Uncovering the Primary X-Ray Emission and Possible Starburst Component in the Polarized NLS1 Mrk 1239

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Abstract

X-ray observations of the unique NLS1 galaxy Mrk 1239 spanning 18 yr are presented. Data from XMM-Newton, Suzaku, Swift, and NuSTAR are combined to observe a broadband, multi-epoch view of the source. There is spectral variability in the 3–10 keV band over the 18 yr. An analysis of the NuSTAR and Suzaku lightcurves also suggests rapid variability in the 3–10 keV band, which is consistent with the NLS1 definition of the source. However, no variability is seen below 3 keV on any timescale. Two distinct physical models are adopted to describe the data above and below ∼3 keV. The low energies are dominated by a hot, diffuse gas likely associated with a starburst component at large physical scales. The higher-energy spectrum is dominated by emission from the central region. Ionized partial covering and relativistic blurred reflection are considered for the central region emission. In both cases, the underlying power law has a photon index of $\Gamma \sim 2.3–2.4$. A distant reflector, a neutral partial covering component with a covering fraction near ∼1, and contributions from starburst emission are always required. The blurred reflection model requires a reflection-dominated spectrum, which may be at odds with the low emissivity index and radio properties of the source. By contrast, the two absorption components required in the ionized partial covering model may correspond to the two distinct regions of polarization observed in the optical. Regardless of the physical model, spectral changes between epochs are driven by the absorption components—and on short timescales, by intrinsic active galactic nucleus variability.

Unified Astronomy Thesaurus concepts: X-ray active galactic nuclei (2035); AGN host galaxies (2017)

1. Introduction

Active galactic nuclei (AGNs) are powered by supermassive black holes, which are accreting material from their surroundings. AGN emit light across the entire electromagnetic spectrum and are typically variable at all wavelengths. Studying the X-ray emission from these objects allows for the characterization of the innermost regions of the system, where extreme relativistic effects occur.

AGN are typically classified based on their viewing angle, where Seyfert 1 (type-1) AGN provide a direct view of the central engine, and Seyfert 2 (type-2) AGN are viewed through the cold, obscuring torus (Antonucci 1993). Seyfert 1 galaxies can then be further classified based on their optical properties—in particular, the full width at half maximum (FWHM) of the Hβ line. Narrow-line Seyfert 1 (NLS1) galaxies have FWHM less than 2000 km s$^{-1}$, while broadline Seyfert 1 (BLS1) galaxies have FWHM greater than 2000 km s$^{-1}$ (Osterbrock & Pogge 1985; Goodrich 1989). The narrower lines observed in NLS1s are typically explained by lower-mass AGNs that are accreting at a higher fraction of their Eddington limit (Pounds et al. 1995; Grupe et al. 2004; Komossa 2008).

The X-ray spectra of type-1 AGNs are dominated by a power law. The origin of the power law is the X-ray-emitting corona, a source of hot electrons located at some height above the black hole. UV seed photons from the accretion disk are Compton upscattered in the corona and re-emitted as X-rays in the form of a power law. Many spectra also show evidence of a prominent emission line at ∼6.4 keV. This is typically attributed to Fe Kα emission from neutral iron, originating in the torus—a distant cloud of neutral gas and dust (e.g., Nandra et al. 2007). Above 10 keV, spectra show evidence for a Compton hump, peaking at 20–30 keV. This feature is produced via Compton downscattering of photons from the corona in an optically thick medium, such as the torus or the accretion disk.

Below ∼2 keV, many Seyfert 1 AGN show a strong soft excess of disputed origin. This feature has been shown to be particularly prominent in NLS1 galaxies (e.g., Puchnarewicz et al. 1992; Boller et al. 1996; Grupe et al. 1998). One commonly adopted interpretation is the partial covering scenario, wherein the soft excess is produced via absorption of X-rays from the corona (e.g., Tanaka et al. 2004). The absorber is typically located close to the corona, and a number of ionization states, densities, and covering fractions of the absorbing material can be adopted to explain the observed emission. This interpretation has been used to model the observed spectra of numerous type-1 AGN (e.g., Miyakawa et al. 2012; Gallo et al. 2015).

An alternative interpretation is known as the blurred reflection scenario (e.g., Ross & Fabian 2005). In this model, some fraction of photons emitted by the corona are incident upon the accretion disk. As the photons interact with the disk, they produce strong emission and absorption features, most of which are associated with iron and have energies below ∼2 keV. As the disk rotates, the material is subject to extreme general relativistic effects, and the features appear broadened. This produces a strong soft excess, as well as a broadened Fe Kα line between 4 and 7 keV. This model has been successfully applied to the spectra of numerous NLS1 galaxies (Fabian et al. 2004; Ponti et al. 2010; Gallo et al. 2019).

When the continuum (power-law) component is significantly suppressed, for whatever reason, the underlying components can often be distinguished. In dim sources, distant reflection
Table 1
Observations Log for Mrk 1239

| Observatory    | Observation ID    | Name      | Start Date (yyyy mm dd) | Duration (s) | Exposure (s) | Counts | Energy Range (keV) |
|----------------|-------------------|-----------|-------------------------|--------------|--------------|--------|--------------------|
| XMM-Newton MOS 1+2 | 0065790101 | MOS       | 2001 Nov 12             | 9959         | 9371/9371    | 1052   | 0.3–8.0            |
| Suzaku XIS 0+3   | 702031010         | XIS       | 2007 May 6              | 126256       | 63128        | 6555   | 0.7–1.5, 2.5–10    |
| Suzaku PIN       |                   | PIN       |                         | 535904       |              |        | 12–20              |
| NuSTAR FPMA/FPMB | 60360006002 | FPMA/FPMB | 2019 Jun 17             | 38053        | 21093        | 2039/1954 | 3–30              |
| Swift XRT        | 00081986001 | XRT       | 2019 Jun 17             | 18624        | 6216         | 183    | 0.5–7              |

Note. The observations and instruments used for analysis are listed in column (1). The observation ID and labels used in this work are given in columns (2) and (3), respectively. The start date of each observation is given in column (4). The duration of each observation, total exposure time, and total counts for each observation are given in columns (5), (6), and (7), respectively. The energy over which each observation was fit is given in column (8). For Suzaku, the combined counts from XIS0 and XIS3 are given (column 7). Similarly, for XMM-Newton, the combined counts from MOS1 and MOS2 are reported.

from the torus and even X-ray emission from star formation in the galaxy can also contribute to the soft excess (e.g., Franceschini et al. 2003; Gallo et al. 2019; Parker et al. 2019). While the partial covering and blurred reflections typically produce smoother soft excesses, the torus and star formation regions lie far away from the central engine and are not subject to extreme relativistic effects. The emission and absorption features therefore appear narrow.

Mrk 1239 (RX J0952.3-0136) is typically classified as an NLS1 galaxy and is found at a redshift of \( z = 0.01993 \) (Beers et al. 1995). The source has been studied at many wavelengths, and numerous interesting properties have been revealed. The mass of the supermassive black hole at the center of Mrk 1239 has been reported as \( 2.4 \times 10^7 \, M_\odot \) (Marin 2016). Véron-Cetty & Véron (2001) measure an FWHM of 1075 km s\(^{-1}\) for the H\(\beta\) line, moderate \([O \, III]\) emission strength \(([O \, III]\) / \(H\beta\) = 1.29), and weak Fe II emission \(([Fe \, II] / H\beta = 0.63)\). Additionally, the optical spectrum shows evidence for polarization on the order of \( \sim 3\%–4\% \), and it has one of the highest degrees of polarization reported in Martin et al. (1983). Goodrich (1989) show that the Balmer lines and forbidden optical lines show different degrees of polarization; they suggest that these features have distinct physical origins, polarized due to dust reflection and transmission.

In the radio regime, Mrk 1239 has been classified as both radio-quiet (Doi et al. 2015) or borderline radio-loud (Berton et al. 2018). Doi et al. (2015) show that the radio emission cannot solely be attributed to starburst activity and must also comprise AGN jet activity. They classify this source as a Fanaroff–Riley Type I candidate (Fanaroff & Riley 1974), meaning that the radio luminosity decreases with increasing distance from the center of the galaxy. Doi et al. (2015) also give clear evidence for kiloparsec-scale nonthermal radio emission attributed to AGN jets; however, most of the radio power is centered in the inner 100 pc.

Based on near-infrared observations, Mrk 1239 has some evidence for star-forming regions based on signatures from polycyclic aromatic hydrocarbon (PAH). Ruschel-Dutra et al. (2016) and Jensen et al. (2017) both report signatures of PAH at 11.3 \( \mu m \), although both also suggest that these features lie not in the inner nucleus but rather a few hundred pc from the center. Rodríguez-Ardila & Viegas (2003), who place only an upper limit on a 3.3 \( \mu m \) PAH detection, also state that starburst activity may be occurring a few hundred pc from the nucleus. An estimated star formation rate (SFR) of less than \( 7.5 \, M_\odot \, \text{yr}^{-1} \) (Ruschel-Dutra et al. 2016) has been measured. Sani et al. (2010) find that Mrk 1239 exhibits weaker star formation relative to AGN emission than the average NLS1. Furthermore, Rodríguez-Ardila & Mazalay (2006) reported a remarkable NIR bump; they interpret it as a massive reservoir of dusty gas between NLR and BLR. This could explain strong continuum absorption.

In the X-ray, observations with ROSAT and XMM-Newton have previously been analyzed. Rush & Malkan (1996) report a soft X-ray slope of \( \Gamma \approx 3 \) using ROSAT, and they find absorption higher than the Galactic \( N_H \) value by a factor of \( \sim 1.5 \). Mrk 1239 is also included in the ROSAT sample analyzed by Boller et al. (1996), where a steep soft X-ray slope of 3.9 and a high column density of \( 8.3 \times 10^{20} \text{cm}^{-2} \) are reported. Grupe et al. (2004) report on a 10 ks XMM-Newton observation of Mrk 1239, using data from the EPIC-pn and MOS detectors. They find that the spectral shape can successfully be reproduced using a power law that is almost entirely absorbed by two distinct absorbers, akin to the two polarization regions reported in Goodrich (1989). They also report a strong feature around 0.9 keV found in all three detectors, which they attribute to a strong Ne IX line due to a supersolar Ne/O ratio (Grupe et al. 2004).

This work presents the spectral and timing analysis of all available X-ray data from XMM-Newton, Suzaku, NuSTAR, and Swift, spanning 18 yr between 2001 and 2019, and seeks to explain the unique X-ray properties of the source. In Section 2, the observations and data reduction techniques are summarized. Section 3 examines the variability of the source across both long (years) and short (hours) timescales, and the spectra are analyzed in Section 4. A discussion of the results is given in Section 5, and conclusions are drawn in Section 6.

2. Observations and Data Reduction

Mrk 1239 was observed with XMM-Newton, Suzaku, and NuSTAR/Swift at three different epochs over 18 yr. The data analyzed here are listed in Table 1. This section describes the observations and data reduction.

2.1. XMM-Newton

Mrk 1239 was observed with XMM-Newton (Jansen et al. 2001) for \( \sim 10 \) ks in late 2001. The source appears in the field of view of the target source, RXJ 095208.7–014818, and is therefore substantially off-axis.
The XMM-Newton Observation Data Files were processed to produce a calibrated event list using the XMM-Newton Science Analysis System, SAS V17.0.0. Examination of the background showed significant flaring in the EPIC-pn detector. A good time interval (GTI) was created and applied. Background flaring was not significant in the EPIC-MOS1 and MOS2 detectors.

For each detector, source photons were extracted from a circular region with a 35″ radius centered on Mrk 1239, and background photons were extracted from an off-source circular region with a 50″ radius on the same CCD. For the pn detector, single and double events were selected, while single to quadruple events were selected for the MOS detectors. The SAS tasks RMFGEN and ARFGEN were used to generate response files. XMM-Newton lightcurves were not examined, due to the short length of the observation (10 ks).

The source and background spectra were binned with a minimum of 10 counts per bin. The final pn, MOS1, and MOS2 spectra were checked for consistency, and all spectra were found to be comparable within known uncertainties. The pn spectrum had low counts due to background flare filtering, and the source was located at the very edge of the detector. For this reason, the combined MOS data are used for further analysis. The ungrouped MOS1 and MOS2 source and background spectra were merged using ADDSPEC, and the corresponding response files merged using ADDRMF and ADDARF. The combined source and background spectra were then binned with a minimum of 10 counts per bin. This combined MOS spectrum had a higher signal and lower background than the pn detector, allowing for improved spectral modeling. Data above 8 keV are background-dominated, so only the 0.3–8 keV range is used for spectral modeling.

2.2. Suzaku

Mrk 1239 was the target of a ~126 ks Suzaku (Mitsuda et al. 2007) observation in 2007 May. The data were taken in XIS nominal mode. Extraction of spectra and lightcurves was performed with XSELECT V2.4G using cleaned event files from the front-illuminated (FI; XIS0 and XIS3) and back-illuminated (BI; XIS1) CCDs.

For each instrument, source photons were extracted using a 240″ region centered around the source, whereas background photons were extracted from a 180″ off-source region, while avoiding the calibration regions in the corners of the CCDs. Response matrices for each detector were generated using the tasks XISRMFGEN and XISSIMARFGEN. Source and background spectra for each detector were then binned using the optimal binning routine in FTGROUPPHA (Kaasra & Bleeker 2016). The XIS spectra were checked for consistency and found to be comparable with one another. The XIS0 and XIS3 source and background spectra were then merged using ADDASCAP. For simplicity, only the merged FI spectra are presented for the remainder of the analysis. The XIS spectrum is modeled between 0.7 and 10 keV, while excluding 1.5–2.5 keV due to calibration uncertainties.

Cleaned event files from the HXD-PIN detector were processed using the tool HXDPINXBP1, resulting in a 54 ks exposure. Both the non-X-ray background (NXB) and the cosmic X-ray background (CXB) are used to determine the background level. The source is detected at ~4.5% between 12 and 20 keV, which is considered marginal (Fukazawa et al. 2009).

2.3. NuSTAR and Swift

Mrk 1239 is part of the NuSTAR (Harrison et al. 2013) Extragalactic Legacy Survey, specifically the NuSTAR Local AGN NH Distribution Survey (NuLANDS). NuLANDS is designed to look at heavily obscured AGN in the local universe (Boorman et al. 2018). There are 30 AGN in the sample, and observations were completed in 2019.

Mrk 1239 was observed in June 2019 with a simultaneous Swift observation shortly after NuSTAR began. FPMA and FPMB data were extracted from source region of 75″. A background was selected from the same chip with a region of 115″. The data were processed with CALDB index version 20181030. The joint Swift-XIS spectrum was obtained from the Swift-XRT data product generator (Evans et al. 2009). The NuSTAR data were optimally binned using FTGROUPPHA. The Swift spectra were binned to have a minimum of 10 counts per bin using GRPPHA.

3. Characterizing the Variability

3.1. Long-term Variability

The unfolded spectra of Mrk 1239 compared to a flat ($\Gamma = 0$) power law are plotted in Figure 1. Plotting the unfolded spectra in this way allows us to directly compare data from different instruments, highlighting any spectral differences at each of the three epochs.

The soft band (0.3–3 keV) is remarkably similar between epochs, displaying the same flux and curved spectral shape in the XRT, XIS, and MOS spectra. The large hump-like feature appears to be a soft excess. This feature has been consistently observed in this source beyond the observations included in this paper. The source was also observed using ROSAT (Truemper 1982) in 1992. Rush & Malkan (1996) fit the source with an absorbed power law and found that was an

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4. https://xmmweb.esac.esa.int/docs/documents/CAL-TN-0018.pdf

5. www.swift.ac.uk/user_objects/
is the hardness ratio. In all panels, the dashed line is the average count rate or HR.

acceptable fit. However, the fit was improved using an additional component, either thermal emission (blackbody or Raymond–Smith thermal plasma) or an emission line at ~0.7 keV. The spectra lacked the data quality to distinguish between any of the models. An emission-line-like feature at ~0.9 keV was also reported by Grupe et al. (2004) in the EPIC-pn spectra. This feature is prevalent in all the data.

The most significant variability appears between 3 and 10 keV. The flux and spectral shape of the source are different in 2019 compared to the earlier XIS and MOS observations. In particular, the NuSTAR and Swift data are a factor of ~2–3 brighter than the XIS and MOS data in this energy range. The MOS and XIS data are remarkably similar across the entire energy range. There is a slight discrepancy around ~6–7 keV, where the MOS data appear slightly brighter; however, the spectra remain consistent within error.

The source is significantly detected in NuSTAR up to ~30 keV. The source is only marginally detected in the PIN, but appears to be comparable in brightness at the two epochs (2007 and 2019). We cannot comment on any change in shape between epochs, because the PIN data are limited.

3.2. Rapid Variability

Having established that there is some long-term variability in the 3–10 keV band, we examine lightcurves for rapid variability over the course of the NuSTAR and Suzaku observations. The FPMA and FPMB lightcurves were merged to improve signal-to-noise, as were the XIS0 and XIS3 lightcurves. Variability was examined using 500 and 5780 s bins, where 5780 s corresponds approximately to the orbital period of the satellites. The lightcurves were binned using LCURVE. Given the modest data quality, all lightcurves and hardness ratios are compared to their mean value to examine variability. The fit quality is given by a reduced $\chi^2$ test. In Figure 2 and Table 2, the lightcurves and fits are presented.

The XIS lightcurve for the soft band (0.5–3 keV) has a mean count rate of ~0.05 count s $^{-1}$. The $\chi^2$/dof for the lightcurves is 144/145 using the 500 s bins and 11/21 using the 5780 s bins. This indicates that the source is not variable below 3 keV on short timescales.

The hard band (10–30 keV) was only observed with NuSTAR, and has a mean count rate of ~0.1 count s $^{-1}$. The $\chi^2$/dof of the 500 and 5780 s bin lightcurves are 53/50 and 4/6, respectively. The slight difference in the $\chi^2$ values may be the result of a flare in the 500 s bin lightcurve at approximately 20 ks. On short timescales, the hard band remains constant in flux within uncertainties.

The intermediate band (3–10 keV) is the only band that has overlap between NuSTAR and XIS. In the XIS lightcurve, the mean count rate is ~0.04 count s $^{-1}$. The AGN is more significantly detected in NuSTAR, and the mean count rate is ~0.2 count s $^{-1}$. Upon visual inspection, the intermediate band appears to have more variability compared to the soft and hard bands. This is confirmed in the constant-fit test. The NuSTAR 500 s and orbital binned lightcurves are inconsistent with constants and have $\chi^2$/dof = 101/50 and 41/6, respectively. The XIS data show marginal variability (23/21) in the orbital binned lightcurve in this band and none in the 500 s bin lightcurve. However, due to the low count rate, it is difficult to rule out rapid variability in the XIS lightcurves.

The hardness ratio (HR) for the XIS lightcurves, $HR_{XIS}$, has a mean value of ~0.2, indicating that the soft count rate is higher than the intermediate count rate. The NuSTAR $HR_{FP}$
has a mean value of $\sim -0.4$, indicates the intermediate count rate is higher than the hard count rate. All HR curves are inconsistent with a constant fit ($\chi^2$/dof $> 1$), indicating a significant amount of spectral variability. This spectral variability is driven by fluctuations in the intermediate (3–10 keV) band. The same result is found on long timescales (Figure 1). On both timescales, there is very little change in the soft band, which remained constant in shape and flux. The intermediate band changes in shape and flux on long timescales, and it also changes in flux on rapid timescales.

The excess variance ($\sigma_{\text{rms}}^2$) (e.g., Ponti et al. 2012) is calculated for the NuSTAR 3–10 keV lightcurve, to further examine the rapid variability. The lightcurve is binned in 200 s and subdivided in 10 ks segments. The excess variance is calculated in each segment and then averaged over all of the segments. The measured average value for Mrk 1239 during the NuSTAR observation is $\sigma_{\text{rms}}^2 = 0.04 \pm 0.01$. The value is comparable to that measured in other NLS1 galaxies (Ponti et al. 2012).

Seyfert 1 AGN can display substantial variability at lower energies, and NLS1s in particular are known to display extreme soft variability on both short and long timescales (e.g., Boller et al. 1996; Leighly 1999; Grupe et al. 2001, 2010; Nikolajuk et al. 2009; Komossa et al. 2017; Bonson et al. 2018; Gallo 2018). The differences in the rapid and long-term spectral variability may be pointing to different origins for the soft (<3 keV) and intermediate (3–10 keV) emission. This suggests that the primary source of the soft excess is highly atypical compared to other NLS1s. However, the variability above 3 keV seen on both short and long timescales is more typical of what is seen in other sources, implying an origin distinct from the soft excess. More discussion for this will be given in Section 5.

4. Spectral Modeling

All data were background modeled in XSPEC, except for the PIN data, which were background-subtracted. We used C-statistics (Cash 1979) to evaluate the fit quality throughout. Errors were calculated at the 90% confidence level using the XSPEC error command. The NuSTAR and Swift spectra were treated as one epoch for all spectral modeling. All model parameters were linked between them. The same was done for the Suzaku XIS and PIN data. A cross-calibration constant was applied to all models and frozen throughout spectral fitting. The constant applied to the PIN data was frozen at 1.18.7 A Galactic column density of $N_H = 4.43 \times 10^{20}$ (Willingale et al. 2013) was applied to all models and frozen throughout spectral fitting. Wilms et al. (2000) abundances were used throughout spectral fitting.

Figure 3 shows each spectrum separately, along with its background model and its ratio for an absorbed power law with $\Gamma = 2$ to represent a typical NLS1. As we can see in Figure 3, all spectra exhibit curvature and none are fit well by the power law. All five spectra show evidence for excess emission between 5 and 8 keV. The MOS spectrum shows a soft excess below 1 keV, and all spectra are overestimated by the model in the 2–5 keV range.

4.1. NuSTAR/Swift

We begin by examining only the NuSTAR and Swift spectra, and only consider data above 2 keV. This is the first time this data set has been examined in detail, and it provides the best view of the AGN above 10 keV. The examination of the unfolded spectrum reveals many key characteristics; an underlying power-law component, extreme spectral curvature around 3–8 keV, and a potential narrow feature at 6.4 keV. To model these features, we apply a power law plus a cold (log $\xi = 0$; where the ionization parameter $\xi = L/nr^2$ and $L$ is the incident luminosity, $n$ is the column density of the cloud, and $r$ is the distance from the cloud to the illumination source), distant reflector representing reflection off the torus. To reproduce the observed spectral curvature, we modify the power law with a single region of neutral absorption. The XSPEC model would appear as: CONSTANT $\times$ TBABS $\times$ (XILLVER $+$ ZPHEABS $\times$ PO). The constant is the cross-calibration constant between FPMA/FPMB and Swift. This model was found to provide a suitable fit to the NuSTAR/Swift data in the 2–30 keV band, and it gives a fit statistic of $C$/dof = 356.46/314.

We extended the model and data down to 0.5 keV to see if this model is also capable of explaining the spectrum at low energies. This results in a much poorer fit ($C$/dof = 449.86/338) and a large excess below approximately 1 keV. The addition of a second neutral partial covering component does not improve the fit quality; however, the addition of an ionized partial covering absorber (ZXPCTR: Reeves et al. 2008) significantly improves the fit quality ($C$/dof = 324.03/335). Despite the large change in the C-statistic, there remain significant residuals at approximately 1 keV, as were noted by Grupe et al. (2004). Additionally, all model fits give very high values of the absorber covering fraction (CF $\sim 0.95$–1). It therefore seems possible that the intrinsic emission from the AGN is largely obscured below $\sim$3 keV and appears only at high energies.

Based on the work of Ruschel-Dutra et al. (2016) in the mid-infrared, we can infer the existence of star-forming regions in Mrk 1239 (see Section 1). Given the lack of evidence for variability at low energies, it is possible that the soft emission does not originate close to the central engine, but rather from star formation on extended scales. We therefore use a MEKAL (Liedahl et al. 1995) component, collisionally ionized emission from hot diffuse gas, to model the SFR. We specify that MEKAL use abundances given by Wilms et al. (2000), with abundance frozen for all spectral fits. This improves the fit to $C$/dof = 307.92/333, and removes the residuals at 1 keV. The measured temperature is $kT \approx 1$ keV.

Alternatively, we examine if the curvature and hard X-ray emission could be attributed to blurred reflection (e.g., Ross & Fabian 2005) rather than the ionized partial covering. By removing the ionized absorber and replacing it with a blurred reflection (RELXILL; García et al. 2014), one gets an acceptable fit with a simple blurred reflection model. A neutral partial covering component and MEKAL are still needed. Furthermore, the use of NuSTAR and Swift spectra alone does not allow for the constraint of many of the blurred reflection parameters. This model will be explored in more detail using additional data in Section 4.2.2.
4.2. Multi-epoch Spectral Modeling

In this section, we attempt to describe the behavior of Mrk 1239 in a self-consistent manner using the multi-epoch spectral data collected over 18 yr. This has the advantage of giving us low energy sensitivity, provided by MOS and XIS, for the soft excess and the Fe Kα region. NuSTAR provides us with good energy coverage up to 30 keV, with simultaneous coverage between 0.5 and 7 keV from Swift. This allows us to simultaneously study the soft excess, Fe K region, and the broadband continuum. We motivate the models used based on spectral features and variability on multiple timescales.

Structures around the neutral Fe Kα band seen in all spectra are suggestive of distant cold reflection, likely originating in the torus. For this, we use XILLVER with log ξ = 0 to represent a cold reflector.

Study of the long-term and rapid variability shows that there is negligible variability below 3 keV. This indicates that direct AGN continuum emission may be highly absorbed and thus not visible. There is structure seen in the MOS and XIS spectra that may be from distant optically thin emission from star formation activity. We use MEKAL for this feature.

It also seems possible that the direct AGN component is revealed in the 3–10 keV band but completely obscured below ~3 keV. This indicates the presence of a partial covering absorber (ZPCFABS). We expand upon Section 4.1 by applying the ionized partial covering model and the blurred reflection model to all epochs. Some intrinsic properties of the system were linked, as they are not expected to change on timescales of years. This included the MEKAL component (both normalization and kT), the distant cold reflector (XILLVER), and some of the blurred reflection parameters discussed in detail in Section 4.2.2.

Upon analysis of Figure 1 and fitting both models, it was found that the Suzaku spectra closely followed the MOS spectra. Linking all parameters between Suzaku and MOS did not significantly decrease the fit quality for either physical model, so they are linked throughout the remainder of the analysis. Allowing for a free constant between the XMM-Newton and Suzaku models is not a significant improvement to the fit (ΔC = 3 for one additional free parameter). This leaves us with two epochs; a historic one containing XMM-Newton MOS, Suzaku XIS, and PIN data, and a recent one containing the NuSTAR FPMA/FPMB and Swift XRT data.

4.2.1. Partial Covering

In a partial covering scenario a cloud of absorbing material with column density (N_H) is positioned in the line of sight of the AGN, obscuring a fraction of the direct emission. The model has some fraction of its source emission absorbed, and the rest is considered direct emission (e.g., Holt et al. 1980; Tanaka et al. 2004). The model includes three parameters: the column density (N_H); the CF, which is the fraction of intrinsic
emission that is absorbed; and the redshift (z), which remains fixed at \( z = 0.01993 \). The direct emission can be either scattered off the clouds or let through patches in the absorbing material (Tanaka et al. 2004). The patchy absorber is often called a “leaky absorber” (Tanaka et al. 2003), as the direct emission photons can “leak” through the absorber.

Partial covering is often employed to fit NLS1s (e.g., Boller et al. 2002; Tanaka et al. 2005; Turner et al. 2007; Gallo et al. 2015; Iso et al. 2016; Grupe et al. 2019). For Mrk 1239, Grupe et al. (2004) use two absorbing components to model a leaky absorber with the EPIC-pn spectrum. A variation of partial covering is ionized partial covering, where the absorbing medium has some ionization. In this scenario, the illumination source is the power-law corona (e.g., Reeves et al. 2008).

We adopt a partial covering scenario, assuming the absorbers are in a compact region and only the primary continuum (power-law) source is absorbed. We include two absorbers, one that is neutral and one with some nonzero ionization parameter. This is not necessarily two distinct absorbers, but could be representative of a ionization and density gradient within one medium. The XSPEC model reads: CONSTANT \( \times \) TBABS (MEKAL + XILLVER + ZXIPCF \( \times \) ZPCFABS \( \times \) POWERLAW).

Three scenarios were tested to explain the variability between epochs: (i) constant power law and varying absorbers; (ii) constant absorbers and varying power law; and (iii) absorbers and power law free to vary. The continuum parameters were \( \Gamma \) and the power-law normalization. The absorber parameters were both CFs, both column densities (\( N_H \)), and the cloud ionization (log \( \xi \)).

The initial model, with all parameters linked between epochs, renders a very poor fit (\( C/\text{dof} = 1563.29/603 \)), and the cross-calibration constant for FPMB is far too large to be acceptable (\( \approx 1.7 \)). Allowing the absorber parameters free to vary (Test (i)), we obtain a significantly better fit. If the CF is free at each epoch the fit improves by \( \Delta C = 860.28 \) for two additional free parameters. If we allow the log \( \xi \) to be free between epochs as well, the fit improves by \( \Delta C = 39.97 \) for two additional free parameter. Allowing all absorber parameters to be free between epochs gives the best fit, with \( C/\text{dof} = 645.50/598 \).

Next, we test a variable continuum with a constant absorber (Test (ii)). Allowing just the power-law normalization to be free between epochs (i.e., linked \( \Gamma \)), the fit quality is \( C/\text{dof} = 850.13/602 \). Alternatively, permitting \( \Gamma \) to be free between epochs and the normalization linked, the fit quality improves by \( \Delta C = 38 \). If both the photon index and normalization are allowed to be free between epochs, the \( C/\text{dof} = 764.24/601 \), an improvement of \( \Delta C = 47.89 \) over the previous fit for one additional free parameter.

If all absorber and continuum parameters are allowed to vary between epochs (Test (iii)), the best fit is \( C/\text{dof} = 645.29/596 \), comparable to Test (i), where the power-law parameters are linked between epochs and absorber parameters are free to vary. The data and residuals (separately by epoch) can be seen in Figure 4. The best-fit parameters can be seen in Table 3. The measured photon index is \( \Gamma \sim 2.3 \). Compared to Grupe et al. (2004), who reported \( \Gamma \approx 4 \), our value of \( \Gamma \) agrees much more with other NLS1s. This highlights the advantage of the high energy sensitivity provided by NuSTAR. The covering fractions of the absorbers in both epochs are very high, each approximately 90%. This is consistent with the high degree of optical polarization seen in Martin et al. (1983), and is also consistent with the CF of 0.995 found in Grupe et al. (2004).

Figure 4 (top panel) shows the results for the best-fitting model applied to only the FPMA data set, for clarity. A number of interesting features are revealed. The intrinsic power law is shown in cyan, and the absorbed power law is shown in blue. This reveals that a large amount of absorption is required to reproduce the observed spectral curvature using this interpretation. This is sensible, as we measure covering fractions near 1.

Figure 4. Upper panel: theoretical best-fit ionized partial covering model shown over the entire X-ray band. Cyan line shows the continuum power-law component with only Galactic absorption applied. Upper middle panel: folded spectra with the best-fit partial cover model applied. Lower middle panel: ratio of data to model for the historic epoch, which includes the MOS, XIS, and PIN spectra. Lower panel: ratio of data to model for the modern epoch, which contains the XRT and FPMA/FPMB spectra.
Table 3
Best-fit Model Parameters for Mrk 1239

| (1) Model                  | (2) Model Component                | (3) Model Parameter | (4) Swift/NuSTAR | (5) MOS/ Suzaku |
|----------------------------|------------------------------------|---------------------|------------------|-----------------|
| Ionized partial covering   | Ionized absorber                   | nH (10^{22} cm^{-2})| 64^{+17}_{-16}   | 114^{+31}_{-56} |
|                            | ZXIPCF                             | log ζ [erg cm s^{-1}]| 2.4^{+0.1}_{-0.2} | 2.7^{+0.2}_{-0.4} |
|                            |                                    | CF                  | >0.86            | 0.9 ± 0.1       |
| Neutral absorber           | nH (10^{22} cm^{-2})               | 13^{+10}_{-9}       | 60^{+19}_{-17}   | 0.96^{+0.03}_{-0.04} | 0.89^{+0.04}_{-0.10} |
| ZPCFABS                    | CF                                 | 0.96^{+0.03}_{-0.04} | 0.89^{+0.04}_{-0.10} |
| Intrinsic                  | power law                          | Γ                   | 2.3^{+0.3}_{-0.1} | 2.32 ± 0.13     |
|                           | norm (10^{-3})                     | 6^{+4}_{-3}         | 5^{+4}_{-3}      |
| FPMB calibration           | constant                           | 1.00 ± 0.06         |                  |
| Swift calibration          | constant                           | 1.0 ± 0.2           |                  |
| Collisionally ionized      | kT [keV]                           | …                   | 0.66 ± 0.03      |
| material                  | MEKAL                              | norm (10^{-4}) [cm^{-3}] | … | 1.3 ± 0.1 |
|                           | Metal abundance [cosmic]           | 1/                  |                  |
| Distant, cold reflector    | norm (10^{-5})                     | …                   | 1.6 ± 0.6        |
| XILLVER                    | Ap [solar]                         | 1/                  |                  |
|                           | log ζ [erg cm s^{-1}]              | 0/                  |                  |
|                           | E_{out} [keV]                      | 300/                |                  |
|                           | Inclination [°]                    | 30°                 |                  |
| Unabsorbed flux            | (0.1–100 keV)                      | 10^{-11} [erg cm^{-2} s^{-1}] | 5.74 | 5.02 |
| Observed flux              | (0.5–10 keV)                       | 10^{-11} [erg cm^{-2} s^{-1}] | 0.289 | 0.137 |
| Fit quality                | C/dof                              | 645.29/596          |                  |
| Blurred reflection         | Neutral absorber                   | nH (10^{22} cm^{-2})| 22 ± 5           | 61 ± 11         |
| ZPCFABS                    | CF                                 | 0.99 ± 0.01         | 0.96^{+0.02}_{-0.01} |
|                           | Intrinsic                          | Γ                   | 2.45^{+0.11}_{-0.14} | 2.4 ± 0.1 |
|                           | power law                          | norm (10^{-4})      | <22              | <18             |
| FPMB calibration           | constant                           | 1.00 ± 0.06         |                  |
| Swift calibration          | constant                           | 1.0 ± 0.2           |                  |
| Collisionally ionized      | kT [keV]                           | …                   | 0.65 ± 0.04      |
| material                  | MEKAL                              | norm (10^{-4}) [cm^{-3}] | … | 9 ± 2 |
|                           | Metal abundance [cosmic]           | 1/                  |                  |
| Distant, cold reflector    | norm (10^{-5})                     | …                   | 2.1 ± 0.06       |
| XILLVER                    | Ap [solar]                         | 1/                  |                  |
|                           | log ζ [erg cm s^{-1}]              | 0/                  |                  |
|                           | E_{out} [keV]                      | 300/                |                  |
|                           | Inclination [°]                    | <19/                |                  |
| Blurred reflector          | q_{in}                             | 3/                  |                  |
| RELXIII                    | q_{out}                            | 3/                  |                  |
|                           | Break radius [r_{g}]               | 6/                  |                  |
|                           | spin                               | 0.998/              |                  |
|                           | Outer radius [r_{g}]               | 400/                |                  |
|                           | Inclination [°]                    | …                   | <19              |
|                           | log ζ [erg cm s^{-1}]              | …                   | 3.00^{+0.07}_{-0.25} |
|                           | Ap [solar]                         | …                   | 4^{+2}_{-1}      |
|                           | E_{out} [keV]                      | 300/                |                  |
|                           | norm (10^{-5})                     | 10^{+5}_{-5}        | 4 ± 1            |
| Unabsorbed flux            | (0.1–100 keV)                      | 10^{-11} [erg cm^{-2} s^{-1}] | 9.85 | 4.32 |
| Observed flux              | (0.5–10 keV)                       | 10^{-11} [erg cm^{-2} s^{-1}] | 0.289 | 0.134 |
| Fit quality                | C/dof                              | 615.64/598          |                  |

Note. Column (1) indicated the tested model, and column (2) indicates the model component. Column (3) gives the value of each parameter for the modern epoch. Column (4) gives the value for each parameter for the historic epoch. If a dash is present, it indicates that the parameters are linked between epochs. All parameters with the superscript "f" are kept fixed at quoted values. The parameters with superscript "Γ" are linked between components. Normalizations with superscript "p" are given by photons keV^{-1} cm^{-2} s^{-1} at 1 keV.
Given this high level of absorption at low energies, the MEKAL component (shown in red) is clearly visible in the total model (shown in dark blue). In particular, the strong 0.9 keV feature found by Grupe et al. (2004) is likely explained by this collisionally ionized plasma. This 0.9 keV feature is produced primarily by Fe L transitions. Contributions from the torus are shown in gray, and emission features at low energies also contribute to the soft excess.

The second panel of Figure 4 shows the folded spectrum along with the models for each instrument. The colors are the same as those used in Figure 1. The model appears to provide a good fit to the data. This is more evident in the bottom panels, where the residuals (data/model) are shown. While some excess residuals are present in the 5–7 keV band in the MOS data, the model is clearly able to explain the overall shape of the spectra at each epoch. In particular, no clear excess residuals are seen at low energies, suggesting that the starburst model provides a satisfactory fit to the data. Effectively, the long-term variability in Mrk 1239 can be explained largely by changes in a partial covering medium and a relatively constant power law. The excess residuals seen in the MOS data could be due in part to a poor fit of a blurred Fe Kα line, suggesting a blurred reflection model must be examined.

4.2.2. Blurred Reflection

While there is a high degree of absorption in Mrk 1239, the variability in the 3–10 keV band suggests we may be probing emission from the inner black hole region. Consequently, we examine whether it is possible to model the intrinsic emission with a combination of power-law and blurred reflection as has been done it some other highly absorbed, type II systems (e.g., Walton et al. 2019).

In blurred reflection, photons emitted by the corona are then incident on the accretion disk, where they are absorbed and re-emitted via fluorescence (e.g., Ballantyne et al. 2001; Ross & Fabian 2005). This reflected spectra is then subject to the general relativistic effects that are at play in accretion disks near black holes (e.g., Miniutti & Fabian 2004). Blurred reflection has been successful in describing the spectral and timing properties NLS1s (e.g., Fabian et al. 2009; Gallo et al. 2012, 2015; Chiang et al. 2015; Jiang et al. 2019; Waddell et al. 2019).

Here, the blurred reflection model, RELXILL (García et al. 2014), replaces the ionized absorber in the partial covering scenario above. Given the data quality, the initial approach is rather conservative. The illumination as a function of distance (r) on the disk (emissivity profile) is described by a power law (\( \propto r^{-\delta} \)) with index \( \delta \). For simplicity, \( \delta = 3 \), implying the primary emitter is radiating isotropically. The cutoff energy (\( E_{\text{cut}} \)) is frozen at 300 keV, as Mrk 1239 shows no evidence for a high energy cutoff. The photon index is linked to the index of the primary power-law component. The inner radius is fixed at the innermost stable orbit (ISCO), and the outer radius is fixed at 400\( r_g \). The dimensionless spin parameter—defined by \( a = cJ/MG^2 \), where \( M \) is the black hole mass and \( J \) is the angular momentum—can take on values of 0 (nonspinning) to 0.998 (maximum spin). The spin is linked between epochs and initially frozen at 0.998, given the complexities in measuring this parameter (e.g., Bonson & Gallo 2016). The inclination is linked with that of XILLVER, which describes the cold, distant reflector (i.e., torus). It is linked between epochs, but left free to vary. The disk ionization parameter (\( \log \xi \)) and the iron abundance (\( A_{\text{Fe}} \)) are free to vary, but also linked between epochs.

We adopt a geometry very similar to that of the partial covering model, where the very central region of the AGN is highly obscured, there is some amount of cold distant reflection, and a star-forming region exists at some large distance from the AGN. The XSPEC model used is \( \text{CONSTANT} \times \text{TBABS} \times (\text{MEKAL} + \text{XILLVER} + \text{ZPCFABS} \times (\text{RELXILL} + \text{POWERLAW}) \). As with the partial covering model, we test three scenarios: (i) constant continuum and varying absorbers; (ii) constant absorbers and varying continuum; and (iii) continuum and absorber parameters both free to vary. Here, continuum refers to the power-law and blurred reflection components together.

The initial model, with all parameters linked between epochs, renders a very poor fit (\( C/\text{dof} = 1538.17/603 \)). Examining Test (i), if the CF was allowed to vary between epochs then the fit statistic improves by \( \Delta C = 841.92 \) for two additional free parameters. If instead \( N_H \) is allowed to vary between epochs and CF is linked, the improvement to the fit is \( \Delta C = 45.2 \). With both \( N_H \) and CF free between epochs, the \( C/\text{dof} = 645.42/599 \).

In Test (ii), we linked absorbers and freed the continuum. If RELXILL normalization was free, but linked between epochs, the fit statistic is \( C/\text{dof} = 720.31/602 \). If instead the power-law normalization was linked, but free to vary between epochs, there was no significant improvement in fit statistic. If both the RELXILL and power-law normalization are allowed free to vary between epochs, the fit statistic is \( C/\text{dof} = 679.53/601 \).

Test (iii) renders the best-fit blurred reflection model. The parameters are given in Table 3. The best-fit blurred reflection model gave a fit statistic of \( C/\text{dof} = 615.64/598 \). This was a marked improvement over linking the continuum or absorption parameters separately. The reflection fraction at each epoch was calculated by determining the unabsorbed flux contributions between 0.1 and 100 keV in the blurred reflector (RELXILL) and power-law components. Errors on the calculated reflection fraction are propagated from the uncertainties in the normalization of each component. Only a lower limit could be calculated at both epochs, as only an upper limit could be placed on the power-law flux. The reflection fraction for the NuSTAR epoch is \( >2.5 \), while that for the MOS epoch is \( >1.3 \), so the model indicates the source to be reflection-dominated.

Only an upper limit could be measured for the inclination (\( <19^\circ \)), indicating the system is nearly face-on. Zhang & Wu (2002) measure an inclination of \( 7^\circ \) from the broadline region, which is in good agreement with our measurement.

Figure 5 (top panel) shows the theoretical best-fit blurred reflection model applied only to the FPMA data set, for clarity. The intrinsic continuum is shown in cyan, and the absorbed power-law and blurred reflection component are shown in blue and green, respectively. This again shows the large amount of absorption that is required for the MEKAL (red) component to be visible. As in the ionized partial covering model, we believe that the MEKAL is responsible for the 0.9 keV feature reported by Grupe et al. (2004). The torus emission is shown in gray and further contributes to the soft excess. The bottom three panels of Figure 5 show the data and residuals (separated by epoch) for the best-fit blurred reflection model; the colors there are the same as in Figures 1 and 4. The fit has the same overall shape as the ionized partial cover model. We still see the residuals in the Fe Kα band of the MOS spectra, despite the fact that our
model requires an overabundance of iron, which is commonly seen in NLS1. Overall, the data fits well, the soft band is again adequately described by the MEKAL component, and the long-term variability is again driven by changes in the absorber.

5. Discussion

The data of Mrk 1239 analyzed in this work highlight distinct physical process that dominate above and below \(~3\) keV. These two regimes feature dramatically different variability properties and physical origins. As such, our discussion shall be divided into these two energy regimes. We interpret the spectra of Mrk 1239 to contain two distinct sources of emission: the first is the low-energy star-forming region, and the second is the higher-energy AGN component.

5.1. Origins of the Soft Excess

To begin, our analysis of the Suzaku data did not give any evidence for variability below 3 keV on short timescales. Furthermore, the unfolded spectra of Mrk 1239 showed a remarkable consistency over the 18 yr of spectra coverage presented in this paper, with virtually no change in flux in the 0.3–3 keV, while the harder band had significant change in flux over the same period. This is at odds with typical NLS1s, where the soft band tends to have more variability (e.g., Leighly 1999). Furthermore, the spectral features present in the soft band, like the strong emission-line-like features observed by Grupe et al. (2004), are inconsistent with smooth spectra typically seen in NLS1s.

The long-term consistency of Mrk 1239, along with its unusual spectral shape, led us to apply different models to explain the soft excess. We use MEKAL to model the possible contribution from starburst activity that may be present in Mrk 1239 (Rodríguez-Ardila & Viegas 2003). This model has been used to describe many AGN that exhibit depressed power-law emission from obscuration (e.g., Franceschini et al. 2003) or intrinsic variability like Mrk 335 (e.g., Gallo et al. 2019). In AGN-dominated flux states, this component is still present, but it overwhelmed by the AGN emission.

There is also a contribution to the line emission at low energies from the distant reflector (Figures 4 and 5). In combination, the MEKAL and XILLVER components nicely describe the line-like features in the spectra without requiring additional Gaussian profiles or abnormal abundances. We considered the possibility that the emission could be due entirely to photoionized gas, perhaps from the narrow-line region. We tested this by replacing MEKAL with a PHOTEMIS component to our best-fit ionized partial covering model for just the MOS spectra between 0.3 and 2 keV. The model was only applied to the MOS spectra, as it is computationally intensive. If there were any improvements over MEKAL, they would be most obvious in the the MOS spectra. The best-fit PHOTEMIS model resulted in a poorer fit than with MEKAL ($\Delta C = 30$) for the same number of free parameters, and positive residuals in the 0.8–1 keV band remained.

Table 4 shows the flux and luminosity for each component between 0.5 and 2 keV at each epoch. We can see that the MEKAL component has a consistently strong contribution in both models with the central engine absorbed. However, when the central engine absorption is removed, the line-emission MEKAL is completely overwhelmed by the power-law contribution in the partial covering scenario and by the power-law and RELXILL contribution in the blurred reflection scenario.

We are using MEKAL to describe the X-ray evidence of starburst activity. Mrk 1239 has significant evidence of starburst activity. The PAH signatures found by Rodríguez-Ardila & Viegas (2003) agree with this interpretation. The starburst regions are included in the X-ray extraction regions of the instruments used due to the modest angular resolution.

A study of ten ultraluminous infrared galaxies (ULIRGs) by Franceschini et al. (2003) used MEKAL to model the SFR in selected galaxies. They measured the average temperature of

Figure 5. Upper panel: theoretical best-fit blurred reflection model shown over the entire X-ray band. Cyan line shows the continuum power-law and blurred reflector components with only Galactic absorption applied. This model appears to be reflection-dominated. Upper middle panel; folded spectra with the best-fit blurred reflection model applied. Lower middle panel: ratio of data to model for the historic epoch, which includes the MOS, XIS, and PIN spectra. Lower panel: ratio of data to model for the modern epoch, which contains the XRT and FPMA/FPMB spectra.
The MEKAL component to be $kT \approx 0.7$ keV, which agrees exactly with the temperature measured in Mrk 1239 ($kT \approx 0.66$ keV). The luminosity we measure for the MEKAL component also agrees with the luminosity Franceschini et al. (2003) measured in their sample.

Franceschini et al. (2003) also give a method to approximate the SFR using $L_{2-10 \text{ keV}}$:

$$SFR_{\text{ULIRG}} \approx \frac{L_{2-10 \text{ keV}}}{10^{39} \text{ erg s}^{-1}} \frac{M_\odot}{\text{yr}^{-1}}. \quad (1)$$

If we measure the $L_{2-10 \text{ keV}}$ for just the unabsorbed MEKAL component, we get an SFR of 5.8 and 3.7 $M_\odot$ yr$^{-1}$ based on the ionized partial cover and blurred reflection model, respectively. This agrees nicely with the SFR predicted by the PAH signatures (Ruschel-Dutra et al. 2016).

Another interesting feature of the MEKAL component is that it appears to be independent of the continuum model tested. The MEKAL temperature and normalization agree with each other to within 1 and 2$\sigma$, respectively. This suggests that, regardless of the mechanism producing the observed curvature at high energies, the soft X-ray emission of Mrk 1239 can be nicely explained by the starburst component and some photoionized emission from distant emission, without the need for significant overabundances of Ne or other elements. We found that the spectral feature Grupe et al. (2004) reported as a Ne overabundance was a blend of many Fe L transitions.

We found that the spectral feature Grupe et al. (2004) reported as a Ne overabundance was a blend of many Fe L transitions. We examined whether adopting different cosmic abundances in XSPEC could alter the fit quality. Regardless of the abundance table used, the MEKAL temperature remained between 0.63 and 0.65 keV and the fit quality was $C = 162-167$ for 165 dof.

### 5.2. The Hard X-Ray Spectrum of Mrk 1239

The lightcurves seen in Figure 2 show rapid variability between 3 and 10 keV. Similarly, the multi-epoch spectra in Figure 1 suggest long-term variability between 3 and 10 keV. In Section 3.2, the excess variance in the NuSTAR lightcurve was calculated and determined to be $\sigma_{\text{rms}}^2 = 0.04 \pm 0.01$. With the caveat that our analysis uses slightly different energy bands and time bins, the measured value of $\sigma_{\text{rms}}^2$ for Mrk 1239 is comparable to the average value Ponti et al. (2012) measured for NLS1s ($\sigma_{\text{rms}}^2 \approx 0.02$). Following the $M_{\text{BH}}-\sigma_{\text{rms}}$ relation found by Ponti et al. (2012), we estimate a black hole mass of $2 \times 10^9 M_\odot$ for Mrk 1239, which is in agreement with other works (see Ryan et al. 2007). Based on the rapid variability in the 3–10 keV band, Mrk 1239 behaves like an unobscured NLS1. The central black hole region is exposed in the 3–10 keV band.

Independent of the scenarios tested (i.e., partial covering or blurred reflection), the photon index of the intrinsic power-law component is comparable ($\Gamma \sim 2.3$). The measured value is much flatter than has been measured in other works (Grupe et al. 2004), but it is more consistent with what is expected from Seyfert galaxies and NLS1s (Grupe et al. 2010). Estimating the Eddington luminosity ratio from $\Gamma$ based on the relationship from Brightman et al. (2013) gives $L/L_{\text{Edd}} \sim 1–1.5$ for Mrk 1239. This is consistent with the value estimated by Yao et al. (2018). The high value implies a rapid accretor, which is also characteristic of the NLS1 class. Alternatively, the value could be overestimated if the primary emission is anisotropic, which might be consistent with the jet interpretation for some of the radio emission (Doi et al. 2015).

Comparing the partial covering and blurred reflection scenarios directly, similar neutral absorbers that are responsible for obscuring the low-energy X-rays and revealing the starburst regions are required in both models. In both models, the column density decreases between the historic and modern epochs. The main difference in the two scenarios is the strength...
of the primary power law. In the blurred reflection scenario, the spectra are extremely reflection-dominated, with reflection fractions $>1.3$ and $>2.5$ for the historic and modern epochs, respectively. The reflection-dominated interpretation may be at odds with the value of the emissivity index being fixed to $\alpha = 3$ (allowing it to be free did not improve the fit), which would imply an inner disk that is truncated at a large radius or a corona that is very high above the disk. A high reflection fraction requires a significant amount of light bending or a nonstandard geometry for the accretion disk.

Though it appears clear that we are observing emission originating close to the black hole, it is difficult to produce a self-consistent blurred reflection model with the current data. The ionized partial covering scenario has the advantage of being consistent with the high levels of polarization seen in the optical band by Martin et al. (1983) and Goodrich (1989).

In both of the scenarios, the primary emission variability is minimal on long timescales. The change in flux above 3 keV observed on long timescales is driven by the absorbers. A possible explanation for the large amount of absorbing material surrounding the AGN could be that it contains a Schwarzschild black hole. According to Ishibashi (2020), nonspinning black holes have less radiation pressure to drive obscuring gas and dust out of our line of sight than Kerr black holes do. The best-fit blurred reflection model with $a = 0$ results in a fit of $C/dof = 625.50/598$. Most fit parameters remained similar to the values we report in Table 3, except for the iron abundance, which decreases to $A_{Fe} = 2.2$. Although the fit is not as good as that produced by the Kerr black hole model, a nonspinning black hole is more consistent with the low emissivity profile that is adopted.

Figure 6 show a diagram for the physical scenario we propose. The top box shows the physical scenario for the ionized partial covering model. Here, photons are emitted by the disk in the UV and are Compton-upscattered by the corona. The primary X-ray photons are then emitted by the corona, where they encounter the partial covering components. This includes a neutral partial cover and an ionized partial cover (warm absorber). In our model, most of the photons interact with the absorbers, and few escape the inner region unaffected. This is due to the high CF we measure. The bottom of the two boxes shows the AGN for the blurred reflection scenario. Here, UV photons are produced by the disk, Compton-upscattered by the corona, and then reflected off of the disk. Both the primary and blurred reflected emission are absorbed by a neutral absorber before leaving the AGN. Once we move out to the torus, our diagrams for the ionized partial cover and blurred reflection scenario are the same. The photons from the AGN interact with the torus to give us cold, distant reflection emission lines. This means that our collisionally ionized material, which we believe is starburst activity, must therefore be located within 400 pc of the central engine, as PAH
measurements show starburst activity here (Ruschel-Dutra et al. 2016). Outside of the starburst region, we see no evidence of further emission in the X-ray band. Alternatively, the cold absorber could be associated with the torus. Perhaps our line of sight is grazing the torus, or the torus may be more patchy and isotropic around the primary source.

The difference in each of these scenarios is how the primary continuum is produced and then absorbed. If the absorbing material is in fact surrounding the AGN, then it stands to reason that the absorbing material is what is driving the long-term variability in Mrk 1239. This is the case regardless of which model (ionized partial covering or blurred reflection) is implied as the additional component to fit the continuum above 3 keV.

6. Conclusion

In this work, multi-epoch X-ray spectra spanning 18 yr of the NLS1 galaxy Mrk 1239 are presented. This study combines data from XMM-Newton and Suzaku with a simultaneous NuSTAR and Swift observation to study the spectrum and variability of this source. A comparison of the unfolded spectra reveals that the spectra are very similar at all epochs below variability of this source. A comparison of the unfolded spectra reveals that the spectra are very similar at all epochs below a factor of 2.

NLS1 and Swift data are brighter by a factor of 2–3 at higher energies. The lightcurves also reveal no short-term variability below 3 keV, while modest variability at higher energies is seen.

Motivated by this, and by signatures of star formation in the infrared spectra presented in previous works, we successfully model the soft spectrum with emission from a hot plasma. When the absorption component is removed, the starburst component accounts for ∼1%–10% of the total emission, which is sensible for a type-1 AGN. Both a blurred reflection and ionized partial covering model are employed to explain the remainder of the emission. Both models have several key components in common: a power-law component with a slope of ∼2.3–2.4, a neutral absorber with a covering fraction near ∼1, and contributions from a distant reflector (e.g., the torus). There are some apparent inconsistencies, which may be difficult to explain in the blurred reflection model, including a high iron abundance, as well as a low emissivity index despite having a reflection-dominated spectrum. By contrast, the two-component absorption model may agree with the two polarization regions found in the optical emission.

Deep observations with calorimeter-type resolution (e.g., Takahashi et al. 2016), such as XRISM (Tashiro et al. 2018), may help to reveal any emission-line features present in the low-energy spectrum from the starburst and distant reflection components. They may also reveal absorption features present at high energies, helping to confirm the high level of absorption required to fit the observed curvature. Additionally, future observations with XMM-Newton may help to confirm the minimal level of low-energy variability and support a starburst emission component to explain the soft emission from this unique source.

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