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Numerical models of magnetorotational core-collapse supernovae: explosions dynamics, gravitational waves, neutrinos, and explosive nucleosynthesis

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The gravitational collapse of a massive star with a fast-rotating core sets the stage for the onset of magnetorotational core-collapse supernovae (CCSN). The accreting central compact object (either a black hole or a proto-magnetar) is believed to be the central engine that can power up outstanding stellar explosions such as hypernovae and long gamma-ray bursts (GRBs). Current magnetohydrodynamic models allow one to make quantitative predictions on the properties of the compact remnant, the multi-messenger signatures of the explosion, the launching conditions of the jet, and the nucleosynthesis of new heavy elements contributing to the chemical evolution of galaxies.

I will present the results obtained by recent 3D magneto-rotational supernova models that aim at characterizing the multi-faceted dynamics of the outstanding stellar explosion. I will show how different magnetic field configurations during the gravitational collapse affect not only the explosion dynamics and the compact remnant properties, but also the associated multi-messenger emission (both gravitational waves and neutrinos).

I will also present recent state-of-the-art explosive nucleosynthesis calculations based on the 3D CCSN models, demonstrating the profound impact of magnetic field topology in determining the efficiency of r-processes during the explosion, the production of heavy elements, and thus the chemical evolution of galaxies. In particular, only for aligned dipolar magnetic fields the supernova ejecta are sufficiently neutron-rich to produce elements beyond atomic number A$\sim$130. Moreover, the impact of the magnetic field's dynamics dominates over the uncertainties related to nuclear physics inputs used for the nucleosynthesis calculations, demonstrating the paramount importance of accurately modeling the dynamics of central engines.

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