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X-RAY CONTINUUM AND LINE EMISSION OF THE SEYFERT GALAXY MCG−5-23-16

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ABSTRACT

We report observations of X-ray continuum and line emission from the highly absorbed and variable Seyfert galaxy MCG−5-23-16, using the low-energy and the medium-energy detectors of the *EXOSAT Observatory.* The galaxy was observed in 1983 December and in 1984 May. The X-ray intensity of the source is observed to vary by ∼25% in the hard (2–10 keV), and by ∼40% in the soft (0.1–2.0 keV) energy bands over a period of 6 months. The 0.1–10 keV X-ray spectrum is adequately explained by a simple power law. The measured energy index (α) lies in the range 0.42–0.89 and shows a dependence on the intensity. Line emission at 6.4 keV is detected in the 1984 observations when the X-ray spectrum is relatively harder. The equivalent width of the line is measured to be 346 ± 146 eV. The presence of line emission is also indicated in the 1983 data. The line-of-sight absorption is much higher than the 21 cm value, suggesting a very high obscuration of the nuclear source. The present observations are well explained by the reflection of X-rays by cold material in an accretion disk around the nuclear source. It is suggested that as the absorption (due to the disk) of the direct component increases with time, so does the amount of the reflected component, thus hardening the spectrum and also producing more line emission.

Subject headings: galaxies: individual (MCG−5-23-16) — galaxies: Seyfert — X-rays: galaxies

1. INTRODUCTION

Evidence for the existence of a substantial amount of "cold" matter close to the central continuum source in active galactic nuclei (AGNs) has accumulated in the last several years. The low-resolution X-ray spectra of a large number of AGNs have indicated the presence of a significant absorption near the central source, in many of the AGNs studied. The detection of soft X-ray excess in some of the sources, often variable on time scales of a few hours, and the detection of 6–7 keV line emission have given further evidence for the existence of the "cold" material around the nuclear source. Recently, observations with the *Ginga* satellite have indicated that the iron K-features may be a common property of the AGNs (Pounds 1989). Although it is believed that the three phenomena discussed above, viz., low-energy absorption, low-energy excess, and the line feature, have their origin in the cold matter, the exact geometry and emission behavior of the source is not yet clear. To understand the physical nature of the material around AGNs, more observations are needed with capabilities of simultaneously detecting both the low-energy spectrum and the line features. In this paper we report the *EXOSAT* observations of the Seyfert galaxy MCG−5-23-16, which showed indications of both the line emission and the low-energy absorption in earlier observations.

The Seyfert galaxy MCG−5-23-16 is an early type SO/a galaxy with an apparent V-magnitude of ∼13.5 and redshift of 0.0083 (Hamuy & Maza 1987; Sersic & Pastoriza 1965; Schnopper et al. 1978). It shows significant small amplitude variability in its magnitude (range of V is 13.41–13.69) and colors (Hamuy & Maza 1987). The galaxy was identified with a highly variable (variability factor = 5) X-ray source by Schnopper et al. (1978) from observations with the *SAS 3* in 1978 February 26–March 2. Similar episodes of variability were later reported by Mushotzky (1982) in the *HEAO 1* scans during 1977 December 2–7 and 1978 December 5–7. X-ray variability on an even shorter time scale has recently been reported by Kruper, Urry, & Canizares (1990) based on observations with the Imaging Proportional Counter (IPC) aboard the *Einstein Observatory*. Variations in the X-ray flux on a time scale of a year have also been reported by Marshall, Warwick, & Pounds (1981) based on 5 yr of observations with the *Ariel 5* satellite.

The X-ray spectrum of MCG−5-23-16, measured with the *HEAO 1* detectors (Mushotzky 1982; Rothschild et al. 1983), the various instruments aboard the *Einstein Observatory* (Reichert et al. 1985; Kruper et al. 1990), and the *EXOSAT Observatory* (Turner & Pounds 1989), is well described by a power law with energy index α in the range 0.5–0.8, and a line-of-sight absorption column which is significantly larger than the Galactic value of 8.5×10^{20} cm^{-2} for the N_H (Stark et al. 1990).

The galaxy was observed with the *EXOSAT Observatory* twice—once in 1983 and once in 1984. Data from the 1983 observations alone were analyzed by Turner & Pounds (1989). In this paper we present the 1984 observations and their analysis for the first time. In addition we have carefully renalyzed the 1983 data. We compare the results from our analysis of the two observations and report on the variability of the intensity and the spectral features of MCG−5-23-16, followed by a discussion.

2. OBSERVATIONS

The observations with the *EXOSAT* were performed on 1983 December 13 and 14, and again on 1984 May 23. Both the medium-energy (ME) detectors (see Turner, Smith, & Zimmermann 1981 for details) and the low-energy (LE) telescope having a channel multiplier array (CMA) as the detector (see de Korte et al. 1981 for details) were pointed simultaneously at the Seyfert galaxy. The LE data were obtained using the Lexan 3000 (LX3) filter (see White & Peacock 1988 for filter efficiencies), and the effective exposure times were 11761.9 s in 1983 and 16550.8 s in 1984. The 1983 ME data were acquired from four argon-filled detectors that constitute the "half 2" array of the ME experiment, whereas the 1984 data were obtained using the full compliment of eight argon-filled detectors. The effective exposure times were 14315.5 and 13978.3 s in 1983 and 1984, respectively. The standard technique of swapping the half-arrays (see White & Peacock 1988) during the *EXOSAT* observations was not used. The background was estimated using the data from the same detectors while they were being moved toward and away from (Slew data) the target source.

3. ANALYSIS AND RESULTS

The data reduction and analysis were performed using the XANADU (X-ray Analysis and Data Utilization) software package. The method of analysis is reported in more detail in Singh, Rao, & Vahia (1991).

3.1. *LE and ME Source Counts*

Soft X-ray emission from a point source coinciding with the optical position of MCG−5-23-16 (Schnopper et al. 1978) was detected with the LE telescope. The background-subtracted count rates corrected for vignetting, telemetry dead time, and the sum-signal distribution are shown in Table 1. The source is detected in the LX3 filter at a confidence level of about 3.0 σ in the 1983 observations, but barely detectable in the 1984 observations. The source counts appear to have declined by nearly 50% in 6 months. The significance of this result taken on its face value is poor; however, the decrease is corroborated by a simultaneous drop in the ME count rate (see below).

The ME count rates detected from MCG−5-23-16 in each half-array are listed in Table 1, following the usual procedure of background subtraction and correcting for vignetting and dead time. The background for the 1983 data was not as accurately determined as for the 1984 data. This is reflected in the higher 1 σ error for the 1983 count rate. There is, however, a clear indication for a significant drop of ∼25% in the ME count rate in 6 months. The ME data when subjected to χ^2 test against the hypothesis of a constant source showed that the source was consistent with being steady on the time scales of 200–2000 s. The count rates observed in the LE range are, however, too small for such an analysis.

3.2. *Spectral Analysis*

The pulse-height (PH) information of the X-ray source counts detected with the LE and the ME detectors was combined and analyzed together for an estimation of the spectral parameters of the X-ray emission of MCG−5-23-16. The four

TABLE 1

OBSERVED COUNT RATES AND THE RESULTS OF SPECTRAL ANALYSIS OF *EXOSAT* LE + ME DATA ON MCG−5-23-16

PARAMETER	DATE OF OBSERVATION: 1983 Dec 13/14	DATE OF OBSERVATION: 1984 May 23
A. Observation Log		
Count rates (10^{-4} cm^{-2} s^{-1})[a]:		
CMA + LX3	0.62 ± 0.20	0.27 ± 0.16
ME (Half 2)[b]	45.5 ± 2.90	33.9 ± 1.60
ME (Half 1)	...	34.2 ± 0.80
B. Model Fitting		
Model 1—Power Law + Absorption:		
Energy index (α)	0.65 ± 0.13	0.47 ± 0.11
Normalization (10^{-2} cm^{-2} s^{-1} keV^{-1})	$1.70^{+0.43}_{-0.33}$	$1.01^{+0.21}_{-0.17}$
N_H (10^{22} cm^{-2})	$1.48^{+0.44}_{-0.42}$	$1.60^{+0.40}_{-0.37}$
χ^2_{min}/dof	194.1/175	347.8/307
Model 2—Power Law + Gaussian Line + Absorption:		
Energy Index (α)	$0.72^{+0.17}_{-0.15}$	$0.61^{+0.20}_{-0.19}$
Normalization (10^{-2} cm^{-2} s^{-1} keV^{-1})	$1.91^{+0.60}_{-0.42}$	$1.25^{+0.33}_{-0.25}$
E_{line} (keV)	$6.60^{+0.8}_{-1.1}$	$6.41^{+0.36}_{-0.34}$
A_{line} (10^{-4} cm^{-2} s^{-1})	1.1 ± 1.0	1.85 ± 0.7
N_H (10^{22} cm^{-2})	$1.63^{+0.50}_{-0.46}$	$1.87^{+0.45}_{-0.42}$
χ^2_{min}/dof	190.6/173	327/305
Equivalent width$_{line}$ (eV)	148 ± 128	346 ± 142
Flux[c] (2–10 keV)	$6.7^{+0.15}_{-0.20}$	$5.23^{+0.1}_{-0.1}$
	$(7.5^{+0.17}_{-0.22})$	$(5.9^{+0.11}_{-0.11})$
Flux[c] (0.1–2.0 keV)	$0.54^{+0.13}_{-0.11}$	$0.31^{+0.06}_{-0.05}$
	$(7.5^{+1.8}_{-1.5})$	$(4.6^{+0.90}_{-0.74})$
Flux[c] (0.2–4.0 keV)	$2.64^{+0.11}_{-0.09}$	$1.79^{+0.05}_{-0.05}$
	$(9.1^{+0.38}_{-0.31})$	$(6.1^{+0.17}_{-0.17})$

NOTE.—Quoted errors for the model parameters are at 90% confidence level (χ^2_{min} + 4.61).

[a] The Count Rate for the ME are for PHA channels 7–24 corresponding to the energy range of 1.5–6.0 keV with the best signal-to-noise ratio. The errors are 1 σ.

[b] Detector number 6 has been excluded due to poor background subtraction.

[c] Observed flux in units of 10^{-11} ergs cm^{-2} s^{-1}. The unabsorbed source flux is in parentheses and in the same units.

detectors of the half-2 array were used for analyzing the 1983 data. The 1984 data were analyzed using seven of the eight ME detectors (detector number 6 was disqualified due to improper background subtraction). The PH channels 7–50, corresponding to energy range of 1.5–14 keV, were used throughout for the analysis. The spectral parameters were estimated by performing a simultaneous fit to the PH data from the selected detectors and grouping them together for plotting purposes only. This avoids systematic errors of combining different detectors before the analysis.

We used a single power-law model along with absorption in the line of sight to fit the data from the LE and the ME detectors selected above. The absorption cross sections given by Morrison & McCammon (1983) were used. Using the χ^2 statistic we find that this simple model gives an acceptable fit to the 1983 data and a marginally acceptable fit for the 1984 data. The results of this model fitting to the combined LE and ME pulse height data are given in Table 1. The 90% confidence error bars for a given parameter were computed by keeping all the other parameters free (χ^2_{min} + 4.61 for two free parameters). The results from the analysis of the ME data alone were identical to those from the LE + ME data except that the LE + ME together provide a better estimate of the absorption column in the line of sight.

In Figure 1*a* we show the PH data from the 1984 May 23 observation along with a histogram of the best-fit model convolved through the detector response. The residuals between the data and the model are shown in Figure 1*b*. An excess of counts near 6 keV can be seen clearly. We, therefore, included a Gaussian feature with a fixed width of 0.1 keV and a variable energy in our models for fitting the data. This resulted in a significant improvement in the overall fit to the 1984 data (see Table 1). The $\Delta\chi^2 = 20.8$ gives a very high significance (>99.99%) for justifying the presence of the line at 6.4 keV using the *F*-statistic. The improvement in the fit can be seen clearly in Figure 1*c* which shows the residuals between the data and the best-fit model including a Gaussian line. The presence of a similar line feature in the 1983 data is also indicated with a confidence of $\simeq$95% using the *F*-statistic. The best-fit values of the parameters from this fit are listed in Table 1 for both the data sets. The allowed values of the line energy and line intensity are shown in Figure 2 for different levels of confidence, viz., 67%, 90%, and 99% for two parameters of interest corresponding to χ^2_{min} plus 2.71, 4.61, and 9.21, respectively.

In Table 1 we also list the observed intensities and the unabsorbed source intensities in the various energy bands. The fluxes are also given in the 0.2–4.0 keV band for an easy comparison with the IPC measurements. Both the soft and hard X-ray fluxes had declined by 22%–43% over the 6 months interval between 1983 and 1984. We have looked for correlated variations in the spectral index and absorption parameter. In Figure 3 we have plotted the allowed ranges for the two interesting parameters, N_H and α, for the 1983 and 1984 data. The contours displayed enclose the allowed parameter space with the confidence associated with χ^2_{min} plus 2.71, 4.61, and 9.21. The contours were generated by keeping the continuum intensity and the line intensity as free parameters. From this figure it

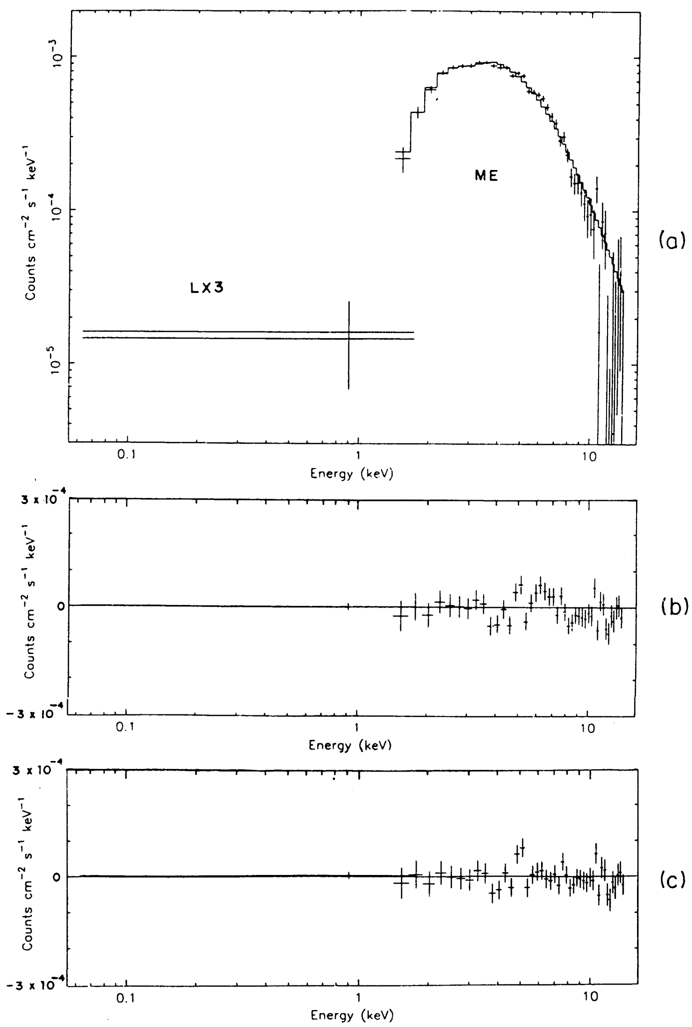

FIG. 1.—(*a*) X-ray spectrum observed with the LE and ME detectors of *EXOSAT* on 1984 May 23. Filter used for the LE observation is indicated. Histogram shows the predicted count distribution from the best-fit single power-law spectrum with low-energy absorption. (*b*) Residuals between the data and the best-fit spectral model. An excess of counts near 6 keV can be seen clearly. (*c*) Residuals after modeling the excess as an additional Gaussian line feature.

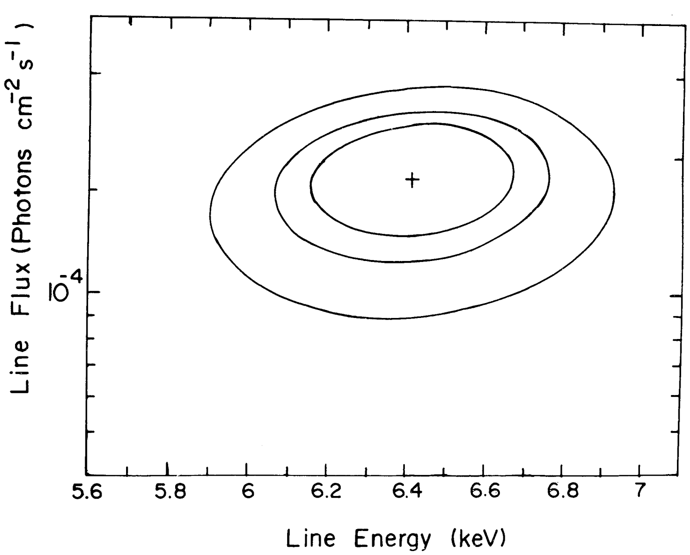

FIG. 2.—Three contours enclosing the allowed range of the 6.4 keV line (modeled as a Gaussian) flux and the line energy are shown for different levels of confidence corresponding to χ^2_{min} + 2.71, 4.61, and 9.21.

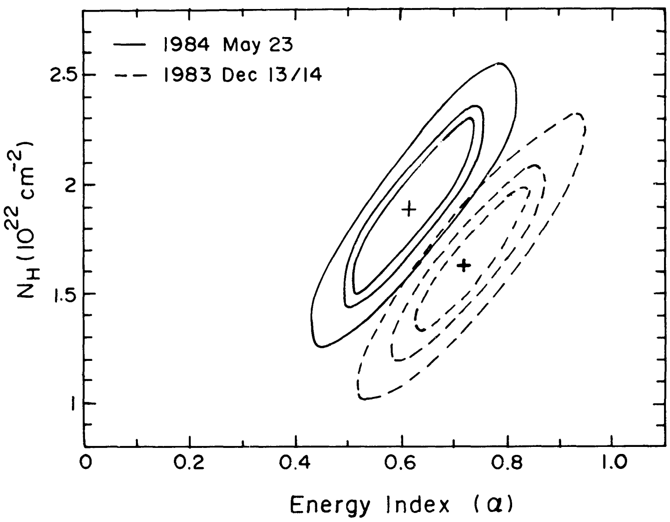

FIG. 3.—Contour diagram of the allowed ranges for the spectral parameters α and N_H. Three contours each for the 1983 and 1984 spectral data are shown. Confidence levels associated with the contours are the same as in Fig. 2.

is clear that the two spectral parameters did vary (confidence level >90%), with the brighter state in 1983 showing a slightly steeper slope and lower absorption.

4. DISCUSSION

4.1. *Comparison with Earlier Analysis*

The LE and ME count rates, as well as the spectral parameters, estimated from the 1983 *EXOSAT* observations are consistent with the previously reported values from the same observations by Turner & Pounds (1989). The final fit reported by Turner & Pounds, however, gives a somewhat high χ^2 ($\chi^2_\nu = 1.63$ for 28 dof; probability $= 1.9 \times 10^{-2}$). The best fits obtained by us are statistically more acceptable (see Table 1). The reasons for this could be in the present analysis procedure that treats each ME detector individually and thus avoids the systematics of combining the detectors, and uses the most optimum box size for measuring the LE count rates (see also Singh et al. 1991).

4.2. *X-Ray Luminosity and Absorption*

The unabsorbed X-ray luminosity emitted by MCG−5-23-16 is found to be in the range 1.8–2.3 × 10^{43} ergs s^{-1} in the hard (2–10 keV) energy band. We assume a distance of 50 Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}; $q_0 = 0$) for the source. Similarly the luminosity in the soft (0.1–2 keV) band is in the range 1.4–2.3 × 10^{43} ergs s^{-1}.

The absorbing column density in the line of sight to the source is found to be higher by about an order of magnitude as compared to the value obtained from the 21 cm observations in this direction (see § 1). The X-ray absorption N_H estimated from the present observations can be compared with the optical reddening A_V. Assuming cosmic abundances and dust-to-gas ratio that is appropriate for our galaxy, thereby using the relationshp $A_V = 5 \times 10^{22}\, N_H$ (Burstein & Heiles 1978), we find that A_V is in the range 6.0–11.5. This is higher than the reddening value of ~4 inferred for the narrow line region (see Reichert et al. 1985; Mushotzky 1982). The solid state spectrometer and the IPC observations (some of the measurements—see Kruper et al. 1990), however, do find an equivalent A_V that is consistent with the optical value. The nonsimultaneity of the optical and X-ray measurements and highly variable estimate of the absorption in the IPC measurements indicate a variable absorption close to the nucleus. As pointed out by Reichart et al. (1985), optical continuum reddening estimates are not available for this galaxy. From a study of Hα and O I λ8446 emission, Morris & Ward (1989) suggest that the optical broad line emission in MCG−5-23-16 is obscured.

4.3. *Line Emission and Spectral Variations*

Evidence for line emission in the 6–7 keV band (in the rest frame of the source) has been accumulating in the recent past from a number of AGNs (see George & Fabian 1991, and references therein). Line emission from MCG−5-23-16 with an estimated equivalent width of 130^{+140}_{-80} eV (1 σ) was first reported by Mushotzky (1982). The line is detected with a very high significance in one of the observations presented here. The presently measured value of 6.4 keV for the line energy from MCG−5-23-16 suggests that it most probably originates due to the fluorescence of cold iron illuminated by the X-ray source. The measurement uncertainty, however, does not completely rule out its origin in a hot thin plasma. The equivalent width (EW) measured for MCG−5-23-16 was 346 ± 142 eV on 1984 May 23 and 148 ± 128 eV 6 months earlier. If the X-ray source were to be surrounded uniformly by the measured column density of ~1.9 × 10^{22} cm^{-2}, it would be difficult to produce such a large equivalent width due to fluorescence (Inoue 1985, 1989). Only a slablike configuration near the source, for example, an accretion disk, can reproduce such an EW (Inoue 1989). The solid angle subtended by the disk, however, must be greater than 2 π or at least a fraction of the directly observed continuum must be intercepted by very dense material ($N_H > 10^{24}$ cm^{-2}) (Inoue 1989; George, Nandra, & Fabian 1990; George & Fabian 1991). The presence of cold dense material very close to the AGN can also give rise to a "reflected" component due to Compton scattering and thus flatten the observed X-ray spectrum between 10 and 30 keV (Guilbert & Rees 1988; Lightman & White 1988). Evidence for such a reflected component has been found in several AGNs (Pounds et al. 1990; Matsuoka et al. 1990; Piro, Yamauchi, & Matsuoka 1990; Singh et al. 1990). The present observations are not sensitive enough to clearly resolve such a component in MCG−5-23-16. These are, however, consistent with the presence of reflection as discussed below.

The present observations suggest that (1) the iron line is stronger when the α is flatter, and (2) the α is flatter when the N_H is higher and the X-ray intensity is lower. In other words it indicates that as the absorption increases and the X-ray intensity falls, the spectrum hardens and also produces more line emission. This fits in very well with a model (George & Fabian 1991) in which the amount of the reflected component, that hardens the spectrum and also produces more fluorescence line emission, is related to covering factor of the direct X-ray emission component by the accretion disk. The increased covering, thus higher absorption and lower intensity, can therefore explain our observations. The model calculations of interaction between X-rays and the cold material in the neighborhood of AGNs also show that the equivalent width of the iron line due to fluorescence decreases as α increases, because the flux of incident photons with $E > 7$ keV decreases (George & Fabian 1991).

Multiple observations spaced by a few days and using an instrument with higher sensitivity, a broad-bandwidth, and higher energy resolution are necessary to verify these effects more clearly and to untangle its seemingly complex spectral behavior.

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