GW170817 CONSTRAINTS ON THE PROPERTIES OF A NEUTRON STAR IN THE PRESENCE OF WIMP DM

International School of Nuclear Physics (41th course)
Erice-Sicily

Abdul Quddus

Department of Physics
Aligarh Muslim University
Aligarh - India

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Collaborators

- **Dr. Grigorios Panotopoulos**
  Centro de Astrofísica e Gravitação, Departamento de Física, Instituto Superior Técnico-IST, Universidade de Lisboa-UL, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

- **Dr. Bharat Kumar**
  Centre for Computational Sciences, University of Tsukuba, Tsukuba-Japan

- **Dr. Shakeb Ahmad** (Supervisor)
  Aligarh Muslim University, Aligarh-India

- **Prof. S. K. Patra** (Co-supervisor)
  Institute of Physics, Bhubaneswar-India

Outline

Dark matter and its evidences

- **The term “dark matter" was coined by Zwicky in 1933 when he found some evidence about the missing mass in studying cluster of galaxies known as “Coma" [1].**
- He found that the expansion of the space (red-shift) in the Coma cluster could not be explained in terms of the known luminous mass and concluded that **a large amount of dark matter must be present to keep these galaxies bound together.** ▸ velocity curve
- The measurements of the cosmic microwave background (CMB), too, suggest that **dark matter is necessary to explain the structure formation [2].**
- Another evidence of dark matter is **the high temperature of the gas detected in clusters through its X-ray emission [2, 3].**

[1] Helv. Phys. Acta 6, 110 (1933). [2] Int. Journal of Mod. Phys. A **19**, 3039, (2004). [3] Phys.Rev. D **74**, 123515 (2006).

Dark matter and its evidences

- Many DM candidates have been proposed and studied over the years by cosmologists and particle physicists. (Some of the candidates for DM: WIMP, axions, gravitino, etc.)
- **Despite that, the origin and nature of DM still remains unknown.**
- The determination of the type of elementary particles that play the role of dark matter in the Universe is one of the current challenges of Particle Physics and modern Cosmology.

WIMP

- Weakly Interacting Massive Particles (WIMPs), which are thermal relics from the Big-Bang, are perhaps the most popular DM candidates.
- Initially, when the Universe was very hot, WIMPs were in thermal equilibrium with their surrounding particles.
- As the Universe expands and cools down, at a certain temperature WIMPs decouple from the thermal bath, and its abundance freezes out.
- After freezing out, they can no longer annihilate, and their density is the same since then comprising the observed DM abundance of the Universe [2].
- If WIMPs, or neutralinos in particular, are the main candidates for DM, they will cluster gravitationally with stars, and also form a background density in the Universe.
- In Ref. [4], it was remarked that our own galaxy, the Milky Way, contains a large amount of dark matter.

[4] Phys. Rep. **187**, 203 (1990).

Experiments working/planned to detect DM

- The interaction of the neutralino with nuclei through elastic [2] or inelastic scattering [5, 6] is being studied in various laboratories.
- More than 20 experiments worldwide for DM direct detection are either running or in preparation, and some of them are the following: the DArk MAtter (DAMA) experiment, Cryogenic Dark Matter Search (CDMS) experiment, EDELWEISS experiment, IGEX, ZEPLIN, GErmanium DEtectors in ONe cryostat (GEDEON), CRESST, GErmanium in liquid NItrogen Underground Setup (GENIUS), and LHC.
- Furthermore, Fermi LAT, GAMMA-400, IceCube, Kamiokande, and AMS-02 are some of the indirect DM detection experiments.
- For review of DM, see [7-10]. ▸ exp curve

[5] Phys. Lett. B **212**, 375 (1988); Phys. Lett. B **317**, 14 (1993). [6] Phys. Rev. Lett. **74**, 2623 (1995). [7] JCAP **0803**, 022 (2008) 022. [8] arXiv:1604.00014 [astro-ph.HE]. [9] arXiv:1702.02430 [hep-ph]. [10] EPJ Web Conf. **95**, 02004 (2015).

DAMA results

- The recently discovered channelling effect on the threshold energy in DAMA give a spin-independent (SI) cross-section of elastic scattering of DM with nuclei in the range [11]

$$3 \times 10^{-41} cm^2 \lesssim \sigma_p^{SI} \lesssim 5 \times 10^{-39} cm^2 \tag{1}$$

while the range of the mass of the DM particle is

$$3 GeV \lesssim m_{DM} \lesssim 8 GeV. \tag{2}$$

- Various studies have taken these results into account [12].
- **In the WIMP scenario, a one-to-one relation is seen between the SI direct detection rate and DM relic density if its elastic scattering on nuclei occurs dominantly through Higgs exchange [13].**

[11] arXiv:1106.4667 [hep-ph]. arXiv:1907.06405 [hep-ph]. [12] arXiv:0804.4518 [hep-ph]. arXiv:0806.3746 [hep-ph]. arXiv:0806.4099 [hep-ph]. arXiv:0807.3758 [hep-ph]. [13] arXiv:0808.0255v2 [hep-ph].

DAMA results

- The SI direct detection cross-section of elastic scattering of DM with nuclei is given by [13]

$$\sigma(\Psi N \to \Psi N) = \frac{y^2}{\pi} \frac{\mu_r^2}{v^2 M_h^4} f^2 m_N^2, \tag{3}$$

  where $v = 246\ GeV$ is the Higgs vacuum expectation value.
- Following the lattice computations [14], we have considered the central value $f = 0.3$ in agreement with [15].
- We have assumed a light Higgs boson with a mass $M_h = 40$ GeV, so that $y < 1$.
- The authors of [16, 17] have shown that such a scenario can be realized in the framework of the NMSSM in agreement with the rest of the experimental constraints.

[14] Annals Phys. **336**, 413 (2013). Phys. Rev. D **88**, 054507 (2013). [15] Phys. Rev. D **88**, 055025 (2013). [16] arXiv:1009.2555v1 [hep-ph]. [17] Phys. Rev. D **82**, 115014 (2010).

NMSSM

The NMSSM [18] is a simple extension of the MSSM [19] in which a singlet supermultiplet is added, and it is characterized by the following properties:

- **It preserves the nice properties of the MSSM, while at the same time it provides us with an excellent DM candidate,**
- **There is a rich Higgs sector with 2 Higgs bosons more in comparison with MSSM.**

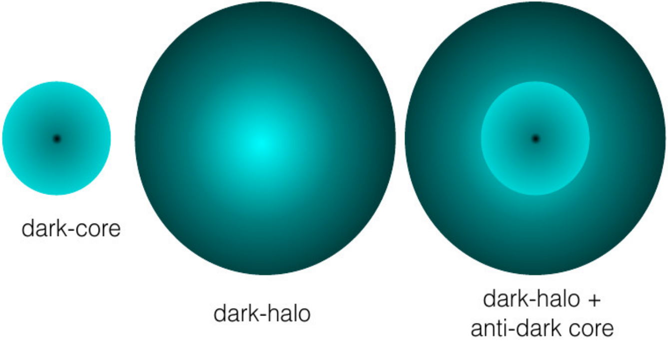
[18] Phys. Lett. B **315**, 331 (1993). Z. Phys. C **67**, 665 (1995). Nucl. Phys. B **492**, 21 (1997). [19] arXiv:1003.0682 [hep-ph].

Neutron star

- Neutron stars (NSs) are excellent natural laboratories to test nonstandard physics.
- The tidal deformability Λ of an NS from the GW170817 data [20], the historical first detection of gravitational waves from the binary neutron-star (BNS) merger by the LIGO-Virgo collaboration, provides a new probe to the interior of NS and their nuclear EOS.
- (Pulsars and) GW170817 observation suggest that the mass and radius of a NS lie in the range $2.01 \pm 0.04 \lesssim M(M_\odot) \lesssim 2.16 \pm 0.03$ [21] and $8.7 < \hat{R}(\mathrm{km})$ 14.1 to a 90% confidence limit [22], respectively.

[20] Phys. Rev. Lett. **119**, 161101 (2017). [21] Astrophys. J. Lett. **852**, L25 (2018). [22] arXiv:1804.08583 [astro-ph.HE].

Neutron star with DM



Sanjay Reddy's talk in Erice school (40th course)

Why DM inside a neutron star?

- It was pointed out in [23] that the mass-radius relation of NS can be affected in the presence of DM inside the object.
- The presence of DM inside NSs can modify the gravitational waves (GWs) signal from BNS merger which may result in yielding an additional peaks in the post-merger frequency spectrum [24]. ▸ Ellis
- These peaks might be detected in future GW signal from BNS mergers.
- **Therefore, the detection of such additional peaks can be an indirect tool to detect DM.**
- In this work, we have examined the effects of DM inside an NS core with the parameters of DM within the NMSSM model.
- We have considered the effective-field theory motivated relativistic mean field field model (E-RMF) to generate the EOSs of NS by considering the IOPB-I [25], G3 [26], and NL3 [27] parameter sets.

[23] Phys. Rev. D **96**, 083004 (2017). [24] Phys. Lett. B **781**, 607 (2018). [25] Phys. Rev. C **97**, 045806 (2018). [26] Nucl. Phys. A **966**, 197 (2017). [27] Phys. Rev. C **55**, 540 (1997).

Overview

- We have considered fermionic dark matter (WIMP's neutralino), which is assumed to be uniformly distributed in the neutron star core with fixed Fermi momentum.
- The WIMP DM candidate must satisfy the DAMA results.
- The Yukawa coupling of Higgs boson $y < 1$.
- Lightest supersymmetric particle (LSP) is considered within NMSSM.
- E-RMF model is applied to generate the EOSs of NS.

Equation of states (EOSs) of pure hadronic matter

Energy density

$$\begin{aligned}
\mathcal{E}_{had.} &= \frac{2}{(2\pi)^3}\int d^3k E_i^*(k) + \rho_b W + \frac{m_s^2\Phi^2}{g_s^2}\left(\frac{1}{2} + \frac{\kappa_3}{3!}\frac{\Phi}{M} + \frac{\kappa_4}{4!}\frac{\Phi^2}{M^2}\right) \\
&\quad -\frac{1}{2}m_\omega^2\frac{W^2}{g_\omega^2}\left(1 + \eta_1\frac{\Phi}{M} + \frac{\eta_2}{2}\frac{\Phi^2}{M^2}\right) - \frac{1}{4!}\frac{\zeta_0 W^4}{g_\omega^2} + \frac{1}{2}\rho_3 R \\
&\quad -\frac{1}{2}\left(1 + \frac{\eta_\rho\Phi}{M}\right)\frac{m_\rho^2}{g_\rho^2}R^2 - \Lambda_\omega(R^2 \times W^2) + \frac{1}{2}\frac{m_\delta^2}{g_\delta^2}\left(D^2\right). \qquad (4)
\end{aligned}$$

EOSs of pure hadronic matter

Pressure

$$\begin{aligned} P_{had.} &= \frac{2}{3(2\pi)^3}\int d^3k\,\frac{k^2}{E_i^*(k)} - \frac{m_s^2\Phi^2}{g_s^2}\left(\frac{1}{2}+\frac{\kappa_3}{3!}\frac{\Phi}{M}+\frac{\kappa_4}{4!}\frac{\Phi^2}{M^2}\right) \\ &+\frac{1}{2}m_\omega^2\frac{W^2}{g_\omega^2}\left(1+\eta_1\frac{\Phi}{M}+\frac{\eta_2}{2}\frac{\Phi^2}{M^2}\right)+\frac{1}{4!}\frac{\zeta_0 W^4}{g_\omega^2} \\ &+\frac{1}{2}\left(1+\frac{\eta_\rho\Phi}{M}\right)\frac{m_\rho^2}{g_\rho^2}R^2+\Lambda_\omega(R^2\times W^2)-\frac{1}{2}\frac{m_\delta^2}{g_\delta^2}\left(D^2\right). \quad (5) \end{aligned}$$

where Φ, D, W, and R are the redefined fields for σ, δ, ω, and ρ mesons as $\Phi = g_s\sigma$, $D = g_\delta\delta$, $W = g_\omega\omega^0$, and $R = g_\rho\vec{\rho}^0$, respectively.

EOSs of pure hadronic matter

While $E_i^*(k)$=$\sqrt{k^2 + {M_i^*}^2}$ $(i = p, n)$ is the energy with effective mass ${M_i^*}^2 = k_F^2 + M_i^2$, and k is the momentum of the nucleon. The quantities ρ_b and ρ_3 are the baryonic and iso-vector densities;

$$\begin{aligned} \rho_b(r) &= \sum_i n_i \varphi_i^\dagger(r)\varphi_i(r) \\ &= \rho_p(r) + \rho_n(r) \end{aligned} \tag{6}$$

$$\begin{aligned} \rho_3(r) &= \sum_i n_i \varphi_i^\dagger(r)\tau_3\varphi_i(r) \\ &= \rho_p(r) - \rho_n(r) \end{aligned} \tag{7}$$

Parameters used

Table: The table for parameter sets. The nucleon mass M taken as 939.0 MeV. All the coupling constants are dimensionless, except k_3 which is in fm^{-1}.

	NL3	G3	IOPB-I
m_s/M	0.541	0.559	0.533
m_ω/M	0.833	0.832	0.833
m_ρ/M	0.812	0.820	0.812
m_δ/M	0.0	1.043	0.0
$g_s/4\pi$	0.813	0.782	0.827
$g_\omega/4\pi$	1.024	0.923	1.062
$g_\rho/4\pi$	0.712	0.962	0.885
$g_\delta/4\pi$	0.0	0.160	0.0
k_3	1.465	2.606	1.496
k_4	-5.688	1.694	-2.932
ζ_0	0.0	1.010	3.103
η_1	0.0	0.424	0.0
η_2	0.0	0.114	0.0
η_ρ	0.0	0.645	0.0
Λ_ω	0.0	0.038	0.024

1

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[1] NL3: PRC **55**, 540 (1997); G3: Nucl. Phys. A **966**, 197 (2017); IOPB1: Phys. Rev. C **97**, 045806 (2018).

EOSs of NS in the presence of DM core

Lagrangian density

- We have considered the lightest mass eigenstate of WIMP, i.e. neutralino (χ) within NMSSM as the Fermionic DM candidate.
- In the presence of DM, the interaction Lagrangian density is given by [28]:

$$\begin{aligned}\mathcal{L} &= \mathcal{L}_{had.} + \bar{\chi}\left[i\gamma^{\mu}\partial_{\mu} - M_{\chi} + yh\right]\chi + \frac{1}{2}\partial_{\mu}h\partial^{\mu}h \\ &\quad -\frac{1}{2}M_h^2h^2 + f\frac{M_n}{v}\bar{\varphi}h\varphi, \end{aligned} \tag{8}$$

where $\mathcal{L}_{had.}$ is the Lagrangian density for pure hadronic matter.

[28] arXiv:1807.10013v1 [hep-ph].

EOS of nuclear matter with DM

$$\mathcal{E} = \mathcal{E}_{had.} + \frac{2}{(2\pi)^3}\int_0^{k_F^{DM}} d^3k\sqrt{k^2+(M_\chi^\star)^2} + \frac{1}{2}M_h^2h_0^2. \tag{9}$$

$$P = P_{had.} + \frac{2}{3(2\pi)^3}\int_0^{k_F^{DM}} \frac{d^3k k^2}{\sqrt{k^2+(M_\chi^\star)^2}} - \frac{1}{2}M_h^2h_0^2. \tag{10}$$

- The Fermi momentum of DM particles (k_f^{DM}) is taken to be a constant throughout the calculation with the value fixed at 0.06 GeV.
- The effective mass of the nucleon (M^*) is modified due to the interaction with the Higgs boson.

$$\begin{aligned} M_i^\star &= M_i + g_\sigma\sigma - \tau_3 g_\delta\delta - \frac{fM_n}{v}h_0, \\ M_\chi^\star &= M_\chi - yh_0. \end{aligned} \tag{11}$$

β stable NS

For the stability of NSs, the $\beta-$ equilibrium condition is imposed, which is given by,

$$\begin{aligned} \mu_n &= \mu_p + \mu_e, \\ \mu_e &= \mu_\mu. \end{aligned} \tag{12}$$

$$\mu_n = g_\omega \omega_0 + g_\rho \rho_0 + \sqrt{k_n^2 + (M_n^\star)^2}, \tag{13}$$

$$\mu_p = g_\omega \omega_0 - g_\rho \rho_0 + \sqrt{k_p^2 + (M_p^\star)^2}, \tag{14}$$

$$\mu_e = \sqrt{k_e^2 + m_e^2}, \tag{15}$$

$$\mu_\mu = \sqrt{k_\mu^2 + m_\mu^2}. \tag{16}$$

The muon comes into play when the chemical potential of the electrons reaches the muon rest mass and maintains the charge of NS as follows

$$\rho_p = \rho_e + \rho_\mu. \tag{17}$$

EOS of NS in the presence of DM core

The total energy density and pressure for $\beta-$ stable NS are given by,

$$\begin{aligned} \mathcal{E} &= \mathcal{E}_{had.} + \mathcal{E}_{DM} + \mathcal{E}_{l} \\ P &= P_{had} + P_{DM} + P_{l}. \end{aligned} \tag{18}$$

Where,

$$\mathcal{E}_{l} = \sum_{l=e,\mu} \frac{2}{(2\pi)^3} \int_0^{k_l} d^3k \sqrt{k^2 + m_l^2}, \tag{19}$$

and

$$P_{l} = \sum_{l=e,\mu} \frac{2}{3(2\pi)^3} \int_0^{k_l} \frac{d^3k k^2}{\sqrt{k^2 + m_l^2}} \tag{20}$$

are the energy density and pressure for leptons (e and μ).

Neutron star properties

For static, spherically symmetric solutions of the form $ds^2 = -e^{\nu(r)}dt^2 + e^{\lambda(r)}dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2$, the TOV* equations are given by,

$$e^{\lambda(r)} = \left(1 - \frac{2m}{r}\right)^{-1}, \tag{21}$$

$$\frac{d\nu}{dr} = 2\,\frac{m + 4\pi p r^3}{r(r-2m)}, \tag{22}$$

$$\frac{dp}{dr} = -\frac{(\mathcal{E}+p)(m+4\pi r^3 p)}{r(r-2m)}, \tag{23}$$

$$\frac{dm}{dr} = 4\pi r^2 \mathcal{E}. \tag{24}$$

* Phys. Rev. 55, 374 (1939); ibid. **55**, 364 (1939).

Neutron star properties

For a slowly rotating NS the MI is given by [29, 30],

$$I = \frac{8\pi}{3}\int_0^R r^4(\mathcal{E}+p)e^{(\lambda-\nu/2)}\frac{\bar{\omega}}{\Omega}dr, \tag{25}$$

where Ω and $\bar{\omega}$ are the angular velocity and the rotational drag function, respectively, for a uniformly rotating NS. The rotational drag function $\bar{\omega}$ meets the boundary condition,

$$\bar{\omega}(r=R) = 1 - \frac{2I}{R^3}, \qquad \frac{d\bar{\omega}}{dr}|_{r=0} = 0 \tag{26}$$

The quantity $\frac{\bar{\omega}}{\Omega}$, evolve in Eq. (22), is the dimensionless frequency satisfying the equation

$$\frac{d}{dr}\left(r^4 j\frac{d\bar{\omega}}{dr}\right) = -4r^3\bar{\omega}\frac{dj}{dr}, \tag{27}$$

with $j = e^{-(\lambda+\nu)/2}$.

[29] Astrophy. J. **150**, 1005 (1967). [30] Astrophys. J. **550**, 426 (2001).

Neutron star properties

The tidal deformability for $l = 2$ quadrupolar perturbations is defined as,

$$\lambda_2 = \frac{2}{3} k_2 R^5, \tag{28}$$

where R is the NS radius, and k_2 is the tidal love number which depends on stellar structure and calculated as [31],

$$\begin{aligned} k_2 = \frac{8C^5}{5}(1-2C)^2(2(1-C)+(2C-1)y_R) \times \\ \{4C^3\left(13-11y_R+2C^2(1+y_R)+C(-2+3y_R)\right) \\ +2C\,(6-3y_R+3C(5y_R-8))+3(1-2C)^2 \\ \times(2+2C(y_R-1)-y_R)\log(1-2C)\}^{-1}, \end{aligned} \tag{29}$$

where $C = M/R$ is the compactness of the NS, and $y_R = y(R)$ is obtained by solving the following differential equation

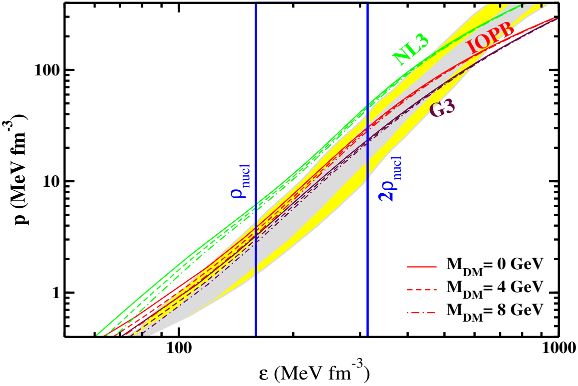
$$r\frac{dy}{dr} + y^2 + yF(r) + r^2Q(r) = 0 \tag{30}$$

one can compute the dimensionless tidal polarizability as: $\Lambda = 2/3k_2C^{-5}$.

[31] Astrophys. J. **677**, 1216 (2008); **697**, 964(E) (2009).

Results and discussions

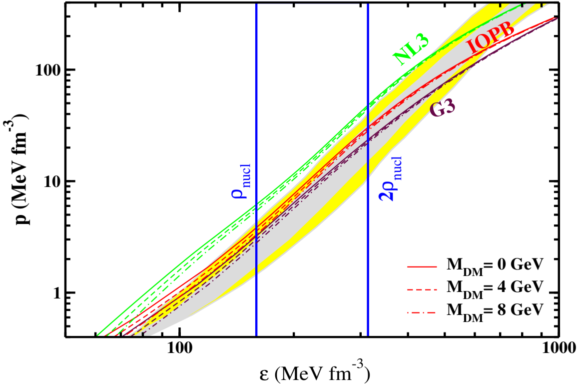
Effect of dark matter on the EOS of neutron star



- The grey and yellow shaded regions represent the 50% and 90% confidence level of EOS, obtained from GW170817 data [32].
- The pressure at twice of the nuclear saturation density is measured to be $21.88^{+16.88}_{-10.62}$ MeV-fm^{-3} [32].

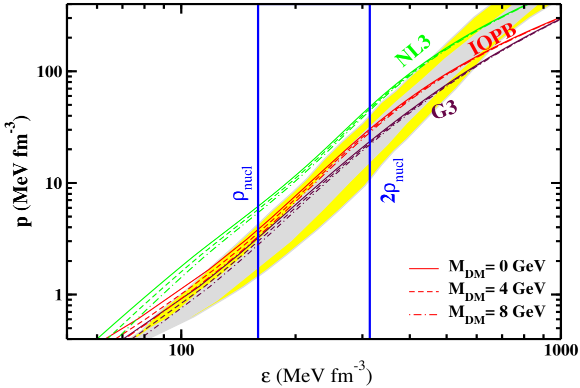
[32] arXiv:1805.11581 (2018) [gr-qc].

Effect of dark matter on the EOS of neutron star



- The presence of DM inside NS softens the EOS. Large mass of DM particle has more impact in softening the EOS.

Effect of dark matter on the EOS of neutron star

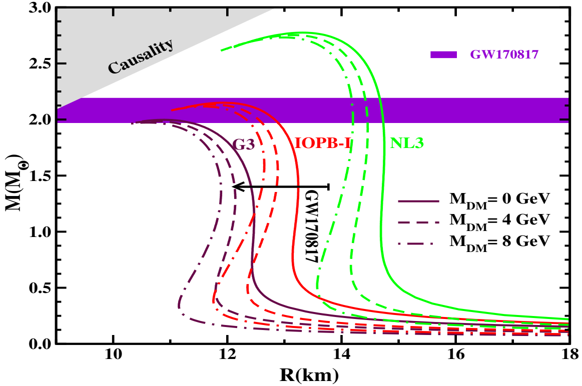


- It is important to mention that the EOS becomes stiffer when considering the DM haloes around NS [33]. In this case, an enhancement in structural properties is reported in [33].

▸ Nelson

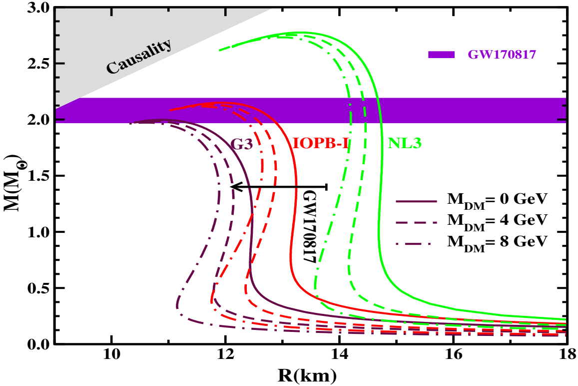
[33] arXiv:1803.03266v1 [hep-ph].

Mass-radius curve



- The violet band ($2.01 \pm 0.04 \lesssim M(M_\odot) \lesssim 2.16 \pm 0.03$) represents the maximum mass range for a non-rotating NS, which is constrained through (Pulsar mass and) GW170817 data [21].
- This band also satisfies the precisely measured mass of NS, such as PSR J0348+0432 with mass $(2.01 \pm 0.04) M_\odot$ [34].

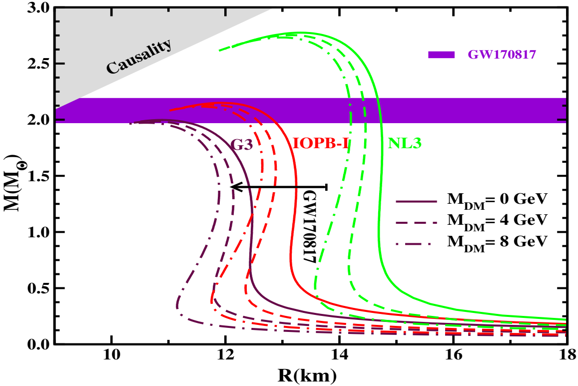
Mass-radius curve



- The black arrow represents the radius at the canonical mass of NS [35] with the maximum value $R_{1.4} \leq 13.76$ km.

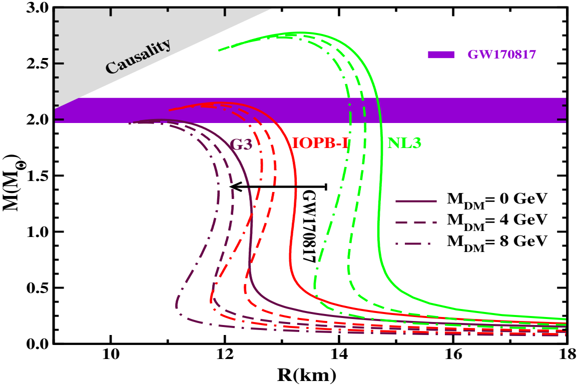
[34] Science **340**, 1233232 (2013). [35] Phys. Rev. Lett. **120**, 172702 (2018).

Mass-radius curve



- The NL3 set, being the stiffest among the considered parameter sets, predicts large mass and radius of NS which is ruled out by GW data.
- The G3 and IOPB-I EOSs with DM predict the maximum masses of NS that satisfy the mass range constrained in [21] from the prior GW data [20].
- Out of the three considered parameter sets, the IOPB-I EOSs with and without DM satisfy the radius range at canonical mass constrained from GW170817 [35].

Mass-radius curve

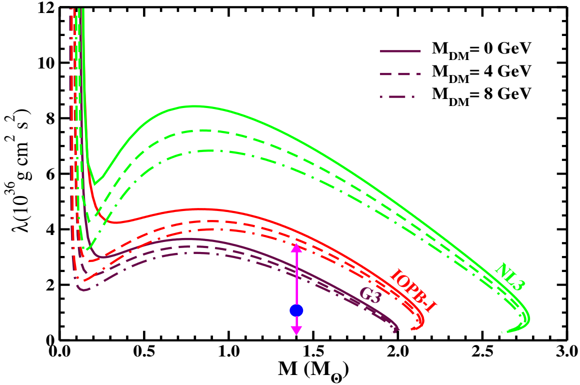


- The lowering in the maximum mass of NS for the EOSs with DM is small. **The effects of DM are more important for masses below the highest mass.**
- In other words, the radius is reduced much at a fix mass other than the maximum masses. ▸ SMHiggs

Tidal deformability

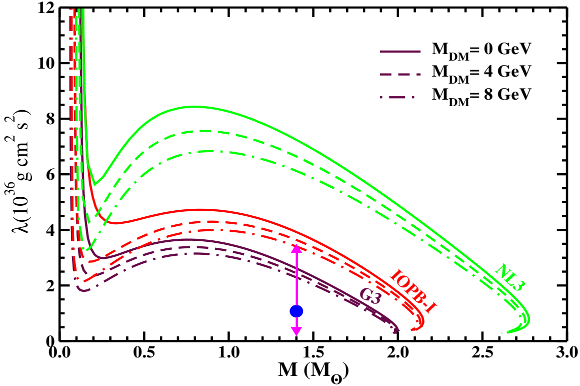
- The tidal deformability of NS depends on its mass quadrupole which is developed due to the tidal gravitational field of other component of NS binaries.
- It is clear from its definition that λ_2 depends on the radius of the star and on its tidal love number k_2, which describes the internal structure of NS.
- As the radius of NS increases, λ_2 values grow, and hence, the surface becomes more deform.
- It simply means that soft EOSs predict less value for λ_2.

Tidal deformability



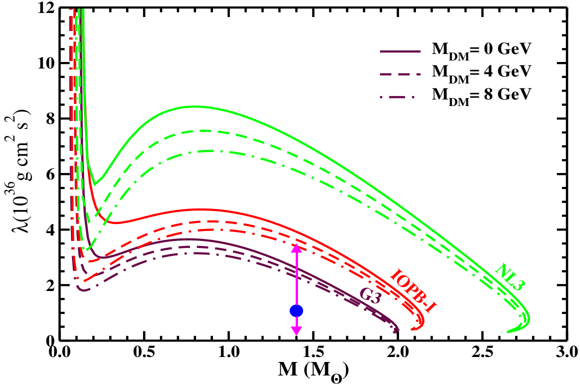
- The blue circle with the arrow bar (error bar) represents the λ_2 of a NS at the mass 1.4M$_\odot$ corresponding to the $\hat{\Lambda}_{1.4} = 190^{+390}_{-120}$, which is constrained from the GW data [32] at 90% confidence level.

Tidal deformability



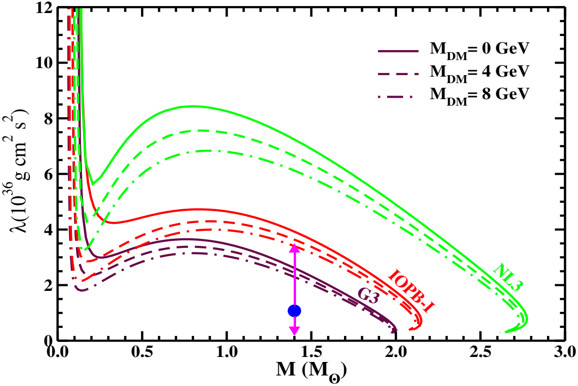
- The NL3 set, which is stiffer, predicts large values for the tidal deformability and hence large deformation.
- The λ_2 corresponding to the NL3 EOSs, even in the presence of DM, does not pass through the experimental range at the canonical mass.

Tidal deformability



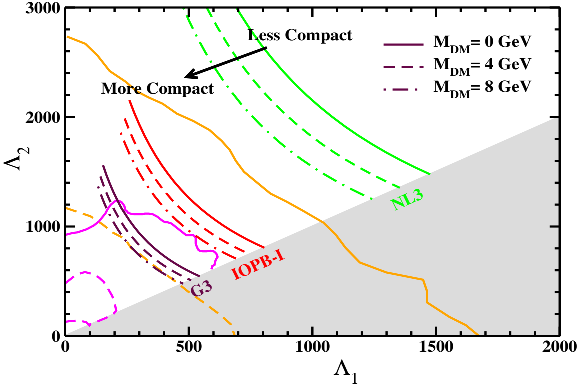
- On the other hand, λ_2 curves for the G3 EOSs lie within the observationally allowed region.
- However, the IOPB-I EOS at neutralino mass $M_{DM} = 8$ GeV predicts a λ_2 value that just satisfies the upper range of the experimental λ_2 value.

Tidal deformability



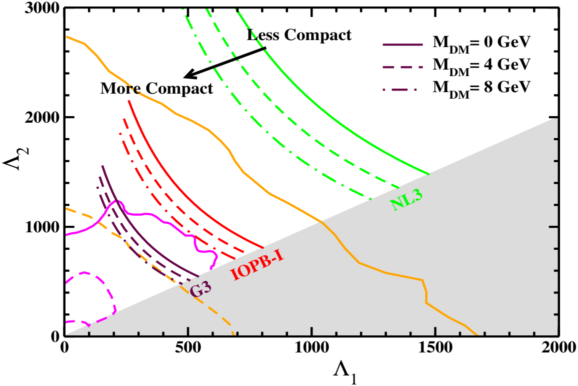
- The significant changes occur in λ_2 due to the DM at the canonical mass of NS.

Dimensionless tidal deformability



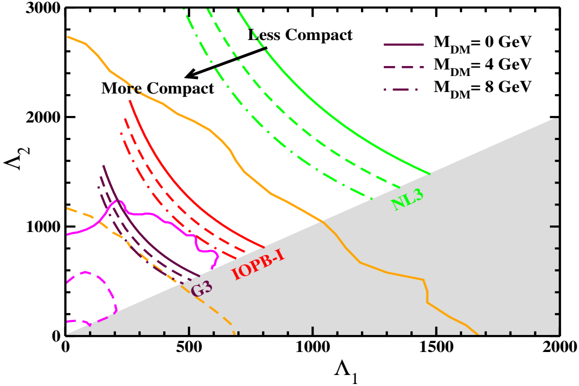
- The individual dimensionless tidal deformabilities Λ_1 and Λ_2 correspond to high mass m_1 and low mass m_2 of BNS.
- We vary the mass m_1 in the range $1.365 < m_1/M_\odot < 1.60$, and determine the range of m_2 by fixing the chirp mass as $\mathcal{M}_c = 1.188\ M_\odot$.

Dimensionless tidal deformability



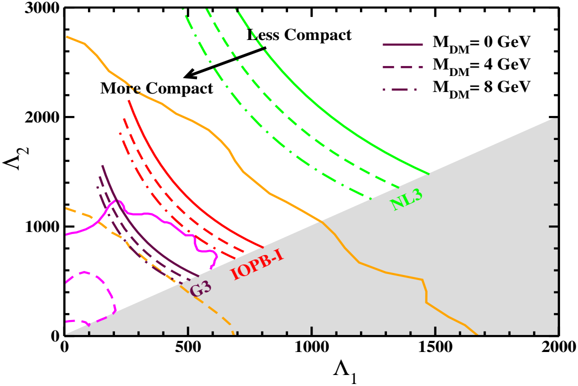
- The $\hat{\Lambda}_{1.4} = 190^{+390}_{-120}$ has been found in [32] at 90% confidence level by imposing the condition of maximum mass at least 1.97 $M_\odot$ and assuming the same EOSs for both objects in the binaries.
- The shaded part (grey color) in the figure marks the $\Lambda_2 < \Lambda_1$ region that is naturally excluded for a common realistic EOS [32].

Dimensionless tidal deformability



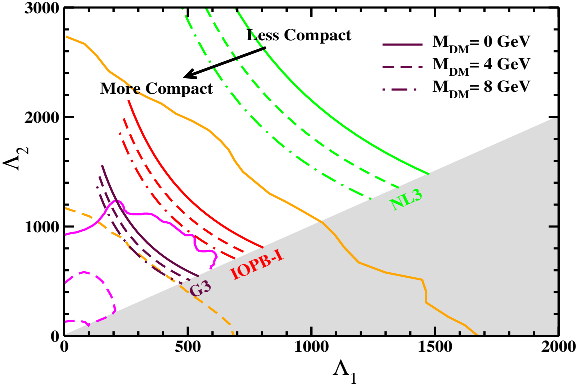
- The IOPB-I sets are in excellent agreement with the 90% (bold line) probability contour of prior GW170817.
- The G3 EOSs, with and without DM, lies within the 90% confidence level allowed region of prior as well as posterior GW170817 data.
- The NL3 EOSs lie outside the 90% confidence lever region (bold line) of prior (orange) as well as posterior (magenta) analysis.

Dimensionless tidal deformability



- For the EOSs corresponding to NS with a DM inside its core, the curves are shifted to the left and predict lower values for $\hat{\Lambda}$ corresponding to less compact NSs.
- The analysis of [32] suggests that soft EOSs, which predict lower values for Λ, are favored over stiffer EOSs.

Dimensionless tidal deformability

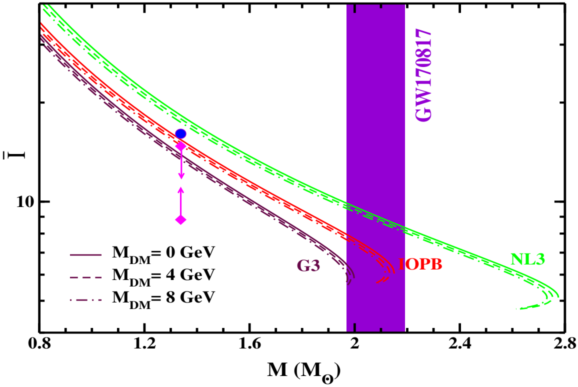


- On adjusting the parameters of the DM Lagrangian for an EOS, the curve can be shifted even more to the left. In this way, the parameters of the DM Lagrangian can be optimized satisfying the GW170817 constraint.

Moment of Inertia

- The moment of inertia (MI) of NS strongly depends on the structure of the object.
- It is one of the most important macroscopic quantities that can be used to constrain the EOS of NS.
- The mass distribution of NS, the final stage of the BNS merger, and $r-$ process nucleosynthesis are determined by the EOS, and therefore a precise measurement of the MI, tidal deformability etc are very important.
- We plot the dimensionless MI, which decreases with the mass of the NS.

Moment of Inertia



- Stiffer EOSs predict a larger MI for a given mass of a NS.
- In the presence of a DM core, the soft nature of EOSs generates a lower MI.
- The overlaid arrows in the figure indicate the MI of PSR J0737-3039, constrained by the analysis of GW170817 [32], while the circle represents the upper bound on MI from minimal assumption analysis [20].

Conclusion

- We have analyzed the effect of a DM core on the properties of NS.
- We have considered the lightest mass eigenstate of WIMP, i.e., neutralinos, which are trapped uniformly in the NS core.
- The lightest CP-even eigenstate of the NMSSM has been taken as the mediator Higgs boson, because within NMSSM, scattering cross section of the DM particle with nuclei satisfies the DAMA results.
- The EOSs of NS are generated using the E-RMF Lagrangian density with G3, IOPB-I, and NL3 parameter sets.
- **Out of the three EOSs considered here, G3 is the softest one, and predicts relatively small values of NS observables in agreement with the GW170817 results.**

Conclusion

- We have analyzed the effect of a DM core on the properties of NS.
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- **Out of the three EOSs considered here, G3 is the softest one, and predicts relatively small values of NS observables in agreement with the GW170817 results.**

Conclusion

- **We have observed that the presence of DM inside NS core soften the EOSs, which result in lowering the values of NS observables, such as mass, radius, tidal deformability, and even the moment of inertia.**
- We have imposed the constraints from GW170807 on the mass, λ_2 values, dimensionless tidal deformability Λ and MI of NSs.
- **The chirp mass may highly be affected by DM core inside NS, which may result in two or three additional peaks in the frequency curve of GWs (work has been planned).**
- **These additional peaks can be detected in near future, and so, NSs may be one of the finest indirect tools to detect DM.**

Acknowledgment

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- Thankful to DST for providing financial support in the form of INSPIRE fellowship to carry out this work.
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Thank You....

Back up

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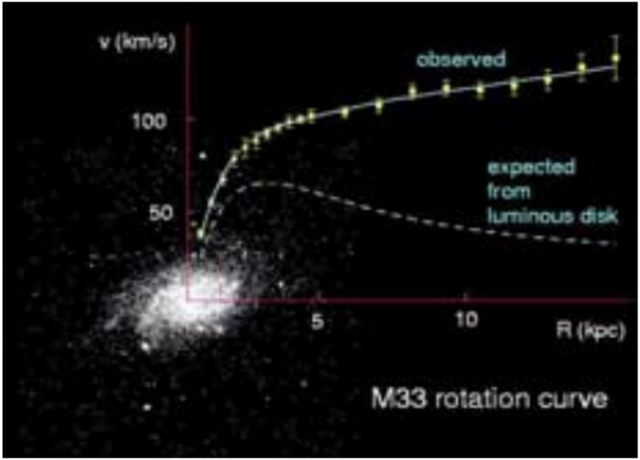

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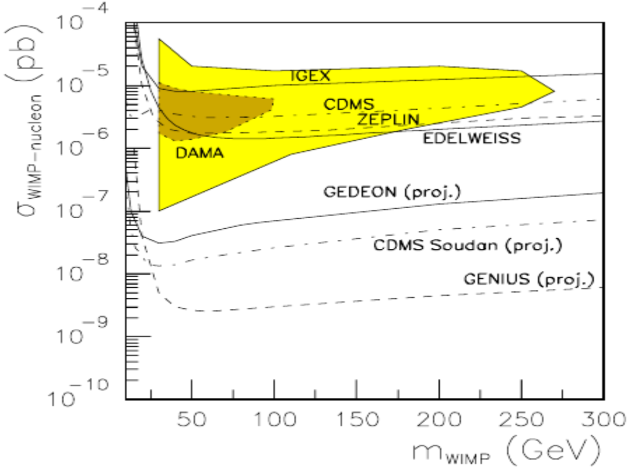
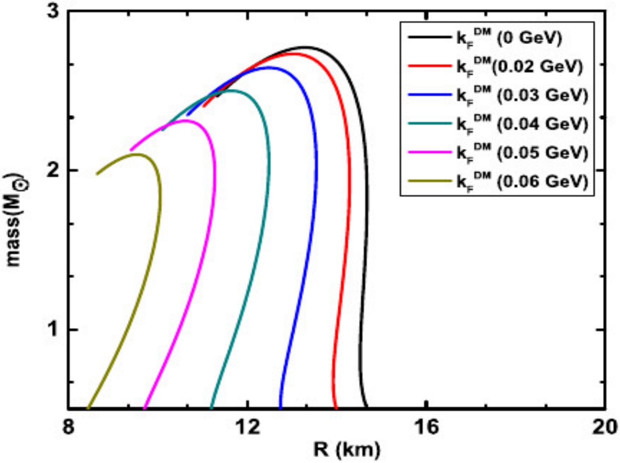

$\sigma_{WIMP-nucleon}$ (pb)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
IGEX
CDMS
ZEPLIN
EDELWEISS
DAMA
GEDEON (proj.)
CDMS Soudan (proj.)
GENIUS (proj.)
50
100
150
200
250
300
m_{WIMP} (GeV)

◀ Go back

SMHiggs

arXiv:1807.10013v1 [hep-ph].



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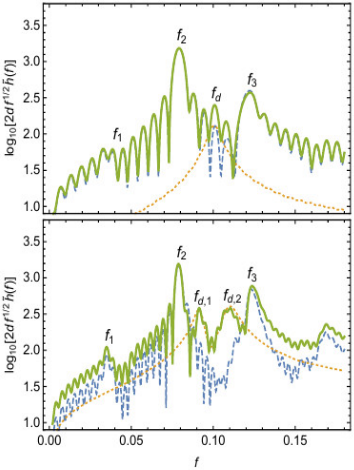

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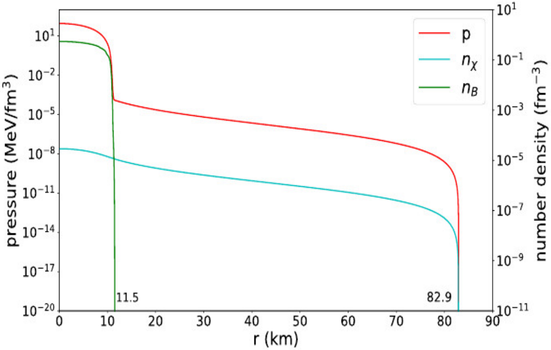

1.4 M_{solar} Neutron star with 10^{-4} M_{solar} of dark matter.

Dark matter: m_χ = 100 MeV

Interactions: g_χ/m_Φ = (0.5/MeV) or (0.5x10^{-6}/eV)

◂ Go back