DAE-SNP-2022, Cotton University, Assam, India, 1-5 December, 2022

Radial oscillations of the dark matter admixed neutron star

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Within the relativistic mean-field model, we investigate the properties of dark matter (DM) admixed neutron stars, considering non-rotating objects made of isotropic matter. We adopt the IOPB-I hadronic equation of state (EOS) by assuming that the fermionic DM within super-symmetric models has already been accreted inside the neutron star (NS). The impact of DM on the mass-radius relationships and the radial oscillations of pulsating DM admixed neutron stars (with and without the crust) are explored. It is observed that the presence of DM softens the EOS, which in turn lowers the maximum mass and its corresponding radius. Moreover, adding DM results in higher frequencies of pulsating objects.

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Introduction

- Oscillating stars emitted different modes frequencies such as f , p, g, etc., mainly in the supernovae. Also, there are various processes, such as dynamical instability, mass accretion, magnetic configuration, fractures in the crust, etc., which are different sources of oscillations [1].
- The oscillations are mainly categorized into two types such as non-radial and radial. In this study, we want to explore various properties of the radial oscillations of the NS, considering the dark matter inside it.
- In our model, we choose non-annihilating WIMPs (Neutralino) as the DM candidate, which is already accreted inside the NS and interacts with baryons via the exchange of standard model-like Higgs boson [2].
- Here, we take the Extended Relativistic Mean Field (E-RMF) model and consider the IOPB-I equation-of-state to calculate various properties of NSs [3]. The final EOS is the addition of nucleons and DM. With that EOS, we investigate the effects of DM on f and p-modes frequencies.

Methodology

1. The governing equation for the radial oscillations is obtained by changing both fluid and space-time parameters while preserving the spherical symmetry of the background body. If we assume a harmonic time dependency and define $\delta r(r,t) = X(r)e^{iwt}$, as the time-dependent radial displacement of a fluid element at position (r) in the unperturbed model, we can obtain the following perturbed equation describing the radial oscillations [4],

$$\begin{aligned} & c_s^2 X'' + \left[(c_s^2)' - Z + \frac{4\pi G}{c^4} r\gamma P e^{2\lambda} - \nu'\right] X' \\ & + \left[2(\nu')^2 + \frac{2Gm}{c^2 r^3} e^{2\lambda} - Z' - \frac{4\pi G}{c^4}(P+\mathcal{E}) Z r e^{2\lambda}\right] X \\ & + \frac{\omega^2}{c^2} e^{2\lambda - 2\nu} X = 0, \end{aligned} \tag{1}$$

2. We construct the DM model Lagrangian by assuming that the DM particles interact with nucleons by exchanging standard model Higgs. The Lagrangian density for the DMANS is in the following [2,5],

$$\begin{aligned} \mathcal{L}_{\rm NS} = & \ \mathcal{L}_{\rm NM} + \bar{\chi}\left[i\gamma^\mu \partial_\mu - M_\chi + yh\right]\chi \\ & + \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{1}{2} M_h^2 h^2 + f\frac{M_{\rm nucl.}}{v}\bar{\varphi} h \varphi \\ & + \sum_{l=e^-,\mu} \bar{\psi}_l \Big(i\gamma^\mu \partial_\mu - m_l\Big)\psi_l, \end{aligned} \tag{2}$$

3. For DMANS EoS, one has to solve the Eq. 2 within mean-field approximations. Here, we use the unified IOPB-I EOS with three different fractions to calculate the properties of the radial oscillations.

Results

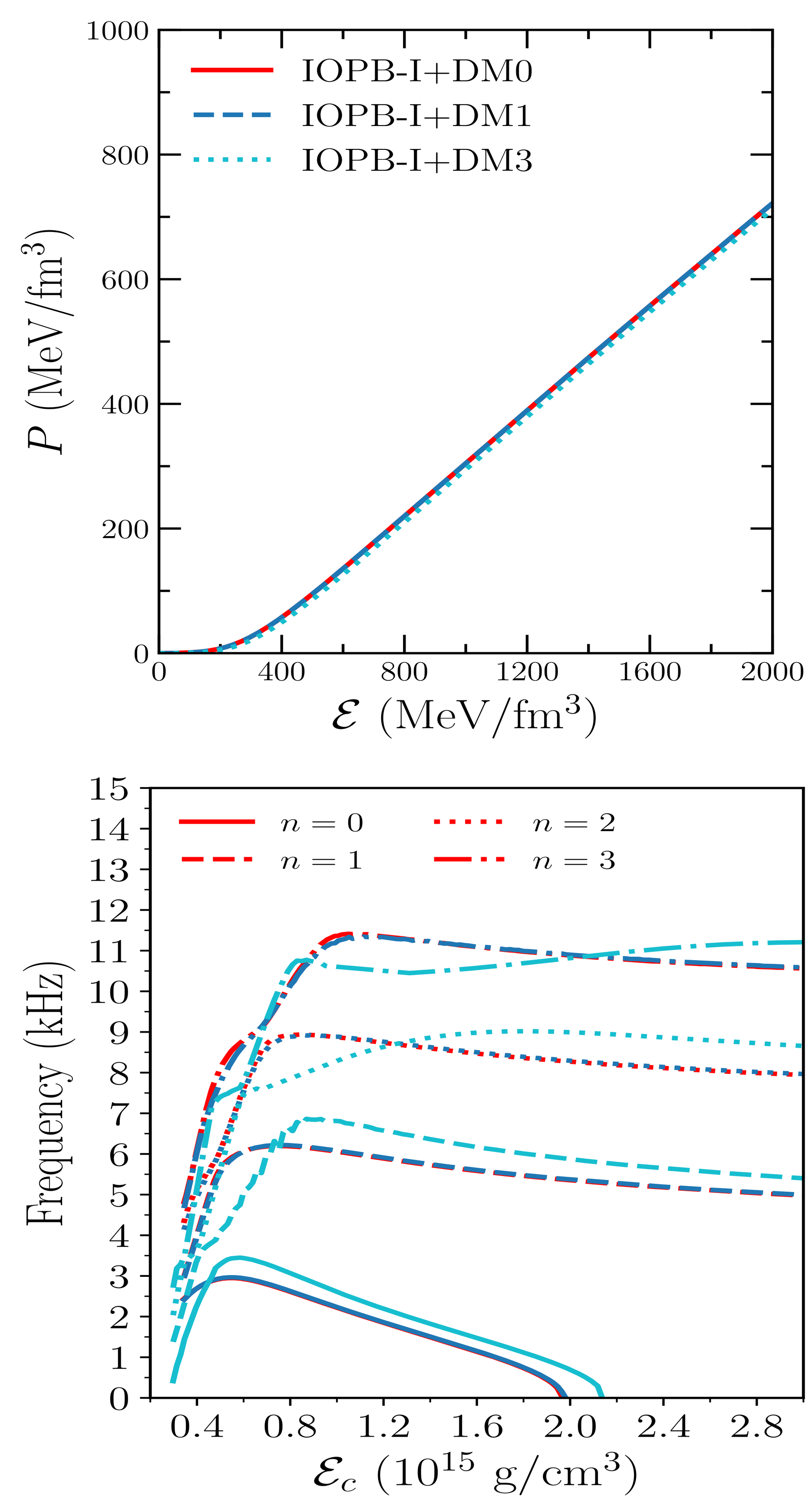

Figure: The unified IOPB-I EOSs are shown for the DM admixed star in the upper panel. The frequency of the DM admixed NS is shown for four nodes in the lower panel.

Conclusions

- In lower panel figure, we can observe that the drop at lower densities can be attributed to the star's homogeneous and non-relativistic behavior, where ω is connected to the adiabatic index as $\omega^2 \propto \rho(4-3\gamma)$ and γ does not vary considerably at lower central densities.
- The evidence of avoided crossings between modes, where the frequencies of two nodes 'repel' each other before getting too close observed. At critical densities, the f-mode falls down and becomes unstable because ω_0^2 becomes negative [4].
- It is observed that the stability point increases with DM percentage since, with the addition of DM, the EOSs become softer, reducing the star's mass and radius. Therefore, less massive NS with higher DM content will remain stable for a bigger range of densities as compared to the same NS without DM.

References

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