Formation environment of Pop II stars affected by the feedbacks from Pop III stars
Gen Chiaki, Hajime Susa (Kanon Univ.), & Shingo Hirano (Texas Univ.)

Abstract
In the halo of our Galaxy and external dwarf galaxies, extremely metal-poor (EMP or Pop II) stars are observed. Their long life time and low metal abundances, they are considered to be the second- or several-generation of stars.

We in this work investigate the formation environment of EMP stars, considering the effects of radioactive and kinetic feedbacks of main-sequence and supernovae (SNe) of the first-generation primordial (Pop III) stars by a series of numerical simulations. We find that in low-mass minihalos (MHs) with $M_{\text{init}}=3-30 M_{\odot}$, the gas around Pop III stars with masses $M_{\text{star}}=13-30 M_{\odot}$ are partly broken by their ionizing photon emission, while in a high-mass MH ($M_{\text{init}}=30-100 M_{\odot}$) the gas is not affected. Then, by SN explosion, a large fraction of metal is expelled to the void region while the other is mixed into the gas accreting along the filament of the large scale structure. The resulting metallicity in the recollapsing region is $10^{-10.2}$ and $10^{-7}$ for low-mass and high-mass MHs, respectively.

Considering that the mass range of MHs are within $3-10^5 M_{\odot}$, (Hirano et al. 2015), we can conclude that the internal enrichment by Pop III SNe is one of the paths to form observed EMP stars.

Method

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- Mass-eq. chemistry
  - $\alpha_{\text{HII}}, \alpha_{\text{H}}, \alpha_{\text{He}}$ initial values
  - $\alpha_{\text{HII}}, \alpha_{\text{H}}, \alpha_{\text{He}}$ evolution
  - $\alpha_{\text{SN}}, \alpha_{\text{He}}$ reactions including
    - $\alpha_{\text{SN}}=\alpha_{\text{SN}}^{\text{initial}}+\Delta \alpha_{\text{SN}}$
    - $\alpha_{\text{He}}=\alpha_{\text{He}}^{\text{initial}}+\Delta \alpha_{\text{He}}$

- Radiation cooling
  - MH re-cooling: cooling in $\alpha_{\text{HII}}, \alpha_{\text{H}}, \alpha_{\text{He}}$
  - MH cooling: $\alpha_{\text{SN}}, \alpha_{\text{He}}$

- Meeting by ionizing photons

Results

We cut out three MHs with a wide range of masses $M_{\text{MH}}$ from a cosmological simulation. MHs and SNe have the mass of $10^{3}$-$10^{5} M_{\odot}$ and $\sim 10^{5}$ $M_{\odot}$, which are the most massive and high end of the mass range of MHs (Hirano et al. 2015).

Discussion

We here consider the metal enrichment from core-collapse SNe (CCSNe). Some researchers report that the elemental abundance of hypernova type IIP (HN) stars with metallicities [Fe/H] $\leq -5$ such as SDSS J0329+1729 with [Fe/H]$=5$ is consistent with more energetic hypernovae (HNe) [e.g., Tombino et al. 2014]. We speculate that, with increasing explosion energy, the fraction of metal which return to the recollapsing region decreases, and the abundance of HN stars can be reproduced. Further, for post-instability SNe (PISNe), we expect that the metallicity in the recollapsing region is lower the critical metallicity, i.e., the Pop III star formation continues. This consistent with the observations by no EMP stars with elemental abundances of PISNe have so far been found.

Conclusion

- The range of metallicity in the region which collapses again after the radiation and kinetic feedbacks from Pop III stars and their SN is $10^{-7}$-$10^{-5}$ for smaller-mass halos MH2 and MH3 ($\sim 30 M_{\odot}$), while $10^{-7}$-$10^{-4}$ for the massive halo MH3 ($\sim 10^{5} M_{\odot}$).

- The mass of these halos covers the mass range of minihalos obtained by the cosmological simulations with a large box size (Hirano et al. 2015; left figure). This indicates that the metallicity range of recollapsing region is $10^{-4}$-$10^{-5}$.

- We can conclude that the internal enrichment by Pop III SNe is one of the paths to form observed EMP stars.