DISCOVERY OF HIGH FREQUENCY QUASI-PERIODIC OSCILLATIONS IN 4U1915-05

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ABSTRACT The type I X-ray burster and dipper 4U1915-05 (also known as XB1916-053) was monitored by the Rossi X-ray Timing Explorer between February and October, 1996. The source was observed in various spectral states; the highest luminosity state ($L_X \sim 1.5 \times 10^{37}$ ergs s$^{-1}$, 10 kpc, 1-20 keV) is associated with a soft spectrum, whereas for the lower luminosity state (down to $\sim 5 \times 10^{36}$ ergs s$^{-1}$) the spectrum is significantly harder. Using the high time resolution data provided by the Proportional Counter Array (PCA), we have discovered High-Frequency Quasi-Periodic Oscillations (HFQPOs) in the persistent X-ray emission of 4U1915-05 while its luminosity was $\sim 8 \times 10^{36}$ ergs s$^{-1}$. The QPO frequency ranges from 600 Hz up to $\sim 1000$ Hz, with typical Full Width at Half Maximum (FWHM) $\sim 50 - 100$ Hz and Root Mean Squared (RMS) values $\sim 15\%$. In addition, by using the “shift and add” technique, we have detected a twin HFQPO ($5.5\sigma$ level) separated from the main peak by $\sim 355$ Hz. 4U1915-05 is the eighth Atoll source displaying simultaneous twin HFQPOs. Based on current knowledge of HFQPO sources, our observations suggest that 4U1915-05 might contain a 2.8 (or 5.6) millisecond rotating neutron star.

KEYWORDS: X-ray Binaries; Neutron Star: Individual 4U1915-05

1. INTRODUCTION

HFQPOs ranging from $\sim 300$ to $\sim 1200$ Hz have now been detected from over 15 neutron star Low Mass X-ray Binaries (LMXBs) (Van der Klis 1998). The origin of these HFQPOs remains unclear, but they are most likely to be produced close to the neutron star. The frequency of the QPOs is generally positively correlated with the inferred mass accretion rate. They are seen over a limited range of luminosity; for instance in Atoll sources, HFQPOs are generally detected in the so-called “Island” state, and on the lower branch of the “Banana” state. In most sources, twin HFQPOs are detected with a frequency separation in the range 250-350 Hz (Van der Klis 1998). In four cases, coherent oscillations during X-ray bursts have been also observed at a frequency which is equal or half the value of the separation between the twin peaks.
| Date       | PCUs | T (s) | R   | $\nu$ (Hz) | FWHM    | RMS (%) |
|------------|------|-------|-----|------------|---------|----------|
| 1996:05:16 | 3 E  | 7600  | 37.89 | 1006.4$^{+16.2}_{-16.6}$ | 79.8$^{+37.2}_{-29.9}$ | 16.4 ± 1.7 |
| 1996:05:23 | 4-5 E| 7400  | 33.22 | 835.1$^{+14.7}_{-14.2}$ | 93.4$^{+35.8}_{-28.1}$ | 16.8 ± 1.3 |
|            |      |       |      |            |         |          |
| segment    |      | 3200  | 32.58 | 818.9$^{+11.4}_{-10.9}$ | 51.2$^{+23.1}_{-18.4}$ | 13.9 ± 1.5 |
| segment    |      | 3200  | 32.96 | 845.5$^{+15.5}_{-15.9}$ | 78.4$^{+36.2}_{-25.5}$ | 15.9 ± 1.6 |
| 1996:06:01 | 5 E  | 5600  | 35.51 | 932.9$^{+14.9}_{-14.9}$ | 111.2$^{+34.7}_{-29.2}$ | 16.8 ± 1.1 |
| segment    |      | 3000  | 35.20 | 911.3$^{+16.8}_{-16.4}$ | 103.2$^{+43.8}_{-28.2}$ | 18.3 ± 1.5 |
| segment    |      | 2600  | 35.88 | 953.1$^{+13.8}_{-13.8}$ | 71.7$^{+24.7}_{-20.4}$  | 14.5 ± 1.4 |
| 1996:06:01 | 5 G  | 2800  | 36.86 | 935.2$^{+13.3}_{-13.2}$ | 89.0$^{+30.1}_{-25.2}$ | 16.6 ± 1.2 |
| 1996:09:06 | 5 E  | 8800  | 33.63 | 869.4$^{+18.2}_{-15.7}$ | 147.5$^{+34.2}_{-28.8}$ | 19.7 ± 1.1 |
| segment    |      | 2400  | 34.05 | 844.1$^{+11.5}_{-10.8}$ | 73.0$^{+22.4}_{-19.5}$ | 20.2 ± 1.5 |
| segment    |      | 2200  | 34.56 | 888.6$^{+32.4}_{-30.2}$ | 172.8$^{+60.4}_{-60.6}$ | 22.5 ± 2.0 |
| segment    |      | 2000  | 34.22 | 923.8$^{+23.2}_{-22.7}$ | 125.4$^{+56.6}_{-45.0}$ | 19.5 ± 1.7 |
| 1996:10:29 | 5 E  | 9000  | 35.11 | 604.4$^{+8.5}_{-8.5}$   | 45.3$^{+17.3}_{-15.9}$ | 11.7 ± 1.1 |
| segment    |      | 2800  | 37.40 | 610.2$^{+4.1}_{-4.1}$   | 20.7$^{+6.5}_{-6.4}$   | 11.9 ± 1.2 |

TABLE 1. The properties of the HFQPOs detected from 4U1915-05. The date of the observation, the number of PCA units (PCUs) operating during the observation, the data used (E or G), the exposure time (T) in seconds, the count rate (R) in units of Counts s$^{-1}$, the centroid frequency of the QPO (fitted by a gaussian), its FWHM in Hz, and its RMS in % in the 5-30 keV range are listed. E stands for Event mode data (122 GoodXenon data), while G means GoodXenon data (0.95µs).

In the simplest interpretation, the burst oscillation reveals the spin frequency of the neutron star, the higher of the two HFQPOs is associated with a disk keplerian frequency, whereas a beat frequency mechanism accounts for the lower of the two QPO peaks. However, this interpretation has recently been called into question by new data, which showed that the frequency separation of the twin peaks was not constant (e.g. 4U1608-522, Mendez et al. 1998a), or even that the burst frequency was not equal to the frequency difference (4U1636-53, Mendez et al. 1998b).

In this paper, we report on the discovery of HFQPOs from the LMXB 4U1915-05; a type I X-ray burster and dipper with a 50 minute orbital period, and a probable Atoll source (Yoshida 1992). A more detailed paper, describing both the correlated timing and spectral behavior, as well as the noise properties of the source (which confirmed its Atoll nature) will appear elsewhere (Boirin et al. 1998).

2. DISCOVERY OF HFQPOs FROM 4U1915-05

4U1915-05 was observed by RXTE for about 140 ksec in 19 snapshot observations covering from February to October 1996. The main data sets were separated in time by roughly one month. The net source count rate varied from ~15 to ~70 Counts
FIGURE 1. Hardness intensity diagram of 4U1915-05. The X-axis represents the background subtracted count rates in the 5-30 keV band, while the Y-axis is the ratio of the counts in the 10-30 keV band to the counts in the 5-10 keV band. Only data recorded with the 5 PCU units are shown. Filled symbols are for observations in which HFQPOs were detected (see below). The dates of the observation are listed on the right-hand side of the plot.

s$^{-1}$ PCU$^{-1}$ (5-30 keV). The source was thus observed in different spectral/intensity states as inferred from the hardness intensity diagram shown in Fig. 1. The global trend is that in the highest count rate regime, the spectrum is soft and cuts off around 10 keV, whereas for the lowest count rates, the spectrum is much harder and takes approximately a power law shape in the PCA energy range with no observable cutoffs below $\sim 20$ keV. A paper devoted to the spectral analysis of the persistent emission of the source will be published elsewhere (Bloser et al. 1998).

To study the $\sim 100$-1200 Hz variability of the X-ray emission, we used both the 122 $\mu$s Event mode and the so-called GoodXenon (0.95$\mu$s) high time resolution PCA data. Each continuous set (bursts filtered out) was divided into segments of 4096 bins lasting 250 $\mu$s. Fast Fourier Transform (FFT) were computed on each segment. 200 of these FFT were then averaged to obtain a final Power Density Spectrum (PDS). The analysis has been carried out in the 5-30 keV band, where we have found that the signal to noise ratio of the HFQPOs was maximum.

We have detected, above the 5$\sigma$ significance level, HFQPOs from 4U1915-05 in 5 observations (see Table 1). The statistical significance of the signals ranges from 5 to $\sim 10\sigma$. In some observations, (e.g. September 6th, 1996), the HFQPOs could also be detected in short ($\sim 2000$ – 3000 seconds) segments of the observation. The three strongest HFQPO signals are shown in Fig. 2. Unfortunately, the weakness
of the signals does not allow to study the RMS of the HFQPOs as a function of energy. Nevertheless in the May 23rd observation, there may be a positive correlation between the HFQPO RMS and energy (see Boirin et al. 1998 for more details). Similar correlations have been observed in other sources (Van der Klis 1998).

FIGURE 2. The three strongest HFQPOs detected. The date of the observation, the 5-30 keV count rate (per PCU and before background subtraction), and the RMS of the signal are shown at the top right of the windows. Note the relative weakness of the signals compared to other sources. Note also the positive correlation between the QPO frequency and the count rate.
Looking at Fig. 1, one can see that HFQPOs were not detected in observations with the largest count rates. We have derived a $3\sigma$ upper limit of $\sim 8\%$ on the RMS of a signal above 200 Hz of FWHM=100 Hz (5-30 keV range). HFQPOs were not detected either in the lowest count rate regime. Unfortunately our upper limit of $\sim 13\%$ on the RMS is not really stringent. A correlation between the QPO frequencies and the source count rate which is common to most sources is also seen from 4U1915-05 as shown in Fig. 3.

![FIGURE 3](image)

FIGURE 3. Correlation between the QPO frequency and the count rate listed in Table 1. Note that for the upper data points, the count rate varies by at most 20% whereas the QPO frequency varies from 800 to 1000 Hz. Note also that for the same count rates, the HFQPO can either be found around 600 Hz or 1000 Hz.

On May 16th and June 1st, a signal (below our confidence threshold) has been detected at 655 Hz ($3.0\sigma$) and 556 Hz ($4.6\sigma$) respectively, implying a frequency separation of $\sim 350$ Hz. We have thus applied the “shift and add” technique (Mendez et al. 1998c) to the May 16th and June 1st observations. As expected, a significant twin HFQPO ($5.5\sigma$) shows up at 650 ±5 Hz (FWHM=25 ± 10 Hz, RMS∼ 10.0%), whereas the main peak is located at 1005 Hz. This yields a frequency separation of $\sim 355$ Hz between the two peaks (Fig. 4).
3. CONCLUSIONS

4U 1915-05 thus joins the class of Atoll sources displaying HFQPOs. In 4U1915-05, the HFQPOs are detected over a limited range of count rates, when the source X-ray luminosity is intermediate in our data set (i.e. $\sim 8 \times 10^{36} \text{ergs s}^{-1}$), most likely on the so-called lower branch of the “Banana” state. HFQPOs were not detected in the higher luminosity states. HFQPOs are not detected either at the lowest count rates, but our upper limits are not very stringent. We have also found evidence for a twin HFQPO, separated from the main peak by about 355 Hz. Thus 4U1915-05 becomes the eighth Atoll source to display simultaneous twin HFQPOs. Further observations of the source are needed to better determine the properties of its HFQPOs; in particular a more complete sampling of its luminosity/spectral states is required. These observations are also needed to determine what is the actual spin frequency of the neutron star. In the framework of the simple interpretation discussed above, and existing observations of similar systems, our data suggest that it could be $\sim 355$ Hz, or half that value. If this is confirmed, this would mean that 4U1915-05 contains a 2.8 (or 5.6) millisecond rotating neutron star.
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