ON THE NATURE OF COSMIC GAMMA-RAY BURSTS

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Abstract. It is show in the following that cosmic gamma-ray bursts (GBs) may be generated when the magnetospheres of single neutron stars (NSs) are excited by strong starquakes. Important new observational data are explained, and several verifiable predictions are proposed on the basis of this approach.

Neutron stars (NSs) are commonly regarded as sources of GBs (see, e.g., Lamb, 1981). However, all searches for these objects in optical, X-ray, and radio spectral regions have been unsuccessul (Hurley, 1983). The only excepticas are optical flash-like images at error boxes of three GBs (Schaefer, 1983). Moreover, the joint analysis of logN/logS statistics, together with the angular distribution of the sources of outbursts, leads to the important conclusion (Jennings, 1982) that neither disk nor halo geometries can reconcile these data, because the large deviation from the law \( S \sim \) is accompanied by isotropy at the sky. To resolve this contradiction, Shklovskii and Mitrofanov (1984) assumed that galactic neutron stars radiating GBs belong to the extended corona of our Galaxy with the outer radius about 200 kpc. These stars are \( \leq 10^9 \) yr in age. Their total number is about \( N_b \sim 3 \times 10^4 (t_r/100 \text{ yr}) \), where \( t_r \) is the mean recurrent time of a source. The analysis of logN/logS distribution based on this hypothesis permits the estimation of the mean energy radiated per gamma-ray burst: \( E_b \sim 3 \times 10^{42} \) ergs.

What is the origin of neutron star outbursts? The most suitable type for identification seems to be the extinct radio pulsars (Shklovskii and Mitrofanov, 1984). Indeed, the total number (~ 3 \times 10^5) and the age (~ 3 \times 10^6 yr) of active pulsars (Smith, 1973) indicate that the number of extinct objects \( \leq 10^8 \) yr in age should be about \( 10^8 \). It is known that pulsars have rather high transversal velocities, in many cases as high as 300 km s \(^{-1}\) (Anderson and Lyne, 1983). These velocities would provide much if not all of the inertia required for the pulsars to escape from the disk to the extended galactic corona. Moreover, there is good observational evidence that these GBs occur at times strong starquakes, because the glitches have been found in the periods of seven radio pulsars (cf. Cordes, 1983). Their amplitudes range from \( \Delta P/P \sim 10^{-9} \) to 10\(^{-6}\), and in one particular case (PSR 0823 + 26), \( \Delta P/P \) reaches 0.03. During a starquake the core or crust of a NS is adjusting to some new configuration. If a change in stellar radius \( \Delta R/R \sim \Delta P/P \) occurs due to some corequake or phase transition, the approximate mean energy

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E_{\text{crack}} \sim E_{\text{tot}} \frac{\Delta R}{R} \sim E_{\text{tot}} \frac{\Delta P}{P} \sim 10^{46} \left( \frac{\Delta P/P}{10^{-7}} \right) \text{ergs}
\]

(1)

should be released during such an event.
The general idea proposed in this paper is the explanation of the GBs phenomenon as 'scintillations' in single old NSs caused by strong starquakes. Similar explanations were suggested in the early days of the study of GBs (Pacini and Ruderman, 1974; Tsygan, 1975) as well as many other physically possible models. However, the present aim of such studies is to find the correct model on the basis of recent observational data.

In addition to statistics, spectroscopy has provided further important conclusions about GBs. Both the shape of continuum above 100 keV and the absorption-like deficit below this energy appear to be strongly variable (Barat et al., 1983a). Sometimes, the GB spectra look like power-law spectra (see also Rieger et al., 1982). This contradicts any thermal mechanisms of generation, because for all of them the Wien-like cutoff at energies of several $kT$ should be observable. Secondly, the line-like features interpreted as redshifted annihilation lines (Mazets et al., 1979, 1981, 1983) have been resolved as short ($\leq 250$ m s), strong flashes (Barat et al., 1984). The peak intensities achieve $\sim 30\%$ of the continuum corresponding to $\sim 10^{47}$ annihilations per second for a source at a distance of about 10 kpc. These flashes have been correlated with peaks of intensity. The linewidth $\Delta E/E \sim 0.3$ indicates that the temperature of annihilating $e^\pm$ pairs does not exceed 10–15 keV. Another resolved line-like spectral feature interpreted as the redshifted iron nuclear line 0.847 MeV (Teegarden and Cline, 1980) was also strongly variable (Mitrofanov et al., 1984).

It is clear that the continuum of GBs is emitted by the optically thin plasma above the surface of NSs. On the other hand, the only possible place where strong flashes of annihilation and nuclear lines could be generated is the 'underground' layers of the crust. Indeed, if these were above the surface, $e^\pm$ would immediately accelerate to relativistic energies, either by the radiative pressure or by the electric force (see below). Thus, in order to explain the GBs, a physical process should be proposed leading to both generation of a nonthermal continuum (and may be optical light) above the surface of the NS and to the emission of annihilation and nuclear lines from the crust.

The perturbation of the magnetosphere by transversal vibrations of cracking NSs seems to be just such a process. To estimate the amplitude of vibrations one may assume that the energy of vibration $E_{\text{vib}}$ is comparable to the total energy of the crack $E_{\text{crack}}$. It is known that the amplitude of vibrations at the surface of neutron stars is about $\times 100$ times larger than this magnitude at its interior (Thorn, 1969). So the surface amplitude of vibrations with frequency $\omega \approx 10^4$ Hz should be about

$$\langle \delta R \rangle_s \sim \frac{\chi}{\omega} \left( \frac{E_{\text{crack}}}{M_{\text{NS}}} \right)^{1/2} \sim 3 \times 10^2 \left( \frac{10^4 \text{ Hz}}{\omega} \right) \left( \frac{\chi}{100} \right) \left( \frac{E_{\text{crack}}}{10^{46} \text{ erg}} \right) \text{cm}. \quad (2)$$

These vibrations of the surface layer lead to variations in the magnetic field and to the generation of a strong variable electric field inside the magnetosphere

$$\mathcal{E} \sim \frac{\omega \langle \delta R \rangle_s}{c} B \sim 10^{10} B_{12} \left( \frac{\chi}{100} \right) \left( \frac{E_{\text{crack}}}{10^{46} \text{ erg}} \right)^{1/2} \text{CGSE}. \quad (3)$$