The properties of massive compact stars using a geometrically deduced equation of state

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Introduction

To construct models of relativistic compact stars, it is vitally important to know exact composition and behaviour of particle interactions at exceptionally high density regime. Knowledge of the equation of state (EoS) of the matter composition of a relativistic matter confined under gravity is rather very crucial to study the physical properties of the star. The complications is that we still lack credible information about the physics of particle interactions at very high densities. While no dependable information is available about the composition and nature of particle interactions, it can be achieved by generating exact solution of Einstein's field equations narrating the interior of a static spherically symmetric relativistic compact star. After all, general relativity comes up with a mutual correlation between matter composition of a compact star and it's correlated spacetime, thus one way out is to adopt the this geometric approach to deal with [1] such a situations. So, in the Present work, we shall utilize the ansatz for metric potential g_{rr} to decide the unspecified metric potential g_{tt} describing the interior spacetime of static spherically symmetric stellar structure. We would like to point out here that anisotropic matter is a very exotic choice for relativistic compact objects like neutron stars, quark stars [2] etc.

When studying neutron stars, we are interested in the relation between the mass and the radius of the star. To find this relation, we need equation for the stellar structure specifically to the underlying equation of state. It has recently been pointed out that the stiffest detainment to the mass-radius relation of neutron stars, the largest mass, the largest radius, and the maximum surface gravity are provided by the observations for pulsars. Here we make an attempt to obtain the mass-radius relation using the geometrical EoS deduced from geometrically, adopted for the core-envelope model of compact objects[3]. An interesting feature of our model is that the solution admits a quadratic EoS. The core is of linear equation of state because it is of strange or exotic matter, therefore, govern by nuclear matter, the envelope is of the quadratic equation of state because of the presence of baryonic matter. Several core envelope models for compact stars in the general relativistic framework have been studied in the recent past years.[4, 5]

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Theoretical Methodology

In the traditional Tolman-Oppenheimer-Volkoff(TOV) treatment, the density and the pressure are apriory assumed to be continuous as well as the local anisotropy of the system. The interior of an anisotropic fluid sphere is described by the non-rotating spherical symmetric space-time metric given by [6]

$$ds^2 = e^{\nu(r)}dt^2 - e^{\lambda(r)}dr^2 - r^2 d\theta^2 - r^2 sin^2\theta d\phi^2 \tag{1}$$

where the $\nu(r)$ and $\lambda(r)$ are only function of the radial coordinate r. Let's numerically calculate the structure of neutron star as following equations for mass, density and pressure as function of radius.

$$\frac{dm(r)}{dr} = 4\pi r^2 \rho, \quad (2)$$

$$\frac{dp}{dr} = -\frac{[p(r)+\rho(r)][m(r)+4\pi r^3 p(r)]}{r[r-2m(r)]}. \quad (3)$$

Eq.(3) turn out to be the TOV equation. In the present study we have solve TOV for two distinct EoSs for core and envelope. We calculate the equation of the state for M-R relation from the EFE's, after solving EFE's we get the density , radial and tangential pressure. Using that we have developed quadratic equation according to pressure as function of density. Thus, we have computed EOS from the Einstein field equations is referred here as geometric EoS. The mathematical expression of the computed quadratic EoS is such that

$$p = \alpha\rho^2 - \beta \quad (4)$$

Where α and β are free parameters. These constants are selected in such a way that all the physical properties of the considered stellar objects are physically allowed. In this case we have taken as $\alpha = 100/km^2$ and $\beta = 0.0000109/km^2$.

Results and Discussion

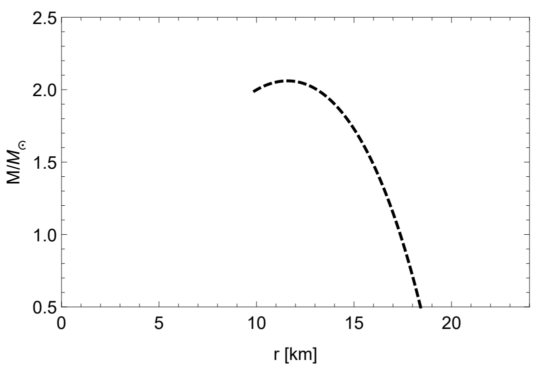

FIG. 1: The relation between the mass and radius of neutron star. The mass is scaled by solar masses $M_{\odot}$ and the radius in Km.

For our numerical computations, we used the expressions for the pressure and density of the geometric EOS to find an equation of state. Using this equation of state, we solved TOV equation and mass continuity equation numerically for a given central density. By iterating over a range of central densities, the relation between the mass and radius of neutron star was found. This curve has maximum mass of $M_{max} = 2.060\ M_{\odot}$, for a radius of $R_{max} = 11.585$ km. This maximum means that there is upper bound on the mass of a neutron star. The maximum mass for the neutron star neutron star happens when the central density is $\rho_0 = 1.064 \times 10^{15} gm/cm^3$ and central pressure is $p_0 = 6.848 \times 10^{34} dyne/cm^2$. The core of a neutron star with this mass is almost 10 times as dense as the nucleus of an atom. The present result is in better agreement with observations, where neutron stars with masses up to 2 $M_{\odot}$ have been found [7]. The present model can be extended in several directions to describe a neutron star or a highly compact star properties and starquakes and bursts.

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References

[1] S. Gedela, N. Pant, J. Upreti, R. P. Pant, *Eur. Phys. J.* C **79**, 556 (2019).

[2] L. Herrera, *Phys. Lett.* A **165**, 206 (1992).

[3] P. C. Vaidya and R. Tikekar, *J. Astrophys. Astron.* **3**, 325 (1982).

[4] R. Tikekar, V. O. Thomas, *Pramana J. Phys.* **64**, 5 (2005).

[5] V. O. Thomas, B. S. Ratanpal, P. C. Vinodkumar, *Int. J. Mod. Phys.* D**14**, 85 (2005).

[6] J. R. Oppenhiemr, G. M. Volkoff, *Physical Review,* D **55**, 374 (1939).

[7] J. T. Munoz-Darias and J. Casares and I. G. Martinez-Pais. *Astrophys. J* , 635:520 (2005).