Stellar Modeling for Nuclear Astrophysics: Constraining the astrophysical origin of the p-nuclei

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NuGrid Collaboration

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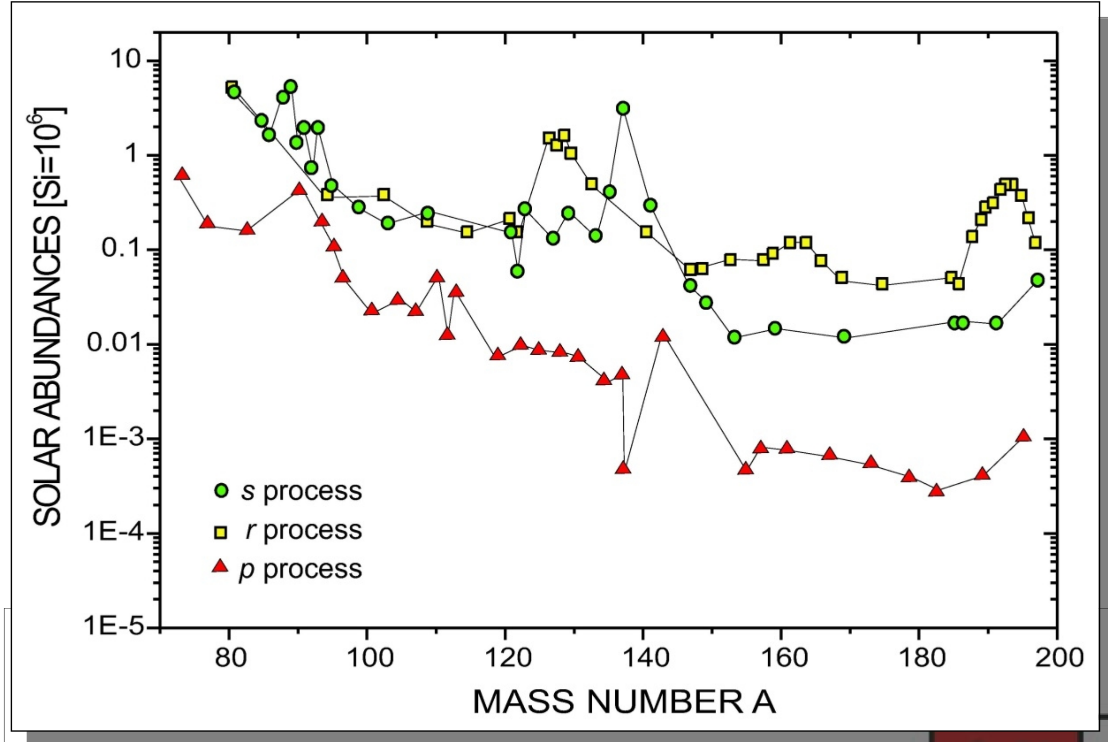
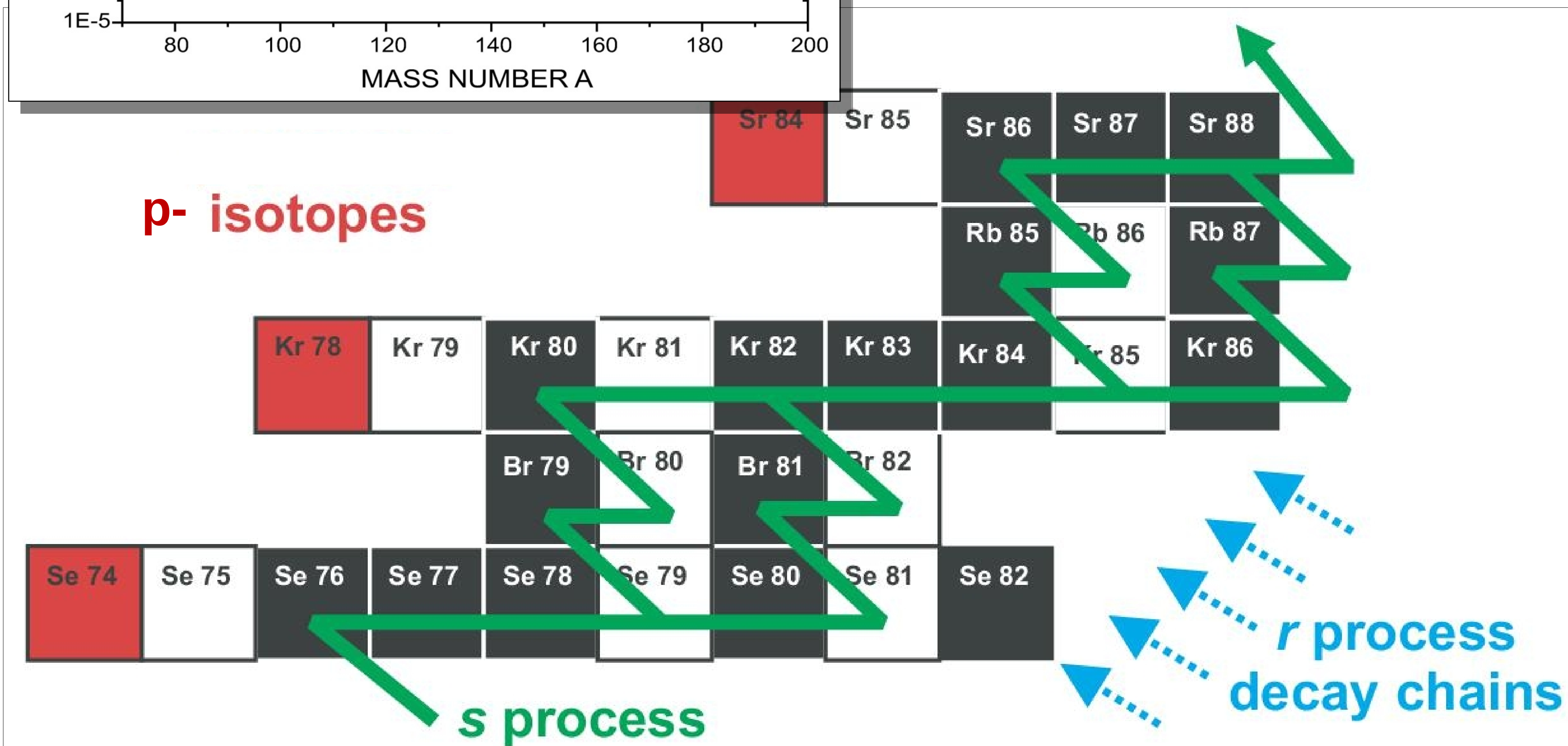
Nuclear Physics in Astrophysics IX
Sep 15-20, 2019 - Castle Waldthausen - Frankfurt

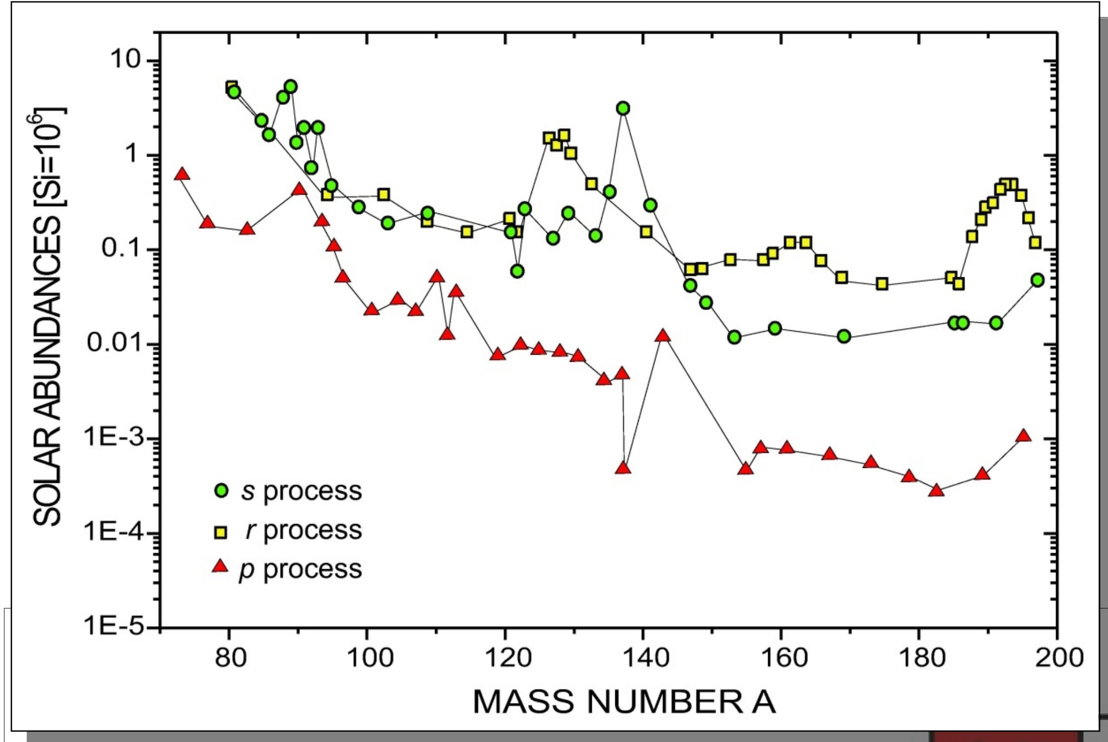
p-Nuclei

(Pictures from T. Rauscher, N. Dauphas, I. Dillmann, C. Fröhlich, Zs. Fülöp, Gy. Gyurky; Rep. Prog. Phys. 76 (2013) 066201)





p-Nuclei



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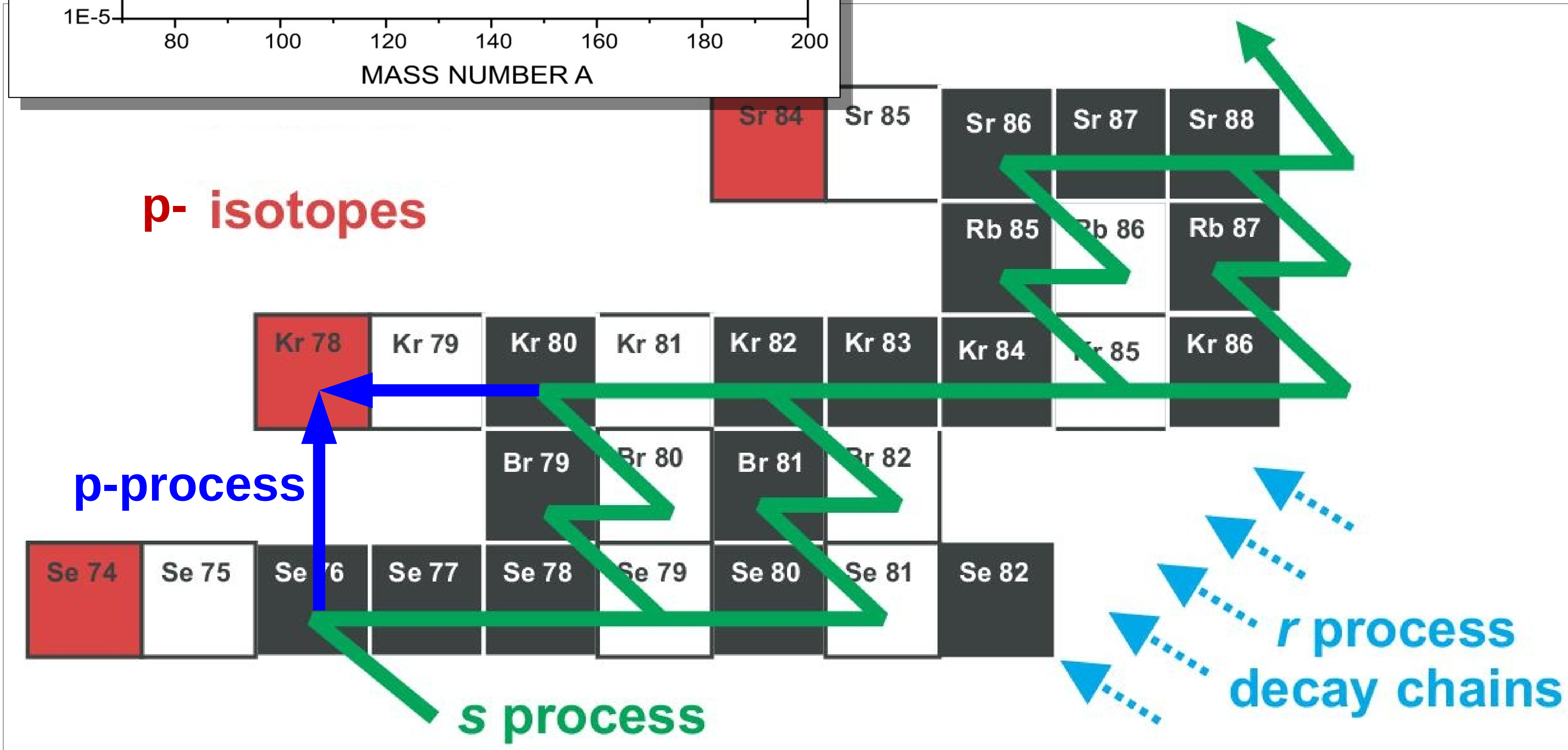
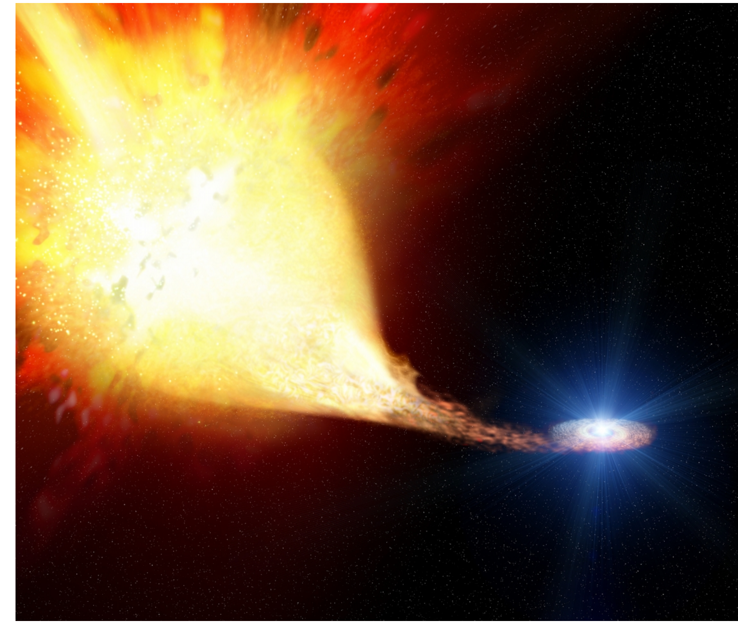


Type Ia Supernovae

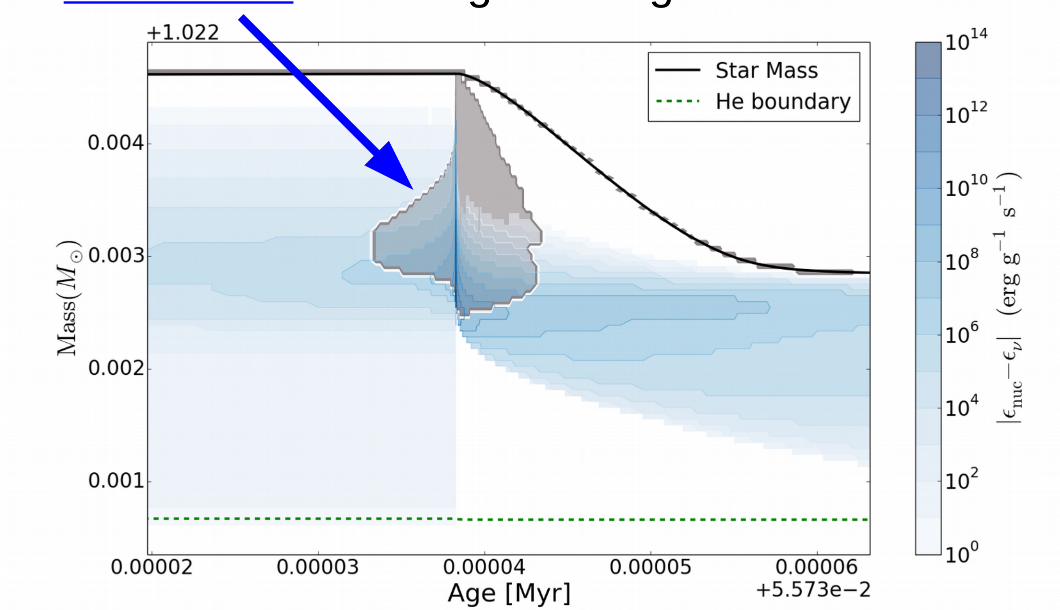
- Type Ia supernovae (SNIa) are luminous stellar explosions which marks the destruction of white dwarfs in binary systems.

- Two main scenatios to make SNIa explosions: **Single-Degenerate** (SD, **here considered;** Whelan & Iben 1972) and **Double Degenerate** (DD; Iben et al. 1984).

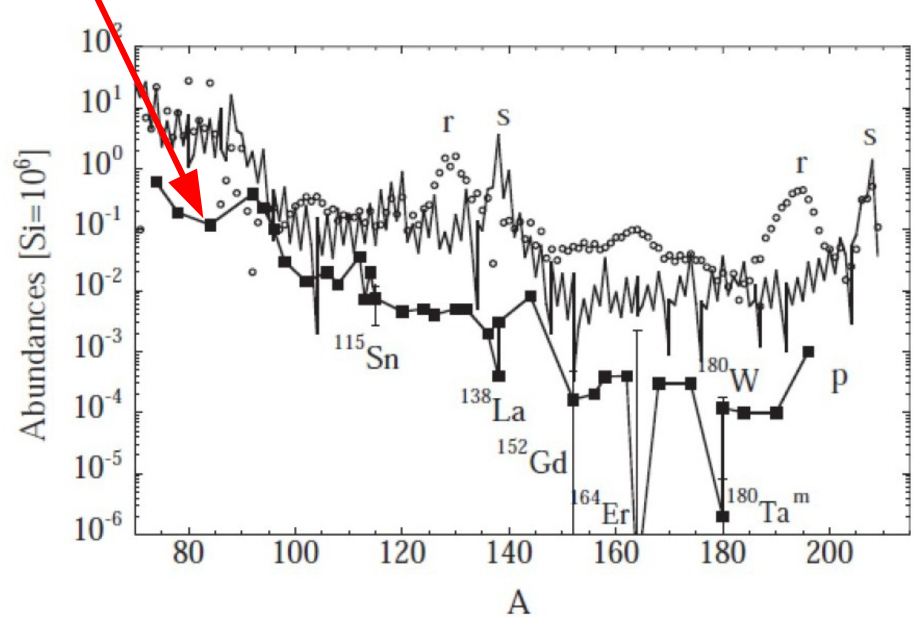
- Travaglio et al. 2011 showed how SNIa could be a relevant source for the ***p*-process isotopes** made by (γ,n), (γ,p) and (γ,α) photo-disintegrations reactions on **ASSUMED** **pre-existing heavy-element seeds distribution** formed from the neutrons released during the **He-flashes** occurring all along the accretion.



SD scenario artist's impression (from Wikipedia)

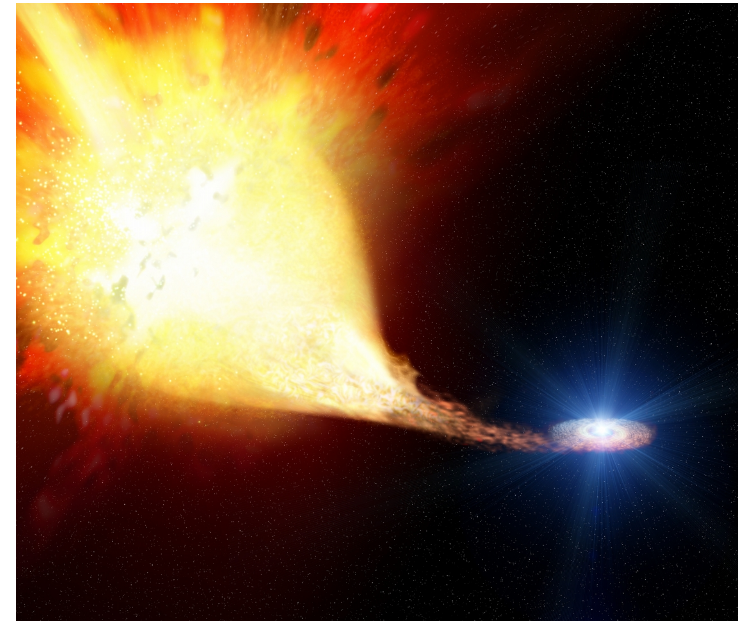


M. Arnould, S. Goriely / Physics Reports 384 (2003) 1–84



Type Ia Supernovae

Main target of this work: to verify and test this assumption by self-consistently computing the nucleosynthesis on the surface of massive accreting white dwarfs



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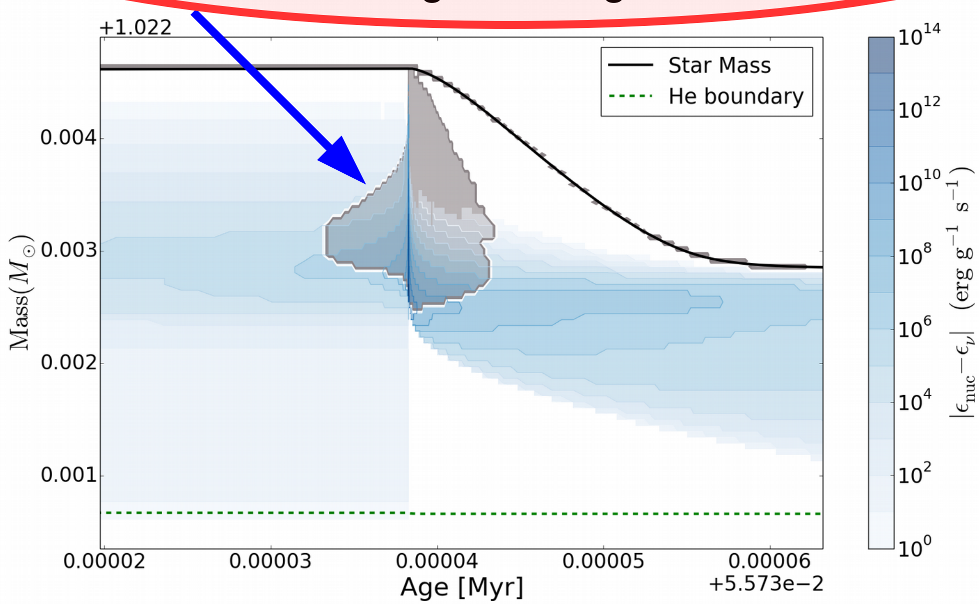
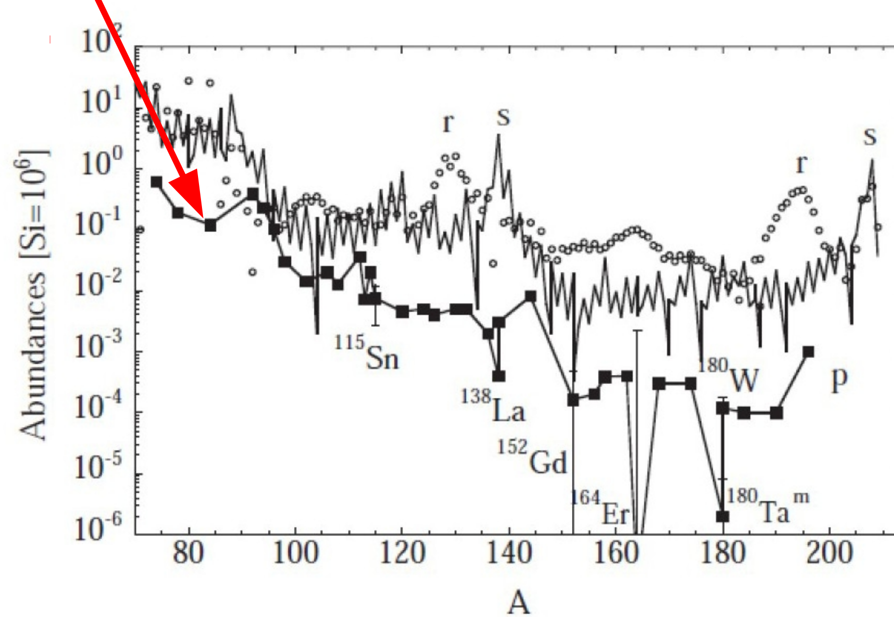
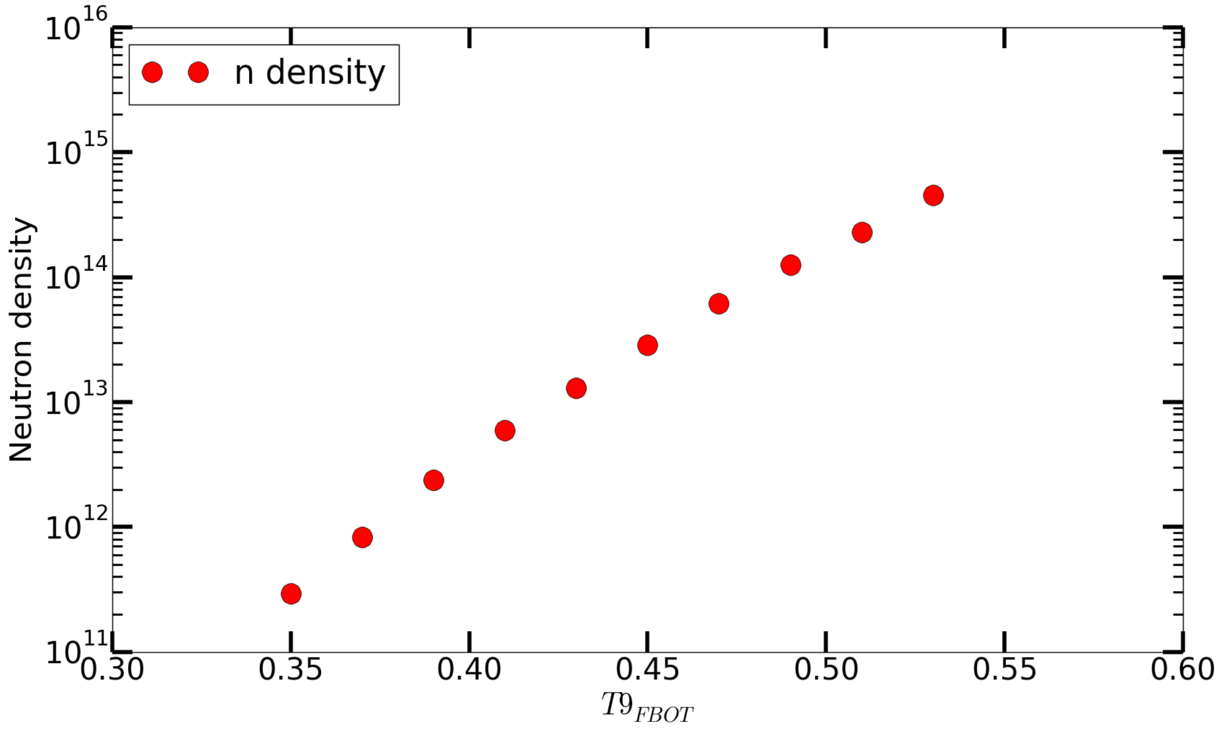




...but here we make another BIG assumption

- SD scenario can only be successful if the WD mass is high (> 1.2 M_{sun}) from the beginning of the accretion (see Denissenkov et al. 2017)…
- ...but the maximum mass with which a CO WD can be born is ~ 1.1 M_{sun} (Umeda et al. 1999)
- How can we reach the Chandrasekhar-mass (~1.4 M_{sun}) then?
  - Rotating stellar progenitor can possibly form more massive CO WD (see Dominguez et al. 1996)… BUT stellar cores already loose most of their angular momentum before the AGB phase is reached (possibly unlikely)
  - ^{12}C + ^{12}C uncertainties can impact the WD size (see Chen et al. 2014 and Tumino et al. 2018). Waiting for the LUNA measurement
  - How you describe convective boundary mixing really matters. In theory, hybrid (C-O-Ne) WD as massive as ~1.3 M_{sun} could be formed (see Chen et al. 2014)

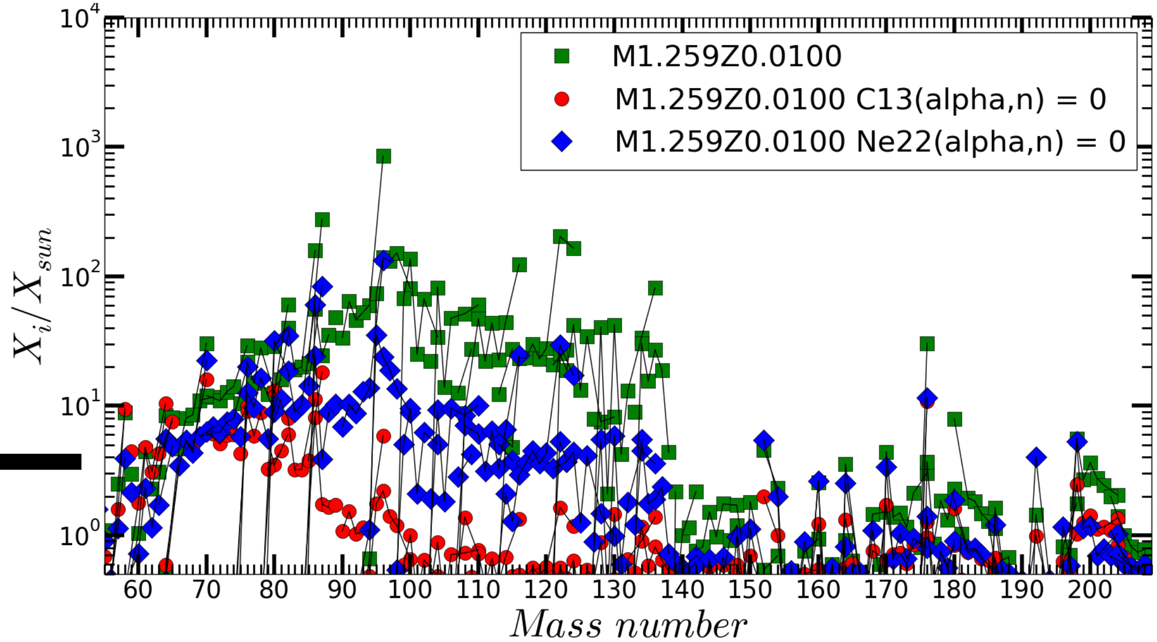
Nuclear rates tests: what is the main neutron source?



T at the bottom of the TP ranging from 0.35GK (M=0.85 Msun) to ~ 0.58 GK (M=1.376 Msun)

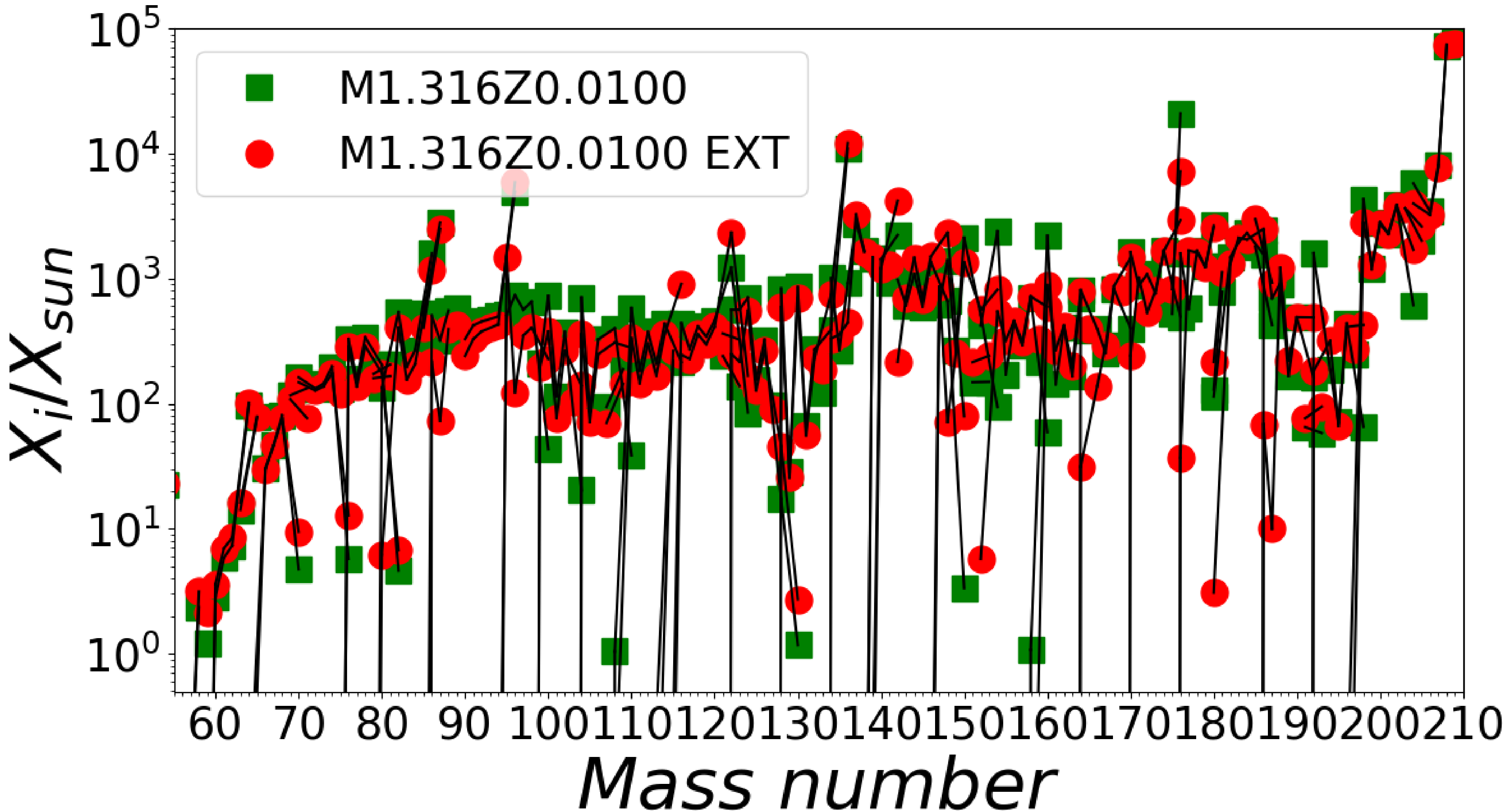
Neutron densities reaching 10^{15} n cm^{-3}

Many branching-points activated (Rb and Zr in particular)

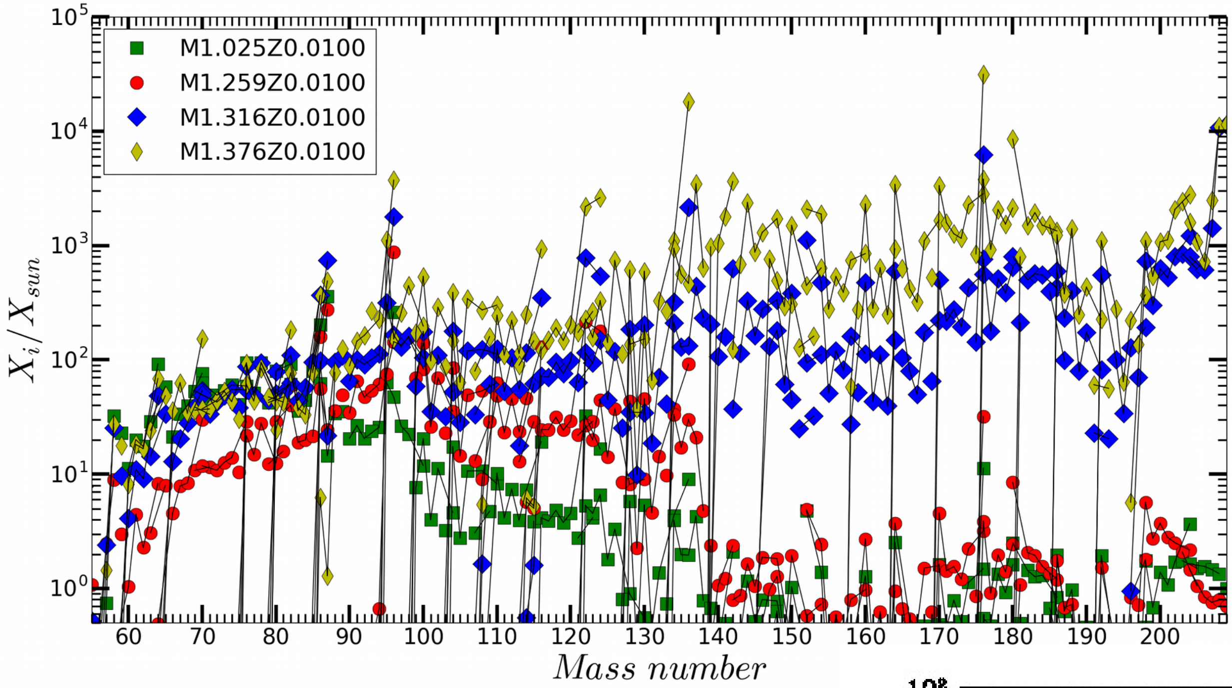


Production on the 1.26Msun and higher masses model is impacted by C13(alpha,n)O16
(C13 coming from HIF events!)

Extended energy network test
(thanks to Sergio Cristallo for suggesting)



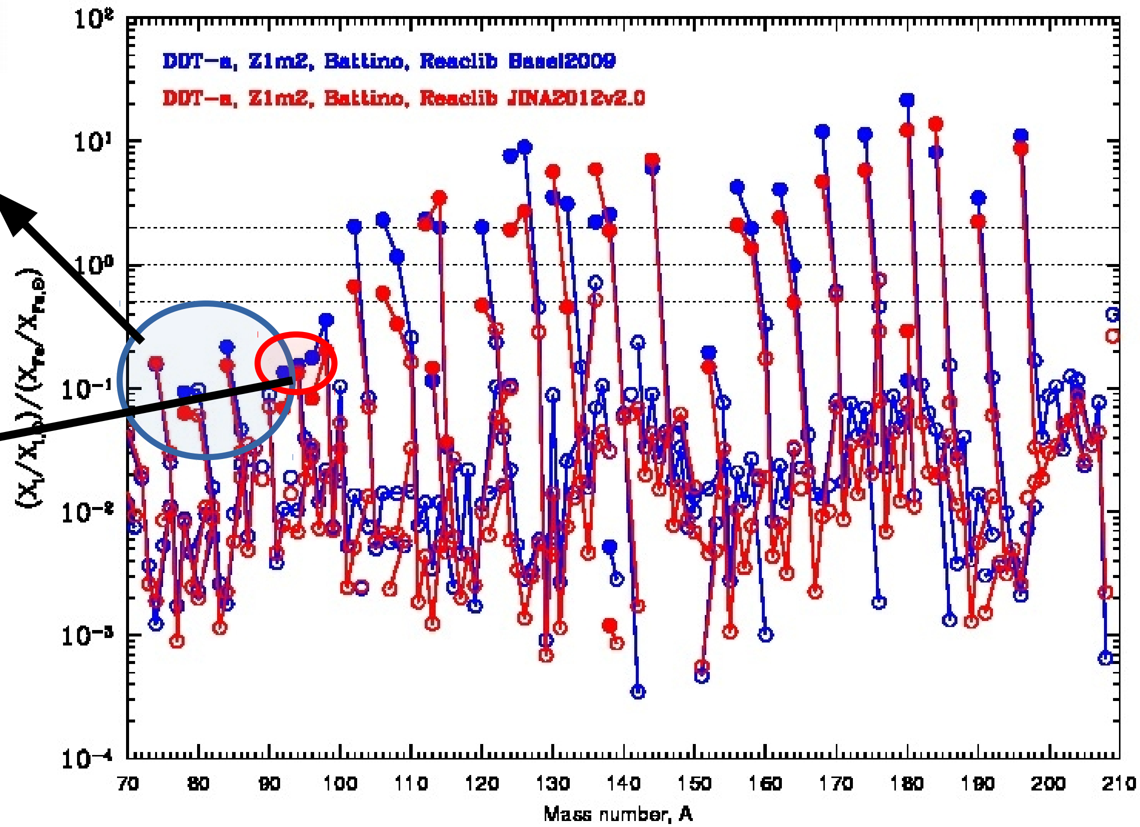
Results



Battino et al 2019b; in prep.

Contribution from γ-process in Type II Sne. ***γ-process in Type-II Sne cannot explain present day Solar System p-process content with A > 94.*** *(Rauscher et al 2016, Travaglio, Rauscher et al 2018).*

^{92}Mo, ^{94}Mo and ^{96}Ru from faint type-II supernova multi-D models (Eichler et al. 2018)



ADDITIONAL POSSIBLE CONTRIBUTION FROM C-O SHELL MERGERS! (see Ritter et al. 2018)

...about Type II Sne… **Reaction rates uncertainties impact:**

Results from Monte Carlo variations

Nuclide	$r_{corr,0}$	$r_{corr,1}$	$r_{corr,2}$	Key rate Level 1	Key rate Level 2	Key rate Level 3	X_0 (2 GK) capture	X_0 (3 GK) capture
^{78}Kr	−0.84			^{77}Br + p ↔ γ + ^{78}Kr			9.63×10^{-2}	4.44×10^{-2}
	0.34	0.87			^{79}Kr + n ↔ γ + ^{80}Kr		1.28×10^{-1}	7.94×10^{-2}
^{92}Mo	−0.74			^{91}Nb + p ↔ γ + ^{92}Mo			8.88×10^{-1}	8.24×10^{-1}
^{96}Ru	−0.73			^{92}Mo + α ↔ γ + ^{96}Ru			1.00	9.86×10^{-1}
	−0.43	−0.69			^{95}Tc + p ↔ γ + ^{96}Ru		7.64×10^{-1}	6.60×10^{-1}
^{102}Pd	−0.87			^{101}Pd + n ↔ γ + ^{102}Pd			5.62×10^{-1}	3.97×10^{-1}
^{112}Sn	−0.88			^{111}Sn + n ↔ γ + ^{112}Sn			7.79×10^{-1}	6.73×10^{-1}
^{114}Sn	−0.77			^{113}Sn + n ↔ γ + ^{114}Sn			1.82×10^{-1}	1.28×10^{-1}
^{120}Te	−0.64	−0.66			^{119}Te + n ↔ γ + ^{120}Te		2.43×10^{-1}	1.77×10^{-1}
^{124}Xe	−0.74			^{123}Xe + n ↔ γ + ^{124}Xe			8.25×10^{-2}	4.38×10^{-2}
^{126}Xe	−0.75			^{125}Cs + p ↔ γ + ^{126}Ba			1.17×10^{-1}	7.41×10^{-2}
	0.30	0.64	0.65			^{127}Ba + n ↔ γ + ^{128}Ba	5.78×10^{-2}	3.59×10^{-2}
^{130}Ba	−0.66			^{129}Ba + n ↔ γ + ^{130}Ba			5.77×10^{-2}	3.55×10^{-2}
^{132}Ba	−0.77			^{131}Ba + n ↔ γ + ^{132}Ba			1.07×10^{-1}	5.85×10^{-2}
^{136}Ce	−0.69			^{135}Ce + n ↔ γ + ^{136}Ce			1.86×10^{-1}	8.94×10^{-2}
	0.31	0.72			^{139}Ce + n ↔ γ + ^{140}Ce		8.56×10^{-1}	6.09×10^{-1}
^{138}Ce	−0.66			^{137}Ce + n ↔ γ + ^{138}Ce			4.16×10^{-1}	2.54×10^{-1}
	−0.16	−0.19	−0.66			^{136}Ce + n ↔ γ + ^{137}Ce	7.57×10^{-1}	4.70×10^{-1}
^{144}Sm	0.70			^{145}Eu + p ↔ γ + ^{146}Gd			8.06×10^{-1}	6.02×10^{-1}
^{152}Gd	−0.74			^{151}Gd + n ↔ γ + ^{152}Gd			6.18×10^{-1}	3.87×10^{-1}
	0.43	0.76			^{153}Gd + n ↔ γ + ^{154}Gd		5.38×10^{-2}	2.78×10^{-2}
	−0.14	−0.26	−0.73			^{148}Sm + α ↔ γ + ^{152}Gd	8.14×10^{-1}	5.22×10^{-1}
^{164}Er	−0.78			^{160}Er + α ↔ γ + ^{164}Yb			2.13×10^{-1}	1.24×10^{-1}
^{180}W	−0.83			^{176}W + α ↔ γ + ^{180}Os			1.83×10^{-1}	1.04×10^{-1}
	−0.19	−0.60	−0.68			^{179}Os + n ↔ γ + ^{180}Os	4.89×10^{-2}	2.49×10^{-2}
^{196}Hg	−0.83			^{195}Pb + n ↔ γ + ^{196}Pb			2.97×10^{-1}	1.89×10^{-1}
	0.31	0.70			^{197}Pb + n ↔ γ + ^{198}Pb		3.28×10^{-1}	2.39×10^{-1}
	0.17	0.35	0.67			^{199}Pb + n ↔ γ + ^{200}Pb	6.37×10^{-1}	3.47×10^{-1}
^{92}Nb	0.76			^{90}Zr + p ↔ γ + ^{91}Nb			1.00	9.95×10^{-1}
^{146}Sm	−0.57	−0.75			^{144}Sm + α ↔ γ + ^{148}Gd		9.99×10^{-1}	9.65×10^{-1}
	0.34	0.44	0.79			^{147}Gd + n ↔ γ + ^{148}Gd	9.92×10^{-1}	9.28×10^{-1}

Rauscher et al 2016

Conclusions

- I presented for the first time a heavy-element distribution calculated from realistic simulations of WD-accretion phase in the single degenerate scenario channel to SNIa.
- Such distribution arised for recurrent TP events very similar to those happening during the AGB phase and characterized by very high temperatures, ranging from 0.35 to 0.59 T9 at the bottom of the PDCZ → *very high neutron densities (~10^{15} n cm^{-3})* when the WD gets close to the Chandrasekhar mass → large quantities of Rb, Zr, Ba-peak isotopes and Pb .
- Globally very similar to the one adopted in Travaglio et al. (2011), when used as a starting abundance distribution, p-nuclei are significantly produced in the mass range 96<A<196. **Full results to be published in Battino et al. 2019, in prep.**
- Suggestion for future reaction rate measurement: $^{91}Nb(p,\gamma)^{92}Mo$

Grazie mille per la vostra attenzione!!!

Mersì per la vostr atensiun!!!

Thank you so much for your kind attention!!!

Vielen Dank für Ihre Aufmerksamkeit!!!

Gratias vobis ago!!!