Barca, April 2013

Mass Loss:

Importance & Uncertainties

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European Research Council
Established by the European Commission

in collaboration with:

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MESA: B. Paxton (KITP), F. X. Timmes, Arizona (US)
SNe: K. Nomoto (IPMU, J), T. Fischer (TUD, D)
Nucleo: F.-K. Thielemann, U. Frischknecht, M. Pignatari (Basel, CH), T. Rauscher (Herts, UK)
NUGRID: F. Herwig (Victoria, Canada), C. Fryer (LANL), UChicago, UFrankfurt, ...

Keele is Not Kiel (Germany) But Where is it?

West Midlands:

Keele

Keele area

is famous for pottery: Wedgwood, ...

and football: Stoke city fc in premier league

Plan

- Introduction

- Mass loss:

    - Driving mechanisms and recipes

    - Z & ROT – dependence

    - Clumping

- RSG/WR → SNII/Ibc

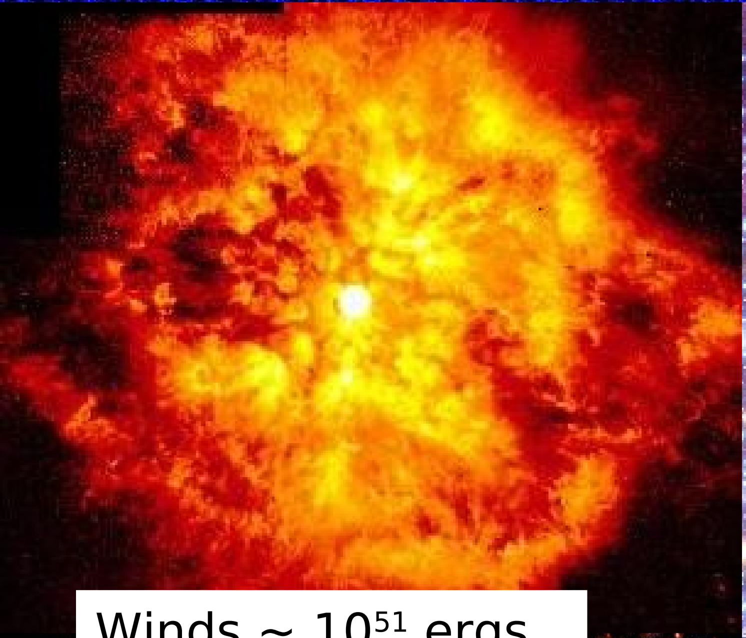
- Most massive stars

- Least-massive massive stars – SAGB transition

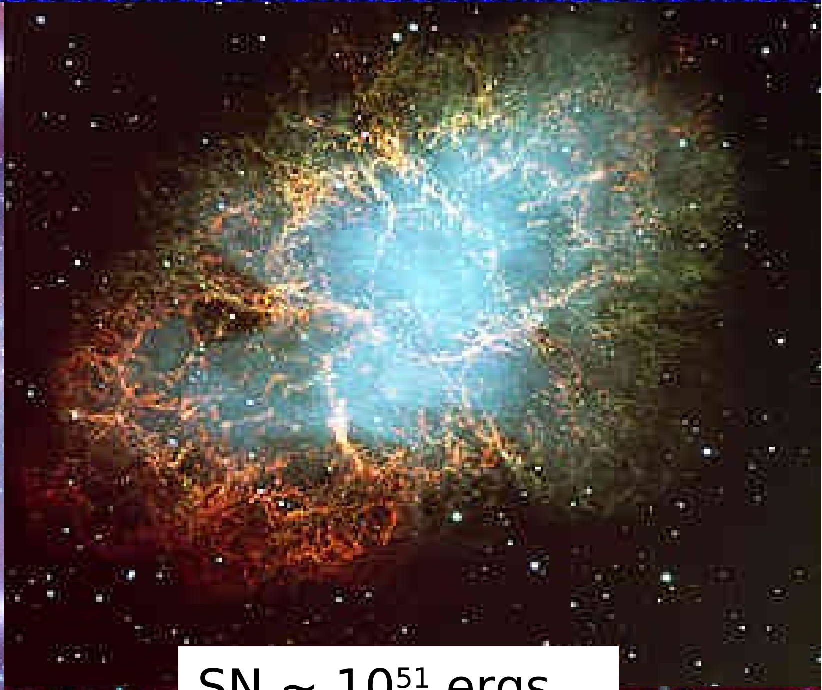
- Conclusions

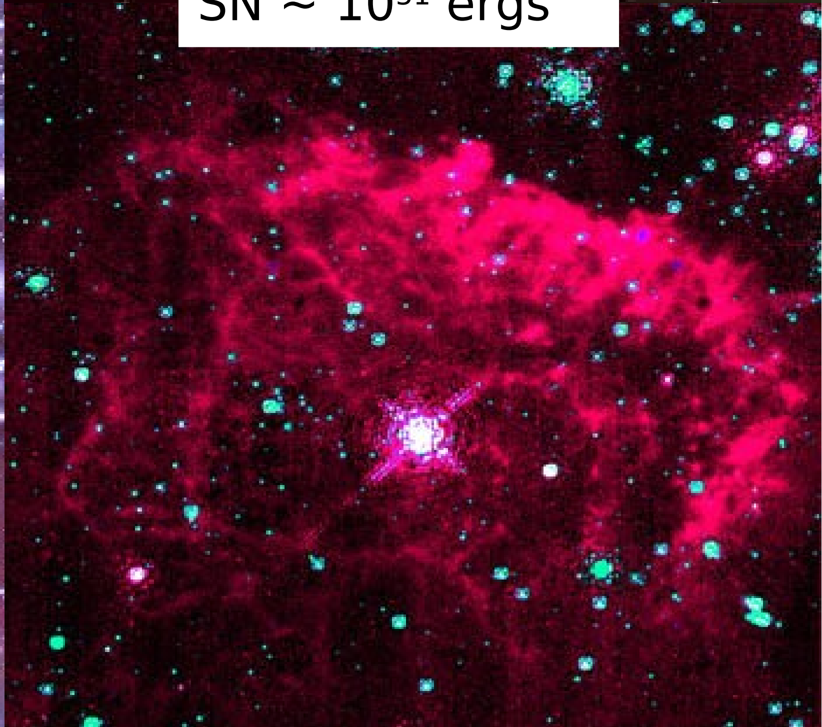
- ERC - SHYNE project

Injection of Mechanical Energy



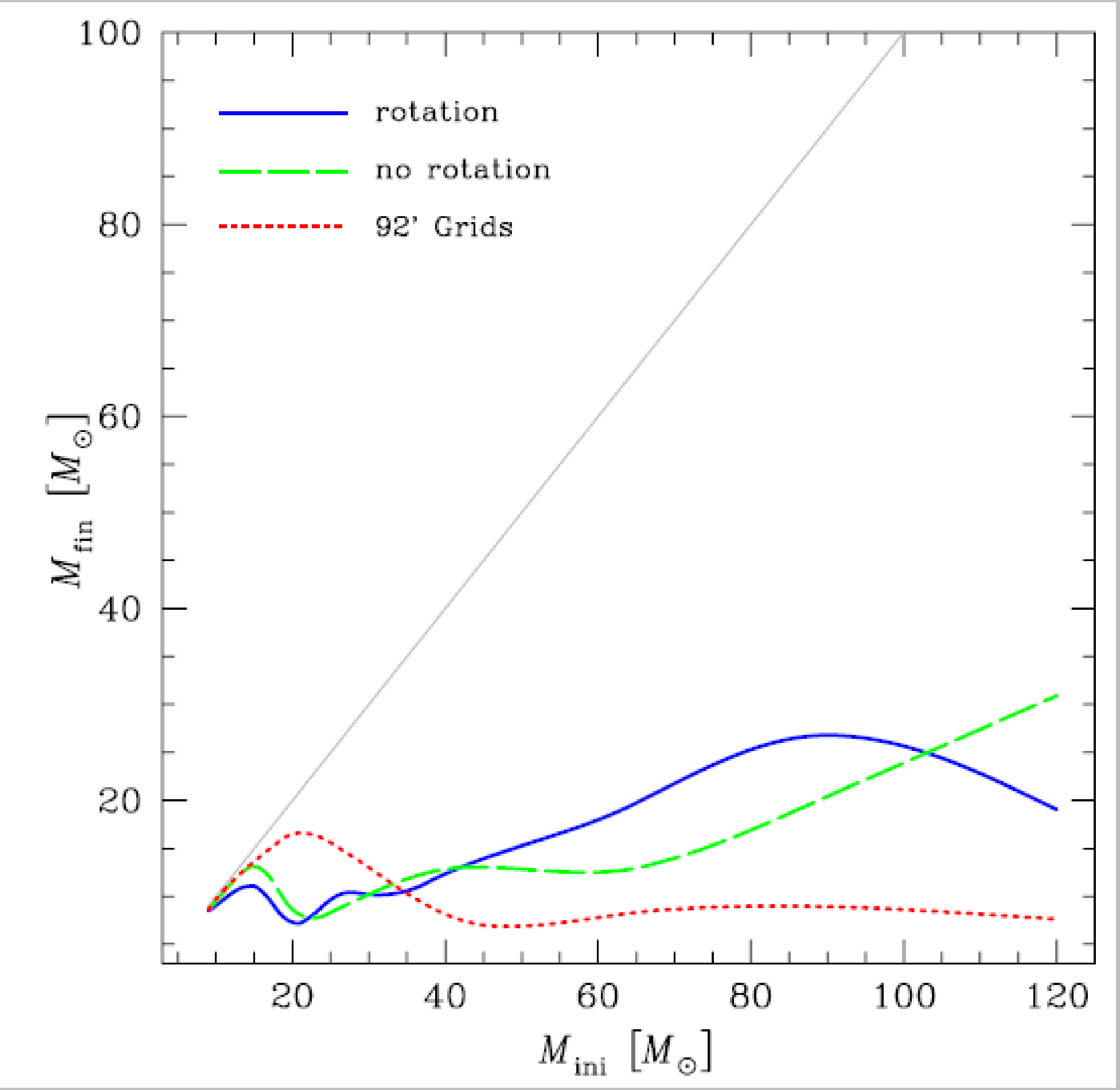
Winds ~ 10^{51} ergs





SN ~ 10^{51} ergs

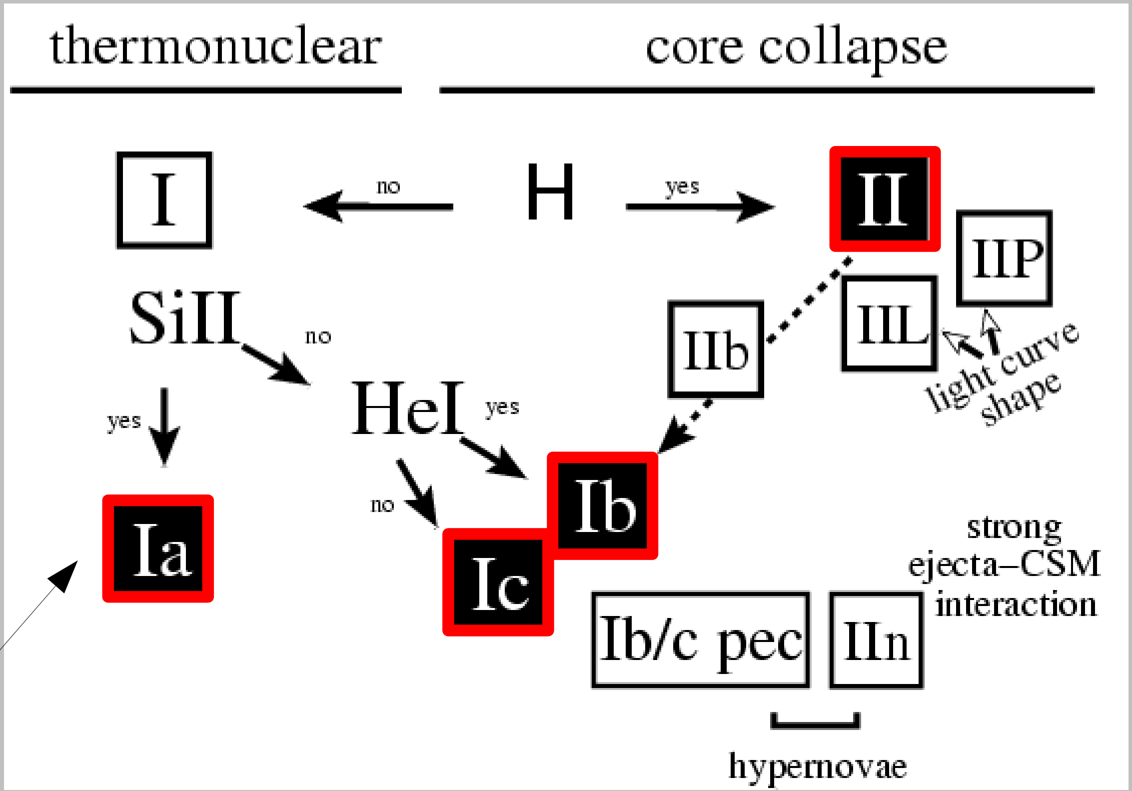
Importance of Mass Loss



Ekström et al 12, see also Chieffi & Limongi 13

Supernova Explosion Types

Massive stars: → SN II (H envelope),
Ib (no H), Ic (no H & He) ← WR



White dwarfs (WD):
in binary systems
Accretion →
Chandrasekhar
mass → SN Ia

(Turatto 03)

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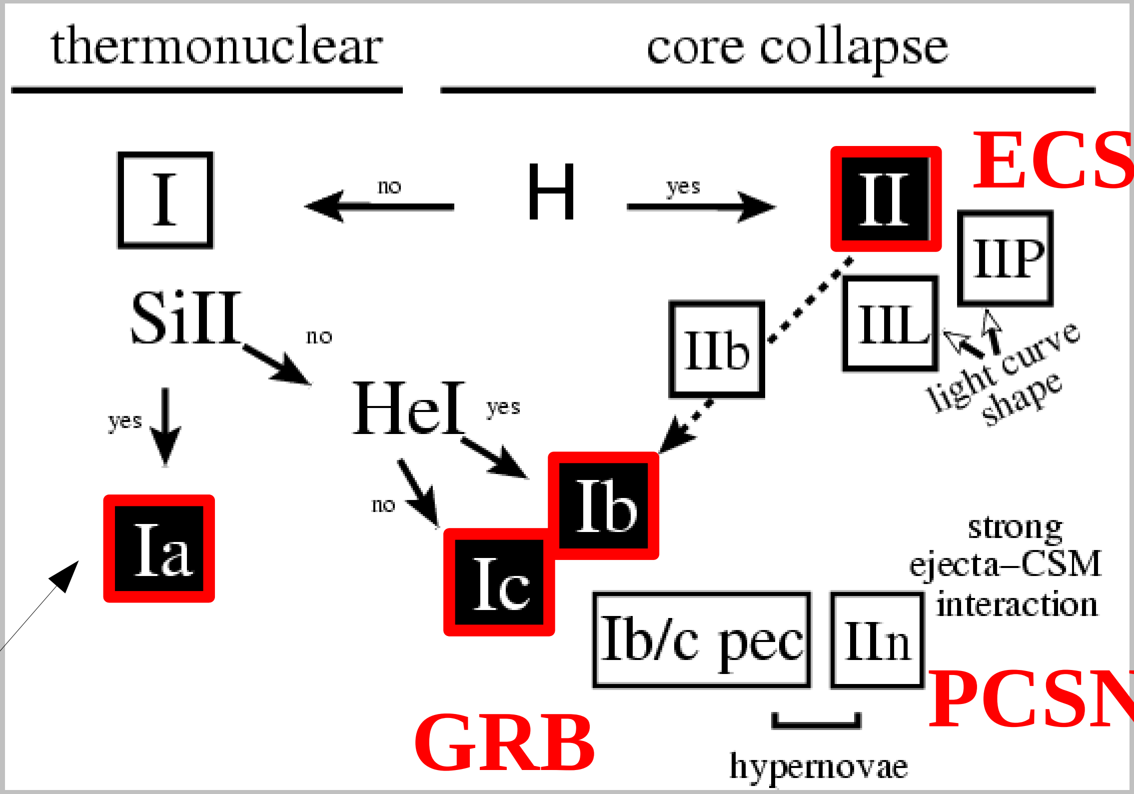

ECSN?

PCSN?

GRB

White dwarfs (WD):
in binary systems
Accretion →
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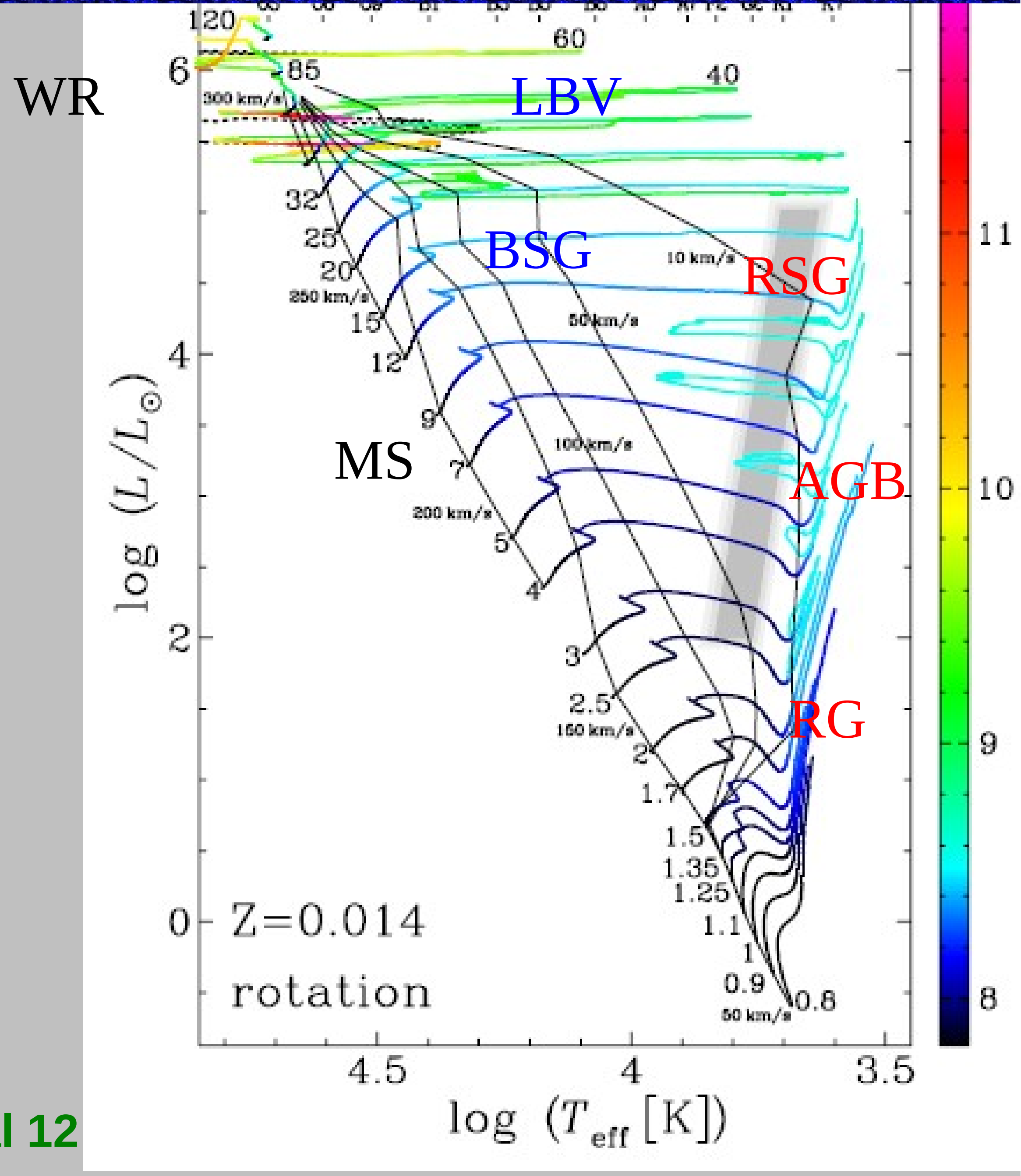
(Turatto 03)

Main Phases



Ekstroem et al 12

Mass Loss: Types, Driving & Recipes

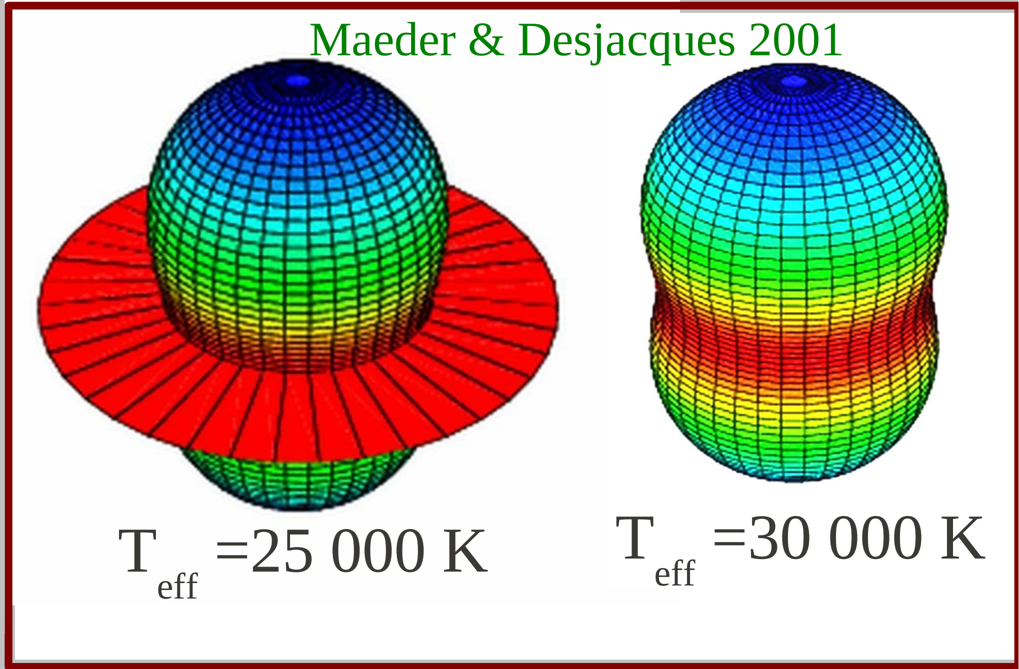
Mass loss driving mechanism and prescriptions at different stages:

- O-type & "LBV" stars (bi-stab.): line-driven Vink et al 2000, 2001
- WR stars (clumping effect): line-driven Nugis & Lamers 2000, Gräfener & Hamann (2008)
- RSG: Pulsation/dust? de Jager et al 1988
- RG: Pulsation/dust? Reimers 1975,78, with η=~0.5
- AGB: Super winds? Dust Bloecker et al 1995, with η=~0.05
- LBV eruptions: continuous driven winds? Owocki et al
- ...

Mass Loss: Rotation Effects

- Enhancement: Maeder & Meynet 2000

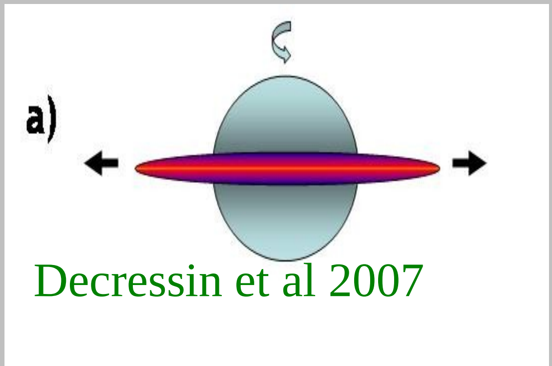
$$\frac{\dot{M}(\Omega)}{\dot{M}(0)} \approx \frac{(1-\Gamma)^{\frac{1}{\alpha}-1}}{\left(1-\frac{4}{9}\frac{v^2}{v^2_{crit,1}}-\Gamma\right)^{\frac{1}{\alpha}-1}}$$



- & anisotropy:

$F_{rad} \sim g_{eff}$: Von Zeipel, 1924 → affects angular momentum loss

- Mechanical mass loss at critical rotation:



What changes at low Z?

- Stars are more compact: $R \sim R(Z_o)/4$ (lower opacities) at $Z=10^{-8}$
- Rotation at low Z: stronger shear, weaker mer. circ.
- Mass loss weaker at low Z: → faster rotation

$$\dot{M}(Z)=\dot{M}(Z_o)(Z/Z_o)^{\alpha}$$

- α = 0.5-0.6 (Kudritzki & Puls 00, Ku02) (Nugis & Lamers, Evans et al 05)
- α = 0.7-0.86 (Vink et al 00,01,05)

$Z(LMC) \sim Z_o/2.3$ => Mdot/1.5 – Mdot/2

$Z(SMC) \sim Z_o/7$ => Mdot/2.6 - Mdot/5

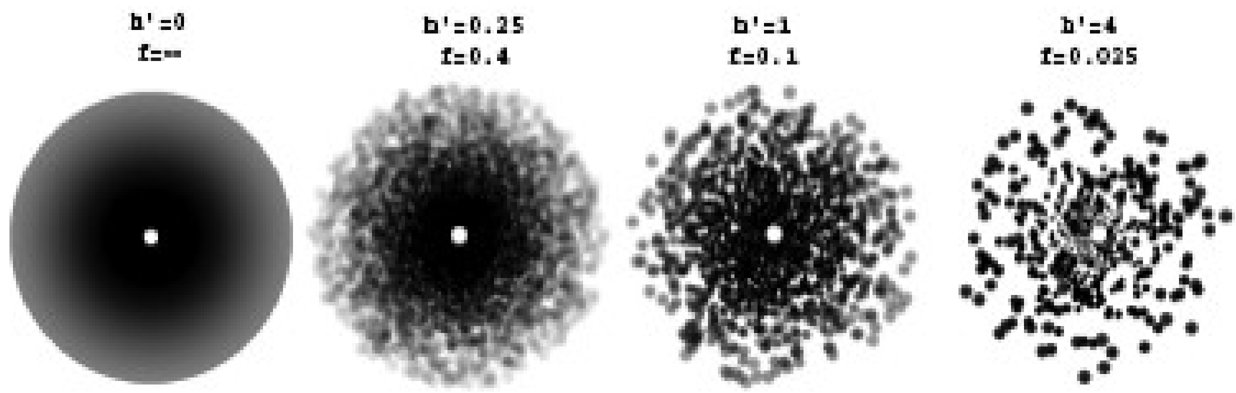
Mass loss at low Z still possible?

RSG (and LBV?): no Z-dep.; CNO? (Van Loon 05, Owocky et al)

Mechanical mass loss ← critical rotation

(e.g. Hirschi 2007, Ekstroem et al 2008, Yoon et al 2012)

CLUMPING



ρ^2

diagnostics

If wind clumped in reality but supposed to be homogeneous

Excess emission from inhomogeneities →
incorrectly interpreted as
arising from a smooth but denser medium

MASS LOSS OVERESTIMATED

Fullerton et al 05: Mdot/10

Bouret et al 05: Mdot/3 or smaller

Surlan et al 13: problem resolved?

RSG/YSG/WR – SN II, IIb, Ibc

Observational constraints:

- RSG Upper Luminosity: Log (L/L_{SUN}) ~ 5.2-5.3
(median value of the most 5 L_{SUN} stars)
(Levesque et al 05)

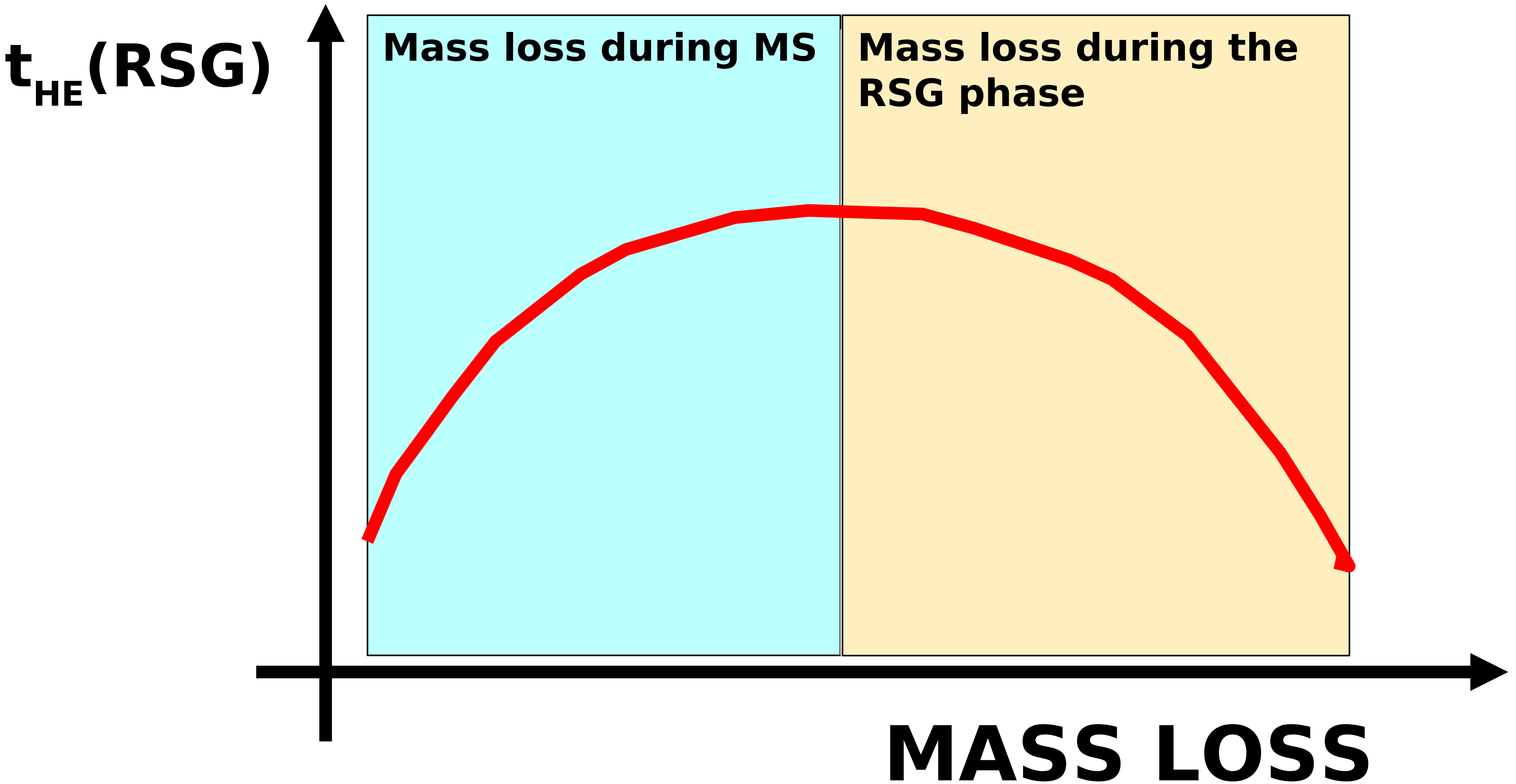
- SNII-P Log (L/L_{SUN}) <~5.1 (Smartt et al. 2009)

- No clear dependence on Z for these upper limit

- WR/O, RSG/BSG ratios vary with Z

CHANGE OF MASS LOSS

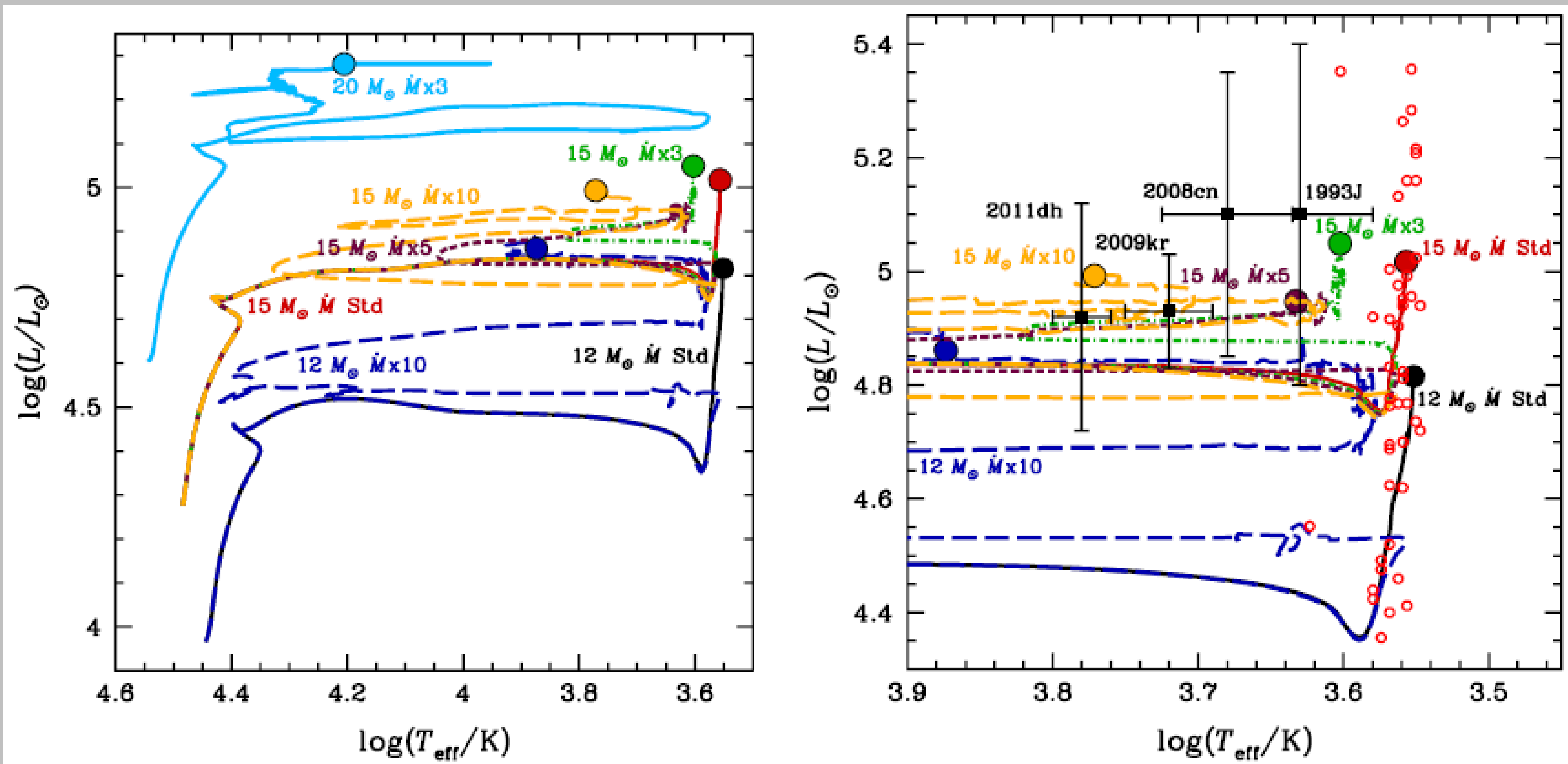
For a given initial mass



RSG/YSG/WR – SN II, IIb, Ib, Ic

RSG Mdot: - log(Teff/K) > 3.7: de Jager et al. (1988)
- log(Teff/K) < 3.7: linear fit from the data of Sylvester et al. (1998) and van Loon et al. (1999) (see Crowther 2001)

$$\dot{M} = -1.479 \times 10^{-14} \times \left(\frac{L}{L_\odot}\right)^{1.7}$$



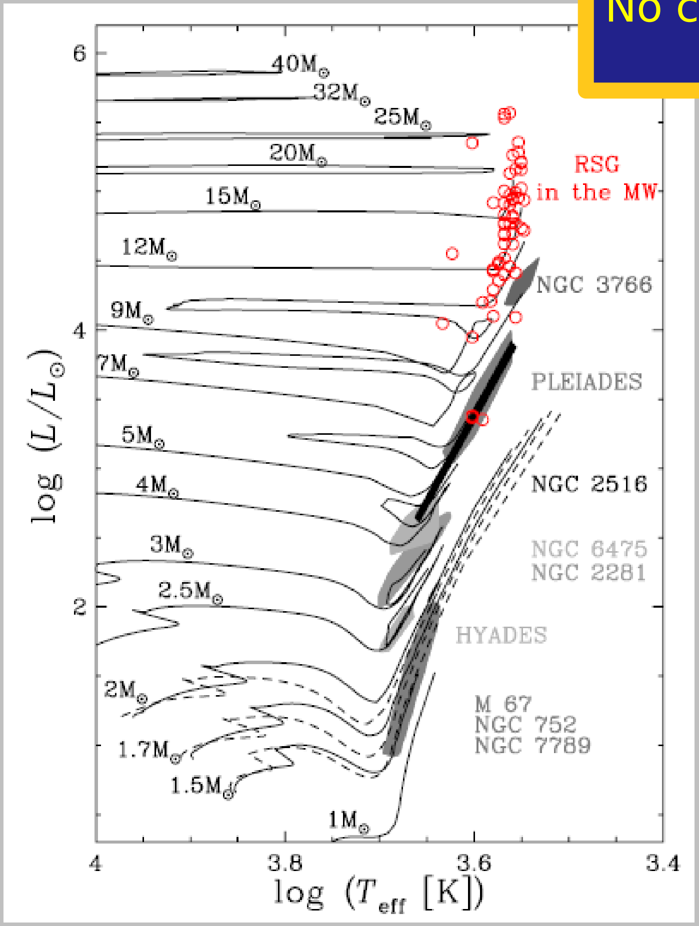
Models: Georgy 12 (see also Eldridge et al 13)

Super-Eddington layers → increased Mdot (see Ekstroem et al 13)

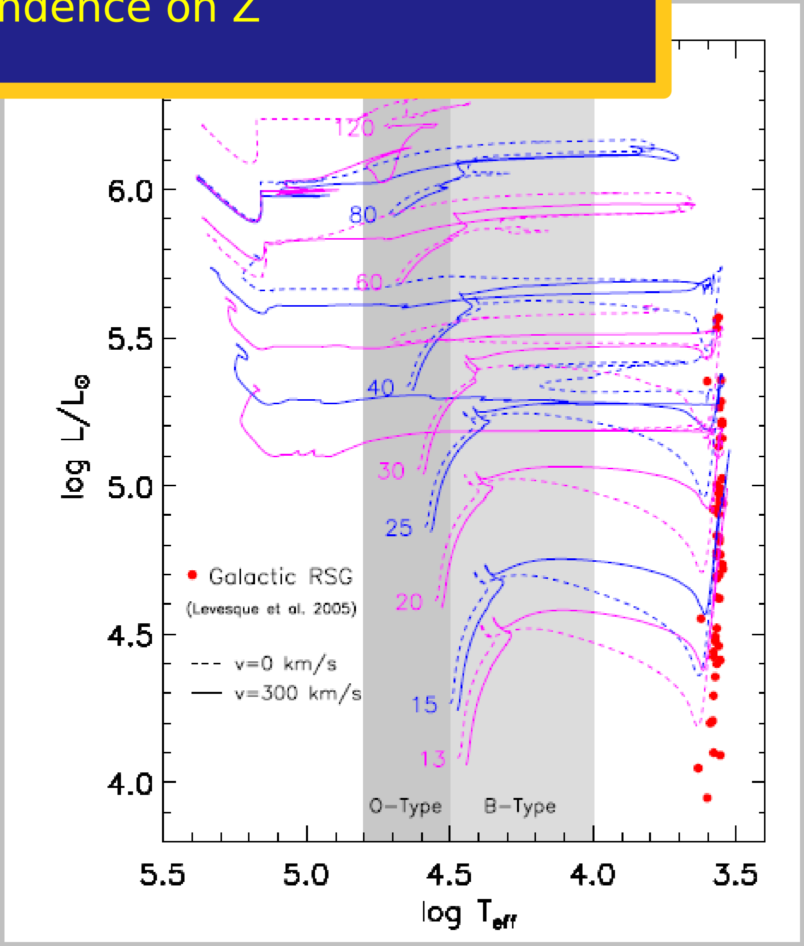
RSG/YSG/WR – SN II, IIb, Ib, Ic

RSG Upper Luminosity ~ 5.2-5.3
(median value of the most 5 L_{SUN} stars)
SNII-P ~ 5.1 (Smartt et al. 2009)

No clear dependence on Z



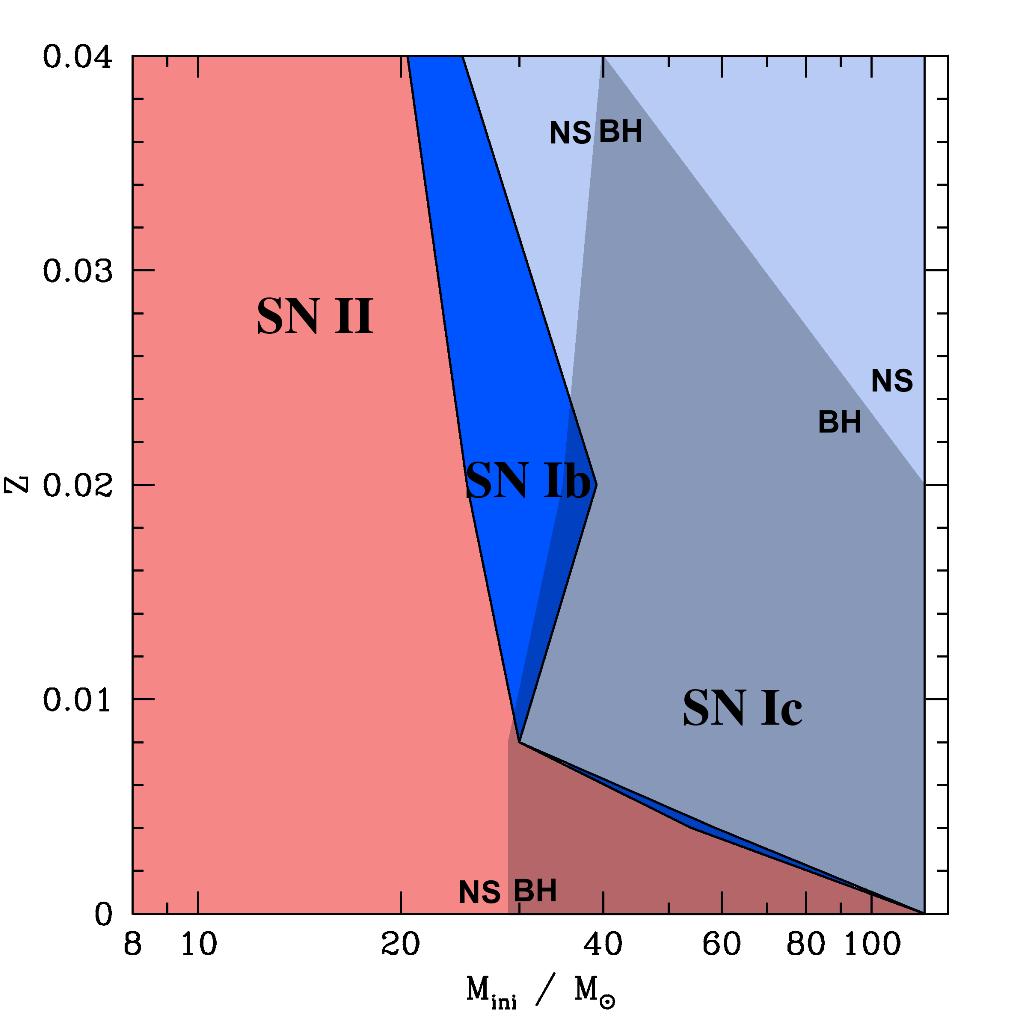
- Tracks: Ekstroem et al 12
- grey areas: obs. See MM89
- red circles: Levesque et al 05



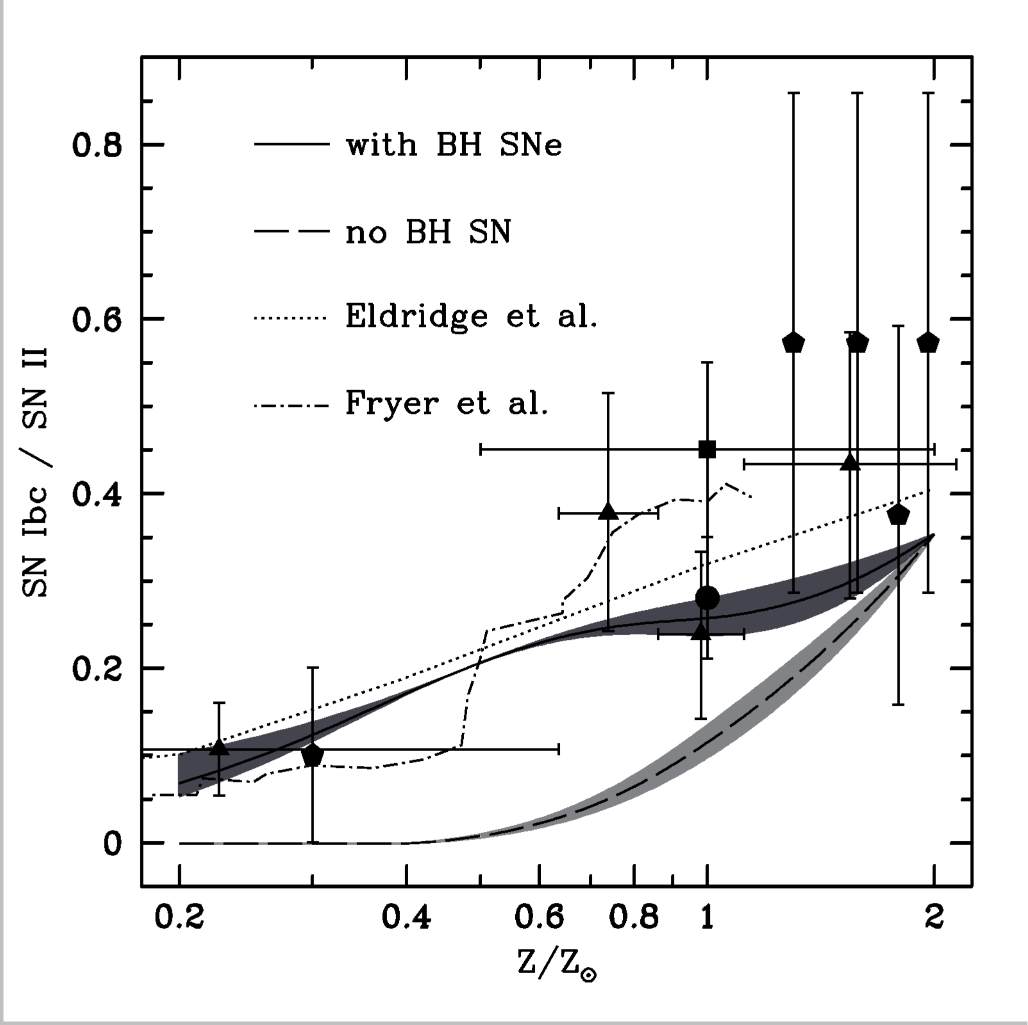
- Tracks: Chieffi & Limongi 13 (CL13)

Final stages & SN type

Ratio SNIbc/SNII: tests final type



Georgy et al 09



- THEORY: Georgy et al 09 (solid line)
  binaries: Eldridge etal 08 (dotted)
- OBS: Prantzos & Boissier 03 (triangles)
  Prieto etal 08 (pentagons)

The fate of VMS ($M>100M_o$): PCSN/BH/CCSN?

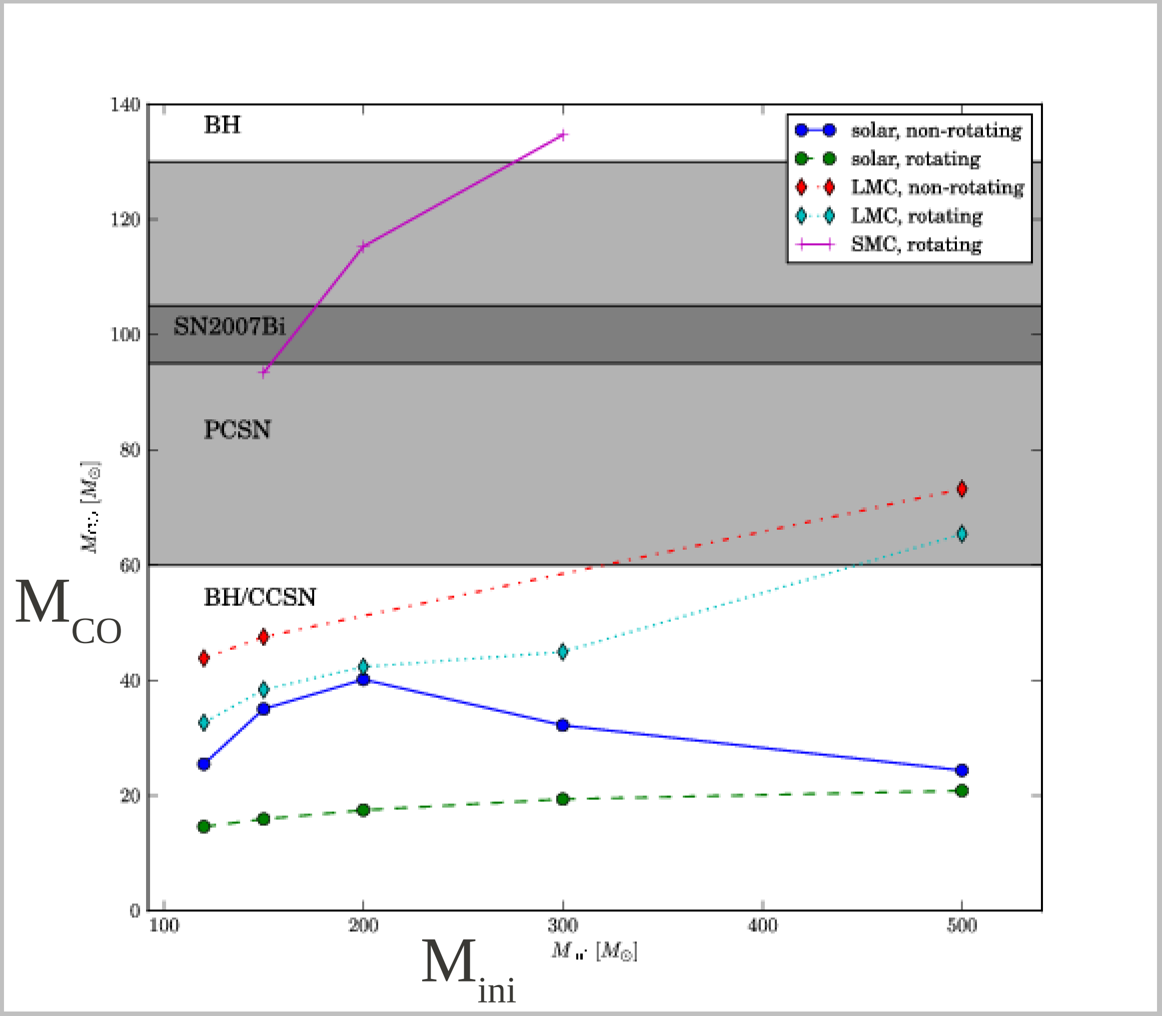
new $M_{max}=320M_o$! (R136a1, see Crowther et al 10, MNRAS)

Z_{solar}: no PCSN

(Rotating) models with Z<Z(LMC) lose less mass,

and enter the PCSN instability region!

BUT mass loss uncertain!



PCSN range from Heger & Woosley (2002)

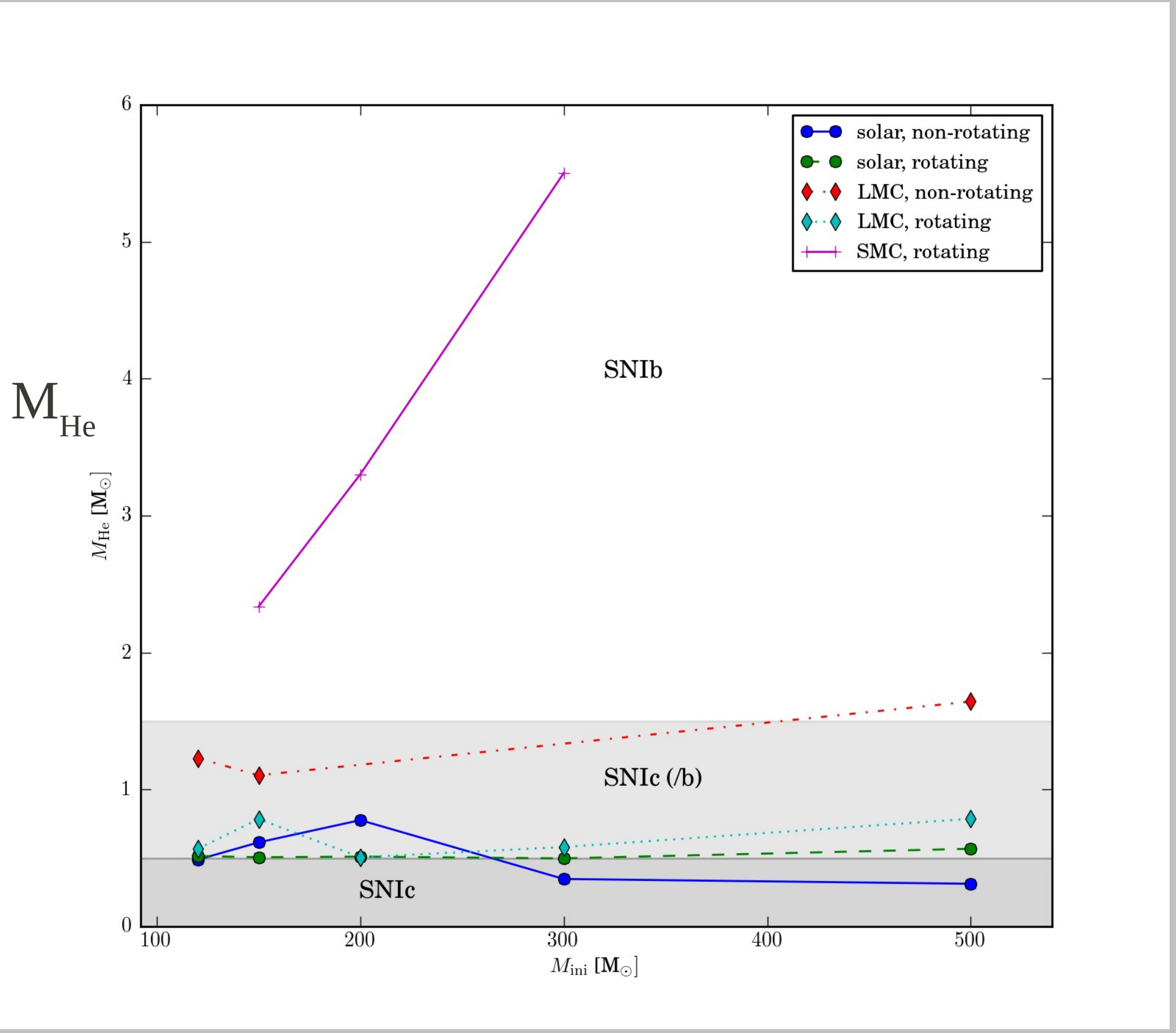
Consistent with Langer et al (2007): PCSN for $Z<Z_0/3$

The fate of VMS: SNII/SNIb-c?

SN type:
- SNIc at solar Z,

- SNIb/c at Z(SMC)
~ ok for SN2007bi
(Gal-Yam 2009)

- NO SNIIn predicted!
~ NOT ok for SN2006gy
(e.g. Woosley et al
2007)



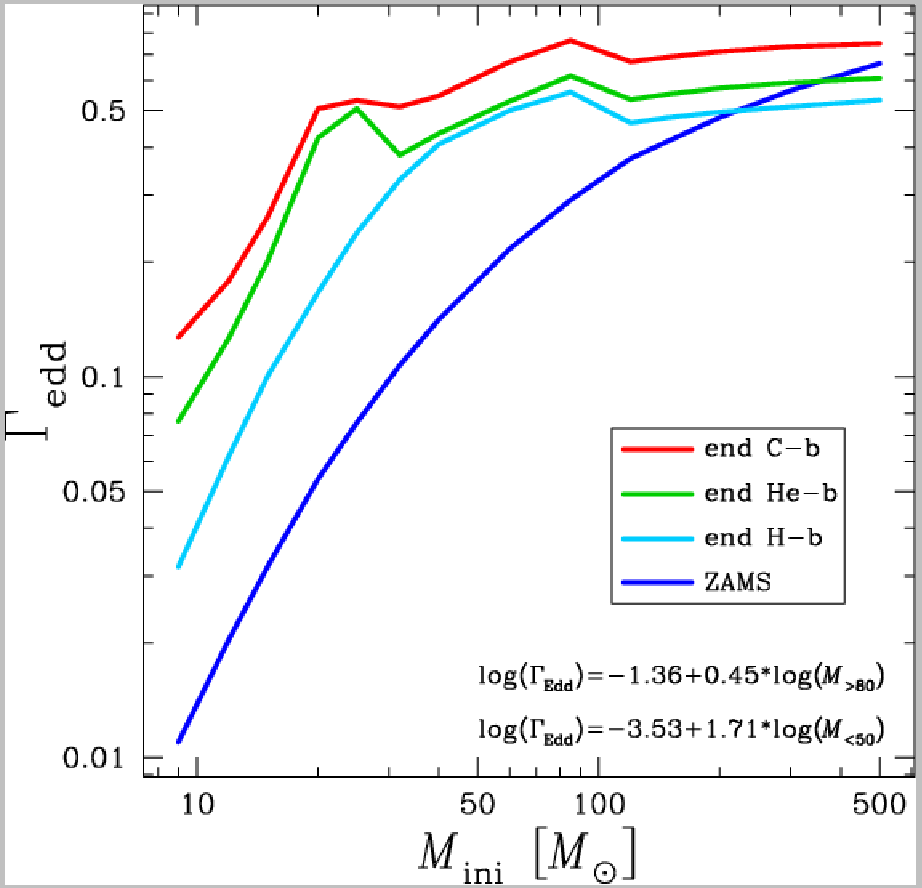
(Yusof et al subm.)

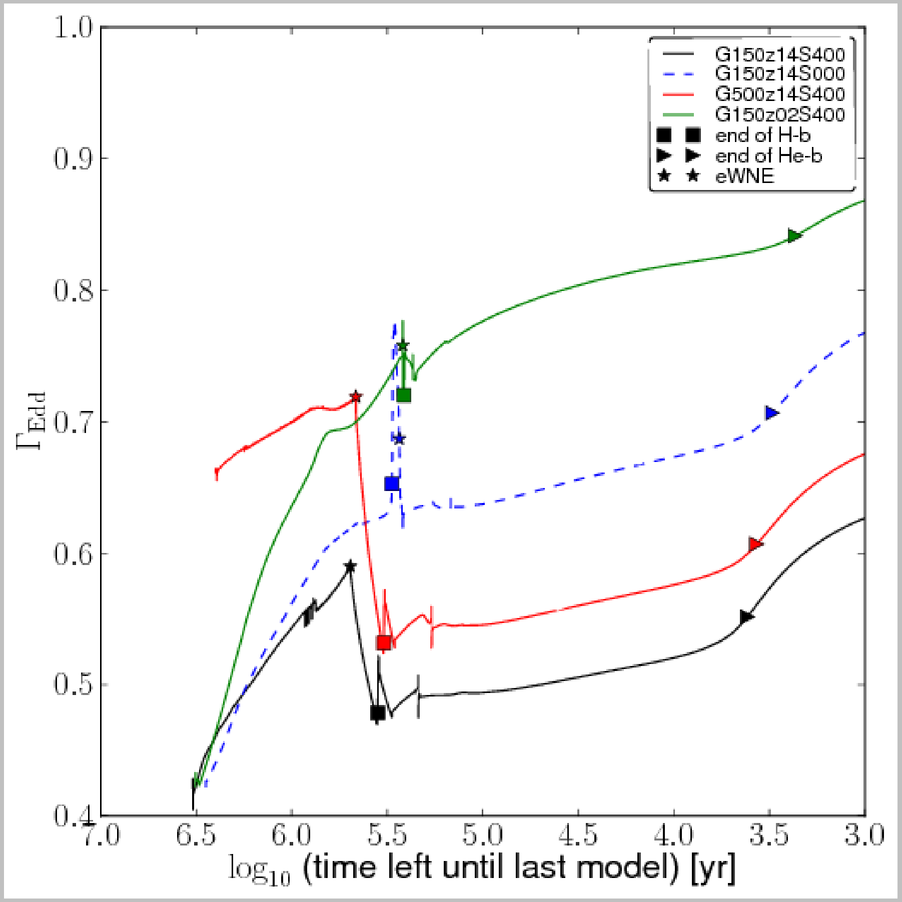
Proximity to the Eddington Limit

Solar Z:

Time evolution:

(Yusof et al subm.)





Stars never reach $\Gamma_{Edd} = 1$

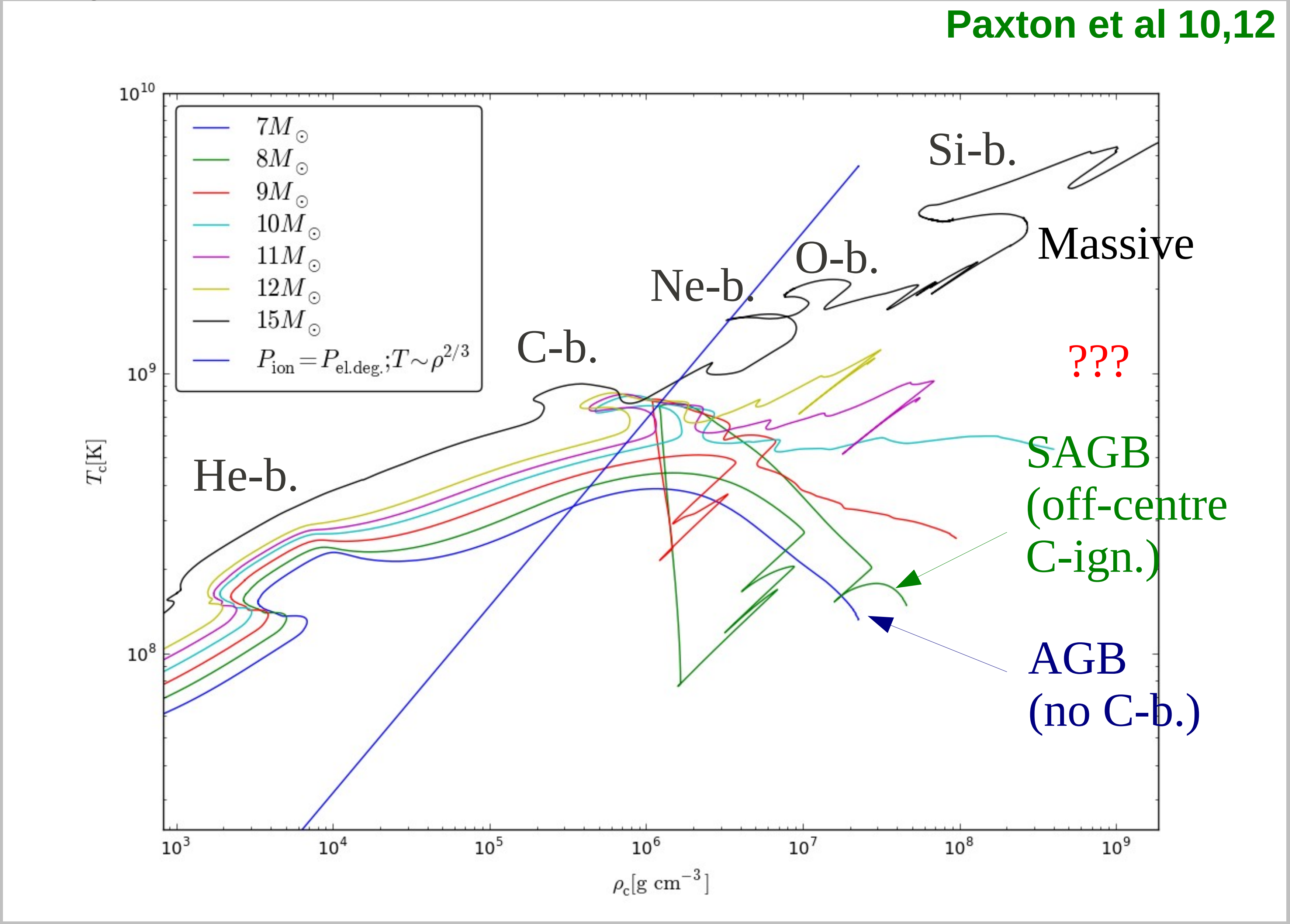
← strong Mdot

$\Gamma_{Edd} \rightarrow 1$ just before collapse

Possible LBV-type Mdot in WR stars?

Massive/AGB Stars Transition

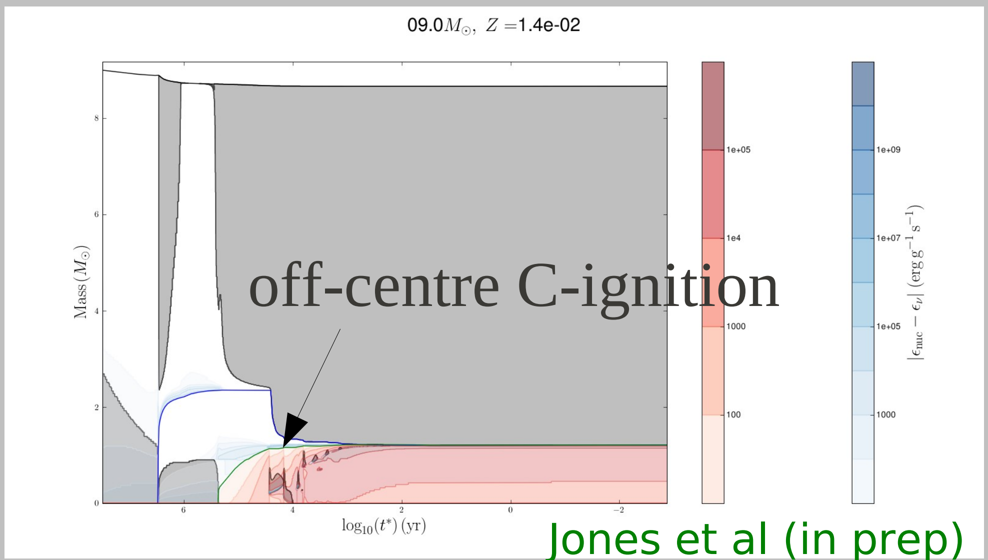
7-15 M_o models ← MESA stellar evolution code: http://mesa.sourceforge.net/



SAGB & ECSN progenitors

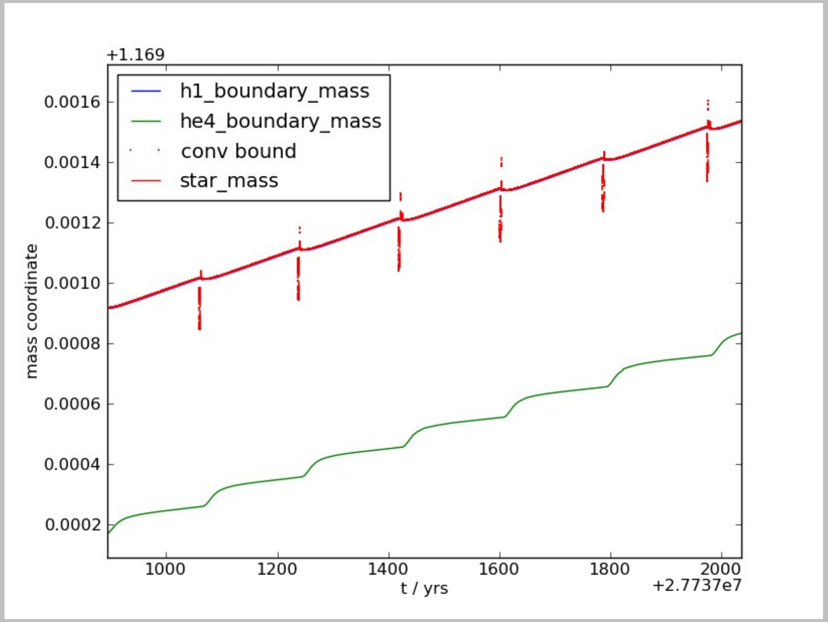
$M_{up} \leq M \leq M_{mas}$; $M_{up} \approx 8M_{sun}$, $M_{mas} \approx 10M_{sun}$ (TRANSITION MASSES)

Early evolution like AGBs;



Jones et al (in prep)

TP-phase → core growth
Dep. on Mdot ↔ mixing



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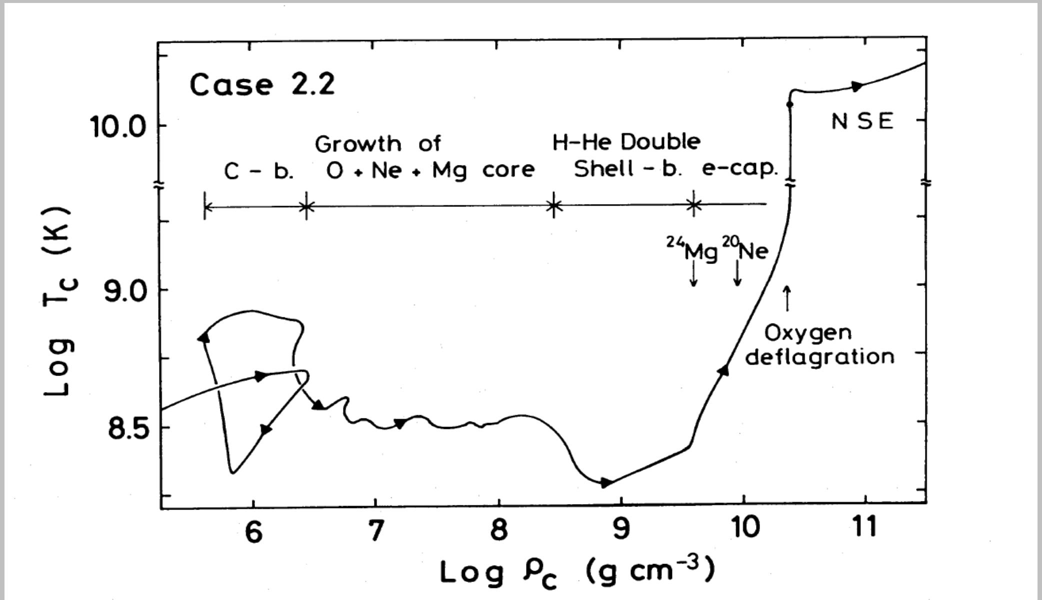
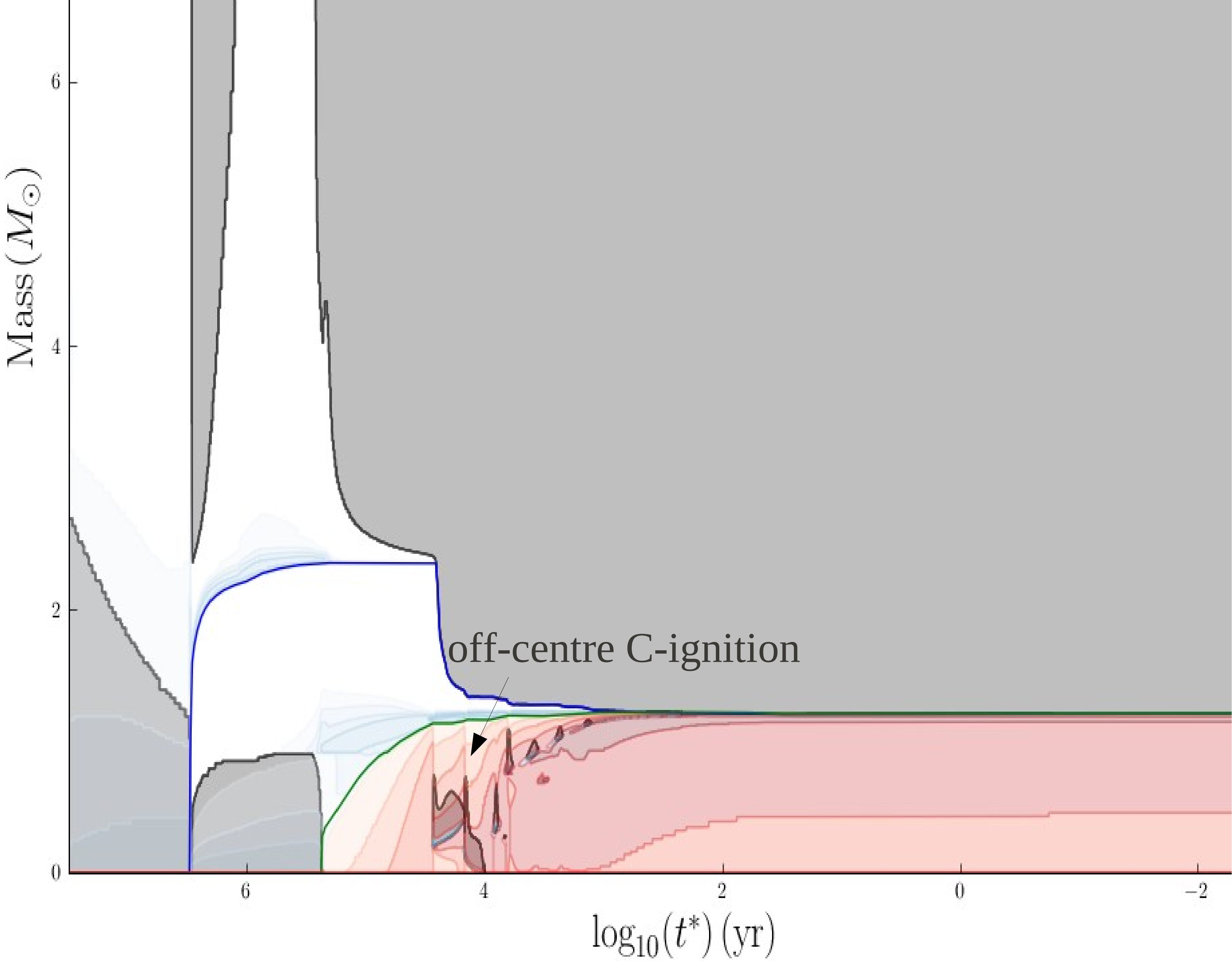


FIG. 4.—Evolutionary track in the central density and temperature diagram

Critical ONeMg core mass = M_{crit} = 1.375

(Miyaji et al. 1980; Nomoto 1984)

See also: Miyaji (1980); Nomoto(1984, 1987); Miyaji & Nomoto (1987); Garcia-Berro, Ritossa and Iben (1990s); Eldridge & Tout (2004); L. Siess (2006, 2007, 2009, 2010), Poelarends (2008); Doherty et al. (2010) ...


Mass $(M_\odot)$
0
2
4
6
off-centre C-ignition
6
4
2
0
−2
$\log_{10}(t^*)$ (yr)

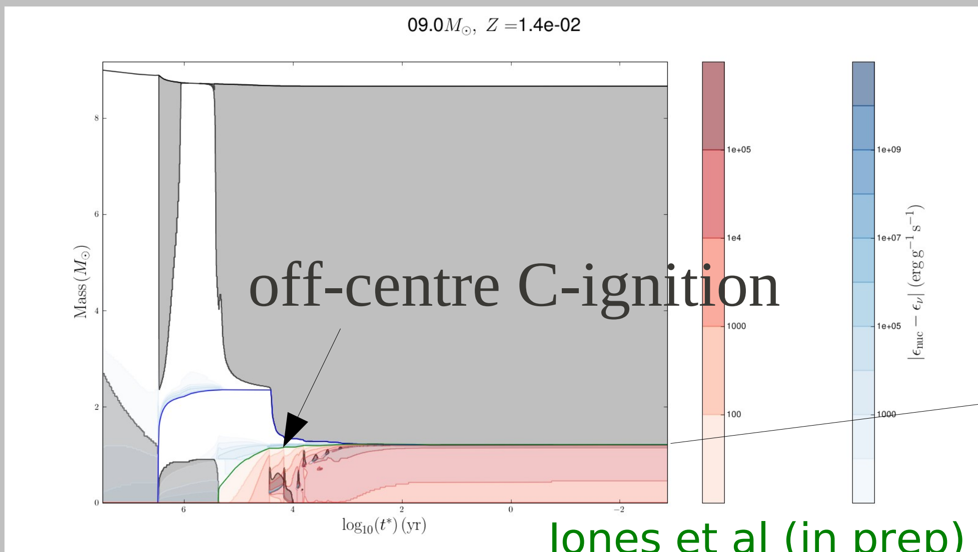
SAGB & ECSN progenitors

$M_{up} \leq M \leq M_{mas}$; $M_{up} \approx 8M_{sun}$, $M_{mas} \approx 10M_{sun}$ (TRANSITION MASSES)

Early evolution like AGBs;

TP-phase → core growth

Dep. on Mdot ↔ mixing



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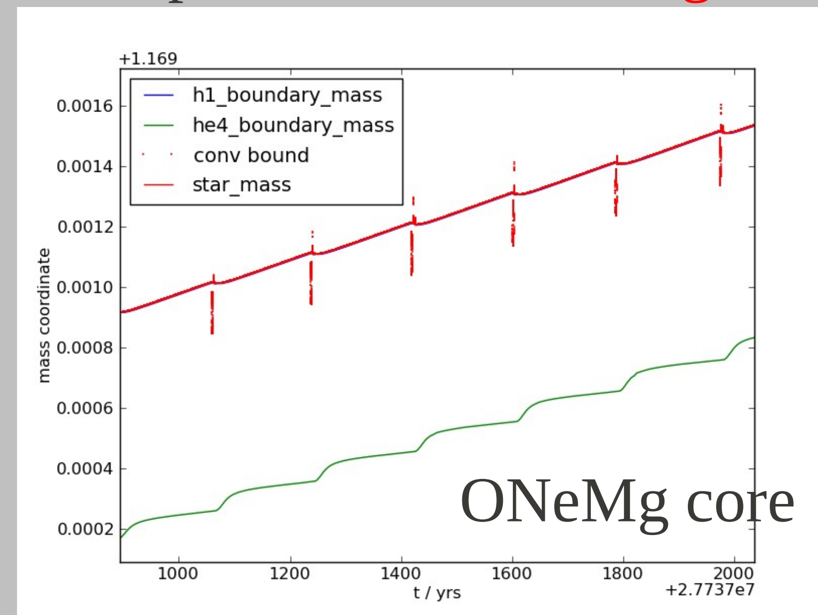

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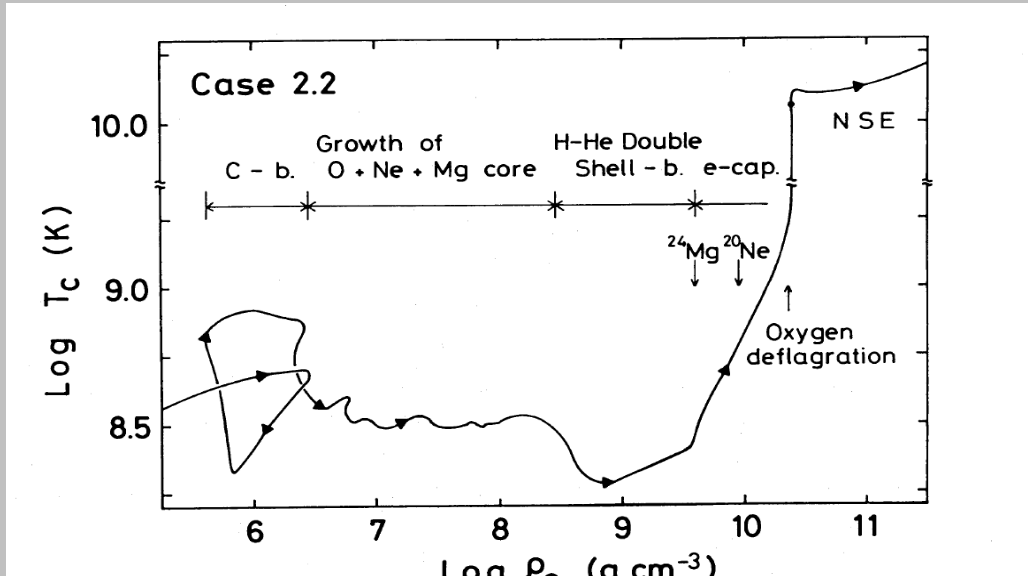

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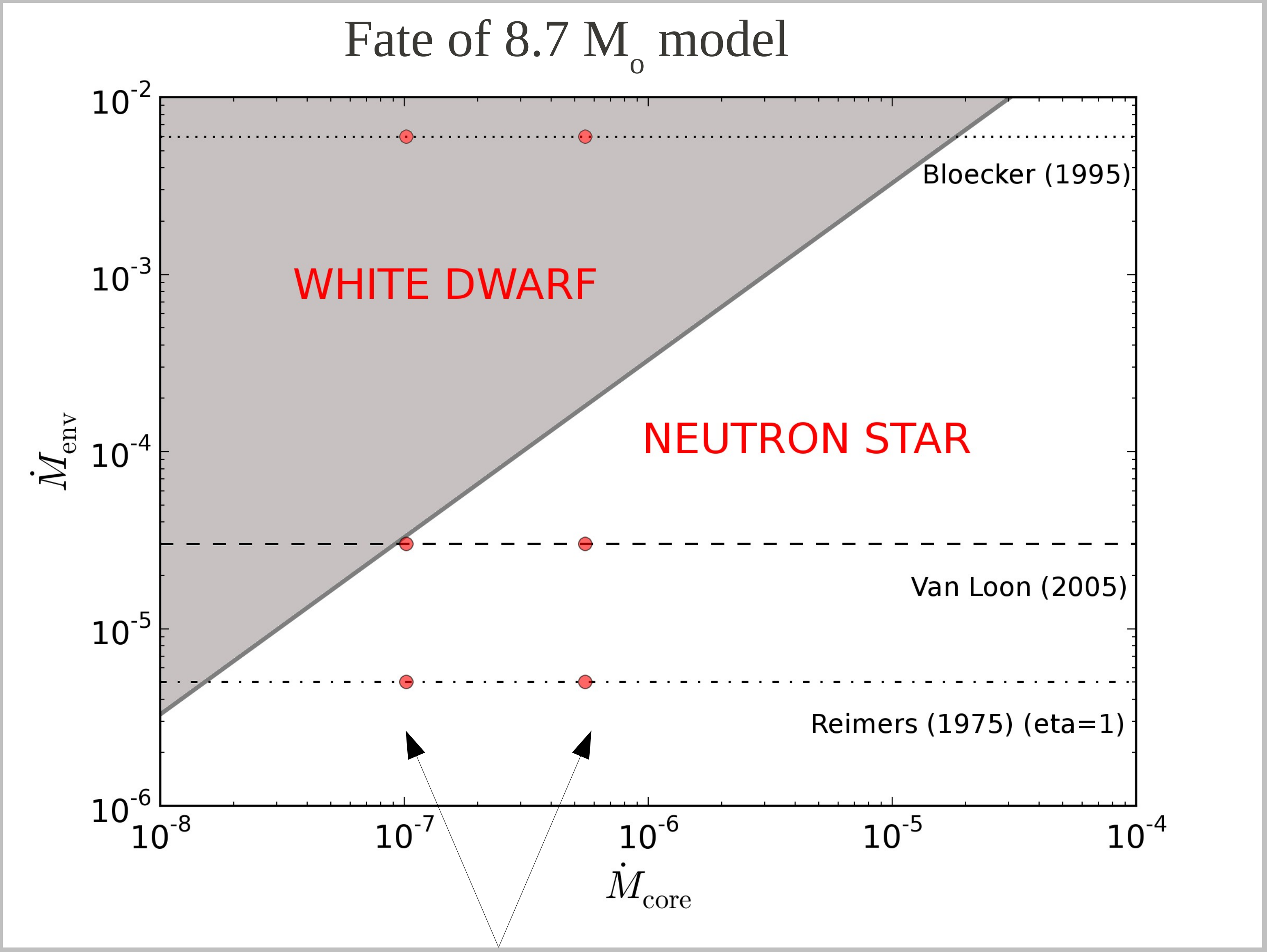
Impact of Mass Loss



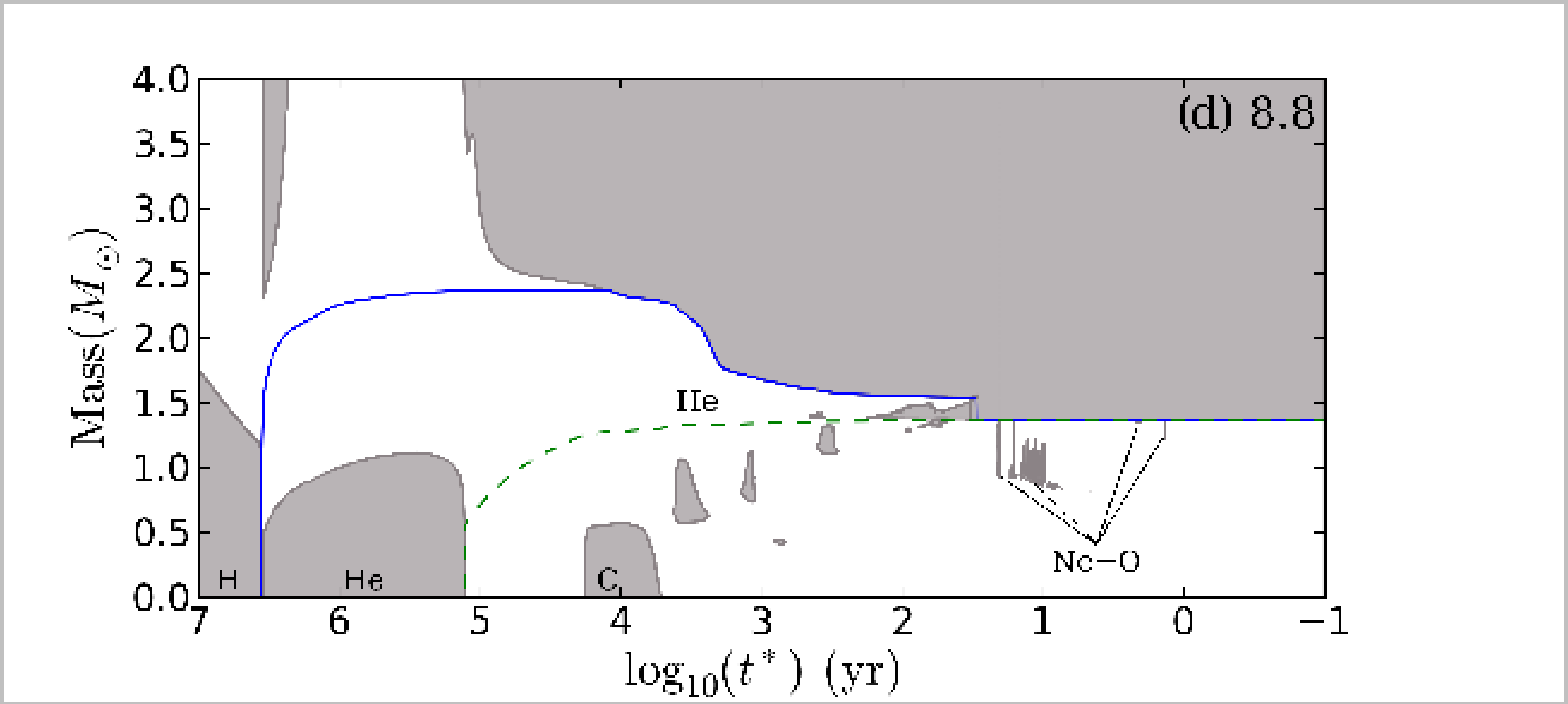
High/low 3rd dredge-up efficiency, respectively

Jones et al (in prog.)

Hard to produce ECSN with Bloecker Mdot!

Can Massive Stars produce ECSN ?

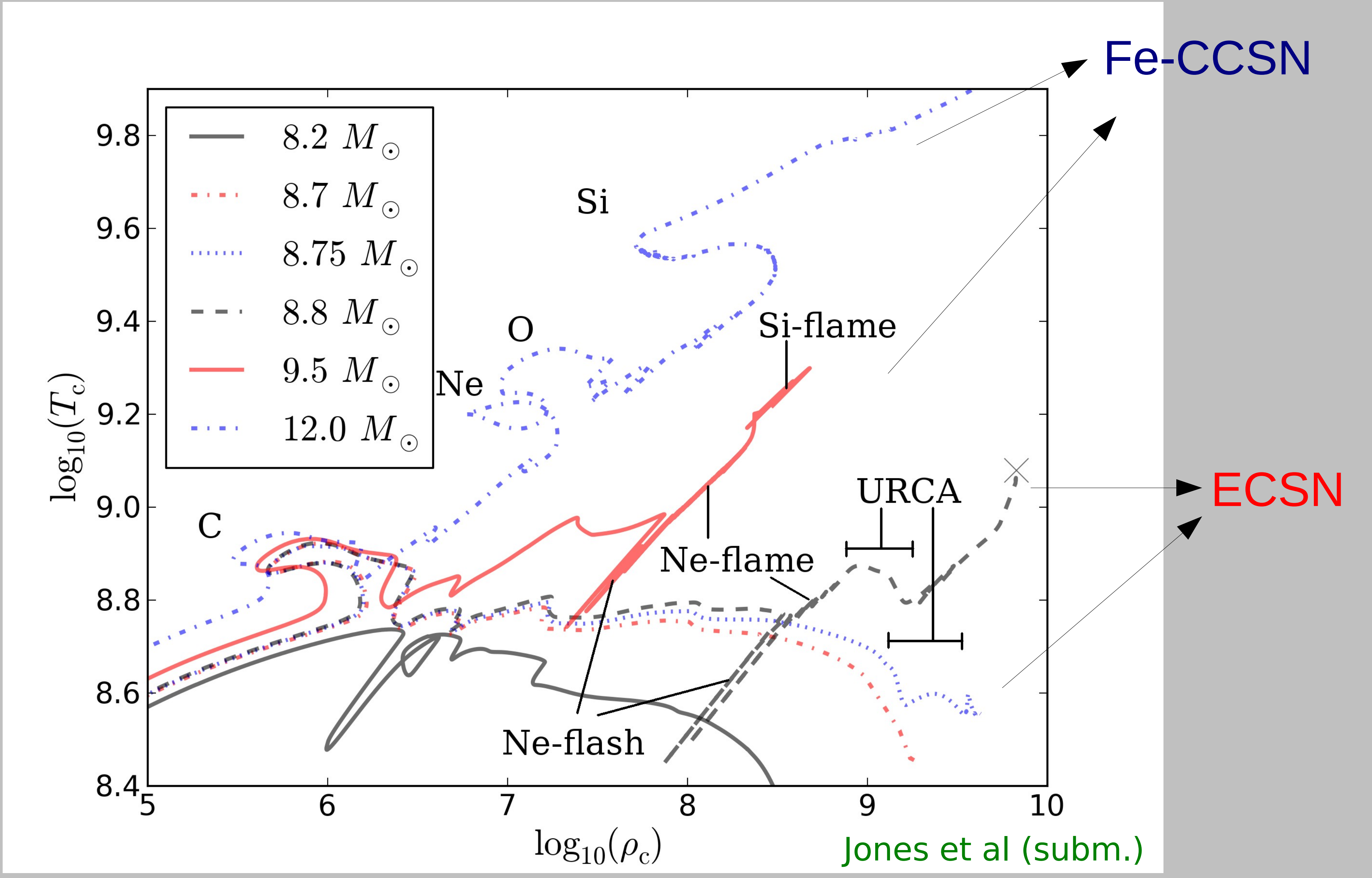
8.8 M_o failed massive star:



Jones et al (subm.)
See also Nomoto 84: case 2.6
Timmes et al 92,94
Eldridge & Tout 04

Ne-b. starts off-centre but does not reach the centre.
MESA → Oxygen deflagration
Agile-Bolztran for collapse + explosion Fischer et al (in prep)
Fate: ECSN

Fate of Least-Massive MS: ECSN/Fe-CCSN?



Both SAGB and failed massive stars may produce ECSN

Conclusions

- Mass loss crucial for evolution of massive stars!

- Mdot depends on phase, ROT, Z

- RSG Mdot uncertain, probably higher than previously thought

  → mass limit for RSG, WR, SNII

- LBV/RSG: Z-dep uncertain

- PCSN may occur for $Z < Z_{LMC}$

- PCSN would be SNIb/c, not SNIIn! SN2007bi ok; SN2006gy X

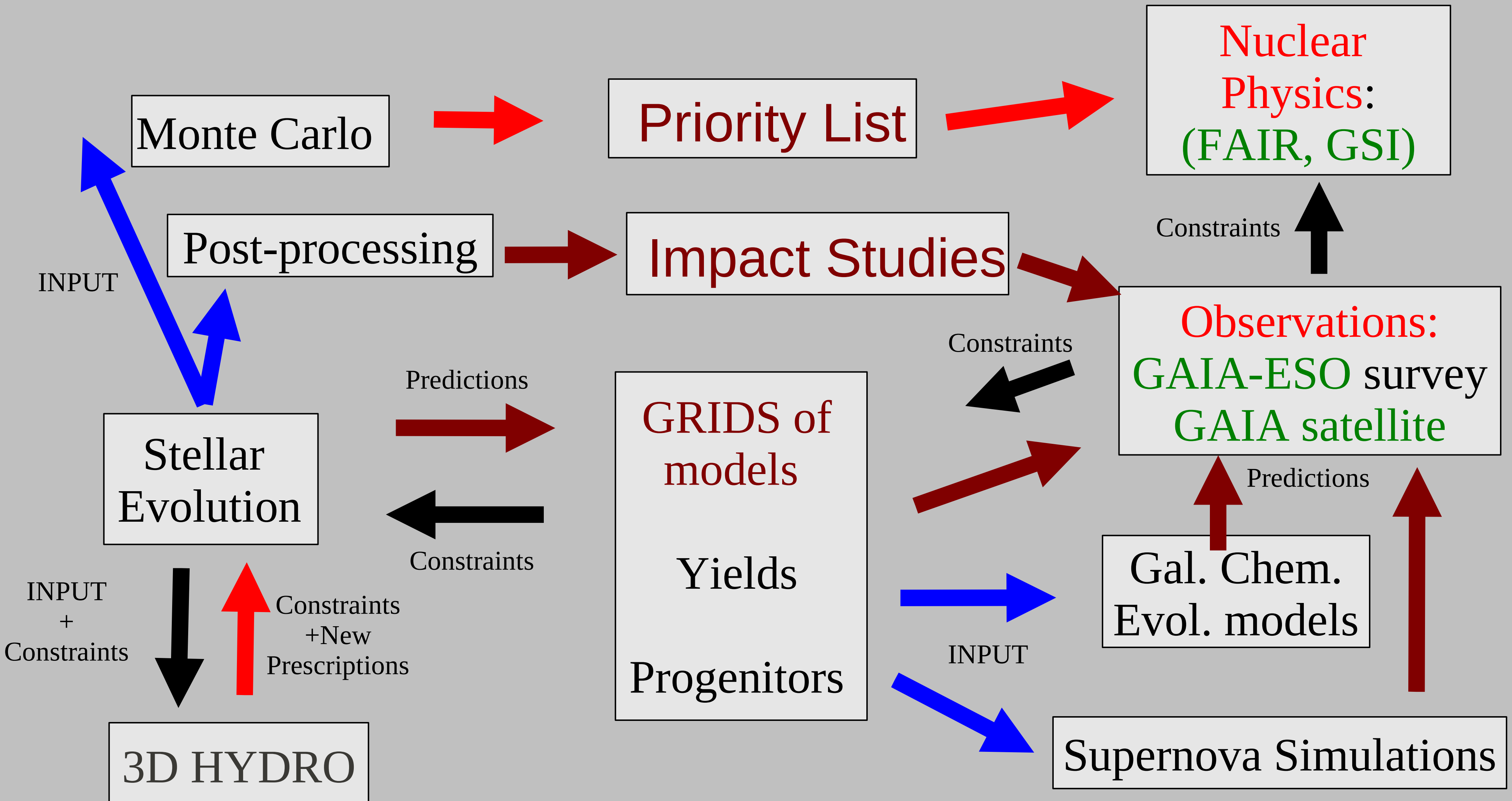
- ECSN: progenitor mass range study underway and promising

- Failed massive star is a possible new channel for ECSN

Stellar HYdrodynamics Nucleosynthesis & Evolution (SHYNE) Project

ERC Starting grant: 5 year; 2 Postdocs; 2 PhDs; 1000+ CPU cluster

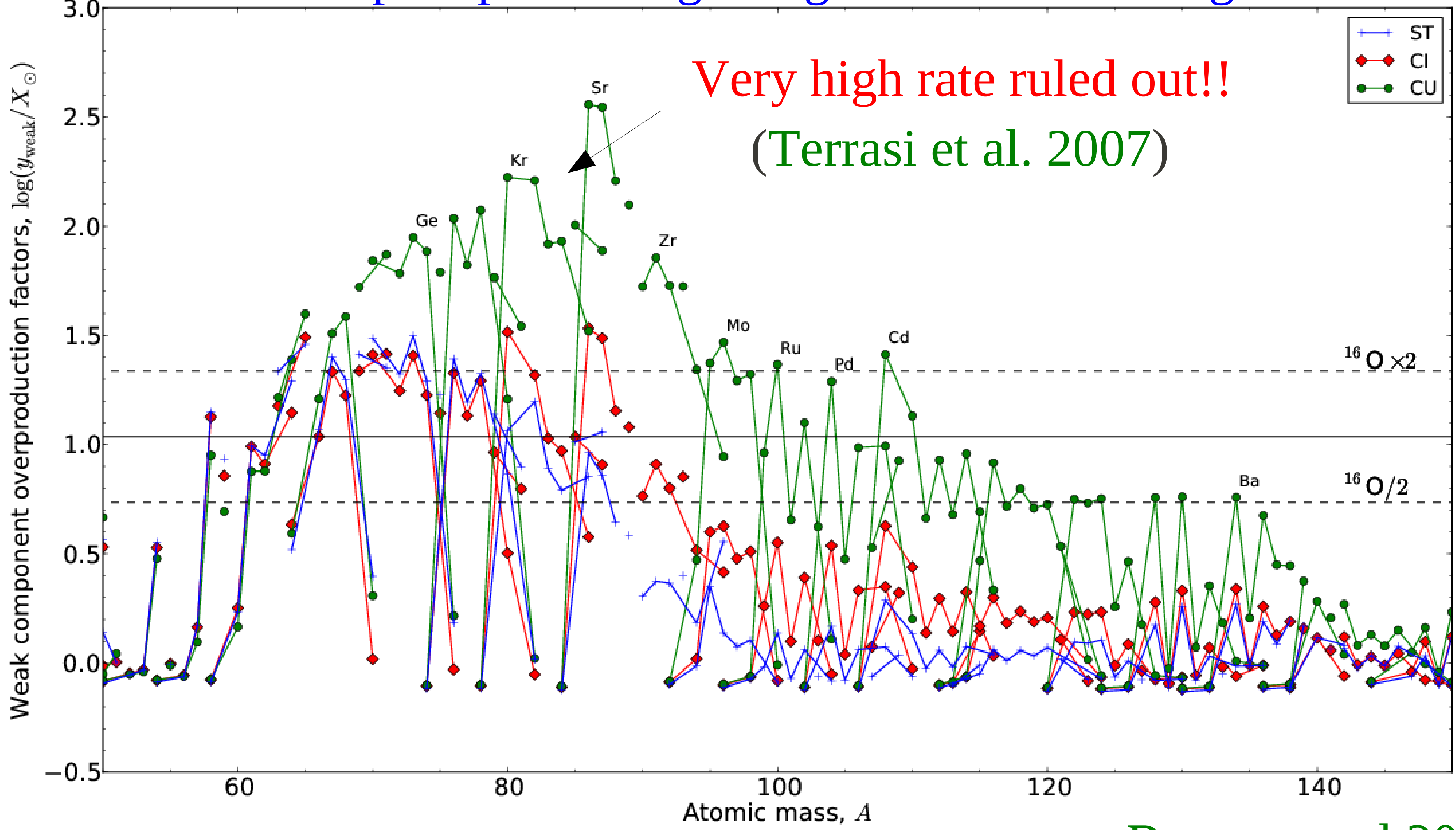
TOOL SUITE → DATASETS → IMPACT



- Efficient pipeline: nuclear/hydro/astro

Constraining Nuclear Physics with Stellar Evolution: ^{12}C-^{12}C rate, 3α

- Full stellar models + post-processing using MPPNP from Nugrid



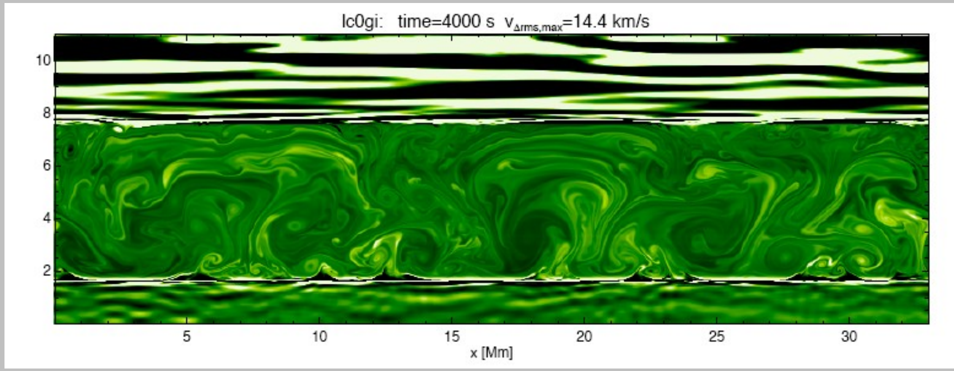
Bennett et al 2011

See Suda et al 2011 for a study constraining 3α reaction

Nugrid collaboration, see http://www.nugridstars.org/

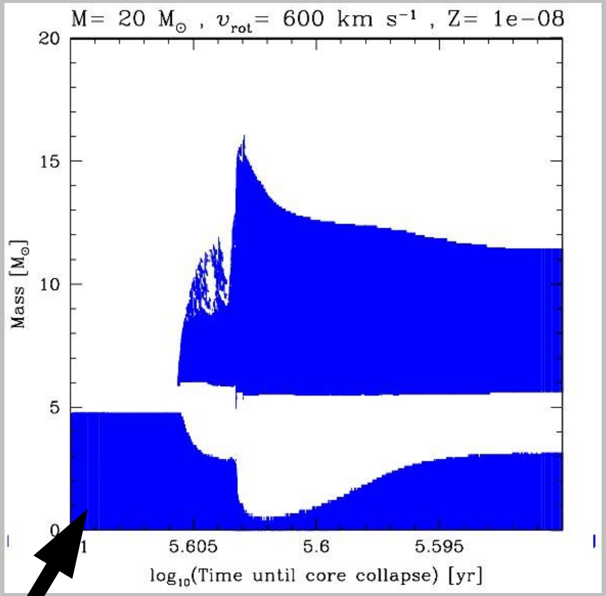
321D link

3D simulations

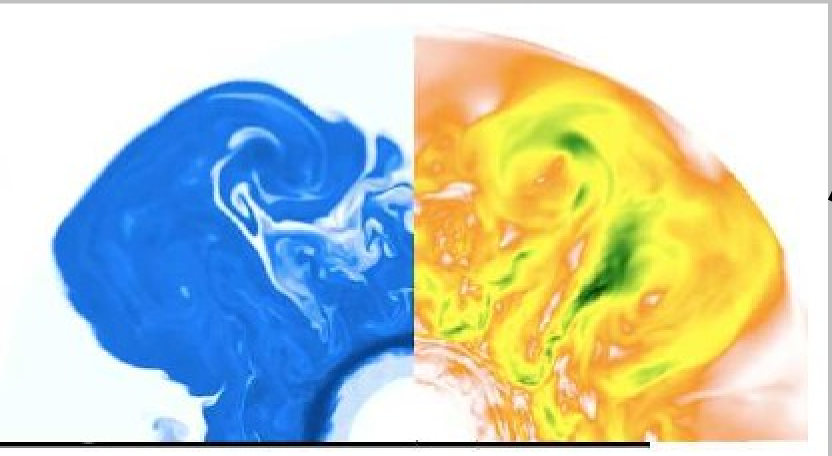


Herwig et al 06

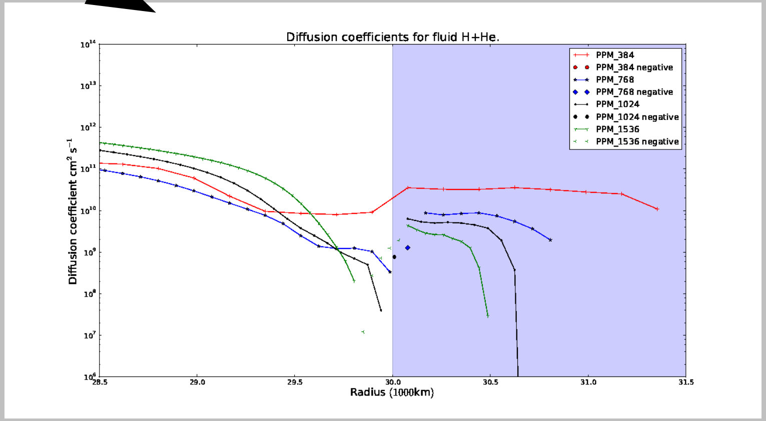
Uncertainties in 1D



e.g. Hirschi 07



e.g. Arnett & Meakin 2011
Mocak et al 2011, ...

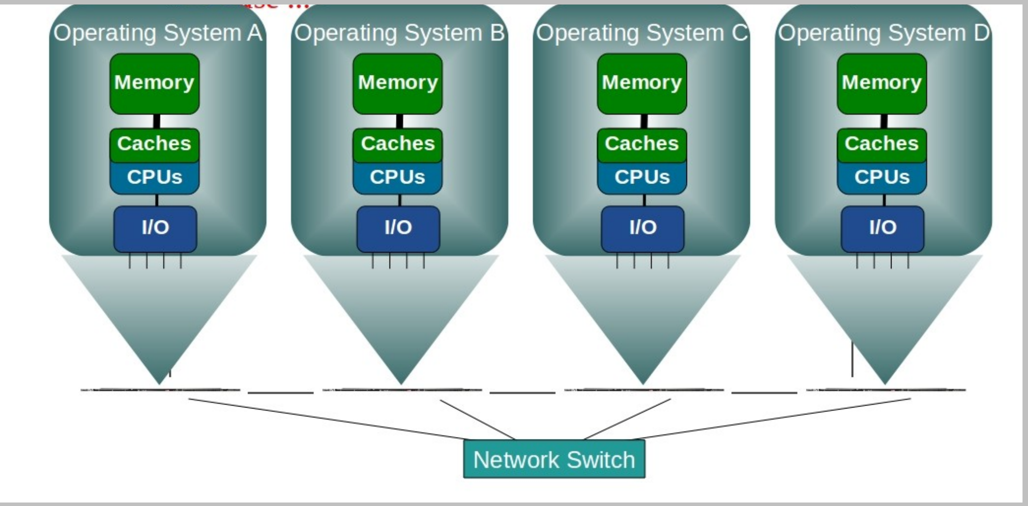


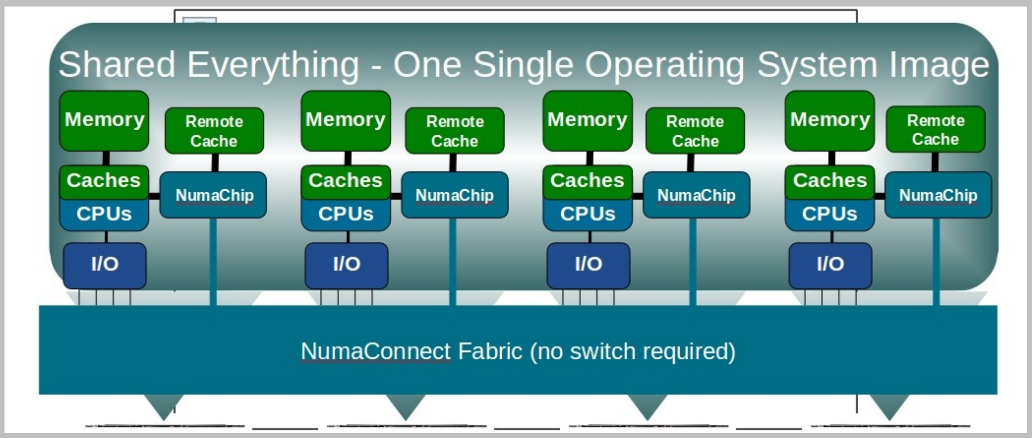
Meakin et al 2009 ; Bennett et al in prep

Determine effective diffusion (advection?) coefficient

Link with Industry

numascale Norwegian HPC company





FROM: distributed memory clusters

TO: scalable shared memory clusters

For the same cost!

- Super-desktop: single OS, 288 CPUs, RAM 576 GB
- Large scale: better balance between shared/distributed memory