Properties of a neutron star in the presence of dark matter

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Introduction

It is well-established fact that the visible universe contains only $\sim 4-5\%$ part of the whole universe. Zwicky introduced the name to the dominant non-relativistic matter component of the universe as "missing mass" or dark matter (DM) [1]. Till date, there are many DM candidates having different properties and based on various models (for details, see the references cited therein Ref. [2]). One of the biggest challenges in modern cosmology is to solve the mystery of the origin and nature of DM. Various experimental searches like DAMA, CoGeNT *etc.* are going on to detect or find its evidences [3, 4]. Recently, Fornal and Grinstein proposed the dark decay of bottle neutron to sort out the discrepancy in the life time measurement of a bottle and beam neutron [5]. Serebrov suggested that this particle could also resolve a reactor anti-neutrino anamoly [6].

Neutron stars (NS) due to their large density are the natural laboratories to test the non-standard physics. Various theoretical studies by considering the presence of DM inside neutron star have been carried out. In this work, We have considered the non-interacting DM core inside the NS and see its effects on the properties of NS. In Ref. [7], it is remarked that the observational data of gravitational waves (GW) from NS-NS merger could be a tool to test on the possible DM models.

We consider the light Fermionic particle named as neutralino which interact with the baryonic matter of NS through the Higgs Boson of next to minimal super-symmetric standard model (NMSSM). We have taken the parameters of non-interacting DM, which are consistent with the DAMA and CoGeNT data for the spin independent cross section of DM-nucleon elastic scattering. The details about the parameters of interaction Lagrangian of DM with baryonic matter through Higgs Boson can be found in Ref. [7].

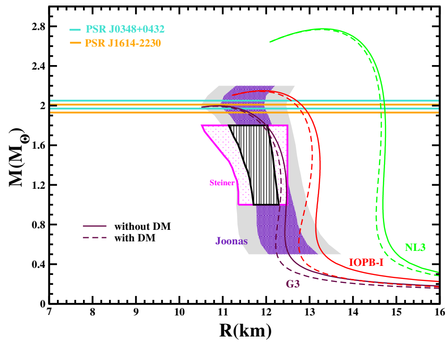

FIG. 1: The mass-radius profile predicted by the chosen EOS with and without considering Dark matter. The recent experimental bounds are also shown.

Results and Discussions

We have used the G3, IOPB-I, and the widely used NL3 equation of state (EOS) of NS within relativistic mean field (RMF) model. The EOSs are used in the Tolman-Oppenheimer-Volkolf equations [8] to study the properties of a NS like its mass radius curve, and tidal deformability *etc.*. The TOV equations have been solved for the EOSs with and without DM inside the NS.

Figure 1 represents the mass-radius (M-R) curve of a NS for the chosen EOS with (dashed

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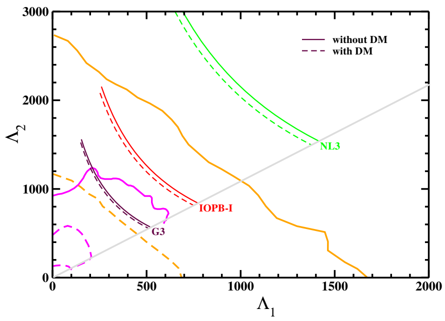

FIG. 2: The effect of Dark matter on the Λ values corresponding to the EOS is shown.

line) and without DM (bold line). The effects of DM on the M-R values can easily be visualized from the figure. In the presence of DM, the mass as well radius go down and the EOSs become softer. It is clear from the figure that at any fix value of mass (except the higher mass near to the maximum value), the radius of NS is decreased slightly. For example, the effects are considerable at canonical mass $M = 1.4M_\odot$ and at chirp mass $\mathcal{M} = 1.188M_\odot$. The calculated results are compared with the available experimental or empirical findings (the references to these data can be found in Ref. [8]). The dimensionless tidal deformabilities Λ for the NS binary merger at the chirp mass $\mathcal{M} = 1.188M_\odot$ in the box size $q = 0.7 - 1.0$ are shown in the Figure 2. The 90%-credible (50%-credible) contours from the Ref. [9] and the further refinement in these limits by considering universal EOS are shown by orange bold (dashed) and pink bold (dashed), respectively. The curves corresponding to the EOS get shifted towards the left in the presence of DM (dashed lines). From this curve (by using GW data), the Fermi momentum of dark particle can be constrain for each EOS by getting the Λ values within the experimental bounds.

Conclusions

We have studied the effects of DM on the properties of NS within RMF model by using the G3, IOPB-I, and NL3 parameter sets. Neutralinos are supposed to interact with baryonic matter via the exchange of the light NMSSM Higgs Boson. The stiffer EOS produce large mass, radius, tidal deformability, and MI of a NS. While, all of these quantities get reduced in the presence of DM. The Fermi momentum of DM particle along with other parameters can also be constrained by using the GW170817 data.

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