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A BeppoSAX observation of the massive X-ray pulsar Cen X-3

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The X-ray binary pulsar Cen X-3 was observed with the BeppoSAX satellite on 14/08/96 for about 20 Ks during the Science Verification Phase (SVP). This source is a typical massive X-ray binary with a pulse period of 4.8 s and an orbital period of 2.1 days. In this observation the source was found in a low state with a luminosity, assuming a distance of 8 Kpc, of about $4.6*10^{36}$ ergs/s in the 2-10 keV energy band. In this paper we present the first simultaneus broad band (1.5 - 50 keV) pulse averaged spectrum and discuss two spectral fitting models. The pulsed light curve in the 1.5 - 10 keV energy band is also shown.

1. INTRODUCTION

The discovery of Cen X-3 was made with a rocket-borne detector [1] and was followed, 4 years later, by the discovery of its binary and pulsar nature with Uhuru [2,3]. This system contains a neutron star which emits pulsed X-ray every 4.8 s while orbiting its companion every 2.1 days. The companion star is the O-type supergiant V778.

The luminosity of Cen X-3 has been reported to alternate between extended high states and low states on a timescale of months but no evidence of periodicity was found [4,5].

The high-low state transitions are probabily due to the progressive immersion of the X-ray source in a strong stellar wind that absorbs the X-ray emission. Although a strong stellar wind emanates from the massive early-type companion [6] intense enough, perhaps, to supply the neutron star with accretion fuel the presence, also, of an accretion disk fed by Roche-lobe overflow is inferred from the optical light curve [7].

The pulse profile usually shows a single peak with a sharp rise and a more gradual decline ending in a shoulder that is more prominent at low energies [8,9]. On several occasion, a double-peaked pulse profile has been detected at low energies [4,10].

The single-peaked pulse profile is strongly asymmetric, the double-peaked one moderately so.

The pulse phase averaged X-ray spectrum of Cen X-3 is represented well by a power law continuum with a photon index of about 1, modified by interstellar absorption and high energy turnover, typical of X-ray pulsars [11,12]. In common with other X-ray pulsars Cen X-3 exhibits iron line features which are useful tools for probing the circumstellar matter.

2. OBSERVATION

The BeppoSAX satellite is a program of the Italian Space Agency (ASI), with the partecipation of the Netherlands Agency for Aerospace Programs (NIVR), devoted to X-ray astronomical observations in the broad 0.1 - 200 keV energy band [13].

The payload includes four Narrow Field Instruments (NFIs) and two Wide Field Cameras. The NFIs consist of Concentrators Spectrometers (C/S) with 3 units (MECS) operating in the 1-10 keV energy band [14] and 1 unit (LECS) operating in the 0.1-10 keV energy band [15], a High Pressure Gas Scintillation Proportional Counter (HPGSPC) operating in the 3-120 keV energy band [16] and a Phoswich Detector System (PDS) with four solid state scintillation detection units operating in the 15-200 keV energy band [17].

Perpendicular to the NFIs are two orthogonal Wide Field Cameras (WFC), coded mask tele-

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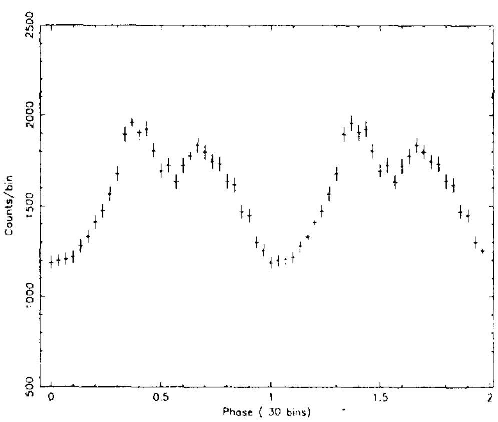

Figure 1. Cen X-3 pulse profile in the 1.5 - 10 keV energy band (SVP observation)

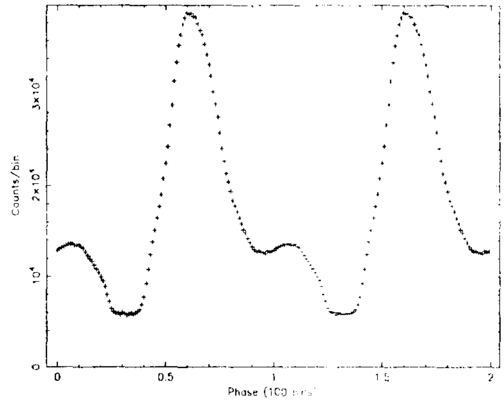

Figure 2. Cen X-3 pulse profile in the 1.5 - 10 keV energy band (GOP observation)

scopes operating in the 2-30 keV energy band, with a field of view of 30 degrees times 30 degrees and angular resolution of 5 arcminute.

BeppoSAX satellite observed Cen X-3 between 1996 August 14 12:38 and August 15 00:36 (UT). The total source exposure times are 4.5 ks for the LECS 24 ks for the MECS 10 ks for the HPGSPC and 6.3 ks for the PDS. The non-imaging HPGSPC and PDS instruments have rocking collimators (96 sec and 50 sec stay time respectively) which alternatively observed source and background regions of sky, resulting in reduced exposure times compared to the MECS. For the LECS the lower exposure time arises because this instrument was operated only during satellite night time.
Moreover different exposure times are due to different filtering criteria during passages in the South Atlantic Geomagnetic Anomaly (SAGA) and before and after Earth occultations.

3. TIMING ANALYSIS

In Fig. 1 is shown the pulse profile in the 1.5 - 10 keV energy band. The double-peaked structure, already observed at low energies and at low luminosity, is clearly visible.

In Fig. 2 is shown the pulse profile, in the same energy band, of another BeppoSAX observation (Guest Observer Program) of this source performed in a state of much higher luminosity ($L \simeq 4.3*10^{37}$ ergs/s) i.e. an order of magnitude higher respect to the present observation. In this case a single peak with an evident shoulder is visible. Similar pulse profile structure has been reported by BBXRT [18] in an alike luminosity state.
The difference in the pulse profile structure may be due to luminosity-induced changes in the structure of the accretion column, or in the configuration of the X-ray emitting region, as observed in the transient pulsar EXO2030+375 where, the correlation between luminosity and pulse profile, can be modeled using both fan and pencil beams of emission from two magnetic poles and assuming that the pulse profile evolution is caused by the dominant beam changing from a fan beam to a pencil beam configuration as the luminosity decreased [19].

4. SPECTRAL ANALYSIS

The broad band pulse averaged spectrum of Cen X-3 is quite complex. We performed fits of the spectrum with two different models :

Table 1
Spectral fitting parameters of Cen X-3

Parameters	Model 1	Model 2
N_H	$(0.7 \pm 0.2) \cdot 10^{22}$ cm^{-2}	$(0.7 \pm 0.2) \cdot 10^{22}$ cm^{-2}
α_1	(0.38 ± 0.09)	(0.3 ± 0.2)
α_2	(4.4 ± 0.1)	
E_{Break}	(16.6 ± 0.2)keV	
E_{Cut}		(16.0 ± 0.3) keV
E_{Fold}		(5.9 ± 0.3) keV
KT_{BB}	(2.8 ± 0.1)keV	(2.8 ± 0.2) keV
E_{Iron}	(6.61 ± 0.03)keV	(6.61 ± 0.03) keV
σ_{BB}	(0.28 ± 0.04)keV	(0.28 ± 0.04) keV
$EQWI_{Iron}$	(650 ± 70)eV	(665 ± 70) eV
$\chi^2_{d.o.f.}$	$(1.14/301)$	$(1.16/301)$

NOTE - All quoted errors represent 90% confidence level for a single parameter

Model 1

$$exp[-N_H\,\sigma(E)]\,(BB + BKN) + Iron\,line \qquad (1)$$

Model 2

$$exp[-N_H\,\sigma(E)]\,(BB + AE^{-\alpha}\,e^{-H(E)}) + Iron\,line \qquad (2)$$

Model 1 includes a low energy exponential absorption, a blackbody (BB), a broken power law (BKN) and an iron line. Model 2 is composed by a low energy exponential absorption, a blackbody, a power law, an exponential cutoff (H(E)) and an iron line. The high energy cutoff is modeled by the function :

$$H(E) = \begin{cases} 0 & E < E_c \\ \frac{E-E_C}{Ef} & E > E_c \end{cases} \qquad (3)$$

where E_c and E_f are the cutoff and folding energies respectively.

In Fig. 3 is shown the broad-band spectrum fitted with model 1. The residuals in the lower panel are given in units of σ.
Both models give a set of physically acceptable parameters and an acceptable fit (see Table 1). No evidence of a cyclotron absorption feature has been found in this observation. The positive detection of a feature at about 28 keV found in another BeppoSAX observation of this source,

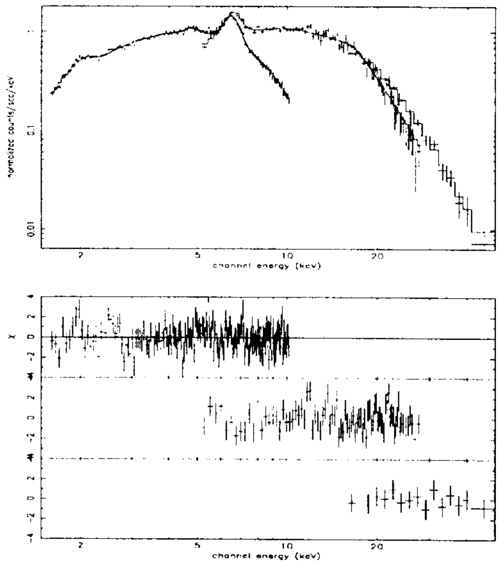

Figure 3. Cen X-3 broad-band spectrum fitted with model 1. The residuals in the lower panel are given in units of σ

[20] in a much higher luminosity state, seems to indicate that in the present case the flux at high energy is too low to allows a clear detection.

An intense iron line has been detected at an energy of 6.61 keV with an equivalent width (EW) of about 650 eV. The energy centroid at 6.61 keV is consistent with a blend of neutral iron 6.4 keV line, probably due to reprocessing by cold cir-

cumstellar matter, plus a 6.7 keV component due to highly ionized Helium-like iron.
It is interesting to note that outside of the eclipse and during the high state the iron line of this source is predominantely composed by the 6.4 keV component. Also, the EW of this observation is between the 1.5 keV observed in the eclipse state [12] and the 150-200 eV observed during the high state. Both the large EW and the value of the energy centroid are consistent with the presence of a spectral component arising from scattering in a highly ionized stellar wind.
Moreover, the large EW may suggest that, in this observation, the central X-ray source is partially hidden from view probabily by a thick accretion disk.

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