Effect of temperature on Keplerian velocity of protoneutron star within 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. The PNS may be born with a large rotational kinetic energy and initially it will be differentially rotating. 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. In addition, viscosity or other mechanisms enforce uniform rotation and the compact star (CS) becomes quasi-stationary. 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. As a result, the gravitational mass of the maximum mass rotating model is roughly 15-20% times higher than the gravitational mass of the maximum mass nonrotating model, for typical realistic hadronic equation of states (EOSs). The corresponding increase in radius is 30-40%. The effect of rotation in increasing the mass and radius becomes more pronounced in the case of strange quark EOSs.

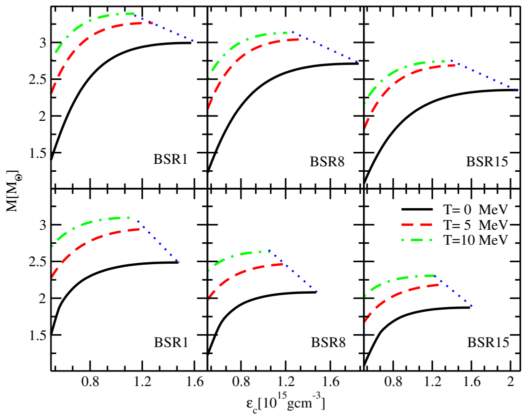

FIG. 1: (Color online)The mass shedding limit (Kepler) is plotted for EOSs obtained by using BSR1, BSR8, and BSR15 parametrizations at 0 MeV, 5 MeV, and 10 MeV temperature in terms of gravitational mass M as a function of central energy density ϵ_c. The upper panel contains EOSs without hyperons whereas lower panel contain EOSs with hyperons having hyperon meson coupling parameter $X_{\omega y} = 0.50$. Slanting dotted blue line corresponds to the axisymmetric instability limit.

The Keplerian configurations of rapidly rotating PNS have been computed in the framework of general relativity by solving the Einstein field equations for stationary axisymmetric space-time (e.g., see Ref. [1] and references therein). The numerical calculations have been performed by employing the rotating neutron star (RNS) code [2]. In Fig.1

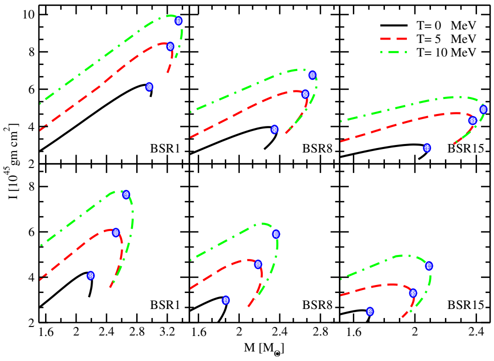

FIG. 2: Moment of inertia (I) plotted s a function of gravitational mass ($M_\odot$) of PNS at Kepler limit for various parametrizations. The upper panels contains I for EOSs without hyperons whereas lower panel contain I for EOSs with hyperons at $X_{\omega y}$=0.50.

the mass shedding limit (Kepler) is plotted for EOS obtained by using the BSR1, BSR8, and BSR15 parametrizations [3, 4] obtained by varying neutron skin thickness Δr for the ^{208}Pb nucleus and ω-meson self coupling parameter ζ at 0, 5, and 10 MeV temperature in terms of gravitational mass M as a function of central energy density ϵ_c. The upper panel contains EOS without hyperons, whereas the lower panel contain EOS with hyperons at $X_{\omega y}$ = 0.50. Keplerian configurations terminate at the central energy density where equilibrium solutions are stable with respect to the small axisymmetric perturbations; the slanting dotted (blue) line corresponds to the axisymmetric instability limit. In the Kepler limit sequences, the gravitational maximum mass of the PNS increase with increases in temperature by 20% − 23% and its corresponding equitorial radius increases by 25% − 46%, with respect to its non rotating gravitational maximum mass and radius, respectively. These observations are reasonably well within the predictions provided in Refs. [1, 5] and slightly higher in case of PNS with hyperons. Compared with the cold nuclear matter compact star, the Keplerian angular velocity of the PNS decreases by 5% − 8% in the case of the PNS without hyperons, and it is 14% − 20% for the PNS with hyperons. In Fig.2 the moment of inertia (I) is plotted as a function of gravitational mass ($M_\odot$) of PNS at Kepler's limits for various parametrizations. The upper panels contains I for EOSs without hyperons whereas lower panel contain I for EOSs with hyperons having hyperon meson coupling parameter $X_{\omega y}$=0.50. The moment of inertia increases on increasing temperature and decreases on increasing the ζ parameter, whereas for a given temperature and ζ parameter, there is no significant change in the value of moment of inertia on increasing Δr.

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