Scientific Report for the Short Visit Grant 3536

References

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Beneficiary of the grant:
Prof. Dr. Stephan Rosswog, Jacobs University Bremen, Germany

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Host of the visit:
Prof. Dr. Matthias Liebenörfer, University of Basel, CH

Report

This visit was part of a recently started, long-term collaboration project between the University of Basel (Prof. M. Liebenörfer, A. Perego) and the Jacobs University Bremen (Prof. S. Rosswog, E. Gafton). During the last years, both groups have developed sophisticated multi-physics codes to study the hydrodynamics of hot and dense matter objects (MAGMA code [Rosswog & Price, MNRAS, 379, 915 (2007)] and FISH code [Kaeppelli et al., arXiv 0910.2854K, 2009; submitted to the Journal of Computational Physics]), and the neutrino radiative transport in multidimensional simulations (a leakage scheme [see, for example, Rosswog & Liebendörfer, MNRAS 342, 673R, 2003] and the IDSA scheme [Liebendörfer et al., ApJ 698, 1174L, 2009]). The aim of this collaboration is to join forces and share competences to study the neutrino-driven winds that emerge from neutron star merger remnants.
A first milestone on neutrino-driven winds from neutron star merger remnants has recently been set by a collaboration between Princeton University (Prof. A. Burrows and collaborators) and Jacobs University (Prof. S. Rosswog). In this first approach we calculated the neutron star merger evolution with the 3D, Lagrangian Smoothed Particle Magnetohydrodynamics code MAGMA. The final time slices were subsequently mapped onto a two-dimensional grid and used as initial conditions for the 2D neutrino-hydrodynamics supernova code VULCAN 2D (Dessart et al., ApJ 690, 1681, 2009). This was the first quantitative study of this phenomenon ever and it showed that neutrino-driven winds have the potential to become a serious threat to the launch of the ultra-relativistic outflow that is needed to produce a gamma-ray burst.
The main aim of this collaborative project is to double-check and extend these recent calculations to three spatial dimensions and to explore whether, and if so, how the double neutron star merger scenario can survive as leading model for the central engine of short gamma-ray bursts.
A good fraction of this second visit was dedicated to extensive discussions about the possible astrophysical implications of our project. This resulted in a prioritized list of steps that need to be taken in the near future, where we considered both aspects of scientific relevance and feasibility. Obviously, this projects involves a serious amount of computation and therefore this aspect received serious attention during the visit. In particular, we are using two different hydrodynamics methodologies (Eulerian and Lagrangian), but we use very similar

microphysics physics components. While such an approach allows to exploit the strengths of each method, particular care has to be taken in the transition between the two. The question of how to obtain a both physically and numerically robust transition between the two approaches has therefore been at the forefront of our attention during this short-term visit. We addressed in particular:

1. The required length and time scales and the required spatial resolution to avoid numerical artifacts. Moreover, we have discussed strategies to treat boundary conditions and discussed the requirements in terms computing time and memory.

2. The necessity to treat coherently the symmetries of the problem (in particular, it will be important to extend the gravity and the free streaming regime of neutrinos from a 1D scheme, designed for core collapse supernovae, to a 2D scheme, more appropriate for the post coalescence phase of neutron star mergers);

3. The necessity to include further physical processes (like the neutrino antineutrino annihilation), which are essential in the post merger phase, and have not yet been included consistently in the neutrino treatment;

4. We discussed and implemented a scheme to map the particle data onto a suitably chosen, equidistant grid

5. These initial conditions have been used in a first set of simulations aimed at quantifying the required numerical resolution;

6. We have discussed and compared the treatments of the nuclear matter equation of state (Shen et al. 1998) that is used in both our approaches.

This short visit was the second step in our collaboration, mainly aimed at illuminating and addressing problems that are rather technical in nature, but essential for the further progress of the project. In the meantime, a student from the Bremen side (Emanuel Gafton) has joined and strengthened our team. The next meeting is projected for late summer/early autumn. Several paper topics have been identified, but first technical issues need to be solved before production simulations can be tackled.