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A BeppoSAX observation of MKN6

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Abstract. We have used the BeppoSAX satellite to study the broad band (0.5–100 keV) X-ray spectrum of the Seyfert 1.5 galaxy MKN6. The source is characterized by a power law of $\Gamma = 1.7^{+0.08}_{-0.07}$ and there is no strong evidence for either a reflection bump or a high energy cut-off. We have detected a narrow iron line at 6.4 keV (rest frame) with an equivalent width of 98^{+33}_{-35} eV. MKN6 also exhibits strong and complex absorption. At least two components ($N_{H_1} = 1.34^{+0.4}_{-0.4} \times 10^{22}$ cm^{-2} and $N_{H_2} = 4.18^{+2.2}_{-1.3} \times 10^{22}$ cm^{-2}) are present and they both partially cover the source with covering fractions of ~90% and ~50% respectively. Comparison with a previous ASCA observation indicates that in both absorbing columns the N_H is variable over a 2 year timescale, while the covering fractions are constant over the same amount of time. The state of each absorber is cold or mildly photoionized. The Broad Line Region (BLR) is suggested as the possible location for this complex absorption.

Key words. X-rays: galaxies – galaxies: Seyfert – galaxies: individual: MKN6

1. Introduction

MKN6 (IC 450) is a Seyfert 1.5 galaxy which has not been observed often in the X-ray regime despite its brightness. The only X-ray study of MKN6 is that of ASCA (Feldmeier et al. 1999) which revealed a very interesting spectrum in the 0.6–9.5 keV band, showing heavy and complex intrinsic absorption in the AGN nucleus, a power law continuum of $\Gamma \sim 1.6$ and an apparently broad 6.4 keV iron Kα line. On the other hand MKN6 is the best known example of an NGC 4151 analogue: both are Seyfert 1.5 galaxies characterized by ionization cones, strong and complex X-ray absorption and a flat high energy spectrum. All these features are quite atypical of type 1 objects and more commonly found in Seyfert 2 s. Observationally Seyfert 1.5 s are widely recognized as a distinct class of Seyfert galaxies (Osterbrock & Koski 1976; Cohen 1983) although their nature has not yet been fully understood. According to Nagao et al. (2000), it could be that they are seen from an intermediate viewing angle between Seyfert 1s and Seyfert 2s so that a significant part of the broad line region (BLR) is obscured by a dusty torus. Alternatively they may be Seyfert 1s where a large part of the BLR emission is obscured by dense, clumpy gas clouds. Finally, they could be Seyfert 2 galaxies where part of the BLR emission can be seen through some optically thin regions of the dusty torus. The latter idea is consistent with the model suggested by Feldmeier et al. (1999) to explain the heavy absorption measured in MKN6 by ASCA i.e. a dusty torus with a low density atmosphere. In this scenario our line of sight skims the surface of the torus and thus passes through the atmosphere which is assumed to have a low column density of the order of 10^{20}–10^{21} cm^{-2} of neutral or low ionization material. However the absorption measured by ASCA in MKN6 (Feldmeier et al. 1999) is much stronger than that expected in a torus atmosphere (i.e. $\sim 10^{23}$ cm^{-2}) and over an order of magnitude higher than that expected based on observations at longer wavelengths. This inconsistency was overcome by Feldmeier et al. (1999) by assuming either an additional absorber located inside the torus atmosphere or that the atmosphere is composed of relatively dust-free gas.

In order to assess the true slope and the broad band X-ray spectrum of MKN6, to compare its characteristics with those of NGC 4151 and to understand the nature of these two peculiar Seyferts, we performed an observation over the 0.5–100 keV band with the BeppoSAX satellite.

2. Spectral analysis

2.1. The BeppoSAX observation and data reduction

MKN6 was targeted by the BeppoSAX NFI in 1999 from September 14th to September 17th. The effective exposure times were 48 ks for the LECS, 109 ks for the MECS23 and 52 ks for the PDS. Spectra were extracted from a region centered on MKN6 with a radius of 4 arcmin. LECS and MECS background spectra were extracted from blank sky fields using

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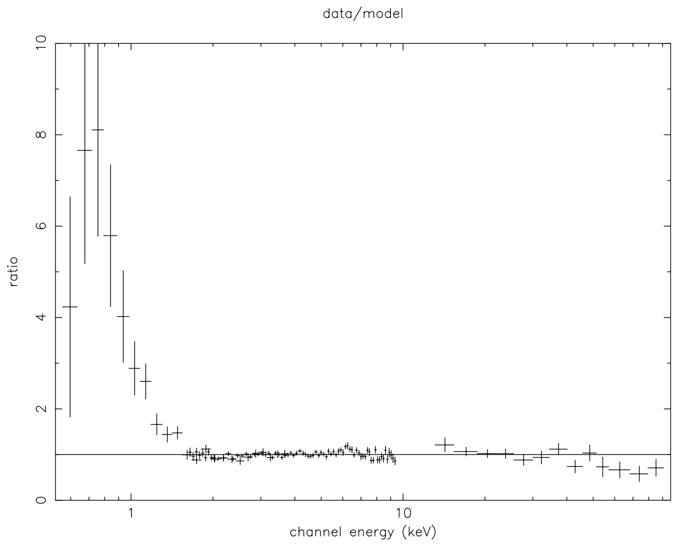

Fig. 1. Data to power law plus Galactic absorption model ratio.

regions of the same size in detector coordinates. The net count rate was $5.02 \pm 0.1 \times 10^{-2}$ cts/s in the (0.5–4 keV) LECS energy band, 0.25 ± 0.002 cts/s in the (2–10 keV) MECS energy range, and 0.5 ± 0.02 cts/s in the (20–100 keV) PDS band. Source plus background light curves did not show any significant variation, therefore a timing analysis has not been performed and all data have been grouped for spectral analysis.

Standard data reduction was performed using the software package "SAXDAS" (see `http://www.asdc.asi.it/software` and the Cookbook for BeppoSAX NFI spectral analysis, Fiore et al. 1998). Spectral fits were performed using the XSPEC 11.0.1 software package and public response matrices as from the 1998 November issue. The spectra were rebinned in order to have at least 20 counts per channel, this allows the use of the χ^2 method in determining the best fit parameters, since the distribution in each channel can be considered Gaussian. Constant factors have been introduced in the fitting models in order to take into account the inter-calibration systematic uncertainties between instruments (Fiore et al. 1998). All the quoted errors correspond to 90% confidence level for one interesting parameter ($\Delta\chi^2 = 2.71$). All the models used in what follows contain an additional term to allow for the absorption of X-rays due to our galaxy, which in the direction of MKN6 is $N_{\rm H_{Gal}} = 6.4 \times 10^{20}$ atoms cm^{-2} (based on 21-cm radio observations, provided by XSPEC).

2.2. Data analysis

The broad band (0.5–100 keV) spectrum of MKN6 was first modeled with an absorbed power law. This model provides a flat photon index ($\Gamma \approx 1.5$) and an $N_{\rm H} \approx 2 \times 10^{22}$ cm^{-2}, but gives a reduced χ^2 of 228 for 105 degrees of freedom and hence is unacceptable. In fact as shown in Fig. 1, it leaves systematic residuals throughout the whole spectrum consisting of: (a) an evident excess emission at low energies; (b) a marginal line-like feature at ~6.4 keV; and (c) possibly a high energy cut-off. Adding a gaussian line to this model (model 1 in Table 1), gives a $\Delta\chi^2$ of 33 for three more parameters, so that the line is statistically significant at >99% confidence using the F-test. The line is centered at $6.39^{+0.13}_{-0.11}$ keV (rest frame), has an equivalent width $EW = 114^{+14}_{-70}$ eV and is consistent with being narrow at the 99% confidence level as demonstrated in Fig. 2; therefore in the following we have fixed the value of sigma to zero. The resulting flat photon index ($\Gamma = 1.52 \pm 0.03$) and the count excess at soft energies could indicate the presence of more intrinsic absorption than assumed in the first instance. We have therefore added to the neutral absorber a partial covering absorption model (PCFABS, model 2) which has been successfully applied to this object in the ASCA observation (Feldmeier et al. 1999). The addition of this partial covering absorber improves the quality of the fit at greater than >99% significance level ($\Delta\chi^2 = 103$ for two more parameters). Using this model, the source is completely covered by cold uniform material with $N_{\rm H} \sim 4$–9×10^{21} atoms cm^{-2}, and partially covered (~70%) by another with $N_{\rm H} \sim 3 \times 10^{22}$ atoms cm^{-2}. Despite the goodness of this fit some residuals below 1 keV are still present.

We have investigated if the presence of a diffuse hot gas located outside the intrinsic absorption and heated by starburst activity in the host galaxy, could be responsible for the soft excess component. The addition of a thermal component (Raymond-Smith model in XSPEC) to model 2 does not improve the quality of the fit ($\chi^2 = 203$ with 99 d.o.f.). Further, this model was also rejected by Feldmeier et al. (1999) when applied to the ASCA data.

If we substitute in model 2 the neutral absorber with another partial covering one (model 3), the fit improves further (>99%, $\Delta\chi^2 = 8$ with one more parameter) and provides our best fit model to the data as also found with the ASCA data. Since the width of the line is sensitive to the underlying continuum, we have left the width free to vary in model 3 and also in this case the line is consistent with being narrow. This is also true for any of the models listed in Table 1. In Fig. 3 the broad band (0.5–100 keV) spectrum of MKN6 fitted with model 3 is shown.

An alternative model used to fit a multicolumn absorber is the *dual-absorber*. This model requires different assumptions on the source + absorber geometry and thus a different interpretation of the data. In the dual-absorber model, two different columns cover the source and the relative normalization of the power law absorbed by these two columns gives the percentage of the source covered by each $N_{\rm H}$ in such a way that the sum of both percentages is 100. We have applied this model to our data (model 4) but no improvement in the quality of the fit has been found.

To check the robustness of our findings, we have also investigated the presence of a warm medium instead of a cold one via the ABSORI model in XSPEC. In the case when the cold medium is represented by a uniform absorber the χ^2 worsens significantly (195/101) thus this model must be rejected. If instead the cold medium is assumed to be an absorber partially covering the source, a combination which was successfully used to model the complex absorption of NGC 4151 (Schurch & Warwick 2002; Piro et al. 2002), then we obtain a statistically acceptable fit to our data. However we are not able to constrain $N_{\rm H_{warm}}$ and ξ with this model. Reasonable values of the ionization parameter, deduced from previous studies

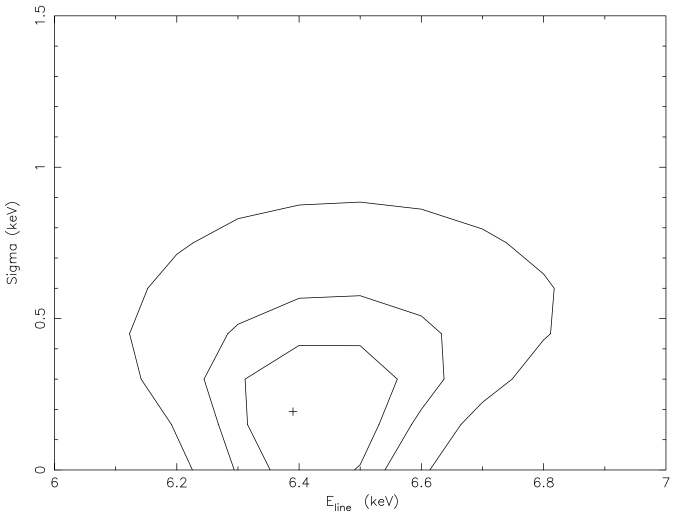

Fig. 2. Confidence contours of the Fe Kα line versus its width (sigma). The line is consistent with being narrow at 99% confidence level.

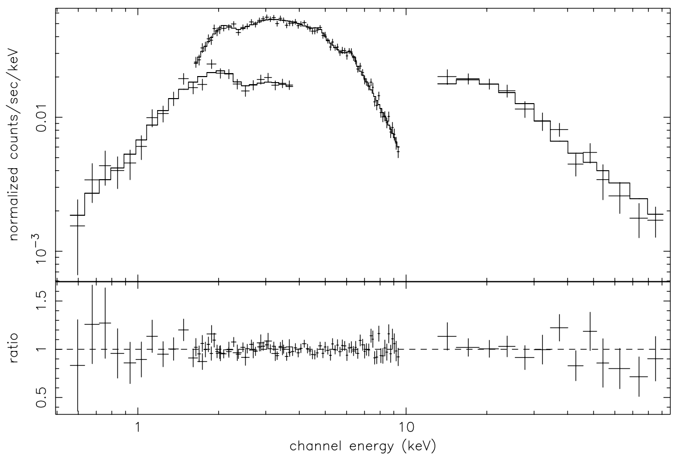

Fig. 3. Broad band (0.5–100 keV) spectrum of MKN6 fitted with model 3 of Table 1.

of Seyfert galaxies (Perola et al. 2002) and compatible with the lack of strong warm absorption features in the spectrum, all provide acceptable fits: for example assuming a column density similar to that obtained in the case of uniform covering, $N_{\mathrm{H_{warm}}} = 3 \times 10^{22}$ cm^{-2} and $\xi \approx 10$ erg cm s^{-1} gives $\chi^2 = 109/100$. Therefore we cannot exclude that the absorbing gas is just mildly ionized on the basis of our data, although we are not able to constrain its properties significantly.

We have also searched for the presence of a high energy cut-off and a reflection component which are typically observed in Seyfert 1 galaxies (e.g. Perola et al. 2002) by replacing the power law with the PEXRAV model (model 5). However, we do not find strong evidence for either of these two components and we are only able to put upper limits on the parameters values: $R < 1.2$ and $E_{\mathrm{c}} > 70$ keV.

2.3. Comparison with the ASCA results

In this subsection we briefly compare two X-ray studies of MKN6: the ASCA observation performed on April 1997 and our BeppoSAX measurement from September 1999. The source shows flux variability in the 2–10 keV energy range; in fact the ASCA absorbed (unabsorbed) flux is $\sim 1\,(1.4) \times 10^{-11}$ erg cm^{-2} s^{-1} while for BeppoSAX it is $\sim 2.5\,(3.1) \times 10^{-11}$ erg cm^{-2} s^{-1}. These flux values are obtained using the same model (model 3 in Table 1) while the absorption correction is performed by forcing both column densities to zero.

The BeppoSAX observation of MKN6 basically confirms the ASCA results i.e. the detection of heavy and complex X-ray absorption towards the source nucleus. In both observations a double partial covering model provides the best statistical fit to the data but from the comparison of our results with those of ASCA a variation in the column densities has been detected. Our analysis of ASCA data provides $N_{\mathrm{H_1}} = 2.99^{+0.13}_{-0.21} \times 10^{22}$ cm^{-2} with a covering fraction of ~90% and $N_{\mathrm{H_2}} = 11^{+3.1}_{-2.2} \times 10^{22}$ cm^{-2} with a covering fraction of ~50%. These values are consistent within the errors with those reported by Feldmeier et al. (1999). BeppoSAX detected smaller column densities of 1.2 and 3.6×10^{22} cm^{-2} with covering fractions $C_{\mathrm{f_1}} = 93^{+0.3}_{-0.7}$% and $C_{\mathrm{f_2}} = 52^{+1.7}_{-1.6}$% respectively. Therefore, while the covering fractions $C_{\mathrm{f_1}}$ and $C_{\mathrm{f_2}}$ are not changed with respect to the ASCA observation, within their individual statistical uncertainties, a significant variation in the column densities of the absorbing materials is found over a two year timescale. This is evident in Fig. 4 where the LECS+MECS BeppoSAX data are fitted with model 3 but imposing the best fit parameters obtained from ASCA: clearly the two data sets cannot be reconciled without changes in the spectral shape parameters. To further prove absorption variations, we show in Fig. 5 the confidence contours of both column densities in the BeppoSAX (solid lines) and ASCA (dashed line) observations. Since both covering fractions are very similar and relatively well constrained, we have fixed them to their best fit values. A check for variations in the absorption over a shorter timescale has also been performed. Since the BeppoSAX observation does not show any significant variation in the continuum light curve, the whole observation (about 100 ks MECS exposure) has been divided in two roughly equal parts and the same spectral analysis of the entire observation has been repeated on both segments of the observation. We find no significant variation in any of the spectral parameters, and in particular in the amount of absorption. We can therefore conclude that no short timescale (one day) variations are present.

Regarding the iron line, we note that the broadening seen by ASCA ($\sigma \sim 230$ eV) is still consistent with our measurement of a narrow feature (see Fig. 2).

Finally, we measure a slightly harder spectrum ($\Gamma = 1.7^{+0.08}_{-0.07}$) than 1.6 as fixed in the ASCA data.

3. Discussion and conclusions

The MKN6 spectrum observed by BeppoSAX resembles that of NGC 4151 in the absorption properties although the broad band spectral characteristics (the power law, reflection component and high energy cut-off) are similar to more classical Seyfert 1 objects (Perola et al. 2002). The absorption is complex and variable. At least two components, each with its own column density and covering fraction, are present. In both

Table 1. MKN6: spectral analysis.

Model	$N_{H_1} \times 10^{22}$	C_{f_1}	$N_{H_2} \times 10^{22}$	C_{f_2}	Γ	E_{Line} (keV)	EW(eV)	R	E_c (keV)	χ^2/ν
(1)	$1.94^{+0.09}_{-0.14}$	-	-	-	$1.52^{+0.03}_{-0.03}$	$6.39^{+0.13}_{-0.11}$	114^{+14}_{-70}	-	-	195/103
(2)	$0.61^{+0.26}_{-0.25}$	-	$3.02^{+0.86}_{-0.51}$	$0.75^{+0.09}_{-0.11}$	$1.66^{+0.07}_{-0.06}$	$6.40^{+0.06}_{-0.12}$	108^{+36}_{-48}	-	-	92/101
(3)	$1.34^{+0.44}_{-0.42}$	$0.93^{+0.03}_{-0.07}$	$4.18^{+2.23}_{-1.29}$	$0.52^{+0.17}_{-0.16}$	$1.70^{+0.08}_{-0.07}$	$6.42^{+0.15}_{-0.14}$	97^{+43}_{-44}	-	-	84/100
(4)	$0.54^{+0.34}_{-0.21}$	$0.30^{+0.22}_{-0.13}$	$3.05^{+1.06}_{-0.40}$	$0.70^{+0.13}_{-0.22}$	$1.66^{+0.09}_{-0.05}$	$6.42^{+0.14}_{-0.14}$	137^{+52}_{-54}	-	-	92/101
(5)	$1.25^{+0.47}_{-0.51}$	$0.93^{+0.02}_{-0.06}$	$3.57^{+1.84}_{-1.07}$	$0.53^{+0.20}_{-0.19}$	$1.63^{+0.08}_{-0.06}$	$6.42^{+0.04}_{-0.06}$	93^{+34}_{-34}	<1.2	>70	83/98

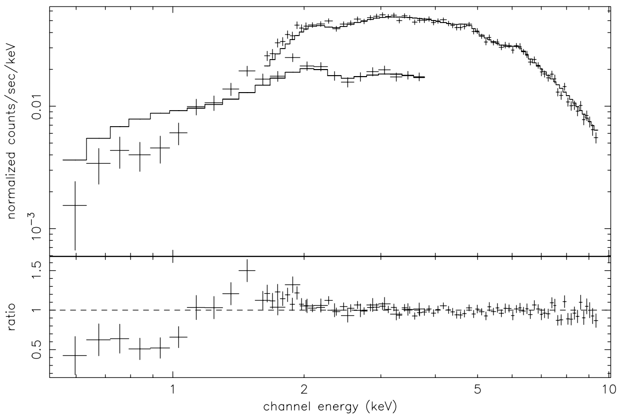

Fig. 4. LECS+MECS BeppoSAX data fitted with model 3 but imposing the best fit parameters obtained by ASCA for both partial covering absorbers.

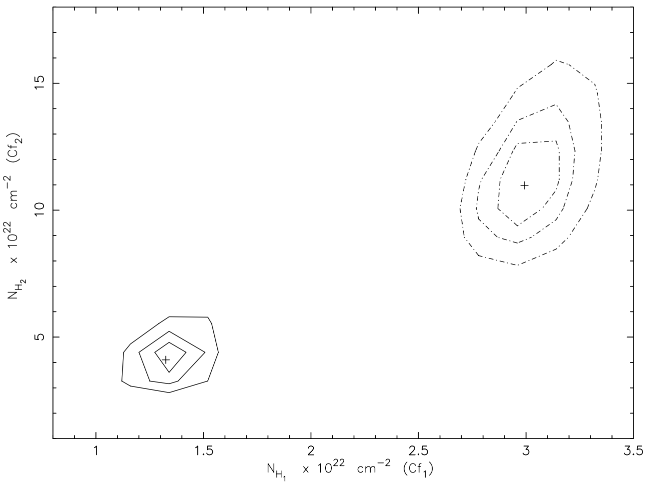

Fig. 5. Comparison of the column densities found by ASCA (dashed lines) and BeppoSAX (solid lines).

columns the N_H is variable over a two year timescales while the covering is constant over the same time. The state of each absorber is cold or mildly photoionized, in fact a combination of cold and warm gas as seen in NGC 4151 is not ruled out by the data. Recently Maiolino et al. (2001) found that the $E(B-V)/N_{H_X}$ ratio estimated from optical/infrared broad band lines and X-ray data is lower than Galactic in a sample of AGNs, including MKN6; this issue was discussed in detail also by Feldmeier et al. (1999). Our results of a variable N_{H_X}, clearly suggest caution in adopting such a ratio as an indicator of anomalous absorption properties. Furthermore, the optical band lines in MKN6 are known to be variable in time (Sergeev et al. 1999); therefore an estimate of the $E(B-V)/N_H$ ratio strongly requires simultaneous optical and X-ray measurements.

The variation observed in N_H can be explained either by a change in the ionization state of each absorber due to a change in the incoming radiation and/or to variation in the amount of the absorbing gas along the line of sight.

A joint fit of ASCA/GIS and BeppoSAX/MECS data are compatible with a change in the ξ parameter although the limitation of the ABSORI model in XSPEC does not allow us to firmly prove a variation in the ionization state of the absorption. The other possibility is that the amount of gas along the line of sight varied between the ASCA and BeppoSAX observation. In this case the absorber must be clumpy and the variation timescales are related to the typical crossing time of an absorbing cloud along the line of sight. Following the reasoning of Risaliti et al. (2002) the location of the absorber is related to the black hole mass, the column density of the absorber, the cloud density and the absorption variation: the BeppoSAX data indicate that the variability timescales are greater than 1 day and smaller than 2.4 years. For reasonable values of the other relevant parameters we find that the molecular torus and the BLR are both viable locations for the absorption (Risaliti et al. 2002). In the first case we go back to the original suggestion of Feldmeier et al. (1999) who propose the atmosphere above the torus as the X-ray absorber. However the column densities measured both by ASCA and BeppoSAX are substantially larger than expected in a torus atmosphere ($\sim 10^{20}$–10^{21} cm^{-2}, Wilson 1996). Considering these difficulties, it is reasonable to consider the BLR as an alternative scenario. The BLR location would be consistent with our variability constraints as well as with the value of column densities and covering fractions observed. Also the requirement for a dust free gas, indicated by the greater absorptions seen in X-rays than at longer wavelengths, is compatible with the BLR. Gas lying here is quite likely to be dust free since this region is within the sublimation radius of the central engine.

Furthermore, the partial covering model itself requires that the location of the absorber is close to, and compatible in size, with the emitting region thus making the BLR a likely site (Reichert et al. 1986). However in this scenario, given the complexity of the absorber, one must assume that the BLR itself is either obscured by dense clumpy gas clouds or is itself complex. This last suggestion is in line with reverberation studies which show that the BLR is slightly stratified into multiple emitting zones with strong gradients both in the ionization parameter and/or density (Baldwin et al. 2003). It is therefore likely that changes in the central engine produce variations in one or more of these stratifications. It remains to be understood why such heavy and complex X-ray absorption is only present in a few objects and not in all Seyfert 1s. The fact that both NGC 4151 and MKN6 are Seyfert 1.5 may bear some relation to the peculiarity in their absorption properties. Based on the results of our analysis it is likely that this enigmatic class is made of Seyfert 1's with a BLR either obscured by extra clumpy gas clouds or peculiar in its geometry.

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