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Equation of State of Dense Matter in Neutron Star Cores

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Given an Equation of State (EOS) for neutron star (NS) matter, there is a unique mass–radius sequence characterized by a maximum mass Mmax at radius Rmax. We first show analytically that the Mmax and Rmax scale linearly with two different combinations of the NS central pressure and energy density, by dissecting perturbatively the dimensionless Tolman–Oppenheimer–Volkoff (TOV) equations governing NS internal variables. The scaling relations are then verified via 104 widely used and rather diverse phenomenological as well as microscopic NS EOSs with/without considering hadron–quark phase transitions and hyperons, by solving numerically the original TOV equations. The EOS of the densest NS matter allowed before it collapses into a black hole is then obtained. Using the universal Mmax and Rmax scalings and Neutron Star Interior Composition Explorer and XMM-Newton mass–radius observational data for PSR J0740+6620, a very narrow constraining band on the NS central EOS is extracted directly from the data for the first time, without using any specific input EOS model. By similar analysis, we demonstrate that the ratio of pressure to energy density in NSs is generally upper bounded as P/e≤0.374, generalizing the apparent requirement (P/e≤1) set by the principle of special relativity (causality). Finally, the strong gravity in general relativity (GR) is found to play a twofold role in the peaked structure in the speed of sound squared: it compresses NS matter and modifies the pressure/energy density ratio from small values in Newtonian stars showing no s^2 peak to large ones for massive NSs possessing a peak in their s^2 profiles, and eventually takes away the peak in extremely compact/massive NSs approaching the causality limit.

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