ABSTRACT

We present the intrinsic spectral energy distribution (SED) of the Narrow-Line Seyfert 1 galaxy (NLS1) Ark 564, constructed with contemporaneous data obtained during a multi-wavelength, multi-satellite observing campaign in 2000 and 2001. We compare this SED with that of the NLS1 Ton S180 and with those obtained for Broad-Line Seyfert 1s to infer how the relative accretion rates vary among the Seyfert 1 population. Although the peak of the SED is not well constrained, in our parameterization most of the energy of this object is emitted in the 10–100 eV regime, constituting roughly half of the emitted energy in the optical/X-ray ranges. This is consistent with a primary spectral component peaking in the extreme UV/soft X-ray band, and with disk–corona models, hence high accretion rates. Indeed, we estimate that $m \approx 1$. We also address the issue of the energy budget in this source by examining the emission lines observed in its spectrum, and we constrain the physical properties of the line-emitting gas through photoionization modeling. The available data suggest that the line-emitting gas is characterized by $\log n \approx 11$ and $\log U \approx 0$, and is stratified around $\log U \approx 0$. Our estimate of the radius of the H\beta-emitting region $R_{BLR} \approx 10 \pm 2$ lt-days is consistent with the $R_{BLR}$–luminosity relationships found for Sy1 galaxies, which indicates that the narrowness of the emission lines in this NLS1 is not due to the Broad-Line Region being relatively further away from the central mass than in BLS1s of comparable luminosity. We also find evidence for super-solar metallicity in this NLS1. We show that the emission lines are not good diagnostics for the underlying SEDs and that the absorption line studies offer a far more powerful tool to determine the ionizing continuum of AGNs, especially if comparing the lower- and higher-ionization lines.

Subject headings: galaxies: active – galaxies: individual (Arakelian 564) – galaxies: nuclei – galaxies: Seyfert – galaxies: NLS1 – galaxies: emission lines

1. INTRODUCTION

The population of Seyfert 1 galaxies has a widely used sub-classification into Narrow-Line Seyfert 1 galaxies (NLS1s) and Broad-Line Seyfert 1 galaxies (BLS1s). While this classification appears to make an arbitrary distinction based on the widths of the optical emission lines (NLS1s having FWHM(H\beta) $\leq$ 2000 km s$^{-1}$, Goodrich 1989), this is in fact an extremely useful scheme since the X-ray properties of the two subclasses are systematically different. As a class, NLS1s show rapid and large-amplitude X-ray variability (Boller, Brandt, & Fink 1996, Turner et al. 1999b), 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. 1999b; Leighly 1999a). Analogously, the spectral properties also vary across the Seyfert population with NLS1s showing systematically steeper spectra than those of BLS1s in both the soft and hard X-ray bands (Boller, Brandt, & Fink 1996; Brandt, Mathur, & Elvis 1997; Turner, George, & Nandra 1998; Leighly 1999b; Vaughan et al. 1999).

One increasingly popular hypothesis to explain the differences in X-ray properties across the Seyfert population is that NLS1s have relatively low masses for the central black hole compared to BLS1s with similar luminosities. Smaller black-hole masses naturally explain both the narrowness of the optical emission lines, which are generated in gas that has relatively small Keplerian velocities, 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). Given that NLS1s have comparable luminosity to that of the BLS1s, Pounds, Done, & Osborne (1995) suggested that they must be emitting at higher fractions of their Eddington luminosity, hence higher fractional accretion rates ($\dot{m} = M/M_{\text{edd}}$) are also required. The closer the luminosity is to the Eddington limit (and the lower the black-hole mass), the greater the fraction of the energy emitted by the accretion disk in the soft X-rays.

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accretion rates across the Seyfert population. However, measurement of that obtained for BLS1s will offer insight into the relative contributions and conditions close to the disk. In particular, examination of the SED of a NLS1, and comparison with the steeper UV/blue continua observed in NLS1s (when compared to AGN continuum in AGN is still difficult due to the severe attenuation by intrinsic reddening, even small amounts of Galactic interstellar gas along the line-of-sight. Another complication comes from intrinsic reddening, i.e., reddening associated with the active nucleus itself. Indeed, the steeper UV/blue continua observed in NLS1s (when compared to AGN spectrum composites) can be attributed at least in part to reddening, though the ionization of the absorbing material and its location with respect to the accretion source is still not well determined (Constantin & Shields 2003).

Arakelian 564 (Ark 564, IRAS 22403+2927, MGC +05-35-012) is a bright, nearby NLS1 galaxy, with \( z = 0.02467 \) and \( V = 14.6 \) mag (de Vaucouleurs et al. 1991), and a mean 2–10 keV luminosity \( L_{2-10 \text{ keV}} \approx 2.4 \times 10^{43} \text{ ergs s}^{-1} \) with flux variations of a factor of a few in a few thousand seconds (Turner et al. 2001, hereafter Paper I). It was the object of an intense multiwavelength monitoring campaign that included simultaneous observations from ASCA (2000 June 1 to July 6, Paper I; Pounds et al. 2001; Edelson et al. 2002), XMM-Newton (2000 June 17, Vignali et al. 2003), Chandra (2000 June 17, Matsumoto, Leighly, & Marshall 2002), HST (2000 May 9 to July 8, Collier et al. 2001, Paper II; Crenshaw et al. 2002, Paper IV), FUSE (2001 June 29–30, Romano et al. 2002, Paper V), and from many ground-based observatories as part of an AGN Watch project (1998 November to 2001 January, Shemmer et al. 2001, Paper III). Ark 564 has shown a strong associated UV absorber (Crenshaw et al. 1999, Paper II; Paper IV; Paper V). There are indications that it also possesses a warm X-ray absorber, as seen by the narrow absorption lines of \( \text{O VII} \) and \( \text{O VIII} \) detected in a Chandra spectrum (Matsumoto, Leighly, & Marshall 2002), and that the UV and X-ray absorbers in Arakelian 564 are physically related, possibly identical, and may be spatially extended along the line of sight (Paper V).

In this paper we present a contemporaneous SED of Ark 564, based on the extensive monitoring of 2000. In §2 we describe the observations and data reduction, summarize the main results of the monitoring campaign, and describe the adopted method for reddening correction. In §3 we present the SED of Ark 564. In §4 we constrain the mean physical properties of the line-emitting gas through photoionization modeling. In §5 we discuss some implications of our investigation. Finally, our results are summarized in §6.

12 All publicly available data and complete references to published AGN Watch papers can be found at http://www.astronomy.ohio-state.edu/~agnwatch.
13 http://tartarus.gsfc.nasa.gov/yaaqob/ccd/ihparam.html.
14 http://lheawww.gsfc.nasa.gov.
15 http://fuse.pha.jhu.edu/analysis/calfuse.html.
developed at NASA’s Goddard Space Flight Center for the STIS Instrument Definition Team (Lindler 1998). The spectra have been corrected for small wavelength intercalibration uncertainties following Korista et al. (1995). The uncertainty in the relative wavelength calibration is on the order of 0.6 Å and 1.7 Å for the G140L and G230L gratings, respectively. A separate mean spectrum was created for the G140L and G230L grating separately, given the different resolutions.

In the optical we combined two spectra. The first one, which covers the 3170–4160 Å wavelength range with a mean spectral resolution of 0.62 Å, was obtained in 1980 at Lick Observatory (D. E. Osterbrock 2002, private communication). The second one is the mean of the spectra taken between 1998 Nov to 2001 Jan at the Tel Aviv University Wise Observatory (Paper III, resolution of ∼10 Å). The host galaxy starlight contribution has been estimated by measuring its flux through PSF fitting to field stars in V-band images of the galaxy taken at Wise Observatory, which corresponds to ∼40% of the total light at 5200 Å, i.e. \( F_{gal} = 2.4 \times 10^{-15} \text{ ergs s}^{-1} \text{ cm}^{-2} \text{ Å}^{-1}\) (Paper III). Given the limited resolution (dominated by a seeing disk of ∼2.5′), it was not possible to separate the components of the host galaxy (bulge and bar) from PSF, hence we subtracted from the mean spectrum a constant host contribution of \( F_{gal} \). No scaling was necessary between the two spectra, in agreement with the low-amplitude variations of the continuum found in Paper II (∼6% over a month-long observation) and III (∼10% during a two-year monitoring). Indeed, there is growing evidence that while NLS1s show very rapid and giant X-ray variability, they show only slow and minor optical variability (O. Shemmer et al. 2003, in preparation).

To extend the SED in the IR, we derived four continuum points between ∼10000 and 24000 Å from Rodríguez-Ardila et al. (2002a,b), which were obtained on 2000 Oct 11 and 13 with the NASA 3m IRTF telescope and the SPEX spectrometer. We also retrieved archival IRAS flux measurements at 12, 25, 60, and 100 μm (Moshir et al. 1990) through the NASA/IPAC Extragalactic Database (NED).

Figure 1 shows the contemporaneous SED of Ark 564 before correction for intervening (and intrinsic, see §2.3) absorption is applied. We note that while the \( HST \) and Wise spectra are simultaneous (as well as simultaneous with the ASCA spectrum), the \( FUSE \) and Lick spectra were obtained one year later, and 20 years earlier, respectively. The FUV/optical rest-frame spectrum of Ark 564 covering the 1000–7790 Å wavelength region is presented in Figure 2 (labeled as (a)).

2.2. Summary of results from the multi-waveband observations

The continuum fit to the mean ASCA spectrum (with a power-law model modified by Galactic absorption, \( N_H = 6.4 \times 10^{20} \text{ cm}^{-2} \), Dickey & Lockman 1990) yields a slope \( \Gamma = 2.538 \pm 0.005 \) (Paper I). The strong excess of emission observed below 2 keV was parameterized as a Gaussian of peak energy \( E = 0.57 \pm 0.02 \text{ keV} \) and mean equivalent width (EW) = 110^{+11}_{-15} \text{ eV}. The soft hump component is also found to be variable in flux on timescales as short as 1 day and in shape on timescales as short as a few days (Paper I). Parameterization of the soft excess as a black-body yields a temperature \( T = 1.8 \times 10^9 \text{ K} \) and luminosity \( L_{bb} = 2.48 \times 10^{38} \text{ ergs s}^{-1} \) (Paper I). A strong, ionized \((E \approx 7 \text{ keV})\) Fe Kα line is detected, which shows variations in flux and EW on timescales as short as a week (Paper I).
of the central black hole, $M \lesssim 8 \times 10^6 M_\odot$ (Paper II). This estimate is uncertain due to the low amplitude of the Ly$\alpha$ emission line variations (1%). However, the estimate in Paper II agrees with the one obtained by Pounds et al. (2001) based on a power spectrum analysis of X-ray variability. The black hole mass and 5100 Å luminosity of Ark 564 are consistent with the hypothesis that NLS1s have lower black hole masses and higher accretion rates than BLS1s of comparable luminosity. The low level variability observed in the emission lines is also different from most Seyfert 1 galaxies, which characteristically display variations of 10% on similar timescales.

2.3. Reddening Correction in the Optical/FUV

Given the indications (Paper IV) that strong intrinsic neutral absorption is present in Ark 564 in excess of the Galactic absorption, special care has been taken in correcting the data for reddening. We used a standard Galactic extinction curve with $E(B-V) = 0.03$ mag plus the intrinsic extinction curve that Crenshaw et al. (2002, Paper IV) derive for Ark 564 and $E(B-V) = 0.14$ mag. The $HST$ extinction correction was extrapolated linearly into the $FUSE$ band, as suggested by Hutchings & Giasson (2001) and Sasseen et al. (2002). The effect of reddening correction in the optical/UV bands is presented in Figure 2, where the observed spectrum in the 1000–7790 Å wavelength range (labeled as (a)) is compared to the absorption-corrected one (labeled as (b)).

3. The Intrinsic SED of Ark 564

Figure 3 shows the Ark 564 data in the IR/X-ray range. A power-law fit of the continuum in the optical/FUV region\(^{16}\) yields $F_\lambda \propto \lambda^{-1.58\pm0.01}$, hence spectral index $\alpha = 0.42\pm0.01$ (specific flux $f_\lambda \propto \nu^{-\alpha}$). Extrapolation of this power law in the X-ray regime greatly overpredicts the X-ray flux (dashed line). Analogously, the hard X-ray continuum slope ($\alpha_{\text{ASCA}} = 1.538\pm0.005$, §2.2, long-dash–dot line) extrapolated to the lower energies overpredicts the optical/FUV flux, as previously noted by Walter & Fink (1993). Clearly, both the optical/FUV and the X-ray power-laws must break at some energy between the FUV and soft X-ray. With the adopted reddening correction (§2.3), the spectral energy distribution peaks at $\sim 50$ eV.

Table 2 summarizes some relevant data from the spectral energy distribution derived using the simple parameterization of the combination of an optical/FUV power law with $\alpha = 0.42$ breaking at $\sim 50$ eV to $\alpha_{\text{ASCA}} = 1.538$ (hereon SEDA), as described above, as well as the $IRAS$ and $IRTF$ data points (§2.1). Column (1) is the rest wavelength/energy, Column (2) and (3) list the observed and reddening corrected values of $\nu L_\nu$, respectively. We estimate that the number of ionizing photons is $Q(\text{SED}) \approx 10^{55}$ photons s\(^{-1}\)

We also considered a more conservative spectral energy distribution (the solid line in Figure 3, hereon SEDB) in which the the FUV and the soft X-ray data are connected with a simple power law ($\alpha = 1.08$), i.e., the combination of an optical/FUV power law with $\alpha = 0.42$ breaking at 1000 Å to $\alpha = 1$, then again breaking at $\approx 0.8$ keV to $\alpha_{\text{ASCA}} = 1.538$. The number of ionizing photons for SEDB is $Q(\text{SED}) \approx 5 \times 10^{54}$ photons s\(^{-1}\), which

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\(^{16}\) The fit was made to 9 bands: $\lambda = 1005–1007, 1029.5–1030.5, 1101–1107, 1114–1118, 1155–1180, 1350–1380, 1460–1500, 1620–1660, \text{and}7040–7050$ Å. The uncertainties are purely statistical. The continuum fit in Paper II was performed only on the $HST$ data corrected for Galactic reddening ($E(B-V) = 0.06$ mag) and produced $F_\lambda \propto \lambda^{-0.82\pm0.01}$; this is comparable to our value for this reddening, $F_\lambda \propto \lambda^{-1.75\pm0.05}$, since the uncertainties are underestimated in both cases.
is consistent with what Crenshaw et al. (2002) found\textsuperscript{17}.

4. Photoionization Modeling

In this section, we address the issue of the energy budget of Ark 564 by examining the emission lines observed in its spectrum, and we deduce the mean physical properties of the line-emitting gas. Hydrogen density $n$ and ionization parameter $U$ ($U = Q(n)/(4\pi r^2 n c$, $r$ being the distance to the ionizing source and $c$ the speed of light) through photoionization modeling given the assumed spectral energy distributions. We expect a range of ionization to exist throughout the BLR, to accurately describe which multi-zone modeling would be required; however, here we use a single density and ionization parameter modeling to derive the mean BLR properties. For each of the input continua (§4.2), we considered a total hydrogen density of $n = 10^9, 10^{10}, 10^{12}$, and $10^{13}$ cm$^{-3}$, and calculated the predicted intensities of the major emission lines, for a range of ionization parameters between log $U = -4$ and log $U = 2$. In the case of “table agn” (§4.2), we specified a grid of $n$ and $U$ values.

For the other input continua, we normalized the SEDs with respect to the measured X-ray luminosity in the absorption-corrected rest-frame 2–10 keV energy range ($L_{2-10 \text{keV}} \approx 2.4 \times 10^{43}$ ergs s$^{-1}$; Paper I), and specified the radius of the cloud, thus obtaining $U$. In the case of SEDA and SEDB, using an observed spectral energy distribution assumes that the gas responsible for the emission lines sees the same ionizing continuum as the observer does; therefore, we expect SEDA and SEDB to yield more realistic predictions of the emitted line spectrum.

4.1. Emission Line Fluxes

The fluxes (relative to H$\beta$) of the most prominent emission lines in the 1150–6817 Å wavelength range have been published in Table 2 of Paper IV; here we report a selection of them in Table 3 (Column (2), relative to Ly$\alpha$). Because of the NLS1 nature of Ark 564, the contribution from the BELR and NELR are strongly blended together and those line ratios include both components. The measured fluxes were corrected for reddening using the continuum reddening curve (Crenshaw et al. 2002), given the similar extinctions for the continuum and emission lines; the errors are propagated in quadrature from the ones listed in Paper IV, and they include photon noise, continuum placement errors, and reddening errors.

Columns (2) and (3) of Table 3 also report the fluxes of C $\lambda\lambda977$ and the O $\lambda\lambda1032,1038$ doublet, which can help better constrain the value of $n$ and $U$. These lines were modeled in Paper V, hence both a broad and a narrow component are available (denoted with BEL and NEL, respectively; Columns (2) and (3)). In order to compare with the other line ratios, we needed to account for the different contribution of BELR and NELR gas to H$\beta$, which we estimated as follows. We assumed that the ratio of the narrow component of H$\beta$ and [O III]$\lambda5007$ in NGC 5548, i.e., 0.12 $\pm$ 0.01 (Kraemer et al. 1998), can be used for Ark 564; we scaled it to the observed [O III]$\lambda5007$ flux for Ark 564, $F$([O III]$\lambda5007$) = (2.4 $\pm$ 0.1) $\times$ 10$^{13}$ ergs s$^{-1}$ cm$^{-2}$ (Paper III), obtaining the NEL ratio $F$($\beta$)/$F$([O III]$\lambda5007$) in Ark 564. Thus, we estimated that roughly 75% of the total H$\beta$ flux is from the BEL, and bracketed this value between 50% and 100%, given that the BEL and NEL contributions to C $\lambda\lambda977$ and O $\lambda\lambda1032,1038$ are the same, and that the total flux is the absolute upper limit to the BEL flux. We notice that Rodríguez-Ardila et al. (2000) found that on average, 50% of the flux of the total H$\beta$ is due to emission from the NELR, and that the $F$([O III]$\lambda5007$)/$F$(H$\beta$) emitted in the NELR varies from 1 to 5, which is much lower than our adopted value ($\sim 8.3$). This result is sustained by the analysis of Contini, Rodríguez-Ardila, & Viegas (2003). However, Véron-Cetty, Véron, & Gonçalves (2001) point out that the low $F$([O III]$\lambda5007$)/$F$(H$\beta$) values found by Rodríguez-Ardila et al. (2000) for NLS1s are due to the fact that they modeled the broad Balmer component with a Gaussian rather than a Lorentzian. In the analysis of Véron-Cetty, Véron, & Gonçalves (2001) the $F$([O III]$\lambda5007$)/$F$(H$\beta$) ratios span the range measured in BLSys, which makes our use of a value derived from a well-studied BLS1s reasonable. Furthermore, Nagao, Murayama, & Taniguchi (2001) also show that $F$([O I]$\lambda6300$)/$F$([O III]$\lambda5007$), $F$([O III]$\lambda4363$)/$F$([O III]$\lambda5007$) are indistinguishable in NLS1s and BLS1s. Given this ambiguity, in the following analysis we will note where our assumptions for the deconvolution of O $\lambda\lambda1032,1038$ and C $\lambda\lambda977$ affect the results.

As a comparison, Column (4) reports the corresponding values for a mean QSO spectrum, which we derived from Baldwin et al. (1995) by applying the reddening correction appropriate for Ark 564; the H$\alpha$/Ly$\alpha$ ratio is derived from Osterbrock & Pogge (1985). Column (5) lists the BEL fluxes of the Sy1.5 NGC 5548, corrected for NEL contribution and Galactic reddening (Korista & Goad 2000 and references therein). Column (6) lists the FWHM of the lines, as drawn from Papers V, II and III (C $\lambda\lambda977$ and O $\lambda\lambda$ are the model BEL and NEL components, while the others are measured on the whole line profile). All errors are propagated in quadrature. Finally, Column (7) reports the references for Columns (2), (3), and (6). Table 3 shows that Carbon in Ark 564 is at the lower end and Nitrogen at the upper end of the mean QSO distribution, and some interesting differences can be found with respect to the Sy1.5 NGC 5548. Indeed, N V $\lambda1240$ is stronger in Ark 564 by a factor of $\sim 2.3$, while C IV $\lambda1550$, C III$^\prime$ $\lambda1909$, and Mg II $\lambda2800$ are weaker in Ark 564 by a factor of $\sim 4.4, 2.5$ and 2.8, respectively.

4.2. Input Continua

We used the code Cloudy\textsuperscript{18} (v94.00, Ferland 1996) to predict the intensities of the lines produced by the BEL gas through photoionization modeling. Our choices of input continua for Cloudy are shown in Figure 4. In brief,

1. The Cloudy “table agn” continuum, which is the Mathews & Ferland (1987) continuum modified with a sub-millimeter break at 10 $\mu$m, so that the spectral index is changed from −1 to −5/2 for frequencies below the millimeter break.

2. The SEDA input continuum, which was created from points chosen from the spectral energy distribution presented in §3 (the circles in Figure 4), as well as one extrapolated point (the empty square), i.e., where the optical/FUV and X-ray power law extrapolations meet. In particular, in the X-ray, we used continuum points from the power-law fit and added a black body component (the dot-dash line in Figure 3) of temperature.

\textsuperscript{17} Note that SEDB corresponds to SED2 in Paper V.

\textsuperscript{18} http://www.astro.umd.edu/cloudy/
3. The more conservative SEDB input continuum, which only uses points from the observed spectral energy distribution (circles only).

4.3. Physical Conditions of the Emission-Line Gas

Figure 5 shows the line intensity of C III] λ1909 relative to Lyα as a function of hydrogen density (log $n$ (cm$^{-3}$)) and input continuum ("table agn", SEDA, and SEDB discussed in §4.2). The horizontal lines correspond to the observed value of C III] λ1909 and its errors listed in Table 3. Solutions to $U$ (as also shown in Figures 6 and 7) are double valued, but we prefer higher values based on line widths, as discussed below. As expected for a semiforbidden transition, the C III] λ1909 line becomes collisionally suppressed as the density increases, arguing for an upper limit for the density of log $n < 12$. Analogously, Figure 6 shows the intensity of C III] λ977 and total N λλ1240 which indicate log $n > 9$. Furthermore, the observed C III] λ1909 implies log $U \approx -3.3$ or log $U \approx -0.7$ for log $n = 9$, both of which are much lower than the values required for O VI, for which we derive log $U \approx -1.1$ or 0.8$^{19}$ (from a plot analogous to Figure 7b relative to log $n = 9$), i.e., no consistent result can be found for low densities.

Considering log $n \approx 11$ as a plausible estimate of the density, we can investigate the value of the ionization parameter. This has been a difficult problem always, because with only optical/UV observations, multiple ionization states of a single element are not observed and so the values of $U$ are highly model dependent. With the multiwavelength, multi-mission observations of Ark 564, we now have observations of both C III (with FUSE) and C IV (with HST), so we can actually measure the ionization parameter. As shown in Figure 7a, the C III]λ977/C IVλ1550 ratio constrains the ionization parameter to log $U = [-2.88, -0.22]^{20}$. Studies of reverberation mapping have shown that the BLR is stratified (Peterson & Wandel 1999), and so a single value of $U$ cannot possibly correspond to the entire BLR, but the range of $U$ determined above must be the dominant range of $U$ where C IV emission is produced. The higher ionization lines, e.g. O VIλ1032, 1038 and He IIλ6678 are likely to be produced closer in with higher ionization parameter. Indeed, as shown in Figure 7b, and Figure 6d, somewhat higher values of $U$ are preferred for O VI (log $U = [-1.52, -1.36]$ or log $U = [0.61, 0.87]$) and N V (log $U = [-1.43, 0.4]$).

Figure 7c shows the C IVλ1550 intensity ratio and implies that either log $U = [-2.94, -2.66]$ or log $U = [0.18, 0.34]$. Figure 7d shows the intensity ratio C IVλ1240/N VIλ1550, for which we derive log $U = [0.07, 0.39]$. The comparison with the BLS1 NGC 5548 shows that N V is stronger in Ark 564 by a factor of $\sim 2.3$, while C IV is weaker in Ark 564 by a factor of $\sim 4.4$ (§4.1 and Table 3). Hence, the observed C IV/N V ratio may be roughly one order of magnitude smaller in Ark 564, and the observed limits in Figure 7d probably reflect an overabundance of N (or C depletion).

To discriminate between the low-$U$ (log $U \approx -1.5$) and high-$U$ (log $U \approx 0$) solutions, we derive the distance of the BEL gas from $R_{\text{BELR}} = (Q/4 \pi c n U)^{1/2} \approx 1.6 \times 10^{16} Q_{55}(U)^{1/2} n^{-1/2}_{10}$ cm, where $Q_{55} = Q/10^{55}$ assuming the above values of $U$ and $n$, and the photon luminosity $Q$ from §3. For log $n = 11$ and log $U \approx -1.5$, the inferred distance of the BEL is $R_{\text{BELR}}^{\text{SEDA}} = 9.2 \times 10^{16}$ cm for $Q($SEDA$)$, and $R_{\text{BELR}}^{\text{SEDB}} = 6.5 \times 10^{16}$ cm for $Q($SEDB$)$. For log $n = 11$ and log $U \approx 0$, $R_{\text{BELR}}^{\text{SEDA}} = 1.63 \times 10^{16}$ cm and $R_{\text{BELR}}^{\text{SEDB}} = 1.15 \times 10^{16}$ cm. For a central mass of $M =$

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19 We find log $U \approx -0.9$ or 0.8 if we do not deconvolve BEL and NEL.
20 log $U = [-3.07, -0.36]$ if we do not deconvole BEL and NEL.
21 log $U = [-1.44, -1.23]$ or log $U = [0.64, 0.79]$ if we do not deconvolve BEL and NEL.
The observed optical/FUV spectral energy distribution did not change, consistent with the one obtained from the Lick spectrum, which was obtained in 1980. This latter fact suggests that, although the flux level changed between 2000 and 2001, the overall shape of the SED of NLS1 Arakelian 564 did not change. Column (6) of Table 3 shows that FWHM(C IV) = 1934 km s⁻¹, FWHM(C III) = 1920 km s⁻¹, and FWHM(N V) = 2809 km s⁻¹. Therefore, the comparison with the observed FWHMs favors the high-U solutions. Finally, Table 3 shows that the FWHM of O VI is larger than that of N V, which is larger than that of C IV, again consistent with the stratified BLR model.

5. DISCUSSION

A non-simultaneous optical, UV and X-ray spectral energy distribution of Ark 564 was presented by Comastri et al. (2001) who found that it peaks in the soft-X-ray band. Here we present a spectral energy distribution which is obtained from contemporaneous data covering almost 5 decades in energy. Simultaneity is particularly important for NLS1s, since, as a class, they are extremely variable in time, although Ark 564 has shown only weak variability in the optical/UV bands (Paper II-III).

We report some relevant data from the spectral energy distribution in Table 2. These were derived using the simple parameterization of the combination of an optical/FUV power law with spectral index \( \alpha = 0.42 \) breaking at \( \sim 50 \text{ eV} \) to \( \alpha_{\text{ASC A}} = 1.538 \) (SEDA in Figure 3), as well as the IRAS and IRTF data points (§2.1). A more conservative spectral energy distribution, instead, connects the FUV and the soft X-ray data with a simple power law (\( \alpha = 1.08 \), the solid line in Figure 3), and is a combination of an optical/FUV power law with \( \alpha = 0.42 \) breaking at 1000Å to \( \alpha = 1.081 \), then again breaking at \( \sim 0.8 \text{ keV} \) to \( \alpha_{\text{ASC A}} = 1.538 \) (SEDB in Figure 3). The ambiguity in the shape of the spectral energy distribution in the 900Å–0.8 keV region is rather unfortunate, since a considerable portion of the energy of Ark 564 might be output in this range. Previous ROSAT (Brandt et al. 1994) and BeppoSAX (Comastri et al. 2001) data showed a flattening of the soft excess toward the lowest X-ray energies available, and the XMM spectrum obtained during the monitoring campaign of 2000 shows a definite curvature in the soft excess (Vignali et al. 2003).

An interesting issue is how Ark 564 compares to other NLS1 galaxies and with BLS1 in terms of its broad-band properties, as they can be quantified by spectral indices. Table 4 reports the intrinsic spectral indices calculated between different wavelength bands for Ark 564 and, as a comparison, the corresponding values for the NLS1 Ton S180 and BLS1s. These show that while the inter-band properties of Ton S180 are not significantly different from the ones observed in BLS1s (Turner et al. 2002), this may not be the case for Ark 564. Table 4 indicates that the two NLS1s have steeper X-ray slopes than BLS1s, Ark 564 more so than Ton S180 (\( \alpha_{\text{ox}} = 1.57 \) and 1.44, respectively, compared to 0.91 for BLS1s), which is consistent with the general characteristics of NLS1s. The optical/X-ray spectral index \( \alpha_{\text{ox}} \), on the other hand, is lower in Ark 564 than in BLS1s and Ton S180 with \( \alpha_{\text{ox}} = 1.11 \) for Ark 564 and 1.52 for Ton S180. This reflects the fact that Ark 564 is relatively more X-ray bright, or that the optical continuum is suppressed, compared to other AGNs. The other indices also reflect the X-ray brightness of Ark 564 when compared to BLS1s. We cannot exclude the possibility that intrinsic reddening in excess of the

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22 The Lick spectrum, which was obtained in 1980 is merely used to fill in a small gap in the optical data, and the 2001 FUSE spectrum shows a continuum slope consistent with the one obtained from the HST spectrum. This latter fact suggests that, although the flux level changed between 2000 and 2001, the overall shape of the optical/FUV spectral energy distribution did not change.

23 The observed \( \alpha_{\text{ox}} \) is 0.94 in Ark 564.
but also that the largest Eddington ratios are found in NLS1s. Indeed, they showed that NLS1s are at the extreme of a well-defined sequence relating the Eddington ratio to the line widths. Furthermore, Wang & Netzer (2003) show that a model of extreme slim disk (which is responsible for the soft X-ray excess, or hump, seen in most NLS1s) and a hot corona (contributing to the hard X-ray emission) can also naturally explain the X-ray spectral variability characteristics observed in Ark 564 such as simultaneous variations of the soft hump and the hard X-ray without a significant time lag (Turner et al. 2001). Through a comparison of the X-ray variability of Ark 564 and the BLS1 NGC 3516, Pounds et al. (2001) estimate that the mass of the central black hole in Ark 564 is $\sim 10^7 M_\odot$, implying an accretion rate in the range $\dot{m} \approx 0.2-1$. With a bolometric luminosity in the order of $10^{45}$ erg s$^{-1}$ and an Eddington luminosity $L_{\text{Edd}} \approx 10^{45}$ ergs s$^{-1}$, we also infer that $\dot{m} \approx 1$. Wang & Netzer (2003) also provide a means of estimating the black hole mass (if the accretion is super-critical) which is independent on the accretion rate itself. For Ark 564, we obtain $M \approx 2 \times 10^8 M_\odot$, which is within a factor of a few from the Collier et al. (2001) estimate.

Figure 8 compares the SED of Ark 564 with the mean SED for radio-quiet quasars (Elvis et al. 1994), the LZ SED (Laor et al. 1997; Zheng et al. 1997), the Seyfert 1.5 galaxies NGC 5548 (Kraemer et al. 1998) and NGC 4151 (Kraemer et al. 2000), and the NLS1 Ton S180 (Turner et al. 2002). There are significant differences in the intrinsic shape of the SED across the AGN population (see, also, Turner et al. 2002), the most evident being the energy of the peak and the presence (or lack of) of the big blue bump (BBB), the signature of the emission from the accretion disk. The radial dependence of the temperature for an optically thick, geometrically thin accretion disk (Shakura & Sunyaev 1973) is, $T(R) \sim 6.3 \times 10^5 (m)^{1/4} M_8^{1/4} (R/R_8)^{-3/4}/K$ (Peterson et al. 2000), where $M_8$ is the mass in units of $10^8 M_\odot$, $R$ is the radius, and $R_8$ is the Schwarzschild radius. For Ark 564, using $m \approx 1$, as we derived above, and $M \approx 8 \times 10^8 M_\odot$ (Paper II), the peak temperature is $\sim 125$ eV; this is within a factor of 3 from the peak of our less conservative parameterization, SEDA (defined extrapolating the optical power-law continuum to meet the extrapolation of the X-ray power law) which peaks at 50 eV. The true SED probably peaks somewhere between these two values. For comparison, the NLS1s RE J1034+396 (Puchnarewicz et al. 2001) and Ton S180 (Turner et al. 2002) peak at $\approx 250$ eV and $\approx 100$ eV, respectively. Therefore, even among the NLS1s, differences in the shape of the SED are observed. However, in none of these NLS1s there is an indication of the presence of optical/UV BBB, and a strong soft X-ray excess is seen, instead. In this light, Ark 564, is also consistent with the paradigm that the accretion disk is so hot in NLS1s that the BBB is shifted in the EUV–soft X-rays.

We also note that Ark 564 is rather FIR bright (with respect to the optical), compared to the sample of radio-quiet quasars and the LZ sample, as can be seen in Figure 9, where the SEDs have been normalized to match their optical/UV slope (as opposed to the 2 keV flux in Figure 8). Indeed, if we use the definition of the IR flux as a function of the IRAS fluxes given by Sanders & Mirabel (1996)$^{24}$, we obtain that $L(8–1000 \mu m) \approx 10^{11} L_\odot$, which makes Ark 564 a luminous IR galaxy. The shape of the IR/optical SED of Ark 564 also resembles the shapes observed in the IRAS Bright Galaxy Survey (see Figure 2 in Sanders & Mirabel 1996, for intermediate values of $f_{\text{IR}}$). Using SEDA, we

$^{24}$ $F(8–1000 \mu m) = 1.8 \times 10^{-14} (13.48 f_{12} + 5.16 f_{25} + 2.58 f_{60} + f_{100})$ W m$^{-2}$, where $f_{12}, f_{25}, f_{60},$ and $f_{100}$ are the IRAS flux densities in Jy at 12, 25, 60, and 100 $\mu$m.
estimate that the FIR luminosity is $L_{\text{FIR}} \approx 1.3 \times 10^{44} \text{ergs s}^{-1}$, i.e., $\sim 10\%$ of the total luminosity and $\sim 20\%$ of the combined optical/UV/X-ray luminosity. Crenshaw et al. (2002) noted that the associated warm UV absorber is lukewarm and dusty. The IR emission observed in this object could then be thermal emission from the dust grains embedded in the absorber as they are heated by the strong UV/EUV continuum. Given the IR brightness in this object and in many NLS1s (Moran, Halpern, & Helfand 1996), it is not unlikely that a contribution might be coming from the host galaxy, in the form of a nuclear starburst (Mathur 2000). Crenshaw et al. (2002), however, did not detect any extended emission in the two-dimensional STIS spectral images that could be due to a nuclear starburst. We compared the FUSE spectrum, which was taken through a much larger aperture, and hence is more likely to show stellar absorption features, with a FUSE 'template' spectrum of the starburst galaxy NGC 7496; using the constraints from the Ly$\gamma$–C III$]\lambda 977$ profiles, we obtained a rough upper limit of the starburst contribution at 1000Å of 50%. A further constraint on the IR starburst contribution would probably come from detection and measurements of the 3.3–3.4μm PAH emission features, which have been found in starburst galaxies, luminous IR galaxies, and obscured AGNs (Moorwood 1986; Imanishi 2002), and which have been successfully detected in the NLS1 NGC 4051 (Rodríguez-Ardila & Viegas 2003).

Using our SEDA and SEDB as inputs to Cloudy we predicted the intensity of the strongest lines in the FUV/UV spectrum and compared them with the observed values in order to constrain the physical parameters of the line-emitting gas, namely, the density and ionization parameter. Figure 6 and 7 show that SEDA and SEDB, because of their strong EUV to soft X-ray flux, for a given observed line ratio predict values of ionization parameter which are lower than those with standard AGN continuum. From C III$]\lambda 1909$, C III$]\lambda 977$, and N V$]\lambda 1240$, we infer that $\log n \approx 11$. Two classes of solutions for $U$ are consistent with this density value, one with low $U$ values ($\log U \approx -1.5$) and one with high $U$ values ($\log U \approx 0$). We discarded the low-$U$ class (§4.3) on the basis that the predicted widths of the lines, derived from the velocity dispersion $V = (GM/R_{\text{BLR}})^{0.5}$, of 740–880 km s$^{-1}$ are too small with respect to the observed ones ($\approx 2000$ km s$^{-1}$; Paper II). As expected, we find that the BLR is stratified around $\log U \approx 0$, with higher ionization lines originating from regions with higher $U$.

Column (6) of Table 3 shows that FWHM(Ly$\alpha$)$= 2114$ km s$^{-1}$, FWHM(N V)$= 2809$ km s$^{-1}$, and FWHM(C IV)$= 1934$ km s$^{-1}$, which indicate that the radii of the L$_{\alpha}$, N V, and C IV broad-line emitting regions are $R_{\text{BLR}} \approx 4.3$ lt-days, $R_{\text{BLR}} \approx 2.5$ lt-days, and $R_{\text{BLR}} \approx 5.2$ lt-days. Using the findings of previous monitoring programs on Seyfert 1s (Netzer & Peterson 1997), we can estimate the size of the H$\beta$-emitting region from $R_{\text{BLR}} \approx 0.5 R_{\text{BLR}}$ and $R_{\text{BLR}} \approx 0.2 R_{\text{BLR}}$. For NGC 5548, furthermore, $R_{\text{BLR}} \approx 0.5 R_{\text{BLR}}$ (Peterson 1993). We can conclude that $R_{\text{BLR}} \approx 10 \pm 2$ lt-days, which is consistent with the $R_{\text{BLR}}$–luminosity relationships of Kaspi et al. (2000) and Peterson et al. (2000), when we assume a luminosity $L_{\lambda}(5100 \AA) \approx 3.2 \times 10^{43}$ ergs s$^{-1}$ (Table 2). This indicates that the BLR radius of this NLS1 is consistent with the distribution of BLR radius in BLS1s, and that the narrowness of the emission lines is not due to the BLR being relatively further away from the central mass than in BLS1s of comparable luminosity.

Table 3 shows that some interesting differences in line ratios can be found with respect to the Sy1.5 NGC 5548. Indeed, N V$]\lambda 1240$ is stronger in Ark 564 by a factor of $\sim 2.3$, while C IV$]\lambda 1550$, C III$]\lambda 1909$, and Mg II$]\lambda 2800$ are weaker in Ark 564 by a factor of $\sim 4.4, 2.5$ and 2.8, respectively. While all line ratios in Ark 564 are statistically consistent with the ones measured for a mean QSO (given the large uncertainties on our measurements), Carbon lines are at the lower end and Nitrogen at the upper end of the QSO distribution, confirming this trend for weak Carbon and strong Nitrogen in Ark 564. Furthermore, C III$]\lambda 977$ would indicate that $-3.13 < \log U < -0.05$ (Figure 6), and for this range, the observed N V/C IV ratio is larger than the model predictions by a factor of $\sim 8$. This may imply super-solar metallicity in this NLS1 as suggested by Mathur (2000) and is consistent with the finding of Shemmer & Netzer (2002) that NLS1s have higher metallicities than BL AGNs for a given luminosity.

An interesting question is how sensitive the emission lines are to the true shape of the ionizing continuum. Given the difficulty related to deblending the BEL and NEL components of the lines and consequent large errors on the observed line ratios, the present emission line data do not allow us to discriminate between SEDA and SEDB. These SEDs differ in the range 1000Å–750 eV (corresponding to the gap in the data between the FUSE and ASCA spectra), with the maximum difference at around 50 eV. This difference should show the most for the high ionization lines of C IV, N V and O VI. However, the predicted strength of their emission lines is very similar for the two SEDs, for a wide range of ionization parameters of interest (Figures 6 and 7). Perhaps, this is the reason why the emission line spectra of most AGNs look so very similar, over a wide range of luminosities. This demonstrates how unsuitable emission lines are as diagnostics for the underlying SEDs.

The absorption lines, on the other hand, are sensitive to the
input SED (Mathur et al. 1994). Column densities of different ions can be inferred from the fractional abundances $f_{\text{ion}}$, the total column density $N_{\text{ion}}$, and the assumed abundances $N_X = N_{\text{ion}} / N_{\text{ion}}$, through photoionization calculations (assuming an SED). Figure 10 (Top) shows the fractional column densities for the same ion calculated with the different SEDs $[N_{\text{ion}}(\text{SEDA}) / N_{\text{ion}}(\text{SEDB})]$, $[N_{\text{ion}}(\text{SEDA}) / N_{\text{ion}}(\text{SED})]$, and $[N_{\text{ion}}(\text{SEDA}) / N_{\text{ion}}(\text{SED})]$, which turn out to be good diagnostics even at lower ionization parameters. Thus, in principle, absorption line studies offer a far more powerful tool to determine the ionizing continuum of AGNs, especially if comparing the lower- and higher-ionization lines. This underlines the power of multiwavelength observations.

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6. SUMMARY

We presented the intrinsic spectral energy distribution of Ark 564, constructed with quasi-simultaneous data obtained during 2000 and 2001. We compared this SED with that of Ton S180 and with those obtained for Broad-Line Seyfert 1s to infer how the relative accretion rates vary among the Seyfert 1 population. The peak of the SED is not well constrained; however, in our parameterization most of the energy of this object is emitted in the 10–100 eV regime, and constitutes roughly half of the emitted energy in the optical/X-ray ranges. This is consistent with a primary spectral component peaking in the soft X-ray band, therefore with the predictions of the slim disk models, hence high accretion rates. Indeed, we estimate that $m \approx 1$.

We constrained the mean physical conditions in the BELR of this AGN, by examining the emission lines observed in its spectrum, and deduced the physical properties of the line-emitting gas through photoionization modeling. We concluded that the line-emitting gas is characterized by $\log n \approx 11$ and $\log U \approx 0$, and is stratified around $\log U \approx 0$. Our estimate of the radius of the $H\beta$ emitting region $R_{\text{BLR}} \approx 10 \pm 2$ lt-days, is consistent with the $R_{\text{BLR}}$ luminosity relationships of Kaspi et al. (2000) and Peterson et al. (2000). This indicates that the narrowness of the emission lines is not due to the BLR being relatively further away from the central mass than in BLS1s of comparable luminosity. We also find evidence for super-solar metallicity in this NLS1, based on the low C IV/N V observed line ratio. While the emission lines turn out to be unsuitable as diagnostics for the underlying SEDs, we showed that absorption line studies offer a far more powerful tool to determine the ionizing continuum of AGNs, especially if comparing the lower- and higher-ionization lines. This underlines the power of multiwavelength observations.
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Table 1
Observing Log for Arakelian 564

| Observatory  | Instrument (1) | UT Dates (2) | Wavelength/Energy (3) | Notes (4) | References (5) |
|--------------|----------------|--------------|-----------------------|-----------|----------------|
| ASCA         | 2000 Jun 1–Jul 6 | 0.75–9.76 keV | 2.98 Ms, continuous | 1         |                |
| XMM-Newton   | 2000 Jun 17     | 0.3–8 keV    |                       | 2         |                |
| FUSE         | 2001 Jun 29-30  | 1000–1175 Å | 63 ks; 30′′x 30′′(LWRS)| 3         |                |
| HST          | STIS/G140L      | 2000 May 9–Jul 8 | 1175–1711 Å | 554304 s; 52′′x 0′′5 | 4,5       |
| HST          | STIS/G230L      | 2000 May 9–Jul 8 | 1711–3143 Å | 24216 s; 52′′x 0′′5 | 4,5       |
| Lick         | 1980           | 3170–4160 Å |                       | 6         |                |
| Wise         | FOSC           | 1998 Nov–2001 Jan | 4160–7790 Å |                       | 7         |
| IRTF         | SPEX           | 2000 Oct 11, 13 | 8200–24000 Å | ∼30 min, 15′′x 0′′8 | 8         |
| IRAS         |                |              | 12, 25, 60, 100 µm   |           | 9              |

- Observed-frame wavelength/energy bands utilized.
- Except for gaps due to Earth occultation and passage of the spacecraft through the SAA.
- Only few continuum points were used for this work.

References. — (1) Turner et al. 2001. (2) Vignali et al. 2003. (3) Romano et al. 2002. (4) Collier et al. 2001. (5) Crenshaw et al. 2002. (6) D. E. Osterbrock 2002, private communication; (7) Shemmer et al. 2001. (8) Rodríguez-Ardila et al. 2002b and references therein. (9) Moshir et al. 1990.
### Table 2

Data from the Spectral Energy Distribution

| Rest Wavelength /Energy | $\nu L_\nu$ (Observed) | $\nu L_\nu$ (Intrinsic, SEDA) |
|-------------------------|------------------------|------------------------------|
|                         | ($\times 10^{43}$ ergs s$^{-1}$) | ($\times 10^{43}$ ergs s$^{-1}$) |
| 97.59 $\mu$m$^a$        | 3.98                   | 4.57                         |
| 58.56 $\mu$m$^a$        | 4.82                   | 5.50                         |
| 24.40 $\mu$m$^a$        | 7.91                   | 8.91                         |
| 11.71 $\mu$m$^a$        | 8.73                   | 9.77                         |
| 2.4 $\mu$m$^b$          | 3.3                    | 3.5                          |
| 1.6 $\mu$m$^b$          | 2.2                    | 2.4                          |
| 1.14 $\mu$m$^b$         | 2.1                    | 2.4                          |
| 1 $\mu$m$^c$            | 2.045                  | 2.165                        |
| 9850 Å$^b$              | 2.0                    | 2.3                          |
| 7000 Å                  | 1.851                  | 2.660                        |
| 5500 Å                  | 1.73                   | 3.057                        |
| 5100 Å                  | 1.694                  | 3.193                        |
| 3000 Å                  | 1.461                  | 4.338                        |
| 2500 Å                  | 1.388                  | 4.819                        |
| 1000 Å                  | 1.075                  | 8.178                        |
| 0.046 keV$^d$           | ⋯                      | 17.5                         |
| 0.25 keV$^d$            | ⋯                      | 7.195                        |
| 0.78 keV                | 2.895                  | 5.240                        |
| 1 keV                   | 3.046                  | 4.668                        |
| 2 keV                   | 2.060                  | 2.419                        |
| 10 keV                  | 0.942                  | 0.970                        |

Note. — The intrinsic optical/UV/X-ray data are from the reddening-corrected, rest-frame SEDA (§3). SEDB is SEDA with the exclusion of the point at $\sim 50$ eV. We adopt $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, $q_0 = 0.5$.

$^a$IRAS data points (§2.1).

$^b$IRTF data points (§2.1).

$^c$Extrapolated value from the optical/FUV power law (spectral index $\alpha = 0.42 \pm 0.01$, §3).

$^d$Extrapolated value from the ASCA power law ($\alpha_{\text{ASCA}} = 1.538 \pm 0.005$, §2.2), peak of SEDA (§3).
Table 3
ARAKeLIAN 564 Emission-Line Characteristics

| Line             | F/F(\text{Ly}α) | F/F(\text{Ly}α) | F/F(\text{Ly}α) | F/F(\text{Ly}α) | FWHM  | References |
|------------------|-----------------|-----------------|-----------------|-----------------|-------|------------|
|                  | BEL+NEL        | BEL             | QSO            | NGC5548         |       |            |
| C III λ977       | 0.053±0.017     | 0.031±0.015     | ...            | ...             | 4000,1100 | 1,2        |
| O VI λ1032       | 0.284±0.032     | 0.200±0.052     | ...            | 0.036           | 4000,1100 | 1,2        |
| O VI λ1038       | 0.141±0.048     | 0.100±0.026     | ...            | 0.018           | 4000,1100 | 1,2        |
| O VI λ1032,1038  | 0.425±0.141     | 0.300±0.076     | 0.1–0.3e       | 0.054           | 4000,1100 | 1,2        |
| Lα λ1216         | 1.00            | 1.00            | 1.00           | 1.00            | 2114  | 3,4        |
| N V λ1240        | 0.275±0.118     | ...             | 0.09–0.26      | 0.119           | 2809  | 3,4        |
| C IV λ1550       | 0.215±0.087     | ...             | 0.28–0.42      | 0.937           | 1934  | 3,4        |
| He II λ1640      | 0.101±0.040     | ...             | 0.06–0.13f     | 0.143f          | 1195,1831 | 3,4      |
| O III| λ1663          | 0.038±0.015     | ...             | ...             | ...    | 3,4        |
| C III| λ1909          | 0.068±0.026e    | ...             | 0.09–0.19h      | 0.171g | 1920       | 3,4        |
| Mg II λ2800      | 0.066±0.008     | ...             | 0.06–0.13      | 0.188           | 1659  | 3,5        |
| Hβ λ4861         | 0.063±0.019     | ...             | 0.02–0.05      | ...             | 700   | 3          |
| Hα λ6563         | 0.240±0.080     | ...             | 0.05–0.09i     | ...             | ...   | 3          |

aReddening-corrected flux relative to \text{Ly}α derived from Crenshaw et al. (2002). The lines are corrected using $E(B-V) = 0.14 \pm 0.04$ mag and Ark 564 reddening curve from Crenshaw et al. (2002) plus $E(B-V) = 0.03$ mag and Galactic curve (§2.3).

bBEL fluxes, corrected for NEL contribution and Galactic reddening of the Sy1.5 NGC 5548; derived from Korista & Goad (2000) and references therein. The O VI line ratios are derived from the BEL values in Brotherton et al. (2002), then corrected for Galactic reddening ($E(B-V) = 0.03$ mag, and extinction law of Cardelli, Clayton, & Mathis 1989).

cModel FWHM of C III λ977 and O VI relative to BEL and NEL components (Paper V), separately; the others are measured on the whole line profile (Paper II). The He II values are relative to the G140L and G230L mean spectrum, respectively (Paper II).

dTotal O VI+Lyβ flux. This compares with 0.434±0.141 for Ark 564.

eTotal He II+O III] λ1666 flux. This compares with 0.139±0.043 for Ark 564.

fTotal C III| λ1909+Si III| λ1892 flux.

gTotal C III| λ1909+Si III| λ1892+Al III| λ1990 flux.

hBased on the range of values of Hα/Hβ (3.97–6.64) from the NLS1 sample of Osterbrock & Pogge (1985).

References. — (1) This work. (2) Paper V. (3) Paper IV. (4) Paper II. (5) Paper III.
### Table 4
**Spectral Indices**

| Index            | Definition                                                                 | Ark 564a | Ton S180a | BLSy1 | References       |
|------------------|----------------------------------------------------------------------------|----------|-----------|-------|------------------|
| $\alpha_{100\mu m-12\mu m}$ | $-1.086 \log (F_{12\mu m}/F_{100\mu m})$ | 0.64     |           |       |                  |
| $\alpha_{12\mu m-2.4\mu m}$ | $-1.431 \log (F_{2.4\mu m}/F_{12\mu m})$ | 1.64     |           |       |                  |
| $\alpha_{2.4\mu m-1.6\mu m}$ | $-5.679 \log (F_{1.6\mu m}/F_{2.4\mu m})$ | 1.94     |           |       |                  |
| $\alpha_{1.6\mu m-1\mu m}$   | $-4.900 \log (F_{1\mu m}/F_{1.6\mu m})$ | 1.18b    |           |       |                  |
| $\alpha_{12\mu m-1\mu m}$    | $-0.927 \log (F_{1\mu m}/F_{12\mu m})$ | 1.60b    |           |       |                  |
| $\alpha_{3000-1000}$ (\(\alpha_{uv}\)) | $-2.096 \log (F_{1000}/F_{3000})$ | 0.42     | 0.66      | 1.25  | 1                |
| $\alpha_{\text{FUSE-ASCA}}$  | $1.08$                                                                       |         |           |       |                  |
| $\alpha_{5500-0.25keV}$      | $-0.489 \log (F_{0.25keV}/F_{5500})$ | 0.82b    | 1.12      | 0.73  | 2                |
| $\alpha_{5500-1keV}$ (\(\alpha_{\text{ox-hard}}\)) | $-0.378 \log (F_{1keV}/F_{5500})$ | 0.93     | 1.38      | 1.13  | 3                |
| $\alpha_{1\mu m-2keV}$ (\(\alpha_{\text{ox}}\)) | $-0.312 \log (F_{2keV}/F_{1\mu m})$ | 1.01b    | 1.35      | 1.14-2.16 | 4 |
| $\alpha_{2500-2keV}$ (\(\alpha_{\text{ox}}\)) | $-0.384 \log (F_{2keV}/F_{2500})$ | 1.11     | 1.52      | 1.46\(^{+0.05}_{-0.07}\), 1.21\pm0.02 | 5,6 |
| $\alpha_{\text{x}}$ | $-1.431 \log (F_{10keV}/F_{2keV})$ | 1.57     | 1.44      | 0.91  | 7                |

Note. — For spectral indices relative to the Ark 564 IRAS points we used the reddening-corrected, redshift-corrected fluxes and wavelengths.

*Intrinsic, i.e, reddening-corrected, redshift-corrected (SEDA).

*Based on extrapolated value (§3, Figure 3).

*Simple power law connecting the high energy end of the FUSE spectrum and the low energy end of the ASCA spectrum (§3, Figure 3).

References. — (1) Cheng, Gaskell & Koratkar 1991; index in the 2200-1200 Å band, based on the BLS1 subsample. (2) Turner et al. 1999a. (3) Grupe et al. 1998. (4) Lawrence et al. 1997. (5) Zamorani et al. 1981. (6) Puchnarewicz et al. 1996. (7) Nandra et al. 1997b.

### Table 5
**Luminosities**

| Energy Range (keV) | $L$ (Observed) ($\times 10^{44}$ ergs s\(^{-1}\)) | $L$ (SEDA)$^a$ ($\times 10^{44}$ ergs s\(^{-1}\)) | $L$ (SEDB)$^a$ ($\times 10^{44}$ ergs s\(^{-1}\)) | $L$ (XMM)$^a$ ($\times 10^{44}$ ergs s\(^{-1}\)) |
|-------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| $10^{-5}$–$10^{-4}$ | $\cdots$                                        | 2.1192                                         | 2.1192                                         | 2.1192                                         |
| $10^{-4}$–$10^{-3}$ | $\cdots$                                        | 1.8108                                         | 1.8108                                         | 1.8108                                         |
| $10^{-3}$–0.01   | $\cdots$                                        | 1.2464                                         | 1.2464                                         | 1.2464                                         |
| 0.01–0.1          | $\cdots$                                        | 3.5175                                         | 2.2589                                         | 4.1430                                         |
| 0.1–1             | 0.2201                                          | 1.6314                                         | 1.8080                                         | 2.7716                                         |
| 1–10              | 0.4086                                          | 0.4485                                         | 0.4485                                         | 0.5285                                         |
| 10$^{-5}$–10      | $\cdots$                                        | 10.7738                                       | 9.6918                                         | 12.6202                                        |

*a*Reddening-corrected, rest-frame luminosities.

Note. — The SEDA luminosities have been calculated using power-law parameterization of the SED with the spectral indices reported in Table 4. The SEDB luminosities refer to the more conservative parameterization described in §3 (Figure 3). The XMM luminosities make use of the XMM spectrum in the 0.05–10 keV band.