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Phase transitions in neutron star and magnetars and their connection with high energetic bursts in astrophysics

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Abstract

The phase transition from normal hadronic matter to quark matter in neutron stars (NS) could give rise to several interesting phenomena. Compact stars can have such exotic states up to their surface (called strange stars (SS)) or they can have quark core surrounded by hadronic matter, known as hybrid stars (HS). As the state of matter of the resultant SS/HS is different from the initial hadronic matter, their masses also differ. Therefore, such conversion leads to huge energy release, sometimes of the order of 10^{53} ergs. In the present work we study the qualitative energy released by such conversion. Recent observations reveal huge surface magnetic field in certain stars, termed magnetars. Such huge magnetic fields can modify the equations of state (EOS) of the matter describing the star. Therefore, the mass of magnetars are different from normal NS. The energy released during the conversion process from neutron magnetar (NM) to strange magnetar/hybrid magnetar (SS/HS) is different from normal NS to SS/HS conversion. In this work we calculate the energy release during the phase transition in magnetars. The energy released during NS to SS/HS conversion exceeds the energy released during NM to SM/HM conversion. The energy released during the conversion of NS to SS is always of the order of 10^{53} ergs. The amount of energy released during such conversion can only be compared to the energy observed during the gamma ray bursts (GRB). The energy liberated during NM to HM conversion is few times lesser, and is not likely to power GRB at cosmological distances. However, the magnetars are more likely to lose their energy from the magnetic poles and can produce giant flares, which are usually associated with magnetars.

Keywords: Stars: neutron; Stars: magnetic fields; Equation of state; Gamma ray: bursts

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1. Introduction

GRB are cosmic gamma ray emission distributed isotropically originating at extra galactic distances. They are inferred to have energy of the order of 10^{53} ergs. If the beaming and the γ-ray production of the GRB are quite high, then the central engine which powers such conversion can release energy to power GRB at cosmological distances. There are various models describing the central engine for GRB. Mergers of two NS or a NS and a black hole in a binary [1] being some popular models. However, recent calculation of Janka and Ruffert [2] had shown that the energy released in such neutrino–antineutrino annihilation is much smaller to account for the GRB, thought to be occurring at large cosmological distances. Therefore, the central engine which powers such huge energies in GRB still remains unclear.

On the other hand, the conversion of a NS to a QS liberates huge amount of energy, simply because the star mass changes during the conversion. Therefore, the mass difference of NS and QS manifest itself in the form of energy release. The first calculation of the energy release by such conversion was proposed by Alcock et al. [3] and Olinto [4]. More detailed similar calculation for the conversion of NS to SS/HS was done by Cheng and Dai [5], Ma and Xie [6] and subsequently by many others [7–13]. Almost all of them found the energy released to be greater than 10^{51} ergs, and connected them with the observed gamma ray bursts (GRB). However, new observation [14, 15] reveals the GRB to occur at cosmological distances. Therefore, energies of the order of 10^{51} ergs are too low to power GRB at such huge distances. A systematic calculation done by Bombaci and Datta [16], using various EOS, estimated the energy released during conversion to be of the order of 10^{53} ergs. Their main assumption was that the initial NS baryonic mass (BM) and the final NS BM is the same, the BM is conserved during such conversion. Their estimation of the energy release can power GRB to such large distances and was in agreement with the observed GRB. However, during the conversion there can be ejection of matter from the outer layers of the star due to several shock bounce. The matter ejected is usually assumed to be low, but Fryer and Woosley [17] showed that the matter ejected can be as high as 0.2 solar mass. For such a scenario the assumption of baryonic mass conservation does no longer hold.

The above calculation of energy release depends on the fact that some of the compact stars are really exotic and quark stars (QS either SS or HS) do really exist. However, the recent measurement [18,19] found the pulsars to have a very high mass, $M \sim 2M_{\odot}$. Pulsars with such high masses, for the first time, has imposed strict constraints in determining the equations of state (EOS) of matter describing compact stars. The EOS of quark matter usually has strangeness [20–22] and therefore, provides an additional degree of freedom. This extra degree of freedom softens the EOS, that is, the reduction of pressure for a given energy density. As a result, it becomes difficult for the quark EOS to generate stars with such high mass which satisfies the mass limit set by new measured heavy pulsars. However, new calculations have found that the effects due to strong interaction, such as one-gluon exchange or color-superconductivity can make the EOS stiffer and increase the maximum mass limit of SS and HS [23–28]. Ozel [29] and Lattimer [30] were the first to study the implications of the new mass limit for SS and HS within the MIT bag model. Therefore, the conversion of NS to QS (SS/HS) is still a viable scenario of astrophysical phase transition (PT).

The only other astrophysical events which can come close to the energy budget of GRB are the recently observed giant flares. Three giant flares, SGR 0526-66, SGR 1900+14 and SGR 1806-20 [31] have been detected so far. The huge amount of energy in these flares can be explained by the presence of a strong surface magnetic field, whose strength is estimated to be larger than 10^{14} G, and such stars are termed magnetars. Simple calculation suggests that the magnetic fields in