

A 12 DAY ASCA OBSERVATION OF THE NARROW-LINE SEYFERT 1 GALAXY TON S180: TIME-SELECTED SPECTROSCOPY

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ABSTRACT

We present an analysis of the X-ray variability properties of the narrow-line Seyfert 1 galaxy Ton S180, based on a 12 day continuous observation with *ASCA*. Examination of the light curves reveals flux variations of a factor of 3.5 in the 0.7–1.3 keV band and 3.9 in the 2–10 keV band. Time-resolved spectroscopy, using approximately daily sampling, reveals that the broad “soft hump” component at energies less than 2 keV shows flux variations on timescales as short as 1 day that are well correlated with the photon index and the 2–10 keV band flux. A broad Fe K α emission is detected. There is also statistically significant evidence for a narrow Fe K α line at ~ 6.8 keV, indicating an origin in ionized material. We do not detect significant variations of the Fe K α line flux or equivalent width on timescales of ~ 1 day to 1 week. Despite evidence for correlated events in the power law and soft hump on timescales of a day, the flux correlations clearly do not exist on all timescales. In particular, the softness ratio reveals spectral variability on timescales as short as ~ 1000 s, indicating that the power-law continuum and soft hump fluxes are not well correlated on this timescale. The softness ratio also shows a slow decline across the observation, due to a combination of the different time variability of the power-law continuum and soft hump flux on timescales of ~ 1 week. Our timing analysis and time-selected spectroscopy indicate that the X-ray emission originates within 12 Schwarzschild radii. The amplitudes and timescales of the rapid variations that we observed are consistent with those expected within disk-corona models. Furthermore, the observed fast variability of the soft hump rules out an origin of the soft emission in large-scale components, such as circumnuclear starburst. The Γ –soft hump correlation is consistent with the soft hump being produced by upscattering of the accretion disk radiation within a patchy, flaring disk corona.

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

1. INTRODUCTION

The population of Seyfert 1 galaxies has a widely used subclassification into narrow-line Seyfert 1 galaxies (NLS1s) and broad-line Seyfert 1 galaxies (BLS1s). While the scheme appears to make an arbitrary distinction based primarily on the widths of the optical emission lines (NLS1s having $H\beta \lesssim 2000$ km s $^{-1}$; Goodrich 1989), this turns out to be an extremely useful terminology since the X-ray properties of the two subclasses are systematically different. Rapid and large-amplitude variability (Boller, Brandt, & Fink 1996, hereafter BBF96; Turner et al. 1999) is a characteristic of NLS1s, with the excess variance (Nandra et al. 1997a) typically an order of magnitude larger than that observed for samples of BLS1s with the same luminosity distribution (Turner et al. 1999; Leighly 1999a). Spectral properties also vary across the Seyfert population, with NLS1s showing systematically steeper photon indices than those of BLS1s across both soft and hard X-ray bands (BBF96; Brandt, Mathur, & Elvis 1997; Turner, George, & Nandra 1998; Leighly 1999b; Vaughan et al. 1999b). The anticorrelations between $H\beta$ FWHM and both X-ray spectral slope

(BBF96; Laor et al. 1997) and excess variance (Turner et al. 1999) reveal a continuous range of parameter values between the NLS1 and BLS1 extremes of the population; the observed differences are now thought to be driven by a range in a fundamental physical parameter, such as the accretion rate.

A popular idea, originally proposed by Pounds, Done, & Osborne (1995), draws an analogy between Seyfert 1 galaxies and Galactic black hole candidates. The latter show steepening in the high state. In this scenario, NLS1s are sources in the high state, emitting at higher fractions of their Eddington luminosity, hence having higher fractional accretion rates ($\dot{m} = \dot{M}/\dot{M}_{\text{Edd}}$). Given that NLS1s have comparable luminosity to that of the BLS1s, it has often been suggested that they also have relatively small central black holes, i.e., $M_{\text{BH}} \approx 10^6 M_{\odot}$, as opposed to $M_{\text{BH}} \approx 10^8 M_{\odot}$, which is typical for BLS1s (e.g., Peterson et al. 2000; Kaspi et al. 2000). Smaller black hole masses naturally explain both the narrowness of the optical emission lines, which are generated in clouds that have smaller Keplerian velocities—hence smaller widths, and the extreme X-ray variability, since the primary emission would originate in a smaller region around the central engine (e.g., Laor et al. 1997).

Higher accretion rates lead to some observational predictions, such as a hotter accretion disk leading (via inverse Compton scattering) to enhanced soft X-ray emission and an ionized surface for the accretion disk (Matt, Fabian, & Ross 1993). Support for the ionized disk is found in the form of K α emission from ionized states of Fe in six NLS1s (Comastri et al. 1998; Turner et al. 1998; Vaughan et al.

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1999a; Comastri et al. 2001; Turner, George, & Netzer 1999; Ballantyne, Iwasawa, & Fabian 2001). However, the observation of similar lines in some BLS1s may point to the luminosity of the central source playing as important a role as accretion rate (e.g., Guainazzi et al. 1998).

Alternative explanations of the extreme properties in NLS1s are that (1) the broad-line regions (BLRs) of NLS1s have larger radii (i.e., the BLR gas is more distant from the nucleus) than those in the BLS1s (Guilbert, Fabian, & McCray 1983; Mason, Puchnarewicz, & Jones 1996; Wandel & Boller 1998), then the narrow width of the lines is a reflection of the lower orbital velocity; and (2) the NLS1s may be low-inclination (i.e., observed nearly face-on) systems (Osterbrock & Pogge 1985). Assuming the motions around the central source to be virialized, the narrowness of the lines is due to the fact that the gas is moving preferentially on a plane that is almost perpendicular to the line of sight; hence, the line widths are reduced by a factor of $\sin i$, where $i = 0$ is face-on. One way to distinguish between these models is to measure the size and virial mass of the BLR via reverberation techniques (Peterson 1993); Kaspi et al. (2000) and Peterson et al. (2000) find that the BLRs of NLS1s and BLS1s have comparable size, while NLS1s have virial masses 1 order of magnitude smaller than BLS1s, but cannot exclude the second model solely on the basis of reverberation results. However, Boroson & Green (1992) and Kuraszkiwicz et al. (2000) disfavor the low-inclination model, while Nandra et al. (1997b) show that the inner regions of BLS1s also appear to be observed close to face-on.

Tonantzintla (Ton) S180 (PHL 912) is a bright NLS1 with a low Galactic column density along the line of sight ($N_{\text{H}} = 1.52 \times 10^{20} \text{ cm}^{-2}$; Stark et al. 1992). This source has FWHM $\text{H}\alpha$ and $\text{H}\beta \sim 900 \text{ km s}^{-1}$ and a redshift $z = 0.06198$ (Wisotzki et al. 1995). Ton S180 has a relatively high luminosity, with absolute magnitude $M_B = -23.1$ mag.

Ton S180 was observed by *ASCA* on 1999 December 3–15, during a multiwavelength monitoring campaign that included observations from the *Hubble Space Telescope* (*HST*), the *Rossi X-Ray Timing Explorer* (*RXTE*), *Chandra*, the *Extreme Ultraviolet Explorer* (*EUVE*), and the *Far Ultraviolet Spectroscopic Explorer* (*FUSE*), in addition to optical–IR observations obtained from ground-based observatories. The results of the long-baseline timing project using *RXTE*, *EUVE*, and *ASCA* are reported in Edelson et al. (2002). The *HST* and *FUSE* data were obtained contemporaneously with *Chandra* and *ASCA* and were undertaken to determine the spectral energy distribution of the source, as reported in Turner et al. (2001b). The *Chandra* spectral result is reported in Turner et al. (2001a). In this paper we present the results from the ~ 400 ks *ASCA* observation of Ton S180. This long observation has allowed us to study the variability of the spectral components on different timescales, from 12 days to ~ 1 day. This is particularly interesting since the results of a 35 day–long observational campaign on the NLS1 Arakelian (Ark) 564 indicate that superimposed on a fast-varying continuum component that dominates the spectrum is a slower varying soft excess emission (Turner et al. 2001c; Edelson et al. 2002). In § 2 we describe our observations and data reduction. In § 3 we discuss the time variability of the source. In § 4 we analyze the mean spectrum, and in § 5 we discuss time-resolved spectroscopy.

In § 6 we present a summary of our observational results and in § 7 a comparison with the properties of Ark 564. Finally, in § 8 we discuss the results.

2. OBSERVATIONS AND DATA REDUCTION

The focal-plane instruments on board *ASCA* comprised two CCDs (the Solid-State Imaging Spectrometers SIS0 and SIS1, 0.4–10 keV; Burke et al. 1991) and two gas scintillation proportional counters (Gas Imaging Spectrometers GIS2 and GIS3, 0.7–10 keV; Ohashi et al. 1996 and references therein); these were operated simultaneously. *ASCA* observed Ton S180 for a total of ~ 1 Ms, starting on JD 2,451,516.051 (for the screened data, see below). The data were reduced using standard techniques as used for the TARTARUS database⁴ (Turner et al. 1999). Data screening yielded an effective exposure time of 338 ks for SIS0, 368 ks for the SIS1, and 405 ks for both the GISs. The mean SIS0 count rate was $0.586 \pm 0.001 \text{ counts s}^{-1}$ (0.5–10 keV band).

Increased dark current levels and decreased charge transfer efficiency have become evident in the SIS detectors since ~ 1993 , causing a divergence of SIS and GIS spectra. The degradation is not completely understood and at the time of writing not corrected for by any of the software (specifically, CORRECTRDD does not correct for the effect). The instruments can diverge by as much as 40% for energies less than 0.6 keV for data taken in 2000 January.⁵ The Ton S180 data were calibrated using the latest calibration file released on 2001 March 29 (sisph2pi_290301.fits). The divergence of the SIS detectors at low energies can be compensated for in the spectral analysis. Yaqoob et al. (2000)⁶ provide a quantification of the apparent loss in SIS efficiency as a function of mission-elapsed time. The efficiency loss can be parameterized as a time-dependent absorption term (“excess N_{H} ”). The correction for SIS0 follows a linear relationship, $N_{\text{H}}(\text{SIS0}) = (T - 3.0174828 \times 10^7) \times 3.635857508 \times 10^{12} \text{ cm}^{-2}$, where T is the average of start and stop times of the observation, measured in seconds since launch. The SIS1 excess absorption term does not follow the simple linear form found for SIS0, but it is usually found that a slightly larger absorption column can be applied to the SIS1 data to bring it into line with SIS0. For our observations, where $T = 2.19 \times 10^8 \text{ s}$, $N_{\text{H}}(\text{SIS0}) = 6.9 \times 10^{20} \text{ cm}^{-2}$, and we adopted $N_{\text{H}}(\text{SIS1}) = 1.0 \times 10^{21} \text{ cm}^{-2}$. Application of the excess N_{H} correction is important for this analysis, since it allows us to use the valuable data at energies less than 1 keV to examine the spectral variability of an interesting spectral component.

3. THE TIME VARIABILITY

Light curves were extracted using bin sizes of 256 s and 5760 s in the full band (0.7–10 keV) for the SIS, the soft band (0.7–1.3 keV) for the SIS data, and the hard band (2–10 keV) for both GIS and SIS data. We adopted 0.7 keV as a lower limit for the SIS data, as appropriate for the setting of the SIS lower level discriminator for these observations. Light curves were constructed combining data from the SIS and GIS detector pairs. The exposure requirements for the combined light curves ensured that the bins were fully exposed in each instrument for the 256 s curves and at least 10%

⁴ Available at <http://tartarus.gsfc.nasa.gov>.

⁵ See <http://heasarc.gsfc.nasa.gov/docs/asca/watchout.html>.

⁶ See <http://lheawww.gsfc.nasa.gov/~yaqoob/ccd/nhparam.html>.

exposed for the 5760 s curves. The observed count rates correspond to a mean 2–10 keV flux of $F_{2-10} = 6.5 \times 10^{-12}$ ergs s^{-1} cm^{-2} and 2–10 keV luminosity $L_{2-10} = 4.9 \times 10^{43}$ ergs s^{-1} ($H_0 = 75$ km s^{-1} Mpc $^{-1}$, $q_0 = 0.5$). This mean flux level is $\sim 20\%$ brighter than that observed during a previous *ASCA* observation on 1996 July 10 (Turner et al. 1998). Figure 1 shows the combined 0.7–1.3 keV SIS soft-band and GIS hard-band light curves in 5760 s bins. The background levels in the source cells are about 4% and 10% of the SIS and GIS source count rates, respectively, and not plotted or subtracted. Figure 1 also shows the softness ratio, defined as the ratio between the count rates in the 0.7–1.3 and 2–10 keV bands. There is significant hardening of the spectrum during the observation, and the softness ratio changes by $\sim 20\%$.

The light curves integrated to 5760 s show trough-to-peak flux variations by a factor of ~ 2.7 in the 0.7–1.3 keV band (SIS) and ~ 2.4 in the 2–10 keV band (GIS). The light curves sampled on 256 s reveal even larger amplitudes because of fast flickering, with a maximum amplitude of variability of a factor ~ 3.5 for the SIS data in the 0.7–1.3 keV band and ~ 3.9 for the GIS data in the 2–10 keV band. Figure 2 shows the 0.7–1.3 and 2–10 keV light curves in 256 s bins for three rapid “events” centered around 603, 608, and 614 ks from the start of the observation (JD 2,451,523.03, 2,451,523.08, and 2,451,523.16). In the first event, the soft- and hard-band data show a variations (trough to peak) of factors of $R_{\max}(\text{SIS}) = 1.32 \pm 0.13$ and $R_{\max}(\text{GIS}) = 1.80 \pm 0.38$, respectively, in $\Delta t = 1972$ s (the errors on R_{\max} are obtained by propagating the errors in the light-curve points). In the second event, $R_{\max}(\text{SIS}) = 1.34 \pm 0.13$ and $R_{\max}(\text{GIS}) = 1.75 \pm 0.37$, respectively, in $\Delta t = 1972$ s. In the

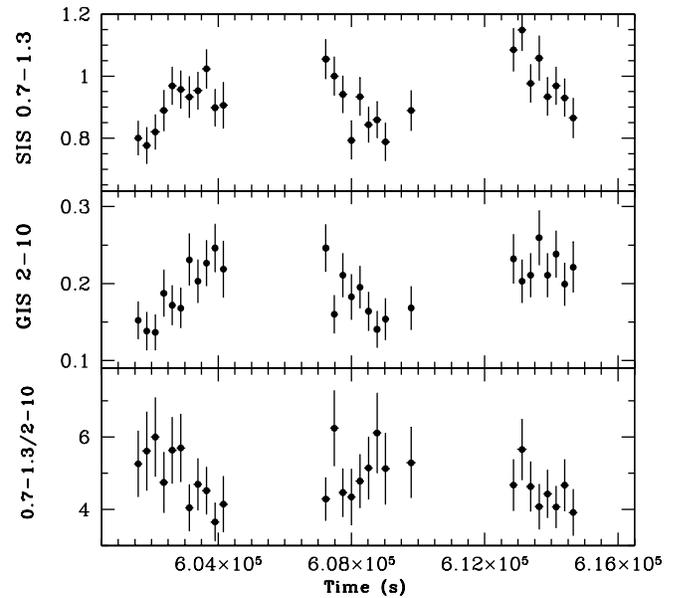


FIG. 2.—Same as Fig. 1, for two “events” at JD \approx 2,451,523. The time is seconds from the start of observation; the bin size is 256 s. In the first and second events, the SIS and GIS data show variations of up to a factor of 2 in $\Delta t = 1790$ s; in the third event, the variation is of a factor of ~ 1.3 in $\Delta t = 1536$ s (§ 3).

third event, the variation is a factor of $R_{\max}(\text{SIS}) = 1.33 \pm 0.13$ for the soft while the hard is consistent with a constant. These events correspond to a variation in luminosity of $\Delta L = (2.4 \pm 0.9) \times 10^{43}$ ergs s^{-1} [as calculated from SIS data, from the first event; GIS data yield $\Delta L = (2.6 \pm 0.9) \times 10^{43}$ ergs s^{-1}]. In the first and second events, the hard X-ray flux variation is sharper than that in the soft band, and there is a change in the softness ratio, in the sense that when the flux increases the spectrum hardens, with a timescale of ~ 1000 s (Fig. 2, bottom panel). However, in the third event a flux change is not accompanied by a strong spectral change. Further examination of the light curves reveals other examples of diverse variability behavior with no obvious general trend. This is a behavior previously reported in *ROSAT* observations (Fink et al. 1997).

The soft and hard X-ray light curves in Figure 1 exhibit similar characteristics, suggesting a short time delay between the variations in each curve. To quantify any correlations, we undertook a cross-correlation analysis using the interpolation cross-correlation function (ICCF) method of Gaskell & Sparke (1986) and Gaskell & Peterson (1987) as implemented by White & Peterson (1994). We calculated the CCFs of the total hard flux in the 2–10 keV band with respect to the total soft flux in the 0.7–1.3 keV band, which has the highest signal-to-noise ratio (S/N). The CCFs are sampled at a resolution of 0.05 days, and the centroids are computed using all points near the peak of the CCFs with values greater than 80% of the maximum value of the correlation coefficient, r_{\max} . The 1σ uncertainties quoted for the ICCF centroid, τ_{cent} , are based on the model-independent Monte Carlo method described by Peterson et al. (1998). We obtain $r_{\max} = 0.748$ and $\tau_{\text{cent}} = 0.025^{+0.024}_{-0.002}$ days. Given the 180 points in our light curves, the probability of exceeding $r_{\max} \approx 0.3$ from uncorrelated samples is $\ll 0.1\%$, and the lag is less than 0.07 days at 95% confidence. Since the power-law component provides $\sim 72\%$ of the flux in the

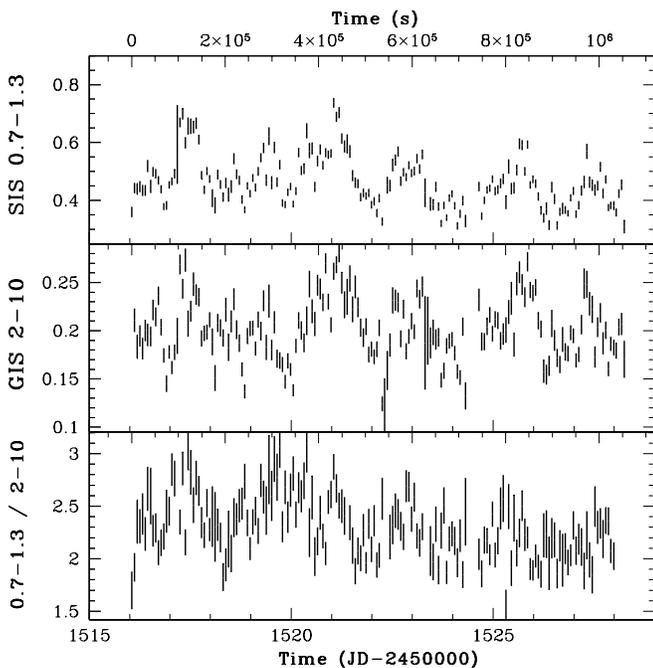


FIG. 1.—Light curves for the *ASCA* data in counts s^{-1} and in 5760 s bins. The top panel is the SIS soft band (0.7–1.3 keV) light curve, the middle panel is the GIS hard band (2–10 keV), and the bottom panel is the ratio of 0.7–1.3/2–10 keV. The background level in the source cell is about 4% and 10% of the SIS and GIS source count rates, respectively, and not plotted. The times are reported both in seconds from the start of exposure (top axis) and in JD – 2,450,000 (bottom axis).

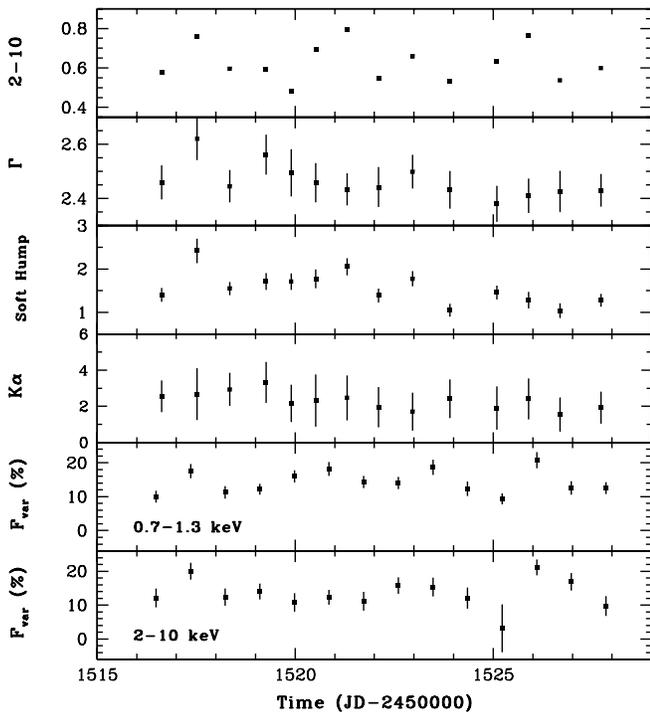


FIG. 3.—Spectral and timing parameters obtained from fits to the individual time-resolved spectra. From the top, the light curves are the (model) continuum flux in the hard band, the photon index Γ , the soft hump flux, the $K\alpha$ flux (Laor), and the fractional variability F_{var} . The continuum fluxes are in units of 10^{-11} ergs s^{-1} cm^{-2} , the soft hump flux in units of 10^{-2} photons s^{-1} cm^{-2} , and the $K\alpha$ flux in units of 10^{-5} photons s^{-1} cm^{-2} .

mean spectrum 0.7–1.3 keV band, as we will show in § 4.1, and the power-law component dominates the 2–10 keV band, this correlation is probably dominated by the rapid variability in the power-law flux.

3.1. Fractional Variability Amplitude

The fractional variability amplitude F_{var} and its error $\sigma_{F_{\text{var}}}$ are defined in Edelson et al. (2002) as

$$F_{\text{var}} = \sqrt{\frac{S^2 - \langle \sigma_{\text{err}}^2 \rangle}{\langle X \rangle^2}}, \quad \sigma_{F_{\text{var}}} = \frac{1}{F_{\text{var}}} \sqrt{\frac{1}{2N} \frac{S^2}{\langle X \rangle^2}}, \quad (1)$$

where S^2 is the total variance of the light curve, $\langle \sigma_{\text{err}}^2 \rangle$ is the mean squared error, and $\langle X \rangle$ is the mean count rate.

First, we calculated F_{var} across the baseline of the entire observation. This quantity measures deviations compared to the mean, integrated over the entire 12 days. We measured this quantity in the soft (0.7–1.3 keV) and hard (2–10 keV) bands, using our light curves with 256 s bins. These bands were chosen to sample energy ranges containing different spectral components (see § 4) while still maintaining good S/N. The term F_{var} thus calculated is $19.12\% \pm 0.58\%$ in the 0.7–1.3 keV band and $17.26\% \pm 0.65\%$ in the hard band, using SIS data for both tests.

To examine the evolution of timing properties of Ton S180 further, we split the data into 14 evenly sampled sections across the 12 day *ASCA* observation. Even sampling is important because F_{var} depends strongly on the duration of the data train. The baseline for each time-selected section of data was 75 ks, with average on-source exposure time of 25 ks. We then calculated F_{var} over each of these 1 day intervals (again with 256 s bins in each “daily” light curve).

This test showed that F_{var} is significantly variable, showing correlated changes in the soft and hard bands on a day-to-day basis (Fig. 3).

As we will demonstrate in § 4.1, in the mean spectrum the power-law continuum provides about 72% of the flux in the 0.7–1.3 keV band, and the power-law variations contribute significantly to F_{var} in both the soft and hard bands, explaining the gross similarity between the quantity in those two bands. The slightly greater F_{var} for the soft band is probably due to a combination of changes in the relative flux levels of two spectral components (power law and hump) and slope changes in the power law, as we will show in § 5.3.

4. THE MEAN SPECTRUM

Source counts were binned with a minimum of 20 counts per energy bin for the spectral analysis. The data from the four instruments were fitted simultaneously, with the relative normalizations free to allow for small differences in calibration of the absolute flux and in the fraction of encircled counts encompassed by the SIS versus GIS extraction cells. Spectral fits were performed using XSPEC version 11.0.1 and response files generated with HEASOFT version 5.0.4. Ton S180 is detected at better than 3σ level in the SIS data for energies $\lesssim 7.5$ keV and in the GIS data for energies $\lesssim 9.5$ keV (observed frame, in the unbinned spectrum).

The photon index Γ (defined by photon flux $P_E \propto E^{-\Gamma}$) was determined by fitting a power-law model attenuated by Galactic absorption with an additional correction applied to SIS0 and SIS1 to compensate for the low-energy degradation as described in § 2. For this fit we used data in the bandpass 1.8–4.71 keV (observer’s frame). The power-law fit yielded $\Gamma = 2.44 \pm 0.02$ and $\chi^2 = 720$ for 683 degrees of freedom (dof). Inclusion of the data in the 7.06–9.42 keV bandpass produces consistent results. This and subsequent errors represent, unless otherwise specified, the 90% confidence level.

The data/model ratio is shown in Figure 4 (*top panel*). A strong soft excess is evident, appearing as a hump of emission rising above the power-law continuum at energies less than 2 keV. This feature was also observed in the *ROSAT* Position Sensitive Proportional Counter (PSPC) observations (Fink et al. 1997; Fig. 4, *top panel, inset*), *BeppoSAX* observations (Comastri et al. 1998), and the earlier *ASCA* observation (sequence number 74081000; Turner et al. 1998). Hereafter, we refer to this component as the “soft hump.” Also evident in the main panel is an excess of emission close to 7 keV, which is due to an unmodeled Fe $K\alpha$ emission line.

Minor calibration problems are visible in such high S/N data at ≈ 1.7 –3.0 keV. They are not so serious as to warrant exclusion from the fit. We note, however, that they contribute significantly to the χ^2 in the soft component fits (§ 4.1) and, to a lesser extent, to the $K\alpha$ fits (§ 4.2).

4.1. The Soft Component

We confirm the presence of the soft X-ray emission component previously observed by Fink et al. (1997), Comastri et al. (1998), and Turner et al. (1998). At the time of writing, the status of the SIS calibration limits the accuracy to which the absolute form of the soft spectral hump can be determined. Thus, we adopted a simple parameterization of the soft hump, which allowed us to perform a sensitive examination of the flux variability of the component. The simulta-

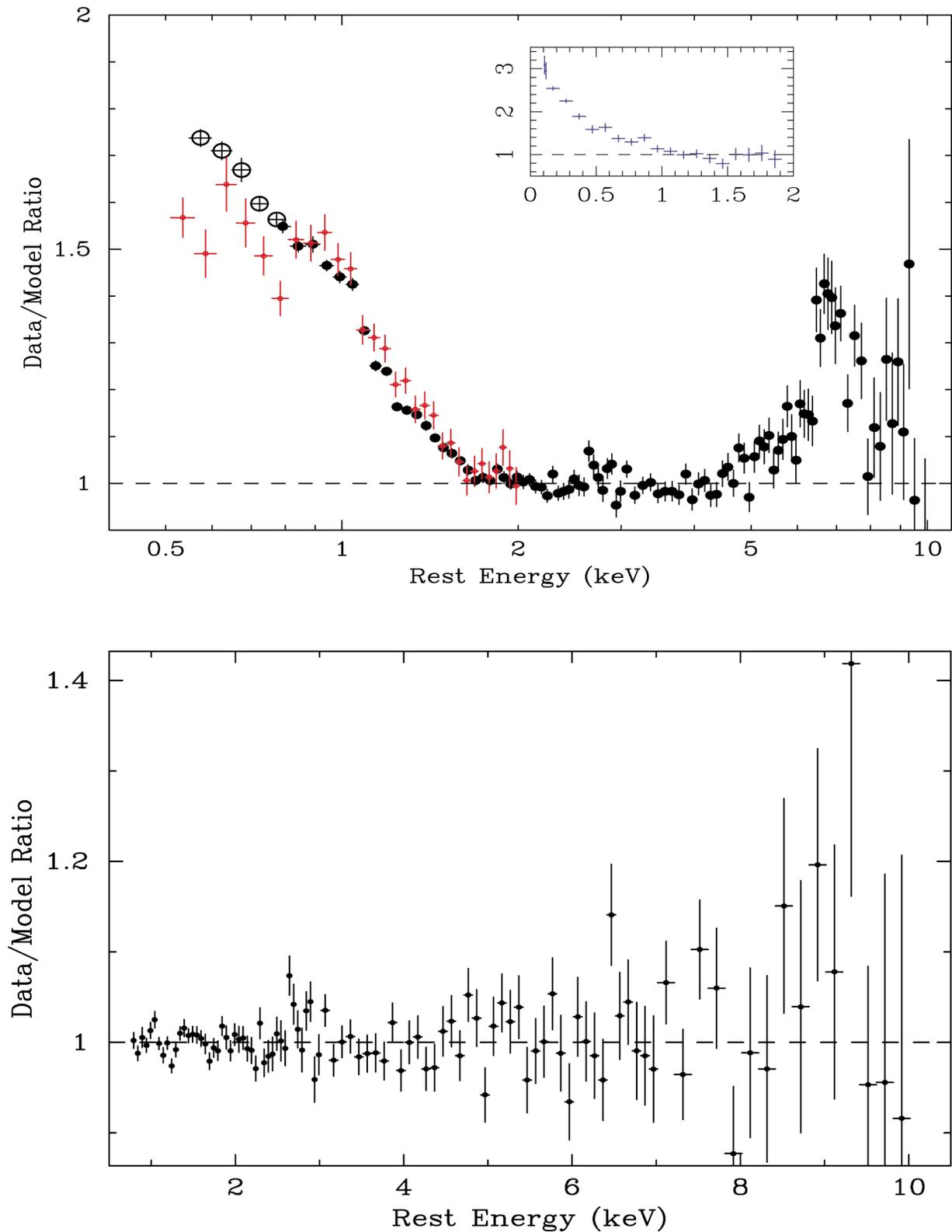


FIG. 4.—*Top panel*: Data/model ratio where the model is a simple power-law fit to the 1.8–4.71 keV data (observer’s frame). The rest of the combined SIS and GIS data are then overlaid, revealing a strong soft hump and Fe emission line, as filled circles. The 0.5–0.7 keV SIS data, though not used, are also plotted, as empty circles. The crosses are the *ASCA* data from 1996 below 2 keV. The inset panel shows the *ROSAT* PSPC data compared to the continuum power law, illustrating the shape of the soft hump at lower energies (§ 4). All data sets confirm the presence of the soft hump and detail its shape. *Bottom panel*: Data/model ratio where the model is a power law plus soft hump (Gaussian; § 4.1) plus a two-Gaussian model for the Fe $K\alpha$ line (§ 4.2).

neous *Chandra* Low-Energy Transmission Grating data for Ton S180 (Turner et al. 2001a) and the results for NGC 4051 (Collinge et al. 2001) show that the soft hump is a smooth continuum component, as opposed to a blend of unresolved spectral features. The variability study afforded by the *ASCA* data is therefore the optimum available tool for exploring the nature of the soft hump. This was also shown to be the case for Ark 564 (Turner et al. 2001c).

We used SIS data in the range 0.7–4.71 keV simultaneously with GIS data in the range 1.0–4.71 keV (observer’s frame). The lower energy limit of the SIS data was based on the level of agreement achieved between the two CCDs using our methods of correction (§ 2). The upper energy limit of both SIS and GIS effectively excluded the Fe $K\alpha$ regime for these fits, in order to avoid an overly complex model (which can result in false or local minima being found). A steep power-law component is an inadequate representation of this excess, as its form shows some curvature. The Gaussian model that best fits the soft hump has an energy of the peak $E = 0.17^{+0.17}_{-0.17p}$ keV (the energy pegged at the lower limit), FWHM = $1.01^{+0.05}_{-0.12}$ keV, and flux $1.50^{+0.37}_{-0.61} \times 10^{-2}$ photons $s^{-1} cm^{-2}$, corresponding to a mean EW = 94^{+23}_{-38} eV. For this fit, $\chi^2 = 1069$ for 896 dof, but there is a contribution to the χ^2 from the ≈ 2.5 –3.0 keV region because of calibration problems (see § 4). Significantly inferior (to better than 99.9% confidence; $\chi^2 = 1096$ for 897 dof) is a parameterization of the soft hump as a blackbody model; the best fit yielded a rest-frame temperature $kT = 153^{+2}_{-3}$ eV, flux $1.07^{+0.03}_{-0.04} \times 10^{-4}$ photons $s^{-1} cm^{-2}$, and absorption corrected luminosity in the 0.7–1.3 keV band $L_{0.7-1.3} = 1.6 \times 10^{43}$ ergs s^{-1} .

Using a Gaussian parameterization of the soft hump, we determined that the power-law continuum contributes to $\sim 72\%$ of the flux in the soft (0.7–1.3 keV) band of the mean spectrum. We also retrieved the 1996 *ASCA* spectrum (Turner et al. 1998) from the TARTARUS database (Turner et al. 1999) and found consistent contributions of the different spectral components to the soft band over the same energy ranges as we used for our 12 day observation.

4.2. The Fe $K\alpha$ Regime

Comastri et al. (1998) and Turner et al. (1998) found evidence for line emission at ~ 7 keV, indicative of an origin

from material containing ionized iron, consistent with the iron line from H-like iron at 6.94 keV. Hence, having found an adequate parameterization of the continuum shape (in the 1.8–4.71 keV band), we included the 4.71–7.45 keV SIS data and the 4.71–9.42 keV GIS data in the analysis and examined the data/model ratio (vs. the best-fit continuum model; Fig. 4, *top panel*). The mean line profile is broad and asymmetric, similar to that observed in the previous *ASCA* observation (Turner et al. 1998).

We utilized the SIS data in the 1.8–7.45 keV range simultaneously with the GIS data in the 1.8–9.42 keV range. Table 1 summarizes our results.

The asymmetry of the profile prompted us to fit the iron $K\alpha$ line using the DISKLINE model profile of Fabian et al. (1989). This model assumes a Schwarzschild metric, with an emissivity law r^{-q} for the illumination pattern of the accretion disk, where r is the radial distance from the black hole. We adopted $q = 2.5$ based on the results of Nandra et al. (1997b). We also assume that the line emission originates within 1000 gravitational radii ($R_g = GM/c^2$). The inclination of the system is defined such that $i = 0$ is a disk oriented face-on to the observer. Fits using this model yielded $\chi^2 = 1353$ for 1368 dof. The rest energy of the line was $E = 6.40^{+0.27}_{-0.00p}$ keV, the inner radius was $r = 6^{+10}_{-6p} R_g$, the inclination was $i = 35^{+22}_{-35p}$ deg, and the flux was $2.06^{+0.54}_{-0.37} \times 10^{-5}$ photons $s^{-1} cm^{-2}$. The equivalent width was $EW = 461^{+120}_{-84}$ eV.

We also tested a model for the line profile assuming a Kerr metric for a maximally rotating black hole as implemented by Laor (1991). This will have the most intense gravitational effects. We fixed the emissivity index as for the Schwarzschild case and the outer radius at the maximum value allowed by the model, $400R_g$. Using the same energy restriction as for the Schwarzschild model, the Kerr model provides a fit statistic $\chi^2 = 1352$ for 1368 dof. The rest energy of the line was $E = 6.55^{+0.16}_{-0.15p}$ keV, the inclination was $i = 23^{+14}_{-23p}$ deg, and the flux was $2.22^{+0.53}_{-0.47} \times 10^{-5}$ photons $s^{-1} cm^{-2}$. The equivalent width was $EW = 517^{+123}_{-111}$ eV.

The line was better fitted as the sum of a broad and a narrow redshifted Gaussian profile, with $\chi^2 = 1328$ for 1359 dof (a broad or narrow Gaussian alone is a significantly worse fit at $> 99\%$ confidence; see Table 1). The rest energy

TABLE 1
SPECTRAL FITS IN THE 2–10 keV BAND

Model (1)	Γ_{2-10} ^a (2)	E_{Fe} ^{a,b} (keV) (3)	EW ^a (eV) (4)	χ^2 /dof (5)
PL ^c	2.37 ± 0.01	1518/1372
PL + DISKLINE	$2.43^{+0.01}_{-0.02}$	$6.40^{+0.27}_{-0.00p}$	461^{+120}_{-84}	1353/1368
PL + Laor	2.43 ± 0.02	$6.55^{+0.16}_{-0.15p}$	517^{+123}_{-111}	1352/1368
PL + NG	2.39 ± 0.01	$6.75^{+0.08}_{-0.04}$	182^{+30}_{-26}	1404/1370
PL + BG	2.44 ± 0.02	$6.71^{+0.12}_{-0.14}$	550^{+184}_{-128}	1352/1369
PL + BG + NG	$2.46^{+0.03}_{-0.02}$	$6.58^{+0.25}_{-0.28}$	512^{+225}_{-136}	1328/1359
		$6.81^{+0.08}_{-0.12}$	90^{+33}_{-31}	

NOTES.—Col. (1): Models. Col. (2): Photon index. Col. (3): Rest-frame energy of the fitted Fe line. Col. (4): Equivalent width. Col. (5): The χ^2 and degrees of freedom relative to the fit. PL indicates the power-law continuum, BG the broad Gaussian, and NG the narrow Gaussian.

^a The 90% confidence level uncertainties.

^b Rest frame of Ton S180.

^c Over the whole hard energy range. The value of the photon index from the continuum fit is 2.44 ± 0.02 (§ 4).

of the narrow line (fixed at 10 eV width) was $E_N = 6.81^{+0.08}_{-0.12}$ keV, with $EW = 90^{+33}_{-31}$ eV. The broad component gave $E_B = 6.58^{+0.25}_{-0.28}$ keV and $EW = 512^{+225}_{-136}$ eV. The residuals of the two-Gaussian fit are shown in the bottom panel of Figure 4. Some excess emission is evident in the 8–9 keV region. However, the S/N in this energy range is so low (the detection level is $\sim 3\sigma$) that no meaningful spectral fit can be performed.

We do not detect any narrow (fixed at 10 eV width) $K\alpha$ emission at rest energy 6.4 keV, in addition to the Schwarzschild, Kerr, single broad Gaussian, or two-Gaussian models.

5. SPECTRAL VARIABILITY

5.1. Method and Selection Details

To examine the spectral evolution of Ton S180, we created 14 time-selected spectra across the 12 day *ASCA* observation by sampling throughout the light curve following flares and dips with Xselect version 2.0. The resulting average baseline for each time-selected spectrum was 75 ks, for an average on-source exposure time of 25 ks. Our choice of intervals is shown in Figure 5. The “events” described in § 3 (Fig. 2) occur during time bin 9. Background, ancillary response, and response matrix files were set to be those of the mean spectrum. The background spectrum and flux did not vary significantly during the observation, and use of the mean spectra yielded the best possible S/N for the time-resolved spectroscopy. Again, spectra were binned to achieve a minimum of 20 counts per energy bin. We performed all fits by fixing the scaling factors for instrument normalization based on the fits to the mean spectrum. Corrections

for the SIS low-energy problem were fixed at the same values used for the mean spectrum. All models were modified with a Galactic absorption. Time assignments for the spectra refer to the midpoint of the observation, at $JD - 2,450,000$. The results of our analysis are shown in Figure 3 in the form of time series curves for the various parameters. These are described in detail in the following sections.

5.2. Variability of the Continuum

We fitted each of the 14 time-selected spectra in the 1.8–4.71 keV range (both SIS and GIS; observer’s frame) with a simple power-law model. The light curves for the (model) continuum flux and the best-fit photon index Γ are shown in Figure 3. The photon index Γ , thus sampled on a ~ 1 day timescale, ranges between 2.38 and 2.62 (i.e., $\Delta\Gamma = 0.24$) across the 12 days, but these variations are not significant (fitting the photon indices to a constant model yields $\chi^2 = 10$ for 13 dof). Therefore, the rapid flux variability evident on timescales as short as ~ 1000 s in the hard band (Fig. 2; § 3) is not due to changes in Γ but is truly flux changes in that band. However, on longer timescales of about a week, significant changes in Γ occur, as we will show in § 5.3.

Figure 6 shows ratio plots obtained by comparing the best-fit model for the first spectrum to the following 13 spectra, without performing any fit. The plot illustrates the variations of the spectral shape and flux compared to the first day of data. Strong variations in the flux and, to a lesser degree, in the continuum slope are evident. The soft hump is always present superimposed on the power-law continuum, although it appears to change in absolute strength, relative

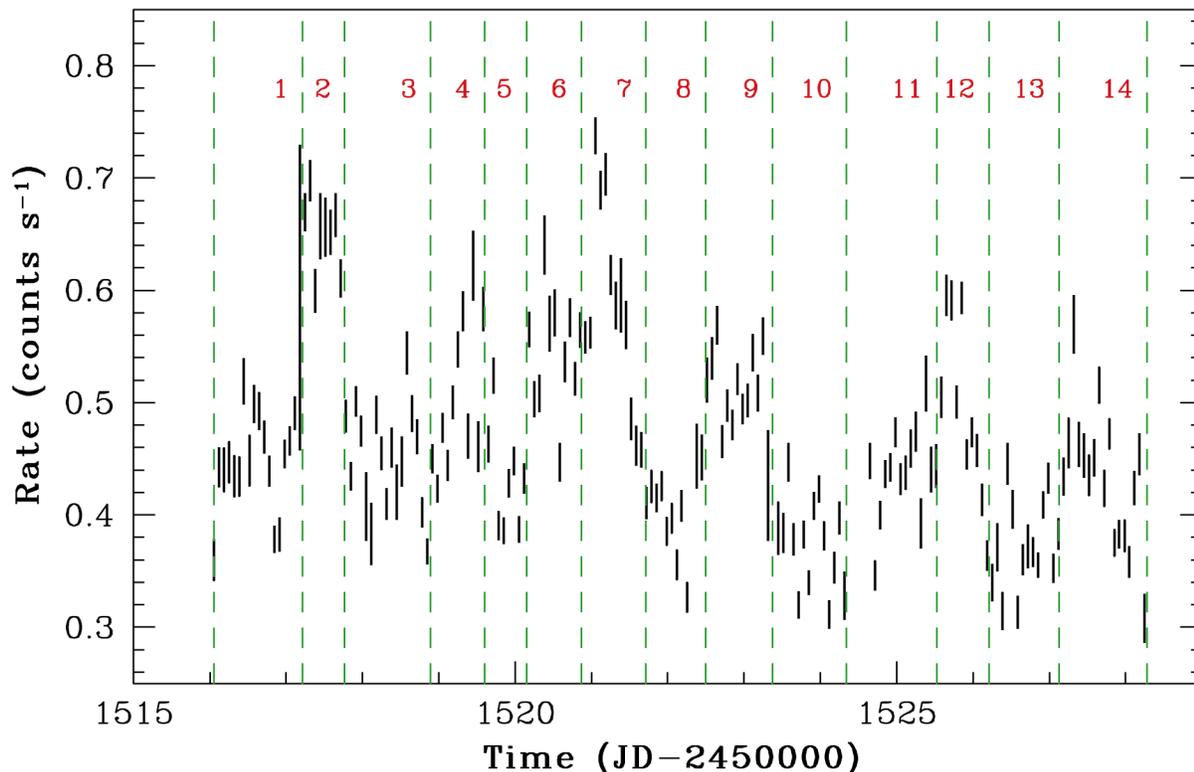


FIG. 5.—Combined SIS 0.7–1.3 keV light curve in counts s^{-1} and in 5760 s bins. The background level in the source cell is about 4% of the source count rate and not plotted or subtracted. The vertical dashed lines show our 14 time intervals within which spectra were extracted (§ 5). The “flares” shown in Fig. 2 (§ 3) are within bin 9.

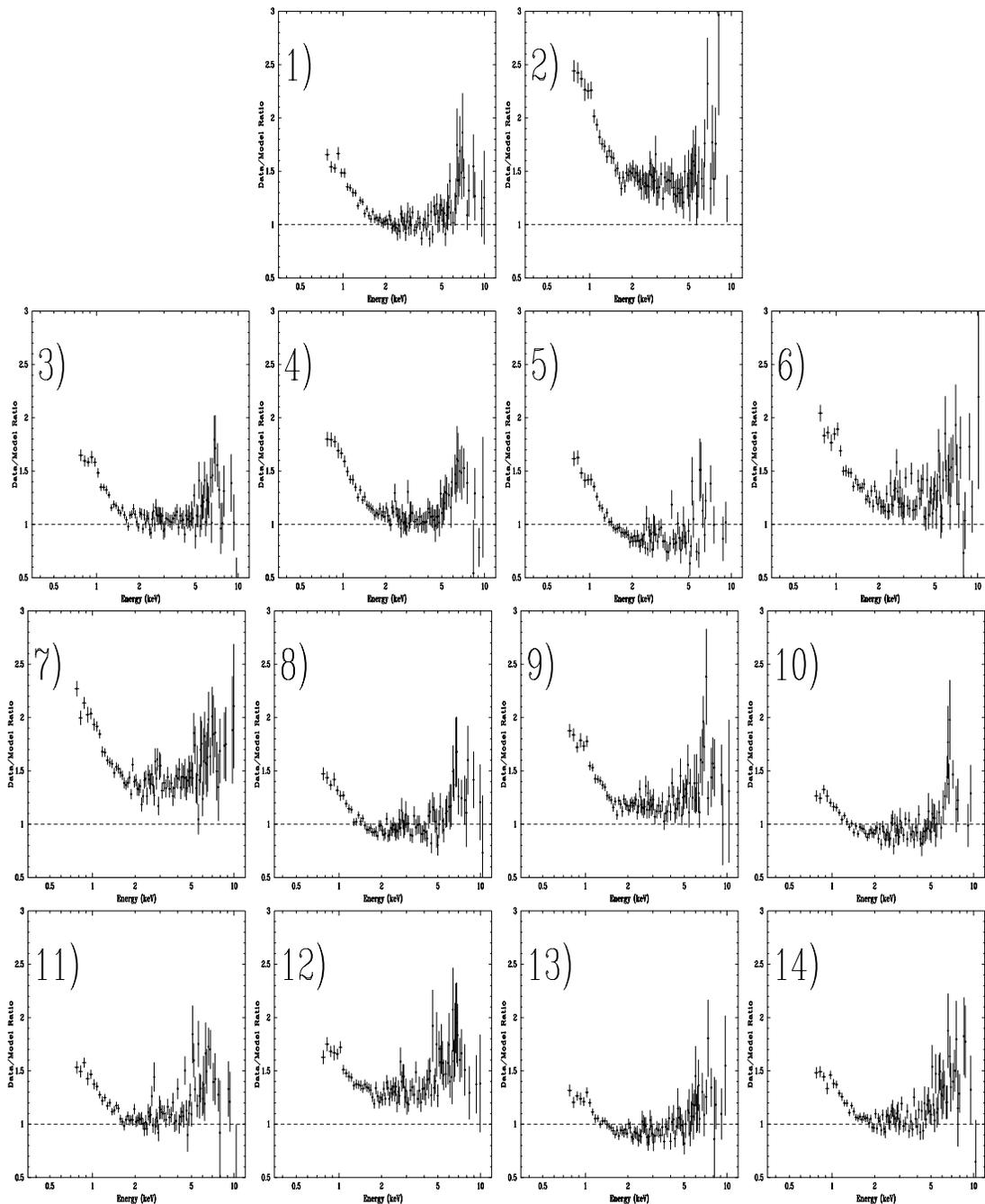


FIG. 6.—Ratio plots obtained by fitting the best-fit model for the first spectrum to the following 13 spectra. Energy ranges and instrument utilized are described in § 5.2. Energies are in the rest frame of Ton S180.

to the power-law continuum, and possibly in shape (see, for example, time cuts 2 and 13) on a timescale of approximately a day. Variations in the shape of the soft hump, however, are a minor effect compared to the flux variations of the soft hump.

5.3. Variability of the Soft X-Ray Hump

We examined the variability of the soft hump using SIS data in the range 0.7–4.71 keV simultaneously with GIS data in the 1.0–4.71 keV range (observer’s frame), as we did for the mean spectrum in § 4.1. The model was a simple power law plus a broad Gaussian for the soft hump, with the Gaussian peak and width fixed at the values noted in

§ 4.1. The flux of the soft hump, the flux of the continuum power law, and the power-law slope were free parameters. The time series for the flux of the soft hump is shown in Figure 3. Fitting a constant model to this flux yields $\chi^2 = 47$ for 13 dof. The soft hump flux varies by a factor of $R_{\max} = 2.33 \pm 0.45$, while the 2–10 keV flux (when binned the same way) varies by a factor of $R_{\max} = 1.65 \pm 0.02$.

In Ark 564, Turner et al. (2001b) showed that the different amplitudes of variability of the soft hump and power law (6.44 ± 3.30 , compared to 3.97 ± 0.06) explain the gross change in softness ratio across the observation. In Ton S180, the amplitude of variation of the soft hump is not so pronounced, although it is clear from the light curves (Fig.

3) that most of the flares in the hard X-ray flux are also present in the soft hump. To clarify the situation in Ton S180, we split the data into “hard” and “soft” states based on the softness ratio. We chose $T < 6.3 \times 10^5$ s for our soft-state spectrum and $T > 6.3 \times 10^5$ s for our hard-state spectrum, where T is the time from the start of the observation (see Fig. 1). Fits were performed on each state, as for the mean spectrum (§ 4.1), and confidence contour plots were generated for the flux of the soft hump versus the photon index, assuming the soft hump shape to be approximately constant during the observation. The resulting Γ –soft hump flux contours are well separated (Fig. 7, *top panel*) in both directions. Hence, the confidence contour plot indicates that the source varies significantly in photon index *and* strength of the soft hump on a timescale of about 1 week. Therefore, both effects are contributing to the change in softness ratio observed across the baseline of the observation. The spectral changes observed between the soft and hard states result in a change of the EW of the soft hump from $EW_{\text{soft}} = 100 \pm 5$ eV to $EW_{\text{hard}} = 84_{-7}^{+6}$ eV.

Since we adopt a fixed soft hump shape in our fits of the 14 time-selected spectra, we are confident that our fitting method can separate the fluxes of the soft hump and power-law continuum. Furthermore, the bottom panel in Figure 7 shows Γ plotted against the strength of the soft hump component and demonstrates a strong correlation (Spearman rank coefficient $r_s = 0.68$; probability of chance occurrence is 8×10^{-3}), as is expected from disk-corona models, as we will see in § 8. If the strength of the soft hump component and the photon index were difficult to separate in the spectral fit, we would expect an anticorrelation instead. Figure 7 also shows that a steeper photon index appears to be associated with a relatively strong soft hump. Finally, as noted in § 5.2, the variations in the shape of the Gaussian soft hump are small so that our model for the soft hump parameterizes most of the flux in each time-selected spectrum and does not weaken our approach in fixing the shape when testing for flux variability.

5.4. Variability of the Fe Emission Line

As we have seen in § 5.2, Figure 6 suggests that there are small variations in the strength of the Fe emission line. To investigate this possibility, we utilized SIS data in the 1.8–7.45 keV range simultaneously with the GIS data in the 1.8–9.42 keV range, as we did for the mean spectrum in § 4.2. The model was a simple power-law continuum plus different models for the $K\alpha$ line, with fixed shape parameters. We initially tested the assumption of a fixed shape by splitting the data with an intensity division equivalent to an SIS0 count rate of $0.6 \text{ counts s}^{-1}$. This yielded high- and low-state spectra with similar S/N. We also calculated confidence contours of line flux versus Γ . Figure 8*a* shows overlapping contours; thus, this division of the data, corresponding to a timescale of about 1 week, reveals no evidence for significant flux variability. Using the high- and low-state data, we then fitted for the mean continuum slope as described in § 4 and overlaid the data in the $K\alpha$ band relative to the local power-law slope in each case. The two line profiles are shown as data/model ratios in Figure 8*b*, and they appear indistinguishable. The same test, performed with the soft- and hard-state division discussed in § 5.3, leads us to conclude that no changes were observed either in the flux or in the shape of the line. Figures 8*c* and 8*d* show the confidence contours and the line profiles,

respectively, for the soft- and hard-state spectra. We further tested the possibility that the shape of the line might be variable on a ~ 1 day timescale by overplotting the line profiles for spectra that looked qualitatively different. No significant changes in the line profile were observed.

Once assured that variations of the line shape, if present, were minor, we returned to our 14 time-selected spectra, where we considered the following models for the $K\alpha$ line: (1) a Laor (Kerr) model, (2) a two-Gaussian model (§ 4.2) with the two fluxes allowed to vary independently, (3) a two-Gaussian model in which either the broad Gaussian flux or (4) the narrow Gaussian flux is fixed to the best-fit value from the mean spectrum, and (5) a two-Gaussian model in which fluxes have fixed ratios derived from fits to the mean spectrum. All fits were performed with the photon index and the flux of the power-law continuum left as free parameters. The shape of the $K\alpha$ line was kept fixed to the best-fit values obtained for the mean spectrum. No model component was included for the soft hump, as we excluded the soft-band data for these fits. Figure 3 shows the time series for the $K\alpha$ line for the Kerr model, yielding results similar to those obtained from models 2–5. Fits to a constant model yield $\chi^2 = 3$ for 13 dof; thus, the line does not show significant changes in flux when sampled on a ~ 1 day timescale. Analogous conclusions can be drawn for all other models considered.

Finally, we considered the spectra extracted in bins 4 and 13, which have the highest and the lowest measured $K\alpha$ fluxes, respectively (Fig. 3). We calculated confidence contours of line flux versus Γ and overplotted the line profiles as we did above. Figure 8*e* shows the contour plots, which demonstrate that the flux variation is insignificant and there is a large overlap of the contours. Figure 8*f* shows the line profiles, whose large equivalent widths are consistent at 90% confidence ($EW_4 = 889_{-368}^{+219}$ eV, $EW_{13} = 411_{-249}^{+252}$ eV). Therefore, we do not detect significant variations in EW or flux of the $K\alpha$ line. With the S/N available using these data, the line flux would have had to vary by at least a factor of 2 for us to detect it at the 99% confidence level (see Fig. 8*e*).

We also applied a Laor model to the 1996 *ASCA* observation (Turner et al. 1998), within the same energy ranges that we used here and with the corrections for the SIS low-energy degradation appropriate to 1996 (see § 2), and obtained peak energy, EW, and inclination for the $K\alpha$ line consistent with what we found in § 4.2.

5.5. rms Spectra

In optical/UV spectroscopy of active galactic nuclei, it is easy to obtain a series of spectra of sufficiently high S/N to perform time-resolved spectroscopic analysis. In this case, a useful way to isolate variable features is to construct an rms spectrum. This *ASCA* long look has allowed us to use our 14 individual time-selected spectra described in § 5 in an analogous way. For each detector, the 14 spectra have been rebinned so that each bin has at least a 5σ detection (but up to a maximum of 10 adjacent bins were combined to achieve an S/N of 5 within a bin), then they were degraded to the resolution of the worst spectrum. We created rms and mean spectra by calculating the rms and mean flux in each bin. The choice of a simple mean as opposed to a weighted mean was dictated by the fact that we did not want to favor the high-state spectra. Figure 9 shows the ratio rms/mean spectrum for SIS1 and SIS0, using data with energy greater

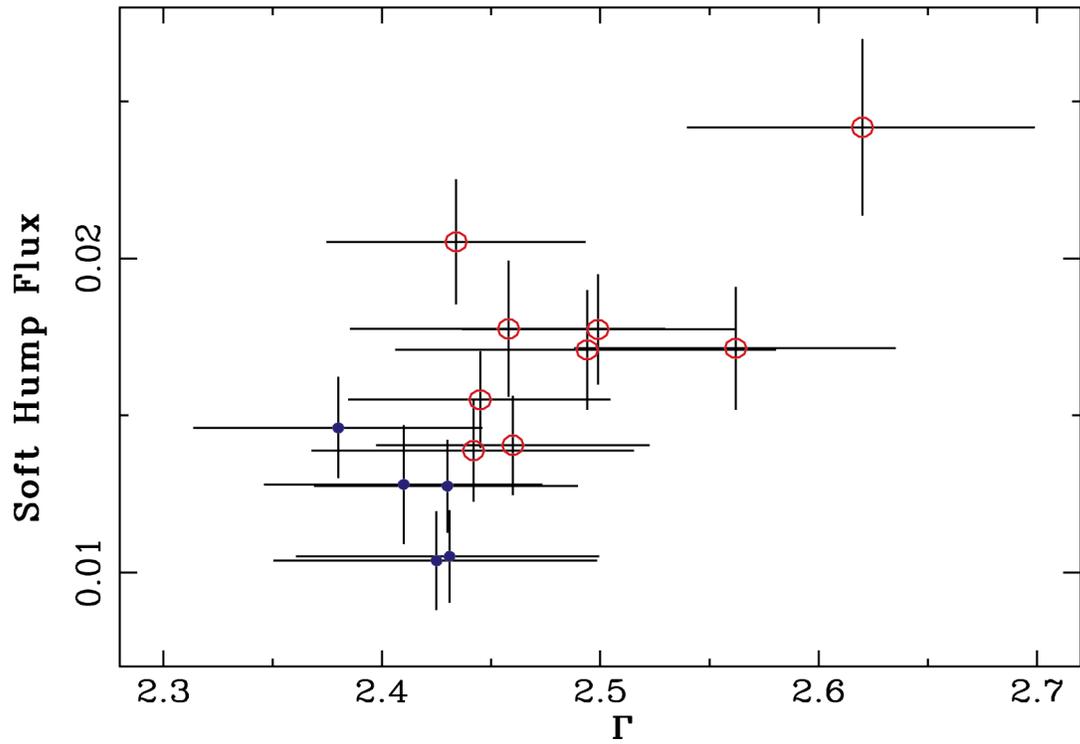
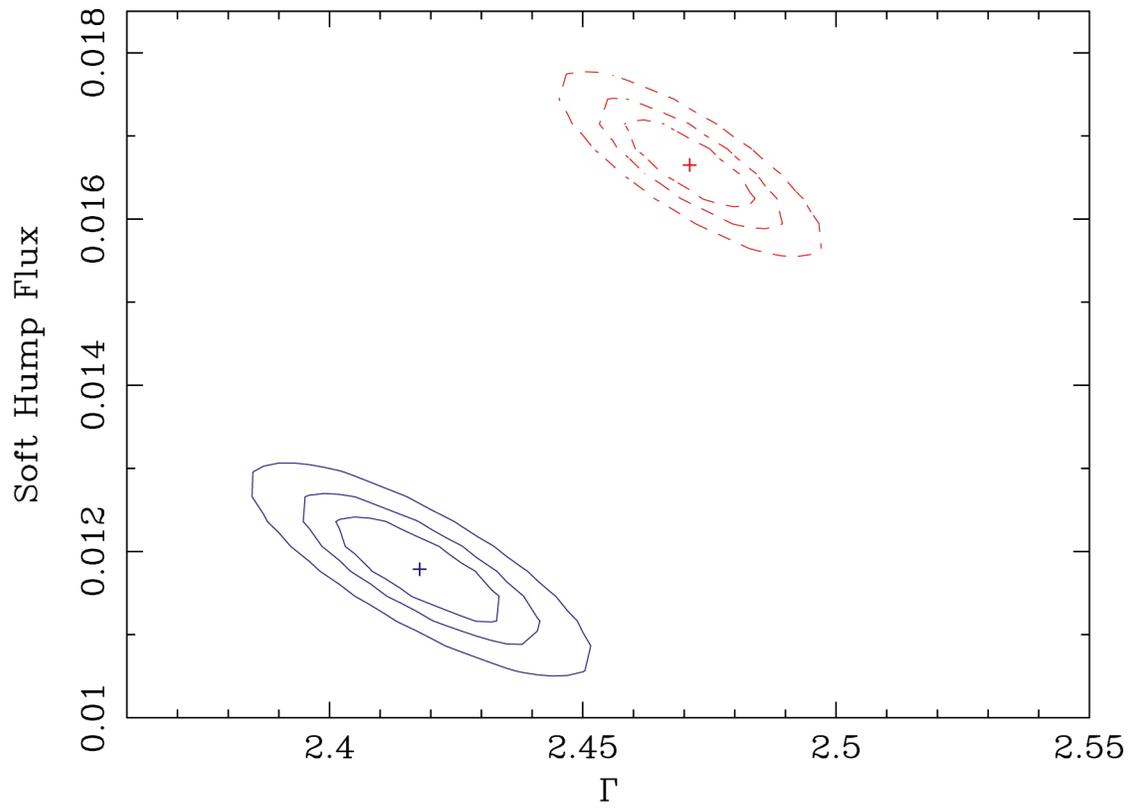


FIG. 7.—*Top panel*: The $\Delta\chi^2 = 2.3, 4.61,$ and 9.21 contour levels for the soft hump flux (in units of photons $\text{s}^{-1} \text{cm}^{-2}$) vs. photon index Γ . The full contours correspond to the hard state (§ 5.4), the dashed contours to the soft state, and the crosses indicate the best-fit values. *Bottom panel*: The strength of the soft hump plotted against photon index Γ in our 14 time-selected spectra with high-state (*open circles*) and low-state (*filled circles*) points overlaid.

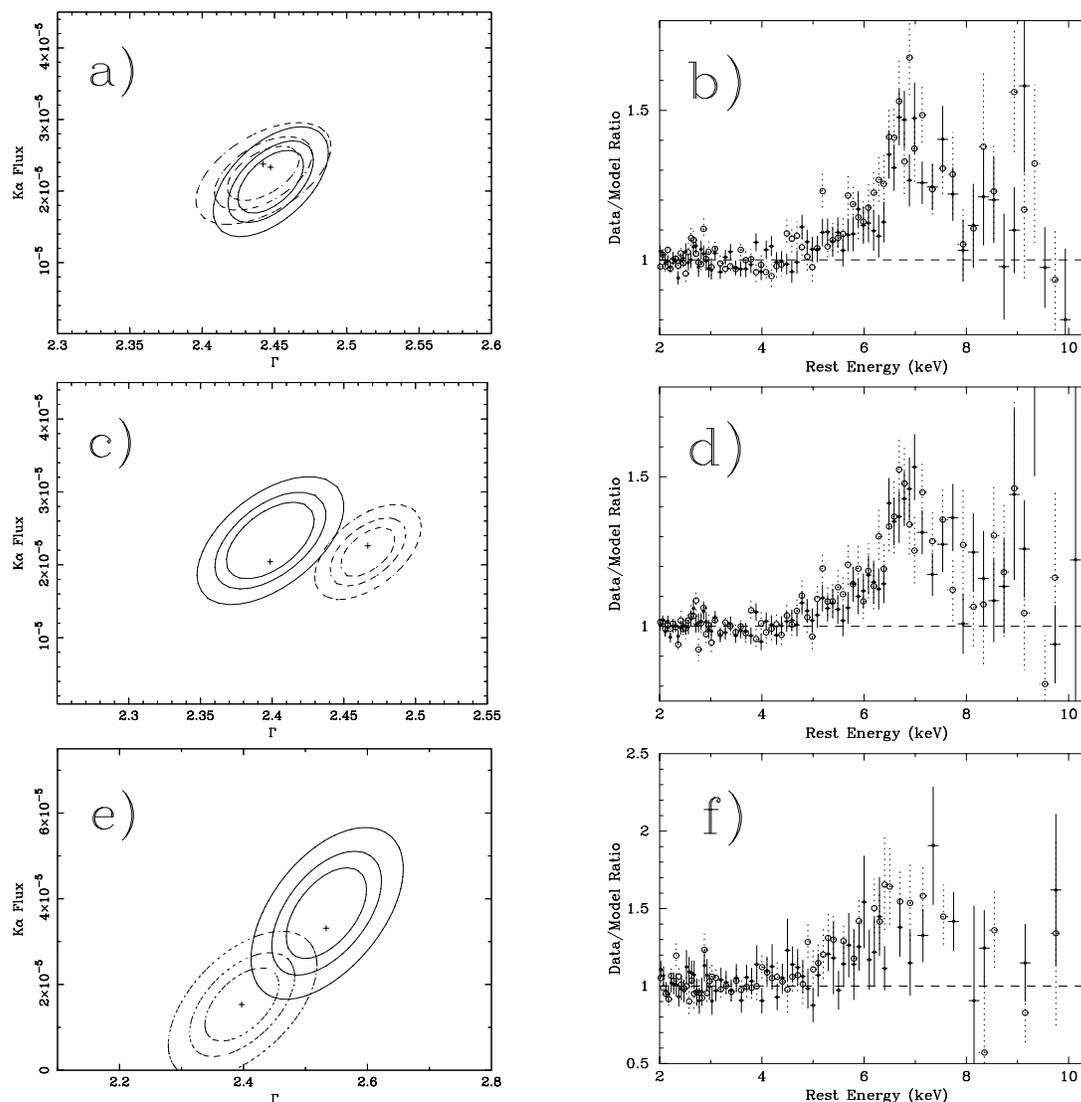


FIG. 8.—(a) The $\Delta\chi^2 = 2.3, 4.61$, and 9.21 contour levels for Fe K-shell line intensity (in units of photons $s^{-1} cm^{-2}$) vs. photon index Γ ; the full contours correspond to the high state (§ 5.4), the dashed contours to the low state, and the crosses indicate the best-fit values. (b) The Fe K α regime compared to the continuum model, with overlay of high state (open circles) and low state (filled circles). (c) Same as (a), with full contours corresponding to the hard state (§ 5.3) and dashed contours to the soft state. (d) Same as (b), with hard state (open circles) and soft state (filled circles) overlaid. (e) Same as (a), with full contours corresponding to the high K α flux bin 4 (§ 5.4) and dashed contours to the low K α flux bin 13. (f) Same as (b), with bin 4 (open circles) and bin 13 (filled circles) overlaid.

than 0.7 keV. The mean value is $\sim 20\%$, and there is no systematic trend for different energies. This is consistent with the results from § 4.1 showing that the power-law continuum component contributes most of the flux in the hard band and $\sim 72\%$ of the flux in the soft band. The possible weak trend for energies less than 2 keV of increased variability for decreasing energy may suggest that the soft hump is partially driving the variability in the soft band. The “spikelike” features at ~ 1.7 – 2.5 keV are probably due to calibration uncertainties.

6. SUMMARY OF OBSERVATIONAL RESULTS

1. On a 12 day baseline, the X-ray flux of Ton S180 presents trough-to-peak variations by a factor 3.5 in the 0.7–1.3 keV band and 3.9 in the 2–10 keV band when sampled using 256 s bins.

2. The mean photon index, calculated from the continuum fit of the mean spectrum, is $\Gamma = 2.44 \pm 0.02$. Time-

resolved spectroscopy reveals significant changes on timescales of ~ 1 week.

3. We confirm the presence of a separate “soft hump” component at energies less than 2 keV. This component shows flux variations down to timescales of ~ 1 day, ranging by a factor of 2.3 in normalization over the 12 days of our observations. Some flux changes appear to match changes in the 2–10 keV flux on this timescale, although the soft hump shows a drop in EW from 100 to 84 eV across the observation. Minor changes in the shape of the soft hump are apparent on timescales of a few days.

4. In our approximately daily sampling, the photon index is correlated with the flux of the soft X-ray hump.

5. Variations in both the photon index and soft hump strength contribute to the change in softness ratio observed across the *ASCA* observation.

6. The softness ratio reveals spectral variability down to timescales of ~ 1000 s in addition to the slow decline across the observation. The power law and soft hump show diver-

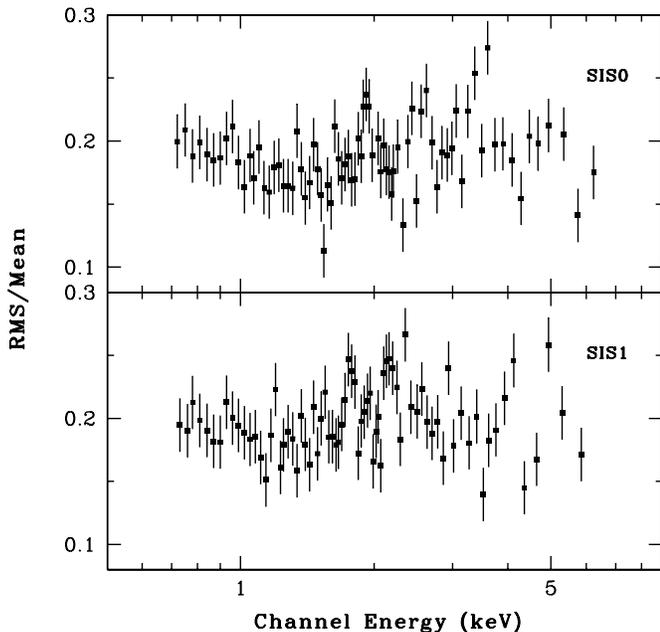


FIG. 9.—Ratio of rms/mean spectrum for SIS1 and SIS0, using data of energy >0.7 keV. The “spikelike” features at ~ 1.7 – 2.5 keV are probably due to calibration uncertainties.

gent behavior on very short (1000 s) or long (2 weeks) timescales.

7. The Fe $K\alpha$ line emission is detected with a narrow component peaking at ~ 6.8 keV, indicating an origin in ionized material. A broad-line component (EW ~ 500 eV) is also evident. We do not detect significant variations of the Fe $K\alpha$ line strength or equivalent width, on timescales of ~ 1 – 12 days.

7. COMPARISON WITH ARAKELIAN 564

Comparison of our results for Ton S180 with those obtained for Ark 564 (Turner et al. 2001c) reveals broad similarity in the overall shape of the X-ray spectra (steep power-law continuum, strong soft excess, and ionized, large-EW Fe $K\alpha$) and variability characteristics. Given these similarities, which may be indicative of the characteristics of the NLS1 as a class, we summarize the properties of these two NLS1s in Table 2.

8. DISCUSSION AND CONCLUSIONS

Ton S180 reaffirms the rapid and large-amplitude X-ray variations that are a characteristic of the NLS1 class. During our 12 day observation, the light curves sampled on 256 s timescales show trough-to-peak flux variations by a factor of ~ 3.5 in the soft band (0.7–1.3 keV) and up to a factor of ~ 4 in the hard band (2–10 keV). Further examination of these light curves shows variations up to a factor of ~ 2 occurring on timescales of ~ 1000 s that are sometimes accompanied by spectral changes. There is a strong correlation ($r_{\max} = 0.748$) between the soft- and hard-band light curves, with a 95% confidence upper limit on the lag of hard with respect to soft of $\tau_{\text{cent}} < 0.07$ days. The strength of this correlation, the short lag, and the fact that $\sim 72\%$ of the flux in the soft band is contributed by the power-law continuum while the hard flux is driven by the power law indicate

that this correlation is dominated by the variations of the power-law continuum itself.

We used these timing data to obtain an estimate of some fundamental parameters for Ton S180. Our estimate of the accretion efficiency is $\eta \gtrsim 7\%$, marginally above the limit for the efficiency in the Schwarzschild geometry, perhaps favoring a Kerr geometry. However, large uncertainties are associated with this estimate (see Brandt et al. 1999). Light-crossing time arguments yield a radius R for the emitting region, $R \lesssim 12R_S$ for $M_{\text{BH}} \gtrsim 8 \times 10^6 M_{\odot}$. The 1000 s timescale for variability observed in Ton S180 indicates that neither thermal nor viscous/radial drift phenomena can be held responsible for the observed fast variability. The values of these parameters are consistent with what is generally found for other Seyfert 1 galaxies. Haardt, Maraschi, & Ghisellini (1994) discuss a model where soft thermal photons from the accretion disk are Compton-upscattered in localized blobs of coronal plasma, constrained by magnetic loops from the disk. The resulting X-rays from the blobs then illuminate the disk and produce the so-called Compton hump and Fe $K\alpha$ emission line. The amplitudes and timescales of the rapid variations observed in Ton S180 are consistent with those expected as a result of stochastic noise in the number of reprocessing blobs, which depends on the formation and reconnection of magnetic loops.

The continuum fit to the mean spectrum yields a photon index $\Gamma = 2.44 \pm 0.02$. Our time-selected spectral fits give $\langle \Gamma \rangle = 2.47 \pm 0.07$ (1σ error) with variations from 2.38 to 2.62. The steep index and the range ($\Delta\Gamma = 0.24$) are comparable with those observed in Ark 564 ($\Gamma = 2.54$, $\Delta\Gamma = 0.27$; Turner et al. 2001c), though the variations on a ~ 1 day timescale are significant in the case of Ark 564 but not for Ton S180 (where we detect variations of Γ in a ~ 1 week timescale). The range of indices is also consistent with that found for the BLS1 NGC 7469 ($\Delta\Gamma = 0.32$; Nandra et al. 2000). This may indicate a fundamental similarity in the process that causes slope fluctuations, over a range of different active galactic nuclei.

We confirm the presence of the soft X-ray emission component at energies less than 2 keV previously observed by Fink et al. (1997), Comastri et al. (1998), and Turner et al. (1998). This component rises above the power-law continuum $\lesssim 2$ keV and has recently been shown to be a smooth continuum component rather than a blend of features, not only in Ton S180 (Turner et al. 2001a) but also in the NLS1 NGC 4051 (Collinge et al. 2001). Therefore, our time-selected spectroscopic analysis is particularly well suited to study its variability properties in particular and to understand the nature of the soft hump in NLS1s in general. The soft hump shows flux variations on timescales as short as ~ 1 day (the shortest timescales that our time-selected spectroscopy can study), ranging by a factor of 2.3 in flux over the observation but always being present. We note that the fast variability observed in the soft hump of Ton S180 rules out an origin of the soft emission in large-scale components, such as circumnuclear starbursts (as also concluded for the soft hump in Ark 564; Turner et al. 2001c). The hard flux, when similarly binned on timescales of a day, has a range of a factor 1.65. The softness ratio shows spectral variability on timescales as short as ~ 1000 s. In Ton S180 such fast spectral variability can be attributed to rapid changes either in the photon index or in the relative strengths of the soft hump and power law. In addition to this evidence for divergent behavior on very short timescales, the soft hump and

TABLE 2
COMPARISON OF THE PROPERTIES OF TON S180 AND ARAKELIAN 564

PROPERTIES (1)	Ton S180 ^a (2)	Ark 564 ^a (3)	REFERENCES ^b	
			Ton S180 (4)	Ark 564 (5)
z	0.06198	0.0247	1	2
Galactic N_{H} (cm^{-2})	1.52×10^{20}	6.4×10^{20}	3	4
V (mag)	14.4	14.6	5	6
L_{2-10} ($\times 10^{43}$ ergs s^{-1})	4.9	2.4	7(3)	8(3)
R_{max} soft band	3.5	16	7(3)	8(3)
R_{max} hard band	3.9	14	7(3)	8(3)
R_{max} soft hump	2.33 ± 0.45	6.44 ± 3.30	7(5.3)	8(5.3)
R_{max} 2–10 keV	1.65 ± 0.02	3.97 ± 0.06	7(5.3)	8(5.3)
F_{var} (12 day, soft) (%)	19.12 ± 0.58	35.81 ± 0.81	7(3.1)	7
F_{var} (12 day, hard) (%)	17.26 ± 0.65	35.73 ± 0.70	7(3.1)	7
F_{var} (1 day, soft) (%)	Variable	Variable	7(3.1)	8(3.1)
Correlates with X-ray	No	No	7(3.1)	8(3.1,7)
F_{var} (1 day, hard) (%)	Variable, <soft	Variable, <soft	7(3.1)	8(3.1)
Correlates with X-ray	No	No	7(3.1)	8(3.1,7)
ICCF r_{max} (soft–hard band)	0.748	0.942	7(3)	8(7)
ICCF τ_{cent} (95% limit) (days) ^c	<0.07	<0.02	7(3)	8(7)
Γ (mean spectrum)	2.44 ± 0.02	2.538 ± 0.005	7(4)	8(4)
$\Gamma_{\text{min}} - \Gamma_{\text{max}}$	2.38–2.62	2.45–2.72	7(5.2)	8(5.2)
$\Delta\Gamma$	0.24	0.27	7(5.2)	8(5.2)
PL soft-band contribution (%)	72	75	7(4.1)	8(3.1)
Soft hump Gaussian fits: E (keV)	0.17 ± 0.17	0.57 ± 0.2	7(4.1)	8(4.1)
FWHM (keV)	$1.01^{+0.05}_{-0.12}$	0.36 ± 0.01	7	8
n ($\times 10^{-2}$ photons s^{-1} cm^{-2})	$1.50^{+0.37}_{-0.61}$	$1.25^{+0.12}_{-0.17}$	7	8
EW (eV)	94^{+23}_{-38}	110^{+11}_{-15}	7	8
$K\alpha$ DISKLINE fits: E (keV) ^d	$6.40^{+0.27}_{-0.00p}$	$7.00^{+0.00}_{-0.13}$	7(4.2)	8(4.2)
EW (eV)	461^{+120}_{-84}	351 ± 85	7	8
i (deg)	35^{+22}_{-35p}	26 ± 2	7	8
$K\alpha$ Laor fits: E (keV) ^e	$6.55^{+0.16}_{-0.15p}$	$6.99^{+0.01p}_{-0.13}$	7(4.2)	8(4.2)
EW (eV)	517^{+123}_{-111}	653 ± 85	7	8
i (deg)	23^{+14}_{-23p}	17^{+11}_{-17}	7	8

NOTES.—Col. (1): Properties. Cols. (2) and (3): Values for Ton S180 and Ark 564, respectively. Cols. (4) and (5): References for Ton S180 and Ark 564, respectively.

^a The 90% confidence level uncertainties.

^b The numbers in parenthesis refer to the sections where the relevant information is found in the given references.

^c Lag of hard relative to soft flux.

^d Best parameterization for Ton S180 is by two Gaussians with peak energy $E_N = 6.81^{+0.08}_{-0.12}$ keV and $E_p = 6.58^{+0.25}_{-0.28}$ keV.

^e Best-fit model for Ark 564 (Turner et al. 2001c).

REFERENCES.—(1) Wisotzki et al. 1995. (2) Huchra, Vogeley, & Geller 1999. (3) Stark et al. 1992. (4) Dickey & Lockman 1990. (5) NED. (6) De Vaucouleurs et al. 1991. (7) This work. (8) Turner et al. 2001c.

power law show different trends on timescales of ~ 1 week. The higher value of F_{var} measured in the soft than in the hard band is probably due to the combined effects of a larger amplitude of variation of the soft hump over the baselines of the observation and the changes in spectral slope (which could preferentially affect the soft band if the pivot point lies within the hard band). The correlation observed between the soft hump flux and the photon index in Ton S180 is expected in disk-corona models, where an increase of the flux in the soft X-ray/UV component can cool the corona and steepen the power-law continuum (Haardt et al. 1994; Pounds et al. 1995). This is not the case for Ark 564, where Turner et al. (2001c) suggest that the corona cooling might be saturated.

Iron $K\alpha$ line emission is detected, with a broad, asymmetric profile. It is best parameterized by two Gaussian components; the narrow component peaks at $E_N = 6.81$ keV, which is consistent with emission from highly ionized

gas, and the broad component is consistent with emission from either neutral or ionized gas. We caution about the reliability of this result because the S/N in this range is low and the errors on the fitted parameters are correspondingly large (Table 1). Therefore, it seems that the best parameterization for the Fe $K\alpha$ line is a broad ionized line, which is consistent with previous *BeppoSAX* (Comastri et al. 1998) and *ASCA* (Turner et al. 1998) observations. The broad component is generally thought to originate in the innermost regions of the accretion disk around the central black hole (e.g., Fabian et al. 2000 and references therein), and so it is due to highly ionized Fe, while the narrow component is thought to be generated in the putative obscuring torus that extends on a parsec scale (Ghisellini, Haardt, & Matt 1994; Krolik, Madau, & Życki 1994; Yaqoob et al. 2001) and so is believed to be due to neutral material. In this context, the result of an ionized narrow Fe $K\alpha$ component is therefore somewhat surprising. Note, however, that obser-

variations of such a feature are not unprecedented: Sako et al. (2000) and Ogle et al. (2000) detected narrow lines due to highly ionized iron in *Chandra* observations of Mrk 3 and NGC 4151, respectively.

The Fe $K\alpha$ emission line has a very large equivalent width, $EW \approx 500$ eV, as previously observed in other *ASCA* and *BeppoSAX* observations of Ton S180, Ark 564, and other NLS1s (Turner et al. 1998; Comastri et al. 1998; Turner et al. 2001c). These EWs are interesting compared to a sample taken across the Seyfert 1 population (Nandra et al. 1997b, who found an average $EW = 230$ eV). One interpretation is in terms of an extreme Fe abundance in NLS1s, as proposed by Turner et al. (1999) for Ark 564; this may, in turn, support the proposition that NLS1s are Seyfert galaxies in an early stage of evolution (Mathur 2000). Alternatively, Matt, Fabian, & Ross (1996) show that the expected EWs for predominantly H- and He-like Fe can be a factor of a few higher than those from neutral Fe. We do not detect significant variations of the Fe $K\alpha$ line on timescales of ~ 1 day or of ~ 1 week. We note that given our S/N in the $K\alpha$ energy range for the 14 time-selected spectra, the line flux would have had to vary by at least a factor of 2 for us to

have detected the variation at greater than 99% confidence level.

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