Relativistic MHD modeling of magnetized neutron stars and their winds

L. Del Zanna$^{1,2,3}$, A. G. Pili$^{1,2,3}$, B. Olmi$^{1,2,3}$, N. Bucciantini$^{2,1,3}$, E. Amato$^{2,1}$

1 Dipartimento di Fisica e Astronomia, Università di Firenze, Firenze, Italy
2 INAF - Osservatorio Astrofisico di Arcetri, Firenze, Italy
3 INFN - Sezione di Firenze, Firenze, Italy

Neutron stars are among the most fascinating astrophysical sources, being characterized by strong gravity, densities about the nuclear one or even above, and huge magnetic fields. Their observational signatures can be extremely diverse across the electromagnetic spectrum, ranging from the periodic and low-frequency signals of radio pulsars, up to the abrupt high-energy gamma-ray flares of magnetars, where energies of $\sim 10^{46}\text{erg}$ are released in a few seconds. Fast-rotating and highly magnetized neutron stars are expected to launch powerful relativistic winds, whose interaction with the supernova remnants gives rise to the non-thermal emission of pulsar wind nebulae, which are known cosmic accelerators of electrons and positrons up to PeV energies. In the extreme cases of proto-magnetars (magnetic fields of $\sim 10^{15}\text{G}$ and millisecond periods), a similar mechanism is likely to provide a viable engine for the still mysterious gamma-ray bursts. The key ingredient in all these spectacular manifestations of neutron stars is the presence of strong magnetic fields in their constituent plasma. Here we will discuss a couple of state-of-the-art numerical studies by the Firenze group: a comprehensive investigation of the steady-state, axisymmetric structure of magnetized neutron stars in general relativity, and dynamical 3-D MHD simulations of relativistic pulsar winds and their associated nebulae.