X-RAY OBSERVATIONS OF THE SEYFERT GALAXY LB 1727 (1H 0419−577)

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ABSTRACT

We discuss the properties of the Seyfert 1.5 galaxy LB 1727, also known as 1H 0419−577, from X-ray observations obtained by ASCA and ROSAT, along with optical observations from earlier epochs. The source flux was $F_{\text{2-10}} \approx 10^{-11}$ ergs cm$^{-2}$ s$^{-1}$ during the ASCA observations that were carried out during 1996 July–August, and we find only modest (≤20%) variations in the flux in this band within or between these observations. In contrast, a daily monitoring campaign over 1996 June–September by the ROSAT HRI instrument reveals the soft X-ray (0.1−2 keV) flux to have increased by a factor of ≈3. Significant variations were also observed down to timescales of ~40 ks. We find that the 2−10 keV continuum can be parameterized as a power law with a photon index $\Gamma \sim 1.45$−1.68 across ~0.7−11 keV in the rest frame. We also report the first detection of iron Kα line emission in this source. Simultaneous ASCA and ROSAT data show the X-ray spectrum to steepen sharply at a rest energy ~0.75 keV, so the spectrum below this energy can be parameterized as a power law of slope $\Gamma \sim 3.6$. The X-ray emission appears to be unattenuated, and we find that ionized gas alone cannot produce such a sharp spectral break. Even allowing the presence of such gas, the simultaneous ASCA and HRI data demonstrate that the underlying continuum is required to steepen below ~0.75 keV. Thus LB 1727 is one of the few Seyferts for which we can rule out the possibility that the presence of a warm absorber is solely responsible for the spectral steepening in the soft X-ray regime. Consideration of the overall spectral energy distribution for this source indicates the presence of a pronounced XUV bump visible in optical, ultraviolet, and soft X-ray data. The source appears relatively weak in infrared emission, and so if dust exists in the source, it is not excited by the nuclear radiation.

Subject headings: galaxies: active — galaxies: individual (LB 1727, 1H 0419−577) — galaxies: nuclei — galaxies: Seyfert — X-rays: galaxies

1. INTRODUCTION

It has long been suggested that the putative accretion disk around the black hole of active galactic nuclei (AGNs) will emit copious amounts of UV and soft X-ray radiation (Shields 1978; Rees 1984). Thus the spectral energy distribution (SED) of an AGN across this range should provide crucial information about the accretion disk, reprocessing mechanisms close to the active nucleus, and physical conditions in the circumnuclear material.

Determination of the X-ray–to–ultraviolet (XUV) continuum in AGNs has been extremely difficult because of the severe attenuation of photons of these energies by even small amounts of material along the line of sight to the AGN. However, some indication of the flux of the unseen continuum has been inferred from the strengths of emission lines such as He II $\lambda$1640 (e.g., Mathews & Ferland 1987). In fact, a long-standing suggestion has been that there is a so-called blue bump of continuum emission peaking in the unseen XUV regime (Shields 1978; Malkan & Sargent 1982). The advent of new and sensitive satellites has started to narrow the "unobservable" bandpass. For example, observations of high-redshift quasars by HST has enabled measurement of the continuum up to the Lyman limit, while the ROSAT Wide Field Camera (WFC) and the Extreme Ultraviolet Explorer (EUV) have provided measurements in the soft X-ray band (~0.1–1 keV). Four Seyferts are listed as detections by the WFC (Pounds et al. 1993); furthermore, (at least) 17 Seyferts were detected by EUVE (Marshall, Fruscione, & Coronoe 1995; Fruscione 1996). Rapid variability in the EUVE flux of several sources indicated the observed radiation to be originating in the inner nucleus (e.g., Marshall et al. 1996, 1997).

Recent work by Zheng et al. (1997, 1995) has suggested that the form of the unseen XUV spectrum is falling between the Lyman limit (at 912 Å) and ~0.5 keV as $f_\nu \propto v^{-2}$. 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. Korista, Ferland, & Baldwin (1997) have discussed the problem that in extrapolating the known soft X-ray spectrum of AGNs there appear 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. Clearly, a careful determination of the detailed shape of the XUV continuum would provide a large step forward in our understanding of many fundamental processes in AGNs. While numerous observations of AGNs have been performed in the past, little is known about the spectral shape below ~0.6 keV. Previous soft X-ray observations have yielded narrowband spectra with...
Low energy resolution (e.g., ROSAT, Einstein IPC, EXOSAT channel multiplier array). ASCA has only yielded reliable spectra above 0.6 keV (although data may eventually be reliable down to 0.4 keV with improved calibration). Disagreements between ASCA and ROSAT data in the overlap bandpass (0.6–2 keV) have led to some controversy as to whether the underlying continua of emission-line AGNs actually do steepen to softer X-ray energies or there is a miscalibration between instruments. ASCA and ROSAT data aside, some sources definitely show a significant spectral softening below ~1 keV in data from earlier missions (e.g., Arnaud et al. 1985; Turner et al. 1993); however, in most cases, the physical origin of this effect is ambiguous. It is now known that the majority of Seyfert 1 galaxies suffer attenuation by ionized material (Reynolds 1997; George et al. 1998b), which can have a reduced opacity in the soft X-ray band and produce an observed spectrum that steepens to soft energies. In most cases studied to date, X-ray spectra do not allow us to distinguish between a single continuum component attenuated by ionized material and steepening of the underlying emission spectrum. Clearly, the best sources for attempting to unambiguously distinguish between the aforementioned pictures should be bright in the soft X-ray regime and have minimal absorption. LB 1727 is the fourth brightest Seyfert galaxy detected by EUVE (Marshall et al. 1995), yet it has a very flat spectrum in the hard X-ray regime (Guainazzi et al. 1998) compared with most Seyfert 1 galaxies (George et al. 1998b and references therein). These two properties suggest that the source might show a marked steepening of spectral slope in the soft X-ray regime; this, combined with the low Galactic column along the line of sight, makes LB 1727 a good target to search for the soft X-ray tail of an XUV bump.

2. The Seyfert Galaxy LB 1727

LB 1727 is a very blue object first noted by Luyten & Anderson (1958) during their search for faint blue stars. The X-ray source 1H 0419–577 was discovered in the sky survey performed by the HEAO 1 A-1 experiment, covering the 0.25–25 keV band, from late 1977 to early 1978 (Wood et al. 1984). At that time, the 2–10 keV flux was ~2 × 10^{-11} ergs cm^{-2} s^{-1} in the rest frame. The HEAO 1 A-1 survey was followed by a program of optical identifications, and an analysis of HEAO 1 A-3 X-ray positions identified a Seyfert galaxy (V = 14.3; z = 0.104) as the optical counterpart to the HEAO 1 X-ray source (Brissenden 1989). The source was later detected in the Einstein slew survey (Elvis et al. 1992) and by ROSAT with both the PSPC and the WFC (Pounds et al. 1993). Thomas et al. (1998) confirmed LB 1727 to be a bright X-ray source and a Seyfert 1.5 galaxy (Grupe 1996; Thomas et al. 1998).

Confusion has arisen on several occasions as to whether LB 1727 and 1H 0419–577 are the same source or not; they are. An error in some EUVE finding charts led to confusion, because 1H 0419–577 and LB 1727 were wrongly marked as two different sources in those charts. This error eventually resulted in an incorrect position assignment for LB 1727 in the Véron-Cetty & Véron catalog (1996). Despite this early confusion, Marshall et al. (1995) did correctly identify 1H 0419–577 as a strong EUVE detection of an AGN. Comparison between the original position found by Luyten & Anderson (1958) and the optical, ROSAT, and EUVE positions confirm LB 1727 and 1H 0419–577 to be the same source, a Seyfert galaxy, and the origin of all data presented here.

Guainazzi et al. (1998) report the results from a BeppoSAX observation of LB 1727 performed 1996 September 30. The exposure time was ~23 ks with the Medium Energy Concentrator Spectrometer, which has an effective bandpass ~1.8–10 keV. Unfortunately, the Low Energy Concentrator Spectrometer, which covers the 0.1–10 keV band, was switched off during the observation because of technical problems. The source was also marginally detected in the BeppoSAX Phoswich Detector System, providing some constraint on the flux up to 36 keV. The BeppoSAX data revealed a flat spectrum in the 1–10 keV (observed) band, with photon index of \( \Gamma \approx 1.6 \) and no evidence for line emission from the K shell of iron. Guainazzi et al. (1998) also reported an index \( \Gamma \approx 2.7 \) from PSPC data covering the 0.1–2 keV band, indicating marked spectral variability and/or a sharp steepening of the spectrum below ~2 keV.

Here we present the results of new X-ray observations of LB 1727, along with several optical spectra. In § 3 we present an analysis of optical spectra from 1988 and 1993. In § 4 we detail the timing and spectral results from two ASCA observations from 1996 July and August. In § 5 we show the ROSAT HRI results from a 2 month monitoring campaign. In § 6 we discuss analysis of some simultaneous HRI and ASCA data and constraints on the amount of ionized gas along the line of sight, and in § 7 we examine the PSPC data in the light of those results. In § 8 we discuss the overall SED of LB 1727 and compare it with other Seyfert galaxies. In § 9 we discuss all of these results, along with implications regarding the presence of an XUV bump.

3. The Optical Spectrum

LB 1727 has been observed several times in attempts to identify sources from hard and soft X-ray surveys (Brissenden 1989; Grupe 1996; Thomas et al. 1998; Guainazzi et al. 1998). The optical position of the source is \((J2000) 04^{h}26^{m}0.83, -57^\circ12^\prime0.45\), with an uncertainty of 1" radius.

The optical spectra of LB 1727 are shown in Figure 1. The first two panels show spectra accumulated during 1988 February 17 and 22, on the Australian National University (ANU) 2.3 m telescope and the 3.9 m Anglo-Australian Telescope (AAT), respectively. The AAT spectrum was obtained with the combined use of the Image Photon Counting System (3 Å FWHM resolution) and the Faint Object Red Spectrograph (20 Å FWHM). A dichroic mirror was used to split the incoming beam at \( \lambda \) 5500 to supply the photons for each device. Similarly, the ANU observations were made with the Double Beam Spectrograph (3 Å FWHM). An optical spectrum was also accumulated on 1993 September 14 with the MPI/ESO 2.2 m telescope at La Silla using the Faint Object Spectrograph and Camera. The ESO 2.2 m observations used grisms yielding 5 Å FWHM resolution over the 6600–7820 and 4640–5950 Å bandpasses, plus 22 Å FWHM over the 3400–9200 Å bandpass, with exposure times of 15, 20, and 5 minutes, respectively. The detailed reduction method for the ESO 2.2 m data is described in Grupe (1996), Grupe et al. (1998a), and for the ANU and AAT data in Brissenden (1989).

Figure 1 shows that the continuum rises very steeply blueward of 4500 Å, most visibly in the AAT data, indicating the presence of a strong blue bump in this source.
optical continuum has an energy index $\alpha_{\text{opt}} = 0.01 \pm 0.40$ measured between 4400 and 7000 Å (Grupe et al. 1998b). The strong EUVE flux (Marshall et al. 1995) and steep spectrum in the soft X-ray regime (Guainazzi et al. 1998) might lead us to expect to see an optical spectrum reminiscent of a narrow-line Seyfert 1 galaxy (NLSy1); however, from an inspection of the line profiles in Figure 1, it is clear that this is not the case. NLSy1s are those objects with the narrowest optically permitted lines in the distribution covered by Seyfert 1 galaxies. The widths of the broad components of Hα and Hβ are typically only slightly broader than the forbidden lines. In general, authors usually use FWHM $H\beta < 2000$ km s$^{-1}$ (or sometimes less than 1500 km s$^{-1}$) and the presence of strong Fe II emission to distinguish between Seyfert 1s and NLSy1s. The ratio [O III]/$H\beta < 3$ is also used to differentiate NLSy1 from Seyfert 2 galaxies. In the case of LB 1727, the width of the broad Hβ component does not fit into the NLSy1 definition. The AAT data yielded FWHM $[O \, \text{III}] = 580 \pm 50$ km s$^{-1}$ (1σ errors are quoted on optical measurements in this section), FWHM $H\beta_{\text{narrow}} = 1225 \pm 200$ km s$^{-1}$, and $H\beta_{\text{broad}} = 4200 \pm 250$ km s$^{-1}$. For the ANU data the $[O \, \text{III}]$ line was fitted with a Gaussian profile, yielding $FWHM = 790 \pm 30$ km s$^{-1}$. A template was made of this line profile, and this was scaled to the flux of the narrow component of Hβ. The scaled template was shifted to the wavelength of the narrow component of the Hβ line and then subtracted from the total Hβ profile. The remaining Hβ profile was then dominated by the broad component of Hβ, which yielded a width measurement $2950 \pm 100$ km s$^{-1}$. This left a residual narrow component of Hβ with FWHM = 1080 ± 100 km s$^{-1}$. (It was not possible to satisfactorily apply this method to the AAT data.) The ESO 2.2 m data yielded FWHM $[O \, \text{III}] = 450 \pm 10$ km s$^{-1}$ and $H\beta_{\text{narrow}} = 700 \pm 100$ km s$^{-1}$, $H\beta_{\text{broad}} = 2900 \pm 100$ km s$^{-1}$, corrected for instrumental resolution (Grupe et al. 1998a). The errors given in this section are 1σ. The measurements might imply variability in the width of Hβ; however, these data were all taken using different instrument combinations with a variety of spectral resolutions,
and conclusive detection of variability could only be obtained by monitoring the source for several days with a single instrument.

The [O \text{III}]/H\beta ratio (\sim 10) is large, and there is no evidence of Fe \text{II} emission, which is most clearly evident from the AAT data. Grupe et al. (1998a) report an upper limit on the equivalent width for Fe \text{II} emission between 4250 and 5880 Å to be 30 Å and an upper limit on the ratio Fe \text{II}/H\beta of 0.4.

To determine the Balmer decrement, we used the total fluxes in the H\alpha and H\beta lines, because it is not possible to estimate the broad and narrow decrements separately owing to problems deconvolving the components of H\alpha. By using the [O \text{III}] template we are able to subtract the narrow-line emission from the H\beta line, but this is not possible with the H\alpha line. Unfortunately, H\alpha is also contaminated by the [N \text{II}] \lambda\lambda 6548 and 6584 emission. To subtract the contributions of these lines, we subtracted 35\% of the [O \text{III}] \lambda 5007 line flux from the total H\alpha line flux. (The [N \text{II}]/[O \text{III}] ratio was suggested by Ferland & Osterbrock 1986.) Subtracting this contaminating flux allows us to make an estimate of the mean Balmer decrement, H\alpha/H\beta = 4.2. This decrement can be interpreted as an optical extinction A_V = 1.21, which in turn corresponds to an X-ray absorption of N_H = 1.8 \times 10^{21} \text{ cm}^{-2}, assuming material with a Galactic dust-to-gas ratio. However, the relatively low value of the decrement and the uncertainty in that ratio make this extinction determination somewhat tentative. In fact, the optical continuum is unattenuated. The latter might imply that the Balmer decrement is attributable to optical depth effects in the line-producing clouds rather than absorption by material in our line of sight.

4. \textit{ASCA} OBSERVATIONS AND DATA REDUCTION

\textit{ASCA} (Makishima et al. 1996) has two solid-state imaging spectrometers (SISs; Burke et al. 1994) and two gas imaging spectrometers (GISs; Ohashi et al. 1996), which are sensitive across the 0.4–10 and 0.8–10 keV bandpasses, respectively. LB 1727 was observed by \textit{ASCA} on 1996 July 22–23 and August 10–11. The data were reduced in the same way as the Seyfert galaxies presented in Nandra et al. (1997) and Turner et al. (1997). For details of the data reduction method, see Nandra et al. (1997). For the July observation, data screening yielded effective exposure times of \sim 24 ks in all four instruments. For the August observation the exposure times were \sim 23 ks in SIS and \sim 26 ks in the GIS instruments.

4.1. Time Variability

During the July and August epochs observed by \textit{ASCA}, the fluxes in the 0.5–2 keV rest frame (0.45–1.81 keV observed frame) were 4.8 and 5.5 \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1}, respectively. The 2–10 keV rest-frame fluxes (1.8–9.06 keV observed frame) were 0.94 and 1.1 \times 10^{-11} \text{ ergs cm}^{-2} \text{ s}^{-1}. The flux variation between epochs is evident in the hard-band light curves (Fig. 2). The 2–10 keV fluxes are consistent with that observed by \textit{BeppoSAX} a month later on 1996 September 30 (Guainazzi et al. 1998) and a factor of 2 lower than that observed by \textit{HEAO 1 A-1} (Wood et al. 1984) 19 yr earlier. The mean \textit{ASCA} flux implies a luminosity of \textit{L}(2–10 keV) = 4.8–5.6 \times 10^{44} \text{ ergs s}^{-1} (assuming H_0 = 50, q_0 = 0.5).

We tested the light curves for variability using the \chi^2 statistic. The source showed no significant variability in either band when sampled in 256 or 5760 s bins. Figure 2 shows the light curves constructed in the 0.5–2 and 2–10 keV observed bands and sampled on 5760 s: this integration time represents one \textit{ASCA} orbit. There is a \sim 60\% increase in soft flux and a \sim 20\% increase in the 2–10 keV flux between 1996 July and August. Integration using 1024 s bins revealed evidence (at greater than 90\% confidence) for flickering at the 10\%–30\% level in both bands during the July observation but no significant variability during the August observation.

4.2. The X-Ray Spectra

\textit{ASCA} data cover the 0.4–10 keV band in the observer frame. However, the SIS data below an energy of 0.60 keV (0.66 keV rest frame) were excluded from the spectral analysis, as it is commonly accepted that there are uncertainties associated with the \textit{ASCA} calibration in that band. Following George et al. (1998b), we make use of the fact that the calibration uncertainty is considered to be \leq 20\% and usually results in a systematic deficit of counts versus the predicted model. If data in the 0.40–0.60 keV band lie above the extrapolation of our model, then the source spectrum most likely does steepen in that band. Later we take the approach of indicating where these data lie, although we never use them in a fit.

4.2.1. 1996 July

Data in the 4.5–6.8 keV range (5–7.5 keV in the rest frame) were initially excluded, in order to temporarily remove the channels in which iron K\alpha emission would occur if present in this source. This exclusion allows us to parameterize the continuum shape more easily. We first considered the continuum in the observed 1.81–9.06 keV band (2–10 keV rest frame) using a power law attenuated by a column of neutral material. Preliminary fits showed no evidence for absorption, so the absorbing column density was fixed subsequently at the Galactic value estimated from 21 cm measurements, N_H = 2.25 \times 10^{20} \text{ cm}^{-2} (Dickey & Lockman 1990). It is worth noting that the extremely large \textit{EUVV} count rate suggests that the effective XUV–absorbing column may be even lower than this (see Marshall et al. 1995). The 1996 July data yielded a photon index \Gamma_{\text{rest}}(2–10) = 1.48 \pm 0.07 and \chi^2 = 280 for 319 degrees of freedom (dof). We then fitted the same model to the full \textit{ASCA} band (0.6–10 keV observed frame, 0.66–11.1 keV rest frame, still excluding the iron K\alpha band). This yielded \Gamma_{\text{rest}}(0.66–11.1) = 1.45 \pm 0.03 for \chi^2 = 488/533 dof. Thus there is no evidence for significant spectral curvature down to a rest energy of \sim 0.7 keV. The ratio of the data compared with this model are shown (in bold) in the top panel of Figure 3, along with the corresponding ratios (dashed line) for the data in the 0.40–0.60 and 4.5–6.8 keV bands (observer frame). There are two points to note from Figure 3: the indication of a steepening of the spectrum below a rest energy of \sim 0.7 keV and a marginal indication of line emission in the iron K\alpha regime.

Given the suggestion of emission in the iron K\alpha regime, we have repeated the spectral analysis; but including the data in the 4.5–6.8 keV band (observer frame), we find the addition of a Gaussian emission component to the model provides a reduction in \chi^2 of 11 for 3 fewer dof (compared with a model without a Gaussian component). This suggests the presence of an emission line at the 95\% confidence level. We find such a model to provide an adequate descrip-
Fig. 2.—Light curves in 5760 s bins for the combined SIS data in the observed frame 0.5–2 keV band (upper panel) and 2–10 keV band (lower panel) for the 1996 July (left panels) and 1996 August (right panels) data.

The line has a rest energy $E = 5.93^{+0.35}_{-0.25}$ keV, width $\sigma = 0.26^{+0.07}_{-0.10}$ keV, intensity $I = 2.4^{+0.6}_{-1.0} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, and equivalent width $EW = 170^{+200}_{-150}$ eV.$^{10}$ This is the first detection of iron K$\alpha$ emission from this source. While the line detection appears marginal in Figure 3, we will show that the August data strongly confirm the existence of an iron K$\alpha$ line in this source. There were too few photons in the line to merit more detailed modeling of the profile.

4.2.2. 1996 August

We treated these data in the same way as the July observation. Considering only the 2–10 keV band (rest frame), but excluding the iron K$\alpha$ regime, we find a power law attenuated by Galactic absorption provides an adequate description of the data ($\chi^2 = 595/647$ dof). The data in the 0.40–0.60 and 4.5–6.8 keV bands (observer frame) are shown dashed. It can be seen that at this epoch there are also clear indications of a steepening of the spectrum below a rest energy of $\sim 0.7$ keV. However, the ASCA data alone do not allow us to distinguish between the presence of a complex absorber or a separate continuum component. These data confirm that LB 1727 exhibits iron K$\alpha$ emission (Fig. 3).

From repeating the spectral analysis, but including the data in the iron K$\alpha$ band, we find the addition of a Gaussian emission component to the model is significant at greater than 99% confidence (providing a reduction in $\chi^2$ of 35 for 3 fewer dof compared with a model without such a component). As for the earlier epoch, such a model provides an adequate description of the full ASCA band (excluding the iron K$\alpha$ regime), giving $\chi^2 = 635/642$ dof and $\Gamma_{\text{rest}}(0.66–11.1) = 1.68 \pm 0.03$, which is significantly steeper than the index observed in the July observation. The data/model ratio for this fit are shown (in bold) in the bottom panel of Figure 3. As above, the corresponding ratios for the data in the 0.40–0.60 and 4.5–6.8 keV bands (observer frame) are shown dashed. It can be seen that at this epoch there are also clear indications of a steepening of the spectrum below a rest energy of $\sim 0.7$ keV.

$^{10}$ A $p$ next to an error indicates that the error calculation reached the highest or lowest value allowed, and thus the actual 90% limit lies at or beyond the limit set in the fit for that parameter.
find the line to have $E = 6.39^{+0.68}_{-0.66}$ keV, with $\sigma = 1.0^{+0.8}_{-0.66}$, $I = 9.6^{+3.4}_{-3.5} \times 10^{-5}$ photons cm$^{-2}$ s$^{-1}$, and $EW = 700^{+330}_{-400}$ eV at this epoch. Again, there were too few photons in the line to merit more detailed modeling of the profile. The photon index is unaffected by the addition of the line, and we note that the source appears steeper at this epoch than during the July observation, with $\Delta \Gamma \sim 0.13$.

5. THE ROSAT HRI OBSERVATIONS

LB 1727 was monitored daily by the HRI, covering a 2 month period from 1996 June 30 to 1996 September 1, including a long integration simultaneous with the ASCA observation in July. The aim of the observations was to examine the variability behavior of this source on a number of timescales, particularly the days-to-weeks timescales that have not been extensively studied in Seyferts as a class.

The HRI data were co-added and an image was produced. The HRI position for LB 1727 is (J2000) 04$^h$26$^m$0.9$^s$, which agrees with the optical position to $[\pm 57\,\pm 12\,\pm 1^\prime]$, within 1". The image shows that the only X-ray sources close to LB 1727 are relatively faint (a few percent of the flux of LB 1727). The nearest two sources are ~4" from the target and would be easily separable from LB 1727 in the SIS images if they had a significant hard X-ray flux.

A radial profile was extracted and compared with the point-spread function (PSF) of the instrument. A small excess is observed over the PSF, between 12" and 18" from the centroid position. However, such an excess is commonly seen in calibration (point) sources. This is thought to be a deficiency in the PSF model, so we conclude that there is no significant evidence for extended X-ray emission associated with LB 1727 in these data.

Figure 4 shows a light curve based on the ROSAT monitoring campaign. Source counts were extracted from a circular region of radius 30", encompassing 90% of the source counts. The background level was small compared with the source flux. The background has not been subtracted from the source light curve but is shown on the same plot (rescaled to the level appropriate to the source extraction cell). We found no evidence for large amplitude and rapid variability in LB 1727. Rapid fluctuations at the few percent level could be attributed to variations in the background rate. Significant variations in source flux were observed on timescales of ~40 ks. Moreover, the source flux increased by a factor of ~3 across the 2 month period covered by the HRI observations, one of the strongest increases being a factor of 2 change in 5 days close to the middle of the campaign. The amplitudes and timescales of variability seen in LB 1727 are similar to those observed in some other Seyfert 1 galaxies, like Mrk 335 (Turner & Pounds 1988). The timescales are long and the amplitude of variability is small compared with behavior observed in some NLSy1 galaxies such as Mrk 478 (Marshall et al. 1996) and IRAS 13224 – 3809, which has shown the most extreme short time variability in X-rays (Boller, Brandt, & Fink 1997).

6. ANALYSIS OF THE SIMULTANEOUS HRI AND ASCA DATA

The known strength of the XUV flux (e.g., Marshall et al. 1995) suggests that we might expect to observe a strong spectral break between the soft and hard X-ray regimes in this source. There is an indication that this does indeed occur, based on the turn-up observed in the lowest channels
of the SIS data (Fig. 3). We fitted the simultaneous HRI and \textit{ASCA} data together and found that a simple extrapolation of the \textit{ASCA} model significantly underpredicted the HRI flux (Fig. 5). The key question then becomes: could the presence of ionized gas, the so-called warm absorber, be the cause of the observed spectral steepening, or is that primarily due to a steepening of the continuum form?

To answer this question, we fitted the data using models based on the photoionization code ION (Netzer 1996). Here we use the ionization parameter, $U_X$, where

$$U_X = \frac{\int r(0.1 \text{ keV}) \frac{L_r}{\hbar \nu} dv}{4 \pi r^2 \rho c}.$$  

$L_r$ is the monochromatic luminosity, and $r$ is the distance from the source to the illuminated gas. $U_X$ provides a quantity directly proportional to the level of ionization of the dominant species observed in the X-ray regime. Comparison between $U_X$ and the other ionization parameters can be found in George et al. (1998b), where the ION model was applied to a sample of Seyfert 1 galaxies. It was not possible to find an acceptable fit using a single power law and an ionized absorber when the HRI point was included in the fit (the best fit yielded $\chi^2 = 636/532$ dof, which is unacceptable at greater than 99% confidence). However, the simultaneous data are adequately fitted with a broken power-law model, which gives $\Gamma_{\text{hard}} = 1.45 \pm 0.05$, $\Gamma_{\text{soft}} = 3.63 \pm 0.46$, a break energy of $0.75^{+0.03}_{-0.36}$ keV, and $\chi^2 = 488/532$ dof. Thus we conclude that a steepening of the continuum is the most natural explanation for the spectral break, and complex absorbers alone cannot mimic such a sharp up-turn.

Despite the requirement for a steepening continuum, we cannot rule out the presence of some ionized gas. If the source has a steepening continuum and is also modified by transmission through a column of (unresolved) ionized gas, then the observed break is a combination of two effects, a turn-up of the emission spectrum and a reduction in gas opacity at soft X-ray energies. We find the addition of a warm absorber does not improve the fit at all, and if the gas is very highly ionized we cannot constrain the amount of gas that might be present. If the ionization parameter is

constrained such that $U_X < 10$, as it was for the Seyfert 1 analysis (George et al. 1998b), then we find $0 < N_H < 2.42 \times 10^{22} \text{ cm}^{-2}$ (90% confidence) with a lower limit $U_X > 0.42$. It is evident that large amounts of highly ionized gas could be present but undetectable.

The data are inconsistent with the screen of neutral gas of column $2 \times 10^{21} \text{ cm}^{-2}$ estimated assuming that the Balmer decrement is an indicator of extinction, even if the covering fraction of the gas is allowed to be as small as 10%.

7. THE PSPC DATA SET

The \textit{ROSAT} PSPC data are of interest with respect to the determination of the soft X-ray spectrum, in particular the energy of the spectral break. LB 1727 was observed by the \textit{ROSAT} PSPC on 1992 April 7. Analysis of these PSPC data has been presented by Guainazzi et al. (1998). Here we present our independent analysis, which is generally consistent with that presented by Guainazzi et al. (1998). The data were corrected for time-dependent effects using the ftool PCPICOR. Source data were extracted from a cell of radius 3' and background data from an annular region centered on the source. The source flux was $F_{0.1-2 \text{ keV}} = 1.9 \times 10^{-11} \text{ ergs cm}^{-2} \text{ s}^{-1}$, corresponding to a luminosity $L(0.1-2 \text{ keV}) \sim 10^{45} \text{ ergs s}^{-1}$. This flux is approximately a factor of 4 brighter than that measured by \textit{ASCA} in the same bandpass 4 yr later and increased by only $\sim 5\%$ over the 40 ks separating the observation intervals comprising this data set.

The mean spectrum was fitted with a simple power law attenuated by a neutral absorber, which was unconstrained. It was impossible to achieve an acceptable fit using this model. The data/model ratio plot is shown in Figure 6, demonstrating a sharp break in the spectrum and confirming the result from the \textit{ASCA} and HRI data. Application of a broken power-law model yields a rest energy of $0.70 \pm 0.08 \text{ keV}$ for the spectral break. The photon index above 0.7 keV is $\Gamma = 2.61 \pm 0.15$. The data below the break energy are not well fitted with a simple power law. In this regime, much of the contribution to $\chi^2$ arises from a mixture of positive and negative data-minus-model residuals in the 0.3–0.4 keV regime. These may indicate the presence of emission and/or absorption features. However, this bandpass is where the effective area of the instrument has a steep gradient and modeling of features in this regime is strongly subject to any small residual inaccuracies in the area curve. Parameterizing this part of the spectrum with a power law gives a photon index $\Gamma = 3.72^{+1.18}_{-0.33}$ below 0.7 keV. In this case the fitted column density was $N_H = 2.93^{+0.70}_{-0.22} \times 10^{20} \text{ cm}^{-2}$, which is slightly higher than the Galactic value and yields $\chi^2 = 35/15$ dof. If the neutral column density is fixed at the Galactic value, then the soft index is found to be $\Gamma = 3.24 \pm 0.08$, but the fit is worse with $\chi^2 = 51/16$ dof. Analysis of the \textit{ROSAT} All Sky Survey (RASS) data spectrum confirms the presence of a spectral break at $\sim 0.7 \text{ keV}$ and shows spectral slopes consistent with the pointed observation.

Another alternative model to describe the spectral shape is that of a power law with an absorption edge. Such a fit yields $\chi^2 = 24/14$ dof for photon index $\Gamma = 3.02^{+0.14}_{-0.11}$ and a rest energy $E = 0.58 \pm 0.05 \text{ keV}$ for an edge of depth $\tau = 0.96^{+0.34}_{-0.32}$. The column density was $N_H = 2.50^{+0.42}_{-0.31} \times 10^{20} \text{ cm}^{-2}$. Again, the dominant contributions to $\chi^2$ are close $\sim 0.3 \text{ keV}$. In this case, the underlying continuum is steeper than that in the \textit{ASCA} regime. The fit featuring an absorp-
The average flux based on data from 1992 July through 1993 known sources of absorption, and the optical fluxes, and RASS data. All data are corrected for and combining our the multi.

The pointed observation from the PSPC found the edge, and an absorption feature is not required once we allow the data to be fitted with a broken power law.

The pointed observation from the PSPC found the source to be much brighter and the 0.6–2.0 keV index much steeper than during the ASCA epochs. Also, for all of the aforementioned fits the PSPC slope is inconsistent with the ASCA spectral index in the overlapping bandpass (which is effectively 0.6–2.0 keV). This disagreement is attributable either to spectral variability of the source or to a greater degree of inconsistency in the cross-calibration between the PSPC and ASCA than previously thought. An astrophysical explanation might be that the soft spectral component was relatively strong during the PSPC epoch and dominated the spectrum up to a higher energy than during the ASCA observation. In this case one would also expect the break to move to a higher energy, which is not observed.

8. THE IR–TO–X-RAY SPECTRUM

In Figure 7 we examine the shape of the SED by utilizing the multi–wave-band data compiled by Grupe et al. (1998b) and combining our ASCA and ROSAT data with infrared, optical fluxes, and RASS data. All data are corrected for known sources of absorption, and the EUVE data represent the average flux based on data from 1992 July through 1993 July (Marshall et al. 1995; Fruscione 1996). The IUE data were extracted from the archival observation of 1994 October 27. The IUE spectrum shows strong emission lines from Lyα and C iv (at z = 0.104) with no evidence for absorption. The IUE data lie a little low compared with the EUVE data; however, these are not simultaneous with any other data set and large-amplitude variations are a property of the XUV bump (Fig. 4).

ASCA and PSPC data are represented by pseudo–bow ties showing the 90% confidence ranges of spectral index and folding in the (10%) uncertainty in the absolute flux calibration. Table 1 summarizes the spectral slopes of LB 1727 between 100 µm and 1 keV for comparison with those calculated for a large sample of AGNs as detailed in Grupe et al. (1998b). The index between 2500 Å and 2 keV is also calculated, as this is widely quoted in the literature. We utilized the PSPC spectrum from the pointed observation of ROSAT to obtain 0.25, 1, and 2 keV flux points for index determination. The pointed data allow a more accurate determination of the fluxes than the RASS data and over a softer bandpass than the ASCA data. LB 1727 lies within the range of indices found between 5500 Å and 0.25, 1 keV for Seyfert galaxies (Grupe et al. 1998b) but at the extreme end of the range, indicating the source to be relatively bright in the soft X-ray band. However, we note that LB 1727 was

| Quantity | Slope | Definition |
|----------|-------|------------|
| 4400 Å–4600 Å | 0.01 | -4.967 log f_{4400 Å}/f_{4600 Å} |
| 5500 Å–0.25 keV | 0.73 | -0.489 log f_{0.25 keV}/f_{5500 Å} |
| 5500 Å–1 keV | 1.13 | -0.378 log f_{1 keV}/f_{5500 Å} |
| 60 µm–5500 Å | 0.70 | -0.491 log f_{5500 Å}/f_{60 µm} |
| 60 µm–0.25 keV | 0.72 | -0.245 log f_{0.25 keV}/f_{60 µm} |
| 60 µm–1 keV | 0.94 | -0.214 log f_{1 keV}/f_{60 µm} |
| 12 µm–5500 Å | 0.84 | -0.747 log f_{5500 Å}/f_{12 µm} |
| 12 µm–0.25 keV | 0.78 | -0.296 log f_{0.25 keV}/f_{12 µm} |
| 12 µm–1 keV | 1.04 | -0.251 log f_{1 keV}/f_{12 µm} |
| 2500 Å–2 keV | 1.23 | -0.384 log f_{2 keV}/f_{2500 Å} |

Figure 6.—Data/model ratio from the ROSAT PSPC data compared with a power-law model, allowing attenuation by an unconstrained column of neutral material, showing the spectral break at a rest-frame energy of ~0.75 keV.

Figure 7.—(Pseudo) bow tie marked by the thick solid line represents the ASCA spectrum for 1996 July, along with the simultaneous HRI point (diamond, with horizontal line showing the bandpass), corrected for Galactic absorption. Also shown are nonsimultaneous multi–wave-band data as compiled by Grupe (1996), EUVE data (open star), ROSAT PSPC pointed data (solid bow tie line), RASS data (dotted bow tie), IR fluxes (solid squares, with the upper limit shown for the 100 µm flux), and IUE spectrum and a low-resolution version of the optical spectrum from the ESO 2.2 m telescope.
relatively bright during the pointed PSPC observation, and the derived indices are slightly shallower than they would be if we had used the RASS or ASCA data. Obviously, combining nonsimultaneous data can only give an approximation to the SED for such a variable source. The index between 2500 Å and 2 keV is 1.23; if we assume a 2 keV flux, a factor of 4 dimmer than observed during the PSPC observation (as observed by ASCA), then the index would be 1.46. These values lie within the normal range for a Seyfert galaxy (Kriss & Canizares 1985).

As was mentioned in § 3, the soft X-ray and UV properties of LB 1727 might lead us to expect it to fall into the subclass of NLSy1s, but it does not; it has a broad width for FWHM (Hβ subclass of NLSy1s, but it does not; it has a broad width for FWHM (Hβ), the [O III]/Hβ ratio is high, and there is little evidence for Fe II emission. We investigated whether LB 1727 fits into the normal correlations found between parameters in other AGNs (e.g., Boroson & Green 1992; Grupe et al. 1998a). We found LB 1727 to have a relatively large ratio [O III]/Hβ for a source with such a flat optical continuum slope (Grupe et al. 1998a). Using the value of X-ray index based on a single power-law fit to the RASS data (Grupe et al. 1998b), we find that LB 1727 fits into the aγ-FWHM (Hβ) relationship observed for Seyfert galaxies (Boller, Brandt, & Fink 1996). If we were to use the steeper spectral index observed below 0.75 keV, then this would no longer hold true. However, using parameters from the broken power-law fit would no longer yield a fair comparison with the simple indices plotted for other sources in those samples, which were fitted with a single power-law model.

Compared with both hard and soft X-ray selected samples of AGNs, we find LB 1727 to be relatively weak in the IR regime (see Grupe et al. 1998b). This is also evident by comparison of the SED with that of other hard and soft X-ray selected AGNs (Fig. 4 of Grupe et al. 1998b). This suggests that if dust exists in this source, it is not excited by the nuclear radiation.

9. DISCUSSION

The hard X-ray spectrum of LB 1727 is flat, with \( \Gamma = 1.5-1.6 \) between rest energies \( \sim 0.75-11 \) keV, and shows no evidence for intrinsic absorption by neutral or ionized material. There are several examples of flat X-ray (2–10 keV) spectra reported for Seyfert galaxies (NGC 4151: e.g., Weaver et al. 1994; NGC 3227: e.g., George et al. 1998a; Mrk 6: George 1999); however, in most known cases these nuclei are also heavily absorbed. The observation of a flat continuum does not appear to be an artifact of confusion between continuum and Compton reflection or between continuum and a complex absorber. We added a model component representing the hard spectral feature due to Compton reflection from neutral material (Magdziarz & Zdziarski 1995). We found the 1996 July ASCA data still required a flat underlying continuum, \( \Gamma = 1.45 \pm 0.06 \), and the additional component did not improve the fit at all and gave an upper limit (at 90% confidence) on the solid angle of the reflector, \( \Omega/2\pi < 2 \) (for reflection from a disk of material observed face-on). For the 1996 August ASCA data, addition of the same model component resulted in a reduced \( \chi^2 = 5 \) and gave a solution with \( \Omega/2\pi = 1.7^{+0.2}_{-0.0} \). In that case the inferred underlying index steepened to \( \Gamma = 1.74 \pm 0.05 \). Thus the ASCA data are inconclusive on the importance of Compton reflection in this source. Models assuming reflection from ionized material may prove appropriate; however, given the limited bandpass of ASCA these data do not merit any more detailed modeling related to reflection.

Allowing the presence of large amounts of absorbing material, ionized or neutral, fully or partially covering the source, did not reveal a solution consistent with a significantly steeper continuum slope. No physical explanation has been offered linking spectral index and absorption. It is, however, plausible that the ionizing continuum could influence the condition of the line-of-sight gas and vice versa. In light of such possibilities, it is interesting to find examples of flat but apparently unabsorbed spectra. The source also shows line emission from the K shell of iron. Unfortunately there are too few line photons to constrain the ionization state of the emitting material or the width of the line.

The requirement for a marked steepening of the soft X-ray continuum, combined with a rise in the optical continuum blueward of \( \sim 4500 \) Å, indicates that a spectral component exists that peaks between these two extremes, the so-called XUV bump. While this has been inferred for many Seyfert galaxies in the past (starting with Arnaud et al. 1985), the discovery of the existence of large amounts of ionized gas along the line of sight to many Seyfert nuclei (e.g., Nandra & Pounds 1992; Reynolds 1997; George et al. 1998b) confused the issue. In many sources, it has become unclear whether the observed steepening to soft X-ray energies is predominantly because of the reduced opacity of ionized species below \( \sim 1 \) keV in an ionized absorber. Thus the existence of an XUV bump has been called into question (e.g., Nandra et al. 1995; Laor et al. 1997). Examination of LB 1727 shows that in this case, the XUV bump is required, even if we allow the possibility of some attenuation by unresolved, ionized gas. Assuming that the nucleus is unattenuated, the spectral break is constrained (by the combined HRI and ASCA data) to lie at 0.75+0.03−0.36 keV. If ionized material is present, then, while we know that this cannot produce all of the observed spectral steepening, it may contribute to it. In this case the continuum break can only be constrained to lie at a rest energy in the \( \sim 0.13-0.75 \) keV range (the lower limit being given by the effective rest energy of the lower bound of the HRI bandpass).

While LB 1727 has spectral indices that are extreme, such properties are not unknown. The source resembles the Seyfert 1 galaxy Mrk 841, which shows a two-component X-ray spectrum. The index of Mrk 841 is variable in the 2–10 keV band and has been observed to be as flat as that reported here for LB 1727 (George et al. 1993). The spectrum of Mrk 841 may also steepen to lower energies: this has been suggested to be due to the presence of an XUV bump, although, as noted above, recent analysis shows the shape of the soft X-ray spectrum could be attributable to the effects of ionized gas along the line of sight in that case, and the soft X-ray spectrum can be simply extrapolated to meet the UV data (Nandra et al. 1995).

In the case of LB 1727, the XUV bump must be a source of copious ionizing photons. Assuming there is no absorption between this bump component and the optical line-emitting regions, then it should have a noticeable effect on optical line ratios. As discussed by Cohen (1983) and Kraemer et al. (1998), the He II 4686/Hβ ratio should depend strongly on the XUV spectrum. In general, examination of the narrow components of these lines is illuminating, as the narrow-line region is free from the strong collisional effects affecting the broad-line region. As shown
by Kraemer et al. (1998), LB 1727 has a relatively strong He II contribution that may be linked to the presence of a strong XUV bump.

The Balmer decrement determined from the sum of the broad and narrow components of Hz and Hβ could be due to the presence of a column density $N_H \sim 2 \times 10^{21}$ cm$^{-2}$ along the line of sight. A column of ionized, dusty material would be consistent with data in both the optical and X-ray regimes. However, the SED indicates that dust is not important in this source, and in any case, some simpler explanations are more compelling. The lack of attenuation of the optical continuum suggests that the Balmer decrement is due to opacity effects in the line-emitting clouds. Alternatively, the gas that obscures the regions producing optical lines may simply be out of the line of sight to the nucleus.

While the HRI and ASCA data have allowed us to determine that the continuum breaks to a steeper form at $\sim 0.75$ keV, we can do little to examine the detailed spectrum of the soft component. Fortunately, it will soon be possible to examine this interesting source with AXAF and XMM. The high spectral resolution afforded by the AXAF and XMM gratings, along with their broad bandpasses, extending down to the soft X-ray regime, allows the opportunity for a significant advance in our understanding of LB 1727.

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