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X-RAY LUMINOSITY AND SPECTRAL VARIABILITY IN THE SEYFERT TYPE I GALAXY: PG 2130+099

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ABSTRACT

We present broad-band (0.1–10 keV) X-ray observations of a bright Seyfert I galaxy, PG 2130+099, using the low-energy (LE) and the medium-energy (ME) detectors of the *EXOSAT Observatory*. The observations were carried out on two occasions separated by a year (in 1984 and 1985), and the X-ray flux was found to have increased by ~35% in the 1.5–6 keV band and by a factor of ~2 in the low energies (0.1–2.0 keV). We have carried out a spectral fit to the combined LE and ME data and found that a two-component spectral model is required to explain the data on both the occasions. The two-component model consists of a hard power-law component and a steep power law ($\Gamma \simeq 6.0$) or a blackbody emission ($kT = 30$ eV) in the low energy. The intensity of the low component and the spectral index of the hard component were found to be significantly different on the two occasions. The photon spectral index of the hard component was ~1.6 in 1984 and increased to 2.0 in 1985 when the source was brighter.

Subject headings: galaxies: individual (PG 2130+099) — galaxies: Seyfert — galaxies: X-rays — X-rays: spectra

1. INTRODUCTION

Bright Seyfert galaxies are thought to be a link between the Seyfert galaxies and the quasars. One of the brightest Seyfert I galaxy is PG 2130+099 (=II Zw 136), which has an apparent blue magnitude of 14.92 and a redshift of 0.061 (Hewitt & Burbidge 1987). It shows broad hydrogen emission lines (Sargent 1968; Fairall 1968), strong Fe II emission (Oke & Shields 1976) and a fuzz around it which can be classified as an N type galaxy (Sargent 1968) or a spiral galaxy (Hickson & Hutchings 1987). It is also included in the bright quasar survey of Schmidt & Green (1983) and classified as a quasar due to its high absolute blue magnitude (−23.2 for $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.1$). Because of its weak radio emission (5.93 mJy at 1.49 GHz; Condon, Gower, & Hutchings 1987) it is often referred to as a radio quiet quasar (Wilkes & Elvis 1987). Strong infrared emission has been reported from this object (Edelson 1986), and it has one of the hottest ($T = 35{,}500$ K) UV bumps (Edelson & Malkan 1986).

The source is variable in the optical band, and a 0.5 mag variation has been seen on a time scale of a few years (Cannon, Penston, & Brett 1971). The optical continuum spectral energy distribution of PG 2130+099 has also been found to be variable over a time scale of 1 yr by Oke & Shields (1976), who carried out low-resolution spectrophotometry. According to them, the optical continuum variability is either due to a change in the continuum spectral shape or the presence of an unresolved variable continuum component. The intensity of the broad permitted line Hβ did not vary during their measurements, however. Oke & Shields (1976) also reported a strong He I emission and suggested photoionization by soft X-rays as one of the possible processes to account for it. X-ray observations with the Imaging Proportional Counter (IPC) on the *Einstein Observatory* show a power-law type of spectrum (Wilkes & Elvis 1987). Subsequent detailed analysis using the IPC and the MPC (Monitor Proportional Counter) data indicates the presence of a low-energy excess in the X-ray spectrum of PG 2130+099 (Wilkes et al. 1989). Wilkes et al. (1989) model the X-ray spectrum with a broken power law and obtain a low-energy photon index of 3.6 and a high-energy photon index of 1.81 with a break point at 0.6 keV.

To investigate the variability and the reported soft excess in the X-rays, we have obtained archival data from two observations of PG 2130+099 carried out in 1984 and 1985 using the *EXOSAT Observatory*. The results from the analysis of this data are presented here for the first time. The details of the observations are given in the next section followed by the spectral analysis (§ 3). We discuss the implication of these results in the last section (§ 4).

2. OBSERVATIONS

The X-ray observations were performed on 1984 November 16 and 1985 November 14/15, using both the medium-energy (ME) detectors and the low-energy (LE) telescope having a channel multiplier array (CMA) as the detector. The ME detectors are sensitive to X-rays in the energy range of 1–10 keV, whereas the LE + CMA combination detects softer X-rays in the energy range of 0.1–2.0 keV. The details of the instruments used are given by Turner, Smith, & Zimmermann (1981) for the ME detectors and by de Korte et al. (1981) for the LE + CMA. The particulars of the observations are given in Table 1. The LE data were obtained with the Lexan 3000 (LX3) and the Boron (BOR) filter on 1984 November 16, and with three filters, namely, LX3, BOR, and Aluminum/Parylene(Al/P) during the 1985 November 14/15 observations (see White & Peacock 1988 for filter efficiencies). The ME data were acquired from eight argon-filled detectors, and these detectors are divided into two half-arrays, viz, the detector numbers 1, 2, 3, and 4 collectively

TABLE 1

LOG OF *EXOSAT* OBSERVATIONS OF PG 2130+099 AND THE COUNT RATES

Detector Combination	Date of Observation	Start Time (UT)	End Time (UT)	Effective Exposure Time (s)	Count Rate[a] 10^{-4} cm^{-2} s^{-1}
CMA + LX3	1984 Nov 16	$15^h06^m10^s$	$17^h12^m10^s$	4139	2.8 ± 0.4
CMA + BOR	1984 Nov 16	17 15 22	21 20 42	14244	<0.26[b]
ME (Half 1)[c]	1984 Nov 16	14 36 50	18 05 06	8526	4.3 ± 0.65
ME (Half 2)	1984 Nov 16	18 16 50	21 26 42	8439	4.4 ± 0.50
CMA + LX3	1985 Nov 14	17 59 54	18 59 22		
CMA + LX3	1985 Nov 15	02 17 14	03 02 50	4808	8.1 ± 0.53
CMA + LX3	1985 Nov 15	09 09 46	10 28 10		
CMA + Al/P	1985 Nov 15	03 06 34	04 10 58	3331	3.14 ± 0.40
CMA + BOR	1985 Nov 15	04 14 18	09 05 54	15332	0.53 ± 0.11
ME (half 2)	1985 Nov 15	02 14 18	04 58 02	7636	5.4 ± 0.55
ME (half 1)[c]	1985 Nov 15	05 06 34	07 40 02	7677	6.3 ± 0.70
ME (half 2)	1985 Nov 15	07 51 14	10 34 18	7774	5.9 ∓ 0.55

[a] The count rate for the ME are for PHA channels 7–24, corresponding to the energy range of 1.5–6 keV with the best signal-to-noise ratio.
[b] 3 σ upper limit.
[c] Data from detector 3 is excluded because of its erratic behavior.

known as the half 1 array, and the other four detectors (numbers 5, 6, 7, and 8) collectively known as the half two array. The ME observations were carried out by alternately pointing one of the arrays at the source while the other array monitored the background. The details of the array pointings on the source are given in Table 1.

3. ANALYSIS AND RESULTS

The data reduction and analysis were performed using the XANADU (X-ray Analysis and Data Utilization) software package.

3.1. *LE and ME Source Counts*

A strong X-ray source coinciding with the position of PG 2130+099 was detected with the LX3 and Al/P filters on both the occasions. With the BOR filter, the source is detected only on 1985 November 14/15. The background-subtracted count rates corrected for vignetting, telemetry dead time, and the sum-signal distribution are shown in Table 1. The background was obtained from regions adjacent to the position of the source. During the 1984 November 16 observations, the source was not detected with BOR filter and a 3 σ upper limit is given in Table 1. As can be seen from the table, there is a substantial increase in the count rates from 1984 to 1985. The count rate increased by a factor of 3 in the LX3 filter (a 10 σ variation). The LX3 data binned over 400 s were searched for short-term (a few 1000 s) variations but no significant variations have been detected ($\chi^2 = 25.2$ for 19 degrees of freedom). In the BOR filter a 5 σ detection was obtained in 1985 compared to its nondetection in 1984 for comparable exposure times.

For the analysis of the ME data we have used the background obtained from the same detectors while offset from the source. Data from each detector were examined separately, and it was found that counts from detector number 3 were varying erratically and it was not used for any further analysis. The count rates obtained in the 1.5–6.0 keV band are listed in Table 1. The count rates showed $\sim 35\%$ increase between the two observations. The significant yearly variation is confirmed by the spectral analysis that follows. No significant short-term (~ 1000 s) variations have been detected in the ME.

3.2. *Spectral Analysis*

The pulse-height (PH) information obtained from the LE and the ME detectors can be used to provide a spectral estimation. The background information for the ME data is obtained from the same detectors, using the "swap" technique (Smith 1984). The subtracted counts were further corrected by using the accumulated "difference" spectra: difference in the background spectra acquired while in the offset position and aligned position, resulting due to changed environment and shielding. The inner detectors are prone to variations in the internal background due to changes in the geometrical configurations resulting from the "swap" technique (Yaqoob, Warwick, & Pounds 1989). We have examined each detector data separately and confirmed proper background subtraction at high energies (where the source contribution is negligible). We have also confirmed that the results agree with that obtained from taking only the "corner" detectors (viz., detectors 1, 4, 5, and 8) for which internal background variations are minimal. As pointed out earlier, detector 3 was not used for any analysis. To avoid possible systematic effects involved in the background subtractions and to study any possible spectral variations in the source, we have used the two sets of data (1984 and 1985) separately for the spectral analysis.

A simple power-law model was used along with absorption in the line of sight to the source to fit the data in the first instance. The absorption cross sections given by Morrison & McCammon (1983) were used. The ME data is not very sensitive to absorption due to a column density that is only a few times 10^{20} cm^{-2}. The absorption in the line of sight was, however, fixed at $N_H = 4.2 \times 10^{20}$ cm^{-2} (the Galactic absorption) as measured by Elvis, Lockman, & Wilkes (1989). The results of fit to high-energy ME data alone are given in Table 2. The ME data of 1984 and 1985 are well fitted by a single power law. There is an indication that the spectral slope is steeper for the 1985 data as compared to the slope of the 1984 data.

The results obtained from fitting a single power law and a variable absorption to the combined data from the LE and ME are shown in Table 3. The error bars quoted in the tables are with 90% confidence, estimated by keeping all the other

TABLE 2

RESULTS OF THE SPECTRAL ANALYSIS OF *EXOSAT* ME DATA ON PG 2130+099

Parameter	Date of Observation: 1984 Nov 16	Date of Observation: 1985 Nov 14/15
Model: power law + absorption[a]		
Photon index (Γ)	$1.86^{+0.42}_{-0.41}$	$2.06^{+0.29}_{-0.28}$
A (10^{-3} cm^{-2} s^{-1} keV^{-1})	$1.7^{+1.0}_{-0.7}$	$2.6^{+1.0}_{-0.8}$
χ^2/dof	35.4/34	31.2/33

NOTE.—Quoted errors are at 90% confidence level.
[a] $N_H = 4.2 \times 10^{20}$ cm^{-2} (Elvis et al. 1989) kept fixed.

relevant parameters free. The combined data with a larger bandwidth is also well represented by a single power law except that it requires a very low absorption in the line of sight to X-ray source. The derived equivalent hydrogen column density (N_H) is much lower than the galactic absorption. The derived values of N_H are less than 2×10^{20} cm^{-2} and less than 1.7×10^{20} cm^{-2}, respectively (90% confidence limit), for the 1984 and the 1985 data sets, whereas the Galactic N_H in the direction of PG 2130+099 is 4.2×10^{20} cm^{-2} (Elvis et al. 1989). When the absorption is fixed at the Galactic value the single power-law model gives unacceptable fits (using χ^2 statistic) for both the sets of the data. The χ^2 values found are 53.2 and 62.3, respectively, for the two sets of observations, with 36 degrees of freedom. The unacceptable single power-law fits to the LE and the ME combined data appear to be due to a low-energy excess. The PH data from the 1985 observations are shown in Figure 1, along with the power-law model convolved with the detector response shown as a histogram. The residuals are shown in the lower panel of the figure. A clear, low-energy excess can be seen from the figure.

TABLE 3

RESULTS OF THE SPECTRAL ANALYSIS OF *EXOSAT* LE + ME DATA ON PG 2130+099

Parameter	Date of Observation: 1984 Nov 16	Date of Observation: 1985 Nov 14/15
Model 1: Power Law + Variable Absorption		
Photon index (Γ)	$1.37^{+0.58}_{-0.13}$	$2.10^{+0.21}_{-0.22}$
A (10^{-3} cm^{-2} s^{-1} keV^{-1})	$0.84^{+0.93}_{-0.14}$	$2.7^{+0.7}_{-0.6}$
N_H (10^{20} cm^{-2})	$0.04^{+1.95}_{-0.04}$	$0.94^{+0.77}_{-0.57}$
χ^2/dof	44.0/35	36.5/35
Model 2: Power Law + Absorption		
Photon index (Γ)	$2.13^{+0.18}_{-0.21}$	$2.67^{+0.08}_{-0.08}$
A (10^{-3} cm^{-2} s^{-1} keV^{-1})	$2.21^{+0.42}_{-0.45}$	$4.98^{+0.34}_{-0.34}$
χ^2/dof	53.2/36	62.3/36
Model 3: 2 Power Laws + Absorption[a]		
High-energy photon index (Γ_{HE})	$1.58^{+0.32}_{-0.35}$	$2.02^{+0.23}_{-0.24}$
A_{HE}(10^{-4} cm^{-2} s^{-1} keV^{-1})	$11.3^{+5.6}_{-4.3}$	$24.9^{+7.3}_{-6.4}$
low-energy photon index (Γ_{LE})	$5.9^{+4.0}_{-4.0}$	$6.6^{+2.6}_{-2.1}$
A_{LE}(10^{-5} cm^{-2} s^{-1} keV^{-1})	$3.3^{+68.7}_{-3.2}$	$3.9^{+63.0}_{-3.2}$
χ^2/dof	40.9/34	31.4/34
Model 4: Power Law[b] + Blackbody + Absorption		
Blackbody temperature (eV)	40.0^{+40}_{-21}	$29.9^{+18.1}_{-29.9}$
Normalization[c] ($10^{-3} L_{39}/D_{10}^2$)	$0.4^{+9.3}_{-0.3}$	$2.8^{+\infty}_{-2.8}$
χ^2/dof	39.7/36	31.4/36
Flux (2–10 keV) ergs cm^{-2} s^{-1}	5.6×10^{-12}	6.3×10^{-12}
Flux (0.1–2.0 keV) ergs cm^{-2} s^{-1}	4.2×10^{-12}	9.5×10^{-12}
Model 5: Broken Power Law[d] + Absorption		
High-energy photon index (Γ_{HE})	$1.60^{+0.31}_{-0.34}$	$2.01^{+0.22}_{-0.23}$
Low-energy photon index (Γ_{LE})	$4.47^{+0.90}_{-0.93}$	$4.66^{+0.57}_{-0.57}$
$A_{1\,keV}$(10^{-4} cm^{-2} s^{-1} keV^{-1})	$2.67^{+4.5}_{-1.8}$	$6.4^{+5.8}_{-3.2}$
χ^2/dof	40.2/35	32.1/35

NOTE.—Quoted errors are at 90% confidence level. Detector No. 3 is excluded.
[a] $N_H = 4.2 \times 10^{20}$ cm^{-2} (Elvis et al. 1989) kept fixed.
[b] The HE power law is fixed from model 3.
[c] $L_{39} = 10^{39}$ ergs s^{-1}, $D_{10} = 10$ kpc.
[d] The break point energy has been fixed at 0.6 keV.

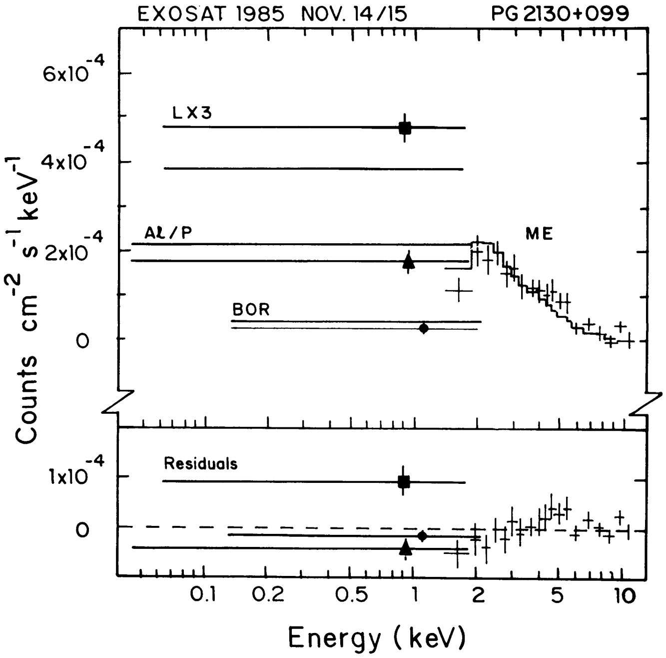

FIG. 1.—The observed count rate spectrum of PG 2130+099 obtained using the LE and the ME detectors (excluding detector number 3) of the *EXOSAT Observatory* during 1985 November 14/15, is shown. The LE data were obtained using three filters, viz., LX3 (*filled squares*), BOR (*filled circles*), and Al/P (*filled triangles*). The best-fit single power-law model with the photon index of 2.7, convolved with the detector response function, is shown as a histogram. The residuals between the data and the best-fit spectral model are shown in the lower panel.

The low-energy excess was modeled as another power law and also as a blackbody emission. In the first case two power-law components were fitted simultaneously to the LE + ME data. The best-fit parameters thus obtained for the power law for the high-energy data were then frozen while modeling the low-energy excess with a blackbody emission. Results of such two-component spectral fittings are shown in Table 3. The absorption in the line of sight was fixed at the Galactic value. Both the two-component fits (two power laws and a power law with blackbody emission) give acceptable χ^2 values. This shows that the low-energy data requires a steep component ($\Gamma \simeq 6.0$ or $kT \simeq 30$ eV) on both the occasions. The PH data and the best-fit two power-law model (convolved with the detector response) are shown in Figure 2 for the 1985 observations. The residuals to the data fit are shown in the lower panel of the figure.

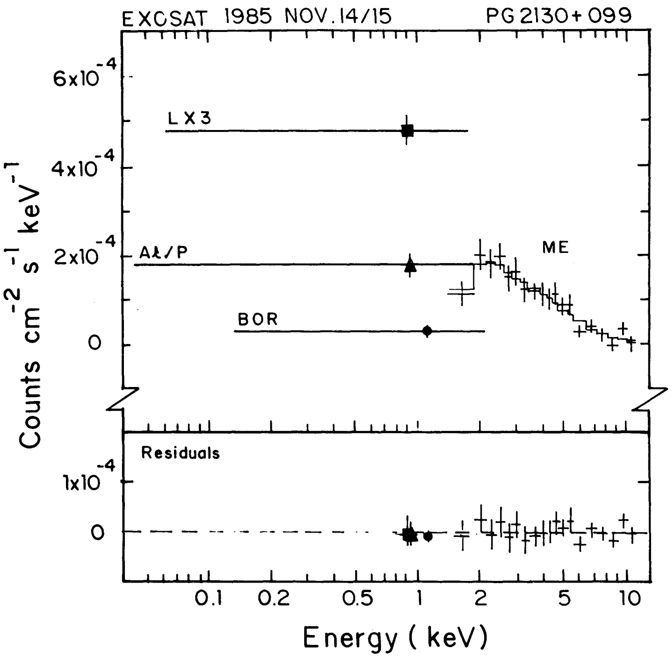

FIG. 2.—The data (1985 November 14/15) and line-style are the same as in Fig. 1. The best-fit model, shown as a histogram, consists of two power laws with photon indices 6.6 and 2.0, for the low and high energies, respectively. For clarity, the bandwidths of LE data points are not indicated.

The X-ray spectrum was also fitted with a broken power law to compare our results with that of Wilkes et al. (1989). The absorption was again held fixed as above, and the break energy between the two components was frozen at 0.6 keV. The best-fit parameters and the associated 90% errors are given in Table 3. The high-energy slopes are found to be the same as from the two-component fit. The low-energy photon indices are slightly steeper than those found by Wilkes et al. from the IPC and MPC measurements. Keeping the break energy variable had no significant effect on the results. The best-fit (from χ^2 minimization) break energy for the 1984 data was $\sim$0.59 keV and $\sim$0.47 keV for the 1985 data. The corresponding Γ_{LE} for the 1984 data is unchanged whereas for the 1985 data it becomes 5.6 instead of 4.7.

There are significant changes in the spectral shape on the two occasions, hereafter referred to as the low state (1984 November 16 observations) and the high state (1985 November 14/15 observations). In the low state the high-energy power law is flat (photon index $\Gamma_{HE} = 1.6^{+0.3}_{-0.4}$) and it is steeper ($\Gamma_{HE} = 2.0^{+0.2}_{-0.2}$) during the high state. The hard X-ray (2–10 keV) flux, however, increased by $\sim$13%. The low-energy component has a similar photon index Γ_{LE} and blackbody temperature on both the occasions although the soft X-ray (0.1–2.0 keV) flux increased by a factor of 2 from 1984 to 1985.

The major changes in the spectra on the two occasions are the large increase in the low-energy flux (also indicated by the broad-band LE count rates; see Table 1) and the indication of steepening of the high-energy power-law index. The low-energy spectral shape is not well determined, although there is an indication of it being similar on the two occasions (see Table 3). To further quantify the spectral changes, we have fitted the data with a broken power law by keeping the break energy fixed at 0.6 keV and the low-energy power-law index fixed at 4.5. The derived values of Γ_{HE} are $1.59^{+0.14}_{-0.15}$ and $2.07^{+0.08}_{-0.08}$, respectively, for the low and high states, showing a significant difference between the two states. The low-energy (0.1–0.6 keV) flux showed an increase by a factor of 3, and the high-energy (0.6–10 keV) flux showed a 40% increase.

There is no indication for the presence of any line feature in the X-ray spectra of PG 2130+099.

4. DISCUSSION

Significant X-ray luminosity and spectral variations have been observed from the Seyfert galaxy PG 2130+099 in a year between 1984 to 1985. Assuming Hubble constant $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$ in the Friedman cosmology, we find that the luminosity distance of PG 2130+099 is 377 Mpc. The X-ray luminosity of the source in the 2–10 keV bandwidth of the observer's frame has thus changed from 9.4×10^{43} ergs s^{-1} in 1984 November to 1.1×10^{44} ergs s^{-1} in 1985 November. In the low-energy range of 0.1–2.0 keV the increase over the same time has been from 7.2×10^{43} ergs s^{-1} to 1.6×10^{44} ergs s^{-1}. The IPC measurements in 1981 April 20 detected a flux of 4.2×10^{-12} ergs cm^{-2} s^{-1} in the energy band of 0.3–3.5 keV (Wilkes & Elvis 1987). The *EXOSAT* detectors measured the same flux in this bandwidth in 1984 November and 2 times higher flux in 1985 November.

The X-ray spectrum of the source is best described by a two-component model: one component for energies greater than 1 keV and one for lower energies. The low-energy component is very steep ($\Gamma_{LE} \simeq 6$) and dominates the spectrum below 0.5 keV, irrespective of whether the source is in a high state or a low state. The presently reported soft excess in PG 2130+099 is steeper than the one found by Wilkes et al. (1989). Soft excess at energies below 1 keV has been found in many Seyfert galaxies (Singh, Garmire, & Nousek 1985; Arnaud et al. 1985; Turner & Pounds 1989; Wilkes et al. 1989). The variable soft excess of the type seen here is normally attributed to emission from an accretion disk surrounding a supermassive black hole believed to be existing in the nucleus of Seyfert galaxies. The soft excess could be part of the "big bump" extending from the UV to X-rays and is expected to be visible from face-on galaxies. Such a situation is possible as this particular galaxy does appear face-on in the picture of Hickson & Hutchings (1987).

For energies greater than 1 keV the X-ray spectrum is relatively flatter with its exact slope being dependent on its luminosity. The high-energy slope (Γ_{HE}) is 2.0 when the source is in the high state and close to 1.6 when it is in the low state. Similar steepening of the 2–10 keV spectrum with increasing luminosity has been reported from many other Seyfert galaxies, e.g., 3C 120 (Halpern 1985), NGC 5548 (Branduardi-Raymont 1986), NGC 7314 (Turner 1987), NGC 4051 and MCG−6-30-15 (Lawrence et al. 1985; Matsuoka et al. 1989; Nandra, Pounds, & Stewart 1990), Mrk 509 (Singh et al. 1990), and NGC 4151 (Yaqoob & Warwick 1989). The observed spectral variation could be due to intrinsic changes in the source with the two components (Γ_{LE} and Γ_{HE}) varying independently or due to a single underlying mechanism for the production of X-rays. As an example of the latter case, Compton scattering of a variable soft photon source incident on the hot inner disk gas has been invoked as an explanation for a similar correlation between the spectral index and intensity seen in NGC 4051 (Lawrence et al. 1985). Predictions for correlation between the softness and intensity variation in active galactic nuclei, based on thermal-Compton models have also been made by Dermer (1988). Recently, Yaqoob & Warwick (1989) have reproduced similar correlations observed in NGC 4151 by using non-thermal models of X-ray production (see Lightman & Zdziarski 1987). Higher sensitivity observations with higher time resolution are required so that time delays between the soft and hard components can be measured to distinguish between the various possible scenarios.

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REFERENCES

Arnaud, K. A., et al., 1985, MNRAS, 217, 105
Branduardi-Raymont, G. 1986, in The Physics of Accretion onto Compact Objects, ed. K. O. Mason, M. G. Watson, & N. E. White (Berlin: Springer-Verlag), p. 407
Cannon, R. D., Penston, M. V., & Brett, R. A. 1971, MNRAS, 152, 79
Condon, J. J., Gower, A. C., & Hutchings, J. B. 1987, AJ, 93, 255
de Korte, P. A. J., et al. 1981, Space Sci. Rev., 30, 495
Dermer, C. D. 1988, ApJ, 335, L5
Edelson, R. A. 1986, ApJ, 309, L69
Edelson, R. A., & Malkan, M. A. 1986, ApJ, 308, 59
Elvis, M., Lockman, F. J., & Wilkes, B. J. 1989, AJ, 97, 777
Fairall, A. P. 1968, PASP, 80, 235
Halpern, J. P. 1985, ApJ, 290, 130
Hewitt, A., & Burbidge, G. 1987, ApJS, 63, 1
Hickson, P., & Hutchings, J. B. 1987, ApJ, 312, 518
Lawrence, A., Watson, M. G., Pounds, K. A., & Elvis, M. 1985, MNRAS, 217, 685
Lightman, A. P., & Zdziarski, A. A. 1987, ApJ, 319, 661
Matsuoka, M., Yamauchi, M., Piro, L., & Molteni, D. 1990, ApJ, 362, 440
Morrison, R., & McCammon, D. 1983, ApJ, 270, 119
Nandra, K., Pounds, K. A., & Stewart, G. C. 1990, MNRAS, 242, 660
Oke, J. B., & Shields, G. A. 1976, ApJ, 207, 713
Sargent, W. L. W. 1968, AJ, 73, 893
Schmidt, M., & Green, R. F. 1983, ApJ, 269, 352
Singh, K. P., Garmire, G. P., & Nousek, J. 1985, ApJ, 297, 633
Singh, K. P., Westergaard, N. J., Schnopper, H. W., Awaki, H., & Tawara, Y. 1990, ApJ, 363, 131
Smith, A. 1984, *EXOSAT Express*, No. 5, 48
Turner, M. J. L., Smith, A., & Zimmermann, H. U. 1981, Space Sci. Rev., 30, 479
Turner, T. J. 1987, MNRAS, 226, 9P
Turner, T. J., & Pounds, K. A. 1989, MNRAS, 240, 833
White, N. E., & Peacock, A. 1988, Mem. Soc. Astr. Italiana, 59, 7
Wilkes, B. J., & Elvis, M. 1987, ApJ, 323, 243
Wilkes, B. J., Masnou, J.-L., Elvis, M., McDowell, J., & Arnaud, K. 1989, in Proc. 23d ESLAB Symposium on Two Topics in X-Ray Astronomy. II. AGN and the X-ray Background, ed. J. Hunt and B. Battrick (ESA SP-296), p. 1081
Yaqoob, T., & Warwick, R. S. 1989, in Proc. 23d ESLAB Symposium on Two Topics in X-Ray Astronomy. II. AGN and the X-Ray Background, ed. J. Hunt and B. Battrick (ESA SP-296), p. 1089
Yaqoob, T., Warwick, R. S., & Pounds, K. A. 1989, MNRAS, 236, 153