Hydrodynamical simulation of neutrino-driven wind for r-process

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Rapid neutron capture process (r-process) is believed to be the origin of heavy elements in the history of the Universe. However, the site of the r-process having enough neutron source is one of the big mysteries in astrophysics. Supernova explosion is most likely the site, but where and how the r-process can occur in supernova has not yet been clarified. We study the neutrino-driven wind as a r-process site by performing hydrodynamical simulations. We simulate the hydrodynamics of the surface layers just above the proto-neutron star, which is born in supernova explosion, to clarify whether the r-process nucleosynthesis can occur or not.

We adopt the numerical code for the general relativistic, implicit hydrodynamics in spherical symmetry.[1)] The general relativistic treatment is essential to study the hydrodynamics around the compact objects such as a neutron star. The heating and cooling processes due to neutrinos are added on top of the hydro code. The implicit time differencing is also essential to follow the hydrodynamics for a long time, which is much longer than the sound crossing time in dense matter of neutron stars. The hydro code uses the lagrangian mesh, which is suitable to follow the thermal history for the nucleosynthesis.

As for the equation of state (EOS) of dense matter, we adopt the table of the relativistic EOS, which is recently derived for supernova simulations.[2,3)] The relativistic EOS is derived by the relativistic nuclear many body framework, which reproduces the nuclear matter saturation and the properties of stable and unstable nuclei in the nuclear chart.[4)] The table covers the wide range of density, electron fraction and temperature, which enables us to perform supernova simulations.

Figure 1 demonstrates the hydro simulations of the neutrino-driven wind. The surface layers above the proto-neutron star are heated up due to neutrino interactions. Mass elements are ejected gradually escaping the gravitational potential. Matter is expanded and cools down as a result. From numerical results, we can examine the hydrodynamical condition of the nucleosynthesis to judge whether the r-process is possible. We found the expansion time scale is shorter than the ones estimated in previous analytic studies. Shorter expansion time scale is favorable for the r-process since it leaves high neutron to seed nuclei ratio. Using the trajectory of the simulation, we have shown that the r-process occurs in the case of a short expansion time scale under a certain condition for neutron star mass and neutrino luminosity by performing the nuclear reaction network calculations.[5)] In summary, we have shown by hydro simulations that the neutrino-driven wind in supernova explosion is a promising site for the r-process to create heavy elements.

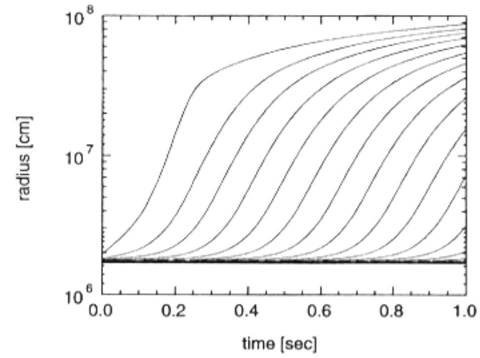

Fig. 1. Trajectories of mass elements in hydrodynamical simulations are displayed as functions of time.

References

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