COMBINING RAYLEIGH TEST AND PIF METHOD FOR TIMING ANALYSIS WITH CODED MASK APERTURE INSTRUMENT. APPLICATION TO QUASI-PERIODIC OSCILLATION DETECTION AND MODELIZATION.

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ABSTRACT

Several X-ray binaries exhibits quasi-periodic behavior from low (a few mHz) to high (≃1kHz) frequencies in the whole electromagnetic spectrum (from radio to hard X-ray). Standard way of data processing with coded mask aperture instruments such as IBIS onboard INTEGRAL requires evolved deconvolution algorithm (e.g OSA 5.0 for INTEGRAL data). We propose here a new way of timing analysis using both Rayleigh test and PIF method in order to detect Quasi-periodic Oscillations(QPO) in X-ray binaries and we applied this method to GRS1915+105 INTEGRAL early observations.
In a second part, we have simulated the linear response of soft X-ray photons comptonized by a warm oscillating corona (sausage mode in a disk geometry) using a Monte-Carlo code. The resulting normalized power spectrum obtained is compatible with some of X-ray binaries observations.

Key words: X-ray binaries; QPO; Monte-Carlo code.

1. DETECTING PERIODIC EVENTS IN CODED MASK INSTRUMENTS DATA

1.1. Method used

Coded mask aperture instruments such as those embarked aboard the INTEGRAL spacecraft (JEMX, IBIS or SPI) are used because of their ability to perform spectro-imaging even at high energies.
However, due to the presence of a coded mask, the data collected by the detectors cannot be trivially interpreted : indeed, the signal of each source in the field of view and emitting in the X-rays is then convolved by the pattern of the mask. Thus a simple power spectrum computation on the whole detector would mix the different signals.

Standard analysis (OSA 5.0) requires powerful softwares and high computering abilities to obtain binned light-curve after long time deconvolution. However, it is also possible to use both following methods to obtain an efficient timing analysis :

- **P.I.F** : Pixel Illumination Factor is more or less the probability that one source illuminates a considered pixel. The more the PIF, the higher the flux coming from the source.
- **Rayleigh test** : A frequency f is chosen arbitrarily. All the $cos(2\pi.f.t_k)$ are then added (t_k being the different photon arrival time, called *events*). The result of this sum is nil unless the source is emitting at the same frequency f.
- As the flux coming from the source is linearly related to the PIF value, the previous computed sum follows the same law. Thus, our method consists in combining both previous methods by linearly fitting the $\sum_k cos(2\pi.f.t_k)$ in the PIF plane. Thus, for a given source s that is oscillating at the frequency f, the higher the PIF, the greater the sum and the higher the slope $I_{f,s}$ of this fitted line ($I_{f,s}$ then represents the oscillation amplitude of the source). On the contrary, for a non oscillating source, $I_{f,s}$ will be nil.

1.2. Tests on the Crab and on GRS 1915+105

Following the previous method, a code was written (in Yorick) to detect automatically any periodic component in a given set of data. We applied it first on Crab IBIS/ISGRI observations (spacecraft revolution #102) and then to GRS 1915+105 early IBIS/ISGRI observations (spacecraft revolution #48). The Crab pulse and a low frequency Quasi-periodic Oscillation (hereafter QPO) of 3 mHz in GRS 1915+105 were detected in both observations using our method (see Fig 1).

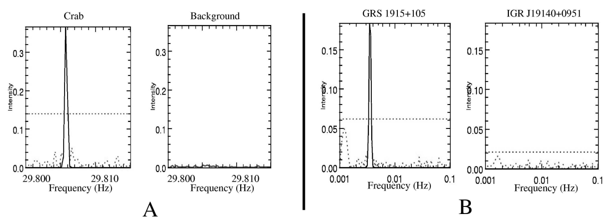

Figure 1. ***A*** *: Intensity I_f plotted vs frequency for the Crab (left) and the background (right) in the 20-25 keV energy band (dashed line). The pulse is well detected by the code (in continuous line) and fitted by a gaussian.* ***B*** *: Intensity I_f plotted vs frequency for GRS 1915+105 (left) and the recently discovered X-ray source IGR J19140+0951 (see Rodriguez et al. (2005) for further information on this source) located 1^o far from the famous microquasar in the 20-25 keV energy band. Our code detect a rather coherent (Δf = 0.8 mHz) low frequency QPO at about 3 mHz for GRS 1915+105.*

2. SIMULATION OF A PULSATING CORONA

2.1. Code used

As the physical processes underlaying the production of QPO is still unclear, we tried to simulate the behavior of an oscillating corona in a simple disk truncated geometry. In this model, the soft thermal photons are emitted randomly : the emission times are just following a poissonian distribution. Then they are comptonized on a high energy plasma (considered as a perfect gas) where the temperature (and thus the electron density) is partially oscillating at a given frequency f (propagation terms of this wave among the disk are taken into account). The code we used was a modified version of a simple linear Monte-Carlo simulation of a comptonizing corona developped by J. Malzac (see Malzac (1999)).

2.2. Early results

We performed a simulation with the following physical parameters : the number of soft seed photons emitted by the thermal component (T_{soft} = 0.2 keV) has been set to 10^7 and the average temperature of the warm plasma T_{corona} has been set to 153 keV. In addition, we took a value of 2.5 Hz concerning the frequency of the warm plasma oscillations and a perturbation level (compared to the mean temperature) ϵ of 0.2. Results can be seen in Fig 2.
We observe the same dependency in energy between the simulated QPO spectra and the observed ones. As it is already suggested in Rodriguez et al. (2004), the fact that the cut-off in the QPO spectra seems strongly related to the energy of the electron gas could be easily interpreted : in that case, the modulation of the X-ray flux would be contained in the comptonized photons and not in the other emission processes (e.g, synchrotron).

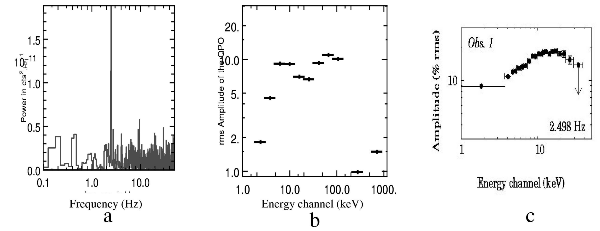

Figure 2. ***a*** *: Power spectrum of the simulated oscillating corona showing the 2.5 Hz QPO in the 45-100 keV energy band.* ***b*** *Spectra (compared to the rms) of the simulated 2.5 Hz QPO clearly showing a cut-off at an energy similar to the value of the temperature T_{corona} of the warm plasma.* ***c****: Spectra of the observed 2.5 Hz QPO in GRS 1915+105 (RXTE PCA/HEXTE data). A cut-off also seems to be required and the energy cut-off value is thus similar to the temperature of a comptonizing corona obtained by spectral fits (see Rodriguez et al. (2004) for further informations).*

3. CONCLUSION AND PERSPECTIVES

Early results using our new timing analysis combining Rayleigh test and PIF method have shown that it is possible to detect efficiently some QPO in INTEGRAL IBIS/ISGRI data and the same method could be extended to other coded mask instruments. Next challenge will be to apply this method to several X-ray sources in order to detect any QPO at higher energy than described before (RXTE/PCA cross-section drops down beyond 40 keV) and to better understand which physical processes are at the origin of the QPO.

In any case, the simulation of a hot oscillating comptonizing corona shows that it can be sufficient to generate QPO, and the fact that the QPO spectra is similar to the observation is also in agreement with the hypothesis that the QPO occurs in the comptonizing corona. New simulations with other parameters (different temperature of the plasma, dependency on the QPO frequency) and their comparison with observations will give us other useful constrains.

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