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A SOFT X-RAY FLARE IN THE SEYFERT 1 GALAXY MARKARIAN 335

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ABSTRACT

Einstein HRI and MPC observations spanning 11 90 minute orbits in 1981 January showed that the Seyfert 1 galaxy Mrk 335 exhibited erratic X-ray activity on all time scales of ~6000–60,000 s. The HRI data very clearly show about 30% decrease in the soft (~0.7 keV) X-ray flux ("dip") followed immediately by a steep increase ("flare") in which the intensity chaged by a factor of about 2.5. Both events have time scales of one to two orbits. Much weaker variations in the MPC (1.2–7.0 keV) flux were correlated with the soft X-ray flare. The ratio of total MPC count rate to HRI count rate, i.e., the X-ray "hardness," rose during the dip and then fell by a factor of 2 during the flare.

We also find that the *time-averaged* spectral index of Mrk 335 measured by the MPC to be $\alpha_{MPC} = 1.25 \pm 0.19$. In addition, a comparison of the HRI and MPC data show that an additional soft X-ray flux component above that expected from the MPC data is very likely to be present.

The observed variations in the X-rays, coupled with data from other spectral regions, are used to argue that the soft X-rays may originate near the inner edge ($r < 3 \times 10^{14}$ cm) of an accretion disk around a black hole of mass 10^7–10^8 $M_\odot$. Emission from a hot confining medium around the optical line clouds is ruled out. The relatively steady hard X-ray spectrum is consistent with an extrapolation of the infrared/optical power law, and could be direct synchrotron or synchrotron self-Compton scattered flux in a region of size similar to that responsible for the soft X-ray flare.

Subject headings: black holes — galaxies: individual (Markarian 335) — galaxies: Seyfert — radiation mechanisms — X-rays: bursts

I. INTRODUCTION

Mrk 335 is a relatively unflattened, modest-luminosity ($M_v \approx -20$) Seyfert 1 galaxy of early-type (E or S0) at a redshift $cz \approx 7500$ km s^{-1} (Heckman and Balick 1981). Shuder (1981) and M. A. Malkan (private communication) reported changes in the nuclear optical emission-line intensity, profile shapes, and equivalent widths on time scales of several months to 2 yr, though no variations were observed by Peterson *et al.* (1982). In order to account for the asymmetric shapes of the optical emission lines, van Groningen (1984) postulated that around the nucleus of Mrk 335 lies a compact and very dense disk which is oriented so that the nucleus is directly exposed to terrestrial observers. In addition, van Groningen argued that emission from a wind is observed. Also, Mrk 335 was recently found to be a very weak 20 cm radio source of 4.1 ± 0.9 mJy (Edelson 1987).

Mrk 335 was first detected in the X-ray by *UHURU*, which showed that the 2–10 keV X-ray luminosity is 7.8×10^{43} ergs s^{-1} (Tananbaum *et al.* 1978). The *HEAO 1* A-2 experiment in 1978 July detected Mrk 335 as one of the faintest objects among 38 active galactic nuclei (AGNs), with a photon flux of 1.1 counts cm^{-2} ks^{-1} and X-ray luminosity (2–20 keV) of 3.9×10^{43} ergs s^{-1} (Tennant and Mushotzky 1983). Despite the relatively large variance in intensity of the source, Tennant and Mushotzky (1983) could not detect short-time variability in Mrk 335 because of possible systematic errors due to source confusion. In a summary of *HEAO 1* A-2 results on AGNs, Mushotzky (1984) listed Mrk 335 with the X-ray luminosity (2–10 keV) of 3.2×10^{43} ergs s^{-1}. A fit of the spectrum to power law gave hydrogen column denisity $N_H < 1.1 \times 10^{22}$ atoms cm^{-2} and energy spectral index $\alpha = 0.78^{+0.22}_{-0.18}$.

Mrk 335 was also included in an extensive survey of Seyfert galaxies and quasars with the *Einstein Observatory* monitor proportional counter (MPC) (Halpern 1982). Although the 2–10 keV luminosity was found to be the same as in *HEAO 1*, the spectrum was much steeper, with $\alpha = 1.77^{+0.16}_{-0.14}$. This was found to be the steepest spectrum among the *Einstein* sample of 50 Seyfert galaxies and quasars, which had a mean spectral index of 0.68 and a dispersion of 0.31.

EXOSAT observations of Mrk 335 were obtained in 1983 November and 1984 December (Pounds *et al.* 1987). They showed that the luminosity (2–10 keV) changed by a factor of ~6 between the two observations, from 5×10^{42} ergs s^{-1} to 2.9×10^{43} ergs s^{-1}. The spectra in the high state could be fitted by (1) a single power law ($\alpha = 0.91$ to 1.8), (2) a hard power law ($\alpha = 0.91^{+0.69}_{-0.39}$) plus soft excess power law ($\alpha = 3.13^{+13.77}_{-1.07}$), or (3) a hard power law ($\alpha = 1.05^{+0.15}_{-0.16}$) plus thermal bremsstrahlung with $kT = 0.1^{+0.16}_{-0.07}$ keV. The two-component fits were required to accommodate a strong soft X-ray excess seen in the *EXOSAT* low-energy detector. The soft and hard components apparently experienced the same factor of 6 change in flux over 1 yr. Factor of 2 variability of the hard component was also observed on a time scale of 5000 s. Also, Pounds *et al.* (1987) reported that "confirmation that the LE [soft X-ray] flux also varies strongly on time-scales ~ 5000 s has, however, been confirmed in a more recent observation of Mrk 335" (see also Turner and Pounds 1988).

In this paper, we report on strong, erratic, and primarily soft X-ray flux variations observed in Mrk 335 with the *Einstein* high-resolution imager (HRI) and MPC. Variations in flux and spectra index occurred throughout the observing period of 60,000 s with time scales of one orbital period and more. The high signal-to-noise ratio of the HRI data and the spectral information from the MPC are of considerable interest in the development of models for the recently discovered soft X-ray excess of AGNs.

II. OBSERVATIONS AND RESULTS

The *Einstein* observations took place on 1981 January 1 over nearly 11 Earth orbits (57,590 s). MPC analysis reported in this paper made use of the final reprocessed data available from the *Einstein* data bank in 1986 April. This includes the use of the revised background prediction algorithm which allows for long-term changes in the particle background spectrum as well as systematic errors due to possible short-term changes (see Elvis *et al.* [1986] for more detailed description of the difference in the old and new calibration of the MPC data).

a) HRI Analysis

The HRI is an imaging device whose sensitivity peaks at ~ 0.7 keV. Separate images of Mrk 335 were made in 11 successive Earth orbits. The effective integration time was $\sim 15{,}000$ s except for the last orbit in which the integration time was ~ 500 s. All images show only the simple soft X-ray point source response within 1″ of the optical position (Clements 1981). Photon count rates in each orbit were determined by adding the events collected within a circle of 18″ radius centered at the peak of the X-ray emission in the images. Background counts were similarly obtained in a circle of 180″ radius which excluded all identifiable X-ray sources in the field. The background rate per pixel did not exceed 1% of the rate observed for Mrk 335. The average count rate of Mrk 335 was 0.51 counts s^{-1} after background subtraction.

A plot of the HRI photon count rate as a function of time is shown in Figure 1*a*. A 30% dip, followed immediately by strong flare, both with time scales of $\sim 10^4$ s, occurred about midway through the observations. The fact that the initial and final HRI fluxes differ by 50% is evidence that longer time-scale variations were occurring during the course of the observations.

The HRI data were rebinned into 500 s intervals in order to search for evidence of flickering. No such evidence was found to within the limits imposed by the statistical uncertainties in the data.

b) MPC Analysis

The MPC is a collimated, argon-filled detector which is sensitive in the range 1.2–20 keV and views the source simultaneously with the HRI. The spatial response of the MPC is approximately triangular with FWZI of 1°.5. Only the pulse-height channels corresponding to energies between 1.2 and 7.0 keV are considered here because of increased particle background contamination and decreased sensitivity at higher energies. Plots of the two low-energy channels (MPC 1 + 2: 1.2–2.4 keV) and the three high-energy channels (MPC 3 + 4 + 5; 2.4–7.0 keV) as a function of orbit are shown in Fig. 1*b*. For each orbit the MPC data were summed over all channels and divided by the HRI fluxes to compute a "hardness ratio" which is plotted in Figure 1*c*.

Figures 1*a*, 1*b*, and 1*c* show clearly that the major events seen in the high-quality HRI data are reflected by variations in the noisier MPC data and the hardness ratio. These plots argue that the events are far more pronounced below ~ 1 keV than above.

For each channel, the MPC data were integrated for the duration of the observations (a total of 29,414 s) and were first fitted with a standard two interesting parameter model consisting of a power-law energy index α, and equivalent neutral hydrogen column density N_H,

$$\frac{dN}{dE} = AE^{-(\alpha+1)}e^{-\sigma(E)N_H} \text{ photons cm}^{-2}\text{ s}^{-1}\text{ keV}^{-1}\,, \quad (1)$$

where $\sigma(E)$ is the Morrison and McGammon (1983) interstellar medium cross section and A is the normalizing factor. The results for the integrated spectrum are summarized in Table 1 and Figure 2. The spectrum is best fitted by a power law index of $\alpha_{MPC} = 1.25^{+0.19}_{-0.18}$ and a value of $N_H \approx 1 \times 10^{20}$ atoms cm^{-2}. The 90% confidence contour of allowed spectral parameters is given in Figure 3, which shows that the fit requires $N_H \leq 2.2 \times 10^{21}$ atoms cm^{-2}. It must be emphasized that because of the strong variability in the flux and hardness ratio of Mrk 335 seen in Figure 1*b* and 1*c*, it is quite likely that the value of α_{MPC} derived here is subject to secular changes.

As noted in the Introduction, values of α reported from the earlier literature lie between 0.78 and 1.77. The value of 1.77 was obtained by Halpern (1982) from the same data set as used in this paper. The difference between these results can be largely attributed to an improvement in the MPC background subtraction algorithm. The value of the spectral index is still steeper than that of any other Seyfert galaxy or quasar in the MPC sample of 50 (Halpern 1982), or the *HEAO 1* A-2 sample of 30 (Mushotzky 1984).

We have fitted α_{MPC} separately to the data of each orbit. However, the errors are large owing to the low count rates (Fig. 1*d*). Within the 90% confidence levels there are no meaningful differences in $\alpha_{MPC} = 1.25$ from one orbit to another. However, we find that all of the value of α_{MPC} which lie above the average value (by about 0.2) occur during the X-ray flare, corroborating our assertion that the flare was most prominent at soft X-ray energies.

c) Joint MPC/HRI Analysis

The large number of counts collected by the HRI is also indicative of a steep spectral slope. The HRI can be used to further constrain the spectrum when there is some independent information from the MPC. Each trial MPC spectrum, includ-

TABLE 1

MPC DATA ON MARKARIAN 335

Parameter	Value
Day	1981 Jan 1
Exposure time	29,414 s
F_x(2–10 keV)	1.46×10^{-11} ergs cm^{-2} s^{-1}
L_x(2–10 keV)[a]	4.0×10^{43} ergs s^{-1}
α_{MPC}	$1.25^{+0.19}_{-0.18}$ [b]
N_H	$<2.2 \times 10^{21}$ atoms cm^{-2} [b]
A	0.0082 keV cm^{-2} keV^{-1}

[a] $H_0 = 50$ km s^{-1} Mpc^{-1} and $q = 0$.

[b] Errors and upper limit are 90% confidence levels.

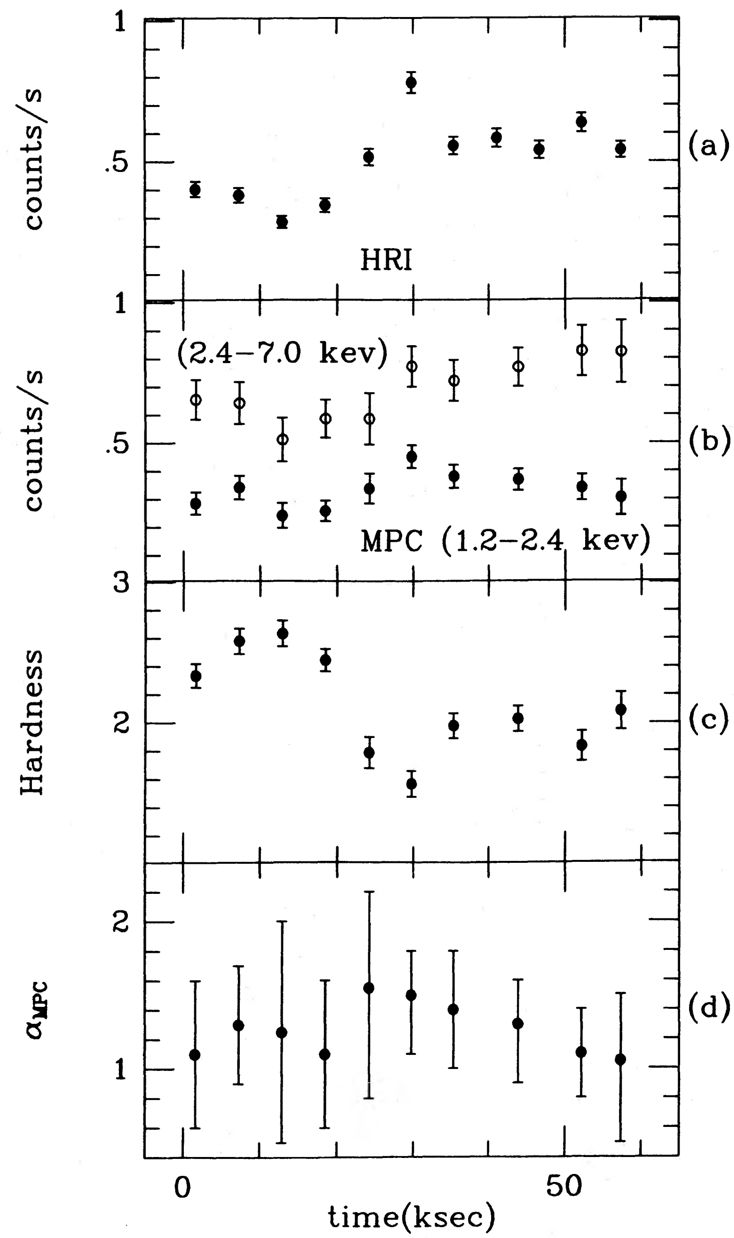

FIG. 1.—The temporal change of (*a*), the HRI photon count rate; (*b*), sum of the count rates in MPC channels 1 and 2 (1.2–2.4 keV) and that in MPC channels 3 through 5 (2.4–7.0 keV); (*c*), the "hardness ratio," or the ratio of the counts in the first five MPC channels to the HRI count rate in each orbit; and (*d*), fitted spectral index α of MPC spectra. The error bars represent 1 σ for (*a*), (*b*), and (*c*), and 90% for (*d*).

ing the normalization, is folded through the HRI effective area function to predict an HRI count rate. The grid of predicted HRI count rates is compared with the measured one to produce a second confidence contour of allowed spectra (Fig. 3). The confidence contour assigned to the HRI includes counting statistics plus 15% for possible systematic uncertainties in relative calibration between the HRI and the MPC.

As can be seen from Figure 3, the total MPC and HRI data are consistent with a simple power law of the form of equation (1) only if $N_H < 2.8 \times 10^{20}$ atoms cm^{-2} and $\alpha < 1.44$. This H I column density is less than the observed Galactic value of 4×10^{20} atoms cm^{-2} (Stark *et al.* 1988) with an uncertainty of $\sim 1 \times 10^{20}$ atoms cm^{-2} (as shown by Elvis *et al.* 1986), implying a hole in the interstellar medium (ISM) in the direction of Mrk 335. Alternately, if we adopt a value for (N_H, α) maximally consistent with the H I and MPC observations, to wit, [$(4 \pm 1) \times 10^{20}$, 1.25], then it is necessary that Mrk 335 have a substantial soft X-ray excess at the time of the present observations. The value of the α expected from the HRI data shown in Figure 3 is 1.66 ± 0.08. (This is essentially the same situation that was found by Pounds *et al.* [1987] and Turner and Pounds [1988] in a comparison of the *EXOSAT* low-energy and medium-energy data.)

In view of the dramatic and prominent soft X-ray variability observed, we (arguably) consider the postulate of a strong and variable soft X-ray excess to be the most likely. The present

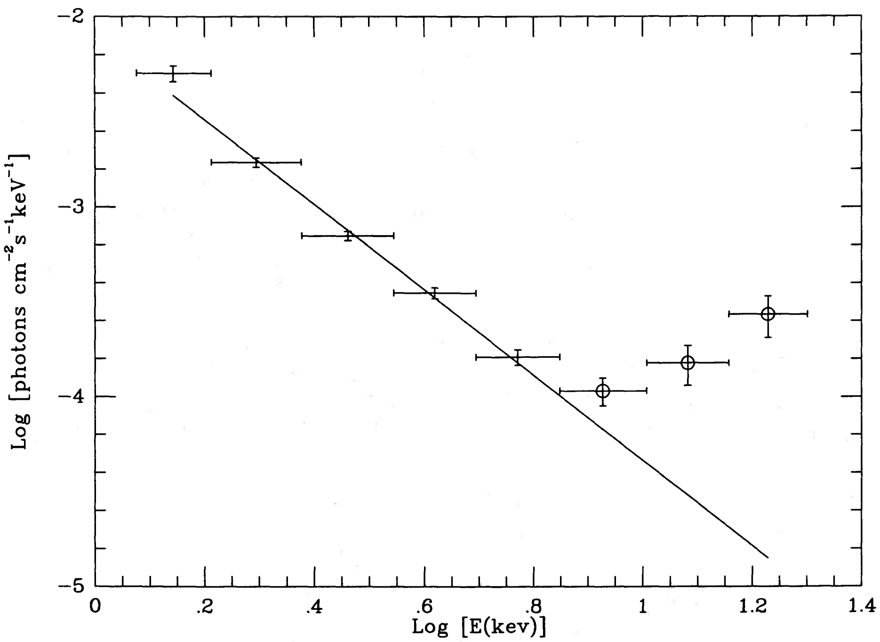

FIG. 2.—MPC spectra integrated over total exposure time (*crosses*), fitted by the power law of $\alpha_{MPC} = 1.25^{+0.19}_{-0.18}$ (*solid line*). The three points in the high energy end (*circles with cross*) are unreliable due to the decreased sensitivity and the increased background and were not used for the fit.

data suggest that variations in the soft X-ray excess are possibly accompanied by changes in harder X-rays, much as Pounds *et al.* (1987) have concluded.

III. DISCUSSION

a) X-Ray Spectral Variations in AGNs

The detection of X-ray flares such as the one reported here in Mrk 335 could be fairly common but difficult to observe except at the softest X-ray energies. Changes in spectral shape which could be qualitatively similar to that observed in Mrk 335 have been documented in a small number of other Seyfert galaxies. In 3C 120, the spectrum is softer when the flux is larger, although the variability time scale in this case is days (Halpern 1985; Petre *et al.* 1984). The source 3C 120 showed a much larger spectral change ($1.0 < \alpha < 1.1$) in the soft X-ray band (*Einstein* solid state spectrometer) than that ($0.48 < \alpha < 0.86$) seen in the hard X-rays.

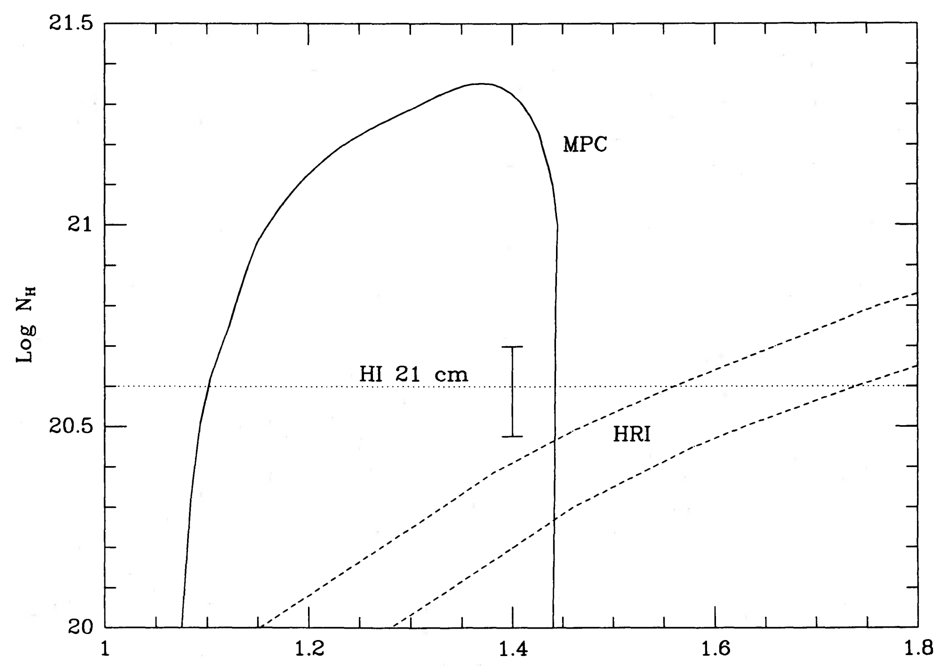

FIG. 3.—*Solid line:* 90% confidence contour for fit of the integrated MPC spectrum. *Dashed lines:* fit of the HRI count rate (with an error of 15%) to the power law. The dotted line represent $N_H = (4 \pm 1) \times 10^{20}$ atoms cm^{-2} obtained in the direction of Mrk 335 from the Galactic neutral hydrogen survey (Stark *et al.* 1987).

Another galaxy whose X-ray behavior is similar to that of Mrk 335 is NGC 4051, a highly variable, low-luminosity Seyfert 1 galaxy (Lawrence *et al.* 1985; Marshall *et al.* 1983). NGC 4051 has a large-amplitude variations with a characteristic time scale of 1 hr. The average spectral index is about 1.1, but the variations in flux below 2 keV are greater than the variations of the 2–10 keV X-rays (Lawrence *et al.* 1985). The effect can be described as a change in spectral index of $\Delta\alpha \sim 0.3$, with higher intensity states having the softer spectra.

Aside from the few cases described above, the majority of Seyfert galaxies exhibit X-ray variability with no obvious change in spectral shape.

b) Soft X-Ray Excesses

There is evidence for an extra soft component above the hard power law in several additional Seyfert galaxies. The *Einstein* spectrum of NGC 5548 (Halpern 1982) required a second component below 1 keV in order to conform with the 21 cm Galactic column density. This soft excess was confirmed by Branduardi-Raymont *et al.* (1984). Similarly, Singh, Garmire, and Nousek (1985) found that Mrk 509 has a second component at energies between 0.2 and 2 keV. A soft X-ray excess was also found in Mrk 841 (Arnaud *et al.* 1985) and in NGC 7469 (Barr 1986).

In all these cases, there was either no evidence for variability of the soft component, or else the amplitude was small and no greater than the amplitude of the hard X-rays. Therefore, it could not be ruled out that the bulk of the soft X-rays arise from extended hot gas, such as perhaps a confining medium in the emission-line regions (see also Pounds, Turner, and Warwick [1986] for this interpretation applied to NGC 4151).

Mrk 335 is important because the rapid large-amplitude (factor of 2 over 10^4 s) variability shows that the putative soft excess must arise in a region less than 3×10^{14} cm in radius. We conclude that the soft X-ray excess is not associated with an extended confining medium in the broad-line or narrow-line regions.

c) Variability Time Scale

Aside from the unusually steep spectrum and the spectral variability, another unusual X-ray property of Mrk 335 is the short time scale ($\leq 10^4$ s) of variability. Very few Seyfert galaxies are known to vary substantially in less than 1 day. Only NGC 6814 (Tennant and Mushotzky 1983), NGC 4051 (Marshall *et al.* 1983; Lawrence *et al.* 1985), MCG-6-30-15 (Pounds, Turner, and Warwick 1986), and NGC 5506 (McHardy and Czerny 1987) have been reported to vary by a factor of 2 in a shorter time than Mrk 335. These four objects have lower X-ray luminosities than Mrk 335. This is to be expected since the time scale of X-ray variability in Seyfert galaxies is known to be inversely correlated with the X-ray luminosity.

IV. COMPARISON WITH THEORY

a) General Considerations

Hereafter we adopt the following values for the X-ray properties of Mrk 335: variability time scale $\Delta t \sim 10^4$ s, and $\Delta L \sim 4 \times 10^{43}$ ergs s^{-1}.

Despite the rather dramatic flaring behavior of Mrk 335, the data are not very restrictive of models involving conversion of matter to luminosity via accretion onto a black hole. The general condition of Fabian (1979) that the efficiency of conversion, η, should exceed $5 \times 10^{-43} \Delta L/\Delta t$ results in $\eta \geq 0.002$. This is well within the limit of 0.057 for a Schwarzschild black hole. Nor does the flaring behavior violate the mass-radius relation for a black hole.

The total accretion-powered luminosity is likely to be $\sim 10^{45.1}$ ergs s^{-1}, where we have integrated the MPC power law from 1000 Å to 100 keV, and added the infrared-ultraviolet power law determined by Edelson and Malkan (1986). The luminosity requires $M \geq 1 \times 10^7 M_\odot$ in order not to exceed the Eddington limit. The Schwarzschild radius for this mass, R_S, is $\sim 3 \times 10^{12}$ cm. If the soft X-ray emission must arise from a region larger than $3R_S$ (the last stable orbit), then variations in as short as 300 s are still possible.

The actual flare rise time of 10^4 s implies that the radius of the emitting region is no larger than 3×10^{14} cm. At this radius, the "gravitational temperature" T_{grav} for the black hole given by

$$kT_{grav} = \frac{GMm_p}{R} . \quad (2)$$

Therefore, $kT_{grav} = 4.6$ MeV for $M = 10^7 M_\odot$, which is ample to account for X-rays via an accretion process. However, spherical accretion is probably inefficient; we use this only to illustrate the order of magnitude of the energy available.

b) The Hard Power Law

More detailed models have been sought to explain the spectral behavior of AGNs in terms of Compton scattering of soft photons by a thermal or nonthermal plasma. The advantage of the synchrotron self-Compton (SSC) mechanism is that it can produce an X-ray spectral index of 0.7 by scattering of the optically thin radio or millimeter photons, which tend to have the same index as many Seyfert galaxies show in the hard X-ray region. In the case of Mrk 335, however, it appears that the average X-ray spectrum is consistent with being a simple continuation of the infrared-ultraviolet power law. Malkan and Filippenko (1983) found that the nonstellar component of the optical spectrum can be described by a power law of $\alpha = 1.1$–1.2 with a normalization of 7.4 mJy at 5400 Å. Extrapolation of a power law of $\alpha = 1.2$ to 1 keV would predict an X-ray flux of 5.0 μJy at that energy. This is an excellent agreement with the MPC spectrum which has $\alpha = 1.25$ and is normalized to 5.4 μJy to 1 keV. Therefore there may be a single power law extending from infrared through X-ray, with a slope of 1.2.

More recently, Edelson and Malkan (1986) fitted a more complicated multicomponent model to the infrared through UV data and found a power law index of 1.34 with a normalization of 5.5 mJy at 5450 Å. This would extrapolate to 1.6 μJy at 1 keV, a factor of 3.4 below the observed X-ray flux. Within the errors of the "optical" decomposition, however, the power law is probably still consistent in slope and normalization with an extension to the hard X-rays. Of course, the near coincidence of an extrapolation of the IR-UV spectrum to the observed MPC spectrum can be fortuitous if several spectral components contribute to the spectrum at different energies.

Whether the hard X-ray flux is direct synchrotron or Compton scattering, one can use the observed X-ray flux, together with the turnover frequency of the infrared spectrum, to derive a lower limit to the size of the region emitting the synchrotron power law. The SSC mechanism produces a predictable X-ray spectrum which depends on the size of the emitting region, the frequency of the synchrotron self-absorption turnover, and the flux at the turnover frequency. Mrk 335 is unusual for a Seyfert galaxy in that the infrared spectrum peaks at 25 μm. This is the highest peak frequency of about 30 AGNs studied by Edelson and Malkan (1986). They interpreted these infrared turnovers as the synchrotron self-absorption frequency. For Mrk 335, they derived a lower limit to the radius of the infrared emitting region of 10^{14} cm (3000 lt-sec) by assuming a brightness temperature of 10^{12} K.

The observed X-ray flux can be used to set a more restrictive and rigorous limit because the predicted self-Compton X-ray flux cannot exceed the observed value. In this case, using the formalism summarized by Madejski (1986), in particular, his equation (4.36), we find that the radius of the infrared emitting region must be greater than 1×10^{15} cm (0.4 lt-day) in order not to exceed the observed X-ray flux. The result $R > 10^{15}$ cm for the synchrotron emitting region would still hold if the observed turnover is due to some mechanism other than synchrotron absorption, such as free-free absorption in the broad-line region. In this case, the true SSC turnover frequency would have to be lower, and so the size of the emitting region would have to be larger. This calculation assumes that the infrared flux is all synchrotron emission, and not thermal dust emission. If the infrared luminosity has some contribution from dust, then the synchrotron region could be smaller.

Note that the lower limit to the radius of the infrared synchrotron emitting region, 10^{15} cm, is somewhat larger than the upper limit to the radius of the soft X-ray flare source, 3×10^{14} cm. However, we believe that within the large errors of the SSC derivation, the regions responsible for the X-ray flare, the infrared power law, and the "steady" X-ray component can be of the same size. Therefore the X-rays are probably consistent with being either Compton scattered or direct synchrotron.

c) *The Variable Soft Component*

The large amplitude variability of the soft X-ray flux on a time scale of 10^4 s rules out any origin in a hot confining medium in either the broad-line or narrow-line regions in Mrk 335. Since the host galaxy is very early in type and has no detectable ISM, the lack of a confining medium is, perhaps, no surprise.

Models in which the soft X-rays arise near the inner edge of an accretion disk (Pounds *et al.* 1987; Czerny and Elvis 1987; van Groningen 1984) are quite viable, since the emitting region can be only a few Schwarzschild radii in size. The soft X-ray flare could result, for example, from changes in accretion rate or fluctuations in the vertical structure of the disk near its inner edge. Alternatively, we speculate that a scattering corona with a varying optical depth could greatly modify the amount of accretion disk light which is scattered into the soft X-ray band.

The unusually high infrared turnover frequency and short variability time scale of Mrk 335 may imply a rather compact source. It is tempting to try to explain the rapid flaring behavior as well as the relatively steep spectrum as being due to this compactness. Several authors have pointed out that, for very compact sources, electron positron pair production by two-photon annihilation can soften the X-ray spectrum by removing high-energy photons. Barr and Mushotzky (1986) showed that most AGNs are close to being pair dominated, and speculated that the steep X-ray slope of many BL Lac objects are severely pair dominated because of their high luminosity. The same mechanism was originally supposed to explain the bimodal behavior of Cyg X-1 (steep spectrum during high states, flat during low states), where the transition naturally occurs at 1% of the Eddington luminosity because the optical depth for pair production becomes of order unity (White, Fabian, and Mushotzky 1984, and references therein).

We may apply this test to Mrk 335, following the analysis of Barr and Mushotzky (1986). The dimensionless compactness parameter is defined as

$$\lambda = \frac{L_X \sigma_T}{R m_e c^3}, \tag{3}$$

where L_X is the total X-ray luminosity and σ_T is the Thomson cross-section. The X-ray luminosity L_X is likely to be at least $\sim 10^{44.5}$ ergs sec^{-1} if the MPC spectrum extends to 100 keV. If we use $R \le 3 \times 10^{14}$ cm, then $\lambda \ge 25$ results. In contrast, Barr and Mushotzky (1986) found that the majority of Seyferts have $\lambda \sim 10$; $\lambda > 4\pi$ is considered to be pair-dominated. In addition, since the Schwarzschild radius must be less than $c\,\Delta t/3$, we have

$$M < \frac{c^3 \Delta t}{6G} = 3 \times 10^8\ M_\odot\ . \tag{4}$$

This leads to $L_{\rm Edd} = 1.26 \times 10^{38}\ (M/M_\odot)$ ergs s^{-1} < 3.78×10^{46} ergs s^{-1}, where $L_{\rm Edd}$ is the Eddington limit. Then $L \sim 3 \times 10^{-2} L_{\rm Edd}$, if the total accretion-powered luminosity is $\sim 10^{45.1}$ ergs s^{-1} (see above). This condition is again consistent with the pair-transition, and the source is in the pair-dominated regime. Consequently it appears plausible to associate the rapid variability of Mrk 335 with compactness, and thus a steepening of the spectrum from the canonical 0.7 index by pair production.

The dip and the flare in the soft X-rays, the step-function increase in the harder X-rays, and the rapid decline in X-ray hardness at the flare onset would seem to suggest that the mechanism responsible for the X-ray variability in Mrk 335 is complex. The observations of Pounds *et al.* (1987) lead to the same caveat. Superficially, the general decline in the X-ray flux prior to the flare suggests that the flare represents a sudden relaxation process. Of course, without simultaneous observations in other spectral regions, the present data are useful primarily to constrain models rather than construct them.

V. CONCLUSIONS

Flux and spectral X-ray variability has been observed in the early-type Seyfert 1 galaxy Mrk 335. The important and new observational results are as follows.

1. The variability time scales Δt lie from $\sim$6000 s to the period of observation ($\sim$60,000 s).
2. The variability consisted of a decrease ("dip") followed by an increase ("flare") at X-ray energies below 2–3 keV. The variability is most pronounced at the softest energies.
3. The X-ray spectrum was harder before the flare than afterward, even after the flare had ended.
4. Averaged over the time of the observations, the MPC data are well fitted by a power-law spectrum with a spectral index $\alpha_{\rm MPC}$ of 1.25 ± 0.19 with no evidence of absorption by foreground neutral hydrogen at energies above 1.2 keV.
5. If the observed value of the Galactic H I column density, $N_{\rm H} \sim (4 \pm 1) \times 10^{20}$ cm^{-2}, is assumed, then the HRI observations requires the existence of an additional soft and variable X-ray component.

Mrk 335 is the best case in which rapid, large amplitude variability is associated with a soft excess X-ray component, and provides strong evidence that the soft excess is generated close to an active galactic nucleus, perhaps at the inner edge of an accretion disk postulated by van Groningen (1984). At least for Mrk 335, an origin of the soft excess in the confining gas associated wtih optical emission-line regions can be ruled out.

It is possible that the hard X-rays are simply an extension of the infrared/optical power law. The respective slopes and normalizations are very similar. On the other hand, theory predicts that a hard X-ray power will become steeper because of pair production if the source is unusually compact. Mrk 335, because of its rapid variability and relatively high luminosity, satisfies the criterion for pair-production, and so the X-ray spectrum may have been modified by this process.

When all available data are considered, the nonstellar infrared, optical, and hard X-ray emission may be coming from the same region of radius less than or equal to 10^{15} cm. It may simply be that optically selected QSOs and Seyfert galaxies have steeper X-ray slope on average than X-ray or radio selected ones. From a study of the *Einstein* IPC spectra of eight PG quasars (Paloma-Green Survey: Green, Schmidt, and Liebert 1986), Elvis *et al.* (1986) found a mean slope of 1.05 and a dispersion of 0.25. Mrk 335 is a member of the PG sample as well, and for all we know may be typical of this class.

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