CHANDRA GRATING SPECTROSCOPY OF THE SEYFERT GALAXY TON S180

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ABSTRACT

We present preliminary results from spectral observations of Ton S180 using Chandra and ASCA. The data confirm the presence of the soft excess, but the Chandra Low-Energy Transmission Grating spectrum reveals it to be broad and smooth rather than resolved into individual emission lines. This excess may represent either a primary or reprocessed continuum component or a blend of broad lines from an ionized accretion disk. The occurrence of a similar feature in five other narrow-line Seyfert 1 galaxies leads us to conclude that this soft X-ray component may be a characteristic of sources accreting at a high rate. The X-ray spectrum shows no evidence for absorption lines, indicating that if gas exists in the line of sight then it is in a very high ionization state or has an extreme velocity distribution. The new ASCA data confirm that the narrow component of the Fe Kα line peaks close to a rest energy of 7 keV, indicating the presence of a significant amount of highly ionized material in the nuclear environs.

Subject headings: galaxies: active — galaxies: individual (Ton S180) — X-rays: galaxies

1. INTRODUCTION

Examination of the Seyfert population shows that narrow-line Seyfert 1 galaxies have relatively strong X-ray variability (Turner et al. 1999b) and steeper X-ray spectra (Puchnarewicz et al. 1992; Laor et al. 1994, 1997; Boller, Brandt, & Fink 1996; Brandt, Mather, & Elvis 1997) than broad-line Seyfert 1 galaxies. A favored model explains narrow-line Seyfert 1 galaxies as systems with relatively low mass black holes accreting at a high rate (e.g., Pounds, Done, & Osborne 1995). Narrow-line Seyfert 1 galaxies are generally bluer and arise in gas with hydrogen column densities consistent with those derived from absorption edges in the 2–10 keV band and showed significant iron Kα emission with a narrow peak at ~7 keV, suggesting the circumnuclear material may be strongly ionized. Some X-ray line emission is also seen, consistent with an origin in the expanding shell of gas (Kaastra et al. 2000).

A Chandra Advanced CCD Imaging Spectrometer (ACIS)/Low-Energy Transmission Grating (LETG) observation of Ton S180 was performed as part of a multisatellite campaign whose results will be presented in T. J. Turner et al. (2001, in preparation, hereafter T01) and R. A. Edelson, P. Dobbie, S. Vaughan, & T. J. Turner (2001, in preparation). Here we concentrate on the Chandra and ASCA results, with reference to relevant results from contemporaneous Far-Ultraviolet Spectroscopic Explorer (FUSE) and Hubble Space Telescope (HST) observations.

2. THE X-RAY DATA

2.1. The Chandra Data

There remain a number of calibration issues associated with LETG data. These make this presentation preliminary; however, the results and conclusions are thought to be robust to the expected refinements. Our simultaneous ASCA data make it easy to determine where the problem areas are. The Chandra data were reprocessed using the latest calibration for the gain of the ACIS chips and screened such that known bad pixels and columns were removed, as were events with detector “grades” not equal to 0, 2, 3, 4, or 6.8 The light curve was examined, and periods of high background were excluded from the analysis. Such screening resulted in an exposure of ~75 ks. The first-order spectra were extracted from the screened event file, and ancillary response files were constructed using CIAO (v1.1.1).

Figure 1 shows the first-order LETG spectra of Ton S180. A lack of strong spectral features is immediately obvious. The soft X-ray emission component discovered using ASCA (Turner et al. 1998) is confirmed, and the LETG data demonstrate that the spectrum is broad and smooth rather than resolved into discrete emission lines. This excess must be due to a previously unknown primary or reprocessed continuum component or a blend of broadened spectral features. In the absence of any detected fea-
might be expected. Assuming the velocity profile of the $\text{FUSE}$ absorption lines and using an appropriate curve of growth, we find an upper limit on $N$(O vii) of about a few times $10^{14}$ cm$^{-2}$.

2.2. The ASCA Data

ASCA observed Ton S180 continuously for an 11 day period starting 1999 December 3. For the full analysis of these data see T01. The subset of data that were simultaneous with $\text{Chandra}$ shows a power-law continuum of $\Gamma = 2.44 \pm 0.04$ but confirms the presence of the soft excess in the 0.5–1 keV band.$^9$ A steep power law or bremsstrahlung component is an inadequate representation of this excess, as its form shows some curvature. However, the excess can be parameterized by a blackbody with rest-frame temperature $kT = 158 \pm 4$ eV and absorption-corrected bolometric luminosity $L = 1.2 \times 10^{44}$ ergs s$^{-1}$.

An alternative possibility is that the excess is the sum of a blend of broad lines from an ionized accretion disk. Simulations show that a wide range of parameter space will result in lines sufficiently broad that the horns of individual disk lines cannot be seen. For example, in Figure 2 we show how such a blend can produce a broad feature inseparable from the continuum in LETG data. Interestingly, Brundard-Raymont et al. (2001) find broad-line emission from the innermost regions of a Kerr disk to describe the $\text{XMM}$ Reflection Grating Spectrometer spectrum of two narrow-line Seyfert 1 galaxies, Mrk 766 and MCG –6-30-15. Ballantyne, Iwasawa, & Fabian (2001) also find an ionized disk to be a good model for the X-ray spectra of five narrow-line Seyfert 1 galaxies. In Ton S180, the soft component shows evidence for some variations in flux within the long ASCA observation on timescales of $\approx 200$ ks, suggesting a size less than $6 \times 10^{15}$ cm for the emitting region. There is no obvious correlation between the flux of the excess and that of the hard X-ray continuum, and thus the EW of the soft component also shows significant variability within the ASCA observation.

The Fe K$\alpha$ line was parameterized using the full 11 days of data, as no significant variability was observed in the line flux. The line profile was broad, asymmetric, and similar to that observed in a previous ASCA observation (Turner et al. 1998). The line could be parameterized as the sum of a broad plus narrow Gaussian component. The rest energy of the narrow line (fixed at 5 eV width) was $E_r = 6.83^{+0.14}_{-0.11}$ keV, with EW $88^{+31}_{-46}$ eV. The broad component gave $E_r = 6.53^{+0.32}_{-0.28}$ keV, width FWHM $\approx 55,000$ km s$^{-1}$, and EW $378^{+63}_{-66}$ eV, yielding an improvement to the fit $\Delta \chi^2 = 105$ for 1510 degrees of freedom (dof). The narrow line improved the fit at greater than 99% confidence ($\Delta \chi^2 = 13$ for 1510 dof) when the broad line was modeled as a Gaussian, but there was no improvement when the broad line was modeled as a disk line. The energy of the narrow line is consistent with emission from Fe xxv–Fe xxvi, while the broad line is consistent with ionization states Fe i–Fe xxv. Unfortunately, it is not possible to simultaneously constrain the ionization state and inclination of the disk.

3. CONTEMPORANEOUS UV OBSERVATIONS

Contemporaneous UV data taken with $\text{FUSE}$ and $\text{HST}$ will be presented in T01. Here we note some relevant results. $\text{FUSE}$ data show absorption at three velocities near the redshift of Ton S180 in the O vi $\lambda\lambda 1032, 1038$ resonance doublet. The O vi absorption line measurements reveal FWHM 75, 27, and 44 km s$^{-1}$ for the three components, each with column density $N$(O vi) $\sim 10^{14}$ cm$^{-2}$. The UV absorbers are within 150 km s$^{-1}$

$^9$ The ASCA analysis utilized an appropriate correction for the Solid-State Imaging Spectrometer detector degradation (Yaqoob 2000).
parameters were determined using both the form of the soft excess and the strongly dominated by emission from the innermost regions of the disk. These UV absorption lines. Although we cannot rule out the possibility of weak absorption at this resolution, we estimate an upper limit on the EW of any C iv λ1550 absorption line to be 0.3 Å [i.e., \( \Delta \lambda \approx 2 \times 10^{13} \text{ cm}^{-2} \)].

4. DISCUSSION

4.1. A New Continuum Component?

ASCA observations of Ton S180 have shown a persistent excess of emission below ~1.5 keV relative to the hard X-ray continuum. It was previously suggested that this was due to unresolved line emission from ionized species of Ne and from the Fe L shell (Turner et al. 1998). However, detailed analysis of a similar X-ray feature in Akn 564 (Turner et al. 1999a) showed that it was impossible to produce enough line emission from either thermal or photoionized gas without producing other strong features (e.g., Si, S, etc.) ruled out by the ASCA data. Another suggestion, based on Position Sensitive Proportional Counter data, was an origin in a curving continuum with absorption features imprinted on it (Brandt et al. 1994). Again, it was impossible to produce sufficiently strong isolated absorption features to explain the ASCA data. The new LETG spectrum now clarifies this issue, showing that the soft excess is not resolved into emission lines but is broad and smooth. Thus, the soft excess emission must be primarily due to a continuum component (primary or Comptonized) or a blend of very broad features, such as emission lines from the innermost regions of an ionized accretion disk.

The luminosity and temperature from the blackbody parameterization indicate emission from a region of remarkably small size, \( \sim 10^{11} \text{ cm} \) in radius. Using the preliminary spectral energy distribution from the multisatellite data (T01), we estimate the bolometric luminosity of Ton S180 to be \( \sim 5 \times 10^{45} \text{ ergs s}^{-1} \). Using this luminosity and the prescription of Laor (1998; based on luminosity and FWHM Hβ), we estimated the black hole mass in Ton S180 to be \( \sim 10^7 M_\odot \). However, the Eddington luminosity is \( L_{\text{Edd}} = 1.3 \times 10^{42} \text{ ergs s}^{-1} \), by avoiding Ton S180 exceeding the Eddington limit, we require the black hole mass to be \( \geq 4 \times 10^7 M_\odot \). Two further independent estimates of the black hole mass can be made based on the variability characteristic of the source (Laor 2000) and the luminosity at 5100 Å (Kaspi et al. 2001). The former yields a mass in agreement with that obtained from Laor (1998), while the latter yields \( M_\bullet \sim 8 \times 10^7 M_\odot \). The innermost stable orbit in the latter case is \( \sim 7 \times 10^{13} \text{ cm} \), or \( \sim 3 \times 10^{13} \text{ cm} \) for a maximally spinning hole. Thus, our estimate of the radius of the emitting region appears inconsistent with the innermost edge of the accretion disk. This indicates that a simple blackbody parameterization of the soft excess is probably inadequate. The possibility of a parameterization as a Comptonized blackbody will be addressed in T01. For black holes operating near \( L_{\text{Edd}} \), the accretion disk surface is predicted to be highly ionized and the disk spectrum can produce a strong soft excess. Matt, Fabian, & Ross (1993) show that for high accretion rates and black hole masses typical of AGNs, strong soft emission will be evident below 1 keV, and Fiore et al. (1998) suggested an ionized disk as the origin of a soft X-ray component in PG 1244+026, which is characteristically similar to that observed in Ton S180. Simulations show that the broad lines expected from an ionized accretion disk can produce a smooth and broad excess of emission, which is consistent with the soft excess, Fe Kα line and the Chandra grating data.

Interestingly, the five AGNs known to possess a soft spectral component similar to Ton S180 are all narrow-line Seyfert 1 galaxies (Fiore et al. 1998; George et al. 2000; Turner et al. 1999b). Thus, we conclude that this particular type of soft

![Fig. 2.—Top: Photon spectrum from an 80 ks simulation of LETG/ACIS data. The simulation shows the mean spectrum expected for the summed first-order data, generated from a model that fits the ASCA data. The solid line shows only the power-law component of the model. It is clear that the sum of several soft X-ray lines from an accretion disk can produce a smooth observed excess of flux over the power law. Bottom: The model used for the simulation was a power law with \( \Gamma = 2.44 \) and Galactic absorption plus four broad emission components emitted from a Kerr accretion disk inclined at 45° to the line of sight. The inner and outer radii were 2.4R_g and 400R_g, respectively. The disk emissivity was found to follow \( R^{-5/2} \); i.e., the total line profiles are strongly dominated by emission from the innermost regions of the disk. These parameters were determined using both the form of the soft excess and the broad Fe Kα component observed in the ASCA spectra.](image)
X-ray component appears to be a characteristic of sources accreting at a high rate. Matt et al. (1993) demonstrate that the spectrum of an ionized accretion disk is a strong function of the accretion rate (and black hole mass), so there may be a critical accretion rate at which the observed characteristics of the source change significantly.

4.2. The State of the Circumnuclear Gas

A lack of absorption lines in Ton S180 means line-of-sight material is absent, is highly ionized, or has turbulent velocities that are either extremely high (many thousands of kilometers per second) or significantly lower (a few hundred kilometers per second) than the resolution of the LETG. In the latter case, we would still be able to detect absorption edges, but none are evident. The 90% confidence limit on O vii (0.7393 keV) is \( \tau < 0.16 \), which places a limit of \( N(O \, \text{vii}) \lesssim 7 \times 10^{17} \text{ cm}^{-2} \). The upper limit from the absorption line, \( N(O \, \text{vii}) \) of about a few times \( 10^{18} \text{ cm}^{-2} \) clearly provides more than an order of magnitude tighter constraint on the column. Combining this limit with the measurement from \( \text{FUSE} \), \( N(O \, \text{vi}) \sim 10^{14} \text{ cm}^{-2} \), yields a ratio \( \text{O \, vii/O \, vi} \sim 250 \), within the expected range for gas in photoionization equilibrium. Indeed, the gas is very likely to be in a high state of ionization since \((\S 3)(A(O/C)/N(O \, \text{vii})/N(C \, \text{vi}) > 3 \) where \( A(O/C) \) is the relative abundance of O and C. Some other narrow-line Seyfert 1 galaxies show significant UV absorption (Crenshaw et al. 1999); thus, it is unclear whether or not conditions in the circumnuclear gas in Ton S180 are linked to the presence of the soft spectral component.

The peak of the Fe Kα line is at \( \sim 7 \text{ keV} \). If this represents a separable narrow line, then the EW implies emission from a full shell of material with \( N_{\text{H}} \sim 6 \times 10^{22} \text{ cm}^{-2} \), using Leahy & Creighton (1993) estimates for neutral material adjusted to a mix of Fe xxv–Fe xxvi. The ionization state is large enough to allow production of the narrow line in the line of sight without a significant soft X-ray opacity. However, the presence of the broad component indicates a significant amount of reprocessing material out of the line of sight.

5. SUMMARY

The \textit{Chandra} ACIS/LETG spectrum shows that the soft excess in Ton S180 is smooth and broad and therefore is not due to a blend of individual narrow emission lines from photoionized or collisionally ionized gas. The soft excess could be a primary or reprocessed continuum component. A simple blackbody can be ruled out on the basis of the inferred size of the emission region. The occurrence of a similar feature in several narrow-line Seyfert 1 galaxies indicates that this type of soft X-ray component may be a characteristic of sources accreting at a very high rate. A blend of very broad emission lines from the inner regions of an ionized accretion disk is consistent with the \textit{ASCA} and \textit{Chandra} data.

The \textit{Chandra} LETG spectrum shows no evidence for line-of-sight absorption. High-resolution UV spectra show only a low column of highly ionized gas, consistent with the upper limit on the strength of absorption lines in the soft X-ray band. The narrow component of the Fe Kα emission line could be consistent with highly ionized gas in the line of sight; however, a strong broad component shows that there must also be a significant amount of circumnuclear material out of the line of sight.

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