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

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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 (Γ ∼ 1.9) and 3 blackbody components (to model the strong soft excess). The XMM 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 Comptonising 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 four years earlier.

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

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 60µm 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 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 Brisenden (1989).

Over the 2–10 keV band, Seyfert galaxies can usually be modelled by a power law, with photon-index Γ ∼ 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 ionised 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 HRI and ASCA observations. However, those authors found the 2–10 keV power law to be unusually flat, with Γ ∼ 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 Γ ∼ 1.55, but provided no independent soft X-ray data, due 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 AGN, where the hard X-ray emission is explained by Comptonisation 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 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 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 broadened and red-shifted (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 (ionised) broad Fe-K line, resolved from a narrow line at 6.4 keV (eg. 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 August 1996). A line is not detected in the SAX data (Guainazzi et al. 1998), but with a rather high upper limit of ~ 250 eV for the equivalent width.

In Section 3 the data from XMM-Newton are summarised, followed by the data analysis in Section 4. Comparisons with the ROSAT, ASCA and BeppoSAX observations are reviewed in Section 4. Note that all fit parameters are quoted at the 90% confidence level (Δχ² = 2.7 for 1 interesting parameter).

2 XMM-NEWTON OBSERVATIONS

The XMM-Newton observation of 1H 0419−577 took place on 4th December 2000 and lasted for just over 8 ks. Because of a co-ordinate error, X-ray data were only obtained from the 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 the SAS. Both single and double pixel events (patterns 0-4 in XMMSSELECT) 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 (corresponds to (87 × 43.5) arcsec).

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 second 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 χ² value was obtained.

First, a single absorbed power law (N_h fixed to the Galactic value of 2 × 10²⁰ cm⁻²) was tried, but found to be a very poor fit across the full 0.2−10 keV band (χ² = 1409/712), mainly due to 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 Γ ~ 1.88, with χ² = 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 (σ = 10 eV) was < 85 eV while for a broad neutral line (σ = 300 eV) the upper limit was < 130 eV. For an ionised line at 6.7 keV the corresponding broad line limit was < 120 eV. We note 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 emission, the breadth of the excess requiring 3 blackbody components to match the observed spectrum (Fig 1). 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 τ < 0.12 and τ < 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 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 × 10⁴⁴ 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 × 10⁴⁵ erg s⁻¹), including the strong ‘soft excess’.

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 Mrk 509 (Reeves et al. 2001, Pounds et al. 2001). However, the XMM-Newton spectra of 1H 0419-577 is dramatically different from the several observations in 1996, which show a much flatter 2−10 keV con-
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with those derived by Turner. Slopes steepen by approximately 0.1, agreeing more closely if present. If we do ignore this region, then the ASCA 5.0–7.5 keV within this range, where iron emission would occur. The entire 2–10 keV band, whereas Turner (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 Figure 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 2 blackbody components. Each ASCA observation was then modelled in this way, with the BB temperatures and relative normalisations frozen to the values determined from the XMM data, since the soft excess is not well constrained for the ASCA datasets. 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 (ΔΓ ~ 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% from July to August 1996 according to Fit 5, in excellent agreement with the ~40% increase in count-rate recorded by the ROSAT HRI data (Turner et al. 1999).

Since only the data from the MECS instrument onboard BeppoSAX were available, BB 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, a simple power law was fitted to the ROSAT and PN datasets, over the range 0.2–2.0 keV, with N_h fixed to the Galactic value. For ROSAT, Γ ~ 2.94, while the PN slope was slightly less steep, at Γ ~ 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 to 1.76 × 10^{-11} erg cm^{-2} s^{-1} as measured by XMM. We stress that a single power law is not a good fit to either the ROSAT or XMM data, both of which show evidence for a more complex soft excess. It has been noted by a number of authors (e.g., Turner 1993; 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

Figure 2. Unfolded plot of the best fit to the XMM data (Fit 4 in Table 2). The model consists of a powerlaw (Γ = 1.88) and 3 blackbody components (kT = 31 eV, 110 eV and 252 eV).

Figure 3. Plot showing the difference between the unfolded spectra for the XMM, ASCA and ROSAT observations. The model used was a powerlaw and 2 BBs. It can clearly be seen that the ROSAT and XMM datasets have steeper powerlaw slopes and stronger soft X-ray emission than the ASCA observations.

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

| Fit Range (keV) | Model | Γ | kT (keV) | χ²/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 | 767/708 |
| 4 0.2–10 PL+3BB| 1.88±0.04 | 0.031±0.002 | 734/706 |

Minimum 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 July and August of 1996 (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 SAX homepage [http://brunello.sdc.asi.it] respectively. Only the data from the SIS instruments on ASCA were used.

We began by fitting a power law plus Galactic absorption to the ASCA and SAX datasets over the 2–10 keV band. In each case the power-law slope was significantly flatter compared to 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...
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*, *SAX* and *XMM* data to search for neutral iron emission. We found no evidence for a narrow line (\(\sigma \approx 10\) eV) in any of the observations. The July 1996 *ASCA* data gave an equivalent width of \(< 81\) eV, very similar to our *XMM* upper limit. The August *ASCA* and September *BeppoSAX* data yielded upper limits of \(\sim 140\) eV. Broad line fits (width 300 eV) also gave only upper limits of order \(< 350\) eV for the July *ASCA* and September *BeppoSAX* data, while for the August *ASCA* data the fit did show a decrease in \(\chi^2\) of 7 for 1 additional degree of freedom (a confidence level of greater than 99\%). This line, if real, has an EW of 335 \(\pm\) 210 eV. Summarising, the August 1996 *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* GOF Calibration Memo (Yaqoob et al. 2000), which quotes the effective increase in \(N_\text{e}\) 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* 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 that of 2 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 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 2 *ASCA* observations a month apart in 1996, with an increase in the *ROSAT* HRI flux of at least 40\%, and the best fit 2–10 keV power law slopes increasing from 1.35 \(\pm\) 0.05 to 1.42 \(\pm\) 0.06 (see also Turner et al. 1999). If the 2000 December spectral state is considered ‘normal’ for a BLS1 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’ Comptonisation).

In order to quantify such a change we have tried a Comptonisation fit to the data (\(\text{comptt}\) in *Xspec*), using a model (as in O’Brien et al. 2001) in which soft photons from the accretion disc are up-scattered by thermal electrons characterised 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 (\(\chi^2 = 1.11\)) across the full 0.2–10 keV spectrum with a ‘cool’ Comptonising component of \(kT = 2.5 \pm 0.1\) keV and optical depth of \(\tau = 3.9 \pm 0.1\), together with a ‘hot’ component of \(kT = 95 \pm 15\) keV and \(\tau = 1.0 \pm 0.1\) (Figure 4). The same double-Comptonisation model was then compared with the *ASCA* data from the 1996 July observation. Again an acceptable fit was obtained, with Comptonising components of \(kT = 2.5 \pm 0.1\) keV with an optical depth of \(\tau = 3.5 \pm 0.1\) (and much smaller normalisation) and \(kT = 168^{+100}_{-30}\) keV (\(\tau = 1.0 \pm 0.1\)). While the indi-
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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 Comptonisation 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 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).

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