Dynamical Properties of Neutron Star

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Introduction

The notion of the neutron star remained as prediction from 1934 to 1967. In 1967, Bell and Hewish [1] discovered the neutron star in the form of radio-pulsar, a rapidly rotating neutron star. At the time of its birth, it is hot with temperature about fermi energy of the constituent particles. From the observational point of view these stars are treated as complex and inherently versatile object as its internal structure as well as evolution with time are the key factor for understanding of physics of matter at extreme conditions. Now a days, the observational data of neutron star become more valuable to impose constraints on the equation of state(EOS), the basic ingradient to study the structure of the star.

As neutron star is highly dense object, Einstein field equation is quite important where all forms of energy contribute to the gravity. Nuclear interaction also plays vital role for the construction of EOS of neutron star matter. When core of the massive star collapses to produce neutron star, conservation of angular momentum assures its enhanced rotation. Our aim is to study dynamical properties like moment of inertia and Kepler angular velocity of the star at temperature T=10 MeV.

Model

We have assumed that our system consists of protons, neutrons and electrons. Charge neutrality condition is imposed. Non relativistic microscopic calculations are made to construct EOS in frame work of Brueckner-Goldstone expansion using density dependent two body Sussex interaction. Zero temperature Brueckner theory is extended to finite temperature and we have calculated grand thermodynamic potential per unit volume which gives the required EOS. Tolmmann Oppenheimer Volkoff(TOV) equation is solved to determine mass and radius of the star. Coupled TOV equations are

$$4(\pi)r^2 dP(r) = -\frac{GM(r)dM(r)}{r^2} \times \left(1. + \frac{P(r)}{\epsilon(r)}\right) \times \left(1. + \frac{4\pi r^3 P(r)}{M(r)}\right) \times \left(1. - \frac{2GM(r)}{r}\right)^{-1}$$

$$dM(r) = 4\pi^2 \epsilon(r) r^2 dr$$

It is well known that the structure equation of slowly rotating neutron star is approximated to those of TOV equation for static and spherical symmetric neutron star. TOV equation was solved with the knowledge of our EOS P=P(E) with arbitary choice of central energy density E_C and initial condition M(0)=0.0 at r=0.0. Integration was performed to the point r=R where pressure becomes zero since zero pressure can not support any overlying matter against gravitational attraction. Then M(R) is the star's mass at r=R and R is the gravitational radius and Kepler frequency are calculated using standard formula.

Results

In Figure-1 moment of inertia is plotted at various values of stable mass at temperature T=10MeV. It is observed that for a given EOS, say proton/electron fraction $y_p =$ 0.1, the moment of inertia decreases with increase in stable mass. While increasing the

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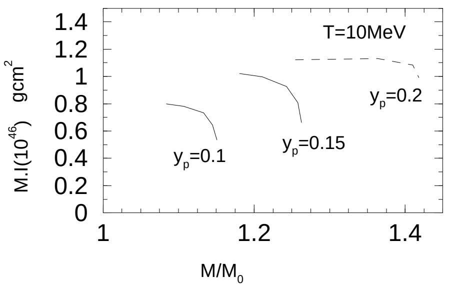

FIG. 1: Moment of inertia is plotted as a function of star mass at temperature 10MeV for proton/electron fraction $y_p = 0.1$, 0.15 and 0.2.

proton/electron fraction to $y_p = 0.15$, 0.2, moment of inertia of the star also increases keeping the same trend. It is also found that when mass attains its maximum value, the curve terminates. We find the moment of inertia as 5.353 x 10^{45} gcm^2 ,5.491 x 10^{45} gcm^2 and 8.545 x 10^{45} gcm^2 for maximum stable masses 1.151$M_\odot$, 1.265$M_\odot$ and 1.420$M_\odot$ for proton/electron fractions 0.1, 0.15, 0.2 respectively. This nature agrees with calculation made by ⊘vergard and ⊘stgaard [2] and Bombaci et al., [3]. ⊘vergard and ⊘stgaard [2] performed the calculation using different models like perturbative QCD model, asymptotic bag model and Fermi gas model. They obtain the moments of inertia 0.25 x 10^{45}gcm^2, 2.36 x 10^{45}gcm^2 and 1.7 x 10^{45}gcm^2 corresponding to their maximum stable mass 0.91$M_\odot$, 1.95$M_\odot$ and 1.3$M_\odot$, in their respective models. Whereas Bombaci et al.,[3] performed the calculation for moment of inertia for various values of baryonic mass. They observed moment of inertia increases with increase in baryonic mass. In Figure-2, we plot Kepler angular Velocity (Kepler frequency) versus stable neutron star mass at temperature 10MeV for various values of proton/electron fractions. It is observed that for a given proton/electron fraction say y_p =0.1, Kepler frequency increases with increase in stable mass. But beyond stable mass, the curve terminates. We also find that the Kepler frequency decreases on increasing proton/electron fraction to $y_p = 0.15$, 0.2, keeping similar trend. We

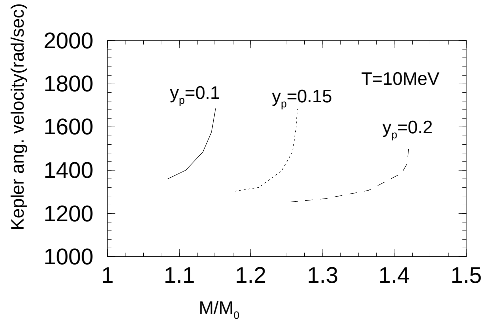

FIG. 2: Kepler frequency (Kepler angular velocity) is plotted as a function of the star at temperature 10MeV for proton/electron fraction $y_p = 0.1$, 0.15 and 0.2.

obtain the Kepler angular velocity 1686 rad/s, 1682 rad/s and 1505 rad/s corresponding to maximum stable masses 1.151$M_\odot$, 1.265$M_\odot$ and 1.420$M_\odot$, for proton/electron fraction 0.1, 0.15 and 0.2 respectively. Takatsuka plotted Kepler angular velocity versus baryonic mass for hot neutron stars at different values of compressibility. He obtained the Kepler angular velocity to be 3800rad/s and 4400rad/s at baryonic mass 1.56 x 10^{57} at compressibility k=250 and 300 MeV respectively. This angular velocity is also calculated by Das et al., [4] for pure neutron matter. They obtain the Kepler frequency is 8367rad/s corresponding to stable mass 0.9 $M_\odot$ at temperature T= 10 MeV.

It is concluded that like the limiting mass and radius of the star, momentum of inertia and Keplerian angular velocity are having their limiting values for a given EOS.

References

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