f-mode oscillation of the dark matter admixed neutron star

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1. Introduction

An isolated neutron star emits gravitational waves with different frequencies when it oscillates from its equilibrium positions. The frequency of the oscillations characterizes the internal structure of the neutron star (NS). Different mode frequencies such as fundamental (f), pressure (p), gravity (g), etc., are emitted with the gravitational waves. Most of this energy is radiated with these modes. Therefore, it is a unique way to find the information about the internal structure of the NS if we detects that frequency.

The different mode frequencies of such modes are in kHz range and more, which can not be easily detected through terrestrial detectors. The present advanced detectors such as LIGO/Virgo and Kagra can detect the frequency in the range of 10 Hz to 10 kHz. In the future, we may detect different mode frequencies with great precision. But, prior to this, we must have enough theoretical knowledge on the different oscillation frequencies and their formation mechanism.

Lindblom and Detweiler have calculated the first theoretical integrated numerical solution for different mode frequencies using the full general theory of relativity approach [1]. Andersson and Kokkotas have given a unique empirical formula from which one can calculate the mass and radius of the NS if one can find the f-mode frequency [2]. Subsequently, the empirical relation have been modified by using the modern equation of state as given in Ref. [4]. In this study, we want to calculate the f-mode frequency of the NS by using the relativistic Cowling approximations. In Cowling approximation, the space-time perturbation can be neglected. In addition to this, we add the dark matter (DM) inside the star to see its impact on f-mode frequency.

DM makes up more than 85% of the matter in the Universe. Hence, the compact object like NS, when evolving in its lifetime in the Universe, there will be the possible accretion of DM inside the NS. This is because NS has huge gravitational potential and immense baryonic density. In this study, we assume that Neutralino is the best candidate of the weakly interacting massive particle which are accreted inside the NS and interacts with nucleons via standard model Higgs [5]. Therefore, the total equation of state is a combination of nucleons and DM.

In this study, we take well known IOPB-I equation of state to calculate the NS properties with addition of DM inside it. The detailed calculations related to f-mode oscillation of the NS can be found in Ref. [4].

2. Results and Discussions

We calculate the non-radial oscillations frequency of the NS with the addition of DM inside it. To calculate the equation of state of the NS, we use relativistic mean-field formalism [3]. We solve the oscillation equations only for the quadrupole case ($l = 2$) as given in Ref. [4]. We plot the f-mode frequencies with different DM Fermi momenta as a function of NS masses in Fig. 1.

With the increase of the DM momenta, the equation of state becomes softer, which reduces the mass and increases the f-mode frequency of the NS. This is because f-mode frequency corresponds to lower mass star oscillates more as compare to heavy mass star. We

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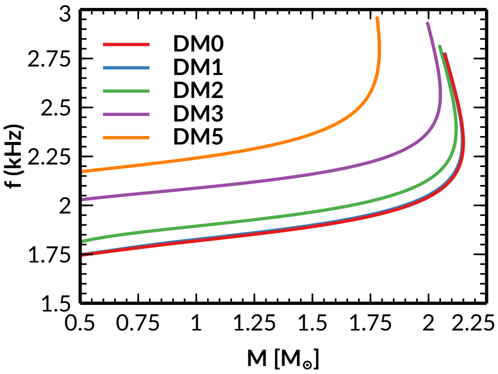

FIG. 1: f-mode frequency as a function of mass with different DM Fermi momenta for IOPB-I parameter set. The DM0-DM6 represents the DM Fermi momenta 0-0.06 GeV respectively.

TABLE I: The maximum mass (M_{max}), f-mode frequency corresponds to maximum mass (f_{max}), f-mode frequency corresponds to canonical mass ($f_{1.4}$), canonical dimensionless tidal deformability (Λ) are given with different DM Fermi momenta (DM0-DM5).

DM momenta (GeV)	M_{max} ($M_\odot$)	f_{max} (kHz)	$f_{1.4}$ (kHz)	$\Lambda_{1.4}$
DM0	2.149	2.325	1.874	689.627
DM1	2.146	2.326	1.883	670.585
DM2	2.119	2.395	1.949	607.660
DM3	2.051	2.574	2.142	463.488
DM5	1.788	2.797	2.329	164.976

give the numerical values of f-mode frequencies, masses, and dimensionless tidal deformability with different DM Fermi momenta in table I. The variation of f-mode frequency as a function of Λ is shown in fig. 2. f-mode frequency decreases with Λ for different DM momenta.

We study the f-mode oscillation of the neutron star using the relativistic Cowling approximation. The macroscopic properties are calculated with the relativistic mean-field equation of state by assuming that the DM particles are inside the neutron star. With the addition of DM, the mass and tidal deformability of the star decreases but the f-mode frequency increases. We find that DM has a significant impact on the mass, dimensionless tidal deformability and f-mode frequencies of the neutron star.

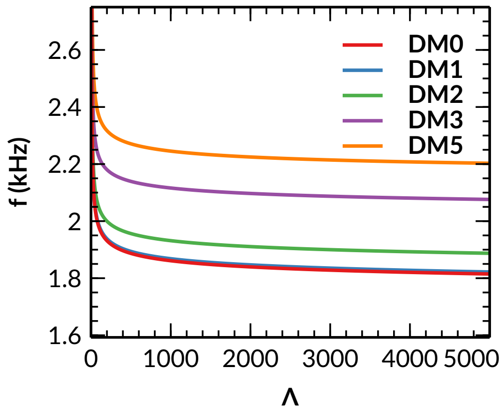

FIG. 2: f-mode frequency as a function of dimensionless tidal deformability (Λ) with different DM Fermi momenta for IOPB-I parameter set. The DM0-DM6 represents the DM Fermi momenta 0-0.06 GeV respectively.

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