Obscuring clouds playing hide-and-seek in the active nucleus H0557–385

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ABSTRACT
This Letter reports on two XMM–Newton observations of the type 1 Seyfert galaxy H0557–385 obtained in 2006, which show the source at an historical low flux state, more than a factor of ∼10 lower than a previous XMM–Newton look in 2002. The low flux spectrum presents a strong Fe Kα line associated with a Compton reflection continuum. An additional spectral line around 6.6 keV is required to fit Kα emission from Fe xxv. The spectral curvature below 6 keV implies obscuration by neutral gas with a column density of ∼8 × 1023 cm−2 partially covering the primary emission, which still contributes a few per cent of the soft X-ray emission. Absorption by ionized material on the line of sight is required to fit the deep trough below 1 keV. The comparison of the two spectral states shows that the flux transition is to be ascribed entirely to intervening line-of-sight clouds with high column density.

Key words: galaxies: individual: H0557–385 – galaxies: nuclei – X-rays: general.

1 INTRODUCTION
A substantial fraction of active galactic nuclei (AGN) show absorption from neutral matter in their X-ray spectra (Matt 2002, for a review). If the column density of this gas is higher than 1.5 × 1024 cm−2, the level of obscuration is such that below 10 keV the X-ray spectrum is dominated by the reflected radiation and the nucleus is only visible above 10 keV. Transitions between Compton-thick (N_H > 1.5 × 1023 cm−2) and Compton-thin (N_H < 1.5 × 1024 cm−2) states have been reported in some obscured AGN observed in X-rays in recent years (Matt, Guainazzi & Maiolino 2003; Guainazzi et al. 2005). The changing look phenomenon may be explained in terms of column density variations, which are frequently observed in type 2 sources (Risaliti, Elvis & Nicastro 2002) or in terms of the fading of the nuclear emission, as proposed for NGC 4051 (Guainazzi et al. 1998).

The type 1 Seyfert galaxy H0557–385 (05h58m20s.0, −38°20′05′′, z = 0.03387) is also known as ESO 0556–20. It was observed by ASCA (Turner, Netzer & George 1996), BeppoSAX (Quadrelli et al. 2003) and XMM–Newton (Ashton et al. 2006, hereafter A06). In all these observations, the source flux was 1–4 × 10−11 erg cm−2 s−1 and the spectrum appeared to be characterized by a strong warm absorber below 1 keV. A06 found that a two-phase ionized medium provided a good description of the high-resolution data obtained by the Reflection Grating Spectrometer (RGS).

XMM–Newton reobserved the source twice in 2006, catching it at an extremely low flux state. This Letter presents the analysis of the spectral transition between the XMM–Newton looks in 2002 and 2006.

2 OBSERVATIONS AND DATA REDUCTION
H0557–385 was observed four times (see Table 1) by XMM–Newton (Jansen et al. 2001). Raw data from all observations were reduced with the Science Analysis System (SAS) using version 8.0. The EPIC data of 2002 were collected in large window mode for the pn camera and in small window mode for the MOS1 and MOS2, whereas the 2006 EPIC data were all collected in small window mode.

Background flares were treated according to the method described by Piconcelli et al. (2004) so to maximize the signal-to-noise ratio of the data. The spectra of the 2002 observations were extracted using pattern 0–4 for the pn and 0–12 for the MOS cameras. The 0.3–10 keV count rate of 10 counts s−1 is just below the pile-up threshold in the pn camera. The source spectra were extracted from a radius of 40 arcsec, yielding a useful exposure of 4 and 6.5 ks in the pn instrument. No flux variability is found in the light curve and since the spectra from the two 2002 exposures are consistent in flux and spectral shape, they have been co-added in a single spectral file.

The same procedure for the data reduction has been applied to the 2006 observations. We note here that due to telemetry loss, the observation 0404260101 produced two event lists (scheduled and unscheduled), which were subsequently merged in a single event list using the SAS task MERGE. Source and background spectra and light curves were then extracted from this merged event list.

An inspection of the light curves for (both) the 2006 observations confirms that the source flux does not vary significantly within each
of the two exposures, so the analysis will be performed on the spectra integrated during each epoch.

As for the RGS data, for the 2002 observations, we will refer to the analysis by A06. For the 2006 exposures, RGS data were processed with the task rgsproc according to the standard method proposed in the SAS threads. Due to the flux decrease in 2006, the source was not detected in the RGS images, therefore no high-resolution spectra are available for this epoch.

The source was observed with the Optical Monitor (OM) telescope with optical and UV filters. Photometry is available for the following filters: 5430 (UVW1), 3440 (B), 4500 (U), 2910 (V), and 2120 (UVW2). A. The data have been analysed with the standard pipeline omichain. The source is detected in all the images in each band. From the fluxes derived from the observed count rates, the level of variability is lower than 15–20 per cent within the two epochs (2002–2006).

3 SPECTRAL ANALYSIS

In order to apply the $\chi^2$ statistic, the EPIC data were rebinned so as to oversample the instrumental resolution by a factor of 3 and to have at least 50 background subtracted counts in each spectral bin for the 2002 data and 25 counts in the 2006 observations. A Galactic column density of $4 \times 10^{20}$ cm$^{-2}$ (Dickey & Lockman 1990) is included in all the following spectral fits. Errors are quoted at 90 per cent (confidence level) for one parameter. Spectral fits are performed over the 0.3–10 keV energy range.

Fig. 1 displays the 2002 and 2006 pn data in the full EPIC energy band (0.3–10 keV): unmistakably, the source undergoes an energy band (0.3–10 keV): unmistakably, the source undergoes an agreement with the pn data; for the sake of brevity, we quote in this section) have been applied to the MOS spectra in each spectral state. This confirms that the MOS spectra are in excellent agreement with the pn data for the two epochs (2002–2006).

3.1 The high flux state: 2002 data

The XMM–Newton observations of H0557−385 obtained in 2002 were published by A06. In the analysis presented herein we assume the two warm absorbers model proposed by these authors based on RGS data.

The co-added EPIC pn spectrum of the high flux state was fitted in the 2–10 keV band with a power-law continuum and a narrow (zero-width) Gaussian line to account for emission in the Fe K$\alpha$ line at 6.4 keV. The best-fitting parameters are $\Gamma = 1.65 \pm 0.02$, $E = 6.40 \pm 0.10$ keV, line flux of $1.60 \pm 0.70 \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, with a 2–10 keV luminosity of $\sim 1 \times 10^{42}$ erg s$^{-1}$. The equivalent width (EW) of the Fe line is $33^{\pm10}_{\pm7}$ eV. If the line width is left free to vary the measured value is $\sigma = 0.20 \pm 0.10$ keV, with EW = 97 ± 33 eV, in agreement with the values reported by A06, yielding $\chi^2/d.o.f. = 284/225$. If the line is fitted with a relativistic profile (DISCLINE, Fabian et al. 1989), the statistic worsens ($\chi^2/d.o.f. = 294/226$). The non-zero-width of the Fe line may indicate the presence of additional emission components from a higher ionization state. We tried to fit the data with two zero-width Gaussians around 6.4 and 6.67 keV (mean energy of the Fe XXV triplet). The fit statistic is $\chi^2/d.o.f. = 290/224$, slightly worse than the broad Gaussian fit, but the parameters for the Fe XXV line are affected by large uncertainties ($E = 6.56 \pm 0.62$ keV and flux = $1.34^{+0.56}_{-0.32} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$). The evidence for the presence of a complex profile or of two Fe line components in this spectrum is none the less very loose, so we assume the model with a single narrow Gaussian Fe line to compare directly the two spectral states (Section 4).

When this model is extrapolated below 2 keV, the data present soft X-ray residuals, therefore two warm absorbers with ionization parameters and column densities initially fixed to the A06 values have been added in the fit. The model ZNIXPCF available in XSPEC as the local model was used. Based on XSTAR, this model was originally developed to describe the effect of a partial covering from ionized matter (Reeves et al. 2008). In the present analysis, the covering factor is fixed to 1 so to mimic a warm absorber with full coverage. Beside the multiphase ionized absorber, neutral photoelectric absorption is required by the data at more than 99.99 per cent confidence level, consistently with what is reported in A06, so we model it with the XSPEC model ZPHABS obtaining $N_H = 7 \pm 1 \times 10^{20}$ cm$^{-2}$. The final best-fitting parameters are listed in Table 2. We briefly note here that there is a good consistency with the analysis by A06; the small discrepancy can be probably attributed to the fact that

Table 1. Observation log of H0557−385 as observed by XMM–Newton. The fluxes have been estimated assuming a soft and hard X-ray power-law model (0.3–2 and 2–10 keV, respectively).

| Observation ID | Date (yyyy-mm-dd) | pn exposure (ks) | $\Gamma_{\text{soft}}$ | Flux$_{0.3-2}$ ($10^{-12}$ erg cm$^{-2}$ s$^{-1}$) | Flux$_{2-10}$ ($10^{-12}$ erg cm$^{-2}$ s$^{-1}$) |
|---------------|-------------------|-----------------|-------------------|---------------------|---------------------|
| 0109130501    | 2002-04-03        | 4               | 1.69 ± 0.08       | 10.37 ± 0.07        | 36.01 ± 0.05        |
| 0109131001    | 2002-09-17        | 6.5             | 1.53 ± 0.07       | 10.91 ± 0.06        | 43.30 ± 0.30        |
| 0404260101    | 2006-08-11        | 40              | 2.15 ± 0.13       | 0.42 ± 0.20         | 3.06 ± 0.12         |
| 0404260301    | 2006-11-03        | 52              | 2.10 ± 0.15       | 0.37 ± 0.15         | 2.60 ± 0.15         |

Figure 1. EPIC pn spectra of H0557−385 in 2002 and 2006.
here only EPIC data are considered and the different models used for fitting the warm absorber.

The spectrum still shows positive residuals around 0.8–0.9 keV; an additional narrow emission line is included in the fit at 0.83 ± 0.03 keV. The improvement in the fit is \( \Delta \chi^2 = 33 \) for two free parameters. The reader is referred to Section 4 for the discussion on the identification of this feature.

### 3.2 The low flux state: 2006 data

As reported in Table 1, the two observations of 2006 were performed with a three month gap in between, making it necessary to check for any spectral variation between the two spectra. In the following, we will refer to the 2006 spectra as 2006 August and 2006 November. At first glance, the two spectra are very similar in shape and flux intensity.

The spectral shape in Fig. 1 suggests that the drop of counts from the high state could be due to absorption in the 1–6 keV band. We therefore start by analysing the longest spectrum (2006 November) and constructing a model where the 2002 best fit is absorbed by neutral gas. The addition of a cold column density to account for the absorption (model ZPHABS, already described in the previous section) does not provide a good description of the data (\( \chi^2/\text{d.o.f.} = 896/233 \)). It seems that the nuclear primary continuum is not totally suppressed, but it still contributes to the soft X-ray spectrum, therefore a partial covering absorber is considered. The partial covering is constructed by adding a power law convolved with the ZPHABS and CABS components in XSPEC. The latter is necessary to produce a correct estimate of the continuum normalization by taking into account Compton scattering by optically thin gas. This partial covering model is able to reproduce the spectral shape correctly, with column density of \( 8 \pm 0.2 \times 10^{22} \) cm\(^{-2} \) and covering fraction \( >93 \) per cent (see Table 3).

The remarkable transition to a low flux state uncovers a prominent iron emission-line complex (see Fig. 2), suggesting that Compton reflection could also contribute to the hard X-ray emission. We therefore added a pure Compton reflection PEXRAV component (Magdziarz & Zdziarski 1995) assuming solar abundances and a 30° inclination of the reflecting material to the observer line of sight. This component is very significant and it improves the fit statistic by \( \Delta \chi^2 = 268 \) for one free parameter. The reflection fraction (i.e. \( R = \Omega/2\pi \)) estimated as the ratio of the PEXRAV and the direct power-law normalizations is \( R = 0.57 \pm 0.04 \).

Four zero-width Gaussian lines have been included to fit the Fe K complex: Kα and Kβ transitions from neutral Fe at 6.4 and 7.06 keV, and Kα lines from Fe XXV–XXVI at 6.67 and 6.96 keV. The parameters for the detected Fe lines are reported in Table 3.

#### Table 2. Best-fitting parameters of the high flux state (pn data) fitted with the following model: POWER LAW + NEUTRAL N\(_{\text{H}}\) + 2 WARM ABSORBERS (ZXIPCF) + 2 GAUSSIANS.

| Year | 2002 spectrum | \( \chi^2/\text{d.o.f.} = 294/226 \) |
|------|---------------|-----------------------------------|
|      | \( \Gamma = 1.87 \pm 0.01 \) | \( N_{\text{H}} (\text{neutral}) = 0.07 \pm 0.01 \) |
|      | \( N_{\text{H}}(\text{warm1}) = 1.02 \pm 0.10 \) | Log \( \xi_1 = 2.16 \pm 0.06 \) |
|      | \( N_{\text{H}}(\text{warm2}) = 0.60 \pm 0.03 \) | Log \( \xi_2 = 0.56 \pm 0.05 \) |
|      | \( E_1 = 6.40 \pm 0.11 \) | Flux \( \chi_1 = 1.51 \pm 0.71 \) |
|      | \( E_2 = 0.83 \pm 0.02 \) | Flux \( \chi_2 = 4.50 \pm 1.02 \) |

Line fluxes in units of \( \times 10^{-5} \) photons cm\(^{-2} \) s\(^{-1} \); line energies in keV; column densities in \( \times 10^{22} \) cm\(^{-2} \); ionization parameter in erg cm s\(^{-1} \).

#### Table 3. Best-fitting parameters of the low flux state (pn data) fitted with the following model: POWER LAW + 2 WARM ABSORBERS (ZXIPCF) + PEXRAV + PARTIAL COVERING (CABS*ZPHABS*PLAW) + 3 GAUSSIANS.

| Year | 2006 August | \( \chi^2/\text{d.o.f.} = 249/217 \) |
|------|-------------|-----------------------------------|
|      | \( \Gamma = 1.94 \pm 0.10 \) | \( R = 0.73 \pm 0.01 \) |
|      | \( N_{\text{H}}(\text{pc}) = 81 \pm 2 \) | \( C_f > 0.93 \) |
|      | \( N_{\text{H}}(\text{warm1}) = 1.02 \pm 0.05 \) | Log \( \xi_1 = 2.28 \pm 0.16 \) |
|      | \( N_{\text{H}}(\text{warm2}) = 0.10 \pm 0.09 \) | Log \( \xi_2 = 0.28 \pm 0.42 \) |
|      | \( E_1 = 6.43 \pm 0.01 \) | Flux \( \chi_1 = 1.08 \pm 0.17 \) |
|      | \( E_2 = 6.66 \pm 0.06 \) | Flux \( \chi_2 = 0.26 \pm 0.15 \) |
|      | \( E_3 = 0.89 \pm 0.01 \) | Flux \( \chi_3 = 1.52 \pm 0.36 \) |

Line fluxes in units of \( \times 10^{-5} \) photons cm\(^{-2} \) s\(^{-1} \); line energies in keV; column densities in \( \times 10^{22} \) cm\(^{-2} \); ionization parameter in erg cm s\(^{-1} \).

Figure 2. EPIC pn spectra of the low flux state in the Fe K band. The dotted lines mark the position of the Kα transitions for Fe I and Fe XXV (6.4 and 6.67 keV).

Fe XXVI Kα and Fe I Kβ are not detected in the spectra, so they are not included in the table. The upper limit on their fluxes was obtained by fixing the peak energy to its laboratory value and they are, respectively, \( 2.2 \times 10^{-6} \) and \( 2.5 \times 10^{-6} \) photons cm\(^{-2} \) s\(^{-1} \).

The neutral absorber observed in the high state with \( N_{\text{H}} \sim 7 \times 10^{20} \) cm\(^{-2} \) is not detected in the 2006 data, with an upper limit on the column density of \( \sim 3 \times 10^{19} \) cm\(^{-2} \).

The effect of the soft X-ray absorbers is still very evident in the data, so the same warm absorbers used for the high state are included in the model. An additional Gaussian line is required to fit residuals around 0.9 keV and it has been included in the fit (\( \Delta \chi^2 = 83 \) for two free parameters).

This model provides a satisfactory fit for 2006 November and it was then applied to 2006 August. The best-fitting parameters for both spectra are reported in Table 3. The two spectra are in very good agreement.
agreement, therefore we can safely assume that the source was not affected by significant spectral change between 2006 August and November.

The drastic change in the X-ray emission could also be explained if the primary emission simply drops, letting only the reflected spectrum be observable (Matt et al. 2003). This hypothesis is tested by fitting the November data with a PEXRAV component to account for the hard X-ray spectrum, and a single power law to model the soft X-ray excess. The warm absorber components and all the Gaussian lines reported in Table 3 are included in the fit. This model yields an acceptable fit statistic ($\chi^2$/d.o.f. = 274/233), but the intrinsic photon index of the reflected component is unrealistic ($\Gamma = 1.13 \pm 0.03$). If the PEXRAV photon index is fixed to the high state intrinsic power law ($\Gamma = 1.9$), the $\chi^2$ worsens considerably, being $\chi^2$/d.o.f. = 458/234. These results allow us to exclude that H0557−385 was reflection dominated in the 2006 low state, therefore this interpretation will not be discussed in the remainder of the Letter.

4 DISCUSSION

The spectral analysis in the previous section reveals a peculiar behaviour for this type 1 Seyfert galaxy. From a general overview of Tables 2 and 3, it is clear that most of the fitting parameters do not vary between the 2002 and 2006 spectra. The photon index of the power law and the warm absorbers column density and ionization state are remarkably consistent within the two epochs. Notably, the 2002 data require a simpler model (Table 2) compared to the one found for the 2006 data in Table 3. None the less, for a more direct comparison of the two states, the low state model is applied to the high state spectrum, as follows.

The normalization of the power law at 1 keV is around $1.45 \pm 0.05 \times 10^{-2}$ and $1.02 \pm 0.05 \times 10^{-2}$ photons cm$^{-2}$ s$^{-1}$ for the high and low states, respectively. These numbers imply that the intrinsic X-ray photon flux remains visible in both states with a variation lower than 50 per cent between 2002 and 2006. As described in Section 3.2, a fraction higher than 93 per cent of the intrinsic flux is absorbed by circumnuclear material with high column density ($\sim 8 \times 10^{21}$ cm$^{-2}$) during the low state. The high state data do not show evidence for partially covering gas. When applying the low state model to these data and after fixing the column density to $8 \times 10^{22}$ cm$^{-2}$ (i.e. the low state value), the upper limit on the covering fraction is about 5 per cent. The emerging picture is that of an active nucleus covered by intervening optically thick cold gas in 2006, which may have been present during the high state epoch with a lower column and/or with sparse coverage, as tested by applying the partial covering model to the 2002 data.

The fluxes of the narrow Fe Kα line at high and low states are in good agreement (Tables 2 and 3). The absence of a Fe Kα broad relativistic component and the lack of Fe K variability seem to point to a scenario in which the Compton reflection occurs on the parsec-scale torus-shaped material expected to be present in Seyfert galaxies (Antonucci 1993). The Fe line intensity measured with respect to the reflection component is $EW = 460 \pm 37\%$ eV in the high state and $EW = 510 \pm 55$ eV in the low state. Both values are considerably lower than the theoretical 1 keV Fe line expected from reflection in a Compton-thick torus (Ghisellini, Haardt & Matt 1994). Alternatively, a substantial fraction of the Fe line could be emitted by transmission in the obscuring clouds. Anyhow, it is very difficult to separate Fe line emission from the torus and from the clouds without a clear picture of the AGN geometry.

We can speculate on the distance of the clouds by estimating their velocity from the full width at half-maximum (FWHM) of the Fe K line at low state. The upper limit on the line width is 45 eV, resulting in a velocity of 5000 km s$^{-1}$. The source is known to have several components of the He line (A06, and references therein) with FWHM of 1035, 2772 and 11 000 km s$^{-1}$, suggesting a location of the obscuring clouds consistent with that of the two lower velocity components of the broad-line region. Assuming that in 2006 the source remained at low state for three months, this gives a minimum duration of the occultation event. The clouds can then be located at a distance higher than $v \times t = 5000$ km s$^{-1} \times 3$ months, i.e. $\sim 3.9 \times 10^{15}$ cm.

Determining more detailed properties of the system such as the precise time-scale for the transit of the cloud or a characteristic size appears very difficult since H0557−385 was observed very sparsely by X-ray observatories. The closest look to the XMMS-Newton ones is an ASCA observation of 1995 (Turner et al. 1996) which shows the source at high state. In the attempt to find additional X-ray data, H0557−385 has been searched for in the XMMS-Newton Slew Survey images (Saxton et al. 2008); luckily, one recent slew (2008 February 25) passed through the coordinates corresponding to the AGN (Saxton, private communication). H0557−385 was not detected, but a reliable upper limit on the flux could be derived: $<1.5 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ for the 0.2−2 keV band and $<1 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ in the 2−12 keV band. Arguably, this demonstrates that after $\sim 2$ yr, the source was still at low state. Whether it has remained in this state since 2006 through February 2008 is, obviously, impossible to tell.

From the analysis of the UV data (Section 2), it is found that the source of UV photons remains essentially unaffected by the X-ray change. This implies that the size of the X-ray source must be very compact compared to that of the UV source.

Highly obscured AGN constitute an excellent laboratory to study the physical properties of the circumnuclear gas via soft X-ray spectroscopy of emission lines produced in the interaction between such gas and the primary nuclear emission (Guainazzi & Bianchi 2007). Unfortunately, the high-resolution cameras did not provide a detection for H0557−385 at low state and so the source does not have the wealth of additional spectral information that was available for other type 1 Seyfert galaxies caught at low state, e.g. Mrk 335 (Longinotti et al. 2008), NGC 4051 (Pounds et al. 2004). None the less, the 2006 EPIC data do show an emission line around 0.9 keV, which is consistent with emission from the Ne IX triplet. We have searched for this component in the RGS spectrum of 2002. Assuming the best-fitting model in Table 2, the line is detected with flux $= 3.41_{-0.34}^{+0.92} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ and $E = 0.916 \pm 0.017$ keV.

In addition to the Ne IX line, the 6.6 keV emission line identified as Fe XXV in the low state spectrum could also be a signature of photoionization. However, the statistical quality of these measurements prevents us from drawing any firm conclusion on the origin of these spectral features.

Detecting soft X-ray emission (both lines and continuum) may lead to interpretation of H0557−385 at low state within the typical type 2 Seyfert galaxy scenario (Bianchi, Guainazzi & Chiaberge 2006; Guainazzi & Bianchi 2007). Remarkably, the presence of the same two phase warm absorber in both states plays a key role in ruling out this scenario. It provides a very robust argument against the ‘type 2 Seyfert galaxy/scattering’ scenario and, consequently, in favour of the partial covering. The fact that the warm gas is still visible through the absorption at low state implies that the soft X-ray emission does not come from an extended region as the narrow-line region in obscured AGN (it would be very unlikely to have a warm absorber at such large scale). Accordingly, the soft X-ray emission
must have been only partially reduced by the obscuring event, as also suggested by the comparison of the power-law normalizations, and therefore it is still observable at low state.

The fact that the type 1 Seyfert galaxy nucleus remains visible at low state makes the spectral transition in H0557−385 a very interesting event, which resembles the occultation phenomenon seen in the type 2 Seyfert galaxy NGC 1365 (Risaliti et al. 2005, 2007), but it is the presence of the warm absorber that makes H0557−385 a unique case where the partial covering scenario is indeed very robust and can be challenged only if other spectral states were observed.

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