PROCEEDINGS OF SCIENCE

KHz QPO studies with IXO - Testing the Moving Hotspots Model

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According to the moving hotspots hypothesis, kHz quasi-periodic oscillations (kHzQPOs) are originated at the surface of the star from the movement of hotspots formed during accretion. In this scenario, the lower peak corresponds to hotspots created by the funnel flow in a hot region around the magnetic pole and moving around it, while the upper peak to hotspots created through instabilities closer to the equatorial zone, moving at a greater velocity than the polar ones. This model predicts that if the star is not almost perfectly aligned (misalignment angle much smaller than the polar hot region), the same movement originating the lower kHz QPO should also produce a dimmer feature at the frequency of the star. Low and high frequency phenomena should also be correlated, the red noise being influenced by the duration and frequency of appearance of the hotspots. The unprecedented collecting area of IXO, increasing the countrate by a factor of ~ 10 with respect to RXTE, would be an extraordinary tool to study the lightcurves of LMXBs and look for features at the frequency of the star in observations where the lower QPO is present. Moreover, it would help study LMXB variability on shorter timescales, helping the investigation of the short-term coherence of QPOs and correlations between high and low-frequency phenomena.

Fast X-ray timing and spectroscopy at extreme count rates: Science with the HTRS on the International X-ray Observatory - HTRS2011,
February 7-11, 2011
Champéry, Switzerland

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[*] Speaker.

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PoS(HTRS 2011)050

1. Moving Hotspots and quasi-periodic oscillations

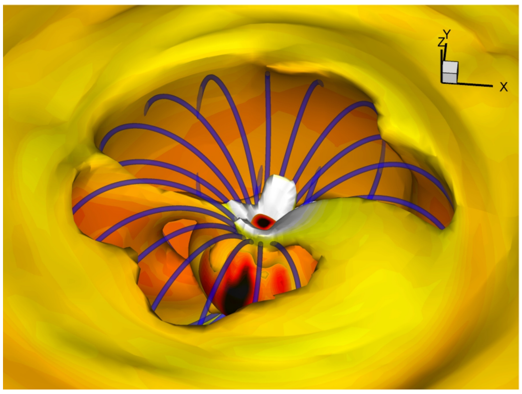

Figure 1: The flow of matter on the surface of a neutron star: in this figure one can see both the funnel flow on the magnetic field and the flow through instabilities at the inner radius

3D MHD simulations [8] show that matter accreting onto a magnetized neutron star takes two paths: the Funnel Flow, where matter is extracted from the disk and follws the field lines until it reaches the magnetic polar region; instabilities at the inner radius, that form tongues of matter falling near the equator of the star. Both accretion paths form hotspots that, because of the intrinsic angular momentum of matter falling onto the star and/or for oscillations originated in the disk, move on the surface [8, 7]. This motion of the hotspots produce variability in the lightcurves, represented by QPOs at the typical frequencies of the inner region of the disk. The hotspots in the magnetic polar region and the ones at the equator have different characteristic frequencies and can therefore be observed simultaneously as two peaks in power density spectra [1]. Their frequencies depend on the position of the inner radius, and so they move together with it.

This mechanism is a very promising explanation for the kHz QPOs observed in accreting neutron stars. These oscillations appear in many low-mass X-ray binaries and their frequencies range between 300 and 1200 Hz. Very often two peaks are observed, whose frequencies change but maintaining an almost fixed separation of about 300 Hz. The values and behavior of the two frequencies, though, cannot be easily described by a beat phenomenon as their "parallel" change of value seems to suggest. The two peaks have different coherences, the lower peak being in general more stable. Understanding the QPO phenomenon has important implications on the study of the relativistic motion of matter around neutron stars, and so on as a possible measure of the stars physical properties (for ex., the measure of the innermost stable circular orbit [2]). Many models have been proposed to explain the phenomenon (e.g. [9, 6, 4, 3], see [11] for a review), but no one has still managed to describe it completely. The movement of the hotspots we observe in simulations explains qualitatively several important features of kHz QPOs like their different coherence (for more information see [1]). In fact, in this model the lower peak is given by the hotspot in the magnetic region, having a more stable motion, while the upper is given by instability hotspots, less stable by definition.

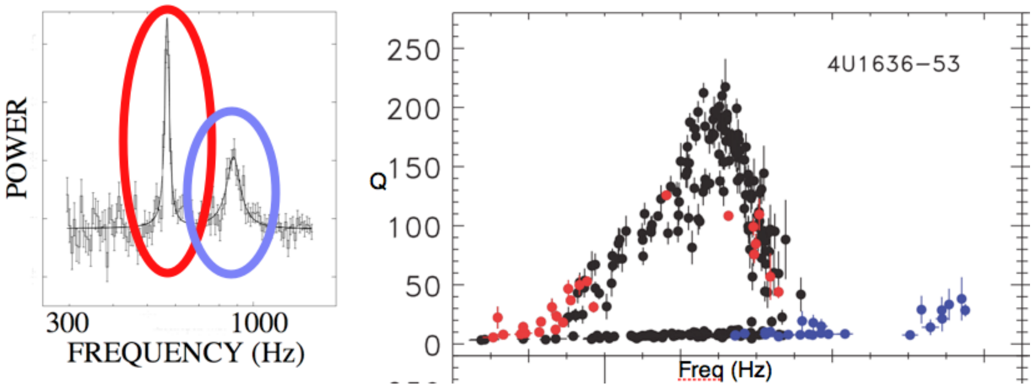

Figure 2: (right) The kHz QPOs as they appear in the source 4U 1608-52 [5] and (left) the coherence of the two peaks in 4U 1636-536 [2]. In the moving hotspots model, the higher coherence of the lower peak is given by the higher stability of the funnel flow with respect to the unstable flow that gives the upper peak.

2. Predictions and possible tests

This model predicts that if the neutron star is not aligned, i.e. there is an angle between the magnetic axis and the rotation axis $\gtrsim 10^\circ$, then the movement of the hotspot in the funnel flow should also produce a feature at the frequency of the star and other beats (Fig. 3). Not seeing the feature means either that the star is aligned or that the QPO is not produced in the funnel flow. I ran some searches for the frequency of the star in several RXTE/PCA observations of systems showing QPOs but no coherent pulsations, whose rotational frequency was known from burst oscillations, finding no such peak. In Fig. 4 one such study is plotted: I selected ~ 100 observations of the source 4U1636-536 where the lower peak was observed but its frequency was significantly larger than the known rotation frequency of the star (from burst oscillations, 581 Hz [10]). I than averaged all power spectra of these observations, with 1Hz frequency resolution, looking for a feature at the frequency of the star (Fig. 4). No such significant feature appears, suggesting either that the model is incomplete, or that the star has a small misalignment angle and/or our instruments are not sensitive enough to detect it.

3. Testing QPO models with IXO

With the unprecedented effective area of IXO/HTRS, the sensitivity to QPOs can be improved drastically, as can be seen in Fig. 5. This means that it will be possible to search for new features, like the one at the frequency of the star here presented, or new QPOs. It will then be possible to perform simultaneous timing and spectral studies on very short timescales, studying these oscillations in the time domain and not only in the frequency domain as we do today. This would mean the possibility to finally understand from which part of the accreting region QPOs are emitted.

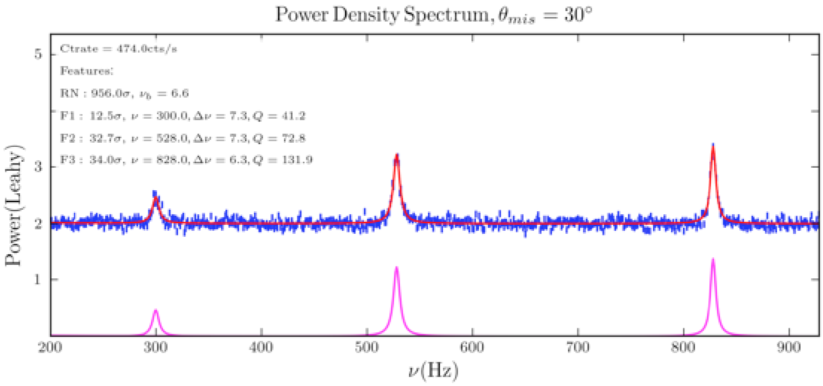

Figure 3: QPOs produced by the movement of a hotspot aroung the magnetic pole of a significantly inclined neutron star. Together with the QPO, a feature appears at the frequency of the star and another at the beat frequency.

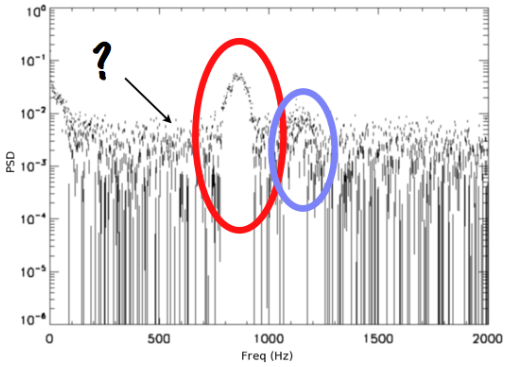

Figure 4: Sum of the power density spectra of ∼ 100 PCA observations of the source 4U1636-536. In each observation the lower QPO was observed. Notice the peaks corresponding to the lower (red) peak and the upper (blue), and the lack of a feature at the frequency of the star (question mark).

Moreover, it will be possible to study the upper limits of the QPO frequencies and the relations on short timescales between high- and low-frequency features, allowing very precise tests on all QPO models.

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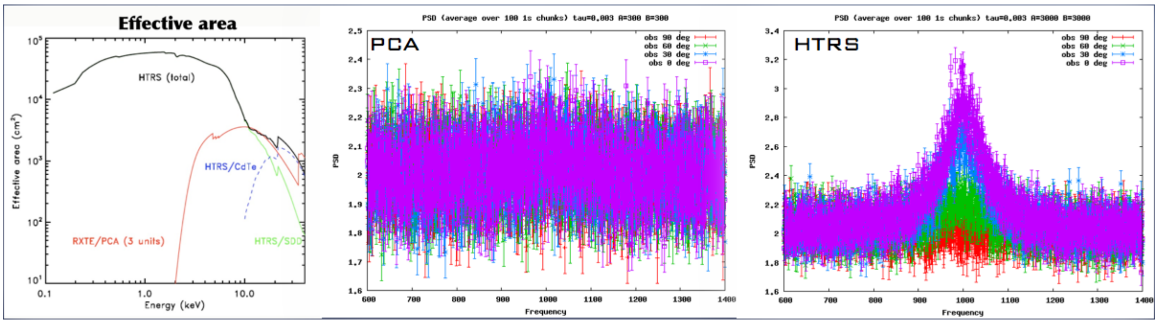

Figure 5: (left) Effective areas of HTRS and PCA compared; (center and right) a simulation of the QPO at the frequency of the star for different misalignment angles, as it would be observed with PCA and HTRS, respectively.

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