SPECTRAL PROPERTIES OF LOW-FREQUENCY QUASI-PERIODIC OSCILLATIONS IN GRS 1915+105

J. Rodriguez,1,2 S. Corbel,1,3 D. C. Hannikainen,4 T. Belloni,5 A. Paizis,2 and O. Vilhu4

Received 2004 April 19; accepted 2004 July 2

ABSTRACT

We report on the timing analysis of RXTE observations of the Galactic microquasar GRS 1915+105 performed in 2003. Out of a total of six ~20 ks observations, we focus here only on the three during which GRS 1915+105 is in a steady C-state (referred to as class χ), resulting in a total of ~50 ks. During these observations, we detect low-frequency quasi-periodic oscillations (QPOs) with high (~14%) rms amplitude in the 2–40 keV energy range. Contrary to what is usually observed in GRS 1915+105, in most of our observations the QPO frequency presents no correlation with the RXTE PCA count rate, nor with the RXTE ASM count rate. We present, for the first time, high-resolution (22 spectral channels) 2–40 keV spectral fits of the energy dependence of the QPO amplitude (“QPO spectra”). The QPO spectra are well modeled with a cutoff power law except on one occasion in which a single power law gives a satisfactory fit (with no cutoff at least up to ~40 keV). The cutoff energy evolves significantly from one observation to another, from a value of ~21.8 to ~30 keV in the other observations in which it is detected. We discuss the possible origin of this behavior and suggest that the compact jet detected in the radio contributes to the hard X-ray (≥20 keV) mostly through synchrotron emission, whereas the X-rays emitted below 20 keV would originate through inverse Compton scattering. The dependence of the QPO amplitude on the energy can be understood if the modulation of the X-ray flux is contained in the Comptonized photons and not in the synchrotron ones.

Subject headings: accretion, accretion disks — black hole physics — stars: individual (GRS 1915+105) — X-rays: stars

1 INTRODUCTION

GRS 1915+105 was discovered by the WATCH instrument on board Granat in 1992 (Castro-Tirado et al. 1992). It is the first Galactic source observed to have apparent superluminal motion in radio (Mirabel & Rodríguez 1994), corresponding to the ejection of plasma at a speed of ~92%–98% of the speed of light. It distance is estimated to be 9 ± 3 kpc (Chapuis & Corbel 2004), and the mass of the compact object in GRS 1915+105 is estimated to be 14.0 ± 4.4 M⊙ (Harlaftis & Greiner 2004).

Systematic monitoring in the X-rays (mainly with the Rossi X-Ray Timing Explorer [RXTE]) revealed a rich pattern of variability on all timescales. GRS 1915+105 is a source of low- and high-frequency quasi-periodic oscillations (LFQPOs, HFQPOs; Morgan et al. 1997), whose properties (frequency, rms amplitude) are tightly correlated with the spectral parameters (Morgan et al. 1997; Munro et al. 1999; Markwardt et al. 1999; Rodriguez et al. 2002a, 2002b; Vignarca et al. 2003). When analyzing data of black hole binaries, the frequencies of LFQPOs have been shown to be best correlated with the slopes of the high-energy tails of the energy spectra (Vignarca et al. 2003). It should be noted that the LFQPO frequency is usually correlated with the soft X-ray flux, thought to originate from the accretion disk.

Belloni et al. (2000; hereafter B00), analyzing 163 RXTE observations, have shown that, although complex, the behavior of GRS 1915+105 could be understood as spectral transitions between three basic states A, B, and C. They identified 12 recurrent classes of variability on a timescale of ~3000 s. GRS 1915+105 spends most of the time in the so-called χ class of variability that corresponds to a steady state in the X-rays, lying in a rather hard part of the color-color diagram (state C or hard state). Based on the X-ray (spectral end temporal) and radio properties of GRS 1915+105, four subclasses (χ₁, χ₂, χ₃, χ₄) can be distinguished. Two of them have a high level of radio emission with a flat spectrum, LFQPOs, and a high-energy tail (B00; Trudolyubov 2001; Muno et al. 2001; Klein-Wolt et al. 2002).

We monitored GRS 1915+105 with the International Gamma-Ray Astrophysics Laboratory (INTEGRAL) during its first AO, for a total of 6 × 100 ks (Hannikainen et al. 2003, 2004), and obtained 120 ks divided into six sequences of simultaneous observations with RXTE. One of our RXTE observations was planned during an INTEGRAL target of opportunity on GRS 1915+105, and it allowed wideband simultaneous spectral and temporal coverage to be performed (Fuchs et al. 2003, hereafter F03). The global analysis of the whole campaign is reserved for a future publication. Here we focus on the timing analysis of the three steady C-state RXTE observations. The data reduction methods are described in § 2, while the results are presented in § 3 and discussed in § 4.

2 OBSERVATIONS AND DATA REDUCTION

The log of the observations analyzed in this paper can be found in Table 1. Each observation covers several satellite orbits. The analysis was first performed on each single revolution, and when no noticeable (spectral or temporal) evolution was found, the different orbits were further averaged to increase the statistics.

We extracted light curves from the Proportional Counter Array (PCA) following the standard method described in the
Cook Book and ABC of RXTE, with the LHEASOFT version 5.3 package. Good time intervals are defined as follows: satellite elevation over the Earth limb is >10°, offset pointing is <0.02, and PCUs 0 and 2 are turned on. Light curves were extracted from “binned” and “event” data. We first accumulated a broadband 2–40 keV (absolute channels 0–94, epoch 5) light curve with the highest time resolution allowed by the (binned) data format (~4 ms). We then extracted light curves in small-energy bins, with the highest spectral resolution allowed by the (binned) data (16 energy bins from 2 to 14.8 keV), and over seven additional spectral bins for the event data (from 15 to ~40 keV). Power density spectra (PDSs) were produced using POWSPEC version 1.0 and corrected for white noise. In the case of the 2–40 keV light curves, PDSs were produced on an interval length of 64 s between 15.625 mHz and 64 Hz. All intervals were averaged together. The energy-dependent PDSs were produced on an interval of 160 s length, between 6.25 mHz and 12.8 Hz. Figure 1 shows, as an example, the PDSs extracted in three energy bands, for observation 1. We extracted background light curves in all these energy ranges and used their count rate to obtain the true rms amplitude following Berger & van der Klis (1994). In addition, to check for short-term evolution of the QPO frequency, we produced dynamical power spectra with ~16 s resolution between absolute channels 0 and 35 (~2–14.8 keV).

3. RESULTS

The preliminary spectral analysis (in a multiwavelength context) of the first observation is presented in F03. The eight other sequences presented here show similar steady light curves (see Hannikainen et al. 2004, hereafter H04, for details on the INTEGRAL/RXTE campaign). The RXTE ASM light curve, showing the dates of our pointed INTEGRAL/RXTE observations, is represented in Figure 2. While the long-term evolution

---

TABLE 1

| Observation | Observation Date (MJD) | Observation ID (P80127-) | Good Time (s) | PCU | Net Count Rate per PCU* (counts s⁻¹) |
|-------------|------------------------|--------------------------|--------------|-----|-------------------------------------|
| 1           | 52,731                 | 01-03-00                 | 9300         | 4   | 1737.5                              |
| 2           | 52,738                 | 02-01-00                 | 5400         | 3   | 1700.8                              |
| 3           | 52,739                 | 02-02-02                 | 1800         | 3   | 1675.8                              |
| 4           | 02-02-01               |                          | 1800         | 4   | 1666.9                              |
| 5           | 02-02-00               |                          | 2060         | 3   | 1660.4                              |
| 6           | 02-03-00               |                          | 11,100       | 3–4 | 1674.7                              |
| 7           | 02-01-01               |                          | 3200         | 3   | 1677.0                              |
| 8           | 52,768                 | 03-01-00                 | 14,000       | 3–4 | 1460.2                              |

Note.—The first of these observations was performed simultaneously with the multiwavelength campaign discussed in Fuchs et al. (2003). Observations are time ordered.

* Measured as counts s⁻¹ in the top layer of PCU 2, both anodes.

---

See http://heasarc.gsfc.nasa.gov/docs/xte/abc/contents.html.

---

Fig. 1.—Example of PDSs extracted in three energy bands (1–3.7 keV, 8.2–9 keV, and 20.6–23.1 keV), as described in the text. These PDSs are from observation 1. The 2.498 Hz LFQPO is obvious in each panel. The same vertical scale is used for each PDS and allows for a direct comparison of the source behavior in those energy bands.
shows a slow decay, a double flare occurs between observation 1 and observations 2–7. This X-ray flare is associated with a radio flare (F03), probably indicative of a discrete ejection. We identify the class of variability of our observations as class C31\textsuperscript{1}. The high level of radio emission detected during each of these observations (F03, H04) allows us to further classify the observations as class C31\textsubscript{1-3}, also known as the radio-loud hard state (Muno et al. 2001) or type II hard state (Trudolyubov 2001). It should be noted, however, that such a long-term decay with the source mostly in class C31 is rather peculiar, and had never been seen previously. A preliminary spectral analysis (F03; H04) shows that the common model of black hole X-ray binaries, i.e., a multicolor disk blackbody and a power law, represents the data well. As mentioned for such classes (Muno et al. 2001), however, the disk temperature returned from the fit is too high (3–4 keV), and the inner radius far too small. Alternative models of broken power law or broken power law plus disk component fit the data well and lead to parameters closer to what is seen in other systems (H04). We also successfully fitted the RXTE 3–25 keV spectra with a cutoff power law with a high-energy cutoff of about 20–25 keV (Rodriguez et al. 2004; Fig. 3). When adding higher-energy spectra, such as those extracted with RXTE HEXTE, a large deviation to the spectrum is seen at high energy, indicating the need for an additional spectral component to the model, e.g., an extra power law (Zdziarski et al. 2001; D. C. Hannikainen et al., in preparation). This is illustrated in Figure 3 (left panel) with the particular example of observation 1.\textsuperscript{7} Furthermore, Rodriguez et al. (2004) have shown that the 20–400 keV combined RXTE HEXTE and INTEGRAL IBIS and SPI spectra could be fitted with a power law of photon index \( \sim 3.5 \). Note that similar results were found from the OSSE spectral analysis of Zdziarski et al. (2001).

For all sequences, the 2–40 keV PDSs were fitted between \( \sim 15 \) mHz and 10 Hz with a sum of two or three Lorentzians (depending on the energy range), to account for the wideband variability (Belloni et al. 2002). A strong LFQPO is detected in all the PDSs and is modeled with an additional Lorentzian (harmonics are also detected, especially during intervals with the longest exposures). A first analysis of observation 8 showed a rather broad QPO, with parameters poorly constrained. As the dynamical power spectrum showed two distinct features, we separated this observation into subintervals and averaged those showing the QPO at the same frequency. This resulted in two distinct sets of data, for which we identified two different QPOs. The LFQPO parameters are reported in Table 2.

At first glance, there is apparently no obvious correlation between the QPO frequency and the PCA 2–60 keV count rate (Tables 1 and 2). To further verify this, we fitted each of the \( \sim 2–15 \) keV 16 s PDSs used to construct our dynamical power spectra with a Lorentzian around the average QPO frequency (Table 2), and could therefore obtain the variations of the QPO frequency with a time resolution of 16 s. No correlation is found between the QPO frequency and the PCA 2–15 keV count rate.

\textsuperscript{7} Note that the details of the RXTE and INTEGRAL spectral analysis will be given in a forthcoming paper, dedicated to the spectral analysis of the whole campaign. However, the RXTE (PCA and HEXTE) spectra have been extracted in the same way as in, e.g., Rodriguez et al. (2003).
from observations 1–7, whereas we do find a correlation in observation 8.

We further averaged sequences showing the QPO at a similar frequency (observation 7, showing the QPO at 1.06 Hz is averaged with observations 2 and 4, whereas observations 3, 5, and 6 are averaged together) and produced PDSs in the 22 energy bins described in §2. These energy-dependent PDSs were fitted between 6.25 mHz and 10 Hz. The energy dependences of the amplitude of the four distinct features are reported in Figure 4.

A clear difference in the shape of the energy dependence of the amplitude of the QPO appears in Figure 4. A clear turnover in the amplitude versus energy relation is visible for the ~2.48 Hz QPO detected on MJD 52,731, and another one is visible for the ~1.09 Hz QPO from the observation of MJDs 52,738–52,739, although it is not as clear as for the first QPO. For the three other features we do not see any clear turnover (Fig. 4), although a flattening is obvious at energies above 10 keV. This may suggest that the turnover energy evolves from one observation to another, and is above the upper energy limit of our QPO “spectra.” To further test this hypothesis, we fitted the QPO spectra in XSPEC version 11.3.0. For all QPOs but the 1.04 Hz one, the spectra are well fitted by a cutoff power law (cutoffpl in XSPEC). The fit parameters are reported in Table 3, while the right panel of Figure 3 shows the QPO spectrum of observation 1 with the best-fit model superimposed. It should be added here that a single power law gives a rather good representation of the 1.878 Hz QPO detected in observation 8, with a reduced $\chi^2$ of 1.89 (20 degrees of freedom). A cutoff power-law model improves the fit (Table 3), although the cutoff energy is poorly constrained (4.7 $\sigma$ significance on this

---

**Table 2**

Parameters of the LFQPO detected in each of the eight sequences

| Observation Sequence | QPO Frequency (Hz) | $Q^*$ | rms Amplitude (%) |
|----------------------|-------------------|------|-------------------|
| 1........................................... | 2.498 ± 0.005 | 5.0 | 12.6 ± 0.3 |
| 2........................................... | 1.040 ± 0.004 | 3.8 | 13.5 ± 0.6 |
| 3........................................... | 1.081 ± 0.004 | 7.2 | 13.2 ± 0.9 |
| 4........................................... | 1.039 ± 0.004 | 7.2 | 12.7 ± 1.3 |
| 5........................................... | 1.097 ± 0.005 | 10.0 | 11.5 ± 1.0 |
| 6........................................... | 1.096 ± 0.002 | 6.4 | 13.4 ± 0.4 |
| 7........................................... | 1.060 ± 0.003 | 6.4 | 13.0 ± 0.9 |
| 8_QPO1.................................... | 1.878 ± 0.003 | 6.8 | 12.9 ± 0.5 |
| 8_QPO2.................................... | 2.332 ± 0.005 | 5.3 | 14.9 ± 0.5 |

* $Q$ is defined as $Q = \text{Centroid frequency}/\text{FWHM}$.  

---

**Fig. 4**—Energy dependence of the LFQPO amplitude. The frequency (or mean frequency) of the feature and the observation numbers are written in each panel.
parameter. It is interesting to note that the break energy seems anticorrelated with the QPO frequency, i.e., the lowest break energy is observed for the highest QPO frequency (Table 3). Caution has to be expressed, however, since the statistical uncertainties on the break energies do not allow us to draw a firm conclusion.

4. DISCUSSION

The presence of LFQPO in GRS 1915+105 during class χ (as well as during other classes) is a known fact (e.g., Muno et al. 1999; Rodriguez et al. 2002a, 2002b). It is also known that QPO parameters depend on spectral parameters in black hole binaries (BHBs) in general. Here we present observations taken during the same state, with few differences between the spectral parameters returned from the spectral fits. The parameters of the QPO change dramatically from one observation to another. Except in observation 8, the frequency of the QPO does not seem to correlate to the PCA 2–15 keV flux or the ASM 1.2–12 keV flux, either (although the highest frequency is observed when the ASM flux is the highest; Fig. 2 and Table 2), contrary to what is usually claimed/observed. This could indicate some definite peculiarities in observations 1–7, which are taken just before and after the X-ray/radio flare (Fig. 2, F03). On the other hand, observation 8 occurs later, after GRS 1915+105 apparently went off the linear decay phase, after the ASM light curve showed some variability again.

The most striking behavior appears when studying the energy dependence of the QPO amplitude. It is expected and a known fact that it presents a turnover at some point (e.g., Tomisic & Kaaret 2001; Rodrigueza et al. 2002a). We report here, for the first time, a clear evolution of the turnover energy between states that are spectrally similar and have similar PCA fluxes. This “cutoff” energy has an origin that is unclear. It could represent, for example, some specific temperature at which the QPO is produced, either through oscillations of a shocked boundary layer between the accretion disk and a hot inner flow (e.g., Chakrabarti & Titarchuk 1995), or by a hot spot orbiting at some specific radius in the disk (e.g., Rodriguez et al. 2002a; Tagger et al. 2004). In these two cases, however, we would expect the frequency of the QPO to scale with the inner radius of the accretion disk and thus the soft X-ray flux (Molteni et al. 1996; Tagger & Pellat 1999), unless the soft X-rays are not uniquely produced by the accretion disk, but by another physical medium, as, e.g., a compact jet (see Markoff & Nowak 2004). The variations of the soft X-ray flux could be due to variations of the compact jet flux (with a steady thermal flux from the accretion disk), as we discuss below.

The spectral approach presented in H04 and Rodrigueza et al. (2004), the systematic analysis of type II states (Trudolyubov 2001), and the detection of a hard tail up to (at least) 600 keV with OSSE (Zdziarski et al. 2001) raise the challenging question of the origin of the third spectral component needed to fit the high-energy spectra well. Models of jet emission (e.g., Markoff et al. 2003; Markoff & Nowak 2004) propose a jet model in which the X-ray spectrum of an X-ray binary would represent the sum of thermal emission from the accretion disk, direct synchrotron from the jet, Comptonization (either through synchrotron self-Compton from the jet, and/or Comptonization on the basis of the jet, the “corona”), and reflection of these radiations on the accretion disk. This proposition has found an echo with the radio flux/X-ray flux correlation found in several BHBs when in the low hard state (when the compact jet is present, e.g., Corbel et al. 2003; Gallo et al. 2003) and also in the case of radio-loud active galactic nuclei (e.g., Merloni et al. 2003; Falcke et al. 2004). Our RXTE observation of MJD 52,731 occurred at a time when the radio flux was high and indicative of the presence of the compact jet (F03). The level of radio emission as measured by the Ryle telescope at 15 GHz is about 130–150 mJy during this observation, with a spectrum extending up to the near infrared range (F03). Unfortunately, we do not have such nice coverage for the following observations, but the observation of MJDs 52,738–52,739 indicates a higher level of 15 GHz emission (~250 mJy, F03) that is dropping rapidly. We remark that this observation occurred just after a radio flare indicative of a discrete ejection. It is thus very likely that the radio emission this day partly originates from the discrete ejection (with a different spectrum). During the last observation, the radio flux is very low compared with the two previous dates, with a level dropping from 107 mJy on MJD 52,767 to 44 mJy on MJD 52,769 (H04). Both our spectral analysis (H04, Rodriguez et al. 2004) and the properties of the QPOs (present work) can be understood easily if the X-ray emission in GRS 1915+105 during radio-loud/type II class χ1–χ3 observations originate (as proposed by Markoff & Nowak 2004) from two different physical processes (besides the thermal emission of the accretion disk): Comptonization and synchrotron radiation. The high-energy spectrum of a source with a compact jet thus represents the sum of these different emission processes. As a result, the spectrum will strongly depend on the relative contribution of each of these emission processes. The break in the energy spectrum could be representative of the energy at which the relative contributions of these components cross each other. Above the break the contribution of the synchrotron radiation would be the dominant process to the spectrum. Then, the higher the relative contribution of the synchrotron component (to the overall spectrum), the lower the break energy is. In this case, to understand the energy dependence of the QPO amplitude, one has to assume that

| QPO Frequency (Hz) | Power-Law Slope (Γ) | Cutoff Energy (keV) | Reduced χ^2 (dof) |
|--------------------|-------------------|-------------------|-----------------|
| 2.498              | −0.77 ± 0.04      | 21.9^{+2.7}_{−2.2} | 1.0 (19)        |
| 1.04               | −0.26 ± 0.02      | No cutoff^a        | 0.92 (21)       |
| 1.09               | −0.59 ± 0.05      | 29.5^{+5.2}_{−3.5} | 0.37 (20)       |
| 1.878              | −0.70 ± 0.07      | 25.6^{+4.3}_{−4.6} | 0.5 (19)        |
| 2.332              | −0.71 ± 0.05      | 26.7^{+4.4}_{−3.3} | 0.28 (20)       |

Note.—Fits to the energy dependence of the QPO amplitude are also referred to as QPO spectra in the text. The errors are given at the 1 σ level.

^a No cutoff is detected in this observation at least up to ~40 keV.
the QPO is contained in the Comptonized flux and not in the synchrotron flux. Then the position of the cutoff in the energy dependence of the QPO amplitude would be linked to the synchrotron flux emitted by the jet. We find this interpretation at least qualitatively in good agreement with several observational facts:

1. The compact jet model has successfully been used in the fitting of different BHBs (e.g., Markoff et al. 2001).
2. Type II states show a 2–30 keV level of variability lower than that of type I (radio-quiet) states (Trudolyubov 2001).
3. A compact jet is detected during the observation showing the clear and well-constrained cutoff in the energy dependence of the QPO amplitude (observation 1, Fig. 4).
4. A high level of radio emission is detected during the observation taken on MJDs 52,738–52,739, and a turnover of the QPO amplitude (Fig. 4, Table 3, although it is absent in the spectrum of the ~1.04 Hz QPO), while for the last observation (MJD 52,768) the radio flux is much lower, a single power law can fit the first QPO spectrum, and the turnover is poorly constrained (Fig. 4, Table 3).

We should add that the optical/UV/X-ray variability (and presence of LFQPO in those bands) seen in XTE J1118+480 (Hynes et al. 2003), a black hole X-ray transient in which the compact jet model has been shown to fit the broadband spectra well (Markoff et al. 2001), is also compatible with our interpretation. Hynes et al. (2003) pointed out that the variability could not originate from the disk itself, but involved another nonthermal source of photons.

The lack of complete simultaneity between the radio and X-ray observations prevents us from drawing any firmer conclusions. In addition, a cutoff in the spectrum of the compact jet is expected in the near infrared domain. Knowing its exact position would allow us to estimate the flux expected from the jet in the hard X-rays accurately and thus test our hypothesis. We hope to obtain such simultaneous coverages in the near future, with INTEGRAL and RXTE for the high energies, but also the Ryle telescope and the VLA in the radio domain, and the Spitzer Space Telescope and ground-based telescopes in the infrared domain.

The authors would like to thank G. Henri for useful discussions and G. Pooley for kindly providing the Ryle data to our group. J. R. acknowledges financial support from the French Space Agency (CNES). D. C. H. acknowledges the Finnish Academy.

REFERENCES

Belloni, T., Klein-Wolt, M., Méndez, M., van der Klis, M., & van Paradijs, J. 2000, A&A, 355, 271 (B00)
Belloni, T., Psaltis, D., & van der Klis, M. 2002, ApJ, 572, 392
Berger, M., & van der Klis, M. 1994, A&A, 292, 175
Castro-Tirado, A. J., Brandt, S., & Lund, N. 1992, IAU Circ., 5590, 2
Chakrabarti, S. K., & Titarchuk, L. G. 1995, ApJ, 455, 623
Chapuis, C., & Corbel, S. 2004, A&A, 414, 659
Corbel, S., Nowak, M., Fender, R. P., Tzioumis, A. K., & Markoff, S. 2003, A&A, 400, 1007
Falcke, H., Körding, E., & Markoff, S. 2004, A&A, 414, 895
Fuchs, Y., et al. 2003, A&A, 409, L35 (F03)
Gallo, E., Fender, R. P., & Pooley, G. G. 2003, MNRAS, 344, 60
Hannikainen, D. C., et al. 2003, A&A, 411, L415
———. 2004, in Proc. 5th INTEGRAL Workshop (ESA SP-552; Noordwijk: ESA), in press (H04)
Harlaftis, E. T., & Greiner, J. 2004, A&A, 414, L13
Hynes, R. I., et al. 2003, MNRAS, 345, 292
Klein-Wolt, M., Fender, R. P., Pooley, G. G., Belloni, T., Migliari, S., Morgan, E. H., & van der Klis, M. 2002, MNRAS, 331, 745
Markoff, S., Falcke, H., & Fender, R. P. 2001, A&A, 372, L25
Markoff, S., & Nowak, M. 2004, ApJ, 609, 972
Markoff, S., Nowak, M., Corbel, S., Fender, R., & Falcke, H. 2003, A&A, 397, 645
Markwardt, C. B., Swank, J. H., & Taam, R. E. 1999, ApJ, 513, L37
Merloni, A., Heinz, S., & di Matteo, T. 2003, MNRAS, 345, 1057
Mirabel, I. F., & Rodríguez, L. F. 1994, Nature, 371, 46
Molteni, D., Sponholz, H., & Chakrabarti, S. K. 1996, ApJ, 457, 805
Morgan, E. H., Remillard, R. A., & Greiner, J. 1997, ApJ, 482, 993
Muno, M. P., Morgan, E. H., & Remillard, R. A. 1999, ApJ, 527, 321
Muno, M. P., Remillard, R. A., Morgan, E. H., Waltman, E. B., Dinhav, V., Hjelmning, R. M., & Pooley, G. 2001, ApJ, 556, 515
Rodriguez, J., Corbel, S., & Tomsick, J. A. 2003, ApJ, 595, 1032
Rodriguez, J., Durochoux, P., Mirabel, F., Ueda, Y., Tagger, M., & Yamaoka, K. 2002a, A&A, 386, 271
Rodriguez, J., Fuchs, Y., Hannikainen, D. C., Vilhu, O., Shaw, S. E., Belloni, T., & Corbel, S. 2004, in Proc. 5th INTEGRAL Workshop (ESA SP-552; Noordwijk: ESA), in press (astro-ph/0403030)
Rodriguez, J., Varnière, P., Tagger, M., & Durochoux, P. 2002b, A&A, 387, 487
Tagger, M., & Pellat, R. 1999, A&A, 349, 1003
Tagger, M., Varnière, P., Rodríguez, J., & Pellat, R. 2004, ApJ, 607, 410
Tomsick, J. A., & Kaaret, P. 2001, ApJ, 548, 401
Trudolyubov, S. 2001, ApJ, 558, 276
Vignarca, F., Migliari, S., Belloni, T., Psaltis, D., & van der Klis, M. 2003, A&A, 397, 729
Zdziarski, A. A., Grove, E. J., Poutanen, J., Rao, A. R., & Vadawale, S. V. 2001, ApJ, 554, L45