Deformation properties of rotating neutron stars

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Introduction

Pulsars are rotating neutron stars with period ranging from seconds to sub-milliseconds. Till date ~2500 pulsars are known. Pulsars are not perfect spheres. A small degree of asymmetry arises as a consequence of their rapid rotation. This asymmetry in the spherical mass distribution, in turn creates a distortion in the gravitational field outside the star [1]. The moment of inertia (I), rotational to gravitational energy ratio (T/|W|) and quadrupole moment tensor (φ) are some of the parameters that lead to explore the deformation properties of the neutron stars. Here, for all models we assume uniform rotations.

The exceptionally dense cores of neutron stars led scientists to believe that apart from neutrons, protons and electrons, these stars are also composed of other sub-atomic strange particles such as hyperons, pion and kaon condensates [2].

The Model Equation of state

We consider a phase transition from hadronic to anti-kaon condensed matter and study its effect on the bulk properties such as quadrupole moment, moment of inertia and the ratio of rotational energy to gravitational energy for the rotating neutron stars. The hadronic phase(np) is made of neutron, proton, and leptons. The anti-kaon condensed phase(npK) in addition consists of the anti-kaon isospin doublet $(K^-, \bar{K}^0)$[3]. We use the traditional meson exchange (σ, ω, ρ) model of interacting baryons, the high density behavior of the matter is taken care by the density -dependence of the meson-baryon couplings and is determined following the DD2 model of Typel et. al [4]. Usually, the strangeness degree of freedom softens the Equation of state (EoS), lowering the maximum mass of the compact stars. However, it was shown in Ref [3], that the DD2 models have scope to accommodate strange hyperons and anti-kaon condensates within the observational mass limit.

Results

The properties of neutron stars and strange stars are found out from the various models obtained from the equations of state with the help of the RNS code [5]. We present various plots of DD2 equation of state with hadronic matter (np) and antikaon condensed matter (npK). We consider a range of potential ($U_{\bar{K}}$= -60MeV to -140MeV) for the anti-kaons in nuclear matter.

Figure 1 shows moment of inertia (in 10^{45}g cm^2) of the stars against their respective radii (in km). Greater the radius, greater is the moment of inertia for a given EoS. For a fixed radius, the moment of inertia of the neutron star is greater than that of the strange star. Moreover, it is seen that the strange star with kaons of potential $U_{\bar{K}}$ = -140MeV have the least moment of inertia.

In Figure 2, quadrupole moment of the star is plotted against its central energy density, ϵ. The Quadrupole moment is minimum for the strange star with kaons of potential $U_{\bar{K}}$ =

-140MeV at a given energy density, ϵ. It increases as the value of $U_{\bar{K}}$ decreases.

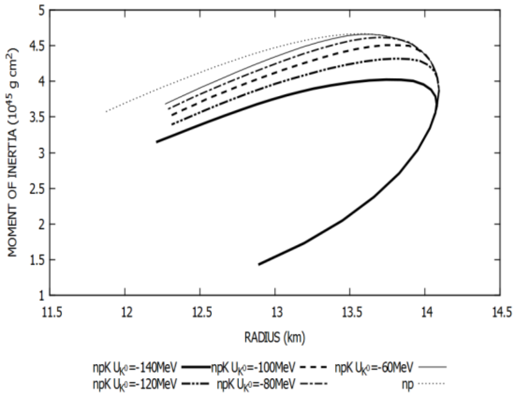

Fig.1 Variation of Moment of Inertia for neutron stars for np and npK matter for different radii.

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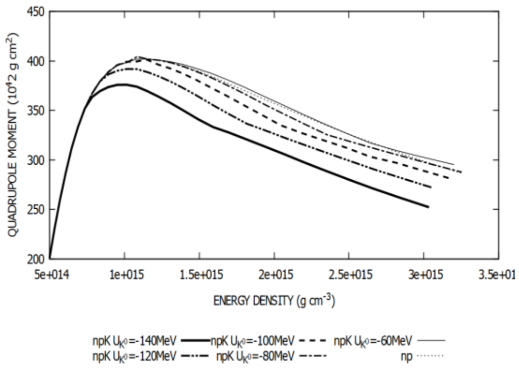

Fig.2 Variation of quadrupole moment with energy densities for neutron stars consisting of np and npK matter.

Figure 3 is the plot between the ratio of rotational to gravitational energy (T/W) and the gravitational mass of the star. The value of T/W increases with mass. It is maximum for a star with hadronic matter (np) and minimum for the star with antikaon condensed matter (npK, $U_{\bar{K}}$=-140MeV).

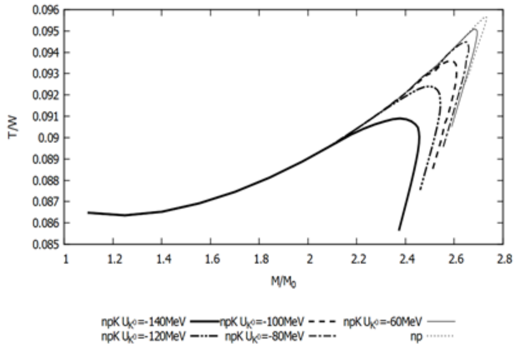

Fig.3 Variation of rotational to gravitational energy ratio of neutron stars for np and npK matter for different gravitational mass values.

Summary:
We have studied the deformation parameters of the rotating neutron stars. The deformed neutron stars are believed to be one of the promising sources of gravitational wave. With the rapid improvement in detector technologies, gravitational wave detection is not far off. It would help us probe the dense interiors of neutron stars.

References

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