Exploring Neutron Stars Potential to Constrain the Mass of Bosonic Dark Matter

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Abstract

This study investigates the potential of a bosonic particle called the sexaquark (uuddss) as a dark matter candidate, focusing on its viability under certain density conditions within neutron stars. We determine lower and upper mass boundaries for this bosonic dark matter based on observational constraints for neutron stars.

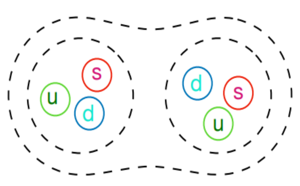
Introduction

Whether a Sexaquark is a candidate for dark matter or not totally depends on its mass.

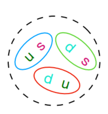
- S is a neutral boson in spin-color-flavor-singlet state
- This exotic particle is proposed to be consist of 3 scalar diquarks (ud, us, ds)
- Baryon number = 2, Strangeness= −2
- **S≡ Λ Λ** $m_{\Lambda\Lambda} = 2231$ MeV
- The lowest channel for Λ decay:

$\Lambda \rightarrow p + e + \bar{\nu}$
$m_\Lambda + m_p + m_e$= 1115.5+938+0.5= 2054 MeV
$2\,(m_p + m_e) = 2(938 + 0.5) = 1877$ MeV

- If 2054 MeV $< m_s <$ 2231 MeV it decays
- If $m_s \leq (m_\Lambda + m_p + m_e) = 2054$ MeV: it will decay with a lifetime more than the age of the universe
- If $m_s \leq 2(m_p + m_e) = 1877$ MeV : S is an absolutely stable particle



- If S is a Molecule state, ΛΛ, since Λ is a color neutral particle, Λs can be bound only by exchange color neutral particles like mesons



- If S is a complex system of 3 colored diquark, these objects should interact via color force which is much stronger than meson exchange force at short distances.

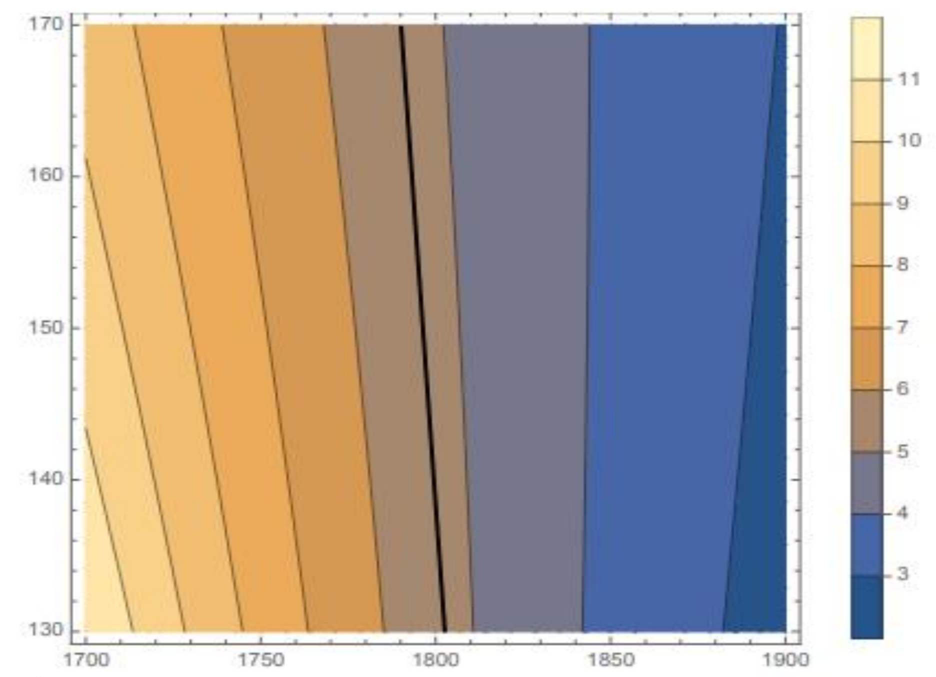


Fig. 1 $^{\Omega_{DM}}/_{\Omega_{bm}}$ versus M_S in MeV and the effective transition temperature in MeV [1].

$^{\Omega_{SDM}}/_{\Omega_{bm}}$ has been found in a good agreement with the measured ratio $^{\Omega_{DM}}/_{\Omega_{bm}} = 5.3 \pm 0.1$

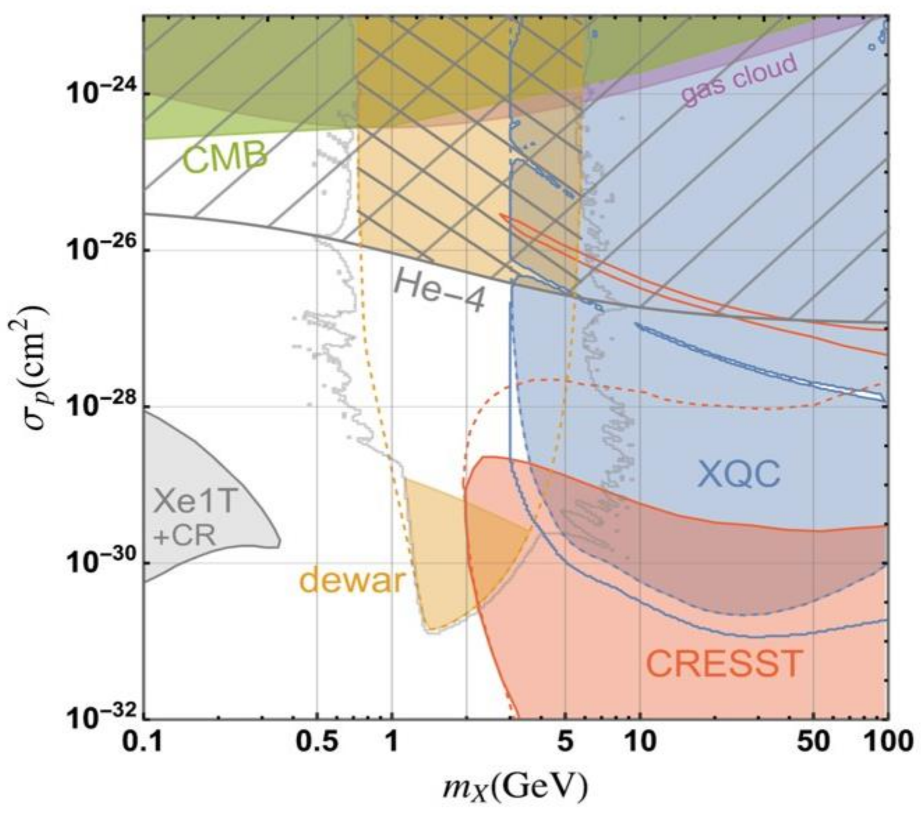


Fig. 2 DM-Baryon scattering cross section versus DM mass. Colored regions are excluded [2].

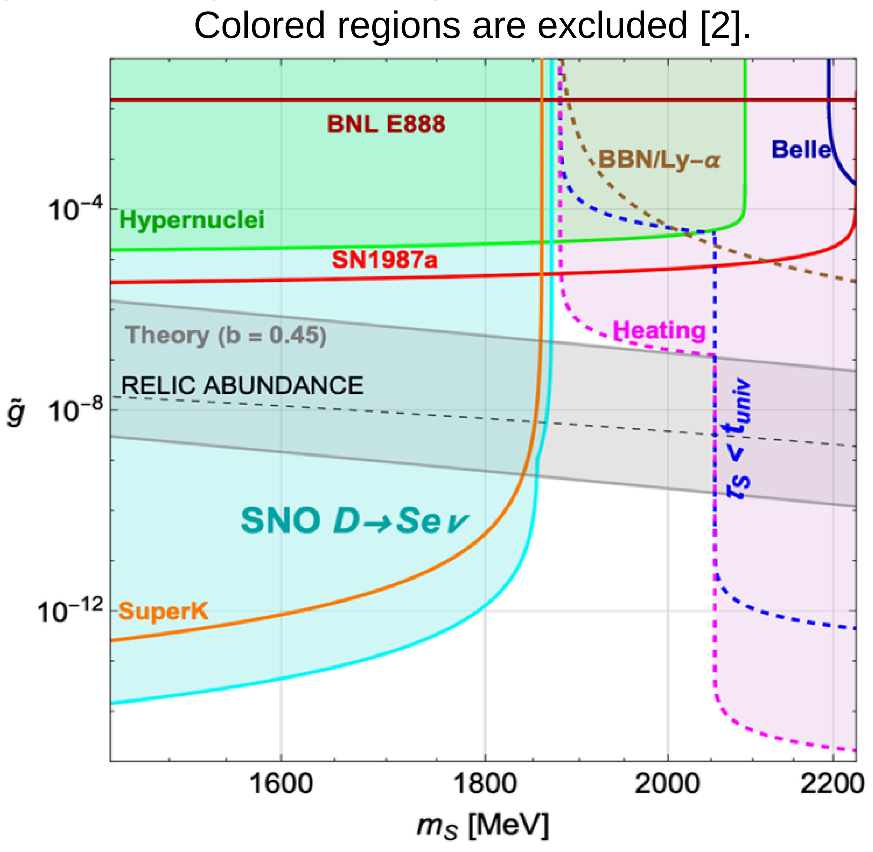


Fig. 3 The interconversion amplitude of S to two baryons. Colored regions are excluded [3].

Results and discussion

Lower limit constraint on the mass of Sexaquark based on a relativistic density functional approach (DD2Y-T)

$$\mu_i = B_i\mu_b + Q_i\mu_q + S_i\mu_s + L_i\mu_l$$

$$n_B = \sum_i B_i n_i^{(v)} = n_p^{(v)} + n_n^{(v)} + n_\Lambda^{(v)} + n_{\Sigma^+}^{(v)} + n_{\Sigma^0}^{(v)} + n_{\Sigma^-}^{(v)} + n_{\Xi^0}^{(v)} + n_{\Xi^-}^{(v)} + 2n_S^{(v)}$$

$$S_S = -\Delta m_S \quad \& \quad \Delta m_S = m_S\left(1 + x_S\frac{n_B}{n_0}\right)$$

$$f = \varepsilon = \Omega + \sum_i \mu_i n_i^{(v)}$$

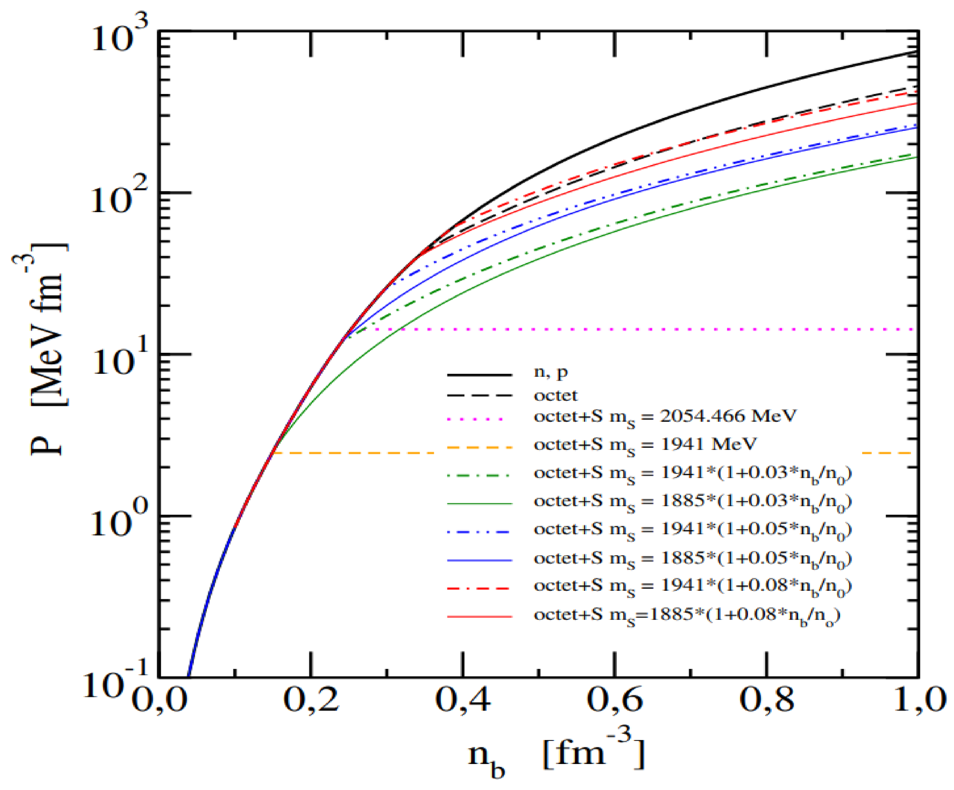


Fig. 4 EoS of hypernuclear matter with sexaquark [4].

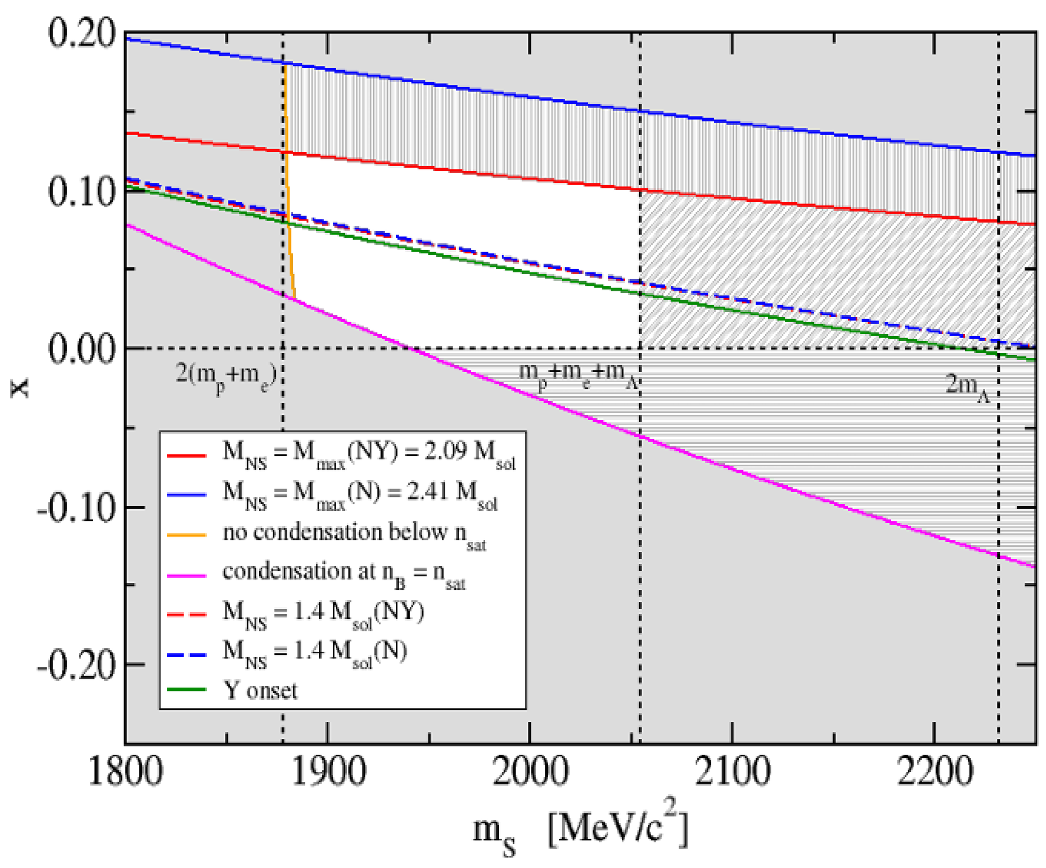


Fig. 5 Allowed (white) and excluded (light and dark grey) regions in the plane of m_S and x values as defined by constraints on the sexaquark condensation both at saturation density and high densities where NSs observables can constraint the EoS. [4].

Sexaquark with a minimum mass of 1885 MeV and minimum value of x = 0.03 can appear in the core of a stable NS.

Higher Mass Limit within hybrid stars

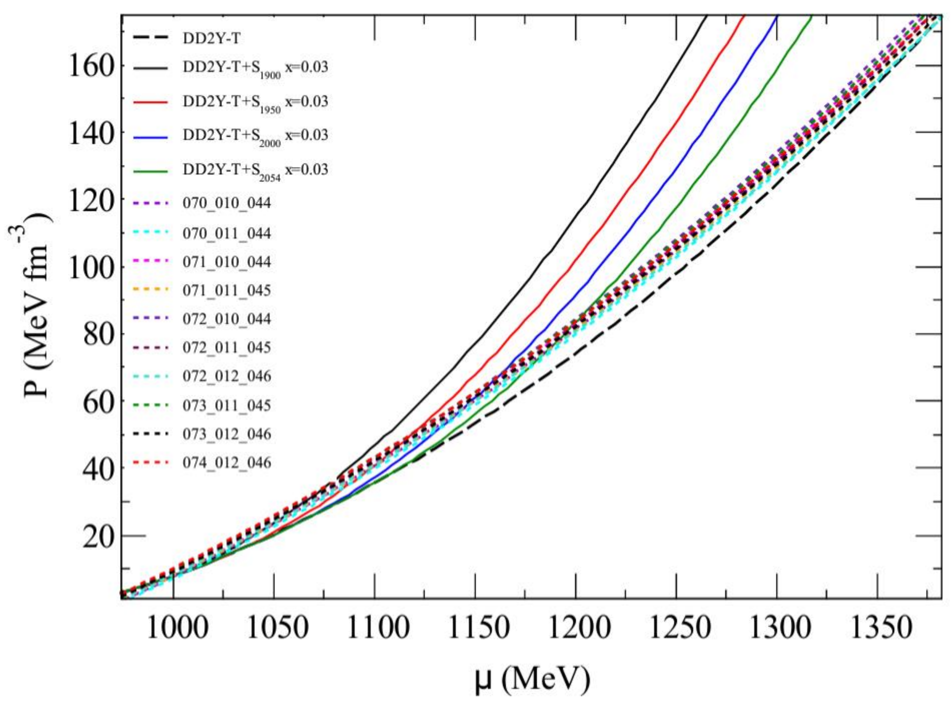


Fig. 6 Pressure vs chemical potential for hadronic matter EoS with sexaquark and quark matter EoS [5].

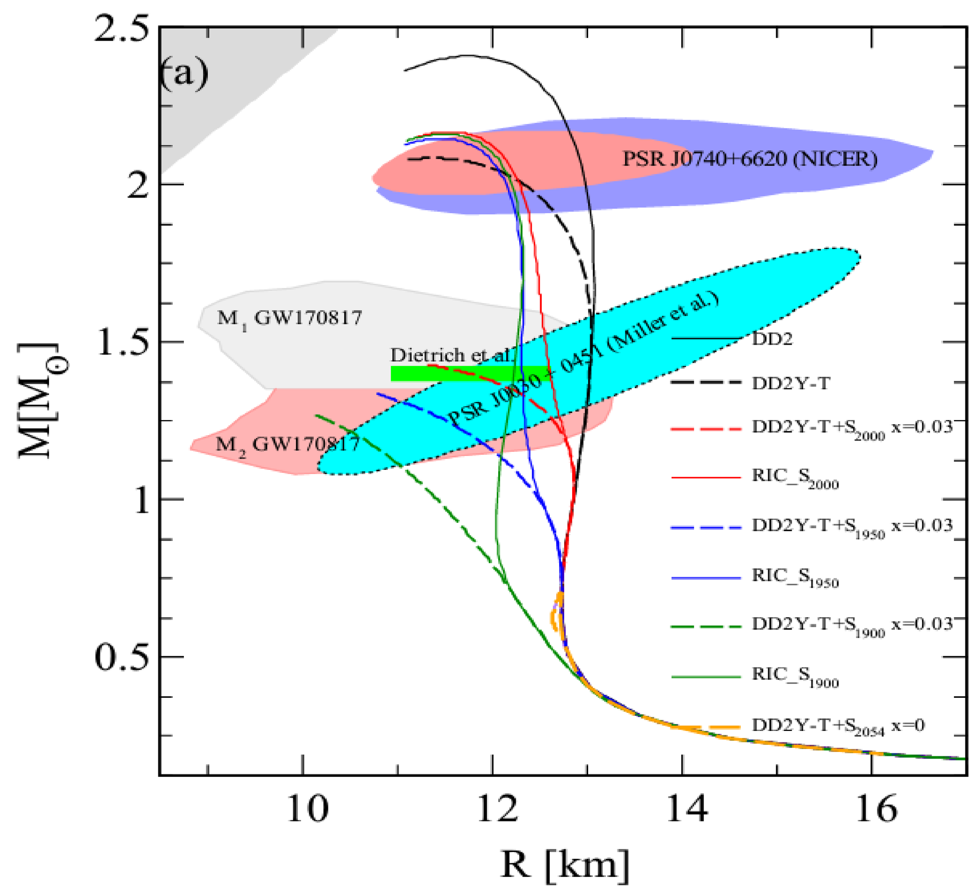


Fig. 7 Mass-Radius curves for compact stars with or without quark core [5].

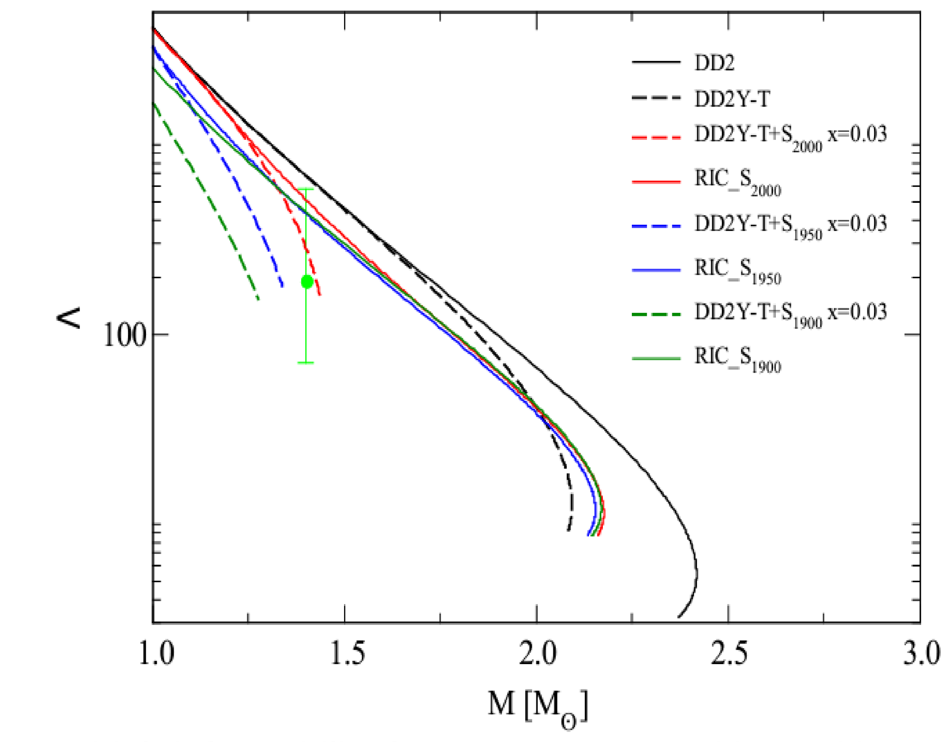


Fig. 8 Tidal deformability for compact stars with or without quark core [5].

The maximum mass of Sexaquark fulfilling NS constraints is 2000 MeV based on our model.

Conclusion

Incorporating a stable sexaquark configuration as a potential bosonic dark matter candidate, we examined its impact on neutron stars (NSs) observables using a relativistic density functional model. Hybrid stars, featuring a quark matter core and hypernuclear matter with strange DM, were modeled in agreement with the most recent observational constraints. We constrained the sexaquark vacuum mass (1885 < m_S < 2000 MeV) and highlighted the need for density-dependent mass adjustments for sexaquark to have stable NSs. However, conclusive evidence for sexaquark presence awaits NS cooling behavior analysis, emphasizing our phenomenological approach.

References

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[5] M. Shahrbaf, D. R. Karkevandi and S. Typel, Constraints on the mass of a bosonic dark matter candidate within the DD2Y-T model, [arXiv:2402.18686 [nucl-th]].

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