# Chemodynamical Evolution of Dwarf Galaxies Deduced from *r*-process Elements


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Abundances of *r*-process elements (such as Eu and Ba) could help us clarify early evolutionary histories of galaxies. The *r*-process abundances in the Local Group galaxies tend to be lower than those of the Milky Way halo. The *r*-process abundances would reflect the star formation rates and mixing of metals in the early stages of galaxy formation.

One of the most promising astrophysical sites of *r*-process elements are neutron star mergers. Previous studies show that it is possible to explain the observed abundances of *r*-process elements by neutron star mergers [1]. However, the relation among *r*-process abundances, star formation rates, and efficiency of metal mixing is not yet understood.

In this study, we perform a series of chemodynamical simulations of dwarf galaxies with different star formation rates and efficiencies of metal mixing to clarify how the star formation rates and efficiency of metal mixing affect the *r*-process abundances. We use the *N*-body/hydrodynamic simulation code, ASURA [4]. In this study, we implement the *r*-process element ejection models by neutron star mergers [1] and metal mixing model [5] to ASURA. We adopt the isolated dwarf galaxy models with different central densities and total masses of halos.

Figure 1 shows *r*-process abundance ratios in dwarf galaxy models with different star formation histories [2]. According to Figure 1, stars with *r*-process elements appear at higher metallicity in higher star formation rates due to their faster chemical evolution. This result suggests that early star formation rates should be less than $10^{-3}\, M_{\odot}\, \mathrm{yr}^{-1}$ to explain the abundances of *r*-process elements in extremely metal-poor stars.

Figure 2 shows *r*-process abundance ratios with different efficiencies of metal mixing [3]. Figure 2 (a) and (b) do not have stars with high *r*-process abundance ratios ([Ba/Fe] $>$ 1). On the other hand, Figure 2 (c), (d), and (e) have these stars. We assume an efficiency of metal mixing estimated from turbulence theory in Figure 2 (a) and (b). This result suggests that it is possible to explain observed abundances of *r*-process elements in dwarf galaxies if the metals are mixed with the efficiency consistent with estimation from turbulence theory. We find that the timescale of metal mixing is less than 40 Myr in Figure 2 (a) and (b). This timescale is significantly shorter than the dynamical times (~100 Myr) of dwarf galaxies. Our results demonstrate that future observations will be able to more precisely estimate star formation rates and efficiency of metal mixing through *r*-process abundances.

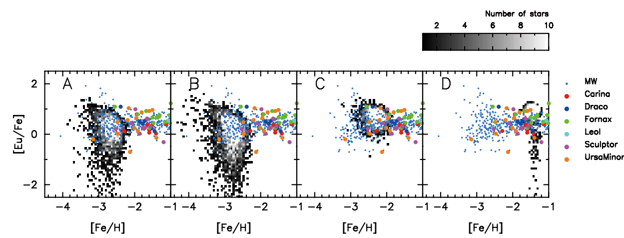


**Figure 1**: *r*-process abundance ratios in galaxies with different star formation rates. Grey scales show model prediction. Small and large dots represent observational results with the Milky Way and the Local Group dwarfs (SAGA database [6]). Star formation rates increase from (A) to (D).

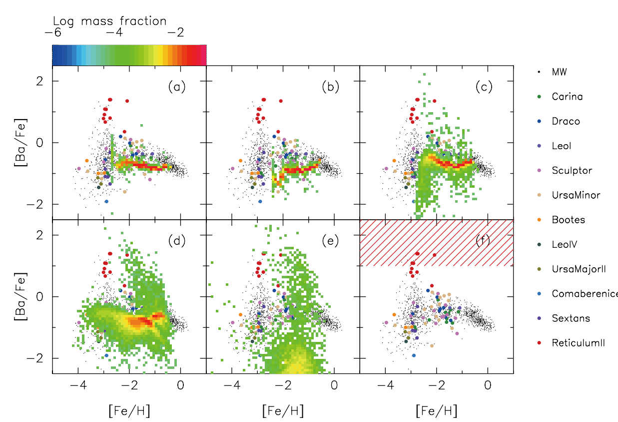


**Figure 2**: *r*-process abundances in galaxies with different efficiencies of metal mixing. Color contours show the model prediction. Small, large, and red dots represent observational results of the Milky Way, the Local Group dwarfs, and the Reticulum II ultrafaint dwarf (SAGA database [6]). Efficiencies of metal mixing decrease from (a) to (d). (e) represents the model without metal mixing. (f) shows observations. The red shaded region shows that the area with no stars in dwarfs. We correct the Ba abundances to only reflect contributions from *r*-process.

## References


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