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XMM-Newton observations of the BL Lac MS 0737+7441*

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Abstract. We report on the *XMM-Newton* observations of the BL Lac object MS 0737.9+7441 during the performance verification phase. A simple power–law fit provides an adequate description of the integrated spectrum in the 0.2–10 keV energy band. The photon index is slightly steeper in the EPIC pn data with $\Gamma = (2.38 \pm 0.01)$ compared to the EPIC MOS data ($\Gamma = (2.28 \pm 0.01)$). The difference is most probably due to the present uncertainties in the calibration of the EPIC MOS and EPIC pn data sets. We report evidence for intrinsic absorption in the distant BL Lac above the Galactic column ($N_{\rm H,Gal} = 3.2 \cdot 10^{20}{\rm cm}^{-2}$) which is $N_{\rm H,fit}^{\rm z=0.315} = (2.70 \pm 0.20) \times 10^{20}$ cm^{-2} in the EPIC pn data and $N_{\rm H,fit}^{\rm z=0.315} = (3.25 \pm 0.25) \times 10^{20}$ cm^{-2} in the EPIC MOS data assuming neutral gas and solar abundances. The flux variations are found to be of the order of 10 %. No significant spectral variability is detected.

Key words. galaxies: active – galaxies: individual: MS 0737.9+7441 – X-rays: galaxies

1. Introduction

The BL Lac object MS 0737.9+7441 was discovered in the *Einstein* Observatory Extended Medium-Sensitivity Survey (EMSS; Gioia et al. 1990, Stocke et al. 1991) with a flux of $f_X = (9.8 \pm 0.6) \cdot 10^{-12}$ erg cm^{-2} s^{-1} in the energy range between 0.3 and 3.5 keV. Its redshift is z = 0.315 (Morris et al. 1991). In the ROSAT All-Sky-Survey observations the source had a count rate of 0.49 counts s^{-1} during an exposure of 456 seconds. Perlman et al. (1996) obtained a best fit power–law photon index of $\Gamma = 1.91$ from the observed hardness ratios assuming Galactic absorption $N_{\rm H,Gal} = 3.2 \cdot 10^{20}{\rm cm}^{-2}$. Lamer et al. (1996) examined pointed ROSAT-PSPC data of MS 0737.9+7441 with a count rate of 0.51 ± 0.01 counts per second for an exposure of 8782 seconds. Using a power–law model the best fit parameters are $N_{\rm H,fit} = (4.16 \pm 0.48) \cdot 10^{20}{\rm cm}^{-2}$ and $\Gamma = 2.39 \pm 0.11$. In a *BeppoSAX* observation (Wolter et al. 1998) MS 0737.9+7441 was detected in the LECS instrument with 37.1 ± 7.8 net counts during an exposure of 3075 seconds, the MECS detector net counts were 735.9 ± 30.6 in 23279 seconds. By assuming a simple power law the best fit parameters are $\Gamma = 2.53^{+0.28}_{-0.23}$ and $N_{\rm H,fit} = (25.8^{+49.3}_{-21.6}) \cdot 10^{20}{\rm cm}^{-2}$. A broken power law resulted in photon indices of $\Gamma_1 = 1.17$ (which they classify as uncertain) and $\Gamma_2 = 2.43^{+0.18}_{-0.16}$. The break energy is 1.05 (1.27–1.61) keV.

In the following we report on the *XMM-Newton* observation of MS 0737.9+7441 obtained during the performance verification program. Two exposures of approximately 20 ksec and 60 ksec were performed on the source between April 12, 2000 and April 13, 2000, either side of the orbital apogee gap. Around the middle of the second PN exposure the camera suffered a short telemetry break. The PN camera was in full frame mode throughout the observation. Both MOS cameras were in large window (300 × 300 pixels) mode. All cameras employed their respective thin–1 filters.

The Hubble parameter was chosen to be H_0 = 70 km s^{-1} Mpc^{-1} and a cosmological deceleration parameter of $q_0 = \frac{1}{2}$ have been adopted throughout the paper.

2. Spectral fitting results

2.1. EPIC pn results

The spectral fitting results described below were obtained from the merged data set. Only single events were used from an extraction radius of 75 arcsec around the source position, the background was taken from the same chip

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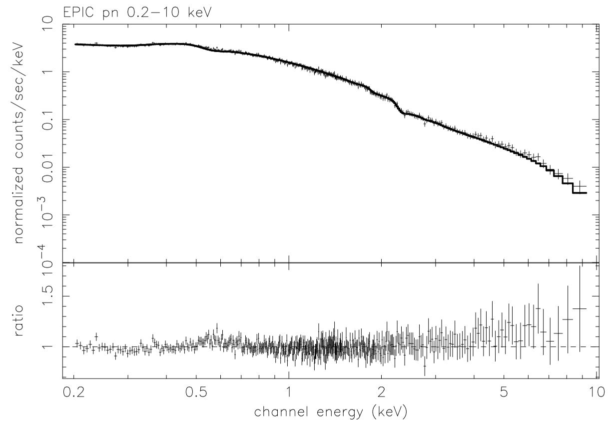

Fig. 1. Power-law fit to the EPIC-pn data. The upper panel shows the count rate distribution of MS 0737.9+7441 (marked by the crosses) in the EPIC pn detector versus energy. The solid line gives the model spectrum. The lower panel gives the ratio between the data and the model.

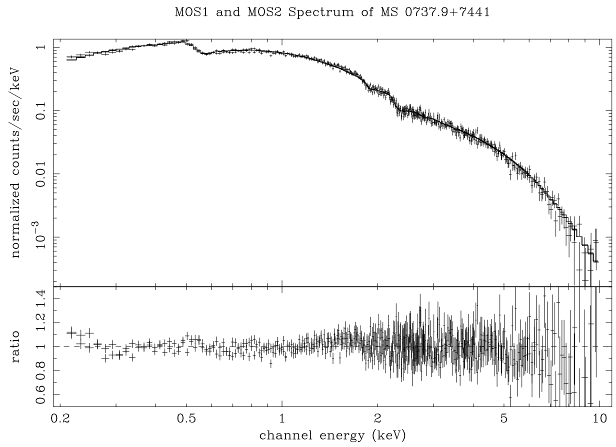

Fig. 2. Power-law fit to the EPIC MOS 1 and MOS 2 data. The upper panel shows the count rate distribution of MS 0737.9+7441 (marked by the crosses) in the EPIC MOS 1 and MOS 2 detectors versus energy. The solid line gives the model spectrum. The lower panel gives the ratio between the data and the model.

with an extraction radius of 110 arcsec. A simple power law fit with the Galactic column fixed to $N_{\rm H,Gal} = 3.2 \cdot 10^{20}{\rm cm}^{-2}$ and allowing the intrinsic absorption and the photon index to be free parameters provides an adequate fit to the *XMM-Newton* data ($\chi^2 = 375$ for 380 d.o.f.; cf. Figure 1). We have used the `XSPEC` models `zphabs` to access the intrinsic absorption in the source and `phabs` for the Galactic absorbing column density. The intrinsic absorbing column density measured with the EPIC pn is $N_{\rm H,fit}^{\rm z=0.315} = (2.70 \pm 0.2) \times 10^{20}$ cm^{-2} assuming neutral gas and solar abundances, consistent with the excess absorption suggested by the ROSAT data. The photon index is Γ=2.38 $\pm$ 0.01. The errors correspond to 90% confidence levels for 1 interesting parameter. Using the F-test for the addition of one free parameter one gets $\Delta\chi^2/\chi^2_\nu = 146$ (cf. equ. 11.50 of Bevington & Robinson 1992). According to Table C.5 of Bevington & Robinson (1992) this corresponds to a highly significant improvement (>99.99 per cent) of the fit quality with intrinsic absorption compared to the fit with no intrinsic absorption. The mean 0.2–10 keV absorbed flux obtained from the *XMM-Newton* observations is $f = 8.6 \times 10^{-12}$ erg cm^{-2} s^{-1}. The unabsorbed flux is $f = 1.3 \times 10^{-11}$ erg cm^{-2} s^{-1}, corresponding to an isotropic luminosity of $L_X = 3.6 \times 10^{45}$ erg s^{-1}. Spectral residua appear between about 0.5 and 0.7 keV in the EPIC pn spectrum (cf. Figure 1). These wiggles might be attributed to uncertainties in the presently available EPIC pn response matrix not allowing us to make definitive statements on the possible presence of soft X-ray emission lines, e.g. emission due to O VIII (653 eV) and Fe XXVII (726 eV) would fall in the energy range of the spectral residua. Better calibration and/or deeper observations are needed to further settle this issue. We note that these features do not significantly influence the spectral continuum shape.

2.2. EPIC MOS results

In the following the spectral fitting results to the combined MOS 1 and MOS 2 observations are presented (cf. Figure 2). All events within the MOS X–ray pattern library were used (*i.e.* Patterns 0 to 12). As with the pn, the MOS data in the 0.2 to 10 keV band are well–fit by a single power law with neutral absorption somewhat higher than the nominal Galactic value. A power–law model with the Galactic absorbing column fixed and adding a redshift corrected neutral hydrogen absorbing column density component gives, $N_{\rm H,fit}^{\rm z=0.315} = (3.25 \pm 0.25) \times 10^{20}$ cm^{-2} and Γ = 2.28 $\pm$ 0.01. The errors are 90% confidence for 1 interesting parameter. The reduced χ^2 value is 1.27 for 531 d.o.f. No significant systematic difference was found fitting the data from the MOS cameras separately. The residuals to the MOS fit reveal correlated variations which are at most discrepant by 10% and in general near to the major instrumental absorption edges at Carbon, Oxygen and Silicon. The measured flux is consistent within 5 % of the pn value.

3. Timing properties

In Figure 3 we show the soft (0.1–1 keV) and hard (1–10 keV) light curves for the three continuous observation segments on MS 0737.9+7441. The amplitude variability does not exceed a factor of about 10 %, both in the soft and the hard band. None of the X-ray variability events shown in Figure 3 exceed the radiative efficiency limit (Fabian 1979; Brandt et al. 1999), sometimes observed in BL Lac objects.

4. Search for spectral variability

While X-ray amplitude variations of about 10 % are present in the EPIC light curves, these flux variations are

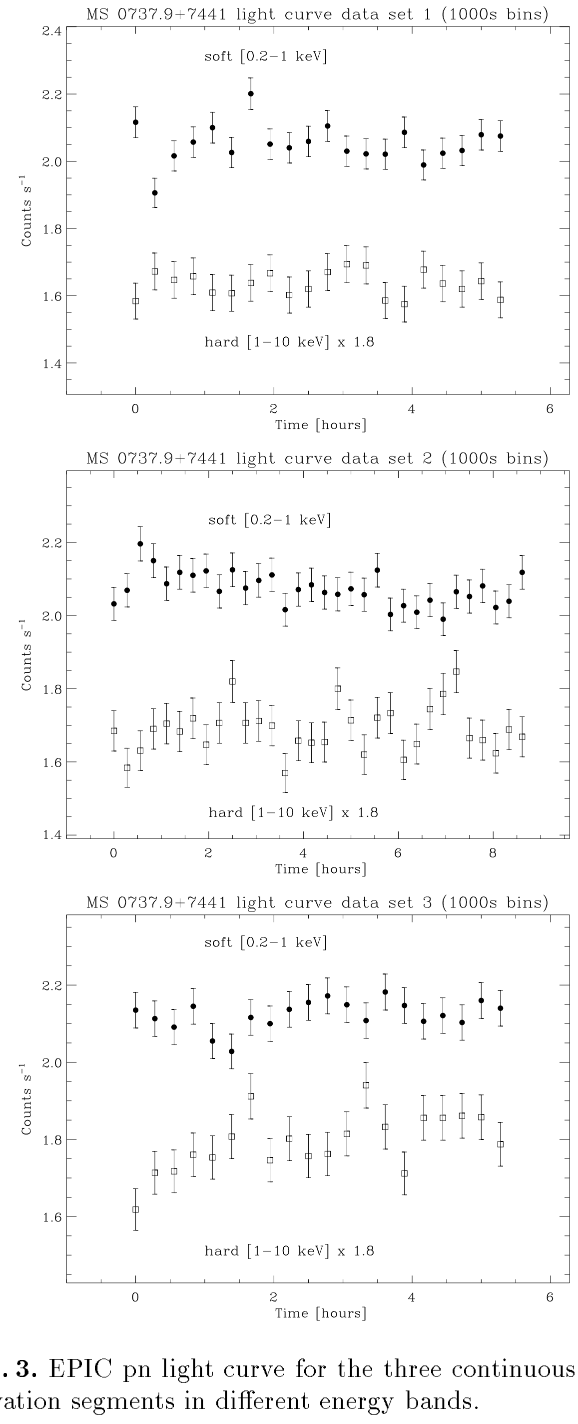

Fig. 3. EPIC pn light curve for the three continuous observation segments in different energy bands.

not correlated with significant spectral variability. No significant difference was found in the variability behavior as seen by the pn and MOS cameras, so for brevity we present the pn results only. In Figure 4 we plot the hardness ratio obtained from the soft (0.2–1 keV) and hard (1–10 keV) energy band in the pn camera versus the count rate. The hardness ratio remains constant within the errors.

5. Summary

XMM-Newton observations reveal that a featureless simple power law model with absorption by neutral hydrogen provides an adequate fit to the data. The photon indices as measured with the EPIC pn and EPIC MOS are slightly different with 2.38 ± 0.01 and 2.28 ± 0.01, respectively, most probably due to present calibration uncertainties for the EPIC detectors. The spectral residua between 0.5 and 0.7 keV might be attributed to uncertainties in the presently available EPIC pn response matrix not allowing us to make definitive statements on the possible presence of soft X-ray emission lines, e.g. emission due to O VIII (653 eV) and Fe XXVII (726 eV) would fall in this energy range. We confirm the presence of intrinsic absorption in the source, which is about $N_{\rm H,fit} = 3.0 \cdot 10^{20}$ cm^{-2} in the source frame ($(2.70 \pm 0.20) \cdot 10^{20}$ cm^{-2} for EPIC pn and $(3.25 \pm 0.25) \cdot 10^{20}$ cm^{-2} for EPIC MOS). The soft X-ray absorption detected in MS 0737.9+7441 appears to be fairly similar to other studies. Beckmann and Wolter (2000) found a mean value for the intrinsic absorption at soft X-ray energies of about $N_{\rm H,fit} = 1.0 \cdot 10^{20}$ cm^{2} with the largest value of $1.0 \cdot 10^{21}$ cm^{-2}. The intrinsic absorption found in the host galaxy of the BL Lac MS 0737.9+7441 is also similar to the soft X-ray absorption of radio-quiet active galaxies (cf. Table 1 of Boller, Brandt & Fink 1996 and Table 2 of Walter & Fink 1993). The flux variations of about 10 % are relatively small for a BL Lac object (compare Giommi et al. 1990). No significant spectral variations are detected during the observations.

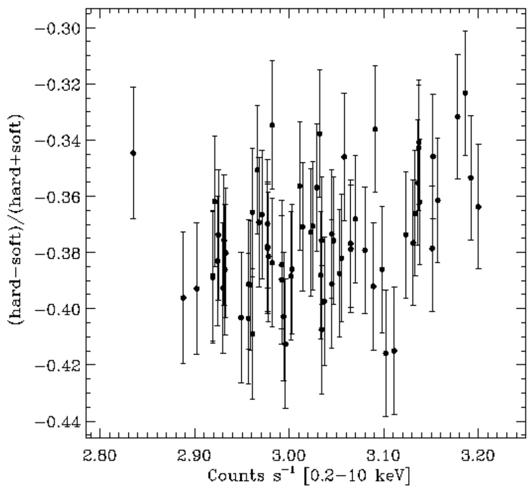

Fig. 4. Hardness ratio obtained from the soft (0.2–1.0 keV) and the hard (1.0–10 keV) energy band ratio versus count rate. No significant spectral variability is detected.

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References

Beckman,n V., Wolter, A., 2000, astro-ph/0007089
Bevington, P.R., Robinson, D.K., 1992, Data Reduction and Error Analysis for the Physical Sciences, Second Edition, McGraw-Hill, New York
Boller, Th., Brandt, W.N., Fink, H., 1996, A&A, 305, 53
Brandt, W.N., Boller, Th., Fabian, A.C., Ruszkowski, M., 1999, MNRAS, 303, L53
Fabian, A.C., 1979, Proc. Roy. Soc. London A, 366, 449
Gioia, I., Maccacaro, T., Schild, R. E., Wolter A., Stocke, J. T., Morris, S. L., Henry, J. P., 1990, ApJS 72, 567
Giommi, P., Barr, P., Garilli, B., Maccagni, D., Pollock, A.M.T., 1990, ApJ, 356, 432
Lamer, G., Brunner, H., Staubert, R., 1996, A&A, 311, 384
Morris, S.L., Stocke, J.T., Gioia, I.M., Schild, R.E., Wolter, A., Maccacaro, T., Della Ceca, R., 1991, ApJ, 380, 49
Perlman, E.S., Stocke, J.T., Wang, Q.D., 1996, ApJ, 456, 451
Stocke, J.T., Morris, S.L., Gioia, I.M., Maccacaro, T., Schild, R., Wolter, A., Fleming, T.A., Henry, J.P., 1991, ApJS, 76, 813
Walter, R., Fink H., 1993, A&A, 274, 105
Wolter, A., Comastri, A., Ghisellini, G., Giommi, P., Guainazzi, M., Maccacaro, T., Maraschi, L., Padovani, P., Raiteri, C.M., Tagliaferri, G., Urry C.M., Villata, M., 1998, A&A, 353, 899