Properties of rotating protoneutron star within the extended field theoretical model

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I. INTRODUCTION

Following the gravitational collapse of a massive stellar core, a protoneutron star (PNS) is born. Initially, it has a large radius of about 100 km and a temperature of 50-100 MeV. Due to the violent nature of the gravitational collapse, the PNS pulsates heavily, emitting significant amounts of gravitational radiation. After a few hundred pulsational periods, bulk viscosity will damp the pulsations significantly. Rapid cooling due to deleptonization transforms the PNS, shortly after its formation, into a hot compact star of T $\sim$ 10 MeV. Since the details of the PNS evolution determine the properties of the resulting cold CSs, protoneutron stars need to be modeled realistically in order to understand the structure of cold compact stars. Compared to nonrotating stars, the effect of rotation is to increase the equatorial radius of the star and also to increase the mass that can be sustained at a given central energy density [1, 2]. The Lagrangian density for the extended relativistic mean field (ERMF) model can be written as $\mathcal{L} = \mathcal{L}_{\mathcal{BM}} + \mathcal{L}_\sigma + \mathcal{L}_\omega + \mathcal{L}_\rho + \mathcal{L}_{\sigma\omega\rho}$ [3]. The Lagrangian terms and the Euler-Lagrangian equations for ground state expectation values of the meson fields are same as in [3]. At finite temperatures the baryon vector density, scalar density and charge density are as defined in [1]. The keplerian configurations of rapidly rotating protoneutron stars have been computed in framework of general relativity by solving the Einstein field equations for stationary axisymmetric space time (e.g. see Ref.[2] and references therein). The numerical calculations have been performed by employing the Rotating Neutron Star (RNS) code [4].

II. RESULT AND DISCUSSIONS

In the present work we have employed BSR1, BSR3, BSR5, and BSR7 parameter set correspond to the value of ω-meson self-coupling ζ = 0.00, BSR8, BSR10, BSR12, and BSR14 parameter set correspond to the value of ω meson self-coupling $\zeta = 0.03$, and BSR15, BSR17, BSR19, BSR21 parameter set correspond to the value of ω meson self-coupling $\zeta = 0.06$, and for each parametrization set the value of neutron skin thickness of ^{208}Pb varies from 0.16 to 0.28 fm in intervals of 0.04 fm [3, 5]. In Fig.1 we present the values of the maximum gravitational mass (M) and corrosponding radius (R)of a rotating PNS rotating with keplerian frequency,as a function of the neutron skin thickness Δr in the ^{208}Pb nucleus. The circles, triangles, and squares represent results for the parametrizations having ζ = 0.00, 0.03, and 0.06 respectively. The black symbols represent the results at $T = 0$ MeV and green symbols represent the results at $T = 10$ MeV. The lower panels contains EOS with hyperons and upper panels represent EOS without hyperons. The maximum gravitational mass and corresponding radius of rotating star is almost same for the set of EOS having a constant ζ parameter. So indicating that on varying Δr there is no significant change in the maximum gravitational mass and radius of a rotating PNS rotating with keplerian frequency. On varying ζ parameter the mass shows a significant changes as compared to corresponding radius, which increases significantly only on increasing temperature. The recent mass measurement of PSR J1614-2230 is also displayed as the orange band [6].

In Fig.2 we present the keplerian angular fre-

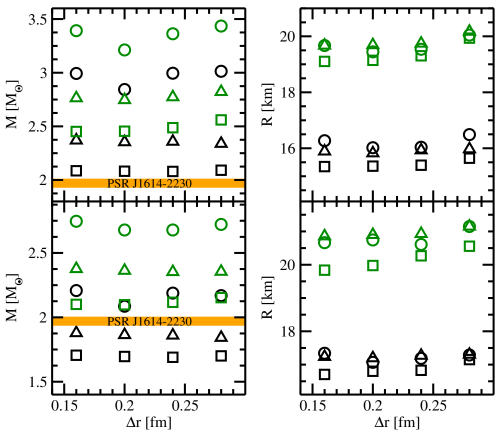

FIG. 1: (Color online)The maximum gravitational mass (M) and radius (R) corresponding to maximum mass of a rotating PNS rotating with keplerian frequency, is plotted as a function of the neutron skin thickness Δr in the [208]Pb nucleus. The lower panels contains EOS with hyperons and upper panels represent EOS without hyperons. The recent mass measurement of PSR J1614-2230 is also displayed as the orange band.

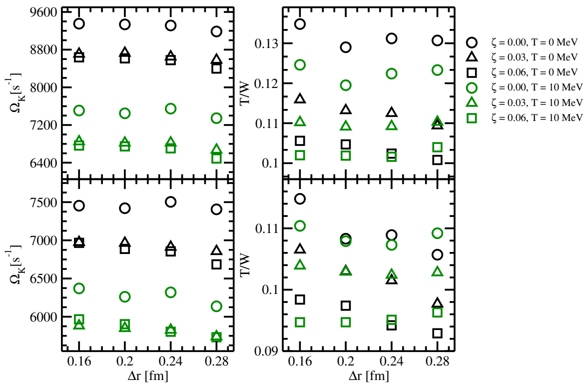

FIG. 2: Same as Fig.1 but for keplerian frequency Ω_K and ratio of rotational kinetic energy to gravitational kinetic energy (T/W).

quency and the ratio of rotational kinetic energy to gravitational kinetic energy ($T/|W|$) as a function of Δr. With increase in temperature and ζ parameter the keplerian angular frequency decreases, which further decreases on including hyperons in the composition of PNS. Although there is decrease in keplerian angular frequency with rise in Δr parameter but this rise is very small. Compared with the cold nuclear matter compact star, the keplerian angular velocity of the PNS decreases by $5-8\%$ incase of PNS without hyperons and, it is $14-20\%$ for the PNS with hyperons. Similarly it is observed that with increase in temperature and ζ parameter the rotational kinetic energy decreases more as compared to gravitational kinetic energy, which further decreases on including hyperons in the composition of PNS. The $T/|W|$ is maximum $= 0.1348$ for BSR1 parametrization (without hyperons) and minimum $= 0.0929$ for BSR21 parametrization (with inclusion of hyperons). We also studied the ratio of equitorial radius at pole to the equitorial radius at the equator r_{pole}/r_{eq}. The equitorial radius at pole increases as compared to equitorial radius at the equator on increasing temperature, ζ parameter and Δr. It also increases further on inclusion of hyperons in the calculations, although the ratio has very small variation ∼ 0.55-0.58.

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