IMF of Extremely Metal-Poor Stars and Formation of the Milky Way

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Abstract

In the Galactic halo, several hundreds of extreme metal-poor (EMP) stars are identified. They are old stars formed in the early universe and can be probes to the first stars and formation of the Milky Way. In previous studies, we investigate initial mass function(IMF) of EMP stars from observational statistics of carbon-enhanced EMP stars which are polluted by binary mass transfer, and show that typical mass of EMP stars are ~10$M_\odot$.

In this study, we investigate abundance distribution of EMP stars using hierarchical model for the very early stages of chemical evolution of the Milky Way. We plant merger trees semi-analytically and compute chemical enrichment history along the trees. We discuss the IMF dependence of abundance of EMP stars and contribution of hypernovae.

EMP stars

In the Galactic halo, many EMP stars with [Fe/H]<-2.5 are detected thanks to large scaled surveys (Beers+ 1992, Christlieb+ 2001). ~400 of them received high resolution spectroscopy and their nuclear abundance are revealed.

([Fe/H]=log(Fe/H)-log(Fe/H)$_\odot$)

In terms of the chemical enrichment history, they are very early generations of stars. They are thought to be formed in the early universe, and can be probes to the first stars and galaxy formation.

All of EMP stars survive to date is low-mass stars with long lifetime. But we can also investigate about massive or intermediate-mass EMP stars from chemical abundance of the EMP survivors.

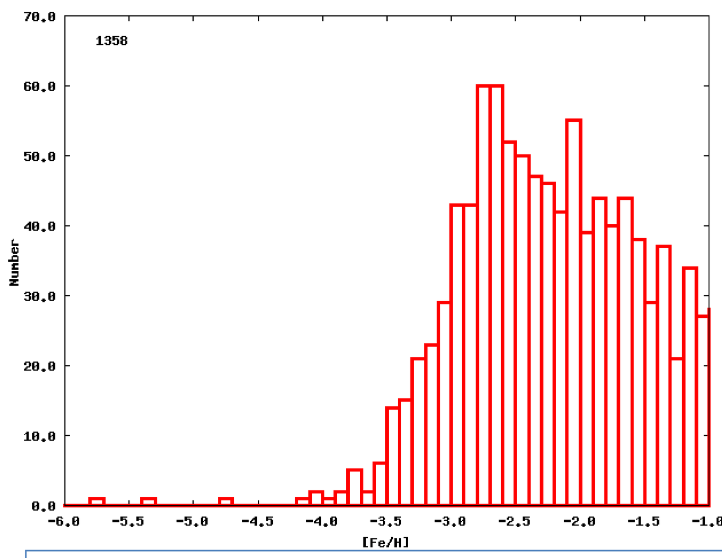


Fig. 1
Metallicity distribution of metal poor stars registered in SAGA database. (SAGA: database for metal poor stars with high resolution spectroscopy. Suda et al.(2009)) .

Chemical evolution model for EMP stars

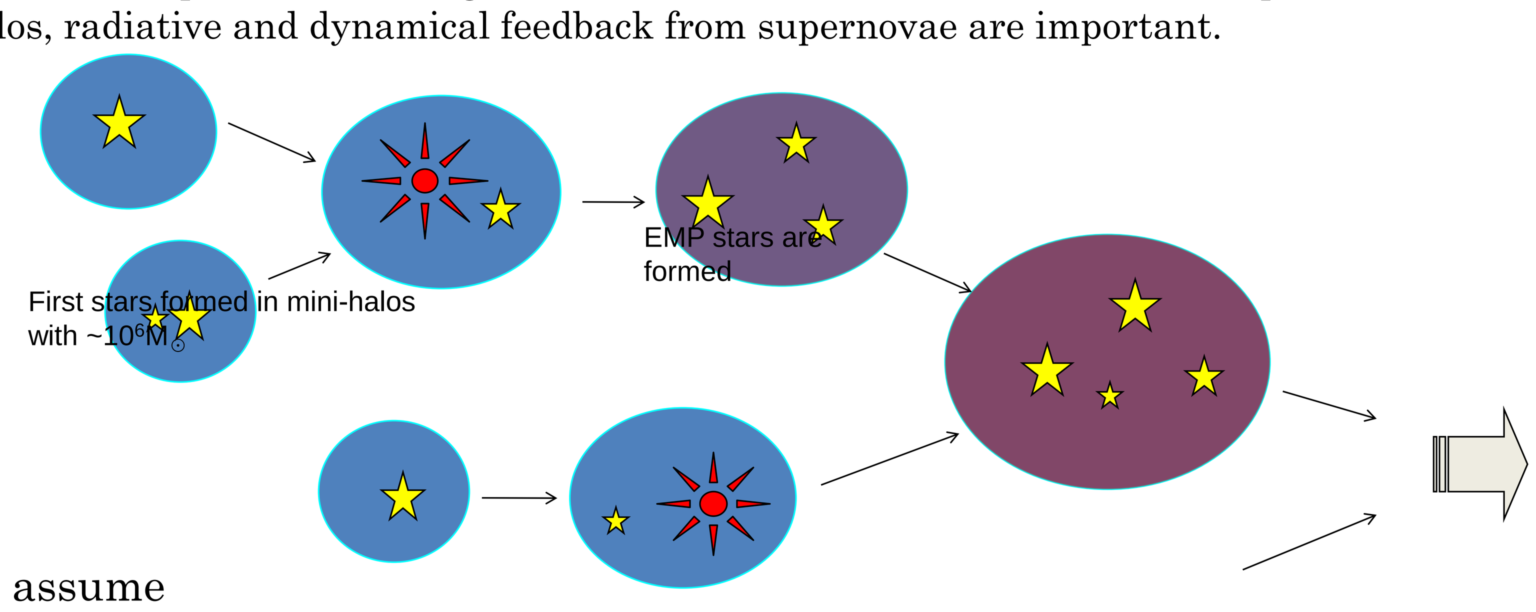
For chemical evolution in early universe and metal poor stars, some special ingredients are required.

Merging history of the Galaxy

In the concordance cosmology, galaxy is formed hierarchically, i.e. galaxies are formed through merger of small scale structures. And most of the halo EMP stars thought to be formed in the mini-halos as building blocks of the Galaxy.

We built merger tree of the Galaxy by the method of Somerville & Kollatt (1999) based on the Extended Press-Schechter theory (Lacy & Cole 1993). And trace chemical enrichment history along the tree with individual EMP stars.

Chemical abundance can be different from mini-halo to mini-halo reflecting characteristics of individual supernovae. We register all the individual EMP stars in out computation. In small halos, radiative and dynamical feedback from supernovae are important.



We assume

- Stars are formed in halo with T_{vir}>10^{3}K,.
- Star formation efficiency is constant
  - First stars suppress star formation in host halos
- Instantaneous mixing inside each halos

We adopt theoretical nucleosynthetic yield by Kobayashi et al. (2006) with hypernovae contribution.

- If 10% of explosion energy of supernovae is larger than binding energy of gas in their host mini-haolo, gas in the mini-halos is blown away.

IMF of the EMP stars (Komiya+ 2007)

Theoretically, typical mass of stars without metal should be larger than metal rich stars.
In previous studies, we gave constraints on the IMF of EMP stars from observations of carbon enhanced EMP (CEMP) stars, (Komiya et al. 2007).
For element abundances of CEMP stars, binary scenario gives plausible explanation. This scenario argue that carbon and *s*-process elements on them had been synthesized in the intermediate-mass primary stars, and transferred to secondary low-mass stars. And *s*-process element abundances are depend on the mass of their primary stars.
Based on this scenario, from observational statistics of the CEMP stars, we can give constraints on mass distribution of primary intermediate-mass stars, and we can give constraints on the IMF.
Observed large number of CEMP stars indicate that typical mass of EMP stars are much higher than more metal rich stars.
Estimated typical mass of EMP stars are ~10$M_\odot$.

We use following 3 IMFs and compare the computation results.

- High-mass IMF (Komiya et al. 2007)
- Low-mass IMF (Chabrier 2004)
- IMF of Lucattello et al. (2004)

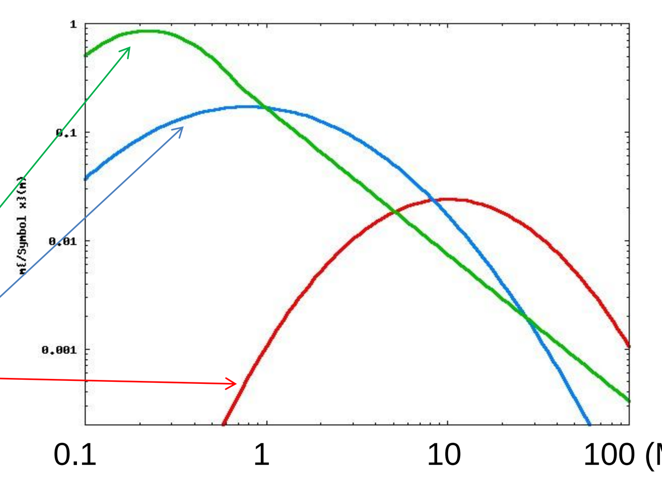


Fig. 3
IMFs adopted in our computations.

Results

IMF dependence

MDF (Metallicity Distribution Function)

Total number of EMP stars predicted by high-mass IMF(Komiya+ 2009) model is consistent with observations. Meanwhile, model with low-mass IMF(Chabrier 2004) predict much more low-mass EMP stars which survive to date.

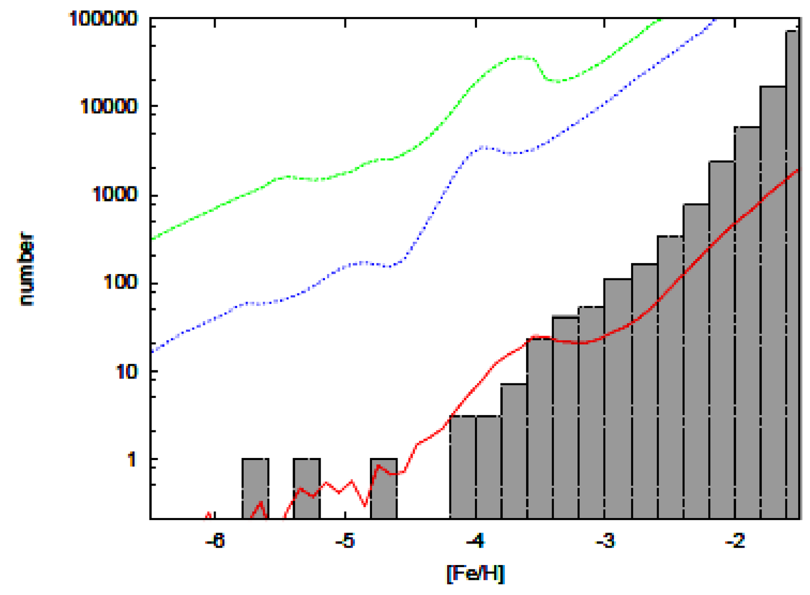
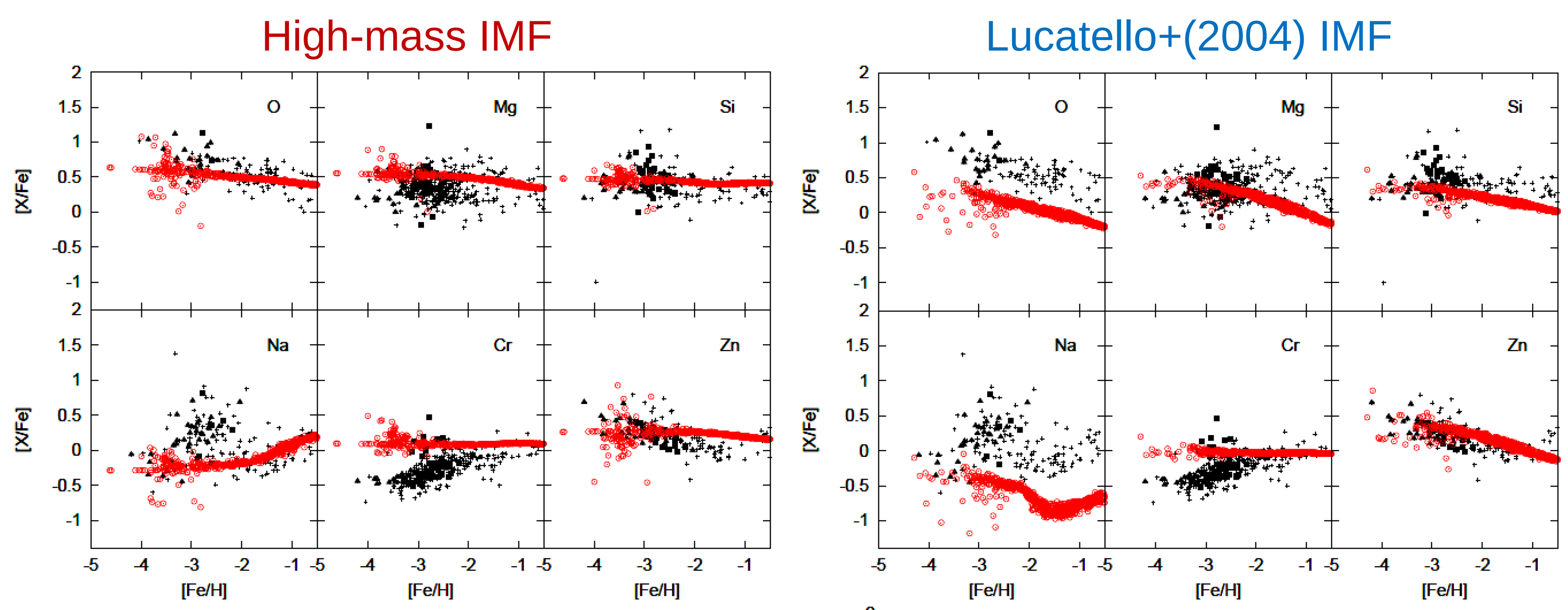


Fig.4
Gray histogram shows observational MDF by Schoerck+ (2009). Lines denote predicted MDFs of the models with High-mass IMF (red), low-mass IMF (green) and IMF of Lucatello+(2004)(blue), respectively.

Relative Abundance distribution

Predicted abundances distributions for high-mass IMF model and low-mass IMF model are similar. α elements are provided by Type II supernovae and their yield relative to iron depend on the mass of supernova progenitor; higher mass star provide larger mass of α-elements. However, because IMF slope at 10-50 $M_\odot$ are similar for both model, distribution of [α/Fe] is similar. Lucatello IMF model predict lower [α/Fe]than observations because of steeper slope of IMF.



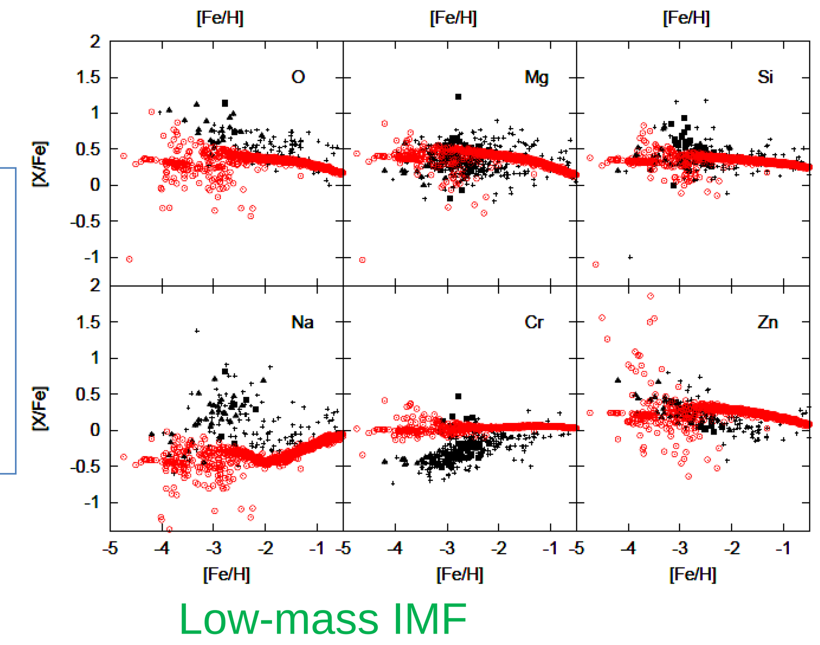


Fig. 5
Relative abundance distributions of O, Mg, Si, Na, Cr and Zn for models with three different IMFs. X axis is [Fe/H] and Y axis is [X/Fe]. Red marks denote model results and black ones denote abundances of observed EMP stars (SAGA database).

Hypernovae contribution

It is said that there was hypernovae with huge explosion energy in the early universe. Above figures show results with hypernovae contribution.
To see the contribution from hypernovae, we also compute a model without hypernovae.
[Zn/Fe] of EMP stars become lower for no hypernovae model. Observationally, EMP stars shows high [Zn/Fe]. Main source of zinc on the EMP stars thought to be hypernovae.
Hypernovae also lower scatter of relative abundance distribution.

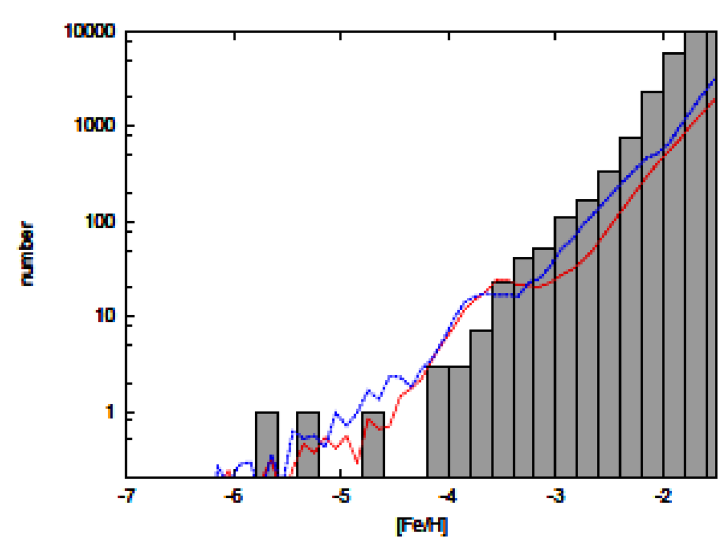


Fig.4
MDFs by the hyoernovae model(red) and no hypernovae model(blue).

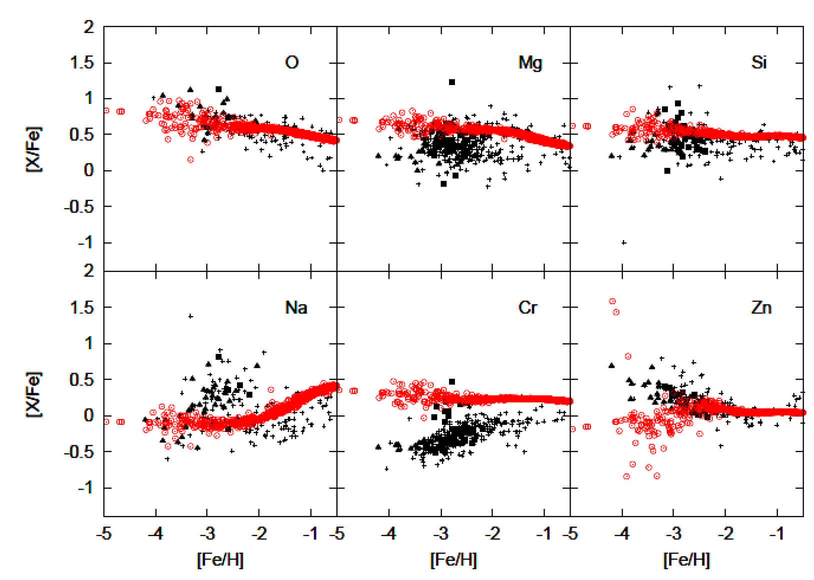


Fig. 5
Relative abundance distributions of no hypernovae model.