Usage Report for Fiscal Year 2019

Project Title: BNS merger simulation

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1. Background and purpose of the project, relationship of the project with other projects

What are the new states of matter at exceedingly high density and temperature is the one of the most attractive questions in the century. The laboratory experiments like heavy-ion collisions could reveal the equation of state(EOS) in the low-density region(below two nuclear saturation density), and the high-density region EOS could be approximately calculation based on the perturbative QCD(above one hundred nuclear saturation density). In between, neutron stars, which the central density could up to ten saturation density, are ideal research objects. The numerical simulations for binary neutron star mergers could make a bridge for the fundamental nuclear physics to astrophysical observations, and it is worthy since the upcoming gravitational astronomy era would bring more multi-messenger information. The constrains for neutron stars equation of EOS were from various ways, such as the neutron stars maximum mass, based galactic radio pulsars observations, tidal deformability based on inspiral gravitational wave template match-filtering, and radius measurements by x-ray observations like the NICER recent result.

2. Specific usage status of the system and calculation method

The GRHD simulations for binary neutron star (BNS)merger were based on Lorene and Whisky codes. Lorene provides tools to solve partial differential equations in numerical relativity by means of multi-domain spectral methods, it could solve TOV equations and generate the initial data for BNSs. Whisky is used to solve the evolution equations of general relativistic hydrodynamics (GRHD) and magnetohydrodynamics (GRMHD) in 3D Cartesian coordinates on a curved dynamical background. During the last year as a quick user, I set the necessary environment and successfully compile and run Lorene and Whisky code in BWMPC. I usually use 16 nodes with 512 cores to run each job, and I used about 20 percent core time of quick user.

3. Result

I used the power law EOS with Gamma=2 to generate the initial data, both of the neutron stars masses are 1.3 M_{sun}. Fig. 1 shows the evolution of fluid density, the binary orbiting for several circles, then merger happens, and the orbital angular momentum transfer to spin angular momentum of the remnant. Some of the material are deformed after merger and eject to outside, some still remain in the system. After losing the angular momentum based on differential rotation, the remnant spin down and become more stable.

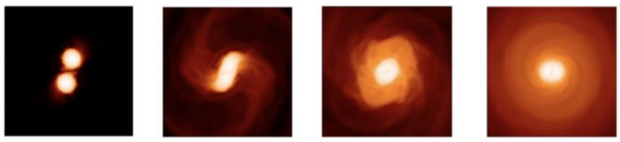

Fig. 1

For exploring the gravitational wave, I did a higher resolution simulation for BBH merger with the same parameters as GW150914, and reproduced the GW template in time-series for last inspire, merger and ringdown phase, which is showed in Fig. 2.

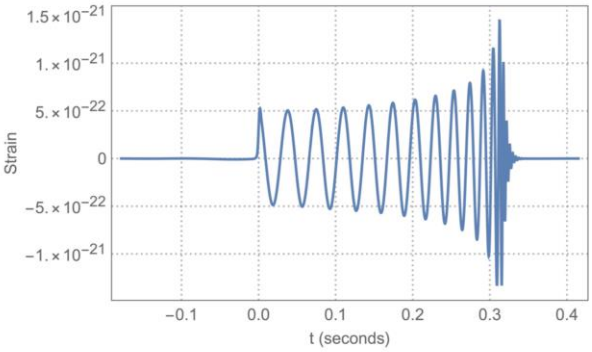

Fig. 2

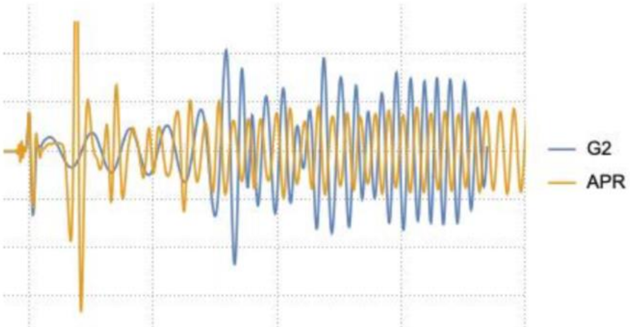

Fig. 3

Fig. 3 shows the time-domain GW output for power law EOS with adiabatic index Gamma =2 and APR EOS table. We could determine the merger time so that post-merger GW could be identified, but since the resolution is not high enough, such templates are not good enough to distinguish different EOS.

4． Schedule and prospect for the future

In the next fiscal year, I would try different grid setup method and mesh refinement configuration in simulation as well as the algorithm related to interpolating the tabulated EOS table, to improve the resolution and efficiency to simulate the BNS merger. As well, an updated code WhiskyTHC could successfully run in BMWPC now, it could handle the simulation based on finite-temperature EOS, and it include the neutrino transport effect. I plan to compare the finite-temperature EOSs and its piecewise polytropic approximation version first and analyze how the approximant affects the gravitational wave spectra, the temperature evolution, and the post-merger dynamic. Then I plan to use the first-order phase transition EOSs at different onset density to do simulations and look for the relations for onset density and peak frequency shift, as well as the influence from mass ratio. I also plan to use the recent developed hardon-quark cross-over EOS based on lattice QCD calculation in our group, to analyze what the difference in temperature evolution of neutron star core between cross-over model and phase-transition model, and further on, how it affects the collapse of the hypermassive neutron stars and the post-merger gravitational wave.

Fiscal Year 2019 List of Publications Resulting from the Use of the supercomputer

[Oral presentation]

Author: Yongjia Huang

Title: Introduction to simulate BNS mergers via Einsteintoolkit

Meeting: RIKEN - RESCEU Joint Seminar 2019

Date:20 March, 2019

Place: The University of Tokyo

Author: Yongjia Huang

Title: GW parameter estimation and BNS merger simulation

Meeting: Workshop to bring together experts on High Energy Astrophysics from Japan and Israel

Date: 23 July, 2019

Place: RIKEN, Kobe Campus