

# Superbursts and long bursts as surface phenomenon of compact objects.

Monika Sinha <sup>1, 2 ‡</sup>, Mira Dey <sup>1, 3 †</sup>, Subharthi Ray <sup>4††</sup> & Jishnu Dey <sup>2, 3 †</sup>

<sup>1</sup> Dept. of Physics, Presidency College, Calcutta 700 073, India

<sup>2</sup> Azad Physics Centre, Dept. of Physics, Maulana Azad College, Calcutta 700 013, India

<sup>3</sup> Senior Associate, IUCAA, Pune, India

<sup>4</sup> Theoretical Physics Division, Physical Research Laboratory, Navrangpura, Ahmedabad 380 009, India

†† e-mail: sray@prl.ernet.in

† permanent address; 1/10 Prince Golam Md. Road, Calcutta 700 026, India; e-mail: deyjm@giasl01.vsnl.net.in.

Work supported in part by DST grant no. SP/S2/K-03/2001, Govt. of India.

‡ CSIR Net Fellow.

27 July 2021

## ABSTRACT

X-ray bursts from compact stars is believed to be due to type I thermonuclear processes which are short lived, typically  $\sim 10$  to  $100$  s. There are some low mass X-ray binaries (LMXB) like 4U 1820–30, 4U 1636–53, KS 1731–260 and Serpens X-1, known as Super Bursters (SB) which emit X-rays close to the Eddington luminosity limit for long periods of several hours. Recently there are reports of some long bursters (LB), which have bursts lasting 6-25 minutes (Kuulkers et al. 2002b) whereas the 4U 1735–44 has a burst period of 86 minutes (Cornelisse et al, 2000). The full explanation of type I bursts in these stars is somewhat problematic, in so far as bursts become less frequent and energetic as the global accretion rates increase, as discussed by Bildsten recently (2000).

We suggest that these bursts from SB and LB may be due to breaking and re-formation of diquark pairs, on the surface of realistic strange quark stars (ReSS). We use the beta equilibrated u, d and s quark model of Dey et al. (1998) (D98) and Li et al. (1999a (Lia) and 1999b (Lib)) and allow for spin dependent hyperfine interaction between quarks. The interaction produces pairing of specific colour-spin diquarks, leading to further lowering of energy by several  $MeV$ -s for each pair, on the average.

Diquarks are expected to break up due to the explosion and shock of the TN process. The subsequent production of copious diquark pairing may produce sufficient energy to produce the very long bursts seen in SB or LB. We do not claim to be able to model the complicated process in full. However the estimated total energy liberated,  $10^{42}$  ergs, can be explained in our model with the calculated pair density  $\sim 0.275/fm^3$  and a surface thickness of only half a micron, if the entire surface is involved. The depth of the surface involved in the process may be only few microns if the process is restricted to small part of the surface near the equator as suggested by Bildsten (2000).

If SB and LB are surface phenomenon, then recurrent superbursts found by 4U 1636–53 by Wijnands (2001) at an interval of 4.7 year and the quick cooling of KS 1731–260 (Kuulkers et al 2002b) could be natural in this model (Wijnands et al. 2001 and 2002).

**Key words:** dense matter – elementary particles: diquarks – stars: superburst

## 1 INTRODUCTION

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.

Recently there has been lot of activity centered around the possibility of lowering of the spin zero state of a diquark in dense matter (see for example the review by Rajagopal &

Wilczek (2000) and references therein). There has also been the suggestion that diquarks may be present (Bhalerao & Bhaduri 2000) like droplets, i.e. with total negative energy rather than just a negative correlation energy as in a superconducting pair.

The large  $N_c$  expansion, for the number of colours  $N_c$ , suggests a tree level mean field calculation for quark matter. Using a realistic two quark potential within this scenario leads to realistic strange stars (ReSS) which are self bound. The matter has a minimum energy at a density which is high ( $\sim 4$  to  $5$  times the normal nuclear matter density,  $\rho_0 = 0.17/fm^3$ ) as shown in D98. We now estimate the spin correlations in this matter, which is washed out in the mean field approximation of D98, being a  $1/N_c$  effect, by a simple perturbative calculation using various sets of smeared spin-spin interaction which were tested out for the isobar-nucleon mass difference in Dey and Dey (1984).

The importance of the exercise may be far-reaching, in so far as there is a rich plethora of unexplained phenomena in the X-ray emission pattern of compact stars. For example the compact object claimed to be ReSS (Lia), the SAX J1808.8–3658, show erratic luminosity behaviour and a very long burst time (Wijnands et al. 2001b). The recent discovery of the compactness of RXJ 1856.5–3754 also supports the possibility of strange stars (Drake et al, 2002)

We suggest that the structure of the surface of the star may be as important as the nature of the accretion disk variations in explaining these phenomena.

It is worth noting that according to Kapoor and Shukre (2001), even radio pulsars are so compact that it is difficult to explain their mass and radius from neutron star models. They prefer ReSS.

## 2 THE ASTROPHYSICAL PROBLEM, SUPER BURSTERS.

Type - I X - ray bursts in LMXB systems are characterized by fast rise times (of the order of seconds), long decay times (seconds to minutes), spectral softening during the bursts, and recurrence times of hours to days. In contrast, the physics behind long lasting ‘super bursts’ seen recently in several stars is not yet well known, which is mostly a result of the very recent discovery of such bursts and the limited information available about them (Wijnands 2001). The first superburst was reported by Cornelisse et al (2000) from the LMXB 4U 1735–44 in 2000. Wijnands (2001) reported two superbursts for 4U 1636–53 and Heise et al. (2000) for KS 1731–4260 and Serpens X-1. For 4U 1636–53 two clear superbursts have been observed, although some of the smaller flares seen might also be related to superburst phenomenon (Wijnands 2001).

Spin alignment may be spoiled during the prolonged strong accretion and the shock of the thermonuclear bursts<sup>1</sup>. The realigning of the spin zero diquarks could be a very natural scenario for the superbursts, - which will be a slower process, since the u, d, s quark and electron percentages are equilibrated with the beta stability and charge neutrality

conditions involving slower weak and electromagnetic processes. The diquark energy lowering is a strong process and the magnitude of energy release is of the same order as that of a thermonuclear reaction (TR).

The mechanism for superburst that we suggest is outlined below :

compact stars with a high rate of accretion undergo thermonuclear bursts lasting typically upto 20 seconds. During the high accretion and the TR, the quark pairs (in particular the ud pairs), - bound by the short range spin-spin interaction, - break. After a sufficiently long time (expected to vary substantially from star to star due to the statistical nature of the processes and also the variation of the surface conditions<sup>2</sup> - most of the pairs are broken and after a final TR, the pairs start realigning.

The realigning of pairs will lead to a prolonged emission of energy which may be transformed into X-rays leading to the superbursts. This time may also vary for the same reasons as above thus explaining the 86 min. superburst in 4U 1735–44 (Cornelisse et al. 2002), 4 hours in Serpens X-1 (Cornelisse et al. 2000) and half a day in KS 1731–260(Kuulkers et al. 2002b).

According to this scenario there will be a link with the extreme macro physics of compact stars of sizes of the order of kms and masses of the order of solar masses with small diquarks paired by a short range force of few  $fm$  and bound by few  $MeV$ . There is no time-scale limit in this model between two superbursts and one may assume that the 4.7 years gap between the two superbursts seen in 4U 1636–53, is the upper limit for the interval since due to the erratic sampling of RXTE/ASM which detected these bursts some intermediate bursts might have been missed or partly recorded (Wijnands 2001).

4U 1820–30 which was a candidate for ReSS in D98 also shows superbursts lasting 3 hrs and a very interesting model has been proposed to explain this Cummings and Bildsten (2001), Strohmayer and Brown (2001). These authors suggest that for this particular star, which they *assume* to be a neutron star, the superbursts are due to unstable carbon burning, the carbon being possible remnants from the ashes of a Helium thermonuclear burst buried deep down ( $\sim 10m$ ) in an ‘ocean’, mixed with iron.

This is in sharp contrast to our scenario where we find enough ud quark pairs, within depth of about  $10^{-5}$  cm of the high density star skin, to provide the energy of the burst (estimated by Strohmayer and Brown (2001) to be  $1.4 \times 10^{42}$  ergs equivalent to  $10^{47}$  MeV). The strongest constraint according to them on their scenario is that another such superburst should not be detected within a time scale less than a decade. So, if 4U 1820–30 shows another superburst within the next few months or years, the assignment of ReSS for this star D98 will find additional support from present considerations.

We thus find that our model admits of a rather attractive alternate solution to the problem which is also applicable to the other superbursters. It must be mentioned that

<sup>1</sup> or the conversion of the normal accreting matter into strange matter if one prefers the other scenario for the short initial burst, (Bombaci and Datta 2000)

<sup>2</sup> This time interval may be a few minutes [for example 6-25 minutes for the 10 superbursts observed in GX 17+2, Kuulkers et al. (2002a)], or several years [for example 4.7 years as in 4U 1636–53, Wijnands 2001]

Wijnands (2001) and (TB) agrees that carbon burning is unlikely for 4U 1636–53 since it seems to be a hydrogen-accreting source and carbon burning is more likely for helium-accreting sources.

In the next following sections we present our model in some details.

### 3 A BRIEF INTRODUCTION OF THE MODEL

The quark (q) star model described in D98, which is also the same model used here, is a realistic model of quark matter composed of three flavours u,d and s as well as electrons. In hadron spectroscopy, using a potential model, a realistic q-q interaction contains asymptotic freedom (short range) and confinement (long range). However, in the case of quark matter, confinement is softened by Debye screening which diminishes the attractive long range part. The effect of this screening increases with density so that deconfinement is further enhanced at high densities.

Another very important consideration is the quark masses. The general belief is that chiral symmetry tends to be restored at high density which means quarks become lighter. The density dependence of quark masses, therefore, is a reflection of the chiral symmetry restoration (CSR in short) of QCD at high density and can be alternatively represented as a density dependence of the strong coupling constant using simple Schwinger Dyson techniques. We refer the interested reader to Ray et al, 2000. The density dependence of quark masses, in this model, is taken care of by the ansatz :

$$M_i = m_i + M_Q \operatorname{sech}(\nu \frac{\rho_B}{\rho_0}), \quad i = u, d, s. \quad (1)$$

where  $\rho_B = (\rho_u + \rho_d + \rho_s)/3$  is the baryon number density,  $\rho_0 = 0.17 \text{ fm}^{-3}$  is the normal nuclear matter density, and  $\nu$  is a parameter. At high  $\rho_B$  the quark mass  $M_i$  falls from its constituent value  $M_Q$  to its current one  $m_i$  which we take to be (D98):  $m_u = 4 \text{ MeV}$ ,  $m_d = 7 \text{ MeV}$ ,  $m_s = 150 \text{ MeV}$ .  $M_Q \sim 310 \text{ MeV}$ . Possible variations of the CSR can be incorporated in the model through  $\nu$ .

With these two ingredients ( along with the constraints of  $\beta$  - equilibrium and charge neutrality) it is found that energy per baryon is lower than that of  $^{56}\text{Fe}$  and has a minimum at a density  $\sim 4$  to 5 times the normal nuclear density  $\rho_0$ . This is a relativistic mean field calculation with a central potential (screened Richardson potential) where only the Fock term contributes. Strange quark matter is thus self bound by strong interaction itself. The energy density and pressure of this matter lead to strange quark star through the TOV equation with mass and radius depending on the central density of the star.

Equations of state obtained for two different values of  $\nu$ , namely, eos1 and eos2, lead to different maximum masses of the stars and their corresponding radii. (Table 1). Also given in Table 1 is the energy/baryon of the strange quark matter to be compared with that of  $^{56}\text{Fe}$ .

The surface of the star starts at this high density of  $\sim 4$  to 5 times the normal nuclear density  $\rho_0$ . The density inside the star can be larger, the limit being  $\sim 15$  times at the core when gravitational instability sets in. Thus at the surface there are massive quarks (about 100 MeV for u,d and 250 MeV for s-quarks) whereas at the centre of a massive

**Table 1.** Properties of the maximum mass strange star configuration obtained for different forms for CSR :  $M_G$  is the gravitational (maximum) mass, R is the corresponding radius,  $n_c$  the central number density,  $\rho_c$  the central mass density. Our EOS for different choices of the parameters are denoted as follow: (eos1)  $\nu = 0.333$ ,  $\alpha_0 = 0.20$ ; (eos3)  $\nu = 0.333$ ,  $\alpha_0 = 0.25$ ; (eos3)  $\nu = 0.286$ ,  $\alpha_0 = 0.20$ . The reference for the binding per baryon B.E./A is 930.6 MeV for  $^{56}\text{Fe}$ .

EOS	$M_G$ ( $M_\odot$ )	R (km)	$n_c$ ( $\text{fm}^{-3}$ )	$\rho_c$ ( $10^{14} \text{ g/cm}^3$ )	B.E./A MeV
eos1	1.437	7.06	2.324	46.90	888.8
eos3	1.410	6.95	2.337	48.19	844.6

star with density  $\sim 10$  to 15 times the normal density  $\rho_0$  the masses approach the current quark masses 4,7 and 150 MeV for u,d and s respectively).

### 4 THE SPIN-SPIN POTENTIAL

The  $\Delta$  isobar is an isospin 3/2 of the spin 3/2 excitation of the nucleon seen at about 1232 MeV. To calculate nucleon and isobar mass difference (of about 300 MeV) we need a finite range spin spin interaction. Indeed, the quark-quark interaction has also 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 (Bhaduri et al, 1980).

The essential idea is to get a smeared Gaussian potential with a renormalized strength. The smearing and the strength can be obtained by fitting them to observables like nucleon-  $\Delta$  mass splitting and the magnetic dipole transition from  $\Delta$  to nucleon. We borrow the allowed sets from Dey & Dey, 1984.

The form of the potential is given below :

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

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

For u-d quarks Dey et al. (1984) found that this gives  $\sigma$  varying from 6 to 2.03  $\text{fm}^{-1}$  for a set of  $\alpha_s$  0.5 to 1.12. The parameters we have used are given in Table 2.

It is found that diquark binding depends strongly on the strength and range of spin-spin interaction which are interconnected via hadron phenomenology. This is irrespective of whether it is deduced from a the Fermi-Breit interquark force or an instanton - like four fermion interaction as talked of, for example, in Rajagopal et al.(2000).

**Table 2.** Parameters of the Gaussian Potential

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

## 5 THE EFFECT OF THE POTENTIAL ON DIQUARKS.

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 ( $\bar{3}$ ) state. In both cases spin-spin force is repulsive<sup>3</sup> 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 ( $\bar{3}$ ) goes with the spin singlet which gives  $(\lambda_i.\lambda_j)(S_i.S_j) = 2$ . With overall negative sign in the potential (2) 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, d and s 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.(2) is evaluated in the momentum space :

$$\frac{1}{4\pi^3} \frac{\alpha_s \sigma^2}{3 x \rho_0 3 m_i m_j} \int f(k) k_i^2 k_j^2 dk_i dk_j d\cos(\theta) \quad (3)$$

where  $x\rho_0$  is the density at the star surface where the energy per baryon is minimum ( $x = 4.586, 4.014$  for eos1, eos3):

$$f(k) = \frac{1 - \exp(-\frac{k^2}{\sigma^2})}{k^2} \quad (4)$$

and

$$k^2 = \frac{k_i^2 + k_j^2}{4} - \frac{k_i k_j \cos(\theta_{ij})}{2} \quad (5)$$

It is to be noted that Fermi momenta for u, d, s particles are different. Thus the contribution of a specific di-quark in the energy can be simply the integral (3) and the colour spin factor. Maximum contribution is around the Fermi surface though. These are given in Table (3).

Note that there is a difference between this energy and the conventional pairing, where the effect of a long-range potential is a shift which is found by solving the gap equation. This is more like a correlation energy for some of the paired diquarks in flavour anti-symmetric state.

**Table 3.** Integrated values for the pairing energy Eq.(2) 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.

EOS	Sets	$\alpha_s$	$\sigma$	diquark type		
				$fm^{-1}$	ud	ds
eos1	1	0.5	6.0	-3.84	-1.45	-1.23
	2	0.5	4.56	-3.79	-1.44	-1.22
	3	0.87	6.0	-6.68	-2.53	-2.22
	4	0.87	2.61	-6.22	-2.37	-2.02
	5	1.12	6.0	-8.59	-3.25	-2.76
	6	1.12	2.03	-7.59	-2.89	-2.48
eos3	1	0.5	6.0	-3.87	-1.40	-1.15
	2	0.5	4.56	-3.83	-1.39	-1.17
	3	0.87	6.0	-6.74	-2.44	-2.06
	4	0.87	2.61	-6.32	-2.29	-1.95
	5	1.12	6.0	-8.68	-3.14	-2.65
	6	1.12	2.03	-7.74	-2.82	-2.40

The Table (3) shows that the variation of the correlation energy is significant, when different sets for the smearing in the spin-spin potential, are chosen. The variation with the equation of state (EOS) eos1 and eos3 is comparatively unimportant<sup>4</sup>. We also see that the ud pairing correlation energy is substantially larger than that of the other pairs su and ds.

Let us recall that the energy per baryon is 888.8 MeV with eos1 and 844.6 MeV with eos3 as compared with 930.4 for <sup>56</sup>Fe- matter. We can see that even in the preferentially ordered spin singlet state, one has only a few MeV extra binding on the average for every diquark, compared to a positive energy of several hundred MeV.

However one should not forget that in a thermonuclear reaction (TR) every fusion produces energy which is precisely of this order. On the other hand TR is fast. To establish a stable high density of about 4.5 times  $\rho_0$  and to get back the ordering of the diquarks after a TR must take long time. If it is established that the concerned stars are indeed strange stars and the diquark pairing is the phenomenon responsible for long lasting bursts, then one could claim a link between the smallest quarks and the densest stars as has been pointed out before Ray et al. (2000).

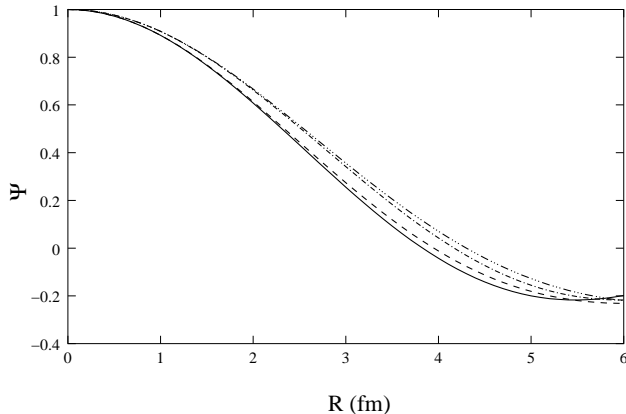
## 6 CONCLUSIONS AND SUMMARY.

Our calculations teach us the following :

(1) There are antisymmetric diquark states for dissimilar quark pairs in the spin parallel and antiparallel states with the attraction six times stronger for the latter compared to the former. But the magnitude of the attraction depends strongly on the form of the interaction, even when the

<sup>4</sup> As stated before, these EOS differ only in one parameter which controls the chiral symmetry restoration for the quark masses at high density (D98)

<sup>3</sup> Private communication, R. K. Bhaduri.



**Figure 1.** The figure shows the similarity between the spherical Bessel function and the appropriate oscillator wave functions. The top pair of curves correspond to  $\cos(\theta) = 1$  in Eq.(5) and the bottom curves to  $\cos(\theta) = -1$ . The oscillator in both cases is the upper curve of the pair. The values of relative  $k$  are 0.75 and  $0.82 \text{ fm}^{-1}$  respectively. At such a relatively large momenta very little angular dependence is seen.

interaction is fitted to observables like the standard isobar-nucleon mass difference.

(2) However, the six parameter sets that we have considered all show an attraction of few  $\text{MeV}$  so that it is comparable to other strong interaction phenomenon like energy release per particle in a thermonuclear burst. Since our model consists of realistic strange stars with quarks at the surface and not in the interior as in hybrid neutron stars, there is bound to be observable surface phenomenon.

(3) 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 2 to 7  $\text{MeV}$ . Once the pairs are misaligned due high level accretion of some binary stars and subsequent violent thermonuclear reactions (lasting typically for  $\sim 20 \text{ s}$ ) their recombination may provide bursts over several hours with energy release estimated to be large. The crucial fact is that the recombination time scale is long, since the strong interaction pairing process is supplemented by beta equilibrium and charge neutralization which are slower weak and electromagnetic processes. The number of pairs is shown to be right to produce the estimated energy release for 4U 1820–30.

(4) The alternative to this calculation is to consider the full 16-component Dirac wave function for the diquark in a manner done by Crater and van Alstine (1984) using the Dirac constraint method for the two body Dirac equation. This is clearly beyond the scope of the present paper which is concerned more with phenomenology. In such a calculation the effect of the spin - spin force will be manifest in the mean field level with more complicated spin wave functions but we are not sure if such states can be used to generate solutions of the TOV equations.

In summary we suggest that the superbursts (sometimes repeated), lasting long hours, may be due to breaking of unlike quark pairing in a specific coloured state in strange quark stars, following conventional quick thermonuclear bursts and their subsequent recombination. If strange

stars are confirmed from astro-phenomenology, such considerations may prove to be very useful.

## ACKNOWLEDGMENTS

The authors MS, SR and JD are grateful to IUCAA, Pune, India, for a short stay. It is also our great pleasure to thank Prof. R. K. Bhaduri and Mr. Ashik Iqbal for many discussions. We are grateful to Dr. Siddhartha Bhowmick for careful perusal of the manuscript.

## REFERENCES

- Bhaduri R. K., L. E. Cohler & Nogami Y. 1980, Phys. Rev. Lett. 44, 1369.
- Bhalerao R. S. & Bhaduri R. K. 2000, ‘Droplet formation in quark-gluon plasma at low temperatures and high densities’, hep-ph/0009333.
- Bildsten L., ‘Theory and Observations of Type I X-Ray Bursts from Neutron Stars’, 2000, astro-ph/0001135
- Blinder S. M. 1980, J. Mol. Spec. 5, 17.
- Bombaci I. & Datta B. 2000, ApJ 530, L69.
- Cornelisse R., Heise J., Kuulkers E., Verbunt F. & in ’t Zand J. J. M. 2000, Astron. & Astrophys. 357, L21.
- Cornelisse R., Kuulkers E., in ’t Zand & Verbunt F. J. J. M. and Heise J., 2002, Astron. & Astrophys. 382, 174.
- Crater H. W., & van Alstine P. 1984, Phys. Rev. Lett. 53, 1527.
- Cummings A. and Bildsten L., 2001, Ap. J. 559, L 127.
- Dey J. & Dey M. 1984, Phys. Lett. B 138, 200.
- Dey M., Bombaci I., Dey J., Ray S. & Samanta B.C. 1998, Phys. Lett. B438, 123; Addendum 1999, B447, 352; Erratum 1999, B467, 303; 1999, Indian J. Phys. 73B, 377.
- Drake J. J. et al, “Is RXJ 1856.5–3754 a Quark Star”, astro-ph/0204159 (2002).
- Heise J., in ’t Zand J. J. M. & Kuulkers E. 2000, AAS HEAD Meeting, 32, 28.03.
- Kapoor R. C. & Shukre C. S. 2001, Astron. & Astrophys. 375, 405 ( astro-ph/0011386).
- Kapusta K. 1981, Phys. Rev. D23, 2444.
- Kuulkers E., Homan J., van der Klis, M., Lewin W. H. G. & Méndez M. 2002, Astron. & Astrophys. 382, 947. (astro-ph/0105386).
- Kuulkers E., in ’t Zand J. J. M., van Kerkwijk M. H., Cornelisse R., Smith D. A., Heise J., Bazzano A., Cocchi M., Natalucci L. & Ubertini P. 2002b, Astron. & Astrophys. 382, 503. (astro-ph/0111261)
- Li X., Bombaci I., Dey M., Dey J. & van den Heuvel E. P. J. 1999a, Phys. Rev. Lett. 83, 3776.
- Li X., Ray S., Dey J., Dey M. & Bombaci I. 1999b, ApJ 527, L51.
- Rajagopal K. & F. Wilczek 2000, ‘The Condensed Matter Physics of QCD’, hep-ph/0011333, to be published in Festschrift in honour of B. L. Ioffe.
- Ray S., Dey J. & Dey M. 2000, Mod. Phys. Lett. A15, 1301.
- Strohmayer T. E. & Brown E. F. 2001, ‘A remarkable three hour thermonuclear burst from 4U 1820–30’, astro-ph/0108420.
- Wijnands R. 2001, Ap. J. 554, L59.
- Wijnands R. et al. 2001, Ap. J. 560, L159.
- Wijnands R. et al., The erratic luminosity behaviour of SAX J1808.8–3658 during its 2000 outburst, 2001b, astro-ph/0105446, Ap. J. (in press).