PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Low energy γ-ray observations with the MISO telescope

By The MISO Collaboration: R. E. Baker†, L. Bassani†, G. Boella‡, R. C. Butler§, J. N. Carter†, A. J. Dean†, A. Della Ventura‡, G. Di Cocco§, R. I. Hayles†, F. F. Perotti‡, D. Ramsden† and G. Villa‡

† *Physics Department, University of Southampton, Southampton SO9 5NH, U.K.*
‡ *Istituto Fisica Cosmica, Via Bassini* 15, *Milan, Italy*
§ *Istituto T.E.S.R.E., Via Dei Castagnoli, Bologna, Italy*

1. Flight details and observational data

The MISO telescope, which has been described elsewhere, (Baker *et al.* 1979), has a sensitive area of 560 cm^2 and an aperture of 3° f.w.h.m. in both the azimuthal and zenithal planes. An alt–azimuth orientation system was used to point the telescope with a precision of $\pm 20'$. A passively shielded hard X-ray detector (20–280 keV) having an effective area of 600 cm^2 was also mounted in parallel with the axis of the main telescope and had a field of view of $3° \times 3°$ f.w.h.m. This instrument was used to study the region of the sky containing NGC 4151 on 30 September 1979 between 15h01 U.T. and 20h40 U.T. A series of five drift scans were performed to survey the region contained within the coordinate points 11h32 and 12h33 in right ascension. The declination was centred on $+39.8°$. The Seyfert galaxy 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 measurements associated with the data presented here, was 8.6×10^3 s. The mean float altitude during the observation was close to 4 mbar (400 Pa) and the telescope was set at a series of zenith angles between 9° and 30°.

To minimize systematic variations in the background due to changes in the zenith and azimuth of the telescope, the data for each scan were analysed separately and the results combined statistically. The only significant source of systematic variation in the background was found to be that which was linearly related to changes in the residual atmospheric pressure. Thus, for each separate drift scan, the background, corrected for atmospheric pressure, was subtracted from the measured on-source counting rate. A mean value of 3.6 ± 0.9 count s^{-1} was found for the low energy γ-ray excess above 260 keV when the data from five drift scans were combined. A correlation was made between the counting 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 source position derived from these data is plotted in right ascension and declination in figure 1*b*. Since the drift scans were made in one direction only, the limits of our error box are represented by the 1σ points in the direction of the scan and by the total aperture of the telescope (6°) in the orthogonal direction. This error box includes a contribution from the random errors in the pointing system. The only known X-ray sources in this region of the sky are NGC 4151 and a quasar a few minutes of arc from this Seyfert galaxy which lies within the 1σ error box. No other hard X-ray sources lie within a region of sky enclosed by a 4σ error box (preliminary HEAO-4 catalogue). It therefore seems reasonable to suppose that the detected excess in fact originates from NGC 4151.

The same method of analysis was repeated for the counts contained within seven energy-loss channels between 20 keV and 19 MeV. A matrix inversion technique, which makes no *a prior* assumptions about the final shape of the spectrum, was used to convert the energy-loss spectrum 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 telescope were taken into account in this calculation. The error in this evaluation was estimated to be less than 10%. This photon spectrum together with a sample of data obtained by other observers from this region of the sky above 10 keV, is shown in figure 2.

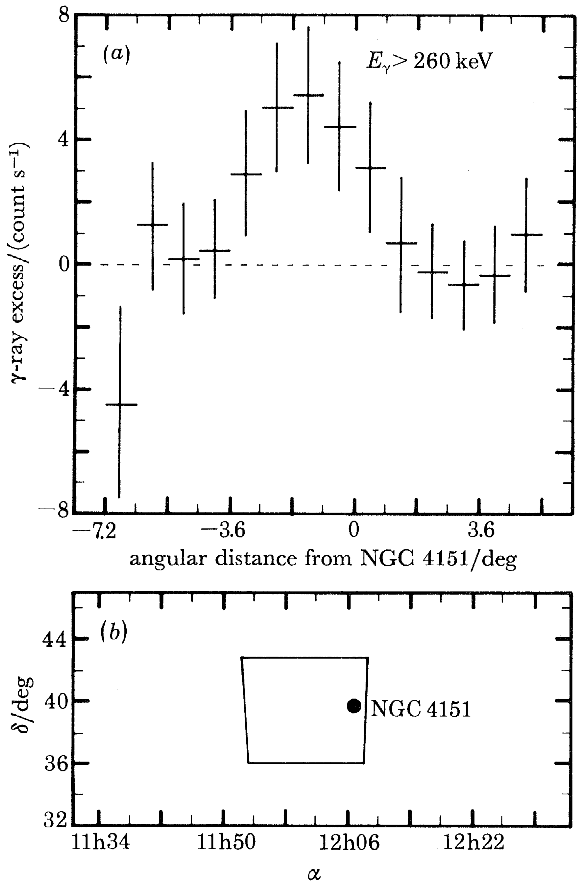

FIGURE 1. (*a*) Excess counts above 260 keV as a function of angular distance from NGC 4151. (*b*) The MISO error box of the observed excess in right ascension and declination (1950).

2. Discussion

An attempt to fit our data with a single power-law gives a reduced χ^2 of 0.85 with five degrees of freedom and a slope of $\alpha = 1.3 \pm 0.3$. If we assume that the upper limits measured by the SAS-2 experiment (Bignami *et al.* 1979) are valid for the epoch of our measurement, it is clear that the emission spectrum must steepen for photon energies above a few megaelectron-volts. Our data are also consistent with a two power-law spectrum with a break at *ca.* 3 MeV (reduced $\chi^2 = 0.95$ with four degrees of freedom). The minimum energy at which the 'break' may occur is close to 1 MeV if the photon spectrum also passes through the SAS-2 upper limits. The γ-ray luminosity of NGC 4151, derived from the data presented here, is L_γ (0.5–5.0 meV)

$= 5 \times 10^{44}$ erg s^{-1} † for a distance of 19 Mpc (H_0 = 50 km s^{-1} Mpc^{-1}). The results of other low energy γ-ray observations of NGC 4151 (Perotti *et al.* 1979; Meegan *et al.* 1979; White *et al.* 1980) are also shown in figure 2. From the MISO data there is some evidence that NGC 4151 is variable at γ-ray wavelengths. The γ-ray luminosity (0.5–5.0 MeV) has apparently varied by more than a factor of 4 over a period of approximately two years.

The ultraviolet emission shows intensity fluctuations of a similar amplitude and time scale

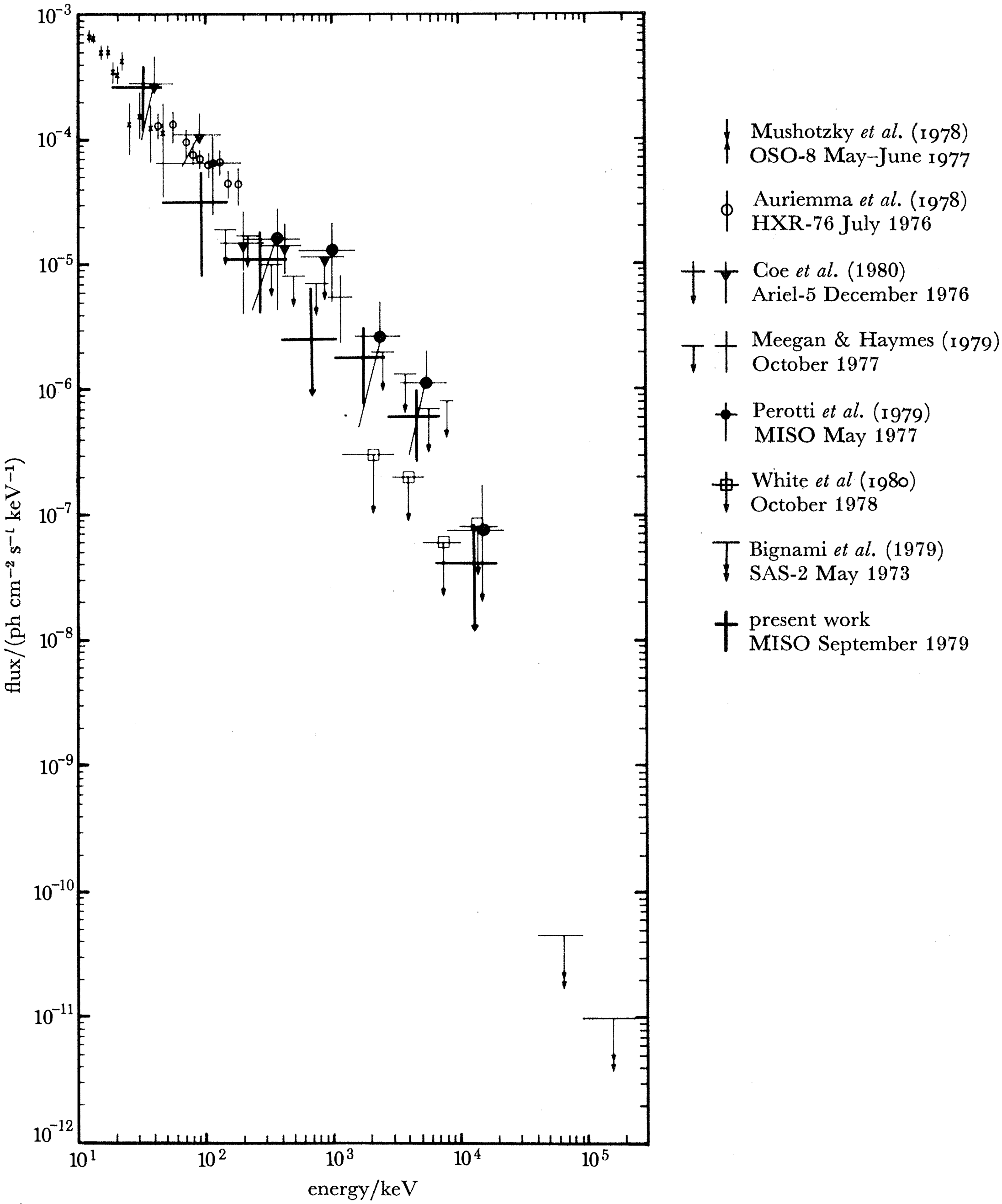

FIGURE 2. The photon spectrum observed by the MISO telescope from the region of NCG 4151 together with other data above 10 keV.

† 1 erg s^{-1} = 10^{-7} W.

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as these γ-ray variations (G. Bromage 1980, private communication). The fluctuations may be a manifestation of the inverse-Compton process blue-shifting the u.v. photons to γ-ray wavelengths. Since no contemporary measurements at other wavelengths are available, it is difficult to draw any quantitative conclusions as to the exact details of the source environment. Clearly, contemporary broad-band observations are desirable. However, the u.v. spectrum has a steeper slope ($\alpha = 1.3$ f.u.) (Boksenberg *et al.* 1980) than our γ-ray data ($\alpha = 0.3$ f.u.). This makes the self-Compton process on the u.v. photons an unlikely explanation of the γ-ray emission. Attempts have been made, (Schmidt & Miller 1980; Cutri *et al.* 1980), to subtract the thermal components from the optical and i.r., total emission spectra leaving a non-thermal residual with a spectral index of $\alpha = 0.3$ f.u. It is therefore possible that the γ-ray photons are self-Comptonized i.r./optical photons and the turnover at $E_\gamma > 1$ MeV is a reflexion of the shape of this u.v. spectrum.

Models based upon Penrose–Compton scattering in the ergosphere of a rapidly rotating black hole have been proposed to explain the γ-ray emission from NGC 4151 (Leiter 1980; Kafatos 1980). Both the 1977 (Perotti *et al.* 1979) and 1979 MISO data are consistent with this model which requires a cut-off in the γ-ray spectrum close to 3 MeV. An estimate of the mass of the black hole may be obtained from the γ-ray luminosity in the range 0.5–5.0 MeV. If we assume a lifetime for the Seyfert phase of 10^8 years and a conversion efficiency of 10 %, we obtain a value of at least *ca.* $4 \times 10^6\ M_\odot$. for the mass of the condensed object. The corresponding lower limit to the size of the region is $R \approx 10^{12}$ cm. On the other hand, photon–photon collisions between the γ-rays and local hard X-ray fluxes, if one assumes a cut-off close to 3 MeV, set an upper limit on the size of the region of *ca.* 6×10^{13} cm. This strongly suggests the presence of a compact object in the nucleus of NGC 4151 if the X- and γ-ray fluxes both originate from this region.

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