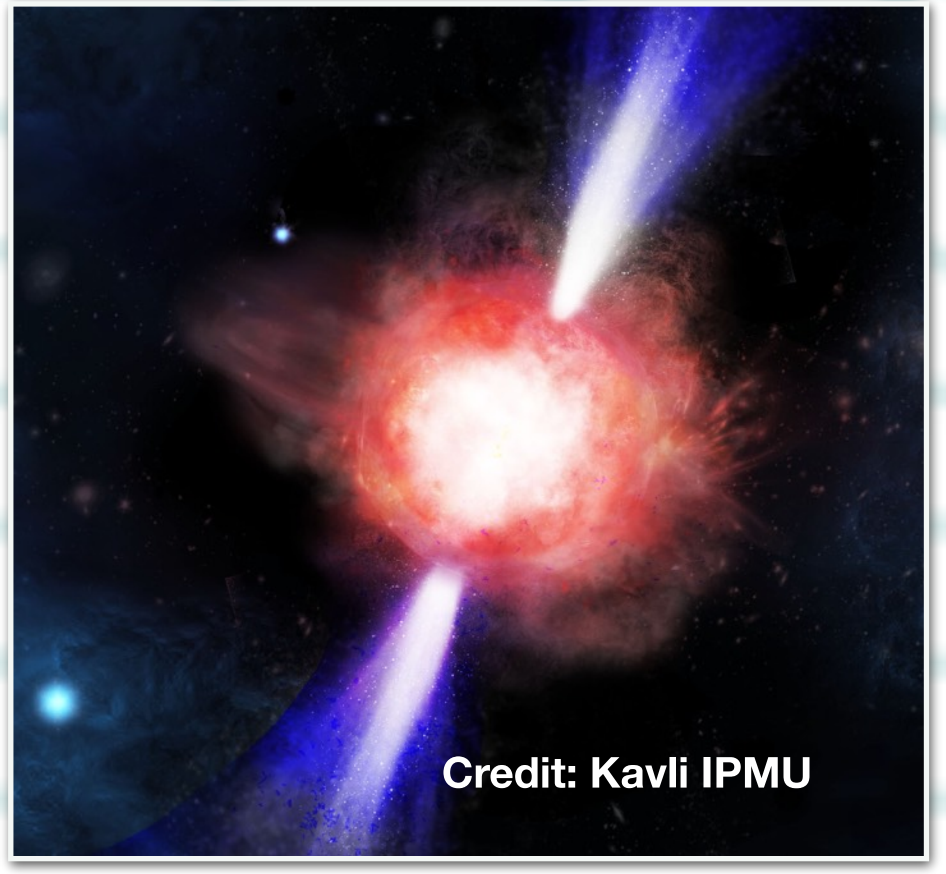
Interpreting spectroscopic survey data for metal-poor stars with supernova yield models

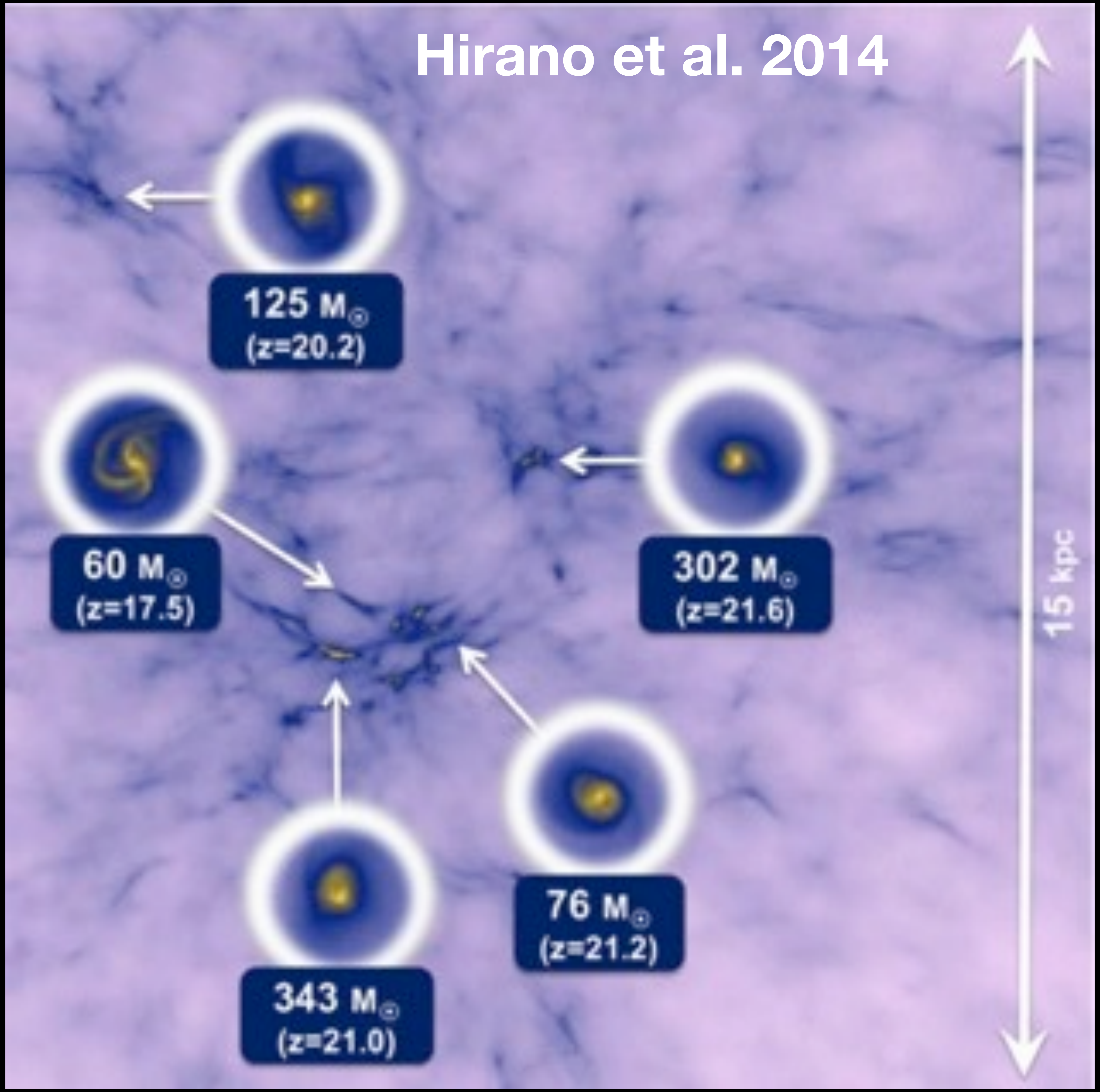


Miho N. Ishigaki (Tohoku U.)

Collaborators: Tominaga, N. (Konan U./IPMU), Hartwig, T.(U. Tokyo), Kobayashi, C. (U. Hertfordshore/IPMU), Nomoto, K. (IPMU), Leung, S.-C. (Caltech), Magg, M. (Heidelberg U.)

Wide-Field Surveys of the Local Group and Nearby Galaxies, Subaru 20th Anniversary Conference
Nov. 18-22, 2019, Waikoloa

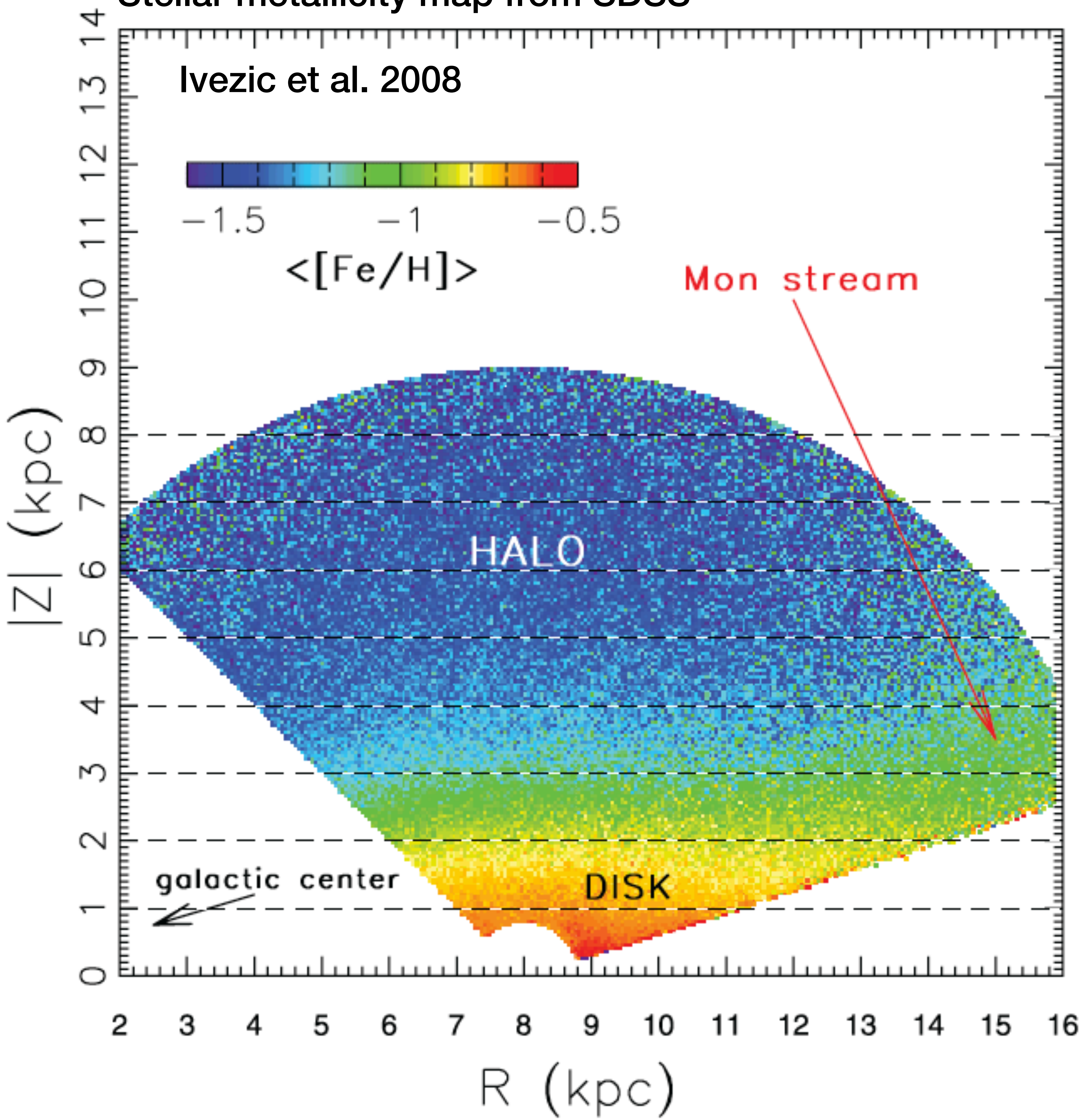
The first (Population III/Pop III) stars in the Universe



- Masses of the first stars
  - Contribution to the cosmic reionization
  - Metal yields
- Cosmological simulations predict a wide range of masses: $M < 1M_{\odot}$ up to $M > 1000M_{\odot}$

Long-lived metal-poor stars

Stellar metallicity map from SDSS



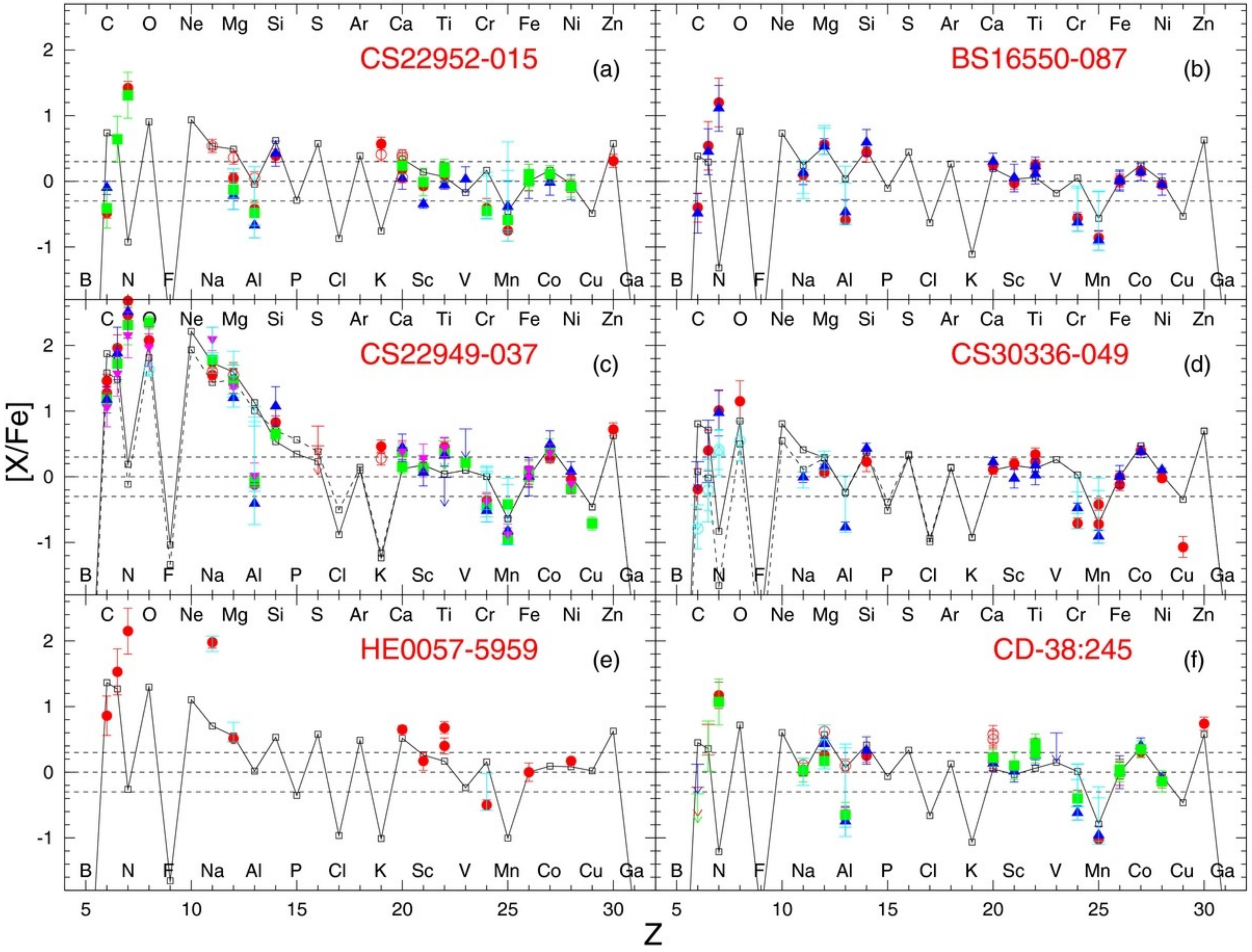
- Extremely Metal-Poor (EMP) stars ($[\mathrm{Fe/H}] < -3$) ➡ candidates of "the first metal-enriched stars"
- Wide-field surveys
  - Prism spectroscopy: HES, HK survey
  - Low-high resolution spectroscopy: SDSS, LAMOST, APOGEE, GALAH
  - Photometory: SMSS, PRISTINE

Near Future:

  - WEAVE, 4MOST, SDSS-III, MOONS, PFS, HSC (with narrow-band filter)
  - Follow-up by GMT (G-CLEF), TMT (HROS)

Supernova yield models of Pop III stars

Tominaga et al. 2014, See also Heger & Woosley 2010, Limongi & Chieffi 2012



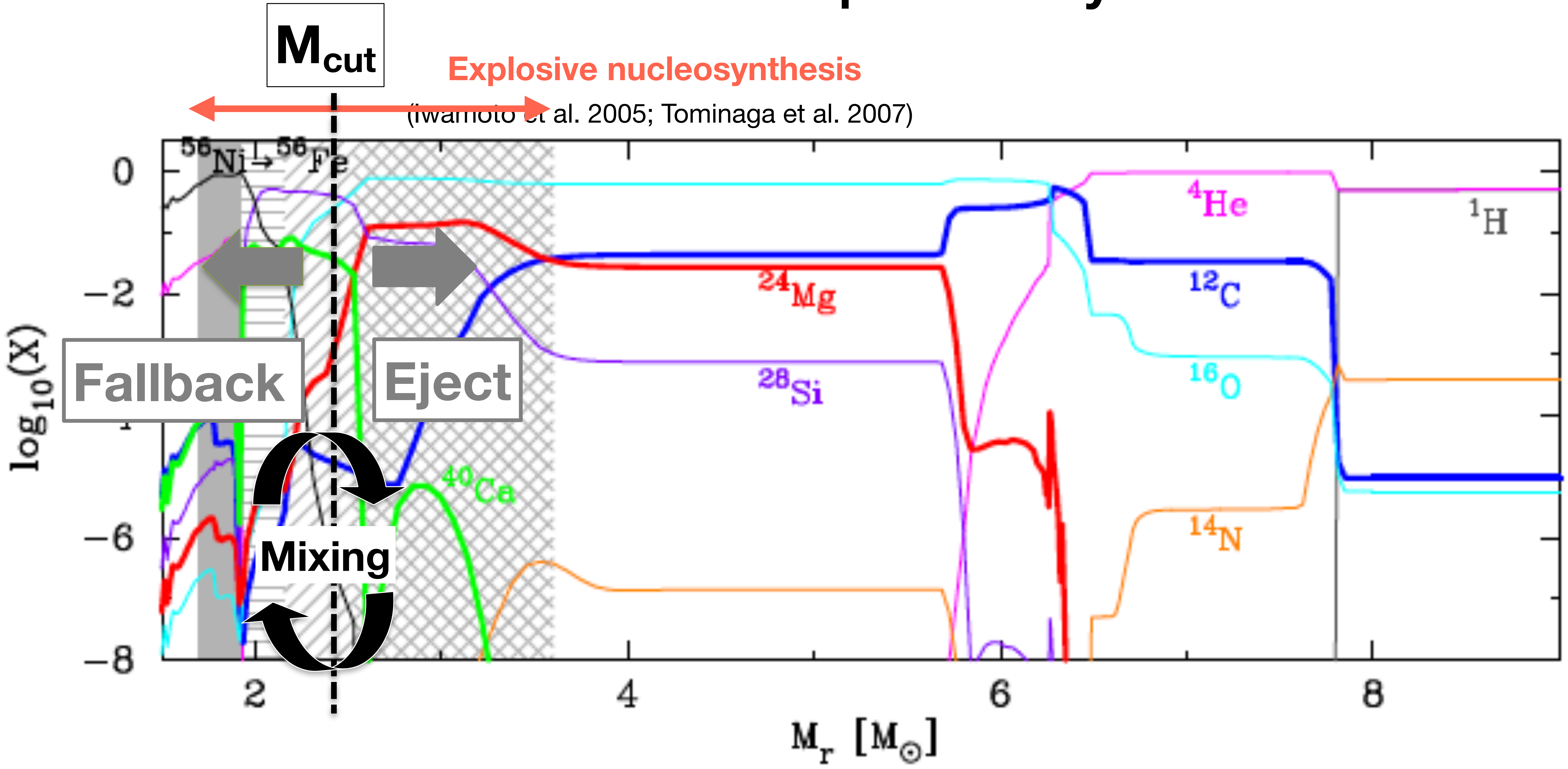
This talk

What can we learn from elemental abundances in metal-poor stars by comparing them with supernova yield models?

- Masses of the first stars
- Metallicity of the first metal-enriched stars

Masses of the first stars

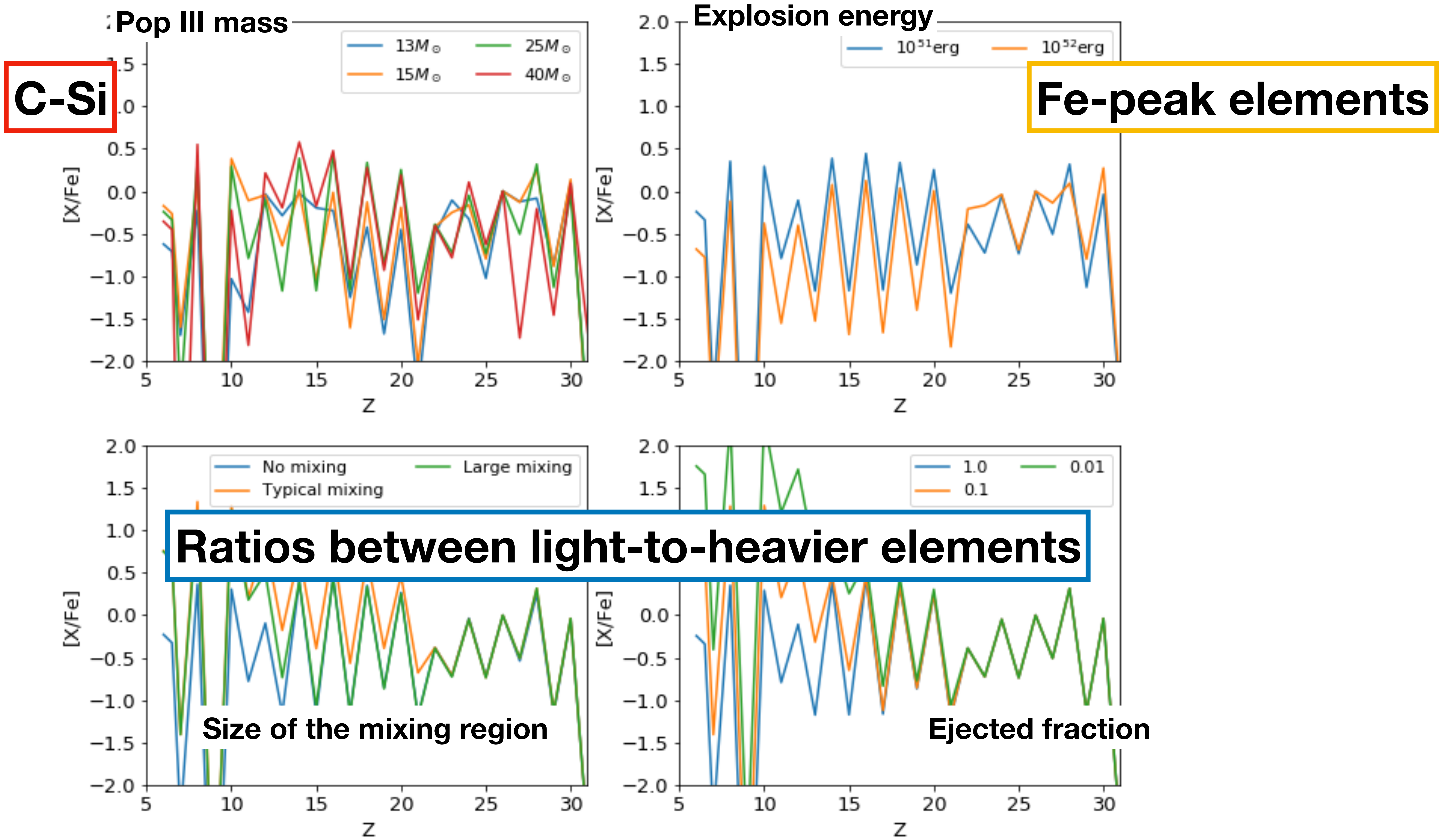
Calculation of supernova yields



Supernova yields depend on the first star’s mass, supernova explosion energy, mass cut, and mixing

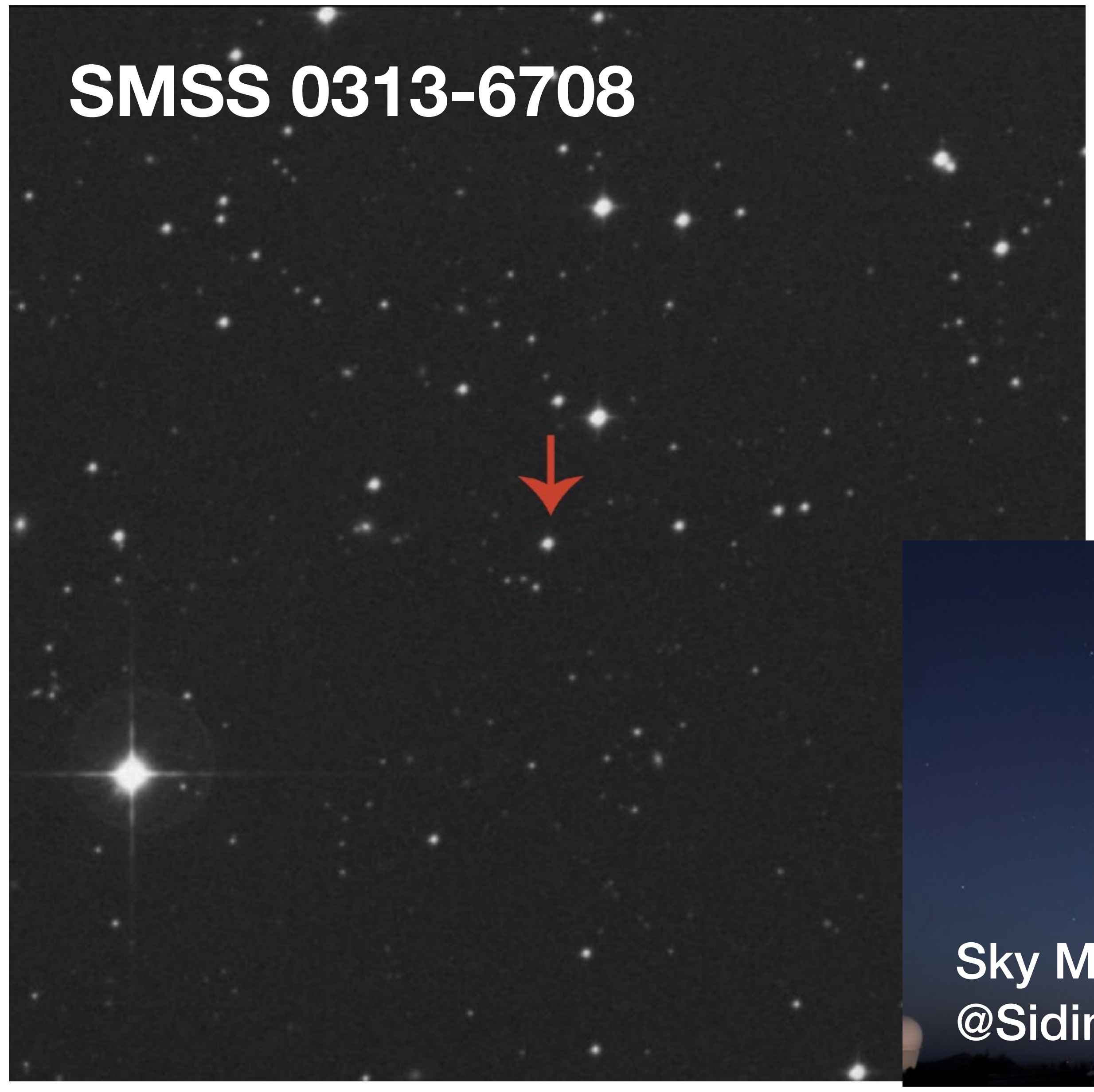
Parameter dependence

The mixing-fallback supernova yield models (e.g. Umeda & Nomoto 2002; Tominaga et al. 2007)



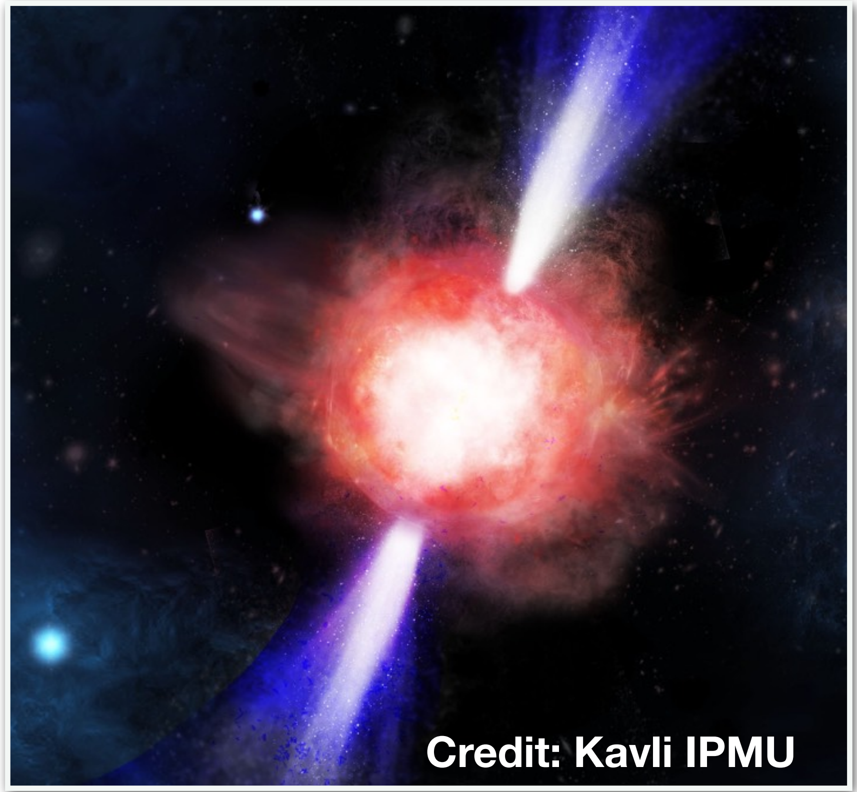
Abundance variation among stars with [Fe/H]<-4.5

MI, Tominaga, Kobayashi & Nomoto (2014), Frebel & Norris 2015



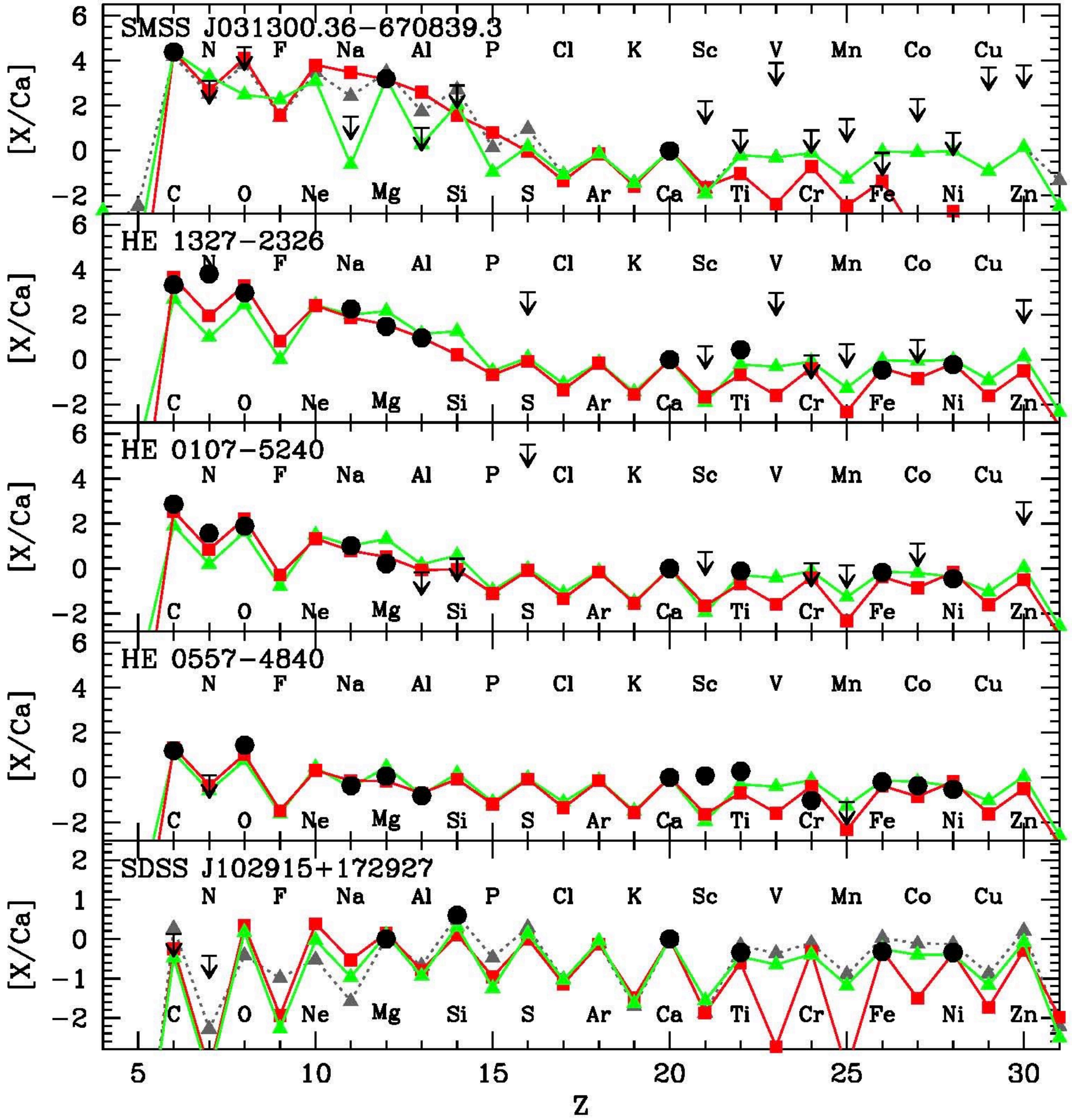
Keller et al. 2014 (LTE); Nordlander et al. 2017(3D-NLTE)

$[\mathrm{Ca/H}] \sim -7$



Variation in mixing and partial fallback
⬅ Non-spherical supernova

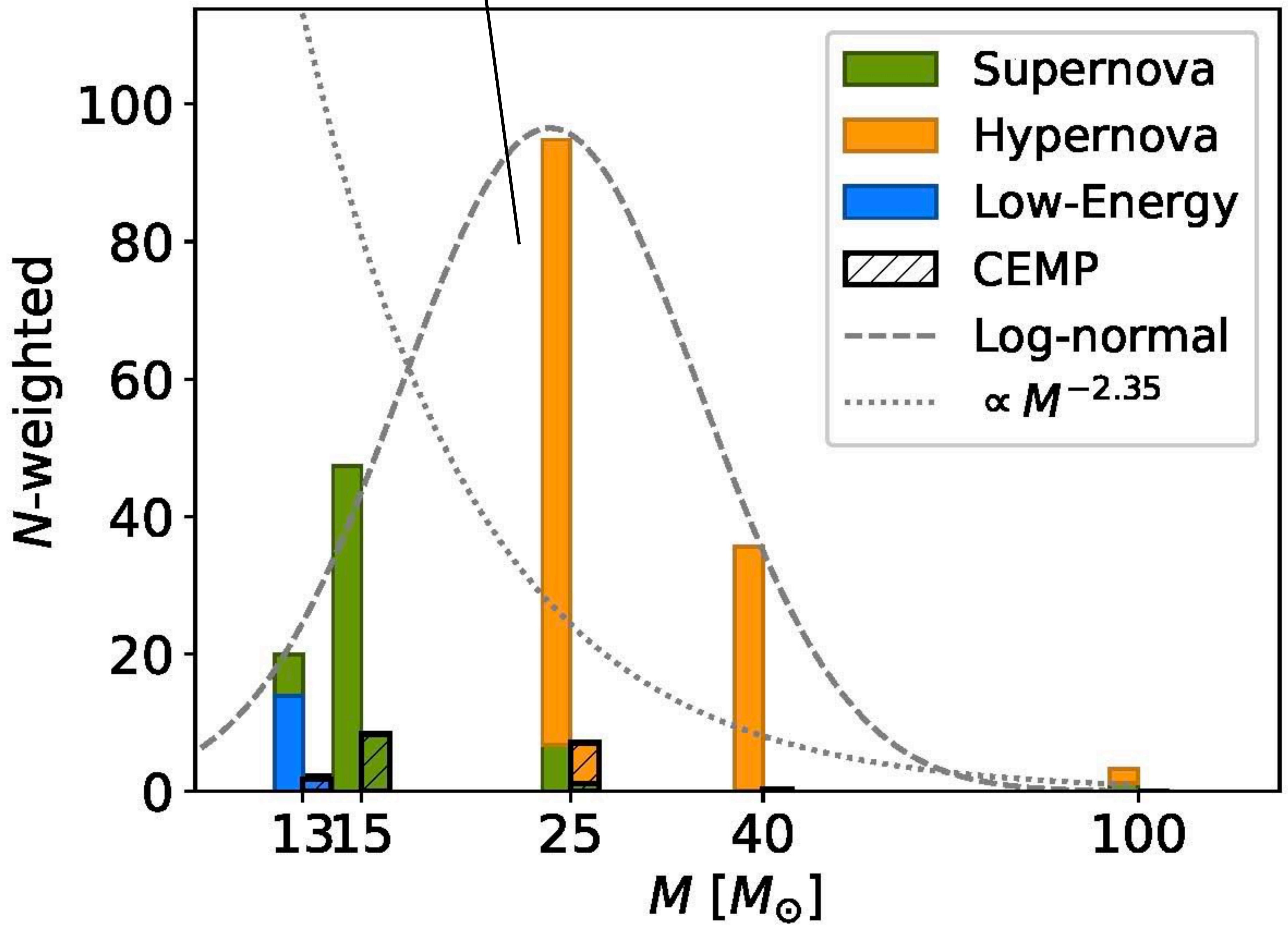
(Tominaga et al. 2009)



Masses of the metal-producing Pop III stars

Analysis of ~ 200 extremely metal-poor stars

$\sim 25 M_\odot$ Pop III SN yields

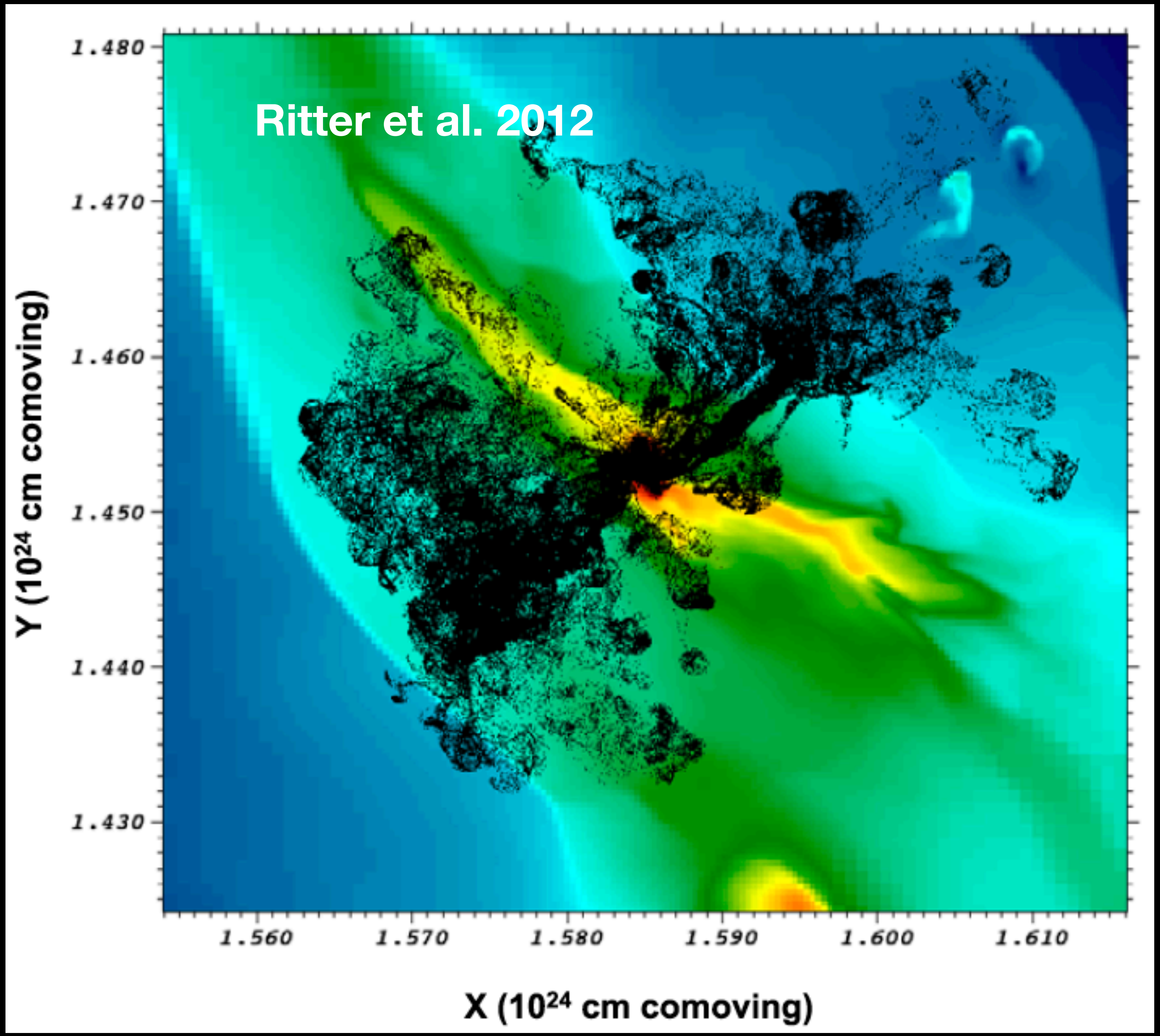


MI, Tominaga, Kobayashi, & Nomoto 2018

- $25 M_\odot$ Pop III supernova yield modes best reproduce observations
- Pop III stars with $\geq 40 M_\odot$ could collapse to blackhole without producing metals
- Smaller contribution from lower masses ➡ incompatible with the power-low IMF
- Consistent with previous studies (e.g. 20 ultra-metal-poor stars by Placco et al. 2015)

Metallicity of the first metal-enriched stars

[Fe/H] of the first metal-enriched stars

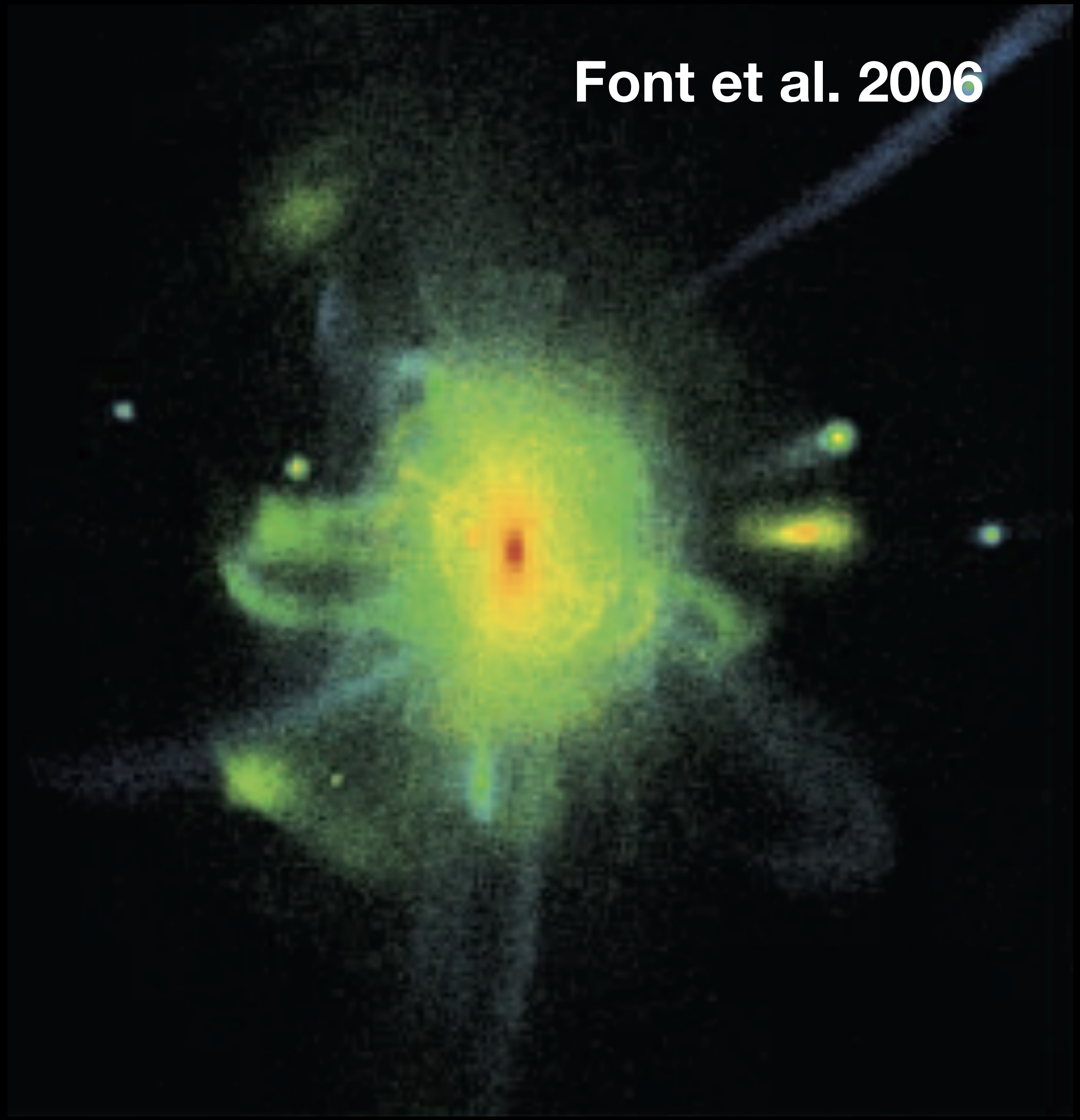


Ejected metals are inhomogeneously mixed with pristine gas from which the first metal-enriched stars form

Can we find the first metal-enriched stars with higher [Fe/H]?

Where is the first metal-enriched stars

A simulated stellar halo in the ΛCDM model

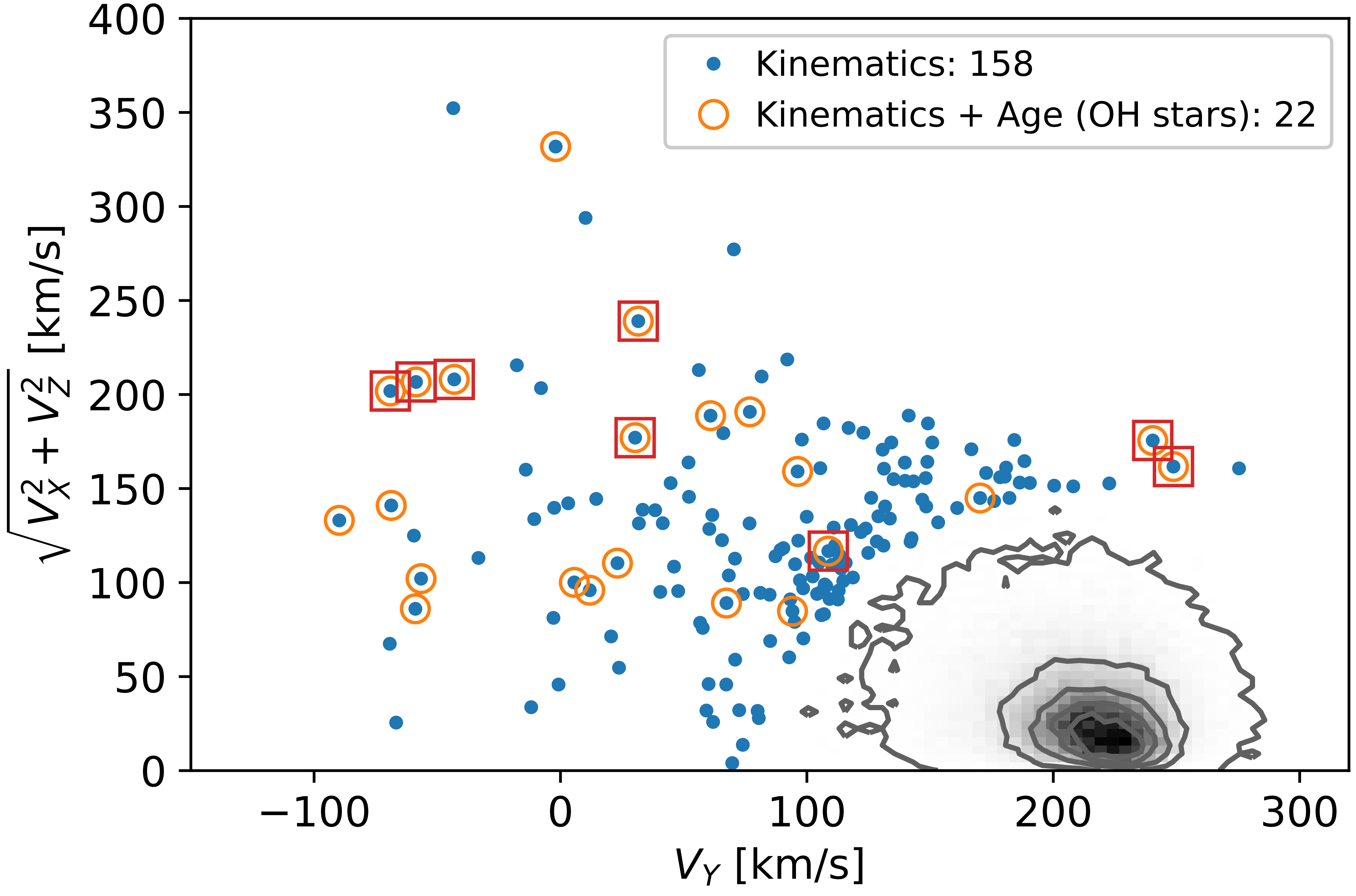


- The first metal-enriched stars are formed in small dark matter halos with $M \sim 10^8 M_\odot$ @ $z \sim 10$ (Bromm & Yoshida 2011)
- They are hierarchically merged to form a larger galaxy like the Milky Way
- Accreted components of the stellar halo

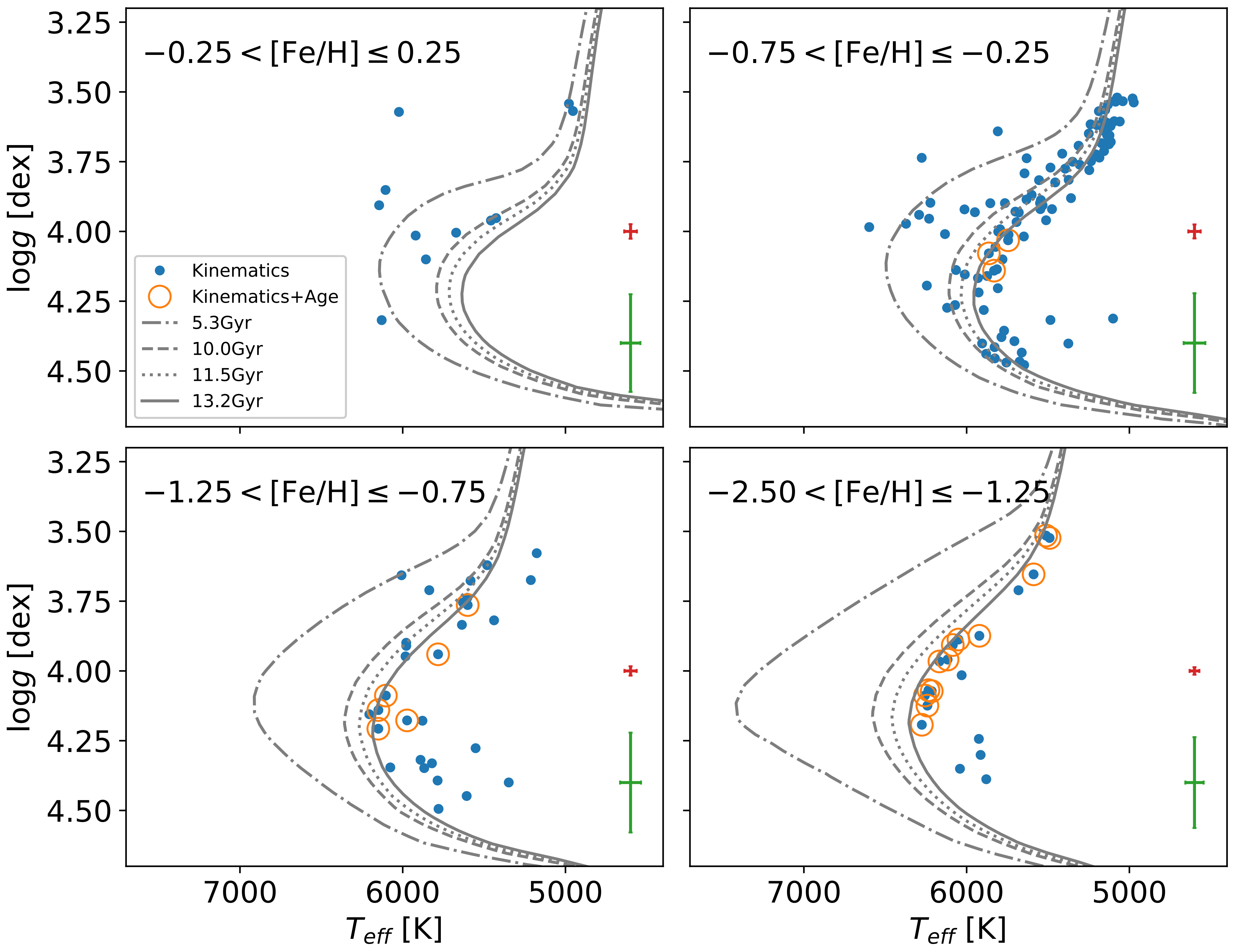
Selection of old stars with halo-like kinematics

Main sequence turn-off stars selected from the catalog of Sanders & Das (2018)

Toomre diagram

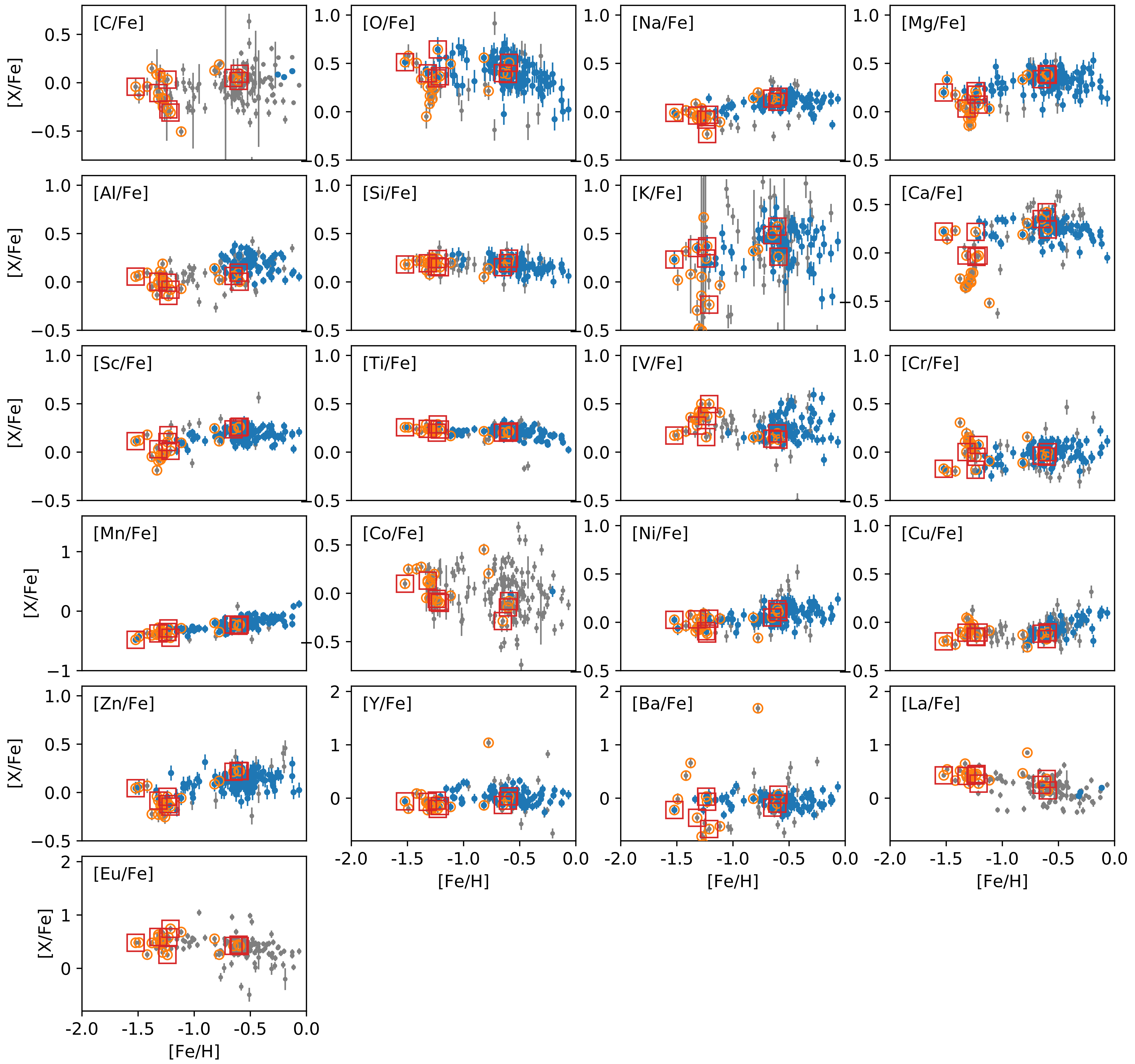


Spectroscopic CMD



◯ 22 stars with age > 12Gyr (relative age uncertainty: 10-50%) ➡ Old halo (OH) stars

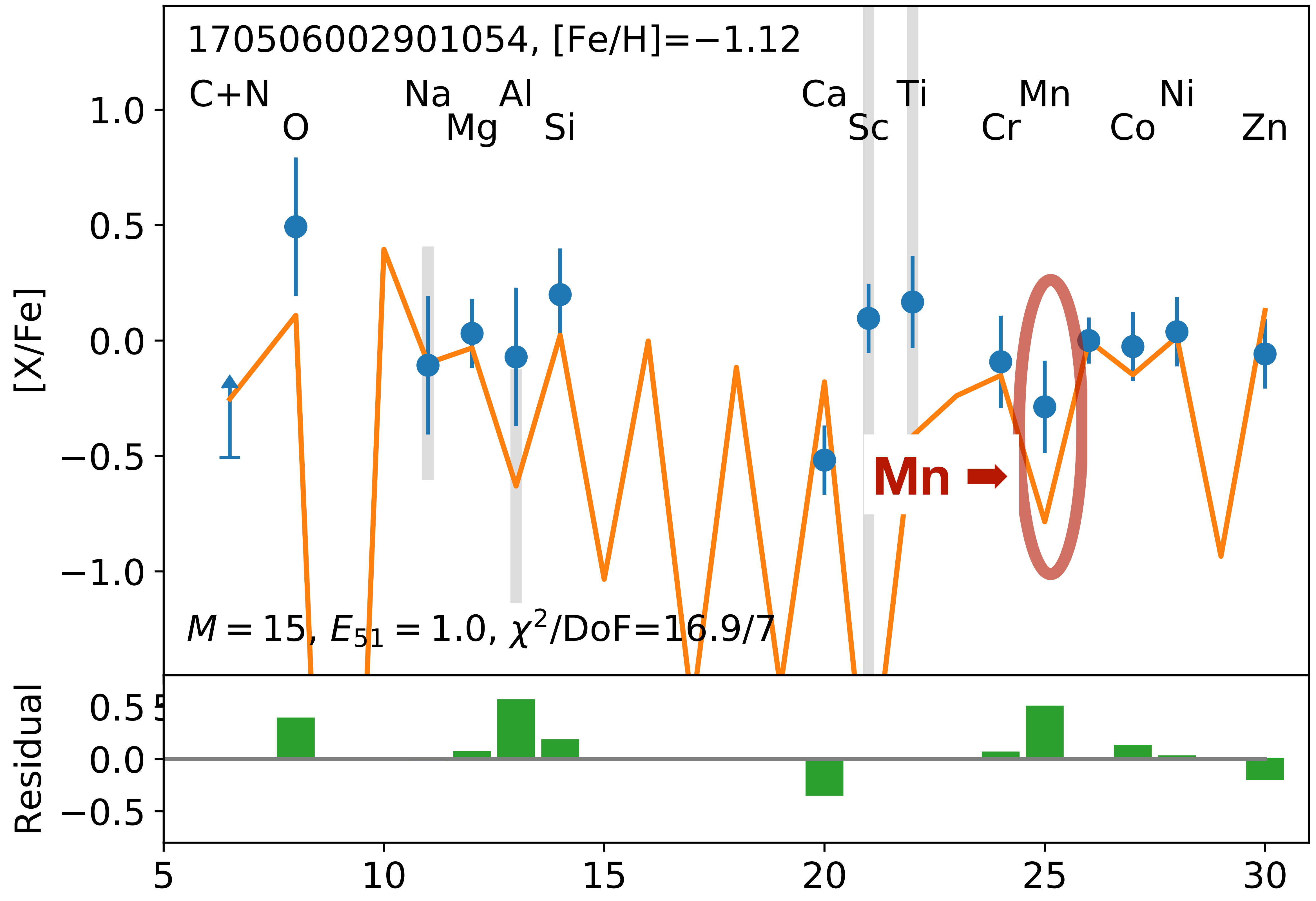
Elemental abundances from GALAH DR2



Data from Buder et al. 2018

Abundances of the old halo stars

— model ● data



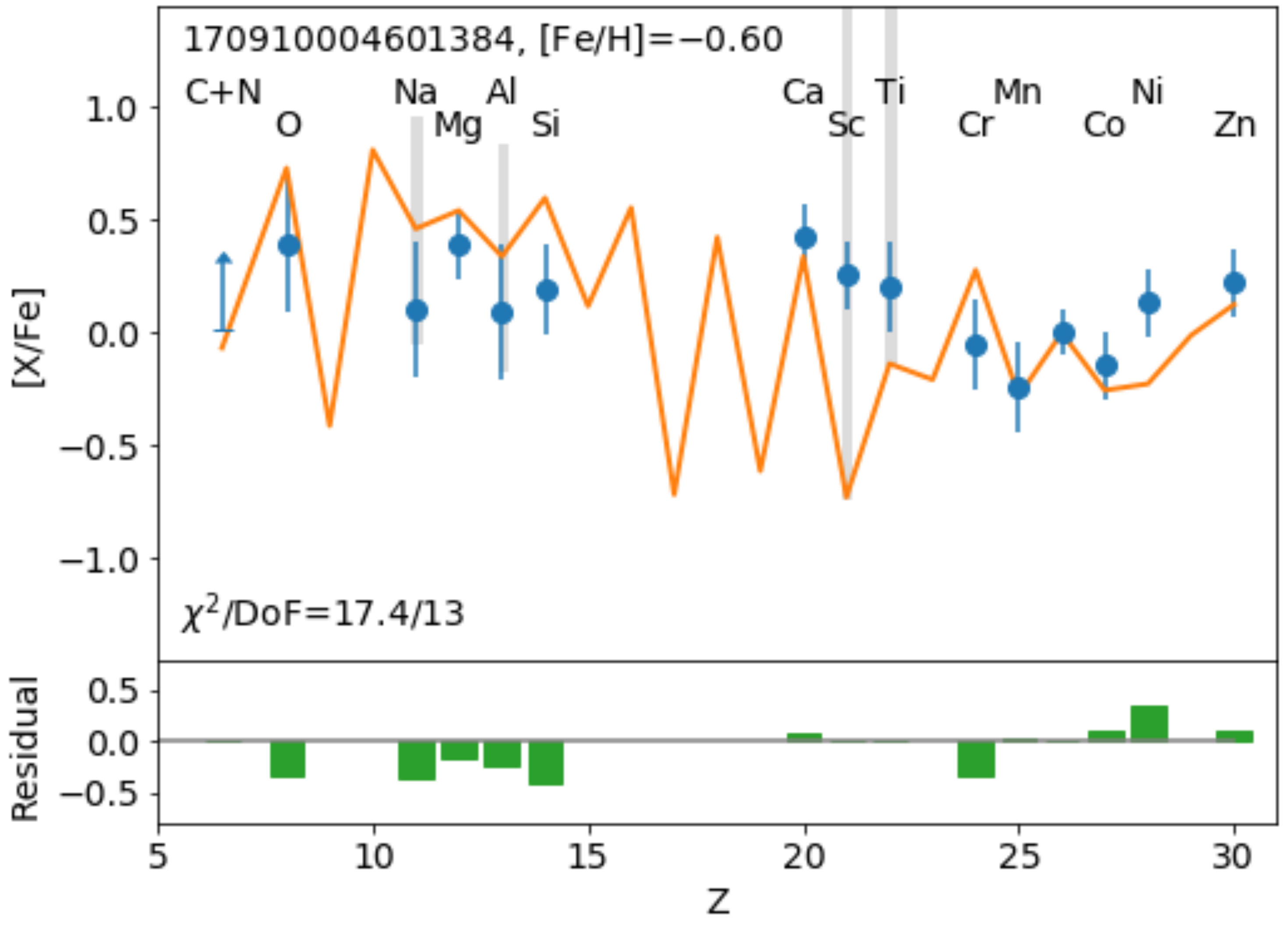
- Pop III supernova yield models underestimate Mn abundances in most of the 22 old halo stars $(-2 < [\mathrm{Fe/H}] < -0.5)$
- Mn is largely produced by Type Ia supernovae

Chemical enrichment by Type Ia supernovae at > 12 Gyrs ago

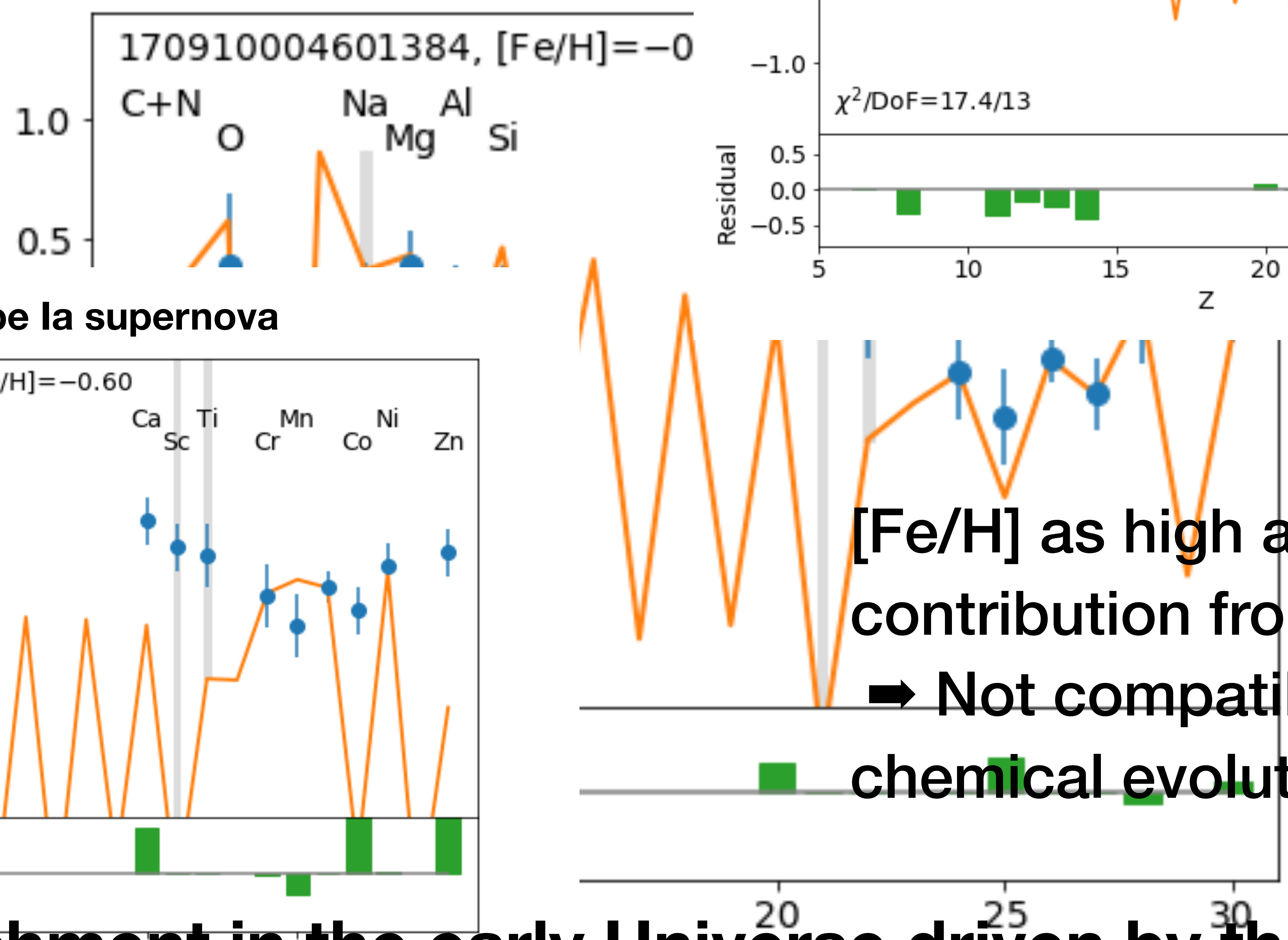
The abundances in old stars with [Fe/H] ~ -0.6

— model ● data

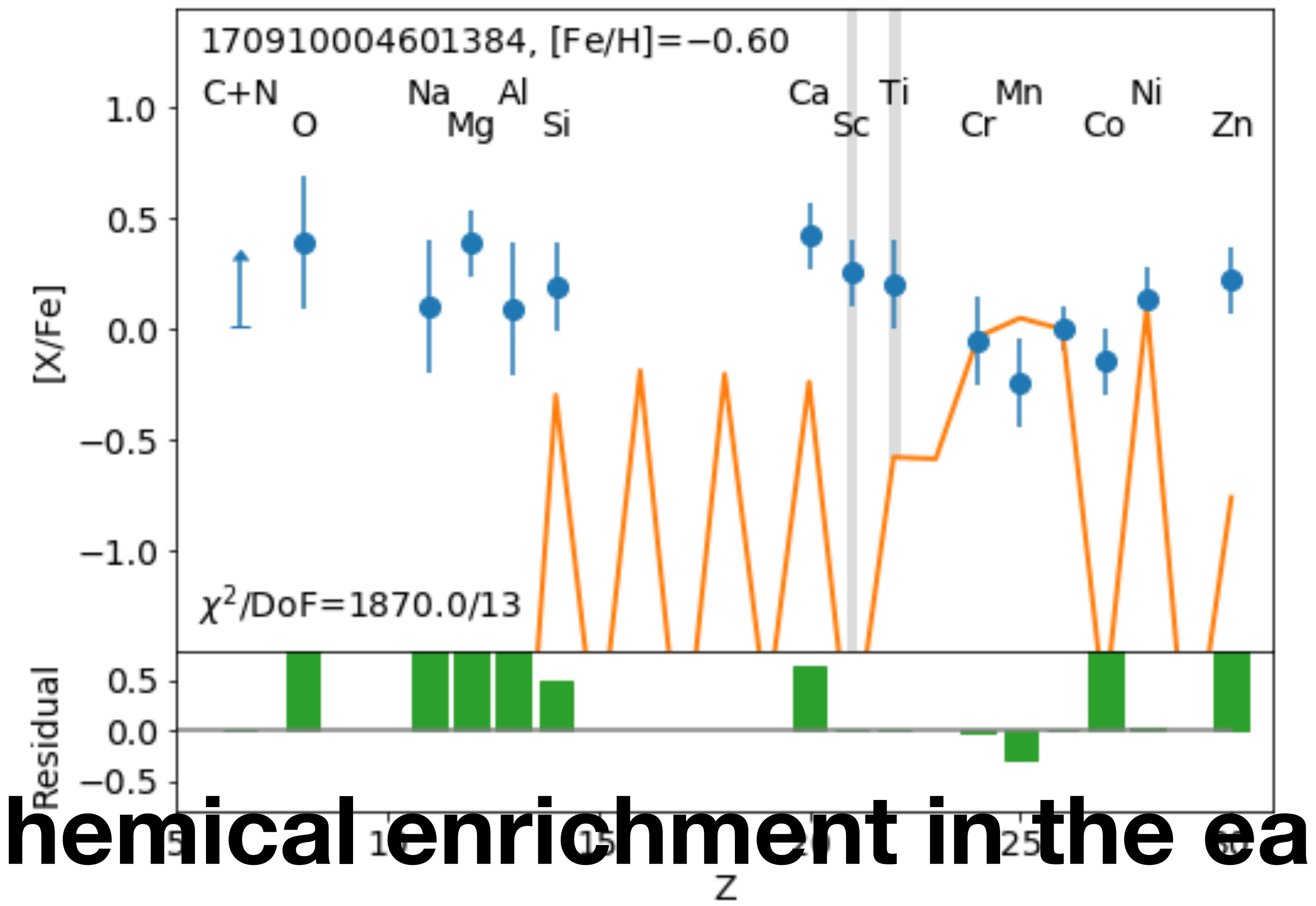
Core-collapse supernova



Pop III super



Type Ia supernova



[Fe/H] as high as -0.6 with negligible contribution from Type Ia supernovae
➡ Not compatible with conventional chemical evolution models

Chemical enrichment in the early Universe driven by the Pop III stars was highly inhomogeneous

Summary: Search for "the first metal-enriched stars" with wide-field surveys

- EMP stars: promising candidates of the first metal-enriched stars
  - To break the degeneracy among Pop III mass, explosion energy, mass cut and mixing, measurements of all of light to heavy elements up to Fe are desirable.
- Old halo stars: age and kinematics help identifying the first metal-enriched stars
  - The stars whose abundance pattern is compatible with Pop III supernova yield models.
  - Better age estimate (< 20%) from asteroseismic data ➡ the first metal enrichment by the Pop III stars