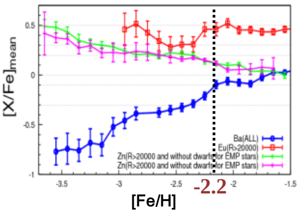
CHANGEOVER OF INITIAL MASS FUNCTION FOR GALACTIC HALO STARS AND HISTORIES OF ZINC, COBALT AND BARIUM ENRICHMENT

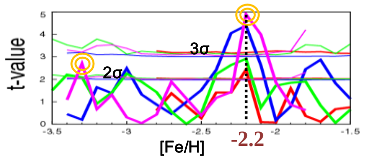
Shimako Yamada[1], Takuma Suda[1], Yutaka Komiya[2] and Masayuki Y. Fujimoto[1]

[1] Hokkaido University [2] National Astronomical Observatory of Japan

For the extremely metal-poor stars (EMP) in the Galactic halo, it has been shown the initial mass function (IMF) is a high-mass one with the peak mass 5-20Mo. Furthermore, such a evidence of a transition to low-mass IMF is found around the metallicity **[Fe/H]≈-2** from the statistics of **carbon**-enhanced stars . We find the mean enrichments of **zinc** and **cobalt** show two breaks around **[Fe/H]≈-2.2 and -3.3** and piecewise flat except them by utilizing SAGA database (http://saga.sci.hokudai.ac.jp/). The former break is attributable to the decrease in the average supernova yields attendant upon the changeover of IMF. The latter break is explicable by hypernovae with large explosion energy and large zinc and cobalt enrichment. We also find the same break **[Fe/H]≈-2.2** for the mean enrichments of **barium** and **europium**, which support the break is attribute to the changeover of IMF rather than to s-process enhancement.



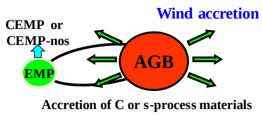
$$\text{t-value}=\frac{\Delta\,[X/Fe]_{mean}\ \text{between adjacent metallicity bins}}{\text{Standard error of }\Delta\,[X/Fe]_{mean}}$$



1. Introduction

1.1 IMF of EMP stars

IMF of extremely metal poor (EMP) stars ([Fe/H]<-2.5) is determined from statistics of carbon enhanced EMP (CEMP) stars and Stellar evolution of AGB stars (Komiya et al. 2007)



Observation

I. 20~25% of EMPstars

II. 1/3~1/4 of CEMP stars

CEMP stars

CEMP –nos

Stellar evolution theory

I. ⇔ M_{AGB} = 0.8~3M⊙ (s-process enhancement)

II. ⇔ M_{AGB} = 3~6M⊙ (no s-process enhancement)

Massive IMF (~5-20 Mo peak) for[Fe/H]<-2.5

Low-mass IMF (0.22Mo peak) of present Milky Way (Chabrier+2003)

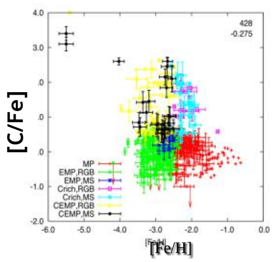
There must be IMF change from massive to low-mass ones at [Fe/H]>-2.5

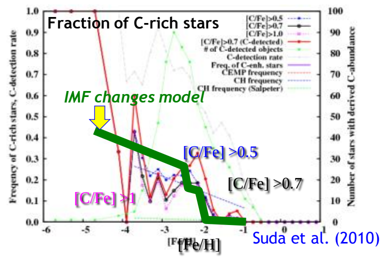
1.2 Changeover of IMF from fraction of C-rich stars

Observed fraction of C-rich stars rapidly decrease around [Fe/H]~ -2.0 from 14% to 0.7%.

➔ IMF change model, which switches IMF from massive IMF with peak mass of Mmd=10Mo to low-mass IMF with Mmd=0.22 at [Fe/H]=-2, can successfully reproduce such a fractional change of C-rich stars.

Fractional change of C-rich star is consistent with the IMF change model





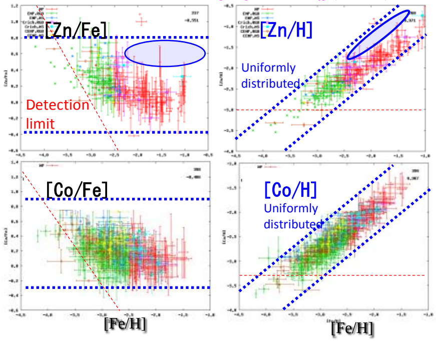
2. The enrichment history of Zinc and Cobalt

[Zn,Co/**Fe**] in EMP stars show increasing monotonically with [Fe/H] decreases is asserted (e.g, Ryan et al. 1996; McWilliam et al, 1995; Cayrel et al, 2004; Saito et al. 2009).

However, in plane of [Zn,Co/H] vs [Fe/H], these abundances data fall in the area bounded by two loci of constant enrichment of [Zn,Co/Fe], and show **uniformly distributed feature rather than monotonically increasing**.

In low-metallicity, it may be influenced by the relative scanty of abundance data and the detection limits which may differ according to the resolution of the spectra. In particular, all stars except 2 below [Fe/H]~ -3 are measured by Cayrel et al. (2004).

Observation data from SAGA Database:http://saga.sci.hokudai.ac.jp/ (Suda+2008)

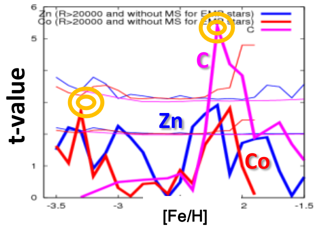


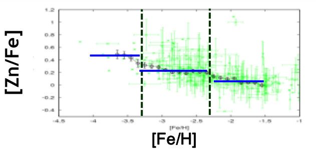
2.1 Variations in the mean enrichment with the metallicity

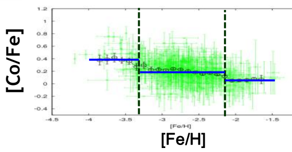
$$\text{t-value}=\frac{\Delta\,[X/Fe]_{mean}\ \text{between adjacent metallicity bins}}{\text{Standard error of }\Delta\,[X/Fe]_{mean}}$$

Mean values of [Zn/Fe] and [Co/Fe] mark **large breaks over 2 or 3σ at [Fe/H] = -2.2** as well as [C/Fe], attributable to the changeover of IMF, and mark another break over 2σ at **[Fe/H] = -3.3**. For Zn, the t-value exceed 2σ at [Fe/H] ~ -3,which is an artifact of the detection limits of Zn abundances for observations except Cayrel et al. (2004) The mean abu-ndance ratios are piecewise flat between the breaks.

[Zn/Fe], [Co/Fe]: × monotonically decreasing as metallicity
○ piecewise flat distribution with breaks







3. Origin of low-metallicity stars

We reveal [Zn/Fe] and [Co/Fe] are piecewise flat with breaks;

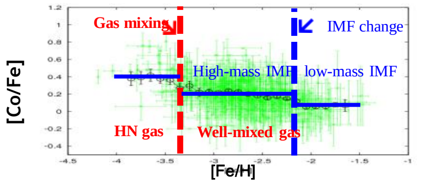
A) metal-rich break ([Fe/H]=**-2.2**) ⇔ IMF change (high-mass → low-mass)

B) metal-poor break([Fe/H]=**-3.3**) ⇔ difference of gas mixing process

▶ Formation process of high-[Zn,Co/Fe] and low-metallicity ([Fe/H]-3.3) stars

1) Assuming the stars formation induced by supernova shock (Tujimoto et al. 1999), stars with [Fe/H]≲ -3.3 were formed by **hypernovae (HNe)** with large explosion energy and high-[Zn,Co/Fe] in a large halo of ~10^6Mo (Umeda & Nomoto 2002), since the swept-up mass by the shock increases, as a result, [Fe/H] becomes smaller but [Zn,Co/Fe] is unchanged.

2) In early epoch, star formation occurs in small minihalo of ~10^5Mo, thus, if HNe occur in such a halo, they expel their ejecta from the host halo. The ejecta is diluted with interstellar gas, and will accrete onto host mini-halos again or be incorporated into more massive halos later. The first stars, formed with accreted gas or in newly formed halo, have small metallicity, and may have observational counterparts for stars with [Fe/H] ≲ -3.3.



4. Constrains on IMF and supernova yields

Deriving constrains, imposed on the IMF and supernova yields which depend on their progenitor mass by employing followings;

1) break between division **B** and **C** ⇔ IMF change

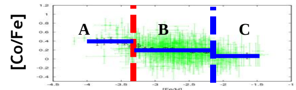
2) division **A** ⇔ **reflect yields of HNe**

3) mean [Zn,Co/Fe] in division A ,B and C are determined from observations.

$([Zn/Fe]_A, [Zn/Fe]_B, [Zn/Fe]_C) = (0.44\pm0.05, 0.07\pm0.02, 0.21\pm0.02)$

$([Co/Fe]_A, [Co/Fe]_B, [Co/Fe]_C) = (0.39\pm0.04, 0.19\pm0.01, 0.07\pm0.02)$

From conditions from 1) to 3), We can constrain Fe yield mass for hypernova and abundance ratios of [Zn,Co/Fe] for normal SN.



4.1 Constrains on IMF and supernova yields

Derived Fe mass of hypernova, $M_{Fe,HN}$, and [Zn,Co/Fe] for normal SN, $[Zn,Co/Fe]_{NS}$, are plotted (*thick lines with shadows for 1σ errors*) as a function of peak mass of high-mass IMF, Mmd, and its variance , Δ_M = 0.6 or 0.33 .

No stars are observed below [Zn,Co/Fe]=-0.2 -0.3 (*thin broken line*), which pose condition on [Zn,Co/Fe] of normal SN, and set lower bounds for Mmd; for Δ_M =0.6 and 0.33, Mmd must be larger than ~10Mo and ~15Mo respectively.

Since the statistics of carbon-enhanced stars predict high-mass IMF of Mmd =5-20Mo with smaller Mmd for smaller Δ_M (Komiya et al. 2007,2009), this implies IMF with Δ_M = 0.33 will be excluded; **IMF in stars in division B must be not only high-mass but also top-heavy.**

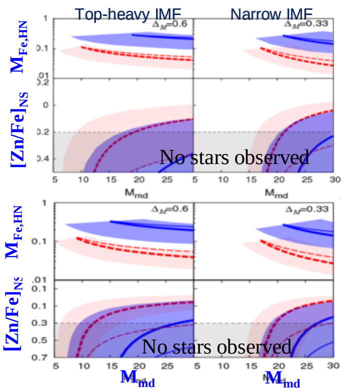
In the case that electron capture SNe produce the same amount of Zn and Co as normal SN (*thin lines*), significant contribution from such SNe lessen $[Zn,Co/Fe]_{NS}$ below observed limits.

High-mass IMF: $\xi(\log m_i)\propto\exp\left(-\frac{(\log m_i-\log M_{md})^2}{2\times\Delta_M^{\,2}}\right)$

HN fraction among SN progenitors with >20Mo

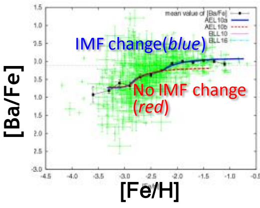
Red shadow : HN fraction = 100%

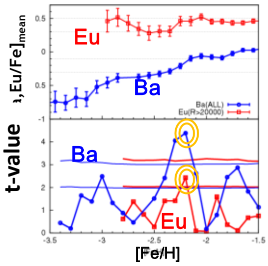
Blue shadow : HN fraction = 50%



5. The enrihcment history of Barium

Mean values of [Ba/Fe] and [Eu/Fe] mark large breaks over 3 or 2σ at **[Fe/H] = -2.2** as well as [Zn, Co, C/Fe], attributable to the changeover of IMF. The difference of mean value of [Ba/Fe] around [Fe/H]=-2.2 is about as large as the one of [Eu/Fe], which supports the break is attribute to the changeover of IMF rather than to s-process enhancement. ➔





🡐 IMF change model at [Fe/H]=-2.2 from high-mass (Mmd=10) to Salpeter one (*blue line*) can reproduce observed mean enrichment trend of [Ba/Fe](*black line*).

6. Conclusions

1. We find that the mean **Zn** and **Co** enrichments in Galactic halo stars exhibit piecewise flat distribution with **two breaks around the metallicity, [Fe/H]=−2.2 and −3.3**, respectively.

2. **The break at [Fe/H]=−2.2** is identified as the **changeover of IMF**, from high-mass to low-mass, deduced from the statistics of carbon-enhanced stars (Suda et al .2010).

3. The break at **[Fe/H]=−3.3** is explicable in terms of the interactions of the **first hypernovae (HNe)** with large explosion energy and Zn and Co yields and the interstellar gas in their host mini-halos. In this case, stars **below [Fe/H] ~ -3.3 reflect yields of HNe.**

4. We derive constrains on IMF and supernova yields on a basis of the changeover of IMF and emplying that below [Fe/H]~-3.3 reflect yields of HNe. In particurally, **the high-mass IMF should be top-heavy** (the variance of IMF is large).

5. We also find the same break **[Fe/H]≈-2.2** for the mean enrichments of **barium** and **europium**, which support the break is attribute to the changeover of IMF rather than to **s-process enhancement.**