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GRMHD simulations of the binary neutron star merger event GW170817

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Abstract. How can a binary neutron star merger launch a relativistic jet and thus produce a short gamma-ray burst? The jet launching mechanism and the very nature of the merger remnant acting as short gamma-ray burst central engine remain uncertain. We address this long-standing open question via magnetohydrodinamics simulations in general relativity, covering the full merger process and up to more than 200 ms of post-merger evolution.

1. Introduction

The first binary neutron star (BNS) merger detected in gravitational waves (GWs) by the LIGO and Virgo interferometers was also accompanied by the observation of a variety of electromagnetic signals across the entire spectrum, including a short gamma-ray burst (SGRB) and a radioactively-powered kilonova. This led to a number of key discoveries and marked the beginning of multimessenger astrophysics with GW sources. In our investigation, we focus specifically on the connection between SGRBs and BNS mergers, addressing the open question about the precise mechanism through which the merger remnant system would be able to launch a relativistic jet and thus act as a SGRB central engine.

In our previous project (INA17_C2A11), we performed a single state-of-the-art general relativistic magnetohydrodynamics (GRMHD) simulation of the merger of two neutron stars (of equal mass) in a binary system. This investigation was unique in two ways.

1. First, previous GRMHD simulations of BNS mergers focused on the case in which a black hole (BH) surrounded by an accretion disk is formed shortly after merger ($<$ 100 ms). This case corresponds to the well-studied SGRB scenario in which the accreting BH acts as the central engine powering the jet. There is however the al-

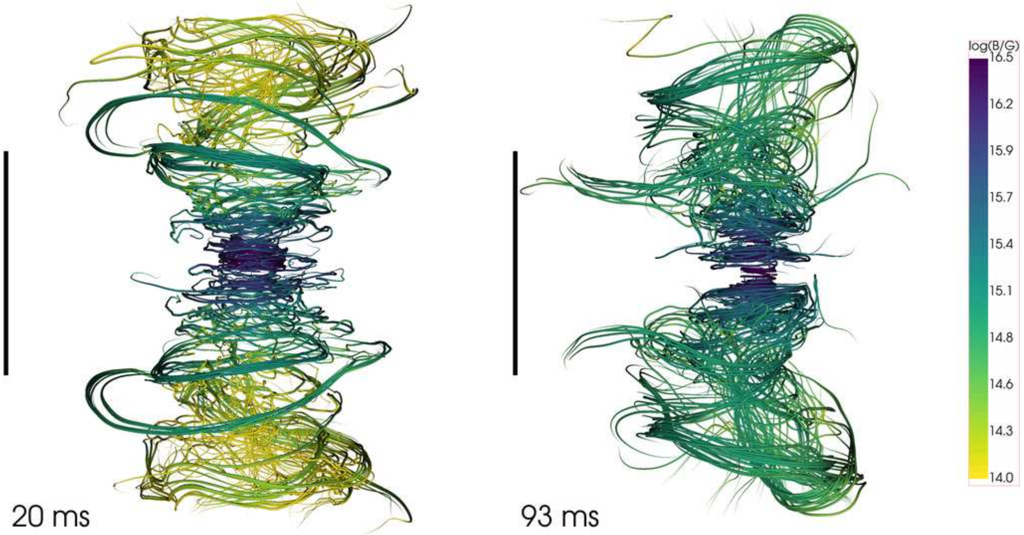

Fig. 1. Meridional (top) and equatorial (bottom) view of the rest-mass density evolution for our magnetized equal-mass BNS model from around merger time till the end of the simulation. Here $t = 0$ corresponds to the merger time.

ternative possibility that the merger results in a long-lived massive neutron star, able to survive for much longer timescales until the eventual collapse to a BH. In this scenario, a jet could be launched before BH formation, via a different mechanism not based on accretion. A systematic investigation of the latter case was initiated only recently in our previous work Ciolfi et al. (2017) and then continued with the project INA17_C2A11, which resulted in the recent publication Ciolfi et al. (2019). No other numerical relativity group has so far published similar results.

2. The second aspect making our investigation unprecedented is the fact that we explored a very long post-merger evolution ($\sim$ 100 ms), much longer than previous GRMHD simulations (typically limited to $20 - 40$ ms). This gave us the opportunity to obtain a much more complete picture on the system rearrangement and the characteristics that define its ability to produce a jet (see Fig. 1).

The project INA17_C3A23 continues along the same lines, but we now consider a set of simulations of an unequal-mass BNS system with the two progenitor neutron star masses differing by a factor 0.9, keeping fixed the neutron star equation of state (i.e. APR4) and the total mass of the system (consistent with the value estimated for GW170817) while changing the initial level of magnetization. The post-merger evolution, now completed, extends way above the 100 ms considered before for 4 different initial magnetic field strengths. We are currently analysing the data and preparing new publications expected in 2020 (Ciolfi 2020, Ciolfi and Kalinani 2020). Until then we cannot present any specific result.

Our two projects based on the MoU INAF-Cineca (INA17_C2A11 and INA17_C3A23) represent a significant step forward in the GRMHD investigation of BNS mergers leading to long-lived NS remnants. As such, they also pose a solid basis for a very competitive new proposal in a future PRACE and/or ISCRA call. In this respect, a project like INA17_C2A11 was extremely useful to maintain our leadership on a cutting-edge research line while providing convincing preliminary steps towards larger computational resource applications.

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