THE ASTROPHYSICAL JOURNAL, 306:508–521, 1986 July 15

NEW RESULTS ON THE X-RAY EMISSION AND ITS CORRELATION WITH THE ULTRAVIOLET IN NGC 4151[1]

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Received 1985 October 14; accepted 1986 January 10

ABSTRACT

A number of observations of the Seyfert galaxy NGC 4151 carried out simultaneously with *EXOSAT* (0.1–25 keV) and *IUE* (1200–3000 Å) in two campaigns (1983 November, 1984 December–1985 January) have led to several new results. (1) The soft X-ray excess discovered by Holt *et al.* appears to be dominated by a new spectral component, as shown by the stability of its flux when the ultraviolet and X-ray (> 1 keV) continua underwent large-amplitude variations. The soft X-ray extension discovered by Elvis, Briel, and Henry explains no more than 30% of the observed flux. (2) If the new component is thermal emission from a hot gas, the best estimate of the temperature is 1.8×10^6 K, and the luminosity is 1.7×10^{42} ergs s^{-1}. This result is shown to be consistent with the hot gas being in pressure equilibrium with the clouds in the narrow-line region and with the [Fe x] λ6374 line being of collisional origin. (3) The variable ultraviolet and X-ray continua in the present observations were well correlated at least down to a time scale of days, possibly shorter, in striking disagreement with the earlier finding (1979 May, Paper II) of an ultraviolet outburst not accompanied by an increase in the X-ray emission. (4) The standard model of a power law with a uniform cold absorber gives a bad fit at low energies in the 1.2–25 keV range. The situation improves if the absorber is assumed to be made of discrete clouds, as originally suggested by Holt *et al.* This model, however, is acceptable only if a further uniform absorber with $N_H \approx 10^{22}$ cm^{-2}, here tentatively identified with the one responsible for the ultraviolet absorption lines, is present to conceal the leak below 1 keV resulting from the uncovered fraction of the source. (5) The spectral index of the power law correlates closely with the flux in the 2–10 keV range, the slope being shallower when the intensity is lower. (6) The iron fluorescence line at 6.4 keV responds very slowly, if at all, to changes in the exciting continuum. A minimum of 4 months for the time scale in the line variations is estimated, thus suggesting that most of the fluorescence comes from the outermost parts of the broad-line region and, by implication, that the "diluted" density of the gas embedded in the broad-line region clouds should drop not faster than r^{-1}. (7) The equivalent width of the fluorescence line is consistent with numerical predictions only if the broad-line region geometry is highly flattened, with the minor axis close to the line of sight. Results similar to (1), (2), and (4) have been reported by Pounds *et al.* on the basis of independent *EXOSAT* observations.

Subject headings: galaxies: individual — galaxies: Seyfert — galaxies: X-rays — ultraviolet: spectra

I. INTRODUCTION

NGC 4151 is the most thoroughly studied among Seyfert galaxies, both in the ultraviolet and in X-rays. The present collaboration has frequently monitored the spectrum of this object with the *International Ultraviolet Explorer* (*IUE*), and the results have been published in Penston *et al.* (1981, on general properties), Perola *et al.* (1982, hereafter Paper II, on the continuum), Ulrich *et al.* (1984, on the emission-line variability), Bromage *et al.* (1985, on the absorption lines), and Ulrich *et al.* (1985, on the discovery of two peculiar emission features). The X-ray spectrum and variability are the subject of numerous papers, several of which will be referred to later. A first step in the study of a possible relationship between the ultraviolet and X-ray variabilities was made in 1979–1980 (Paper II), and the opportunity after 1983 May to use in conjunction the *IUE* satellite (Boggess *et al.* 1978*a*, *b*) and the X-ray satellite *EXOSAT* (Taylor *et al.* 1981) was taken in order to pursue this study and to widen its scope. The two major objectives, which could take advantage of repeated and simul-

[1] Based on observations with *IUE*, collected at the Villafranca Satellite Tracking Station (ESA), and with *EXOSAT*, collected at the European Satellite Operation Center (ESA) in Darmstadt.
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taneous observations with the two satellites, were a closer investigation of possible correlations between continuum variability in the two bands and a test on the nature of the soft X-ray excess discovered by Holt *et al.* (1980). The latter, if interpreted either as a leak through the very thick ($N_H \approx 5 \times 10^{22}$ cm^{-2}) absorber of the X-ray spectrum (as proposed by the discoverers) or as the far tail of the ultraviolet spectrum, should display simultaneous variations with either one or the other of the two spectral components. The monitoring campaigns conducted in 1983 and 1984 have led to several new findings, some unexpected, which are the subject of this paper. The ultraviolet spectra did not show any significant difference with respect to the previous results; hence, they will not be described in detail. To guide the reader, the evidence of a new spectral component in the soft X-rays and a discussion on its nature are given in §§ III and IV; the variability and the ultraviolet-X-ray correlation are described in § III; the spectral variability above 1 keV and the temporal behavior of the iron fluorescence line at 6.4 keV are discussed in § V, where also an improved estimate of the iron abundance in the absorber is given and the inadequacy of a cold and uniform model of the absorber is demonstrated. Preliminary results from the 1983 observations (Perola *et al.* 1984, 1985) are superseded by the findings in this paper. In the following the distance to NGC 4151 is assumed to be 20 Mpc.

TABLE 1A

Log of the *IUE* Observations

Date	Image	Ap	Exposure (minutes)
1983 Oct 30.61...	SWP 21408	L	50
30.65...	LWP 2181	L	30
30.68...	SWP 21409	L	40
30.71...	LWP 2182	L	30
1983 Nov 04.52...	SWP 21449	L	50
04.56...	LWP 2216	L	30
04.59...	SWP 21450	L	50
04.63...	LWP 2217	L	35
07.53...	SWP 21470	L	45
07.57...	LWP 2241	L	30
07.59...	SWP 21471	L	65
07.64...	LWP 2242	L	35
11.54...	SWP 21515	L	45
11.58...	LWP 2254	L	50
11.61...	SWP 21516	L	66
15.53...	SWP 21547	L	50
15.57...	LWP 2269	L	30
15.59...	SWP 21548	L	60
15.64...	LWP 2270	L	35
19.52...	LWP 2296	L	30
19.54...	SWP 21578	L	120
19.63...	LWP 2297	L	40
1984 Dec 16.40...	SWP 24703	L	45
16.43...	SWP 24703	S	30
16.46...	LWP 5014	L	30
16.48...	SWP 24704	L	33
19.43...	LWP 5038	L	25
19.45...	SWP 24717	L	45
19.48...	SWP 24717	S	30
19.51...	LWP 5039	L	45
24.39...	LWP 5068	L	25
24.41...	SWP 24742	L	45
24.45...	SWP 24742	S	30
24.47...	LWP 5069	L	45
24.51...	SWP 24743	L	45
28.41...	SWP 24766	L	45
28.45...	LWP 5092	L	25
28.47...	SWP 24767	L	45
28.50...	LWP 5093	L	50
1985 Jan 02.32...	SWP 24808	L	45
02.36...	LWP 5118	L	20
02.38...	SWP 24809	L	40
02.41...	SWP 24809	S	30
02.44...	LWP 5119	L	15
08.32...	SWP 24863	L	40
08.35...	LWP 5161	L	25
08.37...	SWP 24864	L	35
14.54...	SWP 24905	L	45
14.57...	LWP 5207	L	20
14.59...	SWP 24906	L	38

II. OBSERVATIONS AND DATA REDUCTION

NGC 4151 was observed several times with *IUE* and *EXOSAT* in two epochs ~1 yr apart (1983 October 30–November 19; 1984 December 16–1985 January 14). The observations are listed in Tables 1A (*IUE*) and 1B (*EXOSAT*), where the start and the exposure times are given for each instrument. With two exceptions (1984 December 22, and the first of the two pointings in 1983 November 19), the *EXOSAT* observations were performed simultaneously with those of *IUE*; furthermore, a few *IUE* observations were made before (1983) and after (1985) the *EXOSAT* campaigns.

The *IUE* data consist of short-wavelength and long-wavelength low-resolution spectra, which were extracted directly in their background-subtracted and calibrated form from the observation tapes provided by the Villafranca Satellite Tracking Station. In addition, the photoelectric data in the Fine Error Sensor (FES) on *IUE* were converted to *B*-band magnitudes, m_B(FES), consistent in passband and aperture (nominally 3″) with the photographic *B* magnitudes measured at the Royal Greenwich Observatory (RGO) in an optical monitoring program of this object (Paper II; Gill *et al.* 1984).

The *EXOSAT* observations reported here were performed with the Medium Energy (ME) proportional counters and the only Low-Energy telescope (LE 1) operational at the time, with the Channel Multiplier Array (CMA) in the focal plane in conjunction with the filters No. 6 (Al-Par), No. 7 (thin Lexan) and No. 8 (boron). The observations with the gas scintillation proportional counter will be reported elsewhere. The data analysis was carried out on the Final Observation Tapes (FOT) provided by the European Satellite Operation Center.

a) Medium Energy Data

The ME detector (Turner, Smith, and Zimmermann 1981) consists of eight argon and eight xenon filled counters, with a nominal energy range of 1–20 and 5–50 keV, respectively. In

TABLE 1B

Log of the *EXOSAT* Observations[a]

Date	ME	LE-6	LE-7	LE-8
1983 Nov 07...	11:50; 14980	13:06; 8486	11:47; 3792	
11...	10:31; 17390	12:26; 4496	10:51; 3330	
15...	10:57; 23460	13:27; 13373	11:18; 4548	
19...	01:46; 11180	01:25; 2975		02:50; 7312
	10:37; 6020		10:33; 3804	
1984 Dec 16...	10:25; 11080	12:11; 6586	10:56; 3479	
19...	07:22; 16780	09:24; 6602	07:49; 4573	
22...	07:00; 20610	11:32; 5799		07:24; 14362
24...	09:36; 13440			09:58; 12131
28...	09:20; 9210			09:49; 12240
1985 Jan 02...	05:43; 29840	11:51; 6236	06:24; 3844	07:33; 14880

[a] Start (h:m, UT) and exposure (s) times.

these observations a usable signal was detected only in the range 1.2–15 keV with the argon and in the range 8–25 keV with the xenon counters. All the ME observations were performed with half the counters on the source and the other half offset by $\sim 2°$ to monitor the background; each observation was divided in two parts of roughly equal duration, in which the two halves were interchanged (because of a technical failure on 1984 December 28, the second part lasted for only one-third of the first part). Spectra from each counter were accumulated every 10 s. After correcting the count rates for dead times due to the sampling rate and generating the energy grid corrected for gain shifts for each observation, the data were analyzed to obtain temporal profiles and net spectra. The spectral fits described in § V were performed using the calibrations made available in 1985 April, after ascribing an additional 1% uncertainty to the net counts, as suggested by Parmar and Smith (1985).

To extract the temporal profiles of the net count rate, the difference between the ON and OFF source halves was corrected for the difference between the background measured in the two halves in the same configuration during the slew maneuvers. This correction is necessary because the background response in the two halves is different, and depends on their angle to the coalignment axis. As we shall see in § III, this analysis revealed significant flux variations within single observations.

The spectral distribution of the net counts obtained from the temporal analysis is affected by the statistical fluctuations in the counts collected during the slew maneuvers. A technique, described by Smith (1984), allows one to obtain the average net spectrum in one observation with somewhat smaller statistical errors. In short, the background spectrum measured with the half experiment in the offset mode during the first (or second) part of one observation is first corrected for the difference between the aligned and offset background spectra of the same half, which is known from calibrations and assumed to be constant, and is then subtracted from the spectrum measured with the same half in the ON source mode during the other part of the observation. To account for slow background variations during the pointing, the spectra extracted from the two halves are summed. Apart from the statistical improvement, the spectra obtained with this technique were practically identical to those from the temporal analysis. On 1983 November 7 and 11 and 1984 December 16 the spectra from the inner and outer xenon counters were found to be inconsistent with each other: the difference is attributed to the inner counters being less shielded and more sensitive to variations in the particle background; hence, the spectra obtained with these counters in the three occasions were rejected.

b) *Low Energy*

The three filters used in conjunction with the CMA (de Korte *et al.* 1981) cover energy bands which overlap considerably—No. 6, 0.04–2 keV; No. 7, 0.05–2 keV; No. 8, 0.1–2 keV— but with substantial differences in their transmission profiles, which allow one to obtain some crude spectral information from their combination. For a source of the strength of NGC 4151 in the soft X-rays, the extraction of the net counts from the CMA images is subject to serious uncertainties. The average background per pixel was estimated in the area enclosed by the two squares centered on the source with half-sides 64″ and 184″. The curves of growth of the net counts often behave rather differently from one observation to the other at half-sides greater than a critical value, where they become comparable to the background in the same area, a consequence of nonflatness in the background. For this reason the total net count rates given in Table 2 were obtained by multiplying the net counts in squares with the critical half-side by a factor derived from the integral point spread function (PSF) given in the FOT and obtained from ground calibrations of filter No. 7. This approach optimizes the statistics (the signal-to-noise ratio is maximum near the critical half-side) and is appropriate for variability tests, but is not equally convenient to obtain absolute values because of the current uncertainties in the PSF pertinent to each of the three filters, which depends on the energy distribution of the incident photons. Particularly serious is the uncertainty in the PSF of filter No. 8, although, according to Davelaar and Giommi (1985), it should not differ strongly from that of No. 7 if most of the photons through No. 8 are concentrated within 1–2 keV, as is the case for this object (see next sections). For this reason, when absolute values are used in the following, those reported in Table 2 are assigned a further 10% systematic uncertainty.

The LE data were also subjected to a temporal analysis, but no evidence of variations was found within a single observa-

TABLE 2

IUE AND *EXOSAT* INTENSITIES[a]

Date	m_B(FES)	f_{2500} (mJy)	f_{1455} (mJy)	LE-7 (10^{-3} counts s^{-1})	LE-6 (10^{-3} counts s^{-1})	LE-8 (10^{-3} counts s^{-1})	ME(2–10 keV) (counts s^{-1})
1983 Oct 30...	12.86 ± 0.06	9.5 ± 0.6	4.6 ± 0.2	...	...	...	...
1983 Nov 04...	12.93 ± 0.02	7.9 ± 0.6	3.8 ± 0.2	...	...	...	...
07...	13.02 ± 0.02	7.2 ± 0.6	3.2 ± 0.2	25.4 ± 3.1	11.1 ± 1.4	...	5.43 ± 0.05
11...	13.04 ± 0.04	7.1 ± 0.6	2.9 ± 0.2	18.6 ± 3.0	9.6 ± 1.9	...	4.96 ± 0.04
15...	13.06 ± 0.02	5.6 ± 0.6	2.4 ± 0.2	27.8 ± 3.0	8.6 ± 1.0	...	3.63 ± 0.04
19...	13.02 ± 0.02	5.6 ± 0.6	2.6 ± 0.2	17.1 ± 2.7	10.6 ± 2.5	1.4 ± 0.7	3.97 ± 0.04
1984 Dec 16...	12.93 ± 0.05	9.0 ± 0.6	5.5 ± 0.3	23.4 ± 3.4	10.0 ± 1.7	...	9.77 ± 0.06
19...	12.84 ± 0.04	10.6 ± 0.6	6.7 ± 0.3	23.8 ± 2.7	11.2 ± 1.7	...	12.78 ± 0.05
22...	...	...	...	...	12.2 ± 2.0	2.8 ± 0.6	15.69 ± 0.05
24...	12.91 ± 0.06	9.4 ± 0.6	5.5 ± 0.3	...	...	3.2 ± 0.7	13.96 ± 0.05
28...	13.01 ± 0.05	8.8 ± 0.6	3.7 ± 0.2	...	...	1.7 ± 0.6	7.36 ± 0.07
1985 Jan 02...	12.79 ± 0.03	11.1 ± 0.6	8.3 ± 0.4	23.9 ± 2.9	11.6 ± 1.7	4.4 ± 0.7	19.71 ± 0.04
08...	12.88 ± 0.02	11.5 ± 0.6	6.8 ± 0.3	...	...	...	...
14...	12.97 ± 0.03	9.3 ± 0.6	6.8 ± 0.3	...	...	...	...

[a] 1 σ errors.

tion. In §§ III and IV it will be argued that the flux in filters Nos. 7 and 6 is dominated by a probably constant and extended spectral component.

III. LIGHT CURVES

The values of the source intensity as recorded by the various instruments are assembled in Table 2. The intensity in the ultraviolet is represented by the continuum fluxes f_{2500} at 2500 Å and f_{1455} at 1455 Å, measured according to Paper II, where the ultraviolet spectrum was described as a mixture of two components, one of which dominates in f_{2500}, the other in f_{1455}. The intensities in the *EXOSAT* instruments are given in the form of count rates, which in the ME are average values over the variations found within several observations.

The light curves are shown in Figure 1. For comparison with the level of intensity reached in earlier epochs the horizontal broken lines (from Paper II) represent the mean values of the *IUE* observations from 1978 to 1980 and the 2–10 keV measurements with the *Ariel 5* Sky Survey Instrument from 1974 to 1979. After 1980, the continuation of the *IUE* monitoring revealed a change in the state of activity of NGC 4151, with the occurrence of several months long periods of quiescence, characterized by a continuum flux a factor 2–3 below the 1978–1980 mean value. Unfortunately, X-ray observations are not available for 1981 and 1982.

Several important results can be extracted from these light curves. Taking into account all the simultaneous *IUE* and *EXOSAT* measurements in the two epochs, the ultraviolet and the X-ray ME fluxes have undergone large variations: the ratio of maximum to minimum intensities is 2 in f_{2500}, 3.2 in f_{1455}, and 5.4 in f(2–10 keV). In contrast, despite the rather large errors, one can exclude variations by more than a factor 1.5 in LE-6 and 2 in LE-7. Moreover, a χ^2 test applied to the string of all points available yields a probability of 12% (in LE-7) and 70% (in LE-6) that the deviations from a constant value were caused only by statistical fluctuations in the measurements. Notably the relatively low probability in LE-7 is due to the fluctuations in the 1983 measurements, which took place when both the ultraviolet and ME fluxes varied the least. This result strongly suggests that in the very soft X-rays the incident spectrum is dominated by a component which is not immediately related to those responsible for the variable ultraviolet and hard X-ray continua, and which could well be constant in flux; a similar conclusion was reached also by Pounds *et al.* (1985, 1986) on the basis of independent *EXOSAT* measurements.

Unlike the results for the two filters which are far more transparent to the very soft X-rays, the LE-8 counts did follow rather closely the variations in the ME counts; hence, they appear to be dominated by the photoelectrically absorbed low-energy part of the ME component.

In agreement with earlier results, the variations in m_B, f_{2500}, and f_{1455} were correlated, but, as was found on at least one previous occasion (see Paper II), the fast variations which took place in the second epoch were much sharper in f_{1455}: the

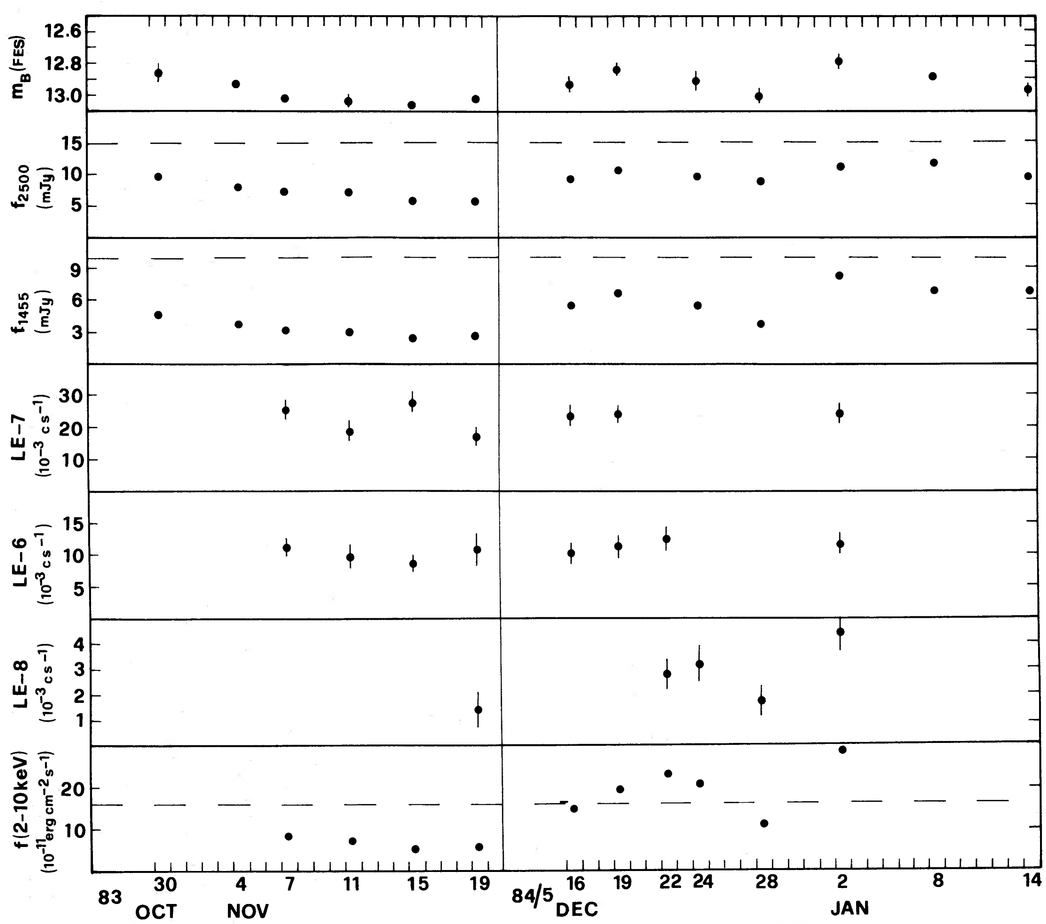

FIG. 1.—Light curves measured with the various *IUE* and *EXOSAT* instruments in the two epochs. Broken horizontal lines represent mean values of measurements performed up to 1980 (from Paper II).

doubling time scale (as defined in Paper II) relative to the rise from December 28 to January 2 was $\sim$2 days in f_{1455} as opposed to $\sim$20 days in f_{2500}.

A correlation is apparent also between the ultraviolet and the ME X-ray fluxes, but, before examining this, the evidence for variations in the ME count rate during single pointings must be illustrated. Significant variations were discovered in six of the present observations; three examples are shown in Figure 2. A small-scale flickering ($<5\%$ in $\sim$1000 s) is occasionally superposed on fairly regular trends, which can be roughly approximated as linear for a few hours. By fitting a line $C/C_0 = 1 + R(t - t_0)$ separately to the two parts of the six observations, the percentage rate of change R and $\tau = 1/R$, approximately the *e*-folding time scale, were determined (Table 3). Notably, the absolute values of R are much greater than those ($\lesssim 1.4\%\ \mathrm{hr}^{-1}$) inferred from adjacent observations. Previous reports on the X-ray variability of this object (Mushotzky, Holt, and Serlemitsos 1978; Lawrence 1980) have shown that large-amplitude (factor of 2–3) variations occur with *e*-folding time scales of 0.5–1 day (for the rise) and 2–4 days (for the fall), while some evidence for changes in a few hours, comparable in amplitude to those reported here, can be discerned in the light curve of the best sampled large, flarelike variation in Mushotzky, Holt, and Serlemitsos (1978). At least some of the falls in Table 3 were clearly much faster than previously reported in large flares, so it is not obvious to what

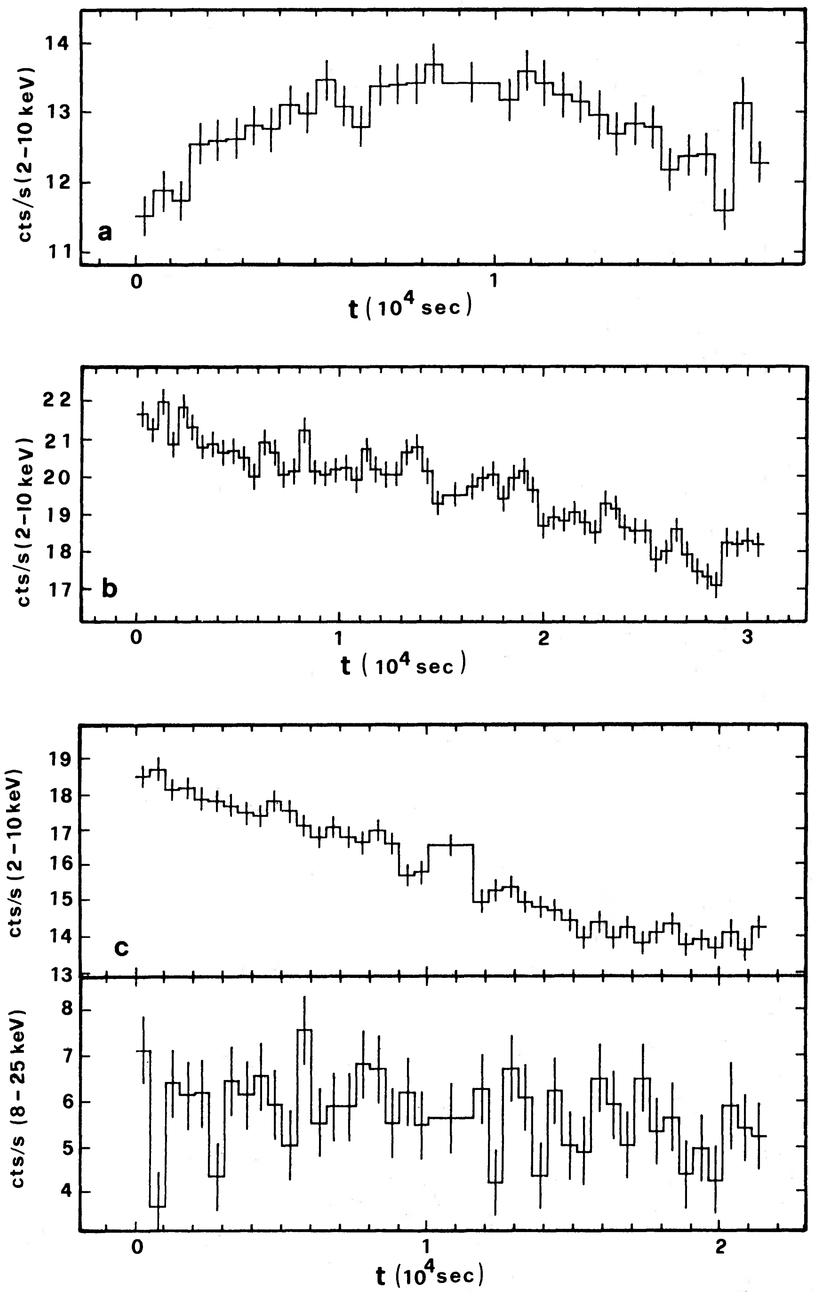

FIG. 2.—Temporal profiles of the net 2–10 keV (argon) counts for (*a*) 1984 December 19; (*b*) 1985 January 2. (*c*) Temporal profiles of the net 2–10 keV (argon) and 8–25 keV (xenon) counts for 1984 December 22. See § V for a discussion of the different rates of change in the two energy intervals.

TABLE 3

PERCENTAGE RATE OF CHANGE AND *e*-FOLDING TIME SCALE IN SINGLE OBSERVATIONS WITH THE ME (argon counters, 2–10 keV)

	FIRST HALF		SECOND HALF	
DATE	R (% hr^{-1})	τ (days)	R (% hr^{-1})	τ (days)
1983 Nov 11...	+1	5	+10	0.4
1984 Dec 19...	+7	0.6	−5	0.8
22...	−5	0.8	−4	1.0
24...	−2	2.1	−2	2.1
28...	+8	0.5	...	...
1985 Jan 02...	−2	2.1	−3	1.4

extent the values of R measured represent the intraday quota of interday large-amplitude variations, or the confirmation of the existence of more modest but fast intraday variations. Therefore it is open to doubt whether the large-scale variations which occurred in the second epoch were sufficiently well sampled by the six observations, a point which is relevant to the following discussion.

The 1983–1985 light curves show the existence of a correlation between the optical-ultraviolet and the ME X-ray fluxes, but with the variations in f_{1455} being closer in amplitude to those in f(2–10 keV). With reference to the broken horizontal lines, the long-term correlation seems not very tight, as if at the end of 1984 the source strength in the ultraviolet, unlike in the X-rays, had not yet recovered the level typical of the 1978–1980 measurements. On the other hand, the detailed correlation of the 1983–1985 points is very good, as illustrated in Figure 3,

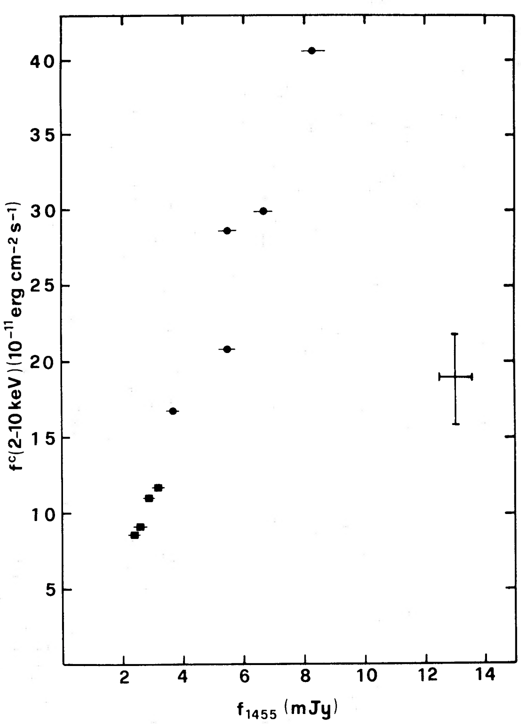

FIG. 3.—Correlation diagram of the ultraviolet and X-ray continua. Squares and circles refer to the 1983 and 1984–1985 campaigns, respectively; cross represents the range of values measured (Paper II) in 1979 May 19–21.

where f_{1455} is plotted against f^c(2–10 keV), the flux corrected for the photoelectric absorption (from Table 5). The linear correlation coefficient is 0.982, corresponding to a chance probability of 2.5×10^{-6}, and the least-squares fit gives

$$f_{1455} = 0.97(\pm 0.29) + 0.18(\pm 0.01) f^c(2\text{–}10 \text{ keV}) \quad (1)$$

where f_{1455} is in millijanskys and f^c(2–10 keV) in 10^{-11} ergs cm^{-2} s^{-1}. A highly significant correlation is found also separately for the first (correlation coefficient = 0.98) and the second (correlation coefficient = 0.95) epoch.

With the present *IUE* measurements, 1 hr being at most the separation between the two images taken with the same camera in each session, it is hard to reveal variations of the amplitude registered with the ME on the time scale of hours. On the other hand, one would like to argue that, were the intraday rates of change described above the signature of a much more complex profile of large-scale variations, the persistence of the correlation in the second epoch would have been rather improbable unless f_{1455} varied almost coherently with the X-rays on time scales shorter than 1 day.

This result contrasts with the one found in Paper II, where the case of an extended ultraviolet brightening (1979 May) not associated with an X-ray brightening was considered evidence of lack of a detailed correlation. Then a sequence of simultaneous measurements for a correlation analysis could not be performed, so in order to illustrate the discrepancy in Figure 3 the range of f_{1455} measured on May 19 and 21 is plotted against the range of f^c(2–10 keV) measured 5 times from May 19.00 to 20.91 with the Monitor Proportional Counter (MPC) on board the *Einstein Observatory*. The discrepancy from equation (1) is so large that it can hardly be attributed to measurement errors. Perhaps the two results can be reconciled by admitting that the slope of the correlation can change dramatically from epoch to epoch, or that large X-ray variations can drive changes in the ultraviolet component which dominates in f_{1455} but not vice versa.

IV. THE SOFT X-RAY COMPONENT

The discovery below 1 keV of a new, probably constant spectral component, not immediately related to the main X-ray source, should explain, at least in part (see § V), the soft X-ray excess detected down to 0.5 keV by Holt *et al.* (1980). The excess counts in LE-7 with respect to LE-6 indicate that this component extends below 0.5 keV and therefore must be located outside the $r \gtrsim 10^{18}$ cm, $N_H \gtrsim 10^{21}$ cm^{-2} screen responsible for the ultraviolet absorption lines (Bromage *et al.* 1985), unless the latter is made transparent below 0.5 keV by the incident ionizing radiation or its spatial distribution is very patchy and leaky. The first possibility seems excluded by the value of the ionization parameter derived by Bromage *et al.* (1985), which, according to the calculations by Krolik and Kallman (1984), is much too small to provide the required degree of transparency; the second one seems excluded by the argument advanced in § V to reconcile the partial transparency of the gas responsible for the strong photoelectric absorption in the main X-ray spectral component and the absence of a significant contribution by this component below 0.5 keV. Elvis, Briel, and Henry (1983), in an image obtained with the HRI instrument on board the *Einstein Observatory*, found evidence of an extended component, probably of thermal emission, centered ~5″ (500 pc) to the southwest of the nucleus. To estimate the flux and other parameters of the new spectral component, and therefore also to test whether it can be accounted for by the HRI extension, a constant emission was assumed to dominate the counts in LE-7 and LE-6, and no attempt was made to correct them for the minor contribution in the 1–2 keV range of the variable component detected in LE-8. The weighted means of the measurements in Table 2, with an additional 10% uncertainty as explained in § II, are LE-7 = $22.7(\pm 2.5) \times 10^{-3}$ counts s^{-1}, LE-6 = $10.1(\pm 1.1) \times 10^{-3}$ counts s^{-1}, and LE-7/LE-6 = 2.25 ± 0.35. The spectral parameters were determined by fitting these quantities in combination with a value of the absorbing column, which was taken equal to the galactic one, N_{HG}.

The thermal fit was performed adopting a recently developed code (Landini and Monsignori Fossi 1986) for collisionally ionized gas with cosmic abundances and assuming the plasma transparent to its own radiation. For three choices of N_{HG}, viz., 1, 2, and 3×10^{20} cm^{-2}, the corresponding values of T are 2.7(+0.5, −0.6), 1.8(+0.7, −0.4), and 1.4(+0.5, −0.2) $\times 10^6$ K. Values of T greater than 2.5×10^6 K are excluded by the minimum count rate registered in the LE-8 measurements. If the most recent estimate of N_{HG}, viz. 2×10^{20} cm^{-2}, is adopted (W. Huchtmeier and O. Richter, private communication), and correspondingly $T = 1.8 \times 10^6$ K, the incident flux is f(0.1–2 keV) = 3.2×10^{-12} ergs cm^{-2} s^{-1} (the same quantity is equal to 3.0×10^{-12} if a recent version of the more commonly used code by Raymond and Smith 1977 is adopted), while the unabsorbed flux and luminosity are f^c(0.01–2 keV) = 3.7×10^{-11} ergs cm^{-2} s^{-1} and L^c(0.01–2 keV) = 1.7×10^{42} ergs s^{-1}. The intensity of the HRI extension is f(0.1–2 keV) = 0.9×10^{-12} ergs cm^{-2} s^{-1}, a value derived by M. Elvis (private communication) adopting the Raymond and Smith code, $N_{HG} = 2 \times 10^{20}$ cm^{-2} and $T = 2 \times 10^6$ K. Therefore the HRI extension contributes no more than 30% of the new component, and could represent a protuberance to the main body of a thermal source with a size less than 200 pc surrounding the nucleus.

Fits were also performed with other spectral shapes, namely a power law, an exponential and a blackbody. The best-fit values of the spectral parameters are collected in Table 4, together with the corresponding predictions in the LE-8 count rate, which are consistent within the errors with the minimum value recorded.

Returning to the thermal interpretation, the emission measure from the best fit temperature and luminosity is $n^2V = 1.9 \times 10^{64}$ cm^{-3}. If at least 70% of the source is assumed spherical and uniform, then the density $n = 3.2 \times 10^2 (r/10 \text{ pc})^{-1.5}$. A lower limit on the radius r can be placed from the assumption of transparency of the plasma sphere to its own radiation: using, to a first approximation, the photoelectric cross section in a collisionally ionized gas at $T = 10^6$ K given by Krolik and Kallman (1984), one finds $N_H < 10^{22}$ cm^{-2}, and correspondingly a radius $r > 10$ pc. The value of the pressure term nT is therefore equal to or less than 5.8×10^8 K cm^{-3}, which compares well with the range of values derived from the forbidden lines, 0.6–2.3 $\times 10^8$ K cm^{-3} (Boksenberg *et al.* 1975). Furthermore, the radius of the narrow-line region (NLR) derived from a photoionization model (Ferland and Mushotzky 1982) is $\sim 17(n_c/10^4)^{-0.5}$ pc, where n_c is the density in the line-emitting clouds. The numerical coincidences suggest that the soft X-ray emission might be direct evidence of a hot gas phase in the NLR, in pressure equilibrium with the cold clouds, an interpretation similar to the one given by Pounds *et al.* (1986).

This result can also be related to the interpretation of the optical lines identified with highly ionized iron as due to a hot, collisionally ionized gas, as originally proposed by Oke and Sargent (1968). Adopting the emission rate derived by Nussbaumer and Osterbrock (1970), with $n(\text{Fe})/n(\text{H}) = 4 \times 10^{-5}$ and $T = 1.8 \times 10^6$ K, the [Fe X] λ6374 luminosity is expected to be 1.6×10^{39} ergs s^{-1}, while the observed luminosity is 1.7×10^{39} ergs s^{-1} (Penston *et al.* 1984). The coincidence is striking, but one should bear in mind that the line emissivity is very sensitive to the temperature, and the predicted luminosity would be a factor 3.5 smaller or greater if $T = 2$ or 1.2×10^6 K. A strong argument would be represented by the confirmation of the presence of the line [Fe XIV] λ5303, originally claimed by O. C. Wilson (see Oke and Sargent 1968) but later disputed by Weedman (1971), and whose strength at $T = 1.8 \times 10^6$ K should be comparable to that of the other line.

The issue of collisional against photoionization of the Fe^{9+} ion remains open, the second possibility being at present favored by the rather marginal evidence of variability in the 6374 Å line, which suggests a size ≤1 pc for the Fe^{9+} region, and the firmer evidence of a correlation between the [Fe X] and [Fe VII]—definitely photoionized—line intensities in different galaxies (Penston *et al.* 1984). On the other hand, the current direct observation of the wavelength region covering the relevant ionization edges imposes further constraints on a photoionization model. For instance, the f(0.1–2 keV) invoked by Osterbrock (1969) in his model would be 2.6×10^{-10} ergs cm^{-2} s^{-1}, a factor 30–40 greater than observed (see Table 4): such a model could only be retained if the ionizing source were hidden by absorption or the Fe^{9+} region were smaller and denser than supposed by Osterbrock.

A final comment concerns the profile of the 6374 Å line, which appears blueshifted by 96 km s^{-1} and has FWHM = 320 km s^{-1} (Penston *et al.* 1984), to be compared with a thermal width of 15 km s^{-1}: if associated with a hot gas, this should be moving at a highly supersonic speed, perhaps in a wind.

TABLE 4

BEST-FIT SPECTRAL PARAMETERS OF THE SOFT X-RAY COMPONENT ($N_{HG} = 2 \times 10^{20}$ cm^{-2})

Spectral Shape	kT (keV)	α	f(0.1–2 keV) (10^{-12} ergs cm^{-2} s^{-1})	f^c(0.1–2 keV)[a] (10^{-12} ergs cm^{-2} s^{-1})	LE-8[b] (10^{-3} counts s^{-1})
Thermal[c]	$0.15^{+0.07}_{-0.03}$	...	3.2 ± 0.8	6.6 ± 1.0	$0.8^{+1.1}_{-0.4}$
Power law $E^{-\alpha}$	...	$2.55^{+0.55}_{-0.60}$	$4.1^{+1.4}_{-1.0}$	$9.1^{+1.5}_{-1.1}$	$2.0^{+0.9}_{-0.6}$
$E^{-1} \exp(-E/kT)$	$0.25^{+0.21}_{-0.09}$	...	$3.4^{+1.1}_{-0.8}$	7.2 ± 1.1	$1.4^{+0.9}_{-0.4}$
Blackbody	0.08 ± 0.02	...	3.0 ± 0.6	6.1 ± 0.7	0.8 ± 0.3

[a] Unabsorbed flux.
[b] Count rate predicted by the fit of the LE-6 and LE-7 values.
[c] See text.

V. THE SPECTRUM BETWEEN 1 AND 25 keV

Although the spectrum of NGC 4151 above 1 keV has been measured several times before and is among the best studied so far, the ME data contain some new results. For each observation the net average count rates in the argon and xenon counters combined (1.2–25 keV) were fitted first with the "standard" model of a power law $AE^{-\alpha}$, with a uniform and cold absorber of column density N_H and cosmic chemical composition (cross sections and abundances from Morrison and McCammon 1983), except for a free relative iron abundance, labeled "RFe" and equal to $N_{Fe}/3.3 \times 10^{-5} N_H$, where N_{Fe} is the column responsible for the 7.1 keV absorption edge, and with the addition of the Fe fluorescence line at 6.4 keV, whose strength is labeled "$I_{6.4}$." The fit (Fig. 4*a*) to the observation on 1985 January 2, when the count rate was the highest, is statistically unacceptable ($\chi_r^2 = 2.6$), and the residuals show particularly marked deviations from the zero line below 5 keV. Were this situation caused by a contribution of the soft X-ray component in the lower energy channels, it should be even more evident in the observations with a smaller count rate, but this is not the case. Furthermore, the soft component, particularly if described by a thermal spectrum, gives a relatively negligible contribution above 1 keV. Hence, in spite of its discovery (as recognized and discussed also by Pounds *et al.* 1985, 1986), the problem encountered by Holt *et al.* (1980) in modeling the low-energy spectrum is still present, and most likely, as they argue, it has to do with the structure and/or the chemico-physical conditions of the absorber.

Before dealing with this issue, in order to minimize the influence of the uncertainty in the standard model at low energies on the estimate of its parameters, these parameters were evaluated by fitting only the counts above 3.5 keV. The χ_r^2 for 1985 January 2, reduced to an acceptable 1.3 (Fig. 4*b*). The complete set of results is given in Table 5, which contains also f^c(2–10 keV), the flux corrected for the absorption already used in § III. The errors in this table are 90% confidence limits for a single parameter.

The first new result is the evidence of a correlation between the slope α and the intensity f^c(2–10 keV), which is illustrated

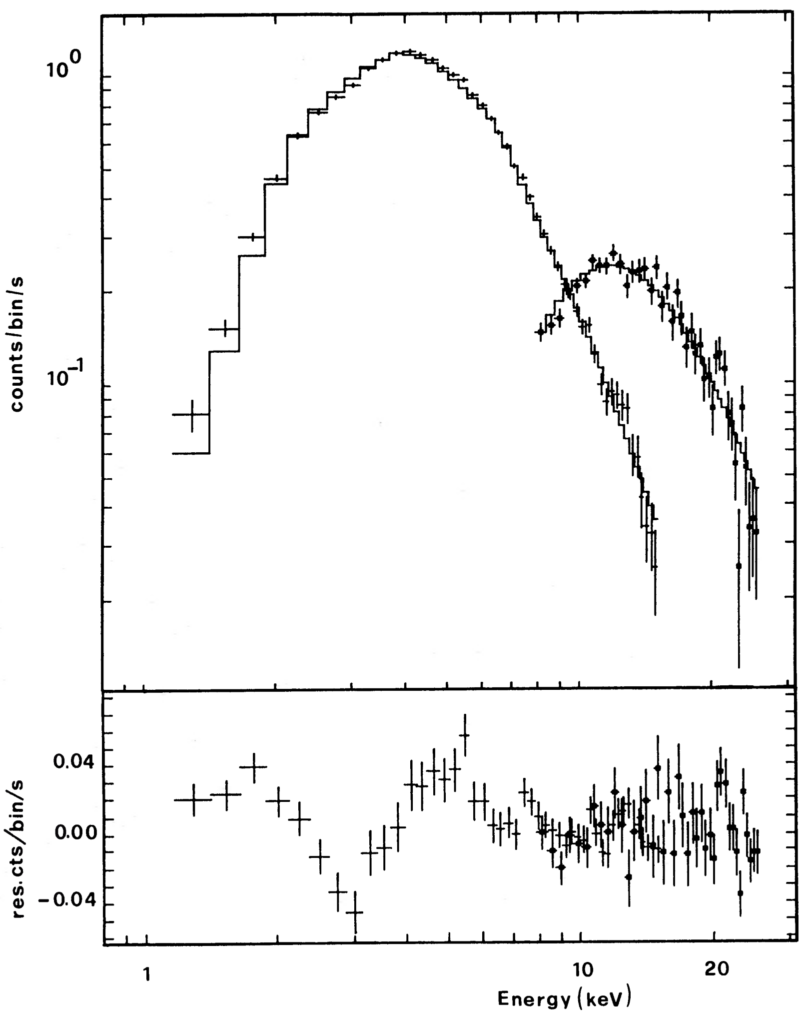

FIG. 4*a*

FIG. 4.—(*a*) Fit of a power law with uniform absorber to the 1.2–25 keV net counts (argon + xenon) for 1985 January 2; $\chi_r^2 = 2.6$, and the residuals show particularly marked deviations from the zero line below 5 keV. (*b*) Fit of a power law with uniform absorber to the 3.5–25 keV net counts (argon + xenon) for 1985 January 2; $\chi_r^2 = 1.3$. (*c*) Fit of a power law with a "Poissonian" absorber to the 1.2–25 keV net counts (argon + xenon) for 1985 January 2; $\chi_r^2 = 1.4$, and the distribution of the residuals is rather flatter than in (*a*).

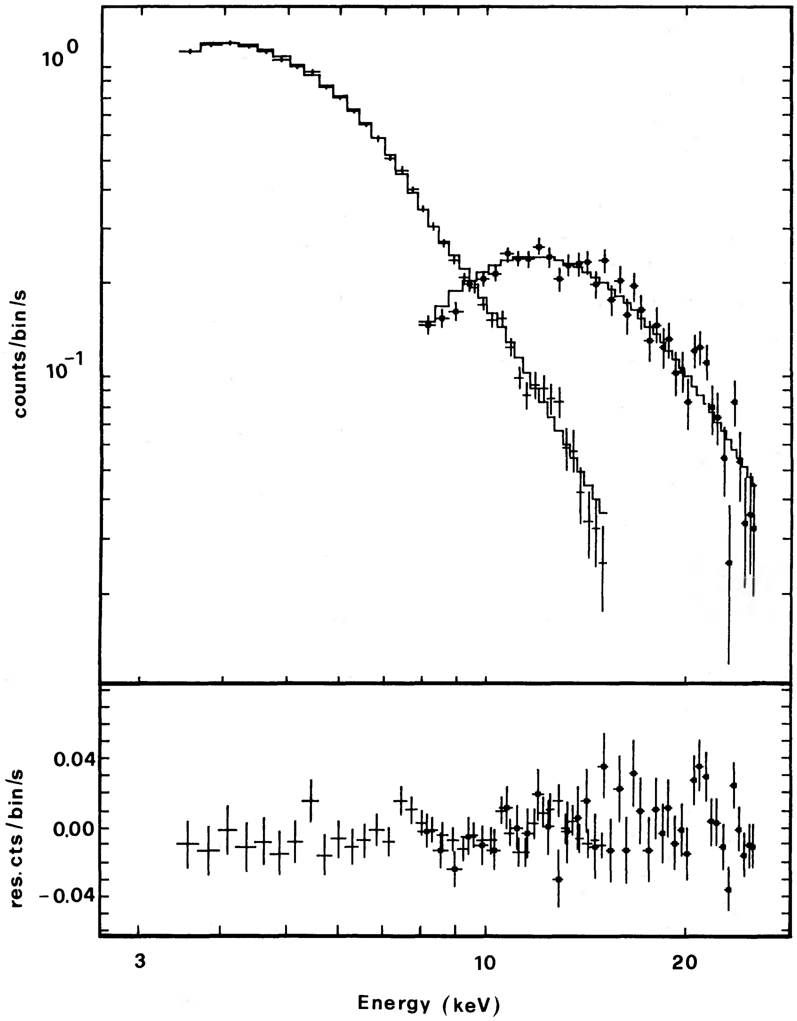

FIG. 4*b*

in Figure 5. The linear correlation coefficient is 0.92, corresponding to a chance probability of 1.4×10^{-4}, and the least-squares fit gives

$$\alpha = 1.18(\pm 0.04) + 0.012(\pm 0.002) f^c(2\text{–}10 \text{ keV}) , \qquad (2)$$

where f^c(2–10 keV) is in 10^{-11} ergs cm^{-2} s^{-1}. A check on whether equation (2) applies also on the time scale of hours is limited by the statistics available. A careful analysis of the observations within which the flux varied led to the following results: (*a*) the correlation on the short time scales is not steeper than equation (2); (*b*) in the observation most suitable for this type of check, where a high intensity combined with a steep fall lasting several hours (1984 December 22, Fig. 2*c*), the rate of change in argon *R*(2–10 keV) was $-4.8(\pm 0.4)\%$ hr^{-1}, while in xenon *R*(8–25 keV) was $-2.2(\pm 1.1)\%$ hr^{-1}, a marginally significant difference which agrees with equation (2).

TABLE 5

STANDARD MODEL SPECTRAL FITS IN THE 3.5–25 keV INTERVAL

Date	A (10^{-2} cm^{-2} s^{-1} keV^{-1})	α	N_H (10^{22} cm^{-2})	RFe	$I_{6.4}$ (10^{-4} cm^{-2} s^{-1})	χ^2_r	f(2–10 keV) (10^{-11} ergs cm^{-2} s^{-1})	f^c(2–10 keV) (10^{-11} ergs cm^{-2} s^{-1})
1983 Nov 07...	1.30	$1.21^{+0.15}_{-0.10}$	$5.1^{+2.0}_{-1.5}$	$2.3^{+3.0}_{-1.5}$	$2.6^{+1.1}_{-1.0}$	1.1	8.5	11.7
11...	1.33	$1.26^{+0.14}_{-0.12}$	$5.4^{+2.1}_{-1.9}$	$4.3^{+5.0}_{-2.8}$	2.7 ± 1.0	0.8	7.1	11.0
15...	1.19	$1.34^{+0.16}_{-0.14}$	$5.1^{+2.9}_{-2.4}$	$6.0^{+5.5}_{-3.5}$	1.9 ± 1.0	1.5	5.4	8.6
19...	1.25	$1.34^{+0.15}_{-0.10}$	$3.0^{+3.0}_{-2.0}$	14^{+35}_{-10}	$2.4^{+1.1}_{-1.0}$	1.2	5.7	9.1
1984 Dec 16...	3.01	$1.37^{+0.10}_{-0.08}$	$3.2^{+1.7}_{-1.4}$	$8.3^{+10}_{-4.4}$	2.1 ± 1.3	1.0	14.6	20.8
19...	5.79	1.55 ± 0.05	6.8 ± 0.9	$1.8^{+0.8}_{-0.6}$	1.9 ± 1.2	0.9	19.4	29.9
22...	7.00	$1.59^{+0.04}_{-0.05}$	$4.9^{+0.8}_{-0.9}$	$3.0^{+1.5}_{-1.0}$	$1.8^{+1.2}_{-1.1}$	1.1	23.0	33.9
24...	5.19	1.51 ± 0.05	4.2 ± 1.0	$3.3^{+2.3}_{-1.5}$	2.5 ± 1.3	1.2	20.3	28.6
28...	2.80	$1.46^{+0.13}_{-0.11}$	$4.4^{+2.4}_{-2.0}$	$5.8^{+4.2}_{-3.5}$	$1.1^{+1.4}_{-1.1}$	1.0	10.9	16.7
1985 Jan 02...	9.50	$1.67^{+0.04}_{-0.03}$	3.9 ± 0.6	$3.7^{+1.5}_{-1.0}$	1.6 ± 1.1	1.3	28.4	40.6

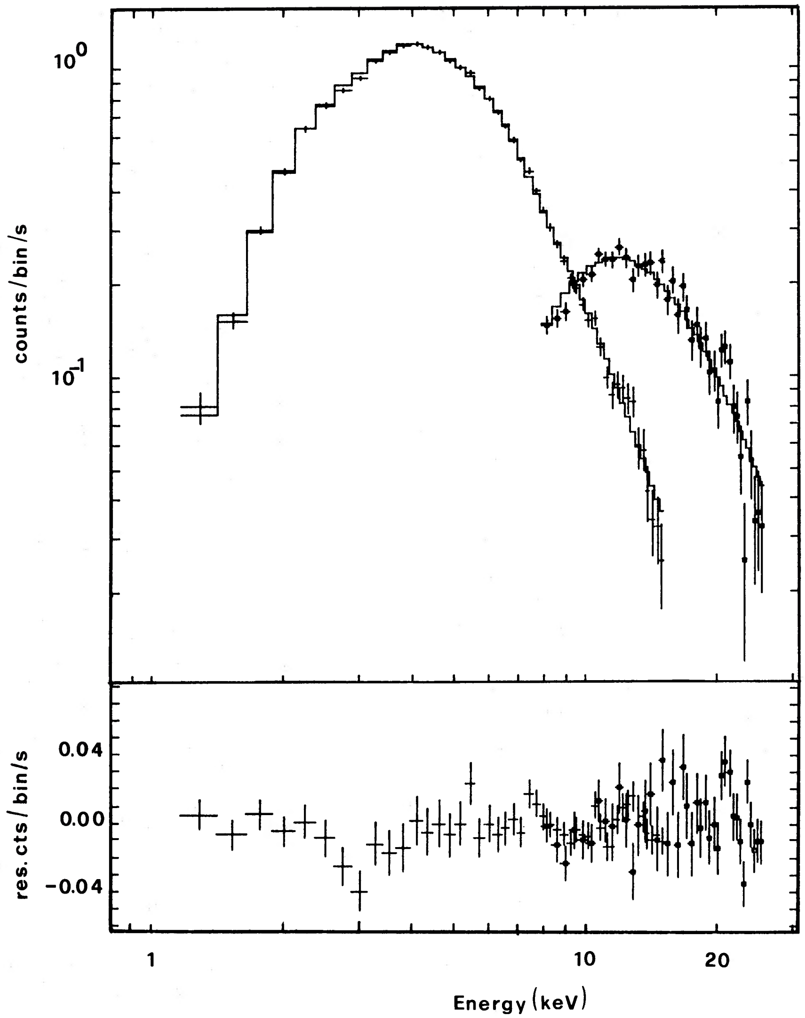

FIG. 4c

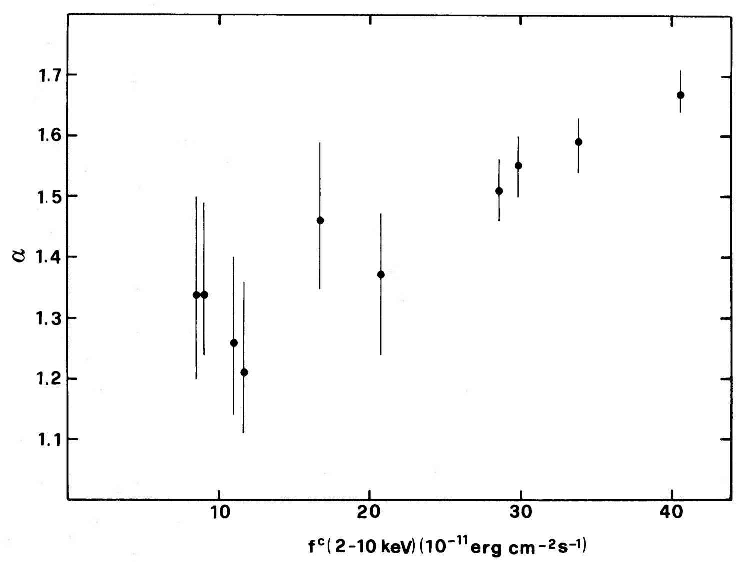

FIG. 5.—Correlation diagram of the X-ray spectral index and intensity

The linear relationship (2) formally implies that a decrease of intensity in the 2–10 keV interval should be accompanied by an increase at appropriately high energies. However, its extrapolation does not agree with the admittedly weak evidence of an opposite correlation between the slope and the monochromatic flux at 100 keV described in Baity *et al.* (1984), but predicts instead a strong compression (from 4 to 1.5) of the range in f(100 keV) compared with f^c(2–10 keV), therefore a wide spread in α for a small spread in the flux.

All the measurements below 50 keV in the literature, made before 1980, are consistent with the best determination of the slope from the *HEAO 1* A-2 pointing in 1978 June, when $\alpha = 1.55(+0.05, -0.08)$ and $f^c(2\text{–}10 \text{ keV}) = 27.9 \times 10^{-11}$ ergs cm^{-2} s^{-1} (Holt *et al.* 1980), a pair of values in good agreement with equation (2). Probably the correlation escaped detection because all determinations of the slope before 1980 happened to take place only over a range of 2 in the source intensity. The observations with the gas scintillation proportional counters on board the *Tenma* satellite (Matsuoka *et al.* 1986) in 1984 January and March, when the object was in a low state of intensity, gave $\alpha = 1.34 \pm 0.11$ and 1.44 ± 0.09, with f^c(2–10 keV) = 6.6 and 6.9×10^{-11} ergs cm^{-2} s^{-1}: the first pair of values is in good, the second in marginal agreement with equation (2).

No significant evidence of variations in N_H is present, neither within nor between the two epochs, the weighted means being 4.8 ± 1.1 and 4.6 ± 0.4 in 10^{22} cm^{-2} for the first and the second epoch, respectively. These two values fall in the range $3.5\text{–}8 \times 10^{22}$ cm^{-2} where most of the measurements in the literature are clustered, the evidence of significantly large variations being based mainly on two estimates, $18(\pm 5) \times 10^{22}$ cm^{-2} (1976 December, *Ariel 5*; Barr *et al.* 1977) and $10(\pm 2) \times 10^{22}$ cm^{-2} (1977 December, *HEAO 1*; Mushotzky *et al.* 1980), when compared with estimates obtained in other epochs with the same instrument. When placed in the historical context of the various measurements, these large variations seem to occur on a time scale of 0.5–1 yr. Based on this evidence, the bulk of the photoelectric absorption is generally attributed to the clouds in the broad-line region (BLR) (e.g., Holt *et al.* 1980).

The best-fit value of RFe in each observation indicates an overabundance of iron. The weighted mean of the 10 measurements is $2.0(+0.6, -0.4)$, which agrees with and improves upon earlier estimates (2.1 ± 1.4, Barr *et al.* 1977; 3.6 ± 1.0, Holt *et al.* 1980).

The second new result concerns the intensity of the iron fluorescence line. Despite the difference by a factor of 3 in the continuum of the two epochs, the line maintained the same strength, and this implies a minimum delay of 18 days (the duration of the second campaign) in the response to a change in the exciting continuum. In Table 6 the weighted means relative to the two epochs are compared with other measurements, some of which indicate that the line strength may have attained larger (~ 2 times) values before 1980, when the average continuum level (see Fig. 1) remained for years well above the intensity in 1983 November. Unfortunately, no X-ray measurements exist between 1981 and 1983, but the optical light curve in Gill *et al.* (1984), complemented by further RGO observations after 1983 July, on the basis of the correlation described in § III, suggests that the X-ray flux remained close to the pre–1980 average value from 1982 July to 1983 July then declined to the values recorded in 1983 November, and declined even further until 1984 August–September, when it started to rise again.

TABLE 6

MEASUREMENTS OF THE 6.4 keV IRON FLUORESCENCE LINE

Epoch	$I_{6.4}$ (10^{-4} cm^{-2} s^{-1})	Equivalent Width (eV)	f^c(2–10 keV) (10^{-11} ergs cm^{-2} s^{-1})
1977 May[a] ..	$4.1^{+4.6}_{-2.9}$	240^{+270}_{-170}	15.2
1977 Dec[b] ...	3.7 ± 1.7	220 ± 100	15.0
1978 Jun[c]	6.8 ± 3.2	223 ± 107	27.9
1980 Jan[d]	9.3:	440:	20.8
1983 Jul[e]	$5.0^{+4.6}_{-4.0}$	163^{+149}_{-130}	29.1
1983 Nov[f] ...	2.4 ± 0.5	207 ± 43	10.1
1984 Jan[g]	2.4 ± 0.6	320 ± 75	6.6
1984 Mar[g] ...	2.5 ± 0.5	316 ± 70	6.9
1984 Dec[f] ...	1.8 ± 0.5	58 ± 16	28.4

[a] Mushotzky, Holt, and Serlemitsos 1978.
[b] Mushotzky *et al.* 1980.
[c] Holt *et al.* 1980.
[d] Hall *et al.* 1981.
[e] Pounds *et al.* 1986.
[f] This paper. Equivalent width relative to the average f(6.4 keV) measured in each epoch.
[g] Matsuoka *et al.* 1986.

This suggestion is confirmed by other *EXOSAT* observations in 1983 July and December, 1984 April (Pounds *et al.* 1986), and on 1984 June 1 (T. Dean and G. Di Cocco, private communication), and by the *Tenma* observations in 1984 January and March (Matsuoka *et al.* 1986). The estimate of $I_{6.4}$ in 1983 July is, unfortunately, affected by errors which are too large to allow one to draw any firm conclusion from a comparison with the value measured in 1983 November. On the other hand, the evidence available from 1983 November to 1984 March, for which $I_{6.4}$ apparently remained constant when the X-ray flux declined by a factor 1.5 (although the errors again do not permit a strong statement), together with the absence of an increase in $I_{6.4}$ in 1984 December following the rise of the X-ray flux which probably started in the late summer of 1984, points to a very slow response of the line intensity to the changes in the continuum, with a time scale of the order of at least 4 months, and possibly substantially larger than this limit.

This conclusion bears some relevant implications deserving further comment. The first concerns the spatial distribution of the absorbing gas. By studying the response of strong ultraviolet lines from the BLR to changes in the continuum, Ulrich *et al.* (1984) found that C III] λ1909, unlike C IV λ1550 and Mg II λ2800, is nearly insensitive to them, and concluded from this evidence that the broad component of the C III] line is mainly emitted by the outermost part of the BLR, whose radius was estimated to be ~ 1 lt-yr (this estimate is confirmed by as yet unpublished results on a gentle decline in the line intensity during the exceptionally long period of quiescence which followed 1980 November). The behavior of $I_{6.4}$ is very reminiscent of that of C III] and suggests that most of the fluorescence, and therefore of the absorbing gas, is located in the outermost BLR. By implication, the "diluted" density of the gas embedded in the clouds should decrease with radius not faster than r^{-1}.

In the literature the equivalent width of the fluorescence line is generally discussed in association with the value of N_H simultaneously measured. This approach overemphasizes the problem of explaining the observed equivalent width, when its value is relative to a very low state of the continuum, as in the discussions by Inoue (1985) and Matsuoka *et al.* (1986), and

TABLE 7

POWER LAW WITH "POISSONIAN" ABSORBER FITTED TO THE 1.2–25 keV COUNTS ON 1985 JANUARY 2

A (10^{-2} cm^{-2} s^{-1} keV^{-1})	N_{HC} (10^{22} cm^{-2})	q	RFe	α[a]	χ_r^2	LE-8[b]	LE-6[b]	LE-7[b]
9.5 ± 0.1	1.1 ± 0.1	3.8 ± 0.3	$3.4^{+1.0}_{-0.8}$	1.67	1.4	5.6	12.4	21.2

[a] Fixed, from Table 5.
[b] Predicted count rate. In units of 10^{-3} counts s^{-1}.

one should bear this caveat in mind when using the equivalent width to inquire into the overall geometry of the BLR. To this end the values measured prior to 1980 are probably the most appropriate, and they average to ~ 220 eV. Yet the conclusions that are reached do not differ significantly from those in Matsuoka *et al.* (1986). Using their Monte Carlo calculations, and adopting, from the present measurements, RFe = 2, the value EW = 220 eV is still a factor of 3 greater than predicted if the gas is distributed in a sphere, and the average N_H over 4π is equal to 5×10^{22} cm^{-2}, the estimate suggested by the majority of the observations, but it agrees with the prediction if the gas is distributed in a highly flattened configuration (idealized as an infinite slab) with the minor axis close to the line of sight.

Returning to the fitting of the ME data at low energies, the most natural modification of the uniform cold absorber model was tested, namely the one suggested by Holt *et al.* (1980) and by Lawrence and Elvis (1982), where the absorber is made of discrete clouds much smaller than the source size, whose number along the line of sight is distributed according to the Poisson statistical law. Models of a partially ionized absorber or with a chemical composition grossly different from cosmic cannot be excluded, but cannot be properly tested either, given the coarse resolution of the spectra available. The 1.2–25 keV counts were then fitted with a power law and a "Poissonian" absorber, described by the average number of clouds along the line of sight, q, and by the thickness of each cloud, N_{HC}. In this process the slope and $I_{6.4}$ were given the values obtained from the standard model fit above 3.5 keV. Since no significant differences were found among the various days, the results relative to the 1985 January 2 spectrum are given in Table 7 and Figure 4*c* as an example. The product qN_{HC} and RFe are practically equal to N_H and the iron abundance in Table 5, but the χ_r^2 is now considerably reduced, 1.4 instead of 2.6, with respect to the standard model fit in the full 1.2–25 keV interval. The only remaining problem is that a nonnegligible fraction, e^{-q}, of the source remains on average uncovered, and the counts predicted in LE-6 and LE-7, given in Table 7, are clearly too large, unless an additional cold absorber, of thickness $N_H \approx 10^{22}$ cm^{-2}, is located outside the BLR. Such an absorber could be represented by the screen of gas responsible for the ultraviolet absorption lines, whose thickness can be of the right order of magnitude (Bromage *et al.* 1985). Therefore the validity of this modification of the standard model cannot be excluded.

VI. CONCLUSIONS

A number of X-ray observations of NGC 4151 with *EXOSAT*, both closely and widely spaced in time, performed simultaneously with ultraviolet observations with *IUE*, have led to several new results, which are now summarized.

1. Large-scale variations in the ultraviolet region and the X-ray region above 1 keV were not accompanied by significant changes in the soft X-ray excess flux over the photoelectrically absorbed hard X-ray component (Holt *et al.* 1980), which we extend to $E < 0.5$ keV. This result proves that the excess cannot be due to a leak of the hard component through the absorber, as suggested by Holt *et al.* (1980), or be identified with the far tail of the ultraviolet continuum, but represents a new spectral component. The lack of significant evidence of variability and the flux below 0.5 keV imply that this component is probably extended and external ($r > 0.3$ pc) to the gas responsible for the ultraviolet absorption lines (Bromage *et al.* 1985). The soft X-ray extension discovered at $r \approx 500$ pc by Elvis *et al.* (1983) explains no more than 30% of the observed flux.

2. If the new component is thermal emission from a hot gas, the best estimate of the temperature (for a galactic $N_H = 2 \times 10^{20}$ cm^{-2}) is 1.8×10^6 K, and the luminosity is 1.7×10^{42} ergs s^{-1}. The density derived from the emission measure makes up a pressure term nT which compares well with its value in the NLR clouds; hence, the soft X-ray excess could be the first evidence in an active galactic nucleus of a hot medium close to pressure equilibrium with the NRL clouds. A striking coincidence between the predicted and observed intensity of the [Fe X] λ6374 line strongly suggests that a collisional rather than a photoelectric origin for the highly ionized iron (as originally suggested by Oke and Sargent 1968) should be seriously considered and further tested with new observations of other lines, in particular [Fe XIV] λ5303.

3. A very significant correlation was found between the variable ultraviolet and X-ray continua, with the amplitude of the variations at 1455 Å being closer than that at 2500 Å to that in the 2–10 keV flux. This correlation implies that the ultraviolet varies coherently with the X-rays at least down to a time scale of days, but possibly down to less than 1 day, as suggested, on the basis of a probability argument, by the fast intraday variations discovered in the 2–10 keV range. A previous finding (Paper II) of an ultraviolet outburst not accompanied by an increase in the X-ray emission (1979 May) is in striking disagreement with the present result, and provides an excellent example of very discrepant behavior of the same object in different epochs, which may serve to deemphasize the discrepancies which are sometime found between different AGNs (e.g., Tanzi *et al.* 1984).

4. The standard model of a power law with a uniform cold absorber gives a bad fit at low energies in the 1.2–25 keV range. This situation cannot be due to a contribution above 1 keV by the new spectral component, and is probably caused by imperfections in the absorber model. When the absorber is assumed to be made of discrete clouds, as originally suggested by Holt *et al.* (1980), the fit becomes statistically acceptable. However, the predicted flux in the soft X-ray region, due to the uncovered fraction of the source, is too large, unless an additional and uniform cold absorber with $N_H \approx 10^{22}$ cm^{-2} is present: this could be identified with the one responsible for the ultraviolet absorption lines.

5. The spectral index of the power law appears to correlate closely with the flux in the 2–10 keV range, the slope being shallower when the intensity is lower, as given in equation (2).

A weak evidence was found that the same correlation applies also during flux variations occurring on the time scale of hours, the counting statistics being the limiting factor in obtaining a stronger evidence. This result contradicts those of previous measurements below 50 keV, which probably lacked sufficient statistics and dynamic range in intensity to reveal the correlation, and agrees with the results obtained by Halpern (1985) on 3C 120 and by Lawrence *et al.* (1985) on NGC 4051, two active nuclei with an X-ray luminosity ~ 10 and 5×10^{-2} times, respectively, that of NGC 4151. Notably, though, while the correlation found in the data collected so far for the other two galaxies could be interpreted as due to differential variations in two components, one hard and one soft, of the spectrum, the correlation in NGC 4151 appears to be intrinsic to a single, hard component. The correlation described by equation (2), extrapolated to around 100 keV, predicts a wide spread in α for a small spread in f(100 keV), which does not agree with the admittedly marginal evidence of an opposite correlation between α and f(100 keV) presented in Baity *et al.* (1984).

6. The iron fluorescence line at 6.4 keV responds very slowly, if at all, to changes in the exciting continuum. The present observations imply a strict minimum of 18 days for the delay in the response, but placed in the context of other observations, lead to an estimate of a minimum of 4 months for the time scale of the $I_{6.4}$ variations. The similarity in behavior with the broad component of the C III] λ1909 line suggests that most of the fluorescence comes from the outermost part of the BLR, and by implication the "diluted" density of the gas embedded in the BLR clouds should drop not faster than r^{-1}.

7. The relative insensitivity of $I_{6.4}$ to changes in the continuum advises a prudent approach to the interpretation of the line equivalent width in terms of the overall geometry of the BLR. Nonetheless, the available evidence appears to confirm the strong disagreement with numerical predictions pointed out by Matsuoka *et al.* (1986) if the geometry is spherical, which however disappears if the geometry is highly flattened, with the minor axis close to the line of sight. Notably, a similar geometry of the BLR was proposed by Osterbrock (1979) for general application to AGNs.

Results similar to (1), (2), and (4) have been reported also by Pounds *et al.* (1985, 1986) on the basis of independent *EXOSAT* observations.

Some of the above results have important theoretical implications both for the continuum source and the gas surrounding it, which will be dealt with elsewhere. Here, to close, it is worth stressing that a number of observational aspects need further investigation, among which are a spectroscopic test on the nature of the soft X-ray component; a search for other epochs, like that of 1979 May, when the ultraviolet and X-ray emissions do not seem to correlate as in the present observations; a search for short term (< 1 day) variability in the ultraviolet; a detailed study of the spectral variability from 1 keV to at least 100 keV; and a better estimate of the variability time scale of the iron fluorescence line.

We wish to thank the *EXOSAT* observatory staff at ESOC, in particular L. Chiappetti, P. Giommi, A. N. Parmar, and L. Stella, for their patient advice, T. Peacock of ESA for the generous allocation of a TOO shift in 1984 December, M. Morini and N. Robba for the invaluable assistance in setting up the data analysis software, A. Pernice for the help in the data reduction, K. Pounds, B. Warwick, and M. Elvis for stimulating discussions, B. C. Monsignori Fossi and M. Landini for providing us with the new plasma code before publication, and W. Huchtmeier and O. Richter, M. Matsuoka, T. Dean, and G. Di Cocco for their private communications. The data reduction was carried out at the Center for Image Processing, Science Faculty, Rome University. G. C. P., L. P., and A. A. acknowledge financial support from the Italian CNR/PSN and MPI.

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