Search for γ-rays from M31 and other extragalactic objects

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1. Introduction. Although the existence of fluxes of γ-rays of energies $> 10^{12}$ eV is now established (Stepanian, 1984) for galactic sources, the detection of such γ-rays from extragalactic sources has yet to be independently confirmed in any case. The detection and confirmation of such energetic photons is of great astrophysical importance in the study of production mechanisms for cosmic rays, and other high energy processes in extragalactic objects. We report here on observations of M31, which was reported as a 10^{12} eV γ-ray source by Dowthwaite, et al (1984). We also give flux limits on a number of other extragalactic objects, chosen for study for reasons which will be detailed below.

2. M31 observations. M31 appears in all respects to be a typical Sb spiral galaxy, and we are aware of no indications of unusual activity in either the disc or nucleus during the period October-November 1984 when the observations discussed here were taken. In contrast to an active galaxy such as Centaurus A (detected at $E > 1000$ GeV by Grindlay, et. al., 1975) where a model involving the central powerhouse could coherently describe the observations through many decades of energy (Grindlay, 1975), a flux of high energy γ-rays from a normal galaxy would be expected to originate as the superposition of discrete sources (e.g., binary pulsars) with a diffuse cosmic-ray inverse-compton component, as in our own galaxy. Thus detection of a flux of γ-rays from M31 could provide a test of this model, as well as another point of comparison of M31 with the Milky Way.

We observed M31 during the two moonless periods of October-November 1984, using the atmospheric Cerenkov technique with the 10 meter aperture reflector at F. L. Whipple Obs. on Mt. Hopkins, Arizona. (See Cawley, et al, 1985, OGG 9.5-4, this proceedings, for details on data acquisition and analysis techniques). The observations were all made by tracking an identical path in the sky (in elevation and azimuth) for two successive time intervals, once while the telescope was centered on M31, and once with a background sky comparison region centered in the

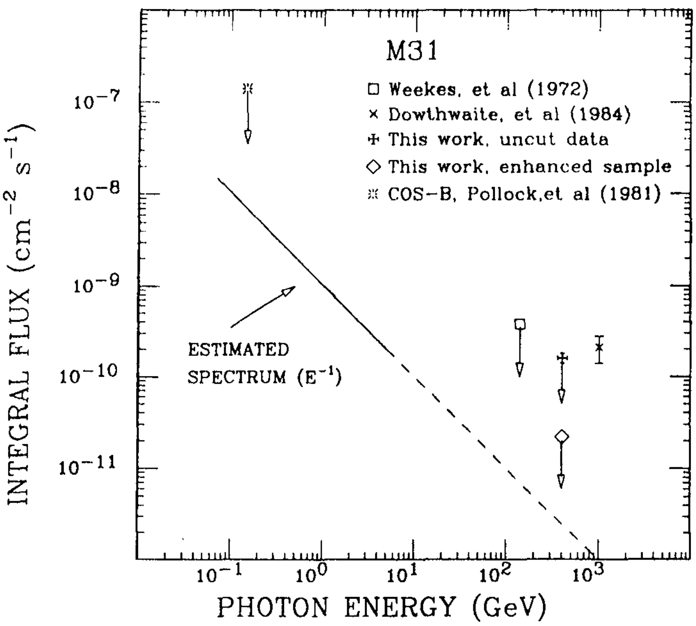

Fig. 1: The limits reported here are plotted along with previous limits and reported flux. The spectrum estimate comes from scaling 70 MeV-5GeV galactic results up to M31.

field. The order was usually ON-source followed by OFF-source, but this was interchanged occasionally to minimize any systematic bias. A run pair was thus (typically) 28 sidereal minutes ON and 28 sidereal minutes OFF. The central PMT in the trigger was removed for both ON and OFF to avoid spurious triggers due to the high sky brightness of M31's nucleus. Observations were made only during cloudless, moonless nights and conditions were monitored in the field of view by a separate video camera, and by cross-checking with observers at the other optical facilities on the mountain.

During the October data run, ten ON/OFF pairs were taken, with 38,322 events ON and 38,340 OFF. During the November data run, six more pairs were taken, with 24,138 events ON, and 24,108 events OFF. These totals represent the uncut data results. The ON minus OFF difference for all triggers is 12 events , which is .031 Poisson standard deviations from zero. After these events were corrected for individual PMT gains and pedestal offsets, the resulting images were subjected to a selection criterion which, based on Monte Carlo simulations of γ-ray- and proton-initiated EAS (see Hillas, 1985, OGG 9.5-3, this proceedings), rejects protons with ~90% efficiency compared to γ-rays. We have determined upper limits for both the uncut data result, and the enhanced sample result; these limits are:

$$\text{(uncut)}\ F(\gamma) < 1.6 \times 10^{-10}\ \text{photons cm}^{-2}\ \text{s}^{-1},\ E > 400\ \text{GeV}$$

$$\text{(enhanced)}\ F(\gamma) \leq 2.2 \times 10^{-11}\ \text{photons cm}^{-2}\ \text{s}^{-1},\ E > 400\ \text{GeV}$$

at the 90% confidence level. Fig. 1 plots these limits, as well as a previous limit by Weekes et al (1972) also using the Mt Hopkins 10 meter telescope, and the lower energy limit obtained by COS-B (Pollock, et al, 1981). The flux shown is that of Dowthwaite, et al(1984), and appears to be inconsistent with the limits shown, assuming a typical spectral index. In fact, if one attempts to join the COS-B limit with the reported flux, the spectral index implied is about -.75, a very hard spectrum for this energy regime. Also plotted as an estimate of the expected spectrum, as discussed below.

3. M31 discussion. In order to provide a basis for what physical constraints these limits and the reported flux may impose upon M31 we now estimate what sort of luminosity is to be expected at these energies. Fortunately in this case it is reasonable to use our own galaxy as an indicator because of its similarities to M31. In particular, estimates of the total galactic luminosity in the energy range 70 MeV to 5 GeV have been made recently by a number of authors (Caraveo and Paul, 1979; Mayer-Hasselwander, et.al., 1982; Godfrey,1983),and lie in the range of 5×10^{38} to 10^{39} ergs/sec.

If we use Godfrey's estimate of 8×10^{38} ergs/sec for 70 MeV< E < 5 GeV which we assume to be isotropic with an E^{-2} differential spectrum in the quoted energy range, this implies a galactic emission of about 3.5×10^{40} photons/sec at 1 GeV. Assuming that the number of sources scales with the mass of the galaxy, we scale this number up by a factor of two for M31, which is about twice our galaxy's mass. Thus the expected integral emission spectrum for M31 is:

$$N(>E) \simeq 7 \times 10^{40}\ E^{-1}(\text{GeV})\ \text{photons/sec} \quad (E > 70\ \text{MeV})$$

If we assume a distance of 670 kiloparsecs, and neglect both galactic and extragalactic absorption and scattering losses, this implies a flux of

$$F < 1.3 \times 10^{-12}\ \text{photons cm}^{-2}\ \text{s}^{-1}\ \text{above 1000 GeV}$$

or

$$F < 3.0 \times 10^{-12}\ \text{photons cm}^{-2}\ \text{s}^{-1}\ \text{above 400 GeV}$$

assuming that the extrapolation from 1 GeV is appropriate (we note that Grindlay,1975, found such an extrapolation to be valid for his 1000 GeV measured flux from Centaurus A, when compared to fluxes at ≈ 1 GeV). This flux is consistent with the limit we have reported, yet more than two orders of magnitude below the flux reported above. We note in addition that the assumptions made in this calculation were all biased toward increasing the flux estimate; in fact, one expects the differential spectrum to be steeper than E^{-2} and for absorption or scattering to play a part. A more careful calculation would probably only increase this discrepancy. We note, however, that recently Dowthwaite, et al (1985) report measurements of the γ-ray flux from the galactic plane which give support to their claim that their M31 flux is consistent with the scaled galactic flux.

4. Other extragalactic observations. As our analysis of M31 has shown, an isotropic emitter of γ-rays must be either very luminous; or, if it has a typical luminosity, very close to be detectable by present methods. However, recent models for active galactic nuclei, as well as BL Lac objects and QSOs, have emphasized the importance of relativistic particle or photon beams (cf: Blandford and Konigl, 1979; Konigl, 1981; Swanenburg, 1978) in the energetics of such objects. In particular, the class of sources characterized as 'blazars' (BL Lac + quasar) may involve beams aligned nearly along our line-of-sight (Angel and Stockman, 1980). Since beam half-angles of a few degrees or less are not unlikely, factors of > 10^3 increase in luminosity over an isotropic source are possible.

All objects reported on here were observed with similar conditions and methods as in M31, except that a lower threshhold of ~150 GeV was obtained by a different triggering requirement, and no trigger adjustments were needed due to the brightness of the source. Observation times varied between 1 and 5 hours total, with equal background times. Table 1 gives a list of the objects, along with: 1) approx. RA and DEC; 2) class of object; 3) z, the redshift (when known); 4) flux upper limits (photons/cm^2/s) for: A) the uncut data totals, and B) enhanced data sample, both 90% confidence level.

TABLE 1.

Object	RA	Dec	Class	z	limit (A)	limit(B)
NGC1275	03 19	+41 25	SEYFERT	.017	1.2E-9	9.5E-11
PKS0735+17	07 35	+17 49	BL LAC	.424	1.7E-10	6.9E-11
PKS0736+01	07 36	+01 44	BL LAC		1.3E-11	1.5E-10
OJ287	08 52	+20 18	BL LAC	.306	4.8E-10	1.2E-10
PKS0906+01	09 06	+01 34	BL LAC		3.1E-10	7.1E-11
OK222	09 13	+29 50	BL LAC		3.7E-10	1.3E-10
3C232	09 55	+32 38	QSO	.53	1.3E-10	1.3E-10
X1052+607	10 52	+60 42	BL LAC		3.6E-12	9.2E-11
MK421	11 01	+38	BL LAC	.030	2.3E-10	6.3E-11
NGC4151	12 09	+39 30	SEYFERT	.003	3.0E-10	1.9E-10
ON325	12 17	+30 12	BL LAC		4.0E-10	1.1E-10
ON231	12 19	+28 30	BL LAC		2.6E-10	1.1E-10
3C273	12 28	+02 09	QSO	.158	3.6E-10	1.7E-10
M87	12 30	+12 29	NORMAL	.003	6.0E-10	8.3E-11
3C279	12 53	-05 31	QSO	.538	4.6E-10	2.0E-10
OQ208	14 05	+28 41	SEYFERT		2.4E-10	7.7E-11
MK501	16 52	+39 48	BL LAC	.034	2.5E-10	1.8E-10
IZW186	17 27	+50 12	BL LAC	.055	1.6E-10	2.0E-10

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