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Research Note

EXOSAT measurement of the spectrum of Markarian 382

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Abstract. The 0.1–10 keV X-ray spectrum of a Seyfert galaxy known as Markarian 382 (Mkn 382) is presented based on observations with the EXOSAT. The energy index (α) for the power-law X-ray continuum of Mkn 382 is measured to be $1.2^{+0.16}_{-0.14}$ which is higher than the canonical value found for the Seyfert galaxies. There is no evidence for intrinsic absorption, soft excess or any line feature in the source. The X-ray emission was found to be steady during the observations. The 2–10 keV X-ray luminosity of Mkn 382 is $2.3\,10^{43}$ erg s^{-1}.

Key words: galaxies: individual – Mkn 382 – galaxies: nuclei of – X-rays: spectroscopy

1. Introduction

The galaxy, Markarian 382 (Mkn 382), is of Seyfert type I at a redshift of 0.034 and with a V magnitude of 15.5 (Markarian & Lipovetski 1971; Khachikian & Weedman 1974; Veron-Cetty & Veron 1989). A significant Fe II emission with equivalent width of 11 Å has been detected from this galaxy (Osterbrock 1977). Mkn 382 is a radio-quiet galaxy with measurements at 1.4 GHz giving an upper limit of 4 mJy for its flux density (Mazzarella & Balzano 1986). At 179 GHz (Ade et al. 1976) and 3.5 μm (Stein & Weedman 1976) upper limits of 56 Jy and 8.76 mJy have been obtained for the flux densities at the respective frequencies. The galaxy was observed with the Einstein Observatory and found to be an X-ray source (Kriss et al. 1980) with a power-law spectrum (Kruper et al. 1990).

As part of our programme for a detailed spectral study of the Seyferts galaxies observed with the EXOSAT, e.g. PG 2130+099 (Singh et al. 1991a), IC 4329A (Singh et al. 1991b), MCG 5-23-16 (Singh et al. 1992), and Mkn 618 (Rao et al. 1992), we have analyzed the EXOSAT archival data for Mkn 382 and report this measurement here for the first time. The result is a useful addition to the sample of Seyferts observed with EXOSAT and analyzed by Turner & Pounds (1989) and us. The importance of the study also stems from the fact that the X-ray emission from such objects is inherently variable and there is need to extend the energy range of the measurements over the previous measurements with the Einstein Observatory. The present observations provide an accurate measurement of the spectral index of Mkn 382 over a broad-energy range of 0.1–10 keV for the first time.

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2. Observations

EXOSAT observations of Mkn 382 were carried out on 1983 November 10 from 14^{h}.3 UT to 22^{h}.7 UT using the low-energy (LE) telescope and the medium-energy (ME) detectors. The details of the instruments used are given by de Korte et al. (1981) for the LE telescope, and by Turner et al. (1981) for the ME detectors. The low-energy (<2 keV) data were collected using the Lexan 3000 (LX3) filter placed in front of the charge multiplier array (CMA) situated at the focus of the LE telescope (see White & Peacock 1988 for filter efficiency). The ME (1–10 keV) data were acquired with one half array of four argon filled detectors pointing at the source while the other similar half array monitored the background. The usual "swap" technique (Smith 1984) was not used and the background was obtained while the same detectors were slewing out from the source position. The effective exposure times with the LE and ME were 22098 s and 25340 s, respectively.

3. Analysis and results

The data were analyzed using the XANADU (X-ray analysis and data utilization) software. The analysis procedure is described in detail in Singh et al. (1991a, b). The background subtracted source count rate in LE corrected for vignetting, telemetry dead time and the sum-signal distribution is $1.75\pm0.14\,10^{-4}$ cm^{-2} s^{-1}. The count rate detected from the source in the ME (pulse-height channels 7–24) is $4.2\pm0.5\,10^{-4}$ cm^{-2} s^{-1}, after correcting for vignetting and dead time. The quoted errors on the count rates are 1σ statistical errors. No short term variations on a time scale of 1000 s were detected.

We have examined each ME detector data individually for any systematics arising from the background subtraction. A simple power law was used and the resultant fit was examined visually and also the results were verified for an acceptable χ^2. On this basis data from one of the four detectors were rejected.

The pulse-height (PH) information obtained from the LE and the ME detectors was analyzed together for determining the spectral parameters of the X-ray emission. To avoid systematic errors, we have treated data from each ME detector separately and fitted them simultaneously, grouping them later for the plotting purpose only. For the spectral fitting, the ME channels 7 to 40 (corresponding to the energy range of 1.5–10 keV) are included. We used simple power-law and thermal bremsstrahlung models along with absorption in the line of sight to the source to fit the data. The absorption cross-sections given by Morrison &

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McCammon (1983) were used. Using the χ^2 statistic we find that the simple models give acceptable fit to the data. The best fit spectral parameters obtained from this analysis along with their 90% confidence error bars estimated by keeping all the other interesting parameters free (χ^2_{min} +4.61 for two free parameters) are listed in Table 1.

The value of the energy index, α, for the power-law fit obtained from the above analysis is $1.3^{+0.8}_{-0.7}$. The simultaneously estimated value for the column density, N_H, in the line of sight is consistent with the more accurately determined value of $5.2\ 10^{20}$ cm^{-2} from the 21 cm observations (Stark et al. 1992). Keeping the N_H fixed at this value in our analysis resulted in a negligible change in the χ^2. This, however, allowed us to improve the accuracy of the spectral index measurement. The value of α is now estimated to be $1.2^{+0.16}_{-0.14}$. Alternatively, a thermal bremsstrahlung continuum with $kT = 1.72^{+0.48}_{-0.34}$ keV also provide a good fit to the data (see Table 1). The PH data obtained from all EXOSAT observations and the best fit power-law spectrum are shown in Fig. 1, alongwith the residuals from such a fit. The allowed values of α and N_H are shown in the inset in Fig. 1 for different levels of confidence. The contours plotted are for χ^2_{min} plus 2.71, 4.61 and 9.21 corresponding to confidence levels of 67, 90 and 99%, respectively, for two parameters of interest.

Two component spectra or a broken power-law spectrum are not preferred over the simple one component continuum. Similarly, addition of a line feature near 6 keV led to no further improvement in the fit. The analysis of the ME data alone gave similar results as above.

4. Discussion

The X-ray luminosity, as observed in the 2–10 keV energy band, is found to be $2.3\ 10^{43}$ erg s^{-1}. We assume a value of 50 km s^{-1} Mpc^{-1} for the Hubble constant and $q_0 = 0$ in the Friedmann cosmology. The observed 0.1–2.0 keV luminosity is found to be $2.9\ 10^{43}$ erg s^{-1}. After correcting for the absorption in this soft X-ray band the luminosity increases to $7.0\ 10^{43}$ erg s^{-1}. In the energy band of 0.2–4.0 keV, the observed X-ray flux of $7.8\ 10^{-12}$ erg cm^{-2} s^{-1} is higher by about 50% compared to the only previously existing measurement by Kruper et al. (1990) in the same energy band.

The spectral index reported by Kruper et al. (1990) from the *Einstein* observation in 1979, was $\alpha = 1.3^{+0.16}_{-0.11}$ over the energy range of 0.2–4.0 keV, with the line of sight absorption being fixed at the 21 cm value. The present measurement of the spectral index over the broader energy band is in close agreement with the above value. The higher energy slope is inconsistent with the canonical Seyfert spectrum (Mushotzky 1984; Turner & Pounds 1989) but consistent with the results of Elvis et al. (1986), who found that for radio-quiet objects like Mkn 382, the energy slopes were generally steeper than the canonical value. It has also been found that the soft X-ray emission, generally below 1 keV, exceeds the extrapolated harder X-ray emission and has a steeper spectrum in many active galactic nuclei (AGNs), and nearly 50% of the AGNs studied with EXOSAT show such excesses (Turner & Pounds 1989). In the present case, however, a single slope extends over the complete energy range of 0.1–10 keV and, therefore, does not appear to support the existence of a separate steep low-energy component. On the other hand, a flatter hard X-ray spectrum and a strong line emission due to Fe, can result from cold-matter reprocessing close to the nucleus of the galaxy (Pounds et al. 1990). The underlying incident spectrum in such a case has a steeper slope ($\alpha \approx 1.0$) than the canonical value. The present observations suggest that we are seeing only the direct (unprocessed) X-ray emission from Mkn 382.

In conclusion, the present observations provide a fairly accurate measure of the X-ray spectrum of Mkn 382. More sensitive observations with broad-band X-ray detectors would be extremely useful for a clearer understanding of its spectral properties.

Table 1. Results of spectral analysis of EXOSAT LE+ME data on Mkn 382

Energy index (α) temperature (keV)	Flux at 1 keV (μJy)	Column density N_H (10^{20} cm^{-2})	χ^2/dof	Flux[a]	
				2–10 keV	0.1–2 keV
(*a*) *Model: power law + line of sight absorption*					
$1.3^{+0.8}_{-0.7}$	$1.8^{+2.6}_{-1.0}$	$6.75^{+15.75}_{-5.70}$	109.7/101	$4.4^{+1.3}_{-0.2}$ ($4.5^{+1.2}_{-0.8}$	$6.1^{+2.0}_{-2.5}$ $17.1^{+100}_{-12.7}$)
$1.20^{+0.16}_{-0.14}$	$1.6^{+0.2}_{-0.2}$	5.2[b]	109.9/102	$4.5^{+0.5}_{-0.4}$ ($4.5^{+0.5}_{-0.4}$	$5.7^{+1.0}_{-0.8}$ $13.6^{+4.6}_{-3.0}$)
(*b*) *Model: thermal bremstrahlung + line of sight absorption*					
$3.8^{+10.2}_{-1.9}$	$0.73^{+1.20}_{-0.13}$	$1.2^{+2.8}_{-1.0}$	110.8/101	$4.1^{+8.8}_{-0.9}$ ($4.1^{+8.5}_{-0.9}$	$4.3^{+4.1}_{-2.4}$ $5.2^{+7.6}_{-2.2}$)
$1.72^{+0.48}_{-0.34}$	$2.40^{+0.73}_{-0.13}$	5.2[b]	117.6/102	$3.1^{+3.9}_{-1.8}$ ($3.2^{+3.9}_{-1.9}$	$6.65^{+4.0}_{-2.7}$ $11.0^{+6.0}_{-4.2}$)

Note: Quoted errors are at 90% confidence level corresponding to χ^2_{min} +4.61.
[a] In units of 10^{-12} erg cm^{-2} s^{-1}. The values in bracket are those calculated without galactic absorption.
[b] Fixed at the value determined from the 21 cm observations.

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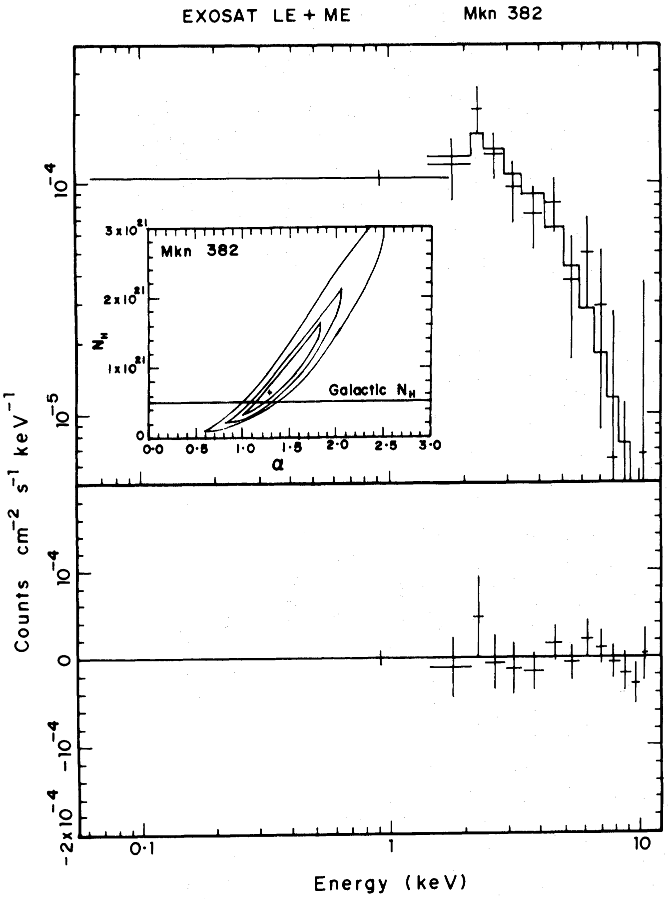

Fig. 1. Pulse-height (PH) data from observations of Mkn 382 with the LE and ME detectors of EXOSAT are shown. The histogram shows the predicted count distribution from the best fit single power-law model with an absorbing column in the line of sight. The lower panel shows the residuals between the data and the best fit spectral model. The inset shows the contour diagram of the allowed ranges of α and N_H. The three contours are for χ^2_{min} plus 2.71, 4.61 and 9.21 corresponding to confidence levels of 67, 90 and 99%, respectively, for two parameters of interest

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