XMM-Newton Observation of the Black Hole Microquasar GRS 1758-258

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Abstract. The XMM-Newton X-ray observatory pointed the galactic black hole candidate and microquasar GRS 1758-258 in September 2000 for about 10 ks during a program devoted to the scan of the Galactic Center regions. Preliminary results from EPIC MOS camera data are presented here. The data indicate that the source underwent a state transition from its standard low-hard state to an intermediate state. For the first time in this source the ultra-soft component of the accretion disk, which black hole binaries display in intermediate or high-soft states, was clearly detected and measured thanks to the high spectral capabilities of XMM-Newton.

INTRODUCTION

The source GRS 1758-258 was discovered in 1990 with the SIGMA soft γ-ray telescope at about 5° from the Galactic Center [1]. The hard spectrum extending up to 200-300 keV [2,3], very similar to the Cyg X-1 spectrum, strongly suggests that this source is an accreting black hole in a galactic binary system with a low mass companion star. The source was then observed in radio and two symmetrical radio lobes were detected at 6 cm with the VLA [4] on either sides of a point-like radio source close to the X-ray source. The radio point source position was compatible with both the SIGMA error circle and the much smaller Rosat error circle (10″ radius) of GRS 1758-258. In spite of a large drop in hard X-ray flux detected with SIGMA in 1991-1992 and some claims of sporadic appearence of a soft component [5], no spectral transitions have ever been clearly observed from this source. We present here the first convincing detection of an ultra-soft disk emission and of a spectral transition in GRS 1758-258 during a XMM-Newton observation.

XMM-NEWTON OBSERVATIONS AND RESULTS

The source was observed on 19th September 2000 with XMM-Newton for about 10 ks, with EPIC cameras EMOS 1 in timing mode, EMOS 2 in imaging refresh frame

store (RFS) mode and PN in small window mode [6]. These modes were selected to avoid as much as possible pile-up effect, expected for such bright source. The medium filter was selected to reduce potential optical loading on the CCDs. We report here preliminary results from the MOS camera data. Data reduction was performed using the XMM SAS (Science Analysis Software), the standard XSPEC, and the XRONOS packages. The observation was contaminated by a large flux of "soft protons" background events; however, thanks to the strength of the source, the signal to noise ratio remained very high.

We have used the MOS 2 data to build an image and a spectrum of the source. Fig. 1 (left) shows the 0.2-10 keV image of the source obtained using the central MOS 2 CCD, which was employed in RFS mode for a effective integration time of 1325 s. The count distribution is compatible with a point-like source positioned at (2000 equinox) $R.A. = 18^h 01^m 12.5^s$ $Dec. = -25° 44' 40''$ with an error radius of $5''$.

To source spectrum was derived by applying standard cuts to events collected within $30''$ from the source center. Background was estimated using offset regions in the same central CCD. The source rate of 11.9 events/frame induced a non negligible pile up [7]. While no attempt has been made at this stage for correcting for it, its effect on the determination of the spectral shape was found to be within the statistical error bars of the derived model parameters. Its influence on the absolute flux is however much more important, and we roughly estimate that it induces a flux loss by a factor of ~ 1.5.

Data were rebinned to reach 20 counts per bin and the derived source count spectrum in the range 0.2-10 keV was compared to several models. As demonstrated in Fig. 2 (left), a simple power law, with a reduced chi-square > 3, does not fit the data, and the residuals indicate the need to include a soft component. The chi-square reaches acceptable values when a soft black body component is included. In Table 1 we report the best fit parameters ($\chi_\nu^2 = 1.026$) for a model of a power-law plus a black body and the unfolded data are compared to the model in Fig. 2 (right). The soft component with a temperature of ≈ 0.3 keV is clearly detected, in addition to a power-law with photon index of ≈ 2.0, and reaches a fraction of 15 % of the total absorbed 0.2-10 keV flux, flux which amounts to $3.7 \ 10^{-10}$ ph cm^{-2} s^{-1}. The column density is $1.7 \ 10^{22}$ cm^{-2} and the derived source luminosity in the 0.2-10 keV band at 8 kpc is $8.7 \ 10^{36}$ erg s^{-1}, out of which ≈ 30 % is due to the black-body component. No iron lines or other relevant features were detected.

Fig. 3 (left) reports the source light curve with time bins of 1.75 s obtained using the EMOS 1 data, collected in timing mode for a total exposure of 9865 s. In timing mode the EPIC instruments record the position on one axis only and the arrival time with a 1.75 ms resolution. The power density spectrum (PDS) was built using events in the central part of the CCD, and grouping the light curve in 21 ms bins. The spectrum regrouped in 14 channels after subtraction of the statistical noise is displayed in units of rms^2 Hz^{-1} in Fig. 3 (right). It can be modeled by a broken power-law with flat slope below a break frequency ν_B of 1.48 Hz, and with slope -1.32 above ν_B and normalization of $7.53 \ 10^{-3}$ rms^2 Hz^{-1} at ν_B.

TABLE 1. Best-Fit Parameters for a Power Law plus Black Body Model

Parameter	Value (errors at 90% c.l.)
N_H ($10^{22}\ cm^{-2}$)	1.74 ± 0.07
α_{pl}	1.99 ± 0.09
N_{pl} ($ph\ keV^{-1}cm^{-2}s^{-1}$)	0.13 ± 0.02
kT_{bb} (keV)	0.32 ± 0.02
N_{bb} (L_{36}/D_{10}^2)	3.95 ± 0.55

COMPARISON WITH PREVIOUS RESULTS

In Fig. 1 (right) the XMM-Newton error circle of GRS 1758-258 is reported on the optical image obtained by Marti et al. [8] and compared to the Rosat error circle of 10″ radius and to the VLA position of the point radio source (named VLA C) found at the origin of the extended radio lobes. The XMM error circle intersects the Rosat circle and includes the VLA C position confirming the identification of GRS 1758-258 with the radio source at the origin of the relativistic jets.

The spectrum obtained with XMM-Newton can be compared to previous X-ray spectra obtained with ASCA [9] or RXTE [10]. In all cases it is clear that a spectral evolution took place, since during the XMM observation the source clearly displayed a significant soft component accounting for more than 15 % of the measured X-ray flux, component which was never clearly detected before. Compared to the ASCA measurement the 1-10 keV flux also increased by a factor > 1.5, and the power-law steepened from 1.7 to 2.0. Variability characteristics of the source also changed. In Fig. 3 (right) we report, on the XMM measured PDS, the model of PDS derived with RXTE data [11]. This plot shows the Belloni-Hasinger effect typical of black hole systems in low-hard state [12]. However the low level of the flat slope and the fact that ν_B reaches values > 1 Hz show that the source state during this observation was strikingly close to the intermediate states of Cyg X-1 [12].

We conclude that the source was probably in an intermediate state considerably different from the standard low-hard state which the source displayed since its discovery. The presence of a soft excess was claimed in the past but not fully demonstrated and the disk parameters could not be derived. A more dramatic state transition was very recently observed with RXTE [13,14] when the source entered a very soft state in March 2001 and in that occasion the black body component was detected with a temperature compatible with the values reported here.

CONCLUSIONS

We have presented preliminary results from a XMM-Newton observation of the microquasar GRS 1758-258 in September 2000. The main findings are the following. 1) The source position is determined with 5″ error radius and is compatible with the position of the radio point source at the center of the 2 radio jets.
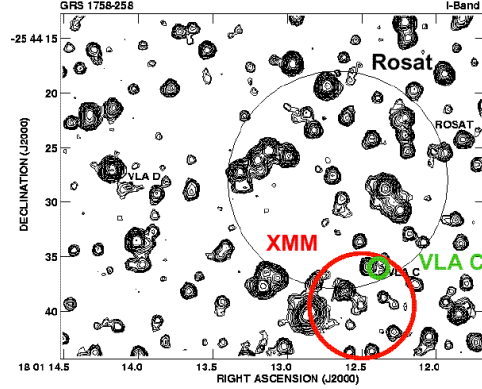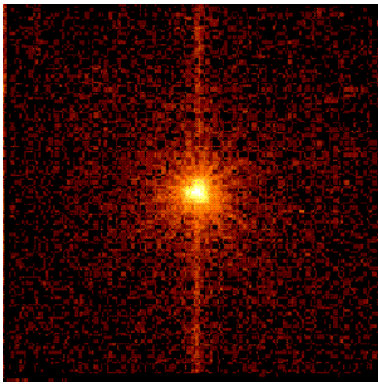
FIGURE 1. XMM Newton 0.2-10 keV image of GRS 1758-258 from the central CCD (11 arcmin size) of EMOS 2 (left). XMM-Newton error circle of GRS 1758-258 (5 ″ radius) reported on the optical image of the field [8] and compared to the Rosat error circle of the X-ray source and to the VLA error circle of the radio point source (named VLA C) at the origin of the jets (right).

2) The spectrum of GRS 1758-258 cannot be fit by a simple power-law and a soft component (accounting for 15 % of the measured flux) must be included.

3) The soft component can be described by a black body of kT = 0.3 keV while the power-law requires a photon spectral index of 2.0. The total luminosity in 0.2-10 keV band increased by factor > 1.5 with respect to the 1995 ASCA observation.

4) The power density spectrum can be described with the standard flat plus power-law function seen in black hole binaries in low-hard state, but the rms has decreased and break frequency has increased significantly with respect to the values found previously for this source with RXTE.

This observation clearly reveals for the first time in this source the ultra-soft spectral signature of an accretion disk, as seen in many confirmed black hole binary systems. Moreover the strength of the disk emission, the steeper power-law and the different variability characteristics indicate that the source underwent a state transition leaving its standard low-hard state to enter a typical intermediate state, as observed in other black hole binaries like Cyg X-1.

These preliminary results, though need to be confirmed by deeper and more complete analysis, further support the black hole nature of this source and strengthen the link between relativistic jets and black holes.

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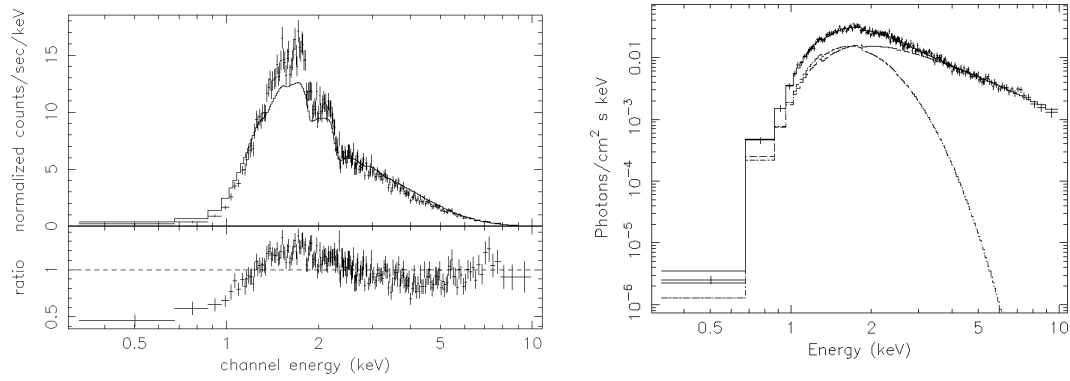6. Turner M.J.L., et al., *A&A* **365**, L27 (2001).

FIGURE 2. GRS 1758-258 folded spectrum obtained from EMOS 2 data compared to the best fit power-law model. Residuals indicate the need to include a soft component (left). The unfolded spectrum compared to the best fit model of a power-law and a black body (right).
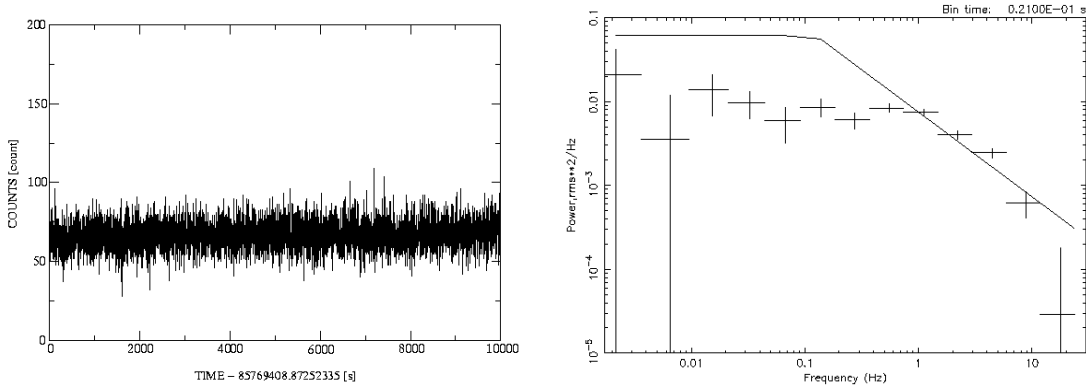

FIGURE 3. GRS 1758-258 light curve from the EMOS 1 data in timing mode with bins of 21 ms (left). Power Density Spectrum (PDS) in units of rms^2 Hz^{-1} derived from the same data and compared to the best fit model of a broken power law found in previous observations of the source (left).

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