Modeling Magnetised Neutron Stars in General Relativity

Student: Pili Antonio Graziano   Supervisor: Niccolò Bucciantini

Neutron Stars (NSs) offer challenging and stimulating puzzles to our knowledge of nature and its fundamental laws. Characterised by extreme physical conditions, such as high density exceeding nuclear density, fast rotation and super-magnetisation, NSs are "perfect" laboratories where theories, developed within different branches of the contemporary physics, can be tested in regimes that are not accessible on Earth. Observationally, NSs manifest themselves as different classes of astronomical sources [1]. Among this variety *Anomalous X-Ray Pulsars* (AXPs) and *Soft Gamma Repeaters* (SGRs) stand out for their persistent high luminosity X-ray emission and their high energy transient flaring activity. On the ground of these observational properties, there is general consensus that SGRs and AXPs are part of a same class of NSs referred as *magnetars*: the most magnetized objects of the Universe. A simple analysis of the energetic involved in their emission processes or of the spin-down evolution suggests that the magnetic field outside a magnetar is of the order of $10^{14\text{-}15}$ G, while in the interior can reach strength as high as 10^{16} G [2].

Nowadays we still do not know precisely either how such strong magnetic field originates or how it rearranges into a stable configuration during the formation of the NS. Nevertheless we certainly know that the morphology of the resulting magnetic field plays a key role in establishing the phenomenology associated with NSs. In particular, the geometry of the internal magnetic field is expected to shape the deformation of the star affecting, consequently, the possible gravitational wave emission. At the same time the topology of the exterior magnetic field reflects on observational features of the electromagnetic emission [3]. An accurate description of the magnetic field is therefore a necessary ingredient to develop realistic physical models able to shed light on the phenomenology of NSs. As a consequence, during the last years many efforts has been devoted to the modelization of equilibrium configurations of magnetized NSs. However, many of the previous studies focused on modelling few specific magnetic field morphologies without a deep investigation of the parameter space.

My PhD program focuses on the development of a comprehensive numerical study of magnetic configurations in NSs, derived in the full general relativistic regime, taking into account different magnetic field geometries as well as the effects of rapid rotation or realistic equations of state. This allow us to investigate how different current distributions affects the structure of the NSs or the morphology of the magnetic field itself both in the interior or in the exterior of the star, deriving trends and relations among different global quantities such as deformations, gravitational mass, stellar radii, magnetic dipole moment and so on [4, 5, 6].

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