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THE X-RAY TO INFRARED ENERGY DISTRIBUTION OF THE QUASAR PG 0026+129[1]

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ABSTRACT

PG 0026+129 was observed with EXOSAT in 1983 and 1984. No variation between the two epochs was detected. The energy distribution from 0.2 to 6 keV is well fitted by a power law of energy index $\alpha = 1.06 \pm 0.25$ and with Galactic absorption. Quasi-simultaneous spectrophotometry in the UV and optical range, together with near-infrared photometry was obtained. The results are compared with previous observations. The overall energy distribution and its variability are briefly discussed.

Subject headings: quasars — spectrophotometry — X-rays: sources

I. INTRODUCTION

Though a large number of quasars have been detected in the X-ray, spectral information, mostly derived from the *Einstein Observatory*, is available only for a small fraction. Thirty-three quasar spectra have been determined from IPC data in the 0.2–4.0 keV band (see Elvis, Wilkes, and Tananbaum 1985; Elvis *et al.* 1986; Wilkes and Elvis 1987). Few objects were studied with the solid state spectrometer in the energy band 0.7–4 keV (Petre *et al.* 1984).

The *EXOSAT* satellite, covering both the low-energy (LE: 0.02–2 keV) and medium-energy (ME: 1–15 keV) X-ray bands, has proved extremely valuable for studying the energy distribution of bright active galactic nuclei over a wide spectral range. Here we report on *EXOSAT* observations of the optically selected quasar PG 0026+129 ($z = 0.142$) at two different epochs, accompanied by quasi-simultaneous coverage in the UV, optical, and IR bands.

II. OBSERVATIONS

a) X-Rays

The *EXOSAT* payload includes a grazing incidence telescope (LE experiment: geometric collecting area ~ 90 cm^2) and an array of eight argon filled proportional counters (ME experiment: geometric collecting area ~ 1800 cm^2). The available focal plane instrumentation of the LE experiment is a channel multiplier array (CMA) with interchangeable filters with different passbands. A full description of the instruments on board *EXOSAT* can be found in Taylor *et al.* (1981).

PG 0026+129 was observed with *EXOSAT* in 1983 and 1984 (see Table 1). The ME observations were carried out with the standard procedure in which one-half of the detector points at the source and the other half is offset to monitor the background. At midobservation the pointing directions of the two halves are interchanged. During both observations of PG 0026+129 the background was carefully checked and found to be stable during the pointing as well as during adjacent maneuvers. The source spectrum was therefore derived by subtracting the background measured by the same half experiment during the offset pointing. A net signal was found in both observations from channel 5 to channel 22 of the pulse height analyzer (PHA), corresponding to the energy range 1–6 keV, while no residual count rate was observed in the highest PHA channels, which strengthens our confidence in the background subtraction. During each observation the hour to hour variability was less than 30%. The mean ME count rates are reported in Table 1.

The LE count rates were obtained by accumulating images for the whole exposure time for each of the three filters used (see Table 1). They were converted into fluxes by using the effective areas corresponding to the telescope + CMA + filter combination reported in Chiappetti and Davelaar (1984). Corrections for dead time, position-dependent background, point spread function, and vignetting, consistent with current ESA software (see Giommi 1985) were applied. The same point spread function has been used for all filters (boron included). The counts were collected in a box of optimum size according to the prescriptions of Giommi (1985).

A power-law spectral model, corrected for absorption with the cross sections of Morrison and McCammon (1983), was fitted to the combined LE and ME data. PHA channels in the ME spectra were grouped so that the signal above background in each resulting bin always exceeded the 5 σ level. This yielded six ME energy bins for the 1983 observation and 13 for that of 1984. The best-fit parameters were obtained by minimizing the χ^2; errors were estimated from the χ^2 contours in the α-N_H plane, corresponding to 90% confidence limit (Lampton, Margon, and Bowyer 1976). The results are given in Table 2. Since the spectra at the two epochs do not differ significantly, the observations have been combined to improve the statistics (see Table 2 and Fig. 1). The range of values for the hydrogen column is fully consistent with that deduced from 21 cm measurements (Stark *et al.* 1987) in the direction of PG 0026+129. A fit of the ME data alone with a fixed $N_H = 5 \times 10^{20}$ cm^{-2} yields $0.6 < \alpha < 1.3$, almost coincident with that deduced from the combined LE + ME data.

The source was previously observed in the X-rays with the image proportional counter (IPC) on board the *Einstein Observatory* on 1979 July (Tananbaum *et al.* 1979, 1986) and 1981 Jan (Worrall and Marshall 1984). The intensity at the two epochs coincide, within the uncertainties, with those measured by us. The spectrum derived from the 1981 *Einstein Observatory* IPC data has been recently obtained by Wilkes and Elvis

[1] Based on observations with the *EXOSAT* satellite and with the *International Ultraviolet Explorer*. Optical and infrared observation were obtained at the European Southern Observatory, La Silla, Chile, and at the Asiago Observatory, Italy.

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TABLE 1

OBSERVATIONS OF PG0026+129

A. X-Ray Observations (*EXOSAT*)

Epoch (UT)	Filter	Expos (s)	LE1 Count Rate (cts per s)	Epoch (UT)	Expos (s)	ME Count rate (cts per s per exp)
1983 Nov 7						
22:02–23:52	Al/Par	6325	0.0110 ± 0.0017	19:47–23:56	11340	1.228 ± 0.103
20:20–21:59	Lexan	5214	0.0151 ± 0.0021			
1984 Jul 16						
04:01–05:43	Al/Par	5930	0.0118 ± 0.0018	01:36–12:09	35160	1.008 ± 0.049
02:13–03:53	Lexan	5520	0.0173 ± 0.0022			
05:47–12:02	Boron	21008	0.0031 ± 0.0006			
1983 + 1984	Al/Par	12255	0.0116 ± 0.0013	...	46500	1.060 ± 0.042
	Lexan	10734	0.0155 ± 0.0015			
	Boron	21008	0.0031 ± 0.0006			

B. UV Observations (*IUE*)

Epoch	Image No.	Expos (min)	Range (Å)	λ	Flux ergs cm^{-2} s^{-1} $Å^{-1}$
1984 Jul 13	SWP23451	150	1200–1950	1500 Å	1.4×10^{-14}
	LWP3758	70	2300–3200	2500 Å	6.0×10^{-15}

C. Optical and Infrared Observations

Epoch	Instrument	λ	Flux ergs cm^{-2} s^{-1} $Å^{-1}$
1983 Nov 7, 8, 9	1.8 m Asiago Reticon (4300–6500 Å)	5550 Å	2.7×10^{-15}
1984 Sep 8	3.6 m ESO In-Sb photometer *J*	1.24 μm	8.3×10^{-16}
	H	1.63 μm	5.5×10^{-16}
	K	2.18 μm	4.3×10^{-16}
1984 Nov 8, 9, 12	1.5 m ESO IDS (4000–8000 Å)	5550 Å	2.7×10^{-15}
1984 Nov 28	1.8 m Asiago Reticon (5300–7000 Å)	5550 Å	2.7×10^{-15}

NOTE.—Flux densities refer to the continuum. The LE count rates shown are corrected for point spread function, vignetting, sampling dead time, and background disuniformity (see text).

(1987). Their fit in the nominal 0.1–3.5 keV range yields $N_H = 5.3^{+2.6}_{-1.9} \times 10^{20}$, $\alpha = 0.9 \pm 0.3$, fully compatible with our findings for a broader energy interval.

PG 0026+129 was also detected in 1978 with the A2 experiment on board *HEAO-1*, at an intensity level consistent with that of the *Einstein* observations (Worrall and Marshall 1984). Therefore no evidence of variability is found in the X-ray range in the five observations spaced over 6 yr.

b) *UV*

PG 0026+129 was observed in 1984 with the *International Ultraviolet Explorer* three days before the second *EXOSAT* observation (see Table 1). One exposure in the short wavelength primary (SWP: range 1200–1950 Å) and one in the long wavelength primary (LWP: range 2000–3200 Å) camera were obtained. The line by line extracted spectra were examined for flaws and particle events, and reduced according to the calibration curves given by Bohlin and Holm (1980) and Blades and Cassatella (1982). The combined (SWP + LWP) spectrum is reported in the top frame of Figure 2. The other spectra available in the *IUE* archives, one SWP exposure taken in 1978 and a couple (SWP and LWR) taken in 1981, were reanalyzed and are also shown in Figure 2. The 1978 spectrum has been reprocessed to correct for errors in the intensity transfer function, with the procedure given by Cassatella and Ponz (1979).

The 2200 Å feature is not detectable in the spectrum taken with the LWR camera (substantially less noisy in this spectral region than the LWP camera), thus allowing us to derive an upper limit to the extinction suffered by the source of $A_v \approx 0.1$

TABLE 2

SUMMARY OF SPECTRAL FIT RESULTS

Observation	DOF	Red. χ^2	Best-Fit and 90% Confidence Interval: H Column Density 10^{20} cm^{-2}			Photon Spectral Index			*F* In *X* (2–6 keV) 10^{-12} ergs cm^{-2} s^{-1}		
1983	6	1.42	1.2	4.3	12.0	1.45	1.85	2.40	4.6	5.5	5.9
1984	15	0.54	1.5	3.4	7.6	1.70	1.98	2.25	4.1	4.5	4.8
1983 + 1984	15	0.38	2.6	5.0	8.6	1.80	2.06	2.30	4.2	4.5	4.7

NOTE.—Combination of LE + ME data. For each parameter three values are reported: The best-fit value and the extremes of the 90% confidence interval, calculated as specified in the text.

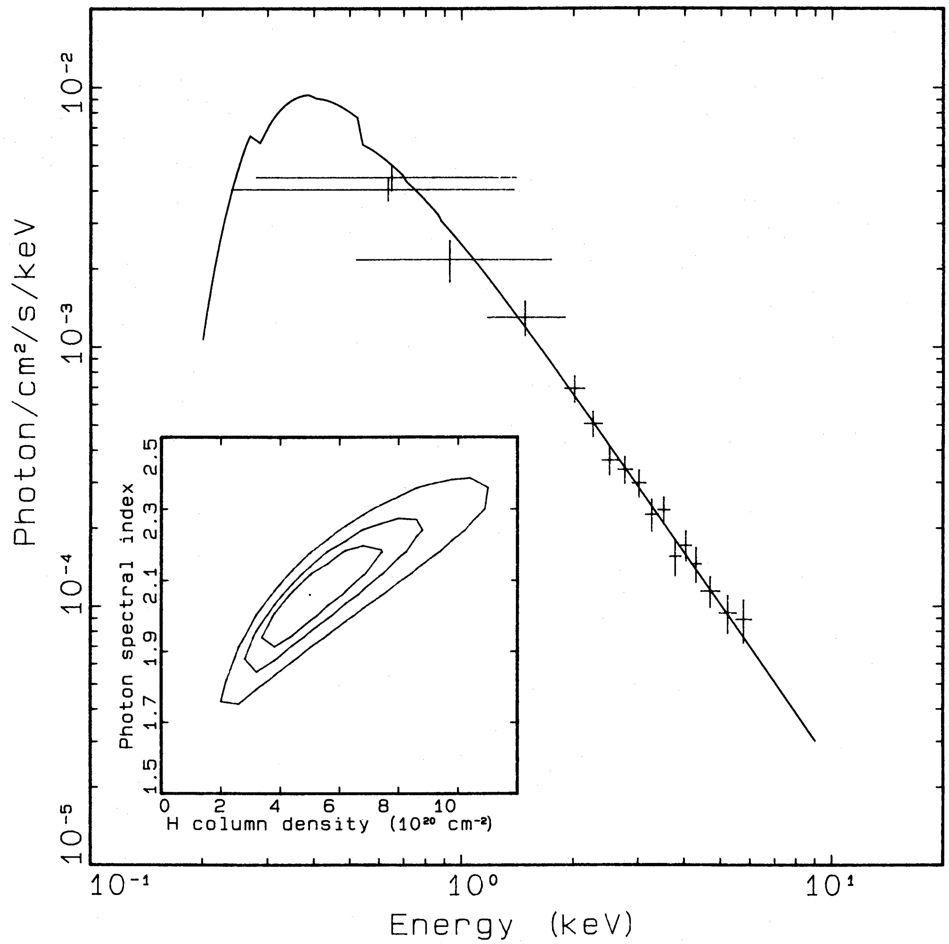

FIG. 1.—The reconstructed X-ray spectrum obtained from the fit of the combined 1983 and 1984 data. The lowest three energy bins correspond to the filters used with the LE experiment (the channel boundaries shown are such to exclude 5% of the counts on either side). The solid curve is the best-fit power law (see Table 2 for the relevant parameters). The inset shows the 68%, 90%, 99% confidence contours. The N_H axis is in units of 10^{20} cm^{-2}.

(R. Viotti, 1987, private communication). This value corresponds, for an average Galactic gas-to-dust ratio (see, e.g., Savage and Mathis 1979), to a hydrogen column density of 2×10^{20} atoms cm^{-2}, within the range derived from the present X-ray observations and is therefore used to convert UV and optical data with the reddening curve computed by Seaton (1979). Note that the fluctuations of the gas-to-dust ratio are quite large, so that even the best-fit value of N_H derived from the X-ray observations is not inconsistent with the upper limit derived for the extinction.

The reddened continuum of the 1984 spectrum (SWP + LWP) is well described by a power law $F_\lambda \div \lambda^{-\alpha_\lambda}$ with $\alpha_\lambda = 1.5$, which seems adequate also for the 1978 spectrum. For the 1981 spectrum a softer and fainter power law is suggested, with $\alpha_\lambda \sim 0.6$ and an intensity ratio of 0.6 at 1250 Å, with respect to the 1984 spectrum. On the other hand, in the 2000–3000 Å range, the 1981 observation does not differ significantly from that of 1984.

Lyα and C IV exhibit a complex profile. A broad asymmetric component extending redward to 3×10^4 km s^{-1} is well discernable in the three spectra, being less conspicuous in 1984. The total Lyα intensity, from 1335 Å to 1510 Å, is respectively 2.3, 1.9, and 1.6×10^{-12} ergs cm^2 s^{-1} for the 1978, 1981, and 1984 observations, indicating a lack of direct correlation with the continuum.

c) Optical and Infrared Observations

On 1983 November 7, 8, and 9, in correspondence with the first X-ray observation, spectrophotometry of the object was obtained at the 1.82 m Asiago telescope in the range 4300–6500 Å with an intensified Reticon (Falomo 1984) attached at the Boller & Chivens (BC) spectrograph at a resolution of 20 Å (FWHM). On 1984 November 8, 9, and 12 the source was observed at the 1.5 m ESO telescope at La Silla. The BC spectrograph with the image dissector scanner (IDS) was used in the range 4000–8000 Å, at a resolution of 15 Å. Further spectra were obtained on 1984 November 28–29 with the 1.82 m Asiago telescope and a new Reticon (Bonanno and Falomo 1987). The spectra taken at the three epochs agree, within the photometric accuracy of 10%, yielding a *B* magnitude of 15.8. The average IDS spectrum is reported in Figure 3. The continuum is best fitted by a power law of index $\alpha_\lambda = 1.4$.

Infrared photometry in *J* ($\lambda_{eff} = 1.24$ μm), *H* ($\lambda_{eff} = 1.63$ μm), and *K* ($\lambda_{eff} = 2.18$ μm) bands was obtained on 1984 September 8, with the InSb photometer attached at the 3.6 m ESO telescope at La Silla. A 15″ circular aperture with chopper throw of 20″ in east-west direction was used. Several reference stars were repeatedly measured during the night, yielding an overall photometric accuracy better than 3% in all bands. HR 2882 was assumed as principal photometric standard with

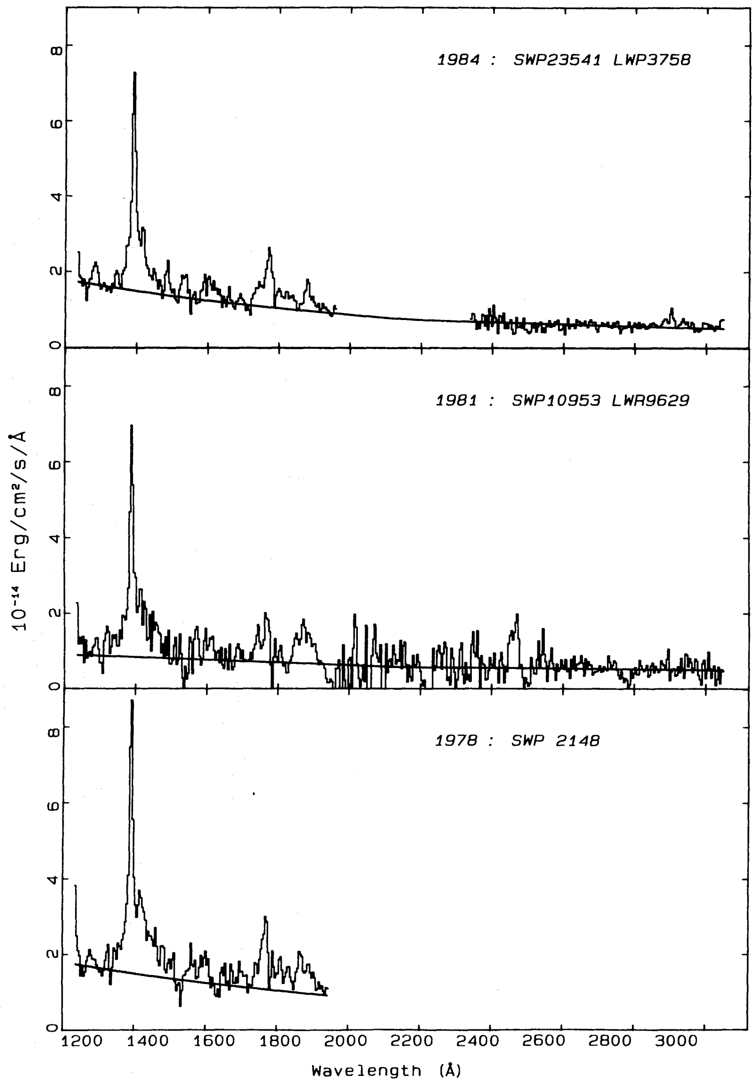

FIG. 2

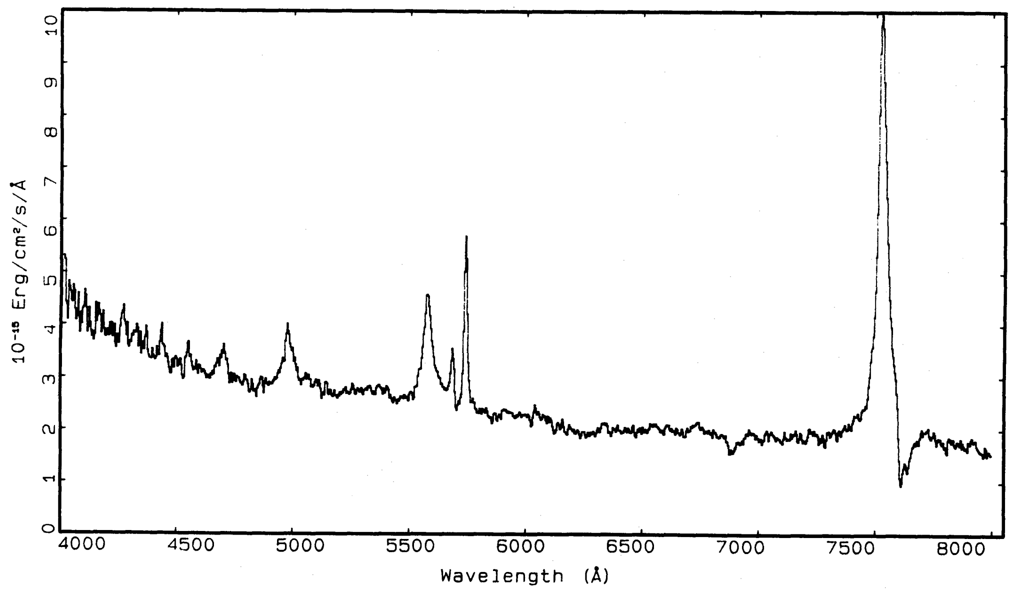

FIG. 3

FIG. 2.—The *IUE* spectrum of PG 0026+129 obtained 1984 July (*top frame*). The lower frames show the archival spectra of 1978 and 1981 (see Baldwin *et al.* 1978; Brosch and Gondhalekar 1984). The continua correspond to power laws reddened with $A_V = 0.1$ (see text), adopting the extinction curve computed by Seaton (1979).

FIG. 3.—Average optical spectrum of PG 0026+129 (1984 Nov 8–12)

$J = 5.53$, $H = 5.22$, and $K = 5.16$. Reduction to flux densities, as reported in Table 1, was obtained with the following 0 magnitude fluxes (in ergs cm^{-2} s^{-1} μm^{-1}): $F(J) = 3.14 \times 10^{-6}$, $F(H = 0) = 1.2 \times 10^{-6}$, $F(K = 0) = 4.12 \times 10^{-7}$.

Optical and infrared photometry covering the period 1975–1983 can be found in Neugebauer *et al.* (1979, 1985, 1987), Puetter, Smith, and Willner (1981), and Moles *et al.* (1985). The *B* magnitude ranges from 15.6 to 15.8. The *H* (1.25 μm) and *K* (2.2 μm) fluxes were respectively in the range 5.1×10^{-16}–7.3×10^{-16} ergs cm^{-2} s^{-1} Å and 4.5×10^{16}–5.8×10^{-16} ergs cm^{-2} s^{-1} Å, the higher values all deriving from observations before 1980, the lower ones from the more recent data.

III. DISCUSSION

Our measurements of 1984 in the IR, optical, UV, and X-ray are summarized in Figure 4. The optical and UV fluxes are dereddened with $A_v = 0.1$. The x-ray data are corrected for absorption with $N_H = 5 \times 10^{20}$. The slope $\alpha = 1$ found in the X-ray, between 0.2 and 6 keV, is typical of radio-quiet quasars, as from the recent survey of bright quasar spectra by Wilkes and Elvis (1987). The X-ray spectral index obtained from the fit to the combined spectrum (see inset in Fig. 1) is nominally inconsistent with the canonical active galactic nuclei (AGN) value of 0.7 (see however the individual observation confidence ranges in Table 2). No significant excess is seen in the soft X-rays (<0.005 counts s^{-1} in the Lexan filter).

A clearly flatter ($\alpha = 0.5$) slope is found in the IR, optical, UV range. The UV spectrum is definitely flatter than the X-ray one even when uncorrected for reddening. The energy distribution (νF_ν), therefore, peaks in the far-UV. The extrapolation of the best fit of the X-ray spectrum to lower frequencies intercepts the infrared flux. On the other hand, given the uncertainty on the slope of the X-ray spectrum, an extrapolation to the far-ultraviolet cannot be excluded.

The sparse optical and infrared photometric data indicate variability of the source at the level of tenths of magnitude. In the far-UV (1200–2000 Å) an increase of 50% is found between 1981 and 1984. It is remarkable that between the same epochs no variation larger than 10% is found in the 2000–3000 Å range. A similar behavior was observed by us in another optically selected bright quasar, PG 1351+64 (Treves *et al.* 1985; Tanzi *et al.* 1986). The two objects exhibit also very similar infrared to optical energy distribution (Neugebauer *et al.* 1987).

The energy distribution of quasars from the IR to the X-ray is usually decomposed into a power law connecting the IR and X-ray bands, plus an excess peaking at or beyond the far-ultraviolet, whose shape can be reasonably approximated, within the uncertainty, by a simple thermal distribution, or by the spectrum of an accretion disk [e.g., Elvis *et al.* 1986; Edelson and Malkan (1986) and references therein].

In the case of PG 0026+129 and PG 1351+64 the spectral dependence of the observed variability can be interpreted in two ways. One can attribute the larger amplitude of variation in the far-UV to a modification of the spectral shape of the thermal component with increasing intensity (e.g., as due to a

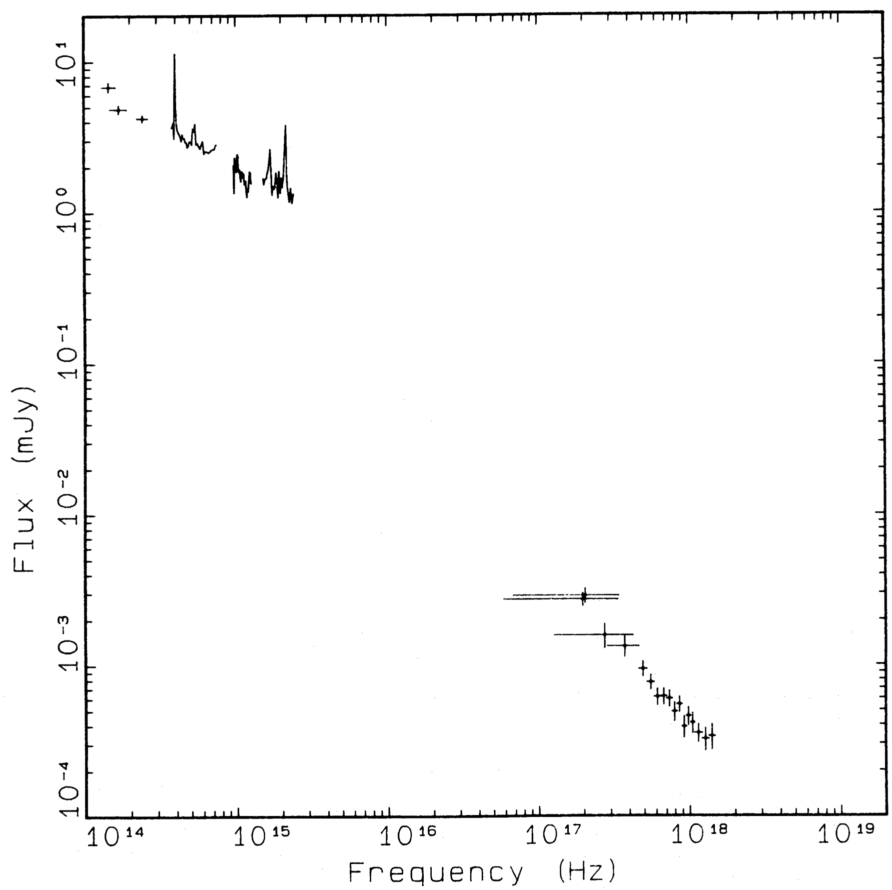

FIG. 4.—Composite energy distribution PG 0026+129, obtained from 1984 observations, corrected for absorption and reddening as described in the text

higher temperature, or to a larger variability of the inner disk regions, which contribute most at higher frequencies). Alternatively, one can assume that the thermal component varies with constant shape and that the different degree of dilution by the underlying power-law component is responsible for the frequency dependence of the variability. In any case the data indicate that the IR to X-ray power-law component is less variable than the thermal emission.

This result is of relevance for a discussion of the emission mechanisms. Models in which the X-ray emission is related to the ultraviolet, either through Compton scattering of electrons off UV photons, or as thermal tail of the ultraviolet bump, tend to predict a similar variability in the two bands, which is not found in our data. A synchrotron origin of the infrared to X-ray power law is possible, especially if produced in a relatively large region (10^{16} cm, $B = 340$ G), as discussed by Band and Grindlay (1986), consistently with the little variability observed. On the other hand this model requires electrons to be accelerated to very high energies ($\gamma \sim 10^5$). A valuable alternative may be Compton scattering off photons other than UV ones, in a region of 10^{16}–10^{17} cm, which eases the requirement on the electron energy and the magnetic field.

However, before pushing the discussion to greater depth, the observational results need to be verified over a wider set of data, and over more objects.

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REFERENCES

Baldwin, J. A., Rees, M. J., Longair, M. S., and Perryman, M. A. C. 1978, *Ap. J. (Letters)*, **226**, L57.
Band, D. L., and Grindlay, J. E. 1986, *Ap. J.*, **308**, 576.
Blades, J. C., and Cassatella, A. C. 1982, *IUE-ESA Newsletter*, No. 15, p. 38.
Bohlin, R. C., and Holm, A. V. 1980, *IUE-NASA Newsletter*, No. 10, p. 37.
Bonanno, G., and Falomo, R. 1987, *Astr. Ap.*, **189**, 349.
Brosch, N., and Gondhalekar, P. M. 1984, *Astr. Ap.*, **140**, L43.
Cassatella, A., and Ponz, D. 1979, *ESA IUE Newsletter*, No. 4, p. 5.
Chiappetti, L., and Davelaar, J. 1984, *EXOSAT Observers' Guide*, Vol. **III**, Section 8.1.
Edelson, R. A., and Malkan, M. A. 1986, *Ap. J.*, **308**, 59.
Elvis, M., Wilkes, B. W., and Tananbaum, H. 1985, *Ap. J.*, **292**, 357.
Elvis, M., *et al.* 1986, *Ap. J.*, **310**, 291.
Falomo, R. 1984, Asiago Obs. Internal Rept.
Giommi, P. 1985, *Exosat Express*, **12**, 33.
Lampton, M., Margon, B., and Bowyer, S. 1976, *Ap. J.*, **207**, 359.
Moles, M., Garcia-Pelayo, J. M., Masegosa, J., Aparicio, A., and Quintana, J. M. 1985, *Astr. Ap.*, **152**, 271.
Morrison, R., and McCammon, D. 1983, *Ap. J.*, **270**, 119.
Neugebauer, G., Green, R. F., Matthews, K., Schmidt, M., Soifer, B. T., and Bennet, J. 1987, *Ap. J. Suppl.*, **63**, 615.
Neugebauer, G., Matthews, K., Soifer, B. T., Elias, J. H. 1985, *Ap. J.*, **298**, 275.
Neugebauer, G., Oke, J. B., Becklin, E. E., and Matthews, K. 1979, *Ap. J.*, **230**, 79.
Petre, R., Mushotzky, R. F., Krolik, J. H., and Holt, S. S. 1984, *Ap. J.*, **280**, 499.
Puetter, R. C., Smith, H. E., and Willner, S. P. 1981, *Ap. J.*, **243**, 345.
Savage, B. D., and Mathis, J. S. 1979, *Ann. Rev. Astr. Ap.*, **17**, 73.
Seaton, M. J. 1979, *M.N.R.A.S.*, **187**, 73P.
Stark, A. A., Heiles, C., Bally, J., and Linke, R. 1987, in preparation.
Tananbaum, H., *et al.* 1979, *Ap. J. (Letters)*, **234**, L9.
Tananbaum, H., Avni, Y., Green, R. F., Schmidt, M., and Zamorani, G. 1986, *Ap. J.*, **305**, 57.
Tanzi, E. G., Falomo, R., Malkan, M. A., Maraschi, L., Mediavilla, E., and Treves A. 1986, in *New Insights in Astrophysics*, (ESA SP 263), p. 617.
Taylor, B. G., Andresen, R. D., Peacock, A., and Zobl, R. 1981, *Space Sci. Rev.*, **30**, 479.
Treves, A., Drew, J., Falomo, R., Maraschi, L., Tanzi, E. G., and Wilson, R. 1985, *M.N.R.A.S.*, **216**, 529.
Wilkes, B. W., and Elvis, M. 1987, *Ap. J.*, **323**, 243.
Worrall, D. M., and Marshall, F. E. 1984, *Ap. J.*, **276**, 434.

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