Neutrino-driven winds from binary neutron star mergers*

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The merger of two neutron stars in a binary system is one of the most powerful events in the Universe. Within a few tens of milliseconds, an extremely hot, hypermassive neutron star (possibly, gravitationally unstable), surrounded by a thick accretion disc, has formed. Besides being a promising progenitor for short gamma-ray-bursts, the expected neutron-rich ejecta can produce a robust r-process. The synthesised neutron-rich nuclei can power an electromagnetic transients, known as kilonova (or macronova) and potentially observed in 2013 [1].

In the post-merger phase, a large fraction of the gravitational energy released during the coalescence process is radiated away by neutrinos, with peak luminosities in excess of $10^{53}\,\mathrm{erg/s}$. The energy deposition caused by the absorption of neutrinos inside the disc, mainly via the processes:

$$n + \nu_e \rightarrow p + e^- \qquad p + \bar{\nu}_e \rightarrow n + e^+,$$

drives a wind on a time scale:

$$t_{\rm wind} \sim \frac{e_{\rm grav}}{\dot{e}_{\nu,\rm heat}} \approx 0.07\,\mathrm{s}\,,$$

for typical remnant conditions.

We performed detailed, three-dimensional radiation hydrodynamical simulations of the neutrino-driven wind that emerges from the remnant of a neutron star binary merger [2]. We used the Newtonian, Eulerian code FISH [3], augmented by a detailed neutrino leakage scheme that accounts for the heating due to neutrino absorption in optically thin conditions. We evolve the remnant for $100\,\mathrm{ms}$ under the influence of neutrino cooling and heating. The initial conditions of our simulation are taken from high resolution SPH simulations of the merger of two neutron stars [4].

We find that a strong baryonic wind is blown out along the original binary rotation axis within a few tens of milliseconds after the merger. After 100 ms, the outer part of the disc has reached an almost stationary state, characterized by smooth gradients in all the relevant quantities. The physical properties of the wind vary significantly between different regions. Due to stronger neutrino irradiation, the polar regions show substantially larger electron fractions ($Y_e \sim$ 0.3 - 0.4) than those at lower latitudes ($Y_e \sim$ 0.2 - 0.3). Because of the radiation absorption, the entropy inside the wind first increases, then stays constant during the adiabatic expansion ($s \sim$ 15 - 20 $k_{\rm B}/\mathrm{baryon}$).

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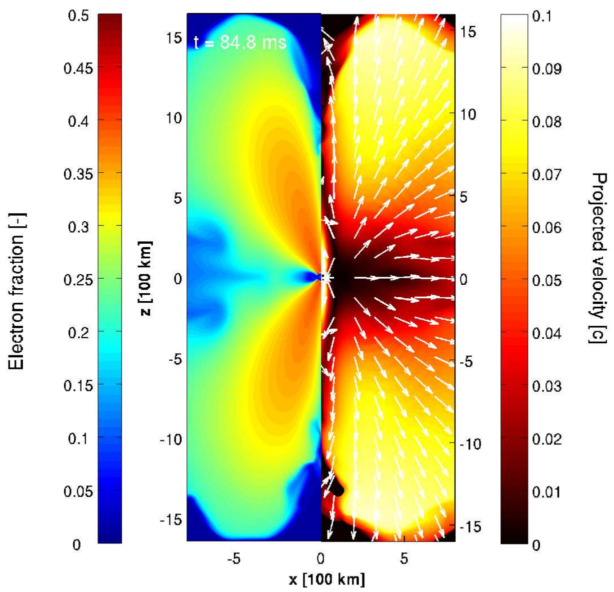

Figure 1: Vertical slices of the 3D domain (y = 0 plane) 85 ms after the beginning of the simulation. We represent the electron fraction (left) and the fluid velocity (right).

Around 100 ms after the merger, $2.1\times10^{-3}\mathrm{M}_\odot$ of matter in the wind is unbound. The polar ejecta produce interesting weak r-process contributions, from $\mathrm{A} \sim 80$ to about 130, while the more neutron-rich, lower-latitude parts produce in addition also elements up to the third r-process peak near $\mathrm{A} \sim 195$. We also calculated the properties of electromagnetic transients that are powered by the radioactivity in the wind. The polar regions produce a transients whose bolometric luminosity peaks around 0.3 days in the UV band. The lower-latitude regions are significantly less bright and peak after $\sim$ 2 days in UV/optical band, due to their much larger content in very heavy elements and the consequently larger matter opacities.

We conclude that the inclusion of the wind contributions in the merger nucleosynthesis and in the light curve prediction is crucial for detailed theoretical predictions, to be compared with present and future observations.

References

[1] N.-R. Tanvir et al., Nature, 2013, 500, p. 547
[2] A. Perego et al., MNRAS, 2014, 443, p. 3134
[3] R. Käppeli et al., ApJS, 2011, 195, p. 20
[4] D. J. Price, S. Rosswog, Science, 2006, 312, p. 719

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