The astrophysical impact of the $^{22}Ne(\alpha,n)^{25}Mg$ nuclear reaction

Umberto Battino (University of Hull, Keele University, NuGrid Collaboration)

Collaborators: Lorenzo Roberti, Ashley Tattersall

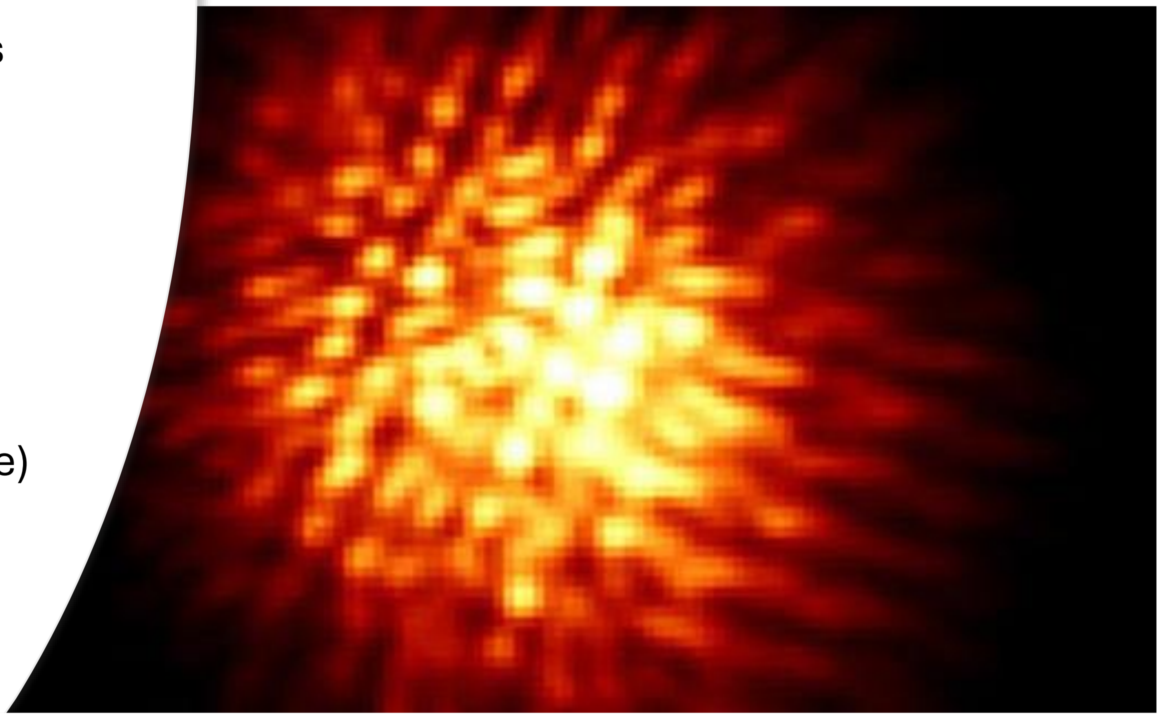
The Big-Three Reactions for Astrophysics: 12C(α,γ)16O, 12C+12C fusion, 22Ne(α,n)25Mg

Why is the ^{22}Ne(a,n) a big one?

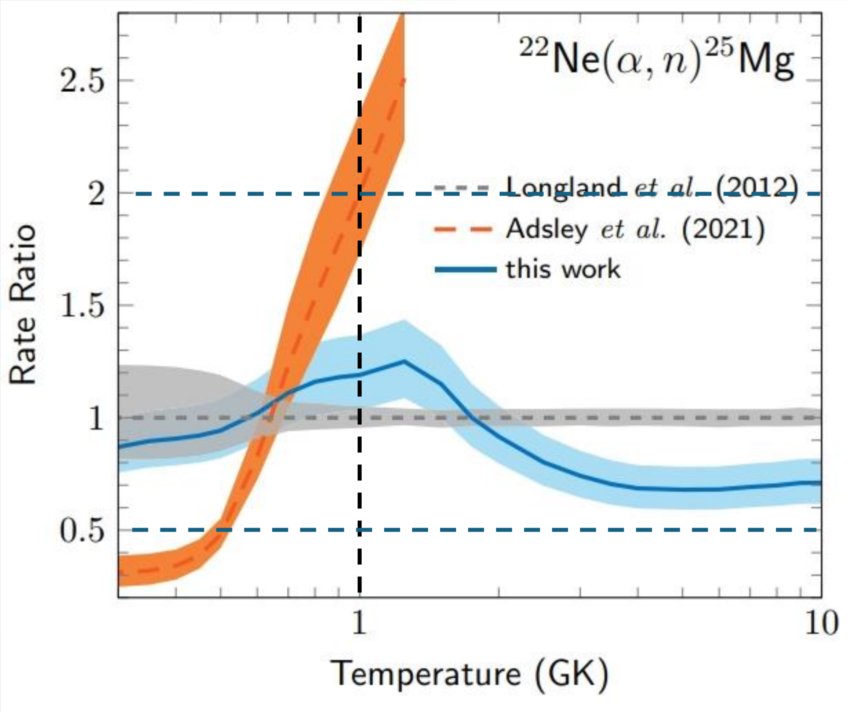
- Main neutron source for weak s-process in massive stars.

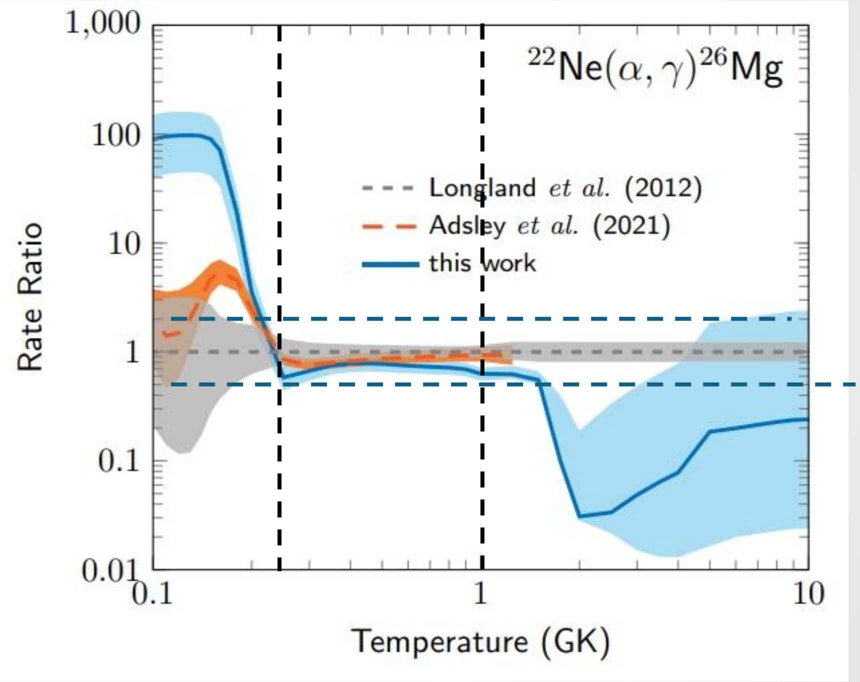
- Visible impact on isotopic ratios observable in presolar grains from AGB stars.

- Important role in explosive nucleosyntesis, e.g. n-process and synthesis of key short-lived radioactive nuclei (e.g. ^{26}Al and ^{60}Fe)



Present Status





Wiescher et al.; 2023

AGB stars: where exactly does s-process take place?

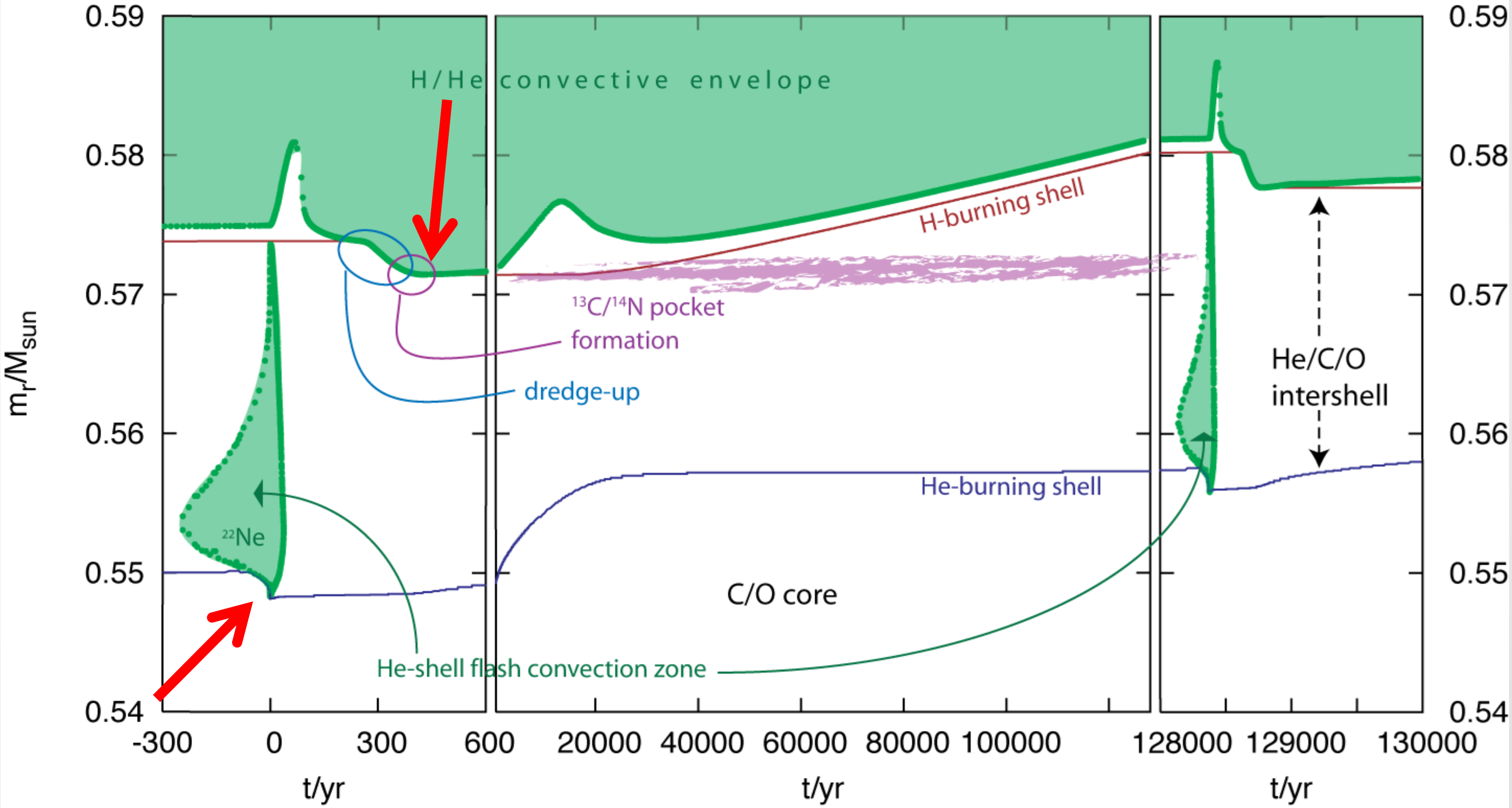


Figure from Herwig 2005

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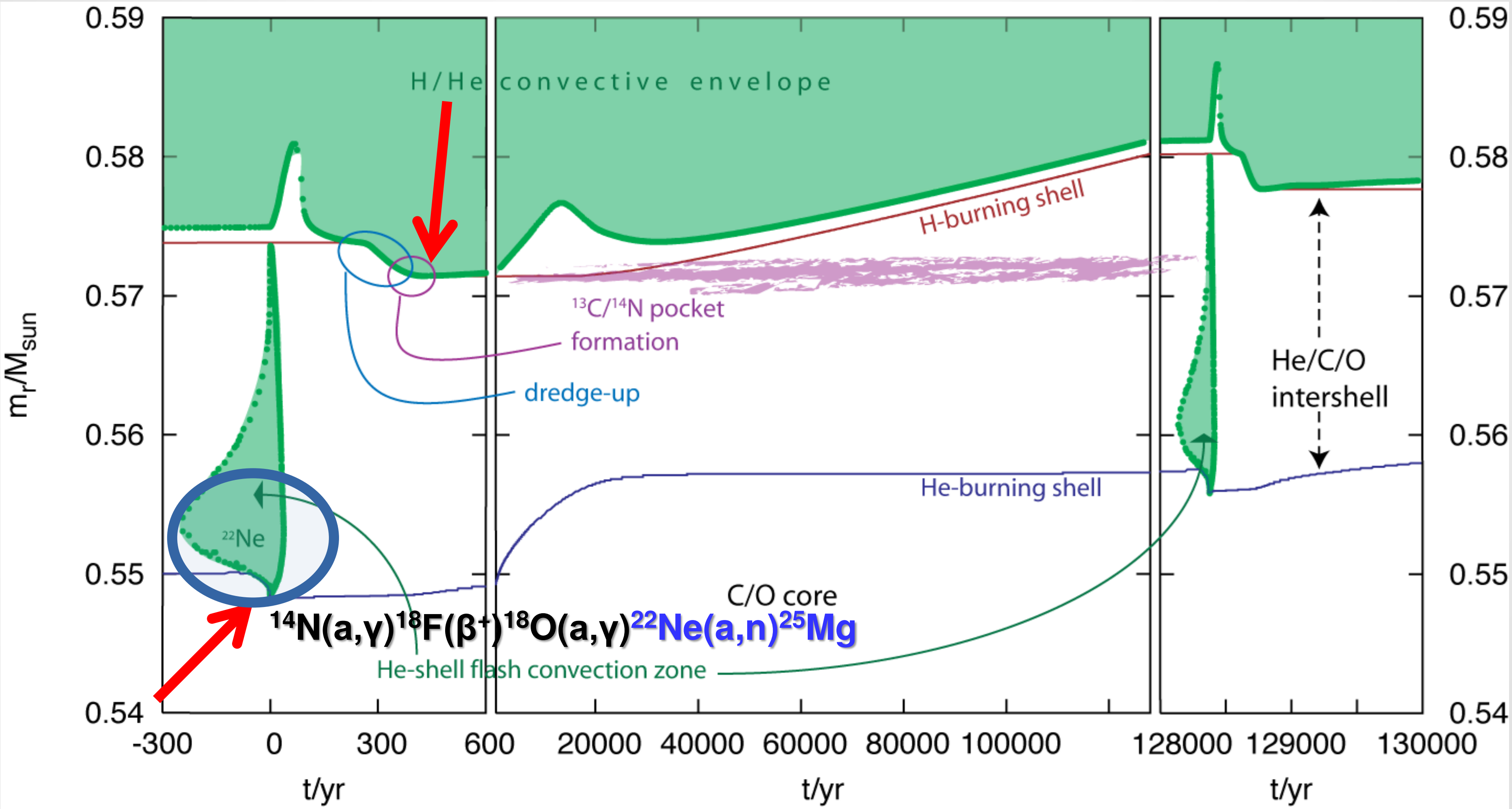
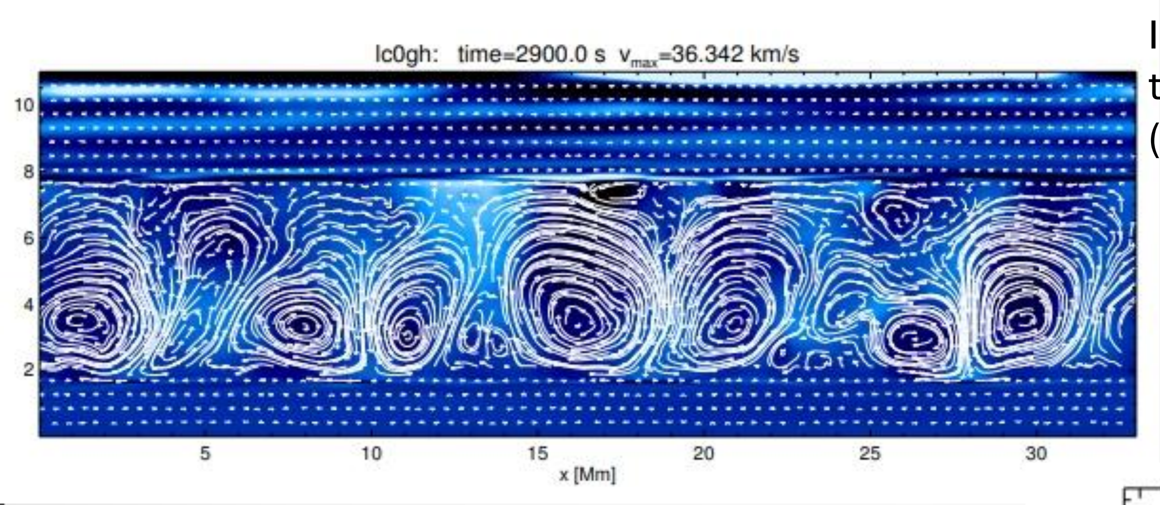


$^{14}N(a,\gamma)^{18}F(\beta^+)^{18}O(a,\gamma)^{22}Ne(a,n)^{25}Mg$

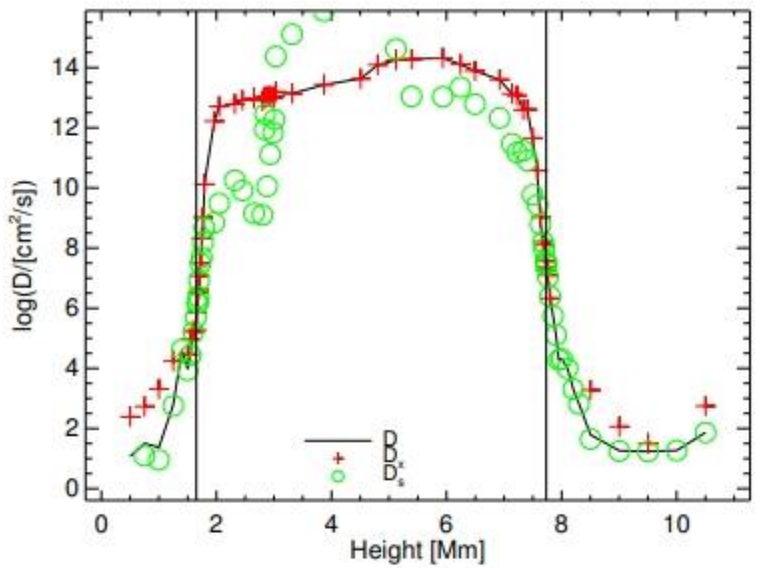
Figure from Herwig 2005

He-shell flash multi-D simulations and convective bounduary mixing processes



Initial structure conditions typical of a 2Msun; Z=0.01 AGB star (just before a He-flash)

Herwig+ 2007



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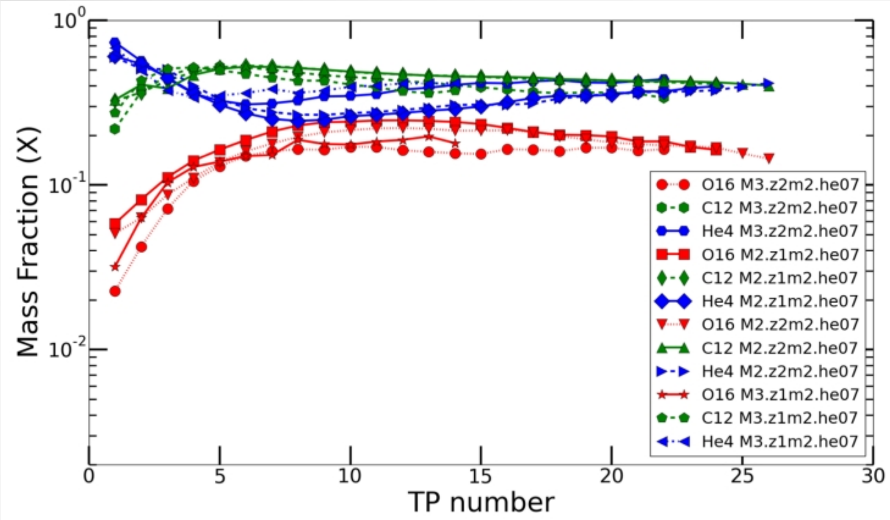
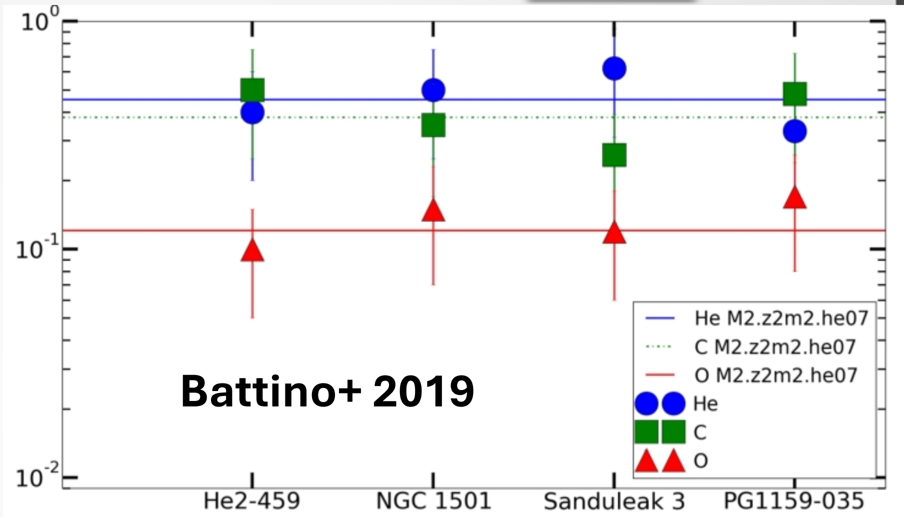
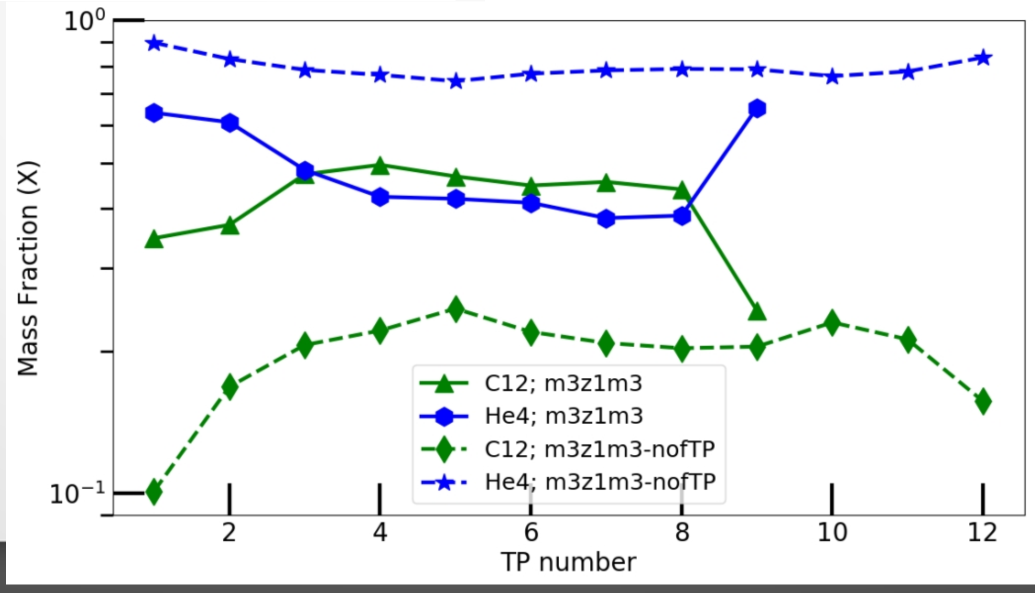
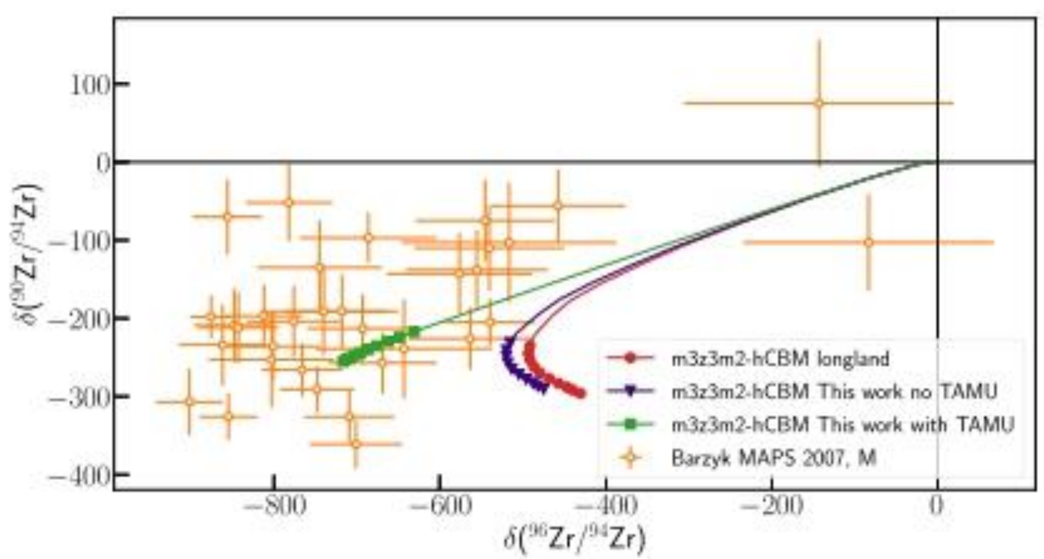




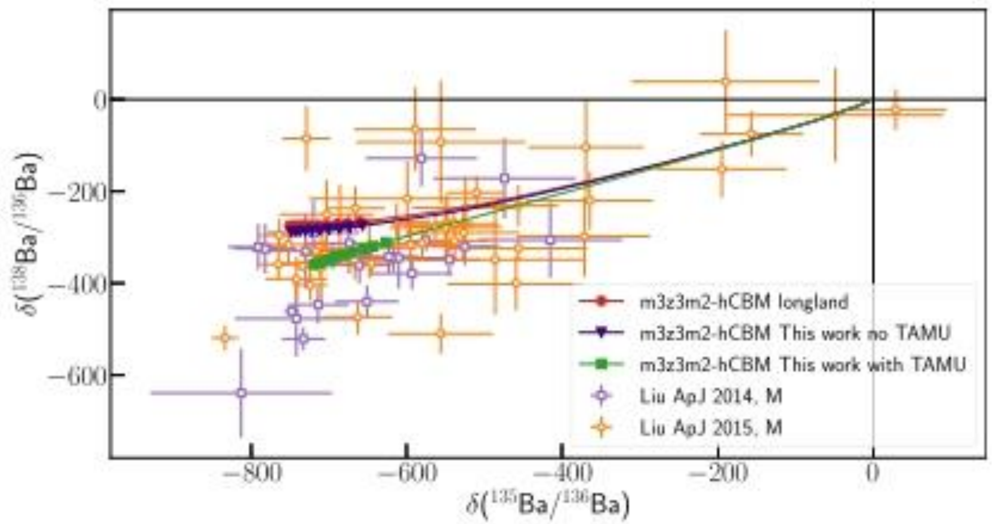


Comparison to presolar grains data



Adsley+2021

^{95}Tc 20.00 h β^+	^{96}Tc 4.28 d β^+	^{97}Tc 4.21 Ma β^+	^{98}Tc 4.20 Ma β^-	^{99}Tc 211.11 ka 781 mb, β^-
^{94}Mo 9.25 102 mb	^{95}Mo 15.92 292 mb	^{96}Mo 16.68 112 mb	^{97}Mo 9.55 339 mb	^{98}Mo 24.13 99 mb
^{93}Nb 100 266 mb	^{94}Nb 20.30 ka 482 mb, β^-	^{95}Nb 34.99 d 310 mb, β^-	^{96}Nb 23.35 h β^-	^{97}Nb 1.20 h β^-
^{92}Zr 17.15 33 mb	^{93}Zr 1.53 Ma 95 mb, β^-	^{94}Zr 17.38 26 mb	^{95}Zr 64.03 d 79 mb, β^-	^{96}Zr 2.8 10.7 mb
^{91}Y 58.51 d β^-	^{92}Y 3.54 h β^-	^{93}Y 10.18 h β^-	[illegible] 18.[illegible]0 m	^{95}Y 10.30 m β^-



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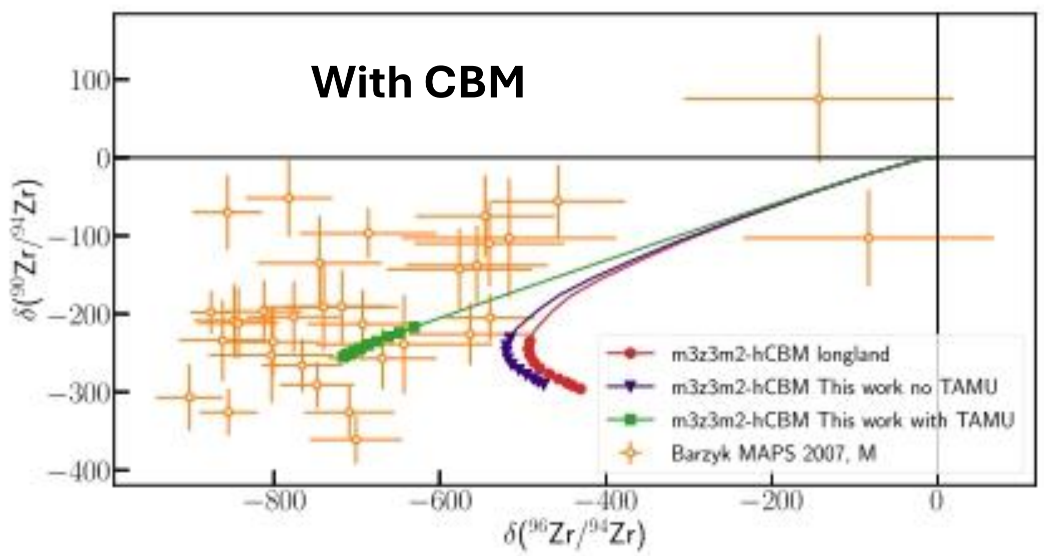

Understanding AGB evolution across the thermal pulsing phase is highly problematic with highly uncertain $^{22}Ne+a$ rates!!!

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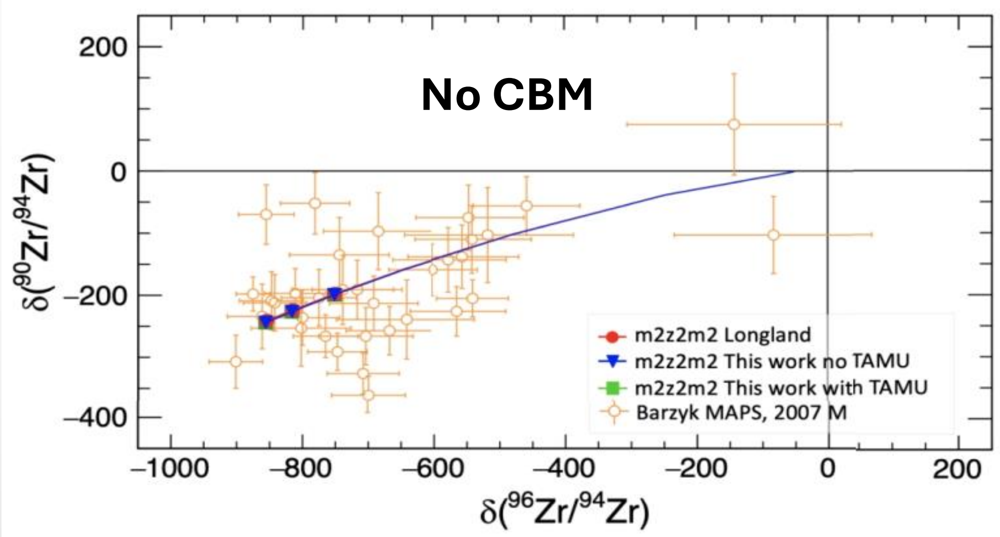
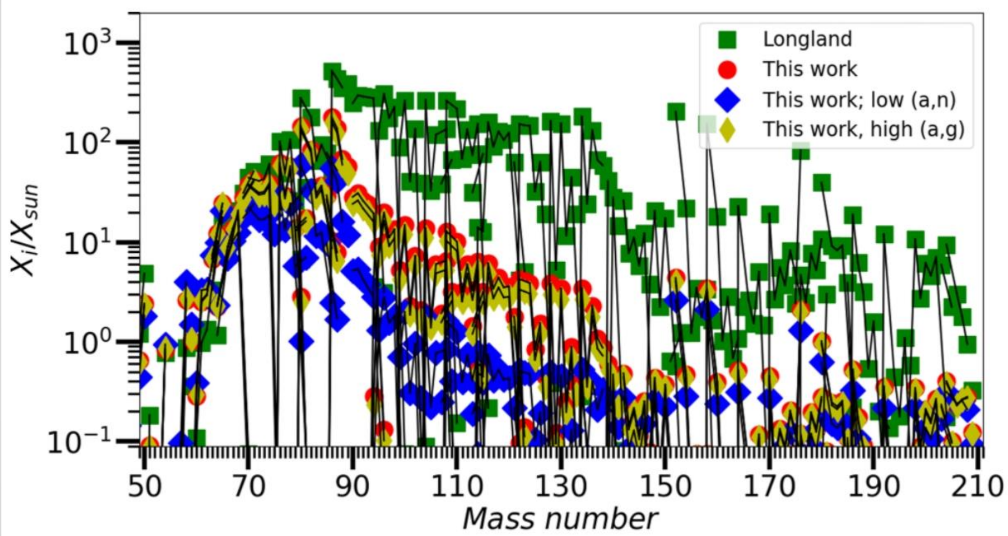


Weak s-process



Adsley+ 2021

^{84}Zr 25.90 m	^{85}Zr 7.86 m	^{86}Zr 16.50 h	^{87}Zr 1.68 h	^{88}Zr 83.40 d	^{89}Zr 3.27 d	^{90}Zr 51.45	^{91}Zr 11.22	^{92}Zr 17.15
^{83}Y 7.08 m	^{84}Y 4.60 s	^{85}Y 2.68 h	^{86}Y 14.74 h	^{87}Y 3.33 d	^{88}Y 106.62 d	^{89}Y 100	^{90}Y 2.67 d	^{91}Y 58.51 d
^{82}Sr 25.55 d	^{83}Sr 1.35 d	^{84}Sr 0.56	^{85}Sr 64.84 d	^{86}Sr 9.86	^{87}Sr 7	^{88}Sr 82.58	^{89}Sr 50.57 d	^{90}Sr 28.90 a
^{81}Rb 4.57 h	^{82}Rb 1.27 m	^{83}Rb 86.20 d	^{84}Rb 33.10 d	^{85}Rb 72.17	^{86}Rb 18.64 d	^{87}Rb 49.69x10^9 y	^{88}Rb 17.77 m	^{89}Rb 15.15 m
^{80}Kr 2.28	^{81}Kr 229.02 ka	^{82}Kr 11.58	^{83}Kr 11.49	^{84}Kr 57	^{85}Kr 10.72 a	^{86}Kr 17.3	^{87}Kr 1.27 h	^{88}Kr 2.84 h
^{79}Br 50.69	^{80}Br 17.68 m	^{81}Br 49.31	^{82}Br 1.47 d	^{83}Br 2.40 h	^{84}Br 31.80 m	^{85}Br 2.90 m	^{86}Br 55.01 s	^{87}Br 55.65 s
^{78}Se 23.77	^{79}Se 294.99 ka	^{80}Se 49.61	^{81}Se 18.45 m	^{82}Se 8.73	^{83}Se 22.30 m	^{84}Se 3.10 m	^{85}Se 31.70 s	^{86}Se 15.30 s
^{77}As 1.62 d	^{78}As 1.51 h	^{79}As 9.01 m	^{80}As 15.20 s	^{81}As 33.30 s	^{82}As 19.10 s	^{83}As 13.40 s	^{84}As 3.24 s	^{85}As 2.02 s
^{76}Ge 7.83	^{77}Ge 11.30 h	^{78}Ge 1.47 h	^{79}Ge 18.98 s	^{80}Ge 29.50 s	^{81}Ge 7.60 s	^{82}Ge 4.55 s	^{83}Ge 1.85 s	^{84}Ge 947.00 ms

Ritter et al. 2018; 15 Msun; Z=0.006, end of C-shell burning

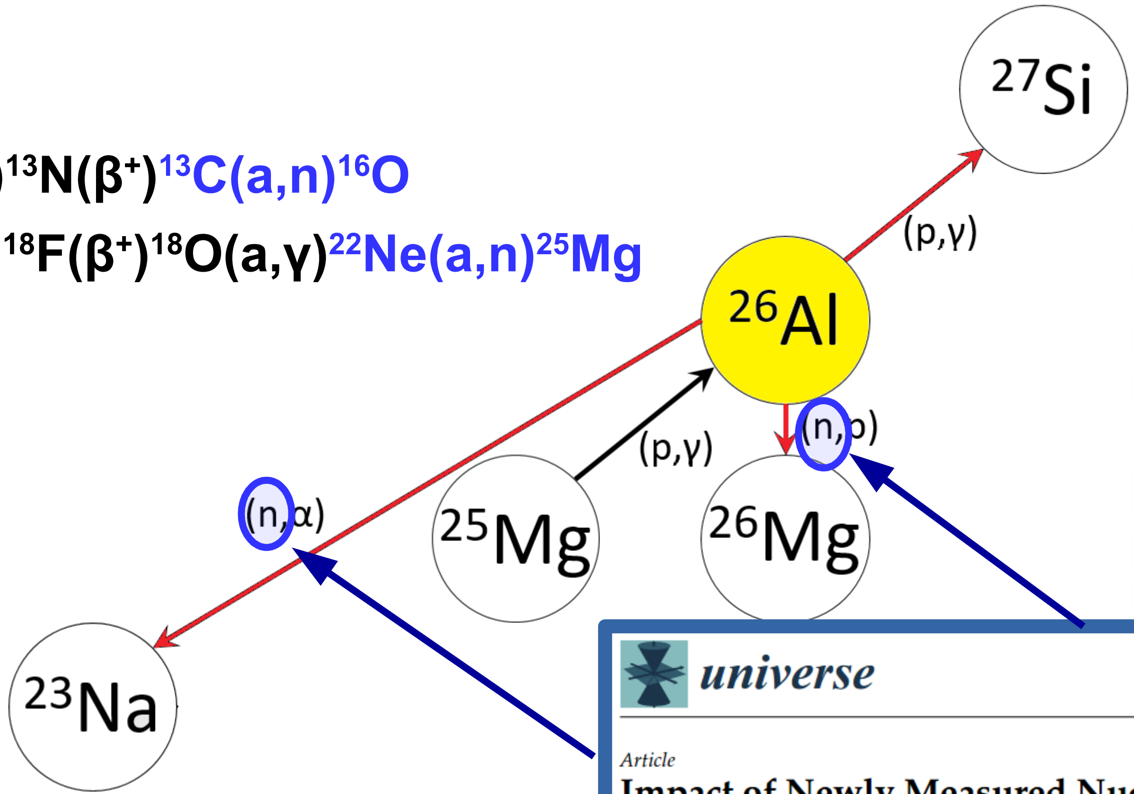
^{86}Kr/^{82}Kr (solar) = 1.49

^{86}Kr/^{82}Kr (Longland) = 0.31 → ~20% ^{86}Kr weak s-process

^{86}Kr/^{82}Kr (Adsley) = 0.17 → ~10% ^{86}Kr weak s-process

Short-lived radionuclides: the case of 26Al nucleosynthesis

- $^{12}C(p,\gamma)^{13}N(\beta^+)^{13}C(a,n)^{16}O$
- $^{14}N(a,\gamma)^{18}F(\beta^+)^{18}O(a,\gamma)^{22}Ne(a,n)^{25}Mg$




universe

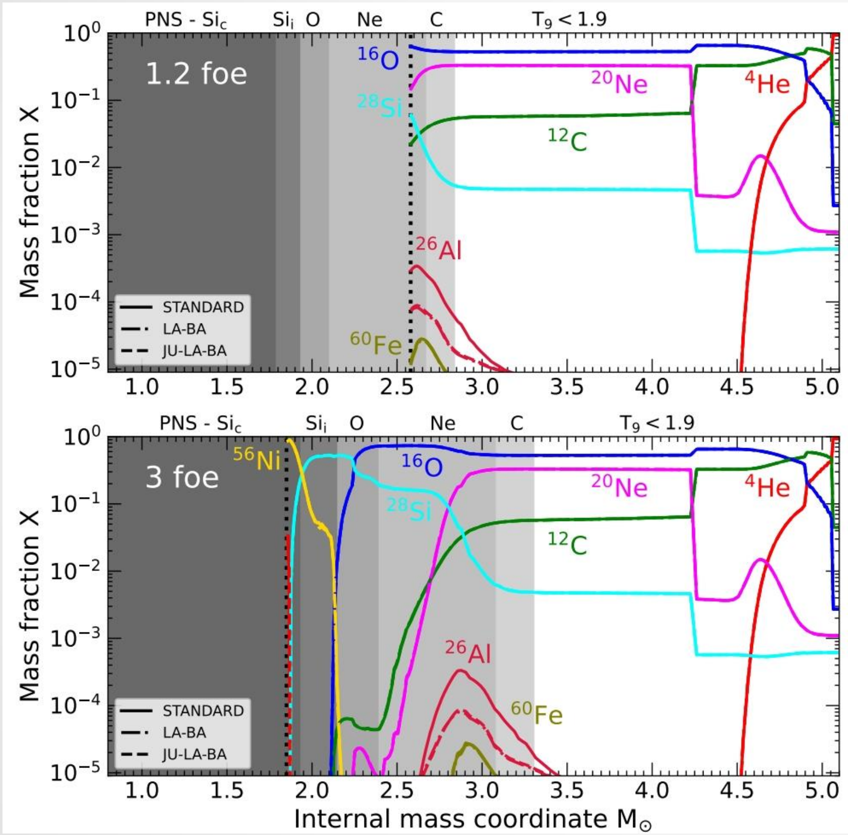
MDPI

Article

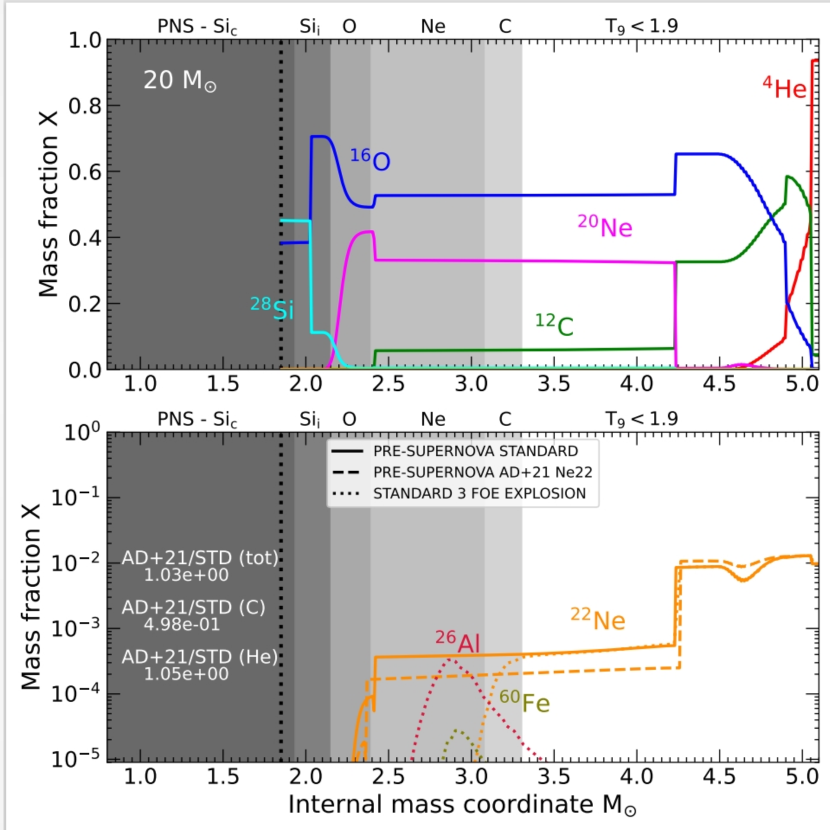
Impact of Newly Measured Nuclear Reaction Rates on ^{26}Al Ejected Yields from Massive Stars

Umberto Battino [1,*,†], Lorenzo Roberti [2,3,4,†], Thomas V. Lawson [1,5,†], Alison M. Laird [6,†] and Lewis Todd [6]

Explosive CCSN nucleosynthesis



Battino + 2024



~x2 more ^{26}Al

→ higher ^{60}Fe/^{26}Al

(to be compared with INTEGRAL data!)

Summary

Significant uncertainties are still affecting the ^{22}Ne(α,n)^{25}Mg reaction.

Indeed, this is reflected in the contradictory results of the latest redetermination of both the ^{22}Ne(α,n)^{25}Mg and the ^{22}Ne(α,γ)^{26}Mg reaction rate (Adsley et al. 2021, Wiescher et al. 2023) in the temperature range of interest for helium burning(~0.25 GK) and carbon burning (~1 GK).

A good scientific opportunity to settle these discrepancies could be represented by future direct measurements of these reactions in underground laboratories, taking advantage of the extremely reduced cosmic-ray-induced background.

Upcoming LUNA measurement!

Summary

This current uncertainty visibly affects the nucleosynthesis in both AGB and massive stars, as well as comparison with observables. In particular…

- Understanding AGB evolution across the thermal pulsing phase is highly problematic with highly uncertain ^{22}Ne+a rates
- Weak s-process production factors at the I peak can vary by up to a factor of ~3
- Important impact on key isotopic ratios affected by branching points
- Ejected yields of key short-lived radionuclide ejected yields (e.g. ^{26}Al and ^{60}Fe) are affected, and so is the comparison with gamma-ray fluxes data from space telescopes.

Grazie!

Thank you!!