The XMM-Newton/HST View of the Obscuring Outflow in the Seyfert Galaxy Mrk 335 Observed at Extremely Low X-Ray Flux

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Abstract

The Seyfert galaxy Mrk 335 is known for its frequent changes of flux and spectral shape in the X-ray band that occurred during recent years. These variations may be explained by the onset of a wind that previous, noncontemporaneous high-resolution spectroscopy in X-ray and UV bands located at accretion disk scale. A simultaneous new campaign by XMM-Newton and the Hubble Space Telescope (HST) caught the source at a historically low flux in the X-ray band. The soft X-ray spectrum is dominated by prominent emission features and by the effect of a strong ionized absorber with an outflow velocity of (5–6) × 10^3 km s^{-1}. The broadband spectrum obtained by the EPIC-pn camera reveals the presence of an additional layer of absorption by gas at moderate ionization covering ~80% of the central source, as well as tantalizing evidence for absorption in the Fe K band outflowing at the same velocity of the soft X-ray absorber. The HST Cosmic Origins Spectrograph spectra confirm the simultaneous presence of broad absorption troughs in C IV, Lyα, Lyβ, and O VI, with velocities of the order of 5000 km s^{-1} and covering factors in the range of 20%–30%. Comparison of the ionic column densities and of other outflow parameters in the two bands shows that the X-ray and UV absorbers are likely originated by the same gas. The resulting picture from this latest multIWavelength campaign confirms that Mrk 335 undergoes the effect of a patchy, medium-velocity outflowing gas in a wide range of ionization states that seem to be persistently obscuring the nuclear continuum.

Key words: accretion, accretion disks – galaxies: active

1. Introduction

Accretion onto supermassive black holes is commonly regarded as one of the most distinctive feature of active galactic nuclei (AGNs). Nonetheless, the apparently counteractive process of ejection has been gaining growing importance in our knowledge of the AGN phenomenology thanks to the many observational results that have emerged in the past two decades. Ejection of gas in the form of winds is now a common property of radio-quiet AGNs, and it is particularly prominent in X-ray and UV spectra of local sources (see Crenshaw et al. 2003, for a review). Association of the X-ray winds to absorption lines detected in the ultraviolet band was historically proposed to relate the properties of the gas in the two bands, possibly indicating a common origin (Mathur et al. 1995, 1998). However, the origin of the winds is not uniquely determined in all AGNs where this phenomenon is observed: at parsec scales thermal outflows arise from the molecular torus (Krolik & Kriss 2001), whereas the accretion disk can launch outflows at a radial distance lower than 10^3 gravitational radii via radiative (Proga & Kallman 2004) and magnetohydrodynamical mechanisms (Königl & Kartje 1994; Fukumura et al. 2010).

In the X-ray domain, the ionization state, velocity, and column density of the outflowing gas are relatively easy to measure. They provide information on the physical properties and, partly, on the location of the outflows, although the radial distance cannot be measured directly in the spectra unless variability of the ionizing continuum takes place (e.g., Krongold et al. 2007). When the distance of the wind is sufficiently well pinned down, from the velocity and the column density it is possible to estimate the mass and energy output expelled by the outflow and quantify the impact that gas ejection may have on the host galaxy. This is particularly important to understand the role of AGN winds in the feedback process (see King & Pounds 2015, for a review). The multitude of results obtained via X-ray spectroscopy of bright AGNs have shown that “slow” outflows of ionized gas, widely known as “warm absorbers,” do not reach the minimum energy output required to alter the AGN star formation activity (e.g., Krongold et al. 2007, 2010). Instead, the so-called ultra-fast outflows (UFOs), which are significantly faster and more massive, were shown to be capable of triggering AGN feedback (Feruglio et al. 2015; Tombesi et al. 2015; Longinotti et al. 2018).

Very recently, another flavor of AGN winds has been observed and studied: with outflow velocity halfway between...
warm absorbers and UFOs, obscuring and intermittent outflows produced by clouds orbiting in the broad-line region (BLR) are now revealed in the X-ray and UV spectra of Seyfert galaxies that undergo important flux and spectral variations on relatively short timescales. Mrk 335 (Longinotti et al. 2013), NGC 5548 (Kaasta et al. 2014), NGC 985 (Ebro et al. 2016), and NGC 3783 (Mehdipour et al. 2017; Kriss et al. 2019) are some examples of obscuration produced by intervening ionized gas in the form of “eclipsing” winds.

The close-by narrow-line Seyfert 1 galaxy Mrk 335 ($z = 0.025785$; Huchra et al. 1999) is one of the few sources where the emergence of an obscuring wind outflowing at a velocity of $5$–$6000$ km s$^{-1}$ was revealed in the X-ray and UV bands (Longinotti et al. 2013), based on nonsimultaneous observations obtained by XMM-Newton and the Hubble Space Telescope (HST). This work also provided the first record of X-ray ionized absorption seen in grating spectra in Mrk 335, a source that in its past UV and X-ray history had shown little evidence for the presence of a typical warm absorber.

Previous works based on CCD-resolution X-ray spectra of Mrk 335 were focused to model in great detail the spectral curvature in terms of intervening gas partially covering the line of sight, and/or relativistically blurred reflection from the accretion disk (e.g., Turner et al. 1993; Grupe et al. 2007, 2008, 2012; Larsson et al. 2008; Gallo et al. 2013, 2015, 2019; Wilkins et al. 2015).

Indeed, in the past Mrk 335 was mainly known as a typical bright Seyfert 1 galaxy (e.g., Longinotti et al. 2007; O’Neill et al. 2007) with relativistic Fe K features and negligible intervening absorption until the year 2007, when Swift discovered it in a very low X-ray flux state (Grupe et al. 2007). The ongoing monitoring with Swift since the sudden drop in 2007 has shown that Mrk 335 has remained in this dim X-ray state with some occasional variability detected along the elapsed $\sim 11$ yr (Gallo et al. 2018). According to the monitoring reported by these authors, the long dimmed X-ray state has not been accompanied by corresponding variability in the optical/UV band, which on average remains similar to measurements obtained prior to 2007. On the contrary, repeated X-ray flaring and dipping episodes have triggered several deep follow-up observations with XMM-Newton, Suzaku, and NuSTAR (e.g., Parker et al. 2014; Gallo et al. 2015; Wilkins et al. 2015; Keek & Ballantyne 2016; Komossa et al. 2017, and references above).

In the present paper the outcome of a more recent simultaneous campaign performed on Mrk 335 by XMM-Newton and HST is presented. The chief goal of this campaign was to determine the properties of the absorbers with contemporaneous X-ray and UV data.

The XMM-Newton and HST observations of Mrk 335 were triggered in 2015 December following a decrease of the UV and X-ray flux revealed by Swift (Grupe et al. 2015). XMM-Newton started observing on December 30 for a total duration of $\sim 140$ ks (ObsID 0741280201), and HST followed on 2016 January 4 and 7 for a total of seven orbits. Unlike the previous report (Longinotti et al. 2013) that relied on archival data obtained 4 months apart, the above timing provides quasi-simultaneity between the observational properties in UV and X-ray bands.

### 2. XMM-Newton Observation and Spectral Analysis

The XMM-Newton EPIC cameras were both set to operate in Full Window mode. Data were processed with SAS 16.0.0.[14]

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[14] https://www.cosmos.esa.int/web/xmm-newton/sas
Both spectra are severely affected by high background above 8 keV. N VII Ly, N VI He, O VII, O VIII Ly, O VII He, O VII He, O VII He, Fe XVII 15.015, Fe XVII 17.073, Ne X Ly.

The Cash statistic was applied throughout its analysis. The EPIC-pn spectra extracted from the steady part of the light curve (first ~100 ks of the observation) and from the “flare” (last 15 ks). The Fe K band is moderately affected by the spectral change induced by the rise of flux. Both spectra are severely affected by high background above 8 keV.

The latest (2015) RGS view of Mrk 335 shows clear signatures of both features; therefore, we constructed a model that includes emission and absorption guided by our previous knowledge of the spectrum.

Table 1. Emission Lines Detected in RGS Spectrum

| ID     | Rest Wavelength | Flux (10^{-5} photons cm^{-2} s^{-1}) | ΔCStat |
|--------|-----------------|--------------------------------------|--------|
| MgXII He α r | 9.228 | 0.247±0.245 | 3.23 |
| Ne X Lyα | 12.134 | 0.555±0.298 | 13.12 |
| Ne IX He α r | 13.447 | 0.420±0.228 | 11.37 |
| Ne IX i | 13.553 | 0.120±0.198 | 1.12 |
| Ne IX f | 13.698 | 0.391±0.226 | 10.37 |
| Fe XVII | 15.015 | 0.301±0.193 | 6.60 |
| Fe XVII | 17.073 | 0.225±0.242 | 2.73 |
| O VII He α | 17.396 | 0.462±0.252 | 9.57 |
| O VII He α | 17.768 | 0.207±0.259 | 1.93 |
| O VII He β | 18.627 | 0.215±0.256 | 1.97 |
| O VIII Lyα | 18.969 | 3.467±0.536 | 146.87 |
| N VII Lyα | 19.826 | 0.346±0.418 | 2.37 |
| O VII He α r | 21.580 | 2.325±0.363 | 28.97 |
| O VII i | 21.790 | 1.250±0.693 | 12.04 |
| O VII f | 22.101 | 3.227±0.473 | 50.15 |
| N VII Lyα | 24.781 | 2.270±0.992 | 17.25 |
| N VI He α i | 29.083 | 0.609±0.090 | 1.35 |
| N VI f | 29.534 | 1.163±0.840 | 4.93 |
| C VI Lyα | 33.736 | 7.314±1.794 | 45.85 |

The entire RGS spectrum is plotted in Figure 3. The spectrum is dominated by very intense emission lines and radiative recombination continua (RRC) features, along with a strong signature of ionized absorption. The emission component was discovered in a previous low-flux, shorter observation by XMM-Newton in 2007 (Grupe et al. 2008) and reported by Longinotti et al. (2008). The higher signal-to-noise ratio (S/N) of the present data allows the effect of absorption lines to be clearly distinguished in the continuum emission. This is not surprising since in another previous XMM-Newton observation obtained in 2009 the emergence of a strong multilayer ionized absorber was revealed in both X-ray and UV bands (Longinotti et al. 2013).

The latest (2015) RGS view of Mrk 335 shows clear signatures of both features; therefore, we constructed a model that includes emission and absorption guided by our previous knowledge of the spectrum.

To fit the soft X-ray continuum in the range 7–38 Å, we start by including a power law with Γ = 2.8 that is absorbed by a Galactic column density fixed to 3.6 × 10^{20} cm^{-2} (Kalberla et al. 2005). The Galactic absorption is modeled by the TMBabs component included in the suite of interstellar medium (ISM) absorption models developed by Wilms et al. (2000).

2.1. The High-resolution X-Ray Spectrum

The effect of line-of-sight absorption was then modeled by employing the suite of photoionization models PHASE (Krongold et al. 2003) and, after constructing the spectral energy distribution (SED) of the source that is necessary to calculate the ionization balance, assumed to compute the absorption spectrum. From the “steady” interval, which represent the most genuine description of the lowest X-ray spectrum of Mrk 335 so far obtained. The detailed analysis of the “flare” interval is reported by Gallo et al. (2019).

The spectral analysis was carried out with XSPEC version 12.9.1 (Arnaud 1996).

The analysis of the grating spectrum was carried out on the combined RGS1+RGS2 data sets obtained through the SAS tool rgscomb. Counts were not binned; therefore, the Cash statistic was applied (Cash 1979). The EPIC-pn spectrum was binned by the SAS tool specgroup; therefore, the χ² statistic was applied throughout its analysis (see Section 2.2). Error bars of spectral parameters are quoted to 1σ. Fluxes in the 0.3–10 keV and 0.3–2 keV bands during the steady part of the XMM-Newton observation were measured to be ≈3.7 × 10^{−12} erg cm^{-2} s^{-1} and ≈1.1 × 10^{−12} erg cm^{-2} s^{-1}, respectively. These fluxes translate to X-ray luminosities of L_{0.3−10} = 5.5 × 10^{42} erg s^{-1} and L_{0.3−2} = 1.5 × 10^{42} erg s^{-1}.

2.1.1. The Emission Features

The effect of line-of-sight absorption was then modeled by employing the suite of photoionization models PHASE (Krongold et al. 2003) and, after constructing the spectral energy distribution (SED) of the source that is necessary to calculate the ionization balance, assumed to compute the absorption spectrum. From
Longinotti et al. (2013) we are well aware of the presence of a complex multicomponent warm absorber in this source. In order to allow a straightforward comparison of the present warm absorber properties with past epochs, we adopted the same SED described by Longinotti et al. (2013). The UV–X-ray SED was built assuming the simultaneous fluxes and spectral shape from the Optical Monitor photometry and the EPIC-pn spectrum of 2009 shown in Figure 4 of Longinotti et al. (2013). This choice is also supported by the long-term behavior of Mrk 335 reported by Gallo et al. (2018), which is summarized in Section 1.

**Figure 3.** Best fit of the RGS spectrum corresponding to the steady interval of the light curve. The continuum is modeled with a power law with $\Gamma = 2.72$; the model includes the emission features and the ionized absorber described in Section 2.1. Data have been binned for plotting purposes.

**Figure 4.** Close-up of the softest region of the RGS spectrum. The labels mark only emission features; the warm absorber is included in the model, but labels have been omitted to avoid overlapping with emission-line markers.

**Table 2**

| ID  | Flux (photons cm$^{-2}$ s$^{-1}$) | $\Delta$Cstat |
|-----|----------------------------------|---------------|
| C V | $< 3.21 \times 10^{-5}$          | 1.4           |
| C VI| $> 1.48 \times 10^{-5}$          | 4.5           |
| O VII| $9.35_{-3.15}^{+3.38} \times 10^{-6}$ | 22            |
| O VIII| $3.44_{-2.10}^{+2.10} \times 10^{-6}$ | 9             |
The absorber in PHASE is described by the following parameters: the gas ionization state defined as $U = Q / (4\pi R^2 \varpi)$ (with $Q$ as the ionizing luminosity, $n_e$ as the gas electron density, and $R$ as the distance of the outflowing gas from the X-ray source), the column density $N_H$, the turbulent velocity $v_{\text{broad}}$ and the outflow velocity. Indeed, the addition of an ionized absorber with initial best-fit parameter log $U$ ~ 0.8 and log $N_H$ ~ 21.8 produces an improvement of $\Delta C_{\text{stat}} = 66$ when compared to the model including the power-law continuum and the emission component.

The detailed warm absorber parameters and errors are reported in Table 3. The outflow velocity of this absorber is of the order of $(5-6) \times 10^3$ km s$^{-1}$, consistent with the velocity measured in the 2009 spectra by Longinotti et al. (2013). The velocity broadening of the lines in the absorber was initially set to 100 km s$^{-1}$ and then left free to vary. A moderately tight constraint on this parameter could be found: $v_{\text{broad}} \lesssim 170$ km s$^{-1}$; therefore, in the rest of the analysis this parameter is kept fixed to 100 km s$^{-1}$. The slope of the underlying power-law continuum is $2.72 \pm 0.18$. Spectra plotted in Figures 3 and 4 include the effect of this layer of absorption. The final fit statistic for the model including the power-law continuum, the ionized absorber, and the emission component is $C_{\text{stat}}/\text{dof} = 3287/2992$.

Figure 5 displays the most intense absorption features that are driving the warm absorber. The strongest absorption feature (left panel) is due to a blend of several lines resulting from M-shell transitions in mildly ionized Fe I-XVI, the so-called Fe unresolved transition array (UTA; Netzer 2004). Further absorption is imprinted by transitions of C VI, N VII, O VII, and O VIII. The question mark labels plotted in the left panel of Figure 5 mark the position of two unidentified absorption lines that could not be fitted self-consistently with another absorption component despite several attempts of finding a coherent model for these features. They will not be discussed in the remainder of this paper.

An exhaustive comparison of the (several) multiepoch X-ray data sets of Mrk 335 is beyond the present scope and will be the subject of a forthcoming publication. However, in Section 4 we will review the properties of the present warm absorber (year 2015) compared to the findings reported by Longinotti et al. (2013) on the absorber that emerged in Mrk 335 in 2009.

### Table 3

| Log $U$ | Log $N_H$ | $v_{\text{out}}$ | $v_{\text{broad}}$ |
|--------|-----------|----------------|----------------|
| 0.85    | 21.82     | 5700            | 100            |

2.2. The Broadband X-Ray Spectrum

The bandpass of the RGS instrument is limited to below 2.5 keV; therefore, to achieve a full understanding of the entire spectrum, we applied the RGS best-fit model to the EPIC-pn data. These data are shown in Figure 2. The RGS model offers a very detailed description of the ionized gas that is responsible for emission and absorption in the soft X-ray band. Nonetheless, the extension of the bandwidth up to 10 keV immediately reveals the effect of unseen spectral components that are missing in this initial model owing to bandpass limitation.

We start by adding to the RGS model a Gaussian emission line to accommodate strong residuals corresponding to an Fe I Ka line that is highly prominent in this source (see details in Section 2.2.2). We then added a blackbody component (bbody) to fit, at least phenomenologically, the strong soft excess that has always been present in X-ray data of Mrk 335 (e.g., Bianchi et al. 2001; Grupe et al. 2008; Chini et al. 2015; Gallo et al. 2015). This addition has the effect of flattening the underlying power law that is now extended to fit the hard X-ray band and that presents a photon index of $\Gamma \sim 0.9$. The parameters of the blackbody component are in the range of the standard values for Seyfert 1 sources: the temperature is $kT = 0.11 \pm 0.02$ keV. We note that the use of the more realistic Comptonized blackbody model (compTT) does not produce significant changes in the spectral fit; therefore, we kept the more basic parameterization with bbody to account for the soft excess. Finally, guided by residuals around $1.7-2$ keV, we added four Gaussian emission lines at the positions of $6.182, 6.740, 7.130,$ and $8.421$ Å to accommodate the transitions of Si XIV Ly$\alpha$, Si XIII He$\alpha$, Si I Ka, and Mg XII Ly$\alpha$. These emission lines cannot be detected in the grating spectrum as they fall out of the bandpass. Nonetheless, considering the realm of features in Tables 1 and 2 along with examples of other AGNs where the emission spectrum could be measured in a wider band (e.g., NGC 4151; Ogle et al. 2000), the presence of emission from...
heavier elements in the pn data of Mrk 335 is highly likely, and indeed, their inclusion significantly improves the residuals in this spectral region.

Even with these modifications, both the fit statistics of \( \chi^2/\text{dof} = 416/141 \) and the hard X-ray curvature in the residuals (see Figure 6) suggest the presence of additional continuum component(s).

2.2.1. Partial Covering Absorber and Reflection Component

To mimic the effect of mildly ionized gas partially covering the primary X-ray continuum, we applied to the power law an additional layer of absorption parameterized by a second PHASE component with an initial low-ionization parameter and a variable covering factor. This partial covering component significantly improves the spectral fit (\( \Delta \chi^2 = 220 \) for 3 dof), and the intrinsic power law gets to a steeper photon index more typical of Mrk 335, \( \Gamma = 1.65 \pm 0.11 \). The column density of this gas is found to be quite high, \( \log(N_{\text{H}}) = 22.99 \pm 0.06 \), and the covering factor is \( 0.79^{+0.02}_{-0.05} \). The ionization parameter could not be constrained precisely (see Figure 7), but the 90% upper limit of \( \log U \) points to a degree of ionization lower than \( \log U \sim 1.35 \). Likewise, the velocity of this absorber could not be measured owing to the limited resolution of the pn CCD; therefore, we kept it fixed to the same value of the RGS warm absorber (\( \sim 5600 \text{ km s}^{-1} \)). We note that testing alternative velocities (e.g., \( v_{\text{out}} = 2000 \) or \( 800 \text{ km s}^{-1} \)) does not provide any relevant change in the spectral fit.

During the fitting process, some parameters of the ionized absorber detected in the RGS have been frozen: the ionization parameter, outflow velocity, and velocity broadening are frozen to the best-fit values reported in Table 3, while the column density is left free. This is justified by considering that the coarser resolution of the CCD cannot improve the parameters already well constrained by grating spectroscopy.

As a conclusive and necessary step of the analysis of the broadband continuum, we also considered the presence of a Compton reflection component. A detailed analysis of the reflection spectrum and the property of the inner accretion disk of Mrk 335 is beyond the scope of this paper and is presented elsewhere (Gallo et al. 2019). However, the presence of inner relativistic reflection in Mrk 335 was intensively studied in recent years (Kara et al. 2013; Parker et al. 2014; Gallo et al. 2015) and eventually confirmed as one of the dominant spectral components of this AGN. Therefore, we included a basic parameterization of the reflection spectrum by removing the partial covering and by adding a pexrav component to the broadband model. This test yields a reduced \( \chi^2 \) of 3.38 and a much flatter power law (\( \Gamma \sim 1.26 \)), indicating that partial obscuration is still required by the data. Once the partial covering is included back into the model with the reflection component, the slope of the continuum goes to \( \Gamma = 2.14^{+0.10}_{-0.13} \) and the fit statistic improves to \( \chi^2/\text{dof} = 174/138 \). The broadband model is plotted in Figure 8. We remark that this parameterization serves merely to test the statistical requirement of the partially covering gas; therefore, a detailed spectral fitting is not envisaged herein and standard reflection parameters are adopted: the cutoff energy is 500 keV, solar abundances are chosen for the elements heavier than He and for Fe, and the inclination angle of the disk is fixed to 30°. The only fitting parameter left free is the reflection fraction that, not surprisingly, pegs to its maximum value \( (R = 10) \), indicating a dominant contribution from the inner accretion disk. These values are broadly consistent with those reported by Parker et al. (2014), who, in their relativistic treatment, had found high reflection fractions in NuSTAR data of Mrk 335 at a very low flux state. This behavior is also reported by Gallo et al. (2019), to which the reader is deferred for a more detailed analysis of the reflection properties of the source. Finally, we note that our coarse parameterization does not exclude the likely contribution of a more distant reflector from the outer part of the disk or the molecular torus of the AGN, as indicated by the narrow Fe Kα line reported in the next section.

2.2.2. The Iron Line Band

We now take a closer look at the Fe K band. Owing to the spectral complexity of the soft X-ray band and with the aim to speed up the fitting procedure, the following analysis was carried out on the data within the range 3–8 keV. This is justified by considering that the opacity of the soft X-ray warm absorber has no effect above 3 keV and that the bulk of strong emission lines are emitted below this energy threshold. The
continuum model from the previous section constituted by a partially covered power law plus Compton reflection has been applied to this restricted band (the blackbody component was dropped since it has no effect in this band). The choice of not extending the bandwidth to the nominal 10 keV is due to the rising of instrumental background above 8 keV that introduces significant uncertainty in the spectral features apparently present above this threshold.

The presence of the Kα emission line from neutral iron is very evident in the spectrum, and it has been fitted with a Gaussian profile with peak energy $E = 6.41^{+0.03}_{-0.02}$ keV and width $\sigma = 0.12 \pm 0.03$ keV. The intensity of the Fe Kα line parameterized with this Gaussian profile and expressed as its equivalent width is $EW = 300 \pm 45$ eV. The continuum model, after the inclusion of the Fe Kα line, yields a fit statistic of $\chi^2$/dof = 97/74. The spectrum fitted by this model is plotted in Figure 9. The Fe line parameters are compatible with emission in the molecular torus via Compton reflection, as proposed by O'Neil et al. (2007) for the high flux state of Mrk 335. We note that the contribution of a distant reflector was not directly tested via spectral fitting in the present data, but it is discussed in Gallo et al. (2019).

Additional residuals on the blue side of the Fe Kα line suggest that we explore the presence of emission from highly ionized iron, which was already revealed when the source was observed in a high flux state with higher photon statistics (O'Neil et al. 2007). We added a narrow ($\sigma = 1$ eV) Gaussian line in emission and measured its position at $E = 6.90^{+0.05}_{-0.04}$ keV, but only an upper limit of $EW \leq 10$ eV could be measured; therefore, this line is no longer included in the following tests.

We then proceed to examine the residuals in absorption that are still present in the spectrum. Indeed, the addition of a narrow ($\sigma = 1$ eV) Gaussian line with negative intensity at a redshift-corrected position of $E = 7.15 \pm 0.09$ keV ("abs1" in Figure 9) improves the fit statistics by $\Delta\chi^2 = 8$ (for 2 dof), and its intensity is measured to $EW = 57 \pm 30$ eV. A second absorption line is found at the position of $E = 6.82 \pm 0.05$ keV ("abs2" in Figure 9) with an intensity of $EW = 68 \pm 25$ eV and statistical improvement of $\Delta\chi^2 = 10$ for 2 dof.

These absorption features suggest the presence of an ionized blueshifted absorber that could constitute a high ionization layer of the outflowing system detected in the soft X-ray. The closest transitions that could originate the Fe K absorption feature at 7.15 keV are Fe XXVI ($E_{lab} = 6.97$ keV) and Fe XXV ($E_{lab} = 6.67$ keV). The corresponding outflow velocity would be $\sim 7500$ and $20,000$ km s$^{-1}$, respectively. With regard to the second absorption line at 6.82 keV, if interpreted as blueshifted Fe XXV, the outflow velocity would be around $\sim 7000$ km s$^{-1}$. Considering these numbers and the large uncertainties in the position of both absorption lines measured in the pn CCD data, the most viable interpretation is that both absorption lines in the Fe K band correspond to He and H-like ion originated in a gas outflowing at a velocity of $\sim 7000$ km s$^{-1}$, in reasonable agreement with the velocity pattern (5700 km s$^{-1}$) of the warm absorber detected in the grating spectrum.
As a final step, we have replaced the two absorption lines in the spectral model with a PHASE component that can self-consistently fit both features. The improvement in the fit statistics corresponds to $\Delta \chi^2 = 19$ for 3 dof, and the parameters of the photoionized wind are $\log U = 3.13^{+0.05}_{-0.09}$, $\log N_H = 23.07$, with an outflow velocity of $5200^{+700}_{-200}$ km s$^{-1}$. This velocity, which is now measured self-consistently, shows a much finer agreement with the value derived from the grating spectrum for the low-ionization component of the absorber.

2.2.3. On the Consistency of the Broadband Model with the Grating Spectrum

Due to bandwidth restriction, neither of the two EPIC-pn absorbers (the highly ionized and the partial covering) seems to imprint obvious features in the RGS data.

With regard to the partial covering, the bulk of absorption comes from continuum opacity, and its effect starts to be visible in the spectrum above 3 keV, therefore virtually impossible to detect in RGS. The inclusion of a PHASE component in the RGS best-fit model with parameters fixed to the EPIC-pn values is formally consistent with the data, although no improvement in the fit statistics is found. When the column density and the velocity are kept frozen, $\log U$ is found around 1.04 with an extremely low covering factor ($C_r = 0.1$), which would not allow any individual absorption line to be strong enough to be detected in RGS.

We now explore the possible presence of the EPIC-pn highly ionized absorber in RGS data. The inclusion of this component into the RGS best-fit model yields a modest improvement of $\Delta \chi^2 = 5$ for three free parameters: $\log U = 2.61^{+0.73}_{-0.33}$, $\log N_H = 23.4^{+0.30}_{-0.99}$, and $v_{\text{out}} = 6500^{+700}_{-400}$ km s$^{-1}$. These parameters are broadly consistent with the EPIC-pn values reported at the end of the previous section.

We fully acknowledge that the presence of the high-ionization absorber is not statistically robust in any of the spectral data. Nonetheless, after running these checks, we conclude that the simultaneous (albeit moderate) significance in CCD and grating spectra of an outflow with velocity consistent with the well-characterized system of winds observed in RGS concurs to indicate that a high-ionization component of the wind is present in the low flux state of Mrk 335.

3. HST Ultraviolet Spectra

3.1. Observations and Data Reduction

The triggered XMM-Newton observations of Mrk 335 were coordinated with two HST observations. The first of these, on 2016 January 4, followed the XMM-Newton observation by 5 days. This visit used all COS far-UV (FUV) gratings (G130M, G160M, and G140L) to cover the full wavelength range from 912 to 2000 Å, specifically including the region surrounding Ly$\beta$ and O VI. The second visit, another 3 days later, on 2016 January 7, supplemented the G140L exposures to obtain better S/N in the Ly$\beta$ and O VI region. Table 4 gives the observational details of the individual spectra. Green et al. (2012) describe the key characteristics of the design and performance of the COS instrument on HST. The G130M and G160M gratings have a resolving power of $R \sim 15,000$ over the wavelength range of 1135–1800 Å. The G140L grating has resolving power $R \sim 2000$ covering 912 Å to 2000 Å with the 1280 central wavelength setting, but with a gap between detector segments from 1190 to 1265 Å. We chose two central wavelength settings for G130M and G160M to bridge the gap between the FUV detector segments. These settings were also chosen to avoid placing the gap on spectral features of interest in Mrk 335. In addition to multiple central wavelength settings, we also used multiple focal-plane positions to avoid flat-field features and other detector artifacts.

We processed the observations using v3.1 of CALCOS, the COS calibration pipeline, supplemented by custom flat-field files developed for lifetime position 3. The wavelength zero points of all spectra were adjusted after processing by measuring the wavelengths of strong interstellar features and aligning them to the line-of-sight velocity for H1, $V_{\text{LSR}} = -11$ km s$^{-1}$ (Murphy et al. 1996). Improvements in the COS wavelength calibration now give relative uncertainties of $\sim 5$ km s$^{-1}$. Comparing the eight exposures in Table 4, fluxes in the wavelength regions common to all exposures agree to better than 2%, and within the statistical errors of each exposure Therefore, we combine all exposures for each grating to make three separate spectra for G130M, G160M, and G140L, and we join G130M and G160M at 1423 Å to make a single high-resolution spectrum covering 1135–1800 Å. Figure 10 shows the full merged COS spectrum from the Lyman limit to 2000 Å.

3.2. Measuring the Broad UV Absorption Lines

Unlike our discovery of broad C IV absorption in the 2009 and 2010 COS spectra of Mrk 335 (Longinotti et al. 2013), in our new observation we know where to look to see whether the absorption features have reappeared in our triggered observations of Mrk 335 in an obscured state. Upon close inspection, broad absorptions in C IV and Ly$\alpha$ were immediately apparent in our 2016 observations. To measure the properties of these
absorption features, we first developed a total emission model for Mrk 335 that includes both the continuum and the emission lines. As in Longinotti et al. (2013), we use a power law for the continuum, $F_\lambda = F_{1000} (\lambda / 1000 \text{ Å})^{-\alpha}$ reddened by $E(B-V) = 0.030$ (Schlaufy & Finkbeiner 2011) using the Cardelli et al. (1989) extinction law with $R_V = 3.1$. Our model includes more components than in Longinotti et al. (2013), as we include components for weaker emission lines as well as Si IV, and the C III λ977, N III λ991, Si III λ1892, and C IV λ1909 lines present in the G140L spectrum.

We fit our model in three separate pieces owing to the complexity of the spectrum and the greatly differing resolutions of the G130M+G160M and G140L gratings. We first fit G130M+G160M, covering 1140–1800 Å as described below, and then separately fit the Si III λ1892 and C IV λ1909 region at the red end of G140L and the Lyβ+O VI region on the blue end. For the G140L fit, we constrain the power-law continuum to have the same spectral index as in the fit to the G130M+G160M spectrum, but we allow its normalization to adjust to the slight ($\sim 2\%$) differences relative to G130M and G160M.

In Longinotti et al. (2013), the restricted wavelength range of the G130M and G160M spectra did not include a substantial contribution from the forest of Fe II emission lines that blend into a pseudo-continuum starting at roughly 1500 Å. This pseudo-continuum is brighter in our current G140L spectrum, but there are no definitive spectral features that enable us to constrain its strength. These lie mostly at longer wavelengths, peaking at $\sim$2500 Å. We therefore used the Faint Object Spectrograph spectrum described in Longinotti et al. (2013) to constrain its normalization, and we included it as a fixed element of our model, using a scaled version of the Wills et al. (1985) model convolved with a Gaussian FWHM of 2800 km s$^{-1}$, approximately the FWHM of the C IV emission line. At 1800 Å, its flux is $3 \times 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$, which is only 2% of the modeled continuum in our spectrum.

We use multiple Gaussian components for each line, choosing an appropriate number to obtain the best-fit for each line. These components have only rough physical meanings. We presume that the narrow components may be more reflective of the narrow-line region in Mrk 335, but we ascribe no significance to the broader components we have used to decompose each profile. We are merely interested in a good characterization of the total emission, which will enable us to normalize the spectrum, measure the strengths of the absorption features, and measure the total flux of the emission components above the continuum. The strongest emission lines in Mrk 335 require at least three, and sometimes four, components. The narrowest portions of the profiles are clearly separated in O VI, N V, Si IV, and C IV, so we include a separate component for each line of the doublet. We link the wavelengths of the doublet lines at the ratio of their vacuum wavelengths, and we fix the ratio of their fluxes at a ratio of 2:1, assuming that they are optically thin. Lyα, N V, Si IV, C IV, and He II all require a very broad Gaussian component with FWHM $\sim 10,000$ km s$^{-1}$. We do not model this separately for the doublets in N V, Si IV, and C IV.

To optimize our fits, we used the IRAF task SPECFIT (Kriss 1994). We first fit the merged G130M+G160M spectra. Our best-fit model has a power-law normalization of $F_{1000} = 4.09 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$ with a spectral index of $\alpha = 1.31$. The fit is excellent, with $\chi^2 = 12049.76$ for 12,285 points and 99 free parameters. The best-fit parameters are given in Table 5. Error bars are calculated from the error matrix of the fit, assuming that a 1σ error corresponds to $\Delta \chi^2 = 1$ for a single interesting parameter. Parameters with error bars of zero were tied to other parameters in the fit, e.g., the fluxes, wavelengths, and widths of doublet emission lines, and the widths of some of the weakest emission components.

Strong, broad absorption in Lyα and C IV is clearly present in our new observations. Figure 11 shows our best fit to the C IV region. Absorption is clearly present on the extreme blue wing of the C IV emission profile (in the same location it appeared in the 2009 COS spectrum). Weak absorption extends all the way down to $\sim 1545$ Å, past the complex of foreground C IV absorption lines from the Milky Way and the Magellanic Stream.

The spectrum and the best-fit emission model for the Lyα region are shown in Figure 11. Unfortunately, absorption corresponding to N V falls directly on the peak and the red side of the steep Lyα emission profile. Our model of the Lyα emission is perfectly acceptable without any N V absorption. Alternatively, if we include N V absorption as Gaussian absorption features approximating the shape of the C IV absorption shown in Figure 11, we can obtain an equally good fit. The parameters of the emission line need only adjust slightly to accommodate the forced inclusion of the absorption features, so it is impossible to get a reliable assessment of any N V absorption, although it is likely present.

There is no absorption visible near Si IV, nor near the lower-ionization transitions of C IIIλ1909 or C IIλ1334. Si IV absorption is visible in the obscuration events seen in NGC 5548 (Kaastra et al. 2014), NGC 985 (Ebrero et al. 2016), and NGC 3783 (Mehdipour et al. 2017), but it was not present in Mrk 335 in 2009. Broad C IIIλ1909 and C IIλ1334 absorption (and other lower-ionization species) was present in NGC 5548, and broad C IIIλ1909 absorption was present in NGC 985. Given this wide array of ionization states seen in the obscured states of other AGNs, we measured upper limits for these lines in our current spectrum of Mrk 335 to provide quantitative constraints on the ionization state of the absorbing gas.

3.2.1. Interstellar Absorption in FUSE Data

We now turn to the analysis of the Lyβ+O VI region in the G140L spectrum. The rich foreground ISM absorption at wavelengths shortward of 1100 Å makes this region difficult to model, particularly given the much lower resolution of the G140L grating. However, as a guide we have retrieved a prior high-S/N spectrum of Mrk 335 from the Mikulski Archive for Space Telescopes (MAST) obtained in 1999 with Far Ultraviolet Spectroscopic Explorer (FUSE). This makes the modeling more tractable since the FUSE spectrum can provide a very accurate model for all the foreground absorption.

We start by fitting an emission model to the FUSE spectrum of Mrk 335 using our fit to the C IV profile as a guide. We add components for C IIIλ977, N IIIλ991, the Si IVλ1064, 1072 doublets beyond O VI, and the He II/N IIλ1085 blend. The continuum power-law index is fixed at the shape of the COS G130M+G160M spectrum (from 1135 to 1800 Å, $\alpha = 1.31$). We model the foreground ISM absorption using the FUSE spectral simulation tool fsim (V5.0; W. R. Oegerle & E. M. Murphy).
This model matches the location of every single absorption feature in the *FUSE* spectrum, but it is not completely correct for all the line strengths.

This is convincing evidence that there was no prior intrinsic absorption visible in these earlier high-resolution spectra of Mrk 335. Remarkably, the *FUSE* data of 1999 provide the ultraviolet view of Mrk 335 nuclear emission during the X-ray-bright state, prior to 2007.

This ISM model allows us to fit the emission spectrum (lines +continuum) of Mrk 335 as observed with *FUSE* very well. We then use this fit to produce a normalized spectrum of Mrk 335. Since all emission is described by our model, and we have

| Feature | $\lambda_0$ (Å) | Flux (10^{-14} erg cm^{-2} s^{-1} Å^{-1}) | $v_{sys}$ (km s^{-1}) | FWHM (km s^{-1}) |
|---------|----------------|-----------------------------------------|------------------------|-----------------|
| C III   | 977.02         | 13.9 ± 5.9                              | −513 ± 82              | 3271 ± 143      |
| N III   | 990.82         | 7.5 ± 5.5                               | −197 ± 101             | 3000 ± 170      |
| O VI    | 1031.93        | 3.9 ± 7.3                               | −114 ± 57              | 700 ± 90        |
| O VI    | 1037.62        | 4.8 ± 1.4                               | −113 ± 0               | 700 ± 0         |
| O VI    | 1031.93        | 40.7 ± 2.1                              | −38 ± 0                | 1193 ± 130      |
| O VI    | 1037.62        | 34.2 ± 3.4                              | −37 ± 0                | 1193 ± 0        |
| O VI    | 1031.93        | 29.1 ± 0.1                              | −123 ± 0               | 6210 ± 220      |
| O VI    | 1037.62        | 29.1 ± 0.0                              | −125 ± 0               | 6210 ± 0        |
| O VI    | 1034.78        | 50.2 ± 0.0                              | −130 ± 0               | 8736 ± 0        |
| Si IV   | 1072.97        | 4.3 ± 1.3                               | 234 ± 120              | 2900 ± 180      |
| P V     | 1117.98        | 1.7 ± 1.0                               | 1 ± 134                | 4393 ± 0        |
| P V     | 1128.01        | 1.0 ± 1.0                               | 1 ± 0                  | 4393 ± 0        |
| C III'  | 1176.01        | 0.4 ± 1.1                               | −3 ± 49                | 1334 ± 96       |
| C III'  | 1176.01        | 13.6 ± 2.2                              | −3 ± 45                | 4393 ± 160      |
| Lyα     | 1215.67        | 1040.0 ± 2.0                            | 92 ± 5                 | 687 ± 10        |
| Lyα     | 1215.67        | 2190.0 ± 4.1                            | 54 ± 5                 | 1724 ± 20       |
| Lyα     | 1215.67        | 1940.0 ± 4.2                            | 112 ± 5                | 4892 ± 118      |
| Lyα     | 1215.67        | 78.3 ± 2.3                              | 92 ± 14                | 10743 ± 196     |
| N V     | 1238.82        | 4.2 ± 1.1                               | 25 ± 5                 | 702 ± 11        |
| N V     | 1242.80        | 4.2 ± 0.0                               | 24 ± 0                 | 702 ± 0         |
| N V     | 1238.82        | 18.6 ± 2.0                              | 56 ± 5                 | 2530 ± 95       |
| N V     | 1242.80        | 18.6 ± 0.0                              | 57 ± 0                 | 2530 ± 0        |
| N V     | 1240.89        | 53.0 ± 1.2                              | 27 ± 18                | 8715 ± 115      |
| Si II   | 1260.42        | 3.0 ± 1.0                               | 574 ± 41               | 1724 ± 0        |
| O I + Si II | 1304.46     | 1.4 ± 1.1                               | −420 ± 5               | 800 ± 133       |
| O I + Si II | 1304.46     | 14.5 ± 1.2                              | −21 ± 5                | 3000 ± 113      |
| C II    | 1334.53        | 1.3 ± 1.0                               | 313 ± 16               | 800 ± 0         |
| C II    | 1334.53        | 5.0 ± 1.0                               | 109 ± 8                | 3000 ± 0        |
| Si IV   | 1393.76        | 4.7 ± 1.1                               | 110 ± 13               | 1021 ± 112      |
| Si IV   | 1402.77        | 4.7 ± 0.0                               | 110 ± 0                | 1021 ± 0        |
| Si IV   | 1393.76        | 6.6 ± 1.1                               | −61 ± 14               | 3645 ± 135      |
| Si IV   | 1402.77        | 6.6 ± 0.0                               | −63 ± 0                | 3645 ± 0        |
| Si IV   | 1398.19        | 24.3 ± 1.1                              | 1045 ± 15              | 10413 ± 149     |
| O IV    | 1401.16        | 1.9 ± 1.1                               | 253 ± 92               | 1021 ± 0        |
| O IV    | 1401.16        | 9.1 ± 1.3                               | 253 ± 0                | 3645 ± 0        |
| N IV    | 1406.50        | 2.1 ± 1.1                               | 13 ± 12                | 1021 ± 0        |
| N IV    | 1406.50        | 3.7 ± 1.0                               | −84 ± 17               | 2590 ± 154      |
| C IV    | 1548.19        | 3.0 ± 2.0                               | 39 ± 5                 | 811 ± 22        |
| C IV    | 1550.77        | 30.8 ± 0.0                              | 38 ± 0                 | 811 ± 0         |
| C IV    | 1548.19        | 39.6 ± 3.0                              | 56 ± 5                 | 1904 ± 112      |
| C IV    | 1550.77        | 39.6 ± 0.0                              | 55 ± 0                 | 1904 ± 0        |
| C IV    | 1548.19        | 43.1 ± 3.0                              | −360 ± 8               | 4294 ± 113      |
| C IV    | 1550.77        | 43.1 ± 0.0                              | −360 ± 0               | 4294 ± 0        |
| C IV    | 1549.05        | 74.4 ± 3.1                              | 56 ± 14                | 8736 ± 119      |
| He II   | 1640.48        | 8.9 ± 1.1                               | 5 ± 5                  | 779 ± 16        |
| He II   | 1640.48        | 8.8 ± 1.1                               | −200 ± 5               | 2272 ± 115      |
| He II   | 1640.48        | 57.1 ± 2.0                              | −1373 ± 22             | 11989 ± 288     |
| O III   | 1660.81        | 3.0 ± 1.0                               | 64 ± 5                 | 1600 ± 43       |
| O III   | 1660.81        | 8.0 ± 1.0                               | 64 ± 0                 | 1600 ± 0        |
| N III   | 1750.00        | 1.1 ± 1.0                               | −1 ± 68                | 3267 ± 324      |
| Si III  | 1892.08        | 6.1 ± 0.9                               | 67 ± 70                | 1169 ± 161      |
| Si III  | 1892.08        | 5.6 ± 2.0                               | −635 ± 541             | 2920 ± 121      |
| C III   | 1908.73        | 16.3 ± 3.4                              | 12 ± 19                | 850 ± 92        |
| C III   | 1908.73        | 31.6 ± 0.9                              | 102 ± 56               | 2677 ± 506      |

*Note.* Parameters with error bars of zero were tied to other parameters in the fit (see Section 3.2).
components for each member of the doublet as in C IV, but no very broad component is necessary. We constrain the FWHM of the two broad components of the O VI emission line profile to match those of C IV, but we allow the strengths and positions to vary freely. Our best fit gives $\chi^2 = 541.51$ for 400 points and 14 free parameters. This fit is illustrated in Figure 12. All narrow absorption features, which correspond to foreground Galactic ISM absorption, are well matched except in the regions we expect to be affected by broad Ly$\beta$ and O VI absorption.

One can see that Ly$\beta$ and O VI absorption appears to be present in our spectrum, but we test for this more quantitatively by adding in broad Gaussian absorption components for Ly$\beta$ and O VI based on the locations and shapes of the Ly$\alpha$ and C IV troughs. We test the significance of adding these components individually and severally, as summarized in Table 6. Including absorption components for all three lines, Ly$\beta$, O VI $\lambda 1031$, and O VI $\lambda 1037$, gives an improvement in $\chi^2$ of $\Delta \chi^2 = 32.19$. For an $F$-test with three added free parameters, this is a significant improvement at greater than 99.9% confidence.

With our emission-model fits to the Mrk 335 spectra, we can now divide these into the data to generate normalized spectra. Figure 13 shows normalized spectra in the C IV, N V, Ly$\alpha$, and O VI regions of the Mrk 335 spectrum illustrating the broad absorption features. We also show the (coincident) locations of the X-ray absorption components identified in Longinotti et al. (2013) and in the present paper.

We measured the strengths of the absorption features in our spectra of Mrk 335 by directly integrating the normalized spectra shown in Figure 13. We chose velocity intervals covering the full range of absorption visible by inspection as given in Table 7. Note that this interval is substantially larger for the blended C IV doublet, not only because the two components are separated by 950 km s$^{-1}$ in velocity space but also because there is no confusion on the blue wing of the absorber. The corresponding blue end in Ly$\alpha$ is buried under

identified all absorption features with foreground ISM features (metal lines plus H$_2$), this normalized spectrum represents the transmission spectrum of the ISM along the line of sight to Mrk 335. All features in this spectrum are foreground ISM absorption, and an independent model of the ISM absorption (which was not quantitatively accurate) is no longer required. We then convolve this transmission spectrum with the COS G140L line-spread function to produce a model of the ISM transmission as it would appear in the COS spectrum.

3.2.2. Interstellar Absorption in COS Data

Given this model for the complex, contaminating foreground absorption, we can now fit an emission model to the COS G140L spectrum of Mrk 335. To test for the presence of O VI and Ly$\beta$ absorption, we first fit the entire region with just emission components. The weak lines of C III $\lambda 977$, N III $\lambda 991$, and S IV $\lambda 1072$ all require only a single Gaussian component. For O VI, we require the narrow, semi-broad, and broad
the damped Ly\(\alpha\) absorption of the Milky Way. Likewise, Ly\(\beta\) is contaminated by geocoronal Ly\(\beta\) emission. For O\(\text{VI}\), the doublet separation is 1814 km s\(^{-1}\), causing blending at higher blueshifted velocities. We therefore limited the range for integration to approximately the same interval used for Ly\(\alpha\). All features have broad widths that are well resolved. This enables us to directly integrate the normalized absorption profiles to obtain equivalent widths (EW). Our direct integrations also yield column densities using the apparent optical depth method of Savage & Sembach (1991).

### 4. Discussion

The latest X-ray–UV observational campaign carried out on Mrk 335 in 2015 and presented in this work fully confirms the scenario proposed by Longinotti et al. (2013) based on nonsimultaneous data. We briefly recall the properties of the absorber in Mrk 335 reported therein.

#### 4.1. The Warm Absorber in 2009 and 2015

In our comparison with present data we consider only the 2009 spectrum, which in Longinotti et al. (2013) is referred to as the “midstate,” and in which the warm absorber properties could be measured at best compared to other epochs. The ionization was there described in terms of the ionization parameter \(\xi = L/m^2\); therefore, we now quote the corresponding number in terms of \(U\) to ease comparison with Table 3.

Table 9 reports the values of the three layers of ionized absorption detected in 2009 adapted from Table 5 in Longinotti et al. (2013). The ionized absorber in 2015 (see Table 3) seems very consistent with WA II in 2009. This seems to indicate that since its first record in 2009, the ionized wind has become a persistent feature of Mrk 335, which is also supported by the conclusions reached by Gallo et al. (2018) in their long-term study. These authors conclude that the current low flux state observed since 2007 is not driven by changes in the structure of the inner accretion disk. Rather, they propose that the variability pattern may be explained in terms of either coronal changes or intervening absorption. The apparent stability of the outflow supports therefore the latter hypothesis. We note that in the first low-state spectrum of 2007 (Grupe et al. 2007) the presence of ionized absorption could not be investigated in detail owing to the low S/N of the grating data (see Longinotti et al. 2013). However, as the presence of the absorber in this epoch could not be excluded either, we speculate that this wind may well have emerged in 2007 when Mrk 335 entered its prolonged low X-ray flux state. In the following we proceed to explore the possible association of the X-ray absorbers to the UV wind with the advantage provided by the simultaneity of the two sets of observations in 2015/16.

#### 4.1.1. X-Ray and UV Absorbers in 2015: The RGS View

We start by comparing the parameters estimated by the UV lines with those of the soft X-ray warm absorber for which

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Figure 13 shows that all the troughs have similar depths. Thus, they are likely saturated, and therefore we quote the column densities as lower limits. Given this likelihood of saturation, we also tabulate for each line the covering fraction implied if the deepest part of the trough is saturated. The properties of the absorbers are summarized in Table 8.

### Table 7

Wavelength Intervals for Mrk 335 Broad Absorption Features

| Feature          | \(\Delta n_{\text{inv}}\) (\(\AA\)) | \(v_{1}\) (km s\(^{-1}\)) | \(v_{2}\) (km s\(^{-1}\)) | \(l_{1}\) (\(\AA\)) | \(l_{2}\) (\(\AA\)) |
|------------------|-----------------------------------|---------------------------|---------------------------|-----------------------|-----------------------|
| Ly\(\beta\)      | 1025.72                          | -5976                     | -4353                     | 1031.4                | 1057.0                |
| O\(\text{VI}\)   | 1031.93                          | -5989                     | -4375                     | 1037.6                | 1043.2                |
| O\(\text{VI}\)   | 1037.62                          | -5966                     | -4648                     | 1043.4                | 1048.0                |
| Ly\(\alpha\)     | 1215.67                          | -5976                     | -4362                     | 1222.4                | 1229.0                |
| C\(\text{IV}\)   | 1549.05                          | -8977                     | -4542                     | 1542.1                | 1565.1                |

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**Figure 13.** Normalized spectra of Mrk 335 showing relative fluxes vs. velocity relative to the systemic redshift of \(z = 0.025785\) (Huchra et al. 1999). Top panel: COS spectrum of the C\(\text{IV}\) region from 2009 October 31. Second panel: COS spectrum from this campaign, 2016 January 4. Red curves give velocities relative to the red component of the doublet, and blue curves are relative to the blue component of the doublet. From third to bottom panel: N \(\text{V}\), Ly\(\alpha\), O\(\text{VI}\), and Ly\(\beta\) regions. Dotted vertical lines indicate X-ray absorption velocities (from this work and from Longinotti et al. 2013). The narrow absorption features in each panel are foreground Galactic or intergalactic (IGM) absorption lines.

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**Table 6**

Statistics of Fits to the Ly\(\beta\)+O\(\text{VI}\) Region of Mrk 335

| Model              | \(\chi^2\) | \(\Delta n_{\text{inv}}\) | \(\Delta \chi^2/\chi^2\) | \(P(\Delta \chi^2)\) |
|--------------------|------------|---------------------------|---------------------------|-----------------------|
| No absorption      | 541.51     | 0                         | 0.0                       | ...                   |
| Add Ly\(\beta\) only | 518.75     | 1                         | 16.22                     | <0.001                |
| Add O\(\text{VI}\) only | 532.58     | 2                         | 6.36                      | 0.002                 |
| Add Ly\(\beta\)+O\(\text{VI}\) | 509.32     | 3                         | 22.95                     | <0.001                |
Note. Velocities and FWHM of O VI and Ly $\beta$ lines are tied to those of C IV, whereas for N V they are tied to Ly $\alpha$ values. Upper limits of C III*, C II, and Si IV were determined with tabulated values.

Table 8
Properties of the UV Broad Absorption Lines in Mrk 335.

| Line   | $\lambda_0$ (Å) | EW (Å) | Velocity (km s$^{-1}$) | FWHM (km s$^{-1}$) | $C_f$ | log $N_{col}$ (log cm$^{-2}$) |
|--------|-----------------|--------|------------------------|-------------------|------|-----------------------------|
| Ly $\beta$ | 1025.72         | 0.91 ± 0.27 | −5.245                 | 807               | 0.29 ± 0.08          | >15.43 |
| O VI   | 1031.93         | 0.97 ± 0.18  | −5.245                 | 807               | 0.29 ± 0.08          | >14.93 |
| O VI   | 1037.62         | 0.93 ± 0.12  | −5.245                 | 807               | 0.27 ± 0.05          | >15.20 |
| Ly $\alpha$ | 1215.67       | 0.74 ± 0.03  | −5.144 ± 36            | 685 ± 74          | 0.22 ± 0.01          | >14.15 |
| N V    | 1240.81         | 0.08 ± 0.02  | −5.144 ± 36            | 685 ± 74          | 0.05 ± 0.03          | >13.86 |
| C III* | 1176.01         | <0.015      | −5.144                 | 700               | …               | <12.15 |
| C II   | 1334.53         | <0.015      | −5.144                 | 700               | …               | <12.84 |
| Si IV  | 1393.76         | <0.017      | −5.144                 | 700               | …               | <12.28 |
| C IV   | 1549.05         | 2.17 ± 0.10  | −5.245 ± 16            | 807 ± 75          | 0.19 ± 0.04          | >14.97 |

Table 9
Warm Absorber Properties in the 2009 RGS Spectrum (Adapted from Longinotti et al. 2013)

| Phase | $\log U$ | $\log N_{col}$ (cm$^{-2}$) | $V_{out}$ (km s$^{-1}$) | $V_{broa}$ (km s$^{-1}$) |
|-------|---------|---------------------------|------------------------|------------------------|
| I     | 0.39$^{+0.04}_{-0.11}$ | 21.34 ± 0.06               | 4000$^{+130}_{-700}$    | ≤100           |
| II    | 1.04 ± 0.03  | 21.63 ± 0.06               | 5200$^{+190}_{-190}$    | ≤100           |
| III   | 2.05$^{+0.05}_{-0.09}$ | 22.55 ± 0.15               | 5300$^{+190}_{-190}$    | ≤100           |

more precise constraints are available owing to the higher detail provided by the grating spectra. The outflow velocity in both bands shows remarkable coincidence. However, the X-ray-estimated ionic column densities provided by the photoionization model of the soft X-ray absorber in Table 3 are only partially compatible with the columns estimated by the UV troughs (Table 8): this X-ray warm absorber does not produce enough C IV absorption ($N_{C IV} = 4.7 \times 10^{12}$ cm$^{-2}$), although it might contribute to the O VI ($N_{O VI} = 7 \times 10^{15}$ cm$^{-2}$) and N V absorption ($N_{N V} = 5.38 \times 10^{13}$ cm$^{-2}$). This partial discrepancy can be visualized in Figure 14, where we can see that the limits traced by the UV columns intersect the X-ray warm absorber columns only for O VI and N V.

As noted in Section 2.1, the spectral fits to the RGS data do not allow us to constrain the width of the X-ray absorption lines, but they seem to favor the presence of narrow rather than broad absorption lines, which may also pose a problem to interpret the two outflows as arising from the same gas. Nonetheless, if it is postulated that X-ray photons cross a smaller range of velocities compared to UV photons as proposed in the sketch of Figure 15, we may explain why broader absorption lines are detected in the UV band compared to the narrow lines observed in the X-rays.

Another considerable difference of the wind in the two bands is the covering fraction of the gas. While the coverage of the soft X-ray ionized gas estimated from the RGS is 100%, the UV absorber covers a small fraction of the ionizing continuum (20%–30%; see Table 8). We tested for the presence of a partially covering warm absorber by using a PHASE version with variable covering factor. This test indicates that the warm absorber coverage is consistent with being as low as 80%, although partial covering is not formally required by the fit statistics. We note that such a value is fully coincident with the constraint obtained for the warm absorber in the midstate flux of 2009. This may indicate that the hotter part of the outflow (seen in X-rays) is organized in a denser/clumpier structure than the gas ionized by the UV continuum, and/or it may also indicate that the UV source is more extended than the X-ray source, as depicted in Figure 15. This interpretation is compatible and may actually explain the presence of the partial covering absorber observed in the broadband X-ray spectrum (see next section).

4.1.2. X-Ray and UV Absorbers in 2015: The EPIC-pn View

The 2015 CCD spectrum of Mrk 335 reveals the presence of two additional layers of absorption: the highly ionized absorber described in Section 2.2.2 ($V_{out} = 5200_{−700}^{+700}$ km s$^{-1}$, $\log U = 3.13_{−0.09}^{+0.09}$, $\log N_{HI} ≥ 23.07$), and the partial covering absorber described in Section 2.2 ($\log(N_{HI}) = 22.99 ± 0.06$, $C_f = 0.79_{−0.02}^{+0.02}$, and $\log(U < 1.35)$). Whereas the former component is too highly ionized to affect the UV spectrum, we explore a possible UV connection with the latter one.

Despite the lack of more detailed properties inferred on the partially covering gas, the X-ray spectral fits show that it has a moderately low ionization and high column density and that it covers around 80% of the X-ray source. Figure 7 shows that its ionization ($\log(U < 1.35)$) overlaps with that of the RGS warm absorber ($\log(U = 0.85_{−0.14}^{+0.09})$, and so does the covering fraction,
Broader than the narrow lines observed in the X-ray spectrum.

Compared to UV photons, which may explain why UV absorption lines are along the line of sight: X-ray photons cross a small range of velocities the partial covering in the continuum. Colors represent the increasing velocity along the line of sight: X-ray photons cross a small range of velocities compared to UV photons, which may explain why UV absorption lines are broader than the narrow lines observed in the X-ray spectrum.

As reported in Section 4.1.1. Unfortunately, the outflow velocity of the partial covering gas could not be measured in CCD data (Section 2.2.1); therefore, it is difficult to pinpoint a more constrained location. In the spectral fitting, we have tied its velocity to the one of the less dense warm absorber detected in RGS assuming that both are part of the intervening gas that crossed our line of sight during the XMM-Newton observation. This is largely justified by the X-ray history of Mrk 335, which, as reported in Section 1, did not show intervening ionized absorption prior to the decrease of X-ray flux (Grupe et al. 2007, 2008) that since 2007 gave rise to the several X-ray campaigns launched on this source.

Moreover, the relatively high velocity measured in the X-ray and also in the UV absorbers (5000–6000 km s\(^{-1}\)) suggests that the obscuring system is located close to the accretion disk or the inner BLR and tends to exclude other possible locations placed farther away (e.g., the inner wall of the torus). These considerations have led us to associate the partial covering and the warm absorber to the same system.

We speculate that the two X-ray absorbers detected in the present work with such a wide range of column densities but overlapping ionization state and coverage may well be tracing the same system of gas where denser filaments/clouds are producing the observed spectral curvature in the broadband data, whereas less dense parts of the outflow are responsible for imprinting the strong Fe UTA absorption. A gas with these characteristics is expected to imprint detectable features in the UV spectrum, which are not currently seen. We plot the predicted ionic columns of this absorber in Figure 14 for the range of the ionization parameter allowed by the best fit. The X-ray curves for the corresponding UV ions show that a partial covering absorber with \(\log U \sim 0.5–1\) is compatible with the same gas producing both the X-ray and UV absorption. As proposed in the previous paragraph, if we postulate that the X-ray and UV absorbers are distributed with very different coverage (80%–100% vs. 20%–30%), then we may well explain why the strong X-ray partially covering gas does not appear in the UV data (see Figure 15).

### 4.2. Conclusions

The obscuring wind in Mrk 335 shows therefore a very rich ionization structure that extends from the UV broad troughs observed by HST up to the highly ionized transitions in the Fe K band, observed in Mrk 335 for the first time. With the exception of the outflow velocity (∼5200 km s\(^{-1}\) in CCD data), the properties of this highly ionized wind (\(\log U = 3.13^{+0.09}_{-0.59}\) and \(\log N_H \geq 23.07\)) are reminiscent of UFOs that are seen in Seyfert galaxies (Tombesi et al. 2011), and whose appearance seems to bear relation to low luminosity states of the sources (Matzeu et al. 2017). The presence of an even faster component of the wind in this low flux state of Mrk 335 cannot be assessed, as the EPIC-pn data are heavily affected by high background at \(E \geq 8\) keV (but see Gallo et al. 2019, for the analysis of the flaring portion of this data). However, we do not exclude the presence of additional and possibly faster outflow components that may also explain unidentified absorption lines in the RGS spectrum (see Figure 4).

Longinotti et al. (2013) extensively discussed the possible interpretation for the appearance of the wind and, based on the variability of the broad UV absorption troughs, concluded that the outflow was transiting our line of sight to the central source at the scale of the BLR ((0.7–4) \(\times 10^{16}\) cm). The present data not only bring a strong evidence of the persistence of the wind, as discussed above, but also provide a more corroborated association of the UV and X-ray outflows. The absorber therefore can be effectively tracing the base of a radiatively driven wind produced by the accretion disk (Proga & Kallman 2004) as suggested for sources with similar behavior to NGC 5548 and NGC 3783 (Kaastra et al. 2014; Mehdipour et al. 2017). In Mrk 335 the situation seems to be akin to NGC 5548, where the obscuring gas covers 70% of the source and where the obscuration is observed to extend for several years as opposed to the isolated eclipsing event that recently characterized NGC 3783 (Mehdipour et al. 2017).

Further results on the behavior of the absorbers in Mrk 335 are expected by an ongoing multiepoch study (M. L. Parker et al. 2019, in preparation) that includes data from very recent X-ray/UV campaigns launched in 2018 and 2019.

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