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The irregular ρ -mode of GRS 1915+105 observed with *BeppoSAX*

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We report the results of the temporal and spectral analysis of the longest *BeppoSAX* pointing (about 770 ks) of the microquasar GRS 1915+105, performed in October 2000. For the largest fraction of the observation GRS 1915+105 was in the so called ρ -mode, characterized by series of sharp pulses with a typical recurrence time of about 50 s, well detectable in the energy range 2–10 keV. This quasi-periodic behaviour was generally quite stable but, occasionally, it changed to a more irregular state in which the pulses are broader and their recurrence time is highly fluctuating. We found that this irregular ρ -mode is associated with an enhanced emission at energies greater than 15 keV. Wavelet analysis of the (2–10 keV) light curves is used to study the time evolution of the ρ -mode.

1. INTRODUCTION

GRS 1915+105, the prototype of galactic microquasars, is since its discovery in 1992 [1] one of the most observed sources, particularly in the X-ray range. The one-day averaged radio and X-ray (RXTE-ASM) light curve shows a high variable behaviour, characterized by strong and structured outbursts interrupted by quiescent phases. The X-ray spectrum is generally fitted by two components at least: a multi-temperature disk blackbody and a power law (eventually with a variable exponential cut-off) extending up to several hundreds keV. It is general opinion, by the analogy with similar sources, that X-ray emission originates in an accretion disk rotating around a few stellar mass black hole. During the flares the main spectral parameters of the thermal component show significant variations, which have been interpreted by the emptying and refilling of the inner portion of the accretion disk (Belloni et al. [2]). In the radio band superluminal motion has been observed by Mirabel & Rodriguez [3] and the measurements of their kinematic properties allowed to evaluate a distance of 12 kpc and an

inclination of the disk axis to the line of sight of about 70°.

Belloni et al. [4], on the basis of a large collection of RXTE observations, defined 12 different variability modes of the X-ray emission, each of them characterized by a time profile and spectral variability as apparent from the dynamical hardness ratio plots. This classification is potentially useful for the understanding of the physical processes occurring in this exceptional source and will be used in presenting our results.

In this contribution we present the preliminary results of a long wide-band X-ray observation of GRS 1915+105 performed with the *BeppoSAX* satellite in October 2000. We present the time analysis of two 2000 second long segments of the MECS (2–10 keV) light curve, together with their Wavelet Power Spectra (WPS) showing the existence of two types of the ρ -mode.

2. THE ρ -MODE

According to the classification of the X-ray variability modes of GRS 1915+105 developed by Belloni et al. [4] the ρ -mode consists of quasi-

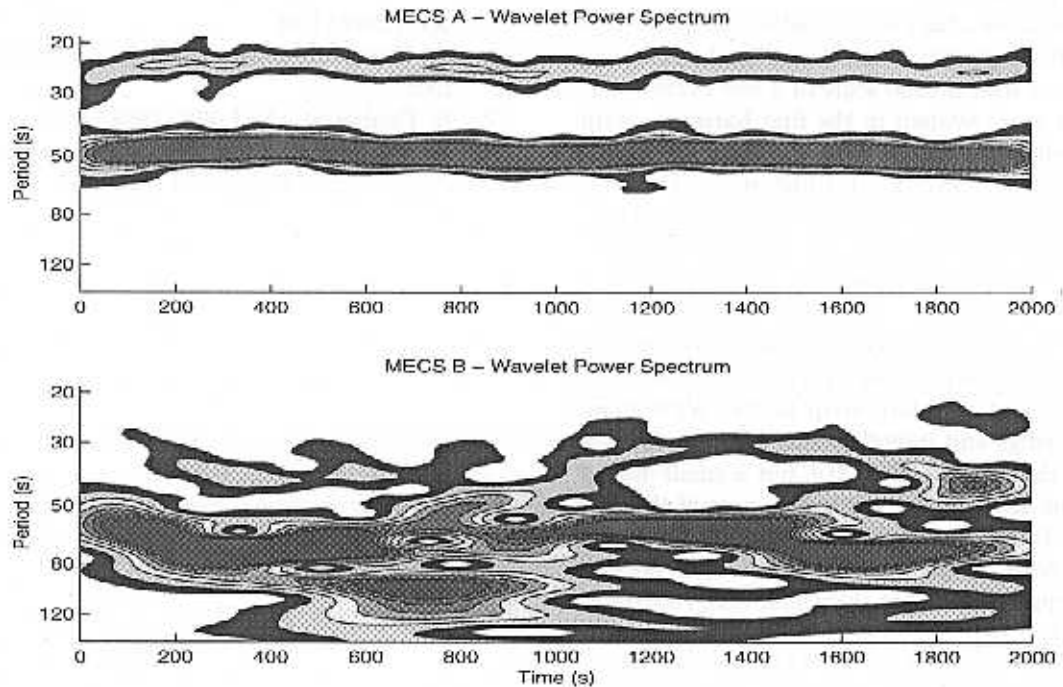


Figure 2. The wavelet power spectra of the A (upper panel) and B (lower panel) segments of the MECS (1.6–10 keV) light curve. Note the different power distributions.

regular phase about 25,000 s long. Another and longer not stable phase was in the interval from about 275,000 s to 375,000 s and after the source showed again for a long time a stable ρ -mode interrupted by a quiescent state at 615,000 s. Finally, in the final part, a transition to the μ -mode [4] occurred.

To study in detail the most relevant characteristics of the ρ -mode we focused our attention over two short segments of the light curve, indicated by the letters A and B, having each the same duration of 2000 seconds. Segment A was selected from the initial phase when the light curve was in that we called the *regular* ρ -mode, while segment B was selected from the following *irregular* ρ -mode. The MECS light curves of the counts, integrated in a time bin of 0.5 s, of these two segments are plotted in the Fig. 1 (upper and lower panel, respectively). It is clear from these figures why segment A describes the regular mode and segment B the irregular one: the pulses of segment A repeat regularly with a stable pattern,

whereas those of segment B have a quite variable recurrence time and show also different widths. The power spectra of the two time series show a very prominent feature at the frequency of 20.28 mHz (period equal to 49.30 s) for segment A, while in that of segment B there are two peaks at 14.11 mHz (70.87 s) and 16.56 mHz (60.37 s).

4. WAVELET POWER SPECTRA

The time behaviour of these time series can also be investigated using the Wavelet Power Spectra. We computed them by means of the Morlet wavelet transform of order 12. The results for the MECS time series A and B are shown in the Fig. 2 (upper and lower panel, respectively). The WPS is represented by a two dimensional map with the level coded in a gray scale.

The WPS of segment A is characterised by an uninterrupted brown horizontal strip, centred at the period value of about 49 s. Another strip at a lower mean level and centred around the value of about 25 s is also present: it corresponds to the

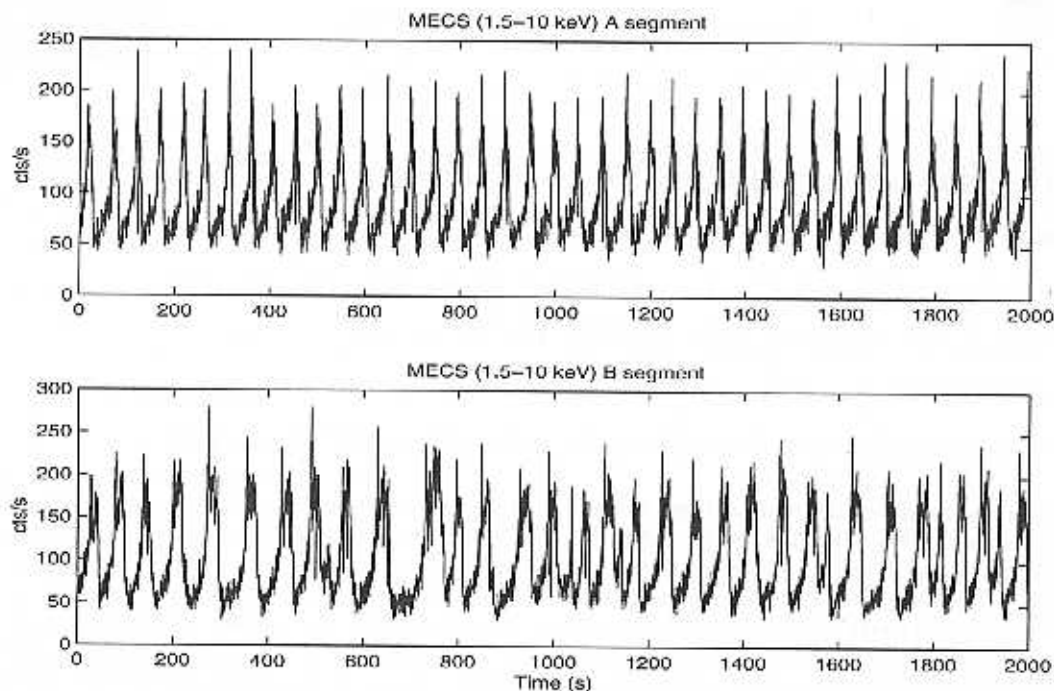


Figure 1. The MECS (1.6–10 keV) light curves of the two segments A (upper panel) and B (lower panel) from the long *BeppoSAX* observations of October 2000, considered in the present analysis.

periodic flares recurring on a time scale of 1 to 2 minutes. This mode was described also by Tamm, Chen & Swank [5] and Vilhu & Nevalainen [6]; other observations were reported by Paul et al. [7]. The shape of the flares is rather stable when described with a moderate time resolution, of the order of 1 second. In the (2–10 keV) band the light curve consists of a rising branch, approximately an exponential curve for about 70% of the entire duration, followed by a short maximum and a quite fast decay (Feroci et al. [8]). Using a finer time resolution, of the order of 0.1 seconds, the peaks can be resolved in a series of narrower pulses with a typical duration of 2–3 seconds [4], and likely in even narrower structures. A characteristic of this mode is the relative stability: the source can remain in this mode for several days. Time resolved spectral analysis [8] of the ρ -mode has shown significant changes of the spectral parameters during the flare.

3. THE LONG OBSERVATION OF OCTOBER 2000

The last *BeppoSAX* pointing of GRS 1915+105 was in October 2000. The observation started on October 20 at 21:27 UT and was concluded on October 29 at 19:00. All the instruments worked well and their parameters were nominal; however because all the NFI were on and the source count rate was quite high, the telemetry was occasionally overloaded and some data packets went lost. This produced a reduction of the observation efficiency of about 3–4%. During the observation of October 2000 the source behaviour was for a large fraction of the time in the ρ -mode. The complete light curve in the MECS band would necessarily be plotted with a scale not good to show the variations on time scales of minutes and therefore we summarize in the following its main characteristics. Starting from the initial epoch (TJD 11837, 21:27 UT) GRS 1915+105 was observed in a *regular* (see next section) ρ -mode which lasted about the first 160,000 s. It was then followed by an *ir-*

first harmonic. Notice that, although quite regular, both strips have a small amplitude oscillating behaviour over a time scale of a few cycles. This effect is more evident in the first harmonic strip. This behaviour means that the pulse recurrence is not exactly periodic: for instance, around the time 1200 the pulses are more closely spaced than around the time 900 (Fig. 1). The fractional amplitude of this recurrence time is of the order of $\Delta T/T \simeq 0.10\text{--}0.15$. The other segment B corresponds to the beginning of a much more irregular phase: the recurrence of the peaks becomes quite irregular and the dark strip in the WPS shows meanderings and interruptions. It is mainly limited in the interval 50–120 s, but a small 'island' at about 40 s appears in the last part of the time series. In the time interval 600–900 the power is high over several ranges of time scales because of the superposition of short and long recurrence time intervals.

We also computed the WPSs of the corresponding PDS (13–200 keV) time series which show interesting differences with those of MECS. The ρ -mode of segment A, for instance, is detectable only in the first section and in a rather short interval around time 1700. The 1st harmonic is only barely detectable, while a small island at time 750 appears like a possible subharmonic. In segment B the power is mainly concentrated in the time interval 300–800 with a large time scale range 55–100 s. A more complex structure appears in the last section of this time series and recalls the similar feature in the MECS data: two main time scales (35 and 70 s, likely in a harmonic ratio) are present at the same time. This feature is produced by a few narrow peaks appearing in the middle of broader peaks with a recurrence time of about 70 s.

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