Rare? types of massive star explosions

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with

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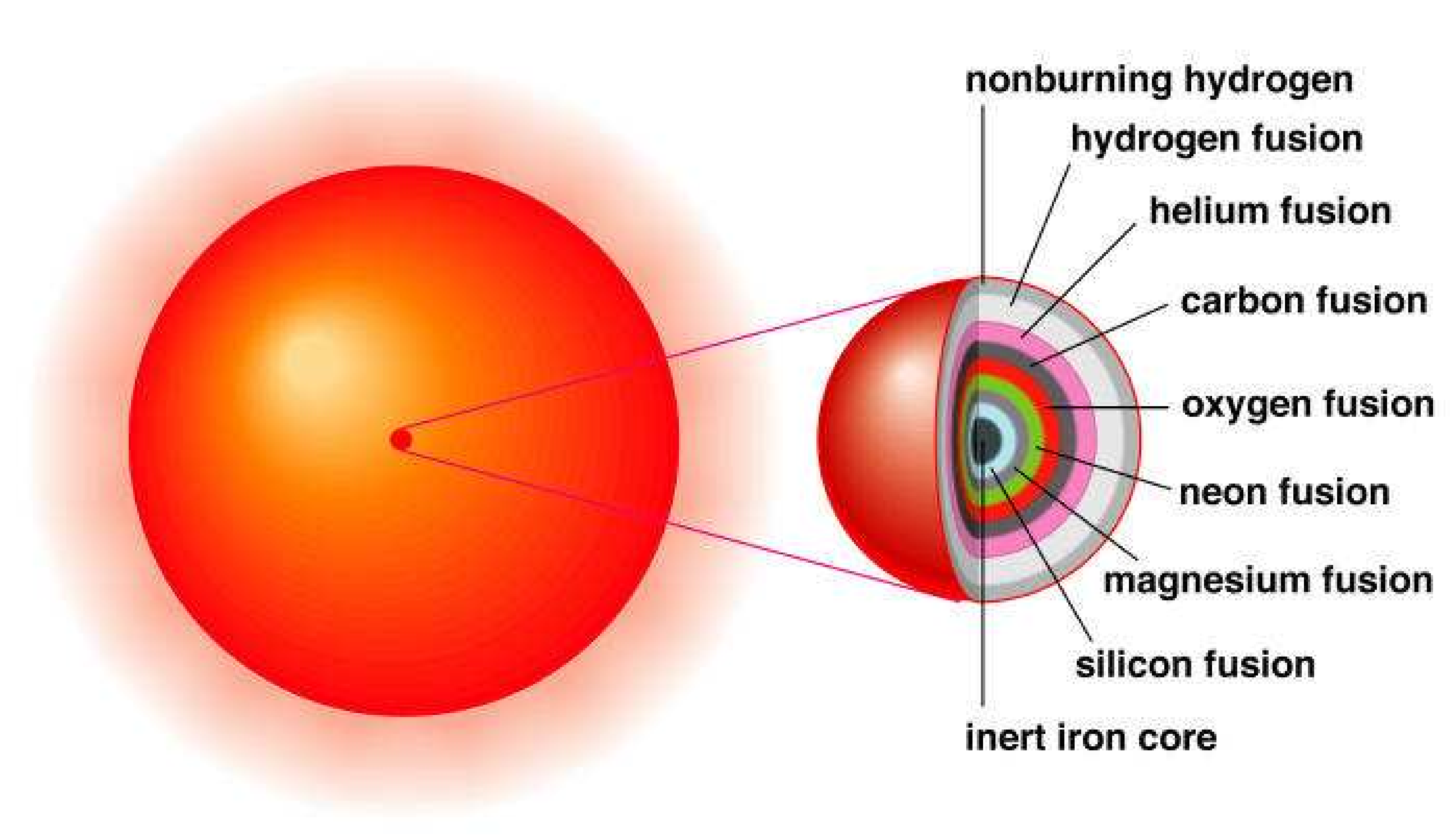
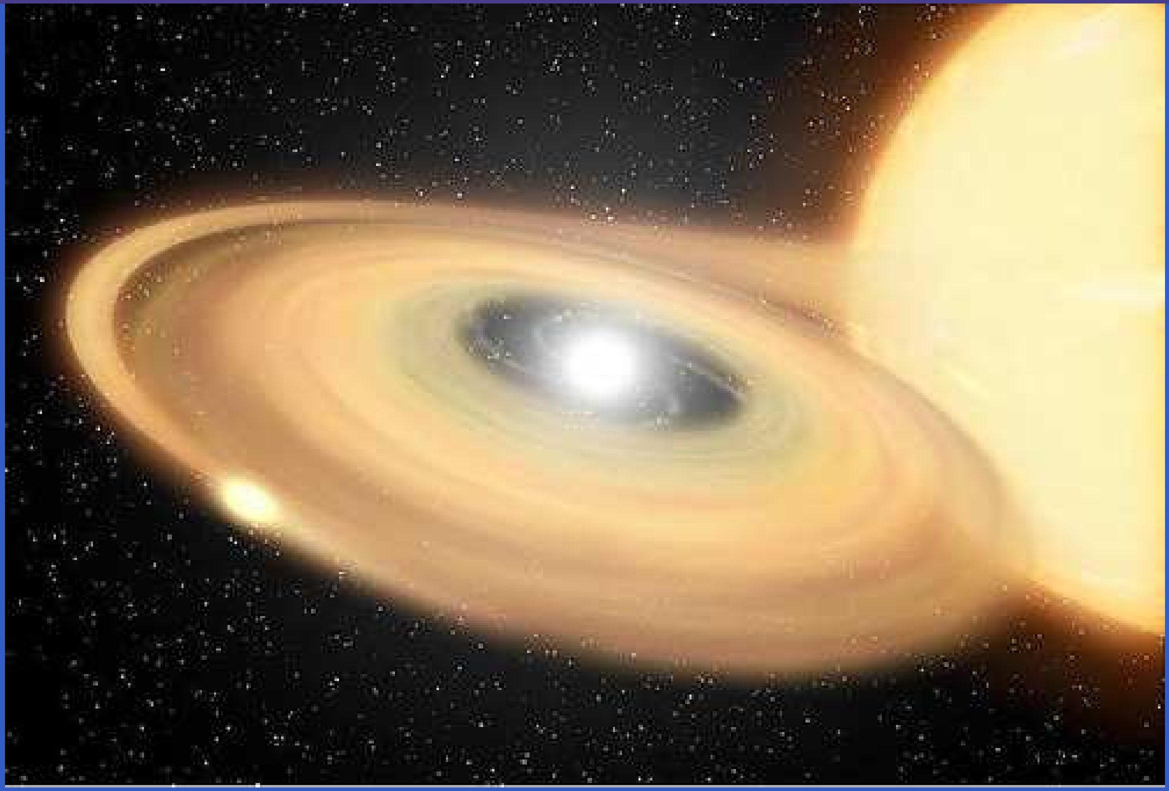
- Thomas Tauris (Bonn)
- Sung-Chul Yoon (Bonn)
- Alexander Heger (Minneapolis)
- Falk Herwig (Victoria)
- Selma de Mink (Baltimore)
- Colin Norman (Baltimore)
- Stan Woosley (Santa Cruz)

70% of supernovae: Fe-core collapse

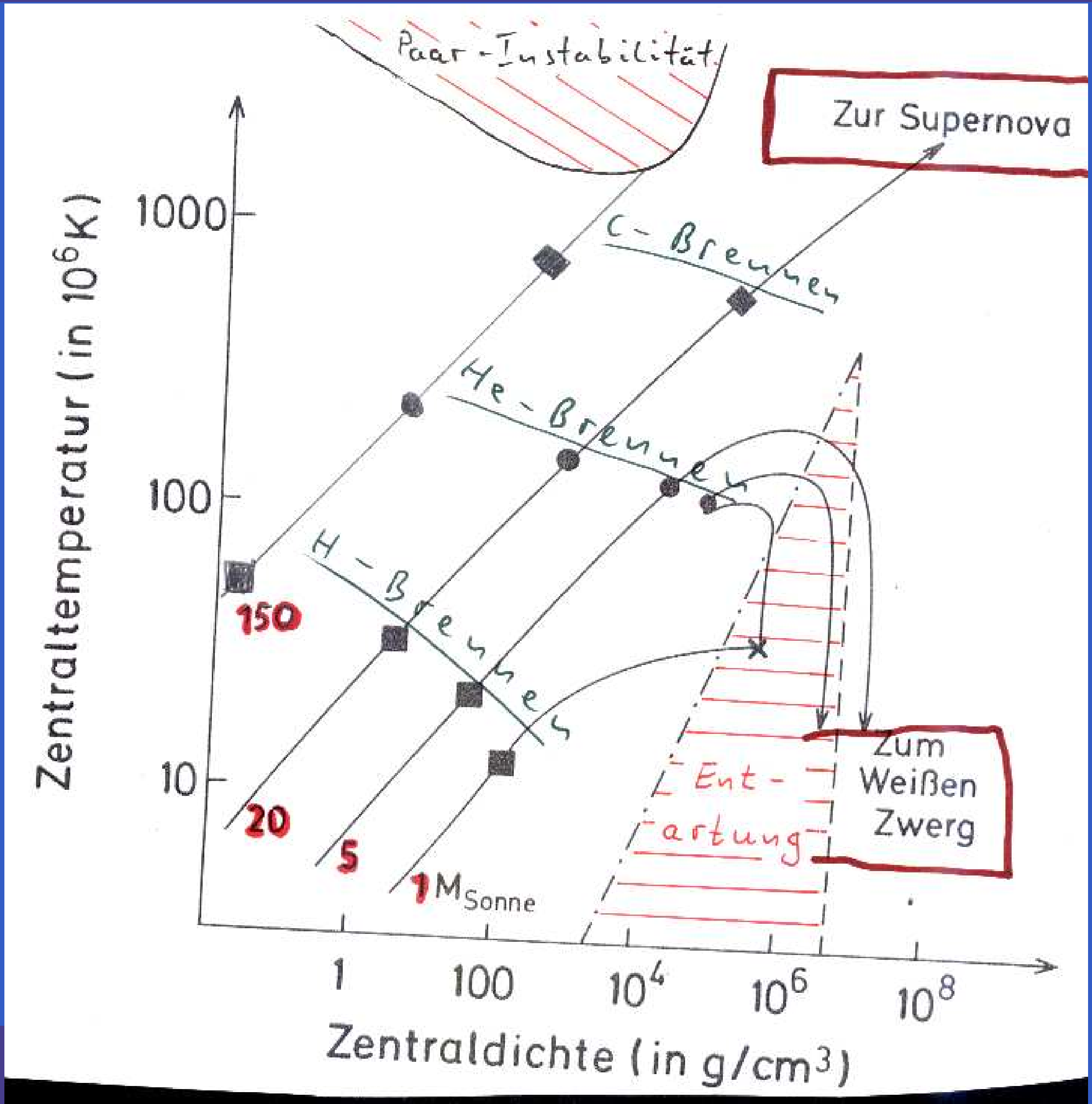


30% of supernovae: expl. WDs

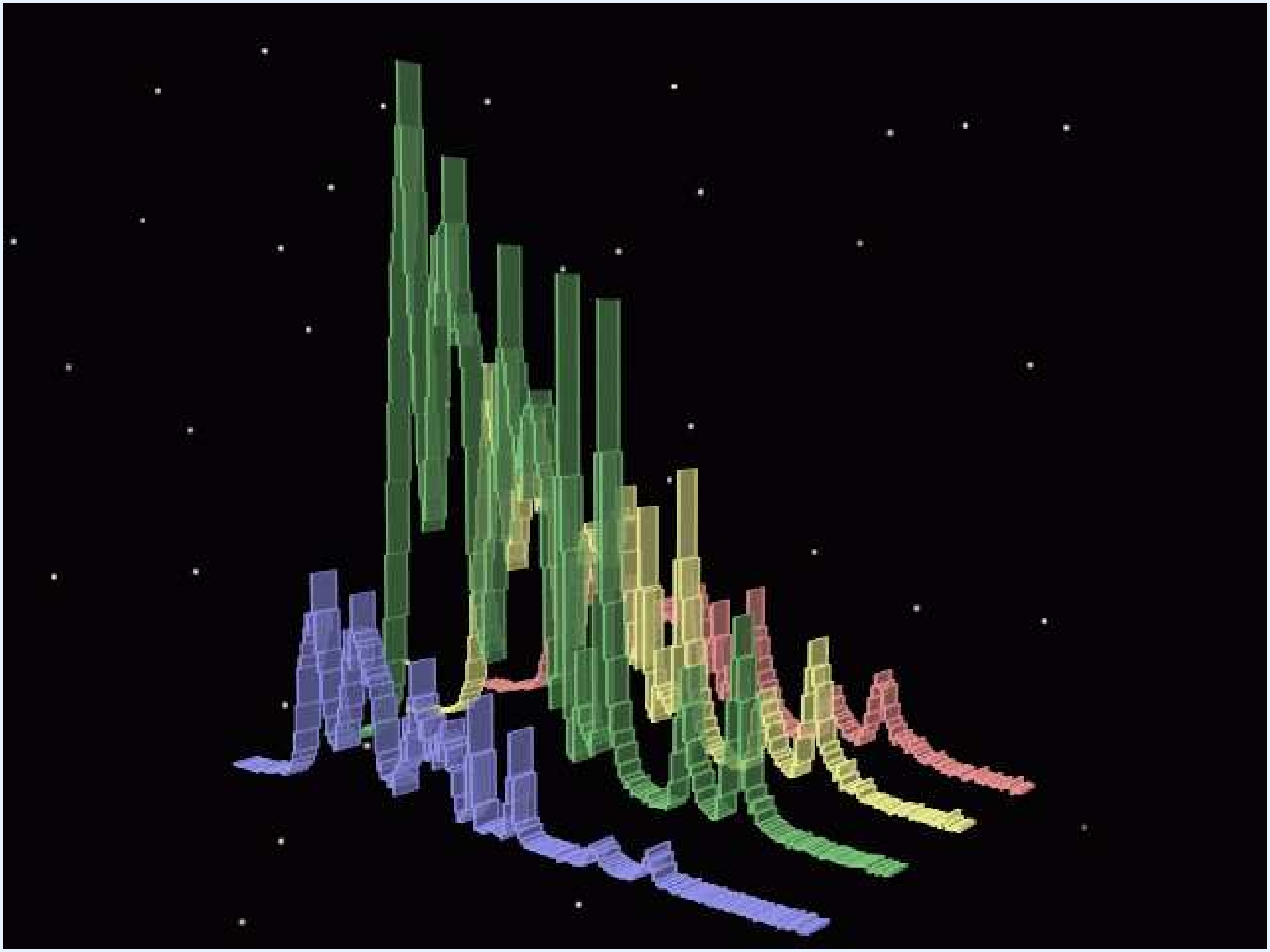


2011 Nobel Prize in Physics

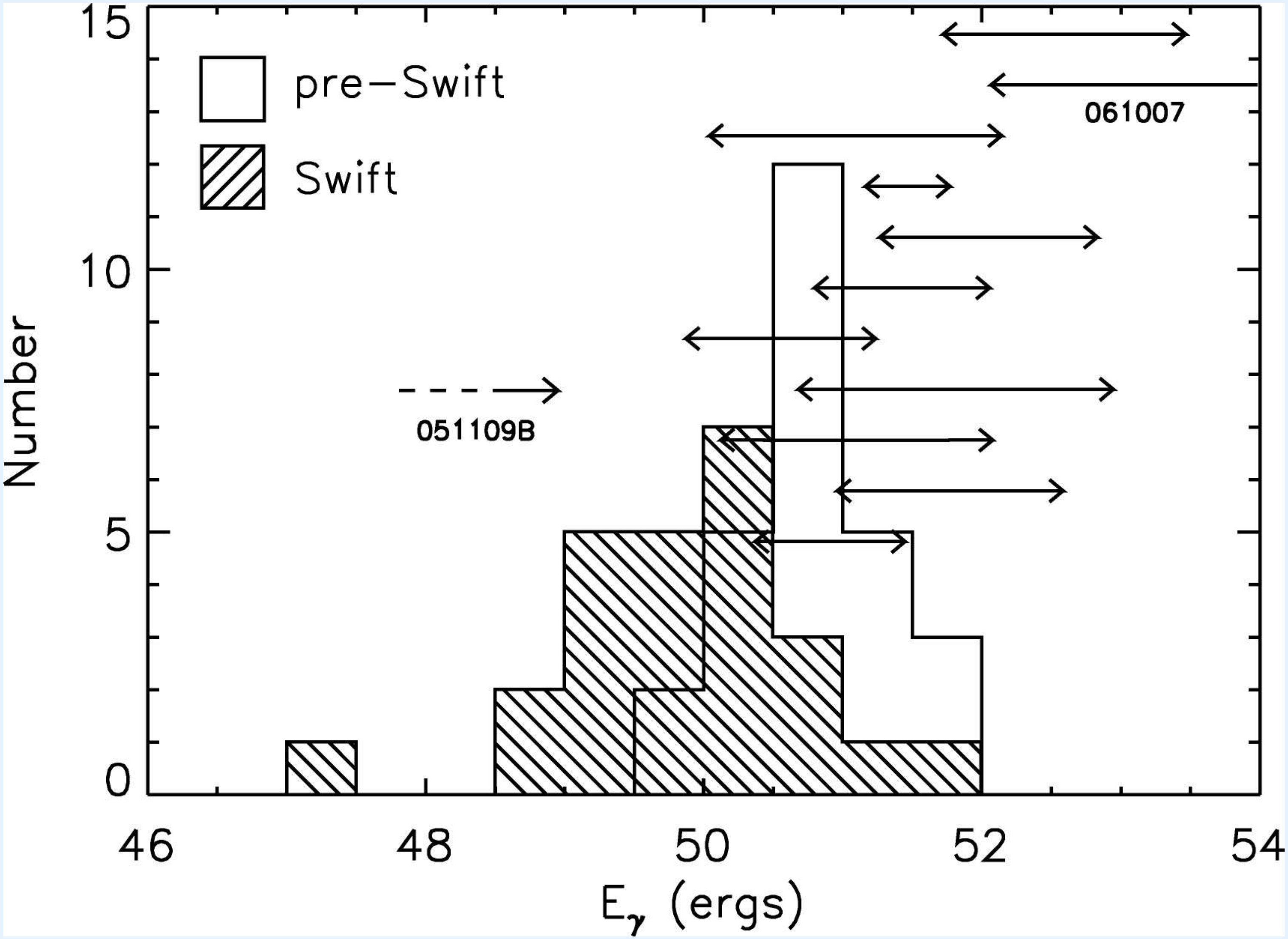
Why mass matters



“long” Gamma-ray Bursts

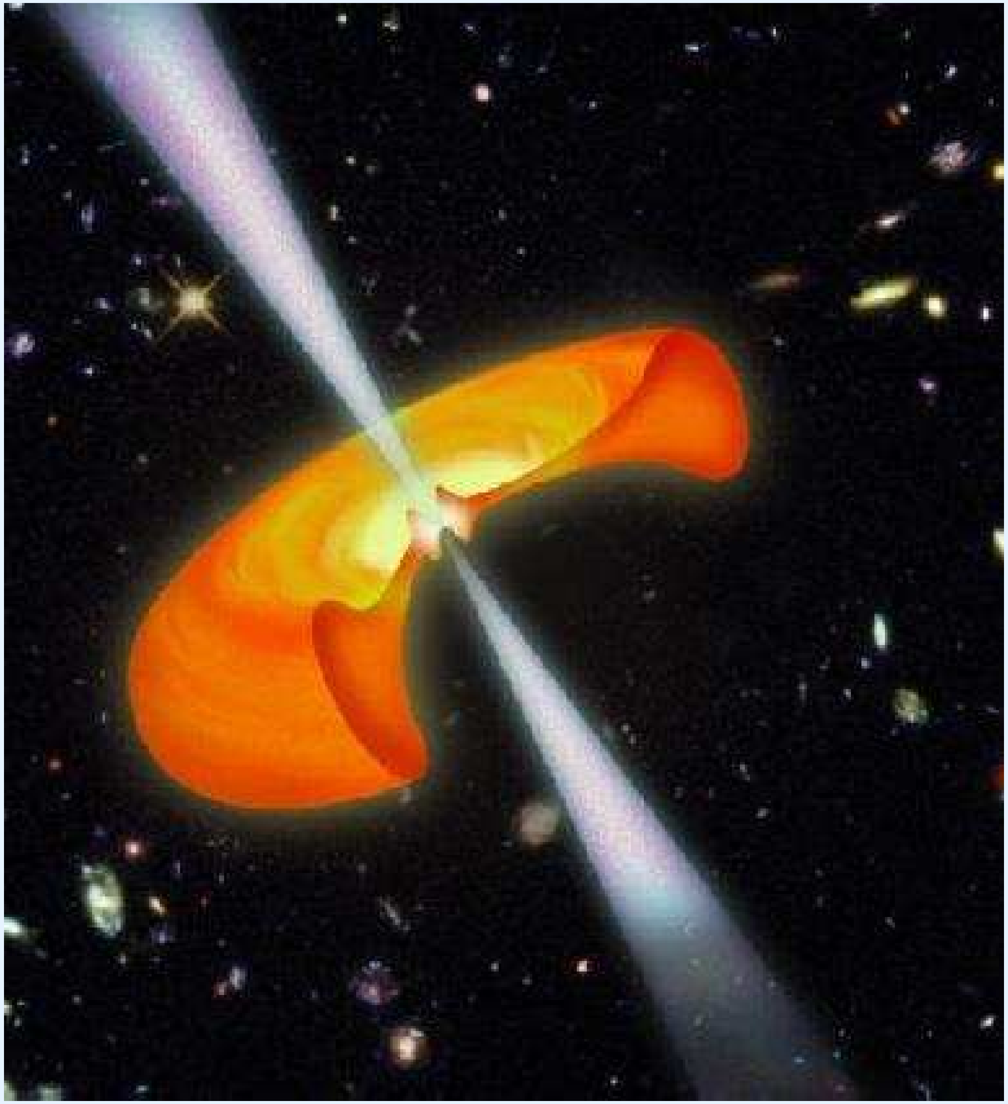


GRB energy & distance



Kocevski & Butler 2008

GRB model: Collapsars

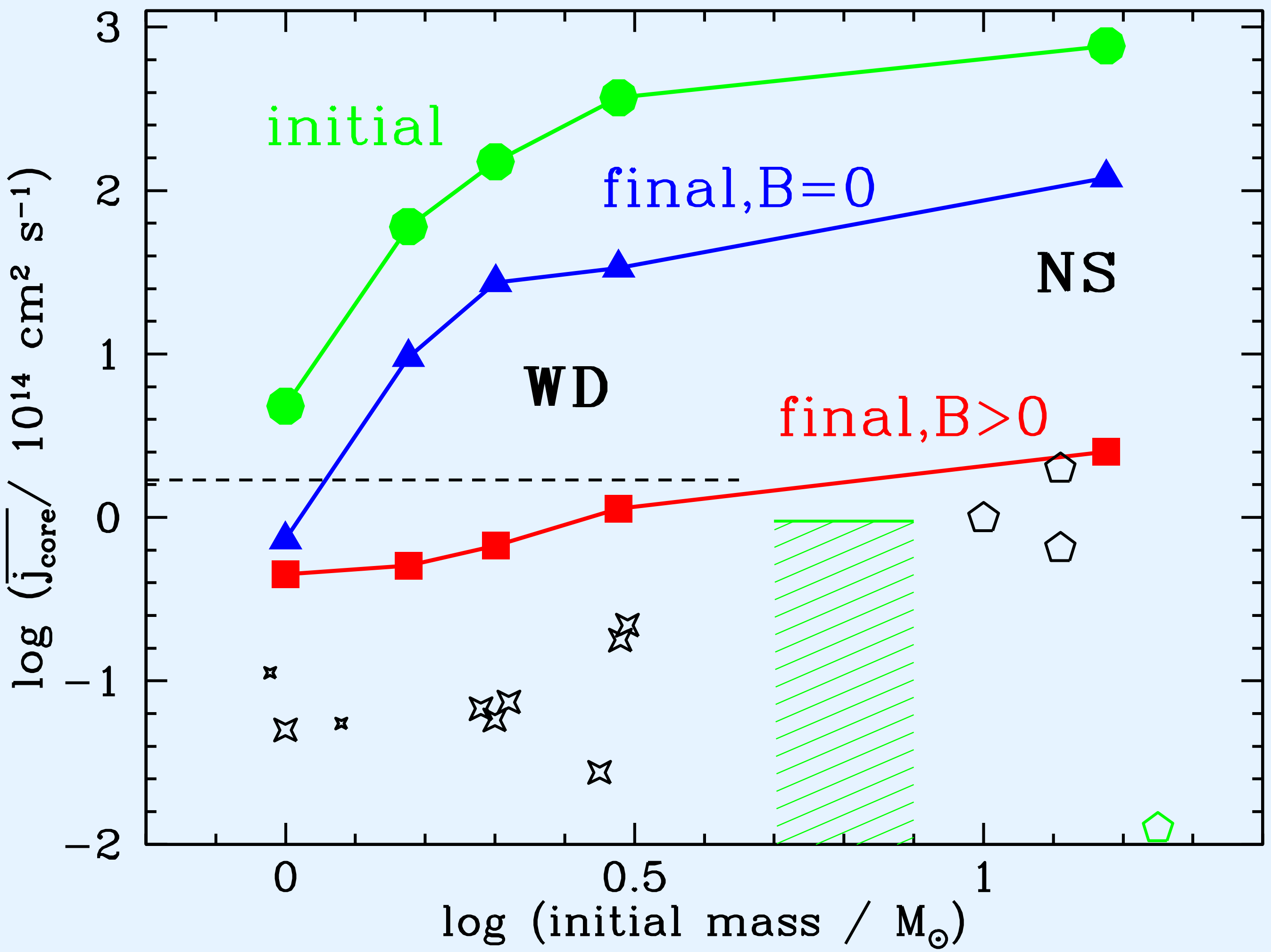


Collapsars

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

Woosley 1996

Galactic stars: slowly rotating cores

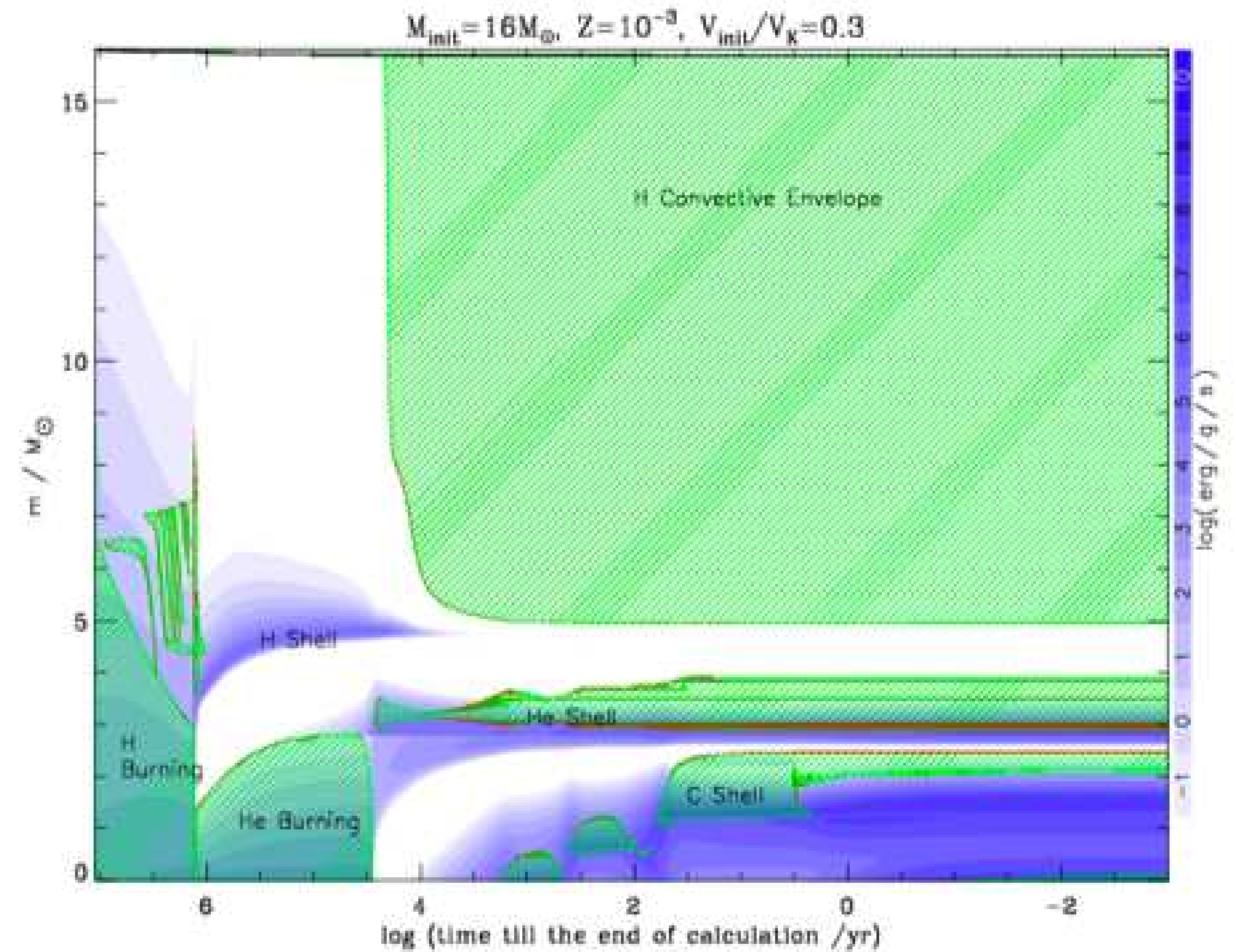


Suijs et al. 2008

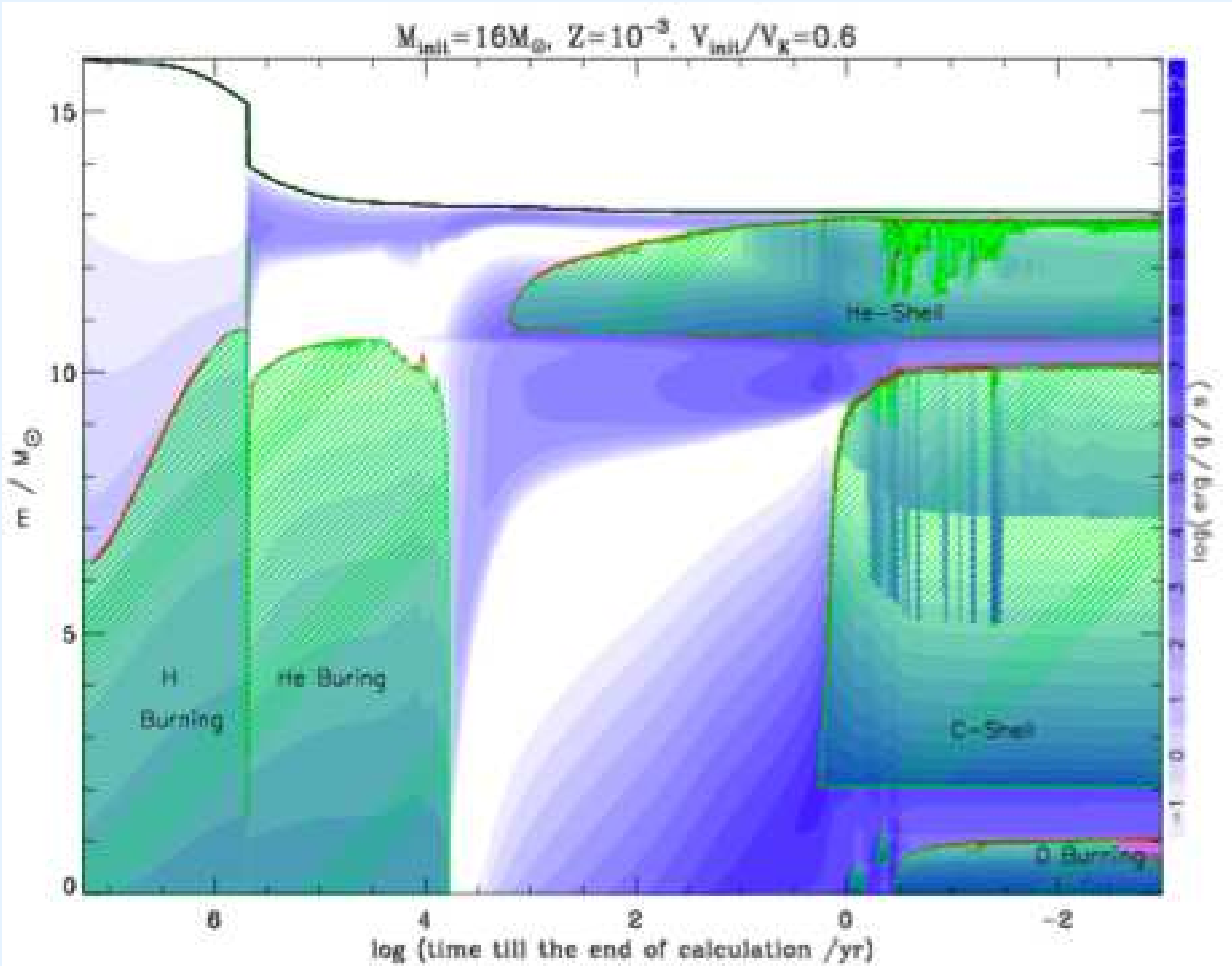
Need stars without envelope

- 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

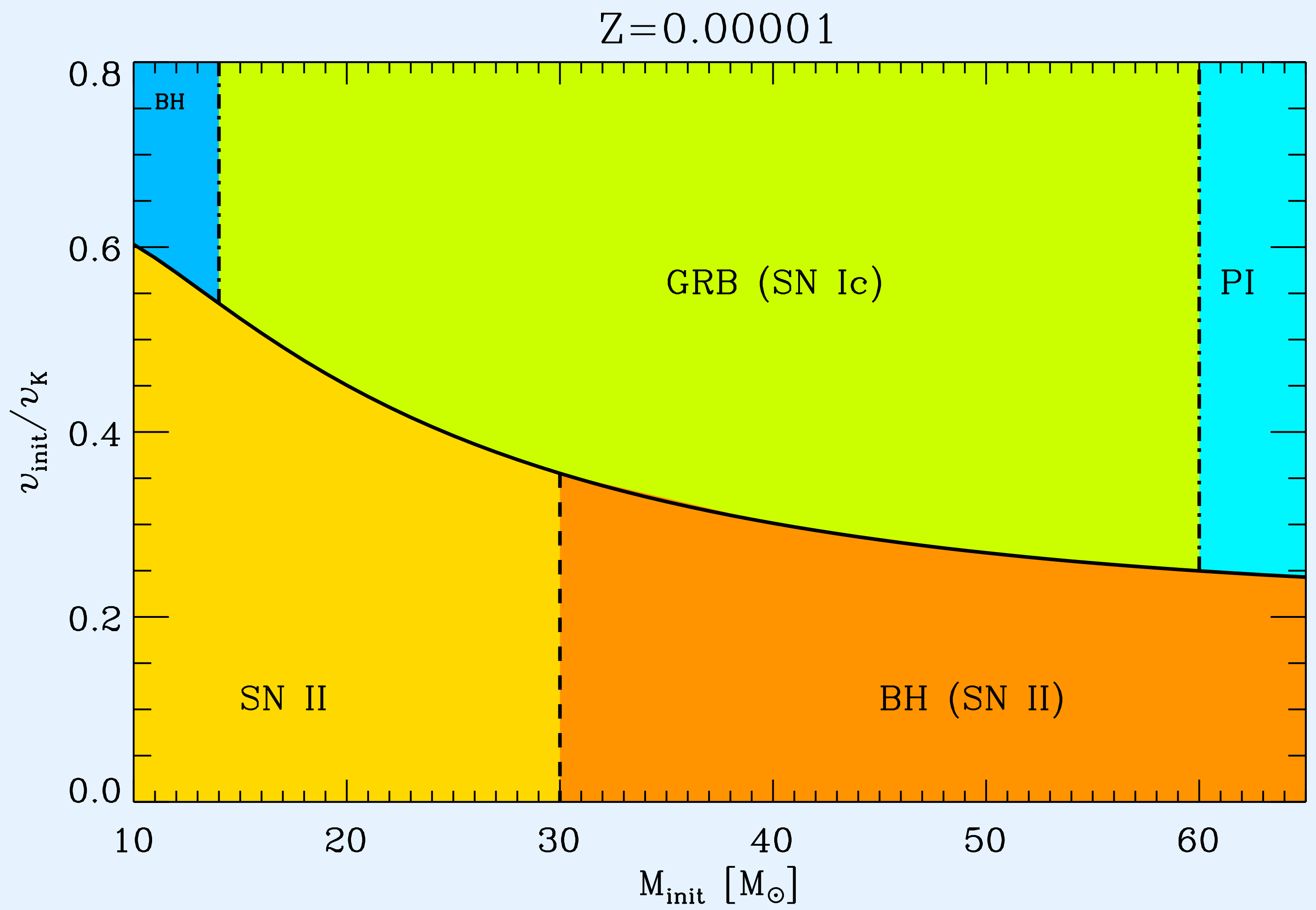
Slow rotator



Fast rotator: chem. homogeneous

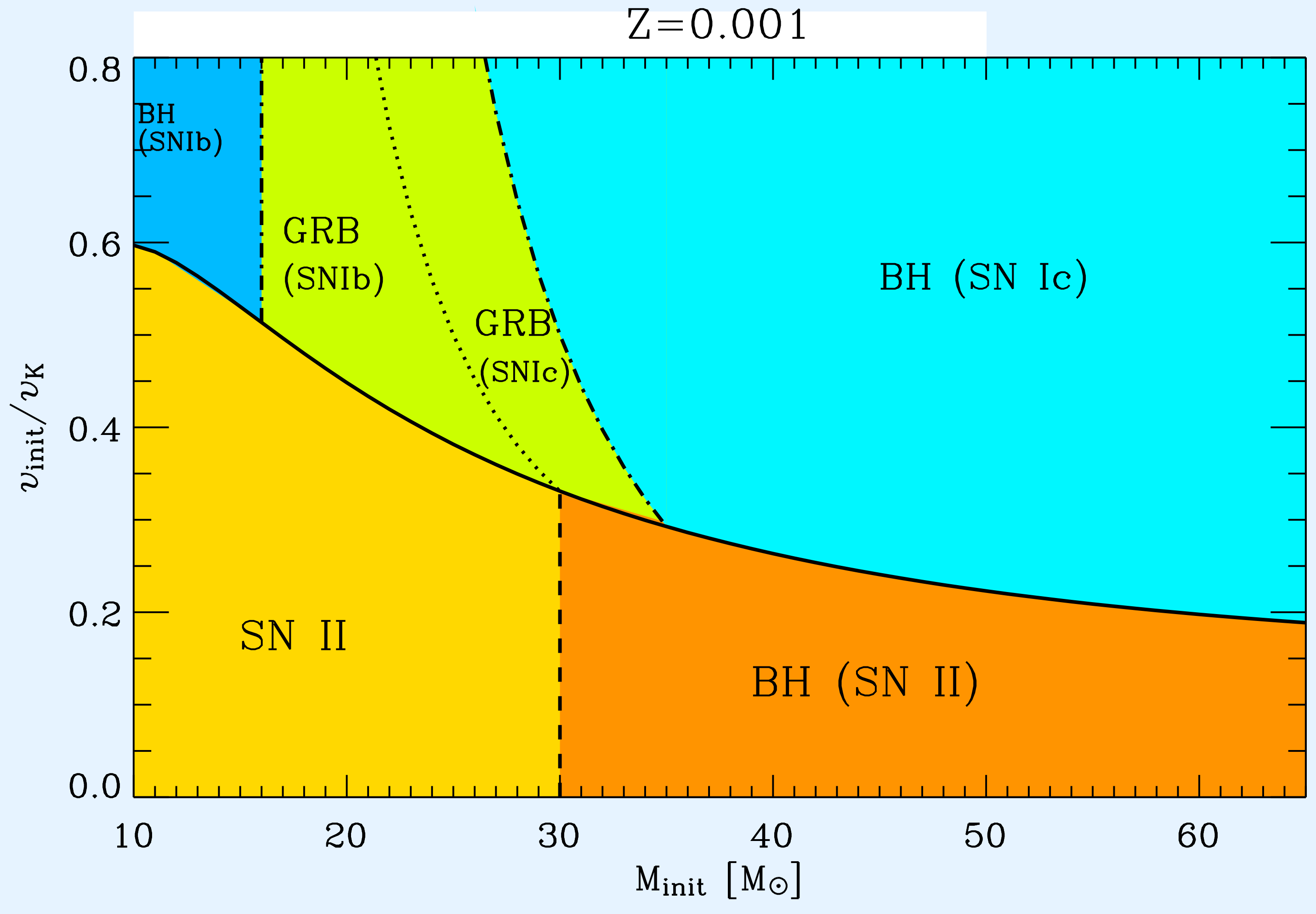


Models at Z=10^{-5}



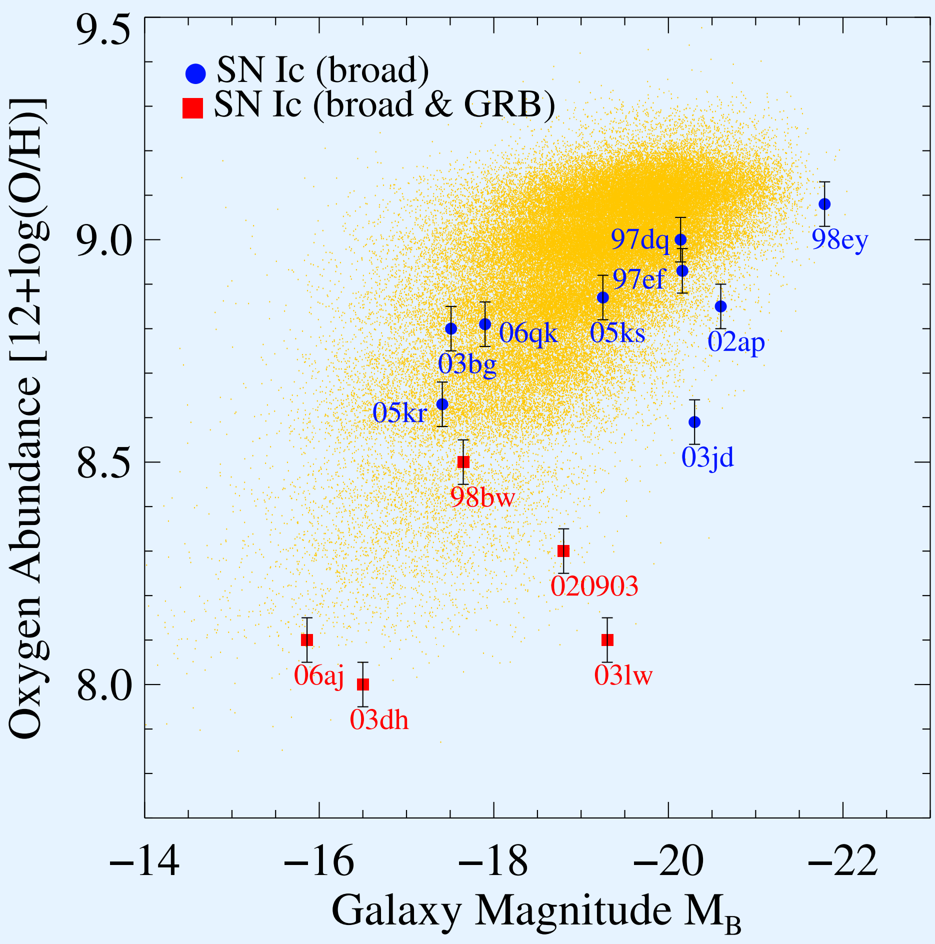
Yoon, Langer & Norman, 2006

Models at Z=10^{-3}



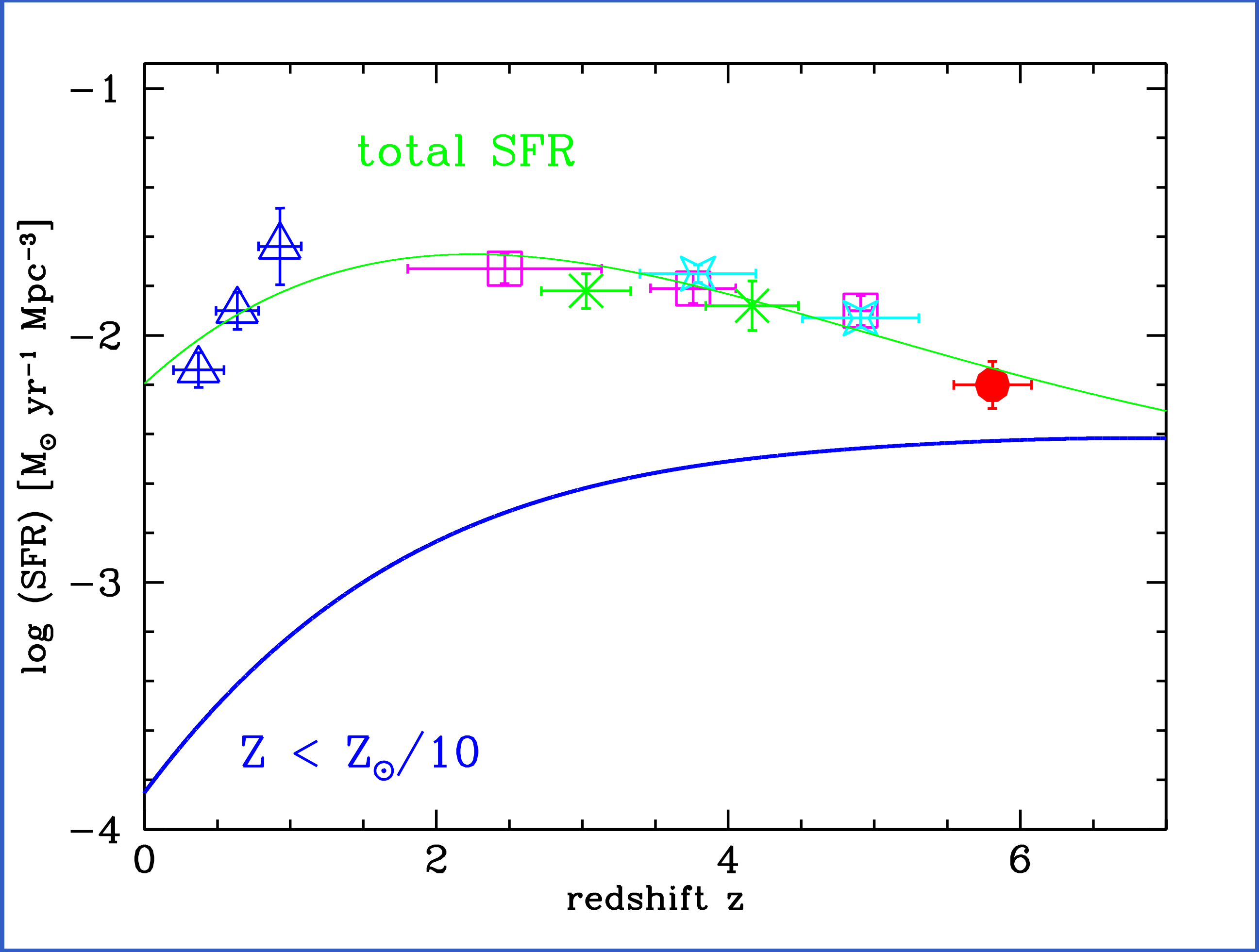
Yoon et al. 2006

GRB metallicity bias!



Modjaz et al. 2007

Metallicity bias



Langer & Norman 2006

GRB Metalicity bias

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

GRB Metalicity bias $\rightarrow$ frequent

locally: 1 GRB / 1000 SNe

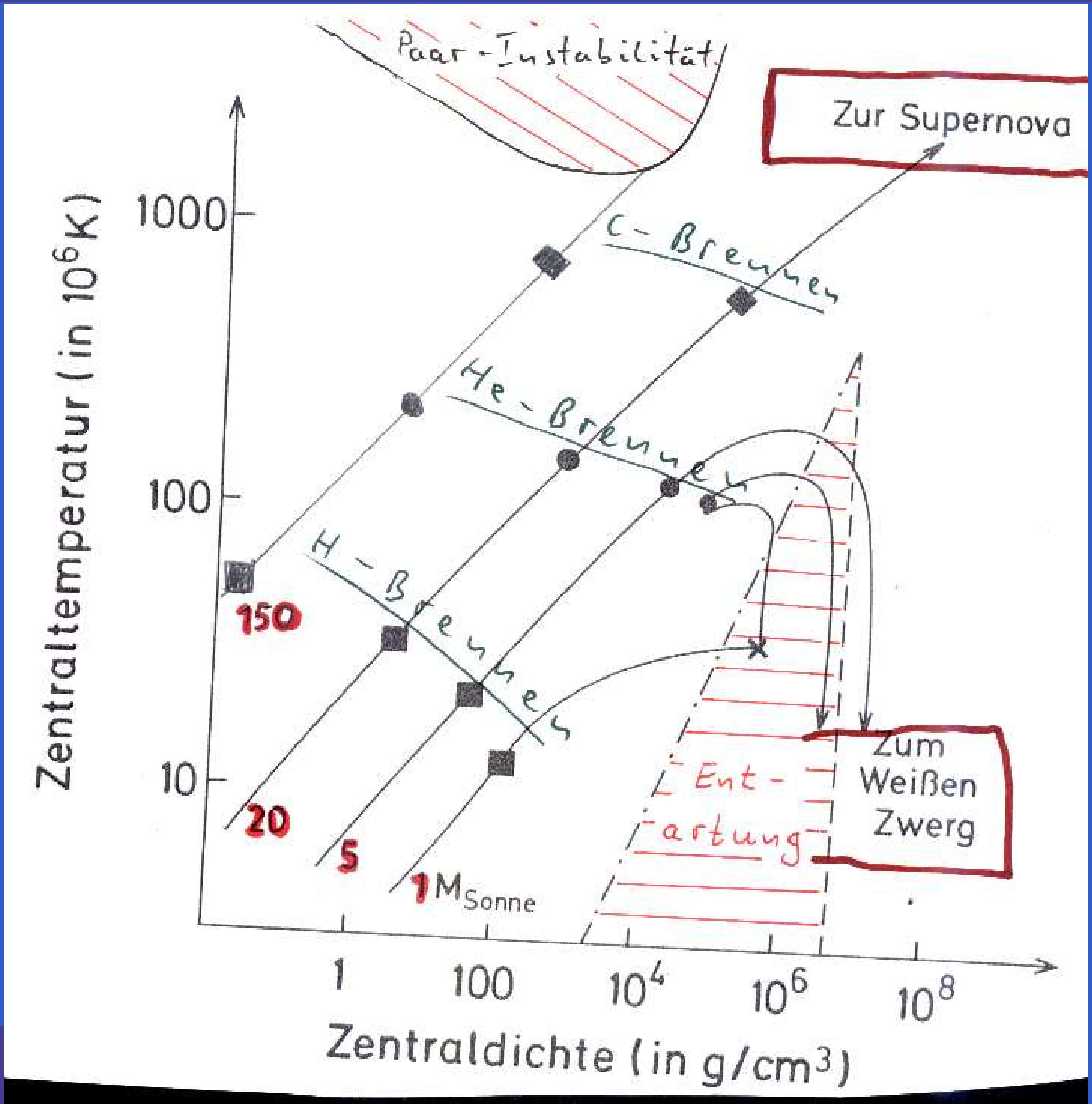
assume GRBs come from $Z < Z_\odot/10$

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

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

$\Rightarrow$ EVERY BH makes a GRB!

Pair instability supernovae



Do PISN occur only in Pop III?

$\Rightarrow$ needs very massive star

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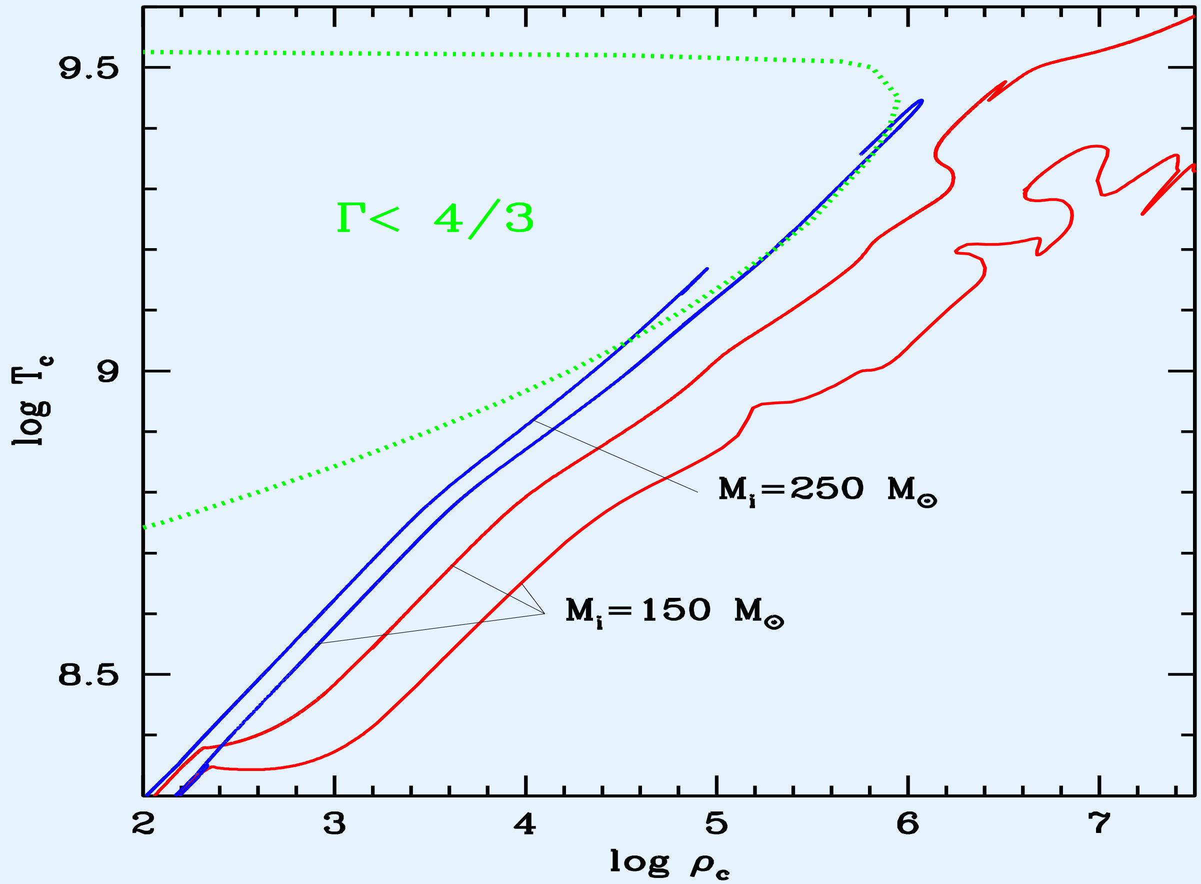
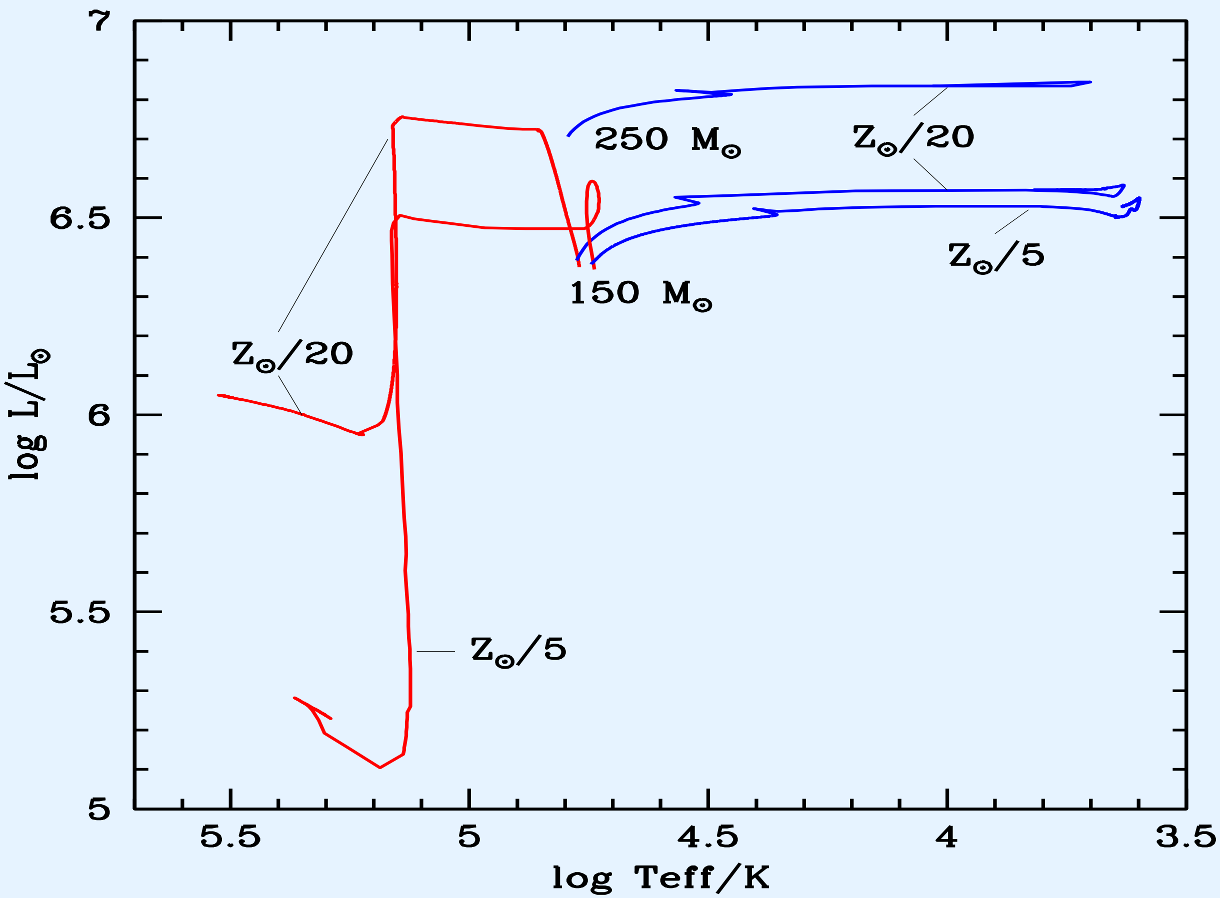
NO:

$T_c - \rho_c$-plane



Langer et al. 2007

Local PCSNe possible?



Langer et al. 2007

Local PISN rate

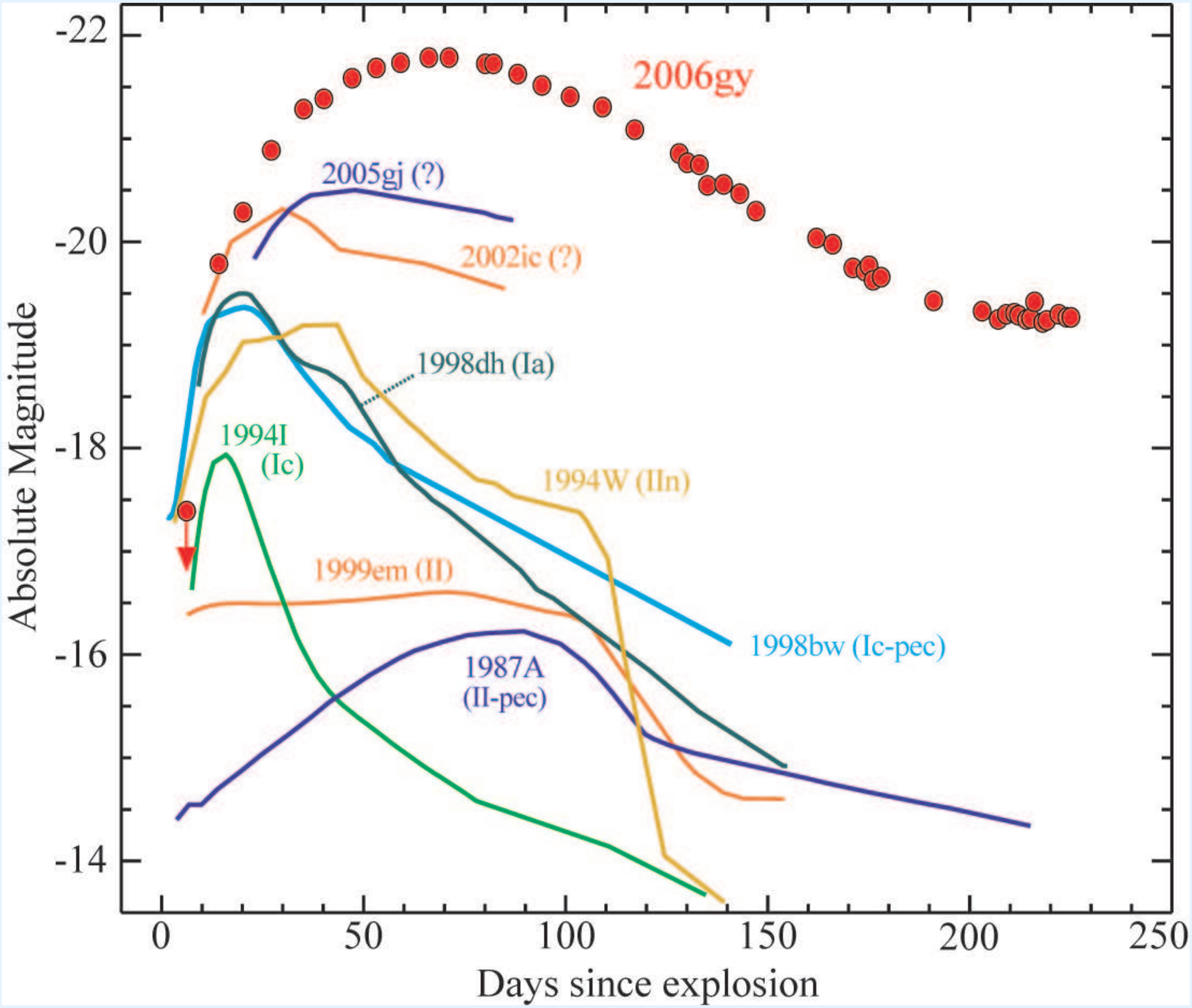
best mass loss rate (Vink & de Koter):
PISNe from $Z < Z_\odot/3$

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

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

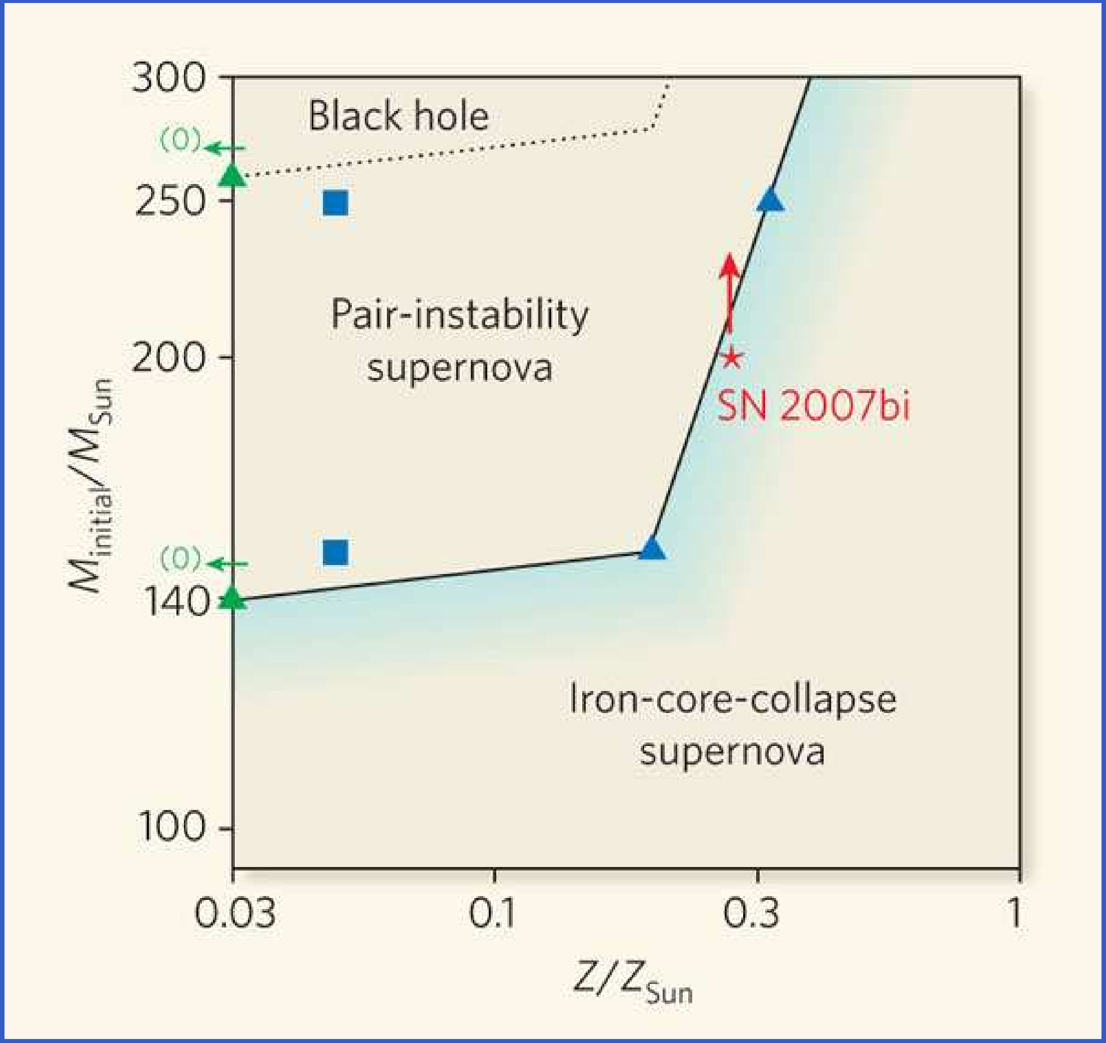
$\Rightarrow$ 1 PISN / 1000 SNe

Was SN 2006gy a PCSN?



Smith et al. 2007

$M - Z$-plane



Langer 2009

Are PISN bright?

$\Rightarrow$ needs very massive star

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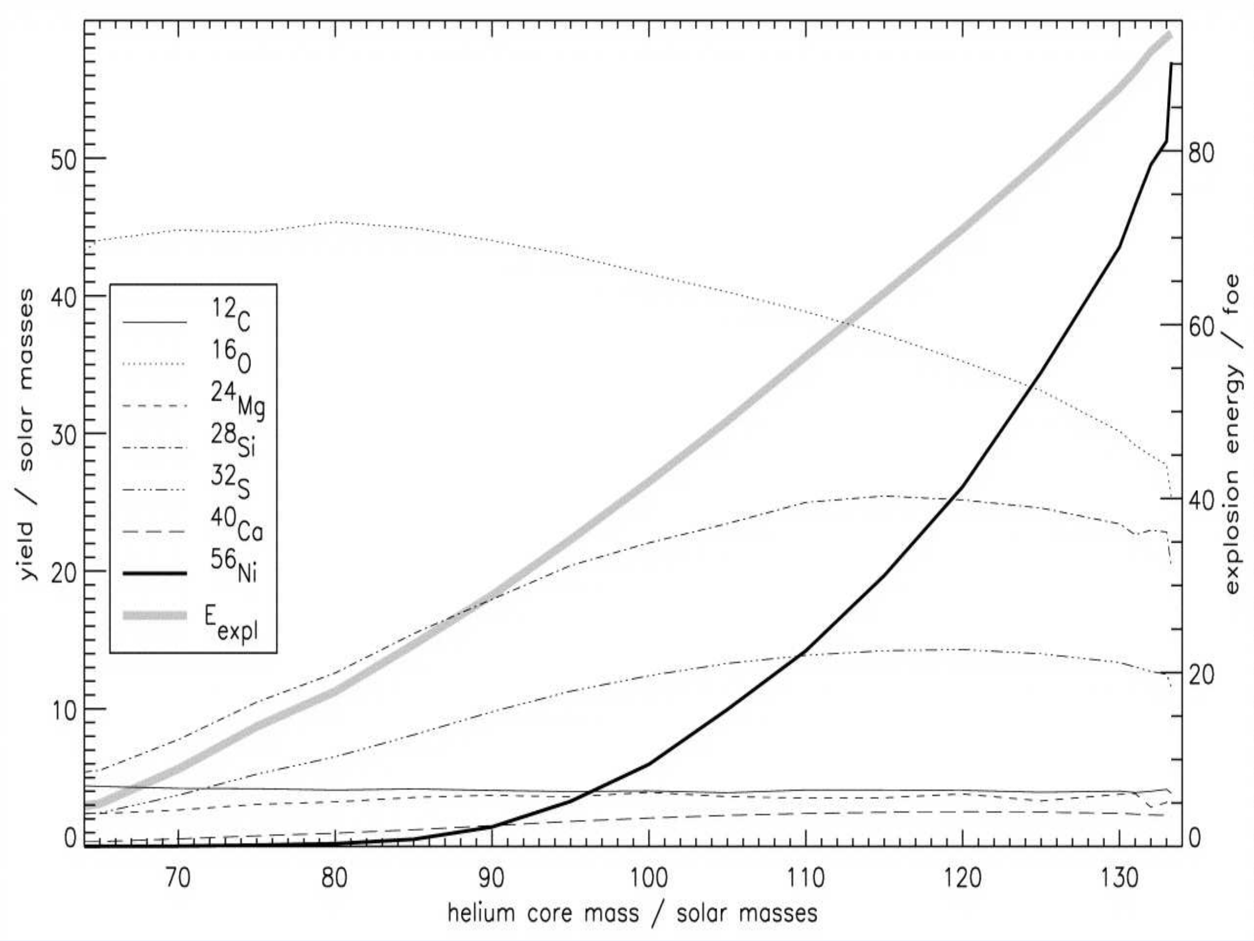
$\Rightarrow$ needs very massive star

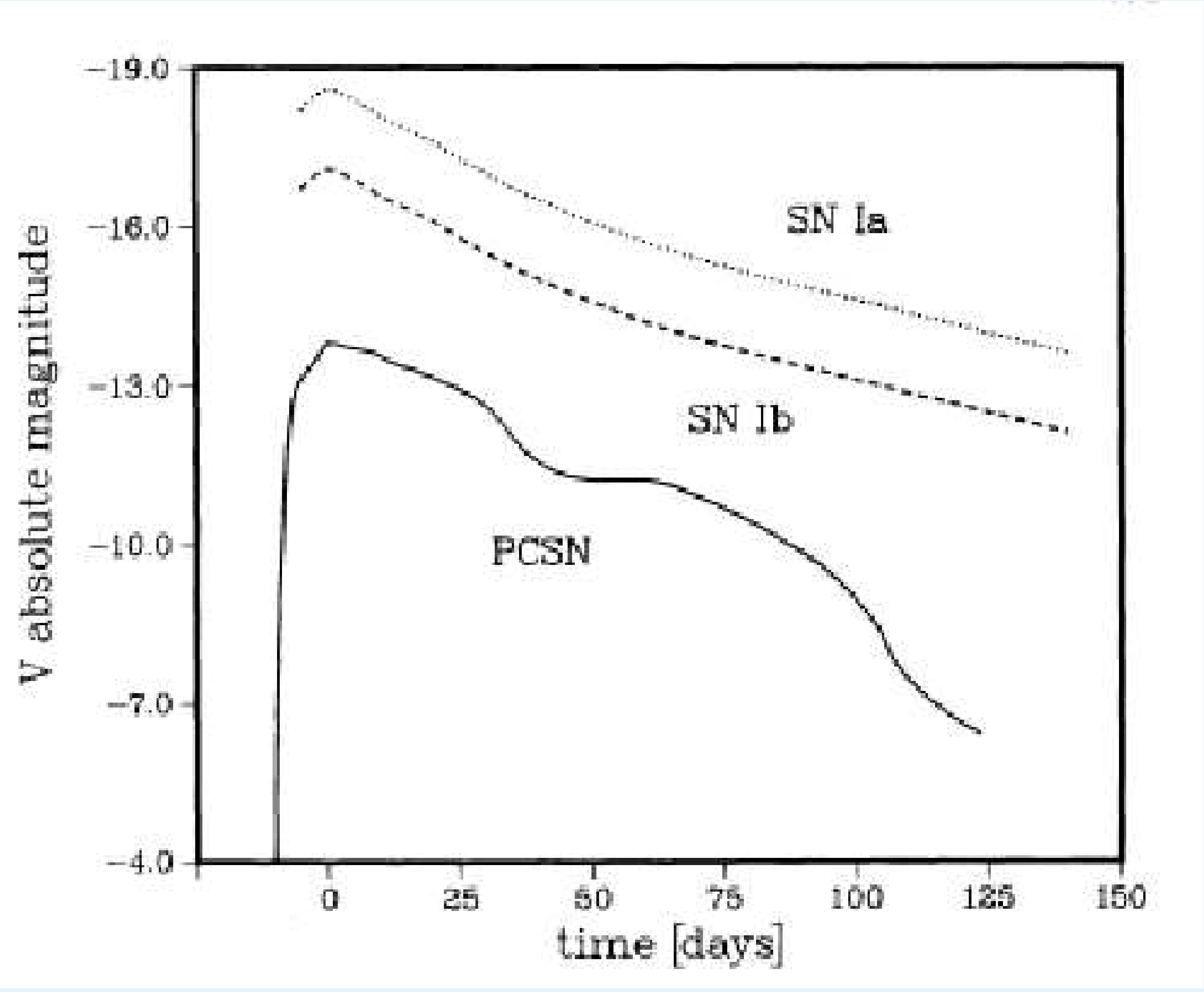
mostly NO:

Most PISN have little Ni



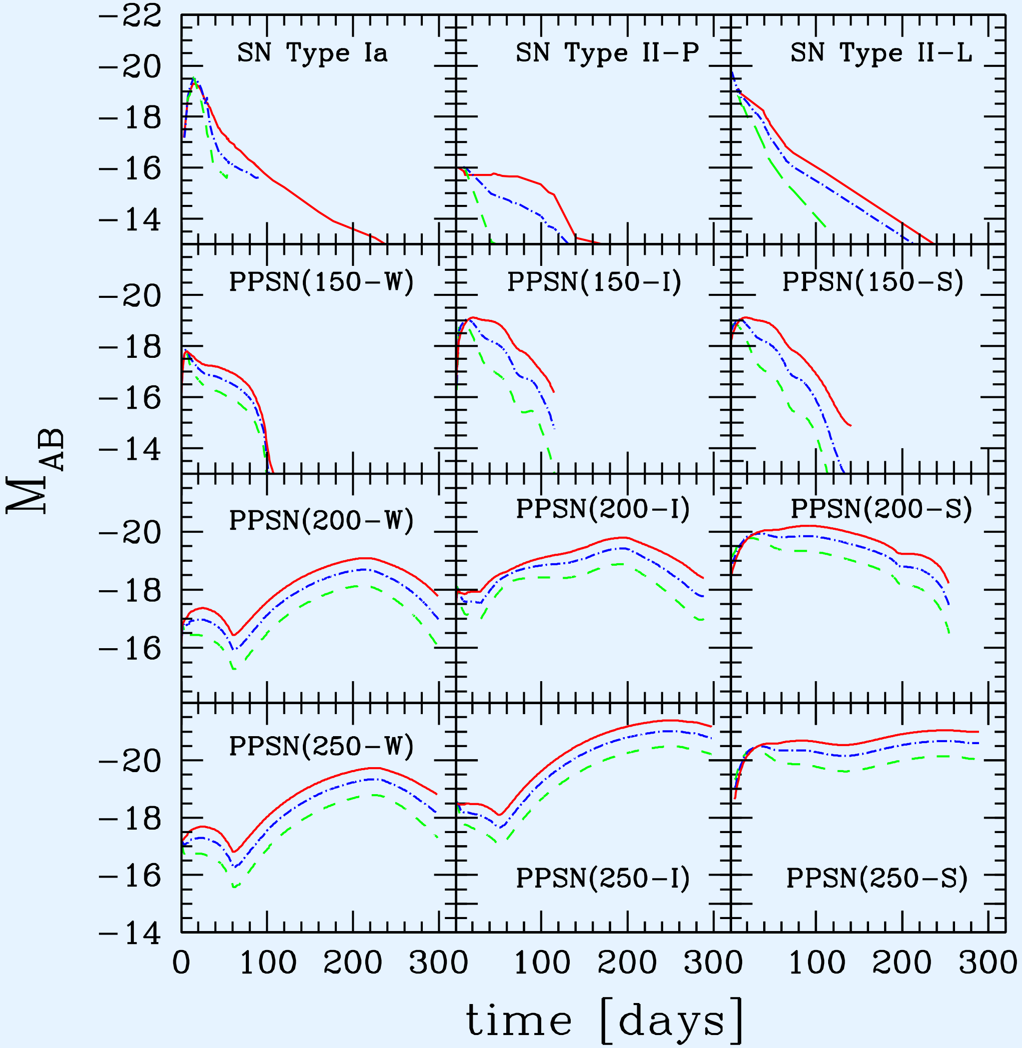
Heger & Woosley 2002

PISN light curves (H-poor)



Herzig et al. 1990

Pop III PCSN light curves



Scanapieco et al. 2007

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

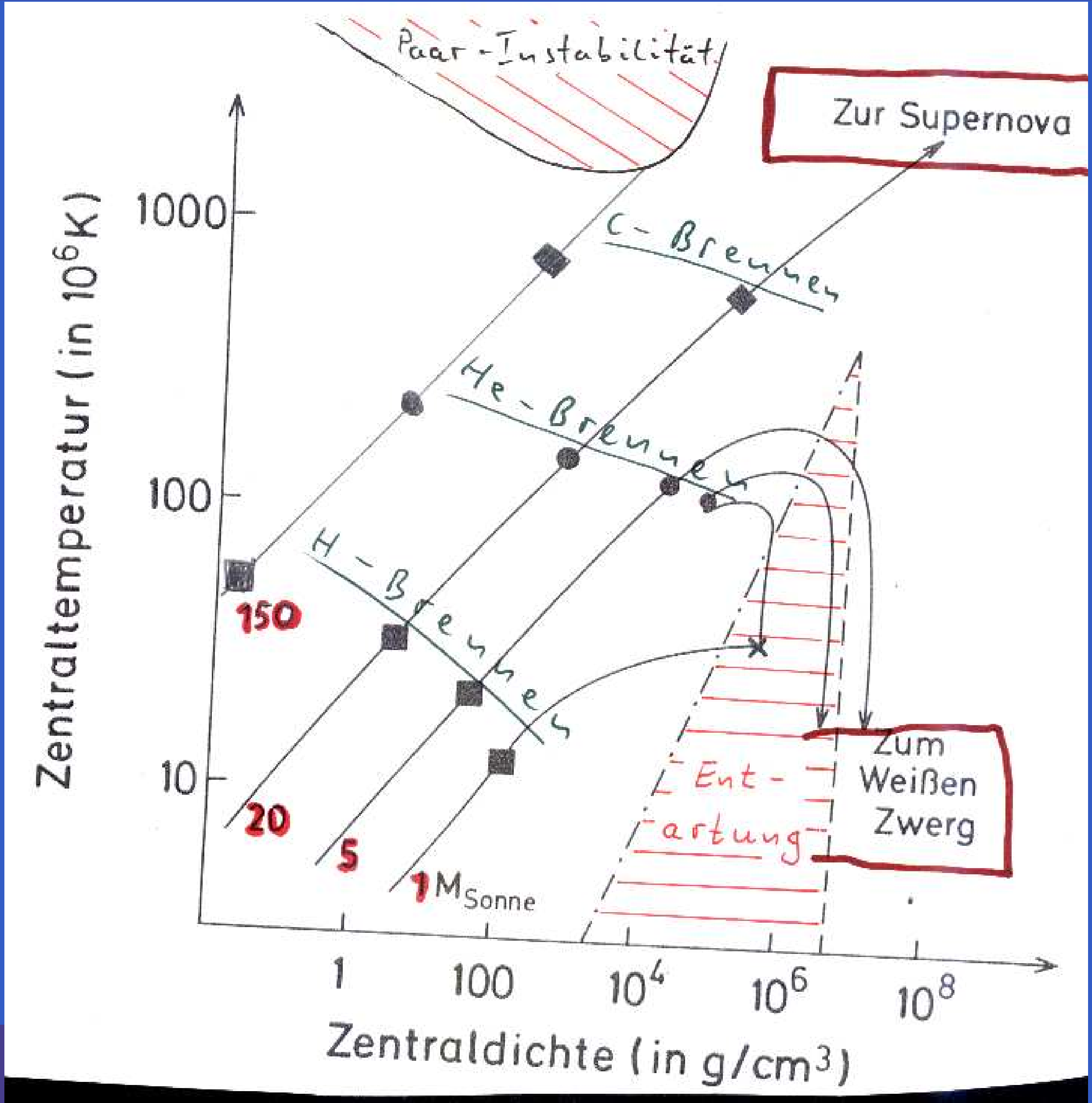
$\Rightarrow$ at $Z < Z_\odot/3$: 1 PCSN/100 SNe

$\Rightarrow$ PCSNe produce 50% of all metals

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

(Heger & Woosley 2002)

e-capture supernovae



e-capture supernovae

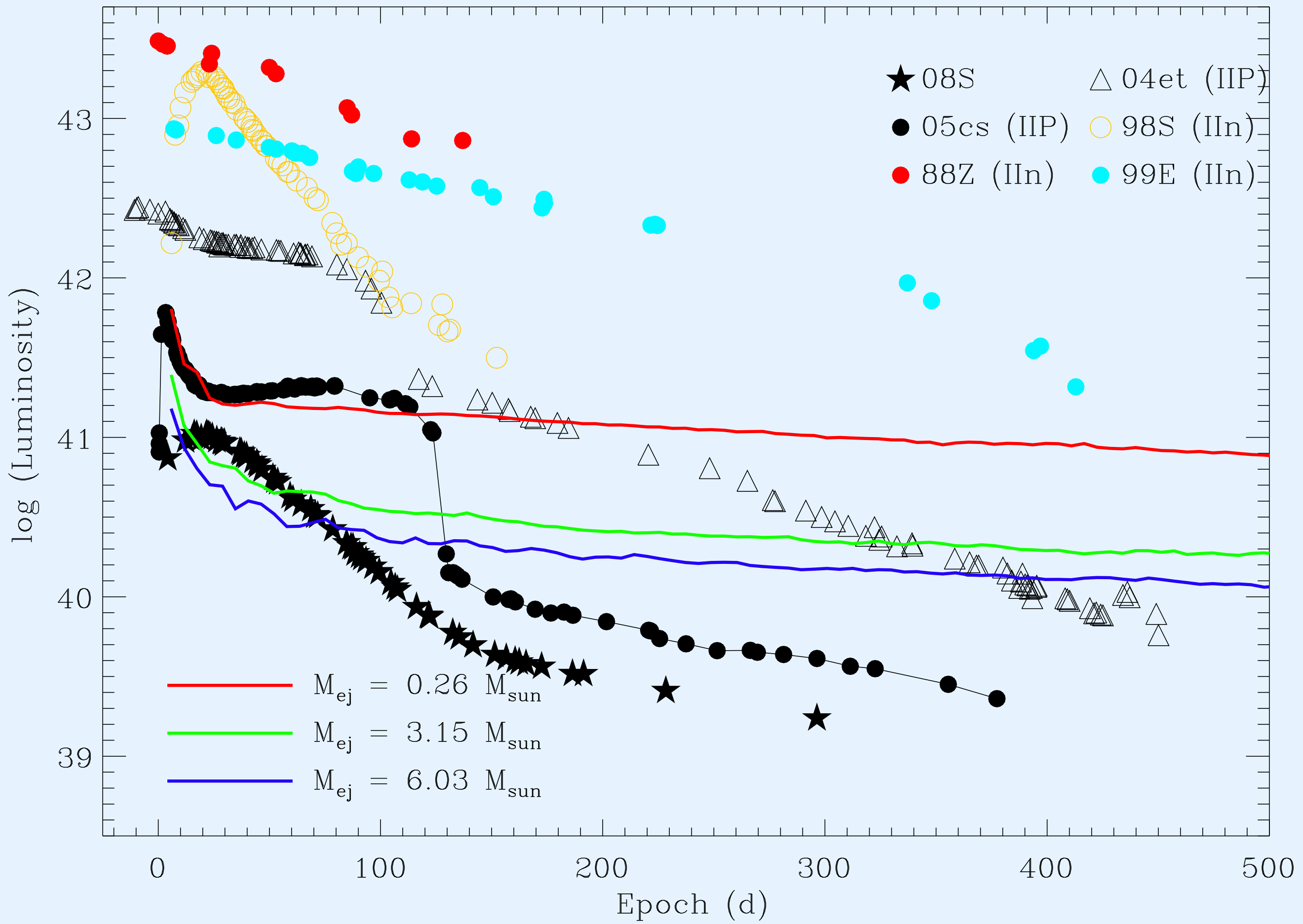
- WD/SN transition "difficult": 8...12 $\mathrm{M}_\odot$? (50% of all SNe?)
- super-AGB stars:
  core carbon burning + th. pulses (= electron-deg. core)
  two possible outcomes:
  1. ONe WD ($\dot{M}$ high, 3rd dredge-up efficient)
  2. ECSN ($\dot{M}$ low, 3rd dredge-up inefficient)
- necessary: 2nd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

ECSN mass range ($Z = Z_\odot$)

	$\lambda =$ parameterized			$\lambda = 0$		
	$M_{\rm low}/\,{\rm M}_\odot$	$M_{\rm high}/\,{\rm M}_\odot$	% EC	$M_{\rm low}/\,{\rm M}_\odot$	$M_{\rm high}/\,{\rm M}_\odot$	% EC
Reimers	8.67	9.25	8.4	7.86	9.25	19.7
VW93	9.03	9.25	3.2	8.82	9.25	6.2
van Loon	9.00	9.25	3.6	8.76	9.25	7.1

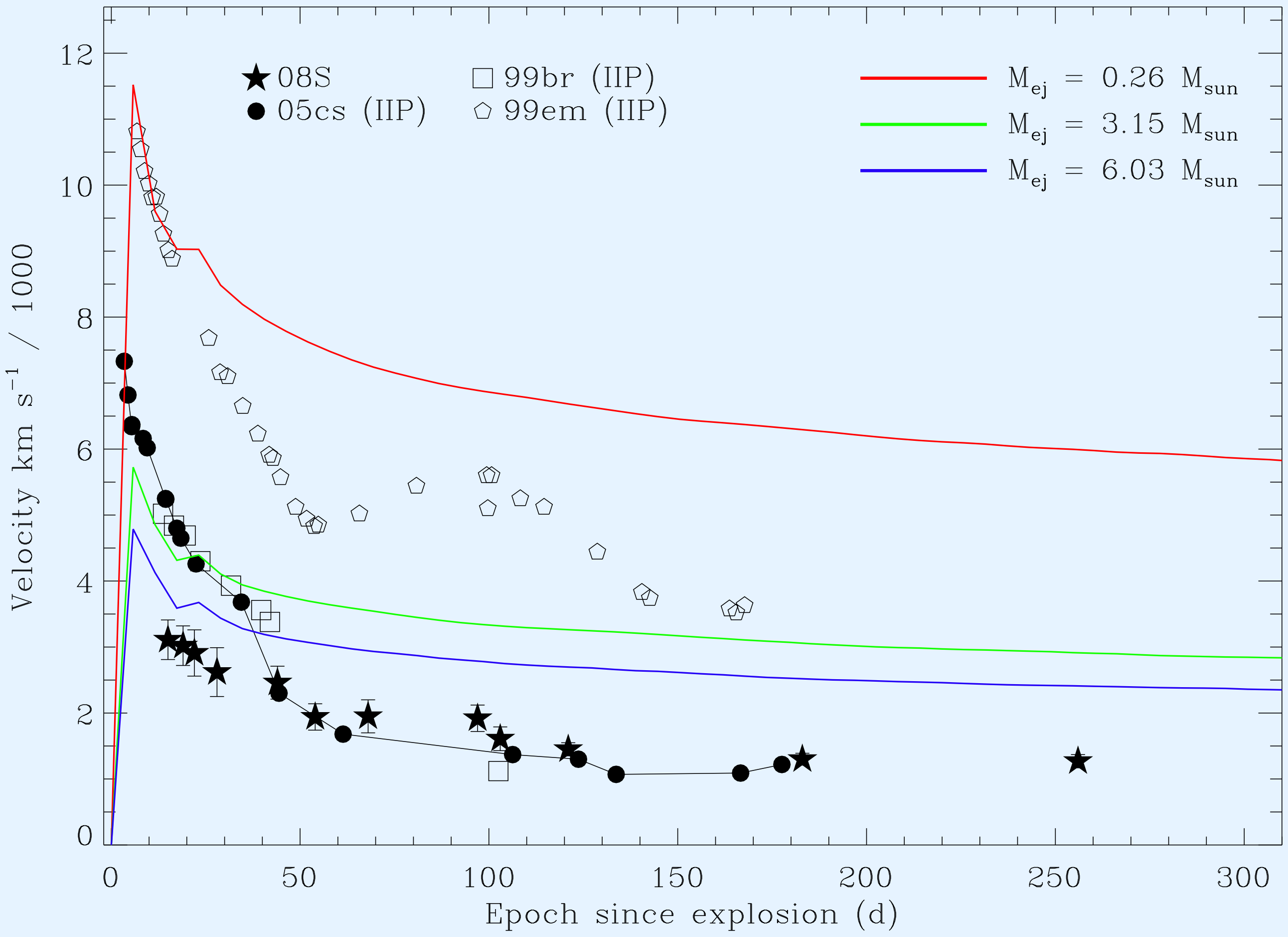
Poelarends et al. 2008

ECSN: dim



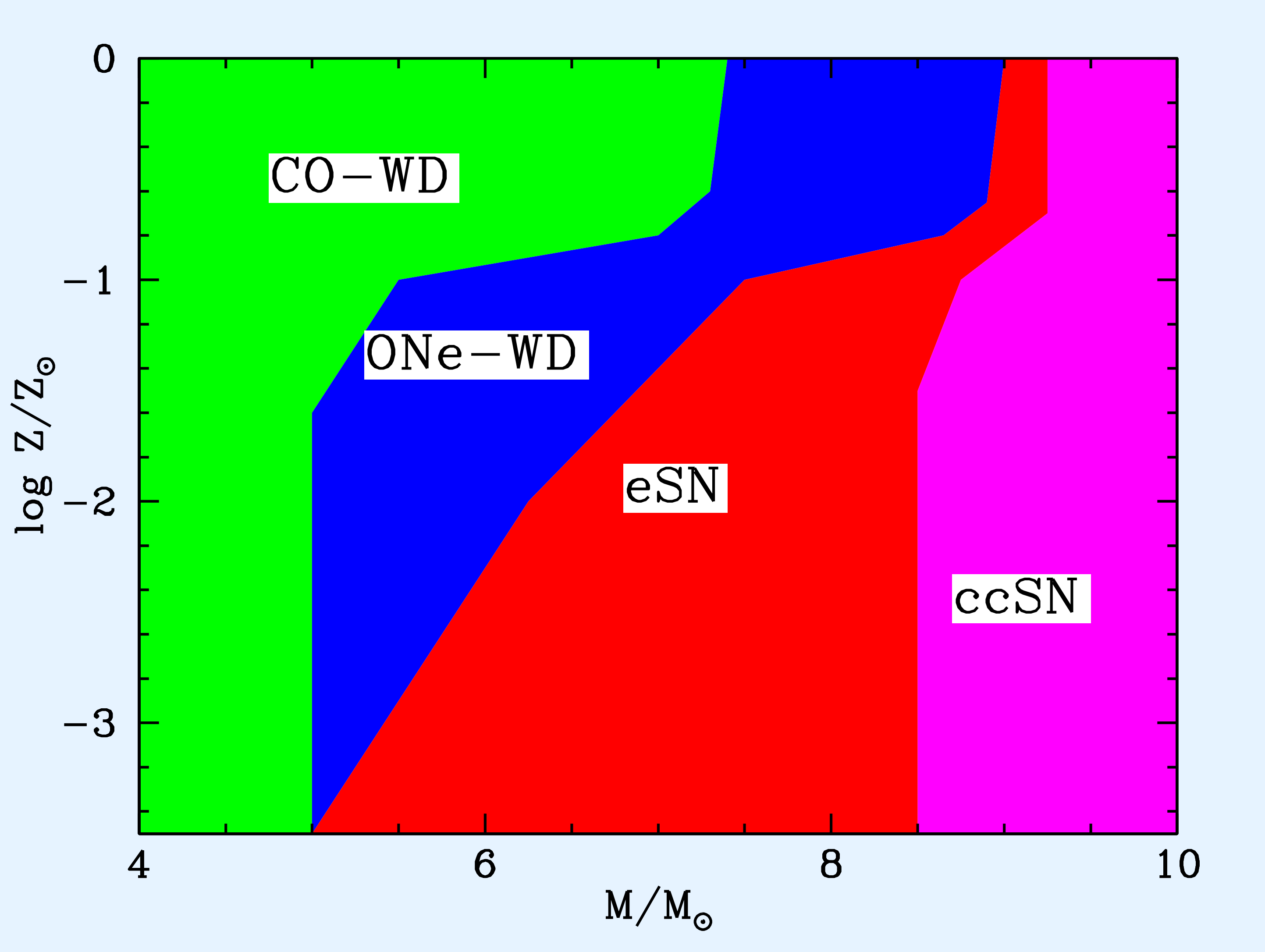
van Veelen et al.

ECSN: slow



van Veelen et al.

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



Poelarends et al. 2006

Conclusions

at low Z:very different stellar explosions

- ecSN: may be most frequent type of SN
- long GRBs: rule rather than exception in BH formation
- PCSNe: could dominate metal production