論文の内容の要旨

Understanding the enrichment of heavy elements by the chemodynamical evolution models of dwarf galaxies

(矮小銀河の化学力学進化モデルによる重元素の化学進化の理解)

平居　悠

Understanding the enrichment of heavy elements in dwarf galaxies help us clarify the astrophysical sites of elements and evolutionary histories of the Local Group galaxies. Astronomical spectroscopic observations have shown that there are large star-to-star scatters in the abundances of elements synthesized by rapid neutron-capture process (r-process elements) in extremely metal-poor stars. On the other hand, the heaviest iron-peak element, Zn shows an increasing trend toward lower metallicity. These observational signatures preserve the information about the early stages of the formation of Local Group galaxies and astrophysical sites of heavy elements. According to the hierarchical structure formation scenario, the Milky Way halo is formed from the clustering of the smaller objects. The chemodynamical properties of the Local Group dwarf galaxies thus help us understand galaxy formation. However, the enrichment of heavy elements and their roles in the chemodynamical evolution of dwarf galaxies have not yet been clarified.

In this thesis, we performed a series of high-resolution *N*-body/smoothed particle hydrodynamics simulations of dwarf galaxies in isolated and cosmological initial conditions. We confirm that our simulations are consistent with the observed properties of the Local Group galaxies such as radial profiles, metallicity distribution, and mass-metallicity relation. We study the enrichment of r-process elements from neutron star mergers in dwarf galaxies. We find that neutron star mergers with merger times of 100 Myr can explain the observed r-process abundances ratios. This is because metallicity is not correlated with time ~ 300 Myr from the start of the simulation due

to the low star formation efficiency in dwarf galaxies. In these galaxies, neutron star mergers with merger times less than 500 Myr can produce r-process elements in very metal-poor stars.

Star formation histories directly affect the abundances of r-process elements in metal-poor stars. We find that galaxies with dynamical times longer than 100 Myr reproduce the observed abundances of r-process elements. These galaxies have star formation rates less than 0.001 solar masses per year. On the other hand, the first neutron star merger appears at a higher metallicity in galaxies with a dynamical time shorter than typical neutron star merger times. The star formation rates of these galaxies are over 0.01 solar masses per year at around 100 Myr from the beginning of the simulation. These galaxies have lower scatters of r-process elements than those of the galaxies with longer dynamical times. We moreover find that the results are insensitive to the total mass of halos and merger times of neutron star mergers.

Enrichment of Zn in dwarf galaxies is also studied in this thesis. We take into account the yields of electron-capture supernovae, hypernovae, iron-core collapse supernovae, and type Ia supernovae in the simulations. We find that the ejecta from electron-capture supernovae contribute to forming extremely metal-poor stars with high Zn abundances. On the other hand, the scatters of the Zn to iron ratios seen at higher metallicity originate from the ejecta of type Ia supernovae. We also find that it is difficult to reproduce the observed abundances without assuming the contribution from electron-capture supernovae.

The scatters of r-process elements mainly come from the inhomogeneity of the metals in the interstellar medium. We find that the scaling factor for metal diffusion larger than 0.01 is necessary to reproduce the observation of abundances of r-process elements and Zn in dwarf galaxies. This value is consistent with the value expected from turbulence theory and experiment. We also find that the timescale of metal mixing is less than 40 Myr. This timescale is shorter than that of typical dynamical times of dwarf galaxies.

To obtain the self-consistent picture for the formation of the Milky Way halo and satellite dwarf galaxies through the enrichment of heavy elements, we performed a series of cosmological zoom-in simulations of a galaxy. We computed the galaxy with a halo mass of 10^{10} solar masses at redshift 2 to resolve the scale of satellite dwarf galaxies. Most extremely metal-poor stars are formed before 1 Gyr from the beginning of the simulation. In the galaxy, there are star-to-star scatters of r-process elements in low metallicity. We find that r-process rich metal-poor stars are formed in halos with a total mass of $\sim 10^8$ solar masses and gas mass of $\sim 10^6$ solar masses.

In this thesis, we identify that neutron star mergers can be major astrophysical sites of r-process elements and electron-capture supernovae contribute to the enrichment of Zn in low metallicity. We demonstrate that abundances of heavy elements in metal-poor stars can be a nice tracer for the star formation histories and metal mixing in dwarf galaxies. From the cosmological simulations, we find that r-process rich stars are formed in the galaxy with a size similar to the ultra-faint dwarf galaxies. Our results demonstrate that the comparison with future high-resolution simulations that can resolve each star and observations of r-process elements in extremely metal-poor stars will be able to constrain the early chemodynamical evolution of the Local Group galaxies.