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Timing analysis of the X-ray transient source XTE J1806–246 (2S1803–245)

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Abstract. An outburst of the X-ray transient source XTE J1806–246 (2S1803–245) was observed by the Rossi X-ray Timing Explorer from April-July 1998. Strong quasi-periodical oscillations (QPO) with a central peak frequency around 9 Hz was detected in one observation of the series performed by the PCA/RXTE experiment. The X-ray flux from the source during the observation with QPO was maximal. The energy spectrum of XTE J1806–246 at this time was softer than for other observations. Statistically significant variability of the QPO parameters was detected, in short-term correlation with the flux variability. Fractional amplitudes of Very Low frequency Noise and the QPO component of the power density spectrum demonstrate a strong energy dependence, while other parameters do not change significantly.

Key words: stars:binaries:general–stars:flare-stars:neutron–stars:individual (XTE J1806–246)–X-rays:general-X-rays:stars

1. Introduction

The X-ray transient source XTE J1806–246 (=2S1803–245=MX1803–24) was discovered by SAS–3 in May 1976 (Jernigan, 1976, Jernigan et al. 1978). An isolated X-ray burst from this region of the sky was detected by the Wide Field Camera 1 (WFC1) on the BeppoSAX observatory on Apr. 2, 1998. The All Sky Monitor (ASM) of the Rossi X-ray Timing Explorer satellite detected the beginning of an X-ray outburst of the source on Apr. 16, 1998 (Marshall et al., 1998). Observations in other wavebands revealed the probable radio (Hjellming, Midouszewski & Rupen, 1998) and optical (Hynes, Roche & Haswell, 1998) counterparts of the object.

Quasi Periodical Oscillations (QPO) were discovered by Wijnands & van der Klis, 1998 in the power density spectrum (PDS) of the source in data obtained on May 3 1998. In this Letter we present results of timing analysis of the PCA/RXTE experiment data, discuss the power density spectrum of the source and report detected correlations of QPO parameters on energy range and X-ray flux.

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Table 1. RXTE observations of XTE J1806–246

#	Obs.ID 30412-01-..	Date, UT	Time start	PCA Exp. sec
1	01-00	27/04/98	19:31:12	4832
2	02-..[a]	28/04/98	18:59:12	1666
3	03-00	29/04/98	20:42:56	3253
4	04-00	03/05/98	21:01:20	2677
5	05-01	17/04/98	00:29:20	1371
6	05-00	17/05/98	12:42:24	3153
7	06-00	22/05/98	11:06:24	3255
8	07-00	08/06/98	07:59:28	2720
9	08-00	14/06/98	20:54:56	3403
10	09-00	01/07/98	19:45:04	991
11	10-00	07/07/98	19:50:08	1581

[a] – This observation consists of several smaller ones: ..-02-00S,..-02-01S,..-02-02S,..-02-03S,..-02-04S

2. Observations and analysis

We analyzed archival data obtained by the RXTE observatory during the outburst of the source in Apr.-July 1998. Brief information about the observations is presented in the Table 1.

The data were analyzed according to the RXTE Cook Book recipes using the FTOOLS, version 4.2 tasks. For background estimations we used the VLE model for observations when X-ray flux was high, and the L7/240 for the observations corresponding to low flux.

The data were collected in different modes (*Standard 2*, *Event Mode*, *Single Binned* and *Binned Mode*) with the best timing resolution of 16μs in hard energy bands ($\gtrsim$13 keV), and of 8 ms and 125 μs in soft energy bands ($\lesssim$13 keV). The X-ray flux from the source appears to be highly erratic, with significant variability at all time scales.

To obtain a broad band power density spectra we used data of two types. For the PDS at frequencies higher than

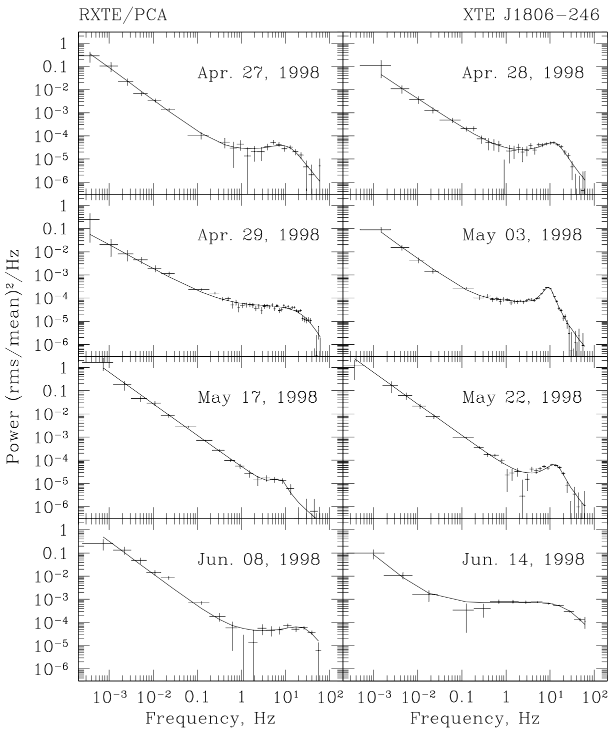

Fig. 1. The power density spectra of XTE J1806–246 during the different RXTE observations (2–13 keV energy band). The solid lines represent models for the PDS, that consist of Very Low Frequency Noise, High Frequency Noise and QPO for observation #4 (see text)

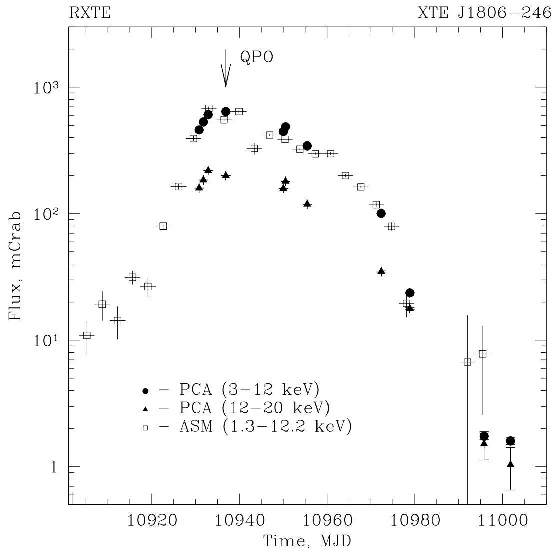

Fig. 2. The light curve of X-ray transient XTE J1806-246 during its outburst of 1998. Empty rectangles represent ASM data, filled points and triangles - PCA data in two energy bands. The date of QPO detection is marked by the arrow.

0.05 Hz we used 16 sec data segments with an 8 ms time resolution. This gave us a set of power density spectra between 1/16 and 64 Hz, which were subsequently averaged and corrected for deadtime modified poissonian noise (Zhang et al., 1995). To obtain PDS in a lower frequency band ($\sim 5\times10^{-4}$ Hz – $\sim$0.1 Hz) we used the 16-second time resolution data of *Standard 2* mode, because it allowed us to take into account the influence of the background variation on the PDS, which might be of importance at such frequencies.

3. Results

3.1. Power density spectra

The power density spectra for different observations are presented in Fig.1. The power law representing the Very Low Frequency Noise (VLFN) component dominates the frequency band 10^{-4} – 1 Hz for all PDSs. The high Frequency Noise component for frequencies higher than 1 Hz can be approximated either by another power law with an exponential cut-off at frequencies of 10–20 Hz or by a wide Lorentzian. The slope of the VLFN component was in the range $\alpha \sim -1.0{-}1.5$ and its fractional variability was from 1.5 to 4 percent in the energy band 2–13 keV. The amplitude of the VLFN fractional variability increases with energy (see Fig. 3 for observation #4) while the slope of the power law remains constant.

In the observation of May 3, 1998, a significant ($>10\sigma$) QPO peak was detected, agreeing with an earlier report by Wijnands & van der Klis, 1998. The central frequency of the QPO, which was obtained by fitting a Lorentzian profile to the power density spectrum averaged over the whole observation (2–13 keV energy band) is equal to $f = 9.11 \pm 0.07$ Hz, with the width of the Lorentzian profile $FWHM = 5.4 \pm 0.2$ Hz. Its fractional variability amplitude in the frequency range $\sim 10^{-4} - 64$ Hz was 4.7 ± 0.1%. The amplitude of the QPO varies with energy similar to the variation of the VLFN (Fig.3).

It is remarkable that this observation was taken when X-ray flux from the source was the highest among all PCA observations. The X-ray light curve of XTE J1806-246 during its outburst of 1998 is presented in Fig.2. It is worth noting that the difference in the X-ray flux detected in observations #3 and #4 is only $\sim$5%, but PDS are qualitatively different.

3.2. QPO parameters

In the observation of May 3, 1998 we detected significant changes in the QPO parameters: the central frequency, width and amplitude of the fractional variability. Fig. 4 shows the variation of QPO amplitude and frequency in comparison with X-ray flux variation (all values were computed for the energy band 3–13 keV).

Because both the X-ray flux from the source and QPO parameters have demonstrated time variability, we tried to look for correlations between them, which might be

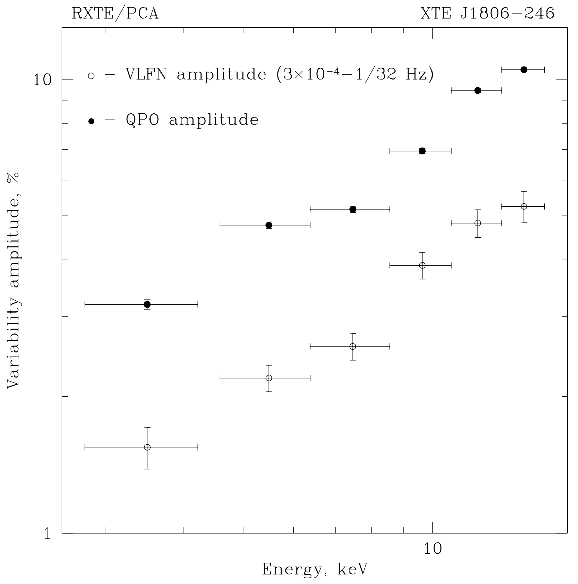

Fig. 3. Variability amplitudes for VLFN and QPO as functions of energy (observation #4).

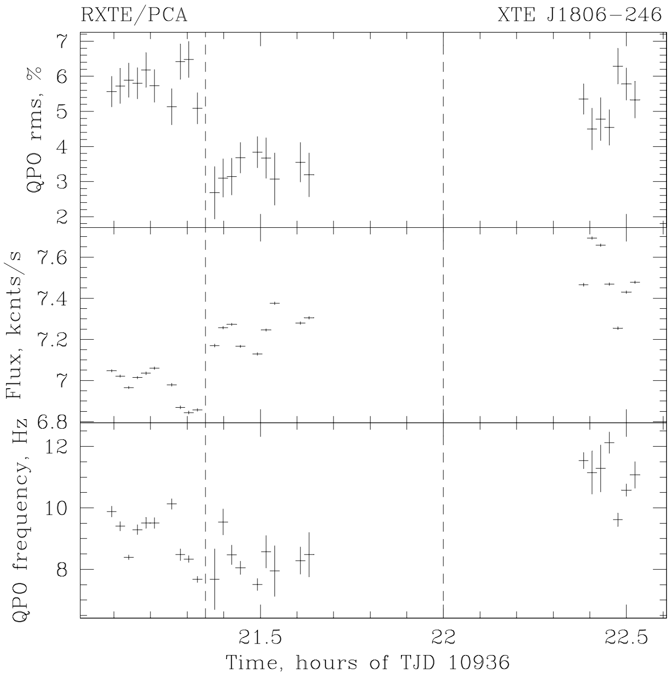

Fig. 4. The time dependence of the QPO parameters (frequency and amplitude) and total X-ray flux variability during the observation #4. Dashed lines mark time intervals with different QPO/flux levels (see text).

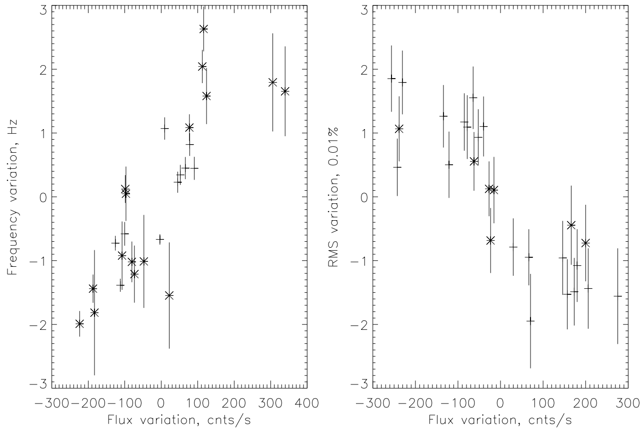

Fig. 5. The correlations between X-ray flux and QPO parameters for short time intervals. On the left panel data for the second and third intervals are marked by stars. On the right panel data for the third interval are marked by stars.

important for the overall understanding of the QPO phenomenon. One might note three distinctive time intervals during the observation of May 3. The first corresponds to "low" flux (below 7100 cnts/s) and "strong" QPO (rms higher than 5%) with "low" frequency (below 10 Hz). In the second interval the flux is "medium" (7100 – 7400 cnts/s), QPO is "weak" (rms $\lesssim$ 5%) and still of "low" frequency. During the third interval the flux is "high" ($\gtrsim$ 7400 cnts/s), QPO is "strong" and of a higher frequency (10-12 Hz). While there is no global correlation between these three intervals, we have found some evidence for short-term correlations within each of them. The results are presented in Fig.5. Parameter variations were calculated by subtraction of the mean value for each interval. For flux-frequency dependence data for the first interval were separated from later data. In order to obtain flux-rms dependence the first two intervals were analyzed together, and the third one - separately. A flux-frequency correlation and flux-rms anticorrelation are clearly seen at short scales, but an influence of other, not related to QPO, processes might be the reason why such correlations could not be expanded for longer time intervals. We would like to note that the measurement of total X-ray flux and the determination of QPO parameters was done by completely independent methods, so any correlation between them must be not methodical, but physical. We were concerned about a possible systematic cross-correlation between QPO amplitude and QPO frequency values, both determined by the same procedure, but our analysis has not revealed any evidence of such a correlation.

3.3. Color-color diagram

We used data in different energy channels to build a color-color diagram (CCD), which allows one to follow spectral changes of the source (Hasinger & van der Klis, 1989). The CCD for the data of the first 7 analyzed observations is shown in Fig.6. For this CCD we used four energy bands in the PCA spectrum: 2.1–3.5 keV, 3.5–6.4 keV, 6.4–9.7 keV and 9.7–16.0 keV.

The overall shape of the points distribution reminds us of the diagrams for some Z-sources, such as GX17+2 and

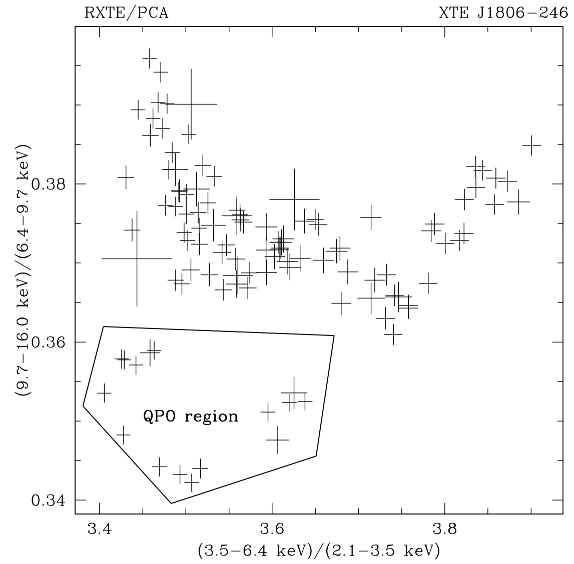

Fig. 6. The color-color diagram of XTE J1806-246 during the first 8 observations. The points within the solid line polygon correspond to the time when the strong QPO was visible on the PDS spectra

Sco X-1 (see Hasinger & van der Klis, 1989). However, we did not find a clear correlation between QPO and one of the branches on diagram. Instead, we found that the QPO region corresponds to a lower value of hard color regardless of the value of soft color.

4. Discussion

Quasi-periodical oscillations in power density spectra have been detected from many sources of different natures (see van der Klis, 1995 for review and references therein). We discuss here a strong QPO in the PDS of the X-ray source XTE J1806-246, which can be considered a typical X-ray transient. The nature of this source is more or less clear because of the definite detection of the X-ray burst from it (Muller et al. 1998), so one can consider XTE J1806-246 a neutron star with a low magnetic field. X-ray bursts are more typical for atoll sources (see the classification in Hasinger & van der Klis, 1989). However, the shape of the color-color diagram, PDS dominated by VLFN and HFN components and the fact that QPO was observed at the maximum X-ray light curve of the source is strongly suggestive for the classification of XTE J1806-246 as another Z-source, known to be neutron stars, probably with a magnetic field stronger than that of typical X-ray bursters, but weaker than that of pulsars (van der Klis, 1994). As mentioned by Wijnands & van der Klis, 1998 it would be then the first ever known Z-transient. Other reputed Z-sources are all persistent X-ray sources (Hasinger & van der Klis, 1989).

The origin of QPOs in Z-sources remains controversial. Some of models proposed include the beat frequency model (Alpar & Shaham, 1985), hot spots in a boundary layer (Hameury et al., 1985), obscuration of the central X-ray source by an accretion disk (Stella, 1986) etc. (for review see Lamb, 1988, van der Klis, 1995 and references therein). The correlation between the X-ray flux and the QPO frequency we found for short time scales could be an indication that the frequency of QPO is linked with the typical radius of the accretion disk in the system, which in turn correlated with the luminosity of the source. An anticorrelation between the source flux and the amplitude of fractional variability associated with QPO demonstrates that short-term increases of X-ray flux (microflares) might be caused by a mechanism, not related with QPO.

The Very Low Frequency Noise was detected in all observations of XTE J1806-246 by PCA/RXTE, in all energy bands with the increasing amplitude of fractional variability towards higher energies. The striking similarity in the energy dependences of QPO and VLFN amplitudes suggests that these components originate in the same region of the binary system. The energy spectrum of the source is probably formed by hard highly variable component and soft constant component, which explains the increase of QPO and VLFN amplitudes with energy.

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