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THE POWER SPECTRA AS A PROBE OF SOME PHYSICAL FEATURES OF X-RAY BINARIES

L. Burderi,* N. R. Robba* and G. Cusumano**

** Istituto di Fisica, Università di Palermo, via Archirafi 36, 90123 Palermo, Italy*
*** Istituto di Fisica Cosmica ed Applicazioni dell'Informatica, via Stabile 19, 90100 Palermo, Italy*

ABSTRACT

We have simulated, using a Monte Carlo method, intensity time series representing the time behaviour of some high mass X ray binaries. Taking into account some physical models of the accretion processes, we have parametrized different physical conditions on the source. The resulting time series have been analysed by Fast Fourier Transform techniques. Using different sets of parameters we have been able to generate power spectra of different shapes. Some preliminary results of these simulations and a comparison with an observed spectrum of a galactic X ray binary are discussed.

INTRODUCTION

Aperiodic variability seems to be a typical behaviour of the emission from some X ray binary sources. In fact, when analysed via the Fast Fourier Transform (FFT) techniques, the Power Spectrum Density (PSD) of the X-ray intensity often shows a power distribution that roughly decreases with increasing frequency, *i.e.* a typical Red Noise (RN) feature /1,2/.

In a very general way the X ray emission from these sources is often associated with the process of the accretion of matter from the "normal" companion onto the compact object (neutron star or black hole). There are several suggestions, in different models describing the physics of the accretion processes, that plasma instabilities could originate in the radial flow of the accreting matter towards the compact object or in the innermost zones of the accreting disks /3/ or during the interactions of the plasma with the intense magnetic fields that could exist near the surface of the degenerate star /4,5/. Only to give some examples of the formation of this kind of inhomogeneities we remind that, in some cases, the plasma of the internal regions of the accreting disk on a black hole could clump in spheroidal structures resembling planets /6,7/, otherwise, when a neutron star with an intense magnetic field is present, the plasma penetration through the magnetosphere (mainly driven by the Rayleigh-Taylor instabilities) occurs via the formation of long filaments of matter falling through the magnetic field lines /8,9,10/. The ultimate fate of these clumps of matter is still unclear: they could either be partially or completely destroyed by gravitational tidal forces or (in the presence of the magnetic field) by the onsets of Kelvin-Helmoltz instabilities, or survive until the impact with the neutron star surface or the approach to the event horizon of the black hole /11,12,13/. In particular, if the compact object is a neutron star, the sudden stop of this falling matter near the neutron star surface can produce, mainly through thermal brehmsstrahlung process, the X-ray emission. So if the matter accretes in a turbulent way, clumped in blobs, this will cause a flickering emission signal, otherwise if the matter accretes with a non turbulent quasi laminar flow this will originate the uniform emission component. We suppose that a single blob can emit X-rays in a shot, so we represent this emission with an intensity that rises abruptly (vertically) and decreases exponentially with time. Due to the casual occurrence of the blobs these emissions are supposed to occur randomly (stochastical) in time. This kind of process is called Exponential Shot Noise Process /14,15,16,17/.

Having this picture in mind we try to study the PSD shape as produced by inhomogeneities (blobs) in the plasma flow during the accretion process in order to obtain informations and constraints on some parameters describing the physics of these systems.

THE LINK BETWEEN THE PHYSICAL MODEL AND SOME FEATURES OF THE PSD

We have simulated, using a Monte Carlo method, a X-ray intensity time series I(t) as built up by two components: an uniform component $I_{un}(t)$ and a shot component $I_{sh}(t)$. The uniform component derives from a homogeneous accretion flow and can be represented as a constant intensity value. The shot component of the signal derives from the accretion flow clumped in blobs and can be represented as a superposition of exponential shots occurring randomly in time. We used the exponential shape as a simple way to represent the shot signal caused by the accreting blobs: blobs of different size and shape are described in this simplified two-parameter model varying the area under the exponential *A* and the decay time τ. In addition we have supposed that different fractions of the two kinds of accretion flows could be forced by the magnetic field strength to accrete onto polar caps of the spinning neutron star so we have coupled the resulting emission with a periodic modulation function. This function is build up as a sum of harmonics of the pulsar spin period and is normalised in order to let the mean involved flux unchanged. The underlying physical scenario described above is sketched in fig. 1.

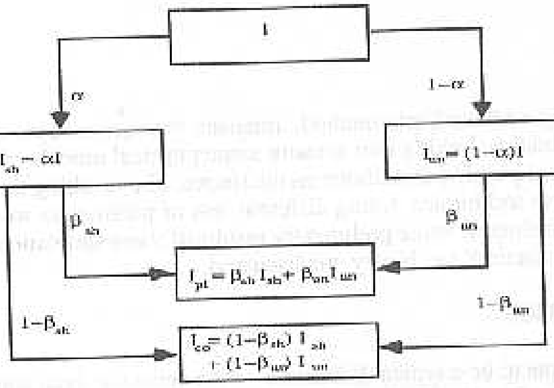

Fig. 1. Decomposition of the intensity time series.

The simulated intensity time series I(t) is suitable for analysis with a Fast Fourier Transform (FFT) algorithm. The resulting PSD is normalised, following Leahy /18/, to the total number of photons of the data set in order to obtain for a pure poissonian counting noise a mean value and a standard deviation of 2. The PSD shape of a pure exponential shot noise with different values of time decay τ, are shown in fig.2.

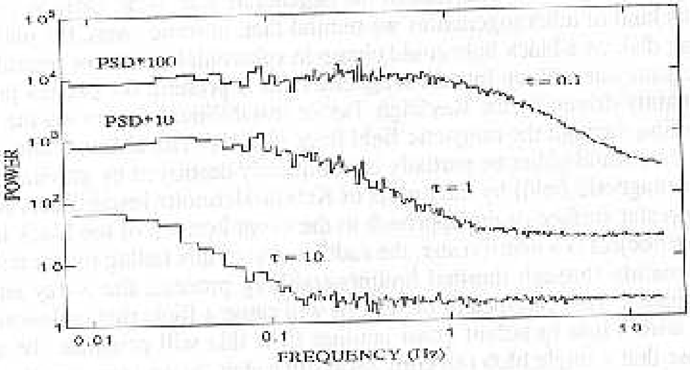

Fig. 2. PSD of exponential shot noise for different values of the shot time decay τ. Note the dependence of the inflexion point on τ ($\nu_{inflexion} = 1/2\pi\tau$).

Assuming a pure exponential shot noise model plus a constant uniform signal each with different degrees of coupling with a periodic modulation, we were able to derive some relations between some characteristics of the PSD and some physical parameters of the model.

$$I_{pl}=\beta_{sh} I_{sh}+\beta_{un} I_{un}\ ; \qquad I_{sh}=I\,\mathrm{rms}\sqrt{2\lambda\tau}\ ; \qquad A\sqrt{\lambda}=\mathrm{rms}\,I\sqrt{2\tau}\ ;$$

$$\frac{1}{\tau}\cong(2\,\mathrm{rms})^2\,\frac{1}{P_{sh}(\nu_{min})}\cdot\frac{1}{2}\left[1\pm\sqrt{1-\left(\frac{\pi\,\nu_{min}\,P_{sh}(\nu_{min})}{\mathrm{rms}^2 I}\right)^2}\,\right] \quad \text{with} \quad \mathrm{rms}=\sqrt{\frac{\int P_{sh}(\nu)d\nu}{I}}$$

where λ is the mean shot rate; ν_{min} is the minimum frequency in the PSD; P_{sh} is the power due to the shot noise.

THE BROADENING OF THE HARMONIC LINES DUE TO THE COUPLING WITH THE SHOT COMPONENT

We have studied the effects on the PSD of a periodic modulation of the shot component. This modulation can produce, under particular circumstances, a broadening of the harmonic lines in the PSD spectra. In fact the periodic modulation of the shot component, consists in a multiplication of the involved signal by a periodic function. In the PSD spectra this corresponds to a convolution of the shot noise spectrum with the harmonic lines of the pulsation leading to a slight broadening of the lines. This broadening is strongly dependent on the shape and the intensity of the shot noise component and mainly on the degree of coupling with the periodic modulation. In addition the relative position of the lines compared to the inflexion point in the exponential shot noise spectrum is also important. Actually if the duration of the shots is shorter than the period of the modulation the broadening effect is, of course, negligible (the shots live too short to "feel" the modulation), otherwise if the decay time of the shots is longer than the pulsar spin period the effect could become detectable. In the PSD's realm this statement implies that if the inflexion point of the shot noise spectra (that roughly gives the inverse of the duration of the shots, see fig.2) lies rightmost than the harmonic lines the effect is undetectable, in the opposite case the effect could become evident. In any case if the pulsed signal is due only to the uniform component no broadening of the lines can occur at all.
These behaviours are shown in fig.3 where we used the same modulation function, different amounts of uniform and shot components, different degrees of coupling with the modulation and different sizes and lengths of the shots.

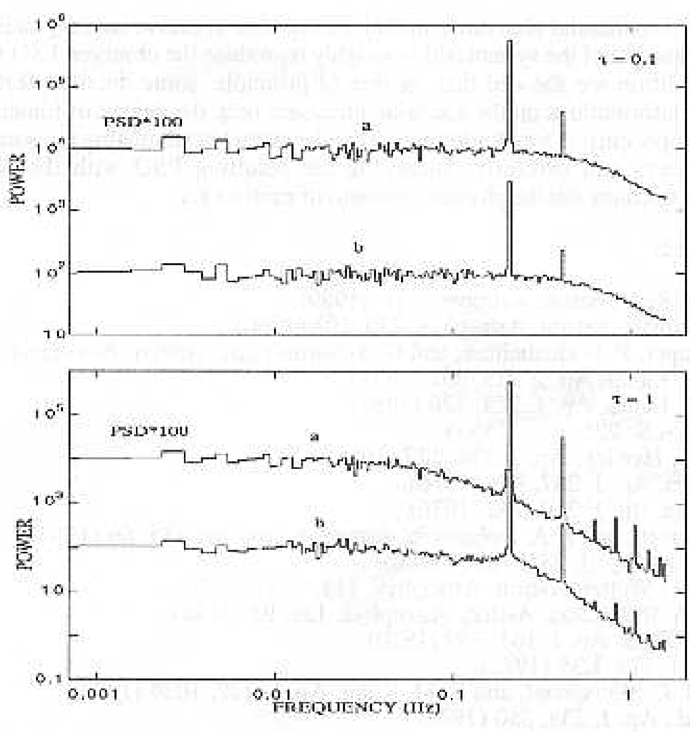

Fig. 3. PSDs of an exponential shot component and an uniform component coupled with a periodic modulation function (curves a); PSDs of an exponential shot component coupled with a periodic modulation function and an uniform component (curves b). Note the broadening effect of the harmonic lines in the case of shot coupling with τ » pulse period (curve b bottom panel).

SIMULATION OF A REAL SOURCE

We have tried to reproduce the PSD of the high mass X-ray binary CEN X-3 obtained using a set of data from EXOSAT archive. This spectrum is shown in fig. 4. Performing an analysis of the light curve and of the PSD of this source we have been able to obtain some characteristics of the intensity time series: I_{co}=202 ph/s, I_{pl}=89 ph/s, $P_{sh}(\nu_{min})$=100, rms=0.22. In the hypothesis of an exponential shot noise model and an uniform component each coupled with a periodic modulation , we have obtained, using the relations listed above, one set of possible values for some characteristics of this X-ray signal: β_{sh}=0.0, β_{un}=1, I_{sh}=202 ph/s, I_{un}=89 ph/s, λ=2.82, τ=1.814 s, A=72 ph. The PSD obtained using these values as input parameters is shown in fig. 4.

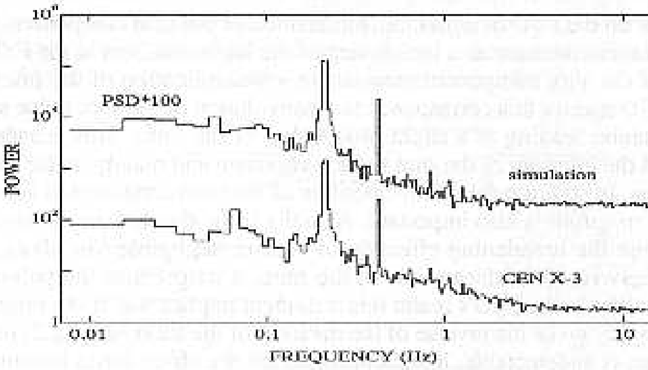

Fig. 4. Observed and simulated PSD of X-ray binary Cen X-3

CONCLUSIONS

Adopting this simplified exponential shot noise model we are able to derive some quantitative relations about some physical parameters of the system and to roughly reproduce the observed PSD spectra of an X-ray binary pulsar. In addition we showed that, in line of principle, some detailed features of a PSD spectrum can give some informations on the accretion processes (e.g. the degree of funnelling onto polar caps of the shot noise component). A lot of information can be extracted simulating the source for different sets of possible parameters and carefully comparing the resulting PSD with the real one. These informations can be used to constraint the physical scenario of each source.

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