Speed of sound bounds in dense matter and its effects on the bulk properties of rapidly rotating neutron stars

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Outline

Motivation

- Determination of maximum neutron star mass (MNSM) and identification of black holes
- Production of neutron stars from supernovae explosions
- Effects of rapid rotation and speed of sound bounds on the bulk properties of NSs
- Equation of state (EoS) of dense matter

Neutron star EoS

- We use the MDI model where the energy per baryon, at $T = 0$, is given by

$$
\begin{aligned}
E(n, I) &= \frac{3}{10} E_F^0 u^{2/3} \left[(1+I)^{5/3} + (1-I)^{5/3} \right] + \frac{1}{3} A \left[\frac{3}{2} - (\frac{1}{2} + x_0) I^2 \right] u \\
&+ \frac{\frac{2}{3} B \left[\frac{3}{2} - (\frac{1}{2} + x_3) I^2 \right] u^\sigma}{1 + \frac{2}{3} B' \left[\frac{3}{2} - (\frac{1}{2} + x_3) I^2 \right] u^{\sigma - 1}} \\
&+ \frac{3}{2} \sum_{i=1,2} \left[C_i + \frac{C_i - 8 Z_i}{5} I \right] \left(\frac{\Lambda_i}{k_F^0} \right)^3 \left(\frac{((1+I)u)^{1/3}}{\frac{\Lambda_i}{k_F^0}} - \tan^{-1} \frac{((1+I)u)^{1/3}}{\frac{\Lambda_i}{k_F^0}} \right) \\
&+ \frac{3}{2} \sum_{i=1,2} \left[C_i - \frac{C_i - 8 Z_i}{5} I \right] \left(\frac{\Lambda_i}{k_F^0} \right)^3 \left(\frac{((1-I)u)^{1/3}}{\frac{\Lambda_i}{k_F^0}} - \tan^{-1} \frac{((1-I)u)^{1/3}}{\frac{\Lambda_i}{k_F^0}} \right)
\end{aligned}
$$

- Data from APR

We introduce two regions in order to specify more precisely the EoS:

1. The core, where $r \leq R_{cr}$ and $n \geq n_{cr}$
2. The envelope, where $r \geq R_{cr}$ and $n \leq n_{cr}$

The speed of sound and its upper bounds

The adiabatic speed of sound is defined as:

$$\frac{v_s}{c} = \sqrt{\left(\frac{\partial P}{\partial \mathcal{E}}\right)_S}$$

We consider the following 3 upper bounds:

1. $\frac{v_s}{c} \leq 1$ (causality limit from special relativity)
2. $\frac{v_s}{c} \leq \frac{1}{\sqrt{3}}$ (QCD and other theories)
3. $\frac{v_s}{c} \leq \left(\frac{\mathcal{E} - P/3}{P + \mathcal{E}}\right)^{1/2}$ (relativistic kinetic theory)

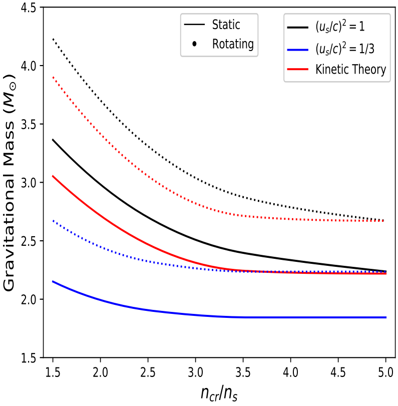
Maximum Mass Configuration

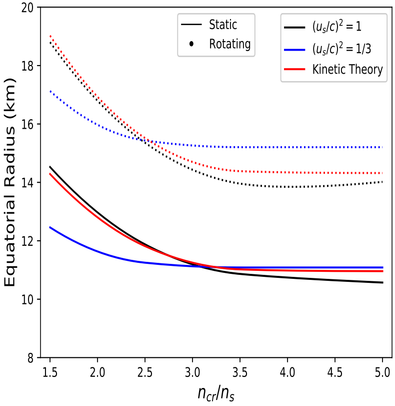
- We consider the following structure for the neutron star EoS:

$$P(\mathcal{E}) \quad = \quad \begin{cases} P_{crust}(\mathcal{E}), & \mathcal{E} \leq \mathcal{E}_{c-edge} \\ P_{NM}(\mathcal{E}), & \mathcal{E}_{c-edge} \leq \mathcal{E} \leq \mathcal{E}_{cr} \\ \left(\frac{v_S}{c}\right)^2 (\mathcal{E} - \mathcal{E}_{cr}) + P_{NM}(\mathcal{E}_{cr}), & \mathcal{E}_{cr} \leq \mathcal{E}. \end{cases}$$

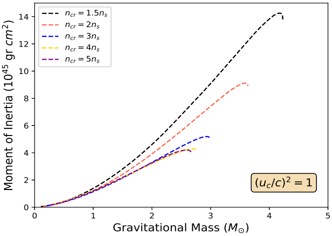
- Calculations with RNS code by Stergioulas and Friedman

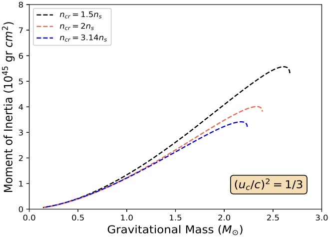
Mass, Radius and Density

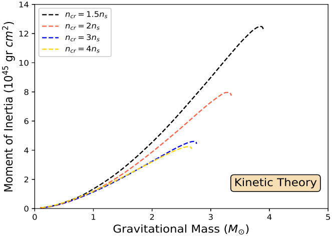




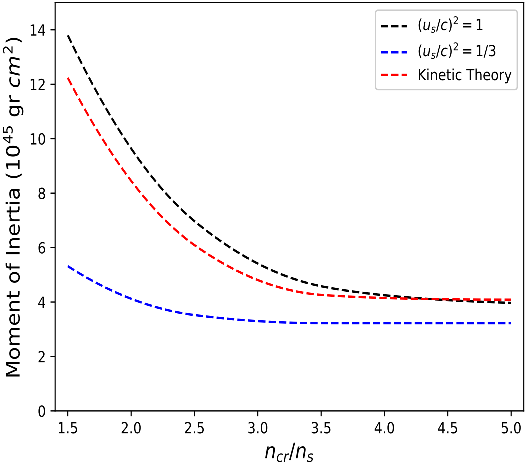
Moment of Inertia and Mass



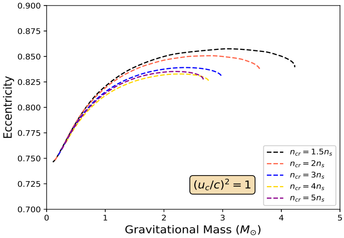


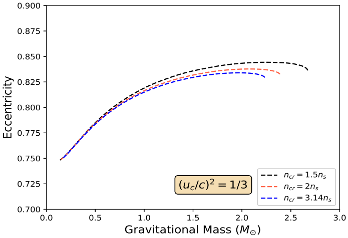


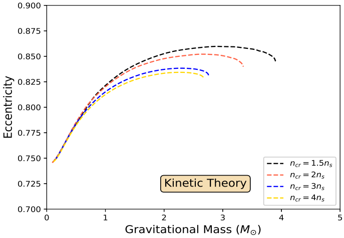
Moment of Inertia and Density



Eccentricity and Mass







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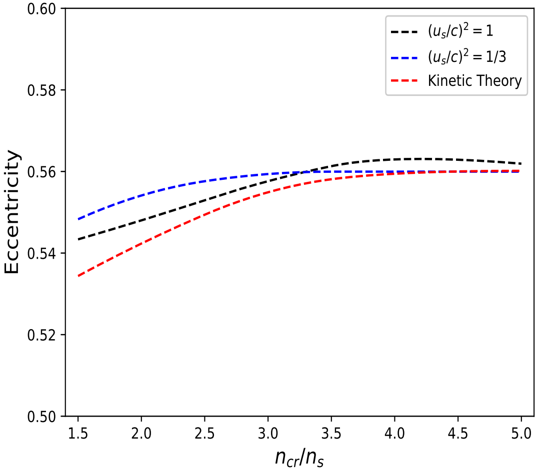
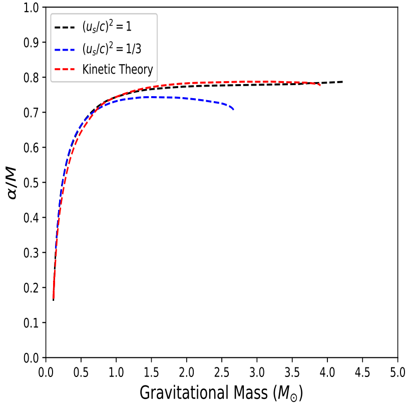
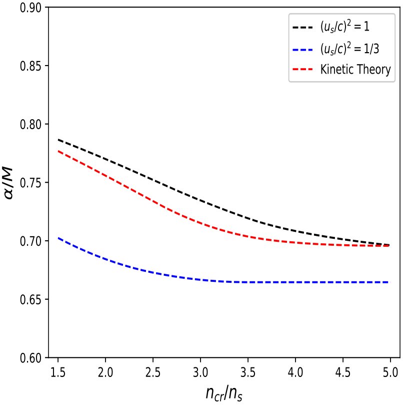
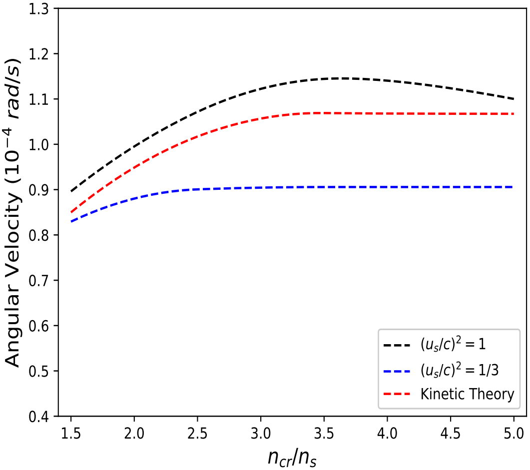


Kerr parameter





Angular velocity



Conclusions

- Accurate estimate of the upper bound of the speed of sound in hadronic matter for consistent prediction of MNSM

- Constraints in the form of absolute upper limits for all above-mentioned properties

- More quantities (some of them observable) to study in rotating NSs in comparison to the static ones, i.e. moment of inertia, angular velocity, eccentricity, quadrupole moment, etc.

THANK YOU!!