NewCompstar STSM report - COST-STSM-MP1304-35714

Neutrino transport approximations for supernovae and neutron star mergers

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Purpose of the STSM

The purpose of this STSM was twofold:

1. continue and nurture an existing, very successful collaboration on neutrino-driven winds in the aftermath of neutron star mergers and
2. establish a new, long-term collaboration on developing, implementing and comparing neutrino transport methods in the context of core-collapse supernovae and neutron star mergers.

DESCRIPTION OF THE WORK CARRIED OUT DURING THE STSM

During this visit several key points for these collaborations were deeply discussed and decided between researchers Rubén Cabezón, Albino Perego, Stephan Rosswog, and his group, keeping the focus on knowledge transfer. A significant fraction of the time was spent discussing and training a new PhD student (Davide Gizzi), who has just started his doctoral studies in Stockholm and who will be directly involved in the forthcoming projects.

NEUTRINO-DRIVEN WINDS IN THE AFTERMATH OF NEUTRON STAR MERGERS

A very important ingredient in simulating neutrino-driven winds from merger remnants is the equation of state (EOS). Its high-density part ($\rho > 10^{14}$ g/cm^3) determines the structure of neutron stars, hence the merger dynamics and the structure of the resulting remnant. This, in turn, characterizes the neutrino luminosity of the remnant and, therefore, its potential to drive winds. The ablated material itself is only a small and rapidly expanding fraction of the remnant. Much of the neutrino absorption and nucleosynthesis happens at densities that are substantially below nuclear matter densities. Thus, an EOS suitable for a neutrino-driven wind simulation needs to cover an enormous range in densities and temperatures.

During this NewCompStar-funded STSM we discussed intensively the requirements on physical equations of state to be used in wind simulations. We also reviewed the existing constraints on nuclear EOS and discussed which existing equations of state we should potentially use, while exploring how to eventually merge different EOS into a tool that is suitable for simulating neutrino-driven winds. Additionally, we also set out a strategy on how to systematically explore the parameter space for neutrino-driven winds.

IMPLEMENTING A NEUTRINO TREATMENT

For this collaboration, Albino Perego and Rubén Cabezón reviewed the details of the Advanced Spectral Leakage (ASL), which is a neutrino approximated scheme developed and used within our numerical simulations of core-collapse Supernova and neutrino-driven winds. The aim is to use ASL in the future neutron star merger simulations of Prof. Rosswog's group. Therefore, we also reviewed the implementation and coupling of ASL with a Smoothed Particle Hydrodynamics (SPH) code. In addition, we discussed the possibility to implement more sophisticated and more computationally demanding neutrino transport schemes, including IDSA and low-order moment schemes. A more detailed analysis and their subsequent implementations has been postponed after the successful implementation of the ASL scheme.

Based on the aforementioned discussions, we expect that Prof. Rosswog's group will benefit from our previous experience. To that extent, we established a series of milestones to fulfill a correct porting of ASL:

1. Design a portable and self-contained version of ASL that produces results based on a spherically symmetric static configuration. In particular, to implement a small test code that feeds ASL with radial profiles of the necessary fluid and radiation properties. Based on them, the code provides the corresponding rates and energy conservation values.

2. Perform a similar test using actual 3D data from a restart file of a SPH core collapse simulation.

3. Implement a driver that performs the conversion from the data structure of the hydrodynamic code to the one of ASL, populating the necessary arrays and gathering the output rates.

4. Repeat step 2 with the new driver and validate with its results.

5. Allow dynamic evolution of the restart data and compare its results with previous calculations.

The first milestone is already accomplished and available through a shared git repository. In this way, future users can get acquainted with the usage and output of ASL. The subsequent steps will be tackled during the next few weeks.

In order to circumvent possible issues related to the parallelization layer of the hydrodynamics code, the present version of ASL was implemented to work on particle-base, meaning that the ASL subroutine is called once for each SPH particle. Second milestone will allow to check this new implementation.

Future collaboration with the host institution and foreseen publications

These two projects will require a long-term collaboration with Prof. Rosswog's group. We will all benefit of the combined expertise to implement, validate and run the simulations relevant for the aforementioned projects. At the present stage, remote communication should suffice for keep advancing the projects. Nevertheless, future visits between the people involved might be necessary.

Regarding publications, we foresee several publications related to both objectives, as the outcome will be one of the first 3D simulations with spectral neutrino treatment of the aftermath of neutron star mergers. We expect that the outcome of these projects will have major implications in our understanding of the formation of a neutrino-driven wind and its consequences in the contribution of neutron star mergers to the r-process elements and the formation of Gamma-ray Bursts.