Superbursts and long bursts as surface phenomenon of compact objects.

Monika Sinha\textsuperscript{a}, Mira Dey\textsuperscript{a}, Subharthi Ray\textsuperscript{b}, Jishnu Dey\textsuperscript{c,}\textsuperscript{*}

\textsuperscript{a}Dept. of Physics, Presidency College, 86/1 College Street, Calcutta 700 073, India

\textsuperscript{b}Inter University Centre for Astronomy and Astrophysics, Post bag 4, Ganeshkhind, Pune 411007, India

\textsuperscript{c}Azad Physics Centre, Dept. of Physics, Maulana Azad College, Calcutta 700 013, India

Abstract

We suggest that superbursts from some low mass X-ray binaries may be due to breaking and re-formation of diquark pairs, on the surface of realistic strange stars. Diquarks are expected to break up due to the explosion and shock of the thermonuclear process. The subsequent production of copious diquark pairing may produce sufficient energy to produce the superbursts.

Key words: dense matter, elementary particles: diquarks, stars: superburst

PACS: 14.65.-q, 95.85.Nv, 96.60.Rd, 97.80.Jp, 98.70.Qy

1 Introduction

Type-I X-ray bursts from Low Mass X-ray Binary systems are believed to be due to thermonuclear fusion. The duration of such bursts is typically of the order of seconds to minutes. Recently some such Type-I X-ray bursters show bursts 1000 times longer in duration and 1000 times more energetic than typical type-I X-ray bursts. That is why they are known as superbursts. Till date superbursts have been observed from eight different sources. Two of them showed repeated superbursts. It should be mentioned that recently repeated superbursts have been observed from the source GX 17+2 with luminosity

\textsuperscript{*} present address: Department of Physics, Presidency College, 86/1 College Street, Kolkata 700073, India
near Eddington luminosity [1] while all other sources have luminosity \( \sim (0.1 - 0.3) \times L_{Edd} \), \( L_{Edd} \) being the Eddington luminosity.

There are models of superbursts for neutron stars in terms of unstable carbon burning [2,3]. But there is disparity between the superburst energies and recurrence time observed and the energies and recurrence time predicted by theoretical models.

We have employed the Realistic Strange Star (ReSS) model [4] to get a good estimate of the large amount of energy liberated in a superbursts. We suggest that diquarks present on the ReSS surface are expected to break up due to the explosion and shock of the thermonuclear processes. The subsequent production of copious diquark pairing may liberate sufficient energy to produce the very long bursts observed.

2 The spin-spin potential and interaction energy

The quark-quark interaction has a spin dependent component which can be obtained either from one-gluon exchange between quarks or from the instanton induced interaction. This part of the potential is of delta function range which can be transformed to a smeared potential by introducing the idea of either a finite glue-ball mass or a secondary charge cloud screening as in electron-physics [5].

The form of the potential is given below:

\[
H_{ij} = - \frac{2\alpha_s \sigma^3}{3m_i m_j \pi^{1/2}} (\lambda_i \cdot \lambda_j) (S_i \cdot S_j) e^{-\sigma^2 r_{ij}^2}.
\]  

(1)

The factor \( \frac{\sigma^3}{\pi^{1/2}} \) normalizes the potential. In this equation \( \alpha_s \) is the strong coupling constant, and the subscripted \( m, \lambda \) and \( S \) are the constituent masses, colour matrices and spin matrices for the respective quarks.

For this spin dependent interaction quarks on the ReSS surface will form diquarks.

For \( N - \Delta \) mass difference (i.e. in \( u-d \) sector) Dey et al. [6] found that this gives \( \sigma \) varying from 6 to 2.03 \( fm^{-1} \) for a set of \( \alpha_s \) 0.5 to 1.12. The parameters we have used are given in Table 1.

Anti-symmetry of flavour symmetric di-quark wave function requires that while space part is symmetric, di-quark must be either in spin singlet and colour symmetric (6) state, or in spin triplet and colour anti-symmetric (3)
Table 1
Parameters of the Gaussian Potential

| Sets | 1  | 2  | 3  | 4  | 5  | 6  |
|------|----|----|----|----|----|----|
| $\alpha_s$ | 0.5 | 0.5 | 0.87 | 0.87 | 1.12 | 1.12 |
| $\sigma (fm^{-1})$ | 6.0 | 4.56 | 0.87 | 2.61 | 6.0 | 2.03 |

state. In both cases spin-spin force is repulsive$^1$ and formation of pair is inhibited.

For flavour anti-symmetric di-quarks, however, the situation is the opposite. Colour symmetric (6) configuration is associated with the spin triplet so that $(\lambda_i, \lambda_j)(S_i, S_j) = 1/3$ and colour anti-symmetric state (3) goes with the spin singlet which gives $(\lambda_i, \lambda_j)(S_i, S_j) = 2$. With overall negative sign in the potential (Eq.1) these channels produce attraction. Hence there is a probability for example of $u, d$ quarks to pair up predominantly in spin singlet state. The effect of this can be found easily in our model since we know the distribution of the $u$ and $d$ quarks in the momentum space and their Fermi momenta are uniquely determined from precise and lengthy calculations satisfying beta stability and charge neutrality.

In addition to spin-colour contribution the potential (Eq.1) is evaluated in the momentum space. Thus on average the contribution of a pair can be found as:

$$-rac{1}{2}(\lambda_i, \lambda_j)(S_i, S_j) \frac{2\alpha_s \sigma^2 \pi}{3m_i m_j} \frac{n_u + n_d}{n_u n_d} \frac{6 \times 2}{(2\pi)^4} I.$$  \hspace{1cm} (2)

where $n_u$ and $n_d$ are number density of $u$ and $d$ quarks respectively at the star surface.

Here

$$I = \int_{k_{fu}}^{k_{fd}} \int_{k_{fd}} \int_{-1}^{1} f(k_u, k_d, \theta) k_u^2 dk_u \int_{k_{fu}}^{k_{fd}} \int_{-1}^{1} f(k_u, k_d, \theta) k_d^2 dk_d \int_{0}^{1} d(cos \theta_d)$$  \hspace{1cm} (3)

and

$$f(k_i, k_j, \theta) = 1 - \exp \left( \frac{-k_i^2 + k_j^2 - k_i k_j \cos(\theta_{ij})}{\sigma^2} \right)$$  \hspace{1cm} (4)

$^1$ Private communication, R. K. Bhaduri.
where subscripted $k$’s are momenta of interacting quarks and $k_{fi}$’s are Fermi momenta for $i$-th species of quark at star surface.

These correlation energies for different sets of parameters (see Table 1) are given in Table 2.

Table 2
Integrated values for the pairing energy Eq.(1) for different pairs for spin singlet (colour $\bar{3}$) states in MeV. For spin triplet (colour 6) state the energies will be six times less.

| Sets | 1    | 2    | 3    | 4    | 5    | 6    |
|------|------|------|------|------|------|------|
| pairing energy | -23.578 | -23.287 | -41.025 | -38.225 | -52.814 | -46.636 |

3 Conclusions

The interaction producing a coloured diquark in spin zero state, for example, is a strong one and its overall effect is lowering of energy by a few $MeV$. Once the pairs are misaligned during normal burst their recombination may provide bursts over several hours with energy release estimated to be large. The estimated total energy liberated, $10^{42}$ ergs, can be explained in our model with the calculated pair density $\sim 0.27/fm^3$ and a surface thickness of only a micron, if the entire surface is involved.

It is intriguing to surmise that the elusive properties of some of the most compressed objects in nature namely the compact stars, showing superbursts, may be accounted for by the spin alignment of pairs of the smallest components of matter, – namely the quarks.

References

[1] J. J. M. in ‘t Zand, R. Cornelisse & A. Cumming, Astron. & Astrophys. 426, 257 (2004).
[2] T. E. Strohmayer & E. F. Brown, Astrophys. J. 566, 1045 (2002).
[3] A. Cumming & L. Bildsten, Astrophys. J. Lett. 559, 127 (2001).
[4] M. Dey, I. Bombaci, J. Dey, S. Ray & B. C. Samanta, Phys. Lett. B 438, 123 (1998) ; Addendum 447, 352 (1999) ; Erratum 467, 303 (1999).
[5] R. K. Bhaduri, L. E. Cohler & Y. Nogami, Phys. Rev. Lett. 44, 1369 (1980).
[6] J. Dey & M. Dey, Phys. Lett. B 138, 200 (1984).