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Non-LTE abundances and Galactic evolution of copper

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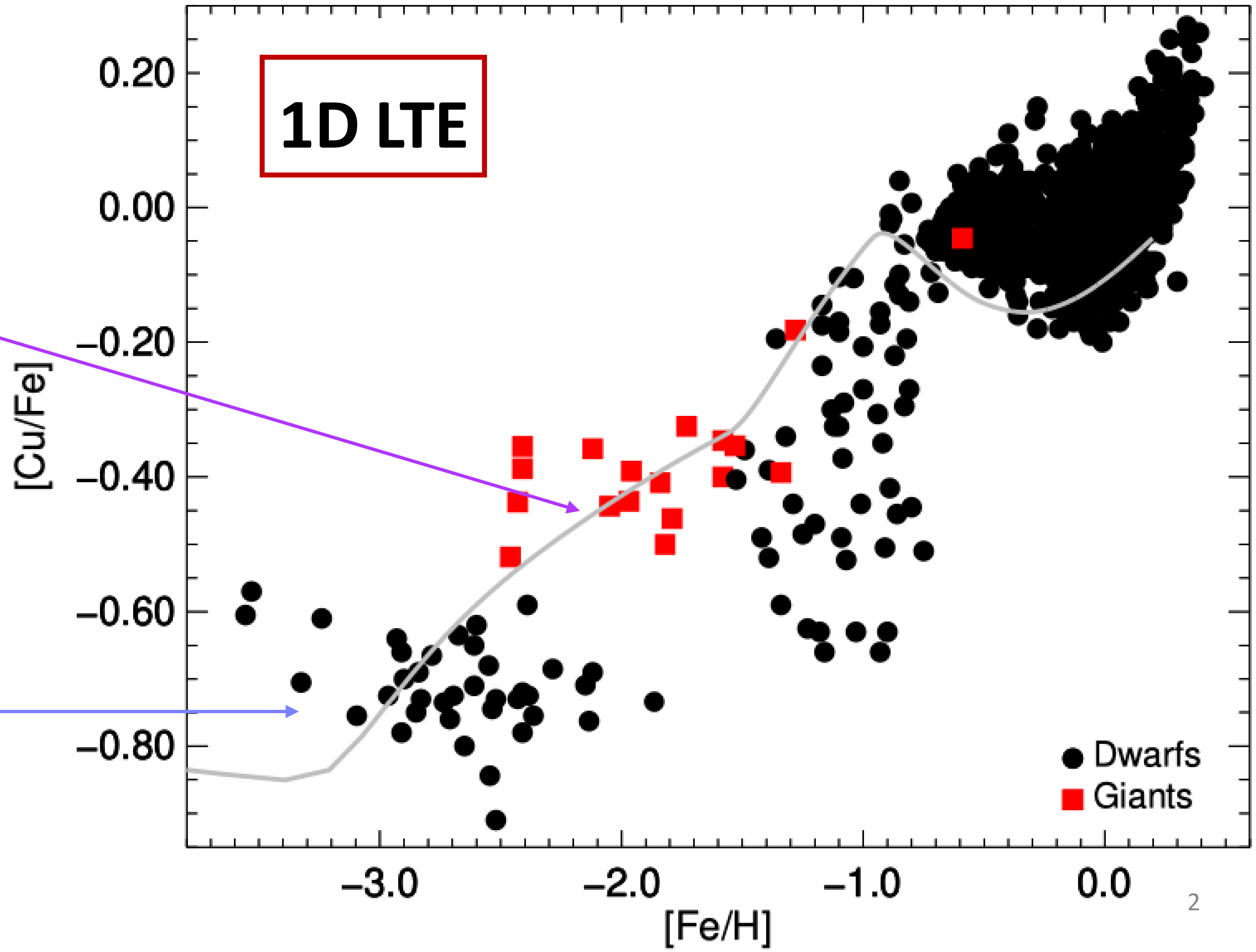
How do galaxies make pennies?

➡ But just how reliable are these results?

Secondary Cu production via weak s-process

Primary Cu production (CC Sne?)



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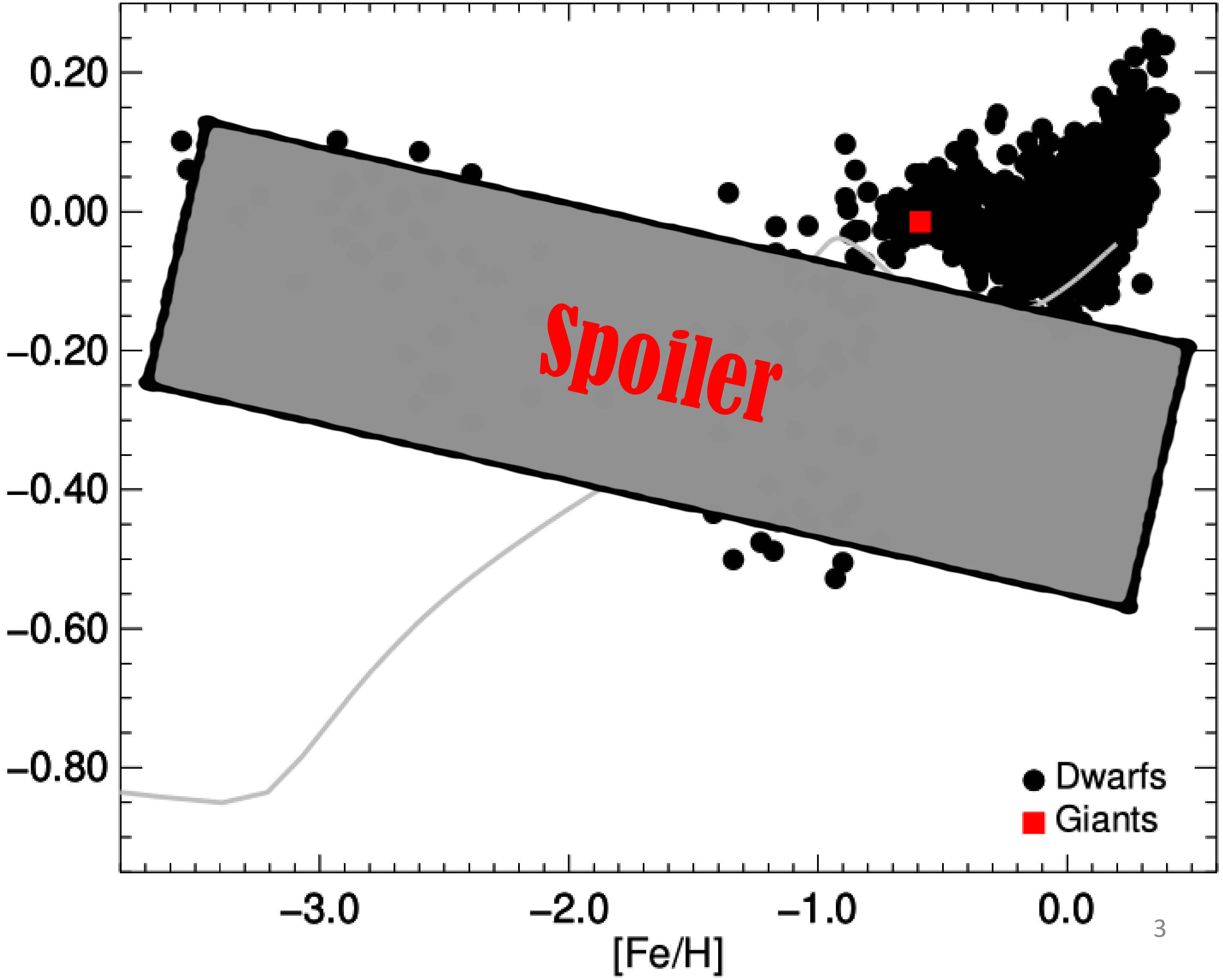

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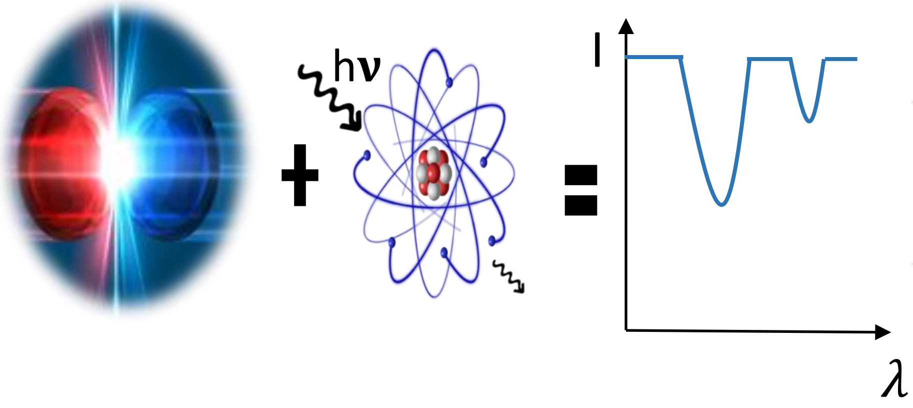
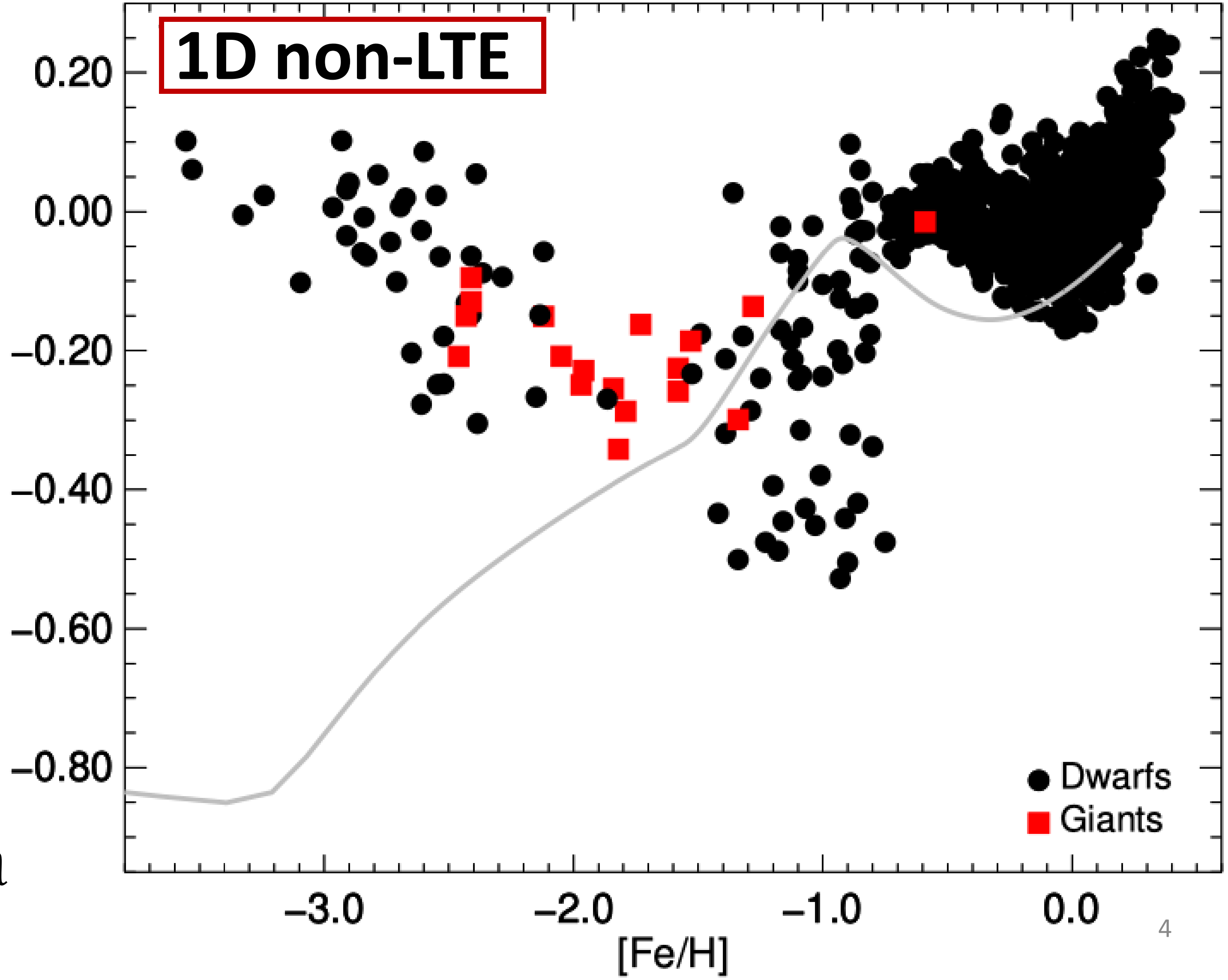
Collisional-radiative modelling in stellar atmospheres:





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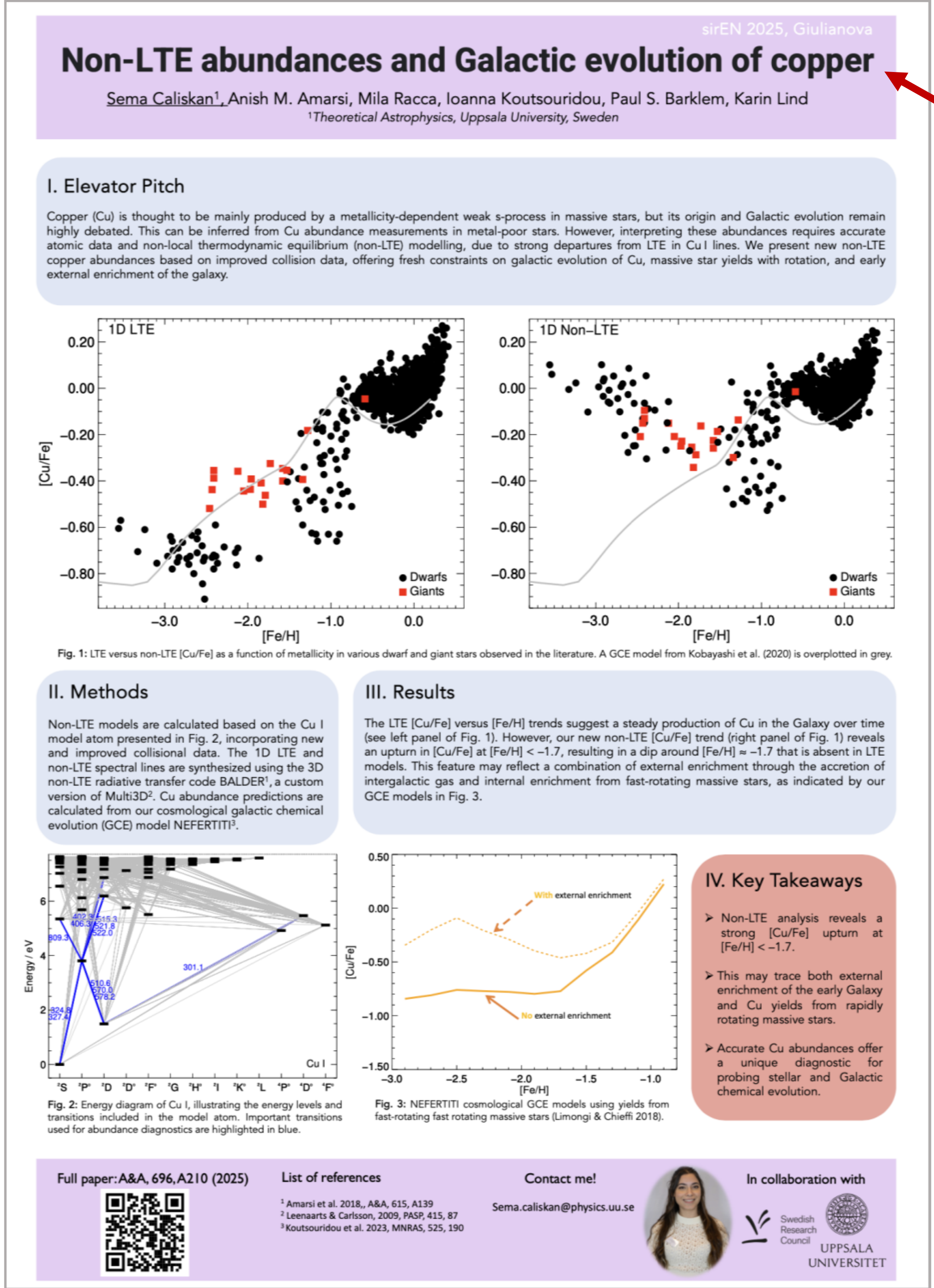
(n° 2)



sirEN 2025, Giulianova

Non-LTE abundances and Galactic evolution of copper

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I. Elevator Pitch

Copper (Cu) is thought to be mainly produced by a metallicity-dependent weak s-process in massive stars, but its origin and Galactic evolution remain highly debated. This can be inferred from Cu abundance measurements in metal-poor stars. However, interpreting these abundances requires accurate atomic data and non-local thermodynamic equilibrium (non-LTE) modelling, due to strong departures from LTE in Cu I lines. We present new non-LTE copper abundances based on improved collision data, offering fresh constraints on galactic evolution of Cu, massive star yields with rotation, and early external enrichment of the galaxy.

Fig. 1: LTE versus non-LTE [Cu/Fe] as a function of metallicity in various dwarf and giant stars observed in the literature. A GCE model from Kobayashi et al. (2020) is overplotted in grey.

II. Methods

Non-LTE models are calculated based on the Cu I model atom presented in Fig. 2, incorporating new and improved collisional data. The 1D LTE and non-LTE spectral lines are synthesized using the 3D non-LTE radiative transfer code BALDER[1], a custom version of Multi3D[2]. Cu abundance predictions are calculated from our cosmological galactic chemical evolution (GCE) model NEFERTITI[3].

III. Results

The LTE [Cu/Fe] versus [Fe/H] trends suggest a steady production of Cu in the Galaxy over time (see left panel of Fig. 1). However, our new non-LTE [Cu/Fe] trend (right panel of Fig. 1) reveals an upturn in [Cu/Fe] at [Fe/H] < −1.7, resulting in a dip around [Fe/H] ≈ −1.7 that is absent in LTE models. This feature may reflect a combination of external enrichment through the accretion of intergalactic gas and internal enrichment from fast-rotating massive stars, as indicated by our GCE models in Fig. 3.

Fig. 2: Energy diagram of Cu I, illustrating the energy levels and transitions included in the model atom. Important transitions used for abundance diagnostics are highlighted in blue.

Fig. 3: NEFERTITI cosmological GCE models using yields from fast-rotating fast rotating massive stars (Limongi & Chieffi 2018).

IV. Key Takeaways

- Non-LTE analysis reveals a strong [Cu/Fe] upturn at [Fe/H] < −1.7.
- This may trace both external enrichment of the early Galaxy and Cu yields from rapidly rotating massive stars.
- Accurate Cu abundances offer a unique diagnostic for probing stellar and Galactic chemical evolution.

Full paper: A&A, 696, A210 (2025)

List of references

[1] Amarsi et al. 2018,, A&A, 615, A139
[2] Leenaarts & Carlsson, 2009, PASP, 415, 87
[3] Koutsouridou et al. 2023, MNRAS, 525, 190

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!Different title!

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Read more about it:

Revisiting inelastic Cu+H collisions and the non-LTE Galactic evolution of copper

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