End-to-end modeling of kilonova signals from binary neutron star mergers

D. F. Hernandez Porras and N. G. Kelkar

Departamento de Física, Universidad de Los Andes,

Carrera 1 No. 18 A - 10, Bogotá 111711, Colombia

Abstract

Binary neutron star mergers (BNSMs) are the confirmed astrophysical site of rapid-neutron-capture (r-process) nucleosynthesis, making them a natural laboratory for connecting nuclear-physics inputs to electromagnetic observables. In contrast to existing literature that often models the three phases of BNSM in isolation, we present an ongoing effort to build a coupled, end-to-end pipeline that follows the merger through three consistently linked stages:

(i) the general-relativistic hydrodynamic evolution of the merger and its ejecta with the Einstein Toolkit [1, 2], including an approximate neutrino-transport treatment that sets the ejecta electron fraction Y_e;

(ii) the nucleosynthetic evolution along ejecta tracer trajectories with the WinNet reaction network [3], where the Y_e distribution and thermodynamic history govern the r-process path and the resulting lanthanide/actinide content; and

(iii) the kilonova light curve, computed with semi-analytical frameworks. The choice for stage (iii) is the xkn model [4], in which the abundance pattern fixes the ejecta opacity and therefore the luminosity, color, and timescale of the transient.

Application of the pipeline to a single representative merger will be presented. The results will be compared against the simpler analytical calculations performed within a modified version of the Li-Paczyński model [5]. This comparison will demonstrate how a comprehensive framework refines theoretical predictions compared to an isolated analytical model.

[1] F. Löffler, J. Faber, E. Bentivegna, T. Bode, P. Diener, R. Haas, I. Hinder, B. C. Mundim, C. D. Ott, E. Schnetter, G. Allen, M. Campanelli, and P. Laguna, The einstein toolkit: a community computational infrastructure for relativistic astrophysics, **29**, 115001.

[2] P. Mösta, B. C. Mundim, J. A. Faber, R. Haas, S. C. Noble, T. Bode, F. Löffler, C. D. Ott, C. Reisswig, and E. Schnetter, GRHydro: a new open-source general-relativistic magnetohydrodynamics code for the einstein toolkit, **31**, 015005.

[3] M. Reichert, C. Winteler, O. Korobkin, A. Arcones, J. Bliss, M. Eichler, U. Frischknecht, C. Fröhlich, R. Hirschi, M. Jacobi, J. Kuske, G. Martínez-Pinedo, D. Martin, D. Mocelj, T. Rauscher, and F.-K. Thielemann, The nuclear reaction network WinNet, **268**, 66.

[4] G. Ricigliano, A. Perego, S. Borhanian, E. Loffredo, K. Kawaguchi, S. Bernuzzi, and L. C. Lippold, xkn: a semi-analytic framework for the modelling of kilonovae, Monthly Notices of the Royal Astronomical Society **529**, 647 (2024), https://academic.oup.com/mnras/article-pdf/529/1/647/56831148/stae572.pdf.

[5] L.-X. Li and B. Paczyński, Transient events from neutron star mergers, **507**, L59.