1 Introduction

X-ray binaries (XRBs) are double systems formed by a stellar remnant that has collapsed to a compact object (typically a black-hole, BH, or a neutron star, NS) and has remained gravitationally bound to its companion. The compact object attracts the matter on the companion star forcing it to leave its surface. The accretion flow that carries matter from the companion star to the compact object originates a so-called ‘accretion disk’ around the compact object, where the gravitational potential energy is converted in kinetic energy and radiation. Accretion disks emit all along the electromagnetic spectrum, even though they are particularly bright in the X-rays, where the radiation coming from the innermost regions of the flow can be observed. Here I will focus on black hole XRBs, even though I will mention some similarities that can be found between BH XRBs and NS XRBs when considering their variability and in particular QPOs.

Almost all BH XRBs are transient systems, i.e. they alternate long quiescence phases to short ‘outbursts’, active periods typically lasting from weeks to months. Besides being very bright in the X-ray sky, XRBs have a very prominent characteristic: differently from most astrophysical objects, they show significant variability on humanly accessible time scales. The longest ones (weeks, months, years) can be appreciated inspecting the long term lightcurves (see e.g. Dunn et al., 2010). These long-term systematic variations, correspond to significant changes in the energy spectrum and can be described in terms of a pattern traced in an X-ray hardness-intensity diagram (HID) (see e.g. Homan et al., 2001 and Belloni et al., 2011). In most BH candidates, four different canonical spectral/timing states are found to correspond to different branches/areas of a q-shaped HID pattern. Sometimes, a so-called anomalous state can also be seen. The analysis of the fast timing variations observed in the sources’ power density spectra (PDS) plays a fundamental role in the state classification (see Homan et al., 2005, Belloni, 2010). The states that have been identified in HIDs from many sources (See Belloni and Motta 2015 and Belloni et al., 2011) are:

- the Low Hard State (LHS), where the emission is dominated by a strong Comptonized emission, occasionally accompanied by a cool and faint thermal component associated to a truncated disk. The intrinsic variability of the sources in this state can reach 30–40%.

- the High Soft State (HSS), where the emission is dominated by a strong thermal component, associated to an accretion disk whose radius can extend down to the innermost stable circular orbit. During this state the variability is very low, often consistent with zero.

- the Hard Intermediate State (HIMS) and the Soft Intermediate State (SIMS). During these two states the spectrum presents both a significant hard component and the contribution of a thermal disk. The variability can vary a lot and normally ranges between 5 and 20%.

- the anomalous (or ultra luminous) state have been shown by only a few sources (e.g. GRO J1655-40 and XTE J1550-564, see e.g. Motta et al., 2012 and Motta et al., 2014b). This state can be compared to the SIMS, even though it is characterized by significantly higher luminosities. As in the case of the SIMS and the HIMS, both the soft, thermal component from the disk and the hard emission are clearly visible in the spectra seen during these states, while the variability is normally found within 5 and 10% rms.

X-ray binaries, however, also show variability on much shorter times-scales, that cannot be easily studied inspecting
a light-curve. Therefore, the Fourier analysis is commonly used to evidence vary fast aperiodic and quasi-periodic variability by producing power-density spectra (PDS).

In the PDS from BH XRBs we observe several different features, ranging from various types of broad-band noise spanning several decades in frequency (i.e. essentially scale-free), to much more narrow features: the so-called quasi periodic oscillations (QPOs). QPOs have been observed in practically all kinds of accreting systems (in CVs, XRBs, ULXs and in AGNs). These peaks yield accurate centroid frequencies that can be associated with motion and/or accretion-related timescales. The study of variability in general, and QPOs in particular, provides a way to explore the accretion flow around BHs in ways which are inaccessible via energy spectra alone. The association of QPOs with specific spectral states and transitions suggests that they could be a key ingredient in understanding the underlying physical conditions that produce these states. Furthermore, being produced in the vicinity of relativistic objects such as BHs and NSs, they are expected to carry information about the condition of matter in the strong field regime. Therefore, understanding them is key to use QPOs as powerful tools to test the predictions of the Theory of General Relativity.

2 Quasi Periodic Oscillations in BH XRBs

QPOs in BH and NS XRBs have been known for many years and have been divided in various classes. QPOs in BH XRBs are normally divided into two large groups, based on the frequency range where they are usually detected: the low frequency QPOs and the high-frequency QPOs. The former are observed below ~50 Hz, the latter are normally found above ~100Hz (but see the case of GRS1915+105, Belloni et al., 2012) and up to ~500Hz.

2.1 Low Frequency QPOs

Low-frequency QPOs (LFQPOs) with frequencies ranging from a few mHz to ~30 Hz are common features in almost all black transient BHBs and were already found in several sources with Ginga and divided into different classes (see e.g. Miyamoto and Kitamoto, 1991 for the case of GX 339-4 and Takizawa et al., 1997 for the case of GS 1124-68). Observations performed with the Rossi X-ray Timing Explorer (RXTE) have led to an extraordinary progress in our knowledge on properties of the variability in BHBs (see van der Klis, 2006, Remillard and McClintock, 2006 Belloni et al., 2011) and it was only after RXTE was launched that LFQPOs were detected in most observed BHBs (see van der Klis, 2004).

Three main types of LFQPOs, dubbed types A, B, and C, originally identified in the Power Density Spectra (PDS) of XTE J1550-564 (see Wijnands et al., 1999, Homan et al., 2001, Remillard et al., 2002), have been seen in several sources.

Fig. 2 Examples of type A, B and C QPOs from our GX 339-4 observations. The centroid peak is indicated with an arrow. The contribution of the Poisson noise was not subtracted. Taken from Motta et al., 2011a

The different types of QPOs are currently identified on the basis of their intrinsic properties (mainly centroid frequency and width, but energy dependence and phase lags as well), of the underlying broad-band noise components (noise shape and total variability level) and of the relations among these quantities.

Type-A QPOs Type-A QPOs (see Fig. 2, top panel and left panel) are the less common type of QPOs in BHBs. In the entire RXTE archive only about 10 type-A QPOs have been found. They normally appear in the HSS, just after the hard to soft transition has taken place, when the overall variability is already quite low. They usually appear close in time to the type-B QPOs.

Type-A QPOs (Fig. 2, top panel) are characterized by a weak (few percent rms) and broad (ν/Δν \lesssim 3) peak around 6-8 Hz. Neither a subharmonic nor a second harmonic are usually present (possibly because of the width of the fundamental peak), whereas a very low amplitude red noise is associated with type-A QPOs. Originally, these LFQPOs were dubbed type A-II by Homan et al., 2001. LFQPOs dubbed type A-I (Wijnands et al., 1999) were strong, broad and associated with a very low-amplitude red noise. A shoulder on the right-hand side of this QPO was clearly fundamental peak), whereas a very low amplitude red noise is associated with type-A QPOs. Originally, these LFQPOs were dubbed type A-II by Homan et al., 2001. LFQPOs dubbed type A-I (Wijnands et al., 1999) were strong, broad and associated with a very low-amplitude red noise. A shoulder on the right-hand side of this QPO was clearly visible and interpreted as a very broadened second harmonic peak. Casella et al., 2005 showed that this type A-I LFQPOs should be classified as a Type-B QPOs.

Type-A QPOs have been associated to the flaring branch oscillations (FBOs) seen in NS low-mass X-ray binaries (see Casella et al., 2005), but the low number of detections in both BHs and NSs prevents a secure association between the two classes. For the same reason, an explanation for the existence of Type-A QPOs is difficult. Tagger and Pellat, 1999 proposed a model based on the accretion ejection instability (AEI), according to which
a spiral density wave in the disc, driven by magnetic stresses, becomes unstable by exchanging angular momentum with a Rossby vortex. This instability forms low azimuthal wavenumbers, standing spiral patterns which would be the origin of LFQPOs. Varnière and Tagger, 2002 and Varnière et al., 2012 suggested that type-A QPOs could be produced through the AEI in a relativistic regime, where the AEI coexist with the Rossby Wave Instability (RWI) (see Tagger and Pellat, 1999).

Type-B QPOs Type-B QPOs have been seen in a several BHBs and they appear during the SIMS, which is essentially defined on the presence of this QPO type. Type-B QPOs (Fig. 2 middle panel and Fig. 1) are characterized by a relatively strong (∼4% rms) and narrow (ν/Δν ≥6) peak, which is found in a narrow range of centroid frequencies, i.e. around 6 Hz or 1-3 Hz (Motta et al., 2011b). A weak red noise (few percent rms or less) is detected at very low frequencies (≤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 QPO shape (see Casella et al., 2004). Rapid transitions in which type B LFQPOs appear/disappear are often observed in some sources (e.g. Nespoli et al., 2003). These transitions are difficult to resolve at present, as they take place on a timescale shorter than a few seconds.

It is worth noticing that type-B QPOs have been associated to the normal branch oscillations (NBOs) seen in NSs and that both type-B QPOs and NBOs appear at about 6 Hz (Motta et al., 2012), where they can reach ∼30 Hz. Type-C QPOs (Fig. 2 bottom panel and Fig. 1) are characterized by a strong (up to 20% rms), narrow (ν/Δν ≥10) and variable peak (its centroid frequency and intensity varying by several percent in a few days; see, e.g. Motta et al., 2015) superposed on a flat-top noise that steepens above a frequency comparable to the QPO frequency. A subharmonic, a second harmonic peak are often seen and sometimes even a third harmonic peak. The total (QPO plus flat-top noise) fractional rms variability can be as high as 40%. The frequency of the type-C QPOs correlates both with the flat-top noise break-frequency (Wijnands and van der Klis, 1999) and with the characteristic frequency of some broad components seen in the PDS at higher frequency (>20Hz, see Psaltis et al., 1999). Type-C QPOs have been associated to the horizontal branch oscillations (HBOs) seen in NS, that also show significant variations in frequency, easily reaching 50-100 Hz.

Differently from type-A and type-B QPOs, there are several models attempting to explain the origin of type-C QPOs. These models are based on two different mechanisms: instabilities and geometrical effects. In the latter case, the physical process typically invoked is precession.

Instabilities: Titarchuk and Fiorito, 2004 proposed the so called transition layer model, where type-C QPOs are the result of viscous magneto-acoustic oscillations of a spherical bounded transition layer, formed by matter from the accretion disc adjusting to the sub-keplerian
boundary conditions near the central compact object. Cabanac et al., 2010 proposed a model to explain simultaneously type-C QPOs and the associated broad band noise. Magneto-acoustic waves propagating within the corona makes it oscillate, causing a modulation in the efficiency of the Comptonization process on the embedded photons. This should produce both the type-C QPOs (thanks to a resonance effect) and the noise that comes with them. In the framework of the AEI, type-C QPOs would be produced in the non-relativistic regime, where the RWI does not play any significant role (see Varnière and Tagger, 2002 and Varnière et al., 2012).

– Geometrical effects: Ingram et al., 2009 proposed a model based on the relativistic precession as predicted by the theory of General Relativity that attempts to explain type-C QPOs and their associated noise. This model requires a core optically thick, geometrically thin accretion disc (Shakura and Sunyaev, 1973) truncated at some radius, filled by a hot, geometrically thick accretion flow. This geometry is known as truncated disc model (Esin et al., 1997) [Poutanen et al., 1997]. In this framework, type-C QPOs arise from the Lense-Thirring precession of a radially extended section of the hot inner flow that modulates the X-ray flux through a combination of self-occultation, projected area and relativistic effects that become stronger with inclination (see Ingram et al., 2009). The broad-band noise associated with type-C QPOs, instead, would arise from variations in mass accretion rate from the outer regions of the accretion flow that propagate towards the central compact object, modulating the variations from the inner regions and, consequently, modulating also the radiation in an inclination-independent manner (see Ingram and van der Klis, 2013).

2.2 High Frequency QPOs

Among the most important discoveries that RXTE allowed there is the detection of the so-called kHz QPOs in NS binaries (see van der Klis, 2006). This result opened a window onto high-frequency phenomena in BHBs. The first observations of the very bright system GRS 1915+105 led to the discovery of a transient oscillation at ~67 Hz (Morgan et al., 1997), the first high-frequency QPO (HFQPO) in a BHB. Since then, sixteen years of RXTE observations have yielded only a handful of detections in other sources (XTE J1550-564, GRO J1655-40, XTE J1859+226, H 1743-322, GX 339-4, XTE J1752-223, 4U 1630-47, GRS J1915+105, IGR J17091-3624), although GRS 1915+105 seems to be an exception, with a remarkably high number of detected high-frequency QPOs (see e.g. Belloni et al., 2012).

The properties of the few confirmed HFQPOs (Belloni et al., 2012) can be summarized as follow:

– They appear only in observations at high flux/accretion rate (see Fig. 1). This might at least partly due to a selection effect, but not all high-flux observations lead to the detection of a HFQPO, all else being equal, indicating that the properties of these oscillations can vary substantially even when all other observables do not change.
– They can be observed as single or double peaks. Only one source, GRS J1655-40 (see Fig. 3), showed two clear simultaneous peaks (Strohmayer, 2001a [Motta et al., 2014a], while all the others only showed single peaks, sometimes at different frequencies (see Tab. 1 in Belloni and Stella, 2014). In XTE J1550-564, the two detected peaks (Remillard et al., 2002) have been detected simultaneously after averaging a number of observations, but the lower one with a 2.3 σ significance (Miller et al., 2001). Méndez et al., 2013 on the basis of their phase lags, suggested that the two detected peaks might be the same physical signal at two different frequencies. H 1743-322 showed a clear HFQPO and a weak second simultaneous peak (Homan et al., 2005). A systematic analysis of the data from GRS 1915+105 (Belloni and Altamirano, 2013) led to the detection of 51 HFQPOs, most of which at a centroid frequency between 63 and 71 Hz. All detections corresponded to a very limited range in spectral parameters, as measured through hardness ratios. Additional peaks at 27, 34 and 41 Hz were discovered by Strohmayer, 2001b [Belloni et al., 2001] and Belloni and Altamirano, 2013. The most recent HFQPO discovered, in IGR J170913624, is consistent with the average frequency of the 67 Hz QPO in GRS 1915+105 (Altamirano and Belloni, 2012).
– Typical fractional rms for HFQPOs are 0.5-6% increasing steeply with energy, in the case of GRS 1915+105 reaching more than 19% at 20-40 keV (see right panel in Fig. 6 of [Morgan et al., 1997]). Quality factors Q are around 5 for the lower peak and 10 for the upper. In GRS 1915+105, a typical Q of ~20 is observed, but values as low as 5 and as high as 30 are observed, too.
– Time lags of HFQPOs have been studied for four sources (Méndez et al., 2013). The lag spectra of the 67 Hz QPO in GRS 1915+105 and IGR J170913624 and of the 450 Hz QPO in GRO J1655-40 are hard (hard photons variations lag soft photons variations), while those of the 35 Hz QPO in GRS 1915+105 are soft. The 300 Hz QPO in GRO J1655-40 and both HFQPOs in XTE J1550-564 are consistent with zero (suggesting that the two HFQPOs in XTE J1550 are the same feature seen at different frequencies).
– For three sources, GRO J1655-40, XTE J1550-564 and XTE J1743-322, the two observed frequencies are close to being in a 3:2 ratio (Strohmayer, 2001a, Remillard and McClintock, 2006), which has led to a family of models, known as resonance models (see e.g. Abramowicz and Kluzniak, 2001). For GRS 1915+105 the 67 Hz and 41 Hz QPOs, observed

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1 Q is defined as the ratio between centroid frequency and FWHM of the QPO peak.
simultaneously, are roughly in 5:3 ratio. The 27 Hz would correspond to 2 in this sequence.

2.2.1 Models for HFQPOs

So far many models have been proposed to describe HFQPOs of BHBs, all involving in some form the predictions of the Theory of General relativity.

- The relativistic precession model (RPM), was originally proposed by [Stella and Vietri, 1998] to explain the origin and the behaviour of the LFQPO and kHz QPOs in NS X-ray binaries and later extended to BHs by the vertical oscillations of a slightly eccentric fluid slender torus formed close to the ISCO. Stuchlik and collaborators proposed a further version of the relativistic precession model, that has been studied in many papers by this group. Here the model is related to the warped-disk oscillations discussed by Kato, 2004a (see below).

- The the warped disc model proposed by [Kato, 2004a] states that the HFQPOs are resonantly excited by specific disc deformations warps. The model was generalized to include precession of the warped disk in [Kato, 2005] and spin-induced perturbations were included in [Kato, 2005].

- Abramowicz and Kluzniak, 2001 and Kluzniak and Abramowicz, 2001 introduced the nonlinear resonance model, which was later studied extensively by them as well as by other authors. This model is based on the assumption that non-linear 1:2, 1:3 or 2:3 resonance between orbital and radial epicyclic motion could produce the HFQPOs observed in both BH and NS binaries. Later on, [Abramowicz et al., 2004] proposed another version of this model, called the Keplerian non-linear resonance model, where the resonance occurs between the radial epicyclic frequency and the orbital frequency instead of between the radial epicyclic frequency and the vertical frequency. These resonance models successfully explain black hole QPOs with frequency ratio consistent with 2:3 or 1:2 (see Sect. 3.2). As a given resonance condition is verified only at a fixed radius in the disk, the QPO frequencies are expected to remain constant, or jump from one resonance to another.

3 Conclusions

After almost 25 years from their discovery, the origin of QPOs in BHBs is still unclear and there is no consensus about their physical nature. However, it is now clear the study of variability in general, and QPOs in particular, provides a way to explore the accretion flow around BHs in ways which are inaccessible via energy spectra alone. We are now starting to comprehend the fundamentally important physical information hidden in the fast variability properties of accreting systems. The enormous amount of data acquired so far and and soon to be available thanks to the currently flying and future X-ray missions (e.g. XMM-Newton, Swift, AstroSat and Astro-H) provide the most desirable workbench to test the growing number of theoretical models attempting to explain the fast variability typical of accreting compact objects.

The knowledge that we obtained over the last decades now allows us to fully exploit the potentialities of timing as a powerful diagnostic tools, especially when used in association with the spectral analysis, in order to unveil the secrets of accretion and of the accretion-ejection mechanism, and, ultimately, of the effects of gravity in extremes conditions.

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References

Abramowicz, M. A. and Kluzniak, W. (2001). A precise determination of black hole spin in GRO J1655-40. A&A, 374:L19–L20.

Abramowicz, M. A., Kluzniak, W., Stuchlík, Z., and Torok, G. (2004). The orbital resonance model for twin peak kHz QPOs. ArXiv Astrophysics e-prints.

Altamirano, D. and Belloni, T. (2012). Discovery of High-frequency Quasi-periodic Oscillations in the Black Hole Candidate IGR J17091-3624. ApJ, 747:L4.

Belloni, T., Méndez, M., and Sánchez-Fernández, C. (2001). The high-frequency QPOs in GRS 1915+105. A&A, 372:551–556.

Belloni, T. M. (2010). States and Transitions in Black Hole Binaries. Lecture Notes in Physics, Springer-Verlag Berlin Heidelberg, Volume 794, p. 53. ISBN 978-3-540-76936-1., 794:53–.

Belloni, T. M. and Altamirano, D. (2013). Discovery of a 34 Hz quasi-periodic oscillation in the X-ray emission of GRS 1915+105. MNRAS, 432:19–22.

Belloni, T. M., Motta, S. E., and Muñoiz-Darias, T. (2011). Black hole transients. Bulletin of the Astronomical Society of India, 39:409–428.

Belloni, T. M., Sanna, A., and Méndez, M. (2012). High-frequency quasi-periodic oscillations in black hole binaries. MNRAS, 426:1701–1709.

Belloni, T. M. and Stella, L. (2014). Fast Variability from Black-Hole Binaries. Space Science Reviews, 183:43–60.

Bursa, M. (2005). High-frequency QPOs in GRO J1655-40: Constraints on resonance models by spectral fits. In Hledík, S. and Stuchlík, Z., editors, RAGTime 6/7: Workshops on black holes and neutron stars, pages 39–45.

Cabanac, C., Henri, G., Petrucci, P.-O., Malzac, J., Ferreira, J., and Belloni, T. M. (2010). Variability of X-ray binaries from an oscillating hot corona. MNRAS, 404:738–748.

Casella, P., Belloni, T., Homan, J., and Stella, L. (2004). A study of the low-frequency quasi-periodic oscillations in the X-ray light curves of the black hole candidate [ASTROBJ, XTE J1859+226/ASTROBJ,]. A&A, 426:587–600.

Casella, P., Belloni, T., and Stella, L. (2005). The ABC of Low-Frequency Quasi-periodic Oscillations in Black Hole Candidates: Analogies with Z Sources. ApJ, 629:403–407.

Dunn, R. J. H., Fender, R. P., Körding, E. G., Belloni, T., and Cabanac, C. (2010). A global spectral study of black hole X-ray binaries. MNRAS, 403:61–82.

Esin, A. A., McClintock, J. E., and Narayan, R. (1997). Advection-dominated Accretion and the Spectral States of Black Hole X-Ray Binaries: Application to Nova MUSCAE 1991. ApJ, 489:865–.

Fender, R. P., Homan, J., and Belloni, T. M. (2009). Jets from black hole X-ray binaries: testing, refining and extending empirical models for the coupling to X-rays. MNRAS, 396:1370–1382.

Homan, J., Buxton, M., Markoff, S., Bailyn, C. D., Nespoli, E., and Belloni, T. (2005). Multiwavelength Observations of the 2002 Outburst of GX 339-4: Two Patterns of X-Ray-Optical/Near-Infrared Behavior. ApJ, 624:295–306.

Homan, J., Wijnands, R., van der Klis, M., Belloni, T., van Paradisj, J., Klein-Wolt, M., Fender, R., and Méndez, M. (2001). Correlated X-Ray Spectral and Timing Behavior of the Black Hole Candidate XTE J1550-564: A New Interpretation of Black Hole States. ApJ, 132:377–402.

Ingram, A., Done, C., and Fragile, P. C. (2009). Low-frequency quasi-periodic oscillations spectra and Lense-Thirring precession. MNRAS, 397:L101–L105.

Ingram, A. and van der Klis, M. v. d. (2013). An exact analytic treatment of propagating mass accretion rate fluctuations in X-ray binaries. MNRAS, 434:1476–1485.

Kato, S. (2004a). Resonant Excitation of Disk Oscillations by Warps: A Model of kHz QPOs. PASJ, 56:905–922.

Kato, S. (2004b). Wave-Warp Resonant Interactions in Relativistic Disks and kHz QPOs. PASJ, 56:559–567.

Kato, S. (2005). Quasi-Periodic Oscillations Resonantly Induced on Spin-Induced Deformed-Disks of Neutron Stars. PASJ, 57:679–690.

Kluzniak, W. and Abramowicz, M. A. (2001). The physics of kHz QPOs—strong gravity’s coupled anharmonic oscillators. ArXiv Astrophysics e-prints.

Méndez, M., Altamirano, D., Belloni, T., and Sanna, A. (2013). The phase lags of high-frequency quasi-periodic oscillations in four black hole candidates. MNRAS.

Miller, J. M., Wijnands, R., Homan, J., Belloni, T., Pooley, D., Corbel, S., Kouveliotou, C., van der Klis, M., and Lewin, W. H. G. (2001). High-Frequency Quasi-Periodic Oscillations in the 2000 Outburst of the Galactic Microquasar XTE J1550-564. ApJ, 563:928–933.

Miyamoto, S. and Kitamoto, S. (1991). A jet model for a very high state of GX 339 - 4. ApJ, 374:741–743.

Morgan, E. H., Remillard, R. A., and Greiner, J. (1997). RXTE Observations of QPOs in the Black Hole Candidate GRS 1915+105. ApJ, 482:993–.

Motta, S., Homan, J., Muñoiz-Darias, T., Casella, P., Belloni, T. M., Hiemstra, B., and Méndez, M. (2012). Discovery of two simultaneous non-harmonically related quasi-periodic oscillations in the 2005 outburst of the black hole binary GRO J1655-40. MNRAS, 427:595–606.

Motta, S., Muñoiz-Darias, T., Casella, P., Belloni, T., and Homan, J. (2011a). Low-frequency oscillations in black holes: a spectral-timing approach to the case of GX 339-4. MNRAS, 418:2292–2307.

Motta, S., Muñoiz-Darias, T., Casella, P., Belloni, T., and Homan, J. (2011b). Low-frequency oscillations in black holes: a spectral-timing approach to the case of GX 339-4. MNRAS, 418:2292–2307.

Motta, S. E., Belloni, T. M., Stella, L., Muñoiz-Darias, T., and Fender, R. (2014a). Precise mass and spin measurements for a stellar-mass black hole through X-ray timing: the case of GRO J1655-40. MNRAS, 437:2554–2565.

Motta, S. E., Casella, P., Henze, M., Muñoiz-Darias, T., Sanna, A., Fender, R., and Belloni, T. (2015). Geometrical constraints on the origin of timing signals from black holes. MNRAS, 447:2059–2072.

Motta, S. E., Muñoiz-Darias, T., Sanna, A., Fender, R., and Belloni, T. (2014b). Black hole spin measurements through the relativistic precession model: XTE J1550-564. MNRAS, 439:L65–L69.

Motta, S. E., Muñoiz-Darias, T., Sanna, A., Fender, R., Belloni, T., and Stella, L. (2014c). Black hole spin measurements through the relativistic precession model: XTE J1550-564. MNRAS.

Nespoli, E., Belloni, T., Homan, J., Miller, J. M., Lewin, W. H. G., Méndez, M., and van der Klis, M. (2003). A transient variable 6 Hz QPO from GX 339-4. A&A, 412:235–240.

Poutanen, J., Krolik, J. H., and Ryde, F. (1997). The nature of spectral transitions in accreting black holes - The case of CYG X-1. MNRAS, 292:L21–L25.
Psaltis, D., Belloni, T., and van der Klis, M. (1999). Correlations in Quasi-periodic Oscillation and Noise Frequencies among Neutron Star and Black Hole X-Ray Binaries. *ApJ*, 520:262–270.

Remillard, R. and McClintock, J. (2006). X-Ray Properties of Black-Hole Binaries. *Annual Reviews*, 44:49–92.

Remillard, R. A., Muno, M. P., McClintock, J. E., and Orosz, J. A. (2002). Evidence for Harmonic Relationships in the High-Frequency Quasi-periodic Oscillations of XTE J1550-564 and GRO J1655-40. *ApJ*, 580:1030–1042.

Shakura, N. I. and Sunyaev, R. A. (1973). Black holes in binary systems. Observational appearance. *A&A*, 24:337–355.

Stella, L. and Vietri, M. (1998). Lense-Thirring Precession and Quasi-periodic Oscillations in Low-Mass X-Ray Binaries. *ApJ*, 492:L59+.

Stella, L. and Vietri, M. (1999). kHz Quasiperiodic Oscillations in Low-Mass X-Ray Binaries as Probes of General Relativity in the Strong-Field Regime. *Physical Review Letters*, 82:17–20.

Stella, L., Vietri, M., and Morsink, S. M. (1999). Correlations in the Quasi-periodic Oscillation Frequencies of Low-Mass X-Ray Binaries and the Relativistic Precession Model. *ApJ*, 524:L63–L66.

Strohmayer, T. E. (2001a). Discovery of a 450 HZ Quasi-periodic Oscillation from the Microquasar GRO J1655-40 with the Rossi X-Ray Timing Explorer. *ApJ*, 552:L49–L53.

Strohmayer, T. E. (2001b). Discovery of a Second High-Frequency Quasi-periodic Oscillation from the Microquasar GRS 1915+105. *ApJ*, 554:L169–L172.

Tagger, M. and Pellat, R. (1999). An accretion-ejection instability in magnetized disks. *A&A*, 349:1003–1016.

Takahawa, 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., and Lewin, W. H. G. (1997). Spectral and Temporal Variability in the X-Ray Flux of GS 1124-683, Nova MUSCAE 1991. *ApJ*, 489:272–+.

Titarchuk, L. and Fiorito, R. (2004). Spectral Index and Quasi-Periodic Oscillation Frequency Correlation in Black Hole Sources: Observational Evidence of Two Phases and Phase Transition in Black Holes. *ApJ*, 612:988–999.

van der Klis, M. (2004). Challenges in X-ray binary timing: current and future. *Advances in Space Research*, 34:2646–2656.

van der Klis, M. (2006). Overview of QPOs in neutron-star low-mass X-ray binaries. *Advances in Space Research*, 38:2675–2679.

Varnière, P. and Tagger, M. (2002). Accretion-Ejection Instability in magnetized disks: Feeding the corona with Alfvén waves. *A&A*, 394:329–338.

Varnière, P., Tagger, M., and Rodriguez, J. (2012). A possible interpretation for the apparent differences in LFQPO types in microquasars. *A&A*, 545:A40.

Wijnands, R., Homan, J., and van der Klis, M. (1999). The Complex Phase-Lag Behavior of the 3-12 HZ Quasi-Periodic Oscillations during the Very High State of XTE J1550-564. *ApJ*, 526:L33–L36.

Wijnands, R. and van der Klis, M. (1999). The Broadband Power Spectra of X-Ray Binaries. *ApJ*, 514:939–944.
