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SHORT SOFT Γ-RAY BURST SPECTRAL EVOLUTION

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ABSTRACT. Short Soft Gamma-Ray bursts are considered as neutron star crust magnetoemission. Statistics of temporal burst properties are shown to display universal features.

Keywords: Soft gamma repeaters. – neutron stars: magnetic field, magnetar.

1. Introduction

The discovery of soft gamma repeaters (SGRs) is associated with pioneering observations of soft gamma-ray burst from SGR 1806-20 on 1979 January 7 by KONUS experiment on the Venera 11 and Prognoz-7 spacecrafts (Mazets et al. 1981). Such repeating outbursts of a short-duration (~ 100 ms), soft-spectrum (below < 100 keV) and super-Eddington luminosity, i.e., L~10^3 – 10^4 $L_{\rm Edd}$ ($L_{Edd} \approx 10^{38}(M_{NS}/M_{\odot})$ ergs/s with neutron star (NS) $M_{\rm NS}$ and solar M_0 masses, see, e.g., (Kondratyev 2002), represent general activity of these pulsars. Such burst emissions tend to concentrate into short intervals (weeks to months) of intense activity separated by relatively long (years) quasi-regular quiescent periods with associated sub-Eddington persistent X-ray luminosity $L_X \sim 10^{34.5} - 10^{36}$ erg/s. More rarely, SGRs emit giant flares that last for minutes and display very hard X- and gamma-ray spectra, extending into the MeV range, enormous energy release and associated with pioneering observations of the famous 1979 March 5 event related to SGR0526_66 (Mazets et al., 1979).

Many observed SGR properties strongly support the magnetar concept suggesting an ultra-magnetized stellar media with magnetic induction strength H up to *tera-tesla*. Such a magnetization can be understood, e.g., as an effect of the magneto-rotational instabilities and/or "dynamo action" processes which might operate in fast rotating stars (Kondratyev, 2014). Respectively, SGR activity is well explained within such `magnetar' concept.

Detailed analysis of burst light curves can provide more constrain for theoretical models and burst triggering mechanisms. In this contribution the randomly jumping interacting moments (RJIM) model (Kondratyev, 2002) is further extended for an analysis of SGR bursts. Particular attention is paid for spectral evolution.

2. Neutron Star Crust Magnetoemission

The RJIM model applications for magnetodynamics simulations in NS crust has already been described by Kondratyev (2002). We briefly remind that in simulations of demagnetization dynamics we use a very general form for magnetic moments m of atomic nuclei $m=\mu Ig$ with the nucleon magneton μ, nuclear spin I and g-factor g. Atomic nuclei occupied a volume $V_{\rm D}$ contribute to the magnetization $Q=m/V_{\rm D}$. Taking $g = 3$ for nuclear component of magnetic induction we get

$$Q = 1.5\ {\rm TG}\ In\ /(10^{13}\ {\rm g/cm}^3), \qquad (1)$$

In a case of comparable sizes for nucleus and occupied volume $V_{\rm D}$ (i.e., $n \sim 10^{13,5}$ g/cm^3) internuclear interaction is ferromagnetic (Kondratyev&Lutz, 1999; Kondratyev, 2002).

We consider adiabatically decreasing in time crust magnetic field H. For certain local field values b_i nuclear magnetic response peculiarities give rise to stepwise change of NS crust magnetization on a value proportional to nuclear spin ΔI (Kondratyev, 2002). The corresponding excess of magnetic pressure is estimated as

$$\Delta P = H\,\Delta Q\ = 10^{23}\ {\rm At}\ (H/{\rm TT})\ (\Delta I\, n/\ 10^{13}\ {\rm g/cm}^3)\ . \qquad (2)$$

and evolves in a crust with a linear speed $c_{\rm m} \sim 10^8$ cm/s , for more details see (Kondratyev 2002). Then for outer crusts of a linear size, $l_{\rm crust} \sim 100$ m, an estimate of the pressure jump region spanning time, $t_{\rm av} \sim l_{\rm crust}/c_{\rm m} \sim 0.1$ ms, is consistent with the rising time for giant flares of SGR (Mazets et.al 1979, Kondratyev 2002, Svinkin et.al 2015). Such magnetic pressure jump excites magnetoplasma waves (i.e., Alfvén waves). Since the Alfvén velocity of is close to the speed of light c, the linear size of the strongly excited magnetosphere region exceeds the value $R_{\rm ex} \sim l_{\rm crust}\, c/c_{\rm m} \sim 10$ km , comparable to NS radius. Subsequent development and cooling of photon-electron-positron plasma via gamma-ray emission from this region generates a short-duration (~ 100 ms) SGR-burst event with rising $\sim 10^{0.5}$ ms and decaying ~ 10 ms fronts of light curve (Kondratyev, 2002).

For a field strength $H \sim 3$TT, typical magnitar crust density $n \sim 10^{13,5}$ g/cm^3, and avalanche linear size of order of outer NS crust thickness, 100 m (i.e., volume of magnetization jump V_a about 10^6 m^3) the amount of released energy $\Delta E = \Delta P\ V_a$ is consistent with an energy of soft gamma-ray bursts, as is obtained from Eq. (2). These values determine burst duration time T. Therefore, quantity $x = t_{\rm av}/T \sim l_{\rm av}/V_a \sim T^{2/3}$

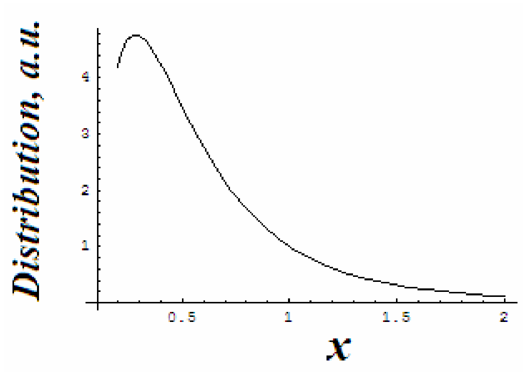

Figure 1: The time ratio x (in units of x_0) distribution (see text).

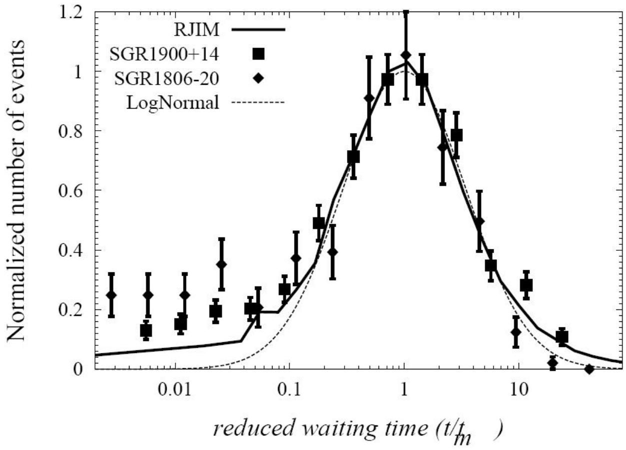

Figure 2: The reduced waiting time distribution between the successive RXTE/PCA bursts from SGR 1900+14 (squares) (Gogus et.al. 1999) and SGR 1806-20 (diamonds) (Gogus et.al. 2000) are compared with the waiting time distribution between avalanches (solid curve). The dashed line represents the fit to the lognormal distribution of the width 3.6.

is distributed according to $[W(x^{-3/2})/x^{5/2}]dx$ where $W(T)$ gives T-distribution. As is seen in Fig. 1 short front rising time relative to value T has higher probability. Such a feature is caused by linear scale for burst front while the duration is determined by volume.

It is worthy to notice in this regards the delayed emission of softer gamma-ray component. Such a time lag is due to cooling of photon-electron-positron plasma in magnetosphere. The Alfvén waves damping and energy loss of respective accelerated electrons lead to softening of emitted radiation. Corresponding time scale is given by region of excited magnetosphere $R_{\rm ex} \sim 10$ km and for multiple wave propargation is estimated as $t_{\rm lag} \sim 1$ ms.

For a constant change rate $\dot{B}$ of the magnetic field the inter-avalanche field interval is proportional to the time interval (i.e. waiting time) between the induced bursts. Taking the respective normalized values, i.e. inter-burst time and inter-avalanche field, we compare the theoretical predictions with observations in Fig. 2. As seen in Fig. 2 for different SGRs the waiting time distributions as a function of the reduced time obey universal function. The data are well reproduced by simulations and fitted at a maximum by the lognormal function. Such a property points out the single time scale for SGR-burst triggering processes. Within RJIM model such a time-scale is determined by the ratio of the disorder parameter R and the field change rate $\tau = R / \dot{B}$. Therefore, the scaling with respective time leads to an universal function.

4. Conclusion

We considered magnetoemission of inhomogeneous nuclear matter relevant for neutron star crusts. As is seen erratic jumps in crusts magnetotransport result in excitations of the Alfvén waves in magnetoplasma that leads to gamma-ray bursts. The properties of such bursts are favorably compared with activity of Soft Gamma Repeaters. As is shown considered mechanism of SGR short burst emission suggest relatively small rising time front and a time lag for softer gamma-ray component.

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