Neutron Star Astrophysics at the Crossroads: Magnetars and the Multimessenger Revolution
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Toward an efficient modeling of neutrino-driven winds in binary neutron star mergers

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Abstract. We present a mesh-free, neutrino transport approximation called Advanced Spectral Leakage, designed as a powerful tool for simulations of neutrino-driven winds in binary neutron star mergers with the Smoothed-Particle Hydrodynamics. We post-process a number of snapshots and compare relevant neutrino quantities with respect to computationally more expensive transport approaches. We find that the scheme recovers neutrino luminosities and mean energies within 25% accuracy and is computationally more efficient.

Keywords. neutrinos, radiative transfer, hydrodynamics, stars: neutron

1. Introduction

Neutrino-driven winds is an ejection channel from binary neutron star mergers powered by the partial re-absorption of streaming neutrinos copiously produced in the hot environment of the merger remnant. Neutrino absorption impacts the neutron richness of the ejected material and consequently the synthesis of r-process nuclei and the properties of the macronova signal. Modeling neutrino-driven winds is therefore crucial for a complete understanding of future macronovae transients. However, realistic models of neutrino transport in mergers require the need of approximations with a trade-off between accuracy and computational expense.

In the following, we briefly describe the novelties of our Advanced Spectral Leakage (ASL), originally implemented for neutrino transport in spherically symmetric core-collapse supernovae (Perego *et al.* (2016)). The scheme is designed for hydrodynamic simulations of mergers with the Smoothed-Particle Hydrodynamics (SPH) approach implemented in the code `MAGMA2` (Rosswog (2020)). The model has been successfully tested over a number of snapshots of a neutron star merger remnant, and compared with results obtained with the two-moment (M1) scheme implemented in the hydrodynamics code `FLASH` (Fryxell *et al.* (2000)) and with the Monte Carlo code `Sedonu` (Richers *et al.* (2015)). For conciseness, we only show results for a snapshot at 38 ms after merger of an equal mass binary where each star has a baryonic mass of 1.4 $M_{\odot}$.

2. Model and results

The first novelty of our ASL is a parametric form of the neutrino absorption (hereafter called *heating*) responsible for driving the winds. Owed by the presence of an optically

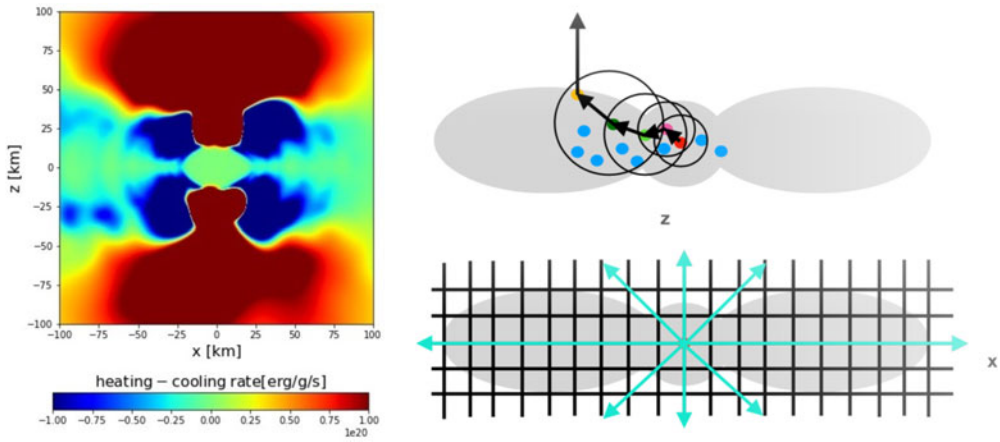

Figure 1. Left panel: Total (i.e., energy and species-integrated) net energy rate. The region of the heating is marked by warm colors. Our parametric form of the heating recovers the expected distribution, with the bulk of neutrino absorption located above the central remnant. **Right panel:** Sketch of two optical depth implementations. At the top is our new, particle-based approach. For each SPH particle, we find the direction that maximizes the local mean free path by searching among the neighbours the particle with the minimum density. Neighbours are located inside a spherical region defined by the smoothing length of each particle. At the bottom is a standard, grid-based approach widely used in the literature. Note that in this case the path is not informed by the matter distribution, but is assumed to be radial and chosen among a set of finite paths.

thick disk around the central object, we modulate the spherically symmetric form of the heating introduced in Perego *et al.* (2016) with an angular function containing a parameter to be gauged in order to maximize the heating above the poles of the remnant. In this way we limit computational costs while achieving the right heating distribution (left panel in figure 1). We refer the reader to Gizzi (2019) for more details.

The second novelty is a particle-based implementation of the optical depth, an integrated quantity describing matter opacity to neutrinos. By means of properties of SPH, we approximate the path neutrinos cross until they decouple from matter by locally picking the direction that maximizes the mean free path (top right panel in figure 1). We refer the reader to Gizzi (2021) for more details.

We find that our ASL is able to recover neutrino luminosities and mean energies within 25% accuracy. The new optical depth model is computationally faster than grid-based ones (bottom right panel in figure 1), and combined with the computationally inexpensive heating calculation, provides an efficient neutrino transport approximation.

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