HIGH-RESOLUTION CHANDRA HETG SPECTROSCOPY OF V404 CYGNI IN OUTBURST

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ABSTRACT

As one of the best-characterized stellar-mass black holes, with good measurements of its mass, distance, and inclination, V404 Cyg is the ideal candidate to study Eddington-limited accretion episodes. After a long quiescent period, V404 Cyg underwent a new outburst in 2015 June. We obtained two \textit{Chandra} HETG exposures of 20 and 25 ks. Many strong emission lines are observed; the ratio of Si He-like triplet lines gives an estimate for the formation region distance of $4 \times 10^{11}$ cm. A narrow Fe K$\alpha$ line is detected with an equivalent width greater than 1 keV in many epochs, signaling that we do not directly observe the central engine. Obscuration of the central engine and strong narrow emission lines signal that the outer disk may be illuminated, and its structure may help to drive the strong variability observed in V404 Cyg. In the highest flux phases, strong P-Cygni profiles consistent with a strong wind are observed, likely radiation or thermally driven as V404 Cyg approaches its Eddington limit. The kinetic power of this wind may be extremely high at $>0.1 L_{\text{Edd}}$.

\textit{Key words:} accretion, accretion disks – black hole physics – ISM: jets and outflows – X-rays: binaries

1. INTRODUCTION

Stellar-mass black holes are known for extreme behaviors, but V404 Cygni (V404 Cyg) stands out even within this class. V404 Cyg, also known as GS 2023+338, was discovered with the all-sky monitor on board \textit{Ginga} on 1989 May 22 (Makino 1989). The transient was extremely bright and observed extensively, varying by a factor of $\sim$500 on timescales of seconds (Kitamoto et al. 1989). A low-mass companion was found in a wide, 6.5-day binary, and dynamical constraints verified that V404 Cyg indeed harbors a black hole of $9.0^{+0.2}_{-0.3} M_{\odot}$ with a binary inclination of $(67^{\pm 1})^\circ$ (Khargharia et al. 2010). The inclination and thus its mass are model dependent, and larger ranges are cited in the literature, (56 $\sim$ 80)\textdegree and 8–12 $M_{\odot}$ (Casares & Jonker 2014 and references therein). Recent radio parallax measurements give a distance of 2.39 $\pm$ 0.14 kpc (Miller-Jones et al. 2009). The Eddington luminosity for V404 Cyg is $1.1 \times 10^{39}$ ($M/9 M_{\odot}$) erg s$^{-1}$, assuming a pure Hydrogen atmosphere and no beaming effects.

A new outburst of V404 Cyg was discovered using the \textit{Swift}/BAT on 2015 June 15 (Barthelmy et al. 2015). Rapid, extreme variability was again observed; flaring up to several tens of Crab was observed with \textit{INTEGRAL} (Natalucci et al. 2015; Rodriguez et al. 2015). Optical P-Cygni profiles were also observed (Munoz-Darias et al. 2015), both during this outburst and the outburst in 1989 (Casares et al. 1991). These outflows denote a spherical outflow unique to V404 Cyg.

Motivated by the opportunity to understand the origin of the extreme behaviors observed from V404 Cyg in terms of its accretion inflow and outflows, we obtained an observation using the \textit{Chandra} High Energy Transmission Grating Spectrometer (HETGS; Canizares et al. 2005). Initial results from our analysis of the incredibly rich spectra that were obtained by King et al. (2015) are the focus of this Letter.

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2. METHODS

We obtained two observations with the \textit{Chandra} High Energy Transition Grating Spectrometer (HETGS) on 2015 June 22 (13:40:27–22:41:07) and 2015 June 23 (21:26:38–05:20:59) for 21 ks and 25 ks, respectively. Owing to the extraordinary flux levels exhibited by the source, the observations were taken with the ACIS-S array in continuous clocking mode with the zeroth-order position located off the detector array. This was a necessary precaution needed to avoid radiation damage to the ACIS CCDs. Used once before to observe Sco X-1, this is an unusual instrumental configuration that requires careful reduction procedures.

The resulting spectra from our setup include the positive orders of the medium-energy grating (MEG) and the negative orders of the high-energy grating (HEG). We used the \texttt{ciao} tools, version 4.7, to reduce the data. The \texttt{pha} files were extracted with \texttt{tgextract} using a masked region that was centered on the nominal point-source position (R.A. $20^\h 24^m 3^s 834$, decl. $33^\circ 52^\prime 23^\prime 33$). This position was then manually iterated in successive reductions, so that the narrow Fe K$\alpha$ line measured centroid energy (as measured with a Gaussian) was aligned in both the first and third MEG positive orders as well as the HEG first negative orders to within measurement errors.

The response files were created with \texttt{mkgresp}. Prominent dips in the high energy of the MEG light curve were observed to coincide with the dither pattern period (707 s). We therefore excluded the last 10 rows of the masked files to remove this periodic behavior. Periodic steepening of the spectra owing to this effect was thereby eliminated.

The configuration also impacted the useful energy range in each dispersed spectrum. We analyzed data from the MEG between 1.4 and 6 keV and from the HEG between 5.6 and 10 keV in the first observation. In the second observation, we utilized data from the MEG between 1.4 and 4 keV and from the HEG between 3.5 and 10 keV. The selected energy ranges vary between the observations due to differences in the effective area curves resulting from the specific pointings and
strong backgrounds observed in the HEG. In a follow-up paper, we will perform a more in-depth analysis of this background with an aim at extending the bandpass to lower energies in order to study Ne, Mg, and Fe L-shell lines.

All spectra were grouped to require at least 10 counts per bin, as per Cash (1979). Grouping only improved the fits above 7 keV.

3. ANALYSIS

3.1. Time-averaged Spectra

The time-averaged spectra for the two separate observations are depicted in Figures 1(a) and (b). The observed 2–10 keV fluxes of these observations are $9.5 \times 10^{-9}$ erg s$^{-1}$ cm$^{-2}$ and $1.3 \times 10^{-8}$ erg s$^{-1}$ cm$^{-2}$, respectively. This corresponds to an observed 2–10 keV luminosity of $6.5 \times 10^{36}$ erg s$^{-1}$ and $8.9 \times 10^{36}$ erg s$^{-1}$, respectively, and does not take into account any absorption along our line of sight.

We initially fit the broadband continuum with a phenomenological power law and a broad Gaussian line (restricted to the 5–7 keV range), as a relativistically broadened Fe Kα line is likely present (see Figures 1(a) and (b)). Narrow Gaussian lines were then fit to Mg xii, Si xiii, Si xiv, S xv, S xvi, Fe Kα, Fe xxv, and Fe xxvi. In addition, changes in spectral shape and a broad excess at 6.4 keV are noticeable between the two observations.

![Figure 1](image_url). This figure shows the unfolded spectrum of the first (a) and second (b) observations. Emission features are observed in Mg xii, Si xiii, Si xiv, S xv, S xvi, Fe Kα, and Kβ, Fe xxv, and Fe xxvi. In addition, changes in spectral shape and a broad excess at 6.4 keV are noticeable between the two observations.

Finally, the neutral Fe Kα line is at line center with an FWHM of 3400 km s$^{-1}$, while the Fe Kβ is redshifted by 700 km s$^{-1}$ with an FWHM of 2500 km s$^{-1}$ (Table 1).

3.2. Time-resolved Spectra

After examining the time-averaged spectra, we divided each observation into 3.2 ks segments. This afforded a minimum of 13,400 counts in even the lowest flux segment, while still enabling us to track the large-scale variations in both the flux and spectral hardness.

Figures 2(a)–(h) plot the ratio of each spectrum to a simple power law. Both the spectral index, Γ, and normalization were allowed to vary in these fits. One can see changes in the ratios of the lines to the continuum and the ratio of the neutral Fe Kα and β lines to Fe xxv and xxvi, indicating changes in the highest ionization ions. In addition, several observations show...
| Energy (keV) | Observation 1 | Observation 2 | \(E_0\) (keV) | Line ID |
|-------------|---------------|---------------|---------------|---------|
| V (km s\(^{-1}\)) | 1.4725\(^{+0.0002}_{-0.0003}\) | 1.4715\(^{+0.0002}_{-0.0001}\) | ... | ... |
| \(\sigma\) (eV) | ... | ... | 1.472 | Mg \(\text{XII}\) (Ly\(\alpha\)) |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| \(N_0\) (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
| \(\sigma\) (eV) | ... | ... | ... | ... |
| Norm (10\(^{-3}\) photons cm\(^{-2}\) s\(^{-1}\)) | ... | ... | ... | ... |
| Energy (keV) | ... | ... | ... | ... |
| V (km s\(^{-1}\)) | ... | ... | ... | ... |
clear absorption features (the fourth panel from the bottom in Figure 2(b) and the top two panels of Figures 2(e)–(h)).

The strength of the narrow Fe Kα, which is the line with highest signal-to-noise ratio, is positively correlated with the observed flux (Figure 3(a)). A positive correlation may indicate the line is responding to the continuum. In contrast, the equivalent width of the line is also inversely correlated with the observed flux and exceeds 1 keV at the lowest continuum fluxes (Figure 3(b)). An inverse correlation between equivalent width and observed flux suggests the continuum is also varying independently of a relatively constant Fe Kα line. Both of these effects illustrate the complexity of this system. The fact that the equivalent width of the Fe Kα line sometimes exceeds 1 keV signals that we are likely not viewing the direct continuum that is photoexciting the Fe Kα line, but rather a reflected or scattered flux into our line of sight. For reference, an equivalent width of 0.1 keV is expected when directly viewing the central source (George & Fabian 1991). A high equivalent width is consistent with the low spectral indices $\Gamma < 1.4$ for most of the observations (Figure 3(c)). Reflection, as seen in the large excess around 6.4 keV in each observation (Figures 1(a) and (b)), may play an important role in these spectra. In a follow-up paper, we will further discuss the continuum variations (A. L. King et al. 2015, in preparation).

Finally, in addition to emission features, there are clear absorption features in several of the brightest epochs. Figure 4(a) shows the absorption in the 8th epoch of the second observation. A P-Cygni profile is observed, with absorption blueward of the redshifted emission lines. This type of line profile is detected in all but the neutral Fe Kα and Fe Kβ lines, which likely originate at a larger radius than the other ions. The absorption features broaden from 1000 km s$^{-1}$ in the Mg xii line to nearly 4000 km s$^{-1}$ in the Fe xxv line, consistent with the 1500 km s$^{-1}$ blueshifts in the optical absorption features (Munoz-Darias et al. 2015). In an accelerated wind, the density, $n$, decreases with both distance, $r$, and velocity, $V_{\text{wind}}$, for a constant mass outflow rate, $M = \Omega \mu m r^2 V_{\text{wind}}$, where $\Omega$ is the covering factor. The terminal velocity of the wind is therefore best estimated by the largest extent of the strongest features (Snow & Morton 1976; Mauch & Raymond 1987). In our spectra, this corresponds to 4000 km s$^{-1}$ in the Fe xxv line. Even this can be a lower limit to the terminal velocity if the fastest components of the wind are overly ionized.

There is clearly a complex structure to the wind that is generated during this outburst. For contrast, line profiles of the 6th epoch are shown in Figure 3(b): lines from that epoch are narrow, close to their rest energy values, and seen only in emission.

### 3.3. Emission and Absorption Lines

Three sorts of narrow spectral lines are observed. First, there are forbidden and intercombination lines (f and i) of He-like ions formed by recombination in photoionized gas. Resonance lines of He-like ions (labeled r) and Lyman lines of H-like ions can be formed in the same way, but recombination produces r lines that are only about 1/3 as strong as the sum of f plus i. Second, P-Cygni profiles with blue edges corresponding to $V_{\text{wind}}$ reaching 4000 km s$^{-1}$ are apparent in the time-resolved spectra. While a spherical wind gives P-Cygni emission weaker than absorption, a wind from a disk seen at a high inclination can give emission much stronger than absorption, as is seen in high M cataclysmic variables (Mauche & Raymond 1987). Third, the Fe Kα and Kβ lines are formed by inner-shell photoionization of weakly ionized iron in relatively cold gas.

The ratio of f-to-i lines is a density diagnostic, but in the presence of a strong UV radiation field, the ratio is determined by photoexcitation between the upper levels of those lines (Mauche et al. 2003). The Si xiii f-to-i ratio in the first observation of 0.9 would indicate a density of about $3 \times 10^{13}$ cm$^{-3}$, while the Fe xxv f-to-i ratio of the first observation of 0.5 would indicate a density of $10^{17}$ cm$^{-3}$. Of course, this assumes the UV radiation field is unimportant. However, the peak V-band magnitude of about 11.3 from AAVSO observations that day together with $A_V = 3.0$ (Shahbaz et al. 1996) and an $E_c \sim 3 \times 10^3$ accretion disk spectrum imply a UV continuum luminosity that gives an Si xiii f-to-i ratio of 0.9 at $\sim 4 \times 10^{13}$ cm$^{-3}$ from the UV source, and a Fe xxv f-to-i ratio of 0.5 at $\sim 7 \times 10^{13}$ cm$^{-3}$. The apparent brightness should be corrected for the 67° inclination of the disk and the obscuration of part of the disk by its edge, suggesting that the actual UV luminosity is an order of magnitude larger, and the diffuse, emitting gas is located at about 10$^{12}$ and 10$^{13}$ cm from the source for the Si xiii and Fe xxv, respectively. Interestingly, the low ionization lines are consistent with the edge of the disk, as the binary separation is $r_{\text{binary}} = 2 \times 10^{12}$ cm (given a mass function of 6.08$M_{\odot}$, a period of $P = 6.4714$ days, and inclination of $\theta = 67°$; Casares & Charles 1994; Sanwal et al. 1996; Khargharia et al. 2010). The high ionization lines appear to be located two magnitudes closer. However, the Fe xxv f and i lines are not fully resolved, and it remains ambiguous as to if there is additional contribution from P-Cygni emission in the i line. Thus, the Fe xxv origin is not well constrained, and we cannot rule out a similar radial position as the lower ionization lines.

The ratio of He-like to H-like lines serves as an indicator of the ionization parameter, $\xi \equiv L/(n_0 E_{\text{ion}}^3)$. If the lines are primarily formed by recombination, the approximate equality of the intensities of the He-like complex and H-like Lyα of silicon implies approximately equal amounts of H-like S xiv
Figure 2. These panels show the data-to-model ratio of each 3.2 ks epoch in the first (a)–(d) and second (e)–(h) observations. Time proceeds from bottom to top. The dashed lines are Lyα, dotted lines are He-like triplets, and the dotted-dashed lines are the Fe Kα and Kβ lines.
and ion SiXV, which in turn implies $\log \xi \approx 3.0$ (Kallman & McCray 1982). The presence of FeXXV and FeXXVI implies a higher ionization parameter, $\log \xi$, of at least 4.0, while the presence of P-Cygni absorption in the SiXIII r line in some time-resolved spectra implies $\log \xi$ below 3. With the wide range of ions observed, there is likely a continuous range of ionization parameters in the emitting gas.

The f and i lines of SiXIII are formed by recombination of Si XIV to the excited triplet states of SiXIII. Their observed intensities, a distance of 2.39 kpc (Miller-Jones et al. 2009), and a factor of 1.4 correction for interstellar absorption give an emission measure ($EM$) of $2 \times 10^{58}$ cm$^{-3}$. Assuming a $1/r^2$ density profile and a radial extent from $r_0$ to infinity, the column density of the flow is

$$N_H = \int_{r_0}^{\infty} \frac{n_0}{(r/r_0)^2} dr = n_0 r_0$$

and the EM is

$$EM = \int_{r_0}^{\infty} 4\pi \left( \frac{n_0}{(r/r_0)^2} \right)^2 r^2 dr = 4\pi n_0^2 r_0^3.$$  

We also assume the disk is blocking half of the emission region, leaving $EM \approx 2\pi n_0^2 r_0^3$. Utilizing a combination of the ionization, $\log \xi \approx 3$, intrinsic bolometric luminosity of $L \approx 10^{38}$ erg s$^{-1}$, and the EM, $EM \approx 2 \times 10^{58}$ cm$^{-3}$, we find

$$r_0 = \frac{n_0 r_0^2}{n_0 r_0} = \frac{L/\xi}{N_H} = \frac{n_0^2 r_0^3}{(n_0 r_0)^2} = \frac{EM}{2\pi N_H^2}$$

yields $N_H = 3 \times 10^{22}$ cm$^{-2}$, $r_0 = 3 \times 10^{12}$ cm, and $n_0 = 2 \times 10^{10}$ cm$^{-3}$. These are somewhat crude estimates considering the enormous variability in both the lines and the continuum, but they are consistent with the diagnostics given above.

### 3.4. Wind Parameters

As a starting point, we assume that all the lines are formed in wind. Then,

$$M = 4\pi \frac{\Omega}{4\pi} \mu n_0 r_0^2 V_{wind} = \Omega \frac{\mu L}{\xi} V_{wind}$$

and

$$L_{wind} = \frac{1}{2} M V_{wind}^2 = \frac{\Omega}{2} \frac{\mu L}{\xi} V_{wind}^3.$$
or

\[ \frac{L_{\text{wind}}}{L} = \frac{\Omega}{2\xi} \mu V_{\text{wind}}^3. \]  

(6)

where \( \Omega \) is the covering fraction of the wind and \( \mu \) is the mean atomic mass assuming solar abundances (Lee et al. 2002; Blustin et al. 2005; King et al. 2013). While \( \Omega \) is on the order of 0.1 in GRO J1655-40 (Miller et al. 2006a), the stronger emission lines and absorption at approximately the same inclination indicate that \( \Omega \) is closer to 1 in V404 Cyg. Thus, the ionization parameter (log \( \xi = 3 \)) and \( V_{\text{wind}} = 4000 \text{ km s}^{-1} \) determined above imply \( L_{\text{wind}}/L \) is about 0.07. As the ionization parameter is the most uncertain and stands to be lower depending on the ions emitted below the bandpass (\(<1.4 \text{ keV} \)), the wind power could be as high as \( L_{\text{wind}}/L \approx 0.7 \), if log \( \xi = 2 \). V404 Cyg may be reaching its Eddington limit, providing enough radiation pressure to disrupt the outer disk, and generating these features. In addition, as the spectrum is extremely hard, a higher Compton temperature is reached and may drive a Compton wind from the outermost disk, which has an escape velocity of \(~6 \text{ keV} \) at \( 10^9 R_G \). It is interesting to note that the wind in V404 Cyg is comparable to the level of feedback from supermassive black holes required in some simulations to explain the well-known \( M-\sigma \) relationship (Di Matteo et al. 2005).

We can also estimate the wind column density. As a lower limit, we take the terminal velocity as the point where the Si xiv P-Cygni absorption is 10% below the continuum, or \( v_{\text{line}} = 0.1 \), giving \( 4000 \text{ km s}^{-1} \) in the segment shown in panel (a) of Figure 4. That requires log \( (N_{\text{Si xiv}}) = 16.85 \) or log \( (N_{\text{HI}}) = 22.6 \) if half the silicon is Si xiv. An upper limit is given by the lack of an Si xiv absorption edge at \( 2.67 \text{ keV} \), indicating \( T_{\text{edge}} < 0.2 \), or log \( (N_{\text{HI}}) < 23.6 \), in agreement with the column density estimate in the previous section.

### 3.5. Line Origins

While the above is a reasonable interpretation of the emission and absorption features, the wild variability of the line strengths (Figure 3) means that it is (at best) some sort of average description of the wind, and alternate interpretations seem quite possible.

The most basic question is whether the emission lines (in particular, the f and i lines of He-like ions) are formed in the wind where the P-Cygni profiles form. The f and i lines are relatively narrow, \( 1700 \text{ km s}^{-1} \) FWHM, compared with \( V_{\text{wind}} > 4000 \text{ km s}^{-1} \) from the blue edge of the P-Cygni profile and the FWHM = 3400 km s\(^{-1}\) higher ionization Fe xxvi lines. The narrow width is compatible with Keplerian rotation at a radius of \( 3.3 \times 10^{11} \text{ cm} (1.2 \times 10^5 R_G) \), consistent to what is inferred above.

A possibility that would explain the relatively narrow line widths would be that the Si and S f and i lines arise in the X-ray-illuminated outer disk, as in Her X-1 in the low state (Jimenez-Garate et al. 2005), while the P-Cygni lines form in a more or less unrelated wind. To match the line-to-continuum ratios and equivalent widths, especially in the fainter spectra in Figures 2 and 3, this picture requires that the outer edge of the disk block our line of sight to the central X-ray source, so that we observe the continuum produced by scattering from the disk or in an accretion disk corona (ADC; e.g., Fabian et al. 2015).

In that case, \( L_X \), which already appears to be up to one-tenth \( L_{\text{edd}} \), must be even higher. This means that the observed mass accretion rate \( \dot{M}_{\text{acc}} \approx 10^{19} \text{ g s}^{-1} \) (assuming 0.1 efficiency) is also likely much higher. In this picture, the continuum variability, which is stronger than the variability in the emission lines (Figures 2(a)-(h) and 3) could be attributed to changes in the height of the edge of the disk rather than changes in accretion rate. This is also evidenced by the changing spectral hardness (Figure 3(c)), which suggests a variable absorption and/or reflection contribution to the continuum.

### 4. DISCUSSION

The two Chandra HETG observations taken on the 2015 June 22 and 23 show strong spectral emission and absorption features. Mg xii, Si xiii, Si xiv, S xv, S xvi, Fe K\( \alpha \) and K\( \beta \), Fe xxv, and Fe xxvi are detected in the time-averaged spectra, as well as the time-resolved spectra. Variability of the line strengths compared to the continuum as well as changes in Fe K\( \alpha \) to Fe xxv ratios suggests changes in equivalent widths as well as the highest ionizations during the observations. In addition, the extreme equivalent widths of the Fe K\( \alpha \) line (EW > 1 keV) and continuum spectral hardness indicate that we are not directly observing the ionizing continuum and that the total luminosity can exceed the \( L_{\text{2-10 keV}} = 0.1L_{\text{Edd}} \) apparent luminosity.

The ratio of the Si xiii f-to-i lines gives a distance from the central source of \( 4 \times 10^{11} \text{ cm} (1.5 \times 10^5 R_G) \). The EM, luminosity, and ionization parameters of Si xiii yield a somewhat larger distance, \( 3 \times 10^{11} \text{ cm} (1.1 \times 10^5 R_G) \), along with a density of \( 2 \times 10^{10} \text{ cm}^{-3} \).

Typical winds from stellar-mass black holes are also observed at high Eddington rates, though in thermally dominated spectral states (Lee et al. 2002; Miller et al. 2006a; Ponti et al. 2012), in contrast to V404 Cyg. These winds are also primarily detected through X-ray absorption features (Lee et al. 2002; Miller et al. 2006a, 2006b; Neilsen & Lee 2009; King et al. 2012; Ponti et al. 2012) in edge-on systems (Miller et al. 2006a, 2006b; Ponti et al. 2012), indicating a small covering fraction and equatorial nature of these flows (Proga 2003).

Recent analyses find P-Cygni profiles and evidence of Keplerian rotation in these stellar-mass winds, with component velocities of \( v/c \approx 0.01 \) (Miller et al. 2015). However, these winds are dense, originate as close as \( \sim 1000 \text{ GM/c}^2 \) (Miller et al. 2006a, 2008), and are anti-correlated with jets (Miller et al. 2006b, 2008; Neilsen & Lee 2009; King et al. 2012; Ponti et al. 2012). In contrast, the winds from V404 Cyg are located further out in the disk, and jets are active during this period (Tsubono et al. 2015).

The winds from V404 Cyg are likely associated with the disruption of the outer disk by radiation pressure from the central region as it reaches or exceeds the Eddington luminosity. A similar scenario has been proposed locally for the very inner disk in GRS 1915+105 (Neilsen et al. 2011). In contrast, radiation pressure is negligible in typical X-ray binary winds (Miller et al. 2006a; King et al. 2013), with magnetic (GRO 1655-40, Miller et al. 2006a) or thermal mechanisms being the dominant driving mechanisms (Lee et al. 2002; Neilsen et al. 2011; Ponti et al. 2012).

Winds are intimately related to the basic physics of disk accretion and offer a view into feedback between massive black holes and their central massive black holes.
holes and host galaxies (e.g., King et al. 2013). Mass outflow rates from typical stellar-mass black hole winds may exceed the accretion rate at the inner disk, but the kinetic power is only a small fraction of the radiated power (Lee et al. 2002; Ponti et al. 2012; King et al. 2013; Fender & Muñoz-Darias 2015). In this sense, even the most extreme stellar-mass black hole winds (with velocities approaching 0.03–0.05c; King et al. 2012) differ from the powerful outflows observed in broad absorption line quasars (BALQSOs). Here, we find the power in the wind driven by V404 Cyg is likely one-tenth of its Bolometric luminosity, similar to BALQSO’s, whose outflows are also driven by radiation pressure (de Kool & Begelman 1995). The wind in V404 Cyg is dramatically different than most stellar-mass black hole winds during its near Eddington accretion outburst.

The calculations presented here are order of magnitude and may have large uncertainties due to the precise nature of the unabsorbed, underlying continuum, chemical abundances, and ionization states. Uncertainties should be taken at at least a factor of a few. In a follow-up paper, we will further quantify the changing continuum and the amount of reprocessed scattered or reflected light that is directed into our line of sight (A. L. King et al. 2015, in preparation). In addition, we will include a physically motivated photoionization model to characterize the ionization state in both emission and absorption described in this paper (A. L. King et al. 2015, in preparation).

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