Received 2005 February 18; accepted 2005 April 14
Preprint typeset using LaTeX style emulateapj v. 6/22/04

THE ABC OF LOW-FREQUENCY QUASI-PERIODIC OSCILLATIONS IN BLACK-HOLE CANDIDATES: ANALOGIES WITH Z-SOURCES

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Received 2005 February 18; accepted 2005 April 14

ABSTRACT

Three main types of low-frequency quasi-periodic oscillations (LFQPOs) have been observed in Black Hole Candidates. We re-analyzed RXTE data of the bright systems XTE J1859+226, XTE J1550-564 and GX 339-4, which show all three of them. We review the main properties of these LFQPOs and show that they follow a well-defined correlation in a fractional rms vs. softness diagram. We show that the frequency behavior through this correlation presents clear analogies with that of Horizontal-, Normal- and Flaring-Branch Oscillations in Z sources, with the inverse of the fractional rms being the equivalent of the curvilinear coordinate S_z through the Z track.

Subject headings: accretion — black hole physics — stars: oscillations — X-rays: binaries

1. INTRODUCTION

Low-frequency Quasi-Periodic Oscillations (LFQPOs) with centroid frequencies from mHz to tens of Hz have been observed in the X-ray flux of many neutron-star and black-hole X-ray binaries (see van der Klis 2005, and references therein). In neutron-star Low Mass X-ray Binaries (LMXRB) the timing behavior has long been known to correlate with spectral variations. In particular, the properties of the LFQPOs vary in systematic fashion along the pattern that these sources describe in the X-ray color-color diagram (CD). In high-luminosity neutron-star systems (the so-called Z sources) (Hasinger & van der Klis 1989; van der Klis 2005), three types of LFQPOs have been associated with the position along the Z-pattern that these sources describe in a CD: the horizontal branch oscillations (HBOs), normal branch oscillations (NBOs) and flaring branch oscillations (FBOs) (for details on these LFQPOs, and how they are tracked through the Z-pattern by using the curvilinear coordinate S_z see van der Klis 1995).

In the case of Black Hole Candidates (BHCs) the general picture is at present less clear. Three main types of LFQPOs, dubbed Type-A, -B and -C respectively, originally identified in the light curve of XTE J1550-564 (see Wijnands et al. 1999a; Remillard et al. 2002), have been seen in several sources (see Section 2). On the other hand, three main bright states (in addition to the quiescent state) have been identified in these sources, based on their spectral and timing properties (for a review see Tanaka & Lewin 1995; van der Klis 1995; McClintock & Remillard 2005; van der Klis 2005; Homan & Belloni 2005). It was only very recently that systematic variations in the energy spectra and intensity of transient BHCs could be identified in terms of the pattern described in an X-ray Hardness-Intensity diagram (HID) (see Homan et al. 2001; Belloni 2003; Homan & Belloni 2005; Belloni et al. 2005). Original states are found to correspond to different branches/areas of a square-like HID pattern. In this scheme the BHC LFQPO phenomenon appears to be confined to within a comparatively small range of spectral properties of these sources, requiring a deeper investigation over a restricted range in parameters' space. Within this small range, attempts to correlate the QPO properties with other properties such as the source position in the CD or the HID across different BHCs have so far given inconclusive results. This is clearly at variance with neutron-star LMXRBs.

Similarities between power spectra in BHCs and in Z sources have been stressed by several authors (see e.g. Miyamoto et al. 1993). van der Klis (1994) discussed the parallelism between NS and BH systems and underlined the importance of quantitatively studying the similarities between them. Wijnands & van der Klis (1999a) and Psaltis, Belloni & van der Klis (1999) found global correlations between characteristic frequencies in both NS and BH systems, involving type-C LFQPOs and HBOs for BHCs and Z sources respectively, plus the low-frequency LFQPOs in atoll sources. These correlations suggested that basic frequencies of these systems likely have the same origin as envisaged in some QPO models, and yielded to propose an association between type-C LFQPOs and HBOs.

In this letter, we show that the QPO type and centroid frequency in BHCs vary systematically as a function of the inverse of the source rms fractional variation. This behavior is reproduced fairly accurately over different BHCs and presents clear similarities with the LFQPOs of neutron star low mass X-ray binaries. Based on this analogy we suggest that C, B and A type LFQPOs in BHCs correspond to HBOs, NBOs and FBOs of high luminosity neutron-star systems of the Z-class respectively.

2. QPO CLASSIFICATION

Several distinct types of LFQPOs showing different properties have been discovered in BHCs. An exhaustive classification has not yet been obtained, given the complexity and variety of the observed behaviors. However, three main LFQPO types (named Type-A, -B and -C) stand out in the present scenario. In Table 1 we summarize their main properties.

2.1. *Type C LFQPOs*

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TABLE 1
Summary of type-A, -B and -C LFQPOs properties

Property	Type C	Type B	Type A
Frequency (Hz)	∼0.1-15	∼5-6	∼8
Q (ν/FWHM)	∼7-12	$\gtrsim$6	$\lesssim$3
Amplitude (%rms)	3-16	∼2-4	$\lesssim$3
Noise	strong flat−top	weak red	weak red
Phase lag @ν_{QPO}	soft/hard	hard	soft
Phase lag @$2\nu_{QPO}$	hard	soft	...
Phase lag @$\nu_{QPO}/2$	soft	soft	...

Type-C LFQPOs are characterized in the power spectrum by a strong (up to ∼16% rms), narrow ($\nu/\Delta\nu \sim 7-12$) and variable peak (its centroid frequency and intensity varying by several percent in a few days, see e.g. C04) at frequencies ∼0.1-15 Hz, superposed on a Flat-Top Noise (FTN) that steepens above a frequency comparable to the QPO frequency (see Wijnands & van der Klis 1999a; Belloni, Psaltis & van der Klis 2002). The total (QPO and FTN) fractional rms variability can be as high as ∼ 30%. A subharmonic and a second harmonic peak are often seen. Phase lags (i.e. the phase delay between two light curves at different energies) depend strongly on the frequency of the QPO, with a trend towards soft lags (i.e. soft X-ray variations lag those at hard X-ray energies) for increasing QPO frequency (see Reig et al. 2000), but they are usually consistently soft at the subharmonic and hard at the second harmonic (see e.g. Remillard et al. 2002; Casella et al. 2004, C04 hereafter). The QPO rms increases with energy, flattening above ∼ 10 keV (see e.g. C04). In some cases a decrease above 20 keV is observed (Tomsick & Kaaret 2001) which might be associated with a higher radio flux (Rodriguez et al. 2004).

Low-frequency QPOs that can be identified as type-C were observed in a number of sources, e.g. GS 1124-684 (Miyamoto et al. 1993; Takizawa et al. 1997), XTE J1550-564 (Remillard et al. 2002), XTE J1859+226 (C04), GX 339-4 (Miyamoto et al. 1991) and GRO J1655-40 (Méndez et al. 1998).

The presence of a strong FTN component and the correlation of the QPO frequency with the source intensity and the FTN break frequency (Wijnands & van der Klis 1999a) strongly suggest the association of this low frequency QPO type with the HBO observed in Z sources (Miyamoto et al. 1993).

2.2. *Type B LFQPOs*

Type-B LFQPOs are characterized by a relatively strong (∼4 % rms) and narrow ($\nu/\Delta\nu \geq 6$) peak which is found in a narrow range of centroid frequencies around 6 Hz. Unlike type C, there is no evidence for FTN, although a weak red-noise (few % rms) is detected at very low frequencies ($\lesssim$ 0.1 Hz). A weak second harmonic is often present, sometimes together with a subharmonic peak. In a few cases, the subharmonic peak is higher and narrower (resulting in a "Cathedral-like" shape, see C04). Phase lags are hard at the fundamental and soft at the second harmonic, i.e. the opposite of the behavior observed for type-C LFQPOs. However, phase lags are soft at the subharmonic as in type-C LFQPOs. The energy dependence of the QPO rms is similar to that of type-C LFQPOs, but the rms values are systematically lower (factor ∼ 2).

The presence of type-B LFQPOs has been reported in different sources: see e.g. GS 1124-684 (Miyamoto et al. 1993; Takizawa et al. 1997), XTE J1550-564 (Wijnands et al. 1999a), GX 339-4 (Nespoli et al. 2003; Belloni et al. 2005), XTE J1859+226 (C04) and GRS 1739-278 (Wijnands et al. 2001).

Rapid transitions in which type-B LFQPOs appear/disappear are often observed in some of these sources. The transitions are unresolved at present, as they take place on a time scale shorter than a few tens of seconds. In GX 339-4, the QPO appearance is related to spectral hardening of the source flux (see Nespoli et al 2004; Belloni et al. 2005), while in XTE J1859+226 transitions towards type-C and type-A LFQPOs appear to be related to a spectral softening and a spectral hardening, respectively (C04). A rapidly transient ∼6 Hz QPO was observed also in the atoll source 4U 1820-30, and was compared with both NBOs observed in Z sources (Wijnands et al. 1999b) and type-B LFQPOs observed in BHCs (Belloni, Parolin & Casella 2004) (other NBO-like LFQPOs have been observed also in the atoll sources XTE J1806-2646 (Wijnands & van der Klis 1999b; Revnivtsev et al. 1999) and Aql X-1 (Reig et al. 2004)).

The centroid frequency of type-B LFQPOs (which shows often marked variability on a time scale of ∼ 10 s, see Nespoli et al. 2003) is close to the frequency range (∼ 5 − 8 Hz) over which NBOs are observed in neutron-star systems of the Z-class (and perhaps also a few lower luminosity systems, see van der Klis 1995). This frequency coincidence, together with the fact that both type-B LFQPOs and NBOs show a low amplitude noise, seem to suggest an association of these two LFQPO types. However, it must be noticed that some important differences still remain between the two LFQPO, as the higher coherence of type-B LFQPOs and the lack of harmonic content in NBOs. Moreover, NBOs are seen simultaneously with HBOs in Z sources (see van der Klis 1995, and references therein), demonstrating they are different phenomena. This does not happen in BHCs, where type-B LFQPOs are seen to switch from/to type-C LFQPOs (see previous paragraph) without any contemporaneity between the two. Furthermore, the centroid frequency of type-B LFQPOs in XTE J1859+226 shows a weak positive correlation with the count rate (Casella et al. 2005). It is thus in principle possible that the ∼1 Hz QPO observed in GX 339-4 at low count rates (Belloni et al. 2005) could be identified as a type-B. This would extend the frequency range where type-B LFQPOs are observed in BHCs.

2.3. *Type A LFQPOs*

Type-A LFQPOs are characterized by a weak (few % rms) and broad ($\nu/\Delta\nu \leq 3$) peak around 8 Hz. A very low amplitude red noise is observed, whereas neither a subharmonic nor a second harmonic were present (possibly because of the width of the fundamental peak). This LFQPO was observed in different sources: GS 1124-684 (Miyamoto et al. 1993; Takizawa et al. 1997), GX 339-4 (Nespoli et al. 2003; Belloni et al. 2005) and XTE

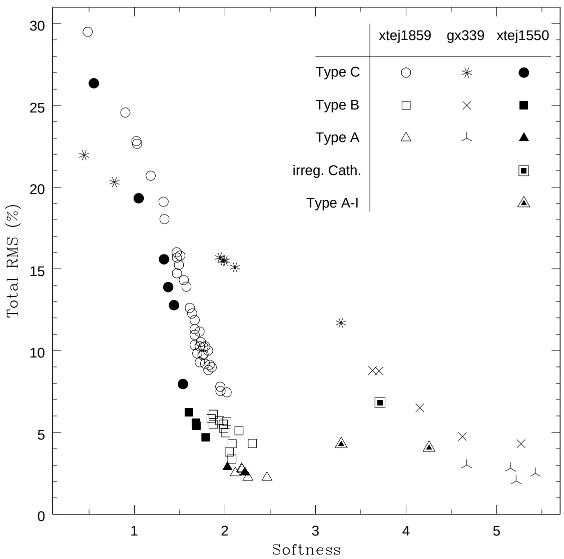

FIG. 1.— Total 0.06-64 Hz rms (in the 2-15 keV band) versus softness (defined as the ratio between ∼2-3.4 keV and ∼9-20 keV) for those observations in which a low frequency QPO was observed. Different symbols are explained in the inset table (see text for the irregular types).

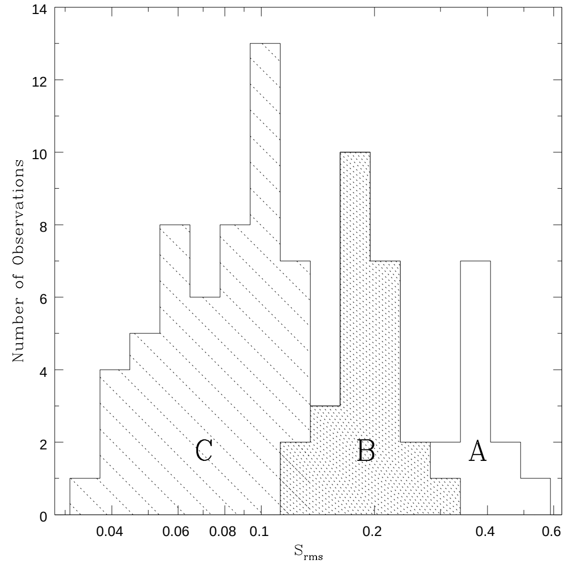

FIG. 2.— Histogram of the S_{rms} values. Different grayscales indicate different LFQPO types.

J1859+226 (C04). C04 showed that phase lags at the frequency of the QPO are soft, while they were not measurable in the rest of the frequency range because of poor statistics. In some sources a deeper analysis is necessary in order to confirm these identifications.

At first, these LFQPOs were dubbed "type A-II" by Homan et al. (2001). LFQPOs dubbed as "type A-I" (Wijnands et al. 1999a) were strong, broad, and accompanied by a very low-amplitude red noise. Moreover, a shoulder on the right hand side of this QPO was clearly visible and interpreted as a very broadened second harmonic peak. In Section 3 we discuss that "type A-I" LFQPOs should be classified as type B.

The higher frequency and lower coherence of type-A LFQPOs, relative to type-B LFQPOs, is suggestive of an analogy with the FBOs observed in Z sources. Moreover, as in Z-sources the flaring branch is effectively "flaring" only in some sources (van der Klis 2005), also in BHCs the soft observations where type-A LFQPOs appear correspond only in some sources to the highest flux values (see e.g. C04 and Nespoli et al. 2003). However, there are also some differences. First, the rms amplitude of FBOs is usually stronger than that of type-A LFQPOs. Second, rapid (tens of seconds) and unresolved transitions appear to take place between type A and B LFQPOs (see C04 and Nespoli et al. 2003). On the contrary, in the case of Z sources fairly continuous evolution is clearly observed in the transition between NBO and FBO (Dieters & van der Klis 2000).

3. CORRELATIONS

The three LFQPO types described in Section 2 are in most cases observed in the top branch of the HID (see Belloni et al. 2005). In the three sources which have unambiguously shown all three types of LFQPOs (XTE J1550-564, XTE J1859+226 and GX 339-4), type-Bs appear at lower hardness than type-Cs and higher hardness than type-As, thus identifying a well definite sequence C→B→A.

However, given the lack of easily identifiable geometrical points of reference, it has not yet been possible to track unambiguously the evolution of LFQPOs properties along the HID as it has been done with the CDs in neutron stars. Perhaps this is due to the fact that, given the softness of the BH spectrum, the most dramatic spectral changes take place shortwards of ∼1-2 keV, where present instrumentation does not permit a detailed characterization of the small region of the HID where the different types of LFQPOs are observed.

In order to find a parameter unambiguously tracking the type-C→B→A sequence, we plot the total integrated rms (0.06-64 Hz, in the 2-15 keV energy range) vs. the softness (defined as the ratio between the PCA counts in the energy bands ∼2-3.4 keV and ∼9-20 keV) of the observations where one of the three LFQPO types was observed in each of the three above-mentioned sources (see Fig. 1). For XTE J1859+226 and GX 339-4, we used the complete samples, using classifications reported respectively by C04 and Belloni et al. (2005). For XTE J1550-564, we chose all type-A and -B LFQPOs for which the identification was incontrovertible, and several type-C LFQPOs covering the observed frequency range (identifications from Wijnands et al. (1999a), Homan et al. (2001) and Remillard et al. (2002)). In order to obtain values of rms and hardness consistent among the three sources, we re-analyzed all the data (for technical details on the analysis we refer to C04).

The behavior of the three sources in Fig. 1 is similar: the softness and the rms show a monotonic, roughly linear anti-correlation between each other, through which the C-B-A sequence is well defined. Only three points deviate from this scheme, all of them from XTE J1550-564 (framed square and triangles, see the inset table). In these three cases, the identification of the LFQPO

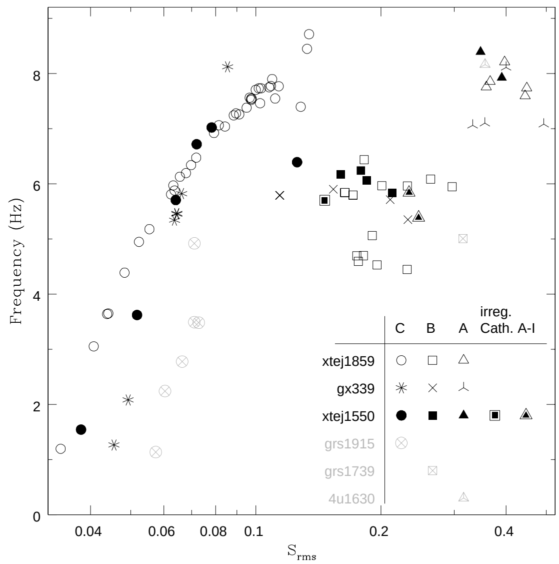

FIG. 3.— QPO frequency as a function of S_{rms}. Different symbols are explained in the inset table (see text for the irregular types).

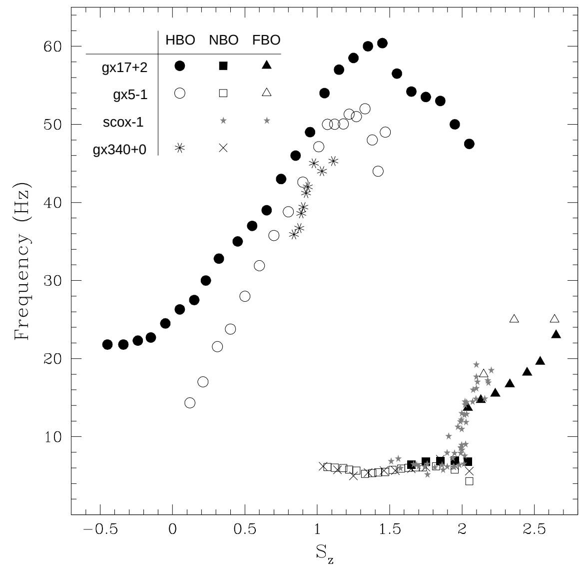

FIG. 4.— QPO frequency through the Z tracks of GX 17+2 (data from Homan et al. 2002), GX 5-1 (Jonker et al. 2002), Sco X-1 (Dieters & van der Klis 2000) and GX 340+0 (Kuulkers & van der Klis 1996; Jonker et al. 2000).

is uncertain: one is a "B-Cathedral" type with an unusual band-limited noise, the other two were classified as type A-I (see Section 2.3 and in the following). It is worth mentioning that in the case of XTE J1859+226, the points where no LFQPOs could be clearly identified (see C04) follow a different correlation in the rms vs. softness diagram, lying on a flatter linear-like track (not shown in Fig. 1) at higher values of softness, and that the same happens in the case of GX 339-4 (Belloni et al. 2005).

However, to study in detail the complete evolution of the outburst in the rms-softness diagram is beyond the scope of this work, in which we concentrate on the study of the unambiguously classified LFQPOs.

While the range in softness differs from one source to another (see in particular the points for GX 339-4) it is apparent from Fig. 1 that all three sources span a similar range in rms fractional variability. This suggest that the rms fractional variability can be used as a parameter tracking the three LFQPO types. In the histogram of Fig. 2 we use a related parameter, the inverse of the rms (hereafter S_{rms}), in order to maintain the C-B-A sequence observed in the HID. It is evident that the points of the three sources cluster around three values of S_{rms}, with the three groups corresponding to the three LFQPO types reviewed in Section 2.

In Fig. 3 we plot the frequency of the LFQPOs versus S_{rms}. The separation among three LFQPO types is well defined, and data from the three sources overlap fairly accurately, creating a unique characteristic shape. The frequency of type-C LFQPOs increases steeply up to $\sim$ 8 Hz at $S_{rms} \sim 0.15$. After this point, type-B LFQPOs appear with frequencies (mainly) close to $\sim$ 6 Hz until $S_{rms} \sim 0.3$. Finally, for higher values of S_{rms}, only type-A LFQPOs are present, with frequencies around 8 Hz. It is worth noting that the three LFQPOs which deviated from the correlation in Fig. 1 lie now in the region of the plot where type-B LFQPOs are concentrated. If in the case of the "Cathedral" LFQPO, this is not surprising, in the other two cases this seems to be either an exception to the separation among the three LFQPO types or a problem with the "type A" definition of the QPO themselves. On the other hand, the clustering of type A-I LFQPOs around ~6 Hz (Homan et al. 2001) clearly makes them standing out among type-A LFQPOs. The strong difference in amplitude between type A-I and A-II leaves room for a separation of the two classes and for an association of the type A-I with the type B. In Fig. 3 we also plot data from a few other sources (see inset table) which show only one of the three LFQPO types, but clearly confirm the general scheme.

The behavior in Fig. 3 is strongly reminiscent of the scheme observed in the Z sources, with the sequence $HBO \rightarrow NBO \rightarrow FBO$ along the Z track. In Fig. 4 we plot the QPO frequency versus the rank number S_z of four Z sources. The similarity with Fig. 3 is evident and further supports the association between Z sources' and BHCs' LFQPOs (see Sect. 2).

4. CONCLUSIONS

We reviewed the evidence that BHCs present three main different types of Low-Frequency QPOs. Each of these three types has well defined properties and shows strong similarities with one of the three types of LFQPOs observed in Z sources. The three types appear in a well defined sequence along the HID, as the three types of LFQPO observed in Z sources do along the CD.

Furthermore, we found that their frequency follows a characteristic trend as a function of the total integrated fractional variability. This trend is clearly reminiscent of that observed along the Z track of Z sources. On the basis of these similarities we propose to associate the C, B and A types respectively to the HBO, NBO and FBO observed in the Z sources, thus strengthening and

TABLE 2
Summary of the main properties of type-C and type-B LFQPOs compared with HBOs and NBOs.

Property	HBO / Type C	NBO / Type B
Frequency (Hz)	intensity dependent	5∼6 Hz
Amplitude (rms)	anti−correlated with frequency	2-4 %
Noise	strong flat−top	weak red

extending the previously proposed associations. In Table 2 we summarize the main similarities in the properties of these LFQPOs.

If these associations are correct, than the Type-Cs in BHCs and the HBOs in Z sources might well be caused by a similar physical mechanism. The fact that the frequencies of the type-Cs are roughly a factor of ∼6-7 lower than the frequencies of the HBOs suggests that these frequencies scale approximately as the inverse of the mass of the compact object, as expected for dynamical frequencies. On the other hand, both NBOs and type-B LFQPOs have frequencies close to 6 Hz, thus it is natural to suppose that the physical mechanism that determines their frequency is independent of (or only weakly dependent on) the mass of the compact object.

The presence of these two mechanisms in both types of compact objects would rule out all models that involve any interaction with the surface or the magnetosphere of the neutron star.

This work was partially supported by MIUR under CO-FIN grants 2002027145 and 2003027534.

REFERENCES

Belloni, T., Psaltis, D., & van der Klis, M., 2002, ApJ, 572, 392
Belloni, T. 2003, to appear in Proc. of the II BeppoSAX Meeting: "The Restless High-Energy Universe" (Amsterdam, May 5-8, 2003), eds. E.P.J. van den Heuvel, J.J.M. in 't Zand, and R.A.M.J. Wijers
Belloni, T., Parolin, I., & Casella, P., 2004, A&A, 423, 969
Belloni, T., Homan, J., Casella, P., van der Klis, M., Nespoli, E., Lewin, W. H. G., Miller, J. M., Méndez, M. 2005, A&A, accepted
Casella, P., Belloni, T., Homan, J., & Stella, L., 2004, A&A, 426, 587
Casella, P., Belloni, T., Homan, J., & Stella, L., 2005, to appear in Proc. of the COSPAR Assembly (Paris, July 2004)
Dieters, S. W., & van der Klis, M., 2000, MNRAS, 311, 201
Ford, E. C., & van der Klis, M., 1998, ApJ, 506, L39
Hasinger, G., 1987, A&A, 186, 153
Hasinger, G., & van der Klis, M., 1989, A&A, 225, 79
Homan, J., van der Klis, M., Wijnands, R., Vaughan, B., & Kuulkers, E., 1998, ApJ, 499, L41
Homan, J., Wijnands, R., van der Klis, M., Belloni, T., van Paradijs, J., Klein-Wolt, M., Fender, R., Méndez, M., 2001, ApJ, 132, 377
Homan, J., van der Klis, M., Jonker, P. G., Wijnands, R., Kuulkers, E., Méndez, M., & Lewin, W. H. G., 2002, ApJ, 568, 878
Homan, J., & Belloni, T., 2005, to appear in Proc. of "From X-ray binaries to quasars: Black hole accretion on all mass scales", (Amsterdam, July 2004), eds. T. Maccarone, R. Fender, L. Ho
Jonker, P. G., van der Klis, M., Wijnands, R., Homan, J., van Paradijs, J., Méndez, M., Ford, E. C., Kuulkers, E., Lamb, F. K., 2000, ApJ, 537, 374
Jonker, P. G., van der Klis, M., Homan, J., Méndez, M., Lewin, W. H. G., Wijnands, R., Zhang, W., 2002, MNRAS, 333, 665
Kuulkers, E., & van der Klis, M., 1996, A&A, 314, 567
McClintock, J. E., & Remillard, R. A., 2005, to appear in "Compact Stellar X-ray Sources", eds. W.H.G. Lewin and M. van der Klis, Cambridge University Press, Cambridge
Méndez, M., Belloni, T., & van der Klis, M., 1998, ApJ, 499, L187
Miyamoto, S., Kimura, K., Kitamoto, S., Dotani, T., & Ebisawa, K., 1991, ApJ, 383, 784
Miyamoto, S., Iga, S., Kitamoto, S., & Kamado, Y., 1993, ApJ, 403, L39
Nespoli, E., Belloni, T., Homan, J., Miller, J. M., Lewin, W. H. G., Méndez, M., & van der Klis, M., 2003, A&A, 412, 235
Park, S. Q., Miller, J. M., McClintock, J. E., Remillard, R. A., Orosz, J. A., Shrader, C. R., Hunstead, R. W., Campbell-Wilson, D., Ishwara-Chandra, C. H., Rao, A. P., & Rupen, M. P., 2003, ApJ, 61, 378
Psaltis, D., Belloni, T., & van der Klis, M., 1999, ApJ, 520, 262
Remillard, R. A., Sobczak, G. J., Muno, M. P., & McClintock, J. E., 2002b, ApJ, 564, 962
Reig, P., Belloni, T., van der Klis, M., Méndez, M., Kylafis, N. D., & Ford, E. C., 2000, ApJ, 541, 883
Reig, P., van Straaten, S., & van der Klis, M., 2004, ApJ, 602, 918
Revnivtsev, M., Borozdin, K., & Emelyanov, A., 1999, A&A, 344, L25
Rodriguez, J., Fuchs, Y., Hannaikainen, D., Vilhu, O., Shaw, S., Belloni, T., & Corbel, S., 2004, Proc. of the 5h INTEGRAL workshop, (Munich, Feb 16-20, 2004), to be published by EDP
Strohmayer, T. E., Zhang, W., Swank, J. H., Smale, A., Titarchuk, L., Day, C., & Lee, U., 1996, ApJ, 469, L9
Takizawa, M., Dotani, T., Mitsuda, K., Matsuba, E., Ogawa, M., Aoki, T., Asai, K., Ebisawa, K., Makishima, K., Miyamoto, S., Iga, S., Vaughan, B., Rutledge, R. E., & Lewin, W. H. G., 1997, ApJ, 489, 272
Tanaka, Y., & Lewin, W. H. G., 1995, in "X-ray binaries", Eds. W. H. G. Lewin, J. van Paradijs and E. P. J. van den Heuvel, Cambridge University Press, Cambridge, p. 126
Tomsick, J. A., & Kaaret, P., 2001, ApJ, 548, 401
van der Klis, M., Jansen, F., van Paradijs, J., Lewin, W. H. G., Sztajno, M.,& Truemper, J., 1987, ApJ, 313, L19
van der Klis, M., 1994, ApJS, 92, 511
van der Klis, M., 1995, in "X-ray binaries", eds. Lewin, W. H. G., van Paradijs, J. and van den Heuvel, E. P. J., Cambridge University Press, Cambridge, p. 252
van der Klis, M., 2005, in "Compact Stellar X-Ray Sources", eds. W.H.G. Lewin and M. van der Klis, Cambridge University Press, in press
Wijnands, R., Homan, J., & van der Klis, M., 1999a, ApJ, 526, L33
Wijnands, R., & van der Klis, M., 1999a, ApJ, 514, 939
Wijnands, R., & van der Klis, M., 1999b, ApJ, 522, 965
Wijnands, R., van der Klis, M., & Rijkhorst, E., 1999b, ApJ, 512, L39
Wijnands, R., Méndez, M., Miller, J. M., & Homan, J., 2001, MNRAS, 328, 451