THE SPECTRAL ENERGY DISTRIBUTION OF THE SEYFERT GALAXY TON S180

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ABSTRACT

We present spectral results from a multisatellite, broadband campaign on the narrow-line Seyfert 1 galaxy Ton S180 (PHL 912) performed at the end of 1999. We discuss the spectral energy distribution (SED) of the source, combining simultaneous Chandra, ASCA, and Extreme Ultraviolet Explorer data with contemporaneous Far Ultraviolet Spectroscopic Explorer (FUSE), Hubble Space Telescope, and ground-based optical and infrared data. The resulting SED shows that most of the energy is emitted in the 10–100 eV regime, which must be dominated by the primary energy source. No spectral turnover is evident in the UV regime. This, the soft X-ray emission, and the overall shape of the SED indicate that emission from the accretion disk peaks between 15 and 100 eV. High-resolution FUSE spectra showing UV absorption due to O vi and the lack of detectable X-ray absorption in the Chandra spectrum demonstrate the presence of a low column density of highly ionized gas along our line of sight. The highly ionized state of the circumnuclear gas is most likely linked to the high luminosity and steep spectrum of the active nucleus. Given the strong ionizing flux in Ton S180, it is possible that the clouds within a few tens of light days of the central source are too highly ionized to produce much line emission. Thus, the narrow width of the emission lines in Ton S180 is due to the emission arising from large radii.

1. INTRODUCTION

A long-standing suggestion has been that there is a so-called big blue bump (BBB) of continuum emission, peaking in the unseen X-ray–to–UV (XUV) regime, perhaps originating in the accretion disk. There are indications of the low-energy tail of this component in the UV spectra of Seyfert 1 galaxies (Shields 1978; Malkan & Sargent 1982). The peak energy of the disk emission is predicted to be dependent on the accretion rate (Matt, Fabian, & Ross 1993). Thus, the spectral energy distribution (SED) of an active galactic nucleus (AGN) provides crucial information about accretion rates and conditions close to the disk. However, determination of the XUV continuum in AGNs has been extremely difficult because of the severe attenuation of photons of these energies by even small amounts of Galactic material along the line of sight. Some indication of the strength of the unseen continuum has been inferred from the strengths of emission lines such as He ii λ1640 (see, e.g., Mathews & Ferland 1987). Zheng et al. (1997) have suggested that the form of the unseen XUV spectrum is \( f_{\nu} \propto \nu^{-\alpha} \), with \( \alpha = 2 \) between the Lyman limit (at 912 Å) and \( \sim 0.5 \text{ keV} \). Laor et al. (1997) combine this with a mean soft X-ray spectrum, based on ROSAT observations of quasars, to dispute the existence of a large XUV bump. Telfer et al. (2002) extend the work of Zheng et al. (1997) by including more data in the extreme-UV band; those authors find the data to be adequately represented by a simple power law with \( \alpha = 1.76 \) between 500 and 1200 Å. Korista, Ferland, & Baldwin (1997) have discussed the problem that when extrapolating the known soft X-ray spectrum of AGNs, there appears to be too few 54.4 eV photons to account for the strength of the observed He ii lines. They consider the possibility that the broad-line clouds see a harder continuum than the observer does or that the XUV spectrum has a double-peaked shape.

Narrow-line Seyfert 1 (NLS1) galaxies were first classified on the basis of their unusual optical properties, most notably lying at the lower end of the distribution of line widths, for permitted optical lines. Specifically, widths of Hβ FWHM < 2000 km s\(^{-1}\) have been taken as the defining quality of NLS1 galaxies, although it is widely acknowledged that this value is arbitrary and that there is a continuous range of broadband properties across the Seyfert population. Nevertheless, the distinction is useful since an object’s place in the line width distribution of the Seyfert population is an indicator of other properties, especially the X-ray properties. NLS1 galaxies appear to have systemati-
cally different, or very extreme, X-ray attributes compared to the rest of the Seyfert population, which we will henceforth refer to as broad-line Seyfert 1 (BLS1) galaxy. For example, examination of X-ray properties across the Seyfert population reveals that Hβ FW1M is strongly anticorrelated with the excess variance \( \sigma_{\text{RMS}}^2 \) (Turner et al. 1999b; where \( \sigma_{\text{RMS}}^2 = \left(1/N\mu^2\right)\sum_{i=1}^N(|X_i - \mu|^2 - \sigma_i^2) \) for a light curve with \( N \) points of counts \( X \), and unweighted mean \( \mu \)) and anticorrelated with X-ray index, in the sense that NLS1 galaxies are most variable and have steeper spectra (Boller, Brandt, & Fink 1996; Brandt, Mathur, & Elvis 1997). These correlations suggest a fundamental difference between BLS1 and NLS1 galaxies, the latter being thought to represent the low-mass and/or high accretion rate systems (see, e.g., Pounds, Done, & Osborne 1995).

For black holes operating near \( L_{\text{Edd}} \), the accretion disk surface is predicted to be highly ionized; thus, the disk spectrum is expected to peak at higher energies in NLS1 galaxies than in BLS1 galaxies. In the soft X-ray regime the NLS1 galaxies Ton S180 and Arakelid 64 show a hump of emission close to 1 keV (see, e.g., Turner, George, & Nandra 1998; Vaughan et al. 1999a, 1999b; Turner et al. 2001a, 2001c), which could be the signature of a hot disk. Fiore et al. (1998) also suggested an ionized disk as the origin of a soft X-ray component in PG 1244+026. Interestingly, at \( 2-10 \) keV, the NLS1 source is at the extreme end of the Seyfert range of line widths with \( \text{FWHM} \text{H}\alpha \) and \( \text{H}\beta \sim 900 \text{ km s}^{-1} \), making it a good choice for isolating the fundamental parameter that determines the classification of a Seyfert galaxy.

BeppoSAX (Comastri et al. 1998) and ASCA (Turner et al. 1998) data from Ton S180 indicated a steep spectrum in the 2–10 keV band, with \( \alpha = 1.5 \); both data sets also showed an Fe Kα emission line peaked at a rest energy \( \sim 7 \) keV, indicating that the circumnuclear material is strongly ionized. ASCA data confirm the complexity of the soft X-ray spectrum first noted in ROSAT Position Sensitive Proportional Counter data (Fink et al. 1997). A Chandra Low-Energy Transmission Grating (LETG) observation has recently revealed the soft hump component to be a smooth continuum or extremely broadened reprocessed component (Turner et al. 2001a).

In this paper we use the energy index \( \alpha \) for quantification of spectral indices, defined such that the flux density \( F(E) \propto E^{-\alpha} \) at energy \( E \). A log of the observations performed in support of the campaign is presented in Table 1. All the data were reduced using standard techniques as outlined below.

### 3. ASCA

#### 3.1. Data Reduction

The ASCA satellite carries four focal-plane detectors, two CCDs (the Solid-State Imaging Spectrometers [SISs] covering 0.4–10.0 keV), and two Gas Imaging Spectrometers (GISs; covering 0.7–10.0 keV); all are operated simultaneously. ASCA observed Ton S180 for a baseline of 12 days.

| Observatory/Telescope | Instrument | UT Dates | Notes | References |
|-----------------------|------------|----------|-------|------------|
| ASCA                  | LETG       | 1999 Dec 3–15 | Continuous\(^a\) | 1, 2 |
| Chandra               | PCA        | 1999 Dec 14-15 | Continuous | 3 |
| RXTE\(^b\)           |            | 1999 Nov 12-Dec 15 | Once every 96 minutes | 2 |
| EUVE                  |            | 1999 Nov 12-Dec 15 | Continuous\(^c\) | 2 |
| FUSE                  |            | 1999 Dec 12 | 15.2 ks; 30° × 30° (LWRS) | 4 |
| HST                   | STIS       | 2000 Jan 22 | 6 ks; 52'' x 0''2 | 4 |
| ESO 1.5 m            | OSIRIS     | 2000 Jan 21 | uoby | 4 |
| CTIO 1.5 m           |            | 2000 Jan 23 | JHKs | 4 |

\(^a\) Except for gaps due to Earth occultation and passage of the spacecraft through the South Atlantic Anomaly.

\(^b\) Those data are not used in the construction of the SED but were taken for the complementary timing project (Edelson et al. 2002).

\(^c\) A subset of these data were used in construction of the SED.

References.—(1) Romano et al. 2002; (2) Edelson et al. 2002; (3) Turner et al. 2001a; (4) this work.
Those data were reduced using the methods and screening criteria of the Tartarus (Turner et al. 2001b) database. As reported by Romano et al. (2002), these screening criteria resulted in an effective exposure of 405 ks in the GISs and 338 and 368 ks in SIS0 and SIS1, respectively. The mean SIS0 count rate was 0.586 ± 0.001 counts s⁻¹. The data were reduced using the calibration file “sisph2pi_290301.fits”, and the degradation of the low-energy response of the SISs was compensated for by the time-dependent absorption term detailed by Yaqoob et al. (2000). Romano et al. (2002) utilized corrections of $N_H = 6.9 \times 10^{20}$ and $1.0 \times 10^{21}$ cm⁻² for SIS0 and SIS1, respectively. The results presented here are primarily based on the analysis of the time-averaged spectra obtained during the simultaneous ASCA-Chandra observations. This means that while all of the Chandra data were used, only a subset of the ASCA data were utilized. Figure 1 shows the periods covered by the Far Ultraviolet Spectroscopic Explorer (FUSE) and Chandra observations, with respect to the entire 12 day observation by ASCA, allowing us to see where these new data sets lie compared to the recent flux history of the source. Figure 2 shows in detail the Chandra light curve with part of the overlapping ASCA data set. In this paper we use only the mean ASCA spectrum from the period simultaneous with the Chandra observation, i.e., within JD 2,451,526.576–2,451,527.498.

3.2. ASCA Results

As is evident from Figure 2, Ton S180 exhibited significant changes in flux. Romano et al. (2002) present a detailed analysis of spectral variability over the full 12 day observation. Romano et al. (2002) find the continuum fit to the mean spectrum to yield $\alpha = 1.44 \pm 0.02$. A strong excess of emission is observed below 2 keV, and this soft component varies in strength down to the minimum timescale determinable via spectral analysis, ~1 day. The variations in hump strength are correlated with the photon index and the 2–10 keV flux, consistent with disk corona models (Romano et al. 2002). The softness ratio shows rapid variability on timescales less than 1000 s, indicating either a breakdown of the correlation between soft hump and power-law fluxes on such short timescales or rapid variations in the photon index. Romano et al. (2002) also find a broad Fe Kα line with narrow peak at a rest energy 6.8 keV, indicating an origin in ionized material.

Analysis of the spectrum acquired simultaneously with Chandra data reveals $\alpha = 1.44 \pm 0.07$ (in agreement with the mean for the full data set). The soft component shows an equivalent width $EW = 63_{-50}^{+119}$ eV when parameterized using a Gaussian model. Since Romano et al. (2002) found no evidence for variability in the flux or equivalent width of the Fe Kα line, we do not fit for the Fe Kα parameters here (and exclude the 5.0–7.5 keV data when fitting for continuum slopes).

4. CHANDRA

4.1. ACIS/LETG Data Reduction

The Chandra data were reprocessed using calibration files from CALBD, Version 2.6. The data were then screened to
remove bad pixels, columns, and events with detector “grades” not equal to 0, 2, 3, 4, or 6. Periods of high background were also excluded. Such screening resulted in an on-source exposure of ∼75 ks. The first-order spectra were extracted from the screened event file and appropriate ancillary response files constructed using CIAO, Version 2.1. Previous analysis of these data (Turner et al. 2001a) was limited to the use of data above ∼0.4 keV because of unacceptable uncertainty in the ACIS/LETG calibration around the C edge. However, the quantum efficiency file “acisD1997-04-17qeN0004.fits,” released 2001 June 7, was utilized in the analysis presented here; this improves the fit to ACIS/LETG observations of calibration sources in the C edge regime. Utilization of the new quantum efficiency file allows examination of data down to 0.2 keV, the lowest energy available from LETG data with ACIS in the focal plane. The entire Chandra baseline is utilized in this analysis since the ASCA observation overlaps the Chandra observation completely (Fig. 2).

4.2. LETG Results

In Figure 2 we show the light curve obtained from the ±first-order Chandra/LETG data. The portion of the ASCA SIS light curve (from Fig. 2) is overlaid for direct comparison. As might be expected, there is good agreement between the light curves from the two instruments.

Turner et al. (2001a) present the first-order LETG spectra of Ton S180, finding no strong spectral features and concluding that the excess soft X-ray emission discovered using ASCA (Turner et al. 1998) must be primarily due to a previously unknown continuum component or very broadened reprocessed component. Turner et al. (2001a) note the lack of strong absorption features in the X-ray spectrum of Ton S180, in contrast to results from many Seyfert 1 galaxies (e.g., the BLS1 galaxies NGC 5548 [Kaasstra et al. 2000] and NGC 3783 [Kaspi et al. 2001] and the NLS1 galaxy NGC 4051 [Collinge et al. 2001]). Analysis using the new quantum efficiency file reveals an improvement to the agreement between ASCA and LETG data in the 1–2 keV regime (cf. results presented by Turner et al. 2001a). We also reexamined the shape of the soft excess. The extrapolation of the hard-band power law to soft X-ray energies reconfirms the presence of excess soft emission as expected, with a sharp turnover of the data below ∼0.3 keV (∼7 × 10^{16} Hz). Figure 3 shows the form of the soft component. The turnover is sharper than that expected due to absorption by edges in neutral or ionized gas. In any case, if there were such a deep absorption edge in the X-ray regime, strong spectral features would be expected in other parts of the spectrum, which are not observed. The soft hump in the data was modeled using the XSPEC “diskbb” model (Mitsuda et al. 1984; Makishima et al. 1986). However, although “diskbb” has some intrinsic spectral curvature, this was not able to account for the shape of the LETG data. A fit to data above 0.3 keV yielded a best-fit temperature of ∼98 eV at the inner edge of the disk. Possible explanations for the apparent shape of the soft excess include continuing problems with the softest energy calibration and the more intriguing possibility of a peak due to the presence of a blend of broadened emission lines, as suggested previously for some Seyfert galaxies (Branduardi-Raymont et al. 2001; Turner et al. 2001a). Comastri et al. (1998) present a BeppoSAX spectrum of Ton S180 down to ∼0.1 keV, with no evidence for a spectral drop below 0.3 keV, supporting the possibility that this is due to residual calibration problems in the LETG. Thus, we do not perform detailed fitting to this feature.

5. THE EXTREME ULTRAVIOLET EXPLORER

Archival Extreme Ultraviolet Explorer (EUVE) data are available covering a period that overlaps the Chandra observation. We processed these data using standard techniques. Source counts were summed in a circular aperture of 25 pixels in radius and the background calculated from a surrounding annulus of 30 pixels in width. The dead time–Primbschinger correction (DPC) was used to correct the count rate for the loss of events due to the dead time of the detector electronics and “Primbsching” caused by the rather limited width of the telemetry buffer. A standard technique calls for data with a DPC factor greater than 1.25 to be discarded since the systematic errors present in the estimates of this correction factor increase with its magnitude. However, during the course of reducing these data, it was noted that the Deep Survey DPC factor frequently lay above 1.5, significantly greater than the more typically observed values of 1.0–1.3. This was likely due to increased geocoronal emission possibly associated with the approaching solar maximum at that epoch and/or the decreasing orbital altitude of the EUVE satellite. These conditions forced us to select data.
within the more liberal limits of $1.0 < \text{DPC} < 2.0$ in order to have adequate counts for construction of a spectrum for the time period simultaneous with the ASCA and LETG overlap observation. The effective on-source exposure was 21 ks within the start and stop times determined from the LETG observation. The background-subtracted count rate for the full band was $(7.1 \pm 3.7) \times 10^{-3} \text{ cm}^{-2} \text{s}^{-1}$.

6. FUSE

6.1. Data Reduction

We used FUSE to obtain the 905–1187 Å far-UV spectrum of Ton S180 on 1999 December 12, 05:50:32–19:41:14 UT. The total observing time was 15.2 ks. For a full description of FUSE and its initial in-flight performance, see Moos et al. (2000) and Sahnow et al. (2000). Briefly, four separate primary mirrors in FUSE collect light to feed four prime-focus, Rowland circle spectrographs. Two photon-counting microchannel plate detectors with KBr photocathodes image the dispersed light. Two of the optical systems use LiF coatings and produce spectra covering the $\sim$990–1187 Å wavelength range. The other two systems use SiC coatings on the optics to provide spectral coverage down to 905 Å. Our observations of Ton S180 used the $30'' \times 30''$ low-resolution apertures. We obtained good spectra from the LiF1 and LiF2 channels covering the 987–1187 Å band and lower signal-to-noise ratio (S/N) spectra from the SiC1 and SiC2 channels covering 905–1091 Å.

The flux scale is accurate to $\sim$10%, and the wavelength scale is accurate to $\sim$15 km s$^{-1}$. For detailed analysis of line and continuum fluxes, we bin this spectrum by 5 pixels, preserving the $\sim$20 km s$^{-1}$ resolution of this observation. Figure 1 shows that while the FUSE observation was not performed simultaneously with Chandra, it does cover a similar mean flux state to that covered by the Chandra observation.

6.2. FUSE Results

As seen in Figure 4, the far-UV spectrum of Ton S180 shows a bright, blue continuum and prominent broad O vi emission. Fainter emission from Si vii $\lambda$9534, 945, C iii $\lambda$977, N iii $\lambda$991, and He ii $\lambda$1085 may also be present. The foreground Galactic and intergalactic absorption visible in this spectrum has already been discussed by Savage et al. (2000), Sembach et al. (2000), and Shull et al. (2000); one noteworthy feature is the deep absorption by Ly$\beta$. In addition to these foreground features, absorption at three velocities near the redshift of Ton S180 is visible in the O vii $\lambda\lambda$1032, 1038 resonance doublet (Fig. 4).

To measure the strengths of these features and that of the broad O vi emission, we used the IRAF task “specfit” (Kriss 1994). We used a power law for the underlying local continuum, a broad Gaussian for each of the O vi emission lines with their fluxes fixed at a 2:1 ratio, and Gaussians for the narrow absorption lines. The broad O vi lines have an FWHM of $2600 \pm 186$ km s$^{-1}$ and a total flux of $(1.10 \pm 0.05) \times 10^{-12}$ ergs s$^{-1}$ cm$^{-2}$. They are blueshifted relative to the systemic redshift by $490 \pm 69$ km s$^{-1}$. Unfortunately, the Ly$\beta$ lines corresponding to these velocities fall in the gaps between the LiF detector segments, and so we must use the lower S/N SiC2A data to measure their strengths. No Ly$\beta$ lines are detected.

For the O vi absorption lines, the measured equivalent widths ($W'_{\lambda}$), column densities, and FWHMs are summarized in Table 2. The doublets have optical depths consistent with a 2:1 ratio, implying full coverage of the underlying continuum and broad emission lines. Given the strength of the O vi absorption and the weakness of any corresponding neutral hydrogen, we conclude that this gas is in a fairly high state of ionization.

7. HUBBLE SPACE TELESCOPE

7.1. STIS Data Reduction

Since the Hubble Space Telescope (HST) was in safe mode during 1999 December, the earliest we could obtain HST/STIS observations of Ton S180 was 2000 January 22 (UT). We used the $52'' \times 0''2$ slit to obtain a UV spectrum over the range 1150–3150 Å at a spectral resolving power of $\lambda/\Delta \lambda \sim 1000$. The exposure times were 1260 s for the...
are labeled; lines are tabulated in detail in Table 3. The strong lines are absorption (using reddening curves from Hutchings & C11 of energy index \( L_{\text{ind}} \). We then combined the G140L and G230L GSFC for use by the STIS Instrument Definition Team (Lindler 1998). We then combined the G140L and G230L spectra in the region of overlap for display purposes.

7.2. STIS Results

Figure 5 shows the STIS spectrum of Ton S180. The underlying continuum form is the primary objective of this study, and to this end, we first fit simple power-law models to the STIS data, absorbed by \( E(B-V) = 0.0296 \), the extinction due to Galactic material in the line of sight. The best-fitting power law has slope \( \alpha = 0.66 \pm 0.14 \). The extrapolation of this continuum slope provides a good fit to the FUSE continuum, after correction of the FUSE data for absorption (using reddening curves from Hutchings & Giasson 2001 and Clayton et al. 1996). However, the source continuum level in the STIS data is lower than that observed in 1999 December by FUSE. We find that the normalizations of the STIS and FUSE data sets show a flux discrepancy, in the sense that the STIS data find the source at 55% of the flux level observed by FUSE.

The uncertainty on absolute flux is \( \sim 10\% \) for FUSE and \( \sim 2\% \) for STIS data. Thus, we attribute the discrepancy to variability in Ton S180 over the \( \sim 5 \) weeks separating those observations. Figure 1 shows that the FUSE observation covered a similar flux state to the Chandra observation, so we do not want to rescale the FUSE data since it samples the same flux state as the X-ray data. Given an expectation of lags between emission in the different wavelength regimes of an AGN, it is always difficult to assess how to construct the most meaningful and instructive SED. The flux discrepancy in data from the overlapping bandpass of the STIS and FUSE data removes ambiguities as to breaks in intrinsic spectral shape; thus, for construction of the SED of Ton S180, we scaled-up the STIS and ground-based data by a factor 1.78 to compensate for the flux variability.

The absorbed power-law continuum extrapolates from the STIS band to agree with the FUSE continuum form. No spectral turnover is evident in these data, indicating that if the BBB component is contributing to the FUSE data, then its peak lies above \( \sim 912 \) \( \text{Å} \) (15 eV). The excesses above the continuum fit are due to known emission features, which are detailed in Table 3, and some weak absorption features are also evident. In addition to the distinct lines, there is evi-

![HST STIS (1150–3150 \( \text{Å} \)) data; the solid line shows a power law of energy index \( \alpha = 0.66 \) convolved with extinction by \( E(B-V) = 0.0296 \) (i.e., neither the data or model has absorption correction). The strong lines are labeled; lines are tabulated in detail in Table 3.

| Feature      | Flux*          | FWHM (km s\(^{-1}\)) |
|--------------|----------------|----------------------|
| Ly\(\alpha\)1216| 30.8 \pm 6.20 | 1961 \pm 122         |
| N\(\text{v}\)1240 | 7.11 \pm 1.40 | 1700 \pm 848         |
| Si\(\text{ii}\)1260 | 0.49 \pm 0.19 | ...                 |
| O\(\text{i}\)1302  | 1.36 \pm 0.45 | 921 \pm 230         |
| C\(\text{ii}\)1335 | 0.87 \pm 0.30 | 1123 \pm 280        |
| S\(\text{ii}\)/O\(\text{v}\)1400  | 4.47 \pm 0.94 | ...                 |
| N\(\text{v}\)/1486 | <0.1          | ...                 |
| C\(\text{iv}\)1550 | 8.31 \pm 0.61 | 2300 \pm 80         |
| He\(\text{ii}\)1640 | 1.95 \pm 0.78 | ...                 |
| O\(\text{iii}\)1663 | 0.60 \pm 0.24 | ...                 |
| N\(\text{iii}\)1750 | 0.45 \pm 0.22 | ...                 |
| Si\(\text{iii}\)1892 | 1.25 \pm 0.25 | ...                 |
| C\(\text{iii}\)1909 | 2.16 \pm 0.43 | ...                 |
| [Ne\(\text{v}\)]2324 | 0.24 \pm 0.10 | ...                 |
| Mg\(\text{ii}\)2800 | 1.21 \pm 0.24 | 1071 \pm 428        |

* Observed fluxes with no absorption correction, in units \( 10^{-13} \text{ergs cm}^{-2} \text{s}^{-1} \).
dence for emission from Fe ii and Fe iii between 1900 and 2300 Å similar to that observed in another NLS1 galaxy, I ZW 1 (Vestergaard & Wilkes 2002). Examination of the detailed STIS data shows that all of the emission lines expected for a Seyfert 1 galaxy are present as well as a number of absorption lines from our Galaxy. The UV emission lines are narrow compared to those in typical Seyfert 1 galaxies; for example, the FWHM of the C iv 1549 line is ~2300 ± 80 km s⁻¹. The peak of C iv is blueshifted by 510 ± 20 km s⁻¹ with respect to the systemic velocity. There is no evidence for intrinsic UV absorption lines, which occur in ~60% of normal and narrow-line Seyfert 1 galaxies (Crenshaw et al. 1999). Although we cannot rule out the possibility of weak absorption at this resolution, we estimate an upper limit on the equivalent width of any C iv absorption to be 0.3 Å.

8. GROUND-BASED DATA

8.1. uvby Photometry

Strömgren uvby observations (Strömgren 1957) were made of Ton S180 with the Danish 1.5 m telescope at ESO, La Silla, Chile, on the night of 2000 January 20–21. Observations of two secondary standards (DM−261339 and DM−38022) were also made. Each standard was observed twice in a uvbybu sequence before and after the single observation, uvby, of Ton S180.

Each image was prereduced in the same standard manner. The bias, calculated as the mean of the overscan region, was subtracted, and then the image was flat-fielded using the adopted sky flat for the observing run. Instrumental magnitudes were extracted from the images using DAOPHOT II. Simple aperture photometry is all that is required since neither the standard stars nor Ton S180 reside in crowded fields. A 250” (32.05 pixel) aperture was adopted. The sky background was estimated using an annulus with inner and outer radii of 64” (50 pixels) and 70.5” (55 pixels), respectively.

For all the uvby photometry discussed here, atmospheric extinction corrections were made based on extinction coefficients determined at the Danish 50 cm telescope. On the night of these observations the extinction was marginally higher than the mean, while the rms residuals between observed and catalog indices of standard stars are a factor of 3–7 larger than on nights of excellent photometric quality.

Transformations have been determined between instrumental and standard systems based on 170 Strömgren uvby measurements of 42 secondary standard stars (observed in 1999 January, February, November, and December).

We transformed the Ton S180 instrumental photometry to the standard system, based on the December standard transformation relations. Correcting for time evolution of the relation and for the difference in b filter used for the target versus that used for the standard stars, we obtain the following Strömgren magnitudes and indices for Ton S180: u = 14.94 ± 0.03 mag, v = 15.03 ± 0.02 mag, b = 14.74 ± 0.02 mag, y = V = 14.58 ± 0.02 mag, (b−y) = 0.16 ± 0.02 mag, and c₁ = −0.380 ± 0.04 mag. To take into account the various possible error sources deriving from (1) the use of a different b filter and (2) the zero-point offsets, we have adopted uncertainties of twice the rms residuals for the full 1999 standard star data set.

We convert uvby magnitudes into monochromatic fluxes via the equation \( f_{\lambda} = 10^{m_{\lambda}/2.5}F_{\lambda,m_{\lambda}} = 0 \), where the calibrating fluxes \( F_{\lambda,m_{\lambda}} \) are taken from Pritchet et al. (1998). The fluxes obtained are listed in Table 4. The errors on fluxes are propagated from those on the magnitudes.

8.2. Infrared Photometry

On 2000 January 23 (JD 2,451,567.54) we observed Ton S180 with the near-IR imager/spectrograph OSIRIS mounted on the CTIO 1.5 m telescope. A total of 300 s in K′ and 150 s in both J and H were recorded for Ton S180 along with the standard star 9103 (Persson et al. 1998). The standard star is located in the vicinity of Ton S180 at a similar air mass. The instrumental magnitudes were transformed to the system of Persson et al. (1998) based on the offsets found for the standard star. This gave \( J = 13.22 ± 0.04 \) mag, \( H = 12.60 ± 0.03 \) mag, and \( K_s = 11.67 ± 0.03 \) mag, where the errors are random errors from photometry and zero points \( (J, H, \text{and } K_s) \) photometry is provided in Table 5). The calibration was checked against another standard observed about an hour later at a similar air mass, yielding good agreement.

To convert the magnitudes to monochromatic fluxes, we use the J and H zero-magnitude fluxes computed by Cohen et al. (1992), which are based on Kurucz models of Vega and Sirius. These models are computed for the UKIRT system (Casali & Hawarden 1992), but Persson et al. (1998) show that their magnitudes have a similar zero point. For the \( K_s \) zero-magnitude flux, we adopt the value from Pogge, Martini, & DePoy (1999) quoted in the OSIRIS users manual. The resulting monochromatic fluxes \( f_{\lambda} \) computed as in the previous section are given in Table 4.

9. EXAMINATION OF THE SED

First we compared the SED data to the power-law continua determined for the UV and X-ray regimes. Figure 6

| Filter | \( \lambda (\text{Å}) \) | Magnitude \( a \) | \( F_{\lambda}^{b} \) (\( \times 10^{-19} \text{ ergs cm}^{-2} \text{s}^{-1} \text{ Å}^{-1} \)) |
|--------|-----------------|-----------------|----------------|
| u........ | 3500            | 14.94 ± 0.03    | 39.75 ± 1.02   |
| v........ | 4110            | 15.03 ± 0.02    | 11.94 ± 0.33   |
| b........ | 4670            | 14.74 ± 0.02    | 7.71 ± 0.13    |
| y........ | 5470            | 14.58 ± 0.02    | 5.26 ± 0.09    |

\( a \) Strömgren magnitude (Strömgren 1957).

\( b \) No rescaling applied for source variability.

| Filter | \( \lambda (\text{Å}) \) | Magnitude \( a \) | \( F_{\lambda}^{a} \) (\( \times 10^{-10} \text{ ergs cm}^{-2} \text{s}^{-1} \text{ Å}^{-1} \)) |
|--------|-----------------|-----------------|----------------|
| J........ | 12,150          | 13.22 ± 0.04    | 3.45 ± 0.10    |
| H........ | 16,540          | 12.60 ± 0.03    | 1.40 ± 0.03    |
| Ks...... | 21,570          | 11.67 ± 0.03    | 1.14 ± 0.03    |

\( a \) No rescaling applied for source variability.
Fig. 6.—Multiwaveband data for Ton S180. In this plot the data have not been corrected for absorption. The blue dashed line shows the (absorbed) power law $\alpha = 1.44$ from the 2–10 keV regime, extrapolated to lower energies. The green solid line shows the power law $\alpha = 0.66$ (convolved with line-of-sight absorption) from the fit to the STIS and FUSE data, extrapolated to higher energies. The open point between log $\nu = 16$–17 Hz represents the EUVE data; the circles represent the ground-based data.

shows that the extrapolation of the best-fitting power law to the $HST$/STIS data ($\alpha = 0.66$) greatly overpredicts the X-ray flux. Clearly the spectrum must break somewhere between the UV and soft X-ray regimes. Also shown is the hard X-ray continuum slope, $\alpha = 1.44$, extrapolated to lower energies. This continuum intercepts the UV data around a few thousand $\AA$, but again, the hard X-ray power law must terminate somewhere between the UV and soft X-ray regimes since it overpredicts the optical and infrared data.

In order to examine the approximate energy distribution for Ton S180, we first corrected the data for the small amount of extinction due to the Galactic line-of-sight gas. In the STIS band the reddening correction was made following Cardelli, Clayton, & Mathis (1989) and in the FUSE band using Hutchings & Giasson (2001) and Clayton et al. (1996), both assuming $E(B-V) = 0.0296$, the Galactic extinction. The absorption correction in the X-ray regime was made following Morrison & McCammon (1983) and assuming a Galactic value $1.55 \times 10^{20}$ cm$^{-2}$. Table 6 summarizes some useful data from the SED. A simple parameterization was made of the spectral shape using the hard X-ray power law, $\alpha = 1.44$ breaking to $\alpha = 2.5$ at 1 keV and then breaking to $\alpha = 0.66$ at 0.1 keV. This parameterization is shown as a solid green line in Figure 7. The peak of the SED in this case is 80 eV. The dotted green lines denote the uncertainty in the intrinsic SED due to some uncertainty in the line-of-sight absorption measurement. Parameterization of the soft X-ray regime as a steep power law is clearly inadequate, and we also overlay an alternative model with continuum plus “diskbb” soft component. It is interesting to see that the best-fitting “diskbb” model, which has a temperature of 98 eV at the inner radius, does not predict that any BBB component would appear in the UV band.

Even application of the physically meaningful models such as “diskbb” leave some unmodeled structure in the soft component, i.e., a sharp spectral break below 0.3 keV. It is currently unclear whether this structure represents the intrinsic form of the soft X-ray emission or a residual uncertainty in the ACIS/LETG calibration. The break is not well modeled using neutral or ionized gas. The most obvious possibility remaining is that this sharp feature is due to the presence of emission features. However, uncertainty in calibration prompts us to note this structure but not to model it in detail.

\begin{table}[h]
\centering
\begin{tabular}{lccc}
\hline
Rest Wavelength/Energy & $\nu L_{\nu}$ (Observed)$^a$ & $\nu L_{\nu}$ (Intrinsic)$^b$ \\
& ($\times 10^{44}$ ergs s$^{-1}$) & ($\times 10^{44}$ ergs s$^{-1}$) \\
\hline
2 $\mu$m & 3.146 & 3.175 \\
1 $\mu$m & 3.842 & 3.953 \\
7000 $\AA$ & 4.283 & 4.544 \\
5500 $\AA$ & 4.485 & 4.823 \\
3000 $\AA$ & 5.272 & 6.124 \\
2500 $\AA$ & 5.356 & 6.371 \\
1000 $\AA$ & 6.053 & 8.892 \\
0.25 keV & 1.521 & 3.180 \\
1 keV & 0.655 & 0.686 \\
2 keV & 0.307 & 0.313 \\
10 keV & 0.156 & 0.156 \\
\hline
\end{tabular}
\caption{Data from the SED}
\end{table}

$^a$ $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0.5$.

Fig. 7.—SED of Ton S180. The data presented here are shown as a solid black line. The data have been corrected for Galactic line-of-sight extinction. The circles represent the ground-based data. The simple model parameterization of the SED is shown as a solid green line. The dotted green line straddling this shows the uncertainty in the SED due to uncertainty in the Galactic line-of-sight absorption. The dashed orange line is the blackbody, and the dotted blue line the power-law model components of the SED; the red dashed line is their sum.
10. DISCUSSION

10.1. Interband Indices

Table 7 shows the indices between various wavebands for Ton S180 compared to some values previously determined for other Seyfert type galaxies. A commonly cited slope is $\alpha_{\text{ox}}$, and the value $\alpha_{\text{ox}} = 1.52 \pm 0.02$ derived for Ton S180 is consistent with $\alpha_{\text{ox}} = 1.46_{-0.07}^{+0.05}$ found for a sample of optically selected radio-quiet AGNs (Zamorani et al. 1981). Ton S180 appears X-ray weak compared to the mean index of 1.14 $\pm$ 0.18 determined for the ROSAT International X-Ray/Optical Survey (RIXOS; Puchnarewicz et al. 1996); however, Ton S180 does lie within the broad range found for RIXOS sources, which include both BLS1 and NLS1 galaxies. The value $\alpha_{\text{ox}}$-hard was defined in Grupe et al. (1998) as the index linking 5500 A and 1 keV, and Ton S180 lies within the broad ranges found for soft X-ray– and hard X-ray–selected AGNs from that study based on ROSAT observations.

There are two questions of interest here: First, do NLS1 galaxies as a class have systematically different interband indices than BLS1 galaxies? Second, is Ton S180 unusual compared to other NLS1 galaxies? Nagao, Murayama, & Taniguchi (2001) have broached the first question by comparing the quantity $\alpha_{\text{ox}}$ for NLS1 galaxies and BLS1 galaxies. Those authors find average values and 1 $\sigma$ deviations $\alpha_{\text{ox}}$-NLS1 $= 1.31 \pm 0.16$ and $\alpha_{\text{ox}}$-BLS1 $= 1.36 \pm 0.24$, thus concluding there to be no significant differences between this quantity for the two extremes of the Seyfert 1 population, contrary to some previous results (see, e.g., Puchnarewicz et al. 1996).

In summary, comparing the interband indices with other studies yields no evidence that Ton S180 has an unusual ratio of optical/UV to X-ray flux. While opinions in the literature differ on whether there is a systematic difference in $\alpha_{\text{ox}}$ for the extremes of the Seyfert 1 population, it seems clear that interband indices have large ranges and that their use is best suited to comparison of large samples of sources. In this study we proceed with more detailed examination of the shape of the SED and comparison of our data with other detailed SEDs.

10.2. The Form of the SED

An SED for Ton S180 was first presented by Comastri et al. (1998), who found the soft X-ray component to contain the bulk of the energy in this Seyfert galaxy. This campaign of observations provides a more complete SED for Ton S180 than previously available with a large amount of simultaneous data.

Examination of the detailed energy distribution of Ton S180 reveals significant differences compared to some other well-studied AGNs. Figure 7 shows the extinction-corrected SED of Ton S180 and some parameterizations of its form. Overlaid on the parameterizations of the SED of Ton S180 are the SEDs of other AGNs; NGC 5548 is shown as a magenta dash-dotted line (Kraemer et al. 1998), while the mean radio-loud and radio-quiet quasars (from Elvis et al. 1994) are shown as dotted black and dashed blue lines, respectively. The most immediate result is that the SEDs of the Seyfert galaxies appear to peak somewhere in the extreme-UV/soft X-ray band, while the quasars peak in the UV regime. Furthermore, the SED of Ton S180 peaks at a higher energy than that of NGC 5548.

Some caution is required in the comparison of SEDs constructed with different data sets and various assumptions. Some apparent difference in SEDs could be an artifact of the assumption of some continuum form for the quasars versus a simple joining of the soft X-ray to UV data for the Seyfert galaxies. However, such assumptions are only necessary in the problematic regime between $\sim$900 A and $\sim$1 keV. We find the evidence for true underlying differences between Ton S180 and the comparison sources to be strengthened by the absence of a contribution from the BBB in the UV band of Ton S180.

A standard optically thick, geometrically thin accretion disk (Shakura & Sunyaev 1973) predicts the temperature of the peak of the disk spectrum $T(R)$ to be a function of the mass of the central black hole and the accretion rate: $T(R) \sim 6.3 \times 10^5 (M/M_{\text{Edd}})^{1/4} M_S^{1/4} (R/R_S)^{-3/4}$ K (Peterson et al. 2000), where $R$ is the radius, $R_S$ is the Schwarzschild radius, $M_S$ is the mass in units of $10^8 M_{\odot}$, and $M$ is the accretion rate in units of the Eddington accretion rate. All other things being equal, a difference of 2 orders of magnitude in mass should yield a disk spectrum whose peak energy is a factor of 3 lower for the higher mass system than the lower mass system; similarly, a factor of 100 increase in accretion rate (relative to the Eddington rate) shifts the peak to a factor of 3 higher energy. Thus, the radio-quiet quasar SED (Fig. 8) represents sources radiating substantially below the Eddington accretion rate and having a high central mass; these yield a relatively cool disk spectrum. At the

| Index | Definition | Observed | Intrinsic | BLS1 Galaxy |
|-------|-----------|----------|-----------|-------------|
| $\alpha_{3000-10000 \text{ A}}$ (ox) | $-2.096\log (F_{10000 \text{ A}} / F_{3000 \text{ A}})$ | 0.53 $\pm$ 0.14 | 0.66 $\pm$ 0.14 | 0.85 $\pm$ 0.06$^a$ |
| $\alpha_{5300 \text{ A}}$ 0.25 keV | $-0.489\log (F_{0.25 \text{ keV}} / F_{5300 \text{ A}})$ | 1.24 $\pm$ 0.03 | 1.12 $\pm$ 0.03 | 0.73$^b$ |
| $\alpha_{5300 \text{ A}}$ 1 keV (ox-hard) | $-0.378\log (F_{1 \text{ keV}} / F_{5300 \text{ A}})$ | 1.37 $\pm$ 0.02 | 1.38 $\pm$ 0.02 | 1.13$^c$ |
| $\alpha_{1 \mu m}$ 2 keV (ox) | $-0.312\log (F_{2 \text{ keV}} / F_{1 \mu m})$ | 1.35 $\pm$ 0.02 | 1.35 $\pm$ 0.02 | 1.14-2.16$^d$ |
| $\alpha_{2000 \text{ A}}$ 2 keV (ox) | $-0.384\log (F_{2 \text{ keV}} / F_{2000 \text{ A}})$ | 1.50 $\pm$ 0.02 | 1.52 $\pm$ 0.02 | 1.46-0.05$^e$, 1.21 $\pm$ 0.02$^f$ |
| $\alpha_{\text{...}}$ | $1.431\log (F_{2 \text{ keV}} / F_{100 \text{ keV}})$ | 1.44 $\pm$ 0.07 | 1.44 $\pm$ 0.07 | 0.91$^g$ |

$^a$ Index in the $\sim$2200-1200 A band (Cheng et al. 1991).
$^b$ Turner et al. 1999a.
$^c$ Grupe et al. 1998.
$^d$ Lawrence et al. 1997.
$^e$ Zamorani et al. 1981.
$^f$ Puchnarewicz et al. 1996.
$^g$ Nandra et al. 1997.
NGC 5548 is shown as a magenta dash-dotted line and NGC 5548 (a Seyfert 1.5 galaxy) is shown as a magenta dash-dotted line (Elvis et al. 1994). The SED of NGC 5548 (a Seyfert 1.5 galaxy) is shown as a magenta dash-dotted line (Kraemer et al. 1998).

Other extreme, NLS1 galaxies are thought to be accreting close to the Eddington limit and have a low mass; the disk spectrum appears hot. The BLS1 galaxy NGC 5548 represents an intermediate system in terms of both the accretion rate and central mass, and this appears to have an intermediate SED. Telfer et al. (2002) find that for a sample of quasars, the entire continuum from 10 eV to 2 keV can be represented by a single power law; this is clearly not the case in Ton S180, where the X-ray spectrum steepens below 2 keV, and neither the soft or hard X-ray components extrapolate to meet the UV data in a satisfactory way.\textsuperscript{16}

NGC 5548 has a central black hole mass estimated at $\sim10^8 M_\odot$ (Kaspi et al. 2000). If the peak of the SED for NGC 5548 is close to the Lyman limit ($T \sim 1.6 \times 10^5$ K), then an accretion rate of 11% of Eddington would be estimated, assuming a standard thin disk picture.

Few strong constraints exist on the central mass in Ton S180. From variability observed in the X-ray regime, Romano et al. (2002) found $M_{\text{BH}} \geq 8 \times 10^6 M_\odot$ for Ton S180; however, those authors assumed a bolometric luminosity that is lower than that revealed by this SED, leading to a revised limit $M_{\text{BH}} \geq 8 \times 10^7 M_\odot$. Mass estimates such as these can be misleading if the X-ray variability is due, for example, to flares on the surface of the accretion disk since the timescale of variation may not be directly related to the scale size of the disk system. Thus, we examine an alternative estimate of mass based on the luminosity at 5100 Å ($\nu L_\nu \sim 3 \times 10^{46}$ ergs s\textsuperscript{-1}). Using the relation derived from other NLS1 galaxies (Fig. 7 of Peterson et al. 2000), we estimate a central mass $M \sim 2 \times 10^7 M_\odot$ (with a factor $\sim2$ uncertainty) and the broad-line region (BLR) to exist at a radius $\sim100$ light days (Fig. 6 of Peterson et al. 2000). This is in keeping with the systematically large BLR radii suggested by Giannuzzo & Stirpe (1996) for NLS1 galaxies compared to BLS1 galaxies. Since the level of starlight contamination of the 5100 Å flux is difficult to assess, this mass should be considered as an upper limit on the true central mass. The difference in SED peak energies is thus expected since Ton S180 has a lower mass than NGC 5548 and NLS1 galaxies are thought to have systematically higher accretion rates than BLS1 galaxies.

Unfortunately, the peak of the spectrum in Ton S180 remains loosely constrained. The EUVE data favor the simple parameterization of the XUV spectrum (Fig. 7), indicating that the peak lies close to or below 100 eV. Assuming a standard disk spectrum, the disk temperature must be greater than $\sim15$ eV, the peak of any cooler component of significant flux would show up in the FUSE data. The SED data indicate a peak close to 100 eV. Assuming a peak in disk emission for Ton S180 at this energy, which corresponds to $4 \times 10^5$ K, then for $M \sim 2 \times 10^7 M_\odot$, $M \sim 0.88 \times M_{\text{Edd}}$. For black holes operating near the Eddington limit, the accretion disk surface is predicted to be highly ionized. There is certainly strong evidence for an ionized disk in Ton S180 since the Fe Kα line appears to be produced in highly ionized material in BeppoSAX (Comastri et al. 1998) and ASCA data (Turner et al. 1998).

The results from Ton S180 appear to fit into the standard disk picture. However, we also note that Cheng, Gaskell, & Koratkar (1991) conclude that the standard disk model is not applicable to the UV spectra of quasars. Their case rests on the lack of any relation between $\alpha_{\text{w}}$ and luminosity. However, since the peak of the disk spectrum is generally at rest wavelengths of 1000 Å or shorter (Zheng et al. 1997; Telfer et al. 2002), $\alpha_{\text{w}}$ is indicative of only the rising edge of the disk spectrum. In the standard disk model, the spectral slope in this region is relatively insensitive to luminosity, so one does not necessarily expect a strong correlation between $\alpha_{\text{w}}$ and luminosity of the BBB.

As a final note, the lowest frequency IR point lies above the adjacent IR points. This has been observed in many AGNs and is due to thermal emission from dust grains heated close to their evaporation temperature (1500 K for graphite) close to the central engine (Rieke 1978). Recently, strong near-IR emission from the Seyfert I galaxy NGC 7469 has been attributed to very hot dust grains ($T > 900$ K) associated with the putative torus (Marco & Alloin 1998); this is also observed in the SED of NGC 3783 (Alloin et al. 1995).

10.3. The Energy Budget of Ton S180

The multi–power-law parameterization of the SED for Ton S180 makes it possible to estimate the luminosity in various energy regimes, helping to constrain reprocessing mechanisms and isolate the primary energy source. Table 8 shows the observed and intrinsic luminosities in several energy bands, defined in the rest frame of the source. The implied bolometric luminosity is $L_{\text{bol}} \sim 10^{46}$ ergs s\textsuperscript{-1}. More luminosity emerges in the 10–100 eV regime than the 100 eV regime.

\textsuperscript{16} While the Chandra data show a turnover at 0.3 keV, this turnover is sharper than that expected from observation of the peak of the disk spectrum, and there is some discrepancy between these data and data from other instruments. For these reasons, henceforth we will assume this turnover does not indicate the peak temperature of the disk.
eV–10 keV regime. Assuming that we are seeing all emitted radiation in each wavelength regime, this indicates that the EUVE soft X-ray band contains the primary spectral component, in keeping with disk corona models (e.g., Haardt & Maraschi 1991).

The energy budget and the SED show that Ton S180 is relatively X-ray weak above ~2 keV (interband indices are insensitive to this since historically X-ray fluxes for comparison with optical fluxes have been taken at soft X-ray energies). One possible reason for this is Compton cooling of the hard spectrum by the large flux of soft X-ray and UV photons, as discussed by many authors, including Pounds et al. (1995).

10.4. The State of the Circumnuclear Gas

The weak O vi absorption features detected in the FUSE data, the absence of absorption from lower ionization species in the HST data, and the lack of detectable X-ray absorption in the Chandra spectrum together indicate the presence of a small column of circumnuclear material that appears to be in a high state of ionization compared to that observed in other well-studied sources such as NGC 5548 and NGC 3783. The outflow velocity of ~500 km s\(^{-1}\) is not unusual. Many Seyfert galaxies have shown evidence for outflow in UV and optical data (see, e.g., Crenshaw 1997).

In the X-ray regime Chandra grating observations have revealed supporting evidence for outflowing gas, with velocities on the order of a few hundred kilometers per second (see, e.g., Collinge et al. 2001; Kastra et al. 2000; Kaspi et al. 2000, 2001). A picture of Ton S180 being shrouded by highly ionized gas is consistent with earlier BeppoSAX (Comastri et al. 1998) and ASCA (Turner et al. 1998) observations of Fe Kα emission as well as the new ASCA data, which show that the narrow component of Fe Kα is consistent with emission from Fe xxv–Fe xxvi.

The ratio of the O vi to H i absorbing columns in the UV regime is comparable to that of the high-ionization component detected in Mrk 509 (Kriss et al. 2000), which was tentatively identified with the X-ray warm absorber in that object. However, in Ton S180 the total equivalent column density of hydrogen associated with the UV absorber must be less than 10\(^{17}\) cm\(^{-2}\), too low to produce detectable X-ray absorption. However, the absence of ionized circumnuclear gas does not appear to be a general property of NLS1 galaxies. Some NLS1 galaxies do appear to show signatures of a warm absorber in the X-ray regime (see, e.g., Lee et al. 2001; Collinge et al. 2001) as well as UV absorption systems (Crenshaw et al. 1999).

To examine the relation between the ionizing spectrum in Ton S180 and the circumnuclear gas, we took two estimates of the SED and total ionizing flux. The conservative estimate links the softest X-ray point at ~0.3 keV to the highest end of the UV data with a simple power law. For this SED, the total luminosity from 0.01 to 10 keV is ~2.0 \times 10\(^{45}\) ergs s\(^{-1}\), and the corresponding luminosity in ionizing photons is \(Q \sim 2.9 \times 10^{55}\) photons s\(^{-1}\). Taking instead the (extreme) SED that peaks in the extreme-UV (green line in Fig. 7), the 0.01–10 keV luminosity is ~3.8 \times 10^{45} ergs s\(^{-1}\) and \(Q \sim 4.5 \times 10^{55}\) photons s\(^{-1}\).

Assuming the typical density and ionization parameter in the optical BLR clouds, the radii at which the BLR exists can be estimated. Wandel, Peterson, & Malkan (1999) used these “photoionization radii” and the measured line widths to derive black hole masses, which were in general agreement with those determined via reverberation mapping. In order to explore the role of luminosity on the line widths, we instead use the masses derived from reverberation mapping and the photoionization radii \(r\) to estimate the line widths. Following Wandel et al. (1999), we assume \(Q/\alpha^{2}\) for the line-emitting gas. Based on our estimates of the ionizing luminosity of the central source in Ton S180, we derive representative radial distances of ~8.8 \times 10^{16} cm and ~10^{17} cm for the conservative and extreme cases, respectively (~40 light days, somewhat smaller than the radius estimated from Peterson et al. 2000).

If the BLR clouds are virialized around the central black hole, the FWHM of the emission lines should be roughly equal to \((GM/r)^{1/2}\); for a black hole mass of \(10^{7}\) M\(_{\odot}\), FWHM ~ 1290 (conservative case) and 1160 km s\(^{-1}\) (extreme case), in reasonable agreement with the observed FWHM of H\(\beta\).

We have estimated the total ionizing flux \(Q\) for two BLS1 galaxies: for NGC 4151, \(Q \sim (2.8) \times 10^{53}\) photons s\(^{-1}\) (Kraemer et al. 2001); for NGC 5548, \(Q \sim 1 \times 10^{54}\) photons s\(^{-1}\) (Kraemer et al. 1998). Assuming the black hole masses quoted by Wandel et al. (1999; 1.2 \times 10^{7}\) M\(_{\odot}\) for NGC 4151 and 6.8 \times 10^{7}\) M\(_{\odot}\) for NGC 5548), the corresponding “typical” BLR cloud distances and velocities are \(r \sim 1.2 \times 10^{16}\) cm and FWHM \(\sim 3700\) km s\(^{-1}\) for NGC 4151 and \(r \sim 1.6 \times 10^{16}\) cm and FWHM \(\sim 7460\) km s\(^{-1}\) for NGC 5548; the FWHMs are in rough agreement with the observed values. Clearly, the narrowness of the emission lines in Ton S180 is partially due to its stronger ionizing flux. Furthermore, given these “typical” BLR conditions, it is likely that the clouds within a few light days of the central source are too highly ionized even to produce much C IV emission (for a discussion of range in conditions in which emission lines form, see Baldwin et al. 1995). Hence, the higher value of \(Q\) for Ton S180 requires that the BLR gas is either more highly ionized than in BLS1 galaxies or, if the emission-line ratios are the same, it must be denser (i.e., denser gas is now ionized enough to contribute significantly to the emission-line spectrum). Either way, conditions are not identical to those in typical BLS1 galaxies.

11. SUMMARY

Construction of the SED for the bright NLS1 galaxy Ton S180 shows that most of the energy is emitted in the 10–100 eV regime, indicating that the primary source of emission dominates that band. The UV and X-ray data together con-

| Energy (keV) | \(L_{\text{observed}}\) \((\times 10^{44} \text{ ergs s}^{-1})\) | \(L_{\text{ intrinsic}}\) \((\times 10^{44} \text{ ergs s}^{-1})\) |
|-------------|-------------------------------|-------------------------------|
| 5 \times 10^{-4}–0.01 | 13.94 | 15.69 |
| 0.01–0.1 | 2.86 | 28.80 |
| 0.1–1 | 2.03 | 8.92 |
| 1–10 | 0.65 | 0.66 |
| 5 \times 10^{-4}–10 | 19.49 | 54.07 |
| 0.1–10 | 2.69 | 9.57 |
strain the peak of any BBB component to lie between 15 and 100 eV. This and the overall shape of the SED indicate that emission from the accretion disk peaks at significantly higher energies in this source than in BLS1 galaxies, as expected if NLS1 galaxies have smaller central black holes and higher accretion rates. High-resolution spectra from FUSE reveal UV absorption due to O vi. The absence of absorption features in the HST data and the lack of neutral hydrogen absorption in the FUSE spectrum indicate a high-ionization state for the absorbing gas, while the absence of soft X-ray absorption shows that the column density is quite low. The highly ionized state of the circumnuclear gas is observed.

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