THE COMPLEX X-RAY SPECTRUM OF THE SEYFERT 1.5 SOURCE NGC 6860

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ABSTRACT

The X-ray spectrum of the Seyfert 1.5 source NGC 6860 is among the most complex of the sources detected in the Swift Burst Alert Telescope all-sky survey. A short XMM-Newton follow-up observation of the source revealed a flat spectrum both above and below 2 keV. To uncover the complexity of the source, we analyze two observations of NGC 6860 and find that the spectrum is still complex with clearly detected warm absorption features. We find that a two-component warm ionized absorber is present in the soft spectrum, with column densities of about $10^{20}$ and $10^{21}$ cm$^{-2}$, ionization parameters of $\xi = 180$ and 45 erg s$^{-1}$, and outflow velocities for each component in the range of $\approx 0$–300 km s$^{-1}$. Additionally, in the hard spectrum we find a broad ($\approx 11,000$ km s$^{-1}$) Fe Kα emission line, redshifted by $\approx 2800$ km s$^{-1}$.

Key words: galaxies: active – galaxies: Seyfert

Online-only material: color figures

1. INTRODUCTION

Through the very hard X-ray survey (14–195 keV) conducted by Swift’s Burst Alert Telescope (BAT), a sample of unbiased toward absorption for $N_H < 10^{24}$ cm$^{-2}$, local ($\langle z \rangle = 0.03$), active galactic nuclei (AGNs) have been identified (Tueller et al. 2008). Among these 153 sources, we obtained 10 ks XMM-Newton follow-ups for 22 previously unstudied, in the X-ray band, BAT AGNs. These sources, selected purely on their significant detection ($\approx 4.8\sigma$) in the BAT and probable optical identification with bright sources in the Two Micron All Sky Survey/Digital Sky Survey, comprise a representative sample of the BAT AGNs, with half of the sources showing low X-ray column densities ($N_H < 10^{23}$ cm$^{-2}$) and half more heavily absorbed (Winter et al. 2008). From our analysis of both XMM-Newton follow-ups and a combination of published spectra and our analysis of Swift XRT/ASCA/XMM-Newton spectra of the remaining sources in the 9 month catalog (Winter et al. 2009a), we found that the majority of the X-ray spectra were well described by simple models, such as an absorbed power law, partial covering, soft excess, warm absorber (through fits with O vii and O viii edges), or reflection. Such simple models can even be applied to the more complicated spectra of Compton-thick sources, where a strong Fe Kα fluorescent line and flat power-law spectrum indicates a reflection-dominated spectrum.

However, such simple models could not fit the 0.3–10 keV spectrum of roughly 10% of the BAT-detected AGNs, including NGC 6860. Unlike any previously known sources, the spectrum of this source was flat ($\Gamma < 1.0$) both below and above 2 keV, no matter how we modeled the continuum. To our knowledge, there is no other known AGN to exhibit a flat spectrum below 2 keV. Likely, this flat spectrum at low energies is due to complex line structure that is unresolved in the $\approx 10$ ks Metal Oxide Semi-conductor (MOS) CCD arrays spectra (the pn spectrum unfortunately could not be extracted due to problems with the observation data files (ODFs)). Further, we found that the spectrum of this source could be explained by a number of models; in particular, a warm absorber or a double partial covering model fits equally well. This degeneracy could not even be broken with the inclusion of the 14−195 keV BAT spectra.

To unravel the complexities of this unusual source, we obtained a long XMM-Newton exposure including both EPIC CCD and reflection grating spectrometer (RGS) spectra. We also include an analysis of the archived Suzaku observation of this source, which provides simultaneous coverage of the soft, hard, and very hard X-rays through the X-ray imaging spectrometer (XIS) and Hard X-ray Detector (HXD) Positive Intrinsic Negative (PIN) detectors. NGC 6860 is a southern hemisphere ($\alpha = 20:08:46.89, \delta = -61:06:00.70$) target optically identified as a Seyfert 1.5 source (Lipari et al. 1993). The source is nearby ($z = 0.014884$) and hosted in a barred spiral galaxy (SBab).

Optical emission line diagnostics reveal the source as an AGN/starburst composite, with the AGN dominating only in the inner 10′. The X-ray observations will also likely include contributions from both the starburst and AGN. In Section 2, we describe the XMM-Newton and Suzaku observations. In Section 3, we include an analysis of the light curves. In Section 4, we discuss the spectral analysis. We discuss some of the unusual properties of this source in Section 5. Finally, we summarize the results of our analysis in Section 6.

2. OBSERVATIONS AND DATA REDUCTION

2.1. XMM-Newton Observations

NGC 6860 was observed on 2009 March 29 for 123 ks (observation 0552170301). The XMM-Newton data were reduced using the Science Analysis System (SAS) version 8.0. Calibrated photon event files were created for the EPIC pn and MOS cameras using the ODFs and the commands emchain and emchain, respectively. The event tables were filtered using the standard criteria outlined in the XMM-Newton ABC Guide.4 For the MOS data, good events correspond to a pulse height in the range of 0.2−12 keV and event patterns that are characterized by

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4 See http://heasarc.gsfc.nasa.gov/docs/xmm/abc/
as 0–12 (single, double, triple, and quadruple pixel events). For the pn camera, only patterns of 0–4 (single- and double-pixel events) are kept, with the energy range for the pulse height set between 0.2 and 15 keV. Bad pixels and events too close to the edges of the CCD chips were rejected using the stringent selection expression “FLAG = 0.”

The source and background spectra, along with response and ancillary response files, were then extracted using the SAS task espcget. The source spectra were extracted from a circular region centered on the source, with a radius of 120′′. The background spectra were extracted from a circular region of the same size on the same chip. The spectra were then grouped using the FTOOL grppha, binning the spectra by 20 counts. The resultant exposure times of the spectra were 100 ks (pn) and 117 ks (for MOS1 and MOS2, respectively). The corresponding count rates for the spectra are 9.5 counts s\(^{-1}\) (pn) and 2.6 counts s\(^{-1}\) (for MOS1 and MOS2, respectively).

Since the XMM-Newton spectrum of our source suffers from high background count rates (particularly during the last ≈8 hr of the exposure), we also extracted a pn spectrum from an event file filtered by count rate. We chose the stringent filtering of keeping only events whose count rates are below 100. The filtered pn spectrum has an average count rate of 9.8 counts s\(^{-1}\) and an exposure time of 66 ks. We compared the spectra of the filtered and unfiltered pn count rates. We find that the only differences in spectral shape occur about 8 keV. At these high energies, the unfiltered spectrum shows a curvature which is not replicated in the filtered spectrum. The filtered high-energy spectrum is instead well fit by a power law. Throughout the text, we use the unfiltered spectrum, which has more counts and thus a higher signal-to-noise ratio, for almost all of the broadband spectral fits (for which we use the filtered pn spectrum).

For the RGS spectra, we extracted first-order spectra for RGS1 and RGS2 using the SAS command rgsproc. Due to flaring seen in the light curve, we created a good time interval file using the SAS task tabgtigen and filtering out all events with count rates >0.2. The spectra were re-extracted using this filtering. Response files were created using the task rgsrmfgen, and the spectra were rebinned to 20 counts per bin using grppha. The exposure times for the RGS spectra are 93 ks, with count rates of 0.21 counts s\(^{-1}\) (RGS1) and 0.25 counts s\(^{-1}\) (RGS2).

### 2.2. Suzaku Observations

In addition to the XMM-Newton observation, we include in our analysis the archived 44 ks Suzaku observation of NGC 6860 (observation 703015010) from 2008 April 7, observed in HXD nominal pointing mode. We used the cleaned version 2.0 processed event files supplied by the Suzaku team. To extract the spectra, we combined the 3 × 3 and 5 × 5 edit modes for each of the front-illuminated (XIS0 and XIS3) and back-illuminated (XIS1) CCDs. Source and background spectra were extracted in circular regions of 210′ and 180′, respectively, in xselect. The response and ancillary response files were created using xissimarfgen and xissimarfgen. We then added the spectra and response files from the front-illuminated detectors (using mathepha, addrmf, and addarf) and rebinned the spectra and rmf files from 4096 to 1024 channels (which is still larger than the resolution of the CCDs). The front-illuminated and back-illuminated spectra each were binned to 20 counts per bin. The resultant exposure times are 44 ks with count rates of 1.34 counts s\(^{-1}\) (XIS1) and 1.13 counts s\(^{-1}\) (the average for the combined XIS0 + XIS3 spectrum).

For the HXD spectra, we only extracted spectra from the PIN instrument. Spectra were extracted using xselect for both the source and Suzaku team supplied instrumental tuned background file. The source spectrum was corrected for instrument dead time. We also included the contribution from the cosmic X-ray background, as suggested by the Suzaku team,\(^5\) as a cutoff power law of the form \(E \times 10^{-9} \times (E/3 \text{ keV})^{-0.29} \times \exp(-(E/40 \text{ keV}) \text{ erg cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1})\). The standard response file from the Suzaku CALDB was used and the spectrum was binned to a signal-to-noise ratio of 3\(\sigma\). The net exposure time for the PIN spectrum is 34 ks with a count rate of 0.31 counts s\(^{-1}\).

### 2.3. The Swift BAT Spectrum

To fully characterize the spectrum of NGC 6860, we also include an analysis of the Swift BAT spectrum generated from the first 22 months of the all-sky survey. The BAT spectrum is an eight-channel spectrum in the 14–195 keV band. Both the spectrum and the diagonal matrix are further described in the 22 month catalog paper (Tueller et al. 2010).

### 3. LIGHT-CURVE ANALYSIS

In our previous analysis of variability in NGC 6860 (Winter et al. 2008), we found that the EPIC MOS spectra were variable over the ≈10 ks observation. We also found that a comparison of this short XMM-Newton observation with the Swift XRT observation showed a change in the soft (0.5–2 keV) flux with no change in the hard (2–10 keV) flux. The difference between these observations was about 3 months. Therefore, the source is known to vary in the soft band both on short timescales and over months.

To determine the nature of variability over the long XMM-Newton observation, we constructed light curves for the EPIC pn and MOS spectra of NGC 6860. We constructed light curves in three separate bands: soft (0.1–3 keV), medium (3–7 keV), and hard (7–10 keV). In this way, we can associate the amount of variability with features prominent in each of these bands—namely, a soft excess and/or warm absorbers in the soft band, the region surrounding the Fe Kα region for the medium band, and the hard continuum in the hard band. In Figure 1, we plot the background-subtracted pn light curves, binned on a short 1024 s timescale and the orbital timescale (5760 s, showing the normalized light curves). The MOS light curves, which are not shown, exhibit the same trends as seen in the pn.

The light curves show that the soft band dominates the total count rate and that this band varies by count rates of as much as 2 counts s\(^{-1}\) over the observation. The mean count rates in each of the bands correspond to 6.9 counts s\(^{-1}\) (soft), 1.3 counts s\(^{-1}\) (medium), and 0.2 counts s\(^{-1}\) (hard). When we look at the normalized light curves, we find that the variability in the soft band correlates well with the variability in both the medium and hard bands.

In a similar way as for the XMM-Newton light curves, we constructed light curves in a soft, medium, and hard band for the Suzaku XIS detectors. Since the response for the XIS detectors extends to higher energies, we used the energy range of 7–12 keV for our XIS hard band. We created a combined (XIS0 + XIS1 + XIS3) background-subtracted light curve for the Suzaku observation, binned by 128 s.

\(^5\) See the Suzaku ABC Guide, Section 7.5.4 at http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/
Figure 1. XMM-Newton pn background-subtracted light curves are shown binned by 1024 s (top) and 5760 s (bottom, normalized by the average count rate in the specified energy band). Light curves are shown for three selected energy bands: 0.1–3 keV (black), 3–7 keV (blue), and 7–10 keV (green). Clearly, the greatest amount of variability is seen in the soft band, which varies by about 2 counts s\(^{-1}\). However, the normalized light curves (bottom) show that the relative amount of variability is the same in each of the bands. Further, each of the normalized light curves varies on the same timescale. We have excluded regions of high background flares from the plot.

(A color version of this figure is available in the online journal.)

...observation, we found that the low-energy band had the highest average count rate \((\langle CtRate \rangle = 0.83 \text{ counts s}^{-1}\)) Background-subtracted mean count rates in the medium and hard bands correspond to 0.34 counts s\(^{-1}\) and 0.05 counts s\(^{-1}\), respectively. In Figure 2, we plot the normalized 128 ks light curves. For the XMM-Newton observations, we find that the variability in the soft, medium, and hard bands is well correlated, particularly for the soft and medium bands.

4. SPECTRAL ANALYSIS

Given the complex nature of the spectra of NGC 6860, we began our spectral fits by analyzing the spectra in the soft and hard energy bands separately. We first determine the parameters of the hard X-ray continuum and the region surrounding the Fe K\(_\alpha\) emission in Section 4.1. This analysis includes spectra from Suzaku and XMM-Newton, focusing on the spectral region from 3 to 50 keV. To determine the properties of the soft band, the region corresponding to the highest count rates for NGC 6860 and the greatest complexity, we examine the XMM-Newton and Suzaku CCD spectra as well as the XMM-Newton RGS spectra in Section 4.2. We then fit the broadband continuum, including the Swift BAT spectra, in Section 4.3. We use the best broadband fit to constrain the continuum in the RGS data, to better determine the properties of the warm absorbers in Section 4.4. All of the spectral fits described were done using XSPEC version 12.5.1 (Arnaud 1996). The quoted errors correspond to a change in \(\chi^2 = 2.71\) or the 90% confidence level for an additional free parameter.

4.1. The Hard X-ray Continuum and the Fe K\(_\alpha\) Emission Region

In the following sections, we describe spectral fits to the hard X-ray emission (>3 keV) for the Suzaku and XMM-Newton...
as fits with a cutoff energy/observations. We include absorbed power-law models, as well as fits with a cutoff energy/reflection component. Also, we fit for additional lines/absorption edges in the region around the 6.4 keV Fe Kα emission.

4.1.1. The Suzaku Spectra

We conducted combined fits of the Suzaku XIS (XIS1 and XIS0+XIS3) and PIN spectra, constraining the PIN data such that their spectra are fixed at a constant level of 1.16 of the XIS1 spectrum, as indicated in the Suzaku Data Reduction Guide.6 We find that a simple absorbed power-law model provides a good fit to the data (reduced $\chi^2$/dof = 1.09/1085). Fixing the Galactic absorption to the Dickey & Lockman (1990) measured value of $4.19 \times 10^{20}$ cm$^{-2}$ with a multiplicative $tbabs$ model (Wilms et al. 2000), we find that the neutral hydrogen column density of the source is best fit as $4.8^{+4.2}_{-3.3} \times 10^{21}$ cm$^{-2}$ with the multiplicative $ztbabs$ model (Wilms et al. 2000). The power-law component measured is typical of the Swift BAT-detected AGN (Winter et al. 2009a), with $\Gamma = 1.70 \pm 0.05$ (from the zpowerlaw model). Residuals to the model indicate the presence of an Fe Kα emission line.

Adding a Gaussian to account for the Fe Kα emission with the zgauss model, we find that the line is significant with an improvement in the fit by $\Delta \chi^2 = -48$. The measured parameters for this line are $E = 6.31 \pm 0.05$ keV, $\sigma = 0.15^{+0.06}_{-0.04}$ keV, $I = 2.6^{+0.6}_{-0.8} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, and EW = $102^{+34}_{-32}$ eV. The width of this line indicates an origin interior to the broad-line region (with AGN Hβ FWHM values typically ranging from 3000 to 10,000 km s$^{-1}$ and measured as $5920 \pm 600$ km s$^{-1}$ for NGC 6860 (Bennert et al. 2006)), with a corresponding velocity of $\approx 17,000$ km s$^{-1}$. This broad width is statistically a better fit than a narrow line fit, with a $\Delta \chi^2 = -7.6$ over a fixed width of $\sigma = 0.01$ keV.

The addition of a 7.11 keV Fe edge (over the edge built into the ztbabs model) is also significant, with $\Delta \chi^2 = -6.1$. The energy of the edge is consistent with cold Fe (Henke et al. 1993), with $E = 7.11^{+0.19}_{-0.10}$ keV. The measured optical depth corresponds to $\tau = 0.08 \pm 0.05$. The Fe edge can be the result of either reflection of the direct emission, a higher than solar iron abundance, or a higher column density of gas than measured from the neutral absorption model. Computing the Fe xvii cross section at 7.11 keV following Verner et al. (1996), we find a cross section of $\sigma(E) = 4.5 \times 10^{-3}$ Mb. From the estimated cross section and our measured optical depth, we find a column density of iron that is $1.80 \times 10^{19}$ cm$^{-2}$ ($N_{Fe} = \tau/\sigma(E)$). Therefore, the estimated iron abundance is very high ($N_{Fe}/N_{H} \approx 139$ (Fe/H)$_{⊙}$) if the edge is associated with the $4.8 \times 10^{21}$ cm$^{-2}$ absorber measured in our fits. If, however, the abundance of iron in NGC 6860 is the solar value, this implies that the Fe edge is instead the result of a much higher hydrogen column density of $\approx 7 \times 10^{23}$ cm$^{-2}$, which does not affect the emission in the softer bands (i.e., a partially covering near Compton-thick absorber). Finally, while the residuals to the model suggest there may be additional emission/absorption features present, we found no statistical support for additional emission features found in the spectra of many AGNs (Fe xxv Kα, Fe i Kβ, Ni i Ka).

In addition to a simple absorbed power-law model, we tried to determine whether a high-energy cutoff or a reflection component is present in the data. To constrain a possible high-energy cutoff, we substituted the zpowerlaw model with a cutoff power-law model. However, we found no measurable improvement in the fit and could not constrain the energy of the cutoff.

Additionally, we tested for the presence of a reflection component, which could alternatively account for the presence of the 7.11 keV Fe edge. Using the pexrav model for reflection off of cold neutral material, we tied the normalization and power-law index to be the same values between the direct power-law component and the reflection component. Statistically, the reflection model does not significantly change the fit, improving

6 http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/
and a fixed narrow line (significant change in spectrum). Fitting an Fe edge at 7.11 keV, however, results in no residuals suggesting an emission feature redward of the neutral photons cm$^{-2}$ s$^{-1}$, and EW = 174$^{+9}_{-4}$ eV. While the line is weak, it is also significant. The energy of the line is unusual, but corresponds to lines seen in the spectra of other AGN sources. For instance, as pointed out in Markowitz et al. (2009), high-resolution spectroscopy of 16 Seyferts has shown narrow features interpreted as blueshifted or redshifted Fe K features from hot spots above the accretion disk (Vaughan & Uttley 2008). The line that we have detected has roughly the same energy, width, and strength as the 6.0 keV feature detected in NGC 3227 by Markowitz et al. (2009).

Comparing the flux from the best-fit absorbed power law + Fe Kα emission model with Suzaku spectrum, we find no change in flux. The XMM-Newton observation has a 3–10 keV observed flux of 1.86 $\times$ 10$^{-11}$ erg s$^{-1}$ cm$^{-2}$ in the pn. The XIS spectra show an average flux of 1.84 $\times$ 10$^{-11}$ erg s$^{-1}$ cm$^{-2}$. Therefore, while the XMM-Newton observations were taken a year after the Suzaku observations, there is virtually no change in the hard X-ray spectra.

4.2. The Soft X-ray Spectra

In the following sections, we detail simple model fits to the soft spectra from the Suzaku and XMM-Newton observations. The base model is an absorbed power law, at the redshift of the source. To account for the additional features in the soft spectra, we use a combination of absorption edge models and Gaussians to fit absorption and emission features.

4.2.1. The Suzaku XIS Spectra

Fitting the soft XIS spectra simultaneously in the 0.3–3 keV band, we find that a simple absorbed power-law model is not a good fit to the data with a reduced $\chi^2$/dof = 1.64/883. Comparing the fitted parameters of this model to the hard continuum, we find that both the neutral hydrogen column density ($N_H = 2.9 \pm 0.9 \times 10^{20}$ cm$^{-2}$) and the power-law index ($\Gamma = 1.36 \pm 0.03$) are lower in the soft band. As shown in Figure 4, the simple power-law model cannot clearly account for the soft spectrum.

We find that the addition of warm absorption signatures, through O vii and O viii edges, to the model greatly improves the fit. Figure 4 shows the improvement in the fit for the ratio of the data/model. With these edges added to the model, we find $\Delta \chi^2 = 514.7$ and a reduced $\chi^2$/dof = 1.07/879. Additionally, while the column density of the intrinsic absorption is still low ($N_H = 7.9^{+0.9}_{-0.5} \times 10^{20}$ cm$^{-2}$), the power-law index from this warm absorber model is consistent with the hard power-law continuum ($\Gamma = 1.74 \pm 0.04$). The best-fit parameters for the oxygen edges correspond to $E = 0.73 \pm 0.01$, $\tau = 0.34 \pm 0.04$ (O viii) and $E = 0.87 \pm 0.01$, $\tau = 0.35^{+0.03}_{-0.04}$ (O vii). In addition to the O vii and O viii edges, the residuals to the model suggest another edge feature near 2 keV. Adding an edge improves the fit by $\Delta \chi^2 = 10$. This edge, which has best-fit parameters of $E = 1.91^{+0.04}_{-0.05}$ keV and $\tau = 0.055^{+0.030}_{-0.027}$, is likely associated with errors in the detector calibration of the Si K edge. For our final best-fit model, the estimated observed flux in the 0.3–3 keV band is 1.34 $\times$ 10$^{-11}$ erg s$^{-1}$ cm$^{-2}$.

For spectral fits of the hard continuum in the EPIC spectra, we simultaneously fit the pn, MOS1, and MOS2 spectra in the 3–10 keV band, using a constant value to allow for variations in the flux levels between CCDs. We find a good fit (reduced $\chi^2$/dof = 1.17/2336) with a simple absorbed power-law model. The parameters of the model indicate a column density (above the Galactic value) and a power-law index similar to those measured in the Suzaku observation: $N_H = 5.8^{+2.7}_{-2.6} \times 10^{21}$ cm$^{-2}$ and $\Gamma = 1.69 \pm 0.04$. The residuals to this model, shown in Figure 3, clearly show an Fe Kα emission line. Additionally, residuals suggest an emission feature redward of the neutral Fe Kα emission and possibly a 7.11 keV Fe edge (in the pn spectrum). Fitting an Fe edge at 7.11 keV, however, results in no significant change in $\chi^2$ of the model. We find an upper limit on the optical depth of the edge at $\tau = 0.07$, which is in agreement with the Suzaku results.

The addition of an Fe Kα emission line is clearly significant, resulting in $\Delta \chi^2 = -190.6$. The measured line parameters are again similar to those found in the Suzaku observation. We find $E = 6.35 \pm 0.02$ keV, $\sigma = 0.11^{+0.03}_{-0.02}$ keV, $I = 2.2^{+0.3}_{-0.2} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, and EW = 85$^{+14}_{-12}$ eV. The line is clearly broad, since there is a $\Delta \chi^2 = 15$ between the fitted broad $\sigma$ and a fixed narrow line ($\sigma = 0.01$ keV). The best-fit energy, width, and equivalent width are consistent between the XMM-Newton and Suzaku observations. Since we would expect an Fe Kβ emission line to also be present if the Fe Kα emission is produced in neutral material, we added this feature to our spectral fits. We fixed the centroid energy to 7.056 keV, the width to 0.01 keV, and the intensity to be 13% of the Fe Kα line. There is virtually no change in $\chi^2$ ($\Delta \chi^2 = -0.01$) and no change in the parameters of this fit upon adding the Fe Kβ line.

Adding a narrow Gaussian ($\sigma = 0.01$ keV) to fit the additional emission line seen in the residuals, we find that the line is significant, improving $\chi^2$ by 15. The fitted parameters of this emission feature are $E = 5.95^{+0.04}_{-0.03}$ keV, $I = 5.1^{+2.7}_{-1.3} \times 10^{-6}$ photons cm$^{-2}$ s$^{-1}$, and EW = 17$^{+4}_{-4}$ eV. While the line is weak, it is also significant. The energy of the line is unusual, but corresponds to lines seen in the spectra of other AGN sources. For instance, as pointed out in Markowitz et al. (2009), high-resolution spectroscopy of 16 Seyferts has shown narrow features interpreted as blueshifted or redshifted Fe K features from hot spots above the accretion disk (Vaughan & Uttley 2008). The line that we have detected has roughly the same energy, width, and strength as the 6.0 keV feature detected in NGC 3227 by Markowitz et al. (2009).

Figure 3. Ratio of the data/model for the XMM-Newton EPIC spectra, fit by a simple absorbed power law from 3–10 keV, is shown for an absorbed power-law model. The pn (black), MOS1 (blue), and MOS2 (green) data are shown specifically around the Fe Kα emission line region. Clearly, the Fe Kα emission line is present. A narrow emission line at 5.95 keV is also significant.

A (color version of this figure is available in the online journal.)
4.2.2. The XMM-Newton EPIC Spectra

Given the much higher signal-to-noise in the XMM-Newton EPIC spectra, a simple absorbed power-law model does not adequately describe the 0.3–3 keV EPIC spectra, with a reduced $\chi^2$/dof = 7.71/894. In Figure 5, we plot the ratio of the data/model for the simple absorbed power-law model. As for the Suzaku spectrum, the best fit requires a lower neutral hydrogen column density ($N_H = 2.4 \times 10^{20} \text{cm}^{-2}$) and a flatter power-law continuum ($\Gamma = 1.46$). However, as shown in the figure, there are more features than can be accounted for with the addition of O vii and O viii edges.

While adding the O vii and O viii edges improves the fit significantly, with $\Delta \chi^2 = -4458.0$, the fit is still not acceptable (reduced $\chi^2$/dof = 2.75/894, see Figure 5). With this higher signal-to-noise data, a better interpretation for the residuals between 0.7 and 1.0 keV, from the absorbed power-law model, is that this feature is from a broad unresolved transition array (UTA) from Fe M-shell ions. Such features are detected in the XMM-Newton and Chandra spectra of a number of Seyfert 1 sources (e.g., NGC 3227, NGC 3783, NGC 4051, Mrk 509).

We find that the addition of Gaussians/edges to the data greatly improves the fit. However, we note that due to inconsistencies in the pn and MOS calibration below 0.5 keV, we used only the pn data to determine properties of lines detected in this low-energy region. In Table 1, we specify the parameters of lines/edges where $|\Delta \chi^2| > 15$. These features include N vi, Ne ix, and Si xii lines. We found that the addition of another edge model, at 1.7 keV, improved the fit greatly ($\Delta \chi^2 = -26$). The most probable identification for this feature is the Mg xxv line with a rest energy of 1.761 keV, which is not near any known energies corresponding to calibration issues for the EPIC pn. The improved fit results in a reduced $\chi^2$/dof = 1.45/855.

From 0.45 to 0.5 keV, the residuals showed complex absorption/emission that could not be resolved in the pn. We found that an emission line at 0.45 keV greatly improved the fit. Given the uncertainties in the pn calibration below 0.5 keV (see the EPIC calibration document\(^7\)), we cannot uniquely identify this feature at 0.45 keV. However, we note that this is possibly N vii.

The associated outflow velocities determined from the fitted energies of the edges and lines are difficult to interpret. We find that the velocities of the O vii and O viii edges are consistent with each other, implying red-shifted velocities of approximately 8000–9000 km s\(^{-1}\). The estimated velocity of the Mg xxv line is consistent with the oxygen edges. However, the energy of the Ne ix emission line suggests a blueshifted velocity of about 5000 km s\(^{-1}\) while the remaining lines are consistent with no velocity shift. The inconsistent velocities are likely due to a combination of poor energy resolution in the EPIC spectra and confusion of multiple features. The 20–30 eV shifts in the fits of the spectral features seen in the pn data are probably due to instrumental effects, since they are not seen in the Suzaku data. Shifts this large, while rare, have been seen in pn, particularly during episodes of high background.

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\(^7\) http://xmm2.esac.esa.int/docs/documents/CAL-TN-0018.pdf
The best-fit neutral column density is much lower than that found from fits to the hard spectrum (we find $N_H = 5.93^{+0.09}_{-0.07} \times 10^{20}$ cm$^{-2}$). However, we find that the best-fit soft band power-law index is consistent with the hard band value (we find $\Gamma = 1.697^{+0.004}_{-0.003}$). The estimated flux in the 0.3–3 keV band is $1.31 \times 10^{-11}$ erg s$^{-1}$ cm$^{-2}$, which is also consistent with the soft flux in the Suzaku observation.

### 4.2.3. The XMM-Newton RGS Spectra

As a first fit to the RGS spectra, we fit an absorbed power-law model (zpov), with absorption fixed at the Galactic value. Unlike with the EPIC CCD data, we find a good fit ($\chi^2$/dof $= 2865.9/1960$) with a slope, $\Gamma = 1.50 \pm 0.02$. The addition of an intrinsic neutral absorber does not improve the fit. The addition of a blackbody component improves the fit significantly, with $\Delta\chi^2 = -105.3$. Adding edge models to account for the O vii and O viii absorption edges further improves the fit with $\Delta\chi^2 = -129.3$. The best-fit parameters are O vii edge energy $= 0.705^{+0.002}_{-0.004}$ keV with optical depth $\tau = 0.15^{+0.06}_{-0.04}$, O viii edge energy $= 0.850^{+0.002}_{-0.002}$ keV with optical depth $\tau = 0.30^{+0.03}_{-0.04}$, and $kT = 0.30^{+0.04}_{-0.02}$ keV with a normalization of $1.97^{+0.08}_{-0.07} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ at 1 keV for the blackbody component. The flux in the 0.3–2.5 keV band is $1.22 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$.

Following this simple power law + blackbody fit (along with the O vii and O viii edges), we determined the significance of additional absorption and emission features seen in the residuals to the model. We significantly detect (i.e., $|\Delta\chi^2| > 10$ when a Gaussian is added) N vi, O vii, and Ne ix in absorption and N vii in emission. Details of these Gaussian fits, including the energy and intensity of the lines, are shown in Table 2. For all of these fits, we fixed the width of the lines to 0.01 keV. An additional absorption line of Mg xi appears in the residuals, but is not as significant in $\chi^2$. We show the ratio of the data/model for the RGS spectra in Figure 6. In addition to the features mentioned, there is evidence of an Fe M-shell UTA between 0.7 and 0.8 keV. While residuals to the model suggest that an Mg xi edge may be present in the RGS spectrum, adding the feature does not statistically improve the fit.

The combination of lower signal-to-noise in the RGS spectra and worse energy resolution in the EPIC spectra makes it difficult to determine why some lines are only detected significantly in either the RGS or EPIC spectra. However, with the exception of the Si xiii line, the discrepancy in detection of lines is at the low-energy range of the bandpass, from about 400 to 550 eV. In this region, there are uncertainties in the pn calibration. Additionally, there are many features which are not easily resolved even with the higher resolution in the RGS spectra. Therefore, we cannot fully determine the emission and absorption properties of lines in this region without a higher signal-to-noise spectrum with the energy resolution of a grating spectrometer.

The lack of detection of Si xiii absorption in the RGS could either be the result of the lower signal-to-noise of the RGS (the intensity of the line may be too low to be detected significantly in the RGS spectra) or this line may be due to calibration uncertainties associated with the Si K edge in the EPIC detectors. One clear conclusion that we can draw from the comparison of the EPIC and RGS data is that the most significant features are the O vii and O viii edges, and the Ne ix absorption line.

Unlike our analysis of the soft EPIC spectra, we find that the implied velocities from the oxygen edge energies do not agree with each other. Assuming the lines are resonant lines, the implied velocities from the oxygen edge energies do not agree with each other. Assuming the lines are resonant lines, the implied velocities from the oxygen edge energies do not agree with each other. Assuming the lines are resonant lines, the implied velocities from the oxygen edge energies do not agree with each other. Assuming the lines are resonant lines, the implied velocities from the oxygen edge energies do not agree with each other.

### 4.2.4. Warm Absorber Model Fits

Having fit the spectra of our sources with simple models for the absorption/emission lines in the soft spectra, we next investigate the properties of the warm absorbers through use of an analytic model. The model warmabs is an analytic version of the XSTAR table models (Kallman & McCray 1982), available as additional models to XSPEC. The model calculates spectra using stored level populations, which are scaled using the elemental abundances specified by the user. The free parameters in the model include the column density of the absorber, the ionization parameter (log $\xi$, where $\xi = L/(nR^2)$) and $\xi$ has

### Table 2

| Energy (eV) | $I(\times 10^{-4}$ photons cm$^{-2}$ s$^{-1}$) | ID | $\Delta\chi^2$ |
|------------|---------------------------------|----|----------------|
| 411.8$^{+1.3}_{-1.1}$ | $-1.38^{+0.34}_{-0.32}$ | N vi | 17.7 |
| 502$^{+8}_{-8}$ | $1.17^{+0.25}_{-0.24}$ | N vii | 48.7 |
| 545$^{+4}_{-4}$ | $-0.77^{+0.32}_{-0.31}$ | O vii | 82.1 |
| 917$^{+7}_{-7}$ | $-1.56^{+0.22}_{-0.26}$ | Ne ix | 163.5 |

Notes. Listed are the fitted energy, intensity, probable identification, and change in $\chi^2$ upon adding a Gaussian to model the indicated line at the redshift of the source ($z = 0.014884$).
units of erg s$^{-1}$), the redshift of the ionized gas, and the turbulent velocity of the gas (which affects the broadening of the spectral features). For the warmabs model, we assume a gas density of $10^4$ cm$^{-3}$ and an illuminating power law with $\Gamma = 2$, as indicated in the population model (xspec, abund = wilms). Additionally, we assume an outflow velocity of 0 km s$^{-1}$ for these initial fits, fixing the redshift of the warm absorber to the source redshift. In Section 4.4, we better constrain the continuum in the RGS spectra and re-fit the ionized absorbers allowing the velocity of the outflow to vary.

We used this analytic warm absorption model to determine the best-fit parameters to the soft X-ray spectrum (0.3–3 keV). First, we fit each of the spectra individually (Suzaku XIS03+XIS1, XMM pn, and XMM RGS) with a base power-law model, absorbed by the fixed Galactic absorption. Since the RGS data required a blackbody fit, an indicator of the “soft excess,” we added this as well as a component for neutral intrinsic absorption to the model fits. The residuals to all of the spectra showed a poor fit, particularly to the Fe UTA feature. Next, we added a single ionized absorber with the warm absorber model. In all cases, the addition of a warm absorber model significantly improved the model fit and provided a good fit to the Fe UTA feature. We then added a second warm absorber model to determine if a second component is required. For both the Suzaku XIS and XMM RGS spectra, the addition of a second component is statistically significant ($\Delta \chi^2 \gtrsim 50$, see Figure 7 for the ratio of the data/model for the RGS spectra). For the XMM pn spectrum, a second component is not required. However, the residuals to the model for the warm absorption models show a poor fit below $\approx 0.7$ keV. The best-fit parameters to the soft spectra with the warm absorption models are shown in Table 3.

From our neutral + warm absorber model fits, we find that the neutral column does not change drastically between the Suzaku and XMM-Newton observations. Additionally, the RGS and pn columns are fairly consistent ($N_{\text{H}} \approx 10^{21}$ cm$^{-2}$). Comparing the XIS and pn observations, we find that the warm absorber (component 1 in the XIS) is consistent within the measured errors. These values point to an ionized absorber with a column density of $\approx 10^{25}$ cm$^{-2}$; an ionization parameter of $\log \xi \approx 2.0$, and a turbulent velocity from $\approx 25$ to 200 km s$^{-1}$. The most notable differences between the Suzaku and pn spectra include the normalization on the blackbody component (which is roughly twice as high in the XIS spectra) and the slope of the power law (which is flatter in the pn observation).

There is clearly a mismatch between the best-fit parameters of the XMM pn and RGS spectra, which were taken simultaneously. The inconsistencies are most apparent in both the blackbody ($kT$) and power-law ($\Gamma$) component. The indicated parameter is an upper limit.

### 4.3. Broadband Spectral Fits

Since we found no significant difference in either flux or spectral shape between the Suzaku and XMM-Newton observations, we fit the Suzaku XIS and XMM-Newton pn data simultaneously with the Suzaku PIN and Swift BAT spectra to obtain the best broadband (0.3–195 keV) spectral fit. A major problem of fitting non-simultaneous data, like the XMM-Newton pn and Swift BAT spectra, is constraining the proper normalization between the softer and hard energy spectra (see Winter et al. (2008) for a discussion of problems with joint XMM-Newton and Swift spectral fits). This problem is mitigated by the addition of the Suzaku data, where the normalization between the PIN and XIS is known. A second potential problem with using the Swift BAT
spectra is that the BAT spectra are time averaged over a 22 month period. Therefore, any changes in the spectral shape and/or flux will not be accounted for in the time-averaged spectrum. For NGC 6860, however, the Swift BAT 54 month light curve shows no significant variation (G. Skinner 2010, private communication).

For the broadband spectral fits, we used a constant value (\( \text{const} \)) to account for differences between the Suzaku XIS and the additional spectra. This constant was set to 1.16 for the Suzaku PIN spectrum but allowed to vary for the XMM-Newton pn and Swift BAT spectra. Our base model is a power law affected by the Galactic neutral column density. To account for the warm absorber features, we added edges to account for the Fe K\( ^{\alpha} \) line, and a cutoff power law. Adding an energy cutoff model to the power-law component improves the fit significantly (\( \Delta \chi^2 = -25 \)). In this model (cutoffpl), the power-law component is multiplied by a factor of \( M(E) = \exp(-E/E_c) \), where \( E_c \) is the cutoff energy. The best-fit cutoff energy is 103\( ^{+71}_{-31} \) keV, which is consistent with a Comptonization model.

Best-fit parameters for this full model (in XSPEC, the model is \( \text{ztbabs} \times \text{zedge} \times \text{zedge} \times (3 \text{zgauss} \text{components}) + \text{bbody} + \text{cutoffpl}) \times \text{const} \)) are shown in Table 4 (we do not include the parameters for the soft energy edges and lines, instead see Table 1). Additionally, we plot the best-fit spectrum in Figure 8.

To determine the importance of reflection in the spectrum of NGC 6860, we included reflection with the XSPEC \( \text{pexrav} \) model for Compton reflection off neutral material (Magdziarz & Zdziarski 1995). We fixed the normalization and power-law component to be the same between the reflection and cutoff power-law models. We also fixed the folding energy of the power-law models. We also fixed the pericentric distance (O \( \Pi \), N \( \Pi \), Ne \( \Pi \)), a blackbody to fit the soft excess, a neutral column of \( \approx 10^{22} \) cm\(^{-2} \), a broad (\( \sigma \approx 0.12 \) keV) Fe K\( ^{\alpha} \) line, and a cutoff power law. Best-fit parameters for this model are shown in Table 4.

(A color version of this figure is available in the online journal.)

### Table 4

| Component | Fitted Value |
|-----------|--------------|
| \( N_H \) \( ^{(cold)} \) | 9.96\( ^{+1.64}_{-1.17} \) |
| \( kT \) (keV) | 0.067\( ^{+0.009}_{-0.009} \) |
| \( \Gamma \) | 0.74\( ^{+0.22}_{-0.17} \) |
| \( E_{\text{cutoff}} \) (keV) | 103\( ^{+72}_{-31} \) |
| \( I_b \) | 51.10\( ^{+0.67}_{-0.60} \) |
| \( E_{\text{FeK}_\alpha} \) (keV) | 6.331\( ^{+0.030}_{-0.022} \) |
| \( \sigma_{\text{FeK}_\alpha} \) (keV) | 0.120\( ^{+0.033}_{-0.036} \) |
| \( \text{FWHM}_{\text{FeK}_\alpha} \) (eV) | 208.9\( ^{+14.2}_{-13.3} \) |
| \( I_{\text{FeK}_\alpha} \) | 0.22\( ^{+0.04}_{-0.04} \) |
| \( \chi^2/\text{dof} \) | 4254.3/3873 |

**Notes.**

\( a \) Column density of the neutral absorber from the \( \text{ztbabs} \) model in units of 10\(^{20} \) cm\(^{-2} \).

\( b \) Intensity of the model component in units of 10\(^{-14} \) photons cm\(^{-2} \) s\(^{-1} \) at 1 keV for either the blackbody component \( (kT) \), the power-law \( (\Gamma) \), or a Gaussian component.

**Figure 8.** Plotted is the unfolded spectrum for the broadband XMM-Newton pn, Suzaku XIS and PIN, and Swift BAT spectral fits. Our best-fit model includes edges and Gaussian lines to fit the prominent warm absorption features (O \( \Pi \), O \( \Pi \), N \( \Pi \), and Ne \( \Pi \)), a blackbody to fit the soft excess, a neutral column of \( N_H \approx 10^{22} \) cm\(^{-2} \), a broad (\( \sigma \approx 0.12 \) keV) Fe K\( ^{\alpha} \) line, and a cutoff power law. Best-fit parameters for this model are shown in Table 4.

4.4. Better Constraining the Properties of the Warm Absorber

Given the small bandpass for the RGS spectra, the AGN continuum emission cannot be constrained without the use of higher energy data. In our earlier fits of the RGS spectra, we found that the fitted power-law continuum was much steeper than the pn in a similar soft bandpass. The value from the soft band pn continuum fits was also not well constrained—with a spectral index...
much flatter than that of the broadband continuum fits. Thus, to develop the best constraints on the warm absorption, we used the best-fit power law value from the broadband fits along with the high resolution RGS spectra. We found it necessary to fix these power-law parameters in the model fits, due to degeneracies between the power law, soft excess, and absorption models.

In the spectral analysis of a similar warm absorber source, NGC 3227, Markowitz et al. (2009) compared three different models to the soft excess in a broadband EPIC spectral fit: a steep power law, a blackbody, and a Comptonized component (using the CompST model). The best statistical fit was with the Comptonization model (though it was only slightly better than a steep power-law model). Therefore, we chose to use this model in our new RGS spectral fit. The values of the parameters from our best-fit model for the Comptonization parameter are a temperature of $kT = 1.09$ keV, an optical depth of $\tau = 12$, and a normalization of $1.7 \times 10^{-3}$ photons keV$^{-1}$ cm$^{-2}$ s$^{-1}$. We could not constrain the errors on this model as the parameters of this Comptonization model were not well constrained.

The final model for this RGS spectral fit includes neutral absorption and two warm absorber components. To constrain the velocity of the outflow, we allowed the redshift of the warm absorber components to vary. However, we kept the turbulent velocity fixed at the default value of 100 km s$^{-1}$. We include the best-fit absorption properties for this model in Table 5. Both the measured column densities of the cold neutral and warm absorbers and the ionization parameters are well matched between the previous model fits in Table 3 and the new values in Table 5. However, we have placed tighter constraints on the model in our new fits by using a fixed power-law component as determined from the broadband fits. Also, we have placed estimates on the velocity of the outflow. The associated systemic velocities of both components (calculated from the redshifts recorded in Table 5) are $v_1 = -184^{(+371)}_{(-110)}$ km s$^{-1}$ and $v_2 = -196^{(+135)}_{(-100)}$. This places constraints on the outflowing gas to be from about 0–300 km s$^{-1}$.

5. THE UNUSUAL PROPERTIES OF NGC 6860

In Winter et al. (2008), we pointed out the unusual spectral properties of NGC 6860 based on a $\approx 10$ ks XMM-Newton follow-up observation. The flat ($\Gamma \approx 1.0$) spectrum at high energies led us to classify the source as a Compton thick candidate. Compton thick sources are those where the optical depth toward Compton scattering is $\tau \gg 1$, corresponding to column densities $N_H \gtrsim 10^{24}$ cm$^{-2}$. Compton thick spectra are reflection dominated, since little to no direct emission escapes below 10 keV. Thus, both a flat spectrum and a high EW Fe Kα emission line—signatures of a reflection spectrum—are diagnostics used in classification of a source as Compton thick.

Another possible diagnostic is a lack of variability, as discussed in Winter et al. (2009b). We classified the short XMM-Newton observation as a candidate Compton-thick source due to the unusual properties of the spectrum. While the source showed a flat spectrum at high energies, the measured column density indicated a column density of only $\approx 10^{22}$ cm$^{-2}$. Additionally, the flat spectral index measured at low energies ($E = 0.3–2$ keV) suggested that the source spectrum also includes a contribution from warm ionized gas. Without a higher signal-to-noise observation we could not further determine the X-ray spectral properties of NGC 6860.

From our analysis of the new higher signal-to-noise spectra presented in this paper, we find that the spectra of NGC 6860 do not meet the criteria typically used to classify a source as Compton thick. The continuum at high energies is no longer flat—marking a clear change in spectral state from the earlier XMM-Newton spectrum. Additionally, the Fe Kα line has an EW too low (EW $\approx 100$ eV) to suggest a reflection-dominated spectrum. Further, the measured column density is well below the Compton thick threshold. Therefore, the source is most likely in a Compton thin state throughout both the Suzaku and long XMM-Newton observations. Still, it is unusual to find a Compton thick source whose flux and spectral shape remain constant over a period of a year, as we have found from our comparison of the Suzaku and XMM-Newton spectra. Further yet, the Swift BAT 54 month light curve shows no variability at the highest energies over the entire 4.5 year period (G. Skinner 2010, private communication).

This lack of variability is surprising considering that the previous analysis of the short XMM-Newton and Swift XRT spectra showed variability in flux and spectral shape between the two observations spaced only 4 months apart. In order to compare the spectra from the high (long exposure XMM-Newton) and low (short exposure XMM-Newton and Swift XRT) signal-to-noise observations, we fit the 0.3–10 keV band of the new EPIC spectra with the partial covering absorbed power-law model used in Winter et al. (2008). This fit is not a good representation of the high-quality EPIC spectra (with a reduced $\chi^2$ value of 3.4), but it allows us to compare the fitted parameters and flux between the old XMM, XRT, and new XMM observations. The best-fit parameters to the new data are $N_H = 2.7 \times 10^{21}$ cm$^{-2}$, with a covering fraction of 43%, and $\Gamma = 1.58$. As stated earlier, the spectral shape is much different than the old XMM observation from 3 years earlier ($N_H \approx 4.5 \times 10^{22}$ cm$^{-2}$, with a covering fraction of <70%, and $\Gamma \approx 1.0$), but similar to the values from the XRT observation. Unfortunately, without a higher quality spectrum during the spectral state exhibited in the earlier XMM-Newton observation, we cannot confirm that the source changed from a Compton thick to a Compton thin phase.

Another noticeable change between the short XMM-Newton and XRT observations and the later Suzaku and long XMM-Newton observation is the change in flux. The Suzaku and long XMM-Newton observations are three times brighter than the
Figure 9. Plotted is the ratio of the data/model of the Fe Kα region using the Gaussian model (top panel) and a diskline model (bottom panel). Both the XMM-Newton pn (black) and Suzaku XIS0+XIS3 (red) spectra are shown. There is a very little difference in the ratio plots from both models. Statistically, the reduced $\chi^2$ is slightly lower with the Gaussian model.

(A color version of this figure is available in the online journal.)

short XMM-Newton observation and 60% brighter than the Swift XRT observation. Whether we happened to catch the source in a similar state or the source somehow changed such that the X-ray spectrum is now constant. However, given the history of past variability as well as the low Fe Kα EW, it is unlikely that this object is truly Compton thick. Although, it is possible that the source changed from a Compton thick state—as is the case for the “changing-look” AGN (Matt et al. 2003).

When we examined the properties of the warm absorbers in NGC 6860, we find more evidence that its spectrum is unusual. We find that there are likely absorption and emission components in the spectrum, but the only strong, clearly identifiable features at soft energies are the Fe M-shell UTA and the Ne IX absorption line. We are unaware of any other warm absorber spectra that show Ne IX as the most prominent line in the soft spectrum. While other absorption and emission features are present, it is impossible to clearly separate the features which are likely blended at the resolution available in the long XMM-Newton spectrum.

One of the clearest indications of this complexity is the discrepancy we get between the estimated velocities of the edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra. We find, for instance, that the fitted energy of the N vii edges and lines identified in the PN and RGS spectra.

Finally, another unusual property of the NGC 6860 spectra involves the fluorescent Fe line in the hard spectrum. The average measured energy for the 6.4 keV Fe Kα line from Chandra grating observations of a sample of AGNs is $6.399 \pm 0.003$ keV (Yaqoob & Padmanabhan 2004). We, however, measure a central energy of $6.331^{+0.030}_{-0.022}$ or redshifted by about 2800 km s$^{-1}$. To confirm the measured energy of this line, we replaced the broad Gaussian model initially used to fit Fe Kα in the broadband spectral fit (Table 4) with a more physical model of line emission from a relativistic accretion disk (using the diskline model of Fabian et al. 1989). In this model, we used the default emissivity index ($\beta = -2$) and outer radius ($1000 GM/c^2$). We allowed the line energy, disk inner radius, and inclination to vary. The best-fit diskline model, with $\chi^2$/dof = 4282.4/3872, is statistically a worse fit ($\Delta \chi^2 \approx 28$) than the simple Gaussian. However, there is little noticeable difference in the ratio of the data/model between the Gaussian and diskline models, as shown in Figure 9. The best fit from the diskline model confirms the energy measured from the Gaussian model, with $E = 6.327^{+0.016}_{-0.017}$ keV. Additional fitted parameters for the diskline model are an inner accretion disk radius of $<23 \, GM/c^2$, an inclination of $<15^\circ$, and a normalization of $2.4^{+0.6}_{-0.5} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$ (with a line EW of 98 eV). With the diskline model, however, the 5.95 keV line is no longer significant in the spectrum.

6. SUMMARY

Following upon the analysis of a short $\approx10$ ks XMM-Newton observation of the Swift BAT-detected Sy 1.5 NGC 6860, we obtained and analyzed higher signal-to-noise observations of this source with Suzaku ($\approx40$ ks) and XMM-Newton ($\approx100$ ks). Though the new observations show NGC 6860 in a different spectral state—with a higher flux and a steeper power-law index—these higher quality spectra confirm the complex nature of the X-ray spectrum of NGC 6860. Even with the high signal-to-noise in these observations, we find that the X-ray spectra are still too complex to be completely characterized.

Still, a number of conclusions can be drawn from our analysis. Among these, we find that while short-term variability is observed in both the Suzaku and XMM-Newton CCD spectra, both the flux and spectral shape remain similar between these observations though they were taken a year apart. The overall spectral shape of NGC 6860 shows clear signs of a warm ionized absorber at soft energies along with a soft excess. While a combination of two warm absorber components and a neutral absorber along with a base blackbody + power law model provides an acceptable spectral fit in the lower signal-to-noise of the Suzaku XIS spectra, the higher signal-to-noise/resolution XMM-Newton pn and RGS spectra are more difficult to describe. Particularly, while the Fe UT features are well fit with the warm absorber models, we find additional absorption features (like the N vii absorption line) which are not well fit by this warm absorber model below $\approx 0.7$ keV.

The properties of the warm absorbers in NGC 6860 are consistent with those of other Sy 1s, as determined through analyses of grating spectra (Blustin et al. 2005; McKernan et al. 2007). For instance, McKernan et al. (2007) found in a sample of 15 AGNs with Chandra HETGS spectra that type 1 AGNs typically have multiple warm absorber components with ionizing columns from $10^{20}$ to $10^{23}$ cm$^{-2}$, ionization parameters of $\xi \approx 10^{-0.10}$, and velocities from $\approx 0$–2000 km s$^{-1}$. Our analysis of NGC 6860 indicates two components with ionized columns of $\approx 10^{20}$–$10^{21}$ cm$^{-2}$, with ionization parameters of $\xi \approx 45$ and 180 erg s$^{-1}$, and outflowing velocities between 0 and 300 km s$^{-1}$. However, the constraints on the outflow velocities are uncertain since measurements of individual lines uncover
different central energies depending on the model used. Thus, UV data will be particularly important to obtain for NGC 6860 to determine the kinematic properties of the outflowing material. We find complexity not only in the soft spectrum but also in the hard X-ray spectrum of NGC 6860. The hard spectra show a broad (∼11,000 km s⁻¹) Fe Kα line with EW ≈ 100 in both the XMM-Newton EPIC and Suzaku XIS observations. The FWHM of the iron line is much higher than the measured FWHM for Hβ (5920 ± 600 km s⁻¹; Bennert et al. 2006), indicating that the Fe Kα line originates in a region interior to the broad-line region and closer to the central black hole. The energy of this line is low (6.35 ± 0.02 keV), suggesting a redshift in the 6.41 keV Fe Kα line corresponding to v ≈ 2800 km s⁻¹. This energy is unusual, considering that typical measurements from Chandra high-energy grating spectra have mean line-center energies of 6.399 ± 0.003 keV (Yaqoob & Padmanabhan 2004). An additional possibly redshifted narrow Fe K emission line is significant in the XMM-Newton spectra with an energy of 5.95 ± 0.03 keV (v ≈ 0.08c) and EW = 17 eV. However, with the more physical diskline model, the 5.95 keV line is no longer significant.

The shape of the broadband continuum—measured from a combination of XMM-Newton, Suzaku, and Swift BAT observations—is well fit by an absorbed power-law model. The column density of the neutral absorber is ≈10²¹ cm⁻². The power-law index (Γ = 1.64) is lower than the typical value of 1.75 measured for the Swift BAT AGN sample (Winter et al. 2009a), but much higher than the value of 1.0 measured in the earlier short XMM-Newton observation of this source. The high-energy cutoff for the power law is about 100 keV, which is consistent with a Comptonization spectrum.

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Facilities: Swift, Suzaku, XMM

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