Equation of State for Neutron Star Matter

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1 Abstract

Neutron stars are among the most enigmatic objects in the Universe. They possess the mass of our sun but are several billion times smaller than our sun. The matter in the cores of neutron stars is therefore composed to densities that are several times higher than the density of atomic nuclei. Under such extreme physical conditions the conventional building blocks of matter as we know them (atoms, protons, electrons) give way to new and widely unexplored states of matter, such as superconducting quark matter and novel particle condensates searched for in the most powerful terrestrial collider experiments. In this paper we study the thermal evolution of neutron stars in order to explore the properties of ultradense matter and the inner workings of neutron stars. The calculations are performed in the framework of Einstein’s theory of general relativity, since neutron stars curve the geometry of space-time so strongly that classical Newtonian theory of gravity fails to describe their properties.

2 The Model

In this model the strong interaction is described by interacting baryons through the exchange of a medium range attracting meson and a short range repulsive meson.

2.1 The Field Equations

The field equations derived from the Lagrangian Density functions at the mean field level are given by

\[ m_B^2 \rho_B = - \sum_{\nu=0}^{3} \phi_0 \rho_0 \phi_0 \nu \phi_0 \nu \]  
\[ \rho_B = - \sum_{\nu=0}^{3} \phi_0 \rho_0 \phi_0 \nu \phi_0 \nu \]  
\[ m_B^2 \rho_B + \rho_0 \phi_0 \nu \phi_0 \nu \sum_{\nu=0}^{3} \phi_0 \rho_0 \phi_0 \nu \phi_0 \nu \]  

The function \( S(m_{\nu \nu}, k_{\nu}) \) is expressed with the use of the integral

\[ S(m_{\nu \nu}, k_{\nu}) = \frac{2 \rho_0 + 1}{\sqrt{k_{\nu} + m_{\nu \nu}}} \frac{1}{\sqrt{k_{\nu} + m_{\nu \nu}}} \]

where \( k_{\nu} \) is the spin projections of Baryon \( \nu \), \( k_{\nu} \) is the Fermi momentum of type \( \nu \), \( m_{\nu \nu} \) is the particle number density in units of \( m^{-1} \), \( m_{\nu \nu} \) is the effective baryon mass generated by the baryon and scalar field interaction and can be defined as

\[ m_B^2 = \sum_{\nu=0}^{3} \phi_0 \rho_0 \phi_0 \nu \phi_0 \nu \]

2.2 Neutron Star Matter

Since we are dealing with a two particle many body interaction it is convenient to introduce a term \( \delta \) that accounts for an asymmetry in the number density between protons and neutrons.

\[ \delta = \frac{\rho_B - \rho_0 \phi_0 \nu \phi_0 \nu}{\rho_B + \rho_0 \phi_0 \nu \phi_0 \nu} \]

where \( \rho_B \) and \( \rho_0 \phi_0 \nu \phi_0 \nu \) are the corresponding number densities for neutrons and protons.

3 Sequence of Stars

We use the previous equation of state as an input for a code which solves the General Relativistic hydrostatic equilibrium equations and obtain the star structure. Here we plot some of the families of stars obtained.

4 Thermal Evolution of Neutron Stars

The thermal evolution of a Neutron Star is strongly dependent on its composition, because of that understanding how a Neutron star cools down might help us to constrain further the equation of state. The General Relativistic Thermal Evolution equations of a Neutron Star are:

\[ \frac{dL}{dT} = \frac{Q_B}{\rho_0 \phi_0 \nu \phi_0 \nu} \frac{1}{\rho_0 \phi_0 \nu \phi_0 \nu} \]

We solved these equations for the equations of state studied in this work and obtained the thermal evolution of Neutron Star.

5 Conclusions

In this project we have studied several different equations of state. We have tried several parameters sets, always constrained by nuclear matter properties. As expected the neutron star properties strongly depend on the equation of state.

One of the objectives of this work was to perform a thorough investigation; we studied studying the neutron star matter and composition, moved to neutron star structure and ended by studying the thermal evolution of the star. All of these processes are extremely important in order to build a more precise theory of Neutron Stars. By comparing theoretical predictions with observed data we can constrain the equation of state for these objects, which will allow us to understand better the fundamental physics that govern our universe.

6 References