\mathrm{M}_\odot$

Ar: $1.3 \pm 0.2\,\mathrm{M}_\odot$

Ni: $6 \pm 1.2\,\mathrm{M}_\odot$

(Gal-Yam et al. 2007)

PCSN nucleosynthesis!

locally: 1 PCSN/1000 SNe

$\Rightarrow$ at $Z < Z_\odot/3$: 1 PCSN/100 SNe

$\Rightarrow$ PCSNe produce 50% of all metals

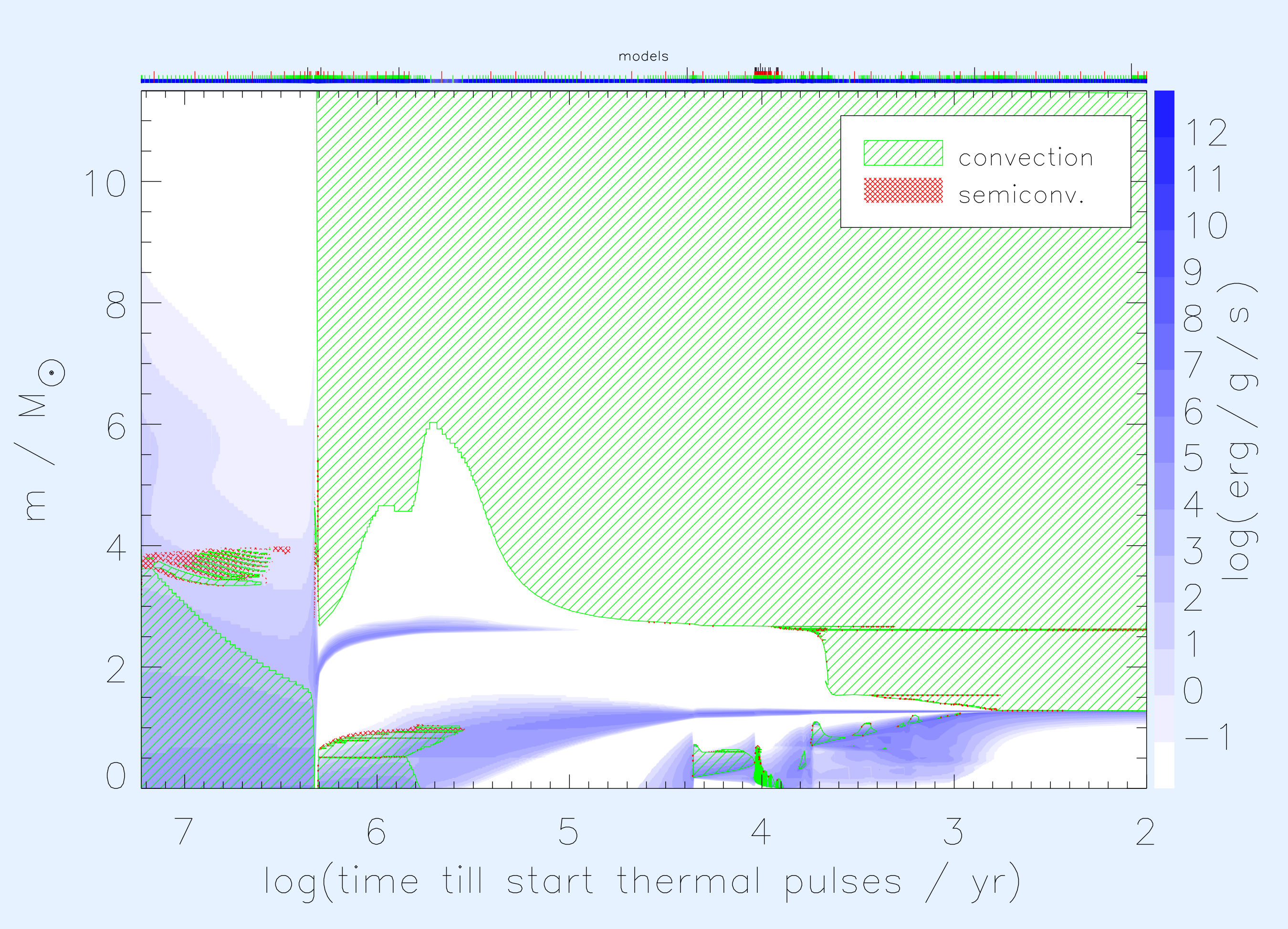
most metals (O...Ni): solar ratios

(Heger & Woosley 2002)

e-capture supernovae

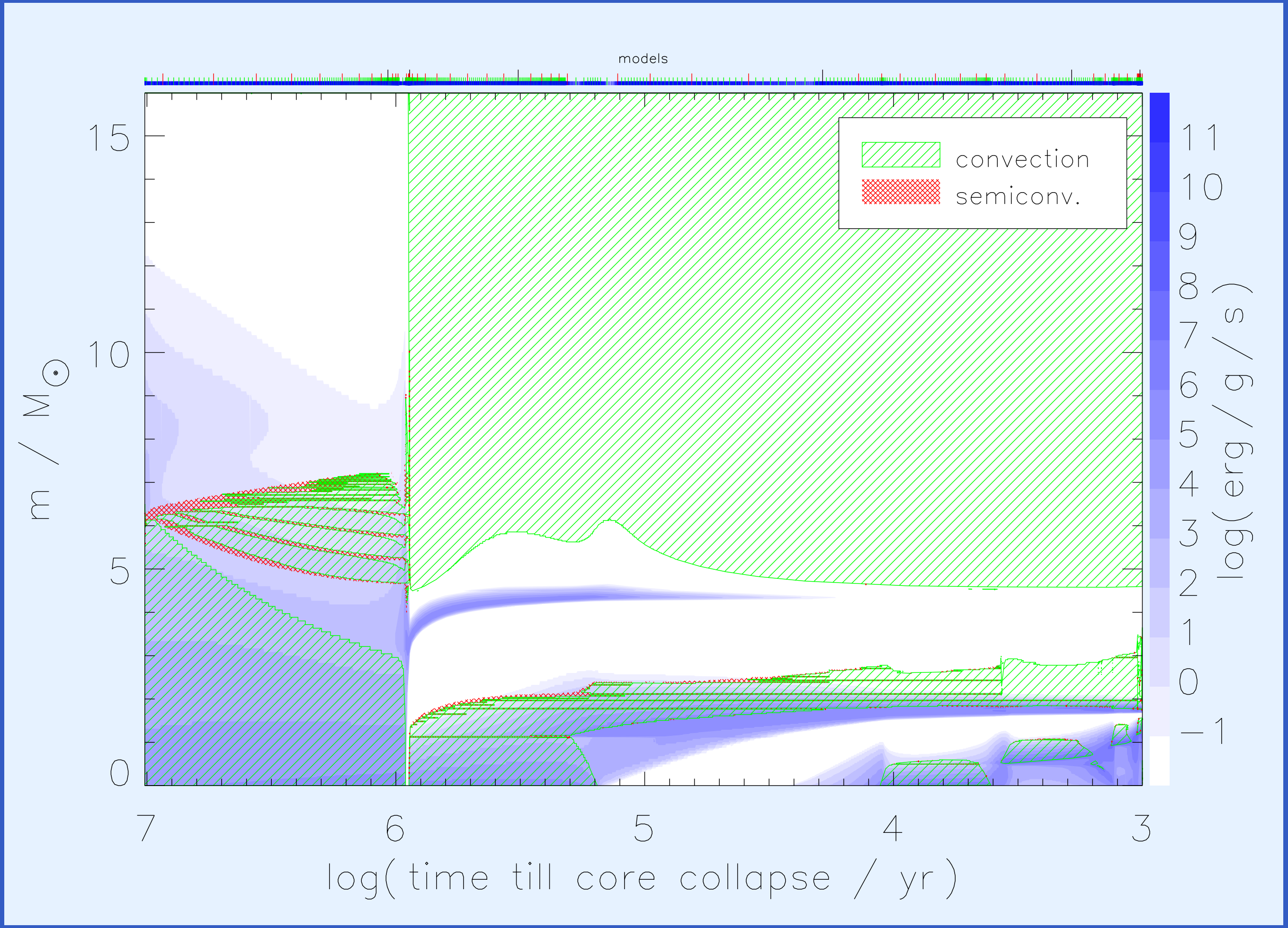
- WD/SN transition "difficult": 8...12 $\mathrm{M}_\odot$? (50% of all SNe?)
- super-AGB stars:
  core carbon burning + th. pulses (= electron-deg. core)
  two possible outcomes:
  1. ONe WD ($\dot{M}$ high, 3rd dredge-up efficient)
  2. ECSN ($\dot{M}$ low, 3rd dredge-up inefficient)
- necessary: 2nd dredge-up down to M_{Ch}
- difficult to make complete models, parameters studies:
  $10^3..10^4$ thermal pulses
  $\rightarrow$ synthetic TP-SAGB models

2nd dredge-up



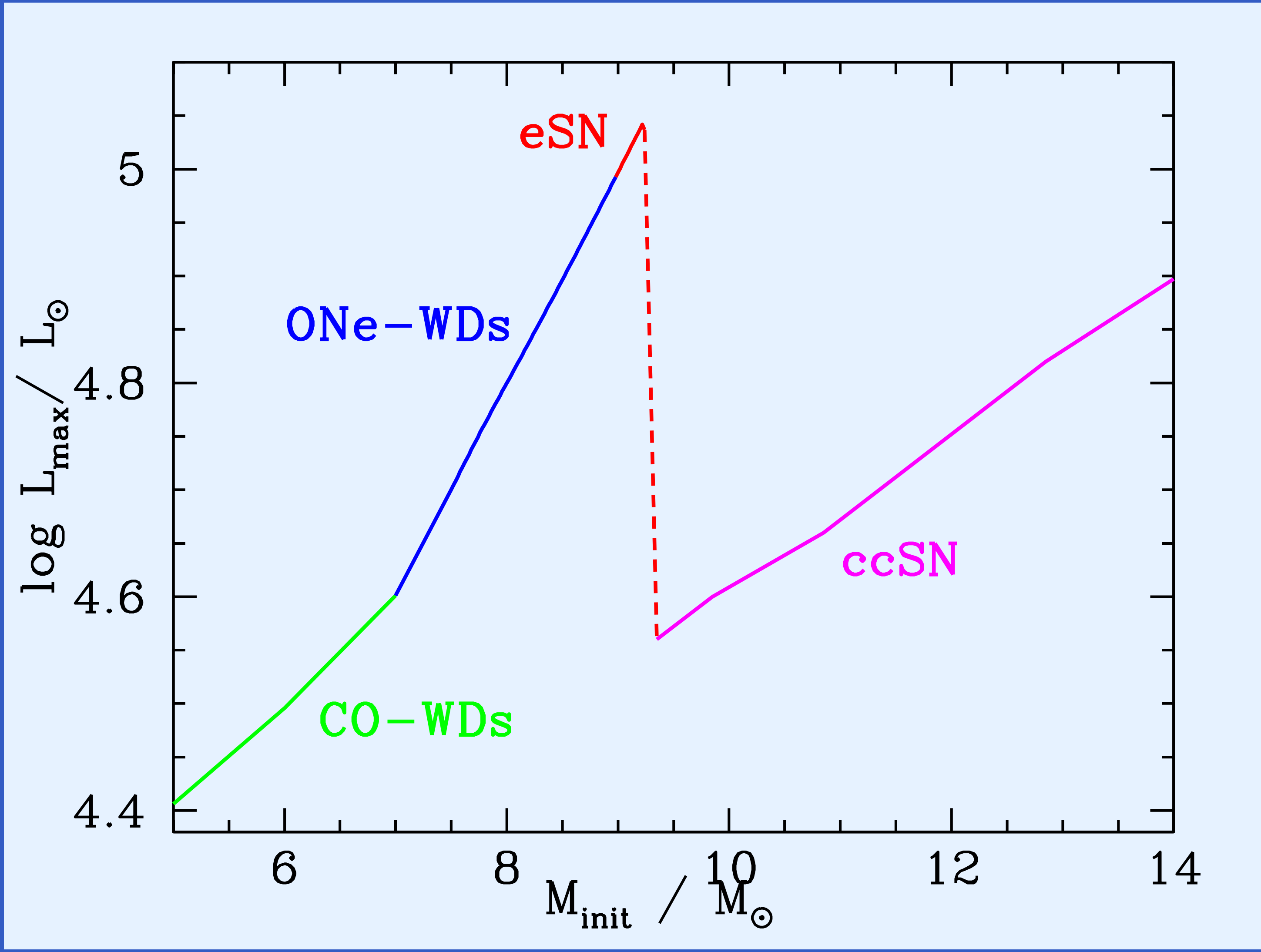
Poelarends et al. 2006

No 2nd dredge-up



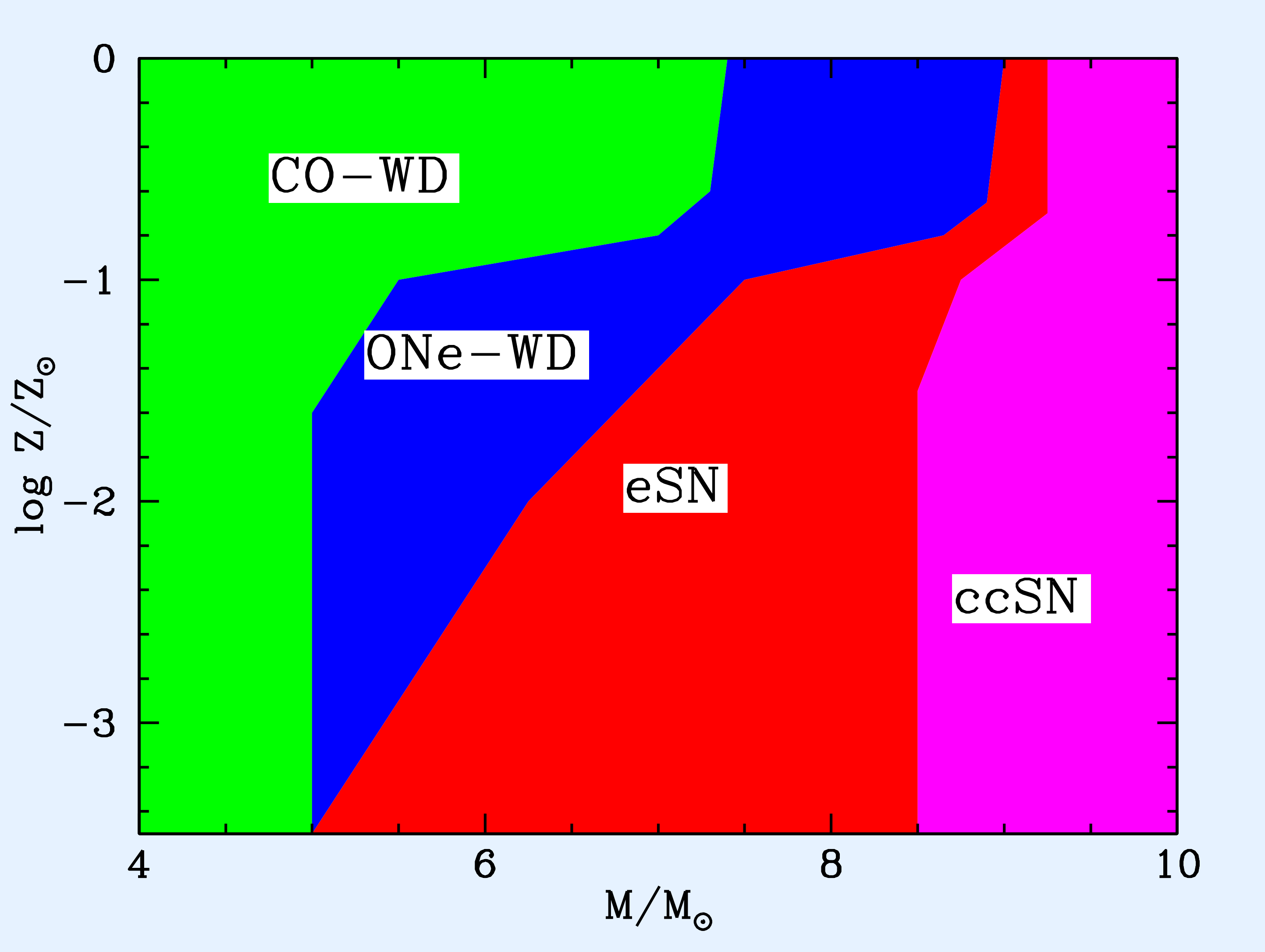
Poelarends et al. 2006

Pre-WD, Pre-SN luminosities



Poelarends et al. 2006

WD-SN transition regime as $f(Z)$



Poelarends et al. 2006

Conclusions

- ecSN: may be most frequent type of SN
  $\rightarrow$ s,r-process?
- long GRBs: rule rather than exception in BH formation
- PCSNe: could dominate metal production for $Z < Z_{\odot}/3$

at low Z:very different stellar explosions