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THE INFLUENCE OF RELATIVISTIC EFFECTS ON THE PARAMETERS OF NEUTRON STAR MODELS

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Abstract: The paper theoretically investigates the equilibrium structure of neutron stars consisting of degenerate relativistic neutron gas, based on the equation of radial mass distribution. The thermodynamic properties of a relativistic Fermi gas are studied, and a relationship between the compressibility coefficient and the particle concentration is established without taking nuclear forces into account. The mass distribution equation is numerically solved for the pulsar PSR J0740+6620, and its radius, as well as the radial distributions of density, pressure, and Fermi energy, are determined. A comparison of relativistic and non-relativistic models was carried out, showing that taking relativistic effects into account leads to a denser star with a smaller radius. Based on numerical calculations, the Oppenheimer–Volkoff limit was estimated.

Keywords: neutron star, degenerate relativistic neutron gas, radial distribution of the star's mass.

Neutron stars are giant cores consisting of degenerate neutron gas, primarily bound by gravitational forces. The density distribution of stellar matter is examined using the example of the pulsar PSR J0740+6620, whose mass is (2.08 ⊠ 0.07) times the mass of the Sun [1]. The radial mass distribution function m(r) of an adiabatic star in the absence of rotation obeys the equation [2]: m^{"}-\frac{2}{r}m^{\prime }+\frac{G}{4\pi }\kappa {\left(\frac{m^{\prime }}{r^{2}}\right)}^{2}m=0, (1) where κ is the compressibility of the substance, G is the gravitational constant. It satisfies the boundary conditions: m(0)=0 and m(R)=M , where M is the mass of the star, and R is its radius. The compressibility of a degenerate relativistic neutron gas is expressed as [3]: \kappa =\frac{9}{\pi }\cdot \frac{(ch)^{3}}{8E_{0}^{4}}\cdot \frac{(1+x^{2})^{1/2}}{x^{5}}, где x=\frac{hc}{2E_{0}}{\left(\frac{3n}{\pi }\right)}^{1/3}. (2) Here, n is the particle concentration; E0 is the rest energy of the neutron; h is Planck's constant; c is the speed of light. In the non-relativistic approximation x«1. The numerical solution of equation (1), taking into account (2), under the given boundary conditions, allows one to calculate the density distribution \rho (r)=\frac{m^{\prime }}{(4\pi r^{2})} and other parameters of the star. The figure 1 shows the density distribution curves for PSR J0740+6620 in the relativistic (red solid line) and non-relativistic (blue dashed line) models.

Fig 1. The dependence of density (kg/m³) on the radial variable (km).

In the non-relativistic model of PSR J0740+6620, the radius is 11.8 km, and in the relativistic model – 10.3 km, which is quite comparable to the gravitational radius of the star in \frac{2GM}{c^{2}}=6.14 km. This indicates that a star with a mass of 2.8 M⊙ is quite close to gravitational collapse.

Literature

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