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A FLARING X-RAY PULSAR IN DORADO

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16. Abstract

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A study of unusual gamma-ray bursts detected on March 5 and March 6, 1979, in the KONUS experiment on the Venera 11 and Venera 12 spacecraft shows their source to be a flaring X-ray pulsar in Dorado. /2*

On March 5, 1979, a very intense gamma-ray burst was observed /3 on the Venera 11 and Venera 12, which was undoubtedly also detected by many instruments operating in space at this time. This event differs sharply in its characteristics from all previously observed gamma-ray bursts [1] and is of exceptional interest. Figure 1 presents the time profile of the initial stage of the burst detected by the Konus equipment over an interval of 2 sec with resolution of 1/64 sec in the energy window 50-150 keV. The burst is characterized by a very sharp onset. The counting rate rises from the background level to a value $\gtrsim 5 \cdot 10^5$ sec^{-1} in 50 msec. This means that in the short time ∿0.1 sec, the flux of hard x-rays exceeds the level of the diffuse cosmic background by 10^4 times. The radiation intensity then rapidly decreases by more than two orders of magnitude. The following stage of the burst is even more noteworthy. Figure 2 presents recordings of the time variation of the burst obtained with a resolution of 0.25 sec and 1 sec. It follows from consideration of these data that the emission of an x-ray pulsar with a period of 8.1 ± 0.1 sec is being observed. The graphs clearly reveal a sequence of more intense pulses and a sequence of intermediate pulses whose relative phase is 0.5. The most remarkable fact is that the mechanism for generating the radiation starts practically instantaneously (with a phase of 0.5) and

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*Numbers in margin indicate pagination in original foreign text.

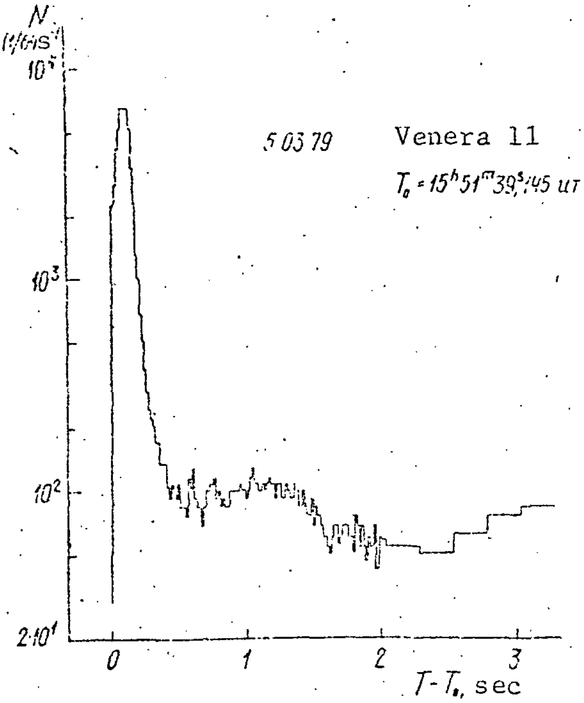

Figure 1. Time profile of the initial stage of the event of March 5, 1979, recorded with a resolution of 1/64 sec. The time T is measured from the time T_0 of actuation of the instrument detecting the bursts

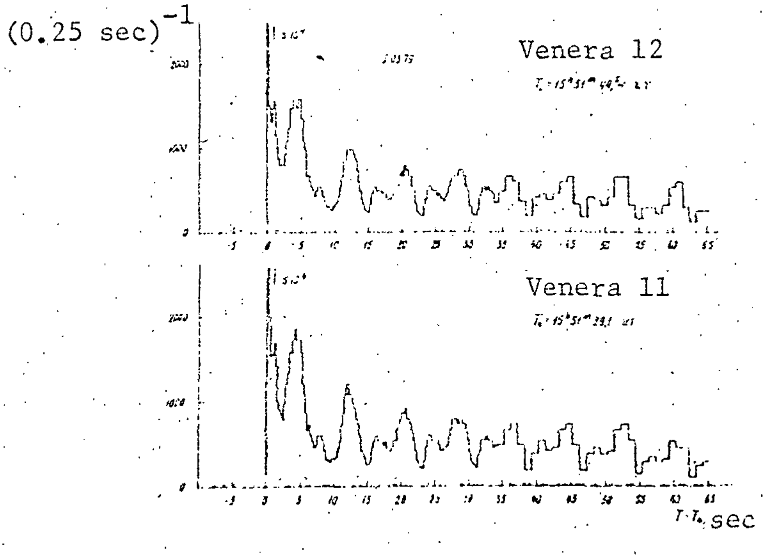

Figure 2. Time profile of the event of March 5, 1979, detected with a resolution of 0.25 sec (with a resolution of 1 sec at the end of the recording). The background level is shown by the dashed line. Individual points before the beginning of the continuous histogram represent recording of the prehistory of the event by the same detector

that the radiation rapidly attenuates. Unfortunately, the standard /6 recording time was insufficient for this event; however, measurement carried out six minutes after the onset of the burst show that the intensity of the radiation had fallen to the usual background level over this time. Besides the modulated radiation, a slowly varying component is clearly observed. The nature of the change in the peaks of the pulses is peculiar and evidently not random. The main pulses decrease during four periods, while the peaks of the intermediate pulses lie at one level. The situation reverses for the next three periods.

In accordance with the standard program measurement of gamma-ray bursts, eight energy spectra were obtained successively, each with an average over a time interval of 4 sec. Only the spectrum obtained over the first interval corresponding to the initial stage of the event differs from all the successive spectra. Thus, Figure 3 presents the spectrum over the first interval and the total averaged spectrum for the intervals from the second to the eighth. The energy spectra also indicate the significant difference between this event and gamma-ray bursts. The photon spectrum at the stage after the initial pulse is closer in its form to the spectra of continuously radiating x-ray sources comprising

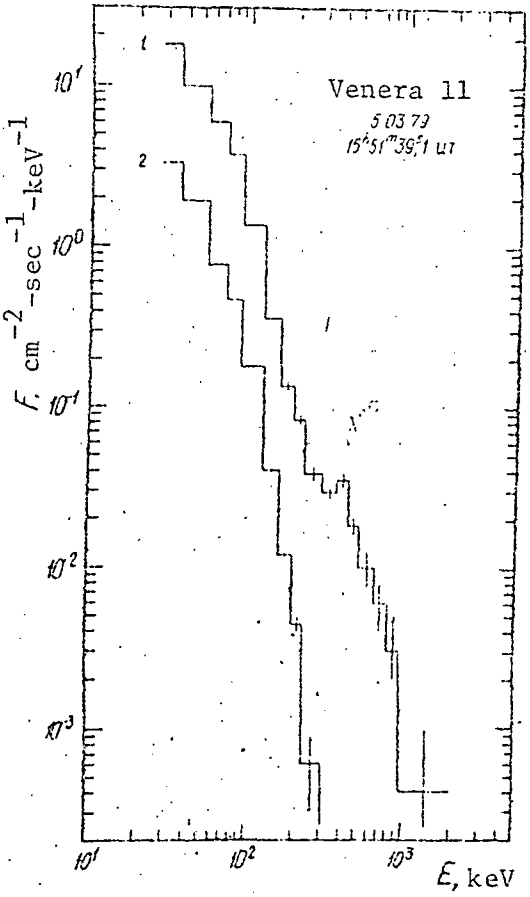

Figure 3. Energy spectra of the event of March 5, 1979. 1 - Spectrum obtained in the first 4-second interval after onset of the event; 2 - averaged spectra over the intervals from the second to the eighth

binary systems, for example, Cyg X-1, than to the significantly harder spectra of gamma-ray bursts. It can be approximated to a sufficiently good accuracy by the dependence of $E^{-1}exp(-E/kT)$ with a temperature of kT = 30.. The spectrum measured over the first 4 sec.has a harder tail, which, as might be assumed, is related to the radiation of the initial pulse. The peculiarity in the region 400-500 keV is a very notable detail of this spectrum. The complete identity of the spectra obtained on Venera 11 and Venera 12 excludes the possibility of explaining it by random causes. Extrapolation of the spectrum from the region 120-300 keV to the region of higher energy according to a power law shows that the observed peculiarity may be related to the presence of a quasi-monochromatic line with half-width 30-40% and peak energy about 430 keV. It is evidently difficult to propose a unique explanation /8
for the nature of this component of the radiation. It is interesting to note that the energy of the radiation agrees precisely with the value of the gravitational red shift $\sqrt{1-2GM/c^2R}$ of the annihilation line 0.511 meV in the field of a neutron star with mass $M = M_\odot$ and radius $R = 10^6$cm. The average value of the radiation flux with energy $E_\gamma > 30$ keV emitted after the initial pulse is $1 \cdot 10^{-5}$ erg/cm^{2}sec. The flux reaches the value $1.5 \cdot 10^{-3}$ erg/cm^2-sec at the maximum of the initial pulse. An estimate of the flux in the line $E_\gamma \approx 430$ keV gives $3 \cdot 10^{-6}$ erg/cm^{2}sec, while under the assumption that this radiation is emitted only in the initial pulse, it gives $5 \cdot 10^{-5}$ erg/cm^{2}sec.

The readings of three detectors with an anisotropic angular sensitivity at each spacecraft and the delay time in the arrival of the burst at one spacecraft with respect to the other were used to determine the coordinates of the source [2]. The observations were carried out with triaxial stabilization of the spacecraft in space. The intersection of the small region on the celestial sphere determined by the first method with the narrow ring given by the second method permits obtaining the coordinates α, δ (epoch 1950.0) of the corners of the box within which the source is located: (75,51°; -67,60°), (75,62°; -67,68°), (81,60°; -65,77°), (81,71°; -65,85°) . The coordinates of the center of the box are $\alpha = 78{,}81^\circ$, $\delta = -66{,}74^\circ$. We will subsequently denote this flaring x-ray pulsar in Dorado as the source FXP 0520-66.

The most acceptable model for this source could be a binary system with a neutron star. The distance between the components of the system must be rather great in order to decrease the accretion rate to the level for which significant radiation in the steady-state mode simulated by rotation is not observed. The neutron star must have a strong magnetic field since the presence of two sequences of pulses in the flare indicates that the plasma moves along the field lines with accretion, and the emitting regions are located in the regions of the magnetic poles. The causes of /10 the time-dependent accretion leading to an outburst requires explanation. The characteristic time over which the total power of the radiation flux is very small, 15-30 msec at most. Thus, processes related to the neutron star itself must play a role in the discharge mechanism, for example, development of instability in the magnetosphere.

The observed radiation flux of this source is so great that if it were to radiate constantly at this level, its radiation only would completely determine the flux of hard x-ray cosmic rays. The diffuse x-ray background and the radiation of all discrete sources would comprise only an insignificant part in the total observed flux. This means without a doubt that although the coordinates of the source also coincide with the Large Magellanic Cloud, it is very close on the galactic scale. If one takes 10^{37} erg/sec as the estimate of the power of the energy evolution in the source, then the distance to it is ∿100 pc. It is possible that the data for the observation of the flare of March 5, 1979 on other spacecraft permit refining the celestial coordinates of this x-ray pulsar and will produce its identification with an object observed in the visible range. The closest x-ray source 4U 0532-66 (2A 0532-664) is separated from the source FXP 0520-66 by an angular distance 1.5°.

The source observed by us was found to be recurrent. On the next day March 6, 1979, the Konus equipment on both spacecraft detected at the same time $\delta t = 14^h\, 25^m\, 46{,}^s1$ a short burst of length $\approx$ 1.5 sec with the same soft spectrum. However, the intensity of the burst was more than 100 times less. Figure 4 presents the time profile of the burst with a resolution of 0.25 sec, and with a resolution of 1/64 sec in Figure 5. The energy spectrum of the burst is presented in Figure 6. This time, the coordinates of the source were determined with somewhat lesser accuracy, but they concided completely within the errors of the measurements with the coordinates for the event of March 5, 1979. It is obvious that the process giving rise to the onset of generation of radiation /13 in the source for the event of March 6, 1979, was significantly weaker and more extended than for the flare of March 5, 1979. We can only assume that the attenuating pulsating radiation could have been correspondingly weaker and therefore unobserved at the given background level.

The source being considered in this work differs rather sharply in its charactersitics from well-known transient x-ray objects (cf., for example, [3]), primarily in the time scales of variability and the presence of the pulsed initial stage. It is unlikely that the flaring x-ray pulsar FXP 0520-66 observed in the events of March 5 and 6, 1979, is unique in the Galaxy. A natural alternate assumption is that other such objects exist and must be observed. However, the average distances to them will be significantly greater, the order of several kpc, and the radiation flux from them must be small and comparable with the flux from other x-ray sources. This fact, if one takes into account the brevity of the phenomenon, means that flaring x-ray pulsars could be observed predominately at their initial pulsed stage in view of the short, hard x-ray bursts. It was reported previously that similar bursts were observed on Kosmos 428 [4], but it was later determined that a large number of them were due to local pulsed background and all the results of the observations were in doubt for this reason. However,

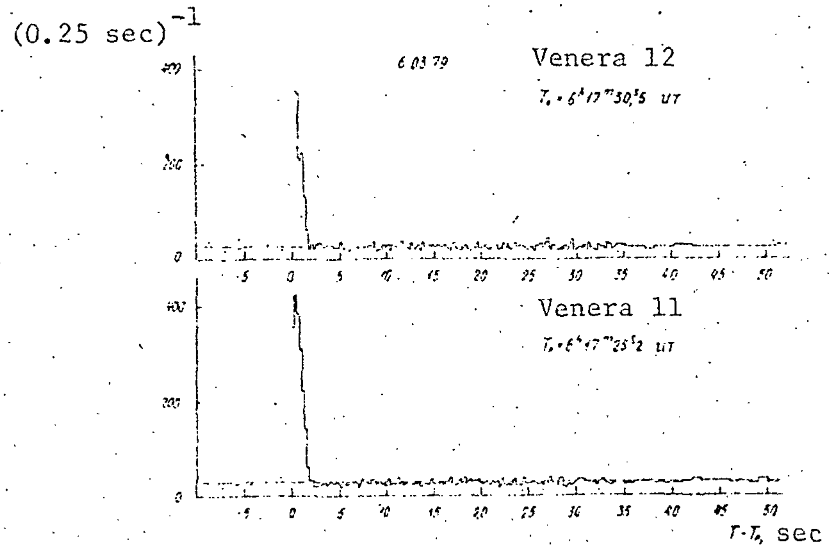

Figure 4. Time profile of the event of March 6, 1979, detected with a resolution of 0.25 sec (with a resolution of 1 sec at the end of the recording)

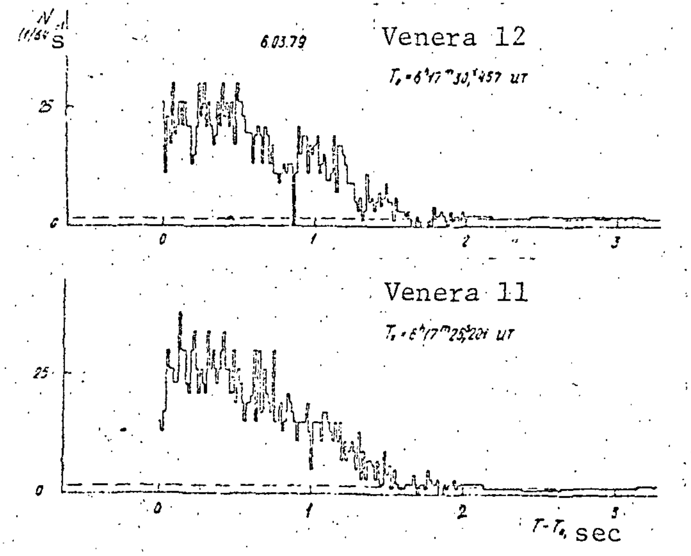

Figure 5. Time profile of the initial stage of the event of March 6, 1979, recorded with a resolution of 1/64 sec

it now seems completely possible that true x-ray sources can be detected, whose sources, because of the recurrence of the phenomenon, can be detected again in the future with observations on well-separated spacecraft.

The data considered in this article give rise to the appearance

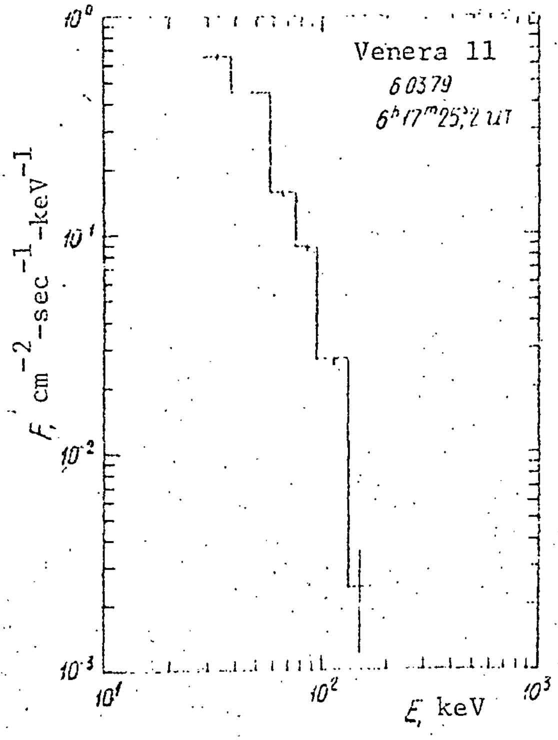

Figure 6. Energy spectrum of the event of March 6, 1979

of a new question in the problem of the origin of gamma-ray bursts. After obtaining convincing evidence of the galactic localization of the sources [2], the favorite assumption about the nature of gamma-ray bursts seems to have become time-dependent accretion onto a compact object in a binary system. We now have observational /14 data about processes of continuous (Hez X-1, Cen X-1, etc.) and time-dependent pulsed (FXP 0520-66) accretion onto a neutron star, and probably also continuous accretion onto a black hole (Cyg X-1). The general feature for all these cases is that the energy spectra of the radiation are relatively soft with an exponential drop in the region 50-100 keV. The energy spectra of the gamma-ray bursts are significantly harder, close in form to a power law. A significant part of the radiation energy is concentrated in the range of many hundreds of keV [1, 5]. This could mean that accretion onto compact objects is not related to gamma-ray bursts. However, a more attractive alternate possibility involves the following. Estimates of the energy evolution in sources of gamma-ray bursts based on the estimates of the average distances to them in view of the distribution of the sources over the celestial sphere give for the power of the radiation $\sim 10^{39} - 10^{40}$ erg/sec. This valus is at least one or two orders of magnitude greater than the luminosity of well-known binary x-ray sources. Thus, it can be assumed that the noted differences in the energy spectra are caused by a very high intensity of the processes of time-dependent accretion in sources of gamma-ray bursts.

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