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Supporting evidence for the signature of the innermost stable circular orbit in Rossi X-ray data from 4U 1636−536

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ABSTRACT

Analysis of archival *Rossi X-ray Timing Explorer* (*RXTE*) data on neutron star low-mass X-ray binaries has shown that for several sources the quality factor Q of the lower kilohertz quasi-periodic oscillations (QPO) drops sharply beyond a certain frequency. This is one possible signature of the approach to the general relativistic innermost stable circular orbit (ISCO), but the implications of such an interpretation for strong gravity and dense matter are important enough that it is essential to explore alternate explanations. In this spirit, Méndez has recently proposed that Q depends fundamentally on mass accretion rate (as measured by spectral hardness) rather than the frequency of the QPO. Specifically, he has suggested that analysis of multiple sources shows trends in Q similar to those previously reported in individual sources, and he surmises that the ISCO therefore does not play a role in the observed sharp drop in Q in any source. We test this hypothesis for 4U 1636−536 by measuring precisely spectral colours simultaneously with the lower QPO frequency and Q after correction for the frequency drift, over a data set spanning eight years of *RXTE* observations. We find that in this source there is no correlation between Q and spectral hardness. In particular, no apparent changes in hardness are observed when Q reaches its maximum before dropping off. We perform a similar analysis on 4U 1608−522; another source showing a sharp drop in the quality factor of its lower kHz QPO. We find that for this source, positive and negative correlations are observed between spectral hardness, frequency and Q. Consequently, if we are to search for a common explanation for the sharp drop in the quality factor seen in both sources, the spectral hardness is not a good candidate for the independent variable whereas the frequency remains. Therefore, we conclude that the ISCO explanation is viable for 4U 1636−536, and thus possibly for others.

Key words: accretion, accretion discs – stars: neutron – X-rays: stars.

1 INTRODUCTION

Kilohertz quasi-periodic brightness oscillations (kHz QPOs) have been observed with the *Rossi X-ray Timing Explorer* (*RXTE*; Bradt, Rothschild & Swank 1993) from some 25 neutron star low-mass X-ray binary systems (NS LMXBs). These QPOs are strong (fractional rms amplitudes are often >10 per cent in the 2–60 keV band), sharp (quality factors up to $Q \equiv \nu/\mathrm{FWHM} \sim 200$), high frequency (commonly 700–1000 Hz, with the highest claimed detection at 1330 Hz for 4U 0614+091; van Straaten et al. 2000) and substantially variable (QPO frequencies in a given source can change by hundreds of hertz). They also commonly come in a pair, with the separation between the upper and lower kHz QPO staying close to the spin frequency ν_{spin} or half the spin frequency despite variations in both QPOs (van der Klis 2006).

There is as yet not a complete consensus about the physical processes that generate these QPOs, let alone their high quality factors which pose severe constraints on all existing models (Barret et al. 2005a). Suggestions include beat-frequency mechanisms (Miller, Lamb & Psaltis 1998), some manifestation of geodesic frequencies (Stella & Vietri 1998) and resonant interactions (Abramowicz et al. 2003, 2005). There is, however, broad agreement that the upper kHz QPO frequency is close to the orbital frequency at some special radius (or the vertical epicyclic frequency in some resonance models, but this is within a few hertz of the orbital frequency for the relevant stellar spin parameters). By itself, this implies that there must be an upper limit to the QPO frequency. For very hard high-density equations of state or very low-mass stars, the limiting frequency could in principle be set by the orbital frequency at the stellar surface, but in realistic cases the maximum will instead be determined by the innermost stable circular orbit (ISCO). If observational signatures of the approach to the ISCO were observed, this would confirm the strong-gravity prediction of unstable orbits, which has no parallel

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in Newtonian gravity. It would also allow us direct measurement of the mass of the NS (see discussion in Miller et al. 1998), hence the search for such signatures is of great importance for fundamental physics and astrophysics.

It was proposed theoretically (Miller et al. 1998, see also Kluźniak, Michelson & Wagoner 1990) that as the radius that determines the upper kHz QPO frequency approaches the ISCO (and thus as the lower peak approaches the ISCO frequency minus $\nu_{\rm spin}$ or $\nu_{\rm spin}/2$), this will lead to (i) asymptoting of the frequency to a limiting value, (ii) decrease in the amplitude of the oscillation and (iii) sharp decrease in the quality factor $Q \equiv \nu/\mathrm{FWHM}$ of the oscillation. Zhang et al. (1998) suggested that the first of these signatures is apparent in the data from 4U 1820−30, but complications in the relation between count rate and frequency (Méndez et al. 1999) have made the interpretation of this result uncertain (see, however, e.g. Bloser et al. 2000). More recently, analysis of archival *RXTE* data from multiple sources has revealed a sharp drop in Q for the lower QPO with increasing frequency, and this drop is qualitatively and quantitatively consistent with what is expected for the approach to the ISCO (Barret, Olive & Miller 2005b,c, 2006).

If confirmed, this result is of great fundamental importance. It is thus essential to examine alternate explanations. In particular, as discussed in Barret et al. (2006), there are many factors that collectively determine Q for an oscillation. Theoretical arguments (Miller et al. 1998) as well as recent observational results (Gilfanov & Revnivtsev 2005) suggest that although the high observed amplitudes require that the energy we see in the QPO is liberated at the stellar surface, the frequency and sharpness of the QPO is determined in the accretion disc. In such a picture, in which the frequencies are generated in some special annulus of the disc, Q depends on the width of the annulus, the inward radial drift speed and the number of cycles a given oscillation lasts. As discussed in Barret et al. (2006), approach to the ISCO can affect the first two of these factors in a way that agrees with the data.

However, it is also possible that other, non-space–time-related, effects play a role, e.g. plasma processes in the disc, corona, or stellar surface, or interaction with the stellar magnetic field. Without a detailed model of this type, one cannot rule definitively for or against such ideas. Generically, though, one expects that such factors in Q will depend fundamentally on the mass accretion rate, whereas the ISCO-related effects depend fundamentally on the space–time. Therefore, a strong correlation between Q and a proxy for the mass accretion rate would suggest plasma or magnetic field interactions, whereas the lack of such a correlation combined with the observed dependence of Q on frequency would argue in favour of an ISCO interpretation.

Recently, Méndez (2006) compiled data from multiple sources and suggested that it is in fact the spectral hardness (his measure for the mass accretion rate) that is the primary factor in determining Q. Here we test this suggestion with *RXTE* data on 4U 1636−536. In Section 2, we discuss our selection of data and processing algorithms. We also present our results, and specifically show that there is no apparent correlation between the quality factor of the lower kHz QPO and the spectral hardness. Therefore, for this source and perhaps others, there is no evidence that the accretion rate is the primary determinant of Q. We discuss the implications in Section 3.

2 DATA ANALYSIS AND RESULTS

We used the data presented in Barret et al. (2005b,c, 2006). The same analysis scheme applies for the data selection. We consider all data recorded up to 2004 September. All PCA Science Event files were retrieved from the HEASARC archive. A file represents a temporally contiguous collection of data from a single pointing. 571 files are considered here. They have been filtered for X-ray bursts and data gaps. Leahy normalized Fourier power density spectra were computed between 1 and 2048 Hz, over 8-s intervals with a 1-Hz resolution.

In parallel, we have analysed the PCA Standard 2 data (a collection of 129-channel spectra accumulated every 16 s), following standard recipes, using REX 0.3.[1] We filtered the data using standard criteria: Earth elevation angle greater than 10°, pointing offset less than 0.02°, time since the peak of the last SAA passage greater than 30 min, electron contamination less than 0.1. The background of the PCA has been estimated using PCABACKEST 3.0, and the latest bright background model as recommended for sources brighter than 40 counts s^{-1} PCU^{-1}. To avoid any possible discontinuity near the loss of its propane layer (in 2000 May), we exclude PCU 0 in our analysis. PCU units 2 and 3 provide a good overlap between the Standard 2 and Science Event data (they both provide twice as much data as PCU unit 1 for instance). For each ObsID, for the 2 PCU units, considering only the top layer (layer 1), we have first generated a response matrix using the latest version of PCARSP 10.1. For comparison with previous works, we intend to compute the colours from data recorded in four adjacent energy bands: 3.0–4.5, 4.5–6.4, 6.4–9.7 and 9.7–16 keV. For each ObIDs, we read out from the response matrix the relative channel values corresponding to these energy boundaries, and we use the FTOOLS CHANTRANS to convert the latter into their absolute channel values, as needed for SAEXTRACT, called by *REX*. Since the energy boundaries are not exactly equal to the above exact values defined above and change in time with the detector gains, a correction must be applied. Following Barret & Olive (2002), for each ObsID, we have extracted for each PCU unit a PHA count spectrum. By fitting the count spectrum with a polynomial function, one can compute the exact number of counts within the exact energy bounds. This gives us an average correction factor, which corresponds to the difference between the counts extracted with SAEXTRACT and the corresponding counts in the exact energy bands. Finally, another smaller correction is applied to account for the fact that when the energy boundaries move, the corresponding effective areas also change. The light curves in the four energy bands are normalized to the same effective area, which is, for each ObsID, estimated directly from the response matrix generated for each PCU. After these two corrections, the light curves become all comparable. These corrections are especially important because the observations span from 1996 to 2004.

We have computed two spectral colours: the soft colour (HR1) defined as the ratio between the 4.5- and 6.4-keV counts and 3.0- and 4.5-keV counts, and the hard colour (HR2) as the ratio between the 9.7- and 16.0-keV counts and 6.4- and 9.7-keV counts. For a given Science Event file, the end product of our analysis at this first stage can be summarized in Fig. 1 where the averaged power density spectrum (PDS) over the file is shown, together with the dynamical PDS and the soft and hard colours as derived from the Standard 2 data.

2.1 Quality factor and spectral colours against frequency in 4U 1636−536

For the sake of clarity, our analysis here is focused on the lower kHz QPO, for which we have argued that the drop of coherence at some

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[1] http://heasarc.gsfc.nasa.gov/docs/xte/recipes/rex.html

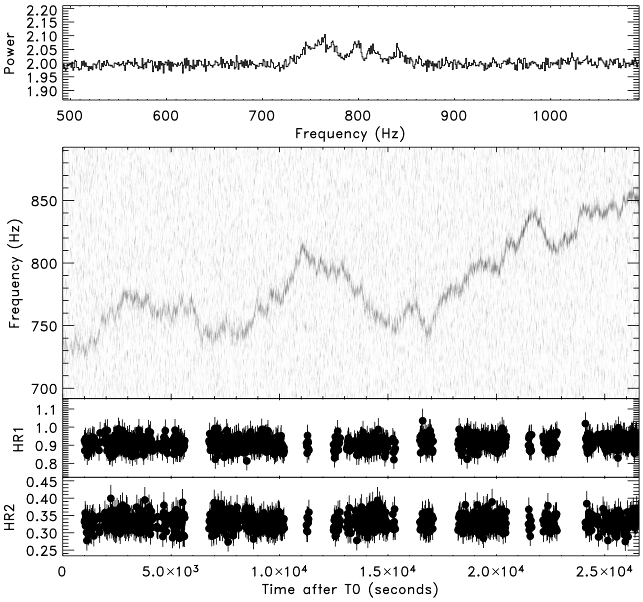

Figure 1. The Leahy normalized PDS averaged over the Science Event file is shown at the top. In the middle panel, a dynamical PDS is shown. The image has been smoothed to make the QPO appear more clearly. The bottom two panels represent the simultaneous evolution of the soft and hard colours (HR1 and HR2, respectively) as computed from Standard 2 data. The non-complete overlap between the two data sets is because the Standard 2 data (only PCU 3 data are considered) are filtered with more stringent criteria than the Science Event data. Note that while the QPO frequency varies from 730 to 850 Hz, there are no apparent changes in both the soft and hard colours.

critical frequency may be related to an approach of the ISCO of the region from which the oscillation originates. We wish to study the dependency of the quality factor versus the soft and hard colours. One would expect that if the drop is indeed related to a space–time effect, it is not primarily dependent on the energy spectrum. This idea can be tested with spectral colours, which allow us to search for subtle spectral variations.

In order to estimate the quality factor of the QPOs, one must first correct for the frequency drifts. Here we use a sliding window based technique. Namely, we group as many consecutive 8-s PDS ($N \leqslant 64$) as needed to detect a QPO with a significance above a threshold of 3σ. The maximum integration time is then $64 \times 8 = 512$ s. In the case of no detection within such an interval starting at T_0, a new search starts at $T_0 + 32$ s. The QPO frequency in each 8-s PDS is then estimated using a linear interpolation between all detected QPO frequencies within a continuous segment. We identify those files containing a lower kHz QPO in the quality factor–frequency plane (see Barret et al. 2005b for details). We keep those files in which the quality factor recovered after correction for the frequency drift is larger than 30, corresponding to a mean QPO frequency larger than 650 and smaller than 950 Hz. We then divide the data into segments of 1024 s, and shift-and-add all 8-s PDS within each segments to a reference frequency which is set to the mean QPO frequency assigned after interpolation to the 8-s PDS over the continuous segment. Some segments are not complete and we have removed all those in which the total number of 8-s PDS shifted is less than 64 (i.e. 512 s). Within each segment, when there is an overlap of at least 50 per cent with the Standard 2 data, we compute the corresponding colours HR1 and HR2. In Fig. 2, we plot the resulting quality factor and spectral colours. No dramatic changes in either the soft and hard colours are observed when the quality factor of the lower kHz QPO shows a clear drop. In particular, over the frequency range spanned by the lower kHz QPO, the hard colour is consistent with being constant (a fit by a straight line yields a χ^2 of 295 and 230 for 260 and 256 degrees of freedom (d.o.f.) for PCU 2 and PCU 3 data). Over a narrower frequency range (780–930 Hz), Di Salvo, Méndez & van der Klis (2003) obtained very similar results. There is a negative smooth anticorrelation between soft colour and lower QPO frequency, but nothing notable around the frequency where the quality factor of the QPO drops off, around 850 Hz.

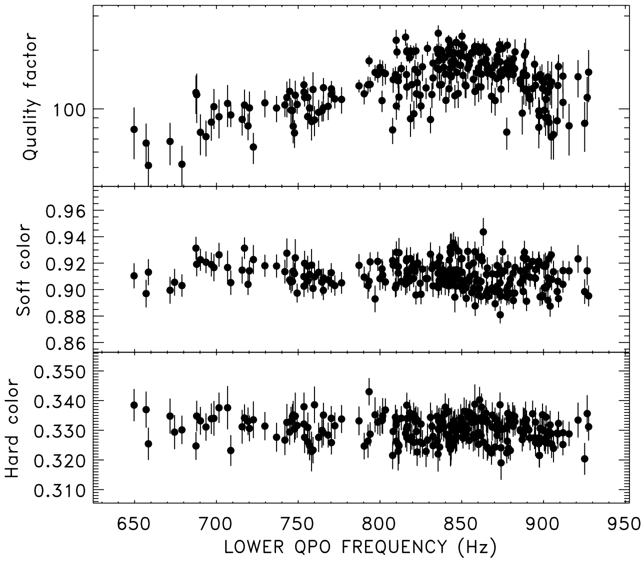

Figure 2. The quality factor–frequency dependency is shown on the top panel. Each point is obtained by shifting-and-adding all 8-s PDS over segments of 1024-s duration (see the text). Only points of significance greater than 4σ are shown. The rise of the quality factor with frequency, followed by a sharp drop, is clear, albeit with larger scatter than in Barret et al. (2005b), who averaged the QPO over longer integration times (typical duration of an ObsID, i.e. 4000 s). The middle and bottom panels show the soft and hard colours measured from PCU 3 data as a function of frequency. Only points for which the overlap between the Science Event data and the Standard 2 data is larger than 50 per cent are shown. There is a slight continuous anticorrelation between soft colours and frequency, but no correlation at all between frequency and hard colour. A fit by a straight line yields a χ^2 of 230 for 256 d.o.f.

In Fig. 3, we show the colour–colour diagram for all the data considered and overlay the region over which the lower QPO was studied with the present technique. The lower QPO is detected only over a very delimited region of the colour–colour diagram, even though that it samples a relatively wide range of frequency and quality factor. This by itself shows that even if subtle correlations are masked by the statistics (but see Fig. 4), the drop of the quality factor is not associated with a dramatic spectral change in this source. It is interesting to note that with the procedure described in this paper, lower kHz QPOs are detected at the intersection between the bottom and diagonal branches of the colour–colour diagram. The count rate varies from 130 to 340 counts s^{-1} in PCU3.

Next, we have grouped the data of Fig. 2 using weighted averages (and the 1σ errors) in the frequency space, with a bin of 20 Hz to get sufficient statistics and still enough points to keep a good description of the overall behaviour of the quality fact and hard colour with frequency. The results are shown in Fig. 4. The size of the error bars on hard colours has been decreased on average by a factor of 2.7 compared to the data of Fig. 2; the mean error on the hard colour is

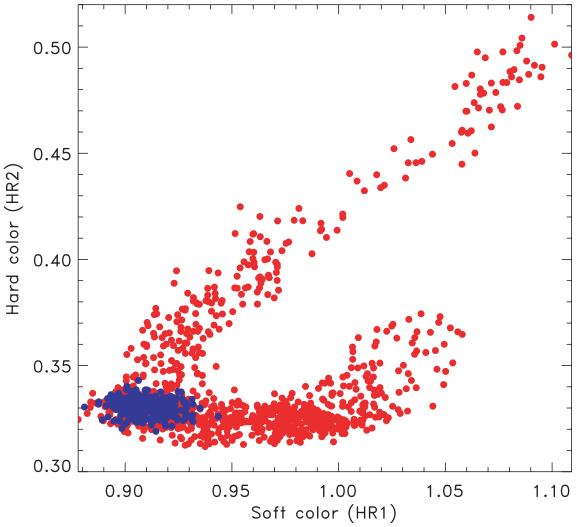

Figure 3. The colour–colour diagram of all the archival *RXTE* data analysed for 4U 1636−536. The colour is averaged over segments of 1024-s duration (red filled circles). Bursts and gaps have been filtered out. In blue, the colours corresponding to the QPO detections are shown. Only data from PCU 3 are shown, but the same results are obtained with PCU 2 data.

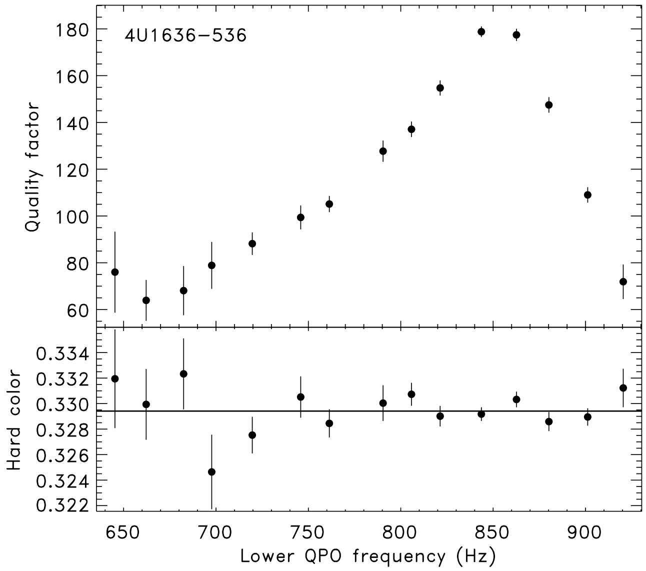

Figure 4. The variation of the quality factor and hard colour with frequency, grouping the data of Fig. 2 with a frequency bin of 20 Hz. The hard colour is consistent with remaining constant over the frequency range sampled by our analysis (a fit yields χ^2 of 15.2 for 14 d.o.f.).

reduced to 0.0016. A fit with a constant yields a χ^2 of 15.2 for 14 d.o.f. for PCU 2 data (15.5 for 13 d.o.f for PCU 3 data).

In Fig. 5, we plot the quality factor against the logarithm of the hard colour to enable a comparison with the data presented for 4U 1608−522 in Méndez (2006).

2.2 Comparison with 4U 1608−522

Using the same technique as described above, we have reprocessed the data of 4U 1608−522 presented in Barret et al. (2006) focusing on the lower kHz QPOs. This enables a direct comparison of two homogenous data sets obtained through the same processing scheme. The data set used includes data presented in Méndez et al. (1999), as well as observations performed in 2002 September, 2003 March and 2004 (proposal numbers 70059, 80406 and 90408). As for 4U 1636−536, we identify segments containing a lower kHz QPO in the quality factor–frequency plane. For 4U 1608−522, as shown in Barret et al. (2006), the lower QPO so identified spans a frequency range going from ∼570 to ∼900 Hz. PCU 2 provides the best overlap between the Science Event and the Standard 2 data for this source. In Fig. 6, we show the quality factor, soft and hard colours against

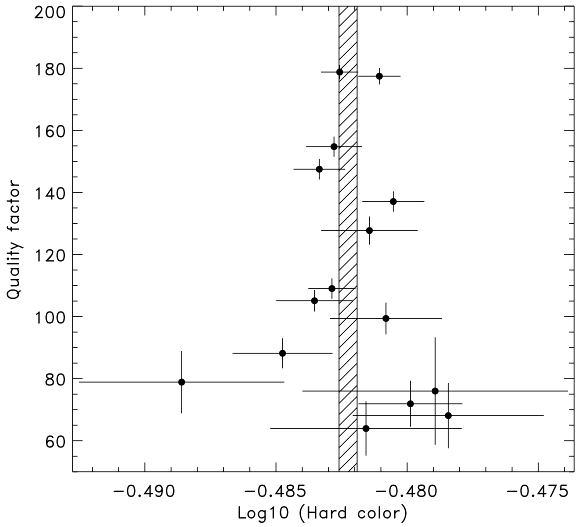

Figure 5. Quality factor versus hard colour for 4U 1636−536 using grouped data of Fig. 2. The 1σ error on the mean hard colour is represented by the hashed region.

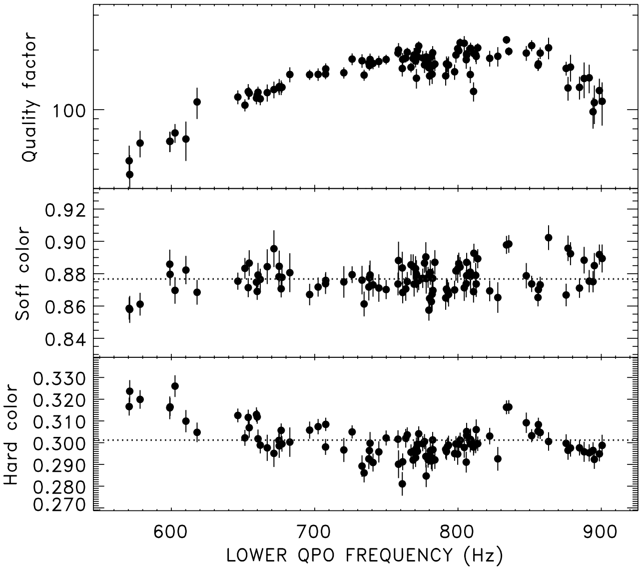

Figure 6. Same as Fig. 2 but for 4U 1608−522. The quality factor–frequency dependency is shown on the top panel. Each point is obtained by shifting-and-adding 8 s over segments of 768-s duration (chosen such that the mean error on the hard colour is the same as the one measured for 4U 1636−536 in Fig. 2). Only points of significance greater than 4σ are shown. The middle and bottom panels show the soft and hard colours measured from PCU 2 data as a function of frequency. Only points for which the overlap between the Science Event data and the Standard 2 data is larger than 50 per cent are shown. The same trends are seen in PCU 1 and 3.

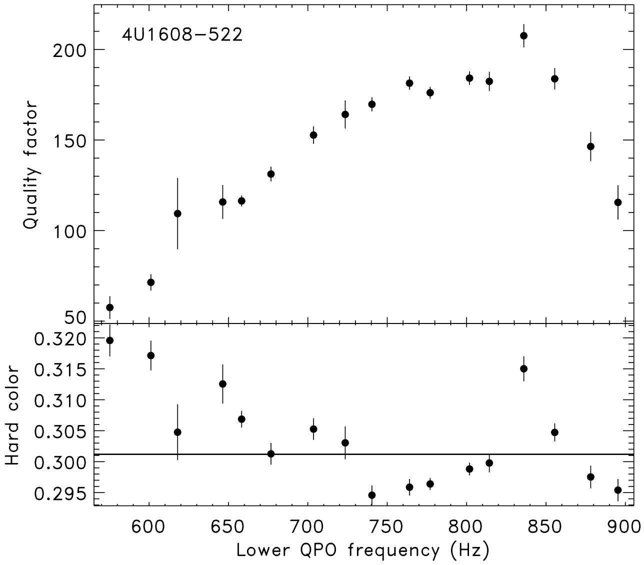

Figure 7. Same as Fig. 4 but for 4U 1608−522. The data are those recorded with PCU 2. Clearly, thanks to the improved statistics, the relationship between the hard colour and frequency is revealed to be more complex than previously thought for this source (e.g. Méndez et al. 1999).

frequency. Due to the larger count rate of 4U 1608−522 (varying from 150 counts s^{-1} up to 480 counts s^{-1} in PCU 2), in order to get similar errors on the hard colour as the one of 4U 1636−536, one can use shorter integration time for estimating the QPO parameters. We have used $8 \times 96 = 768$ s for 4U 1608−522, instead of 1024 s for 4U 1636−536. For 4U 1608−522, the hard colour is clearly not consistent with being constant: a fit by a constant yields a χ^2 of 371 for 103 d.o.f. Negative and positive correlations between hard colour and frequency are observed (the same behaviour is seen in other PCA units).

We then grouped the data shown on Fig. 6 also with a bin of 20 Hz to produce Figs 7 and 8. The mean error on hard colours for 4U 1608−522 is reduced to 0.0020, i.e. slightly larger than those of Fig. 4. Fitting the hard colour with a constant results in a χ^2 of 263 for 16 d.o.f. Restricting the frequency range to above 650 Hz (the minimum frequency in 4U 1636−536) yields a χ^2 of 147 for 13 d.o.f. Since we are interested in the region where Q reaches its maximum before dropping off, one can consider only those points from, say, 100 Hz before the peak (around 840 Hz) up to the last point, at ~930 Hz in 4U 1636−536 and ~900 Hz in 4U 1608−522, respectively. We obtain a χ^2 of 9 for 8 d.o.f and 95 for 7 d.o.f for 4U 1636−536 and 4U 1608−522. Clearly for the latter, the hard colour is not consistent with being constant over the frequency range spanned by the lower QPO, including the interesting part which encompasses the Q drop-off. We have verified that the same conclusion is reached, independently of the integration time used to estimate the QPO parameters. For instance, using 64 s for 4U 1608−522 as in Méndez et al. (1999), the mean error on the hard colour after binning is 0.0025 (20 per cent larger than with 768 s), and the χ^2 is 164 for 15 d.o.f. Looking at Fig. 6, it is worth noting that the relationship between the hard colour and frequency is revealed to be more complex than, and certainly not as smooth as, previously thought, based on measurements obtained with lower statistics (e.g. Méndez et al. 1999).

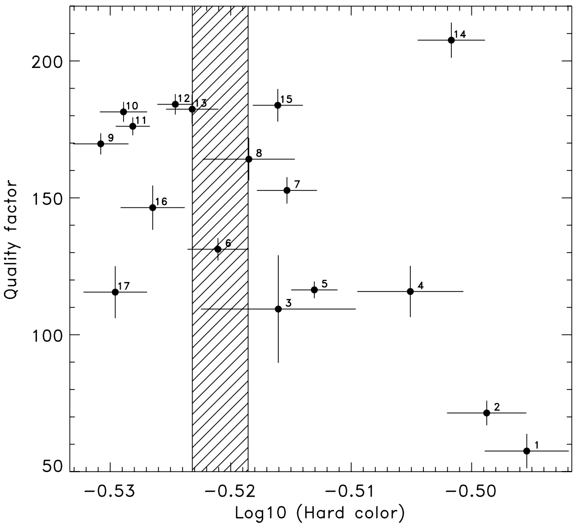

Figure 8. Same as Fig. 5 but for 4U 1608−522. The data are those recorded with PCU 2. The data points are labelled in ascending order with increasing frequency.

Comparing Figs 4 and 6 requires some comments. First, given that the size of the error bars are fully comparable, it shows that if a similar trend as seen for 4U 1608−522 were to be present in 4U 1636−536, we would have observed it. Secondly, we note that in 4U 1608−522, significant variations of the hard colour (still limited at the ~5 per cent level) are observed around the peak of the quality factor–frequency curve. These variations may reflect some changes in the source behaviour (e.g. accretion rate; Méndez 2006), but Fig. 4 shows that the effect produced is by no means universal, as we failed to detect it in a similar way in 4U 1636−536. It could be that the drop of the quality factor and change in hard colour are simply concomitant in 4U 1608−522.

From this comparison, one can therefore conclude that if we are to search for a common explanation for the sharp drop in the quality factor seen in both sources, the hard colour is not a good candidate for the independent variable whereas the frequency remains.

3 DISCUSSION

The results presented in this paper demonstrate that the drop of the quality factor of the lower kHz QPO in 4U 1636−536 is not accompanied by a significant change in the energy spectrum of the source, as measured by the spectral colours. Therefore, in this source, if the quality factor depends fundamentally on mass accretion rate, it must somehow do so in a way that leaves no detectable correlation between quality factor and either spectral measures or count rate (see Barret et al. 2005b,c, 2006). This seems difficult and contrived. In contrast, the strong correlation of Q with frequency in the lower peak is as expected if it is largely driven by approach to the ISCO. Together with the observed steady drop in rms amplitude, saturation of the QPO frequency with increasing count rate and the quantitative consistency of ISCO models with the Q versus frequency curve (Barret et al. 2005b,c, 2006), 4U 1636−536 behaves as expected if the phenomenology is linked to the space–time and not to the mass accretion rate. Other sources need to be analysed similarly, but the ISCO hypothesis and its attendant implications for strong gravity and dense matter are still entirely viable.

What, then, could be the explanation for the results of Méndez (2006), in which he found a correlation between hardness (or average luminosity) and maximum reported Q over sources spanning a range of two orders of magnitude in luminosity? The left-hand panel of his fig. 3 shows that the maximum reported quality factor is low for the lowest luminosity source [4U 0614+091, at $L/L_{\mathrm{Edd}} \approx 6 \times 10^{-3}$ and $Q_{\max} \sim 30$ (Barret et al. 2006 obtained $Q_{\max} \sim 50$ for this source)], high ($Q_{\max} \approx$ 100–200) for sources with $L/L_{\mathrm{Edd}} \sim$ 0.02–0.2 and low ($Q_{\max} \sim$ 10–20) for sources with $L \sim L_{\mathrm{Edd}}$. A similar pattern, although less monotonic, is shown in his fig. 4, of Q versus hard colour. Because this pattern with luminosity or hard colour is similar to the behaviour in individual sources with frequency (Q is low at low frequency, rises to a peak, then drops sharply), Méndez concludes that it is unlikely that the ISCO plays a role in any of these systems.

We believe that there is another interpretation. At the low-luminosity end of Méndez's correlation, there is a single key source: 4U 0614+091. Fig. 1 of Barret et al. (2006) shows that there is no apparent drop in the quality factor of the lower QPO up to ~700 Hz. On the other hand, lower QPOs at frequencies above 700 Hz have been reported with low Q values (van Straaten et al. 2000), yet without correction for the frequency drift. The status of 4U 0614+091 is thus different than the status of sources such as 4U 1636−536 for which, thanks to the necessary frequency drift correction applied, a clear maximum has been observed. This is an issue because if the 1330-Hz detection of the upper QPO is real, one would not expect, for any plausible spin frequency of the NS, that the frequency at which Q starts decreasing to be ~700 Hz or so. A careful re-examination of the 4U 0614+091 data is thus underway.

At the high-luminosity end, the sources all have very high luminosity indeed, comparable to Eddington. Standard disc accretion theory (e.g. Shakura & Sunyaev 1973) then suggests that the disc thickness will be comparable to the orbital radius, and that as a consequence the inward radial drift speed [which scales as $(h/r)^2$, where h is the disc half-thickness] will be large as well. As discussed in Barret et al. (2006), a large inward speed will necessarily decrease Q regardless of other factors. We note that this effect can also be important in reducing the maximum Q from ~200 to ~100 around a luminosity $L \sim 0.1$–$0.2 L_{\mathrm{Edd}}$, as seen by Méndez (2006). It is therefore not surprising that high-luminosity sources have low Q, but it is also not relevant to the evaluation of the behaviour of Q with frequency in much lower luminosity sources.

As a final remark, as we have discussed previously (e.g. Barret et al. 2005b,c, 2006), if the ISCO interpretation is correct for our data, then one can infer a mass of the order of 2 $\mathrm{M}_\odot$ for the NS. This is consistent with phase-resolved spectroscopy of 4U 1636−536 at the Very Large Telescope by Casares et al. (2006), who assume plausible binary parameters (inclination, disc flaring angle, mass of the donor star) and infer a mass 1.6–1.9 $\mathrm{M}_\odot$ for the NS. In addition, a variety of modern models for NS matter, involving hyperons, quarks or normal matter, predict maximum NS masses as large as ~ 2 $\mathrm{M}_\odot$ (Jha et al. 2006; Klähn et al. 2006). Our results thus add to the growing evidence for heavy NSs in accreting systems.

4 CONCLUSIONS

The case for the ISCO is still promising. Analysis of the type that we perform in this paper will be needed for other sources, to determine the strength of evidence in those cases. In addition, focused observations or re-analysis of specific objects will be useful, starting with 4U 0614+091.

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