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BL Lac Object PKS 0548-322

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Abstract

Spectrophotometric observations of the BL Lac object PKS 0548-322 have been made with ultraviolet and X-ray instruments on the IUE and HEAO-2 satellites. We present two observations in each spectral region, one set of which were obtained simultaneously. A power law of energy index ~ 1.0 gives a good description of the data from ultraviolet through X-ray frequencies. This source is reported to be variable on short timescales (Gilmore 1980); the implications of the spectral properties and apparent variability are discussed in light of a relativistic jet model, and our findings support the jet picture of BL Lac objects.

I. Introduction

Observations of the spectral energy distribution of BL Lac objects provide crucial information on the emission mechanism operating in these sources. Among the several models thus far advanced is the synchrotron self-Compton (SSC) model, which is consistent with, and can account for, the continuum emission seen from radio through X-ray frequencies. Application of the SSC model, in its simplest isotropic form or in conjunction with relativistic jet geometries, yields further information on the physical conditions in the object. BL Lac objects may turn out to be quasars with relativistic jets pointed towards the observer (see Blandford and Rees 1978). Spectral analysis is one of the very few available means for verification of the presence of these jets, since the jets would be quite difficult, if not impossible, to resolve spatially. Thus, broad band continuum spectra are likely to be very important in elucidating the nature of the BL Lac phenomenon.

Because BL Lac objects are highly variable, it is particularly important to have simultaneous or nearly simultaneous coverage in the different frequency ranges. Such observations, and the associated analyses, have been conducted for the BL Lac objects Mrk 501 (Kondo et al. 1981, Mushotzky et al. 1982), Mrk 421 (Mufson et al. 1980), 1218+304 (Ledden et al. 1981), 1727+50 (=IZw186) (Bregman et al. 1981), 0735+178 (Bregman et al. 1981), and PKS 2155-304 (Urry and Mushotzky 1982). In this paper, we present two International Ultraviolet Explorer (IUE) far-ultraviolet spectra, taken on 1979 April 6 and 1980 April 1, as well as two X-ray spectra from the Solid State Spectrometer (SSS) on the Einstein satellite, taken on 1979 March 10 and 1979 April 6. The first IUE spectrum and the second SSS spectrum were thus taken simultaneously.

In Section II of this paper, we describe the observations and data analysis, and in Section III we present the results of that analysis. Finally, in Section IV, we discuss possible interpretations of our results.

II. Observations and Analysis

(A) Ultraviolet Regime

Two IUE spectral observations of PKS 0548-322 were made in the range 1250-1950 Å using the short-wavelength prime (SWP) camera in the low resolution mode ($\Delta\lambda \sim 5$ Å). The instrumentation and performance of the satellite observatory have been described by Boggess et al. (1978a) and Boggess et al. (1978b). Spectral image SWP 4874 was obtained as a 372-minute exposure commencing 1979 April 6 at 13:08 UT, with the target well-centered in the large aperture of the spectrograph. For image SWP 8625, exposed 400 minutes beginning 1980 April 1 at 11:28 UT, the target was located near the aperture edge, increasing the uncertainty in the spectral information extracted from this image. Both observations were made at IUE orbital phases which minimize the noise due to the earth's radiation belts, and the average signal-to-noise ratio in each exposure of this faint source is about 2:1 (2.5 Å sampling interval).

The gross spectral signal and background for each IUE image were assembled from geometrically and photometrically rectified data samples in the line-by-line files of the guest observer tapes, following the recommended procedure (Turnrose and Harvel 1980) which is most consistent with the derivation of the absolute flux calibration of the camera. Correction for the erroneous photometric intensity transfer function which was in use at the time the SWP 4874 tape was written was made using the algorithm of Cassatella et al. (1980) with quadratic interpolation of samples to recover pixel-by-pixel exposure information (Holm and Schiffer 1980). Background smoothing was performed with a 15-sample median filter followed by a two-pass 7-sample running average. The net signal after subtraction of the smoothed background was calibrated to absolute flux density using the SWP camera sensitivity function of Bohlin and Holm (1980), modified as indicated by the study of Hackney and Hackney (1981). The study, based upon BL Lac objects with different redshifts, identified apparent residual errors as large as ten percent in the determination of the shape of the SWP calibration function. Similar effects attributable to calibration error were noted in stellar studies by Greenstein and Oke (1979). The effect of the calibration modification is to reduce the residuals of the smoothed continuum about the fitted power law for the PKS 0548-322 observations. Correction of observed fluxes for interstellar reddening was made using the extinction curve of Seaton (1979), estimating $E(B-V) \approx 0.03$ for the target direction on the basis of the study by Burstein and Heiles (1978). The estimated uncertainty $\Delta E(B-V) \approx \pm 0.03$ corresponds to an uncertainty of about ∓ 0.08 in the power law index intrinsic to the continuum source ($\Delta\alpha / \Delta E(B-V) \approx -2.5$). Before attempting a power law fit for the continuum, it was necessary to reduce the potentially severe effects of radiation events and fixed-pattern noise artifacts in the spectra. A median filter was used to smooth the data, effectively eliminating noise excursions less than 25 Å in extent. The smoothed data were used to estimate mean flux densities in 100 Å bins, and the errors in the determination of bin means were estimated from the r.m.s. residuals of the original data about the median curve. A weighted least-squares fit of a power law ($f_\nu \sim \nu^{-\alpha}$) was made for the bin means following principles discussed by Avni (1976), with the quoted 95% confidence interval for the power law index, α, derived considering the index as the only interesting parameter of the fit.

(B) X-Ray Regime

The SSS is a cryogenically cooled Si(Li) detector at the focus of the Einstein Observatory (HEAO 2) X-ray telescope. The energy range covered is from 0.6 to 4.5 keV, (corresponding roughly to 2.7 to 21 Å), with a spectral resolution of about 160 eV FWHM over that range. The field of view of the detector is a circle six arcminutes in diameter. Detailed descriptions of the SSS system and the Einstein Observatory itself are given in Joyce et al. (1978) and Giacconi et al. (1979), respectively.

The first SSS observation was made between 1979 March 10 17:49 and 1979 March 11 00:48, with a total of 44 good minutes of data collected; the second SSS observation (which overlapped our first IUE observation) was made on 1979 April 6 between 12:08 and 14:56, for a total of 54 useful minutes. We followed the standard spectral analysis procedures for SSS data which are described by Holt et al. (1979) and Becker et al. (1979), although with observations of BL Lac objects the process is somewhat simpler than what they discuss. There are no lines evident in the X-ray spectra; therefore, only a continuum is fitted to the data. A trial model, generally a power law or a single temperature thermal bremsstrahlung, is folded through the detector response and compared with the pulse-height-analyzed data using the chi-squared statistic.

III. Results

The ultraviolet data, in bins roughly 100 Å wide, are shown in Fig. 1 . The best fit power law indices for the two ultraviolet observations are $\alpha = 0.84 \pm 0.39$ and $\alpha = 0.76 \pm 0.48$, for 1979 and 1980 respectively, (with 95% confidence errors). They are effectively the same. The average flux density in the SWP bandpass does not change between the two observations, having the values 0.34 mJy and 0.32 mJy, respectively. The results are essentially unchanged if the unmodified calibration of Bohlin and Holm (1980) is used, yielding power law indices of $\alpha = 0.80 \pm 0.39$ and $\alpha = 0.71 \pm 0.48$, respectively, and an average flux density of 0.32 mJy for each image. We note that while there is a substantial contribution to the observed flux at visible wavelengths due to the elliptical galaxy apparently surrounding the non-thermal source, the situation in the ultraviolet waveband is quite different. Based on the relative flux contributions of the elliptical galaxy and power law components in the V band (Weistrop et al. 1979), we estimate that the galaxy contribution is negligible (< 1%) in the SWP bandpass; the IUE observations define the local power law index and flux level intrinsic to the compact non-thermal source component.

The two SSS observations of PKS 0548-322, (see Fig. 2), are well-fit by simple power law models; thermal models also give acceptable, though slightly worse, fits. A power law spectrum is what one expects if the emission is due to the synchrotron process. The best fit spectral indices, with 95% confidence errors, are $\alpha = 1.2 \pm 0.3$ (for

1979 March 10) and $\alpha = 1.1 \pm 0.3$ (for 1979 April 6), with average flux densities of 5.8 ± 1.1 μJy and 3.9 ± 0.8 μJy, respectively. These spectral indices are consistent with one another, indicating no marked spectral change between the two observations, which were separated by 27 days. The best fit hydrogen column density was $\lesssim 1.4 \times 10^{21}$ atoms cm^{-2}, consistent with the galactic line of sight value of 4×10^{20} (Heiles 1975). The spectrum may have changed since the HEAO-1 A2 observations on 1977 September 19-21 and 1978 September 30, reported by Riegler, Agrawal, and Mushotzky (1979), (hereafter RAM), and Worrall et al. (1981), respectively, where the low energy x-ray spectrum was much steeper. However, comparisons between different instruments are not straightforward. For instance, the LEDs (of the HEAO-1 A2 experiment) are sensitive to lower energies than the SSS, and the LED spectral fits are steeper than the SSS fits, but the actual data, where they overlap in energy, are quite similar. Finally, we note that the X-ray spectral index and normalization for the April 6 observation are consistent with a straight extension of the ultraviolet power law for the same date (see Fig. 3). In particular, the effective spectral index from the ultraviolet to the X-ray of 0.93 is consistent with the slope in each spectral region alone.

As mentioned above, a single temperature thermal bremsstrahlung model also gives an acceptable fit, with temperature kT $\approx$ 2.8 keV. If this is a valid picture of the emission process, then there has been a change since the observations reported in RAM, where a substantially different thermal fit (with kT $\approx$ 0.34 keV) was obtained. More likely, the emission mechanism is non-thermal, because the simultaneous IUE data seem to support the power law picture, and a single thermal component

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could not explain both the ultraviolet and X-ray observations. Furthermore, we see no X-ray lines characteristic of a hot plasma. We can set upper limits to the amount of line emission which might be present: the equivalent width of a silicon line at 1.8 keV is less than 50 eV and the equivalent width of a sulfur line at 2.5 keV is less than 85 eV (at 99% confidence).

Finally, we note that the X-ray data may indicate an intensity variability on a timescale of less than two weeks (see Table 1). In particular, the flux reported by Maccagni and Tarenghi (1980) for their Imaging Proportional Counter (IPC) data from 1979 March 26 is higher than that we saw with the SSS on 1979 April 6 by four standard deviations. As discussed above, there may be complications due to the fact that different instruments were used, and because of the spectral dependence of the conversion from IPC counts to ergs s^{-1} cm^{-2}, the IPC flux is uncertain. However, this change is consistent with prior reports of the existence of short timescale X-ray variability in BL Lac objects (e.g., Synder et al. 1979, Wilson et al. 1979, Marshall et al. 1981), and implies either a very small size for the varying region or the presence of bulk relativistic motion in the source (see discussion below). Table 1 does not include the two observations of Worrall et al. (1981), which were made above 2 keV. This is because even small uncertainties in the power law index they obtained causes large uncertainties in the extrapolated flux at lower energies. Within the errors, the low-energy data do appear consistent with the higher energy data of Worrall et al., with the flux at 3 keV measured by each instrument agreeing almost exactly.

IV. Discussion

By examining the overall spectrum of PKS 0548-322, we can address the question of whether or not the observed continuum emission is compatible with the relativistic jet picture of BL Lac objects. The canonical SSC model can be approximated by three power laws. Two are due to synchrotron emission: a relatively flat power law extending from the self-absorption frequency in the radio to the break frequency in the infrared, optical, or ultraviolet, and a steeper power law from that break frequency to higher frequencies. The underlying self-Compton radiation, which has a flat spectrum like the radio emisson but less intense by several orders of magnitude, becomes important when the high energy synchrotron emission falls off sufficiently.

In the case of PKS 0548-322, the ultraviolet and X-ray emission reported here are presumably from the broken (high energy) part of the synchrotron spectrum. We note that the radio-to-optical index of $\alpha =$ 0.43 is ~ 0.5 flatter than the ultraviolet-to-X-ray index of 0.93 . This is what is expected in a simple synchrotron model if continuous injection occurs and if the radio-to-optical emission is from the optically thin component.

The flat, higher energy X-ray component found by RAM may correspond to the self-Compton component. The same experiment, one year later, did not detect this hard component (Worrall et al. 1981). If the hard component reported by RAM were present (at the same intensity) at the epoch of our SSS observation, we would not have seen it, because below 4 keV, it is weaker than the steep component we did see. In the absence of better information, we will use the high energy X-ray flux found by

RAM to represent the self-Compton part of the spectrum when we apply the SSC model to our observations. This is actually a conservative assumption with respect to the prediction of relativistic bulk motion.

Knowing the radio spectrum, as well as the angular size of the source, we can predict the amount of self-Compton X-ray flux which should be seen, and compare this value to our upper limit. In doing this calculation, we take into account the possible presence of relativistic bulk motion in the source. If BL Lac objects have relativistic jets beamed at small angles toward the observer, the continuum emission expected as a result of the SSC process is modified. The timescale for variability is shortened, and the apparent brightness increased, by suitable powers of the Doppler factor, $\delta = (\Gamma(1 - \beta\cos\theta))^{-1}$, where $\Gamma = (1 - \beta^2)^{-1/2}$, β = velocity of the jet in units of the speed of light, and θ = angle between the line of sight to the source and the jet axis. Extensive details of this kind of analysis are given in Urry and Mushotzky (1982), and we refer the reader to their paper for the relevant formulae.

Basically, we need to know seven quantities: (1) the self-absorption frequency from the radio synchrotron emission (or an upper limit to it), (2) the flux at that frequency, (3) the radio spectral index, (4) the break frequency, (i.e., where the two synchrotron power laws meet), (5) the redshift (or distance), (6) the variability timescale, and (7) the self-Compton X-ray flux (or an upper limit). The analysis is complicated by the fact that the radio, optical, ultraviolet, and X-ray observations were not all simultaneous. However, we proceed assuming that the radio parameters of the source in April 1979 were not dramatically different from those reported at an earlier epoch. The first two quantities are estimated from radio data in the literature. Of the published data on PKS 0548-322, the lowest frequency observation is from the Parkes survey at 2.7 GHz, with a flux of 0.31 Jy, (Shimmins and Bolton 1974). Comparison of this flux to the 0.23 Jy measured by Disney (1974) at 5 GHz suggests that the radio spectrum is rising below 2.7 GHz; therefore, 2.7 GHz is an upper limit to the self-absorption frequency, ν_m. We use ν_m = 2.7 GHz in our calculation below, which is a conservative assumption with respect to the value of the Doppler factor thus derived, and we take S = 0.31 Jy accordingly. The third quantity, α = 0.43, is obtained by fitting a power law to the two radio fluxes and the optical data of Weistrop, Smith, and Reitsema (1979). (This power law is shown in the composite spectrum in Fig. 3.) For the break frequency, we use $\nu_b = 10^{15}$ Hz, which was estimated from the composite radio through X-ray spectrum. (The result is fairly insensitive to this quantity.) The redshift, z = 0.069, was determined by Fosbury and Disney (1976). The upper limit to the self-Compton flux at 10^{18} Hz is roughly 1.4×10^{-29} ergs cm^{-2} s^{-1} Hz^{-1}, as can be seen in Fig. 3. For a variability timescale of ~ 5 days, suggested by the optical observations of Gilmore (1980), we find that δ is 7 or greater. This corresponds to $\beta \gtrsim 0.96$, $\Gamma \gtrsim 3.7$, and $\theta \lesssim 8^{\circ}$. That is, according to this model, the beam is relativistic, and pointed within eight degrees of our line of sight.

If the relativistic jet picture of BL Lac objects is correct, we should find that most BL Lac objects have $\delta \gtrsim 3$, while quasars typically have $\delta \sim 1$. Schwartz, Madejski, and Ku (1981) have argued that factors greater than 1 are not a distinguishing characteristic of BL Lac objects. Our analysis differs from theirs in several respects. They have VLBI angular sizes for each source in their sample, while we rely on variability to indicate size. We use more comprehensive spectral information, however. In particular, the simultaneous ultraviolet - X-ray coverage explicitly suggests the SSC mechanism is producing the observed emission, lending justification to the application of that model. Similar analyses are being planned for other X-ray emitting BL Lac objects for which coordinated observations in the X-ray and ultraviolet ranges have been obtained. These include Mrk 501, Mrk 421, Mrk 180, and PKS 2155-304. A true test of the relatvistic jet - SSC model must await complete, simultaneous spectral coverage of a large sample of BL Lac objects and quasars.

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Table 1.

Observation Date	Instrument	Flux (0.2 - 3.5 keV) $\times 10^{-11}$ ergs cm^{-2} s^{-1}
1977 September 19-21	LED,MED	4.0 ± 1.2 *
1979 February 28	IPC	5.52 ± 0.09 **
1979 March 10	SSS	4.6 ± 0.9 ***
1979 March 26	IPC	5.59 ± 0.17 **
1979 April 6	SSS	3.1 ± 0.6 ***

*Riegler, Agrawal, and Mushotzky (1979)
**Maccagni and Tarenghi (1981)
***Extrapolated down to 0.2 keV using the best fit spectral parameters for the SSS data.

References

Avni, Y. 1976, Ap. J., 210, 642.

Becker, R. H., Holt, S. S., Smith, B. W., White, N. E., Boldt, E. A., Mushotzky, R. F., and Serlemitsos, P. J. 1979, Ap. J. (Letters), 234, L73.

Blandford, R. D. and Rees, M. J. 1978, in Pittsburgh Conference on BL Lac Objects, ed. A. M. Wolfe, (Pittsburgh: University of Pittsburgh), p. 328.

Boggess, A., et al. 1978a, Nature, 275, 372.

Boggess, A., et al. 1978b, Nature, 275, 377.

Bohlin, R. C. and Holm, A. V. 1980, IUE NASA Newsletter, 10, 37.

Bregman, J. N., et al. 1981, in The Universe at Ultraviolet Wavelengths, ed. Robert D. Chapman, (Greenbelt, Maryland: NASA Conference Publication 2171), p. 751 .

Burstein, D. and Heiles, C. A. 1978, Ap. J., 225, 40.

Cassatella, A., Holm, A., Ponz, D., and Schiffer, F. H. 1980, IUE NASA Newsletter, 8, 1.

Disney, M. J. 1974, Ap. J. (Letters), 193, L103.

Fosbury, R. A. E. and Disney, M. J. 1976, Ap. J. (Letters), 207, L75.

Giacconi, R., et al. 1979, Ap. J., 230, 540.

Gilmore, G. 1980, M.N.R.A.S., 190, 649.

Greenstein, J. L. and Oke, J. B. 1979, Ap. J. (Letters), 229, L141.

Hackney, R. L. and Hackney, K. R. 1981, B. A. A. S., 13, 532.

Heiles, C. 1975, Astr. Ap. Suppl., 20, 37.

Holm, A. V. and Schiffer, F. H. 1980, IUE NASA Newsletter, 8, 45.

Holt, S. S., White, N. E., Becker, R. H., Boldt, E. A., Mushotzky, R. F., Serlemitsos, P. J., and Smith, B. W. 1979, Ap. J. (Letters)

234, L65.

Joyce, R. M., Becker, R. H., Birsa, R. B., Holt, S. S., and Noordzy, M. P. 1978, IEEE Trans. Nucl. Sci., NS-25, 453.

Kondo, Y., et al. 1981, Ap. J., 243, 690.

Ledden, J. E., O'Dell, S. L., Stein, W. A., and Wisniewski, W. Z. 1981, Ap. J., 243, 47.

Maccagni, D. and Tarenghi, M. 1980, Ap. J., 243, 42.

Marshall, N., Warwick, R. S., and Pounds, K. A. 1981, M.N.R.A.S., 194, 987.

Mufson, S., et al. 1980, Ap. J., 241, 74.

Mushotzky, R. F., et al. 1982, in preparation.

Riegler, Guenter R., Agrawal, Prahlad C., and Mushotzky, Richard F. 1979, Ap. J. (Letters), 233, L47.

Schwartz, D. A., Madejski, G., and Ku, W. H.-M. 1981, talk presented at I. A. U. Symposium No. 97 on Extragalactic Radio Sources, in Albuquerque, New Mexico, August 6, 1981.

Seaton, M. J. 1979, M. N. R. A. S., 187, 73p.

Shimmins, A. J., and Bolton, J. 1974, Austr. J. Phys., Ap. Suppl., No. 32.

Snyder, W. A., et al. 1979, Ap. J. (Letters), 237, L11.

Turnrose, B. E. and Harvel, C. A. 1980, IUE Image Processing Information Manual, Version 1.0, 6-6.

Urry, C. M. and Mushotzky, R. F. 1982, Ap. J., 253, 38.

Weistrop, D., Smith, B. A., and Reitsema, H. J. 1979, Ap. J., 233, 504.

Wilson, A. S., Ward, M. J., Axon, D. J., Elvis, M. and Meurs, E. J. A. 1979, M.N.R.A.S., 187, 109.

Worrall, D. M., Boldt, E. A., Holt, S. S., Mushotzky, R. F., and Serlemitsos, P. J. 1981, Ap. J., 243, 53.

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Figure Captions

Figure 1. Ultraviolet spectra of PKS 0548-322, taken with the IUE short wavelength camera on 1979 April 6 and 1980 April 1. The data are in bins of width ~ 100 Å. The best fit power laws for each observation ($\alpha = 0.84$ and $\alpha = 0.76$ for 1979 and 1980 respectively) are indicated by the solid lines.

Figure 2. X-ray data for the 1979 April 6 observation of PKS 0548-322. (The data from March 1979 look very similar.)

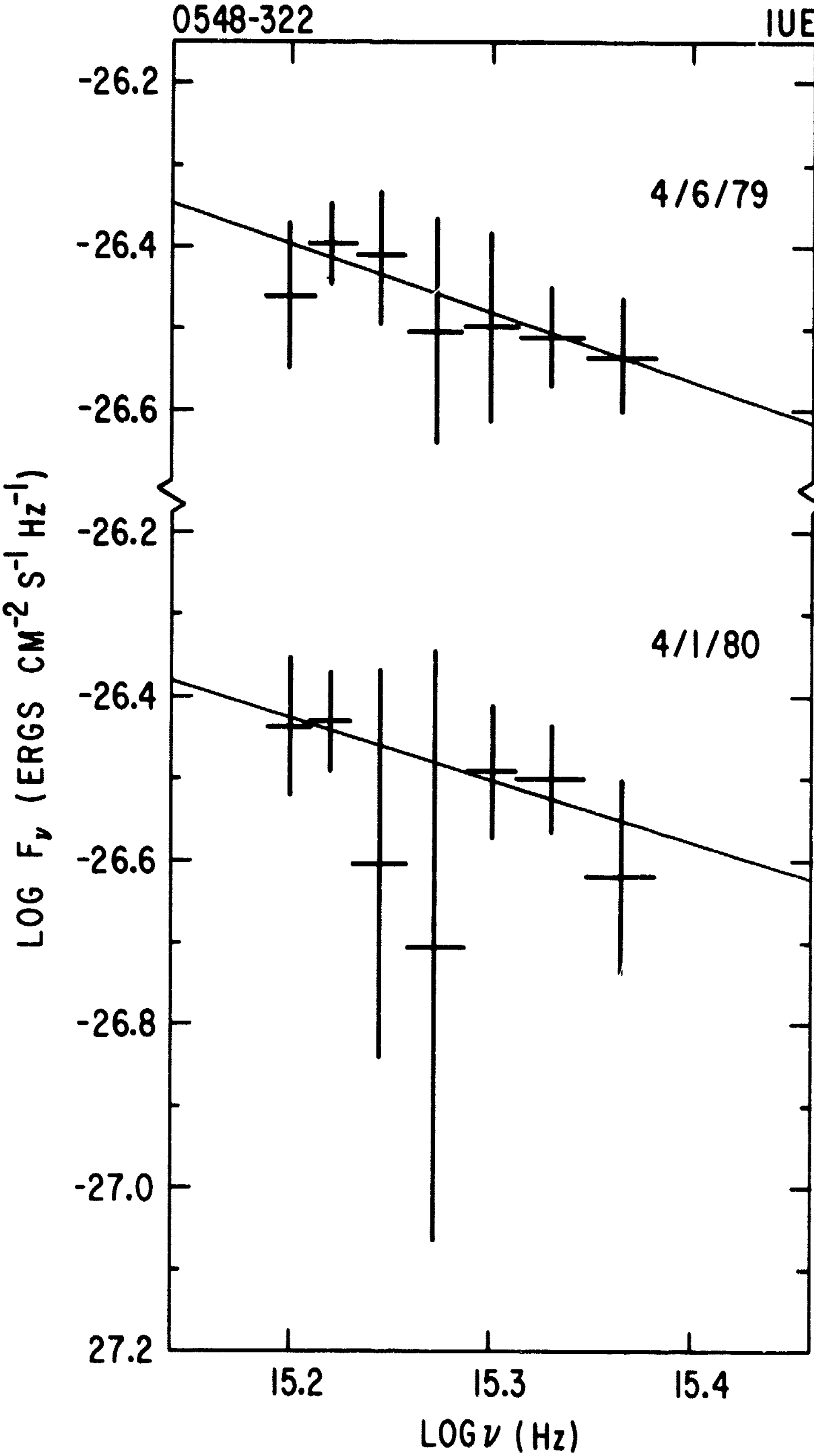
(a) Pulse-height-analyzed counts versus energy, with the best fit power law spectrum drawn in.

(b) Incident photon spectrum which, when folded through the detector response, gives the best fit to the PHA data. The solid line is the best fit spectrum, with absorption; the dashed line is the same power law without absorption, since the hydrogen column density is largely, if not completely, extrinsic to the source.

The best fit power law is $0.0138\ E^{-2.08}$ photons $cm^{-2}\ s^{-1}\ keV^{-1}$, with a hydrogen column density of 1.4×10^{21} atoms cm^{-2}.

Figure 3. Composite spectrum of PKS 0548-322, from radio through X-ray frequencies. Radio data are from Shimmins and Bolton (1974) and Disney (1974), for 2.7 GHz and 5.0 GHz respectively; optical-IR data are from Weistrop, Smith, and Reitsema (1979); the ultraviolet and soft X-ray data are the IUE and SSS observations from 1979 April 6 reported in this paper; the hard X-ray data (above 10^{18} Hz) are the HEAO-1 A2 results from Riegler, Agrawal and Mushotzky (1979). The

four dashed lines represent the following: (1) the best fit to the combined radio, optical, and IR points, with (2) the best fit to the IUE data, with $\alpha = 0.84$, (3) the best fit to the SSS data, with $\alpha = 1.1$, and (4) the best fit to the A2 (MED and HED) data, with $\alpha = 0.3$. Note that the spectrum is composite, with only the ultraviolet and soft X-ray data being simultaneous.


0548-322
IUE
4/6/79
4/1/80
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-26.4
-26.6
-26.2
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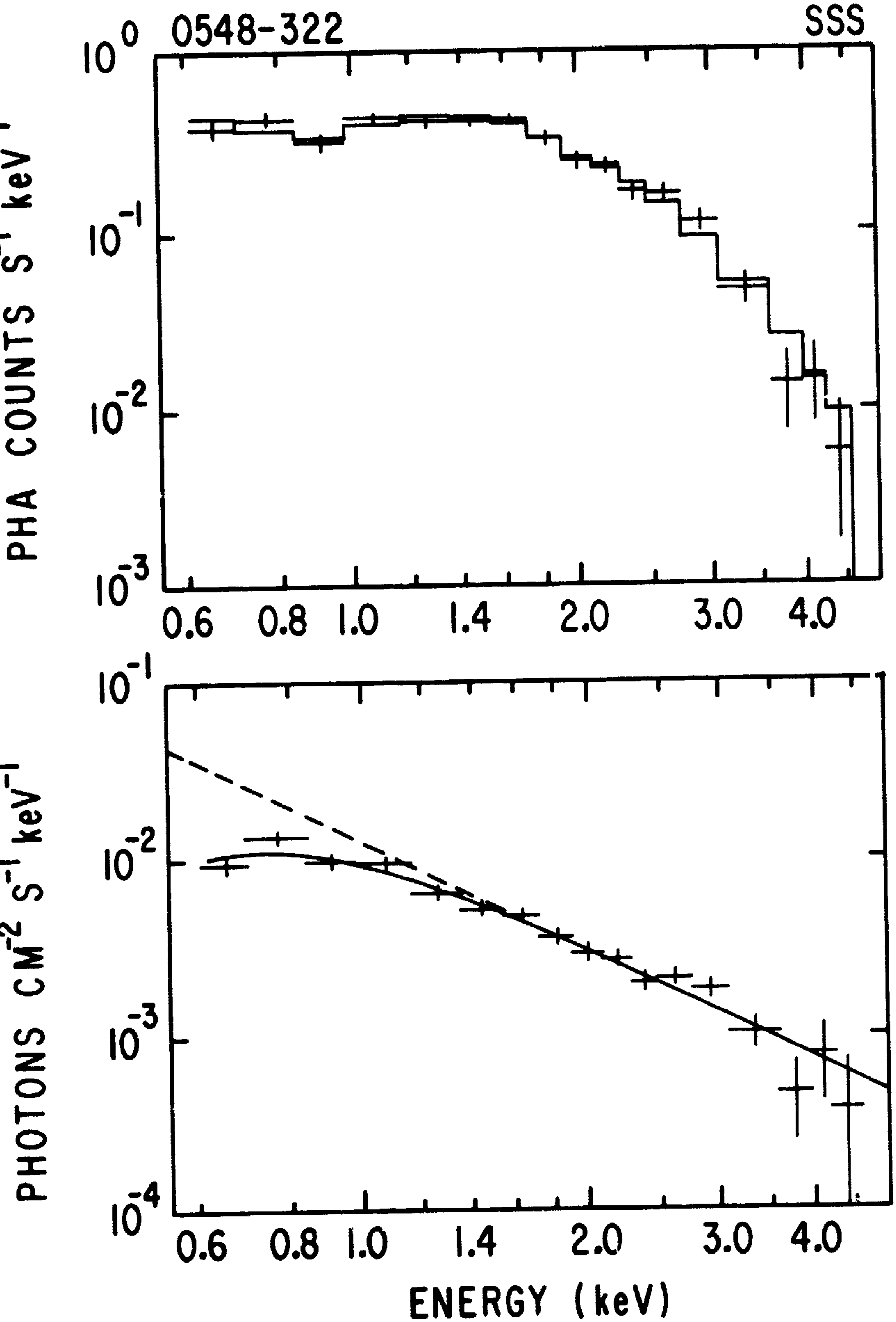
27.2
15.2
15.3
15.4
LOG ν (Hz)


0548-322
SSS
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10^-2
10^-3
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0.8
1.0
1.4
2.0
3.0
4.0
PHOTONS CM⁻² S⁻¹ keV⁻¹
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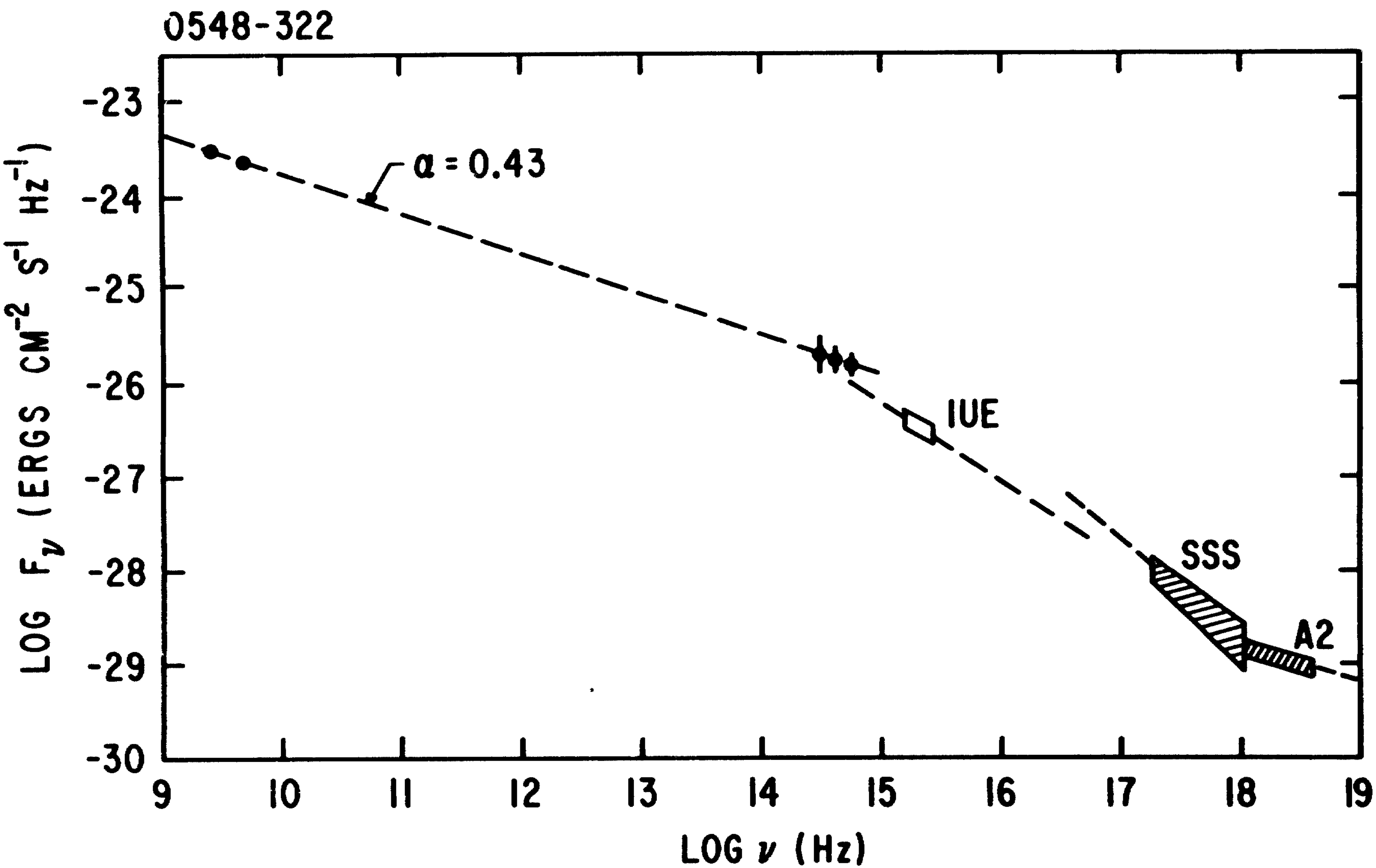
2.0
3.0
4.0
ENERGY (keV)


0548-322
α = 0.43
IUE
SSS
A2
LOG F_ν (ERGS CM^{-2} S^{-1} Hz^{-1})
-23
-24
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19
LOG ν (Hz)

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