Discovery of a QPO in the X-ray pulsar 1A 1118-615

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Introduction

1A 1118-615 is an accretion-powered X-ray pulsar which was discovered in December 1974 by the Ariel V satellite (Eyles et al. 1975) during an observation of Cen X-3. The same data revealed pulsations with a period of 405±0.6 s (Ives et al. 1975). The X-ray spectrum was fitted by a highly-absorbed power law with photon index ~1. The remarkable measured absorption indicated that the circumstellar environment played a significant role in absorbing the X-ray emission. In 1979 and 1985, the system was observed by Einstein and EXOSAT satellites, respectively (Motch et al. 1988). Only weak signal was detected in both occasions, showing that low-level accretion was occurring.

The second giant outburst from 1A 1118-615 since its discovery was detected in January 1992 after a long period of quiescence, and the third one at the beginning of 2009. Low frequency observations showed very strong Hα emission ($EW_{H\alpha}$= -80 Å), and high IR excess from the disk of the companion star (E(J − K) =0.47), indicating a very large circumstellar disk (Coe et al. 1994).

We performed a detailed spectral and temporal study of the third major outburst of the system using RXTE data. We focus on the aperiodic variability of the source and study the evolution of the spectral and timing parameters throughout the entire outburst.

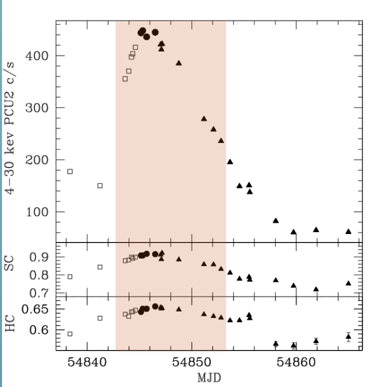

Fig. 1. PCA light curve and color behavior during the 2009 outburst (one point per observation analyzed in this work). The colored area highlights observations where the QPO was detected. Different symbols mark the different phases of the outburst: rising (empty squares), peak (full circles), and decay (full triangles).

QPOs in X-ray pulsars

Quasi-periodic oscillations (QPOs) have been detected in 16 accretion-powered high-magnetic field pulsars, comprising many HMXBs and a few LMXBs, both transient and persistent. **QPOs in X-ray pulsars provide strong evidence for the presence of an accretion disk during giant outbursts because they are believed to be related to inhomogeneities in the inner disk** (Paul & Rao 1998). While black-hole binaries and LMXBs show QPOs with frequencies from a few Hz to a few hundred Hz, high-magnetic field neutron stars only show low-frequency QPOs, in the range between 10 mHz and about 1 Hz.

Discovery of a QPO

The power spectra continuum was fitted with the sum of, at most, three components: a power law, at low frequencies, and two zero-centered Lorentzians, L_1 and L_2. **We detected a QPO the PSD of 1A 1118-615 during the brightest observations.** When the X-ray luminosity goes below ~40% of the maximum luminosity, that is for flux below 4×10^{-9} ergs cm^{-2} s^{-1}, the QPO disappears.

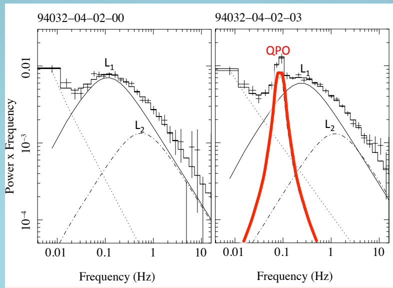

Fig. 2. Example of low-luminosity (L_X = 2.31 × 10^{36} erg s^{-1} , left panel) and high-luminosity PSD (L_X = 2.50 × 10^{37} erg s^{-1}, right panel) with fitted components: a power law (dotted line), L1 (solid line), L2 (dash- dotted line) and the QPO (red solid line). On the top of each panel the RXTE observation ID is reported.

The QPO was fitted by a narrow Lorentzian. Its maximum frequency, ν_{QPO}, is ~0.08 Hz, and the measured quality factor $Q=\nu_0/FWHM$, varies in the range 3–9. If one assumes that QPOs are produced as a result of Keplerian motion of inhomogeneities in an accretion disk, then the longer implied timescales of the QPOs in HMXBs are somehow expected since the inner radius of the accretion disk must be larger than the magnetospheric radius R_M ~ 10^8 cm. The inner disk radius can be expressed as $r_0 = (GM/4\pi^2\nu_k^2)^{1/3}$, where ν_k is the Keplerian rotation frequency at the inner edge. An 80 mHz QPO implies a disk radius of 8–9×10^8 cm, that is, outside the magnetosphere, as models foresee.

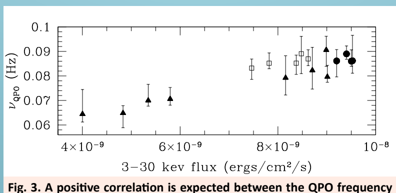

Fig. 3. A positive correlation is expected between the QPO frequency center and the X-ray flux, because at larger mass accretion rate, corresponding to increasing flux, the size of the magnetosphere decreases, and the accretion disk is expected to extend closer to the neutron star. This implies shorter characteristic time-scales, which means higher frequencies. In the case of 1A 1118-615 during the outburst analyzed in this work, we have indeed detected a positive correlation between the QPO frequency and the 3–30 keV flux.

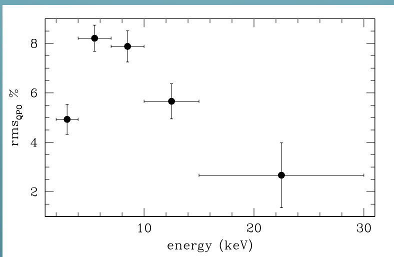

Fig. 4. We found evidence for a decrease of the QPO variability with energy, for energies higher than 4 keV.

Correlated spectral/ timing behavior

Figure 5 allows a quick comparison of the X-ray temporal variability as a function of spectral shape**. This is the first time that such correlation is reported in an accretion-powered pulsar.**

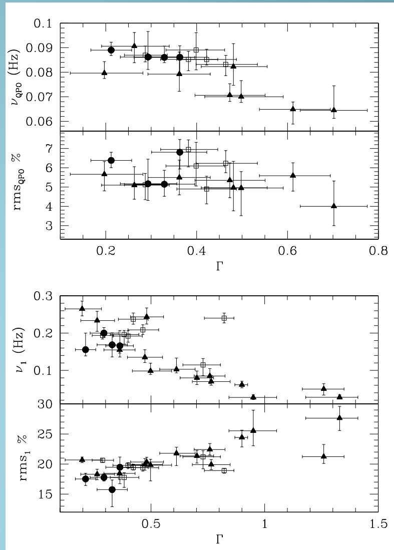

Fig. 5. Relation between the photon index and the timing parameters, characteristic frequency (upper panel) and rms (lower panel), for the QPO and the L_1 broad-band component.

The source is more variable when it shows a soft spectrum and, more importantly, the physical region where the aperiodic variability originates and the emission region are strongly linked to each other. The aperiodic variability is supposed to arise from a region outside the magnetosphere at $R \geq 10^8$ cm, while the emitting region that originates the energy spectra lies in the accretion column, *i.e.*, at distances close to the neutron star surface, namely 10^6 –10^7 cm. Nevertheless, these two regions are somehow physically connected.

The correlation between rms and photon index might be explained by simple Comptonization models, if one assumes that the source of variability is variations in the soft photon input. In this case, low-energy photons would retain most of the variability of the seed photon input since they did not spend much time in the Comptonization medium and have not undergone many scatterings. In contrast, the variability of high-energy photons would be smeared out since these photons have spent longer time in the accretion flow. The overall result would be higher variability in correspondence to a soft spectrum, as observed.

More…

The full analysis will be available in a forthcoming paper, "*Discovery of a QPO in the X-ray pulsar 1A 1118-615: correlated spectral and aperiodic variability*", submitted to A&A.

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