Constraints on Nucleosynthesis from Chemical Abundances

Richard Hoppe, MPIA Heidelberg
Supervisor: Maria Bergemann

5.3.2024, 19th Russbach School on Nuclear Astrophysics

European Research Council
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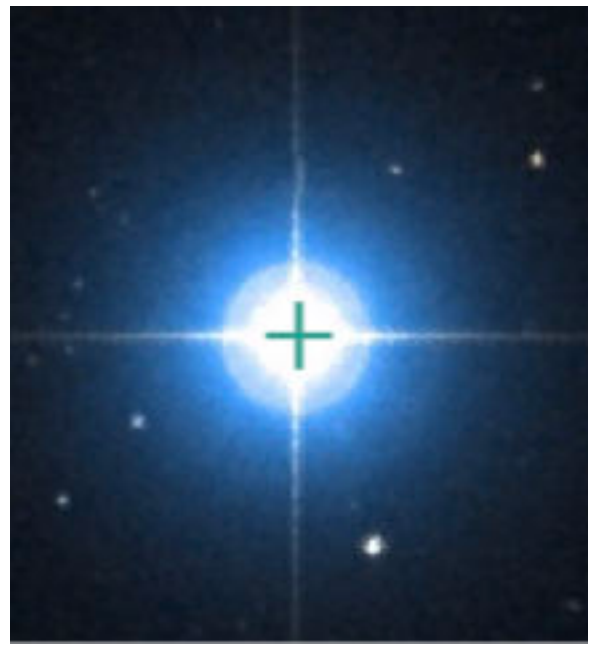
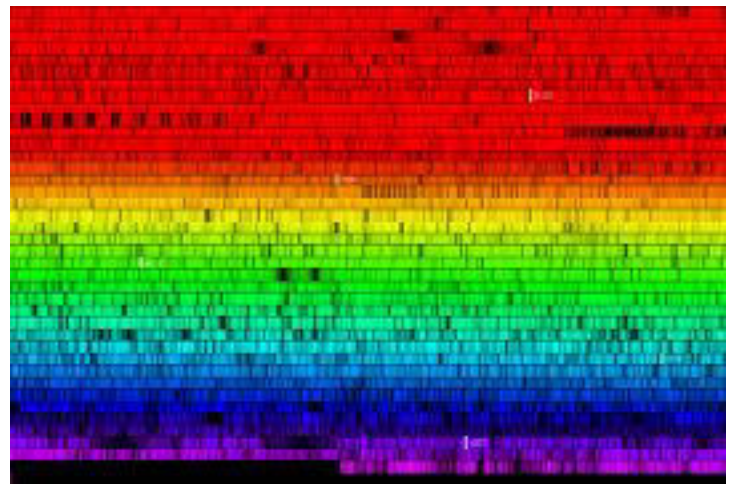
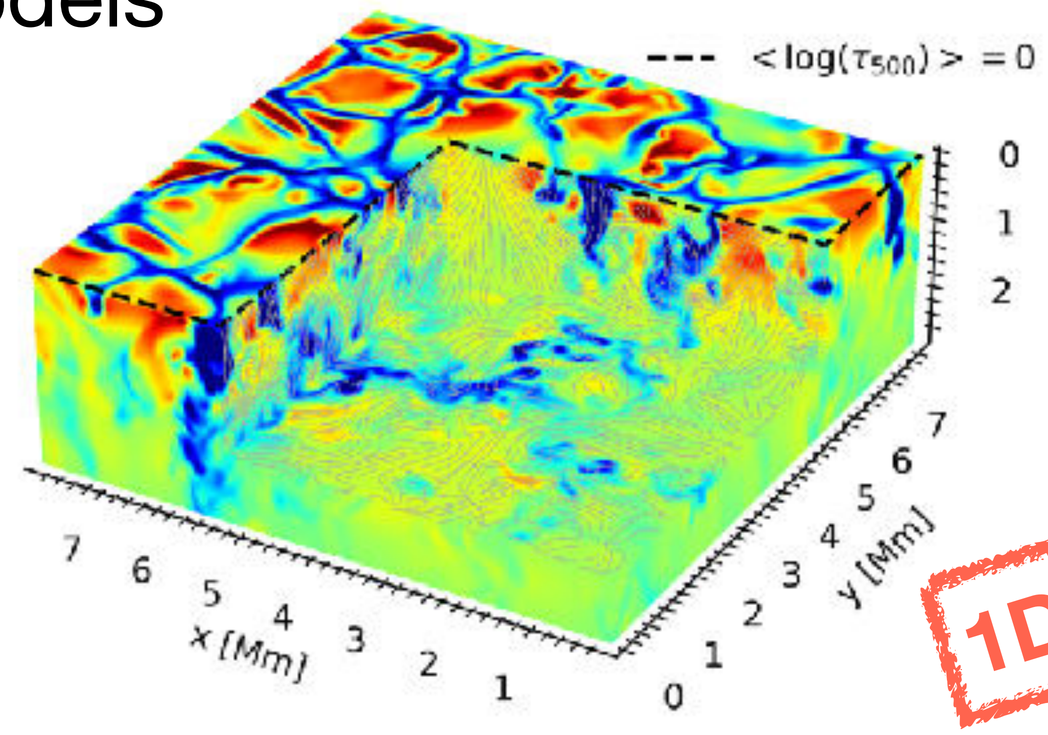
How are stellar abundances “measured”?



Observed spectra



Atmosphere models
radiation-
hydrodynamics

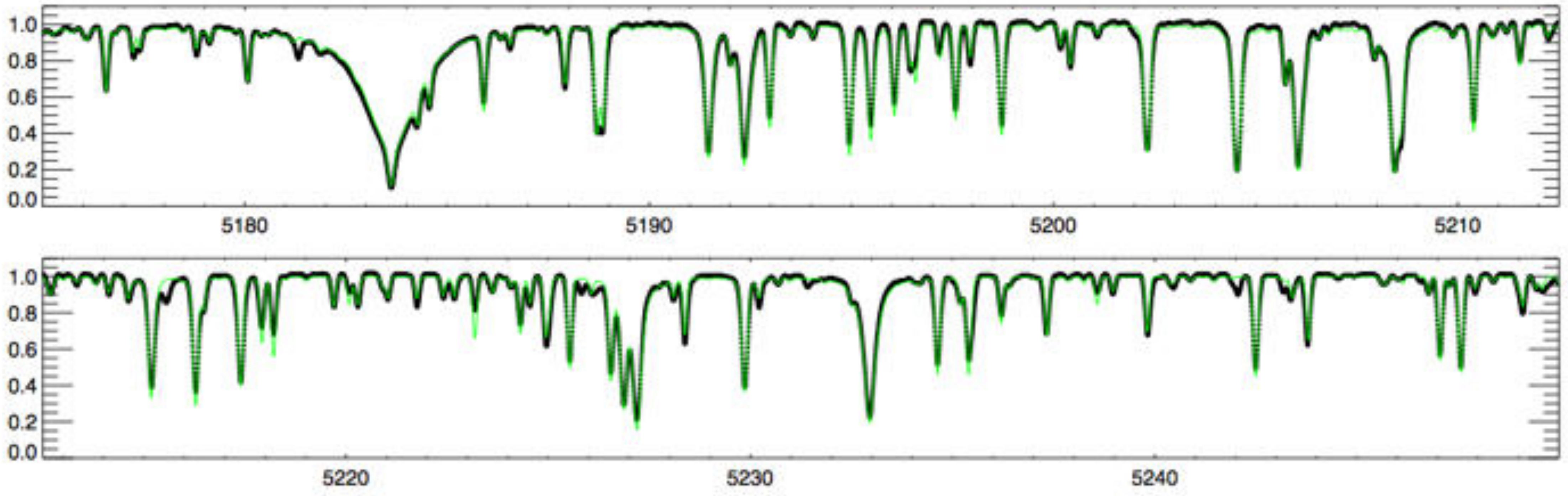


1D or 3D?

LTE or non-LTE?

Line formation
nuclear dynamics
atomic/molecular data
(lab + theory)

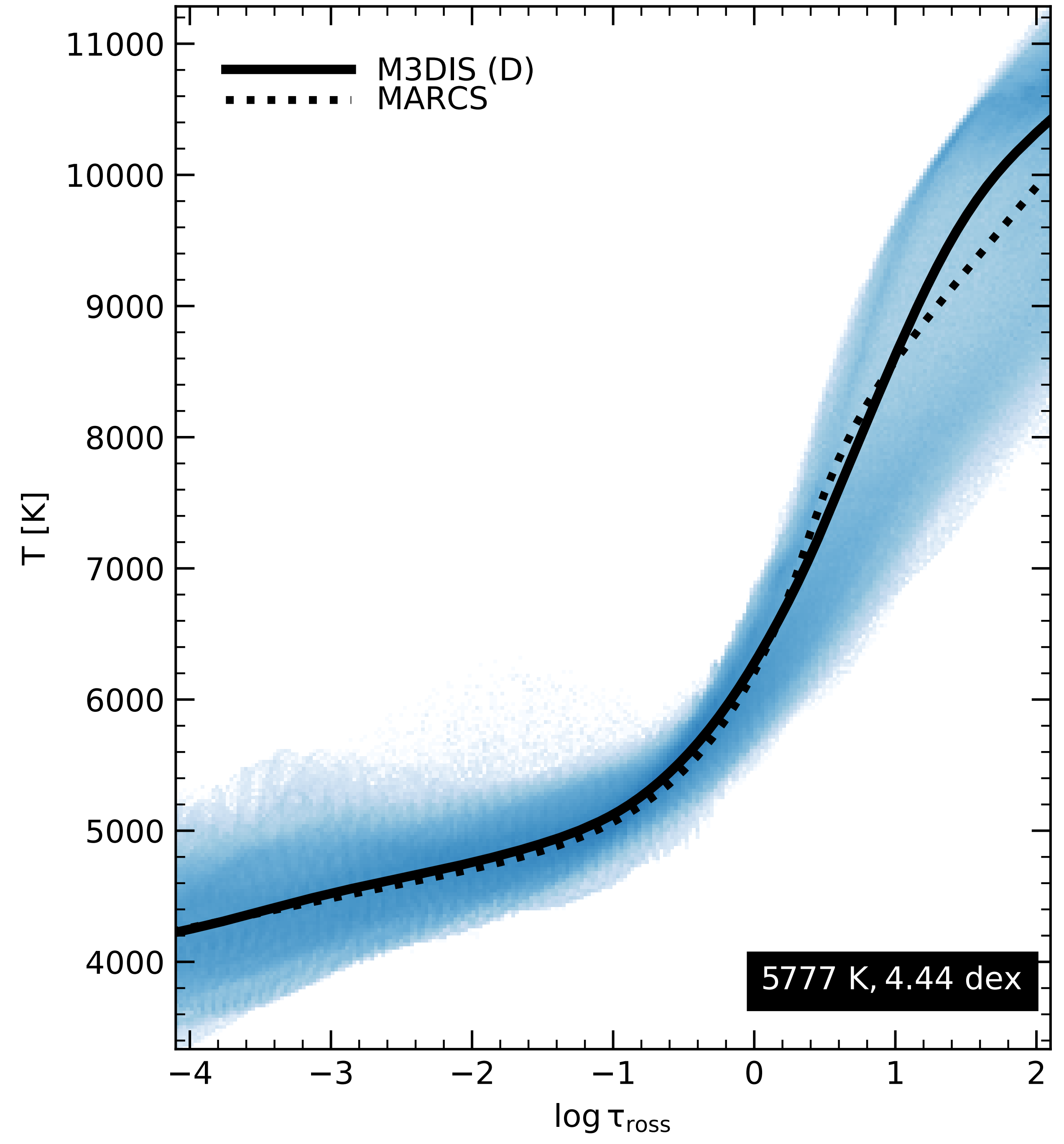
Grid calculations for large T_{eff}-logg-[Fe/H] space

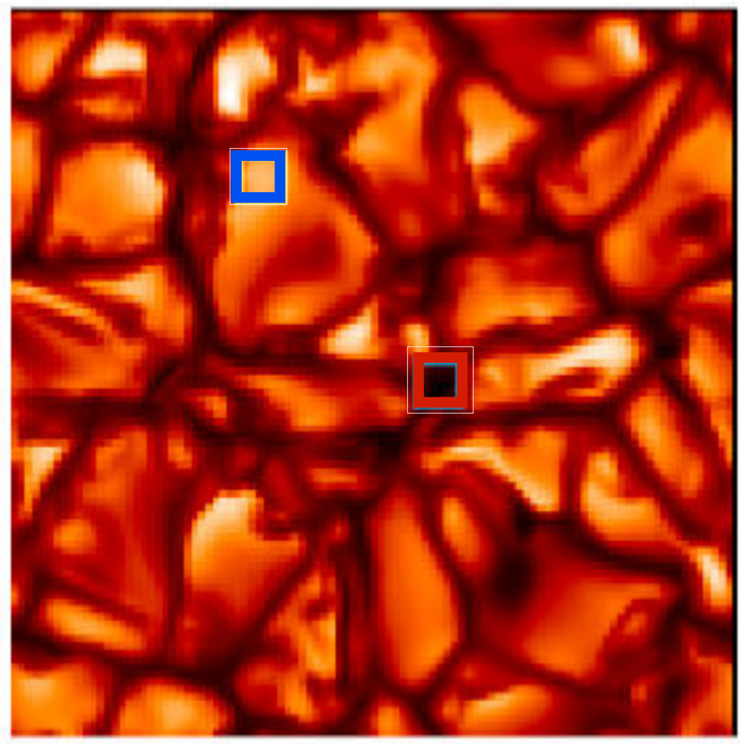


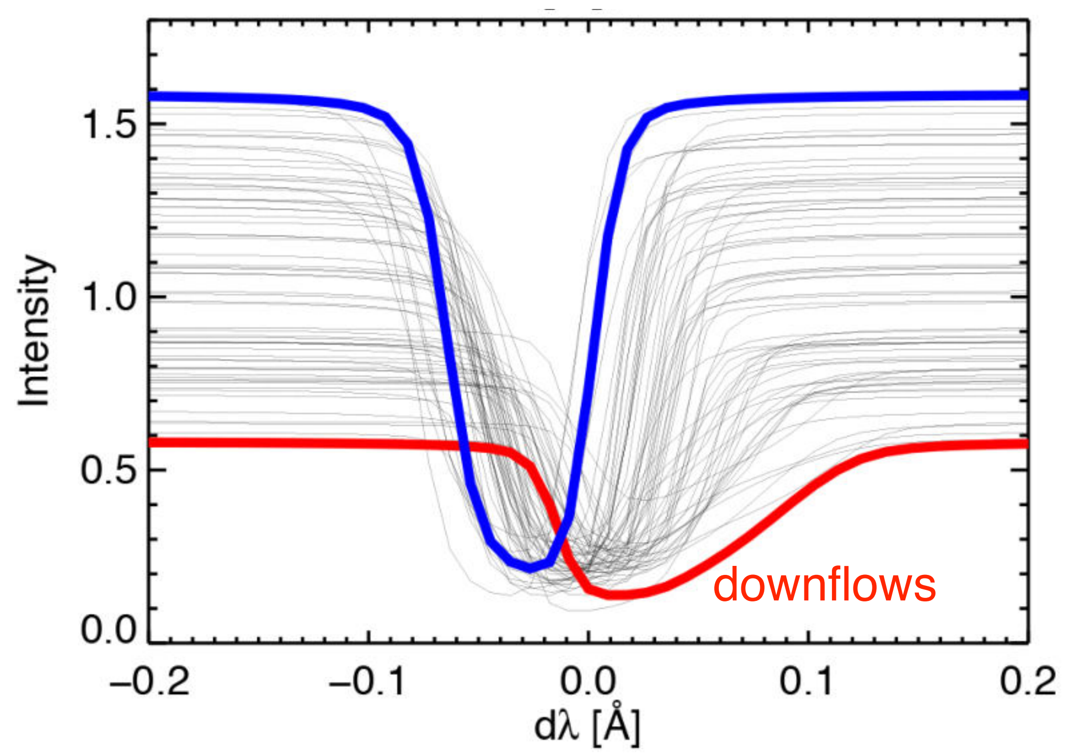
Get abundances by
interpolating synthetic spectra
to fit observed spectrum

3D Line Formation

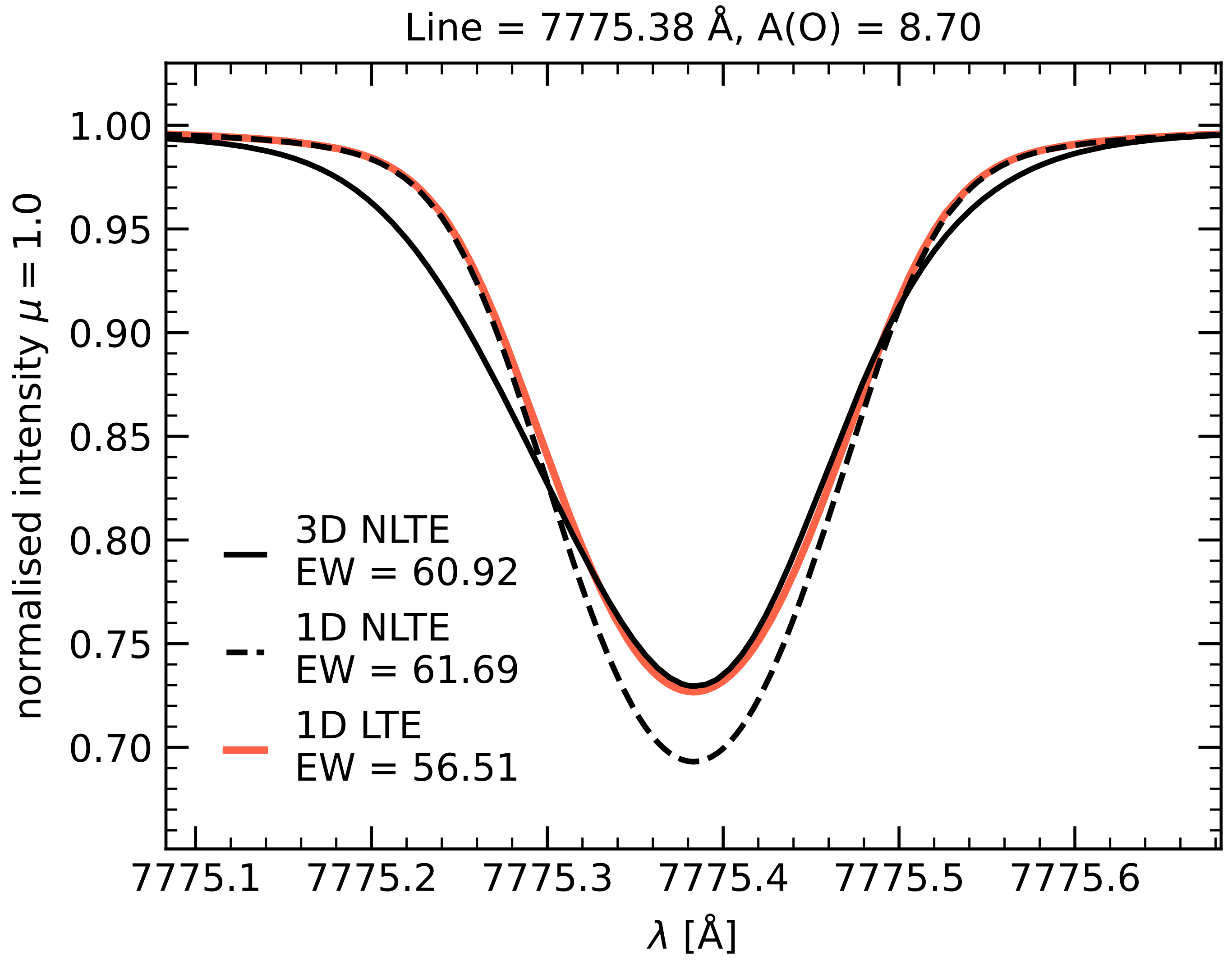
- Asymmetric line profiles can only be modelled accurately using 3D model atmospheres with convection
- Also nearly symmetric lines can differ significantly due to the different temperature structure in 3D model atmospheres.







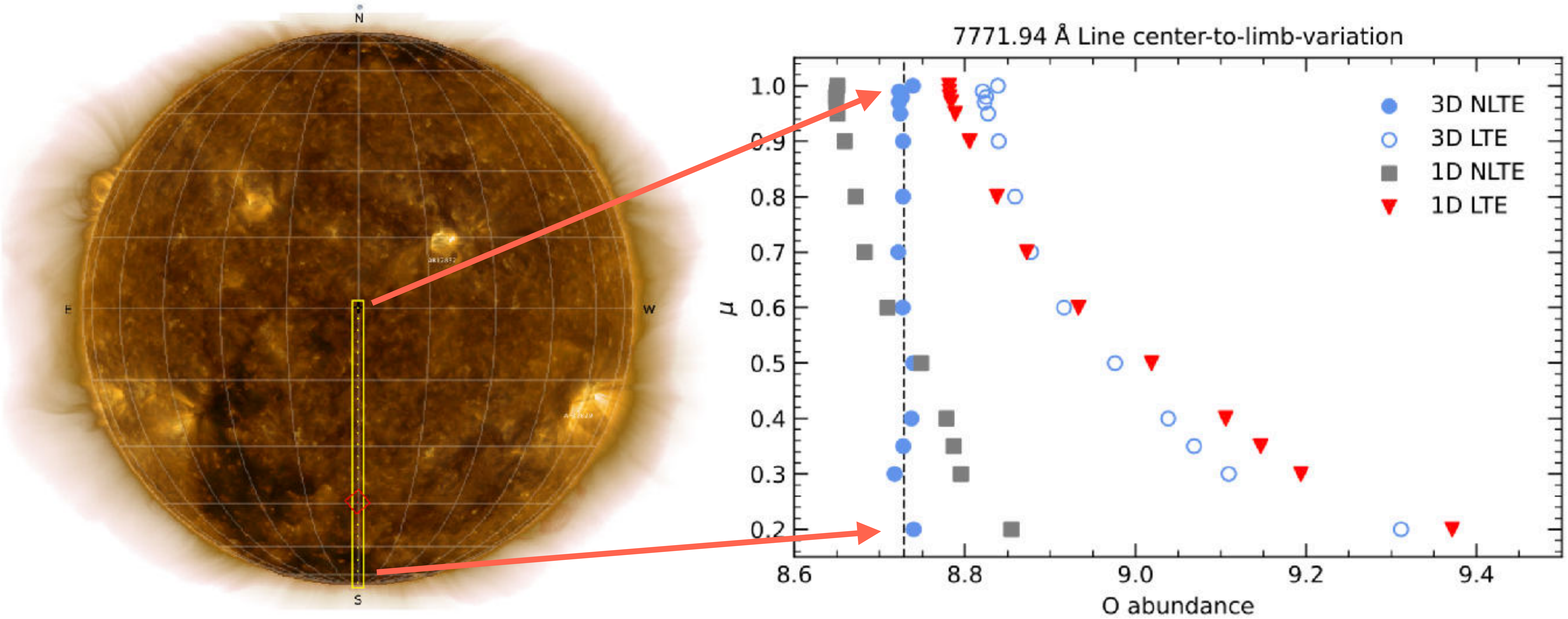
Bergemann, Gallagher, Eitner et al. 2019



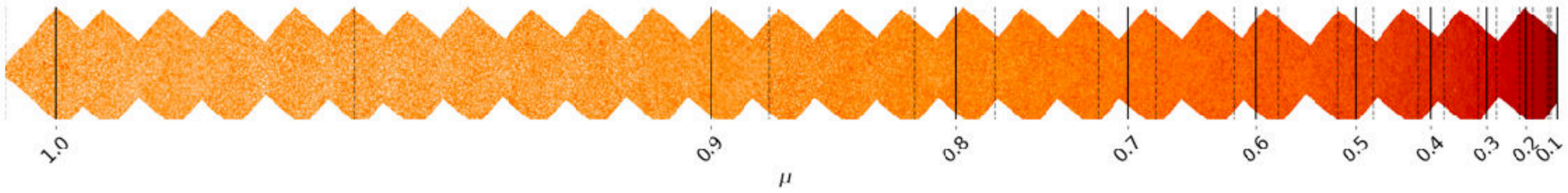
Bergemann & Hoppe et al. 2021

3D NLTE analysis of O

The first test of the solar O abundances, not fine-tuning the models in NLTE, previously described by the 'Sh' scaling factor for O+H collisions (Asplund+2009, Steffen+2015)



Pietrow, Hoppe, Bergemann 2023
Bergemann, Hoppe et al. 2021



Galactic Chemical Evolution Models

- "[Aim] to predict reliable abundances for all observationally accessible isotopes and the variation of these abundances with location and time in our Galaxy." (Timmes+ 1995)

- Models require following yields from nucleosynthesis sites:
  1. Yields of the Big Bang
  2. Yields of core-collapse supernovae
  3. Yields of type 1a supernovae
  4. Yields of the winds and planetary nebulae of light stars $< 8M_\odot$
  5. Yields from cosmic rays
  6. Yields from type 1b supernovae
  7. Yields from compact object mergers

Tracking an isotope's mass density

Death rate = birth rate adjusted by lifetime

Initial mass function

$$\frac{d\sigma_i}{dt} = \int_{0.08}^{40} B(t - \tau(m))\, \Psi(m)\, X_i(m)\, dm + \ldots$$

Stellar yields
(ejected isotope
mass fraction)

→ Lifetimes are taken from stellar evolution calculations.

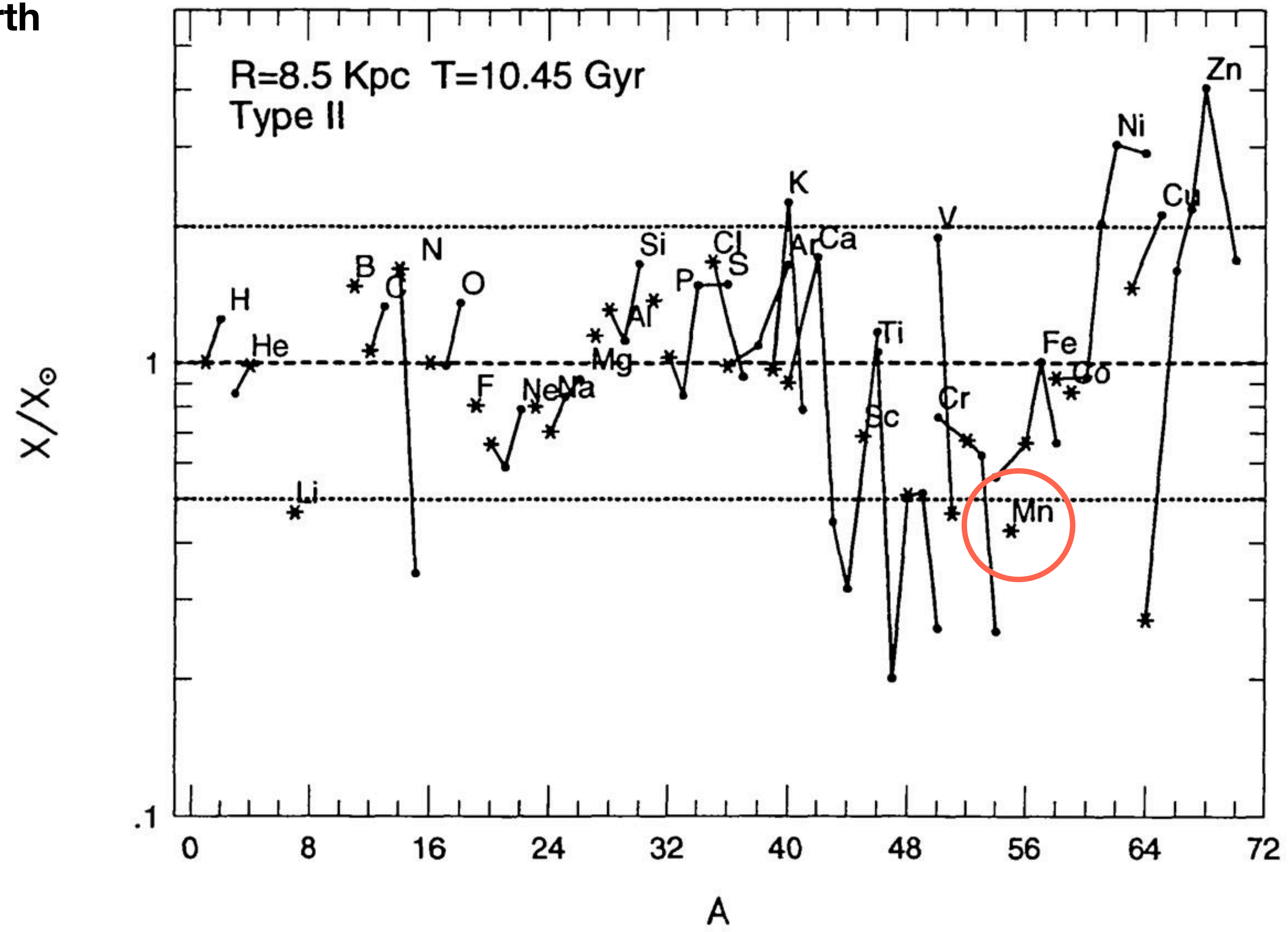
→ Yields are taken from nucleosynthesis simulations.

→ Birthrate, initial mass function and nucleosynthesis site fractions are free parameters fitted to observables

Chemical composition of solar neighbourhood at birth time of our solar system

Without yields from Type Ia supernovae

Timmes et al. 1995



Chemical composition of solar neighbourhood at birth time of our solar system

With yields from
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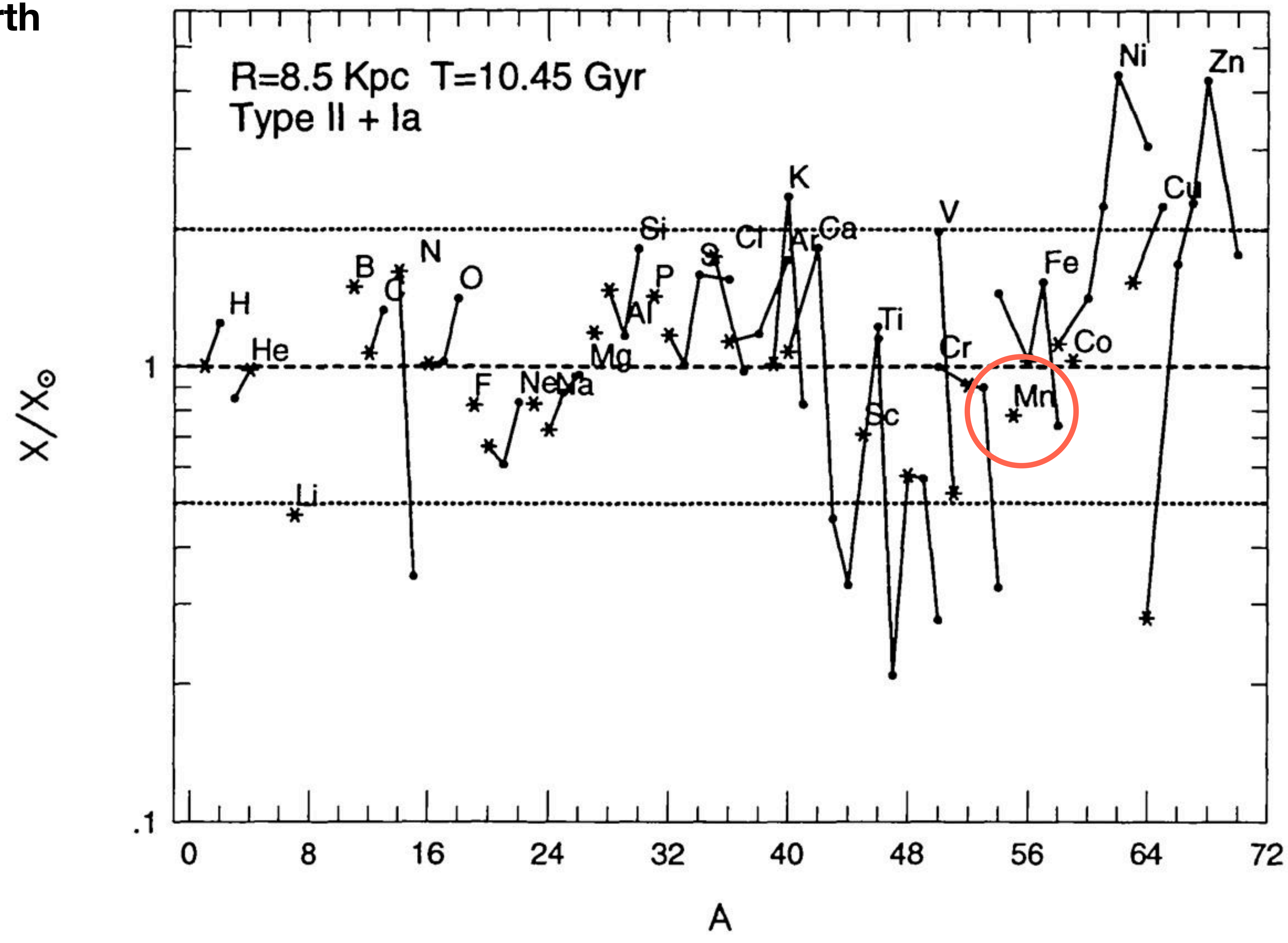
Timmes et al. 1995



Free parameters are fitted to observed abundance patterns.

Jianhui Lian

Lian et al. 2023

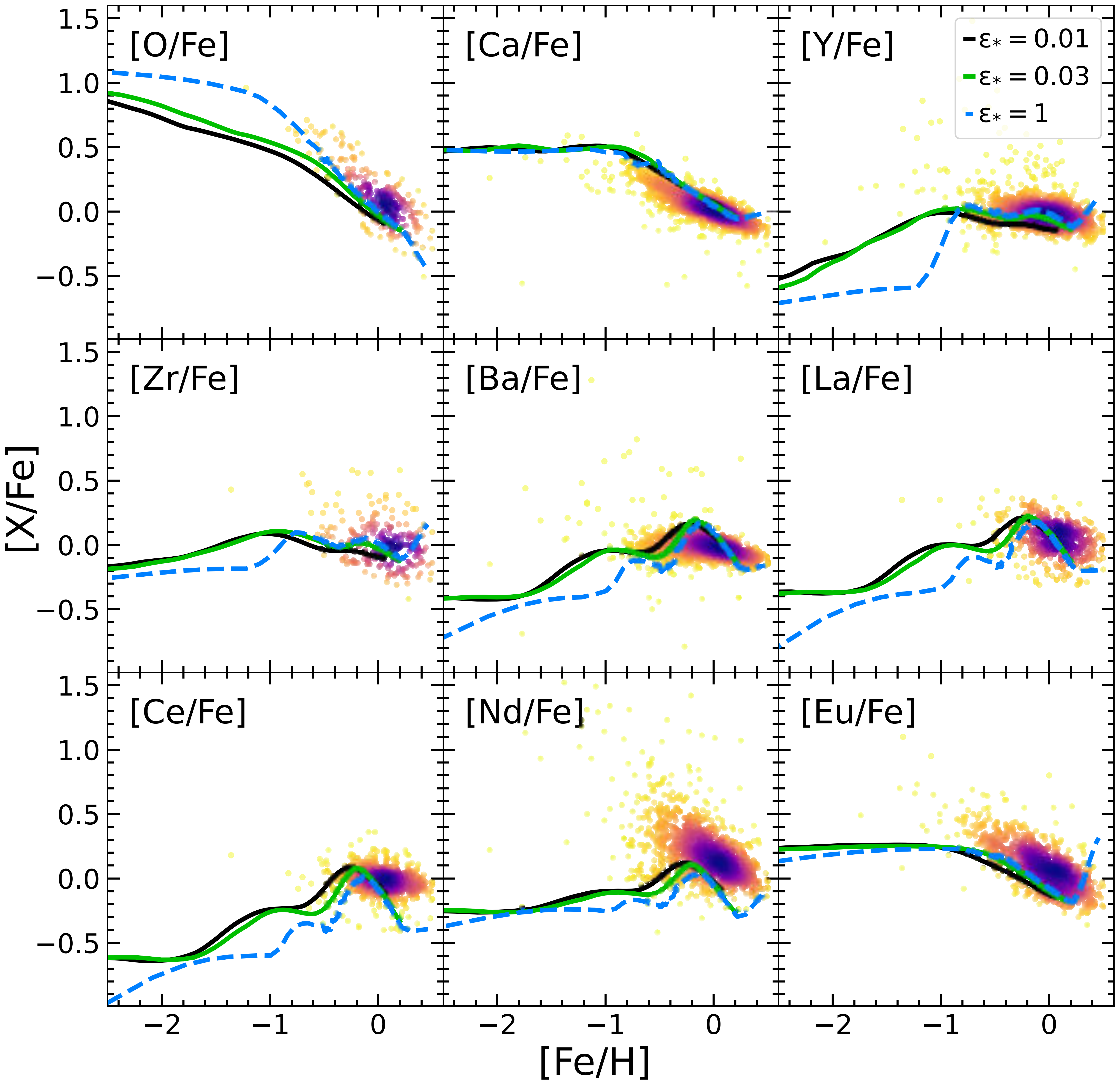
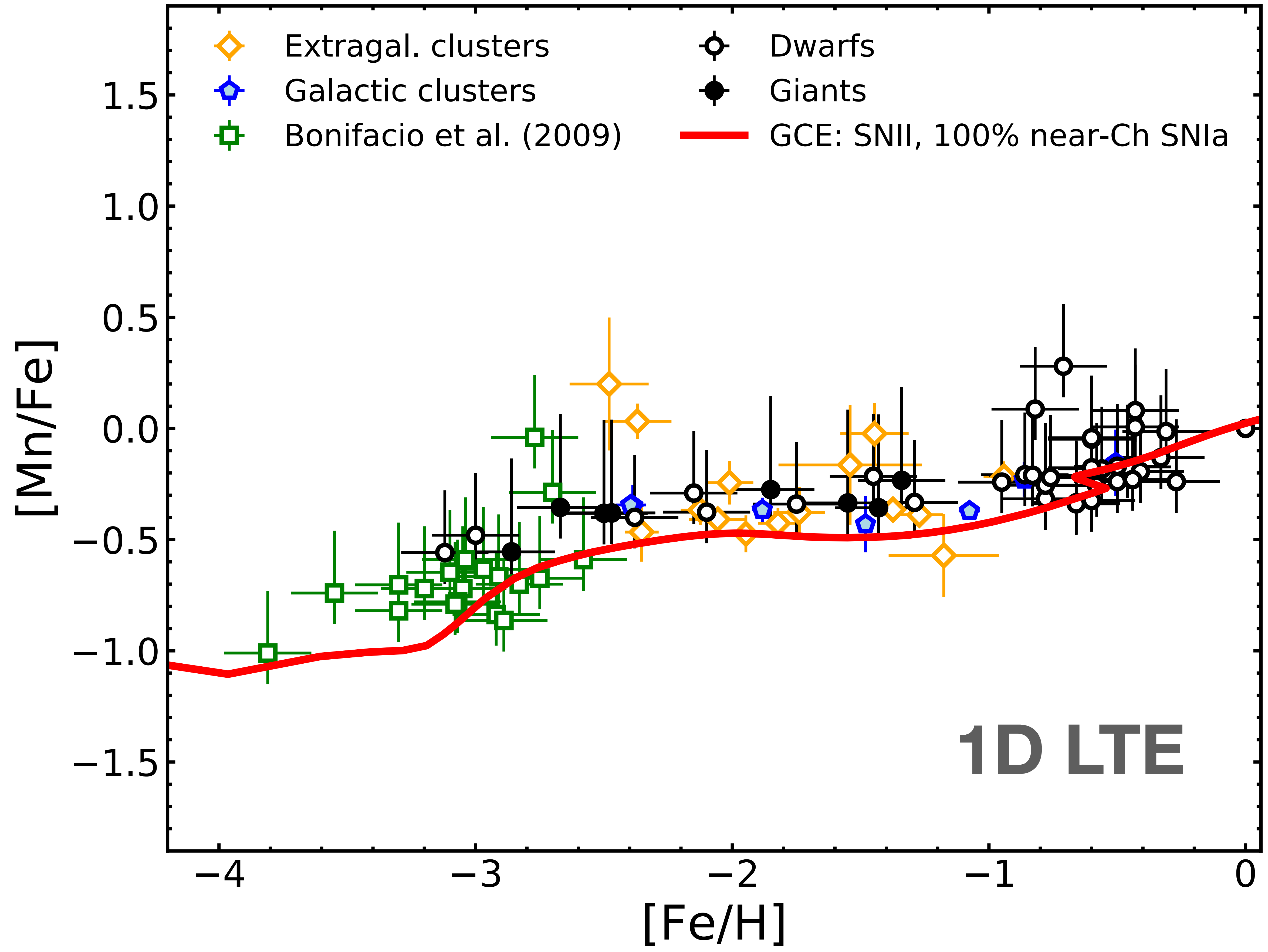


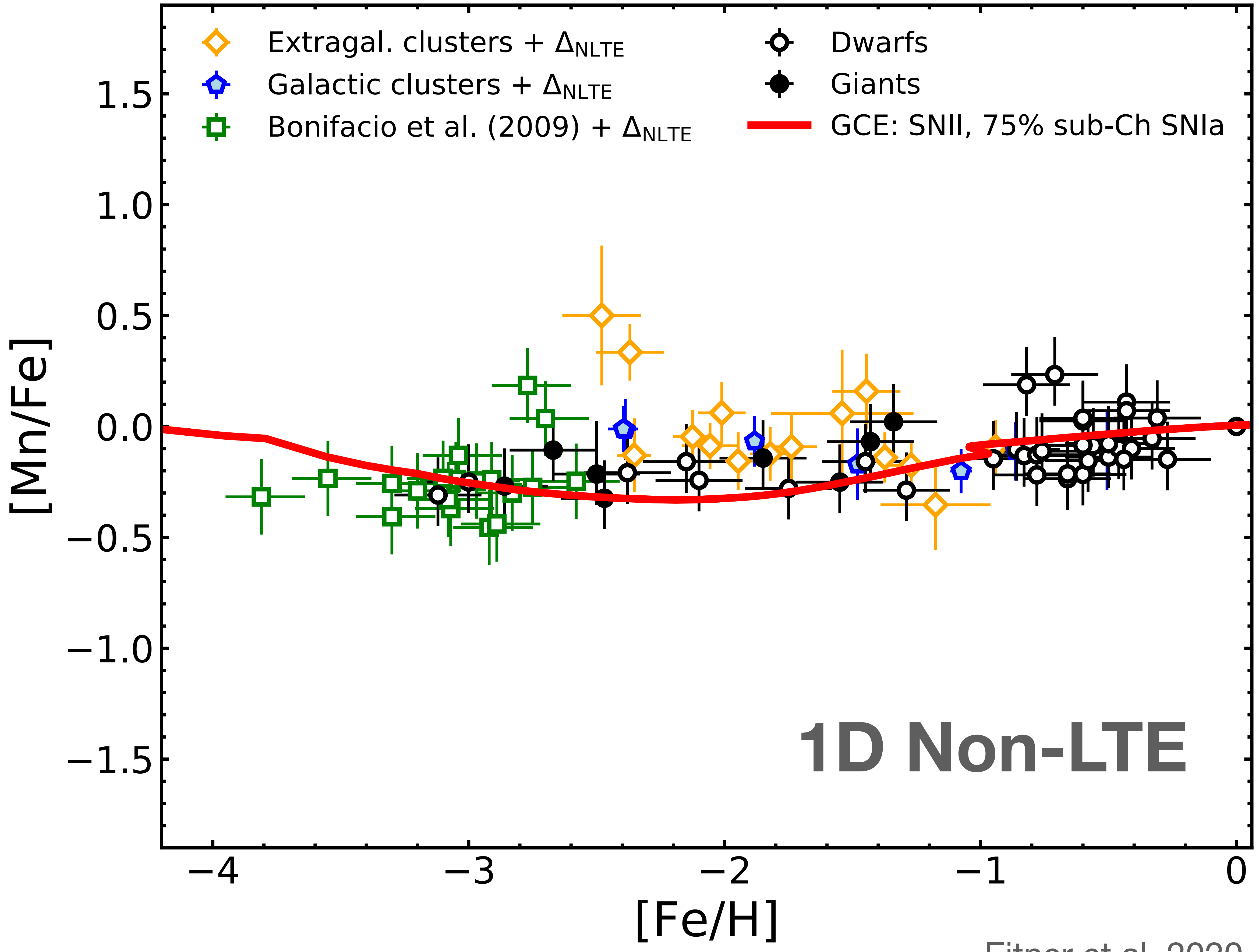
Figure 2. Comparison of GCE tracks calculated with different star formation efficiency parameters ϵ_* with observations.

In practice there are even different supernovae explosion types within type Ia, Ib and type II classifications, which yield different abundance patterns.

Non-LTE manganese abundances predict sub-Chandrasekhar mass SN Ia are more common than “classical” Ia supernovae.

Philipp Eitner





Eitner et al. 2020

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Thank you for your attention! Any questions?

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