International Symposium on Nuclei in the Cosmos XVIII

Girona, June 17, 2025

The Role of Carbon-Oxygen Shell Interactions in the Nucleosynthesis and Final Fate of Massive Stars

Lorenzo Roberti, INFN – Laboratori Nazionali del Sud, Catania, Italy

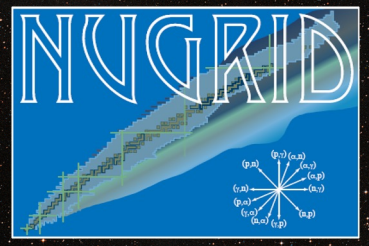
Main collaborations:

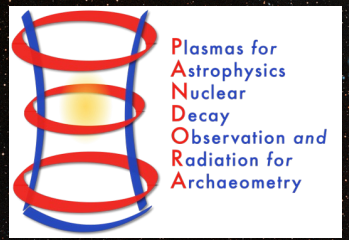
AsFiN + Pandora groups

Budapest group: M. Pignatari, M. Lugaro

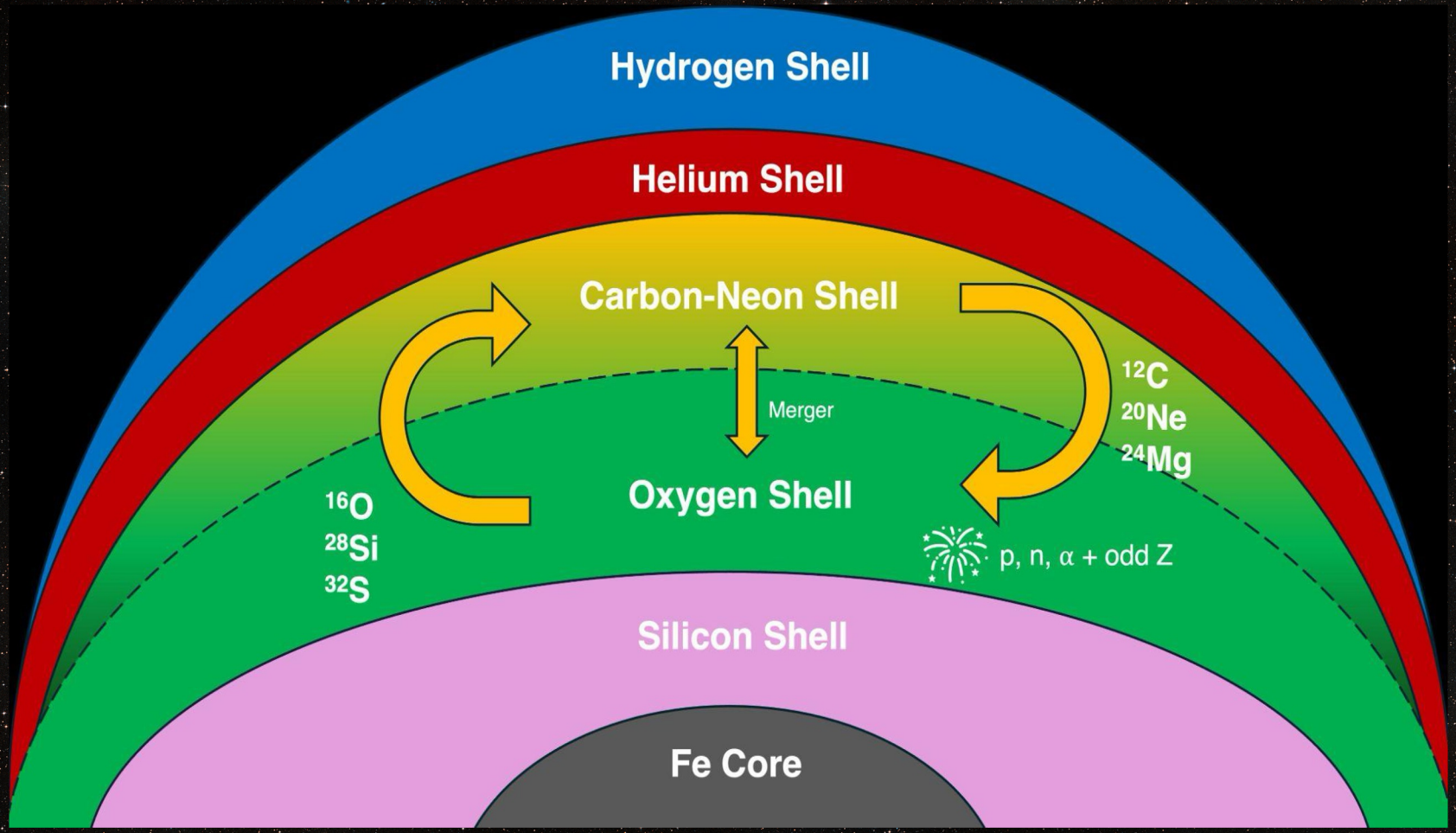
Rome + Berkeley group: M. Limongi, A. Chieffi, A. Falla, L. Boccioli

NuGriD collaboration





Carbon-oxygen shell mergers in massive stars



- Ingestion of some C (and Ne) in the O burning shell during late stages of the evolution;
- Convective-reactive event →Formation of an extended mixed convective zone;
- Peculiar **nucleosynthesis** and impact on the **explodability**;
- Found often in 1D stellar models with $M_{ini} \leq 25\ M_{\odot}$;
- Confirmed by 3D simulations (e.g., Rizzuti+24).

Carbon-oxygen shell mergers in massive stars

SCAN ME

Astronomy & Astrophysics manuscript no. aa54461-25
May 21, 2025

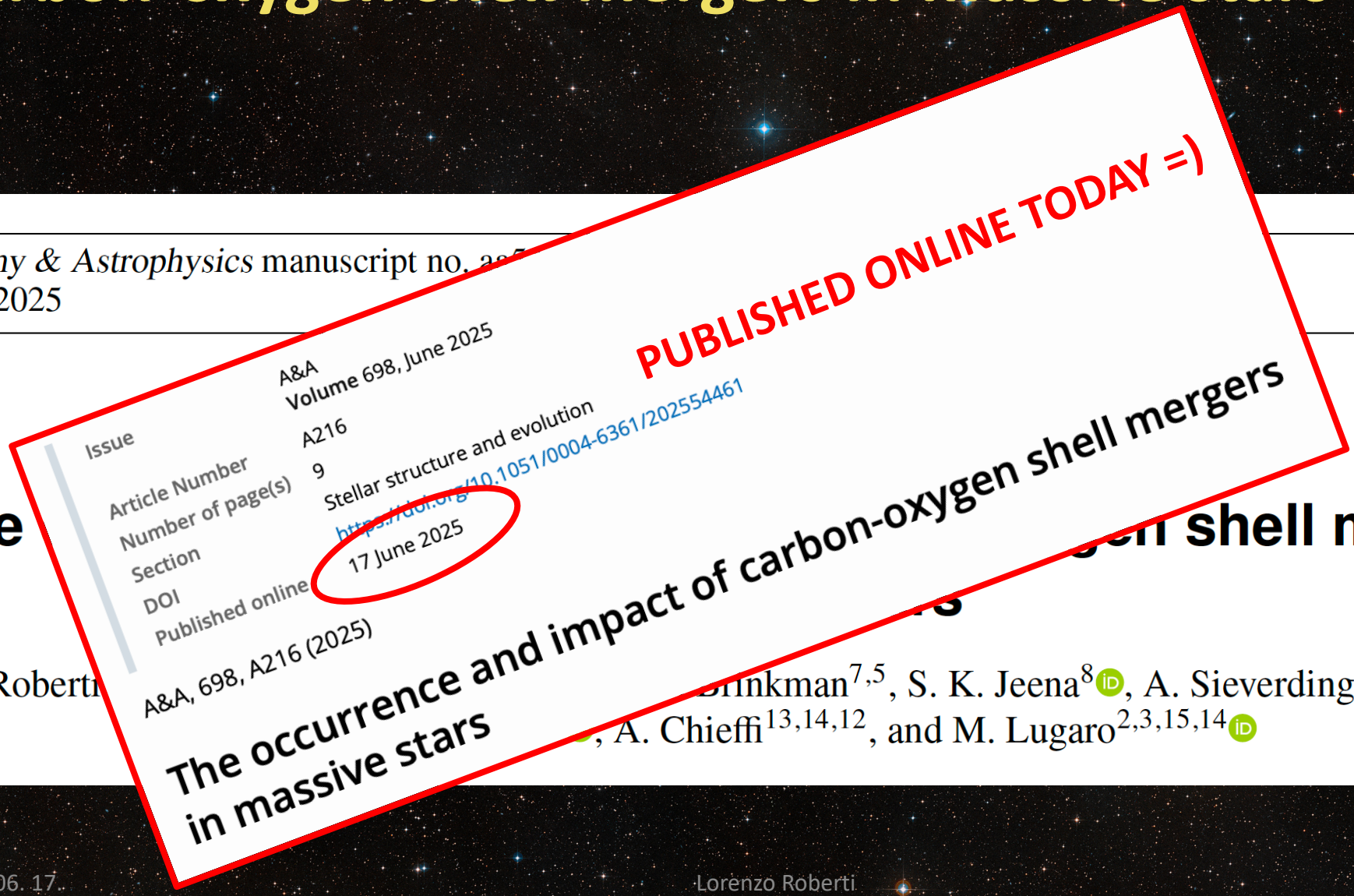
ACCEPTED!
DOI: 10.1051/0004-6361/202554461

The occurrence and impact of carbon-oxygen shell mergers in massive stars

L. Roberti[1,2,3,4,5,★], M. Pignatari[2,3,6,5], H. E. Brinkman[7,5], S. K. Jeena[8], A. Sieverding[9], A. Falla[10,4], M. Limongi[4,11,12], A. Chieffi[13,14,12], and M. Lugaro[2,3,15,14]

Carbon-oxygen shell mergers in massive stars

SCAN ME



Astronomy & Astrophysics manuscript no. as5
May 21, 2025

The **shell mergers in**

L. Roberti, [illegible]Brinkman[7,5], S. K. Jeena[8], A. Sieverding[9], A. Falla[10,4], [illegible], A. Chieffi[13,14,12], and M. Lugaro[2,3,15,14]

Nucleosynthesis in a C-O shell merger

- Enhanced O-burning products and production of odd-Z elements (P, Cl, K, Sc);

- Efficient photodisintegration of heavy elements: production of the weak s-process and γ-process nuclei.

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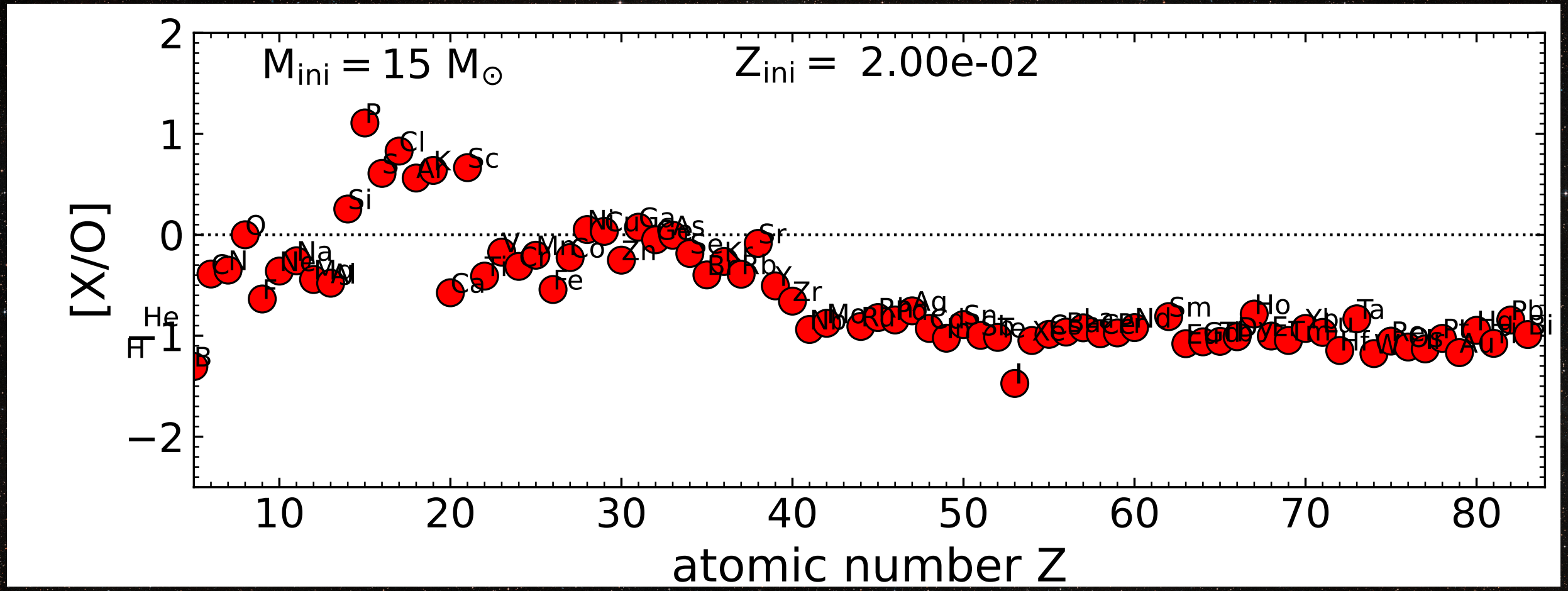
Nucleosynthesis: odd-Z element production



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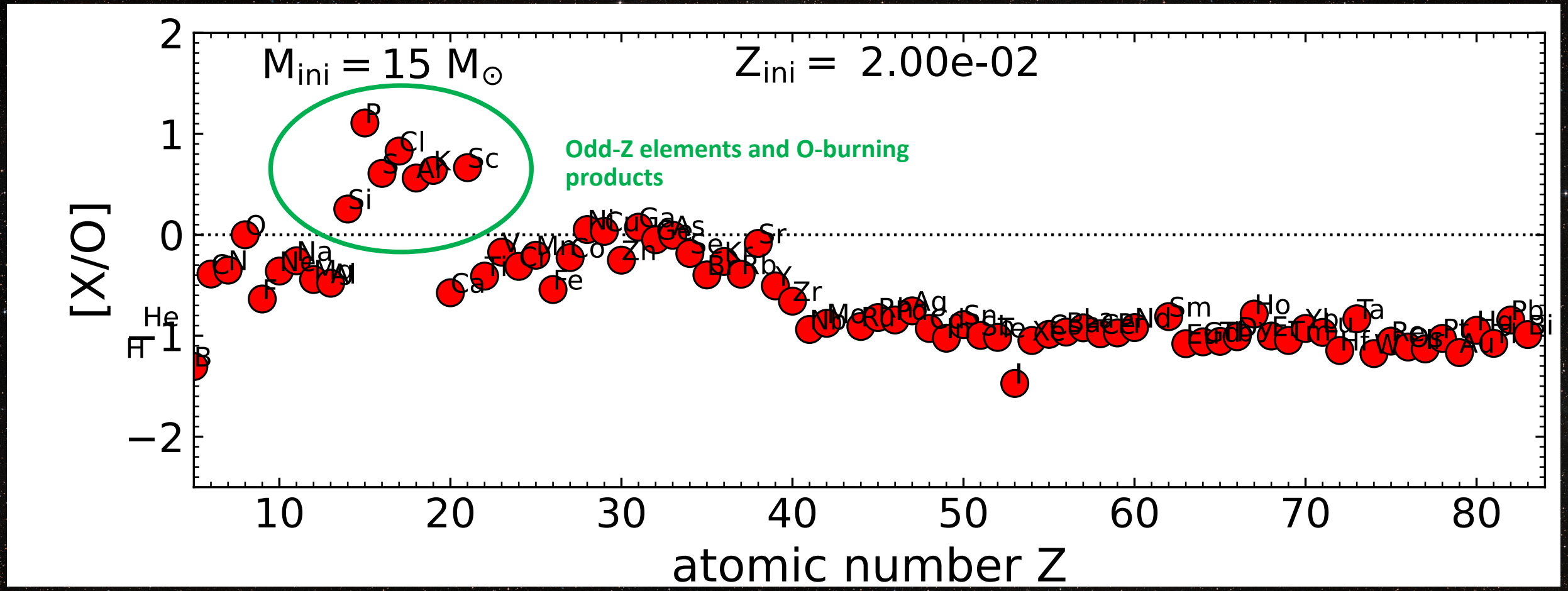

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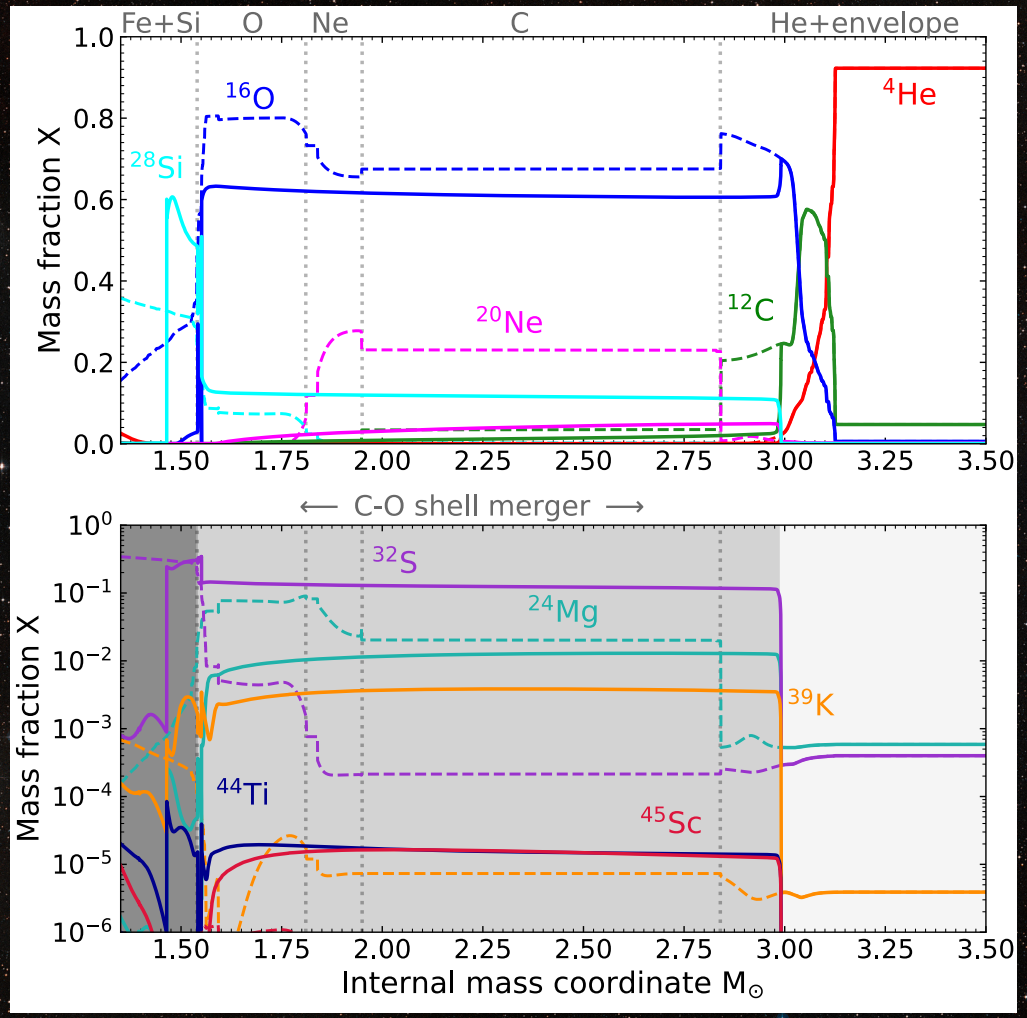

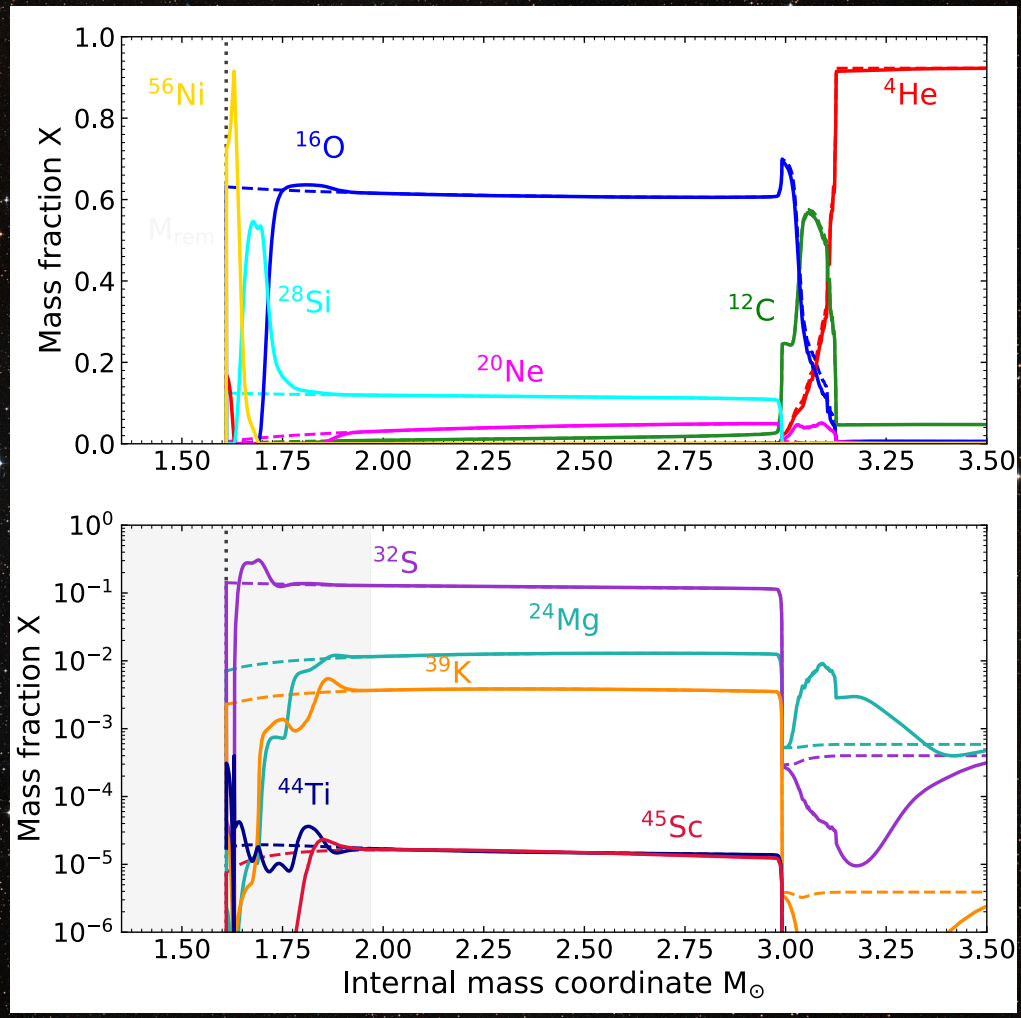

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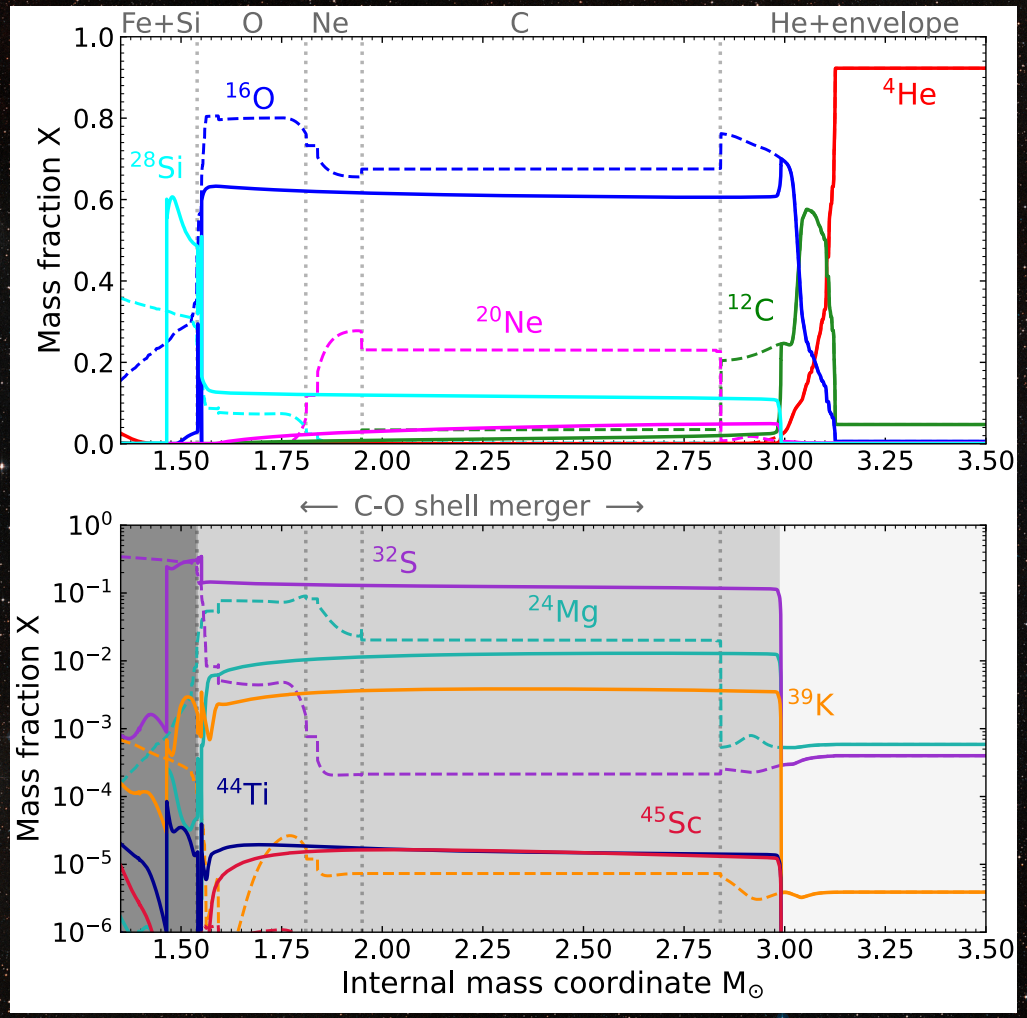

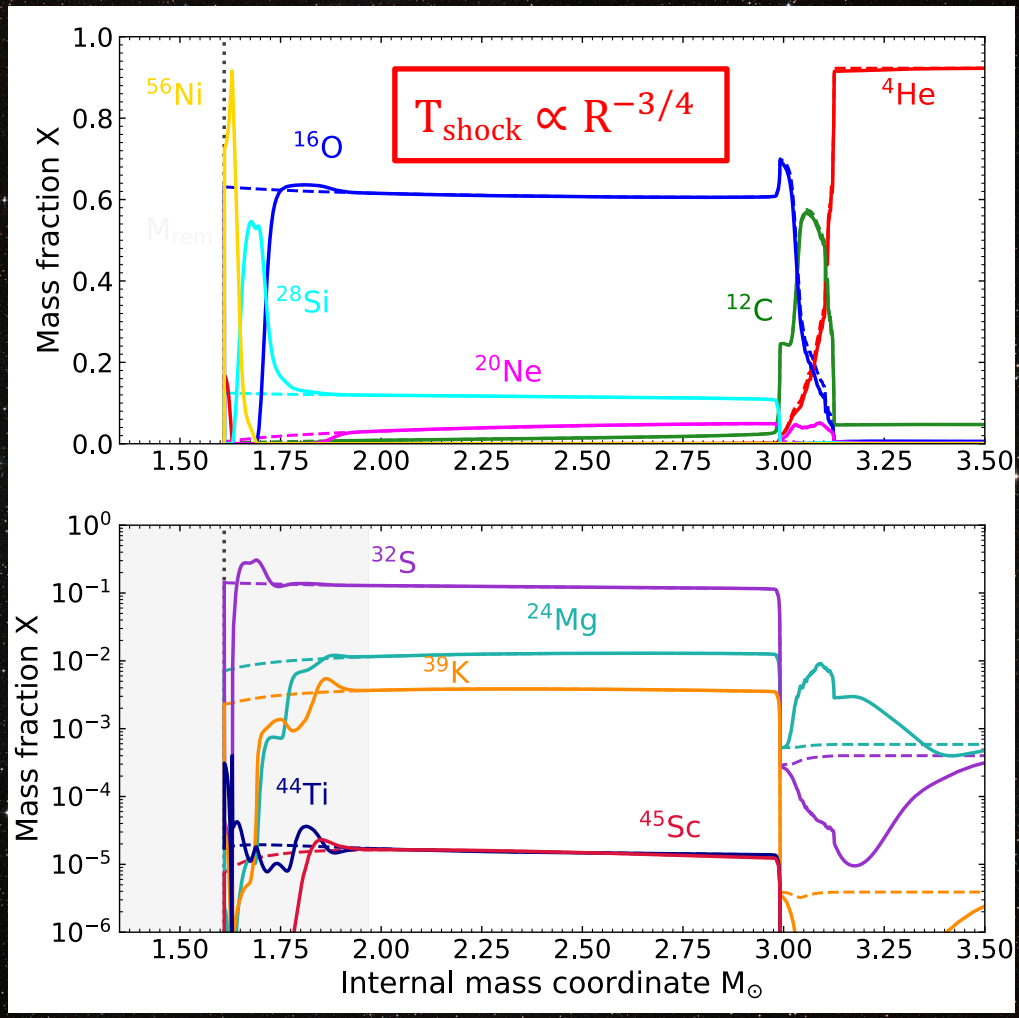

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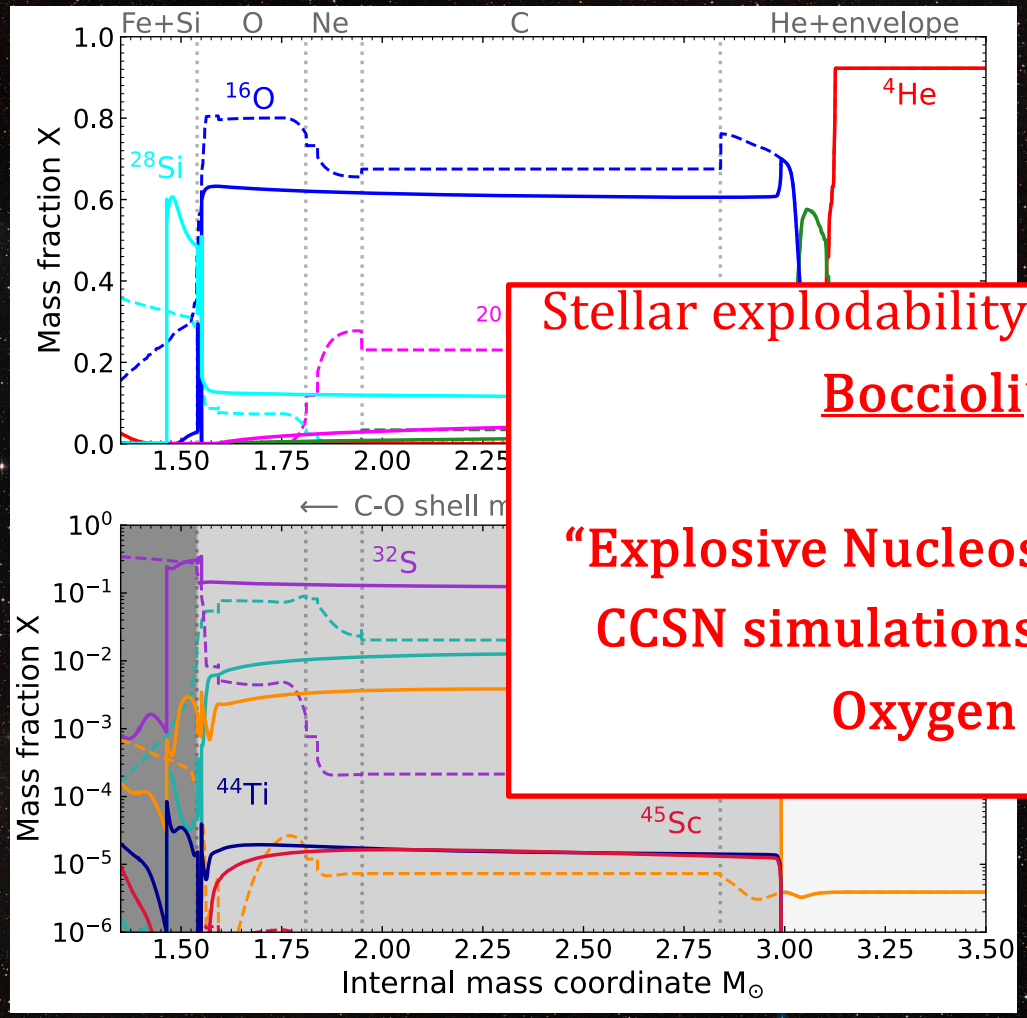
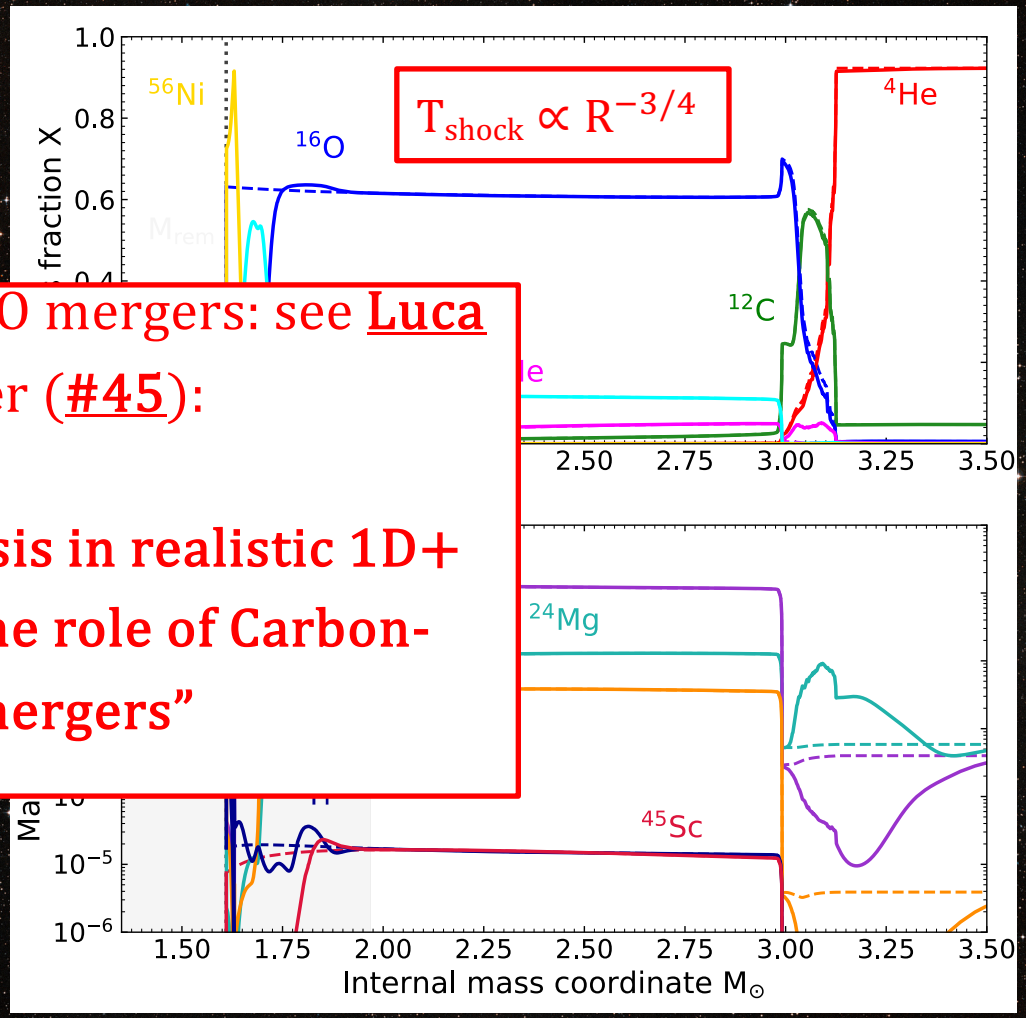
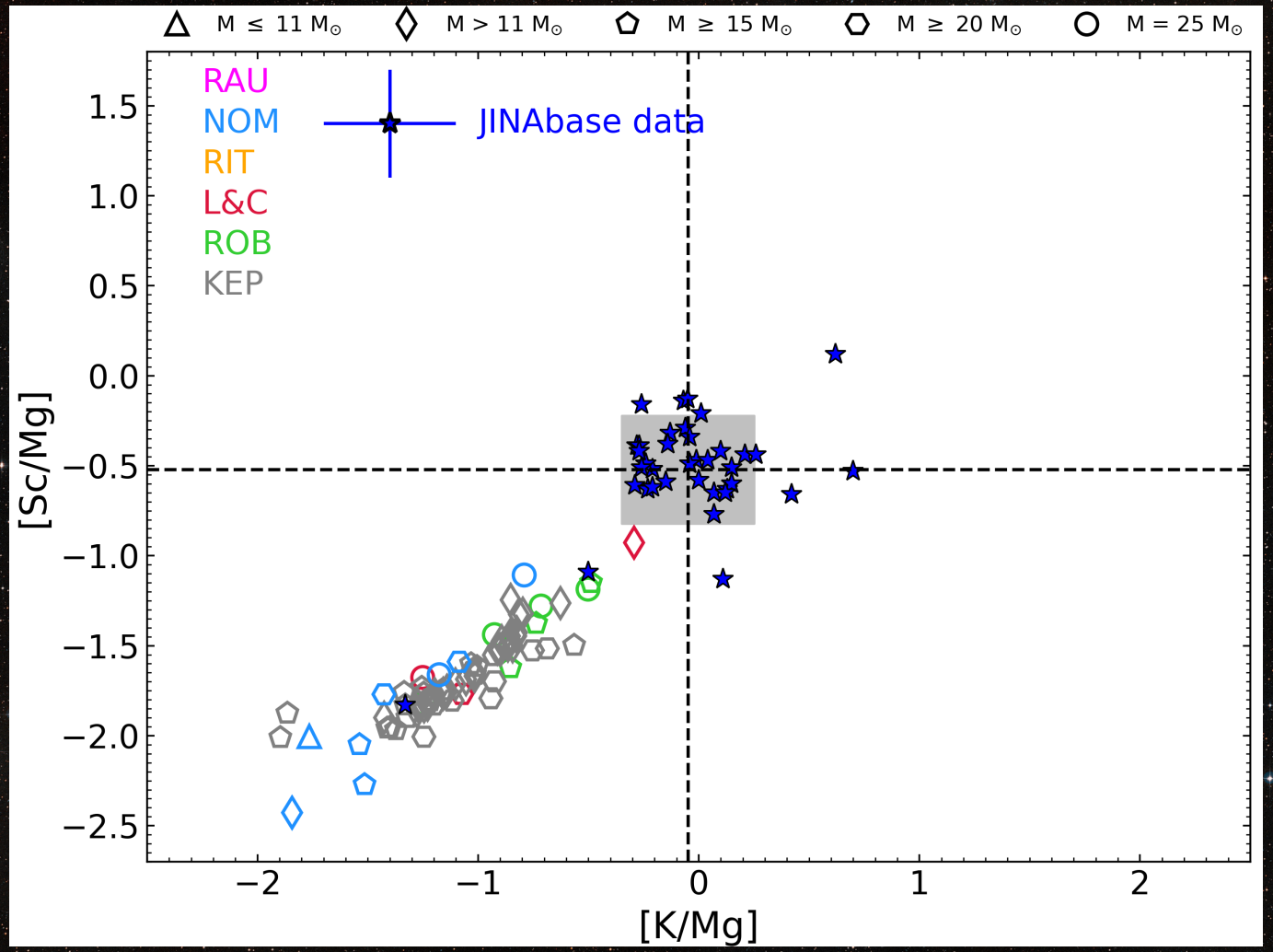




Stellar explodability and C-O mergers: see **Luca Boccioli**'s poster (**#45**):

"Explosive Nucleosynthesis in realistic 1D+ CCSN simulations and the role of Carbon-Oxygen shell mergers"

Stellar Archaeology: odd-Z elements



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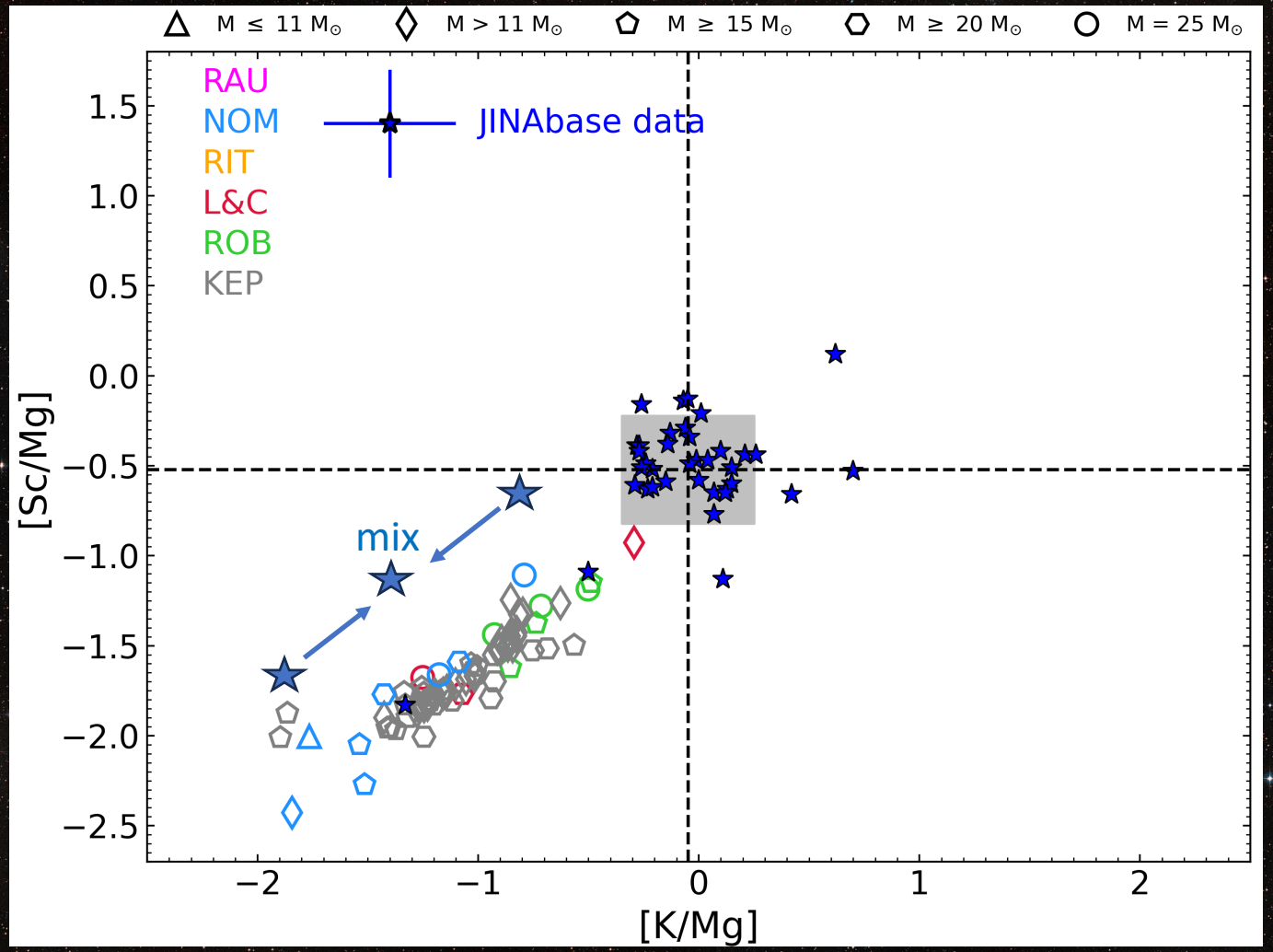

- Comparisons between Pop III models and observations with [Fe/H]<-3 → one or few enrichment episodes;
- Mixing between more stars does not allow the ratios to move to the observations!

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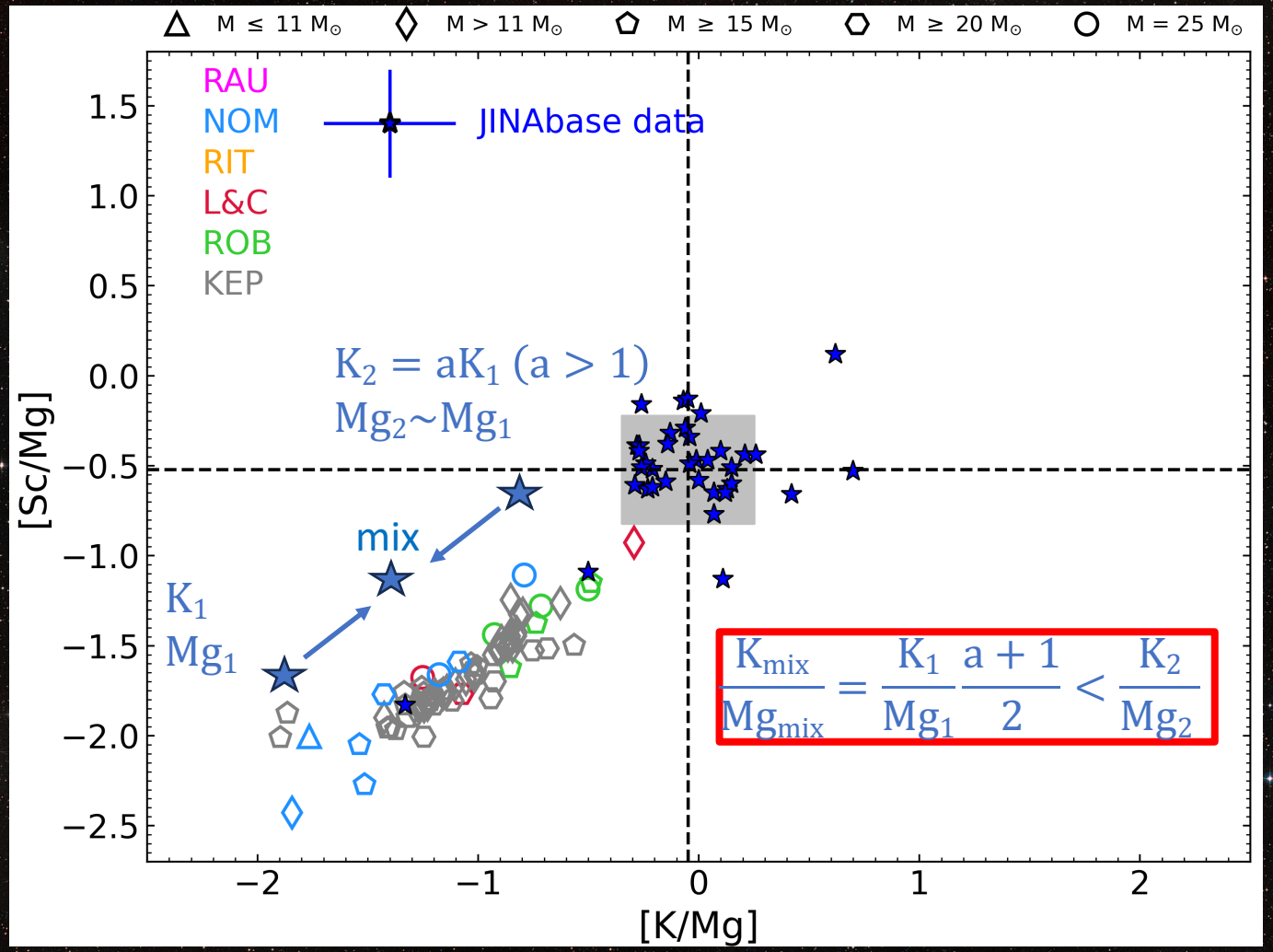

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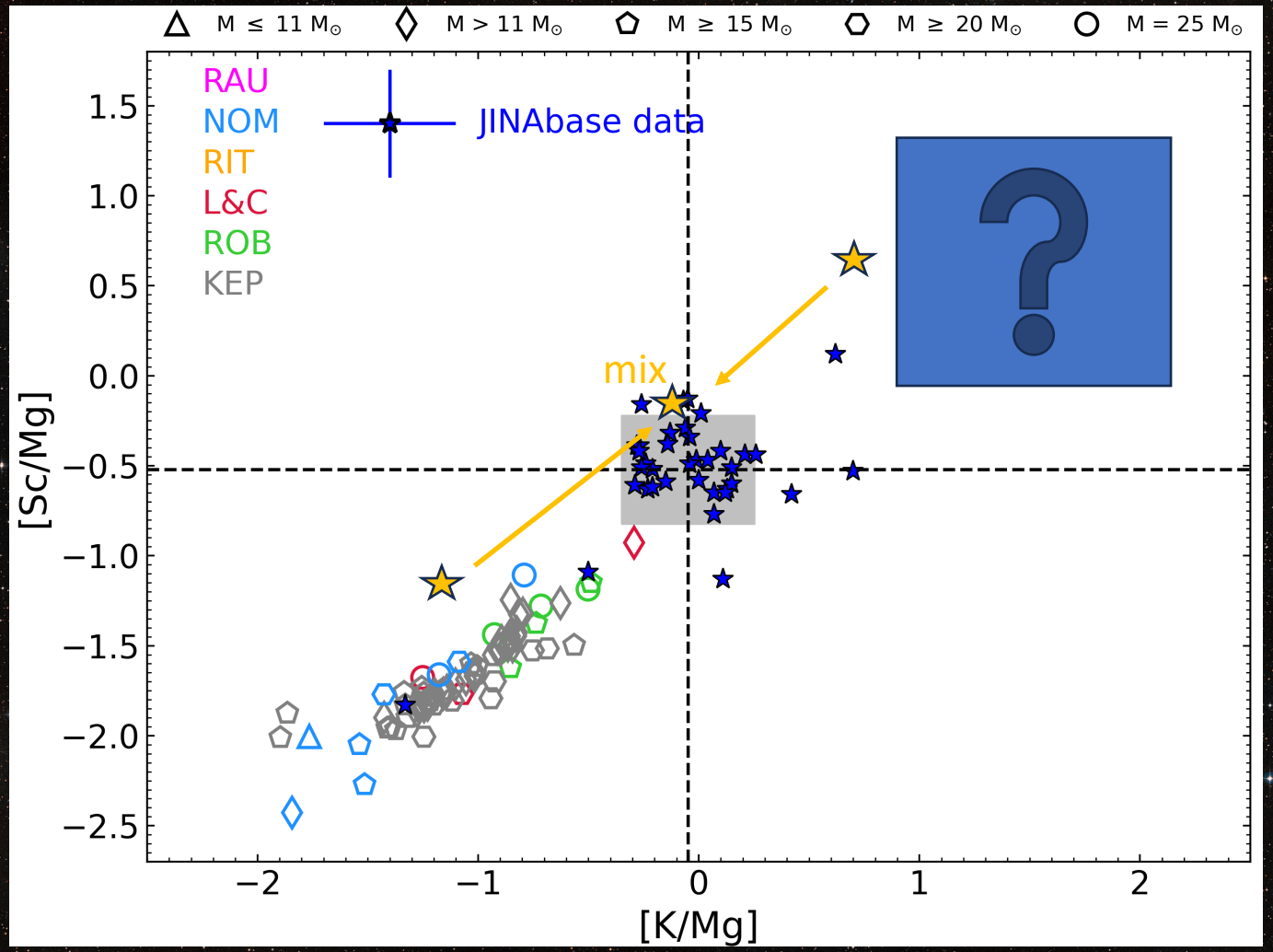

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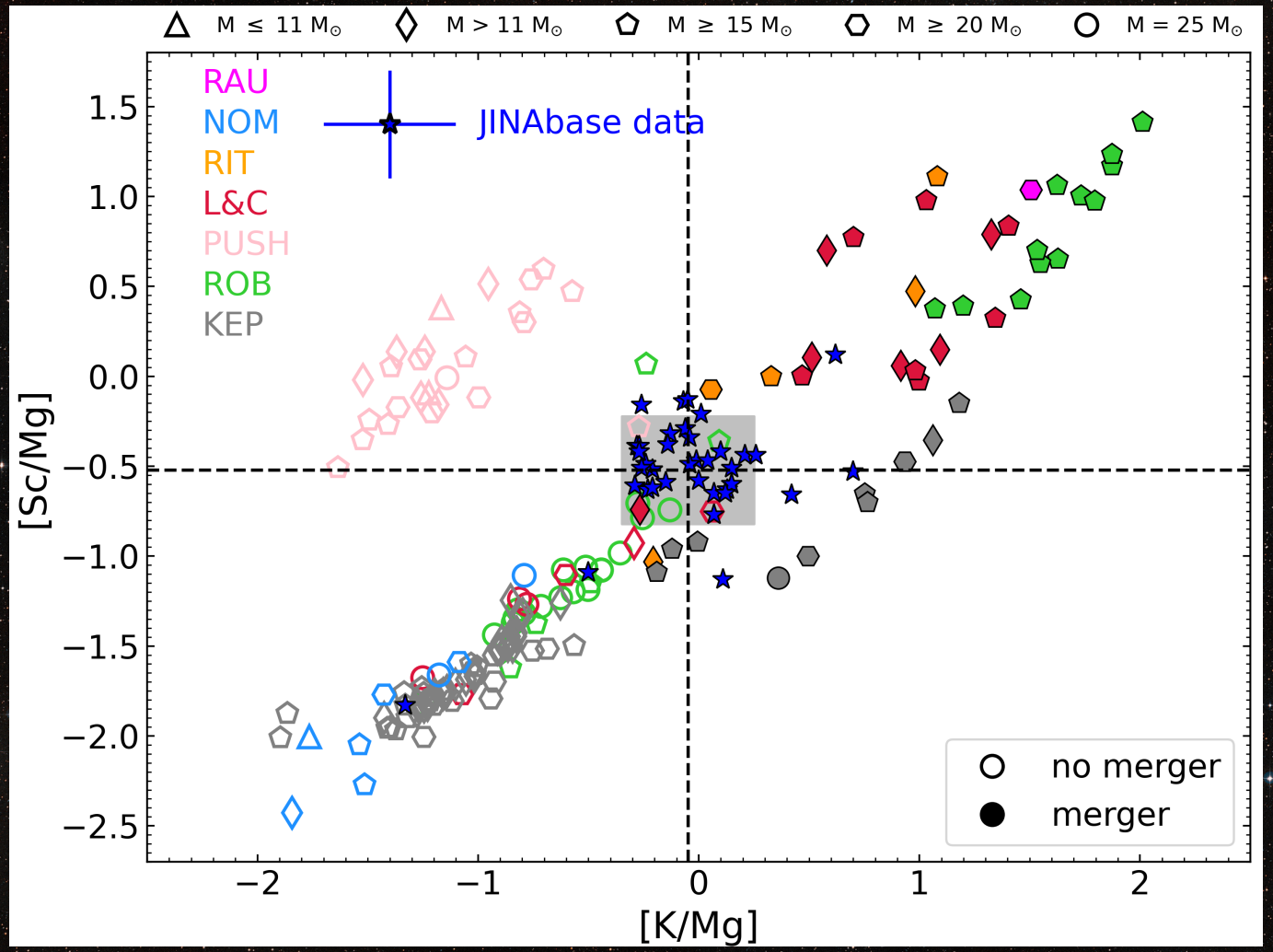

- Comparisons between Pop III models and observations with [Fe/H]<-3 → one or few enrichment episodes;
- Mixing between more stars does not allow the ratios to move to the observations!
- An extra (super-solar) component is required;
- Models with C-O shell mergers naturally populate the required quadrant!

Summary and conclusions

- Carbon-oxygen (C-O) shell mergers in massive stars have a crucial impact on the explosion and on the ejecta composition of CCSNe;
- Indications from 3D modeling seem to confirm their existence;
- Production site for **odd-Z elements**: possible enrichment already in the early universe!
- Large density jump at the Si/O interface because of the extended mixed convective region: easier explosion? **In progress, stay tuned!**
- **Questions**: frequency? Trend with mass/metallicity/rotation? Nuclear physics?

THANK YOU!