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Self-similarities of Equations of State and Mass–Radius Curves of Neutron Stars

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Determining the equation of state (EoS) of superdense matter from neutron star (NS) observations is an important problem of modern physics. In the literature one can find several hundreds of EoS models (nucleonic, hyperonic, hybrid), based on different approaches to the NS microphysics. In spite of the differences, for a wide set of such models, the relation between pressure P and density ρ of the NS core matter can be accurately described by a single family of curves defined by few parameters (Lindblom, 2010, PRD, 82, 103011). There is a bijection between $P-\rho$ and mass M − radius R relations called the Oppenheimer-Volkoff mapping (Lindblom 1992, ApJ, 398, 569). Thus, the families of $M-R$ and $P-\rho$ curves have the same number of parameters.

In this work, using a sample of 160 EoS models, we show that it is instructive to choose two of these parameters as properties of maximum-mass NS (specific to a given EoS), namely either its mass $M_{\rm max}$ and radius $R_{\rm Mmax}$, or pressure $P_{\rm max}$ and density $\rho_{\rm max}$ at its center. For different EoSs, the dimensionless relations $M/M_{\rm max} - R/R_{\rm Mmax}$ and $P/P_{\rm max} - \rho/\rho_{\rm max}$ show self-similar behavior. This allows us to build the analytical fits for the $M-R$ and $P-\rho$ curves, which are universal with respect to EoS model.

In addition, there is an approximate one-to-one mapping between the pairs of values $M_{\rm max}$, $R_{\rm Mmax}$ and $P_{\rm max}$, $\rho_{\rm max}$ (Ofengeim 2020, PRD, 101, 103029), also described by universal analytical fits. We use these fits together with those of $M-R$ and $P-\rho$ to propose a semi-analytical inverse Oppenheimer-Volkoff mapping from mass-radius relation to the pressure-density dependence. It appears to be a handful tool to constrain the high-density EoS from modern observational data on masses and radii of NSs.

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