AN XMM-NEWTON OBSERVATION OF THE SEYFERT 1 GALAXY 1H 0419–577
IN AN EXTREME LOW STATE
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ABSTRACT

Previous observations of the luminous Seyfert 1 galaxy 1H 0419–577 have found its X-ray spectrum to range from that of a typical Seyfert 1 galaxy with a 2–10 keV power-law index of 1.9 to a much flatter power law of 1.5 or less. We report here a new XMM-Newton observation that allows the low-state spectrum to be studied in much greater detail than hitherto. We find a very hard spectrum (1.0), which exhibits broad features that can be modeled with the addition of an extreme relativistic Fe K emission line or with partial covering of the underlying continuum by a substantial column density of near-neutral gas. Both the EPIC and Reflection Grating Spectrometer (RGS) data show evidence for strong line emission of O vii and O viii requiring an extended region of low-density photoionized gas in 1H 0419–577. Comparison with an earlier XMM-Newton observation when 1H 0419–577 was “X-ray–bright” indicates that the dominant spectral variability occurs via a steep power-law component.

Subject headings: galaxies: individual (1H 0419–577, LB 1727) — galaxies: Seyfert — X-rays: galaxies

1. INTRODUCTION

1H 0419–577 (also known as LB 1727) is a radio-quiet (8.4 GHz flux ~3 mJy; Brissenden et al. 1987) Seyfert galaxy at a redshift z = 0.104 and one of the brightest active galactic nuclei (AGNs) in the extreme ultraviolet, being detected by both the ROSAT Wide-Field Camera (Pye et al. 1995) and EUVE (Marshall, Fruscione, & Carone 1995). Optical spectra from the Anglo-Australian Telescope (Turner et al. 1999) and ESO (Guainazzi et al. 1998) showed 1H 0419–577 to be a typical broad-line Seyfert 1 galaxy with a strong “big blue bump.”

1H 0419–577 was observed by XMM-Newton in 2000 December for ~8 ks, although a command error meant X-ray data were restricted to the EPIC pn camera. Analysis of the X-ray spectrum found a high 2–10 keV luminosity of ~10^{45} erg s^{-1}, with a “canonical” Seyfert 1 power-law continuum of 1.9, together with a strong soft X-ray excess (Page et al. 2002). However, simultaneous ROSAT HRI and ASCA (Turner et al. 1999) and BeppoSAX (Guainazzi et al. 1998) observations of 1H 0419–577 4 years earlier had found an unusually hard spectrum for a Seyfert 1 galaxy, with 1.4 and only a very weak “soft excess.” A still earlier ROSAT observation of 1H 0419–577 in 1997 showed that the source had once more been in a high/soft state (Guainazzi et al. 1998). 1H 0419–577 therefore appears to exhibit unusually large spectral variability, with a factor of 10 change in soft X-ray flux and variations in power-law index by 0.5, over several years or less. In this respect, 1H 0419–577 is similar to Galactic black hole sources, which frequently vary between low/hard and high/soft states (see Zycki, Done, & Smith 2001 for a review). Although the spectral changes in 1H 0419–577 are not quite so extreme, the unusually large variability makes it a particularly interesting probe of the accretion-driven processes that make AGNs characteristically powerful X-ray emitters.

The impression from the published observations of 1H 0419–577 is that the soft X-ray flux shows the most dramatic changes, much greater than the integrated hard X-ray flux, suggesting the spectral change is driven by the thermal disk emission. In the framework of the widely accepted disk/corona model (Haardt & Maraschi 1991), in which thermal photons from the accretion disk are Compton scattered by high-energy electrons to form the observed X-ray power law, an enhanced disk emission should cool the electrons and lead to a steeper power law. Structural changes in the scattering corona may also be required by the observed power-law slope change of 0.5, with the additional constraint that the total 2–10 keV luminosity increased by only 20% over the same 1996–2000 period (Page et al. 2002).

In considering changes in the structure of the disk, one possibility is that the low/hard state corresponds to a truncated inner disk, or advection-dominated accretion flow (ADAF), which would lead to reduced reflection, no broad Fe Kα line, and a weaker coupling between the disk and the corona. In that simple picture a hot “photon-starved” corona could evolve to a high/soft state when a higher accretion rate extended the disk boundary inward, with enhanced thermal emission, a steeper power law, and broad Fe Kα line. That might describe the change occurring in 1H 0419–577 between 1996 and 2000 (although the sensitivity of none of the contemporary observations was sufficient to usefully constrain the Fe K emission line: Guainazzi et al. 1998; Turner et al. 1999; Page et al. 2002).

To improve the X-ray data on 1H 0419–577 a new series of six XMM-Newton observations, at approximately 3 month intervals over the period 2002 September–2003 November, was recently completed. The first of those new observations, when 1H 0419–577 was found to be extremely faint, is reported in the present paper.

2. OBSERVATIONS

The first XMM-Newton observation of 1H 0419–577 in the new series took place on 2002 September 5 (orbit 512) yielding a useful exposure of ~14.9 ks. Five further observations of similar length were successfully carried out over...
the following 15 months and will be reported later. The present paper describes the results from the first new observation, which are of particular interest given the extremely low flux state in which 1H 0419–577 was found. X-ray data were available throughout the observation from the EPIC pn (Strüder et al. 2001) and MOS (Turner et al. 2001) cameras, and the Reflection Grating Spectrometer (RGS) (den Herder et al. 2001). In addition, the Optical Monitor (Mason et al. 2001) obtained simultaneous flux measurements in $V$, $B$, $U$, and two ultraviolet wave bands.

The X-ray data were first screened with the XMM SAS version 5.4 software and events corresponding to patterns 0–4 (single- and double-pixel events) were selected for the pn data and patterns 0–12 for MOS1 and MOS2, the latter then being combined. A low-energy cut of 300 eV was applied to all X-ray data, and known hot or bad pixels were removed. Source counts were obtained from a circular region of 45" radius centered on 1H 0419–577, with the background being taken from a similar region offset from, but close to, the source. The X-ray light curve of 1H 0419–577 was essentially flat throughout the observation, and the background rate was low. We therefore integrated the total data set for spectral analysis. Individual EPIC spectra were binned to a minimum of 20 counts per bin to facilitate use of the $\chi^2$ minimization technique in spectral fitting. RGS data were initially grouped in sets of 10 spectral bins to aid the detection of weak features. Spectral fitting was based on the XSPEC package (Arnaud 1996), and all fits included absorption due to the line-of-sight galactic column $N_H = 2 \times 10^{20}$ cm$^{-2}$. Errors are quoted at the 90% confidence level ($\Delta \chi^2 = 2.7$ for one interesting parameter).

3. EPIC SPECTRUM

Figure 1 shows the overall shape of the EPIC 0.3–10 keV spectrum, compared with a simple power-law fit, with photon index $\Gamma \approx 1.49$. In addition to the usual (but more extreme) curvature found in such a fit to Seyfert 1 spectra, sharp features are seen in both pn and MOS data at $\sim 0.5$ and $\sim 6$ keV. The former feature lies close to the neutral oxygen edge in the instrument response but also coincides with potentially strong O vii and O viii emission lines (a possibility we check in § 4 with the higher resolution RGS data). The high-energy spectral feature is suggestive of a strong, relativistically broadened Fe K emission line or a deep Fe K absorption edge. We test those alternatives below.

3.1. 2–10 keV Spectral Fit with a Laor Line and Continuum Reflection

We began our spectral analysis of the EPIC data by fitting a power law over the hard X-ray (2–10 keV) band, hoping thereby to exclude the effects of soft X-ray emission and/or low-energy absorption. This fit yielded an extremely flat power law, with a photon index of $\Gamma \sim 1.06$ (pn) and $\Gamma \sim 1.02$ (MOS). Statistically, the simple power-law fit over the 2–10 keV band was quite good, with $\chi^2$ of 692 for 626 degrees of freedom (dof). However, the spectral feature below $\sim 6$ keV is clearly seen in both pn and MOS data (Fig. 2). The addition of an absorption edge improved the fit ($\chi^2$ of 617/622 dof), with an edge energy (in the AGN rest frame) of 7.10 $\pm$ 0.06 keV (pn) and 7.07 $\pm$ 0.07 keV (MOS). The coincidence of this value with the K edge of neutral Fe is a clear indicator of strong reflection or line-of-sight absorption in "cold" matter. However, the power law plus absorption edge fit still left substantial curvature in the data: model residuals.

Since the spectral curvature in the 2–6 keV band is reminiscent of an extreme relativistic Fe K emission line, a Laor emission line (Laor 1991) was then added to the power-law continuum (without the added absorption edge). An excellent fit was then obtained ($\chi^2$ of 589 for 620 dof) for a (rest-frame) line energy of 6.4 $\pm$ 0.3 keV, disk emissivity index $\beta \sim 4.5$, and inner radius $r_{\text{in}} \sim 1.5r_g$, where $r_g$ is the gravitational radius. The disk inclination was 44° $\pm$ 4° in this fit. In addition to being extremely broad, the required line equivalent width (EW) was also large, at $\sim 0.9$ keV in both pn and MOS spectral fits. The underlying power-law slope was essentially unchanged by the addition of the Laor emission line.

Since the Laor line arises by reflection (implicitly from the inner accretion disk) it must be accompanied by strong continuum reflection in a physically realistic fit. Given that the above absorption edge fit lies close to 7.1 keV (the K edge energy of neutral Fe), we chose to model the continuum reflection with PEXRAV in XSPEC (Magdziarz & Zdziarski 1995), setting the high-energy cutoff at 150 keV, with solar abundances and the reflection factor $R$ initially at 4 (to match the high Laor line EW). The subsequent best fit, with $R$ set...
free, was again very good ($\chi^2$ of 584 for 619 dof), with the power-law slope increased by $\Delta\Gamma \sim 0.34$ in both pn and MOS (normalization $\sim 5.3 \times 10^{-4}$ photons cm$^{-2}$ s$^{-1}$) and a reflection factor $R = 3.5 \pm 1.5$. The Laor line parameters were little changed by the addition of the continuum reflection, the line being still broad and strong.

### 3.2. Extending the Spectral Fit to 0.3 keV

Fixing the above 2–10 keV spectral parameters and extrapolating the fit to 0.3 keV showed a shallow deficit of flux between $\sim 1$ and 2 keV and a strong excess below $\sim 1$ keV. The addition of a blackbody component of $kT \approx 90$ eV modeled the soft excess quite well, but it was necessary to free the power-law and Laor line parameters to fit the data at 1–2 keV. A flattening of the power-law indices by power-law and Laor line parameters to fit the data at 1–2 keV. The addition of a blackbody component of $kT$ between extrapolating the fit to 0.3 keV showed a shallow deficit of flux blackbody component, $0^\circ$ (normalization power-law slope increased by $10^\circ$ then formally acceptable ($^\circ$ to $^\circ$). The significant improvement to the broadband fit, which was $^\circ$ of the main contributor to the data: model residuals. The addition of a Gaussian emission line to model this feature gave a further significant improvement to the broadband fit, which was then formally acceptable ($^\circ$ of 991 for 1039 dof), for a narrow line ($\sigma = 40 \pm 20$ eV) at 0.61 $\pm 0.01$ keV (pn) and 0.57 $\pm 0.01$ keV (MOS), with an EW $\sim 50$ eV.

We illustrate the overall “Laor line/PEXRAV” model spectrum in Figure 3 and list the parameters of the model in Table 1. While complex, this model does provide an excellent fit to the data. We briefly discuss the physical implications in § 6.1.

The good match of model and data allows the mean X-ray fluxes and luminosity of 1H 0419$-$577 during the 2002 September XMM-Newton observation to be derived. These were $1.9 \times 10^{-12}$ ergs s$^{-1}$ cm$^{-2}$ (0.3–1 keV), with $\sim 67\%$ in the blackbody component, $0.9 \times 10^{-12}$ ergs s$^{-1}$ cm$^{-2}$ (1–2 keV), and $8 \times 10^{-12}$ ergs s$^{-1}$ cm$^{-2}$ (2–10 keV). Combining these fluxes yields a 0.3–10 keV luminosity for 1H 0419$-$577 in the “low state” of $2.3 \times 10^{44}$ ergs s$^{-1}$ ($H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$).

### 3.3. Partial Covering Fit

Several recent studies (e.g., MCG$-$6-30-15: Inoue & Matsumoto 2003; PG 1211+143: Pounds et al. 2003c) have pointed out that partial covering of the power-law continuum by absorbing matter can impose spectral curvature over the $\sim 3$–7 keV band that is very similar in appearance to a relativistic Fe K emission line. To test this alternative fit for the low-state EPIC data of 1H 0419$-$577, we next considered a model in which a fraction of the power-law continuum is obscured by an ionized absorber, using the ABSORI model in XSPEC. The outcome was that both the 3–6 keV spectral curvature and the absorption edge (observed at $\sim 6.4$ keV, but at $\sim 7.1$ keV in the AGN rest frame) were well fitted with 60% $\pm 15\%$ of the power law being covered by weakly ionized matter of ionization parameter $\xi = L/n_e^2 \lesssim 0.3$ ergs cm$^{-1}$ and column density $N_H = 4.3 \pm 0.4 \times 10^{22}$ cm$^{-2}$. The power-law index in this fit was less extreme, with $\Gamma \sim 1.48$ (pn) and $\Gamma \sim 1.36$ (MOS). While these partial covering parameters are not unique, nonsolar abundances and a range of ionization parameters allowing alternative fits to the spectral curvature, the observed absorption edge near 7 keV requires the mean ionization state to be low. Higher resolution spectra will be required to further constrain such absorbing matter.

Unlike for the Laor line/PEXRAV model, extrapolation of the 2–10 keV partial covering model remained a good fit to $\sim 1$ keV, below which a blackbody component was required to model the strong soft excess. Once again, this broadband continuum fit left a significant excess of flux near $\sim 0.5$ keV. Modeling this feature with a Gaussian emission line produced similar parameters to those found in § 3.2, giving a 0.3–10 keV broadband fit of very similar overall quality ($\chi^2$ of 997 for 1038 dof). In this partial covering fit it is interesting to note the data: model residuals now show an excess just below 6 keV. Adding, finally, a Gaussian emission line to the partial covering model gave a further small, but statistically significant, improvement of $\Delta\chi^2 \sim 16$ for four additional parameters. The full details of the partial covering fit are listed in Table 2, and the model is illustrated in Figure 4. We discuss the physical implications of this model and compare it with the Laor line/PEXRAV model in § 6.1.

To clarify the $\sim 0.5$ keV emission feature seen in both the above fits to the EPIC spectra, and search for other structure in the soft X-ray spectrum of 1H 0419$-$577, we then examined the simultaneous RGS data.

### 4. Spectral Lines in the RGS Data

Both Laor and PC fits to the EPIC data indicate a strong soft excess above an extension of the hard power law and a narrow emission feature at $\sim 0.55$–0.65 keV.

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**TABLE 1**

| Parameter                  | pn   | MOS  |
|----------------------------|------|------|
| Power-law $\Gamma$         | 1.26 $\pm 0.09$ | 1.23 $\pm 0.09$ |
| O vi/O viii Emission:      |      |      |
| $E$ (keV)                  | 6.9 $\pm 0.4$   |      |
| $\sigma$ (eV)              | 7.5 $\pm 0.5$   |      |
| Flux (10$^{-4}$ photons cm$^{-2}$ s$^{-1}$) | 1.3 $\pm 0.2$   |      |
| EW (keV)                   | 46 $\pm 4$      |      |
| Blackbody $kT$ (eV)        | 1.1 $\pm 0.3$   |      |
| Laor Line:                 |      |      |
| $E$ (keV)                  | 6.9 $\pm 0.4$   |      |
| $\beta$                    | 7.5 $\pm 0.5$   |      |
| $n_0$ ($n_e$)              | 1.3 $\pm 0.2$   |      |
| $\theta$ (deg)             | 46 $\pm 4$      |      |
| EW (keV)                   | 1.1 $\pm 0.3$   |      |

**Fig. 3.**—Unfolded model spectrum described in § 3.2. Components are power law (red) plus reflection (green), Laor line (purple), blackbody (dark blue), and narrow Gaussian emission line (pale blue).
To gain further insight on the soft X-ray spectrum, we examined the simultaneous XMM-Newton grating data of 1H 0419−577. We began by jointly fitting the RGS-1 and RGS-2 data with a power-law and blackbody continuum (from the corresponding EPIC 0.3–10 keV fits) and examining the data: model residuals by eye. The only obvious features (Fig. 5) were emission lines observed at ~21 and ~24 Å. To quantify these features we then added Gaussian emission lines to the power-law plus blackbody continuum fit in XSPEC, with wavelength, line width, and flux as free parameters. In each case the line width is unresolved, indicating a FWHM ≤ 2000 km s⁻¹, although this value is not well constrained given the low RGS count rates. The fitted spectrum is shown in Figure 6.

In the rest frame of 1H 0419−577 the line wavelengths are 22.02 ± 0.05 and 18.99 ± 0.05 Å, corresponding closely to the laboratory wavelengths of the forbidden O vii line (22.095 Å) and the resonance O viii Lyα line (18.969 Å). The fitted line fluxes were 6.1 and 7.7 × 10⁻⁵ photons s⁻¹ cm⁻², respectively, corresponding to equivalent widths of 18 and 28 eV. When blended in the lower resolution EPIC data, these two strong emission lines match well with the Gaussian emission feature required in both pn and MOS spectral fits. The statistical quality of the joint RGS fit was significantly improved by the addition of the two lines, with a reduction in χ² of 36 for 4 fewer dof.

Although the constraints on other emission (or absorption) lines in the RGS data are weak, because of the low-flux state of 1H 0419−577, the dominance of the forbidden line of the O vii triplet is a clear signature of a photoionized plasma, with an electron density ≤ 10¹⁰ cm⁻³ (Porquet & Dubau 2000). The equally strong O vii Lyα emission indicates an ionization parameter ξ (≡ L/nr², where n is the gas density at a distance r from the ionizing source of luminosity L) of order 45 ± 10 (Kallman & McCray 1982). Assuming a solar abundance of oxygen, with 40% in O vii, 50% of recombinations from O viii direct to the ground state, and a low temperature recombination

Table 2: Partial Covering Model (Parameters in AGN Rest Frame)

| Parameter                  | pn     | MOS    |
|----------------------------|--------|--------|
| Power Law:                 |        |        |
| Γ                          | 1.50 ± 0.05 | 1.38 ± 0.06 |
| Normalization (10⁻² photons cm⁻² s⁻¹ keV⁻¹) | 6.3 ± 0.2 | 6.2 ± 0.2 |
| Partial Covering Absorber: |        |        |
| Normalization (10⁻² photons cm⁻² s⁻¹ keV⁻¹) | 9.6 ± 1.4 | 7.2 ± 1.4 |
| N_0 (10²² cm⁻²)            | 4.3 ± 0.4 | ...    |
| ξ                          | ≤0.3   | ...    |
| Blackbody 𝐾 total (eV)     | 87 ± 2 | ...    |
| O vii/O viii Emission:     |        |        |
| E (keV)                    | 0.61 ± 0.01 | 0.57 ± 0.01 |
| σ (eV)                     | 48 ± 15 | ...    |
| Flux (10⁻⁴ photons cm⁻² s⁻¹) | 2.9 ± 0.7 | 2.5 ± 1.6 |
| EW (eV)                    | ~65    | ~53    |
| Emission line:             |        |        |
| E (keV)                    | 6.21 ± 0.11 | ...    |
| σ (eV)                     | 160 ± 110 | ...    |
| Flux (10⁻⁴ photons cm⁻² s⁻¹) | 11 ± 8   | 10 ± 7 |
| EW (eV)                    | ~84    | ~88    |
| χ²/dof                     | 981/1034 | ...    |

Fig. 4.—Unfolded model spectrum described in § 3.3. Components are partially covered power law (red and purple), blackbody (green), and Gaussian emission lines (blue) at ~0.6 and ~6.3 keV.

Fig. 5.—Ratio of RGS data to a power-law and blackbody continuum fit revealing apparent emission lines near 21 and 24 Å.
rate of $10^{-11}$ cm$^3$ s$^{-1}$ (Verner & Ferland 1996), we deduce an emission measure for the forbidden line flux of order $2 \times 10^{66}$ cm$^{-3}$.

A further constraint on this ionized emission region can be obtained from the relevant ionization parameter. Assuming a "typical" (mean 1H 0419-577 flux) ionizing luminosity for K-shell oxygen of $L_{\text{ox}} = 2 \times 10^{44}$ ergs s$^{-1}$, with $\xi \approx 45$, we find $m^2 \approx 4 \times 10^{42}$ cm$^{-1}$. Combining this value with the above emission measure then gives $r \approx 3 \times 10^{19}$ cm for a uniform spherical distribution of photoionized gas and a particle density $n \approx 8 \times 10^{19}$ cm$^{-3}$. Such a low-density plasma would have an equilibration time of $\sim 1$ yr, supporting the above assumption of a flux-averaged ionizing luminosity. In our analysis of the later XMM-Newton observations of 1H 0419-577, it will be instructive to see how the strong line emission from O vii and O viii varies, if at all, noting also the light travel time across a region as large as we estimate will be $\sim 30$ yr.

5. COMPARISON WITH THE EARLIER HIGH-FLUX XMM-NEWTON OBSERVATION

A detailed analysis of the large-scale spectral variability in 1H 0419-577 should be possible by combining the data from all six XMM-Newton observations made over the 15 month period from 2002 September. The scale of the broadband variability may already be indicated, however, by comparing the present low-flux state spectrum with the previously published pn observation from 2000 December (Page et al. 2002). Figure 7 illustrates the degree of variability by comparing the ratio of the 2000 December data to the best-fit 2–10 keV power law ($\Gamma = 1.9$), with the ratio of the 2002 September data to the same power law. The two data sets are seen to be quite similar at the highest energies, while diverging strongly below $\sim 5$ keV.

To assess the gross features of the spectral variability, we then obtained the difference spectrum of the two background-subtracted pn data sets (adjusted for the different exposures) and compared the resulting data with a simple power law. The fit was surprisingly good, with a power law of $\Gamma = 2.45 \pm 0.1$ modeling the difference spectrum closely from 0.3 to 2 keV (Fig. 8). To check the apparent steepening of the power law at higher energies we regrouped the data to a minimum of 500 bins, to ensure adequate statistics in the highest energy data points. Fitting the difference spectrum above 2 keV then confirmed a significant steepening in the spectral slope, to $\Gamma = 2.7 \pm 0.1$ (2–10 keV).

That comparison of the new "low-state" EPIC spectrum with the earlier "high-state" spectrum shows rather unambiguously that the large-scale spectral variability in 1H 0419-577 is dominated by a steep power-law component. Furthermore, the steep power-law fit to the difference spectrum, $\Gamma \approx 2.45$, implies that no "separate" variable soft emission (blackbody) component is required. The gradual steepening of the difference spectrum at higher energies appears to be real and may offer an important clue to the physical origin of the variable component. One obvious candidate is Comptonization, and a trial fit with $\text{compTT}$ in XSPEC (Titarchuk 1994) gave an excellent fit ($\chi^2$ of 101 for 105 dof), with input photons of $kT \approx 70$ eV and an optically thick Comptonizing plasma ($\tau = 4.5 \pm 1$) at $kT = 2.6 \pm 0.9$ keV reproducing the mean slope and high-energy downturn in the difference spectrum.
Future analysis of the full XMM-Newton data set should shed further light on this interesting outcome.

6. DISCUSSION

There are three points of particular note resulting from the XMM-Newton observation of 1H 0419−577 reported here.

Particularly remarkable is the extremely hard (flat) power-law spectrum that approximates to the EPIC data over the 2–10 keV band. A spectral index $\Gamma \sim 1.0$ is flatter than any reported previously for this highly variable source, lying below all previous X-ray spectra (see Fig. 3 in Page et al. 2002). In comparison, we recall that the $\sim 2–10$ keV continua of radio-quiet AGNs have a photon index usually in the range $\Gamma = 1.7–2.0$ (Nandra & Pounds 1994; Reeves & Turner 2000). Second, although the RGS features are relatively faint, the unambiguous detection of emission lines of O vii and O viii provides clear evidence for an extended region of photoionized gas in the nucleus of 1H 0419−577. Finally, a comparison of the raw EPIC data with data obtained in 2000 December, when 1H 0419−577 was considerably brighter, gives a model-independent indication that the large-scale spectral variability in 1H 0419−577 is primarily due to a variable, steep power-law component.

6.1. Relativistic Fe K Line or Partial Covering?

However modeled, the 2–10 keV spectrum of 1H 0419−577 observed in 2002 September was very unusual. Although the addition of strong reflection, or of partial covering, allowed for a steeper underlying power-law continuum, it remained sufficiently flat to require rather extreme conditions for Comptonization models (Svensson 1994; Haardt, Maraschi, & Ghisellini 1997), suggesting in particular a “photon-starved” scenario. Although still to be proven by the analysis of further observations, the simple form of the difference spectrum (obtained by subtracting the present EPIC spectrum from that of 2000 December) suggests the hard “low-state” spectrum remained “constant” over that 21 month interval. The implication might be for a “core” accretion disk component that is located in a region of high gravity (the reflection-dominated Laor line fit) or is overlain by substantial cool absorbing matter.

Our finding that extreme relativistic Fe K emission-line and partial covering models fit the spectral curvature in the $\sim 3–7$ keV band adds equally well to a growing number of such cases, most recently the low-luminosity Seyfert NGC 4051 (Pounds et al. 2003b). Both models raise obvious questions in applying to a low-flux state, as seen here for 1H 0419−577. In the former case there is the concern that strong illumination of the innermost accretion disk, required to explain the extreme relativistic broadening of the Fe K emission line, is counterintuitive when the X-ray luminosity is apparently so low (but see Miniutti & Fabian 2003), while in the latter the partial covering requires a structured absorber covering the hard X-ray source, but not the region of soft X-ray emission. Statistically, our fits to the EPIC data are equally good, and—once again—higher energy data are needed to discriminate between the two models. Although not conclusive, it is interesting to note that extending the EPIC fits to 12 keV offers some support for the PC model, where the data: model residuals remain small (Fig. 4), whereas for the Laor line/PEXRAX model the flatter model continuum significantly overpredicts the data (Fig. 3).

Further circumstantial evidence in favor of the PC model fit may be taken from the detection, in that case, of a nonrelativistic Fe K line. The line is weak, having an EW (against the total power-law continuum) of only $\sim 85$ eV, and hence poorly constrained. Although the line energy is only barely compatible with fluorescence from neutral iron, the partial covering model does offer a natural origin for an Fe K emission line of that order, by continuum absorption and fluorescent reemission from the substantial column of overlying gas (Makishima 1986). Incidentally, that explanation would leave little room for the narrow 6.4 keV line found to be a prominent feature in many lower luminosity Seyfert galaxies (and believed to arise from matter distant from the black hole, e.g., a molecular torus), consistent with an emerging view that the EW of the narrow Fe K line is anti-correlated with luminosity (Page et al. 2004).

6.2. Extended Photoionized Gas in 1H 0419−577

Although only two emission lines were clearly detected in the RGS spectrum of 1H 0419−577, taken together they provide a surprisingly powerful diagnostic of the emitting gas. Most useful is the detection of the forbidden line of O viii, since its relative strength (in the O vii + O viii triplet) shows photoionization to be the dominant process and sets a limit on the plasma density, while the measured line flux provides a straightforward estimate of the emission measure. The detection of a similarly strong O viii Ly$\alpha$ resonance line (usually seen in absorption in Seyfert 1 galaxies, and perhaps enhanced here because of the low-continuum flux of 1H 0419−577) allows the ionization parameter of the photoionized gas to be calculated, assuming a common location of the O vii and O viii gas. The emission measure and ionization parameter then provide estimates of the scale ($3 \times 10^{19}$ cm) of a spherical emission region of particle density $\sim 8 \times 10^3$ cm$^{-3}$. A corresponding mass for this extended gas envelope is then $8 \times 10^5 M_\odot$. Although evidence that this gas is associated with an outflow must await a search for the corresponding absorption lines in the later XMM-Newton observations of 1H 0419−577, a typical (Seyfert 1) outflow velocity of 300 km s$^{-1}$ (e.g., Kaspi et al. 2002) could replenish this region in $\sim 3 \times 10^4$ yr.

6.3. Spectral Variability

Comparison of the EPIC pn data from the observation reported here, with that from a much brighter state of 1H 0419−577 in 2000 December, has yielded some fascinating indicators. The large-scale change in the X-ray spectrum can be described by a variable intensity, fixed slope, power law, which is sufficiently steep as not to require a separate variable soft (blackbody) component. This is similar to the conclusion of Fabian & Vaughan (2003) from the long XMM-Newton observation of MCG$-$6-30-15, although in that case the index of the variable power-law component was lower. We also note that if the hard power-law component does remain unchanged (as implied by the simple form of the difference spectrum), then it seems reasonable to conclude that the corresponding emission mechanism and location are physically distinct from the variable power-law component.

If the variable X-ray component arises by Comptonization of accretion disk photons, the scale of spectral change between the two XMM-Newton observations may be sufficiently great to require a structural change in the inner accretion disk and/or corona. We have some evidence that the thermal disk emission
was significantly stronger during the 2000 December observation, since the OM UVW1 channel (the only live one) was 0.9 mag brighter than on the second occasion. Again, it is interesting to note that the variable power-law component has a spectral index ($\Gamma \sim 2.5$) similar to that predicted for scattering in an optically thick ($r \sim 1$) corona (Haardt et al. 1997), suggesting the change is mainly in the scattering medium. Our simple $\text{compTT}$ fit to the difference spectrum ($\S$ 5) is consistent with that interpretation.

In addition to direct or upscattered disk radiation, a significant emission component might be associated with an energetic outflow, as recently found in several luminous AGNs (Chartas et al. 2002; Pounds et al. 2003a, 2003c; Reeves, O'Brien, & Ward 2003). While in those cases in which high-velocity outflows have been confirmed they appear to be linked to a high (Eddington or super-Eddington) accretion rate (King & Pounds 2003), the evidence for column densities of highly ionized gas in excess of $N_H \sim 10^{23}$ cm$^{-2}$ is becoming more common for Seyfert 1 galaxies (e.g., Bianchi et al. 2003). The important point is that the kinetic energy in a high-velocity flow can be comparable to the accretion energy, offering the possibility—perhaps via shocks in the outflow—of an additional X-ray emission component. It is interesting to speculate that the steep power law characterizing the spectral variability in 1H 0419−577 might arise in this way, by providing the additional Comptonizing electrons or even by thermal emission.

The extensive new $\text{XMM-Newton}$ observations of the large-scale spectral variability of 1H 0419−577 should shed new light on the emission mechanism(s), which make AGNs characteristically powerful X-ray sources.

7. SUMMARY

A new $\text{XMM-Newton}$ observation of the luminous Seyfert 1 galaxy 1H 0419−577 has found the source to be in an extreme low flux state. The 2−10 keV spectrum is unusually hard, being approximated by a power law of $\Gamma \sim 1.0$. However, significant residuals are seen in the power-law fit, which can be modeled by either a relativistic Fe K emission line or by partial covering by a substantial column of near-neutral gas. Detection of emission lines of O vii and O viii indicates the presence in 1H 0419−577 of an extended region of highly ionized gas. A comparison of the present X-ray spectrum of 1H 0419−577 with that obtained in a short observation by $\text{XMM-Newton}$ 2 years earlier, when the source was much brighter, shows that the spectral variability is dominated by a previously unrecognized steep power-law component.

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