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Macroscopic rotational constraints on the neutron-star radius

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The macroscopic model for neutron stars (NSs) as a cold perfect fluid in equilibrium within the Tolman-Oppenhiemer-Volkoff (TOV) theory is extended to a small rotational angular momentum I around the symmetry axis. The deformed NS surface was taken into account in the leptodermic approximation $a/R << 1$, where a is an inner crust thickness and R is the NS radius. Using the linear perturbation approach, $I/M^2 << 1$, where M is the NS mass (c=G=1), and the outer-inner Schwarzschild solutions in the zero-order approximation, one obtains analytically the first-order GRT results for the off-diagonal metric element $g_{t\varphi}$. Within Kerr approach using the spherical Boyer-Lindquist outer ($r > R$) and Hogan inner ($r < R$) coordinates, the GRT equation for $g_{t\varphi}$ has been solved in a separable outer-inner form. The surface density-gradient terms are taken into account through the macroscopic energy density $E(\rho)$ for the equation of state (EoS) within the Extended Thomas-Fermi (ETF) approach adopted to a strong gravitational field. Using a macroscopic rotational self-consistent approach we show that the relativistic moment of inertia (MI) Θ has a pole structure as function of the NS radius R, $\Theta_{av}/(1-\Theta_{t\varphi})$, through the statistically averaged Θ_{av} and time-angle gravity correlation $\Theta_{t\varphi}$ contributions. The latter appears because the off-diagonal gravitational element $g_{t\varphi}$ is self-consistently related to the NS angular momentum I. The MI contributions Θ_{av} and $\Theta_{t\varphi}$ are the sums of the volume and surface components derived through the ETF energy density $E(\rho)$. As the MI is asymptotically divergent at a certain NS radius R_{rot}, one obtains the constraint, $R < R_{rot}$, which is additional to the well-known radius restrictions coming from the Schwarzschild gravity metric and TOV approach. We obtained R_{rot} as function of the radius R in terms of the Schwarzschild parameters. For several well-known NSs with the observed mass M and radius R for enough large rotation periods, larger or of the order of 5 ms, one finds a good condition $I/M^2 << 1$ for applicability of the linear perturbation approach. We found also the essential dependence of the MI Θ and radius constraint R_{rot} on the surface tension coefficient σ, leptodermic parameter a/R, gravitational-nuclear incompressibility K, and deformation parameters. As perspectives, we are planning to find the rotation corrections to the TOV equations over the angular momentum parameter I/M^2 up to second order.

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