Abstract
of the thesis entitled

Magnetic fields in isolated neutron stars:
from the interior to the exterior

in English

Neutron stars are natural laboratories that allow us to study many phenomena under extreme conditions. These compact objects are characterized by strong magnetic fields with non-trivial origins and evolution. It is important to understand the field properties when interpreting observational data. We are able to probe parameters of electro-dynamical processes at scales unavailable in terrestrial laboratories through observations of diverse types of neutron stars. A long-standing challenge is to understand the properties of neutron stars' internal magnetic fields which are poorly constrained by observations at present. Assaying the stability of a given magnetic field geometry is therefore an important step in determining whether the geometry will be stable over multiple Alfven timescales, thus constituting a viable description of neutron star interiors. The simple cases, such as the purely poloidal or purely toroidal fields, have so far been meticulously analyzed through perturbation theory and, most recently, by means of non-linear magnetohydrodynamic simulations. This thesis investigates the different configurations of magnetic fields using both magnetohydrodynamic and general relativistic magnetohydrodynamic simulations and studies the distribution of magnetic energy into poloidal and toroidal components. Our results show that the final configuration, known as the "twisted-torus," has a toroidal field that is 10-20 % of the total magnetic field energy, and is threaded by poloidal field-lines extending into the outer atmosphere. However, our simulations do not consider the effect of the crystalline solid crust that forms when the protoneutron star cools down. In such a scenario, the crust evolves to Hall equilibrium states while the core is composed of superconducting protons, and magnetic equilibria can be determined from solutions of the Grad-Shafranov equation involving two arbitrary functions of the poloidal flux. The equilibria found by using the simple, but physically sound, choices of these functions with adjustable parameters present only a small fraction of the magnetic energy stored in the toroidal component (5%). Identifying these barotropic equilibria points the way to understanding their stability and studying their properties. The evolution of the magnetic field plays a significant role in different emission processes such as flares from magnetars, radio jets, and gravitational waves. In light of the fact that we need extremely strong magnetic fields inside a neutron star to cause significant deformation and produce gravitational waves, we suggest that a newly born magnetar can form columns of matter at the magnetic poles from fallback accretion which may emit detectable gravitational waves. Additionally, the study provides us with information about the survival time ($\sim$ 50s) before the NS collapses to a black hole through the fallback accretion channel.