Time lags of quasi-periodic oscillations across the source states of the low-mass X-ray binary 4U 1636–53

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1. Introduction

4U 1636–53 is a neutron star LMXB with an ordinary low-mass star ($M \lesssim 1.0 M_\odot$). Systems like this one (and the ones containing a black hole), and accreting systems in general, show a myriad of variability features in the power density spectra, ranging from millihertz to kilohertz. When the feature is narrow it is called QPO.

Here we extend our previous work [1] using the same data set to analyse the frequency-dependent time and phase lags of all QPOs detected through properly defined regions in the colour-colour diagram (CCD) (see also [2] for the labels and properties of the QPOs). Our methodology allowed us to study, for the first time, the dependence of the lags upon the frequency of the QPO itself for all detected QPOs in a NS-LMXB as the source changes its states as it moves through the CCD.

The time (phase) lags and Fourier coherence are Fourier-frequency-dependent measures of, respectively, the time (phase) delay and the degree of linear correlation between two concurrent and correlated time series, in this case light curves of the same source, in two different energy bands.

We gently refer the reader to our paper [1] to a more complete discussion about the data set and the results for the kHz QPOs of this source. Otherwise it will be a pleasure to personally talk to you.

2. Results

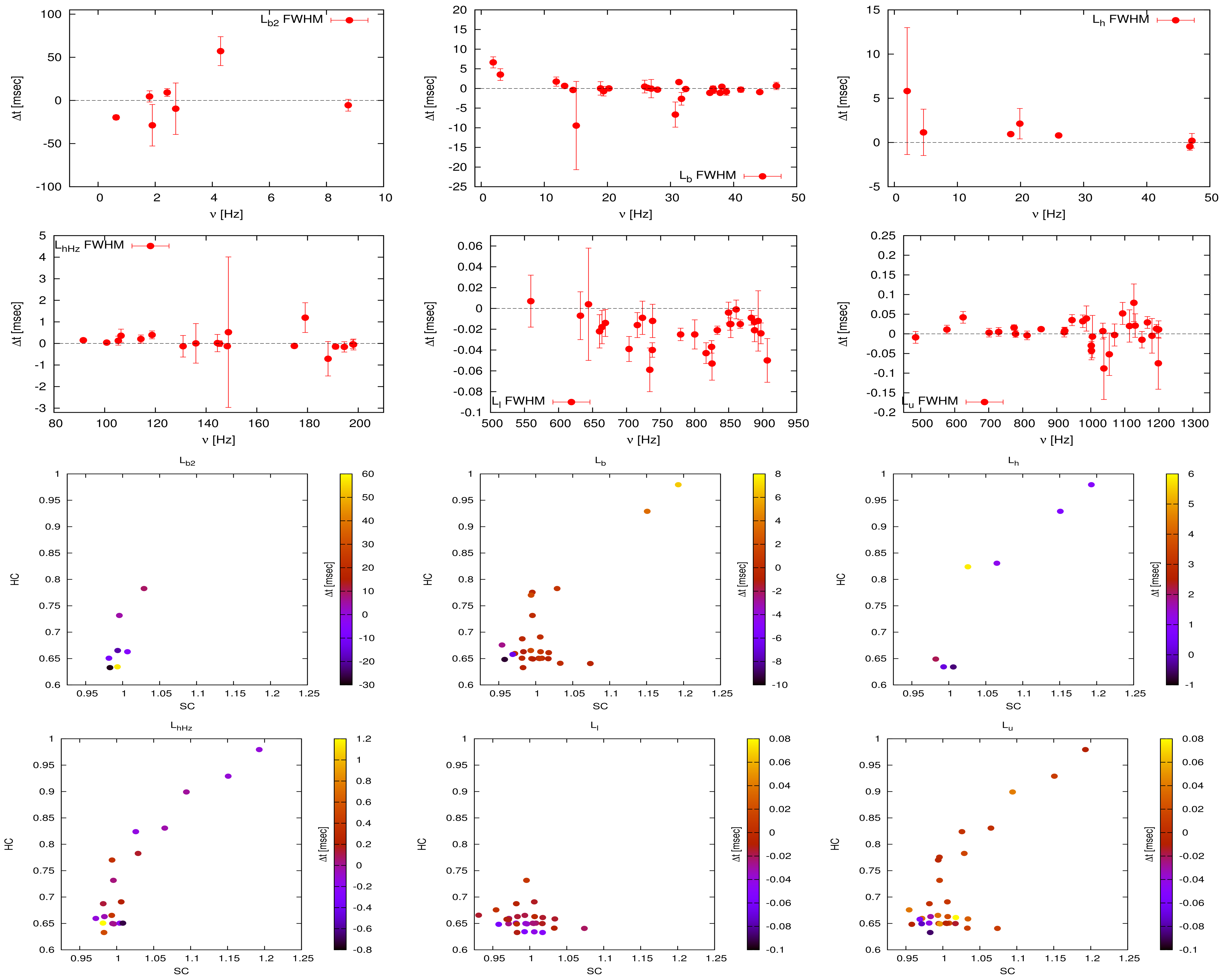

Figure 1: *Frequency dependence of the time lags (two first rows) and time lags on the CCD (two bottom rows) respectively of: the QPO at the break frequency # 2; the QPO at the break frequency; the hump QPO; the hHz QPO; the lower kHz QPO; the upper kHz QPO.*

3. Discussion of the results

1. We find at least for L_{b2}, L_b, L_l and L_u a statistically significant **dependence of the time lags upon the frequency** of the QPO (see, for example, the bumps for higher frequencies in the kHz QPOs). The lower the frequency range of the QPO, the higher is the order of magnitude of its time lags. Because of the complicated frequency dependence we cannot draw a complete picture of the energy dependence yet.

2. Light travel time arguments are useful to give a upper limit for the size of the medium in which the time lags are produced. Taking the constant fit values for the QPOs as simple estimators, the scale sizes of the medium where the lags of each QPO are produced are: 1) for L_{b2}: $\Delta t = -8.69\ msec \Rightarrow \Delta S = 2607\ km$; 2) for L_b: $\Delta t = 0.049\ msec \Rightarrow \Delta S = 14.7\ km$; 3) for L_h: $\Delta t = 0.796\ msec \Rightarrow \Delta S = 238.8\ km$; 4) for L_{hHz}: $\Delta t = 0.0082\ msec \Rightarrow \Delta S = 2.46\ km$ (this scale size can be as big as $300\ km$ due to the high dispersion of the data); 5) for L_l: $\Delta t = -0.021\ msec \Rightarrow \Delta S = 6.3\ km$; 6) for L_u: $\Delta t = 0.010\ msec \Rightarrow \Delta S = 3.0\ km$;

3. Recently, [7] studied the **phase lags frequency dependence** of high-frequency QPOs in four **black hole candidates**. For one source, GRS 1915+105, the phase lag of the QPO at $35\ Hz$ is soft and the phase lag of the QPO at $67\ Hz$ is hard and inconsistent with the phase lags show by the QPO at $35\ Hz$. One suggestion is that the **same mechanism** that produces the (inconsistent) phase lags of the QPOs at $35\ Hz$ and $67\ Hz$ also applies to the lower and upper kHz QPOs of 4U 1636–36; the hHz QPO of 4U 1636–36 could be somehow related to the QPO of the black hole candidates spanning the range $180 - 450\ Hz$.

4. We can see from CCD *vs* lags plots **a general smooth trend**, except maybe for the LhHz QPO, for a “softening” of the lags, i.e., a change **from hard to soft**, when the source moves from the hard states to the soft states.

5. **Our results for the time lags of all QPOs, when taken all together, disfavour simple models of Comptonization and also the reflection model. Our results could be signalising that variable corona or a multi-component system may be operating for producing the time/phase lags.**

References

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