Quark Star Properties with Density Dependent Bag Model

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Introduction

The composition at the dense core of compact objects is still unknown. There are many propositions regarding possible composition. One possible candidate is strange quark matter (SQM). It is already known that energy per baryon number is lower in case of SQM (which is composed of u, d and s quarks) than that of pure nucleonic system. This suggests that SQM can be the possible ground state of matter at such high density. There are many models to describe such strange quark stars (SQSs), MIT Bag model being the first one.

In this work, we consider the original MIT Bag Model. As quarks enjoy asymptotic freedom at high density, the bag pressure is justifiably density dependent rather than being constant [1, 2]. So here density dependent bag pressure $B(\rho)$ is invoked in the form of Gaussian distribution function involving three parameters [1]. We investigate the impact of variation of these parameters on structural properties of SQSs by varying one parameter at a time keeping the other two fixed. We try to obtain a allowed range of these parameters constrained by Bodmer-Witten conjecture for stability of SQSs and different observational and astrophysical limits.

Formalism

For SQSs to be stable and SQM to be the ground state of such dense objects, there is an upper limit on allowed values of bag constant B (based on Bodmer-Witten conjecture),

$$\epsilon/\rho_B \leq \ 930 \text{ MeV} \tag{1}$$

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where ϵ and ρ_B are energy density and baryon density respectively at the surface of SQSs and 930 MeV is the binding energy of iron [3, 4]. The lower bound is obtained with 2 flavor QM.

The density dependence of the bag constant is given by Gaussian distribution

$$B(\rho) = B_{as} + (B_0 - B_{as}) \exp[-\beta(\rho/\rho_0)^2] \tag{2}$$

where B_{as} is asymptotic freedom parameter, $B_0 = B(0)$, β controls the fall of $B(\rho)$ with ρ and ρ_0 is nuclear saturation density. We consider the second term of RHS of equation 2 as

$$\Delta B = B_0 - B_{as} \tag{3}$$

We obtain EoS of SQM with different combinations of (B_{as}, ΔB and β) and compute the structural properties of SQSs using the Tolman-Oppenheimer-Volkoff (TOV) equations.

Results

It is seen that higher values of β and ΔB make $B(\rho)$ closer to the B=constant case. Therefore we choose moderate values of each parameter. For different combinations of (B_{as}, ΔB and β) we first perform the stability check, which helped us to discard a large number of combinations. Among the combinations that survived the stability test, each parameter was varied at a time to obtain the structural properties of SQSs with respect to the various astrophysical constraints. We checked for a large number of such combinations of (B_{as}, ΔB and β) and here we present as example the results obtained with a few such chosen combinations.

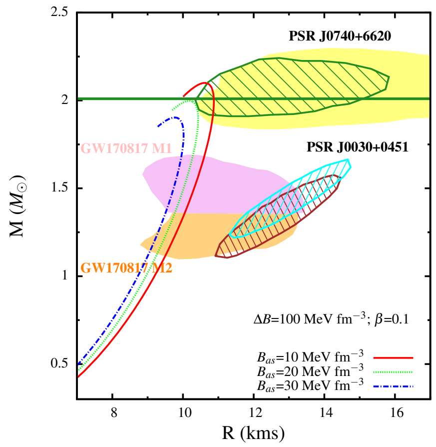

FIG. 1: Mass-radius relationship of QSs for variation of B_{as} keeping ΔB and β fixed.

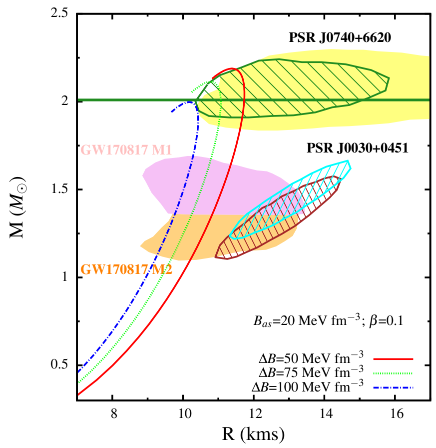

FIG. 2: Mass-radius relationship of QSs for variation of ΔB keeping B_{as} and β fixed.

Considering the results we find that overall, the SQS configurations are massive enough to satisfy the maximum mass constraint from PSR J0740+6620 and its corresponding predicted radius. Moreover, the constraint from GW170817 is also well-satisfied with the various combinations of (B_{as}, ΔB and β). However, the NICER data for PSR J0030+0451 is largely violated by all the possible combinations of (B_{as}, ΔB and β) that survived the stability test.

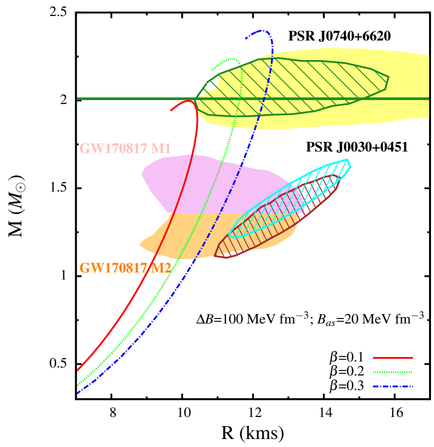

FIG. 3: Mass-radius relationship of QSs for variation of β keeping B_{as} and ΔB fixed.

Summary

We computed of the structural properties of SQSs in the framework of MIT Bag model by considering the bag pressure to be density dependent. This dependence is obtained by using a Gaussian distribution form involving the parameters B_{as}, ΔB and β. The combinations of (B_{as}, ΔB, β) that survived the stability test were used to obtain the structural properties of SQSs by varying one among the three parameters at a time and keeping the other two fixed. Rigorous check showed that none of the combinations of (B_{as}, ΔB, β) could satisfy the NICER data for PSR J0030+0451 although the other astrophysical constraints on the $M - R$ plane are well satisfied. Thus the NICER data for PSR J0030+0451 serves as a vital constraint to conclude that SQSs with density dependent bag pressure may be massive enough but too low in radius.

References

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