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ON THE X-RAY AND ULTRAVIOLET SPECTRUM OF THE HIGH-REDSHIFT QUASAR 3C 446[1]

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ABSTRACT

Existing *IUE* and *Einstein* observations of the high-redshift ($z = 1.414$) quasar 3C 446 have been analyzed. In the UV the continuum is characterized by a steep slope. The lack of signal shortward of 2300 Å is probably due to the Lyman continuum absorption at the source. The X-ray spectrum shows the "universal" slope of active galactic nuclei coupled with a hydrogen columnar density in excess of the Galactic value, suggesting that the absorption occurs in or around the source.
Subject headings: quasars — ultraviolet: spectra — X-rays: spectra

I. INTRODUCTION

3C 446 is a high-redshift quasar ($z = 1.414$; Burbidge, Crowne, and Smith 1977) with strong optical and X-ray emission (Tananbaum *et al.* 1979). It has been classified as a highly polarized quasar (HPQ) by Moore and Stockman (1984). In the optical, bursts up to $\Delta m \approx 3$ (with a few weeks' duration) are frequently detected (Pollock *et al.* 1979; Grandi and Tifft 1974) superposed on luminosity fluctuations with smaller amplitude and shorter time scale (0.13 mag over ~2 hr, Miller 1981). The high degree of optical variability does not seem to be a common feature at other wavelengths. At 87 GHz it has been seen varying by only 40% over six months (Barvainis and Predmore 1984). In the X-ray region Zamorani *et al.* (1984) report a variability of 37% between 1979 May and December.

During outbursts, the slope of the optical continuum is sometimes steeper (Sandage, Westphal, and Strittmatter 1966; Oke 1967; Wampler 1967) and sometimes flatter (Visvanathan 1973) than during quiescent states. On several occasions, in the optical range weak emission lines have been observed, the intensities of which do not seem to vary with the optical flux (Sandage, Westphal, and Strittmatter 1966; Oke 1967; Visvanathan 1973; Miller and French 1978).

In this paper we present the X-ray spectrum we derived from the imaging proportional counter (IPC) data obtained through the *Einstein Observatory* Data Bank, together with two ultraviolet spectra available from the *International Ultraviolet Explorer* (*IUE*) Archival Data. The results of our spectral analysis are discussed, paying particular attention to the derived columnar H I density.

II. THE DATA

a) X-Ray Energy Spectrum

3C 446 has been observed three times by the *Einstein Observatory* with the IPC instrument (Giacconi *et al.* 1979). Two of these observations are now available from the *Einstein* Data Bank (see Table 1). The integrated flux (0.5–4.5 keV) obtained from the first observation has been published by Zamorani *et al.* (1981). They show that 3C 446 is a very luminous quasar

[1] Based on data obtained through the *Einstein Observatory* Data Bank and the *International Ultraviolet Explorer* Archive.

TABLE 1
SUMMARIES OF DATA

Date (1)	Energy Range (Hz) (2)	Exposure Time (s) (3)	F_ν (mJy) ν (Hz) (4)	α (5)	X^a (6)	χ^2_{red} (7)
A. X-ray						
1979 May	3.87×10^{17}	1379	9.71×10^{-4}	...	$6.0 \times 10^{20\,b}$	...
	8.2×10^{17}		4.84×10^{17}			
1979 Dec	7.25×10^{16}	8655	1.26×10^{-3}	0.83	2.8×10^{21}	1.77
	1.14×10^{18}		4.84×10^{17}			
B. Ultraviolet						
1980 Jun	1.36×10^{15}	9000	0.86	2.9	0.15	10.0
	9.7×10^{14}		1.2×10^{15}			
1981 Sep	1.36×10^{15}	9000	0.4	2.15	0.15	3.0
	9.7×10^{14}		1.2×10^{15}			

[a] N_H (cm^{-2}) for X-ray; A_v for ultraviolet.
[b] Zamorani *et al.* 1981.

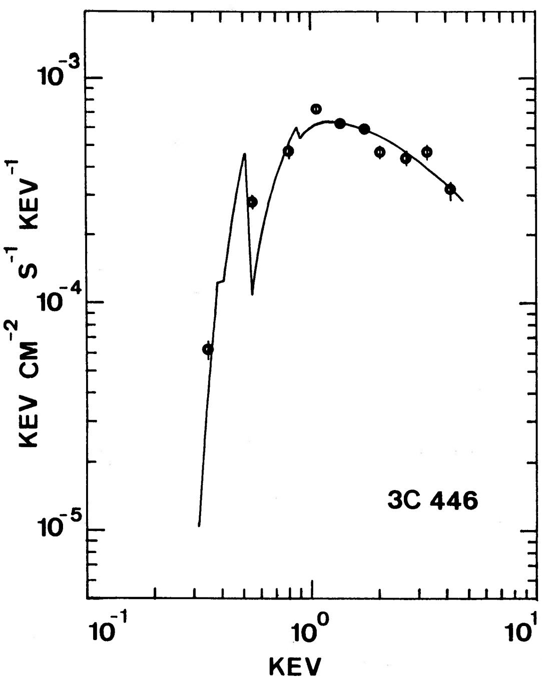

FIG. 1.—The derived 0.3–4.7 keV energy spectrum of 3C 446. Circles represent the observed fluxes with 1 σ error bars, and the solid line shows the best-fit incident spectrum.

($L_x = 9.6 \times 10^{46}$ ergs cm^{-2} s^{-1}). The long exposure of the second observation, 1979 December (more than 8000 s) and the intrinsic strength of the source (about 0.18 counts s^{-1}) has allowed us to make a spectral analysis of the data. Such analysis has been carried out at the Center for Astrophysics with the standard procedure (see Harnden *et al.* 1984 for details). Figure 1 shows the best fit (reduced $\chi^2 = 1.77$, 8 degrees of freedom) obtained with a power law ($F_E = KE^{-\alpha}$) between 0.3 and 4.7 keV with a low-energy cutoff due to photoelectric absorption. The corresponding parameters at the 90% confidence level are $\alpha = 0.83(\pm 0.66)$ and $N_H = 2.8(-2.2, +1.8) \times 10^{21}$ atoms cm^{-2}. The fit has been obtained assuming that the X-rays are absorbed in our Galaxy. Figure 2 shows the 90% and 99% two-parameter confidence contours, together with the value of the Galactic N_H (Burstein and Heiles 1982). If most of the absorption occurs at the source or at intermediate redshifts, the data are fitted by hydrogen column densities of the order of 10^{22} atoms cm^{-2} (see right-hand scale in Fig. 2). The flux obtained from the third observation has been published by Bregman, Glassgold, and Huggins (1982).

b) *Ultraviolet Spectral Analysis*

Ultraviolet data were obtained in 1980 June (see Bregman, Glassgold, and Huggins 1982) and in 1981 September, both in the short- (1200–3000 Å) and the long-wavelength (1900–3200 Å) range. The large aperture (10″ × 20″ oval) of the spectrograph in the low-resolution (~6 Å) mode was used, and standard *IUE*-SIPS reduced spectra were adopted. No signal is present in both short-wavelength band (SWP) exposures. In the long wave range, a weak continuum is detected longward of about 2300 Å (Fig. 3). In order to improve the signal-to-noise ratio, the mean flux over 100 Å intervals was computed (see inserts in Fig. 3), avoiding hot spots and reseaux marks. The standard deviation of the mean is assumed to represent the associated uncertainty. This is comparable with the photometric accuracy of *IUE* discussed by Bohlin *et al.* (1980) and Holm (1982). Correction for interstellar absorption was made using the extinction curve of Seaton (1979) with $E(B-V) = 0.05$, as derived from H I and Galaxy counts (Burstein and Heiles 1982).

The best-fitting power law $F_\nu = k\nu^{-\alpha}$ was obtained minimizing the χ^2. These are (see Table 1B) 10.0 for 4 degrees of freedom (1980 June) and 3.0 for 6 degrees of freedom (1981 September). The 90% confidence values are respectively $\alpha = 2.9 \pm 0.9$ and $\alpha = 2.15 \pm 0.7$. The fit for 1980 June can of course be considered only a very rough indication. The absence of the Lyα emission line (2930 Å in the observer's frame) in both the observations is compatible with the line strengths of this object in bright states. In fact, for a full width zero intensity of 300 Å, an upper limit of 50 Å equivalent width can be derived for Lyα, which is reasonably consistent with the C IV equivalent width of 40 Å measured by Oke (1967) at

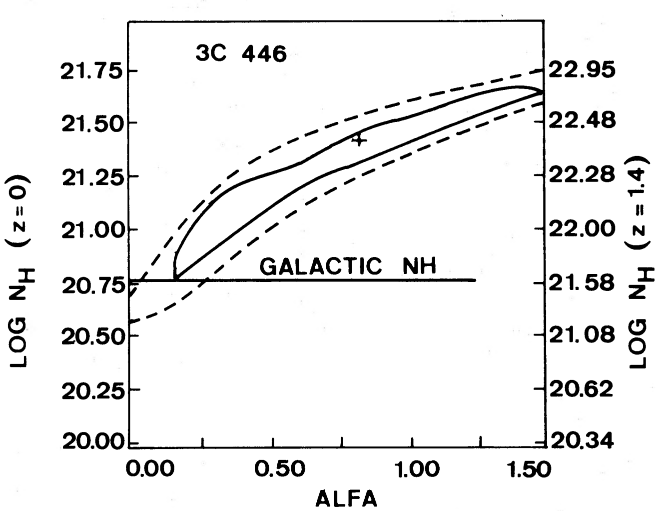

FIG. 2.—90% (*solid line*) and 99% (*dashed line*) two-parameter confidence contours for the X-ray spectrum shown in Fig. 1. The plus indicates the best-fit value, and the horizontal line the amount of Galactic hydrogen as computed from Burstein and Heiles (1982). The left-hand scale gives the N_H corresponding to a cutoff energy at $z = 0$, while the right-hand scale gives the N_H corresponding to a cutoff energy redshifted to $z = 1.414$.

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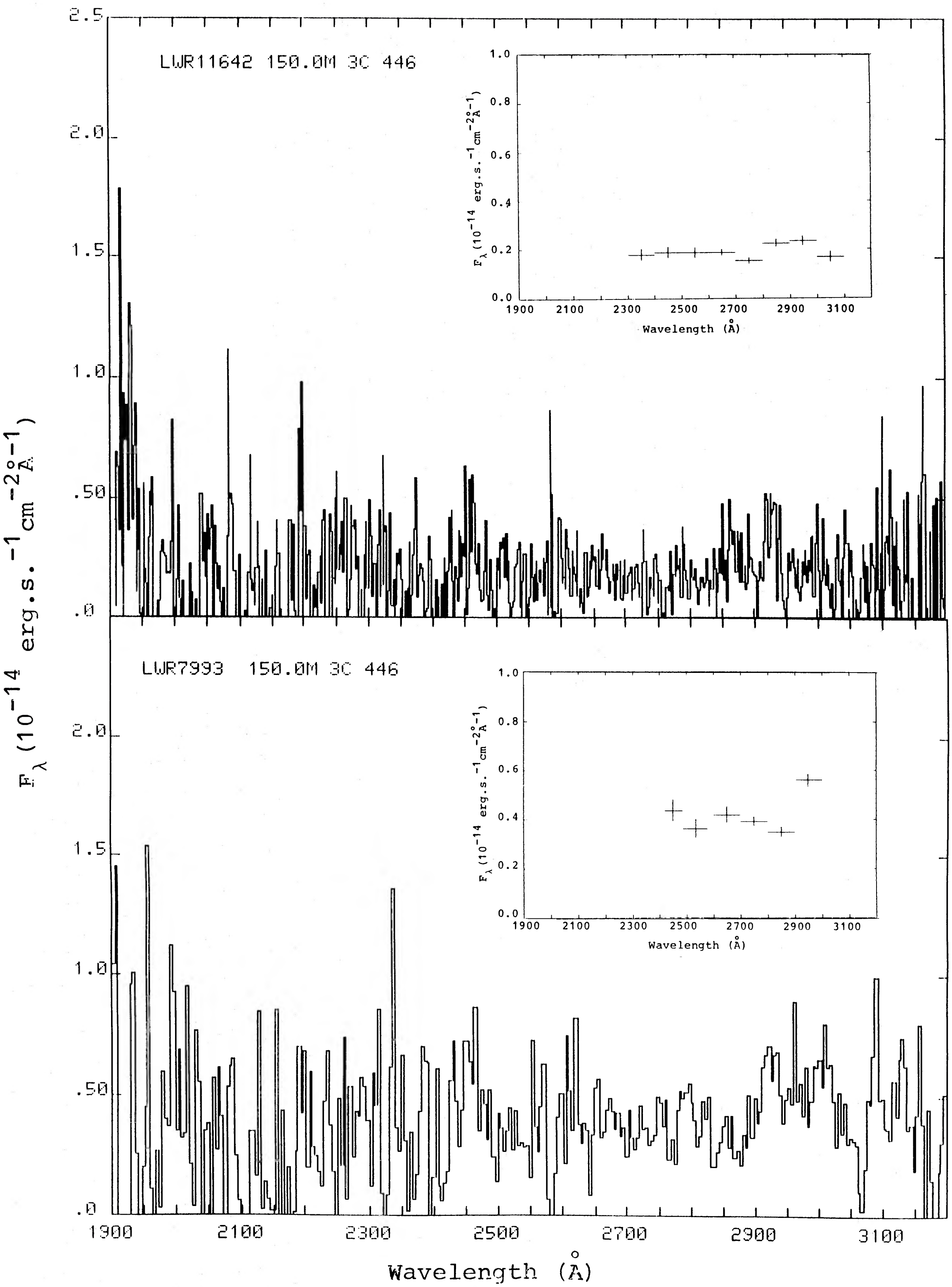

FIG. 3.—Ultraviolet spectrum of 3C 446. (*top*) 1981 September, (*bottom*) 1980 June. The inserts show the 100 Å binnings used to fit the data.

$m_v \approx 15.6$. The lack of signal shortward of 2300 Å is probably due to the Lyman limit of the source, which falls at 2200 Å. A similar behavior in high-redshift quasars has been found by Bechtold *et al.* (1984), even if in our case the Lyman limit can be attributed to the source itself rather than to an intervening cloud, which would cause the absorption to occur below 2200 Å.

c) *Overall Spectrum*

Table 1 gives the relevant parameters obtained from the X-ray and UV data: date of the observations (col. [1]), frequency range (col. [2]), exposure time (col. [3]), monochromatic flux together with the frequency at which it was computed (col. [4]), spectral index over the frequency range (col. [5]), hydrogen column density or interstellar reddening (col. [6]), and significance of the fit (col. [7]).

In Figure 4 we plot the observed energy distribution of 3C 446, reporting the maximum and minimum fluxes as observed at different frequencies. The overall behavior is representative of the dichotomy shown by HPQs. Up to UV frequencies it is quite similar to that of BL Lac objects, even in the fact that, at least in the bright states, when emission lines are weaker, a break is present between optical and UV frequencies, as shown by Bregman, Glassgold, and Huggins (1982). The spectrum then flattens in the X-rays, thus becoming typical of usual quasars.

III. DISCUSSION

From the longest X-ray observation we have obtained a power-law spectrum with slope $\alpha = 0.83(\pm 0.66)$. This value is in agreement with the universal slope for active galactic nuclei (AGNs) $\langle \alpha \rangle = 0.7 \pm 0.1$ (Rothschild *et al.* 1983). However, recent results on the X-ray spectral slope of quasars (Elvis, Wilkes, and Tananbaum 1984) seem to invalidate the hypothesis of a universal slope. One of the explanations put forward by Elvis and Lawrence (1984) is a luminosity or redshift dependence of the X-ray spectral index. This is at variance with the case of 3C 446, which is both very luminous and at high redshift. Apart from the statistical significance of these examples, we would like to note that the rest frame energy range of the IPC spectrum of 3C 446 is very close to that of the spectra of AGNs used in deriving the universal slope.

The hydrogen column density N_H, as derived from the X-ray spectral fit, is only marginally compatible with that obtained from H I and galaxy counts for our Galaxy ($N_H = 6 \times 10^{20}$ atoms cm^{-2}) (Burstein and Heiles 1982). If one considers the hypothesis that the X-ray measured absorption is not satisfactorily explained by the hydrogen column density in our Galaxy, two possibilities arise: the X-rays are absorbed either at the source itself or in some intervening cloud. As reported by Miller and French (1978, see also Barbieri *et al.* 1985) Mg II and Fe II absorption doublets have been observed in the optical spectrum of 3C 446 at a redshift $z = 0.847$. The equivalent widths of the Mg II lines correspond to a hydrogen column density between 10^{18} and 10^{19} atoms cm^{-2} depending on the element abundances assumed (Briggs *et al.* 1980) for the absorbing cloud. This value can be considered only as a lower limit, because of the uncertainties connected with the method. However, if the cloud were a galactic halo, an upper limit of about 5×10^{20} atoms cm^{-2} can be assumed for the hydrogen column density. Anyway, such a galactic halo, together with the absorption due to our Galaxy, could not explain the N_H as derived from the X-ray observation, which at the redshift of the cloud must be $\sim 10^{22}$ atoms cm^{-2}. We would therefore be left

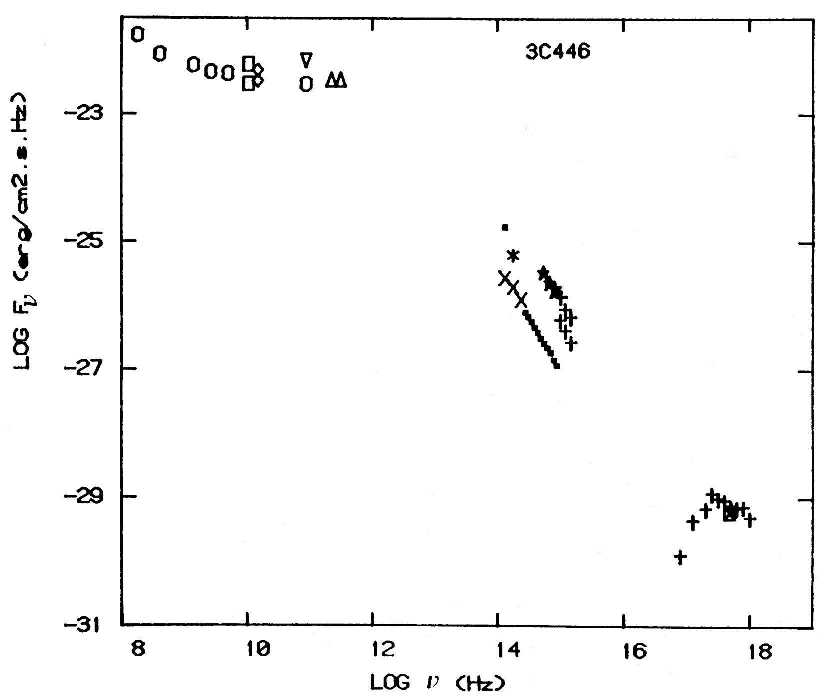

FIG. 4.—Overall energy distribution of 3C 446. At each frequency the maximum and minimum fluxes observed have been plotted. No corrections for interstellar absorption have been made, with the exception of the X-ray flux from Zamorani *et al.* (1981), which they give corrected for a hydrogen column density of 6×10^{20} atoms cm^{-2}. ○, Angel and Stockman (1980); □, Andrew *et al.* (1978); ◇, Kellermann and Pauliny-Toth (1967); ▽, Barvainis and Predmore (1984); △, Landau *et al.* (1983); ■, Neugebauer *et al.* (1979); *, Impey *et al.* (1982); ×, Allen, Ward, and Hyland (1982); ★, Bregman *et al.* (1982); +, this paper; ⊠ Zamorani *et al.* (1981).

with the possibility of absorption occurring in or around the quasar itself. If this gas had Galactic abundances and were coupled with the standard amount of dust, the attempt to deredden the optical-UV data would lead to an inverted spectrum. Such a spectral behavior is unlikely because 3C 446 is a HPQ, and it is well known that blazars have steep optical spectra. On the other hand, the presence of dust in the immediate surroundings of a luminous quasar is not expected, because the emitted radiation certainly can either evaporate or blow out the dust grains. Therefore the hypothesis that the X-ray absorption is intrinsic is not contradicted by the data at other wavelengths.

3C 446 would not be the only quasar where intrinsic absorption has been detected. Halpern (1984) has observed a strong and variable absorption in the quasar MR 2251 − 179. Unfortunately, in the case of 3C 446, the other two *Einstein* observations do not have sufficient statistics to confirm the suggestion of intrinsic absorption. Higher resolution XUV and X-ray spectroscopic measurements are needed to constrain the confidence levels on the spectral parameters.

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