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Tidal Love Number as a Distinguishing Feature between a Boson Star and a Fermion Star

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Abstract. The paper analyzes tidal behaviour to distinguish between a boson star and a fermion star. The authors assume two different stellar compositions of identical mass and radius: one composed of a self-interacting scalar field (boson star) and the other composed of fermions (quark star). The model parameters of the equation of state (EOS) describing the material composition of the two configurations are so chosen that the resultant stellar configurations take identical values of mass and radius. The tidal behaviour of the stellar compositions is then examined. In particular, the tidal Love Numbers are calculated for the two different configurations which show distinct behavior. The study highlights the significance of tidal Love Number as a distinguishing feature between a boson star and a fermion star.

Keywords: boson star, quark star, tidal love number

Introduction. A boson star is a self-bound system composed of self-interacting real or complex scalar field whose mass and radius can be made comparable to that of a neutron star or a quark star. The question then arises: how can we distinguish a boson star from that of a fermion star of equal compactness? In this paper, we propose a novel method to distinguish between a boson star and a fermion star by analyzing the tidal behaviour of two stars. It should be stressed that the current era of multi-messenger astronomy has opened up new windows of opportunity to constrain the EOS of a compact star. In particular, the gravitational waves data provide valuable insight into the structure and matter composition of a compact star. Estimation of the tidal deformability of a star, characterized by the tidal Love Number (tLN), is one such avenue through which one may gain valuable information about the composition and structure of a compact star. Note that tLN increases from zero to higher values depending on the difficulty level in deforming a body subjected to an external gravitational field.

Methods and materials; results. We consider the X-ray pulsar Her X-1 as a test body for our analysis. Her X-1 is estimated to be a highly compact star and consequently, many authors have suggested it to be composed of quarks [1–4]. It has also been suggested that Her X-1 might be a di-quark star, i.e., a boson star described by a self-interacting scalar field [5, 6]. Consequently, we consider two different EOS to describe the pulsar Her X-1: EOS corresponding to a self-interacting scalar field (boson star) and EOS corresponding to a fermionic matter (quark star).

In our calculation, we use the EOS developed in reference [7] for the bosonic configuration and use the MIT bag model type linear EOS for the quark star configuration. Using the EOS, we numerically integrate the Tolman-Oppenheimer-Volkoff (TOV) equations to calculate the mass and radius of the star. In this method, the model parameters are fixed so that in the both cases, identical masses and radii are obtained, which lie well within the estimated mass and radius of the pulsar Her X-1 [8]. The data set is then used to calculate the tLN [9]. It is interesting to note that even though we have two different stellar compositions providing identical mass and radius, they show distinct tidal behavior. The tLN for the bosonic configuration is estimated to be 0.057 which is more than its fermionic counterpart which is 0.035.

Conclusion. Our analysis shows that tidal behaviour can be used to distinguish between a boson star and a fermion star. It is noteworthy that while the tLN is zero for a black hole, it is expected that a bosonic configuration should experience more tidal deformation than a fermion star which is confirmed by our numerical analysis.

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