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Transient pulsar dynamics in hard x-rays: Prognoz 9 and GRIF "Mir" space experiments data

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Abstract. The long-term observations of the Galactic Centre as well as the Galactic anti-Centre regions in hard X-rays (10-300 keV) were made in experiments on board Prognoz-9 satellite and "Mir" orbital station (GRIF experiment). Some transient pulsars including A0535+26, GS1722-36, 4U1145-619, A1118-615, EXO2030+37, Sct X-1, SAX J2103.5+4545, IGR 16320-4751, IGR 16465-4507 were observed. The pulsation flux components of A0535+26 and GS1722-36 X-ray emission were revealed at significant level. For other observed pulsars the upper limits of pulsation intensity were obtained. The mean pulsation profiles of A0535+26 in different energy ranges as well as the energy spectra were obtained at different stages of outburst decreasing. The pulsation intensity-period behavior does not contradict the well-known correlation between spin-up rate and X-ray flux, while the stable character of the energy spectrum power index indicates on the absence of thermal component. The energy spectrum and mean pulsation profiles were also obtained for one time interval of GS1722-36 observations. The upper limits of pulsation fluxes obtained for other observed transient pulsars at the orbital phases more than 0.14 correspond the quiescent state or final stage of the first type outburst.

1. Introduction

It is well known that so called X-ray pulsars are associated with strongly magnetized rotating neutron stars (NS), which are characterized by great energy release as the result of accretion (accretion-powered pulsars) or rotation (rotation powered pulsars). The
X-ray accretion-powered pulsars are generally divided into different classes based on the spectral type classification of the mass donor companion star (Mergetti 2001). The temporal behavior of such objects was always a problem of great interest for high-energy astrophysicists. Modern observations are usually made in a wide range of wavelengths from radio waves to gamma rays. While optical observations are in some respects more accurate, the observation of X-ray pulsars has provided an important information on the physics of NS, including the processes in the region of great energy release, and on the evolution of stars in binary systems.

The temporal behavior of NS binary system in hard X-rays reflects the physical processes in matter and fields surrounding NS. The properties of such matter and field determine quasi-periodic variations, while the rotation of NS itself and of binary system components produce pulsation, orbital and super-orbital periodic changes in X-ray source luminosity. X-ray pulsations with pulse period of about dozens and hundreds seconds were clearly detected. Long-term variability of most of transient pulsars appears as their flaring activity.

The most of transient X-ray pulsars have Be (or Oe) star companions. Accreting NSs in Be systems typically have long periods and eccentric orbits. It is to be thought, that the source of accreting material is the slow, dense stellar wind, presumably from the circumstellar disk confined to the equatorial plane of the rapidly rotating Be star. The Be-transients display a marked correlation between their spin and orbital periods. This correlation arises from the fact that given identical companion masses and mass loss rates, NSs in binary systems with lower orbital periods are further away from their companions, these leading to lower mass accretion rates and higher equilibrium periods (Bildsten et al. 1997). Various instabilities in the accretion process lead to the flaring activity of some kind of X-ray pulsars. It is known that X-ray behavior of Be transient pulsars is characterized by regular increases of the X-ray flux modulated with the orbital period. Such recurrent flares (type 1 outbursts) with typical times about days often begin soon after periastron. The typical X-ray luminosity of type 1 outbursts in BeX systems is about $10^{36}$ erg/s (Blay et al. 2004). Besides the series of periodically occurring outbursts, the so-called giant outbursts with higher luminosity (type 2 outbursts) were observed. The type 1 outbursts are associated with the direct wind accretion of the Be circumstellar disk, while the type 2 outbursts can be described by the disk-fed accretion after the bound material has collapsed into a standard but temporary accretion disc (Stella et al. 1986; Raguzova & Lipunov 1998). The outburst peaks occur at phase 0-0.5, depending on the wind characteristics and orbital eccentricity. The bright giant outbursts have high spin-up rates, longer duration, and often have peak at an orbital phase delayed relative to the mean normal outburst X-ray maximum (e.g. 4U0115+63 (Whitlock et al. 1989), 3A0535+26, Bildsten et al. 1997)).
Extensive data on periodicity in hard X-rays from many transient pulsars were obtained during the BATSE experiment onboard the Compton orbital observatory (CGRO) (Bildsten et al. 1997). As the result of BATSE CGRO experiment no association had been observed between giant and normal outbursts. It was found that many of the giant outbursts are in the middle, or followed by, series of normal outbursts. Sometimes type 2 outbursts last for several orbital cycles (e.g. V0332+53, Stella et al. 1986). The phasing of this outbursts should be dictated mainly by the time variability of the Be star mass outflow rate. It is still unclear what causes the giant outbursts. They may be observed if the circumstellar disk undergoes a sufficiently large increase in its radial extent and density to intersect the NS orbital path. If a disk can be sustained between giant outbursts, it may be also present during normal outburst. In this case the large tidal torque experienced by the disk during periastron passage could explain the repeating normal outburst (Bildsten et al. 1997). Not far ago it was proposed that the thermal disk instability like one causing dwarf nova outbursts affect accretion disk around Be X-ray pulsars and could be the cause of the giant outburst (van Paradijs 1996; King et al. 1996).

The pattern of X-ray outbursts is affected by the size, eccentricity and orientation of the NS’s orbit with respect to the Be star. The orbit could be complanar with the Be star circumstellar disk or offset such a way that the NS may pass through the disk. In some case the consequent outbursts can have different intensities (e.g. XTE J1946+274, (Campana et al. 1999)). This might suggest that the NS is orbiting the Be companion in an inclined orbit crossing twice the Be disk plane and giving rise to two outbursts per orbit. Two flares per orbit also observed in 4U1907+097 (Makishima et al. 1984) and in GRO J2058+42 (Wilson et al. 1998). Be transient pulsars also display long-term X-ray variability with typical times about months, consisting of low and high-activity X-ray states. By this the type 1 outbursts are only seen during bright states (Baykal et al. 2002).

Nevertheless moderate and pulsating X-ray flux was detected at various orbital phases of Be transient binary systems, from A0535+26, for example (Motch et al. 1991; Steele et al. 1998). In the RXTE-PCA observations this source was detected at a much lower luminosity of \((2.0 - 4.5) \cdot 10^{33} \text{ erg/s}\) at which so-called propeller effect is expected. It means that accretion onto the NS surface is inhibited by the centrifugal action of the rotating magnetosphere. Thus the X-ray luminosity that was still detected in this regime can be ascribed to material leaking through the magnetosphere or thermal emission from the heated core of the NS (Negueruela et al. 2000). The BeppoSax-NFI observations of A0535+262 in quiescence show that X-ray pulsations are still present for luminosity as low as \(2.0 \cdot 10^{33} \text{ erg/s}\), but they have not been detected at lower luminosity \(\sim 1.5 \cdot 10^{33} \text{ erg/s}\) while the nonzero moderate flux was measured (Mukherjee and Paul 2005). This means at such luminosity a transition between centrifugal inhibition and direct accretion when a fraction of the disk material is going onto the surface of the NS along the magnetic field lines. The luminosity obtained in the BeppoSax-NFI observations gives
for A0535+262 in quiescence an accretion rate $\dot{M} = 2.05 \cdot 10^{13}$ g/s and magnetospheric radius $r_m$ about $9.35 \cdot 10^9$ cm (Mukherjee and Paul 2005).

In the case of type 1 outbursts caused by the wind-fed accretion, there will be less efficient angular momentum transfer compared to a standard transfer disk accretion (Inam et al. 2004). On the contrary, the disk-fed accretion can transfer angular momentum either at the vicinity of the magnetosphere radius where the disc is disrupted and the material is channeled from the inner edge of the disc to the magnetic poles, or from the overall interaction of the accretion disc and magnetic field lines of the NS. Thus, the material torque from a prograde accretion disk, being proportional to mass accretion rate, always acts to spin-up the NS, while the contribution of magnetic torque from the magnetic field lines threading the disk outside the corotation radius is negative. The resultant torque can either be a spin-up or spin-down. The large and steady spin-up rates were seen during the giant outbursts. This implies the correlation between torque and observed X-ray flux, which is difficult to explain with direct wind accretion. Assuming observed X-ray luminosity is proportional to the bolometric luminosity, i.e. mass accretion rate, spin-up rate and X-ray flux correlation can be explained by accretion from accretion disk when the net torque is positive and of the order of the material torque (Ghosh and Lamb 1979, Ghosh 1993). Thus, it means that transient accretion disks are forming during the giant outbursts (Kriss et al. 1983, Stella et al. 1986, Motch et al. 1991).

When the NS in a Be/NS binary system leaves the dense equatorial disc of the companion, the accretion disk can no longer be fed by the surrounding material. In this case, accretion disc may disappear an the NS may either continue to accrete from the non-equatorial wind of the companion or may enter the propeller phase (Illarionov and Sunyaev 1975). In case accretion is the result of the companion’s non-equatorial wind, it is possible to see erratic spin-up and spin-down episodes (Bildsten et al. 1997, Inam and Baykal 2000). In case wind of the companion does not cause accretion, propeller phase may set in, when spin pulsation cessation is accompanying by the flux decreasing (Cui 1997). However, the pulsations may not cease completely even in the propeller phase (Negueruela et al. 2000). Spectral hardening, which was observed in the low state spectra of NS soft X-ray transients like Aql X-1 may be interpreted as the sign of propeller stage (Zhang et al. 1998). While anti-correlation of spectral power law index with the X-ray flux (i.e. softening of the spectra) might be the sequence of mass accretion rate changes (Meszaros et al. 1983, Harding et al. 1984). In this case, neither a transition to propeller stage nor an accretion change is needed to explain the softening in the spectrum with decreasing flux (Inam et al. 2004). Consequently, decrease in mass accretion rate with a softening in the spectrum does not lead to any significant changes in pulse profiles and pulse fraction (Baykal et al. 2002).
result of not only accretion rate changes but also accretion geometry changes for the low flux parts, which occur just before the periastron for which the NS should have accreted almost all of the accretion disc material around it. Correlation between spin-up rate and X-ray flux in different energy bands has been observed in outbursts of different transient X-ray pulsar systems: EXO 2030+375 (Wilson et al. 2002), A0535+26 (Bildsten et al. 1997), 2S 1845-024 (Finger et al. 1999), GRO J1744-28 (Bildsten et al. 1995), GRO J1750-27 (Scott et al. 1997), XTE J1543-568 (In't Zand et al. 2001), SAX J2103.5+4545 (Baykal et al. 2002), 2S 1416-62 (Inam et al. 2004). In the last source the correlation between spin-up rate and X-ray flux was found for both main outbursts and the following mini outbursts (Inam et al. 2004). However, the correlation between torque and flux, which was observed in BATSE experiment for some Be X-ray pulsars (Finger et al. 1996a; Finger et al. 1996b), does not confirm the pulsar spin-up rate \( \dot{\nu} \) dependence on accretion rate \( \dot{M} \), such as \( \dot{\nu} \sim \dot{M}^{6/7} \), which was predicted by accretion torque theory. It is still unclear if this disagreement can be explained by bolometric or beaming corrections (Bildsten et al. 1997). The BATSE instrument does not measure bolometric flux, but only pulsed flux in definite bands, while the large changes in beaming fraction imply the changing pulse profiles. Thus, it seems clear that new data on transient pulsars dynamics implying the flux, pulse profile and rotation period measurements on the long-term database including different luminosity regimes are quite useful for further progress on these phenomenon understanding. Below we will discuss the results of the search and study of periodic processes in hard X-rays from some transient pulsars during the observations which were carried out on the Prognoz-9 and "Mir" orbital station (OS) missions.

2. Monitor observations of temporal phenomena during the "Prognoz 9" mission and "GRIF" experiment on board "Mir" station

2.1. The Prognoz 9 and "Mir" OS GRIF experiments.

Both, Prognoz-9 and GRIF experiments use wide-field, hard X-ray spectrometers, which provide long-term observations of periodic process sources. Although the observational conditions were specific in the each experiment, the main X-ray instruments as well as the technique of the periodic sources revealing were quite similar. The observations of galactic sources in hard X-rays (10-200 keV) were made in 1983-84 during the complex experiment on a high-apogee (\( \sim 720000 \) km) satellite Prognoz-9 with a wide field of view (FOV) (\( \sim 45^\circ \) FWHM) scintillator spectrometer (\( \sim 40 \) cm\(^2\) effective area) (Kudryavtsev and Svertilov 1985). The X-ray instrument was installed in such a way that the center of its field of view, averaged over the satellite’s rotation period (\( \sim 120 \) s), coincided with the spin axis which pointed in the solar direction every 5-7 days. According to the experiment conditions sky areas adjacent to the ecliptic plane (\( \pm 25^\circ \) - for instru-
ment beam FWHM) were observed and slow (1°/day on average) scanning along the ecliptic was made. The count rates for X-ray photons were measured over the energy ranges of 10-50, 25-50, 50-100, 100-200 keV. The region of the sky that was observed during the experiment is shown in equatorial coordinates in Fig. 1. The points of the sky toward which the satellite’s axis was pointed at different times (the dates in the figure refer to the origin of the corresponding intervals of constant orientation) are also marked in this figure. The main X-ray transient pulsars and the Galactic equator are shown. During the observations from November 1983 to February 1984 of the sky region near the Galactic Centre (outlined by the closed solid line in Fig. 1), the count rates were considerably higher than the background count rates. Since each source in that region can be observed as long as 100 days, while virtually continuous measurements of count rates averaged over 10 s were made, the experiment provided favorable conditions for the study of periodic events over a wide range of periods.

The long-term observations of the Galactic Center region as well as of some other sky regions were also conducted during the GRIF experiment on-board "Mir" orbital station (mean altitude ~ 400 km, orbit inclination 51°, orbital period ~ 90 min) from October, 1995 to June, 1997 (Kudryavtsev et al. 1998). The scintillation spectrometer PX-2 for the energy range $\Delta E_\gamma = 10 - 300$ keV of detected photons with the effective area $S \sim 300 cm^2$, and field of view $\Omega \sim 1$ sr was the main instrument for astrophysical observations. It consists of 7 identical detector units of the "Prognoz-9" instrument type with crossed FOVs. The axes of these detector units were shifted on 5° respectively to each other. This allowed us to observe almost the same area of the sky with all detectors simultaneously, and on the other hand, in the case of temporal phenomena registration to determine the source direction by the output data from each detector. The instrument

Fig. 1. The region of the sky observed in the experiment onboard Prognoz 9 satellite.
provides flux measurements in energy ranges: 10-50, 25-50, 50-100, 100-200 and 200-300 keV. Information was transmitted to the Earth in 16h-long sessions of continuous observations; the interval between them typically ranged from several hours to several days. A total \(\sim 200\) sessions were conducted during the experiment, from which \(\sim 150\) without many telemetry failures and incorrect times of output data recordings were chosen for subsequent analysis. Due to the rigid fastening of the detector units to the station instrument panel its orientation was determined by the station orientation mainly in two modes: 3-axes stabilization and orbital. In the first case the instrument axis had fixed orientation in space while in the second case it slowly (\(\sim 4^\circ/\text{min}\)) scanned the sky by the station orbital motion. Thus the different parts of the sky including Galactic Centre and Anti-Centre regions were accessible for observations during this experiment.

The sky region observed during the experiment is shown in Fig. 2 in equatorial coordinates. Different shades of gray represent the exposure time throughout the entire experiment. When estimating the exposure time, we assumed the angle between the source direction and the PX-2 axis to be no larger than 30°. In addition, we exclude the "Mir" residence time in the regions of trapped radiation. As a condition for the source being not shadowed by the Earth, we considered the requirement of PX-2 orientation to the sky, i.e. the angle between the PX-2 axis and the nadir-zenith direction should be within the range 0° – 90°. The figure also shows the brightest X-ray sources, slow pulsars and the Galactic equator. The typical exposure time can be determined by using observing conditions for the Galactic Center. Figure 2 shows a circumference with a
radius of 30° whose center coincides with the Galactic Center. There are sources within the region in the sky bounded by this circumference during the observations of which the PX-2 effective area accounted for no less than 50% of its geometric area. As one can see from the figure, the total observing time of the Galactic Centre with \( \geq 50\% \) efficiency was \( \sim 200 \) h. The exposure times of other Galactic sources (for example, 4U1700-37) are similar.

2.2. The data processing technique

To reveal the periodic processes the time sets of X-ray instrument outputs were analyzed. In the case of the Prognoz 9 experiment such primary outputs were the mean count rates for 10 s. In the case of ”Mir” GRIF experiment primary outputs were the mean count rates for 5 s. These time sets were subject to random and regular variations, which produce the background for periodicities. These include rises in the X-ray flux due to solar flares and cosmic gamma-ray bursts, changes of the background count rate in the X-ray channels caused by variations of charged particle fluxes that bombarded the spacecraft, and some others. The counts in X-ray channels can be caused partially by the stochastic variations in the total intensity of the emission from the sources, which were simultaneously within the instrument’s field of view. Both, Prognoz 9 and ”Mir” GRIF experiments were capable of eliminating the effect of some background factors with the use of direct measurements of the individual background components. Significant sporadic rises in the count rates in the X-ray channels were mainly attributed to hard X-ray bursts from solar flares and cosmic gamma-ray bursts. Since the latter were recorded during the experiments rather rarely [Kudravtsev and Svertilov 1988, Kudravtsev et al. 2002], they could not significantly affect the background in the search for periodicities. In the Prognoz 9 experiment the Sun was constantly within instrument’s field of view, thus its X-ray activity was monitored continuously, and about 800 solar X-ray bursts were detected [Abrosimov et al. 1988]. To identify such bursts the data from the Prognoz 9 RF experiment [Valnicek et al. 1979], during which the Sun was continuously monitored in the band 2-10 keV by an instrument with a small (\( < 10^\circ \)) field of view, as well as the data of ground-based optical and radio observations of the Sun [Coffey 1984] were used. In the search for periodicities the time intervals during which the solar bursts were detected were excluded from analysis. Since such bursts are rather short-lived, the total duration of the time intervals rejected in this way in Prognoz 9 experiment was short, no longer than 0.3% of the total exposure time, for example, for the observations of the Galactic-Centre region. During the OS ”Mir” GRIF experiment solar X-ray bursts were not detected at all because of the low solar activity during that time (1995-1997) [Coffey 2001].
The relation between the count rate in a given X-ray channel and the count rate of charged particles detected by the anticoincidence cap can be assumed to be linear. Thus, the initial count rates in the analyzed time series can be represented as a superposition of the count rates that characterize the photon flux \( N^*_x \) under study and the additional count rates due to the charged particles \((\alpha N_z)\):

\[
N_x = N^*_x + \alpha N_z.
\]

The linear regression coefficients \( \alpha \) were determined from the sufficiently long (\( \sim 100 \) days) time series that corresponded to the regions of the sky under consideration. The most significant linear regression coefficients were obtained for the channels 50-100 and 100-200 keV (\( \alpha \sim 0.04 \) photon per particle). The effect of variations in the flux of charged particles in the channels 10-50 and 25-50 keV turned out to be weak. The \( \alpha \) coefficient values were used to obtain the time series of count rates \( N^*_x = N_x - \alpha N_z \) for subsequent analysis.

One of the main peculiarities of the GRIF experiment was the possibility of simultaneously monitoring all the principal components of background-producing emissions in the near-Earth space on “Mir” station orbits. Thus, the large-volume CsI(Tl) scintillator detectors of NEGA-1 instrument independently detected the local gamma-quanta (\( \Delta E_\gamma = 0.15 - 50 \) MeV, \( S_\gamma \sim 250 cm^2 \)) and neutrons (\( \Delta E_n > 20 \) MeV, \( S_n \sim 20 cm^2 \)) produced by the interaction of cosmic rays with the spacecraft material and the Earth’s atmosphere. The FON-1 electron detector (\( \Delta E_e = 40 - 500 \) keV) of high sensitivity was used to check the sporadic increases in X-ray flux attributable to bremsstrahlung from precipitating energetic magnetosphere electrons, which could simulate astrophysical phenomena (gamma-ray bursts, transients). Due to a large geometric factor (\( \Gamma \sim 80 cm^2 sr \)) it could detect even relatively small electron fluxes outside the zones of captured radiation. The FON-2 charged-particle detector (\( \Delta E_e = 0.04 - 1.5 \) MeV, \( \Delta E_p = 2 - 200 \) MeV), which was free from overloading in the radiation belts because of its small geometric factor (\( \Gamma \sim 0.5 cm^2 sr \)), was used for background measurements when the ”Mir” station crossed the South-Atlantic anomaly and spurs of the outer radiation belt.

Since the relatively large orbital inclination and periodic crossings of the zones of captured radiation the PX-2 instrument background count rates underwent variations. However, the combination of active and passive shields greatly reduced the background variations, in particular, the latitudinal variations in the main X-ray channels 25-50 and 50-100 keV. To extend the sensitivity range of the instrument the latitudinal count rate variations in high energy photon channels (100-200, 200-300 keV) were removed using regression analysis of the PX-2 X-ray channel outputs (\( N_x \)) and the NEGA-1 gamma-quanta channel outputs (\( N_\gamma \)). Since the NEGA-1 detectors were inside the OS ”Mir” orbital module, they detected mainly the local gamma-emission. The additional count...
rate in a given X-ray channel attributable to the local emission may be assumed to depend linearly on the count rate of gamma-quanta detected by NEGA-1. In this case, the initial count rates in the analyzed time series \(N_x\) can be represented as a superposition of the X-ray count rate proper \(N^*_x\), which characterizes the photon flux under study, and the additional count rate \(\alpha N_\gamma\) attributable to the local gamma-emission:

\[
N_x = N^*_x + \alpha N_\gamma.
\]  

(2)

The linear regression coefficients \(\alpha\) were determined over the entire observation interval when there were no bright sources of hard emission within the PX-2 field of view. The \(\alpha\) coefficient values were used to obtain the time series of count rates \(N^*_x = N_x - \alpha N_\gamma\) for the subsequent analysis. The suppression of background variations with the use of readings in the 150-500 keV gamma-quanta channel yielded the most significant result. After applying the regression procedure, the residual variations in the X-ray channels attributable to the latitudinal variations accounted for no more than \(\sim 3\%\) of the corresponding means, which is several times less than the expected amplitude of the variations attributable to the emission from the most intense Galactic source.

In the search for periodicities, the time series of count rates (which were cleaned from solar bursts and background variations caused by charged particles) were processed by the standard epoch-folding technique (see, e.g. Terebizh 1992), which was modified to accommodate the specific features of the Prognoz 9 and GRIF data. The intervals of observations were broken up into segments with duration equal to the trial period under consideration. The sequences of count rates that corresponded to these segments were added together, and an average phase dependence of the count rate was constructed for this trial period. The amplitude of the periodicity corresponding to the trial period (the actual or randomly simulated one) can be described by the rms deviation \((\sigma^2)\) of the numbers \(M_i\) that constitute the average phase dependence:

\[
\sigma^2 = \frac{\sum_{i=1}^{k} (M_i - \bar{M})}{k - a}.
\]  

(3)

Here \(\bar{M}\) is the mean count rate determined from the entire analyzed time series, \(k = \frac{T}{\Delta T}\), where \(\Delta T\) is the bin duration of the count rates that constitute the mean phase profile; and \(T\) is the trial period. If the periodicity related to the period under study contains both a real periodic component and a noise component, then because of their independence, \(\sigma^2\) can be represented as the superposition:

\[
\sigma^2 = \sigma_{pp}^2 + \sigma_{noise}^2,
\]  

(4)

where \(\sigma_{pp}^2\) and \(\sigma_{noise}^2\) characterize the amplitudes of the corresponding components. In general, the dependence \(\sigma^2(T)\) (periodogram) can be represented as the superposition of a noise continuum (ideally, a smooth function of \(T\)) and discrete peaks of the existing periodicities that correspond to the main period and its multiplies. The continuum in
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the periodogram is determined by a superposition of different (noise) components. One of such noise factors, shot noise ($\sigma_{\text{shot}}^2$), is related to the finite number of photons with a Poisson distribution recorded per bin. This component in the periodogram can be calculated from the mean count rates in the channels; it is linear for periodograms with a constant bin length,

$$\sigma_{\text{shot}}^2(T) = \bar{N} \cdot \frac{1}{\Delta T} \cdot \frac{T}{T_{\text{max}}},$$  \hspace{1cm} (5)

where $\bar{N}$ is the mean count rate, $\Delta$ is the bin length. Clearly, this component is always present in the noise, and the observed continuum can not be lower. The excess over the "shot" component in the total noise continuum can be explained by non-periodic variations in the fluxes from the observed X-ray sources (Galactic noise) and by variations in the instrumental background. For a wide range of periods, the results of data processing by the epoch-folding technique are more conveniently presented by plotting the inverse period (frequency) along the x-axis and by specifying a linear frequency grid in the calculations. In this case, the absolute FWHM of the peaks corresponding to periodicities with similar shapes is the same in the frequency spectrum at any periods. If we plot the parameter $\frac{\sigma^2}{T}$ (T is the period in bins) along the y axis, the frequency continua of noise components correspond, to an accuracy of a factor, to those of a power spectrum in a Fourier analysis. In particular, the quantities that characterize shot noise are constant at all frequencies (white noise). The scatter of points in the real spectrum about the frequency-averaged values of $\frac{\sigma^2}{T}$ in the noise segments in the vicinity of the peak under consideration gives the variance $\sigma_{\sigma}$, which can be used to estimate the significance of the periodicity corresponding to this peak (in the case of Prognoz 9 data $\sigma_{\sigma}$, values were calculated with the use of $\pm 50 \cdot \Delta T_{\text{FWHM}}$ relative to the peak, where $\Delta T_{\text{FWHM}}$ is the mean width of the peak on the periodogram; for these intervals, the background level between peaks was essentially constant). Since the determining of the mean values of $\frac{\sigma^2}{T}$ was performed by averaging over a large number of points in the spectrum, the error of the mean itself can be ignored, while the significance of the identification of a periodicity is determined by the ratio $\frac{\sigma_p}{\sigma_{\sigma}}$.

3. Results of x-ray transient pulsars observations in the Prognoz 9 and GRIF experiments

3.1. The Transient Pulsars under Consideration and the Criterion of the Detection of Significant Flux.

Using the method described above, all the data obtained in the Prognoz 9 and GRIF "Mir" experiments were analyzed. To select the significant periodicities the condition that the amplitude of the peak corresponding to the main period should exceed the mean noise value $\frac{\sigma^2}{T}$ by more than $k\sigma_{\sigma}$ was established. For each observation the real
amplitude distribution of peaks in the search interval was analyzed (amplitude of points was measured in \(\sigma\) units). Thus the level of significance was chosen according to the characteristics of peak amplitude distribution individually for each frequency spectrum. The reason of such approach is that the nature of a significant part of background on frequency spectra is not stochastic. It is connected with real processes in other frequency range or with peculiarities of used periodogram method described above. To search the periodic emission from X-ray pulsars in Prognoz 9 and GRIF "Mir" experiments it is necessary to analyze the frequency spectra in the range of small periods comparable with the duration of one telemetric data output record. In such a way the number of bins in trial period \(T\) was chosen constant and equal 20 only for the large period values (more than \(20\Delta t\), where \(\Delta t\) is the time of one output record), while for periods shorter than \(20\Delta t\) the number of bin was chosen equal to the ratio \(\frac{T}{\Delta t}\) rounded off to the nearest integer. The mean phase profiles constructed with such dividing on bins allow to obtain the pulsation profile in details and provide the sufficient elimination of random component. The minimal trial period for all periodograms and frequency spectra was equal \(5\Delta t\). The analyzing time sets are the numbers of count rate values averaging actually for the time from the beginning to the end of an output telemetric record. These count rate values correspond to all intermediate time moments of the record but not only to one of them. Thus, to obtain the mean phase profile in the case, when the bin boundary lays in the output record time interval, we add to the summing up counts in each bin the mean count in given output record with the weight proportional to the time of that part of record.

The unavoidable features of frequency spectra in the range of small periods several times greater than the time between the points of time series (\(\Delta t\)) is caused by the Nykvest noise number of narrow peaks with periods \(\Delta t \cdot (n + 1/2), \Delta t \cdot (n + 1/3), \Delta t \cdot (n + 2/3), \Delta t \cdot (n + 1/4)\), where \(n\) is integer \((n = 5, 6, ...\)). The nature of these peaks is connected with the averaging technique by the mean phase profile construction. Such peaks were excluded from the frequency spectra under their consideration. All frequency spectrum points corresponding to the periods in the limits \(\pm 0.01 \cdot \Delta t\) from the periods multiple to \(\Delta t, \Delta t \cdot 1/2, \Delta t \cdot 1/3, \Delta t \cdot 1/4\) were also excluded. The total length of the all excluded parts of frequency spectrum is negligible.

Another background peak series appear on the frequency spectra because of the spacecraft rotation. In the case of Prognoz 9 data (Prognoz 9 satellite rotated with period about 2 min) a peak with period 120 s and a number its multiples appear. Except for these series impair the analyzed spectra themselves the rotation of the instrument increase total variability resulting in increase of value of peaks multiple to the time of an output record. To clean the primary time set from variations caused by the satellite rotation the "whitening" procedure was used. Before the analysis those data time sets were identified, for which period and phase of satellite rotation were constant. Usually
the time of such intervals was about 1 day. The frequency spectrum in the vicinity of the expected satellite rotation period peak was calculated for each of those intervals. From this spectrum the accurate satellite rotation period was determined. The mean phase profile corresponding to that period value was also obtained. Then after some smoothing such phase profile many times repeated with the phase conservation was subtracted from analyzed data series. After that the satellite rotation peak amplitude was at the level of the frequency spectrum points random dispersion. As it was mentioned above count rates were measured in the Prognoz 9 experiment every 10 s. In the GRIF experiment this time was 5 s. According to this, X-ray pulsars with pulsation period in the range 30-1500 s were considered. To the present time about 20 X-ray pulsars are known with periods in this range (Bildsten et al. 1997). All of them are accretion-powered pulsars in binary systems including several Be transients.

The time intervals during which these objects were in the FOV of the X-ray spectrometer PX-2 the main astrophysical instrument of the GRIF experiment were determined at first. Because the full FOV of PX-2 instrument was $\pm 45^\circ$ from its axis, let us decide that given source is in the instrument’s FOV if $\theta < 30^\circ$, where $\theta$ is the angle between instrument axis and the direction toward the source. Some aspects of GRIF experiment described above leads to that time set of instrument output data obtained for given pulsar according to the condition $\theta < 30^\circ$ was usually discontinuous. The parts of such time set when the source was in the FOV limits alternate with the time intervals, when the source was shadowed by the Earth, or the instrument was in the radiation belt or redirected. The frequency spectra restored from such ”bit-continuous” data change strongly from point to point like a ”saw”. Without the separate peak corresponding to the periodic process there will be a ”comb” of nearest peaks on the periodogram or frequency spectrum if they were obtained from data separated by large time intervals. It makes difficult to search pulsar periodicities if the pulsation period is not known with enough accuracy. Thus, further analysis was made only for the pulsars, for which the value of pulsation period in different epoch of observations could be estimated basing on the world data about the drift of their period. Taking into account the BATSE CGRO and some other experiment data (Bildsten et al., 1997) 7 transient pulsars were chosen, for which both criteria as on the pulsation period, as on the $\theta$ angle were valid. For these pulsars the time intervals $[T_{\text{min}}, T_{\text{max}}]$ in which their pulsation periods should lay in the GRIF observations epoch were chosen.

The same criterion was used for Prognoz 9 experiment: the $\theta$ angle between the instrument axis and direction toward the source was defined in different time intervals for each of known transient pulsars with appropriate pulsation period, then only objects for which $\theta < 30^\circ$ were considered. Only 3 transient pulsars appeared in the ”Prognoz 9” field of view not more than about $30^\circ$ far from the instrument’s axis. They are also listed in the GRIF catalogue. The interval $[T_{\text{min}}, T_{\text{max}}]$ of periods for the search for pulsations
from A0535+26 was chosen by the extrapolation of its period value to Prognoz 9 epoch. In the case of Sct X-1 and GS1722-36 pulsars in view of insufficient data about drift of their periods the interval of search for periodicities was chosen about 1% of corresponding periods measured in epoch when they were discovered. The best sensitivity in both experiments was achieved in the channels corresponded to energy ranges 10-50, 25-50 keV (the typical energy spectra of transient pulsars were taking into account also). Thus, just these ranges were chosen for primary search of pulsation. The data in other ranges were analyzed in case of revealing of significant peaks on the frequency spectra in the channels 10-50 and 25-50 keV.

By the analysis of GRIF experiment data the time intervals containing the sufficient number of output readings were chosen for each of considered pulsars. Typically they were several consequent seances each lasting for about 16 hours with gaps between them. Besides such rather comfortable intervals the analysis was made also for more long ones. The time of analyzed intervals was increased for those pulsars, which were in the instrument FOV rarely and during a short time. The time sets obtained as the result of primary data processing in the ranges 10-50, 25-50, 50-100, 100-200 keV were analyzed by the epoch folding technique, which was described above in details. As the result the periodograms (frequency spectra) have been obtained for the range of periods $30 \cdot 1.5 \cdot 10^3$ s with the trial period net uniform on the inverse period value, which includes 500000 points. Such detail is sufficient enough to resolve the peaks corresponding to the real pulsation. The view of the all set helps to interpret correctly the frequency spectrum peculiarities connected with the satellite orbit period harmonics. This is especially important in the case of study of pulsars with long (more than 200 s) periods.

To reveal the periodic pulsation on the obtained periodograms the software providing the subtraction of stochastic component and allowing evaluate the peak significance was elaborated. With the use of this software the periodograms were transformed into a form trial period, $T$ (or its inverse value frequency, $T^{-1}$) versus the number of standard derivation characterized the dispersion of points on the primary periodogram near the analyzed peak, $\sigma_\sigma$. To elaborate the criterion of significance of separate peak on the periodograms the dispersion $\sigma_\sigma$ was analyzed. The $\sigma_\sigma - T^{-1}$ representation allows to determine the significance criterion uniformly on the all spectrum. To exclude the influence of non-stochastic peaks (of astrophysical origin or imitated due to the some methodic reasons) on the mean and the standard deviation values they were calculated from the ±5000 points on the frequency spectrum in two steps. On the first step all points where the peak amplitudes were higher than four standard deviations ($4\sigma$) were excluded.

For the estimation of the peak amplitude significance level it was taken into account that the amplitude distribution of the points on the frequency spectrum is not normal. Moreover, it is determined by the several background factors with various contributions on the different intervals of observations as well as on the different parts of frequency
spectrum. From this reason, the amplitude distributions of the points on the frequency spectra were evaluated empirically for each case. The parts of the frequency spectrum near the expected inverse pulsation period in the limits $\pm 6\%$ from the corresponding value were used. As the result the empirical distributions characterizing the dispersion of points on the periodograms were obtained. With the help of these distributions the significance levels were estimated for each time intervals were the pulsation with corresponding periods could be observed. The exact values of threshold amplitude were chosen taking into account the form of each distribution.

To reveal the periodicity of astrophysical origin the sufficiently hard condition was used: the probability of that at least one random peak on the interval of search exceed the chosen threshold should be less than 1\% with the real peak amplitude distribution. Obviously the threshold value depends not only on the stochastic process parameters but also on the width of the frequency range of the search, which could be expressed via the numbers of FWHM. If some peak on the range of search exceeded the threshold level, we can conclude that the corresponding X-ray intensity variation is not casual. In those cases when the maximal peak amplitude did not exceed the threshold, we decided that periodic process was not detected. The amplitude of maximal peak on the interval of search was used for estimation of the upper limit of pulsation component intensity. It means that in some cases it was not the absence of maximums on the frequency spectrum, but the absence of significant peaks on the frequency spectrum.

The frequency range of search of pulsation was determined separately for each pulsar from the evaluation of the possible uncertainty of pulsation period due to its drift. In the most cases this range several hundreds times exceeded the experimental resolution of the period value. To analyze the dynamics of pulsation period the specific programs, allowing compare the periodic process intensity in the different interval of observations, were elaborated. As the result, the two-dimensional diagrams reflected the dependencies on time as of period value as of periodic process intensity were obtained. In such a way the time variations of pulsation periods of those sources, which could be observable in the GRIF experiment, were examined. Additionally the search and timing of pulsation of the same sources with the use of Prognoz 9 data were made to study the pulsation period dynamics on the long-term database.

3.2. The Prognoz 9 and GRIF “Mir” summary catalogue of observed transient pulsars

The results of the search of periodic emission from X-ray transient pulsars in the GRIF Mir and Prognoz 9 data are presented in the Tables 1, 2. The periods corresponding to the maximal peaks on the frequency range of search as well as the pulsed fluxes (significant values or upper limits) obtained from those peak amplitudes are presented in the
Table 1 for different intervals of observations in the GRIF experiment. It is necessary to note that searches of pulsation in the GRIF data were made only in the 25-50 keV energy range because it was the most pure from the background variations. For those transient pulsars which were observed in the GRIF experiment the mean total and pulsed fluxes obtained in the BATSE CGRO (Harmon et al. 2004; Bildsten et al. 1997) and the Integral (Lutovinov et al. 2004a; Revnivtsev et al. 2004; Molkov et al. 2004) observations in the energy range nearest to the GRIF one were also added in the Table 1 to compare with GRIF data. The mean orbital phase values in the time of GRIF observation form the last column of the Table 1.

The same parameters as in the Table 1, but for the transient pulsars observed in the Prognoz 9 experiment are presented in the Table 2.

The values of the period of pulsations and the corresponding flux values are printed with bold font for the cases of significant detection. As it can be seen from the Tables only two sources: A0535+26 and GS1722-36 demonstrated significant fluxes. The upper limits of pulsation intensity were obtained for other transient pulsars. The mean phase profiles concerning to those pulsation processes, which intensity exceeded the significance level, analyzed in details. The forms of mean pulsation profiles in different energy ranges were compared with results of other experiments - BATSE CGRO (Bildsten et al. 1997), Ginga (Nagase 1989). The properties of pulsation emission from A0535+26 and GS1722-36 observed in the Prognoz 9 experiment will be discussed in details below.

3.3. A0535+26

With the use of the presented above technique periodograms were obtained for the output count time sets in the ranges 10-50, 25-50, 50-100 keV, which were chosen for the intervals of observation when the Prognoz 9 X-ray instrument’s axis was near the direction toward the location of the well-known X-ray transient pulsar A0535+26. Those periodograms are presented in Fig. 3a. The significant discrete peaks corresponding to the 103.3 s period are quite reveal on the periodograms. The value 103.3 s is equal to known A0535+26 pulsation period in the error limits caused mainly by the uncertainties due to the drift of period.

The mean phase profiles of pulsation (light curves) were obtained for the most probable period equal to the value which was weight-averaged over the peak on the periodogram. The mean phase profiles of that period pulsation in the energy ranges 10-50, 25-50, 50-100 keV are presented in Fig 3b. In the range 100-200 keV pulsation was not revealed at the level of background variations. As it could be seen from the figures, the forms of presented light curves in the different energy ranges are similar and characterize the rather complicated mean pulsation profile. To the all profiles the narrow dip is typical. Its width decrease with increasing of the detected photon energy: about 20% of
A.The periodograms obtained by processing July, 1983 data of Prognoz 9 experiment in 10-50 keV, 25-50 keV and 50-100 keV energy channels. B.The mean phase profiles of 103.3 s pulsations from A0535+26 transient pulsar in correspondent energy ranges.

the full phase in the 10-50 keV range, and about 10% of the full phase in the 50-100 keV range. Also some peculiarities probably being present on the phase profile near the \(\sim 0.8, \sim 1.1, \sim 1.3\) of the full phase are seen better in higher energy range. In general the presented curves do not contradict the A0535+26 pulsation profiles measured in other experiments (Nagase 1989, Giovannelli and Graziati 1992, Bildsten et al. 1997).

The time intervals when the significant pulsation fluxes from A0535+26 were observed in the Prognoz 9 experiment presented in the Table 2 correspond to the orbital phases 0.066-0.122 i.e. the outburst decrease phase. Indeed, it was the July, 1983 pulsar outburst decreasing (Sembay et al. 1990). The mean pulsation intensity values in the 25-50 keV energy range on the consequent time intervals during the Prognoz 9 observations are presented in the panel "a" of Fig 4. Those intensity values were obtained as the counts in the most probable peak at the period search interval on the periodograms folded over the corresponding intervals of observations. As it follows from the figure, despite the rather high error values the steady decreasing of pulsation intensity can be seen quite evidently.

The time dependence of the mean pulsation period obtained for those time intervals that pulsation intensity values are presented on the panel "b" of Fig 4. The same values of the period of pulsations are presented on Fig 5 together with SMM data (Sembay et al. 1990) corresponding to the primary stage of A0535+26 June 1983 outburst. We may conclude from this figure, that taking into account the limits of errors,
Fig. 4. A. The mean pulsation intensity values in the 25-50 keV energy range on the consequent time intervals during the Prognoz 9 observations. B. The time dependence of the mean pulsation period obtained for those time intervals that pulsation intensity values.

that during the Prognoz 9 period of observation the period value has not changed significantly, so the acceleration of the NS rotation stopped at the final stage of the outburst. Moreover, quite evident trend of the period increasing as the intensity fall down can be noticed. This small period increasing does not contradict the correlation between spin-up rate and X-ray flux (and pulsed X-ray flux as well), which is well-known for many Be transient pulsars including A0535+26 (Bildsten et al. 1997; Finger et al. 1996).

The energy spectra of A0535+26 hard emission pulsation component, which were constructed for consequent time intervals marked on Fig. 4a as "I" and "II" are presented in Fig. 6. The best-fit power approximation of the spectrum obtained for the interval...
Fig. 5. The time dependence of the mean pulsation period of A0535+26 obtained in Prognoz 9 and SMM missions during June-July, 1983 outburst.

"I", i.e., for the first half of observed intensity decreasing gives the slope $\sim 1.7$. As it could be seen from the Figure, such slope in the error limits also well approximates the spectrum for the second interval "II", when the pulsation intensity was sufficiently less. Thus, we may conclude that the energy spectrum of X-ray pulsation component does not change essentially on the outburst-decreasing phase. The obtained energy spectra do not contradict the "canonical" model for X-ray pulsars which is used often for the approximation of the full flux energy spectrum of transient pulsars ([White et al. 1983]). This three parameter approximation gives $I(E) = I_0 \cdot E^{-\gamma}$ for low energy part $E < E_c$ and $I(E) = I_0 \cdot E^{-\gamma} \cdot \exp(-(E - E_c)/E_f)$ for $E > E_c$. The spectra obtained in Prognoz 9 experiment are satisfactorily described by the "canonical" model using the parameters similar with ones of the full flux in 1984, April normal outburst of A0535+26 ([Borkus et al. 1998]). There are photon index $\gamma \sim 1.2$, cutoff energy $E_c \sim 23$ keV and e-folding energy $E_f \sim 19$ keV. It indicates on that spectral hardness of the full flux and its pulsation component may be similar. Besides, there is no indication on the presence of any soft excess near the 10 keV. Such soft excess like a thermal or black body spectral components was observed in some binary X-ray pulsars including A0535+26 ([Mukherjee and Paul 2003]). It was interpreted as the emission of a hot region near NS polar caps where accreting plasma
Fig. 6. Energy spectra of A0535+26 pulsed radiation obtained in Prognoz 9 experiment for TJD5516.8-5518.7 (upper) and TJD5518.7-5522.7 (down) intervals of observation. Power low approximation with slope $\sim 1.7$ is shown.

Taking into account the probable distance to the A0535+26 source about 2 kpc (Steele et al. 1998; Giangrande et al. 1980), we obtain the luminosity in the pulsed component $\sim 1.5 \cdot 10^{35}$ erg/s, which corresponds to the measured pulsation flux $3.6 \cdot 10^{-10} \text{erg/cm}^2 \cdot \text{s}$ in the 10-50 keV energy range (see Table 2). The fraction of pulsed component is varied from 30\% to 70\% for typical A0535+26 outbursts (Borkus et al. 1998). Supposing that during Prognoz 9 mission just typical outburst was observed, we may estimate the full luminosity $\sim 3 \cdot 10^{35}$. The comparison with the luminosity in the quiescent state $\sim 3 \cdot 10^{33}$ erg/s (the BeppoSAX results in 2-20 keV range (Mukherjee and Paul 2003)), $\sim 2.5 \cdot 10^{35}$ erg/s (EXOSAT measurements between outbursts in 1-20 keV range (Motch et al. 1991)) and on the other hand with the luminocity of A0535+26 in ”normal” outbursts $\sim 10^{37}$ erg/s (Borkus et al 1998) allows to conclude that we have observed the final phase of the outburst. In favor of this guess the mentioned above absence of soft spectral component also may be caused by the squeezing of emitting region due to the accretion exhaustion. Nevertheless, the quite evident revealing of pulsation on the outburst-decreasing phase indicates on that considerable fraction 

deposits its energy. The absence of thermal component probably indicates on the very small radii of emitting region.
of accretion disk material continued to fall onto NS surface, or centrifugally inhibited regime was achieved.

As the result of A0535+26 observations in the "Mir" GRIF experiment the only upper limits on the pulsation flux in 25-50 keV were obtained (see table 1). This source was observed during five time intervals. In two of them (10580.310580.9, 10614.4-10614.6 TJD) the orbital phase was more than 0.5, i.e. it was not any condition for outburst rise. Two intervals (10091.5-10092.0, 10218.2-10218.9 TJD) corresponds the orbital phase 0.144, 0.282, i.e. principally the outburst finale stage may be found. However, the obtained upper limits ((1.3 − 1.7) · 10^{-10}erg/cm^2 · s) are of the same order than the pulsation fluxes at the same energy range, which was observed in the Prognoz 9 experiment for the "joined" orbital phases (< 0.122). Thus, it is quite possible that on the orbital phases > 0.14 the pulsation fluxes really less than those limits, which are presented in Table 1.

As for the last interval (10370-10460 TJD) it was too wide to reveal significant pulsation from any outburst phase on that rather intensive X-ray background variations in the GRIF experiment.

3.4. GS1722-36

The significant peak at the 411.7 s period, which is known as the pulsation period of the transient pulsar GS1722-36 (EXO1722-36), was revealed on the periodogram in the energy range 25-50 keV. The periodogram was obtained for the time interval (5668.40 5675.31 TJD) of the most favorable observational conditions of this source in the Prognoz 9 experiment: the angle between the X-ray instrument’s axis and the direction toward the pulsar was no more than 20°. The mean phase profiles corresponding to the 411.7 s period in different energy ranges are presented in Fig. 7a. For comparison the pulsation profiles obtained as the result of the Ginga observations of the GS1722-36 [Nagase 1989] are also presented in Fig. 7b. As it could be seen from the figures, in 10-50 and 50-100 keV energy ranges the 411.7 s periodicity is characterized by the single- maximum mean phase profile. The form of these profiles do not contradict to the Ginga data, according to which the 19-38 keV profile is quasi-harmonic while at the lower energies it could be characterized by the evident twin peaks form with the second maximum sufficiently more intensive than first one. Although the Prognoz 9 profile significance in the 50-100 keV energy is not high enough to make some conclusions about its form in details, it is quite evident that maximum becomes narrower at higher energies: it is about a half of period in the 10-50 keV energy range and about 25 – 30% of the period in the 50-100 keV. The 411.7 s periodicity in the energy range 100- 200 keV was not revealed with sufficient significance, thus the corresponding profile was not presented in the Figure.

The energy spectrum of GS1722-36 pulsations is presented in Fig. 8. This spectrum corresponds to the pulsation intensities obtained from the peaks revealed on the per-
Fig. 7. A. Mean phase dependencies obtained for GS1722-36 pulsations in several energy ranges. B. The Phase dependencies of GS1722-36 X-ray pulsations obtained in Ginga experiment (Nagase 1989).

riodograms calculated for the same time interval (5668.40 - 5675.31 TJD)in different energy channels. The best-fit power law approximation of the spectrum gives the slope $\sim 1.2$. Thus this spectrum is sufficiently harder than the typical spectrum of the most of transient X-ray pulsars (Bildsten et al. 1997). Even taking into account that higher energy range used for power law approximation in BATSE experiment leads to the increase of estimated power index one may conclude that the obtained spectrum of pulsations is harder than typical total one.

There is no any information about GS1722-36 orbital phases in the epoch of Prognoz 9 observations, thus we could not make evident conclusions about the stage of the source, when 411.7 s periodic process was observed. However, taking into account the probable
Fig. 8. Energy spectra of GS1722-36 pulsed radiation obtained in Prognoz 9 experiment for TJD5668.40-5675.31 interval of observation. The line corresponds to the best-fit power law approximation of the spectrum with the slope $\sim 1.2$.

distance to the source about 10 kps, the luminosity in the pulsed component may be obtained at the level $\sim 5 \times 10^{36}$ erg/s, which is typical for the ordinary (non-giant) outburst. This value is similar to one obtained in Ginga experiment (Tawara et al. 1989).

In the "Mir" GRIF experiment the upper limits on the GS1722-36 pulsation flux in 25-50 keV were obtained (see table 1). The source was observed during four time intervals. As it could be seen from the Table 1 the pulsation flux upper limits in all intervals are of the same order than the full flux according to the Integral data (Lutovinov et al. 2004a). Due to the rather short orbital period ($\sim 9.7d$) (Lutovinov et al. 2004a) it is difficult to estimate the orbital phases, which corresponded to those intervals, which time was longer than orbital period or more than one half of it value, as in the case of the last interval (10410.0 10415.0 TJD). Thus, the presented in Table 1 upper limits characterize the pulsation intensity averaged over the orbit. Their quite ordinary values may indicate on that there were no any giant outburst during those time intervals.

4. Discussion

As it could be seen from the Tables 1 and 2, the values of pulsation flux upper limits obtained in the Prognoz 9 and GRIF "Mir" experiments are in the range of typical vari-
ability of correspondent transient pulsars. Taking into account flux variability, these data can be used for the estimation of the transient pulsar activity for different epochs of observations. Besides the considered above A0535+262 and GS1722-36 the data about seven transient pulsars (4U1145-619, A1118-615, EXO2030+37, Sct X-1, SAX J2103.5+4545, IGR 16320-4751, IGR 16465-4507) are also presented. By the observational conditions only one of them (Sct X-1) was observed in both experiments, others were visible only in the GRIF X-ray spectrometer FOV. For the time of observation of three pulsars (4U1145-619, A1118-615, EXO2030+37) in the GRIF experiment the BATSE CGRO data as well as the information about those binary systems orbital parameters were also accessible (Bildsten et al. 1997). It allows to compare the pulsation flux values in the near energy ranges and to connect the time of the GRIF observations with corresponding orbital phase, if this time was not so long to surpass the half of the orbital period. As for the Sct X-1, the only fragmentary observations are known, there were no any other experiments, which could be intersected in time with Prognoz 9 and GRIF observations. Thus, it makes difficult to realize any comparison on the pulsation flux limit and orbital phase for this source. The last three pulsars (SAX J2103.5+4545, IGR 16320-4751, IGR 16465-4507) are the newly discovered objects (Hulleman et al. 1998; Molkov et al. 2004) and there were no observations near in time to the GRIF experiment. As the result, for those pulsars we have no information about the orbital phases corresponding to the times of GRIF observations. However for two of them (IGR 16320-4751, IGR 16465-4507) the Integral data are already known (Lutovinov et al. 2004a; Molkov et al. 2004), which allow to estimate their fluxes. The upper limits of pulsation flux obtained in the GRIF experiment for IGR 16320-4751 and IGR 16465-4507 transient pulsars do not exceed their full fluxes according to the Integral data. The presented values as well as the pulsation flux upper limits for SAX J2103.5+4545 and Sct X-1 indicate, probably, on those pulsars were in the quiescent state or in the finale stage of the first type outburst, because the main stage of the ordinary outbursts and second type (giant) outbursts are usually characterized by sufficiently higher fluxes.

Those pulsars, for which it was possible to determine orbital phases, were evidently observed between outbursts (orbital phase >0.3) or in the outburst decreasing state (orbital phase 0.14-0.5). If to assume the probable distance to these sources about few kps, we may conclude that typical flux upper limits from Tables 1 and 2 about \((3-5) \cdot 10^{-10} \text{erg/cm}^2 \cdot \text{s}\) correspond to the limits on the luminosity in the source \(\sim 10^{35} \text{erg/s}\), which are indeed of the order of transient pulsar luminosity between outbursts. Thus, the given overview of the estimations of the different pulsars activity from the long-term observations made in the Prognoz 9 and GRIF space X-ray experiments confirm the accepted point on the transient pulsar activity, according to which the regular intensive raises of fluxes (first type outbursts) associated with periastron passage (orbital phase 0
The results of Prognoz 9 and GRIF experiments indicate the absence of the giant (second type) outbursts in correspondent epoch of observation.

The mean phase profiles of pulsations of the detected transient pulsars A0535+26 and GS1722-36 demonstrate the general similarity of their phase curves with ones obtained in other experiments. However some significant difference in details is present. It is still unclear if this difference is caused by qualitative changes of accretion region geometry in transient pulsar binary system from one normal outburst to another or the variations in total amount of accreting matter can explain all the observational data. It is important to understand if there is any systematic evolution of the phase profiles shape from one epoch to another. Additionally the energy dependency of the shape of phase profile as well as its dependency on the total or pulsed x-ray intensity in the different stages of normal outbursts are of the great interest and may become the theme of further exploration.

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Table 1. The results of the search for periodic emission from transient pulsars in the GRIF Mir experiment.

| Pulsar       | $T_{\text{beg}} - T_{\text{end}}$ | $T_{\text{puls}}$ | Flux · $10^{10}$ | Flux · $10^{10}$ | Flux · $10^{10}$ | Flux · $10^{10}$ | $T_{\text{orb}}$ | orbital phase |
|--------------|----------------------------------|-------------------|-----------------|-----------------|-----------------|-----------------|----------------|---------------|
|              |                                  |                   | Pulsed Mean total | Pulsed Total | GRIF BATSE BATSE INTEGRAL |
|              |                                  |                   | erg/cm$^2$s     | erg/cm$^2$s     | erg/cm$^2$s     | erg/cm$^2$s     |                |               |
|              |                                  |                   | 25-50 keV      | 20-40 keV      | 20-40 keV      | 20-60 keV      |                |               |
| A0535+26     | 10091.5-10092.0 102.916          | 1.72              | 1.14±0.08      | 0-150           | 110            | 0.144          |                |               |
|              | 10218.2-10218.9 103.395          | 1.28              |                 | 0.282           |                |               |                |               |
|              | 10370.0-10460.0 102.935          | 0.689             | wide            | 0.533           |                |               |                |               |
|              | 10580.3-10580.9 103.491          | 2.84              |                 |                |                |               |                |               |
|              | 10614.4-10614.6 103.356          | 2.65              |                 | 0.837           |                |               |                |               |
| 4U1145-619   | 10092.8-10095.7 291.319          | 5.59              | 1.68±0.08      | 2-15            | 187            | 0.56           |                |               |
|              | 10385.0-10457.0 291.169          | 3.40              |                 |                | 0.12-0.50      |                |                |               |
|              | 10092.0-10581.0 291.252          | 4.46              |                 |                | 4-30           |                |                |               |
| A1118-615    | 10385.0-10454.0 405.540          | 8.03              | 0.174±0.06     | 6.54            |                | wide           |                |               |
|              | 10092.0-10581.0 406.123          | 6.44              |                 |                |                |                |                |               |
| EXO2030+37   | 10102.4-10105.4 41.643           | 2.44              | 0.129±0.053    | 2-12            | 46.0           | 0.30-0.40      |                |               |
|              | 10396.4-10477.0 41.644           | 1.43              |                 |                |                | wide           |                |               |
| Sct X-1      | 10072.7-10103.6 110.776          | 0.802             | n/d             |                |                |                |                |               |
|              | 10430.6-10442.4 111.391          | 1.04              |                 |                |                |                |                |               |
|              | 10604.7-10615.0 110.452          | 1.26              |                 |                |                |                |                |               |
| EXO 1722-36  | 10050.0-10110.0 416.150          | 1.02              | 1.0052         | 9.7             |                |                |                |               |
|              | 10070.0-10090.0 415.696          | 1.09              |                 |                |                |                |                |               |
|              | 10604.0-10616.0 415.810          | 1.56              |                 |                |                |                |                |               |
|              | 10410.0-10415.0 414.195          | 0.941             |                 |                |                |                |                |               |
| SAX          | 10028.6-10103.3 359.221          | 3.95              | 0.091±0.068    |                |                |                |                |               |
| J2103.5+4545 | 10383.7-10474.7 360.818          | 2.82              |                 |                |                |                |                |               |
|              | 10383.7-10580.9 360.818          | 2.74              |                 |                |                |                |                |               |
|              | 10580.0-10581.0 357.137          | 1.18              |                 |                |                |                |                |               |
| IGR 16320-4751 | 10051.0-10052.6 1232.494       | 5.15              | 1.82           |                |                |                |                |               |
|              | 10410.8-10414.4 1237.460         | 6.12              |                 |                |                |                |                |               |
|              | 10434.6-10436.3 1170.022         | 3.00              |                 |                |                |                |                |               |
|              | 10580.2-10580.8 1326.165         | 7.94              |                 |                |                |                |                |               |
|              | 10609.7-10615.1 1249.065         | 2.30              |                 |                |                |                |                |               |
| IGR 16465-4507 | 10051.0-10052.6 223.900        | 3.17              | 1.232          |                |                |                |                |               |
|              | 10410.8-10414.4 230.858          | 1.75              |                 |                |                |                |                |               |
|              | 10434.6-10436.3 205.683          | 1.85              |                 |                |                |                |                |               |
|              | 10580.2-10580.8 243.831          | 4.08              |                 |                |                |                |                |               |
Table 2. The results of the search for periodic emission from transient pulsars in the Prognoz 9 experiment.

| Pulsar     | $T_{\text{beg}} - T_{\text{end}}$ | $T_{\text{puls}}$ | Prognoz 9 Pulsed flux | Prognoz 9 Pulsed flux | $T_{\text{orb}}$ orbital phase |
|------------|-----------------------------------|-------------------|------------------------|------------------------|-------------------------------|
|            |                                   |                   | 25-50 keV              | 10-50 keV              |                               |
| A0535+26   | 5516.97-5522.73                   | 103.303           | 1.61E-10               | 3.61E-10               | 110                           |
| A0535+26   | 5516.79-5518.70                   | 103.294           | 1.76E-10               | 6.48E-10               |                               |
| A0535+26   | 5518.73-5522.73                   | 103.304           | 1.05E-10               | 3.07E-10               |                               |
| A0535+26   | 5522.73-5528.74                   | 103.124           | 1.14E-10               | 1.82E-10               |                               |
| A0535+26   | 5528.74-5534.66                   | 103.090           | 1.36E-10               | 3.21E-10               |                               |
| Sct X-1    | 5681.49-5688.36                   | 111.789           | 1.95E-10               | 3.01E-10               |                               |
| Sct X-1    | 5688.36-5695.40                   | 110.673           | 1.20E-10               | 2.33E-10               |                               |
| Sct X-1    | 5695.40-5705.27                   | 110.694           | 1.03E-10               | 1.70E-10               |                               |
| Sct X-1    | 5705.27-5711.27                   | 111.743           | 1.29E-10               | 2.05E-10               |                               |
| Sct X-1    | 5681.49-5711.27                   | 111.484           | 6.93E-11               | 1.40E-10               |                               |
| EXO 1722-36| 5668.40-5675.31                   | 411.147           | 3.80E-10               | 6.38E-10               | 9.7                           |
| EXO 1722-36| 5675.31-5681.49                   | 415.866           | 1.75E-10               | 3.18E-10               |                               |
| EXO 1722-36| 5681.49-5688.36                   | 417.425           | 1.18E-10               | 2.06E-10               |                               |
| EXO 1722-36| 5688.36-5695.40                   | 412.939           | 1.08E-10               | 1.84E-10               |                               |
| EXO 1722-36| 5695.40-5705.27                   | 415.379           | 1.03E-10               | 1.54E-10               |                               |
| EXO 1722-36| 5668.40-5705.27                   | 419.215           | 5.88E-11               | 1.03E-10               |                               |