Neutrino-driven Core-collapse Supernova Yields in Galactic Chemical Evolution

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Motivation

Core-collapse supernova (CCSN) yields are key in models of Galactic chemical evolution (GCE). These models require a large grid of stellar progenitors, varying in mass and metallicity. Simulating hundreds of CCSN models for several seconds is only feasible with one-dimensional (1D) simulations owing to computational cost. Our neutrino-driven CCSN simulations have two main advantages compared to previous methods used for applications in GCE. Firstly, the mass cut between remnant and ejecta evolves naturally. Secondly, the neutrino luminosities and thus the electron fraction are not modified. Both are key to obtain an accurate nucleosynthesis. We use different calibrations and **explore the impact of the new CCSN yield sets in a well-tested GCE model of the Milky Way**.

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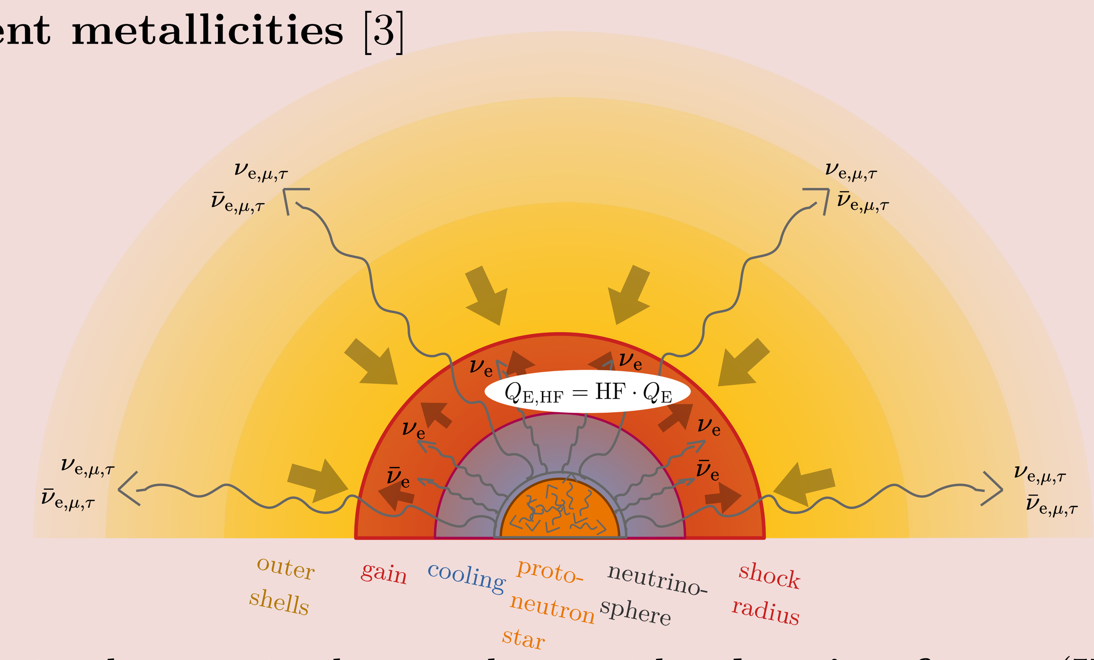
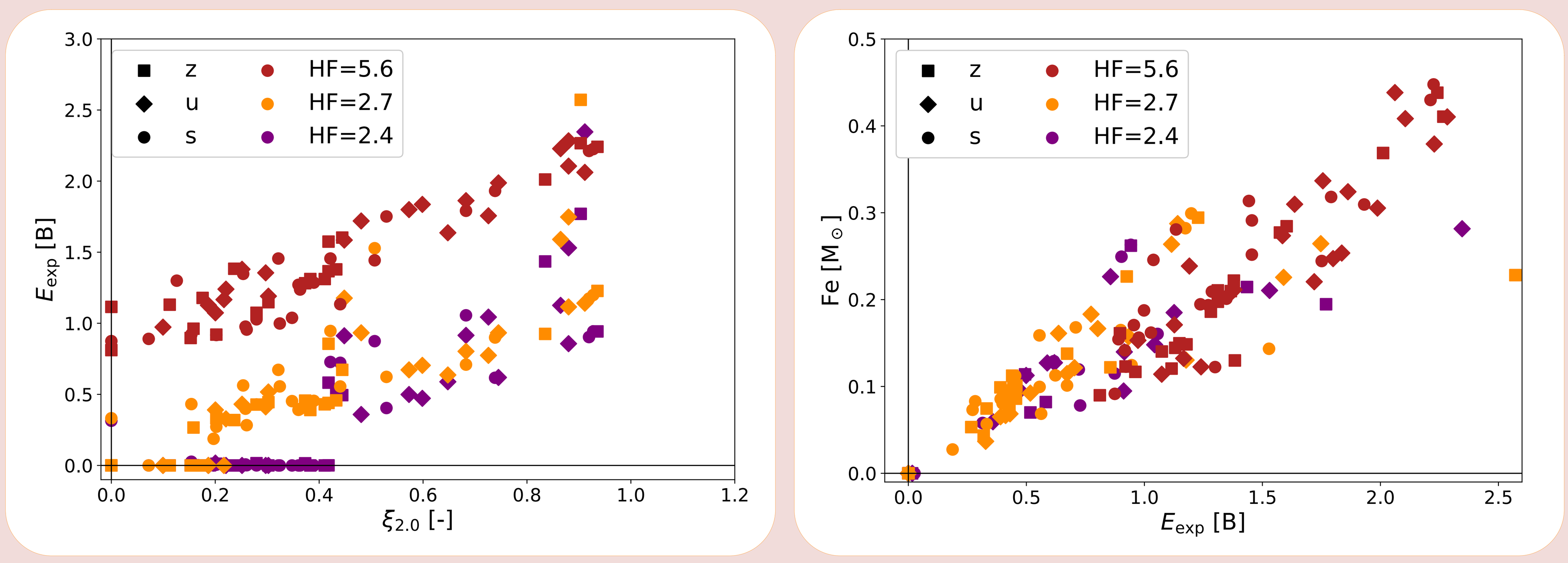
Core-collapse supernovae

- **189 neutrino-driven CCSN simulations** with the AENUS-ALCAR code [1]
- Composition evolved with a **reduced in-situ nuclear reaction network** including the 16 most abundant isotopes [2]
- Progenitors cover zero-age main sequence masses **between 11 and 75 $M_\odot$** and **three different metallicities** [3]



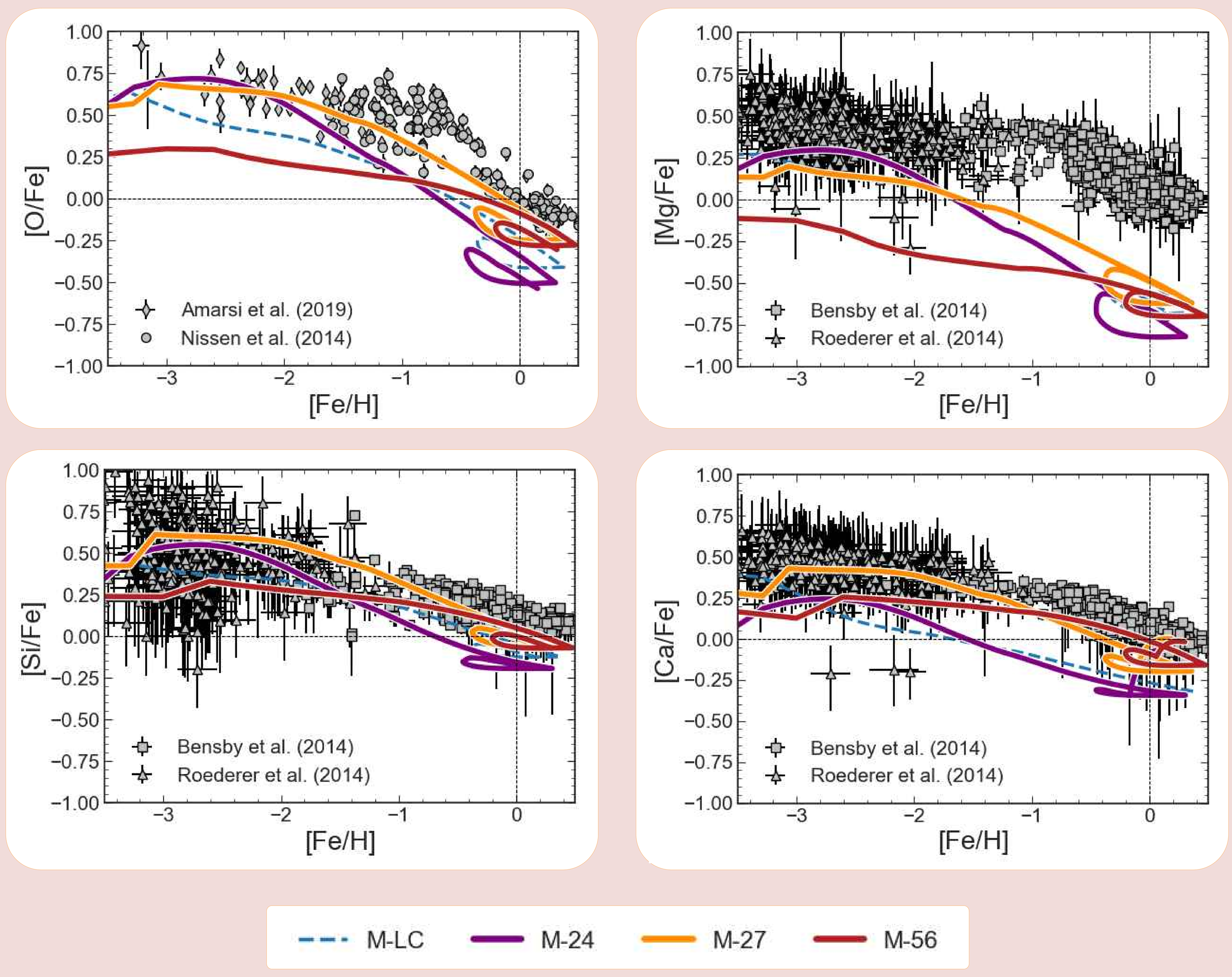
- Enhanced neutrino heating in the gain layer with a **heating factor** (HF) allows for **explosions in 1D**. In this method, the mass cut between remnant and ejecta evolves in the simulation and the electron fraction is not modified.
- Wide variation of free parameter (HF) using **different calibrations** (SN1987A and 3D simulation) allows to propagate uncertainty



- Generally, a **higher HF results in more energetic explosions**
- Progenitors with larger compactness parameter (ξ) explode more easily (i.e. with lower HF)
- **Correlation of the explosion energy with the compactness** of the progenitor links the progenitor structure to the explosion outcome (left panel)
- Similar results were obtained with the STIR method [4] and in 3D simulations [5]
- **Correlation of ejected iron with explosion energy** is reproduced (right panel)

Galactic chemical evolution

- GCE model takes into account **two infall episodes of gas** [6] and includes nucleosynthesis from a **large variety of stellar sources** [7]: low-intermediate mass stars, Type Ia SNe, nova systems, *CCSNe,* neutron-star mergers, magneto-rotational SNe
- Calibrated to reproduce the main features of the solar vicinity
- Prediction of abundance ratios with respect to Fe for: C, O, Ne, Mg, Si, S, Ar, Ca, Ti, and Cr
- Our three sets correspond to different HF: 2.4 in purple, 2.7 in orange, 5.6 in red
- As a reference, we show predictions of the same GCE model with different CCSN yields [8] (M-LC in blue)



- The **abundance ratios** and their **trend with metallicity are well reproduced** with the **known exceptions of Mg and Ti**
- **M-27 reproduces best** the order of magnitude and shape of the α-elements abundance ratios, the solar metallicity distribution function, and iron abundance
- **M-25 underproduces** almost all elements, because only **few stars explode**
- For **M-56**, the **enhanced iron production suppresses** the abundance ratios

Conclusion

We find a **big impact of the CCSN yields on our GCE predictions**. The model that **best reproduces the observations** is the one **with HF = 2.7**. With the lowest HF, only about half of the stars explode, which results in lower production of all elements. Since the set with **the lowest HF underproduces** almost all elements, this suggests that **at least half of the massive stars have to explode** to fit the observed chemical evolution of the solar neighbourhood. All yields are increased with higher explosion energy, but Fe scales most strongly. If the explosions are **too energetic** (with the highest HF), the **high amount of iron reduces the abundance ratios**. This indicates that the typical CCSN explosion energy should be lower than about 2 Bethe. We conclude that using late advances in CCSN simulations to obtain yields for GCE models can provide useful constraints to both fields.

References:

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