THE ASTROPHYSICAL JOURNAL, 359:98–103, 1990 August 10

X-RAY AND ULTRAVIOLET OBSERVATIONS OF THE SEYFERT GALAXY MCG 8-11-11

A. TREVES,[1] G. BONELLI,[2] L. CHIAPPETTI,[2] R. FALOMO,[3] L. MARASCHI,[1] G. TAGLIAFERRI,[4] AND E. G. TANZI[2]

Received 1989 June 6; accepted 1990 February 12

ABSTRACT

MCG 8-11-11 was observed in the 0.5–8 keV band with the *EXOSAT* observatory at 9 epochs in 1983–1986. Quasi-simultaneous UV observations were obtained in all but one case. The X-ray spectra are well fitted by absorbed power laws ($N_H \simeq 1.5 \times 10^{21}$ cm^{-2}, $\alpha_{ph} \simeq 1.7$). Small variations of the spectral shape are found with softening of the source at brighter states. No correlation between UV and X-ray fluxes is apparent, suggesting an independent origin of the UV, consistent with the absence of indication of a soft X-ray excess.

Subject headings: galaxies: individual (MCG 8-11-11) — galaxies: Seyfert — galaxies: X-rays — radiation mechanisms — ultraviolet: spectra

I. INTRODUCTION

MCG 8-11-11 is one of the brightest Seyfert galaxies in the X-ray band (see, e.g., Kriss, Canizares, and Ricker 1980), and in fact the Seyfert nature of the galaxy was discovered only after the detection of the X-ray emission (Ward *et al.* 1977).

The object has been observed over a broad energy range. The radio emission is accounted for by a power law ($F_\nu \propto \nu^{-\alpha}$) of index 0.74; the infrared and near-infrared are much above the extrapolation of the radio and are fitted by a power law $\alpha = 1.2$ (see Spinoglio *et al.* 1985 and reference therein). Observations in the UV are reported by Clavel and Joly (1984) and Tanzi *et al.* (1984) and indicate some excess with respect to the extrapolation from the optical. Table 1 and Figure 1 give a compilation of the X-ray fluxes observed from 1970 to 1986, which clearly show the variability of the source in medium-energy X-rays. Detection of the source in hard X-rays (20–90 keV) and low-energy gamma rays (90 keV–3 MeV) is reported by Ubertini *et al.* (1984) and Perotti *et al.* (1981).

The high X-ray flux and its variability motivated a program of observations with the *EXOSAT* satellite, which permitted a spectral study of the source in the 0.5–8 keV band at nine different epochs in 1983–1986 (see Table 2). At eight epochs quasi-simultaneous coverage in the UV (see Table 3) was obtained with the *International Ultraviolet Explorer* (*IUE*). Part of the data were presented in preliminary form at conferences in Tanzi *et al.* (1984), and Chiappetti *et al.* (1987).

II. X-RAY OBSERVATIONS

The *EXOSAT* observations were performed with the argon-filled chamber proportional counter (1–20 keV; ME experiment) and with the channel multiplier array (0.02–2 keV; LE experiment) with the Lexan (3000 Å) and Al-Par filters. Details on the instrumentation can be found in White and Peacock (1988).

a) ME Data Reduction

In order to discriminate the source counts from the background, most observations were performed by pointing one of the two halves of the proportional counter array on the source and the other 2° off the source and then inverting the configuration (array swapping). Count spectra are obtained from subtraction of on- and off-source spectra, and combining data before and after the swap. Corrections for dead time and difference in response between aligned and offset detectors were applied as appropriate. In two cases (1984 January 26 and 1988 March 18), no swapping was performed and the background was derived from observations during the slew maneuvers. Periods when large background variability was detected due to solar activity were rejected. Within each epoch no indication of variable intensity of the source was found.

A net signal above the background is seen from PHA channel 5 to channel 31 (1–8 keV). Count rates for each observation are reported in Table 2A. During the last four observations one of the four detectors which constitute one-half of the array (detector C) was no longer available. The count rates have been normalized to the full half.

b) LE Data Reduction

Net count rates are obtained in a box of optimum size from a direct estimate of the background in an annulus off the source. Corrections for dead time, point spread function, background nonuniformity, and vignetting effects have been taken into account. Count rates reported in Table 2A refer to Lexan 3000 and Al-Par filters.

c) Spectral Fitting

A given spectral law convolved through the response matrix of the instrument can be fitted to the count spectrum through a minimum χ^2 procedure. We have adopted a power law corrected for cold gas absorption (cross sections after Morrison and McCammon 1983). Confidence intervals are obtained according to the prescriptions of Lampton, Margon, and Bowyer (1976), considering as interesting parameters the hydrogen column density and the slope of the power law.

The results of the fitting procedure are given in Table 2B for the combination of LE and ME data. Reconstructed spectra for observations 1 and 7, representing a low and a high state, are reported in Figure 2, and the 90% confidence contours in the α-N_H plane are reported in Figure 3 for all spectra. The spectrum of 1984 November 2 was examined by Turner and Pounds (1969) in the course of a systematic study of *EXOSAT* spectra of Seyfert galaxies. The results of their analysis are very similar to ours.

[1] Dipartimento di Fisica, Università di Milano.
[2] Istituto di Fisica Cosmica, C.N.R. Milano.
[3] Osservatorio Astronomico, Padova.
[4] *EXOSAT* Observatory, ESTEC, Noordwijk.

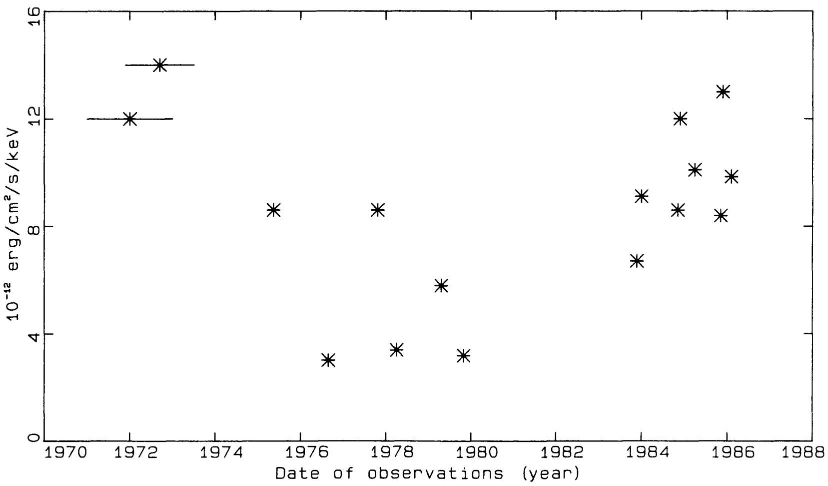

FIG. 1.—Long-term variability of MCG 8-11-11 at 3 keV (ergs cm^{-2} s^{-1} keV^{-1}). For details see Table 1.

III. UV OBSERVATIONS

A log of the *IUE* observations is reported in Table 3. Spectra were extracted with the standard IUESIPS procedure. Fluxes were measured in regions free from strong lines and not affected by cosmic-ray hits and camera flaws. Correction for reddening assumes $A_V = 1.2$, as derived from the column density deduced from 21 cm observation (see following text), and use of the extinction curve computed by Seaton (1979). Short- (SWP) and long-(LWP) wavelength spectra were combined when obtained in contiguous observations. The best-fitting (minimum χ^2) power law on the whole 1200–3200 Å range were computed (see Table 3). An example of *IUE* spectra with the best fit to the continuum is reported in Figure 4. The fits are not particularly good, but in view of the few available spectral points and the absence of a definitive theoretical model, more complex spectral shapes were not explored. There is a significant correlation between spectral slope and intensity in the UV band, in the sense that the spectrum hardens with increasing intensity, a fact which is rather common in Seyfert galaxies, and is ascribed to a nonvariable component contributing longward of 2000 Å deriving from Fe II multiplets and Balmer continuum (see, e.g., Ulrich 1986).

IV. DISCUSSION

In Table 1 we compare the fluxes measured with *EXOSAT* at 3 keV with those derived by other X-ray missions. The *EXOSAT* fluxes range between a medium and a very bright state. Within our observations the X-ray luminosity varied by a factor of 2 (Tables 1 and 2).

The energy index $\alpha \simeq 0.7$ found here is close to the value given by Petre *et al.* (1984) in the 0.5–4.5 keV band and by Mushotzky *et al.* (1980) in the 2–25 keV band. It corresponds

TABLE 1

X-RAY OBSERVATIONS OF MCG 8-11-11

Satellite	Epoch	F(3 keV) × 10^{12} ergs cm^{-2} s^{-1} keV^{-1}	Reference
Uhuru	1970 Dec–1973 Mar	12	a
OSO 7	1971 Oct–1973 May	14	b
Ariel 5	1975 Mar–Jun	8.6	c
	1976 Jul–Aug	3	c
HEAO 1	1977 Oct	8.6	d
	1978 Mar	3.4	d
Einstein	1979 Apr	5.8	e
	1979 Oct	3.2	f
EXOSAT	1983 Nov	6.7	g
	1984 Jan	9.1	g
	1984 Oct	8.6	g
	1984 Nov	12.0	g
	1985 Mar	10.1	g
	1985 Oct	8.4	g
	1985 Nov	13.0	g
	1986 Feb	9.6–10.1	g

REFERENCES.—(a) Forman *et al.* 1978; (b) Markert *et al.* 1979; (c) Ward *et al.* 1977; (d) Mushotzky *et al.* 1980; (e) Petre *et al.* 1984; (f) *Einstein* satellite data base; (g) this paper.

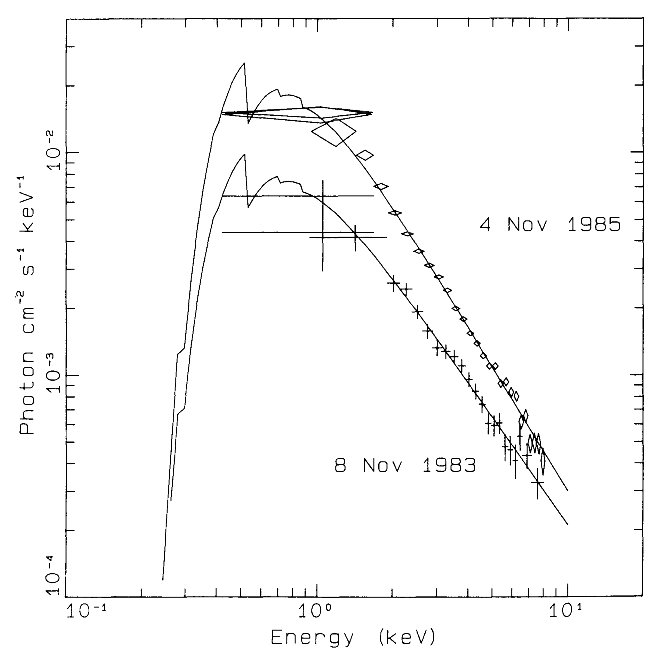

FIG. 2.—Photon spectra of MCG 8-11-11 at two epochs (*crosses:* 1983 Nov 8; *diamonds*: 1985 Nov. 4). The continuous curves represents the best fit for a power law corrected for absorption.

TABLE 2A

X-Ray Observations with *EXOSAT*

Number	Date	ME Exposure Time (s)	ME Count Rate (counts s^{-1})	LE-7[a] Exposure Time (s)	LE-7 Count Rate (counts s^{-1})	LE-6[b] Exposure Time (s)	LE-6 Count Rate (counts s^{-1})
1..........	1983 Nov 8	7570	5.86 ± 0.13	2757	$2.02 \pm 0.35 \times 10^{-2}$	2532	$1.21 \pm 0.29 \times 10^{-2}$
2..........	1984 Jan 26	6200	7.53 ± 0.07	1778	$1.66 \pm 0.39 \times 10^{-2}$	2284	$2.51 \pm 0.42 \times 10^{-2}$
3..........	1984 Oct 6	14460	7.21 ± 0.10	4553	$2.33 \pm 0.29 \times 10^{-2}$	3925	$2.02 \pm 0.29 \times 10^{-2}$
4..........	1984 Nov 2	14520	8.43 ± 0.10	4550	$2.80 \pm 0.31 \times 10^{-2}$	6559	$2.01 \pm 0.22 \times 10^{-2}$
5..........	1985 Mar 18	870	9.99 ± 0.16	6084	$3.60 \pm 0.31 \times 10^{-2}$	6769	$2.71 \pm 0.25 \times 10^{-2}$
6..........	1985 Oct 9	24130	7.18 ± 0.07	11733	$2.98 \pm 0.21 \times 10^{-2}$	6597	$2.13 \pm 0.23 \times 10^{-2}$
7..........	1985 Nov 4	25080	10.8 ± 0.07	11915	$4.71 \pm 0.27 \times 10^{-2}$	6205	$3.51 \pm 0.30 \times 10^{-2}$
8..........	1986 Feb 8	29060	8.07 ± 0.06	12923	$3.19 \pm 0.22 \times 10^{-2}$	6133	$1.95 \pm 0.23 \times 10^{-2}$
9..........	1986 Feb 26	10690	7.96 ± 0.11	13919	$2.00 \pm 0.33 \times 10^{-2}$	3006	$2.00 \pm 0.33 \times 10^{-2}$

[a] LE-7 is the low-energy experiment with the Lexan 3000 Å filter.
[b] LE-6 is the low-energy experiment with the Al-Par filter.

TABLE 2B

Best Fit Parameters

Number	Photon Index	N_H (10^{21} cm^{-2})	Flux (1–8 keV)[a] (10^{-11} ergs cm^{-2} s^{-1})	χ^2	dof
1..........	1.61 ± 0.12[b]	1.40 ± 1.00	4.51 ± 0.16	14.4	22
2..........	1.80 ± 0.12	2.43 ± 1.00	5.76 ± 0.17	29.3	22
3..........	1.68 ± 0.09	1.70 ± 0.75	5.77 ± 0.11	34.6	19
4..........	1.67 ± 0.07	1.63 ± 0.37	6.76 ± 0.10	37.0	23
5..........	1.80 ± 0.15	2.00 ± 0.50	8.05 ± 1.50	37.7	26
6..........	1.61 ± 0.07	1.02 ± 0.25	5.48 ± 0.06	34.4	24
7..........	1.86 ± 0.04	1.58 ± 0.18	8.38 ± 0.06	34.2	25
8..........	1.56 ± 0.04	1.03 ± 0.30	6.26 ± 0.06	33.8	25
9..........	1.74 ± 0.09	2.29 ± 0.55	6.69 ± 0.14	22.9	21

[a] The flux is corrected for absorption.
[b] All uncertainties shown correspond to 90% confidence levels.

also to the mean energy index in the 2–10 keV range of hard X-ray–selected Seyfert galaxies, (see, e.g., Mushotzky *et al.* 1980; Turner and Pounds 1989), and in this respect MCG 8-11-11 may be taken as a prototype for the class.

Variations in the ME and LE bands are clearly correlated, as shown in Figure 5. The variation of the spectral slope, though small, is significant. The spectral index appears to correlate with the X-ray luminosity (Fig. 6), in the sense that the higher the luminosity, the softer the spectrum. This behavior is rather common in Seyfert galaxies. We quote the cases of Fairall 9 (Morini *et al.* 1986); of NGC 4051 (Lawrence *et al.* 1985; Matsuoka *et al.* 1989); of MCG 6-3-15 (Matsuoka *et*

TABLE 3

IUE Observations of MCG 8-11-11

Epoch	Spectra	Photon[a] Index	χ^2 red	$\phi(1300–1500)$[b] $\phi(2600–2800)$	L_U[c]
1983 Nov 8	SWP 21481+ LWP 2244	2.53 ± 0.10	8.8	1.2 4.2	1.6
1984 Jan 26	SWP 22109+ LWP 2707	2.75 ± 0.09	6.3	2.5 5.2	1.7
1984 Oct 5	SWP 24123+ LWP 4505	2.37 ± 0.07	6.3	3.5 5.7	2.3
1984 Nov 1	SWP 24368+ LWP 4696	2.67 ± 0.7	7.6	2.9 5.2	1.9
1985 Mar 19	SWP 25479+ LWP 5547	2.56 ± 0.10	2.7	7.9 5.3	1.9
1985 Oct 9	SWP 26906+ LWP 6880	2.19 ± 0.07	5.0	5.0 8.0	3.6
1986 Feb 7	LWP 7637	...	...	4.5	...
1986 Feb 25	SWP 27790+ LWP 7718	2.46 ± 0.10	6.8	2.8 5.2	2.0

[a] The photon index refers to the spectrum dereddened with $A_V = 1.2$.
[b] Mean flux in the band in 10^{-15} ergs cm^{-2} s^{-1} A^{-1}.
[c] Luminosity at the source in the 1000–3000 Å band in units of 10^{44} ergs s^{-1}.

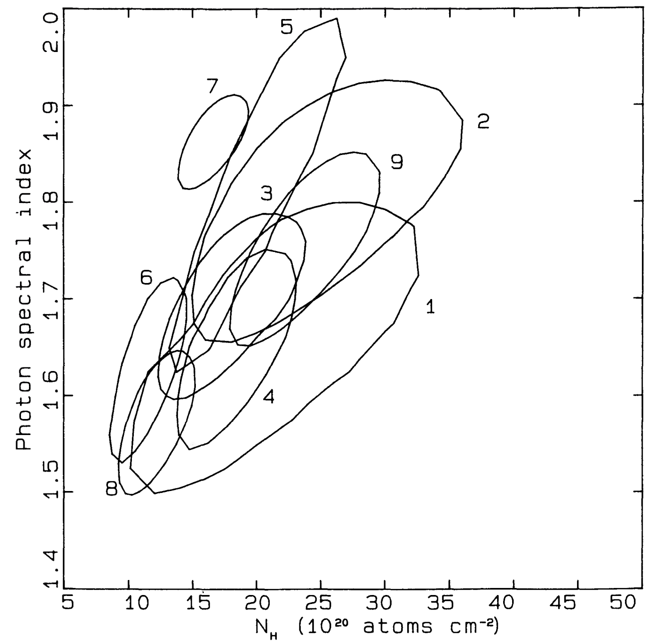

FIG. 3.—90% α-N_H confidence contours for the various observations

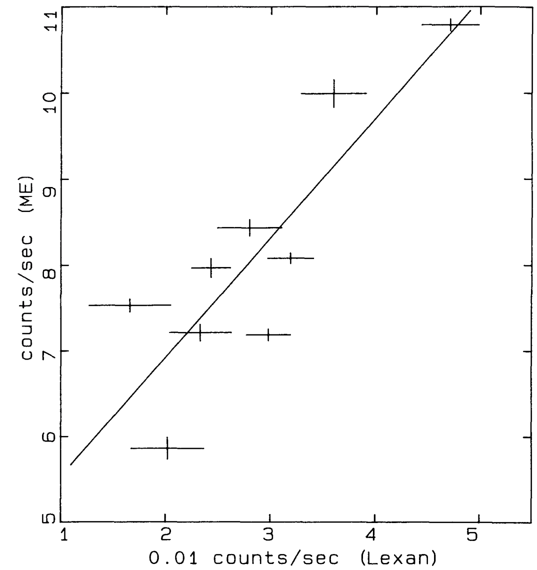

FIG. 5.—Correlation between count rates in the LE and ME bands. The continuous line is the result of a linear regression.

al. 1989), NGC 7314 (Turner 1987), NGC 5548 (Branduardi-Raymont 1986), and NGC 6814 (Mittaz and Branduardi-Raymont 1989).

The observed correlation corresponds to a larger variability in the soft X-ray band with respect to the medium-energy one. In fact LE count rates vary by a factor 3, while ME count rates vary only by a factor 2 (see Table 2A). Taking as a variability parameter the ratio of the standard deviation to the mean flux $v = \sigma/\langle f \rangle$, we obtain $v = 0.34$ and $v = 0.2$ in the LE and ME bands, respectively, and $v = 0.2$ in the UV (1500 Å). This dependence of variability with energy is not far from that of the two other Seyfert galaxies Fairall 9 and 3C 120 (see Table 4), while it differs from that of NGC 4151, where a steady soft X-ray component seems to be present (Perola *et al.* 1986).

The column densities derived from each observation of MCG 8-11-11 (Table 2B) are consistent with a constant value ($\chi_r^2 = 1.3$ for the hypothesis of constancy, which corresponds to a probability of 78%). The weighted average is $N_H = 1.5 \pm 0.4 \times 10^{21}$ cm^{-2}, which is consistent with that given by Mushotzky *et al.* (1980) and by Petre *et al.* (1984) on the basis of *HEAO 1 A2* and *Einstein* SSS observations; the present observations reduce significantly the uncertainty. One can compare the value of the column density obtained from the low-energy X-ray absorption with that from the 21 cm data $N_H = 2.02 \times 10^{21}$ cm^{-2} (Elvis, Lockman, and Wilkes 1989). There is a marginal indication that the radio value is larger than the X-ray one. In order to ascertain if this may be an indication of some soft X-ray excess, we have examined the behavior of the residuals with respect to the best fit calculation with a fixed column density as given by the radio observations.

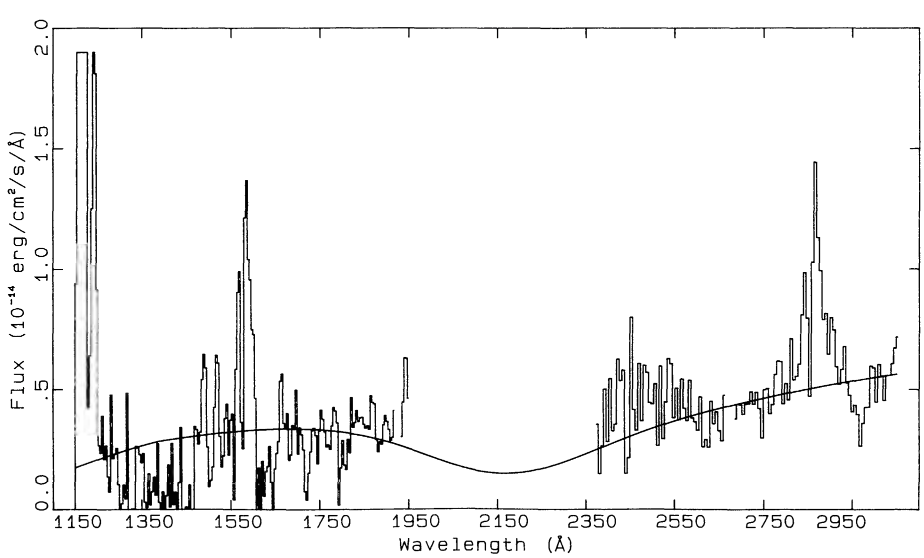

FIG. 4.—*IUE* spectra of 1988 Nov. 8. The continuum line is a reddened power law which best fits the regions of the spectrum free of strong lines.

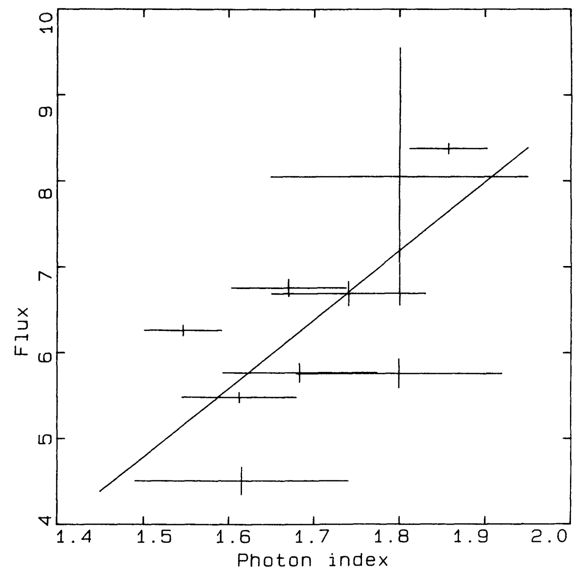

FIG. 6.—Correlation between the X-ray flux (10^{-11} ergs cm^{-2} s^{-1}) and the spectral index in the 0.5–8 keV range. The continuous line is the result of a linear regression.

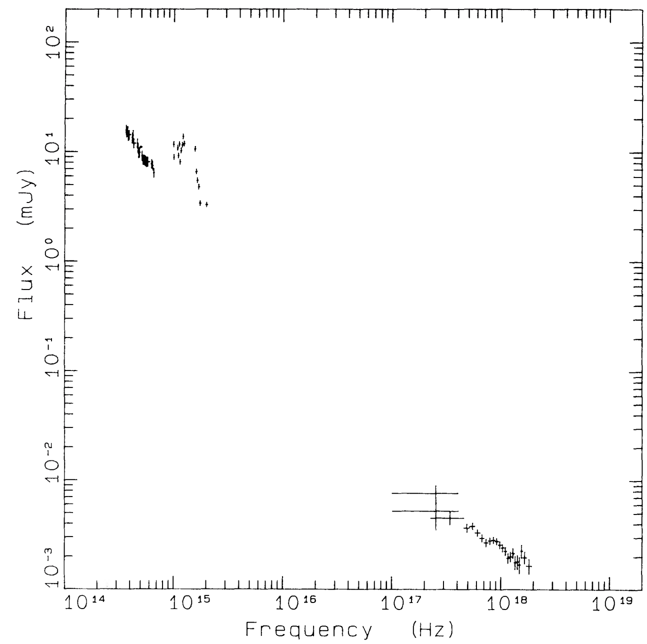

FIG. 8.—Overall spectrum of 1983 Nov. 8–9 corrected for absorption and extinction.

No excess is found in the low-energy channels. The same analysis shows that no 6–7 keV Fe feature is apparent above the noise.

The absence of a soft excess, together with the fact that for each observation LE and ME data are well-fitted by the same power law, is a clear indication of a common origin of soft and medium-energy X-rays. On the contrary, a different origin of the UV emission is indicated by the absence of a direct correlation with the X-rays, as shown in Figure 7. In fact, the UV emission most probably derives from a thermal component (3000 Å bump), which is invoked in a number of Seyfert galaxies (see, e.g., Edelson and Malkan 1986).

Figure 8 gives a composite spectrum from optical to X-ray frequencies, corresponding to our simultaneous observations of 1983 November 8 (see Tanzi *et al.* 1984). Optical spectrophotometry (1983 Nov. 9) in the range 4500–8300 Å was obtained at the Asiago 1.8 m telescope by using an intensified reticon (Falomo 1984) attached to a Boller and Chivens spectrograph. The photometric accuracy as derived from observations of standard stars (Stone 1977) is 20%. The X-ray fluxes are corrected for absorption and optical-UV ones for reddening. Although the reddening correction is somewhat

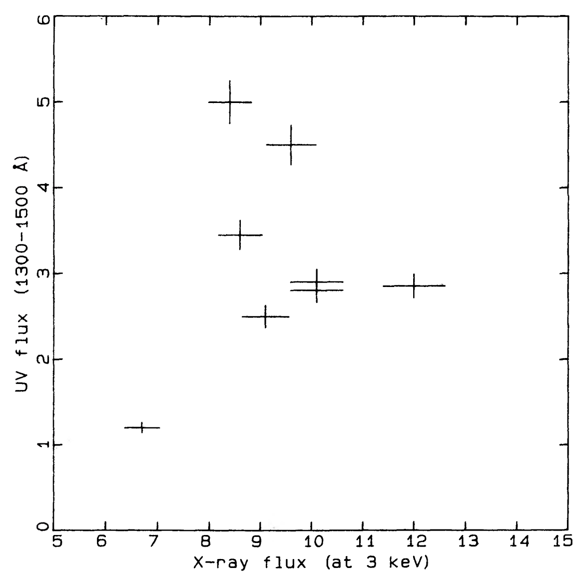

FIG. 7*a*

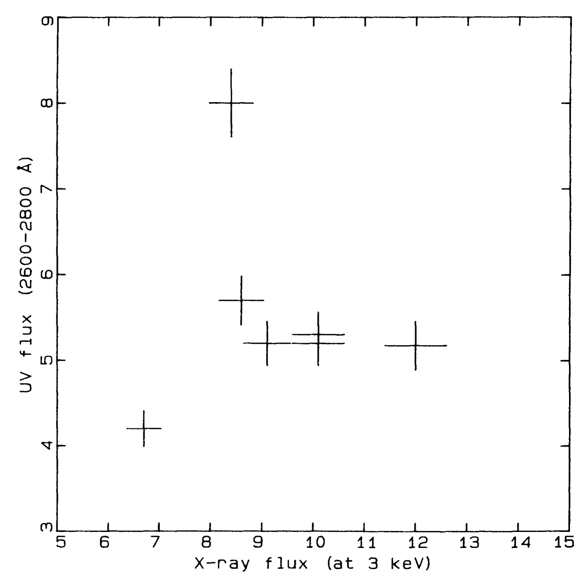

FIG. 7*b*

FIG. 7.—UV flux (1400 Å and 2700 Å, 10^{-15} ergs cm^{-2} s^{-1} $Å^{-1}$) vs. X-ray flux at 3 keV (10^{-12} ergs cm^{-2} s^{-1} keV^{-1}). The two quantities do not appear to correlate.

TABLE 4

SPECIFIC VARIABILITY[a] IN SEYFERT GALAXIES

Source	v (1500 Å)	v (0.2 keV)	v (3 keV)	Reference
Fairall 9	0.6	0.6	0.5	1
NGC 4151	0.4	0.2	0.6	2
MCG 8-11-11	0.2	0.3	0.2	3
3C 120	0.4	0.2	0.2	4

[a] Specific variability: $v = \sigma/\langle f \rangle$.

REFERENCES.—(1) Morini *et al.* 1986; (2) Perola *et al.* 1986; (3) this paper; (4) Maraschi *et al.* 1986.

uncertain, the UV excess is rather clear, while there is no indication of the contribution of the bump to soft X-rays.

It is possible that if one takes into account a delay in the variability in the two bands, some correlation between X-rays and UV may turn out. A delay would appear, for instance, if the UV were produced by reprocessing in an accretion disk. However, if the delay between the two bands were of days or weeks, the correlation would not appear in our observations, because of the modest coverage of the source.

The correlation between soft and medium-energy X-rays, and the similarity of variability time scales in the two bands, which is not uncommon in Seyferts (see Table 4), is rather different from what is observed in BL Lac objects (see Celotti, Maraschi, and Treves 1989). In that case one finds that the variability increases with frequency (in this regard see also Giommi *et al.* 1989), a fact which is interpreted as a dependence of the source dimension with the emitted frequency. In the case of MCG 8-11-11 the region responsible for the ME emission could coincide with (or even be larger than) that producing the LE emission.

In summary, the main results of our X-ray observations of MCG 8-11-11 are that the spectrum in the 0.5–8 keV range is well-fitted by a power law of energy index ≈ 0.7, and that its small variations correlate with the intensity. Both points appear common among Seyfert galaxies, but a unique interpretation is still far. In particular it is unclear what is the basic emission mechanism (e.g., synchrotron self-Compton, multi-Compton, bremsstrahlung, pair-dominated atmosphere). Clearly, in order to constrain the models, observations of increasing accuracy are needed, and we hope that the present ones are a step in this direction.

REFERENCES

Branduardi-Raymont, G. 1986, in *The Physics of Accretion onto Compact Objects*, ed. K. O. Mason, M. G. Watson, and N. E. White (Berlin: Springer), p. 407.

Celotti, A., Maraschi, L., and Treves, A. 1989, in *BL Lac Objects*, ed. L. Maraschi, T. Maccacaro, and M. H. Ulrich (Berlin: Springer), p. 332.

Chiappetti, L., Allegrini, A., Maraschi, L., Tagliaferri, G., Tanzi, E. G., Treves, A., and Wamsteker, W. 1987, in *Variability of Galactic and Extragalactic X-Ray Sources*, ed. A. Treves (Milano: Ass. Av. Astr.), p. 37.

Clavel, J., and Joly, M. 1984, *Astr. Ap.*, **131**, 102.

Edelson, R. R. A., and Malkan, M. A. 1986, *Ap. J.*, **308**, 59.

Elvis, M., Lockman, F. J., and Wilkes, B. J. 1989, *A.J.*, **97**, 777.

Falomo, R. 1984, Asiago Obs. Internal Rept.

Forman, W., *et al.* 1978, *Ap. J. Suppl.*, **38**, 357.

Giommi, P., Barr, P., Garilli, B., Maccagni, D., and Pollock, A. M. T. 1989, submitted to *Ap. J.* (6-10-90).

Kriss, G. A., Canizares, C. R., and Ricker, G. R. 1980, *Ap. J.*, **242**, 492.

Lampton, M., Margon, B., and Bowyer, S. 1976, *Ap. J.*, **207**, 359.

Lawrence, A., Watson, M. G., Pounds, K. A., and Elvis, M. 1985, *M.N.R.A.S.*, **217**, 685.

Maraschi, L., *et al.* 1986, in *IAU Symposium 121, Observational Evidence of Activity of Galaxies*, ed. E. Khachikian, G. Melnick, and K. Kricke (Dordrecht: Reidel), p. 215.

Markert, T. H., *et al.* 1979, *Ap. J. Suppl.*, **39**, 573.

Matsuoka, M., Yamauchi, M., Piro, L., and Murakami, T. 1990, submitted to *Ap. J.* (not scheduled through Sept 1).

Mittaz, J. P. D., and Branduardi-Raymont, G. 1989, *M.N.R.A.S.*, **238**, 1029.

Morini, M., *et al.* 1986, *Ap. J.*, **307**, 486.

Morrison, R., and McCammon, D. 1983, *Ap. J.*, **270**, 119.

Mushotzky, R. F., Marshall, F. E., Boldt, E. A., Holt, S. S., and Serlemitsos, P. J. 1980, *Ap. J.*, **235**, 377.

Perola, G. C., *et al.* 1986, *Ap. J.*, **306**, 508.

Perotti, F., Della Ventura, A., Villa, G., Di Cocco, G., Butler, R. C., Carter, J. N., and Dean, A. J. 1981, *Nature*, **292**, 133.

Petre, R., Mushotzky, R. F., Krolik, J. H., and Holt, S. S. 1984, *Ap. J.*, **280**, 499.

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

Spinoglio, L., *et al.* 1985, *Astr. Ap.*, **153**, 55.

Stone, R. P. S. 1977, *Ap. J.*, **218**, 767.

Tanzi, E. G., *et al.* 1984, in *Proc. 4th European IUE Conference* (ESA SP-218), p. 111.

Turner, T. J. 1987, *M.N.R.A.S.*, **226**, 9P.

Turner, T. J., and Pounds, K. A. 1989, *M.N.R.A.S.*, **240**, 833.

Ubertini, P., Bazzano, A., La Padula, C., Polcaro, V. F., and Manchanda, R. K. 1984, *Ap. J.*, **284**, 54.

Ulrich, M. H. 1986, in *New Insights in Astrophysics* (ESA SP-263), p. 523.

Ward, J., Wilson, A. S., Disney, M. J., Elvis, M., and Maccacaro, T. 1977, *Astr. Ap.*, **59**, L19.

White, N. E., and Peacock, A. 1988, *Mem. Soc. Astr. Italiana*, **59**, 7.

G. BONELLI, L. CHIAPPETTI, and E. G. TANZI: Istituto di Fisica Cosmica del C.N.R., Via Bassini 15, 20133, Milano, Italy

R. FALOMO: Osservatorio Astronomico, Vicolo dell'Osservatorio 5, 35100, Padova, Italy

L. MARASCHI and A. TREVES: Dipartimento di Fisica dell'Università, Via Celeria 16, 20133 Milano, Italy

G. TAGLIAFERRI: *EXOSAT* Observatory, ESTEC, 2200 AG Noordwijk, The Netherlands