Detection of a 5-Hz QPO from X-ray Nova GRS 1739-278

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ABSTRACT

The X-ray nova GRS 1739-278 flared up in 1996 near the Galactic center. Here we report on the discovery of a \(\sim 5\)-Hz quasi-periodic oscillations (QPO) in RXTE/PCA measurements of the Nova. The QPO was only present when the source was in its very high state, and disappeared later, when it made a transition down to a high state. The energy spectrum of this black hole candidate is presented in the context of this QPO. The similarities between this system and other X-ray transients are discussed.

1. INTRODUCTION

Many bright X-ray transients are reputed black hole candidates and demonstrate similar X-ray spectra and fast variability. During the outburst these systems are typically found in one of two qualitatively distinguishable spectral states: in the high state composed of the bright thermal component and the extended hard power-law, or in the low state with the hard power-law spectrum with a photon index of \(\sim 1.5\) and an exponential high energy cutoff. A more detailed description of these states can be found elsewhere (Sunyaev et al. 1994, Tanaka and Lewin 1995, Tanaka & Shibazaki 1996). A third, very high, state has been recognized also, with two component spectrum similar to the high state, but with somewhat stronger power-law component and with much stronger fast variability (Miyamoto et al. 1991, Takizawa et al. 1997). The spectral evolution of X-ray transients is usually in correlation with X-ray flux changes, so it is widely believed that state transitions are driven by the variable accretion rate. Such transitions were also observed in the persistent black hole systems, namely, Cyg X-1 and GX 339-4, but the dynamics of these systems is much slower, so they are more often observed in one of these states and typically switch to another state once every several years (Sunyaev & Truemper 1979, Makishima et al. 1986, Dove et al. 1998, Trudolyubov et al. 1998).

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The new hard X-ray source GRS 1739-278 was discovered near the Galactic Center on March 18, 1996 by the SIGMA gamma-ray telescope on board the Granat satellite (Paul et al. 1996). The initial SIGMA localization of GRS 1739-278 was refined by the TTM instrument (Borozdin et al. 1996). VLA radio observations revealed a radio source within the TTM error region (Durouchoux et al. 1996). Mirabel et al. (1996) measured the optical/infrared flux from this object.

In 1996, the source was observed in the X-ray band by ROSAT (Greiner et al. 1997), Granat (Vargas et al. 1997), RXTE (Takeshima et al. 1996), and the Kvant module of the Mir Space Station. Borozdin et al. (1998) presented the spectral analysis of Mir-Kvant and RXTE data, and classified the GRS 1739-278 as a soft X-ray nova and a black-hole candidate. In this letter, we report on the discovery of a 5-Hz QPO in power density, which supports the black hole classification of this system.

2. OBSERVATIONS AND DATA REDUCTION

The RXTE satellite observed the X-ray nova GRS 1739-278 on March 31, 1996 and nine more times from May 10 through May 29 of that year, each with an exposure of several kiloseconds. The total exposure was about 24 ks.

The RXTE satellite has two aligned spectrometers with a ∼1 degree field of view each: a set of five xenon proportional counters PCU-PCA with a maximum sensitivity in the energy range 4-20 keV and the HEXTE scintillation spectrometer which consists of eight NaI(Tl)/CsI detectors sensitive to the range 15-250 keV. The HEXTE detectors are combined into two clusters of four detectors each; each cluster observes the source in turn. Concurrently, the second cluster measures the instrumental and external X-ray background.

For the timing analysis the PCA Binned and Single Binned mode data were used. We generated power density spectra (PDS) in the 0.001–256 Hz frequency range (2–13 keV energy band), combining the results of the summed Fourier transforms of a short stretches of data with 0.002 s time bins for the 0.3 – 128 Hz frequency range and a single Fourier transform on the data in 0.125 s time bins for lower frequency band. The resulting spectra were logarithmically rebinned when necessary to reduce scatter at high frequencies and normalized to square root of fractional variability rms. White–noise level due to the Poissonian statistics corrected for the dead–time effects was subtracted Vikhlinin, Churazov & Gilfanov 1994, Zhang et al. 1995. For spectral analysis we used the latest versions of the FTOOLS software package, which was developed by the RXTE team, to reduce the PCA data [see Jahoda et al. (1997) for computations of the matrix; see Stark et al. (1997) for
3. THE LIGHT CURVE OF THE SOURCE

The light curve for the 1996 outburst of the GRS 1739–278 is shown in Fig. 1. The data shown were obtained with the All-Sky Monitor (the ASM instrument) and PCA experiment on board the RXTE satellite. Overall shape of the outburst is of FRED type (Chen, Shrader & Livio 1997), with secondary maxima, as typical for many black hole X-ray Novae (Sunyaev et al. 1994, Tanaka & Shibazaki 1996).

4. 5-HZ QPO IN POWER DENSITY SPECTRUM

A power density spectrum (PDS) of the source for the observation of March 31, 1996 (Fig. 2a) revealed the presence of a QPO feature with central frequency near 5 Hz. Our derived QPO parameters are presented in Table 1. A band-limited noise component was also present in the PDS for the source on that day, and significant variability at low frequencies was seen both in PDS (Fig. 2a), and in light curve of the source (Fig. 3). In contrast, much weaker fast variability was detected in observations made in May 1996 (Fig. 2c).

The pointing position for the observations of GRS 1739–278 was slightly offset in order to reduce an influence from the pulsar-burster GRO 1744–28 (Takeshima, Canizzo and Corbet 1996). We were still concerned about the possible contamination of our power density spectra by this bright nearby source. So we analyzed the data from its observation of March 30, 1996, just one day before the first observation of GRS 1739–278 with RXTE took place. Power density spectrum of GRO J1744–28 is presented in Fig. 4. The prominent peak at ∼2 Hz corresponding to the pulsar period dominates the PDS. We don’t see however any indication of increased variability at this frequency in PDS of GRS 1739–278. So we conclude that a contamination of GRS 1739–278 observations by GRO J1744–28, if any, was not significant factor.

The RXTE spectra for all observations of GRS 1739–278 have the appearance that is typical of the spectra of X-ray Novae (Tanaka & Shibazaki 1996). In general, such spectra are well fitted by a two-component model composed of ”multicolor” accretion disk component (Makishima et al. 1986) in the soft part of the spectrum and by a power-law component at high energies. Detailed spectral analysis for GRS 1739–278 RXTE observations was presented by Borozdin et al. (1998). During the observations on March
31, 1996, when QPO was detected, the power-law component in the spectrum was more prominent (see Fig.2b). During the subsequent observations in May 1996, the power-law component considerably weakened and emission was not detected by HEXTE (see Fig.2d).

Based on results both timing and spectral analysis we can conclude that the source was in a very high state (Miyamoto et al. 1991) on March 31 1996, and made a transition down to a high state sometime before May 10.

5. DISCUSSION

Broad-band spectroscopy of black-hole candidates has revealed at least three distinct spectral states. In the low state, the spectrum is very hard and can be fitted by a power law that extends up to energies of 100 keV or higher with an index of 1.5-2.0. In the high state, the spectrum is dominated by a soft component, which is described by the spectrum of a "multicolor" accretion disk with a characteristic temperature of 0.7-1.5 keV, and the flux at energies above 10 keV is low and often undetectable. Of particular interest is the very high state; its spectrum exhibits a noticeable power-law component with a characteristic index 2.5, in addition to a bright soft component similar to the high-state spectrum. Since this very high state has not been observed so far in systems whose compact component is a neutron star, this type of spectrum can be considered as evidence for the presence of a black hole in the system. In fact, as was demonstrated, for example, by Borozdin et al. (1999), this type of spectrum can be satisfactorily fitted by the models that explicitly assume the absence of an emitting surface of the compact component in the binary system (Chakrabarti & Titarchuk 1995, Titarchuk, Mastichiadis, & Kylafis 1997).

The RXTE spectrum of the source on measured March 31, 1996 is comparable to the very high state spectra, which have been observed in many other X-ray Novae (a review of observations is presented in Tanaka & Shibazaki 1996; for more recent results see Revnivtsev, Trudolyubov & Borozdin 1999, Trudolyubov, Borozdin & Priehorsky 1999). The fast X-ray variability detected at the same time is also typical for very high state emission. QPO features in power density spectra have been detected in this state for a variety of black hole candidates including GX 339–4 (Miyamoto et al. 1991), Nova Muscae (Miyamoto et al. 1993, Ebisawa et al. 1994), and 4U 1630–47 (Trudolyubov, Borozdin & Priehorsky 1999). During observations of GRS 1739–278 in May 1996, the amplitude of fast X-ray variability from the source was lower and the energy spectrum was much softer. The source entered typical high state, observed from almost any Galactic black hole candidate (see Tanaka and Lewin 1995 for a review). The correlation between the intensity of PDS noise components and the power-law shape of the high-energy spectrum supports
the idea that there is a direct phenomenological link between these two features of black hole candidates.

Significant low-frequency variability have been observed in Galactic microquasars GRS 1915+105 (Morgan et al. 1997) and GRO J1655–40 (Remillard et al. 1999), and also during the 1998 outburst of recurrent X-ray Nova 4U 1630–47 (Trudolyubov, Borozdin & Priedhorsky 1999). All listed were in their very high states during these observations. Somewhat similar variability was observed from GRS 1739–278 on March 31, 1996 (Fig. 3), also in very high state.

An interesting energy spectrum was observed with TTM telescope on Mir-Kvant module in March 1996 during the rise of the flux from the GRS 1739–278 (Borozdin et al. 1998). It is well described by a power law with absorption and does not require the introduction of an additional soft blackbody component. At the same time, the slope of the power-law component (2.3-2.7) is much steeper than the typical value for the low state of black-hole candidates (1.5-2.0). A similar spectrum was observed earlier by Ginga and Granat satellite from the X-ray Nova Muscae 1991 (Grebennev et al. 1991, Gilfanov et al. 1991, Ebisawa et al. 1994) and by TTM/Kvant and SIGMA/Granat from KS 1730-312 (Borozdin et al. 1995, Trudolyubov et al. 1996). Later this type of spectrum was observed with RXTE from XTE J1748-288 (Revnivtsev, Trudolyubov & Borozdin 1999), 4U 1630-47 (Trudolyubov, Borozdin & Priedhorsky 1999), and XTE J1550-564 (Trudolyubov & Borozdin 1999). These examples show that the power-law shape of the spectrum with a variable slope is typical of soft X-ray Novae during their flux rise before the primary maximum. There is a tendency for the spectrum to steepen as the outburst develops. However, total X-ray luminosity of hard spectrum can be even higher than for typical very high spectrum observed later (Revnivtsev, Trudolyubov & Borozdin 1999, Trudolyubov, Borozdin & Priedhorsky 1999).

6. CONCLUSIONS

The X-ray source GRS 1739-278 have a set of properties that allow to classify it as a black-hole candidate and X-ray Nova. The light curve after the maximum exhibits a quasi-exponential decline with secondary maxima. The source’s spectrum at that time corresponds to the very high and high state spectra of black-hole candidates. The fact that the object belongs to this class is confirmed by optical and radio observations.

The discovery of ∼5-Hz QPO, strong fast variability of the source during this observation, and significant low-frequency excess in PDS confirm that the source was in
very high state during the observation of March 31, 1996. During the series of observations carried out in May of 1996, the character of fast variability changed significantly, which showed that the source entered high state at this time. Simultaneously an X-ray flux from the source dropped down in comparison with the level of March 31, and energy spectrum became softer, with substantially weaker high-energy component.

During the rise phase of the outburst, a power-law spectrum of variable hardness was recorded before the primary maximum, with clear tendency to steepen with time (Borozdin et al. 1998). Similar spectrum at the rise phase has been detected from several other X-ray Novae; we can thus speak of a clear pattern in the behavior of X-ray Novae during the flux rise.

7. ACKNOWLEDGMENTS

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REFERENCES


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* - integrated total rms amplitudes in the 0.03 – 100 Hz and 0.003 – 100 Hz frequency ranges.
Fig. 1.— The 2-10-keV light curve of GRS 1739-278, according to ASM/RXTE data. Times of PCA/HEXTE observations marked by tick marks. The time of 5-Hz QPO detection is marked by arrow.
Fig. 2.— Power density spectra (upper row) and energy spectra (lower row) of GRS 1739-278 during the outburst of 1996. Left column presents observation of March 31, when 5-Hz QPO was observed. Right column present PDS and energy spectrum typical for the series of observations in May.
Fig. 3.— The PCA light curve of GRS 1739-278 during the observation of March 31, 1996. Flux variations at time scales of tens of seconds are clearly seen.
Fig. 4.— Power density spectrum of GRO J1744–28 for the observation of March 30, 1996. Dominating peak at \( \sim 2 \) Hz corresponds to the pulsar period. The absence of significant variability increase at this frequency in PDS of GRS 1739–278 (Fig. ??) shows that contamination from GRO J1744–28, if any, was not significant factor.