Structure Properties of Hadron Stars Under Strong Magnetic fields

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Introduction

The Astrophysical compact stars are providing us the opportunity to study the strongly interacting dense nuclear matter under the extreme condition in their interior, which has not yet reproduced in the laboratory environment. Theoretically, it is discussed that the composition of compact stars is ranging from the mixture of hadrons, leptons to various phases of superconducting quark matter under beta equilibrium. Many recent observations of gravitational maximum masses and extraction radius of the neutron stars and pulsars have imposed restriction on their composition, to as a plausible set of equations of state (EOS) must support the limits of observed maximum gravitational masses of compact stars. Other physical properties characterises a neutron star, their fast rotation (or spin) and their strong magnetic field.

In the present work, we study the effect of strong magentic fields on the structure properties of neutron star. We have constructed a set of equations of state with composition of neutron, proton, hyperons and lepton in beta equilibrium under the strong magnetic field varying upto eB = 1.2 × 10^{-2} GeV^2. To study the influence of magnetic field in the stellar interior, we consider altogether two decay modes of a density-dependent magnetic field, a fast decay(γ=3.00, β=0.02), a slow decay(γ=2.00, β=0.05).

Theoretical Framework

The total energy density and total pressure of dense nuclear matter in the framework of Field Theoretical Based Relativistic Mean Field (FTRMF) can be written as,

$$\mathcal{E}^H = \mathcal{E}_m + \mathcal{E}_l + \frac{[B(\rho/p_0)]^2}{2}, \quad (1)$$

$$P^H = P_m + P_l + \frac{[B(\rho/p_0)]^2}{2}, \quad (2)$$

where $\mathcal{E}_m$ and $\mathcal{E}_l$ corresponds to energy densities of baryons and leptons, respectively. The $P_m$ and $P_l$ corresponds to pressures of baryons and leptons, respectively. The $B(\rho/p_0)$ is representing density-dependent magnetic field [1]. The expression of $\mathcal{E}_m$ in FTRMF can be written as,

$$\mathcal{E}_m = (\mathcal{E}^e_m + \mathcal{E}^n_m) + \frac{1}{2} m^2_0 \sigma^2 - \frac{1}{2} m^2_0 \omega^2 - \frac{1}{2} m^2_0 \rho^2 + \frac{1}{2} E_b \sigma^2 + \frac{1}{2} B^2 \omega^2 + \frac{1}{2} B^2 \rho^2 + \frac{1}{2} \sum_B (g_{\omega B} \omega \rho_B + g_{\sigma B} \sigma \rho_B + g_{\omega \omega B} \omega_B \rho_B) + \sum_B \left( \frac{g_{\omega B} \omega \rho_B + g_{\sigma B} \sigma \rho_B + g_{\omega \omega B} \omega_B \rho_B}{B} \right)$$

Results and Discussions

In present theoretical calculation, we have employed BSR12 parametrisation [2] for computing the energy density and pressure of EOSs. The Interaction strength couplings of
hyperons with the meson fields and hyperons with strange meson field are employed as suggested in [2]. For charged particles, the effect of Landau quantization appears as $\sqrt{m^2 + 2\nu eB}$ in the energy spectra from field equation. Here, $\nu$, representing the Landau level, varying in integer as, $\nu = 0, 1, 2, \ldots, \ldots$.

In Fig.(1), we present the variation of energy density $\mathcal{E}^H$ and pressure $P^H$ in units of MeVfm$^{-3}$ with increasing magnetic fields from $eB = 0 - 1.2 \times 10^{-2} GeV^2$.

It is observed that EOS get stiffened as the magnetic fields increased and the EOS of dense matter become unstable beyond $eB = 1.2 \times 10^{-2} GeV^2$, in the present model calculation for both case of decays.

In Table (I and II), we present variation in gravitational radius $R$ in km, gravitational maximum mass in unit of solar $M_\odot$ and coresponding values of moment of inertia of neutron stars with increasing magnetic fields in fast decay.

TABLE I: The variation in gravitational radius $R$ in km, gravitational maximum mass in unit of solar $M_\odot$ and corresponding values of moment of inertia of neutron stars with increasing magnetic fields in fast decay.

<table>
<thead>
<tr>
<th>B</th>
<th>R(km)</th>
<th>$M_{\text{max}}$($M_\odot$)</th>
<th>$\text{MI}(10^{45}\text{gcm}^2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0G$</td>
<td>10.1576</td>
<td>1.4522</td>
<td>0.664</td>
</tr>
<tr>
<td>$10^{12}G$</td>
<td>12.7448</td>
<td>1.9262</td>
<td>1.522</td>
</tr>
<tr>
<td>$2 \times 10^{13}G$</td>
<td>12.6219</td>
<td>2.1109</td>
<td>1.660</td>
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</tbody>
</table>

TABLE II: Same as Table I but in slow decay.

<table>
<thead>
<tr>
<th>B</th>
<th>R(km)</th>
<th>$M_{\text{max}}$($M_\odot$)</th>
<th>$\text{MI}(10^{45}\text{gcm}^2)$</th>
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<tr>
<td>$10^{12}G$</td>
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<td>1.9262</td>
<td>1.525</td>
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<td>2.0539</td>
<td>1.610</td>
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</table>

In Fig.(2) we present the Mass-Radius relationship of neutron stars under the influence of strong magnetic field for BSR12 model parametrisation.

In Table (I and II), we present variation in gravitational radius $R$ in km, gravitational maximum mass in unit of solar $M_\odot$ and corresponding values of moment of inertia of neutron stars with increasing magnetic fields in fast decay.

ACKNOWLEDGMENTS

Suman Thakur thank Himachal Pradesh University for providing financial assistance Junior Research Fellowship.

REFERENCES


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