Variable X-ray reflection from 1H 0419–577

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ABSTRACT
We present detailed broadband X-ray spectral variability of a Seyfert 1 galaxy 1H 0419–577 based on an archival Suzaku observation in July 2007, a new Suzaku observation performed in January 2010 and the two latest XMM-Newton observations from May 2010. All the observations show soft X-ray excess emission below 2 keV and both Suzaku observations show a hard X-ray excess emission above 10 keV when compared to a power-law. We have tested three physical models – a complex partial covering absorption model, a blurred reflection model and an intrinsic disk Comptonization model. Among these three models, the blurred reflection model provided statistically the best-fit to all the four observations. Irrespective of the models used, the soft X-ray excess emission requires contribution from a thermal component similar to that expected from an accretion disk. The partial covering absorption model results in a nonphysical high temperature (kT_e ≈ 100 eV) for an accretion disk and is also statistically the worst fit among the three models. 1H 0419–577 showed remarkable X-ray spectral variability. The soft X-ray excess and the power-law both became weaker in January 2010 as well as in May 2010. A moderately broad iron line, detected in July 2007, is absent in the January 2010 observation. Correlated variability of the soft X-ray excess and the iron Kα line strongly suggest reflection origin for both the components. However, such spectral variability cannot be explained by the light bending model alone and requires changes in the accretion disk/corona geometry possibly arising from changes in the accretion rate.

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

1 INTRODUCTION
Active Galactic Nuclei (AGNs) exhibit complex X-ray spectra. Seyfert 1 galaxies generally show three primary components – power-law continuum, soft X-ray excess below 2 keV and reflection including an Fe Kα line. The powerlaw component is thought to arise due to Comptonisation of soft photon from an accretion disk in a hot corona, either above and below the accretion disk in a sandwich configuration or around the central super-massive black hole (SMBH) (Sunyaev & Titarchuk 1980; Haardt & Maraschi 1991; Reynolds & Nowak 2003). The origin of the soft X-ray excess emission is not clearly understood. It is likely the blurred reflection from a partially ionised accretion disk (Ross & Fabian 1993; Fabian et al. 2002a). The soft excess could also arise due to the Comptonization of optical/UV radiation from the accretion disk in a low temperature, optically thick medium (Magdziarz et al. 1998; Done et al. 2012). The Fe Kα line near 6 keV and the Compton hump in the ~ 10 – 40 keV band are together known as the X-ray reflection. The Fe Kα line arises due to the photoelectric absorption followed by fluorescent line emission. The Compton hump is the result of two competing processes, the photoelectric absorption and the Compton scattering of the illuminating powerlaw continuum (Guilbert & Rees 1988; Lightman & White 1988). The reflection features arising from the inner disk are strongly modified due to the relativisitc effects near the SMBH, thus giving rise to the broad relativistic iron line (see e.g., Fabian et al. 2000; Reynolds & Nowak 2003). In most cases, Seyfert 1 galaxies exhibit the narrow iron Kα line and the Compton hump from distant optically thick matter such as the putative cold torus, and sometimes show a broad line (Reeves et al. 2007; Murphy & Yaqoob 2009).

The primary X-ray emission of Seyfert 1 galaxies may be affected by absorption in the neutral and partially ionised material along the line of sight. Approximately 50% Seyfert galaxies show absorption features e.g., due to OVII and OVIII, in their spectra near 1 keV (e.g., Blustin et al. 2005; Piconcelli et al. 2005). These absorption lines and edges are due to the presence of the warm ionised matter which is named as “warm or ionised absorber” (Halpern 1984; Turner et al. 1991; Netzer 1993; Kaastra et al. 2000). In some cases, the absorption lines are found in the Fe K band (Pounds et al. 2003; Dadina et al. 2005; Risaliti et al. 2005; Braito et al. 2007; Reeves et al. 2009; Cappi et al. 2009; Tombesi et al. 2010a). Sometimes emission lines from the warm absorbing clouds are also observed (e.g., Laha et al. 2011). The absorbing clouds may be neutral or partially ionised and may obscure the central source partially (see e.g., Turner et al. 2009). The mul-
multiple warm and partial covering absorbers may modify the primary continuum in a complex way (Pounds et al. 2004a,b; Turner et al. 2009; Maiolino et al. 2010). These absorbers can mimic reflection features in the X-ray spectrum (Turner & Miller 2009; Risaliti et al. 2009). Thus the reflection and absorption play a crucial role in shaping the X-ray spectrum. The broad iron Kα line and the reflection are the most important signatures currently available to probe the central engine. Hence it is important to investigate the presence of the complex absorption and remove its effects on the reflection features in order to probe the central engine. Sometimes the complex absorption and reflection models both describe the data equally well and it is difficult to rule out one of these models (Miller et al. 2008; Turner & Miller 2009). The variability of different spectral components and the relationship between them i.e., the broadband X-ray spectral variability can provide additional constraints that may help unravel the real physical model. Here we study the broadband spectral variability of Seyfert 1 galaxy 1H 0419–577—an AGN in which the complex absorption and/or the reflection may be shaping the broadband continuum.

1H 0419–577 is a radio-quiet AGN at a redshift \( z = 0.104 \) and is optically classified as a broad-line Seyfert 1 galaxy (Brisken et al. 1987; Grupe 1996; Guainazzi et al. 1998; Turner et al. 1999). It was observed by both the Extreme Ultraviolet Explorer (EUVE) (Marshall et al. 1995) and ROSAT Wide Field Camera (Pye et al. 1995). It has been detected as one of the brightest AGN in the extreme ultra-violet band. 1H 0419–577 has also shown interesting spectral variability – strong steepening (\( \Gamma \sim 2.5 \)) to a more flat power-law continuum (\( \Gamma \sim 1.6 \)). This variable spectral form has suggested a strong transition due to a decrease in high energy X-axis rate from quasi- to sub-Eddington rates (Guainazzi et al. 1998; Turner et al. 1999; Pounds et al. 2004a). The first Suzaku observation of 1H 0419–577 has been studied by Turner et al. (2009) and Walton et al. (2010) in detail. Turner et al. (2009) described the broadband X-ray spectrum of this source by a power-law modified by multiple partial covering absorption (PCA) components – (i) absorption column \( N_{\text{H}} \sim 1.8 \times 10^{24} \text{ cm}^{-2} \), covering fraction \( C_f \sim 66\% \), and (ii) \( N_{\text{H}} \sim 5.4 \times 10^{22} \text{ cm}^{-2} \), \( C_f \sim 16\% \). They could not explain the hard excess by reflection and claimed that the hard excess is caused by the Compton thick absorber (\( N_{\text{H}} \sim 1/1.25 \sigma_T > 1.25 \times 10^{24} \text{ cm}^{-2} \)). Whereas, Walton et al. (2010) showed that the broadband X-ray spectrum obtained from the same Suzaku observation is well described by a complex blurred reflection model with a broken emissivity law (emissivity indices: \( q_0 > 8.7 \) below a break radius \( r_{br} \sim 2.4 r_g \) and \( q_{out} \sim 5 \) above the break radius) and inferred a large inclination angle (\( \sim 55^\circ \)). Here we investigate these models using a new Suzaku observation and two new XMM-Newton observations in addition to the first Suzaku observation already studied by Turner et al. (2009) and Walton et al. (2010). In section 2, we describe the Suzaku and XMM-Newton observations and data reduction. We present spectral modelling in section 3. Finally, we discuss our results in section 4, followed by conclusions in section 5. We used the cosmological parameters \( H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \Omega_m = 0.27 \) and \( \Omega_{\Lambda} = 0.73 \) to calculate the distance.

2 OBSERVATION AND DATA REDUCTION

2.1 Suzaku observations

1H 0419–577 has been observed twice with the Suzaku X-ray observatory. The first observation was performed in July 2007 for an exposure time of 205 ks and the second observation was performed in January 2010 for an exposure time of \( \sim 123 \text{ ks} \) (see Table 1). The first observation has been analysed by Turner et al. (2009) and Walton et al. (2010). Here, we present a detailed analysis of the second new Suzaku and recent XMM-Newton observations and compare with the first Suzaku observation.

We reprocessed XIS and PIN data using the software HEASOFT v6.12 and the recent calibration data following the Suzaku ABC guide (v3.2) \(^1\). We used apipeline to reprocess and filter the unfiltered event lists and created the cleaned event files. We used xselect to extract spectral products for each of the XIS camera. We extracted source spectra from a circular region with a radius of \( 260'' \) centred on the source position. We also extracted the background spectra using circular regions with radii in the range \( 83–123'' \) avoiding the source and the chip corner where the calibration sources are registered. We generated the ancillary response and the redistribution matrix files for each XIS spectral dataset using xissimarfgen and xisrmfgen.

The HXD is a collimating rather than an imaging instrument and the estimation of background requires the non X-ray instrumental background (NXB) and cosmic X-ray background (CXB). We used hxdpinxbpi to create source and combined NXB+CXB background spectra. This script requires cleaned event file, the pseudo event file, and the NXB file. We obtained the tuned background file for this observation provided by the Suzaku team \(^2\). This script also applies dead time correction to the source spectrum using hxdtdcorr.

We grouped the XIS and PIN spectral data in order to use the \( \chi^2 \) statistics in our spectral fittings. The XIS spectra were grouped to result in \( \sim 250 \) bins so that there are about three energy bins per resolution element of size \( \sim 100 \text{ eV} \). The PIN spectra were grouped to result in \( \sim 50 \) energy bins. Our grouping scheme ensured that there are more than 20 counts per bin in the grouped spectra.

\(^1\) http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/
\(^2\) ftp://legacy.gsfc.nasa.gov/suzaku/data/background/pinxbver2.0tuned/
seven observations have been studied by various authors (Tombesi et al. 2003; Pounds et al. 2004a,b; Page et al. 2002). The latest X-ray observations of 1H 0419–577 were performed in May 2010 (observation ID: 0604720301 and 0604720401) with exposure times of 106.4 ks and 106.2 ks. The EPIC-pn camera (Turner et al. 2001) was operated in the small window mode using the thin filter. The deviations of the observed data XIS0 (solid triangle), XIS1 (open circle), XIS3 (cross) and PIN (open square), from the best-fitting models wabs(powerlaw+zgauss) (upper panel), wabs(powerlaw+zbbbody+zgauss) (middle panel) and wabs×zpcfabs(powerlaw+zbbbody+zgauss) (lower panel) in the 0.6 – 50 keV band.

2.2 XMM-Newton May 2010 observation

XMM-Newton has observed 1H 0419–577 nine times. The previous seven observations have been studied by various authors (Tombesi et al. 2012, 2010b; Walton et al. 2010; Turner et al. 2009; Fabian et al. 2005; Pounds et al. 2004a,b; Page et al. 2002). The latest two observation were performed in May 2010 (observation ID: 0604720301 and 0604720401) (see Table 1) with exposure times of 106.7 ks and 61 ks. The EPIC-pn camera (Turner et al. 2001) was operated in the small window mode using the thin filter.

Table 1. Suzaku and XMM-Newton X-ray observations of 1H 0419–577

| Observatory | Obs. ID | Date             | Instrument          | Net exposure (ks) | Rate \(^{a}\) counts s\(^{-1}\) |
|-------------|---------|------------------|---------------------|-------------------|-------------------------------|
| Suzaku      | 704064010 | Jan. 16–18, 2010 | XIS0                | 123               | 0.91 ± 0.003                  |
|             | "       | July 25–28, 2007 | HXD/PIN             | 105               | (3.8 ± 0.2) × 10\(^{-2}\)    |
|             | "       | May 30–31, 2010  | XIS0                | 205               | 1.4 ± 0.003                   |
|             | "       | May 28–29, 2010  | HXD/PIN             | 143               | (4.8 ± 0.2) × 10\(^{-2}\)    |
| XMM-Newton  | 0604720301 | May 30–31, 2010  | EPIC-pn             | 107               | 11.86 ± 0.02                  |
|             | "       | May 28–29, 2010  | EPIC-pn             | 61                | 10.88 ± 0.02                  |

Note-- Count rates for XIS0 and HXD/PIN are quoted in the 0.6 – 10 keV band and 15 – 50 keV band, respectively.

Table 2. Best fit parameters of powerlaw plus Gaussian line model fitted to the 2.5 – 10 keV Suzaku XIS and XMM-Newton EPIC-pn spectra.

| Parameter                          | Suzaku (704064010) | Suzaku (702041010) | XMM-Newton (0604720301) | XMM-Newton (0604720401) |
|------------------------------------|---------------------|---------------------|--------------------------|--------------------------|
| \(\Gamma\) \(\text{keV}\)        | 1.77 ± 0.02         | 1.78 ± 0.01         | 1.67 ± 0.03               | 1.64 ± 0.03               |
| \(E_{FeK\alpha}\) \(\text{keV}\) | 6.35\(^{+0.03}_{-0.04}\) | 6.35 ± 0.11         | 6.30 ± 0.15               | 6.35\(^{+0.34}_{-0.32}\) |
| \(\sigma\) \(\text{keV}\)       | < 0.12              | 0.37\(^{+0.17}_{-0.14}\) | 0.2\(^{+0.3}_{-0.1}\)     | 0.4 ± 0.3                 |
| \(f_{FeK\alpha}\) \(^{a}\)      | 0.5 ± 0.2           | 1.3\(^{+0.5}_{-0.4}\) | 1.0\(^{+0.9}_{-0.8}\)     | 0.9\(^{+0.7}_{-0.6}\)    |
| \(f_{PL}\) \(^{b}\)            | 1.47\(^{+0.03}_{-0.02}\) | 1.76\(^{+0.02}_{-0.01}\) | 1.29\(^{+0.03}_{-0.01}\)  | 1.26 ± 0.01               |
| \(\chi^{2}/\text{dof}\)         | 367.2/343           | 386.2/353           | 310.7/295                | 189.5/176                 |
| \(\Delta \chi^{2}\) \(^{c}\)   | −18.5              | −46.9               | −15.4                    | −8.1                      |

Note – (a) Iron K\(\alpha\) line flux in units of \(10^{-5}\) photons cm\(^{-2}\) s\(^{-1}\); (b) 2 – 10 keV power-law flux in units of \(10^{-11}\) erg cm\(^{-2}\) s\(^{-1}\); (c) Represents reduction in \(\chi^{2}\) with extra three parameters for iron K\(\alpha\) line.

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Figure 2. The deviations of the observed data XIS0 (solid triangle), XIS1 (open circle), XIS3 (cross) and PIN (open square), from the best-fitting models wabs(powerlaw+zgauss) (upper panel), wabs(powerlaw+zbbbody+zgauss) (middle panel) and wabs×zpcfabs(powerlaw+zbbbody+zgauss) (lower panel) in the 0.6 – 50 keV band.
Table 3. Best fit parameter for Suzaku and XMM-Newton observations, and Fixed parameters are indicated by an asterisk.

| Component       | Suzaku (January 2010) | Suzaku (July 2007) | XMM-Newton (May 2010) | XMM-Newton (May 2010) |
|-----------------|-----------------------|--------------------|-----------------------|-----------------------|
| Gal. abs.       | $N_H (10^{20} \text{cm}^{-2})$ | 1.83 (*)           | 1.83 (*)              | 1.83 (*)              | 1.83 (*)              |
| Powerlaw        | $\Gamma$              | 2.27$^{+0.02}_{-0.03}$ | 2.33$^{+0.01}_{-0.01}$ | 2.52$^{+0.03}_{-0.03}$ | 2.44$^{+0.03}_{-0.03}$ |
| $n_{pd}$ (10$^{-2}$) | 2.0$^{+0.2}_{-0.2}$   | 3.1$^{+0.2}_{-0.2}$   | 2.9$^{+0.2}_{-0.2}$   | 2.6$^{+0.2}_{-0.2}$   |
| Zxpfc (1)       | $N_H (10^{23} \text{cm}^{-2})$ | 5.1$^{+0.7}_{-0.8}$ | 4.6$^{+0.4}_{-0.4}$ | 4.2$^{+0.5}_{-0.5}$ | 4.5$^{+0.5}_{-0.5}$ |
| $C_f$ (%)       | 50.0$^{+2.4}_{-5.2}$  | 60.0$^{+2.4}_{-5.2}$  | 66.1$^{+2.4}_{-5.2}$  | 67.2$^{+2.4}_{-5.2}$  |
| $\xi$ (erg cm$^{-s^{-1}}$) | 0.28$^{+0.07}_{-0.04}$ | 0.06$^{+0.04}_{-0.04}$ | 1.4$^{+1.1}_{-0.4}$ | 1.4$^{+1.1}_{-0.4}$ |
| Zxpfc (2)       | $N_H (10^{23} \text{cm}^{-2})$ | 1.4$^{+0.1}_{-0.1}$ | 1.3$^{+0.06}_{-0.06}$ | 0.53$^{+0.06}_{-0.05}$ | 0.58$^{+0.06}_{-0.05}$ |
| $C_f$ (%)       | 46.6$^{+1.3}_{-2.9}$  | 46.9$^{+1.3}_{-2.9}$  | 52.7$^{+2.8}_{-2.8}$  | 50.3$^{+2.8}_{-2.8}$  |
| $\xi$ (erg cm$^{-s^{-1}}$) | 88.2$^{+5.8}_{-5.8}$ | 77.8$^{+4.6}_{-4.6}$ | 20.0$^{+6.5}_{-6.5}$ | 23.4$^{+7.5}_{-6.5}$ |
| Pexmon          | $R$                    | $-0.13^{+0.07}_{-0.12}$ | $-0.12^{+0.07}_{-0.12}$ | $-0.10^{+0.10}_{-0.19}$ | $-0.002^{+0.002}_{-0.16}$ |
| $\chi^2/\nu$    | 613.3/500              | 786.9/541           | 560.5/423             | 585.0/419             |

| Component       | Model 2: Blurred reflection model |
|-----------------|----------------------------------|
| Nhcomp          | $\Gamma$                         |
| $kT_{in}$ (eV)  | 36.0$^{+1.7}_{-1.9}$             | 30$^{+0.0}_{-0.0}$   | 25.6$^{+6.7}_{-6.7}$  | 23.18$^{+0.01}_{-0.01}$ |
| $n_{bh}$ (10$^{-3}$) | 4.3$^{+0.05}_{-0.05}$ | 5.4$^{+0.02}_{-0.02}$ | 3.8$^{+0.2}_{-0.2}$ | 3.5$^{+0.1}_{-0.1}$ |
| Diskbb          | $kT_{in}$ (eV)                   |
| $\xi$ (erg cm$^{-s^{-1}}$) | 37.3$^{+3.1}_{-3.1}$ | 197.9$^{+79.6}_{-79.6}$ | 25.2$^{+4.1}_{-4.1}$ | 21.0$^{+5.8}_{-5.8}$ |
| Pexmon          | $R$                              |
| $\chi^2/\nu$    | 8.2$^{+0.0}_{-0.0}$              | 0.4$^{+0.4}_{-0.4}$  | 14.0$^{+4.0}_{-4.0}$  | 15.0$^{+3.0}_{-3.0}$  |

Notes— (a) $n_{pd}$, $n_{bh}$, $n_{diskbb}$ and $n_{pex}$ represent normalization to respective model component; where $n_{pd}$ and $n_{pex}$ have same units as photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$ at 1 keV; (b) ionised PCA (1 or 2); (c) Flux in units 10$^{-11}$ ergs cm$^{-2}$ s$^{-1}$; (d) Luminosity in units 10$^{44}$ ergs s$^{-1}$; (e) Electron temperature is fixed to 100 keV.

3 SPECTRAL MODELLING

We used XSPEC v12.7.1 to analyse the Suzaku and XMM-Newton X-ray spectra of 1H 0419–577. We used the $\chi^2$ minimisation technique to find the best-fit models. Below we quote the errors on the best-fit parameters at the 90% confidence level unless otherwise specified.

3.1 January 2010 Suzaku data

First we compared XIS spectra to find if there are any instrumental cross-calibration issues. We fit an absorbed power-law model (constant× wabs× powerlaw) to three XIS (XISO, XIS1 and XIS3) spectra in 2–10 keV band. We fixed the constant to 1 for XISO and varied for the XIS1 and XIS3 datasets in order...
XIS1 is affected by high background near 10 keV and therefore we ignored XIS1 data above 8.9 keV. Moreover, all XIS datasets show the calibration uncertainties near Si-K edge which led to the exclusion of 1.78–1.9 keV spectral range. We also excluded any bad channels from the spectral modelling.

We began with the spectral modelling of the 2.5–10 keV XIS data to find the hard power-law component. An absorbed power-law model resulted in a minimum $\chi^2 = 385.7$ for 346 degree of freedom (dof). We noticed a narrow emission line near 6 keV. Addition of a redshifted Gaussian line improved the fit by $\Delta \chi^2 = -18.5$ for three additional parameters. The width of the line ($\sigma$) was consistent with zero. The 90% upper limit on the Gaussian $\sigma$ is 120 eV. We found an equivalent width of 24.7 eV for this narrow K$\alpha$ line. The best-fit powerlaw photon index is $\Gamma \sim 1.8$ in the 2.5–10 keV band. The best-fit parameters are listed in Table 2. Next, we fitted the absorbed power-law plus narrow iron line model to the 0.6–10 keV XIS data and the 15–50 keV HXD/PIN data jointly. We fixed the relative normalisation of the PIN data at 1.18 appropriate for this observation at the HXD nominal position. The fit resulted in $\chi^2$/dof = 2202.1/505. We show the residuals in Figure 2 (a). It is clear that the broadband continuum of 1H 0419–577 consists of a power-law, soft X-ray excess below ~1 keV and possible hard X-ray excess above ~10 keV.

The soft excess is a common feature of type 1 AGNs (e.g., Boller et al. 1996; Leighly 1999; Vaughan et al. 1999; Gierliński & Done 2004; Crummy et al. 2006) and its origin is still unclear. Several models such as single blackbody, multiple blackbodies, multicolor disk blackbodies, blurred disk reflection from partially ionised material, smeared absorption, and thermal Comptonization in optically thick medium can provide statistically good fit to the observed soft excess (Magdziarz et al. 1998; Fabian et al. 2002b; Gierliński & Done 2004; Crummy et al. 2006; Dewangan et al. 2007). We used a simple blackbody model to describe the soft excess emission of 1H 0419–577. The addition of the blackbody component to earlier absorbed power-law plus narrow Gaussian line model improved the fit from $\chi^2$/dof = 2202.1/505 to $\chi^2$/dof = 774.4/503 for two additional parameters. The best-fit blackbody temperature is $\sim 0.17$ keV. We show the fit-residuals in Figure 2 (middle panel).

### 3.1.1 Partial covering absorption (PCA) model

The blackbody plus powerlaw model poorly describes the observed spectrum. There are features in the residuals below 2 keV and slight spectral curvature in the 2–5 keV range (see Fig. 2, middle panel). These features may arise due to the presence of PCA. We used a neutral PCA model zpcfabs. This model describes absorption by neutral cloud that may cover the source partially. The model wabs$\times$ zpcfabs(zbody + powerlaw + zgauss) improved the fit to $\chi^2$/dof = 671.4/501 ($\Delta\chi^2 = -103.0$ for two additional parameters). However, the fit is still not satisfactory as the fit-residuals show “hard excess” above 10 keV as shown in Figure 2 (lower panel). This hard excess could arise due to the presence of another partial covering absorber as suggested by Turner et al. (2009). Using a second PCA i.e., the model wabs$\times$ zpcfabs(1)$\times$ zpcfabs(2) (zbody + powerlaw + zgauss) (the neutral PCA model), improved the fit further ($\chi^2$/dof = 618.3/409). Using a third neutral PCA model wabs$\times$ zpcfabs(1)$\times$ zpcfabs(2)$\times$ zpcfabs(3) (zbody + powerlaw + zgauss) (the neutral PCA model), improved the fit further ($\chi^2$/dof = 618.3/409)
did not improve the fit ($\Delta\chi^2 = 0.05$ for two additional parameters). We therefore find a good fit with two PCAs. However a blackbody model is not a physical model for the soft X-ray excess emission. We therefore tested if ionised PCA can cause the spectral curvature. Turner et al. (2009) used two partially ionised PCA models to describe the 2007 Suzaku observation of 1H0419–577. We constructed a similar model for the 2010 Suzaku data. We used the (zxipcfd) model for the ionised absorption. This model uses a grid of XSTAR photoionised absorber for the low energy spectral curvature and another ionised absorber for the hard excess. Thus, we fitted the ionised PCA model $wabs\times zxipcfd\times zxipcfd\times$powerlaw resulted in $\chi^2/dof = 620.9/501$. A narrow line feature near 6 keV was modeled by using a Gaussian with $\sigma = 0.01$ keV. This further improved the fit to $\chi^2/dof = 608.8/499$. The best-fit iron line parameters are $E_{FeK\alpha} = 6.35 \pm 0.05$ keV, $f_{FeK\alpha} = 8.3^{+4.9}_{-3.9} \times 10^{-6}$ photons cm$^{-2}$ s$^{-1}$ and equivalent width, $EW = 18.6$ eV. The neutral and narrow iron line is thought to be associated with the distant, cold reflection. Therefore, we used the pexmon model to describe both the iron line and the reflection hump. We set the pexmon model to produce the reflection component only by making the relative reflection parameter ($R$) negative, and tying the photon index and the normalisation with the corresponding parameters of the primary powerlaw. We fixed the high energy cutoff of the illuminating powerlaw at 100 keV and the abundances of the distant reflector to the solar values. We also fixed the inclination angle to 50 degrees. Thus, our final ionised PCA model $wabs\times zxipcfd\times zxipcfd\times$powerlaw$pexmon$ resulted in $\chi^2/dof = 613.3/500$. The spectral data, the best-fitting complex ionised PCA model and deviations are shown in Figure 3(a). The best-fit parameter are listed in Table 3. The quoted errors are at the 90% confidence level.

### 3.1.2 Blurred reflection model

The soft X-ray excess below 2 keV and the hard excess above 10 keV can also be described as reflection from partially ionised disk. Walton et al. (2010) have shown that the broadband spectrum of 1H 0419–577 obtained from the first Suzaku 2007 observation can be well described by the blurred reflection model. Following Walton et al. (2010), we fit the 2010 Suzaku observation with a reflection model. We used the reflionx model which describes the reflection from partially ionised accretion disk (Ross & Fabian 2005). In this model, the lamp post geometry is assumed in which a compact corona located above the black hole illuminates the accretion disk resulting in radius dependent irradiation. Thus, the emissivity associated with the reflection depends on the radial distance and parameterised as $\epsilon(r) \propto r^{-q}$. In this geometry, the irradiation decreases as $r^{-3}$ far away from the black hole but the light bending affects the illumination strongly in the central regions and focuses some fraction of the coronal emission. The emissivity law can be much steeper in the innermost regions (Miniutti & Fabian 2004).
Table 4. Best fit parameter for Suzaku and XMM-Newton observations, and * is used for fixed parameters.

| Model Component | Parameter | Suzaku 704064010 (January 2010) | Suzaku 702041010 (July 2007) | Suzaku 0604720301 (May 2010) | XMM-Newton 0604720401 (May 2010) |
|-----------------|-----------|--------------------------------|----------------------------|----------------------------|---------------------------------|
| Gal. abs.       | $N_H$ ($10^{20}\text{cm}^{-2}$) | 1.83 (+)                       | 1.83 (+)                    | 1.83 (+)                    | 1.83 (+)                        |
| powerlaw       | $\Gamma$ | 1.753$^{+0.02}_{-0.03}$        | 1.67$^{+0.06}_{-0.04}$       | 1.64$^{+0.05}_{-0.06}$       | 1.66 $^{+0.02}_{-	ext{-}}$    |
| Pexmon $^{b}$  | $n_{pl}$ ($10^{-2}$) $^{a}$ | 0.38$^{+0.03}_{-0.02}$        | 0.45$^{+0.01}_{-0.04}$       | 0.27$^{+0.002}_{-0.004}$     | 0.29 $^{+0.01}_{-	ext{-}}$    |
| R               | 1.76 $^{\pm}$ 0.02             | 1.75$^{+0.02}_{-0.03}$        | 1.60$^{+0.05}_{-0.07}$       | 1.55$^{+0.07}_{-0.05}$       |                                 |
| optxagnf $^{c}$| $n_{pec}$ ($10^{-3}$) $^{a}$ | 3.8 (+)                        | 4.5 (+)                      | 2.78 (+)                     | 2.9 (+)                         |
| $L/L_{Edd}$    | $kT_x$ (keV) | 0.30$^{+0.05}_{-0.03}$        | 0.56$^{+0.11}_{-0.09}$       | 0.6 $^{+0.1}_{-0.0}$         | 1.2$^{+0.3}_{-0.2}$            |
| $\tau$        | $r_{\text{cor}}$ ($r_g$) $^{a}$ | 16.0$^{+4.9}_{-3.2}$          | 8.2$^{+1.1}_{-0.6}$          | 7.7$^{+0.6}_{-0.7}$          | 5.3$^{+1.0}_{-0.3}$            |
| $\alpha$      | 0.90$^{+0.02}_{-0.01}$         | 0.80$^{+0.02}_{-0.01}$        | 0.49$^{+0.14}_{-0.21}$       | 0.47$^{+0.20}_{-0.30}$       |                                 |
| $f_{\text{pl}}$| 1.76 $^{\pm}$ 0.02             | 1.73$^{+0.02}_{-0.03}$        | 1.66$^{+0.05}_{-0.06}$       | 1.55$^{+0.07}_{-0.05}$       |                                 |
| $F_X$          | $\chi^2/\nu$         | 568.7$^{+542}_{-579}$               | 750.0$^{+474}_{-425}$                 | 585.9$^{+425}_{-425}$                 | 635.0$^{+425}_{-425}$            |
| $f_{0.6-2\text{keV}}$ | 0.98                     | 1.22                         | 0.90                         | 0.8                          |                                 |
| $f_{2-10\text{keV}}$ | 1.46                     | 1.77                         | 1.3                          | 1.3                          |                                 |
| $L_X$          | $f_{10-50\text{keV}}$ | 2.7                         | 3.3                          | –                           | –                              |
| $L_{0.6-2\text{keV}}$ | 2.7                      | 3.3                          | 2.5                          | 2.3                          |                                 |
| $L_{2-10\text{keV}}$ | 3.9                      | 4.7                          | 3.4                          | 3.4                          |                                 |

Note— (a) $n_{pl}$ and $n_{pec}$ represent normalisation to respective model components in units of photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$ at 1 keV. (b) Iron abundance relative to solar was fixed to unity and the inclination was fixed to $50^\circ$. (c) Black hole mass, distance and normalisation are fixed to $10^8 M_\odot$, 474 Mpc and unity, respectively. (d) X-ray flux in units of $10^{-11}$ ergs cm$^{-2}$ s$^{-1}$. (e) X-ray luminosity in units of $10^{44}$ ergs s$^{-1}$.

Thus, the emissivity law can be approximated as a broken power-law (Fabian et al. 2012) over the radial extent of the disk. We began with a single reflection component for broadband ($0.6 - 50$ keV band) modified by the Galactic absorption ($N_H(G) = 1.83 \times 10^{20}$ cm$^{-2}$). In this model, we tied the shape of the illuminating power-law in the reflection model to that of the primary power-law continuum. We excluded the narrow Gaussian line from the fit because the reflection model can take care of all the emission lines. Initially we did not smooth the reflected emission due to the relativistic effects. Thus it showed a number of emission lines below $E_{\text{in}}$. Initially we did not smooth the reflected emission due to the relativistic effects. Thus it showed a number of emission lines below $E_{\text{in}}$. Finally, we modeled the soft excess as the intrinsic disk emission from the region $r_{\text{out}}$ to $r_{\text{cor}}$ and Compton upscattering of this emission in the upper layers of the inner disk, $r_{\text{cor}}$ to $r_{\text{Isco}}$, consisting of optically thick, low temperature electron plasma. This model also includes the hard power-law component. We varied the diskbb normalisation. The model, $\text{wabs(nthcompiskbb+kdblurreflionx)}$ (blurred reflection), resulted in $\chi^2/dof = 582.1/500$ similar to the earlier fit as expected. We also varied the inclination angle which resulted in $\chi^2/dof = 580.5/499$ and $i = 57.8^{\pm 6.5}_{\circ}$ degrees. This inclination angle is similar to that obtained by Walton et al. (2010) for the July 2007 Suzaku observation. We also tested a more complex two component reflection model similar to that used by Walton et al. (2010) for the July 2007 observation. We used the model $\text{wabs(powerlaw+kdblurreflionx+kdblurreflionx)}$ and tied the outer radius of first kdblur component to the inner radius of the second kdblur component. We refer this model as the complex blurred reflection model. Thus, we made the emissivity index and the ionisation parameter radius dependent. This model did not result in a statistically significant improvement $\chi^2/dof = 576.3/497$. Thus, the complex blurred reflection model with the broken emissivity law is not required by the 2010 observation. The observed data, the best-fitting blurred reflection model, and the deviations are shown in Figure 3 (b) and the best-fit parameters are listed in Table 3.

3.1.3 Intrinsic disk Comptonization model

Finally, we modeled the soft excess as the intrinsic disk emission including Compton upscattering in the disk itself as implemented in the optxagnf model by Done et al. (2012). In this model, the soft excess can be explained partly by a colour temperature corrected intrinsic disk emission from the region $r_{\text{out}}$ to $r_{\text{cor}}$ and Compton upscattering of this emission in the upper layers of the inner disk, $r_{\text{cor}}$ to $r_{\text{Isco}}$, consisting of optically thick, low temperature electron plasma. This model also includes the hard power-law com-
ponent arising from the Comptonization of disk emission in a hot (kT\textsubscript{e} \approx 100 \text{ keV}), optically thin corona (r \approx 1) below a radius r\textsubscript{cor}. The hard power-law constitutes a fraction f\textsubscript{pl} of the gravitation energy released between r\textsubscript{cor} and r\textsubscript{isc}, and the remaining fraction 1 - f\textsubscript{pl} is emitted as the optically thick thermal Comptonization contributing to the soft X-ray excess emission. In the optxagnf model, the soft excess is the intrinsic disk emission and so its strength is set by the black hole mass, spin and mass accretion rate through the outer disk (Done et al. 2012).

We started with the absorbed power-law in the full band (0.6–50 \text{ keV}) as described above. We added XSPEC model optxagnf and excluded the powerlaw model. In the optxagnf model, we used a black hole mass, M\textsubscript{BH} \sim 1 \times 10^8 \text{ M}_\odot, for 1H 0419–577 estimated by Pounds et al. (2004b). Thus, we fixed the black hole mass and the luminosity distance (d\textsubscript{L} = 474 \text{ Mpc}). We also fixed the normalisation to unity, spin parameter to 0.9 (Fabian et al. 2005) and varied L/L\textsubscript{Edd} to obtain the flux. We fixed r\textsubscript{cor} to its best-fit value 15 r\textsubscript{g}. The rest of the parameters were varied to obtain a good fit. The fit resulted in \chi^2/dof = 615.9/502. We note that varying r\textsubscript{cor} did not improve the fit and kept this parameter fixed. We noticed a narrow iron line near 6 \text{ keV} in the residuals.

To be able to model the narrow iron line and the associated reflection, we used the optxagnf model to describe the soft excess only by fixing f\textsubscript{pl} to zero and included a separate powerlaw for the hard component. To fit the iron line and reflection from cold matter like putative torus, we included pexmon model and tied its normalisation and \Gamma to the normalisation and \Gamma of power-law component, respectively. We also fixed abundances to unity and inclination to 50\degree in the pexmon model. We note that the geometry of the distant reflector is likely more complex than a disk and the inclination angle may not be meaningful. This fit resulted in \chi^2/dof = 600.5/503. Since optxagnf model is more realistic than a simple powerlaw, we switched back to inbuilt Comptonization model in optxagnf by removing the power-law component but this time fixing the normalization of the pexmon at the best-fit values obtained in the earlier fit. We also tied the photon index of the pexmon to that in optxagnf and varied both f\textsubscript{pl} and \Gamma. The fit resulted in \chi^2/dof = 600.5/503. Now we varied the spin as well as r\textsubscript{cor} together. This improved the fit to \chi^2/dof = 568.7/501. The best-fit parameters are listed in Table 4 and the spectral data, the model and the residuals are shown in Figure 3 (c).

3.2 July 2007 Suzaku data

For our spectral analysis, we used 0.6 – 50 \text{ keV} band but the cross calibration for PIN data was fixed at 1.16 rather than 1.18 as the observation was performed at the XIS nominal position. First we compared the XIS0, XIS1 and XIS3 data. We fitted an absorbed powerlaw multiplied by a constant component to account for any differences in the overall normalisation between different datasets obtained from the three XIS instruments. We plotted the data-to-model ratios in Figure 4 (a) after extrapolating the 2 – 10 \text{ keV} absorbed powerlaw down to 0.6 \text{ keV}. We found a small discrepancy among these instruments below 0.8 \text{ keV} and large calibration uncertainties near 2 \text{ keV}. We therefore excluded the 1.78 – 1.9 \text{ keV} band in all our fits below.

For a comparison with the 2010 observation, we fitted an absorbed powerlaw plus Gaussian line model to the 2.5–10 \text{ keV} XIS spectra. The best-fit parameters are listed in Table 2. It is clear that the source was brighter and the iron K\alpha line was broader and stronger in 2007 compared to that in 2010 Suzaku observation. We address this spectral variability after modelling the broadband spectra.

As before we used the 15 – 50 \text{ keV} HXD-PIN data and fitted the XIS+PIN band 0.6 – 50 \text{ keV} with the wabs*powerlaw model that revealed different spectral components – soft X-ray emission excess below 2 \text{ keV}, a broad iron line near 6 \text{ keV} and hard X-ray emission excess above 10 \text{ keV}. First we fitted the broadband (0.6 – 50 \text{ keV}) spectrum of 2007 with the neutral PCA model (wabs*zpcfabs(1)*zpcfabs(2)*(zbody+powerlaw+zgauss)). This model resulted in \chi^2/dof = 803.7/542 with kT\textsubscript{bb} = 115 \pm 7 \text{ eV}, \Gamma = 2.06^{+0.02}_{-0.03}, N_H = 1.45^{+0.3}_{-0.2} \times 10^{23} \text{ cm}^{-2} and C_2 = 23.5^{+2.4}_{-2.7}\% for PCA(1), N_H = 1.21^{+0.2}_{-0.1} \times 10^{23} \text{ cm}^{-2} and C_2 = 46.1^{+3.6}_{-3.9}\% for PCA(2). As before, we then fitted the broadband data with the three different models, the ionised PCA, the blurred reflection and the intrinsic disk Comptonization model. The complex ionised PCA model resulted in \chi^2/dof = 786.9/541 (see Table 3 for the list of best-fit parameters). The blurred reflection model with a single reflection component (wabs(nthcomp+diskbb+kdblur*reflionx)) resulted in a statistically unacceptable fit (\chi^2/dof = 774.9/541) with some nonphysical parameters. We therefore used a reflection model with radius dependent emissivity law and the ionisation parameter following Walton et al. (2010). We used the model wabs(powerlaw+kdblur*reflionx+kdblur*reflionx) and tied the outer radius of the first kdblur component to the inner radius of the second kdblur component. The photon index of the illuminating continuum in both the reflection components were tied to the photon index of the power-law component. This model resulted in \chi^2/dof = 733.8/538 and we noticed that the best-fit parameters are consistent with that obtained by Walton et al. (2010). We replaced the powerlaw by nthcomp in the composite model and fixed the seed photon temperature to 30 \text{ eV}. This model wabs(nthcomp+kdblur*reflionx+kdblur*reflionx) resulted in \chi^2/dof = 735.2/538 (see Table 3). The intrinsic disk model wabs(pexmon+optxagnf) resulted in \chi^2/dof = 750.0/542 (see Table 4).
3.3 The difference spectrum

Our spectral analysis of 2010 and 2007 Suzaku observations show spectral variability. The reflection including the broad iron was stronger in 2007 compared to that in 2010 (see Table 2 and 3). To further investigate the variability of the soft X-ray excess, we performed a joint spectral fitting of the XIS spectra of the two observations. First we improved the signal-to-noise of the XIS data by combining the XIS0 and XIS3 spectra (XIS03) for each observation using FTOOL “ADDASCASPEC” and then grouped each of the combined spectra by a factor of 8. We modeled the soft X-ray excess with diskbb+zbbbody as both the components are required to describe the data statistically well. We used a powerlaw for the hard component and multiplied all the components by the Galactic absorption. In the joint fit of 2007 and 2010 XIS03 data, we tied all the model parameters except the powerlaw normalization. We varied the tied parameters together for both the datasets. We used different power-law normalisations and varied separately for the two observations. This resulted in a poor fit $\chi^2/dof = 649.6/357$. Next we varied the normalisations of both the soft excess components separately for both the datasets, the fit improved to $\chi^2 = 495.9/355$. This shows that the soft excess and the power-law component both varied. Next we kept all the model components the same for both the observations but used an overall multiplicative factor which we fixed at 1 for 2007 observation and varied for the 2010 observation. The fit resulted in $\chi^2/dof = 499.2/357$ with the multiplicative factor of $0.80 \pm 0.003$ for the 2010 spectrum. Thus both the soft excess and power-law components varied by almost the same factor between the two Suzaku observations.

To further establish the spectral variability in a model independent way, we obtained a difference spectrum by subtracting the 2010 XIS spectral data from the 2007 XIS spectral data. We first fitted the difference spectrum with an absorbed power-law model in the $2 - 10$ keV band. The power-law model resulted in $\Gamma \sim 1.8$. We extrapolated this power-law to low energies that revealed strong soft X-ray excess. Figure 5 shows the difference spectrum and the soft excess below 2 keV. Clearly, the soft X-ray excess varied between the two Suzaku observations. Addition of a diskbb component for the soft excess improved the fit to $\chi^2/dof = 213.9/181$ with $kT_{in} = 173 \pm 13$ eV, $\Gamma = 1.82 \pm 0.04$.

3.4 XMM-Newton May 2010 datasets

In addition to Suzaku observations, we analysed 0.3–10 keV spectral data obtained from the two observations in May 2010 as mentioned in Table 1. We used EPIC-pn data corresponding to each observation due to high signal to noise ratio. We performed the spectral fitting step by step as described above for both the Suzaku observations. We fitted the three models – the complex ionised PCA, the blurred reflection and the intrinsic disk Comptonization model in the 0.3 – 10 keV band. These models fitted to the first observation (Obs. ID: 0604720301) resulted in $\chi^2/dof = 560.5/423$, 460.8/422 and 558.9/425 for the ionized PCA, blurred reflection (wabs(diskbb+ntchcomp+kdblur+reflionx)) and the intrinsic disk Comptonization model, respectively. The best-fit models for the second observation (Obs. ID: 0604720401) resulted in $\chi^2/dof = 585.0/419$, 447.7/418 and 635.0/421 for the ionized PCA, blurred reflection and the intrinsic disk Comptonization model, respectively. The best-fit parameters are listed in Table 3 and 4. The best-fit model, spectral data and residuals for the first observations are shown in Figure 6.

4 DISCUSSION

We have studied the broadband X-ray spectrum of 1H 0419–577 and confirmed the presence of the soft X-ray excess below 2 keV and the hard X-ray excess above 10 keV earlier detected by Turner et al. (2009) and Walton et al. (2010). We also detected iron Kα line near 6.4 keV. Our spectral analysis of the two Suzaku and two XMM-Newton observations have revealed that the spectral components – the soft X-ray excess, the iron line, the primary power-law component and the hard X-ray excess all are variable. Below we discuss the nature of these spectral components based on their spectral shape and variability.

4.1 Hard X-ray excess emission

The neutral PCA, the ionised PCA and the reflection models provide satisfactory fit to the two Suzaku observations of 2007 and 2010. In the PCA models, the observed hard excess is the result of a Compton thick PCA of the primary powerlaw component while in the blurred reflection model, the hard excess arises due to the reflection hump. We found that the reflection model resulted in statistically better fits for both the observations (see Table 3). An ad hoc blackbody component used in the neutral PCA model for the soft excess emission resulted in a high temperature ($kT_{BB} \sim 85$ eV and 115 eV for the 2009 and 2007 observations, respectively (see below). The soft X-ray excess emission cannot be easily explained in the framework of neutral PCA model. Moreover, the ionised PCA model provided poor fits to the soft X-ray excess emission observed with XMM-Newton (see Fig. 6). On the other hand, the blurred reflection model describes the hard excess and the soft excess when combined with the tail of the thermal emission from an accretion disk. In addition, if the hard X-ray excess emission is due to the Compton thick PCA, the absorption corrected $2 - 10$ keV luminosity of the powerlaw component alone is $10^{45}$ ergs s$^{-1}$ for the 2010 Suzaku observation and the implied bolometric luminosity is $L_{bol} \sim 10^{47}$ ergs s$^{-1}$ where we have used a bolometric correction factor of $k_{2-10}$ keV = 100 (Vasudevan & Fabian 2009). This results in $L_{bol} \sim 10 \times L_{Edd}$ for a SMBH of $M_{BH} \sim 10^{8} M_{\odot}$ estimated by Pounds et al. (2004b) for 1H 0419–577. Thus, we find that the blurred reflection is a better description both statistically and physically for the hard X-ray excess than the Compton thick PCA model.

4.2 Nature of the soft X-ray excess emission

Both the reflection and the intrinsic disk Comptonization models describe the soft X-ray excess emission observed with Suzaku equally well (see Table 3). However, the intrinsic disk Comptonization model provided poorer fit to the soft excess emission observed with XMM-Newton (see Table 4). The intrinsic disk Comptonization model fitted to the XMM-Newton data resulted in an excess emission feature near $\sim 0.5$ keV, this caused the poor quality of the fit. Since the well calibrated Suzaku XIS events start at 0.6 keV, the deviations near 0.5 keV are excluded and the intrinsic disk Comptonization model provided good fits. On the other hand, the reflection describes the hard X-ray excess emission well, it alone cannot explain the observed soft X-ray excess emission. Our spectral analysis has revealed that three of the four observations require a contribution from an additional blackbody or multicolor accretion disk blackbody with inner disk temperature ($kT_{in} \sim 20 - 35$ eV). From the theory of standard accretion disks (Novikov & Thorne...
where $M$ is the mass of black hole in units of $10^8 M_\odot$, $r$ is the distance from the central black hole, $\dot{M} E$ is the relative accretion rate. This equation shows that the temperature of the accretion disk can not be beyond the extreme UV range if $r \sim 3 R_S = 6G M/c^2$ for a relative accretion rate of 1 and a black hole mass $M_{BH} \sim 10^8 M_\odot$. In this case the expected inner disk temperature is $\sim 27$ eV. For a maximally rotating black hole, the inner disk temperature is $\sim 50$ eV. Thus, the expected disk temperature is similar to the best-fit temperature obtained from the model with blurred reflection.

In the reflection model, substantial fraction of the soft X-ray excess emission is due to the blurred reflection from the partially ionised material. However, we did not detect a broad iron line from the 2010 Suzaku observation. Thus, in the framework of the blurred reflection model, either the iron line is weaker or the disk/corona geometry changed from 2007 to 2010 Suzaku observations. From Table 2, we note that the iron line flux decreased by a factor of about three in 2010 Suzaku observation compared to that in 2007 observation.

### 4.3 Variable reflection & the light bending model

1H 0419–577 varied between the two Suzaku observation. The soft ($0.6–2$ keV), hard ($2–10$ keV) and $10–50$ keV band fluxes decreased by $\sim 20\%$ (see Table 3). The simple absorbed powerlaw model to the $2.5–10$ keV showed the presence of a broad iron line with Gaussian $\sigma \sim 0.37$ keV in the 2007 observation while such a broad line was not detected in the 2010 observation. The iron line was weaker and narrower in January 2010. The absence of a clear broad iron line in the 2010 data is also inferred from the results of best-fitting reflection model (see Table 3). Overall the emissivity index is much steeper ($q \sim 6$) and the strength of the reflection component is weaker in 2010 data compared to that in the 2007 data (see Table 3). The reflection spectrum inferred from the 2007 observation is complex and best described by a reflection model with radius dependent emissivity index and ionisation parameter. Such a complex reflection model is not statistically required in the case of 2010 Suzaku observation but the reflection emission arises from the innermost regions only as suggested by the high emissivity index of $q \sim 8$. Thus, in the reflection model, the broad component of the iron line is undetected in the 2010 data due to extreme smearing of a weaker reflection component in the innermost regions of high emissivity. In the 2007 Suzaku observation, the dominant contribution to the reflection emission arises from the disk at intermediate radii as suggested by the second reflection component and relatively flatter emissivity index. This region is likely responsible for the increased reflection and the detection of broad iron line. Thus, the iron line and the reflection component both weakened from 2007 to 2010 observations. The spectral variability is also revealed in the difference spectrum obtained by subtracting the 2010 spectral data from the 2007 spectral data (see Figure 5). The difference spectrum shows strong soft X-ray excess below $2$ keV implying that the soft excess was stronger in the 2007 observation. Thus, if the soft X-ray excess is interpreted as the blurred reflection, the observed variations imply variation in the reflection component as inferred from the detailed spectral modelling.
Variable X-ray reflection from 1H 0419–577

Figure 7. Variations in the nthcomp and reflection emission based on the four observations. Triangle represent the Suzaku observations. The circle and the square represent the first and second XMM-Newton observations of May 2010.

Figure 7 shows the spectral variability of 1H 0419–577. The reflection component appears to follow the thermal Comptonization component when the photon index is similar. This is true for the flux in the reflection component in both the 0.6–10 keV and 10–50 keV. The observed correlation does not seem to hold for one of the XMM-Newton observation when the continuum shape was slightly steeper. This may be due to the increased flux of the primary component below ∼ 2 keV resulting in an increased soft excess reflection. However, it is difficult to draw a firm conclusion as the spectral variability between the two XMM-Newton observations is not very striking.

The variability properties of the reflection emission revealed in the two Suzaku observations of 1H 0419–577 is different than that observed earlier with XMM-Newton. Based on multiple XMM-Newton observations in different flux states, Pounds et al. (2004a,b) showed that the spectral variability is dominated by a steep power-law component. Fabian et al. (2005) reanalysed the six XMM-Newton observations and demonstrated that the observed spectral variability is well modeled by a strongly variable power-law component (Γ ≃ 2.2) and a relatively constant reflection from an ionised accretion disk. Fabian et al. (2005) identified the soft excess with the reflection component and its weak variability resulted in the lack of soft excess in the difference spectrum. The strongly variable power-law and the weakly variable or almost constant reflection component in the multiple XMM-Newton observations are fully consistent with the predictions of the light bending model (Fabian et al. 2005). In this model, the observed spectral variability is caused by the variations in gravitation light bending depending on the changes in the location of the power-law source with respect to the black hole. As the power-law source moves closer to the black hole, light bending increases and therefore the observed power-law flux drops and the spectrum becomes more and more reflection dominated.

The spectral variability of 1H 0419–577 observed with Suzaku is unusual. In the low flux state of 2010, the soft excess is weaker than that in the high flux state of 2007. Also the iron line is weaker in the 2010 observation. This implies that the blurred reflection became weaker in the low flux state. Though the variability of both the soft excess and the broad iron line seem to be consistent with the disk reflection models where the disk responds to the continuum flux but the weaker reflection in the low flux state is not consistent with the variability predicted by the light bending model alone. If the decrease in the power-law flux is solely due to the movement of the power-law source towards the black hole, thus light bending causing both the decrease in the observed power-law flux and steeper emissivity index as observed. However, this should result in the increased reflection emission which is contrary to the observations.

In the framework of reflection model, the observed spectral variability of 1H 0419–577 with Suzaku can possibly be explained in terms of changing disk-corona geometry. During the 2007 Suzaku observation, the corona was likely more extended illuminating both the inner and outer regions. In the inner regions, light bending causes very steep emissivity index. In the regions of intermediate radii, the light bending is less effective likely due to the extended corona and the emissivity index is relatively flatter. Thus, the extended corona both provides higher flux and higher reflection with relatively flat emissivity law. During the 2010 Suzaku observation, most likely the corona is more compact without the extended part resulting in reduction of the observed power-law flux and no strong illumination to the intermediate and outer regions of the disk. A weaker and smaller corona results in very steep emissivity law and reduced reflection from the inner regions only. Thus, the dynamical nature of the corona can qualitatively explain the spectral variability of 1H 0419-577. We speculate that a fraction of the gravitational energy release is fed to the hot corona in the innermost regions only if the accretion rate is low. At higher accretion rates, gravitational energy release is also fed to larger radii, thus making the corona extended. Such a scenario would explain both the stronger continuum and reflection including the soft excess and the broad iron line in a high flux state.

4.4 Spectral Variability and the intrinsic disk Comptonization model

The intrinsic disk Comptonization model (optxagnf: Done et al. 2012) provides slightly poorer fit to both the Suzaku observations compared to the blurred reflection model. Both the models, however, require intrinsic disk emission at softest X-ray energies. In the optxagnf model, only the outer regions of a disk emit thermal emission and the gravitational energy release is split into two parts in the inner regions. A fraction of the gravitational energy release powers the inner optically thick Comptonised disk producing the soft excess and the other fraction powers the hot corona. In this model, the strength of thermal outer disk emission, the soft X-ray excess and the hard power-law depend on the accretion rate. Thus, in the framework of the intrinsic disk Comptonization model,
the weaker soft excess and the power-law components in the 2010 Suzaku observation suggest lower accretion rate. The absence of broad iron line in the 2010 data may be due to the weaker illuminating power-law and/or a truncated accretion disk possibly resulting from lower accretion rate.

We note that the optxagnf model provided high black hole spin $a > 0.9$ for the two Suzaku observations. This suggests that the accretion disk extends very close to the black hole. Thus we expect strong blurred reflection from the disk unless the corona is moving away from the disk with large velocity and the iron abundance is very low. However, we have shown that the blurred reflection model alone best describes the observed data. This implies that the dominant mechanism causing the soft excess and the spectral curvature is most likely the blurred reflection.

5 CONCLUSIONS

We have performed detailed spectral modelling of the broadband spectra of 1H 0419–577 obtained from two Suzaku observations separated by nearly three years and two XMM-Newton observations in May 2010. We tested three different physical models - (i) the complex PCA model, (ii) the blurred reflection model, and (iii) the intrinsic disk emission. The main results of our paper are as follows.

(i) The blurred reflection model provides statistically the best fit among the three models. The PCA model resulting in the worst statistics is unlikely to be a correct physical model as it results in $L_{\text{disk}} \sim 10 L_{\text{Edd}}$ for 1H 0419–577.

(ii) Irrespective of the models, the soft strength excess requires intrinsic thermal emission from an accretion disk. Reflection emission alone is not sufficient to explain the observed soft excess.

(iii) We find remarkable spectral variability between the two Suzaku observations. The soft X-ray excess, the iron line and the power-law continuum became weaker in the 2010 compared to that observed in 2007. A moderately broad iron line observed in the high flux state of 2007 appears to have weakened in the 2010 observation.

(iv) Variations in the soft X-ray excess and the iron line from 1H 0419–577 are unusual among AGNs. Such spectral variability demonstrates possible physical association between the soft X-ray excess and the iron line and is expected in the blurred reflection model. However, such variability is not easily explained by simple light bending model. Changes in the accretion disk/corona geometry are likely responsible for the observed spectral variability.

(v) The intrinsic disk Comptonization model of Done et al. 2012 can also describe the broadband Suzaku spectra and the spectral variability. However, a contribution from blurred reflection is required. The EPIC-pn spectra below 1 keV are not well described by the intrinsic disk Comptonization model.

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