Progenitors of electron-capture supernovae

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F.O.E., Raleigh, NC 01.06.15

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Outline

Why study 8-12 M⊙ stars, and what are ECSNe?

Can ECSNe occur? Should we care?

Physics in the 8-12 M⊙ range

Summary and open questions

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Progenitor evolution for ECSNe

(ONe core-collapse SNe)

Miyaji+ (1980); Nomoto (1984, 1987); Miyaji & Nomoto (1987); Ritossa+ (1999); Poelarends+ (2008); Jones+ (2013); Takahashi+ (2013)

1. Formation of degenerate ONe core through C-burning

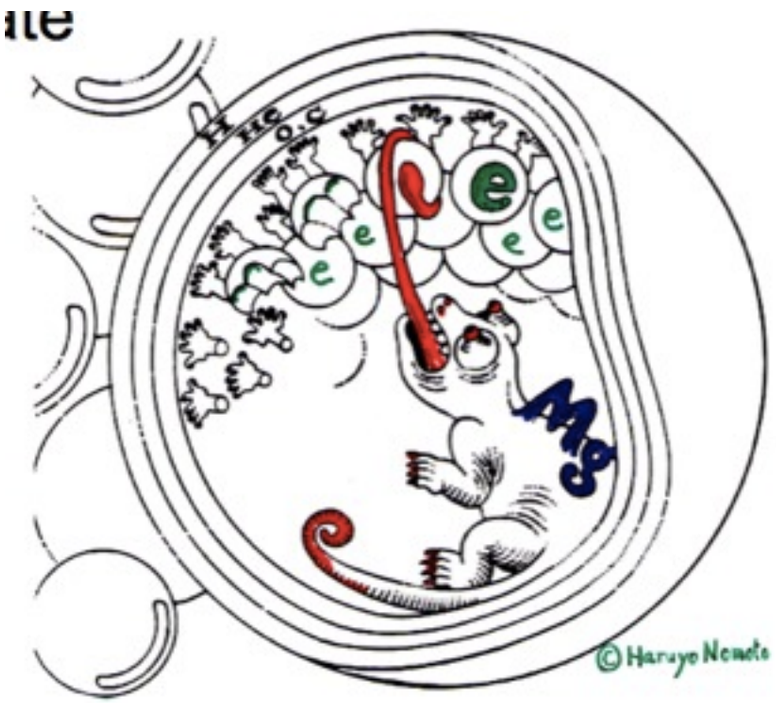
2. Growth of core towards M_{Ch}

3. Electron capture by ^{24}Mg

3. Central density reaches ϱ_{crit} : $\mu_e = Q(^{20}Ne \rightarrow {}^{20}F)$

4. Double e^--captures instigate collapse and heat the material to O-ignition

5. O-deflagration leaves NSE ash, which also captures electrons



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Progenitor evolution for ECSNe

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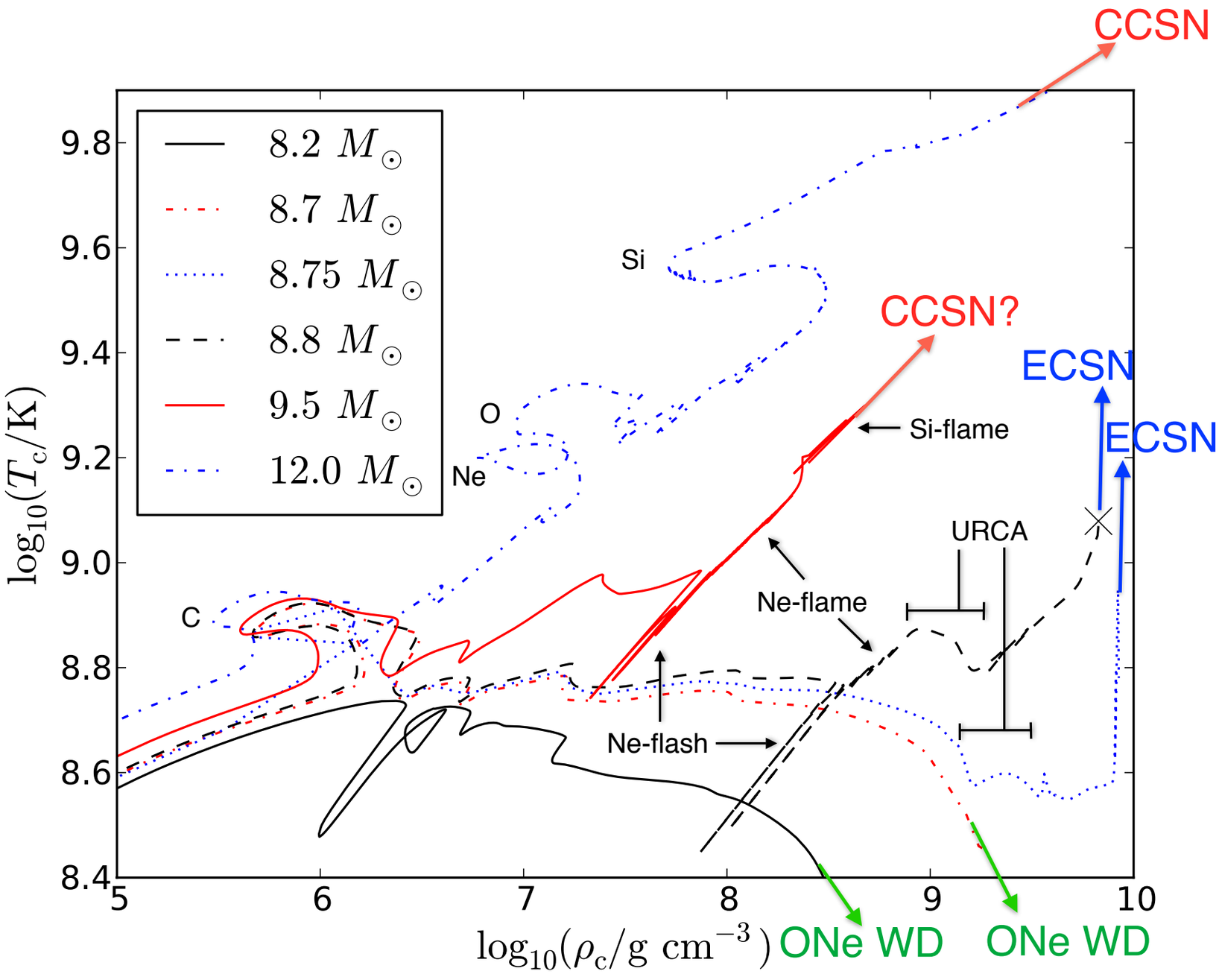
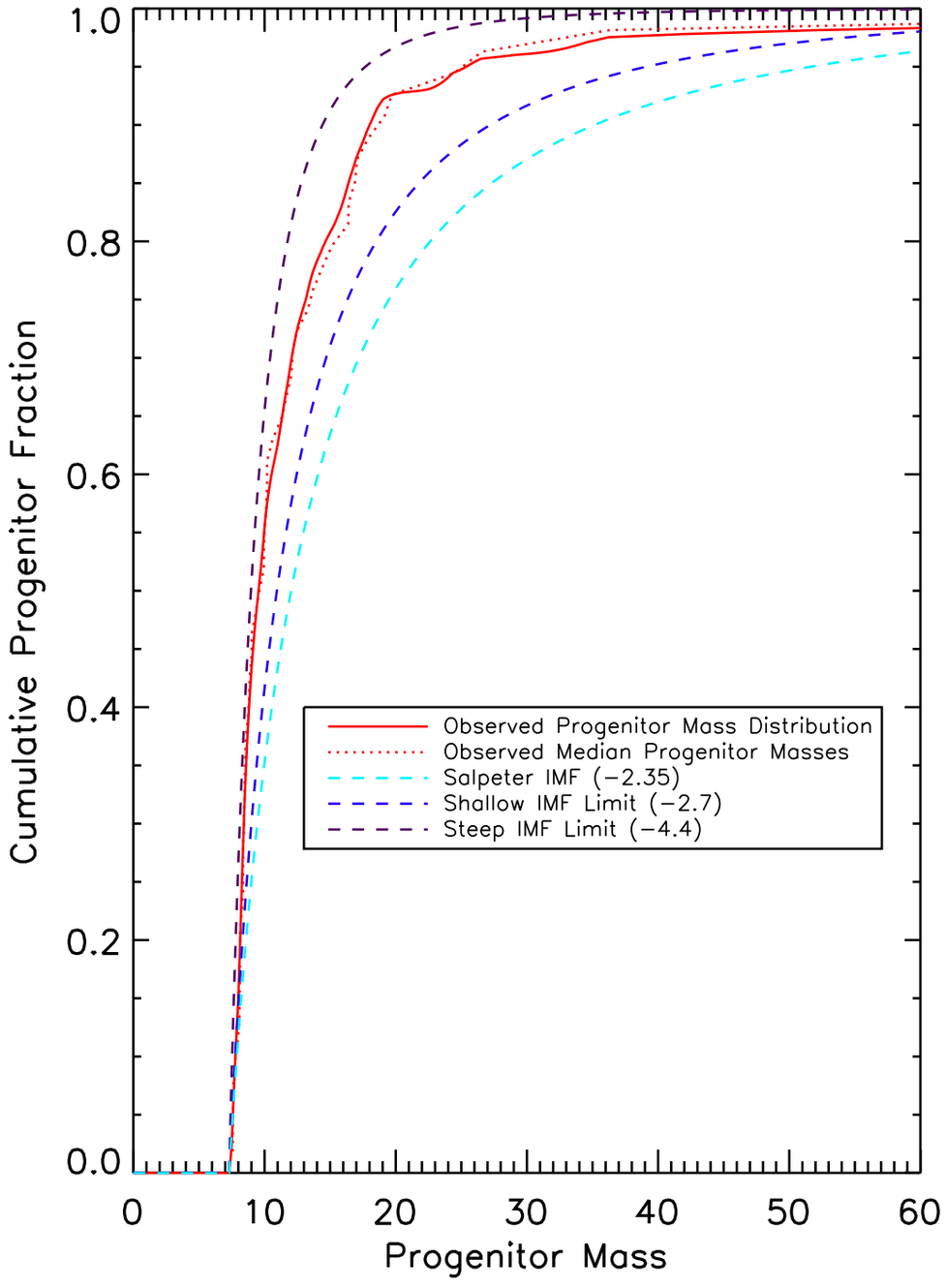


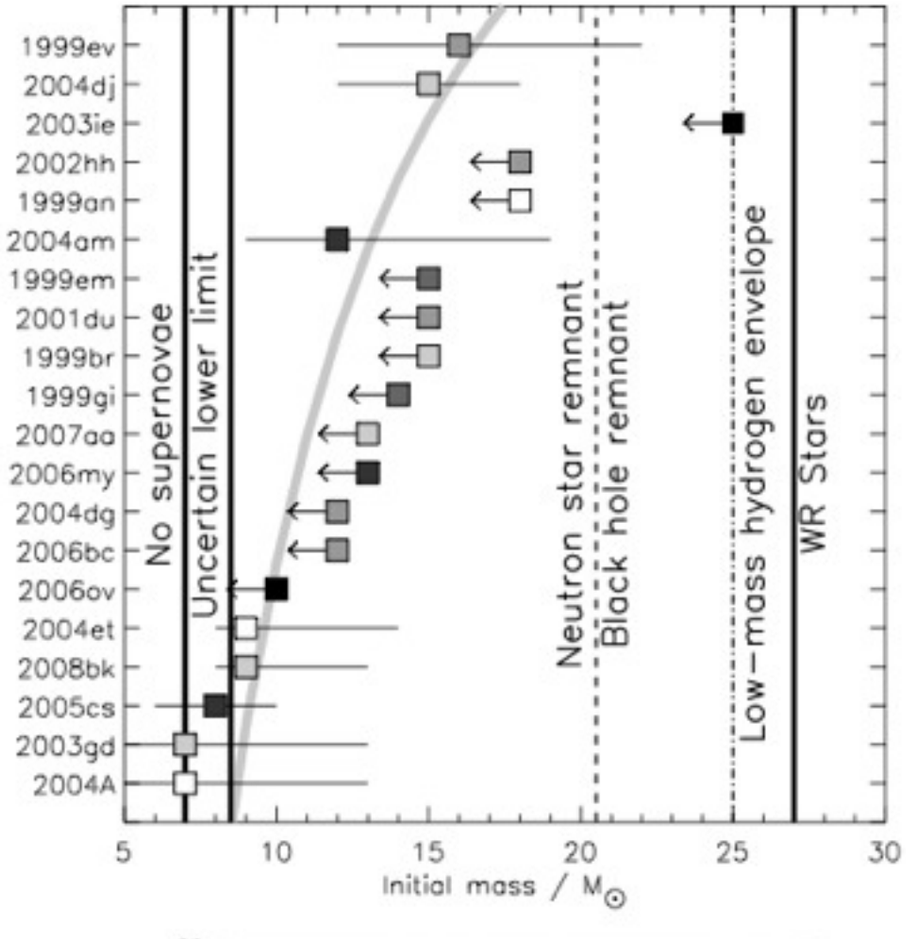
Jones+ (2013)

Why 8-12 M⊙?

- α=-2.35 ⇒ N(8-12 M⊙)/N(M>8 M⊙) = 0.42

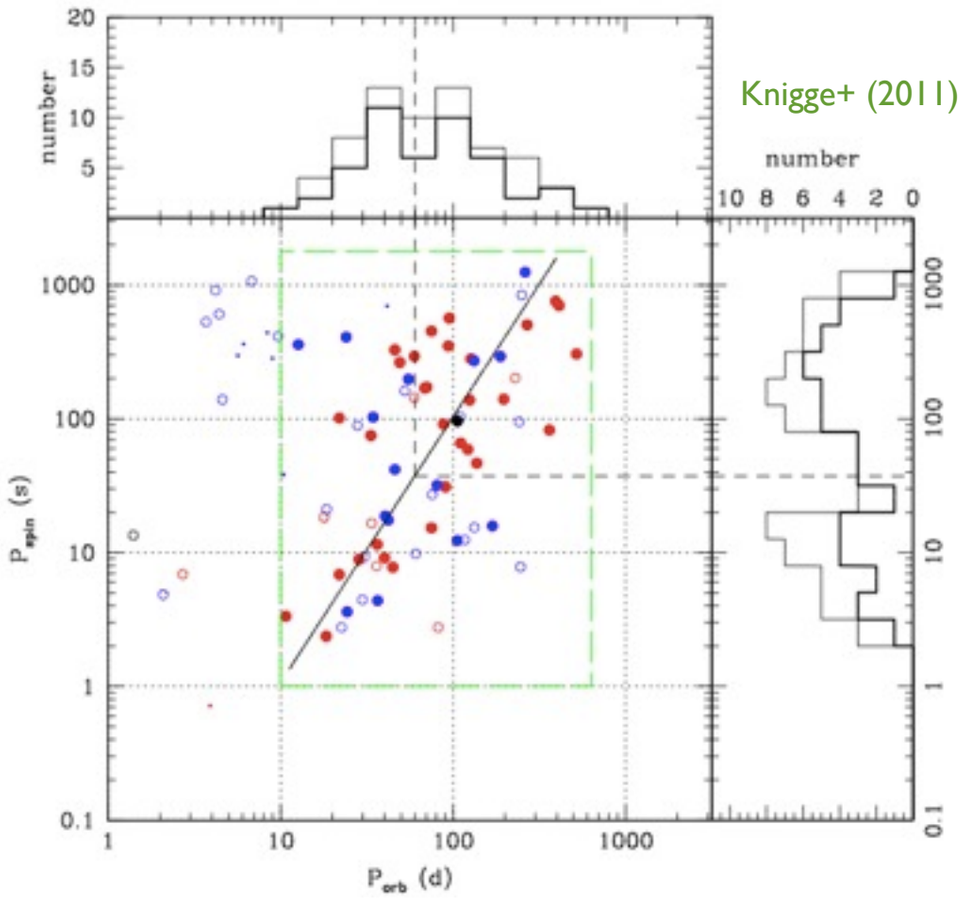


Jennings+ (2012)



Smartt+ (2009)

See Scott Adam's poster



Knigge+ (2011)

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Why 8-12 M⊙?

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THE *r*-PROCESS IN COLLAPSING O/Ne/Mg CORES

J. CRAIG WHEELER,[1] JOHN J. COWAN,[2] AND WOLFGANG HILLEBRANDT[3]

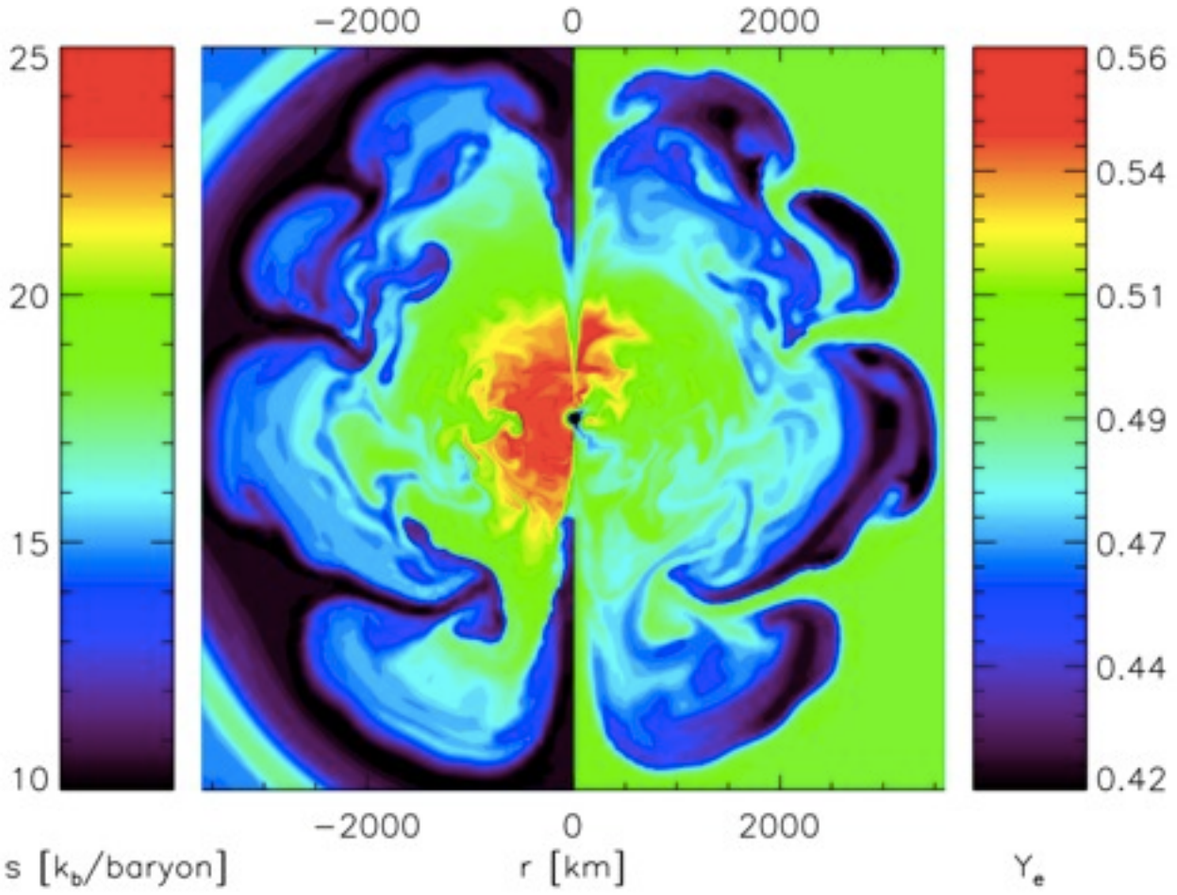
Received 1997 September 17; accepted 1997 November 21; published 1998 January 14

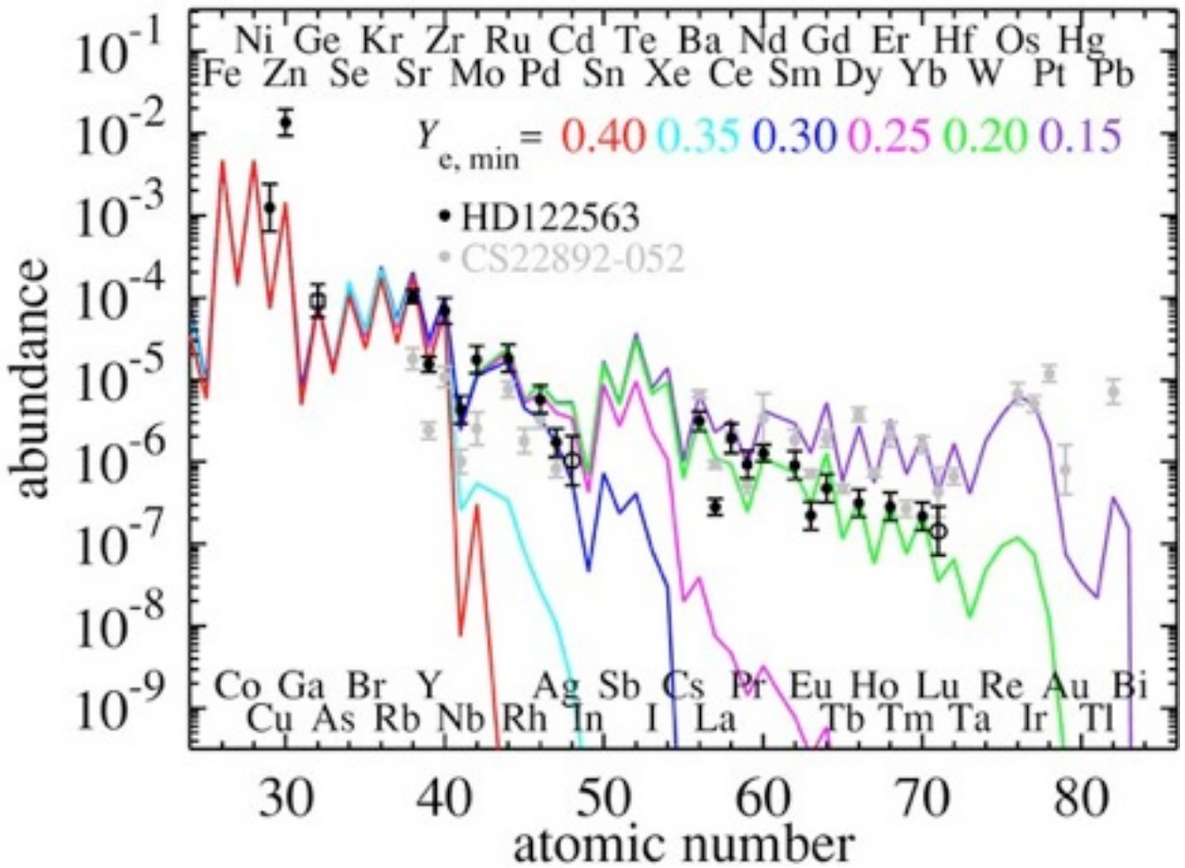
ApJ 493:L101–L104, 1998

Explosions of O-Ne-Mg cores, the Crab supernova, and subluminous type II-P supernovae

F. S. Kitaura, H.-Th. Janka, and W. Hillebrandt

A&A 450, 345–350 (2006)





Wanajo+ (2011)

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Why 8-12 M⊙?

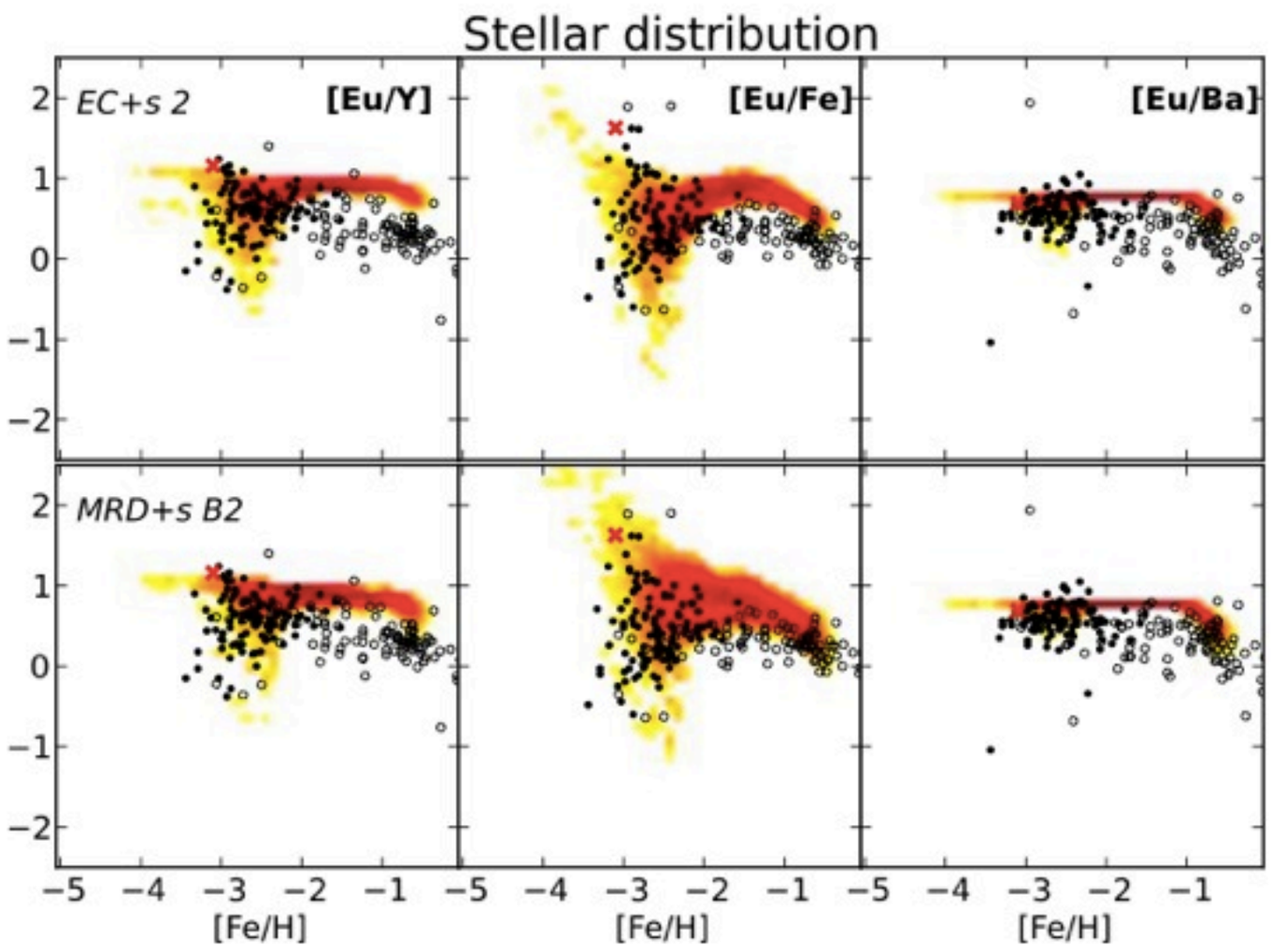
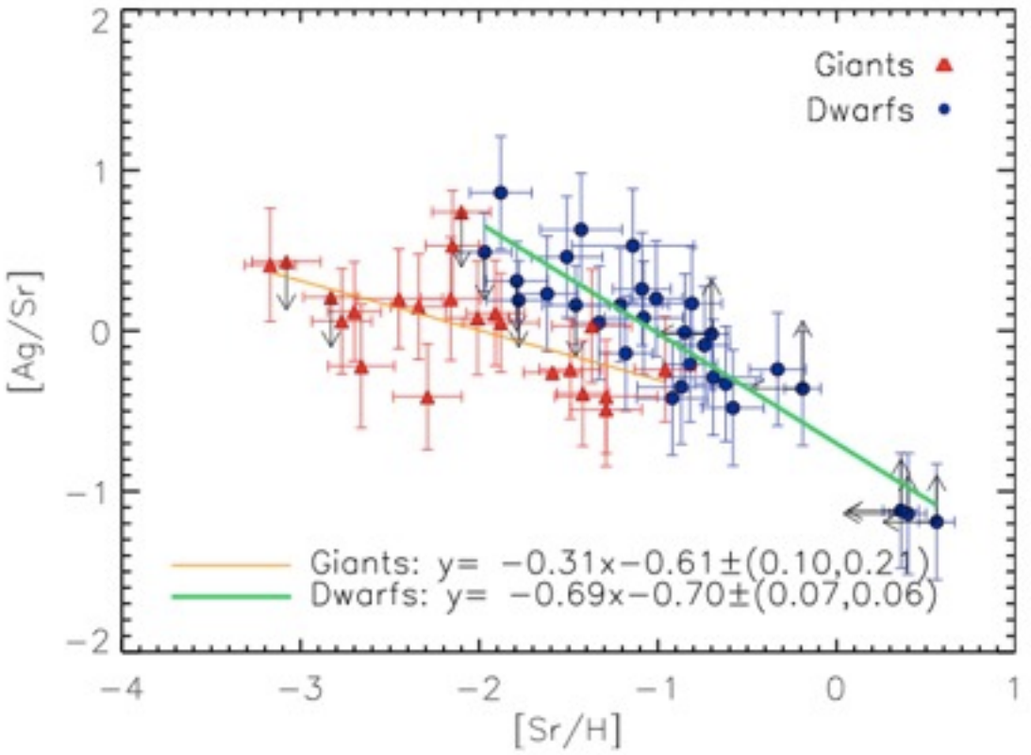


Fig. 4. From the left [Eu/Y], [Eu/Fe] and [Eu/Ba] vs [Fe/H] in the halo; the density plot is the distribution of simulated long-living stars for our halo models, see bar below Fig. 1 for the color scale; the data are the same as Fig. 1.

Cescutti & Chiappini (2014)



Hansen+ (2012)

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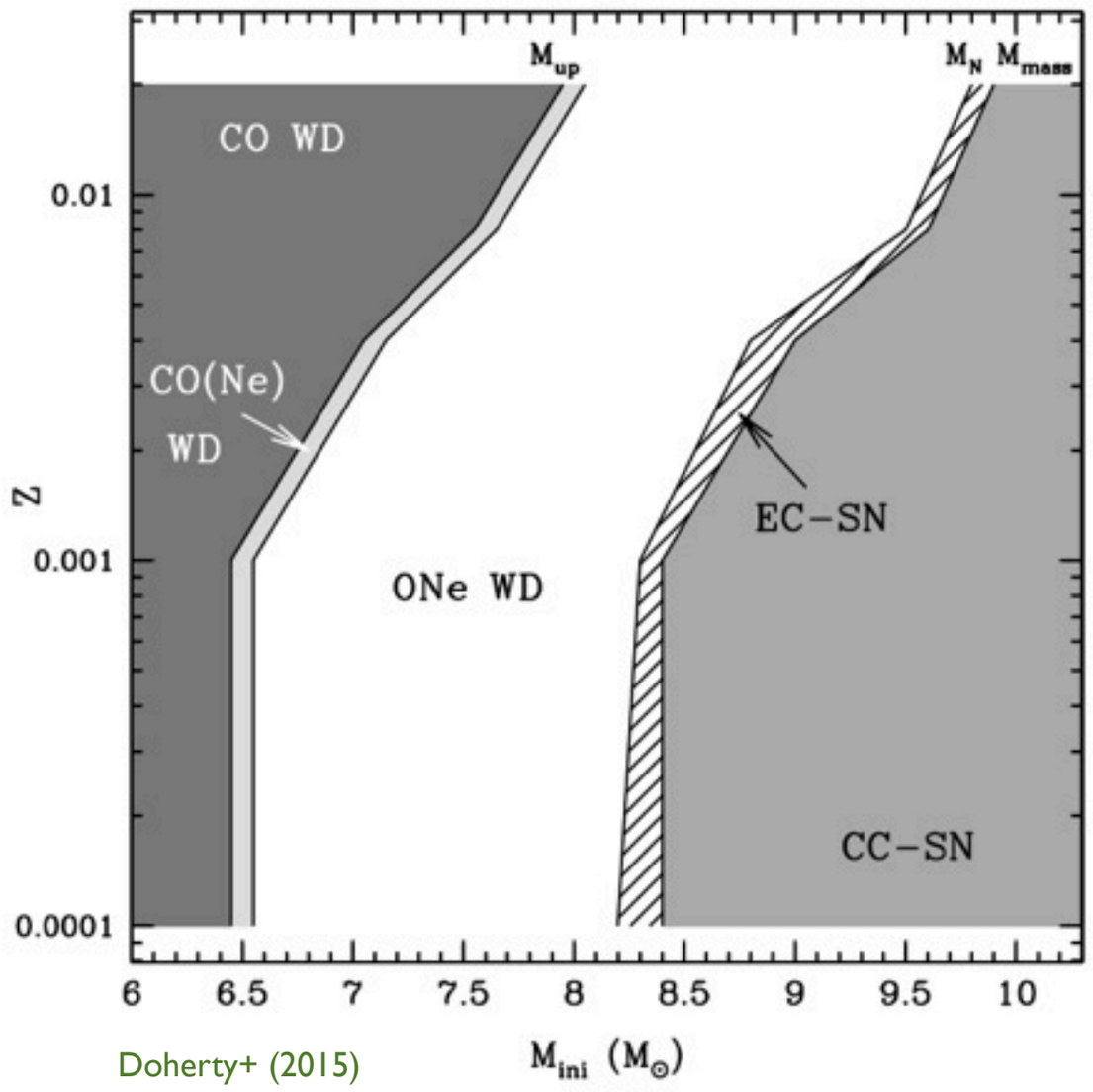
Initial mass range for ECSNe



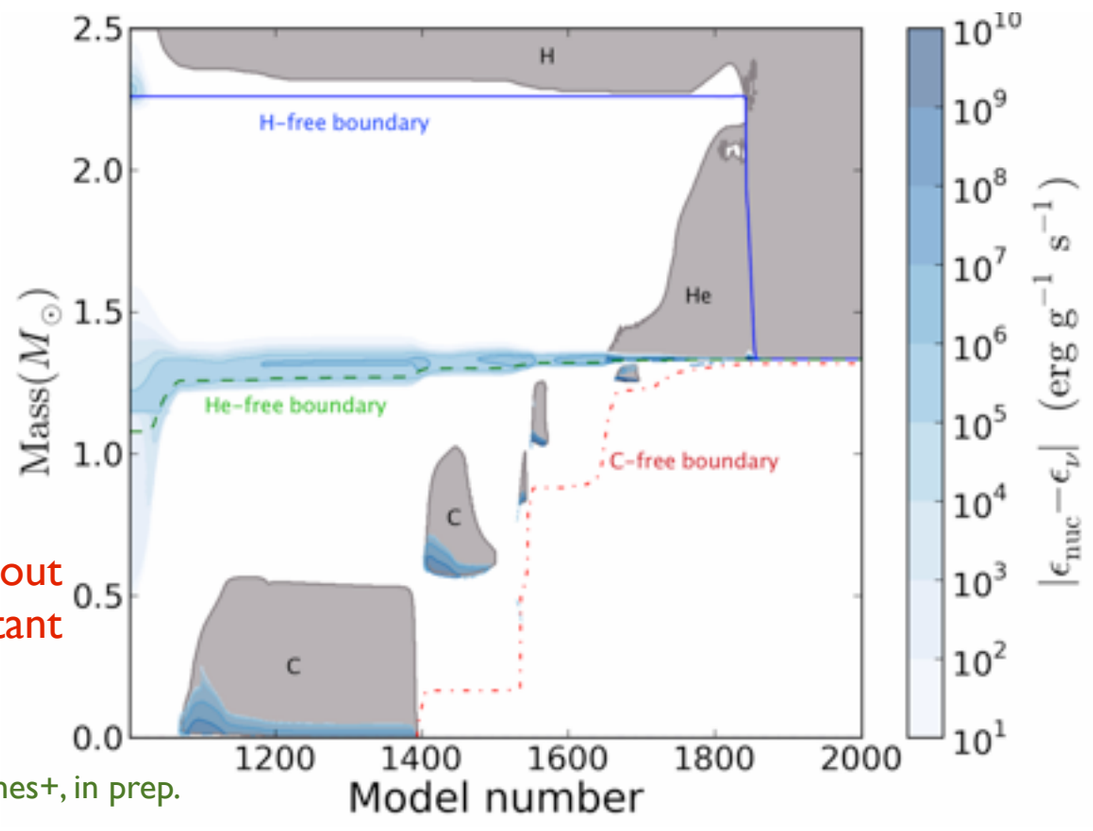
Doherty+ (2015)

TABLE 3

INITIAL MASS LIMITS FOR ECSNe AND RATIO OF ECSNe TO SNe AS A FUNCTION OF THE DREDGE-UP EFFICIENCY AND MASS-LOSS PRESCRIPTION

	λ = parameterized			$\lambda = 0$		
SOURCE	M_{low} ($M_\odot$)	M_{high} ($M_\odot$)	% EC	M_{low} ($M_\odot$)	M_{high} ($M_\odot$)	% EC
Reimers ($\eta = 4$)	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
vL05	9.00	9.25	3.6	8.76	9.25	7.1

Poelarends+ (2008)



Jones+, in prep.

H-burning during dredge-out likely dynamically important

- Contribution from "failed massive stars"?

MESA model of dredge-out in a 7 Mo Z=0.001 star

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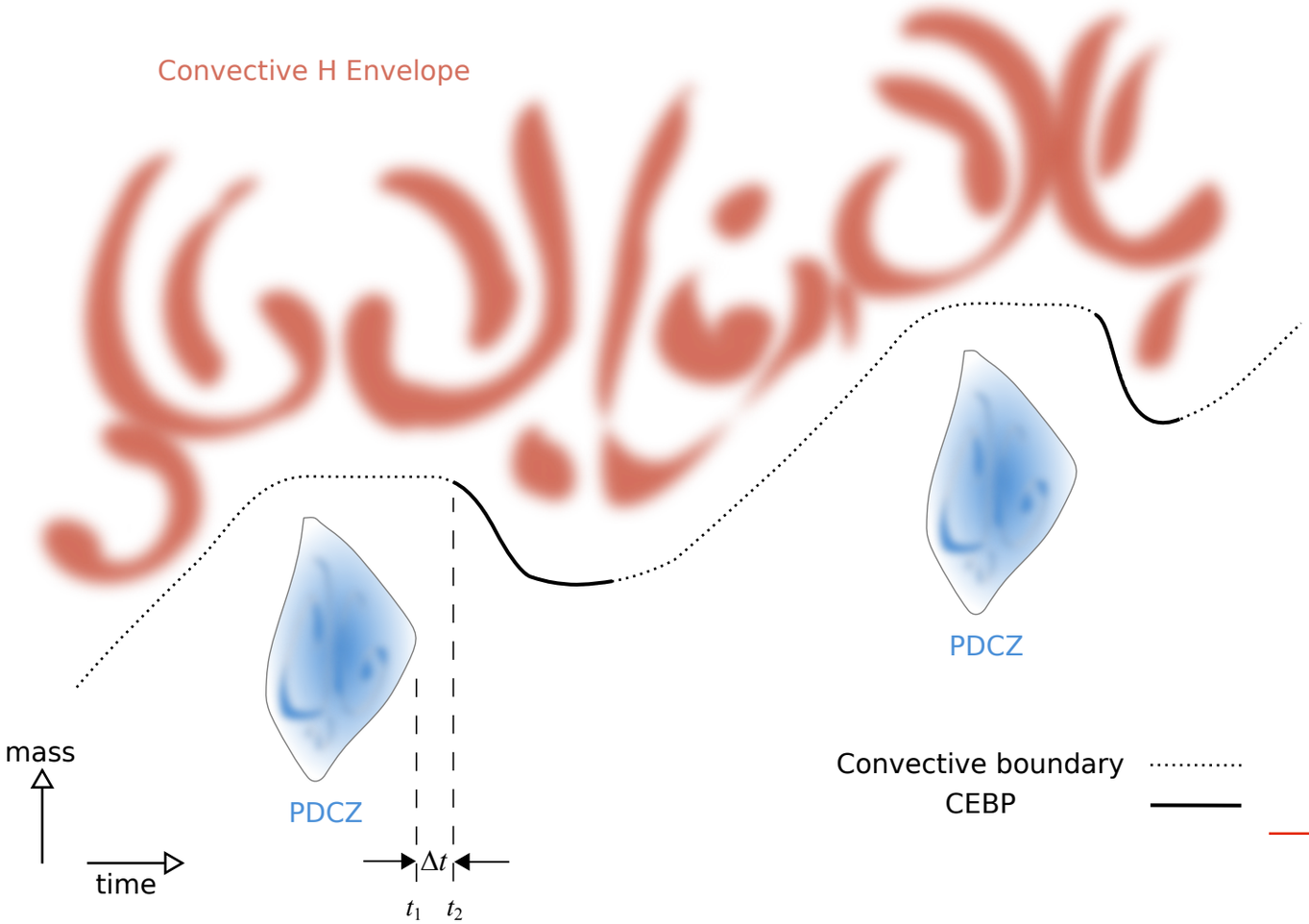
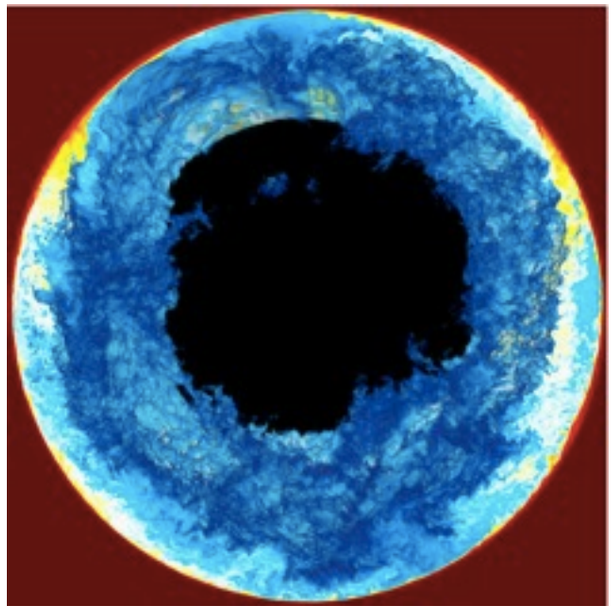
Other complications in super-AGB stars





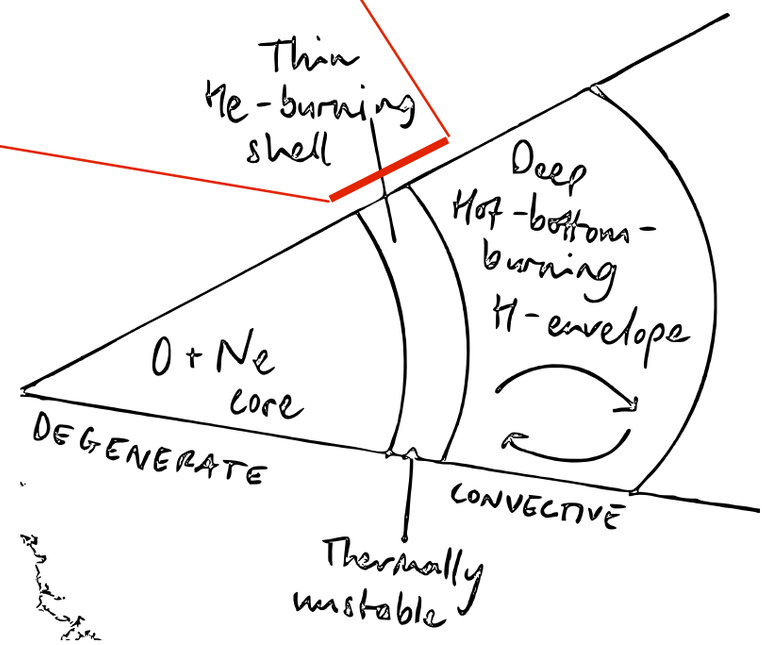
Herwig+ (2014)

t_1 : switching off of pulse-driven convection zone (PDCZ)
t_2 : beginning of convective envelope base penetration (CEBP)

see also Justin Brown's poster

Jones+, in prep.

see also Mowlavi (1999)



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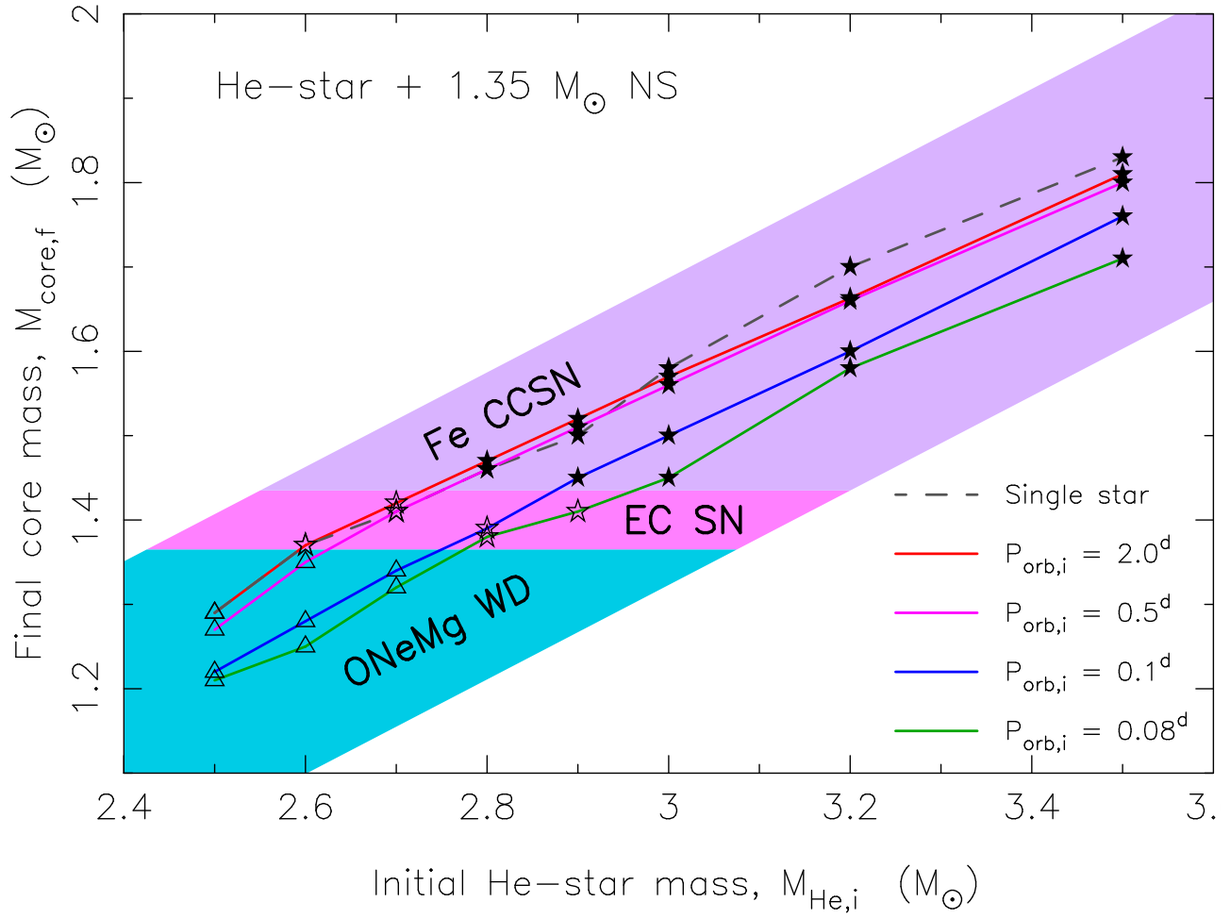
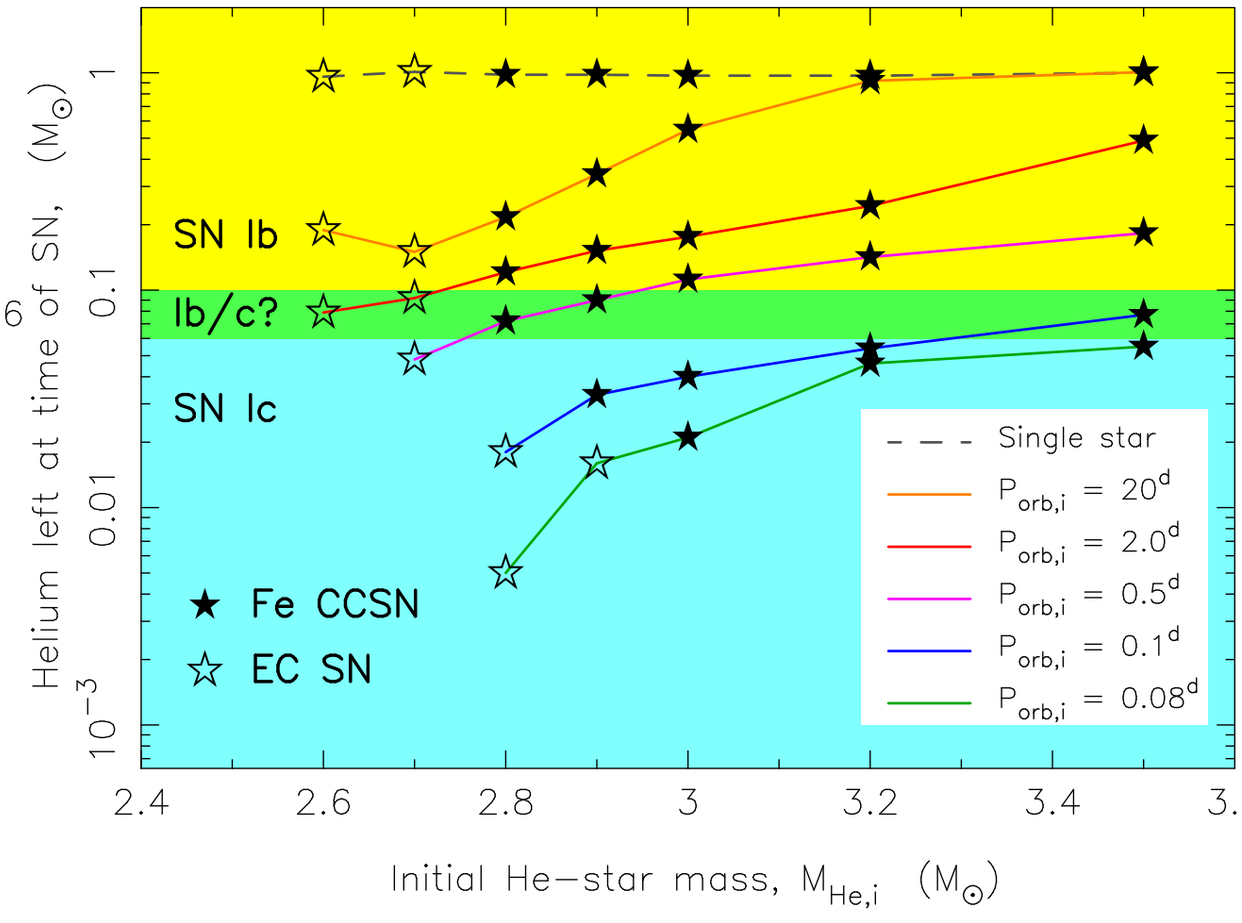
ONe core collapse in X-ray binaries



Tauris, Langer & Podsiadlowski (2015)



Helium stars formed in HMXB systems do not suffer from the same issues as single-star progenitors

However, these supernovae will be of type Ib/c

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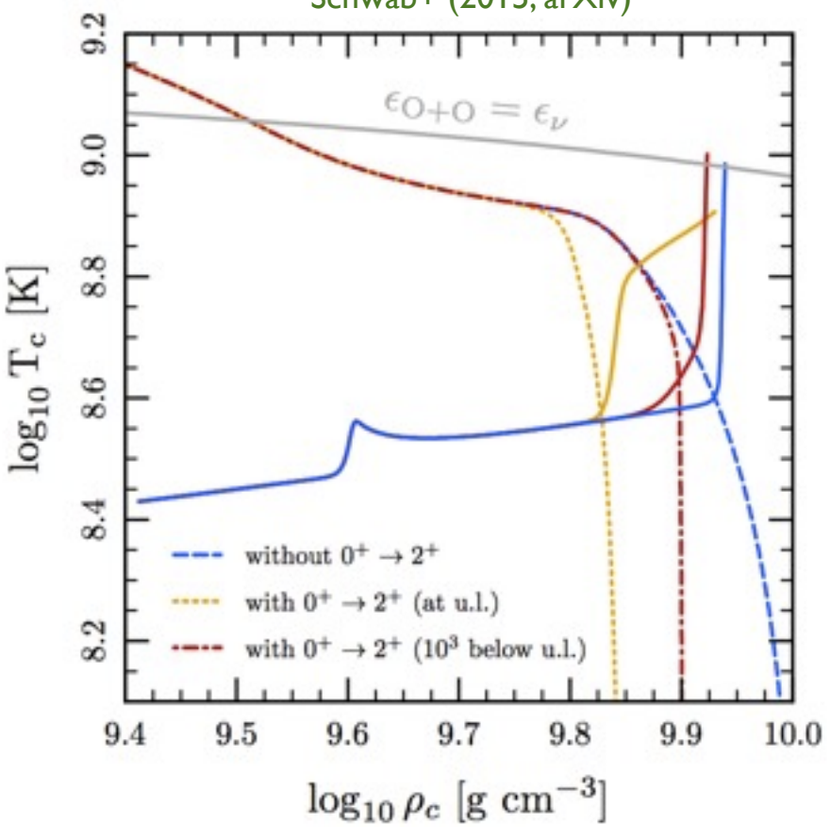
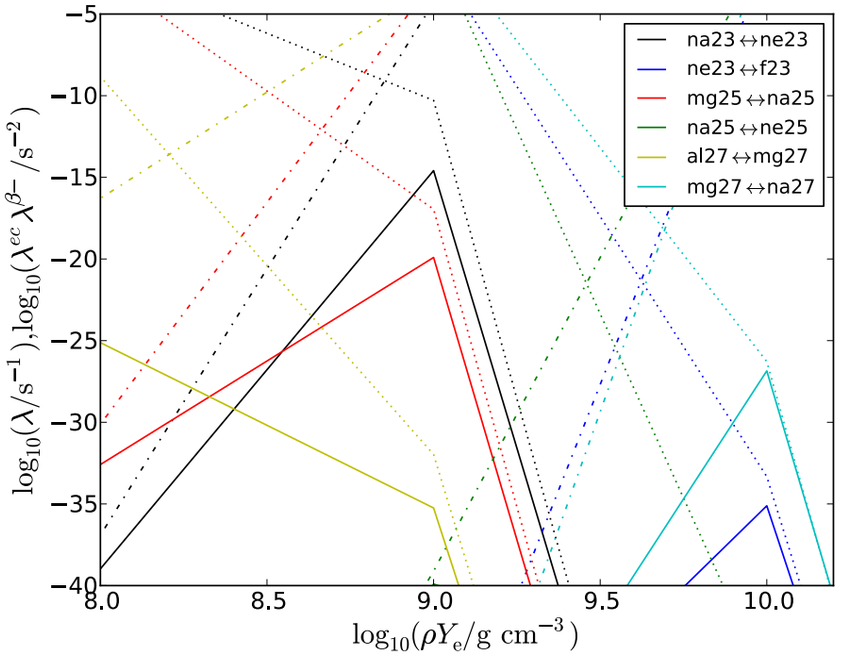
Nuclear reactions in ONe CC progenitors

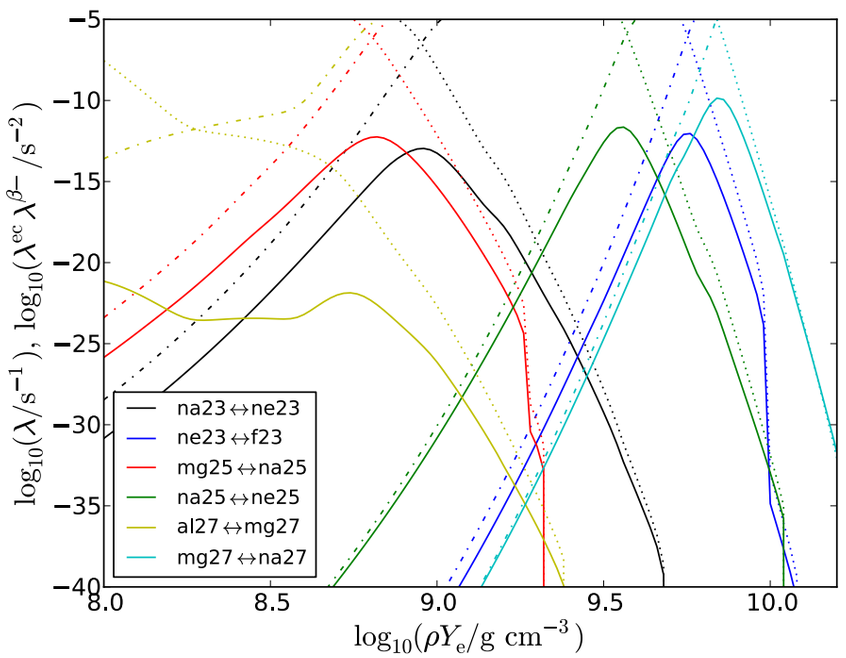
Schwab+ (2015, arXiv)



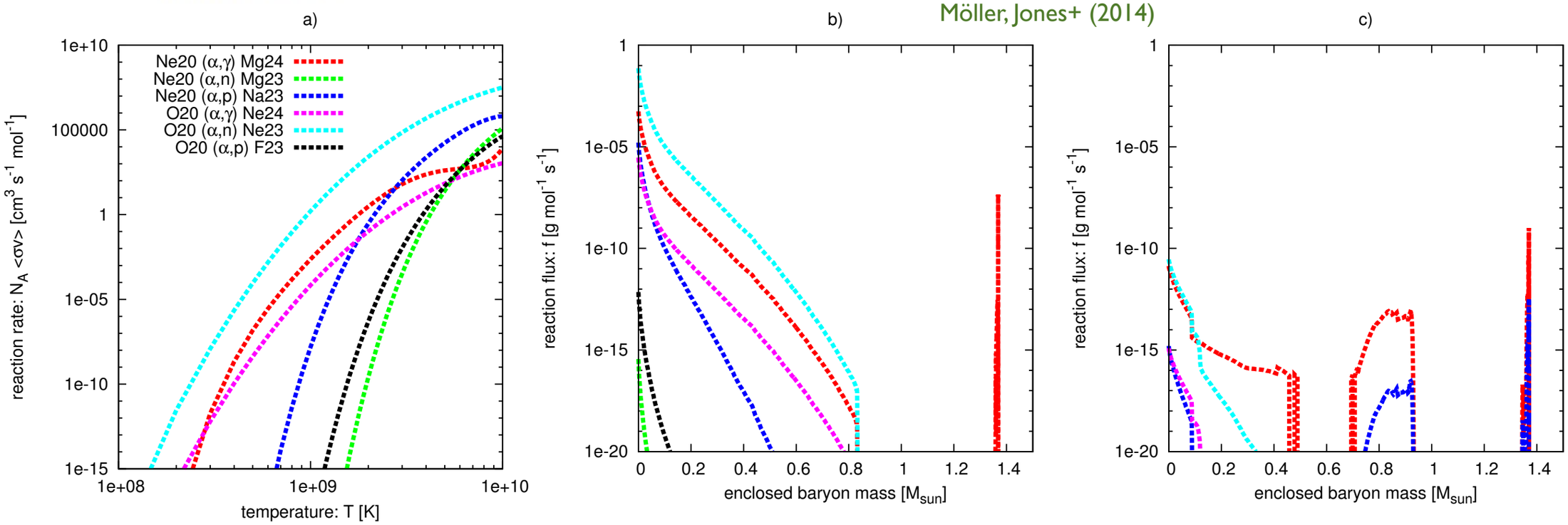
Oda+ (1994)



Toki, Jones+ (2013)



Möller, Jones+ (2014)



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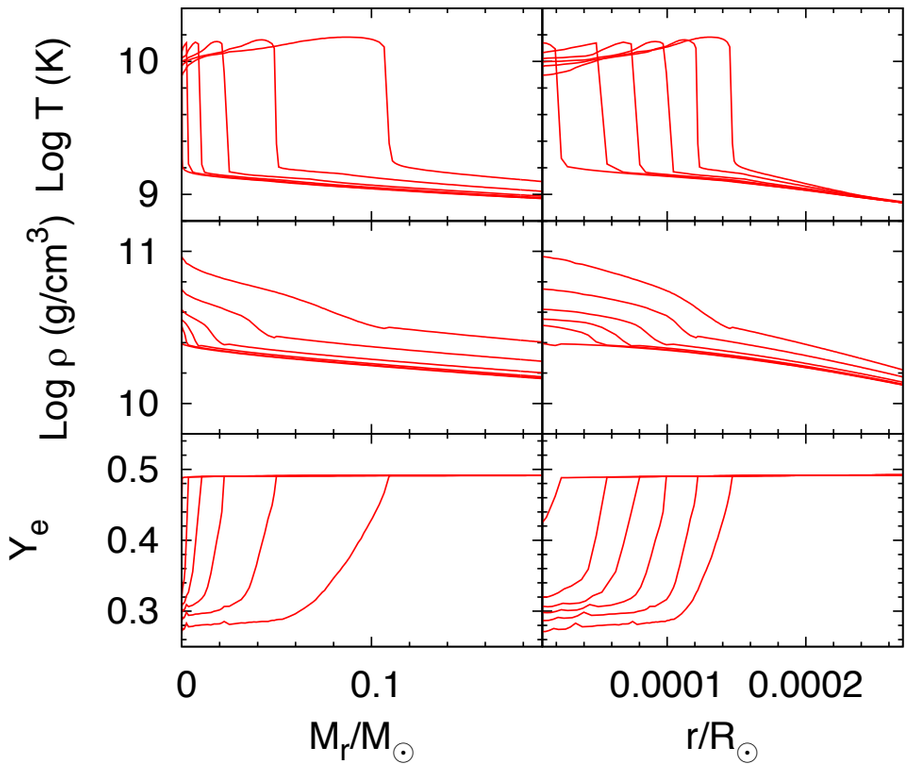
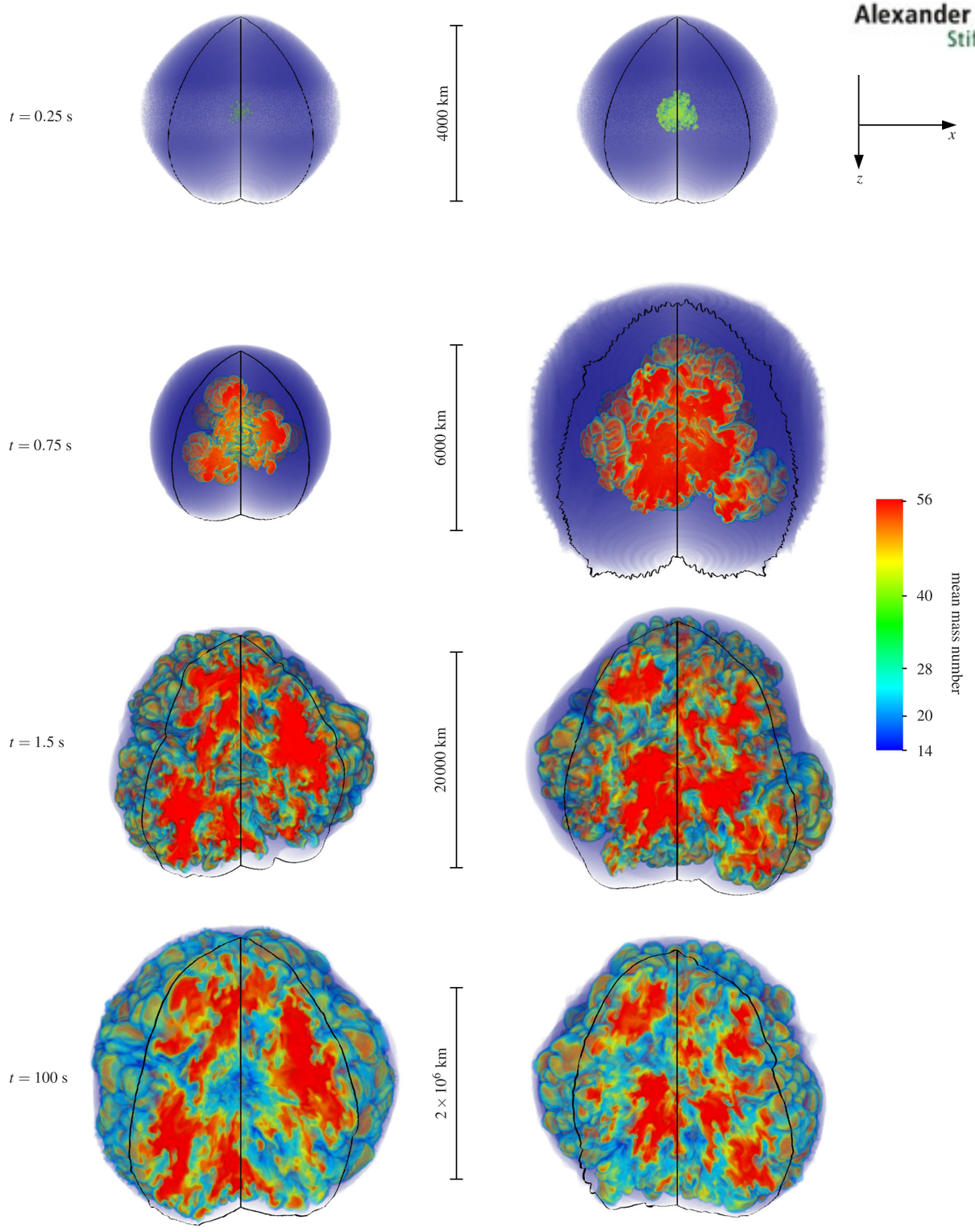
O-deflagration?

Takahashi+ (2013)



Central, one-point ignition?

Interaction with URCA shells?



Carbon deflagration, Fink+ 2014

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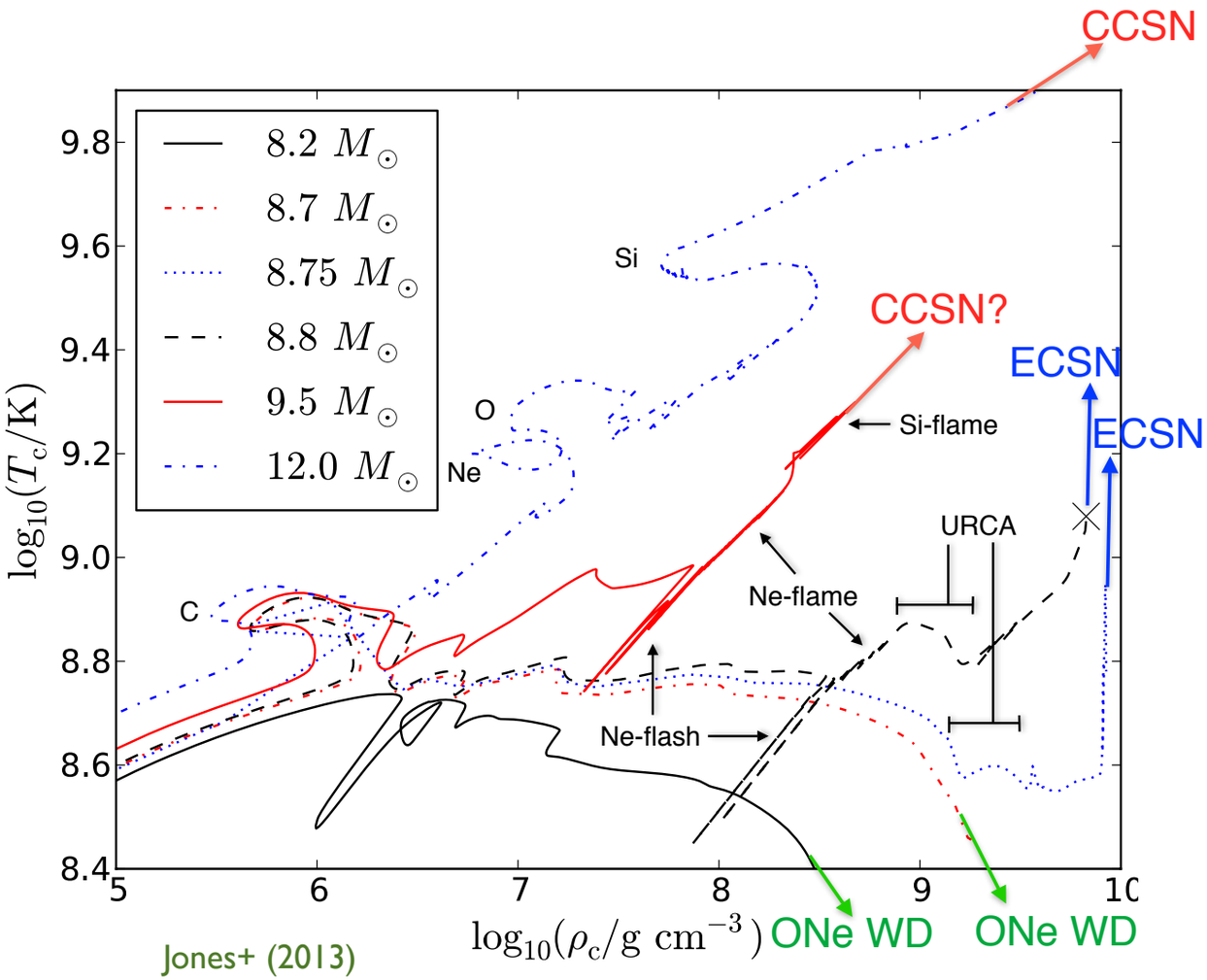
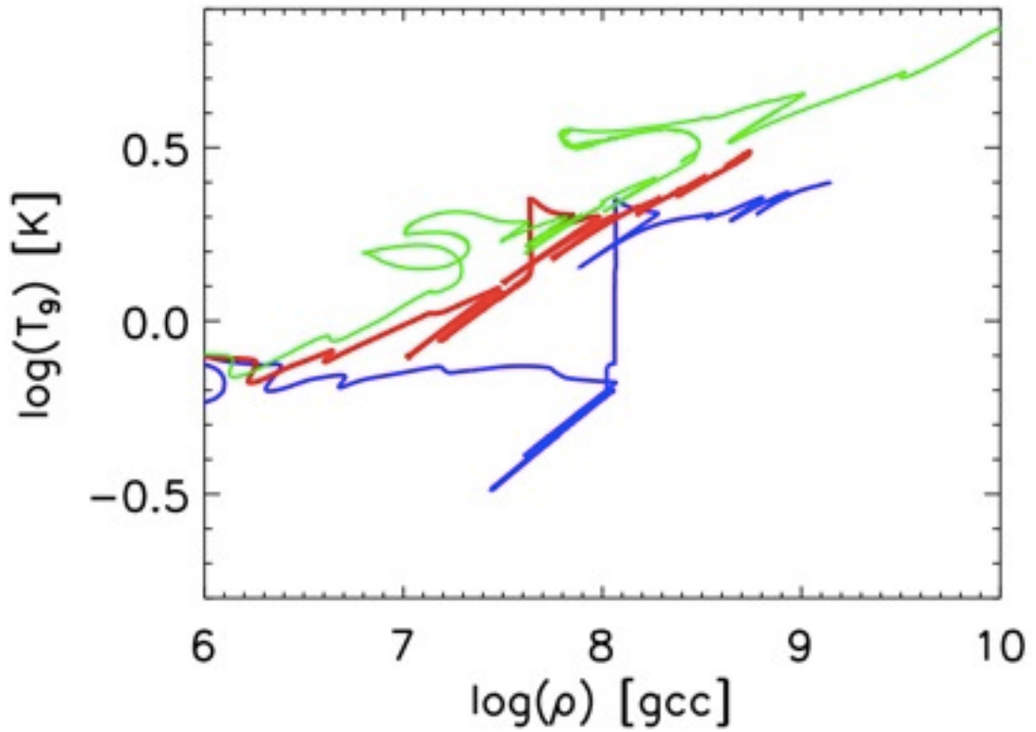
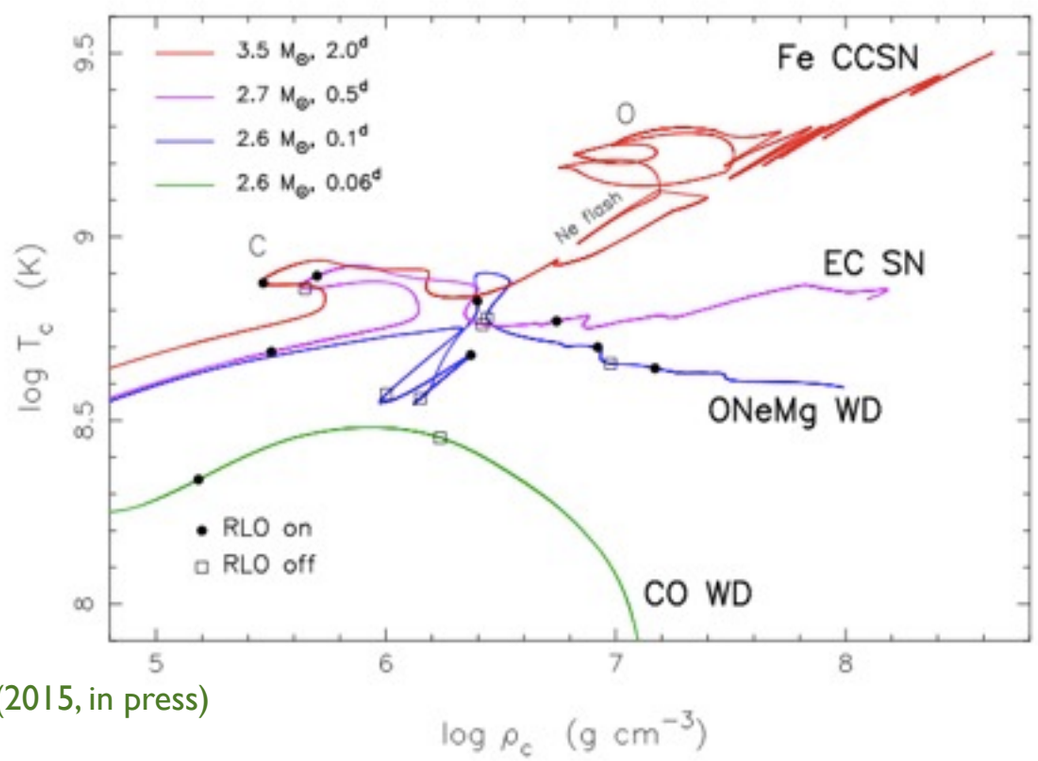
Off-centre ignition in 8-10 M⊙ stars



Jones+ (2013)



Woosley & Heger (2015, arXiv)



Tauris+ (2015, in press)

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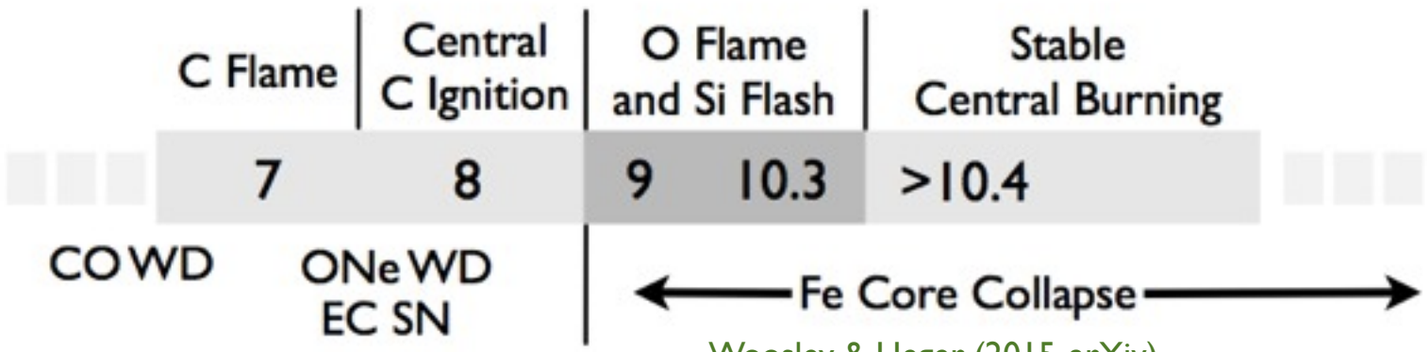
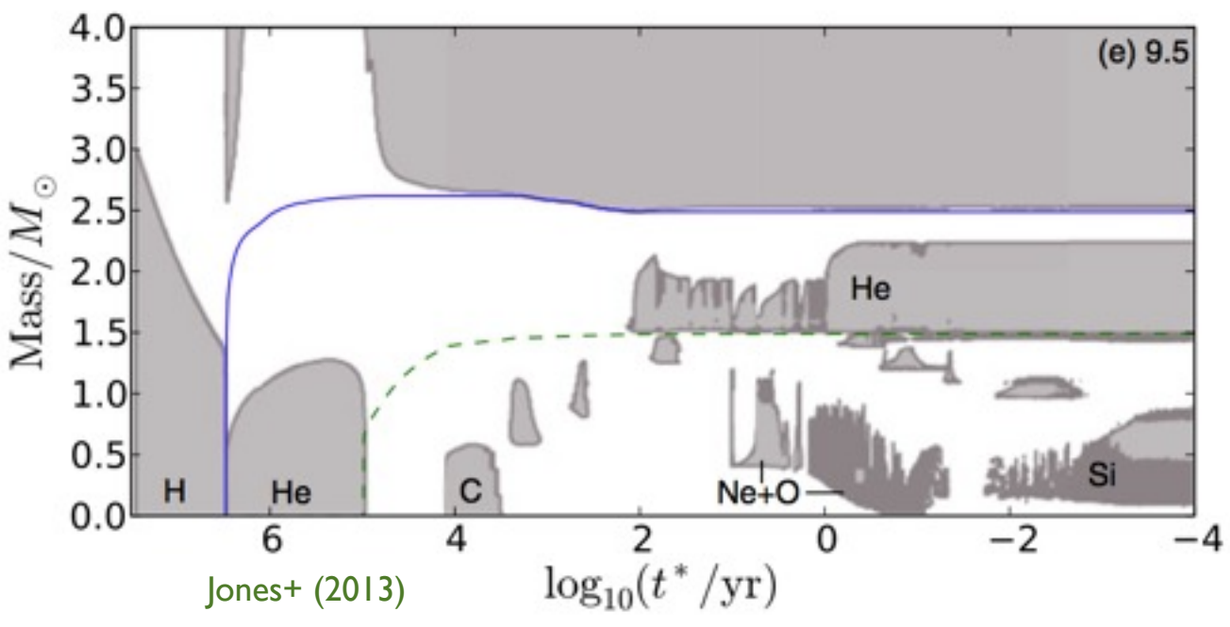
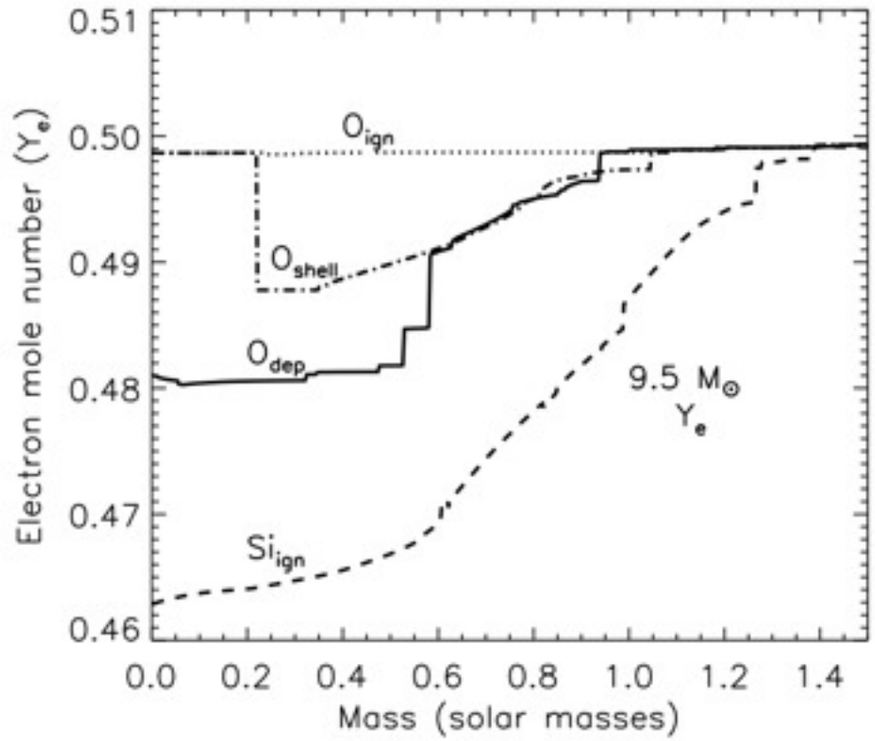
Oxygen CBFs (convectively bound flames)



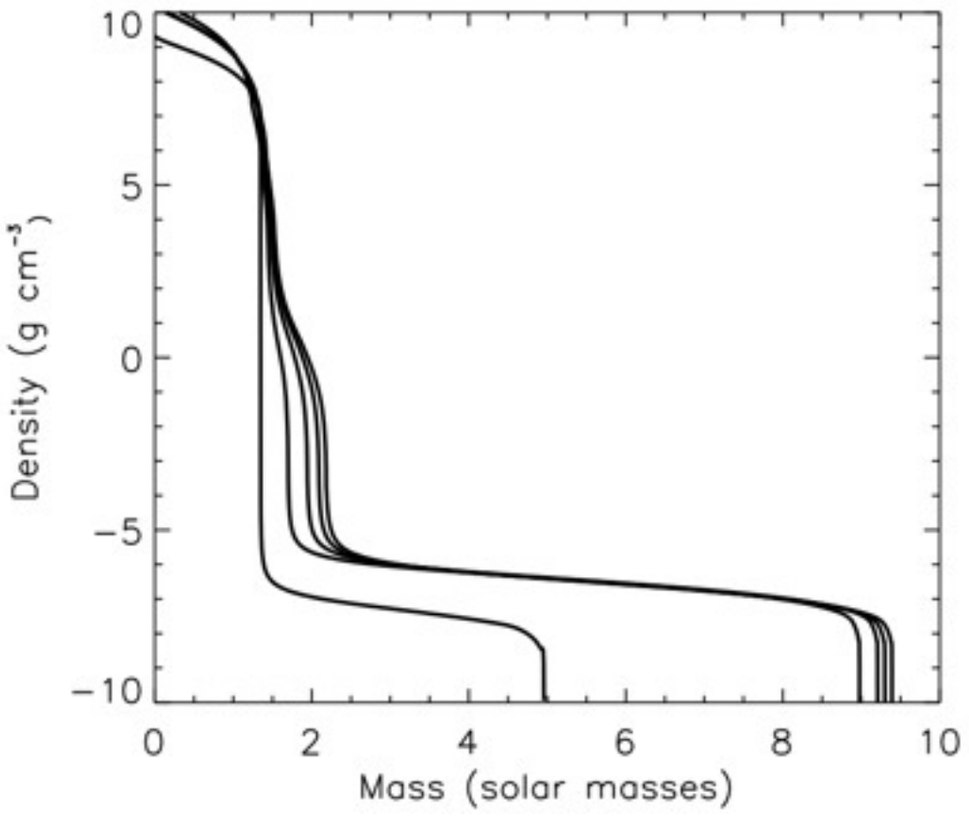
Woosley & Heger (2015, arXiv)



Jones+ (2013)



Woosley & Heger (2015, arXiv)



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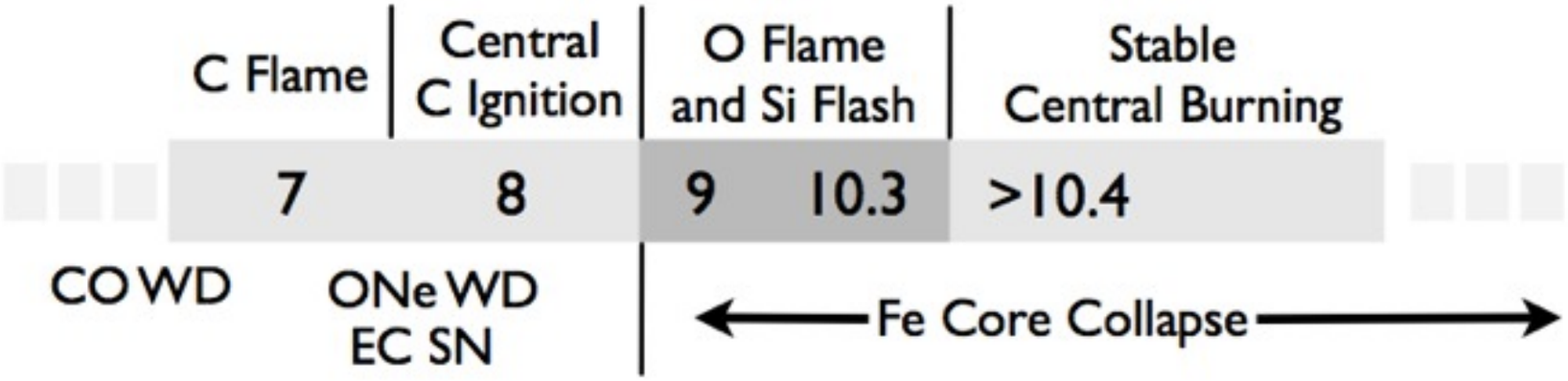
Off-centre silicon burning

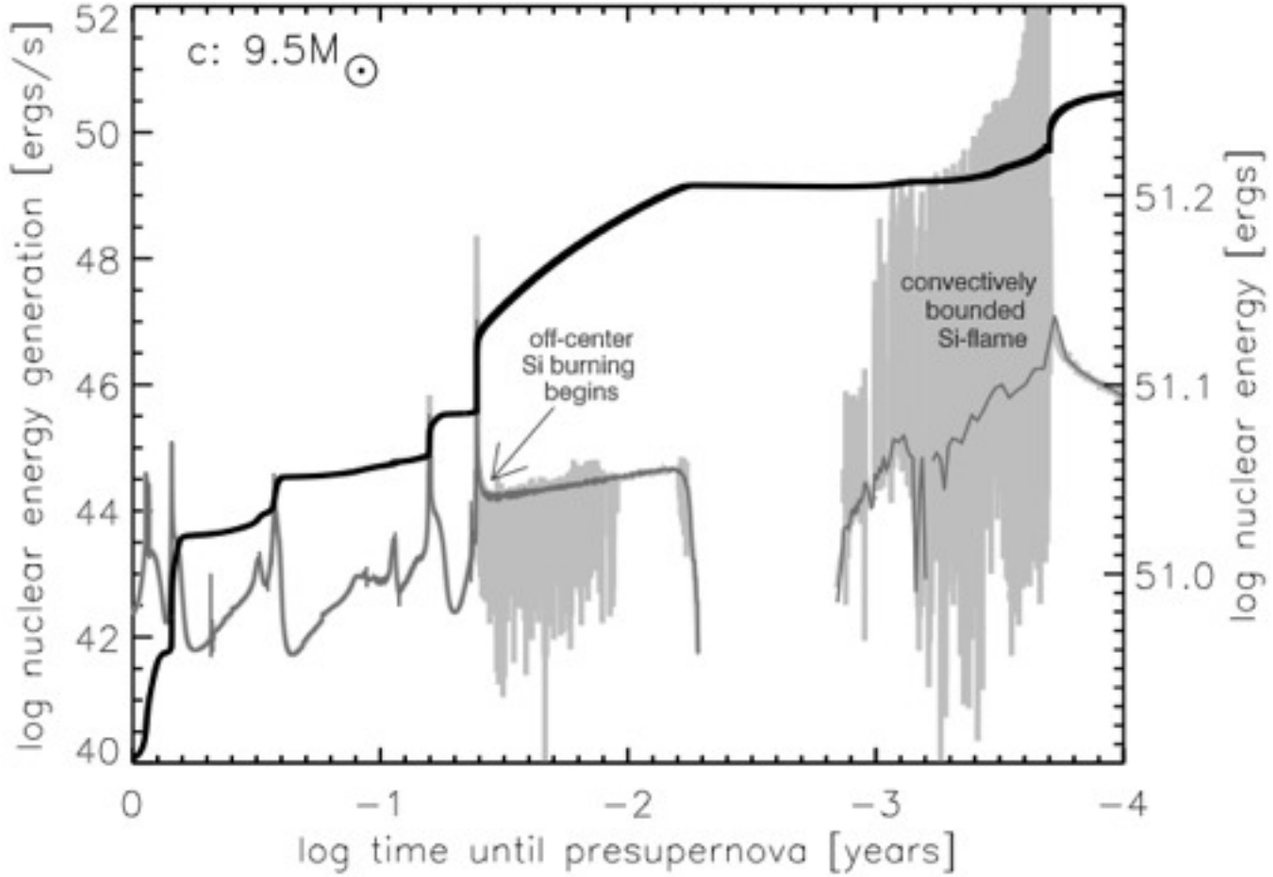


Woosley & Heger (2015, arXiv)

Silicon flashes induce dynamical behaviour, propagating through the envelope - two supernova-like displays?

Maria Drout's Talk

Explosive silicon burning in 9.8 -10.3 M models: outcome?



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Summary and open questions

The frequency (or even the occurrence) of EC-SNe from single stars unfortunately remains, for now, very uncertain. Mass loss, CBM and hydrogen ingestion events all play a role.

EC-SNe from HMXBs do not suffer the same uncertainties, however would not produce SN IIP.

Lowest-mass CCSN progenitors display similar progenitor density profiles. They themselves pose interesting questions to be addressed in the coming years with multi-dimensional hydrodynamic codes.

What are the yields form 8-10 $M_\odot$ stars?

How much will the progenitor, explosion and nucleosynthesis properties change when all relevant nuclear physics is included?

How much does the ECSN picture change when multi-dimensional simulations of the O-deflagration emerge?