Extrapolation of nuclear EOS from mass-radius relationship

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Introduction

A number of attempts have been made on measuring the radii and masses of neutron stars (NS) to constrain the uncertainties in the high density behavior of the equations of state (EOS). The observations on double NS [1], glitches in radio pulsars [2], thermal emission [3] from accreting NS and from millisecond X-ray pulsars lead to constraints on mass-radius (M-R) relationship of NS. Recently the pressure of neutron star matter at supranuclear densities are measured by Ozel *et al.* [4] directly from observations favors smaller masses lying within 1.6-1.9 $M_\odot$ with radii 8-10 kilometers. Certain models for the hadronic equation of state [5] extrapolated to to high density low temperature regime can be ruled out if those fail to reproduce the recent M-R data.

In this work, a systematic study of the static as well as rotating NS is presented in view of the recent observations of the massive compact stars. We will see later in the text that the present EoS unlike other nucleonic EoS can successfully reproduce the recently observed M-R data.

Nuclear matter EoS

The nuclear matter EoS is calculated [6] using the isoscalar and the isovector components of M3Y interaction along with density dependence. The density dependence of the effective interaction, DDM3Y, is completely determined from nuclear matter calculations. The equilibrium density of the nuclear matter is determined by minimizing the energy per nucleon. In a Fermi gas model of interacting neutrons and protons, the E/A for isospin asymmetric nuclear matter is the sum of the kinetic part and nuclear potential part calculated using the volume integral of the isoscalar and isovector components of M3Y effective NN interaction. We numerically determine the EOS for the beta equilibrated charge neutral neutron star matter in which the beta equilibrated proton fraction are determined from the knowledge of the symmetry energy. Then this EOS is used to solve the Einstein's field equations by Green's function technique to explore the various properties of rotating and static NS. The details of the present methodology were described in a recent work by P. Roy Chowdhury *et al* [6].

Results and discussion

The mass-radius relationships for the sequence of rotating stars with angular frequencies 4190 Hz (red line) and 3140 Hz (green line) are shown in the Fig.1. We choose those frequencies here to ensure that the time periods (T= 2ms and 1.5ms) should not lower than the minima set by r-mode instability. Our EOS provide higher upper limit of mass for rotating NS $\sim$ 1.93-1.95 $M_\odot$ with radii around 10 kilometer compared to that for static NS ($\sim$ 1.9 $M_\odot$) with radius about 9.6 kilometer. Due to the rotational effect, the star rotating with frequency at keplerian limit are bigger in size along the equator than the static one of same mass. The r-modes (axial fluid oscillations governed by the Coriolis force) of rapidly rotating NSs are generically unstable to the emission of gravitational waves. The r-mode (Rossby wave) instability could slow down newly-born relativistic stars and limit their spin during accretion-induced spin-up, which would explain the absence of millisecond pulsars with rotational periods less than $\sim$ 1.5 ms. However, the fastest-

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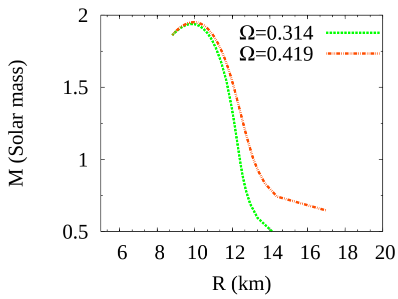

FIG. 1: Mass-Radius relationship for rotating stars. The red line is for angular frequecy 4190 Hz and green line is for 3140 Hz.

spinning neutron star PSR J17482446ad rotating with a frequency of 716 Hz (i.e. period ∼1.39 ms) exceeds this limit. It is also not clear whether the driving of these modes by gravitational waves can overcome viscous damping in the star. The possible importance of rapidly rotating NSs near the r-mode oscillation limit are as the gravitational wave sources for detectors like LIGO.

Summary

We have applied our nucleonic EOS with a thin crust to solve the Einstein's field equations to determine the mass-radius relationship of neutron stars. We ensure that rotating stars used in this work are not suffered by the r-mode instability. We have obtained the rotating star mass around 1.93-1.95 solar masses with radii around 10 kilometer. Therefore, unlike other nucleonic EOS we are able to reproduce the recently observed M-R data for static as well as rotating stars.

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