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DETECTION OF A SOFT GAMMA-RAY EMISSION FROM THE REGION OF NGC 4151

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ABSTRACT

During a balloon flight on 1979 September 30, a region of the sky containing the Seyfert galaxy NGC 4151 was studied over the photon energy range 0.02–19 MeV. A 4 σ excess above 260 keV was detected within an error box encompassing this galaxy. With respect to the 1977 May observation of this source with the same telescope, the γ-ray luminosity in the energy range 0.5–5 MeV shows a reduction at the 99% confidence level, and the ratio between the two luminosities is 4 ± 2. The emission spectrum has been evaluated, and it may be represented by a single power law over the entire range, with a photon spectral index of $\alpha = 1.3 \pm 0.3$. The γ-ray data are discussed in the light of some recently proposed models of γ-ray emission from NGC 4151.

Subject headings: galaxies: Seyfert — gamma rays: general

I. INTRODUCTION

The Seyfert galaxy NGC 4151 was discovered to be a source of hard X-rays a few years ago (Baity *et al.* 1975; Paciesas, Mushotzky, and Pelling 1977; Auriemma *et al.* 1978). Its photon spectrum above 10 keV is very hard, with a spectral index of $0.9 < \alpha < 1.6$. Low-energy γ-ray emission up to several MeV from a region of the sky containing this galaxy was detected for the first time by the Milan/Southampton (MISO) telescope (Di Cocco *et al.* 1977; Perotti *et al.* 1979). The measured γ-ray photon spectrum was interpreted as an extension of the hard X-ray emission up to about 3 MeV, followed by a break and a steeper spectrum above this energy.

Other attempts from balloon altitude have failed to detect a soft γ-ray emission from the region of NGC 4151 (Meegan and Haymes 1979; White *et al.* 1980), and the upper limits suggest that the source is variable by a factor of 3–10 on a time scale of several months. In the X-ray range, up to $\sim$ 50 keV variability by a factor of 2 on a time scale ranging from 10 minutes (Tananbaum *et al.* 1978) to a few days (Elvis 1976; Mushotzky, Holt, and Serlemitsos 1978) has been reported.

During a balloon flight on 1979 September 30 from Palestine, Texas, of the MISO telescope, NGC 4151 was studied over the photon energy range 0.02–19 MeV. In this *Letter*, we present the results of this observation in which an excess at the 4 σ level in the γ-ray flux above 260 keV was detected in a region of the sky which contains NGC 4151. The present data confirm the variability of the γ-ray source on a time scale of several months or years.

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II. OBSERVATION AND DATA ANALYSIS

The MISO telescope has been described elsewhere (Baker *et al.* 1979) and consists of two scintillators, S1 (liquid scintillator NE 311) and S2 (sodium iodide), that form the Compton-coincidence detection system S1, S2. The sensitive area is about 560 cm^2, and the aperture is 3° FWHM in both the azimuthal and zenithal planes for both the single and Compton-coincidence events. The energy range of the whole detector was set to be 0.05–19 MeV for this flight. A passively shielded hard X-ray detector (20–280 keV), having an effective area of about 600 cm^2 and the same field of view of 3° FWHM, was mounted parallel with the main telescope. An alt-azimuth orientation system was used to point the two telescopes with a precision of 0°.3.

This instrument was used to study the region of the sky containing NGC 4151 on 1979 September 30, between 15^h01^m UT and 20^h40^m UT, using the drift-scan technique (i.e., the method of observation in which the telescope has steering coordinates constant in time and therefore the sky moves in its field of view). Five drift scans were performed to survey the region contained within the coordinate points 11^h32^m and 12^h33^m in right ascension and centered on +39°.8 in declination. NGC 4151 was in the field of view of the telescope for a total period of 7.5×10^3 s. The total time spent on the background evaluations was 8.6×10^3 s. The mean float altitude during the on-source periods was close to 4 mb, and the telescope was set at zenith angles between 9° and 30°.

In order to avoid adverse effects of systematic variations in the background due to changes in the zenith and azimuth of the telescope, the data for each scan were analyzed separately and the results combined statistically. The only significant source of systematic variation in the background was found to be linearly related to the changes of the residual atmospheric pressure between 3.5 and 4.8 mb. Thus, for each separate scan the background, corrected for the atmospheric pressure variation, was subtracted from the measured on-source count rate. A mean γ-ray excess of 3.6 ± 0.9 counts s^{-1} above 260 keV (4.5 ± 1.0 counts s^{-1} above 20 keV) was found when the data from the five drift scans were combined.

A correlation was made between the count rate excess above 260 keV and the angular distance between the estimated direction of NGC 4151 and the axis of the MISO telescope. This is shown in Figure 1*a*. The error box for the observed γ-ray excess is plotted in right ascension and declination (1950 equinox) in Figure 1*b*. Since the drift scans were made in one direction only, the limits of our error box are represented by the 1 σ points along the scanning direction and by the total aperture of the telescope (i.e., 6°) in the orthogonal direction, which represents the 100% probability of containing the emitting object. The uncertainty of the pointing system has been included. The coordinate points for the corners of the MISO error box are:

$$\alpha(1950) = 11^h54^m, 12^h08^m, 11^h53^m, 12^h07^m;$$

$$\delta(1950) = 42.^\circ8, 42.^\circ8, 36.^\circ2, 36.^\circ2.$$

The only known X-ray sources that lie within our error box, even if extended up to the 4 σ level, are NGC 4151 and a point source situated a few arc minutes from this Seyfert galaxy (J. P. Henry in Holt *et al.* 1980).

The same method of analysis was repeated to evaluate the contribution of the source flux in individual energy-loss channels of both the main telescope and the hard X-ray detector, between 20 keV and 19 MeV. A matrix inversion technique which does not make any *a priori* assumptions about the final shape of the emission spectrum was used to convert the energy-loss spectrum of both the telescopes to a photon spectrum at the top of the atmosphere. The absorption of photons in the residual atmosphere, the redistribution of photon energies through Compton interactions and pair production, and the energy resolution of the detectors were taken into account. The error in this evaluation was estimated to be less than 10%. This photon spectrum is shown in Figure 2 and in Table 1 (the data between 20 and 150 keV come from the X-ray detector). A sample of measurements made by other observers at energies greater than 10 keV from the same region of the sky has been included.

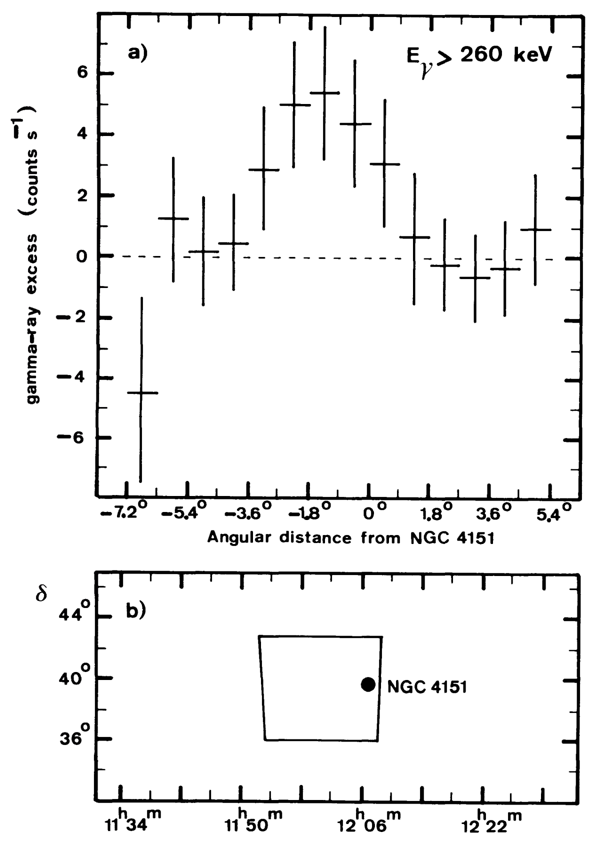

FIG. 1.—(*a*) Gamma-ray excess count rate above 260 keV vs. the angular distance between the axis of the MISO telescope and the estimated direction of NGC 4151. (*b*) The MISO error box for the observed γ-ray excess above 260 keV is shown in right ascension and declination for the 1950 equinox. This error box has 68% probability across the scan direction and 100% across the other. The uncertainty due to the pointing system has been included.

III. DISCUSSION

An attempt to fit our data between 20 keV and 19 MeV with a single power-law photon spectrum leads to a reduced $\chi^2 = 0.85$ with five degrees of freedom and a

TABLE 1

PHOTON SPECTRUM OBSERVED BY THE MISO TELESCOPE IN THE REGION OF NGC 4151

Energy Range (MeV)	Flux (photons cm^{-2} s^{-1} keV^{-1})
0.02–0.045[a]......	$(2.6 \pm 1.3) \times 10^{-4}$
0.045–0.150[a]	$(3.2 \pm 2.4) \times 10^{-5}$
0.150–0.400......	$(1.1 \pm 0.7) \times 10^{-5}$
0.400–1.050......	$(2.5 \pm 4.2) \times 10^{-6}$
1.050–2.50.......	$(1.8 \pm 1.1) \times 10^{-6}$
2.50–6.80........	$(6.1 \pm 3.5) \times 10^{-7}$
6.80–19.00.......	$(4.0 \pm 4.7) \times 10^{-8}$

[a] From the X-ray detector.

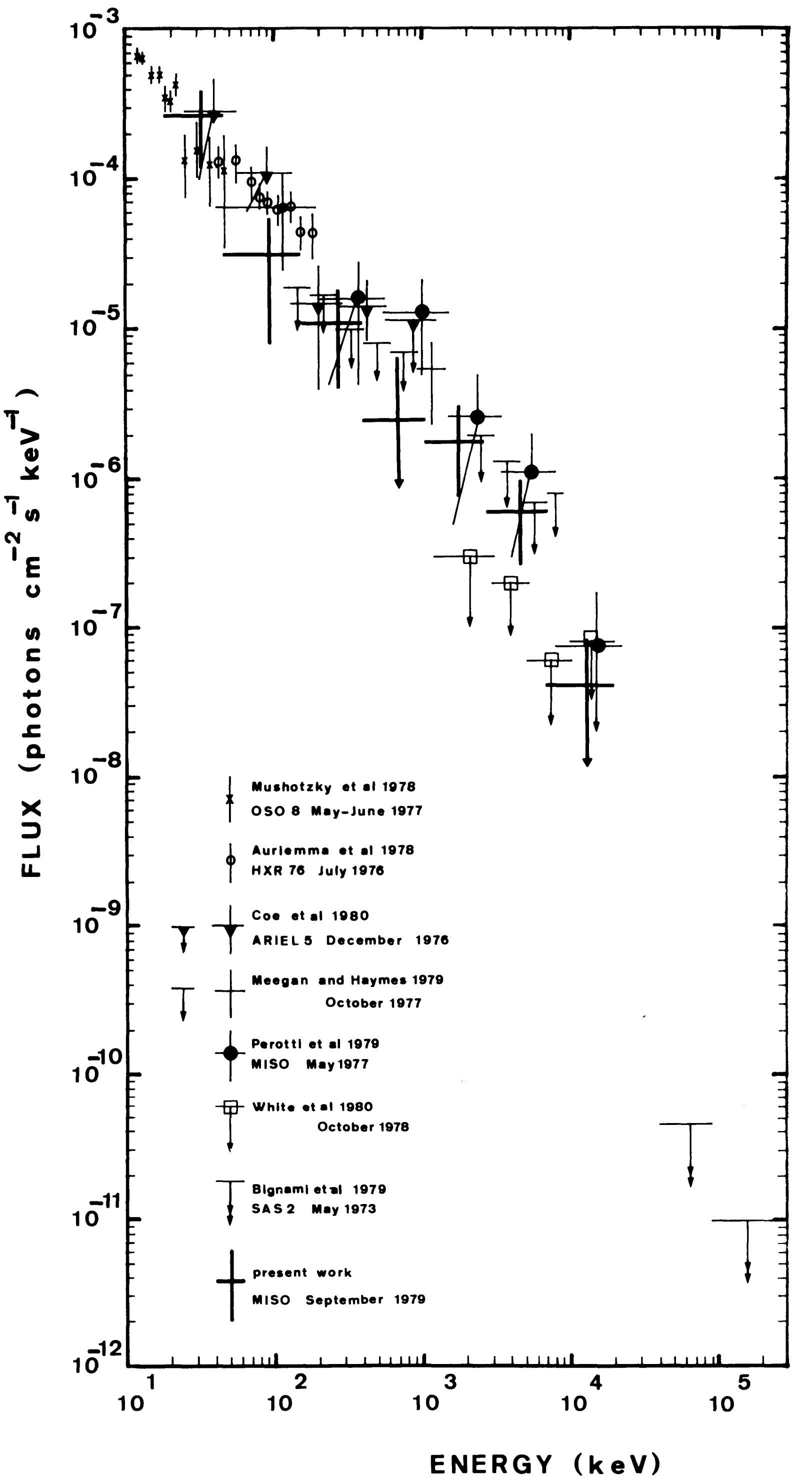

FIG. 2.—The photon spectrum observed by the MISO telescope in the region of NGC 4151 is shown together with a sample of other measurements above 10 keV from the same region of the sky.

spectral index of $\alpha = 1.3 \pm 0.3$. If we assume that the upper limits set by the *SAS 2* satellite experiment between 40 and 200 MeV (Bignami *et al.* 1979) are valid for the epoch of our observation, the emission spectrum must steepen at MeV photon energies.

Assuming that we have detected a γ-ray emission from NGC 4151, the luminosity of this galaxy derived from the data presented here is $L_\gamma(0.5–5\ \mathrm{MeV}) = 5 \times 10^{44}$ ergs s^{-1} for a distance of 19 Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}), which is lower than the luminosity quoted for the 1977 observation (Perotti *et al.* 1979) at the 99% confidence level. The ratio between the 1977 and 1979 γ-ray luminosities is 4 ± 2. The 1979 September MISO spectrum is systematically lower than the 2 σ upper limits set by Meegan and Haymes (1979) in 1977 October and represents an intermediate situation between the 1977 May MISO spectrum and the 1978 October 2 σ upper limits set by White *et al.* (1980) above 1.1 MeV. On the other hand, the data up to 500 keV obtained by the scintillation telescope on *Ariel 5* (Coe *et al.* 1980) in 1976 December are in agreement with both the 1977 and the 1979 MISO results in the same energy range. This means that the source is variable above $\sim$ 500 keV by a factor of 3–10 on a time scale up to 1 year, while in the hard X-ray range the variability is not greater than a factor of 2. Evidence for X-ray variability up to a factor of 2 on a time scale ranging from 10 minutes to a few days has been reported (Tananbaum *et al.* 1978; Elvis 1976; Mushotzky *et al.* 1978).

Recently, a two-component emission has been suggested by Schlickeiser (1980) in which the ultraviolet and soft X-ray photons below 20 keV are scattered by relativistic electrons, via the inverse-Compton process into the hard X-ray and γ-ray regions. The predicted γ-ray flux is directly related to the X-ray flux at about 10 keV. Since the observed variability at $E_\gamma > 500$ keV is a factor of 2–3 greater than that observed in the X-ray range, it is unlikely that this mechanism is operative in NGC 4151. However, no definite conclusions can be reached until this galaxy is observed simultaneously at X-ray and γ-ray wavelengths.

Two burst models have been proposed to explain the γ-ray emission from NGC 4151. In the Compton-scattering model suggested by Pinkau (1980), a burstlike injection of electrons, having a lifetime of several weeks, produces a γ-ray spectrum expected to vary widely in both the intensity and spectral shape from one burst to another. On the other hand, if a massive ($M > 10^8\ M_\odot$) Kerr black hole exists in the nucleus of NGC 4151, the Penrose Compton-scattering mechanism (Leiter 1980) can lead to the production of a γ-ray emission spectrum with a cutoff at the same energy of about 3 MeV for each burst. Because of the low statistical accuracy of the MISO 1977 and 1979 data, it is difficult to locate the high-energy cutoff with sufficient accuracy to distinguish between these two models.

The UV emission from NGC 4151 shows intensity fluctuations of a similar amplitude and time scale as the γ-ray variations (Penston *et al.* 1980). However, the UV photon spectrum has a steeper slope, $\alpha = 2.1–2.3$ (Wu and Weedman 1978; Boksenberg *et al.* 1980) than that of our γ-ray data ($\alpha = 1–1.6$). This makes a self-Compton process on the UV photons an unlikely explanation for the observed γ-ray emission. Attempts have been made (Schmidt and Miller 1980; Cutri *et al.* 1980) to subtract the thermal component from the optical and infrared total emission spectra of NGC 4151, leading to a nonthermal residual spectra with a photon spectral index of $\alpha \approx 1.3$. It is therefore possible that the hard X-ray and the soft γ-ray photons up to a few MeV are self-Comptonized infrared/optical photons, providing that there is a continuous injection of relativistic electrons. The change in the slope of the emission spectrum between the optical and the UV regions would generate a similar break at γ-ray energies.

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