Mem. S.A.It. Vol. 88, 856

Memorie della

Formation environment of Pop II stars affected by the feedbacks from Pop III stars

G. Chiaki[1], H. Susa[1], and S. Hirano[2]

[1] Department of Physics, Konan University, 8-9-1 Okamoto, Kobe, 658-0072, Japan
e-mail: `chiaki@center.konan-u.ac.jp`
[2] Department of Astronomy, The University of Texas, Austin, TX 78712, USA

Abstract. Stars with metallicities [Fe/H] < -3 are called extremely metal-poor (EMP) stars, and considered to be formed in clouds enriched with metal from a single or several supernovae (SNe) of the first-generation (Pop III) stars. To confirm this, we numerically follow the enrichment process of minihalos (MHs) which have hosted Pop III stars. During their main-sequence (MS), the ionizing photons can not or partly break the gas around the Pop III stars because the halo binding energy is marginally larger than the radiation energy. After SN explosions, the gas continues to accrete along filaments of the large-scale structures, and the gas collapses again in the MHs within $\sim$ 10 Myr for low-mass MHs (3×10^5 $M_{\odot}$) while $\sim$ 1 Myr for massive MHs (3×10^6 $M_{\odot}$). The metallicity in the recollapsing regions is 10^{-4}–10^{-2} $Z_{\odot}$ and 10^{-6}–10^{-5} $Z_{\odot}$, respectively. This indicates that EMP stars are formed in the clouds enriched by a single SN in low-mass MHs.

1. Introduction

Stars with metallicities [Fe/H] < -3, so called extremely metal-poor (EMP) stars, have been enthusiastically investigated as the clues of the enrichment process in the early Universe (Beers & Christlieb 2005). They are consider to be the second-generation of stars enriched by a single or several supernovae (SNe) of the first metal-free (Pop III) stars (Ryan et al. 1996). Ritter et al. (2012) numerically estimate the metallicity of self-enrichment of a mini-halo (MH) with an initial mass of $M_{\rm halo} = 1 \times 10^6$ $M_{\odot}$ by a Pop III star with a mass of $M_{\rm PopIII} = 40$ $M_{\odot}$. They find that half of metal is fallen back and the metallicity of the enriched region is 10^{-3}–10^{-2} $Z_{\odot}$. However, they study only for one case of $M_{\rm PopIII}$ and $M_{\rm halo}$. We in this paper estimate the metallicities in the recollapsing regions for wide ranges of these parameters to compare with metallicities of observed EMP stars.

2. Method

We employ the N-body/SPH code Gadget-2, implementing networks of the non-equilibrium chemical reactions and radiative cooling/heating of primordial species based on Nagakura et al. (2009). During main-sequence (MS) of Pop III stars, the photoionization of H atoms and photodissociation of H_2 molecules are added. Their reaction rates are calculated from the column densities of H and H_2 from the source, which are derived with the procedure presented by Susa (2006) After the lifetime of Pop III stars, $t_{\rm exp}$, we add the explosion energy $E_{\rm SN} = 1 \times 10^{51}$ erg as thermal

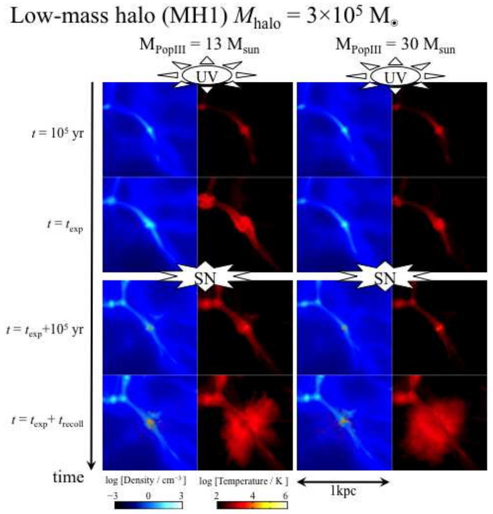

Fig. 1. Density and temperature distributions for CCSNe with progenitor masses $M_{\rm PopIII}$ = 13 and 30 $M_\odot$) hosted by a low-mass halo (MH1: $M_{\rm halo} = 3\times10^5$ $M_\odot$) in the time sequence from top to bottom.

energy to the central 200 SPH particles. The motion of metal is followed by 10^5 Lagrangian particles, hereafter called metal particles.

3. Results

The top two rows of Figure 1 show the density and temperature slices during MS of Pop III stars for MH1. The ionizing front barely propagate for the low-mass MHs (MH1 and MH2) because the halo binding energy is marginally larger than the radiation energy. The bottom two rows of Figure 1 show the density and temperature projections after SN explosions. The orange dots indicate the positions of metal particles. For MH1 and MH2, SN shocks propagate in the direction of the void for several hundred parsecs while the gas continues to accrete into the MHs along the cosmological filamentary structures and starts to collapse again ∼ 10 Myr after the SN.

The metallicity in the recollapsing region is 10^{-4}–10^{-2} $Z_\odot$ as shown in Figure 2.

For the massive MH (MH3), the ionization front cannot expand to the interstellar medium.

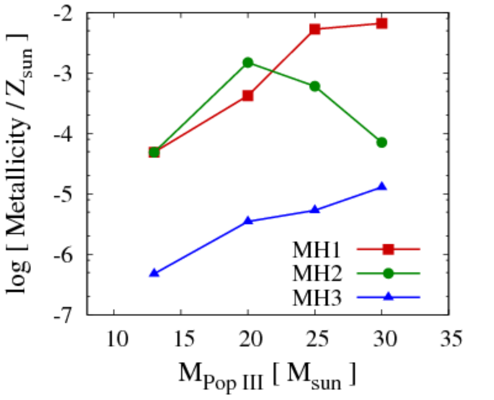

Fig. 2. Metallicites in the recollapsing region as a function of the progenitor mass $M_{\rm PopIII}$ for MH1 (red), MH2 (green), and MH3 (blue).

The density of the central region remains large. After the SN explosions, the shocks go through the dense region. The gas collapse again only for ∼ 1 Myr. The metallicity is 10^{-6}–10^{-5} $M_\odot$, smaller than for MH1 and Mh2 because the metal can not fully penetrate into the dense regions along the cosmological filaments where the gas recollapses.

4. Discussion

The metallicity range in the self-enriched regions by SNe is consistent with that of observed EMP stars. This indicates that the formation of EMP stars can be explained by the self-enrichment of low-mass MHs by a single SN explosion.

Acknowledgements. We would like to thank N. Tominaga, S. J. Tanaka, and T. Ishiyama for discussions.

References

Beers, T. C., & Christlieb, N. 2005, ARA&A, 43, 531
Nagakura, T., et al. 2009, MNRAS, 399, 2183
Ritter, J. S., et al. 2012, ApJ, 761, 56
Ryan, S. G., et al. 1996, ApJ, 471, 254
Susa, H. 2006, PASJ, 58, 445