Mon. Not. R. Astron. Soc. **330,** L1–L5 (2002)

The highly variable X-ray spectrum of the luminous Seyfert 1 galaxy 1H 0419−577

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Accepted 2001 November 22. Received 2001 November 13; in original form 2001 August 15

ABSTRACT

An *XMM-Newton* observation of the luminous Seyfert 1 galaxy 1H 0419−577 is presented. We find that the spectrum is well fitted by a power law of canonical slope ($\Gamma \sim 1.9$) and three blackbody components (to model the strong soft excess). The *XMM-Newton* data are compared and contrasted with observations by *ROSAT* in 1992 and by *ASCA* and *BeppoSAX* in 1996. We find that the overall X-ray spectrum has changed substantially over the period, and suggest that the changes are driven by the soft X-ray component. When bright, as in our *XMM-Newton* observation, it appears that the enhanced soft flux cools the Comptonizing corona, causing the 2–10 keV power law to assume a 'typical' slope, in contrast to the unusually hard ('photon-starved') spectra observed by *ASCA* and *BeppoSAX* 4 years earlier.

Key words: galaxies: active – galaxies: individual: 1H 0419−577 – galaxies: Seyfert – X-rays: galaxies.

1 INTRODUCTION

1H 0419−577 (also known as LB 1727, 1ES 0425−573 and IRAS F04250−5718) is a radio-quiet Seyfert galaxy, with a 60-μm flux of 0.18 Jy and an apparent magnitude of 14.1. It is a moderate-redshift object ($z = 0.104$) and relatively bright X-ray source which has been observed over recent years by *ASCA*, *ROSAT* and *BeppoSAX*. 1H 0419−577 was also one of the brightest Seyfert galaxies detected in the extreme-ultraviolet (EUV) by the *ROSAT* Wide Field Camera (Pye et al. 1995) and *EUVE* (Marshall, Fruscione & Carone 1995). Optical spectra taken over the same period in 1996 as the *ASCA* and *BeppoSAX* X-ray observations (Guainazzi et al. 1998) show 1H 0419−577 to be a typical broad-line Seyfert 1, in accordance with the classification by Brissenden (1989).

Over the 2–10 keV band, Seyfert galaxies can usually be modelled by a power law, with photon index $\Gamma \sim 1.8$–2. Below about 1 keV a 'soft excess' is often reported, although the limited bandwidth and resolution of previous missions have made it difficult to distinguish a soft *emission* component from the effects of absorption by ionized matter. In the case of 1H 0419−577, Turner et al. (1999) did conclude that there is a soft emission component on the basis of simultaneous *ROSAT* High Resolution Imager (HRI) and *ASCA* observations. However, those authors found the 2–10 keV power law to be unusually flat, with $\Gamma \sim 1.5$–1.6, and to extend down to 0.7 keV. The *BeppoSAX* observation of 1H 0419−577 in 1996 September (Guainazzi et al. 1998) also found an unusually flat power law (over 3–10 keV) of $\Gamma \sim 1.55$, but provided no independent soft X-ray data, owing to technical problems with the Low Energy Concentrator Spectrometer (LECS).

The link between the hard X-ray power law and a soft X-ray emission component is critical in the context of the accretion disc/corona model for active galactic nuclei (AGN), where the hard X-ray emission is explained by Comptonization of optical/EUV photons from the disc by energetic electrons in an overlying corona (e.g. Haardt & Maraschi 1991). In this model the energy balance between the soft photon flux and the corona then determines the hardness of the spectrum in the 2–10 keV band. The soft excess may be the tail of the big blue bump, representing the thermal emission from an accretion disc surrounding the central black hole (Shields 1979; Czerny & Elvis 1987; Ross & Fabian 1993).

In our *XMM-Newton* observation, reported here, we find a strong and broad soft emission component [consistent with an earlier *ROSAT* Position Sensitive Proportional Counter (PSPC) observation in 1992 (Guainazzi et al. 1998)] and a 2–10 keV power-law continuum slope typical of Seyfert 1 galaxies. We discuss our result in terms of the stronger soft photon flux cooling the coronal electrons, with a resulting steepening of the power law, and suggest that it represents direct observational support for the disc/corona model for the hard X-ray emission from radio-quiet AGN.

In that general class of models, back-irradiation of the accretion disc by the hard X-ray flux can result in additional features being imprinted on the emerging X-ray spectrum. The most obvious of these 'reflection' features (Pounds et al. 1990; Nandra & Pounds 1994) is often an emission line at 6.4 keV arising from fluorescence in near-neutral Fe. This line has emerged as a powerful diagnostic of the inner regions in AGN since *ASCA* observations found it to be

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broadened and redshifted (Tanaka et al. 1995; Nandra et al. 1997a,b). Early observations from *XMM-Newton* have shown a rather different situation to apply in several high-luminosity Seyferts (similar to 1H 0419−577), with a weaker and higher energy (ionized) broad Fe K line, resolved from a narrow line at 6.4 keV (e.g. Reeves et al. 2001; Pounds et al. 2001). The latter component, interpreted as scattering from neutral matter distant from the hard X-ray source (e.g. in the molecular torus), is emerging as a common feature in AGN observations by *XMM-Newton* and *Chandra*.

In previous observations of 1H 0419−577, Turner et al. (1999) found evidence for an emission line in the *ASCA* data at 6.39 keV, with equivalent width (EW) of 700 ± 400 eV (data from 1996 August). A line is not detected in the *BeppoSAX* data (Guainazzi et al. 1998), but with a rather high upper limit of ∼250 eV for the equivalent width.

In Section 2 the data from *XMM-Newton* are summarized, followed by data analysis in Section 3. Comparisons with the *ROSAT*, *ASCA* and *BeppoSAX* observations are reviewed in Section 4. Note that all fit parameters are given for the rest frame of the AGN, with values of $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $q_0 = 0$ assumed throughout. Errors are quoted at the 90 per cent confidence level ($\Delta\chi^2 = 2.7$ for one interesting parameter).

2 *XMM-NEWTON* OBSERVATIONS

The *XMM-Newton* observation of 1H 0419−577 took place on 2000 December 4 and lasted for just over 8 ks. Because of a coordinate error, X-ray data were only obtained from the European Photon Imaging Camera (EPIC) PN camera (Strüder et al. 2001).

The PN data were reduced with the *XMM* SAS (Science Analysis Software), using EPCHAIN to produce the event list. This was further filtered using XMMSELECT within SAS. Both single- and double-pixel events (patterns 0–4 in XMMSELECT) were selected, with the low-energy cut-off being set to 200 eV. The spectrum was extracted within a box-shaped region of size 20 by 10 pixels (corresponding to $87 \times 43.5\,\mathrm{arcsec^2}$).

The XSPEC v11.0 software package was used to analyse the background-subtracted spectrum, using the most recent response matrices. (The spectrum was first binned, using the FTOOL command GRPPHA, to provide a minimum of 20 counts per bin.)

3 SPECTRAL ANALYSIS

Since no significant changes occurred in the X-ray flux over the 8000-s observation, the summed data were used in modelling the spectrum. The spectral analysis was begun in the conventional way, comparing the data for 1H 0419−577 with a range of parametric models until the best reduced χ^2 value was obtained.

First, a single absorbed power law (N_H fixed to the Galactic value of $2 \times 10^{20}\,\mathrm{cm^{-2}}$) was tried, but found to be a very poor fit across the full 0.2–10 keV band ($\chi^2_\nu = 1409/712$), mainly because of a strong upward curvature in the measured spectrum. Constraining the model to the 2–10 keV band, however, provided a good fit for a photon index $\Gamma \sim 1.88$, with $\chi^2_\nu = 325/349$. A Gaussian component was then added to the model but yielded no significant detection of either a narrow or a broad Fe line. At a rest energy of 6.4 keV (appropriate to neutral iron emission), the equivalent width of a narrow line ($\sigma = 10$ eV) was <85 eV while for a broad neutral line ($\sigma = 300$ eV) the upper limit was <130 eV. For an ionized line at 6.7 keV the corresponding broad-line limit was <120 eV. We note that these upper limits are consistent with the weak Fe emission lines detected in objects of similar luminosity (Reeves et al. 2001; Pounds et al. 2001).

Extrapolating the above 2–10 keV power-law fit down to 0.2 keV revealed a strong and broad ('hot') soft excess (Fig. 1). The soft excess was then modelled by the addition of blackbody

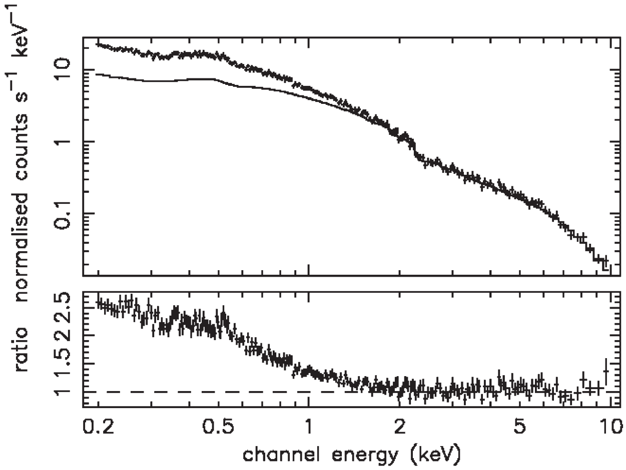

Figure 1. Fit 1 for the PN spectrum, extrapolated down to 0.2 keV, showing the soft excess of 1H 0419−577. The lower panel shows the ratio between the data and fitted model.

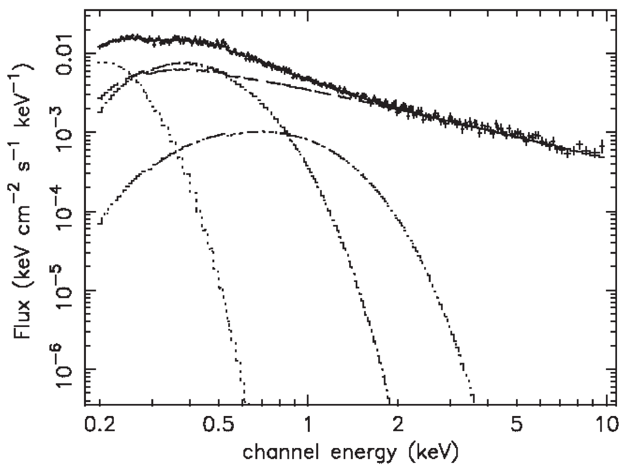

Figure 2. Unfolded plot of the best fit to the *XMM-Newton* data (Fit 4 in Table 2). The model consists of a power law ($\Gamma = 1.88$) and three blackbody components ($kT = 31$, 110 and 252 eV).

Table 1. Fits to the *XMM-Newton* data from 2000 December.

Fit	Range (keV)	Model	Γ	kT (keV)	χ^2/dof
1	2–10	PL	1.88 ± 0.03		325/349
2	0.2–10	PL+BB	2.05 ± 0.01	0.108 ± 0.002	839/710
3	0.2–10	PL+2BB	1.99 ± 0.02	0.033 ± 0.002 0.121 ± 0.003	767/708
4	0.2–10	PL+3BB	1.88 ± 0.04	0.031 ± 0.002 0.110 ± 0.005 0.252 ± 0.030	734/706

Table 2. Fits to the *ASCA*, *BeppoSAX* and *XMM-Newton* data.

Mission	Fit	Model	Γ	*kT* (keV)	χ^2/dof	Flux (erg cm^{-2} s^{-1})
2–10 keV						
ASCA (1996 July)	1	PL	1.35 ± 0.05		162/134	9.32×10^{-12}
ASCA (1996 August)	1	PL	1.42 ± 0.06		91/140	1.13×10^{-11}
BeppoSAX (1996 September)	1	PL	1.63 ± 0.04		140/111	1.15×10^{-11}
0.5–10 keV						
XMM-Newton	5	PL+2BB	1.87 ± 0.03	0.093 ± 0.006 0.225 ± 0.020	661/650	2.20×10^{-11}
ASCA (1996 July)	5	PL+2BB	1.32 ± 0.03	0.093^f 0.225^f	222/185	1.27×10^{-11}
ASCA (1996 August)	5	PL+2BB	1.53 ± 0.03	0.093^f 0.225^f	143/191	1.61×10^{-11}

^{f}Blackbody components frozen to PN values, with normalizations tied to the same ratio.

emission, the breadth of the excess requiring three blackbody components to match the observed spectrum (Fig. 2). Details of this fit are given as Fit 4 of Table 1. The soft excess has no obvious superimposed absorption features, the limits for the optical depths of the O VII and O VIII edges being $\tau < 0.12$ and $\tau < 0.06$ respectively. A small excess of counts at ~0.55 keV could be a calibration residual, although emission from the O VII triplet has been previously identified, close to this energy, in objects of similar luminosity [e.g. Mrk 359 (O'Brien et al. 2001); Mrk 509 (Pounds et al. 2001)]. Without the benefit of Reflection Grating Spectrometer (RGS) data, we cannot investigate this further.

The measured flux of 1H 0419−577 at 2–10 keV was 1.12×10^{-11} erg cm^{-2} s^{-1}, corresponding to a luminosity of 5.67×10^{44} erg s^{-1}, with a flux of 2.88×10^{-11} erg cm^{-2} s^{-1} over the full 0.2–10 keV band (1.91×10^{45} erg s^{-1}), including the strong 'soft excess'.

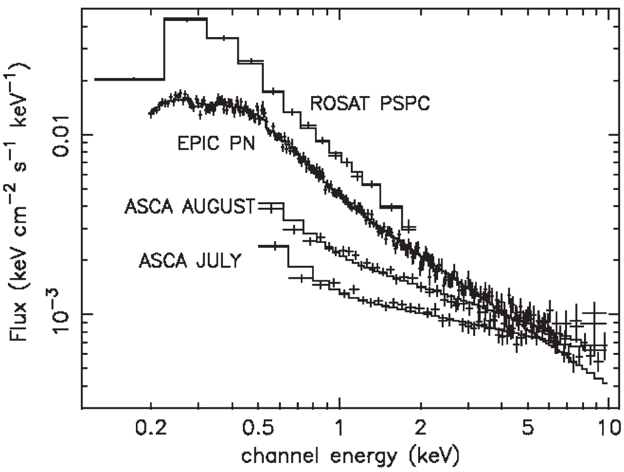

Figure 3. Plot showing the difference between the unfolded spectra for the *XMM-Newton*, *ASCA* and *ROSAT* observations. The model used was a power law and two blackbodies. It can clearly be seen that the *ROSAT* and *XMM-Newton* data sets have steeper power-law slopes and stronger soft X-ray emission than the *ASCA* observations.

4 COMPARISON WITH OTHER OBSERVATIONS

The *XMM-Newton* spectrum of 1H 0419−577 is, on its own, unremarkable, being very similar in overall continuum shape to the recent *XMM-Newton* observations of the comparably high-luminosity Seyfert 1 galaxies Mrk 205 and 509 (Reeves et al. 2001; Pounds et al. 2001). However, the *XMM-Newton* spectrum of 1H 0419−577 is dramatically different from the several observations in 1996, which show a much flatter 2–10 keV continuum and weaker soft excess. To confirm this spectral change, we have re-examined in a consistent way the data from those previous missions, beginning with the *ROSAT* PSPC observation in 1992, then those of *ASCA* in 1996 July and August (observation numbers 74056000 and 74056010) and in September of that year by *BeppoSAX*. The *ROSAT* HRI also monitored 1H 0419−577 simultaneously with *ASCA*, between 1996 June 30 and September 1. The data from these observations were retrieved from the LEDAS website (http://ledas-www.star.le.ac.uk), the Tartarus Database (http://tartarus.gsfc.nasa.gov) and the *BeppoSAX* homepage (http://www.asdc.asi.it/bepposax) respectively. Only the data from the Solid-state Imaging Spectrometer (SIS) instruments on *ASCA* were used.

We began by fitting a power law plus Galactic absorption to the *ASCA* and *BeppoSAX* data sets over the 2–10 keV band. In each case the power-law slope was significantly flatter compared with *XMM*. Details of these power-law fits are given in Table 2. It should be noted that we have fitted over the entire 2–10 keV band, whereas Turner et al. (1999) ignored 5.0–7.5 keV within this range, where iron emission would occur if present. If we do ignore this region, then the *ASCA* slopes steepen by approximately 0.1, agreeing more closely with those derived by Turner et al. Interestingly, although the slopes are very different, the 2–10 keV flux remains essentially constant between the *XMM*, *ASCA* and *BeppoSAX* observations. This is a point also illustrated in Fig. 3.

The PN spectrum was then re-fitted over the 0.5–10 keV *ASCA* band, so that the *ASCA* and *XMM-Newton* data could be compared directly. Over this band, the PN data are well fitted with a power law and only two blackbody components. Each *ASCA* observation was then modelled in this way, with the blackbody temperatures and relative normalizations frozen to the values determined from the *XMM* data, since the soft excess is not well constrained for the *ASCA* data sets. The results of this fit (Fit 5) are given in Table 2. The 0.5–2 keV flux is a factor of ~3 higher in the *XMM-Newton* observation and the power law is much steeper ($\Delta\Gamma \sim 0.4$). The power-law slope and soft excess change in the same sense, but to a lesser degree, between the two *ASCA* observations, with the soft flux increasing by 42 per cent from 1996 July to August according to Fit 5, in excellent agreement with the ~40 per cent increase in count rate recorded by the *ROSAT* HRI data (Turner et al. 1999).

Since only the data from the Medium Energy Concentrator

Spectrometer (MECS) instrument onboard *BeppoSAX* were available, blackbody components could not be constrained for that observation. The power-law slope is 1.63 ± 0.04, implying that the slope was continuing to steepen, as hinted at between the *ASCA* observations.

To compare the flux between *ROSAT* and *XMM-Newton*, a simple power law was fitted to the *ROSAT* and PN data sets, over the range 0.2–2.0 keV, with $N_{\rm h}$ fixed to the Galactic value. For *ROSAT*, $\Gamma \sim 2.94$, while the PN slope was slightly less steep, at $\Gamma \sim 2.46$. This corresponds to a flux over the 0.2–2 keV band of 3.42×10^{-11} erg cm^{-2} s^{-1} for *ROSAT*, compared with 1.76×10^{-11} erg cm^{-2} s^{-1} as measured by *XMM-Newton*. We stress that a single power law is not a good fit to either the *ROSAT* or *XMM-Newton* data sets, both of which show evidence for a more complex soft excess. It has been noted by a number of authors (e.g. Iwasawa, Brandt & Fabian 1998) that the *ROSAT* PSPC spectral indices are up to 0.4 steeper than those found from other missions. Allowing for these uncertainties, we consider that the *ROSAT* PSPC observation of 1992 is consistent with the soft excess at that time being as strong as in the 2000 December *XMM-Newton* observation.

The next step was to compare the *ASCA*, *BeppoSAX* and *XMM-Newton* data to search for neutral iron emission. We found no evidence for a narrow line ($\sigma = 10$ eV) in any of the observations. The 1996 July *ASCA* data gave an equivalent width of <81 eV, very similar to our *XMM-Newton* upper limit. The August *ASCA* and September *BeppoSAX* data yielded upper limits of ~140 eV. Broad-line fits (width 300 eV) also gave only upper limits of the order of <350 eV for the July *ASCA* and September *BeppoSAX* data, while for the August *ASCA* data the fit did show a decrease in χ^2 of 7 for one additional degree of freedom (a confidence level of greater than 99 per cent). This line, if real, has an equivalent width of 335 ± 210 eV. Summarizing, the 1996 August *ASCA* data suggest that a broad iron line may exist, although none of the other observations detected such emission.

It is known that the low-energy response of the *ASCA* SIS has been degrading and that this leads to an underestimate of the soft X-ray flux. In order to estimate the decrease in the low-energy efficiency of *ASCA* in the 1H 0419−577 observation, we used the formula given in the *ASCA* Guest Observer Facility (GOF) Calibration Memo (Yaqoob et al. 2000), which quotes the effective increase in $N_{\rm h}$ as a function of time. The net effect of this in our fits is a change of $\Gamma \sim 0.05$ in the spectral slope. This does not, therefore, alter our conclusions about the change in state of 1H 0419−577 between the *ASCA* and *XMM-Newton* observations.

5 DISCUSSION

Our *XMM-Newton* observation of 1H 0419−577 found the source in a bright/soft state. The overall 0.2–10 keV spectrum is very similar to those of two other luminous Seyfert galaxies recently observed with *XMM-Newton*, Mrk 205 (Reeves et al. 2001) and Mrk 509 (Pounds et al. 2001), exhibiting a typical 2–10 keV power-law slope and strong soft excess. However, the new observation of 1H 0419−577 contrasts markedly with both *ASCA* and *BeppoSAX* spectra obtained in 1996, where the 2–10 keV continuum was significantly flatter, and the soft excess much weaker. We suggest that the strong soft excess in our recent observation is the key to the overall spectral change, with increased cooling of the coronal electrons yielding a steeper/softer hard power-law component. Interestingly, it seems possible that this effect was already apparent between the two *ASCA* observations a month apart in 1996, with an increase in the *ROSAT* HRI flux of at least 40 per cent, and the best-fitting 2–10 keV power-law slopes increasing from 1.35 ± 0.05 to 1.42 ± 0.06 (see also Turner et al. 1999). If the 2000 December spectral state is considered 'normal' for a broad-line Seyfert 1 galaxy then, in the framework of the disc/corona model, we can attribute the unusually flat/hard 2–10 keV continuum in the 1996 observations to a lack of soft photons ('photon starved' Comptonization).

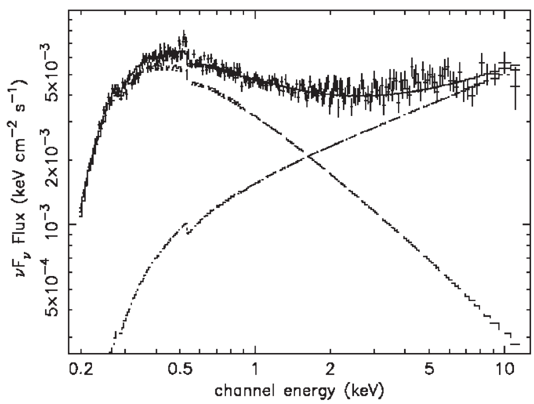

Figure 4. Best-fitting Comptonization model for the EPIC PN data set. Input photons at $kT = 20$ eV are Comptonized by electron distributions of $kT = 2.5$ and 95 keV.

In order to quantify such a change we have tried a Comptonization fit to the data (COMPTT in XSPEC), using a model (as in O'Brien et al. 2001a) in which soft photons from the accretion disc are up-scattered by thermal electrons characterized by two temperatures, to yield the observed broad soft excess and the harder power law respectively. For the *XMM-Newton* data we assumed an input photon distribution of $kT = 20$ eV (appropriate to thermal radiation from the inner disc of a 10^8-M$_\odot$ black hole).

For the *XMM-Newton* data we obtained an acceptable fit ($\chi^2_\nu = 1.11$) across the full 0.2–10 keV spectrum with a 'cool' Comptonizing component of $kT = 2.5 \pm 0.1$ keV and an optical depth of $\tau = 3.9 \pm 0.1$, together with a 'hot' component of $kT = 95 \pm 15$ keV and $\tau = 1.0 \pm 0.1$ (Fig. 4). The same double-Comptonization model was then compared with the *ASCA* data from the 1996 July observation. Again an acceptable fit was obtained, with Comptonizing components of $kT = 2.5 \pm 0.1$ keV with an optical depth of $\tau = 3.5 \pm 0.1$ (and much smaller normalization) and $kT = 168^{+100}_{-30}$ keV ($\tau = 1.0 \pm 0.1$). While the individual parameters should not be taken too literally, since there is a close coupling of temperature and optical depth, the fits support the view that the steepening of the power law between the 1996 and 2000 observations of 1H 0419−577 follows a significant cooling of the hot Comptonizing electrons. This is consistent with the much stronger soft X-ray flux detected in the *XMM-Newton* observation.

Finally we note that the relatively short exposure of the *XMM-Newton* observation means that the limits on the Fe K lines are not very severe. However, it might be expected that any broad line would be weakened if the disc had an optically thick, ionized skin, as our Comptonization model suggests.

6 CONCLUSIONS

A new measurement of the X-ray spectrum of the luminous Seyfert 1 galaxy 1H 0419−577 with *XMM-Newton* has shown it to have a strong soft excess and 'normal' power law slope, very similar to the comparably luminous Seyferts Mrk 205 and 509. No iron line was found, but the upper limits are consistent with the Fe K emission found in *XMM-Newton* observations of objects of similar luminosity. A comparison with archival data shows the 2–10 keV continuum to have been much flatter in 1996, together with a far weaker soft excess. We interpret our overall *XMM-Newton* observation in terms of two-temperature Comptonization of thermal photons from the inner accretion disc, and explain the hard continuum seen in 1996 as being due to 'photon starving' of the hotter electron component. We note that the spectral changes we have observed in the Seyfert galaxy 1H 0419−577 are similar to, but smaller than, those seen in the changes in 'state' for several galactic black hole candidate sources (e.g. Vilhu et al. 2001).

ACKNOWLEDGMENTS

The work in this paper is mainly based on observations with *XMM-Newton*, an ESA science mission, with instruments and contributions directly funded by ESA and NASA. The authors thank the EPIC Consortium, led by Dr M. J. L. Turner, for all their work during the calibration phase, and the SOC and SSC teams for making the observation and analysis possible. This research has also made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Support from a PPARC studentship and the Leverhulme Trust is acknowledged by KLP and JNR respectively.

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