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General relativistic simulations of magnetized binary neutron star merger on K

KIUCHI, Kenta[1*] ; KYUTOKU, Koutarou[2] ; SEKIGUCHI, Yuichiro[1] ; SHIBATA, Masaru[1]

[1]Yukawa Institute for Theoretical Physics, [2]University of Wisconsin-Milwaukee

Binary neutron stars are a binary which is composed of two neutron stars and nine binaries have been observed so far. They gradually lose the orbital energy and angular momentum due to gravitation wave emission and merge in the end. Within the observed binaries, six of them will merger within the Hubble time. Gravitational waves emitted during the merger would be detectable with the ground-based gravitational wave detectors such as KAGRA, advanced LIGO, and advanced VIRGO at a frequency of about ten times per year. If we could observe the gravitational waves, they would tell us the validity of General Relativity in a strong gravitational field and the equation of state of neutron star matter which is poorly known to date as well.

This situation facilitates a theoretical study of binary neutron star mergers. During the merger, the density is as high as 10^{15} g/cc and the temperature rises as high as 10^{10} degrees. Therefore, any analytical approaches break down and we need a numerical modeling. Our group is approaching this problem in the framework of Numerical Relativity. It is a research field whose aim is figuring out phenomena in a strong gravitational field by solving the Einstein equation as well as the hydrodynamical equation and neutron radiation transfer.

The observations of the pulsars have revealed that the neutron stars are magnetized with about 10^{12} Gauss in general. Moreover, some of them could have 10^{14} Gauss. However, it is still unknown what the role of magnetic field during binary neutron star mergers is. There are several hydrodynamical instabilities which amplify the magnetic field and a short wavelength mode is essential in all cases. Therefore, it is mandatory to perform a high-resolution simulation. In the previous studies of this subject, it is hard to say that enough resolution is assigned to resolve these instabilities. Our group is performing a numerical simulation with the highest resolution on the supercomputer K and figuring out the role of the magnetic field during the merger of binary neutron stars. We summarize the result as follows.

When the two stars come into contact, the shear layer between the stellar surface becomes unstable against the Kelvin-Helmholts instability. The vortices are produce by this instability and the shorter the wavelength is, the larger the growth rate of the instability is. If there exists magnetic field lines, they are curled by these vortices and are expected to be amplified exponentially. By performing the convergence study against the numerical resolution, we have found the maximum magnetic field is amplified by the factor of about thirty at least at the merger.

After the merger, a hypermassive (HMNS) neutron star is transiently formed, which is supported by a rapid and strong differential rotation in addition to the thermal pressure. Although this star is unstable against the magnetorotational instability (MRI), it is difficult to resolve the MRI because the wavelength of the unstable mode is quite short due to the high density and high angular velocity of the HMNS neutron star. In our simulation, we have resolved this unstable mode and we have shown that the HMNS neutron star has the magnetic field as large as 10^{16}-10^{17} Gauss as a result.

In the HMNS neutron star, the angular momentum transport due to the non-axisymmetric structure as well as due to the MRI works. In addition, the star loses a significant amount of the angular momentum due to the gravitational wave emission. Then, the star collapses to a black hole which is surrounded by the accretion disk. Inside the accretion disk, the magnetohydrodynamical turbulence transports the angular momentum and its surface is unstable against the Kelvin-Helmoholts instability. Vortices produced by these two mechanisms transport the energy outwardly and the disk wind activates as a result. In this talk we will introduce the simulation result in details.