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GAMMA RAY EMISSION FROM THE REGION OF THE GALACTIC CENTER

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13. ABSTRACT

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ABSTRACT

A combination nuclear emulsion-spark chamber gamma ray (E>100 MeV) telescope has been used to study the region of sky that includes the Galactic Center. 95% confidence upper limits on the flux from the reported sources Gγ 2+3 and Sgr γ-1 were placed at 4.4 and 8.8×10^{-5} photons/cm^2 sec, and a similar limit on the emission from the Galactic Center as a point source ($\pm$ .75°) was placed at 3.3×10^{-5} photons/cm^2 sec. No enhanced emission was observed from the Galactic Plane ($\pm 6°$) and an upper limit of 2×10^{-4} photons/cm^2 sec. rad. was obtained. Three regions of enhanced emission were observed that had a combined Poisson probability of occurrence of less than 5.10^{-3}. One of these is associated with a region of enhanced emission reported by other workers. The observations were made against an integral atmospheric background intensity of 1.4 ± 0.4γ's/cm^2 sr. sec. mb that had a spectral index of 0.8 ± 0.2 in the energy range from 0.1 to 2.5 GeV.

Introduction.

During the past few years a good deal of attention has been devoted to observing the emission, or non-emission, of energetic gamma rays from extra-solar sources. While the majority of these observations have produced null results, finite intensities have been reported from the galactic plane and from several "point" sources. At this time these results are either controversial or unconfirmed and there is some uncertainty as to the present status of gamma ray astronomy. In a recent review, Frye (1971) summarized the position as of the summer of 1971, illustrating two main topics. Firstly, emission from the galactic plane, and in particular that part of the plane near the galactic center, has been observed from satellites and balloons at an intensity level of the order $1\text{-}2.10^{-4}$ γ/cm^2 sec rad, by Clark et al. (1968), Kraushaar et al. (1972), Fichtel et al. (1971) and Bennett et al. (1972). Several other groups have reported observations of marginal statistical significance for emission from various parts of the galactic plane. On the other hand, Frye et al. (1971) have set 95% confidence limits on this emission which are in clear contradiction with these high intensity values unless the source has a very wide, $\pm 15\%$ lateral spread, although even in this case the upper limit quoted is a factor of two below the reported intensity. Browning et al. (1972a) have also reported a low upper limit to this emission. Both these groups have also reported the observation of several point sources with appreciable statistical significance at flux levels of $1\text{-}3 \times 10^{-5}$ γ/cm^2 sec. As yet these observations of point sources have not been confirmed by other workers, nor has there been any appreciable correlation between reports by different groups. Browning et al. (1972b) have also reported that in the Cygnus region they observed significant deviations from a Poissonian distribution of events mapped on the sky, suggesting the possibility that point sources were also present in that region.

In this paper, we present our final results from an observation made to study the gamma ray emission from the sky in the region of the galactic center.

Observational Technique.

A combination nuclear-emulsion-spark chamber detector or telescope basically similar to those described before, (May and Waddington, 1969; Valdez et al., 1970) was used. However, the configuration of this detector was changed quite appreciably and a schematic representation is shown in Figure 1. Omitted from this figure is the folded optical bench that w s used to view the spark chambers, the pressure can in which the entire telescope was mounted and the orientation device (Anderson, 1969) that ensured that the telescope was dynamically centered at a predetermined azimuthal angle.

An incident gamma ray entering this telescope first traversed the anti-coincidence shield before entering the emulsion block which was approximately one radiation length thick. If it converted to an electron pair, and at least one of these electrons passed through scintillators S_1 and S_2 and the plastic Cerenkov counter at the bottom, then the resulting triple coincidence caused the spark chambers to trigger and the event was recorded. The geometry factor of the resulting telescope was 84 cm^2sr, while the top surface area of the emulsion block was 670 cm^2. The technical details of the operation of this telescope are discussed in detail elsewhere (Dahlbacka, 1972).

This telescope was flown on a balloon launched from Mildura, Australia at 13:52 hours GMT on March 25, 1970. It floated at an altitude of 131.4 ± 1.6 K ft. for 11:20 hours but only operated for 2:35 hours while at a mean pressure of 2.8 ± 0.1 mb. Due to the limited exposure and a partial technical malfunction the telescope did not achieve the design goal of being able to detect point sources having a flux ≥ 1-2×10^{-6} γ/cm^2 sec.

Data Analysis.

During the operation of the telescope 18,000 spark chamber events were recorded. 42% were events that had some identification with particles present in the instrument but were insufficiently defined to be classified. 30% were caused by camera runaway that was the result of a marginal inhibit function. 22% were single tracks predominantly produced by low energy Compton electrons. 5% were double tracks and 1% multiple tracks, predominantly produced by gamma rays converting in the emulsions. This last 5%, or 1050 events, were then examined for their suitability for study in the nuclear emulsion. After making certain geometrical selections 193 events remained that were looked for in the emulsion. Of these 115 were found and verified as having been produced by gamma rays.

The energies of each electron were measured from the multiple scattering and the celestial coordinates of the incident photons were subsequently determined to within $\pm$ 45 mins. of arc.

Results.

(1) Atmospheric Background.

Because of the difficulty of making absolute calibrations of the detection efficiencies of gamma ray telescopes, it is essential to evaluate the atmospheric background and compare the results with those obtained by other detectors. Theoretical calculations, e.g. Beuermann (1971), show that the production of secondary gamma rays will depend linearly on atmospheric depth for the first few mb of overlying air. Thus the results from different observations made at slightly different residual depths can be compared by expressing the measured intensities in units of intensity per mb. Furthermore, the production is not a strong function of the precise geomagnetic cut-off energy. For example, Frye et al. (1971) have shown that in going from a cut-off rigidity of 4.5 GV to 8.8 GV the background only falls by 30%, although the particle intensity falls by 64%. Thus, it is reasonable to compare directly results obtained at slightly different cut-offs.

Details of the calculation of the results on the atmospheric background spectrum are presented elsewhere (Dahlbacka, 1972). Basically, by considering the total useful area of the telescope, live time of exposure, geometry factor of the coincidence elements and estimating an overall detection efficiency, it is possible to calculate the intensity of this background. In this case the overall detection efficiency was calculated using a Monte Carlo simulation of the detector response as a function of energy developed previously by Valdez(1970), making an estimate of the energy dependence of the finding efficiency in the emulsion and integrating the resulting differential spectrum. The differential energy spectrum of atmospheric background gamma rays is shown in Figure 2, where it is compared with the results of other workers. It can be seen to be in good agreement with the results of Valdez et al., (1970), but only in fair agreement with those of other workers. Basically these spectra have systematically higher intensities than those obtained by other detectors. If this difference is significant and real then the most likely explanation is that we have underestimated our detection efficiencies, which results in an overestimate of the true intensities of fluxes of any point, line or diffuse sources. We feel that this error, if indeed it is an error, is in the right direction leading to conservative estimates of intensity limits. The magnitude of this "conservatism" is expressed by the observation that a generally accepted value for the atmospheric intensity of $E > 100$ MeV gamma rays is $\leq 1 \times 10^{-3}$ γ/cm^2 sr. sec. mb, whereas we obtain values of $1.4 \pm 0.4 \times 10^{-3}$ (1972) and $1.5 \pm 0.3 \times 10^{-3}$ γ/cm^2 sr. sec mb. In what follows we quote intensities and fluxes based on our efficiencies, but in parentheses we also give the values if the detector efficiency was great enough to produce the "accepted" background value.

Sources.

The point of origin of each found gamma ray is shown in Figure 3 as a function of galactic coordinates, b^{II} and ℓ^{II}. The 95% confidence upper limit to radiation from various point sources of predetermined interest have been calculated using the method outlined by Hearn (1969) and are given in Table I.

The results show that none of the three source regions of possible interest observed in this survey, albeit with low efficiency, two of those reported by Frye et al. (1971) and the galactic center, produced any measurable gamma ray emission. The resulting limits on the reported sources are higher than the quoted flux values and hence not in contradiction. The same table also shows the limits on emission from a line source along the galactic plane between $\ell^{II} \approx -16$ and $+6$, for various values of Δb^{II}. Figure 4 shows the histogram of the number of events in each 1.5° strip. For $\Delta b^{II} = 3°$ and 6° these 95% confidence upper limits are of the same magnitude as the actual fluxes quoted by Kraushaar et al. (1972) and Fichtel et al. (1971) but appreciably larger than the upper limit quoted by Frye et al. (1971). However, as Δb^{II} increases, so does our flux limit, and for $\Delta b^{II} > 6°$ these limits are not in contradiction with the finite values reported. (Note however, the parenthetical values obtained using the "accepted" background intensity.)

Another estimate for the line flux which is independent of the emulsion finding efficiency was made from a study of those events observed in the spark chambers as double track events. The angular resolution was smeared out from $\pm$ 0.75° to $\pm$ 3° but the effective area and live time were increased. 186 events were observed within the 0.5 relative efficiency curve. The absolute efficiency was computed from the previously calculated value for the atmospheric background. Since, once again, no enhanced emission was observed from the galactic plane (see Figure 4) upper limits were computed as before. These are also shown in Table 1 and are somewhat lower than those obtained from the emulsion analysis, due principally to the improved statistics. These limits, particularly if the higher efficiencies implied by the lower atmospheric background are used, are barely consistent with the quoted finite values.

Several groups have found evidence for relatively numerous sources of emission at levels near the limit of detectability. For this reason we have studied our data, as well as that reported previously, Valdez and Waddington (1970), for any significant deviation from a Poissonian distribution using arbitrarily selected bins of constant collecting power. The results of this analysis are illustrated in Figure 5. From this it can be seen that in the earlier data there is just one apparently significant deviation. One bin was observed containing seven events compared with the mean of 1.14 per bin. This bin, at RA = 300° , $\delta = 35^{\circ}$, had a Poissonian probability of 1.6×10^{-4} and since there were 103 bins, a net probability of 1.7%. No apparent source was reported in this location by Browning et al. and examination of the raw data suggests the events are not all associated. The data reported in this paper show three bins with 5 events in each. The Poissonian probability of each of these is 1.3×10^{-3}. Thus, the probability that three such bins shall all be due to statistical fluctuations, in the sample of 133 bins used, is $\leq 0.5\%$.

Examination of Figure 3 indicates three regions that could be those producing excess emission. The coordinates, possible fluxes and approximate independent levels of significance are presented in Table 2. Although no single region is significant at better than the 95% confidence level the probability that all three should independently be due to chance is very small, $\simeq 5 \times 10^{-4}$. We conclude, therefore, that there is evidence for at least one source in this area of the sky, having a flux of the order of 10^{-5} γ/cm^2 sec, a value comparable to those reported by others. In addition, Frye and his co-workers (see Frye et al. (1972))

have observed the region 352 + 16 to have an excess emission that is significant at the 3σ level when the results of three separate flights were summed. While not reported previously, due to the relatively low level of significance, this coincidence between our results strongly suggests a presence of a genuine gamma ray source. No X-ray sources have been reported at any of the three positions listed in Table II.

Since only one of these three possible sources lies near to the galactic plane, the inclusion or removal of the gamma rays associated with that source cannot appreciably affect our estimate of the line emission. This is fortunate, since the criteria for removing marginally significant point sources from a region containing a possible diffuse component that could manifest itself as a Poissonian distribution superimposed upon that of the atmospheric background are not well defined, see e.g. Browning et al. (1972).

Discussion.

A gamma ray flux of 10^{-5} γ/cm^2 sec for $E_\gamma \gtrsim 100$ MeV implies a luminosity for a source in the vicinity of the galactic center of $\approx 4 \times 10^{37}$ erg/sec. This is equal to the X-ray luminosity of 2-10 keV photons for a source, similarly located, having a flux of 200 counts/sec in the 2nd UHURU catalog, Giacconi et al. (1971). (Note: The Crab is 947 $\pm$ 21 counts/sec.) The detection of any gamma ray sources at this level of emission is therefore rather remarkable, even if they can be associated with X-ray sources, since a typical power law response, such as that from a synchrotron emission mechanism, would lead to luminosities two orders of magnitude greater in the X-ray region.

A source region with the characteristics of high gamma ray luminosity and low X-ray luminosity must satisfy rather special requirements. Either the energetic photon production is occurring in a region that is behind or within a screen that is optically thick to X-rays, or the gamma ray production is essentially unaccompanied by X-ray production. Practically speaking, this latter requirement would exclude all mechanisms that involve electrons, since any population of electrons must result in X-ray emission, and leaves only pion production by nuclear interactions as a plausible possibility. However, the X-ray optical depth may indeed be appreciable for sources in the vicinity of the Galactic Center. In that case we must assume that sources emitting gamma rays may or may not be associated with detectable X-ray sources, in a manner that depends purely on the precise amount of screening material. Furthermore, any associated X-ray sources should have energy spectra that reveal the operation of severe absorption on the primary spectrum.

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Table I

FLUX LIMTS FOR VARIOUS SOURCES

Source	# Observed	95% Number	F(95%)
SGR γ-1	0	3	$<8.8 \times 10^{-5}\ \gamma/cm^2$.sec. (5.8)
G γ2 + 3	0	3	$<4.4 \times 10^{-5}\ \gamma/cm^2$.sec. (2.9)
Galactic Center	0	3	$<3.3 \times 10^{-5}\ \gamma/cm^2$.sec. (2.2)
LINE EMISSION (Emulsion Analysis)			
$\pm 1.5°$	5	4.6	$<1.3 \times 10^{-4}\ \gamma/cm^2$.sec.rad. (0.87)
$\pm 3.0°$	16	7.1	$<2 \times 10^{-4}\ \gamma/cm^2$.sec.rad. (1.3)
$\pm 4.5°$	31	11.6	$<3.4 \times 10^{-4}\ \gamma/cm^2$.sec.rad. (2.3)
$\pm 6.0°$	42	13.6	$<3.9 \times 10^{-4}\ \gamma/cm^2$.sec.rad (2.6)
(Spark Chamber Analysis)			
$\pm 3°$	35	10.9	$<1.6 \times 10^{-4}\ \gamma/cm^2$.sec.rad. (1.1)
$\pm 6°$	69	13.5	$<2.0 \times 10^{-4}\ \gamma/cm^2$.sec.rad. (1.3)
$\pm 9°$	107	19.1	$<3.0 \times 10^{-4}\ \gamma/cm^2$sec.rad. (2.0)

Table II

FLUXES OF POSSIBLE SOURCE REGIONS

Coordinates	Significance Level	Flux $\gamma/cm^2.sec.$
ℓ^{II}, b^{II}		
352, +16	95%	$2-5 \times 10^{-5}$ (1.4 - 3.6)
349, +3	88%	$0.7 - 2.7 \times 10^{-5}$ (0.5 - 1.9)
4, -12	91%	$2.2 - 8.9 \times 10^{-5}$ (1.6 - 6.3)

Figure 1. A schematic representation of the gamma ray telescope. AA resresents an optically decoupled portion of the anti-coincidence shield used to detect heavy nuclei.

Figure 2. The differential energy spectrum of the atmospheric background, expressed in units of gamma/cm^2.sec.sr. MeV.mb.as measured in this work and by Valdez et al (1970), Niel et al. (1972), Frye et al.(1966), Fichtel et al. (1969) and Fazio et al. (1968).

Figure 3. The point of origin of each found gamma ray as a function of galactic coordinates b^{II} and ℓ^{II}. Each small circle represents a region that has a 60% probability of containing the true coordinate of the gamma ray.

Figure 4. A histogram of the number of events in strips parallel to the galactic plane. The upper histogram is 1.5^o strips of events found in the emulsions, the lower is 3^o strips of events found in the spark chambers. The dotted curves in each case represent the expected shape if there were no excess emission from the galactic plane.

Figure 5. Comparison of experimental data from this analysis and that of Valdez and Waddington (1969) with the expected Poissonian distributions for the mean values, m.

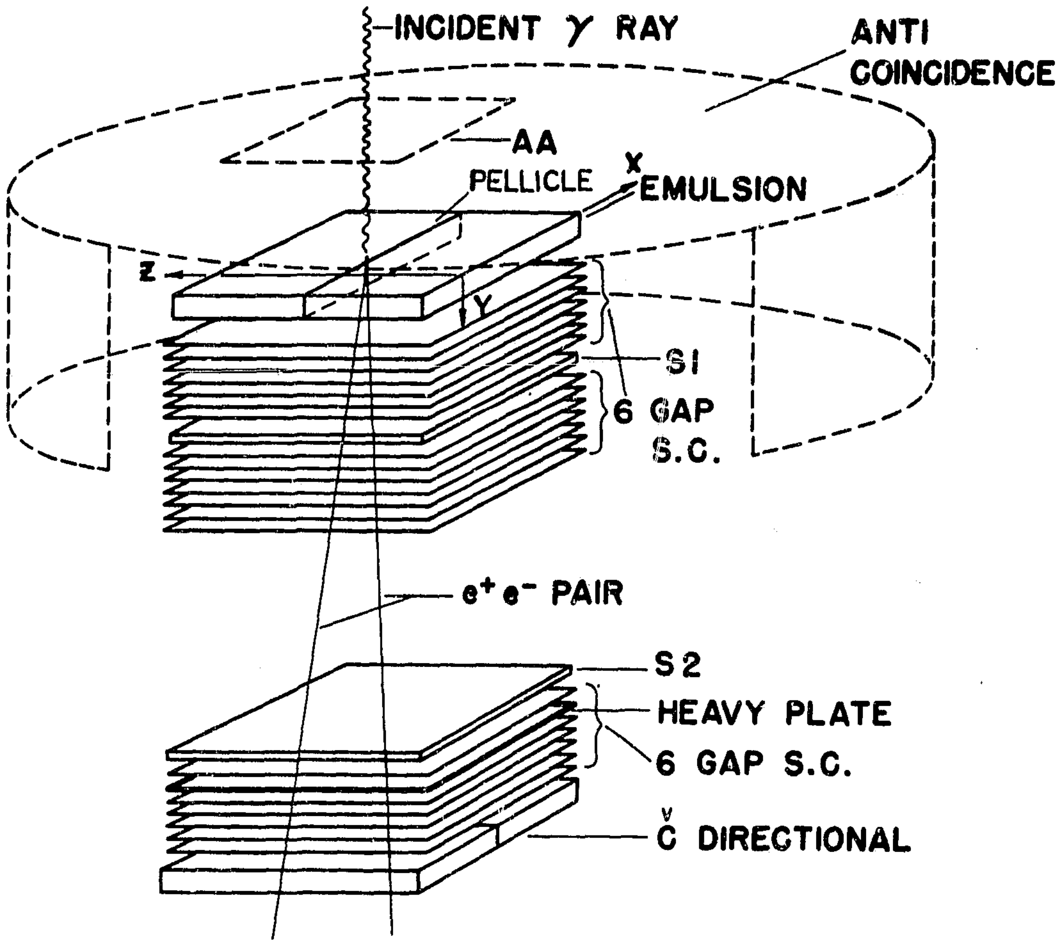

INCIDENT γ RAY
ANTI
COINCIDENCE
AA
PELLICLE
X
EMULSION
Z
Y
S1
6 GAP
S.C.
e+ e- PAIR
S2
HEAVY PLATE
6 GAP S.C.
Č DIRECTIONAL

Figure 1

12c

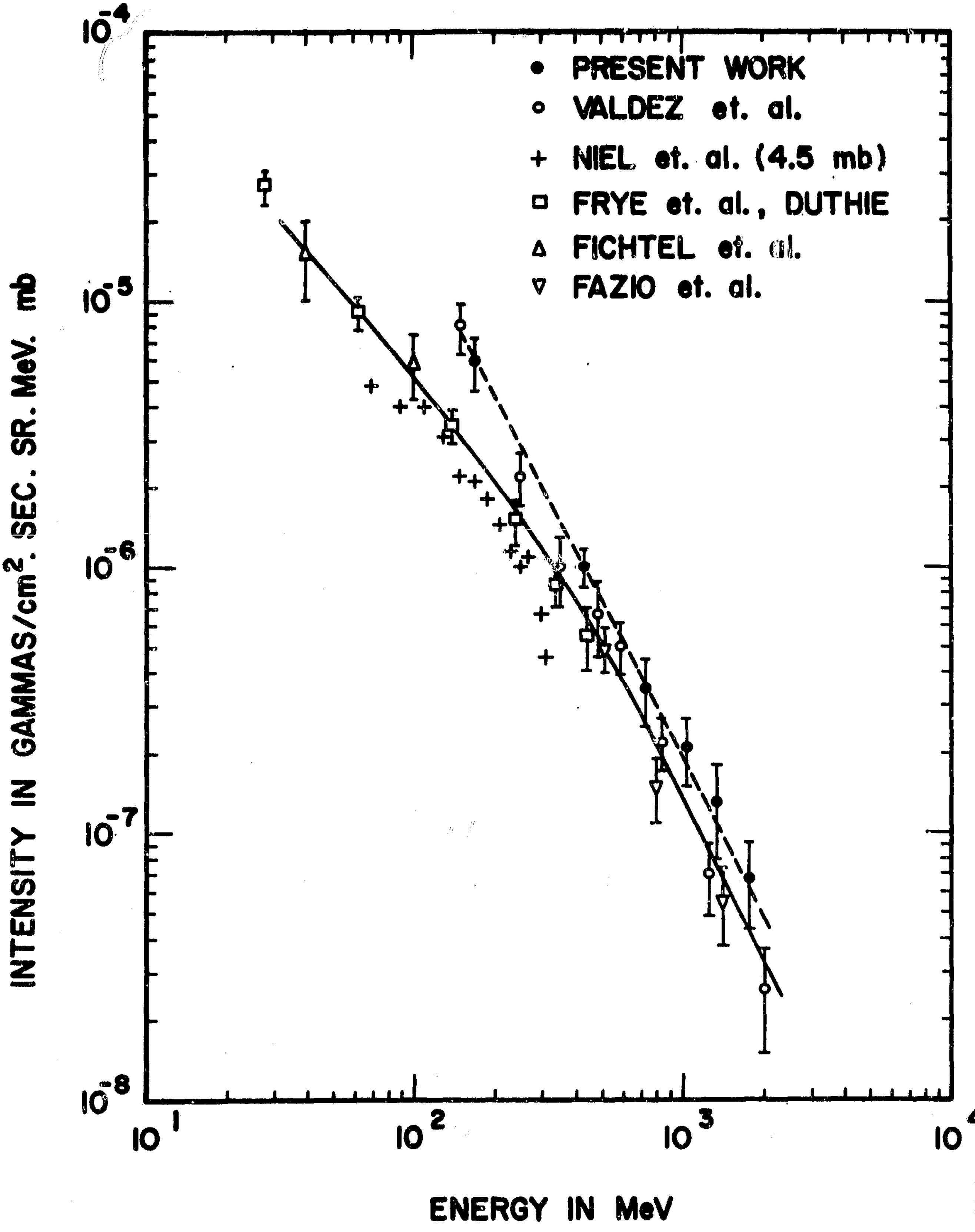

PRESENT WORK
VALDEZ et. al.
NIEL et. al. (4.5 mb)
FRYE et. al., DUTHIE
FICHTEL et. al.
FAZIO et. al.
INTENSITY IN GAMMAS/cm². SEC. SR. MeV. mb
ENERGY IN MeV
10^-4
10^-5
10^-6
10^-7
10^-8
10^1
10^2
10^3
10^4

Figure 2

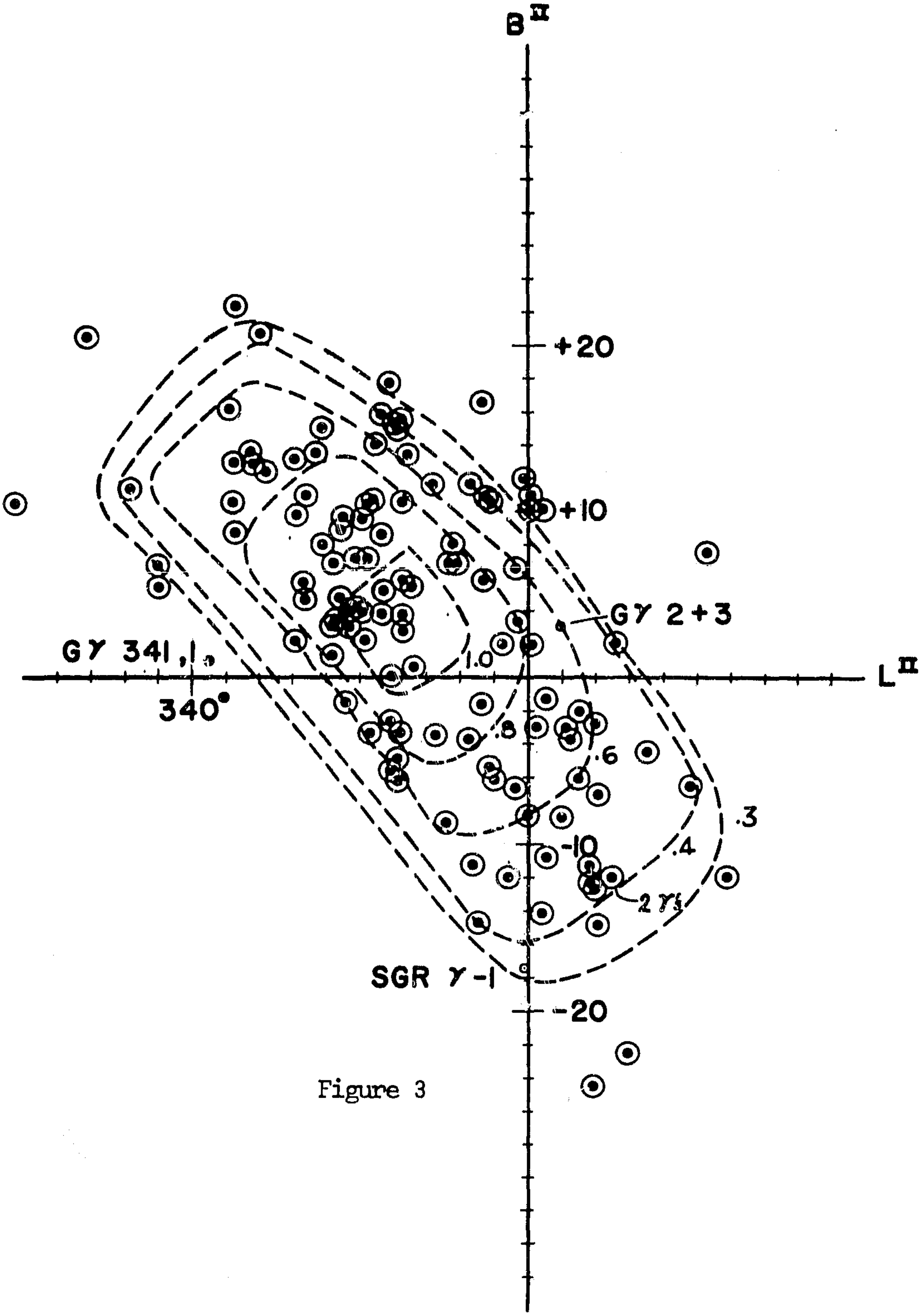
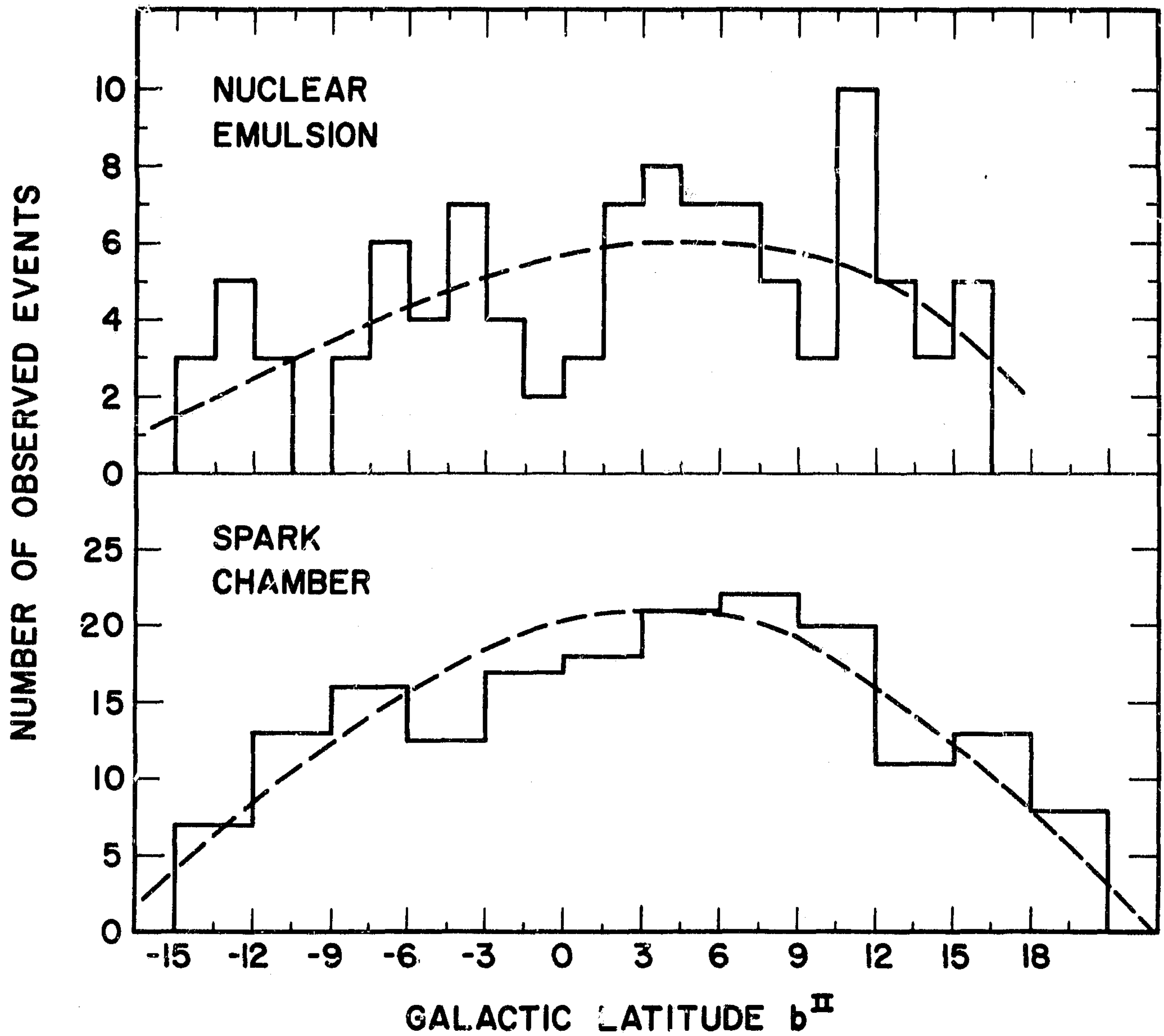


Figure 3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NUCLEAR
EMULSION
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2
4
6
8
10
SPARK
CHAMBER
0
5
10
15
20
25
-15
-12
-9
-6
-3
0
3
6
9
12
15
18
GALACTIC LATITUDE b^{II}

Figure 4

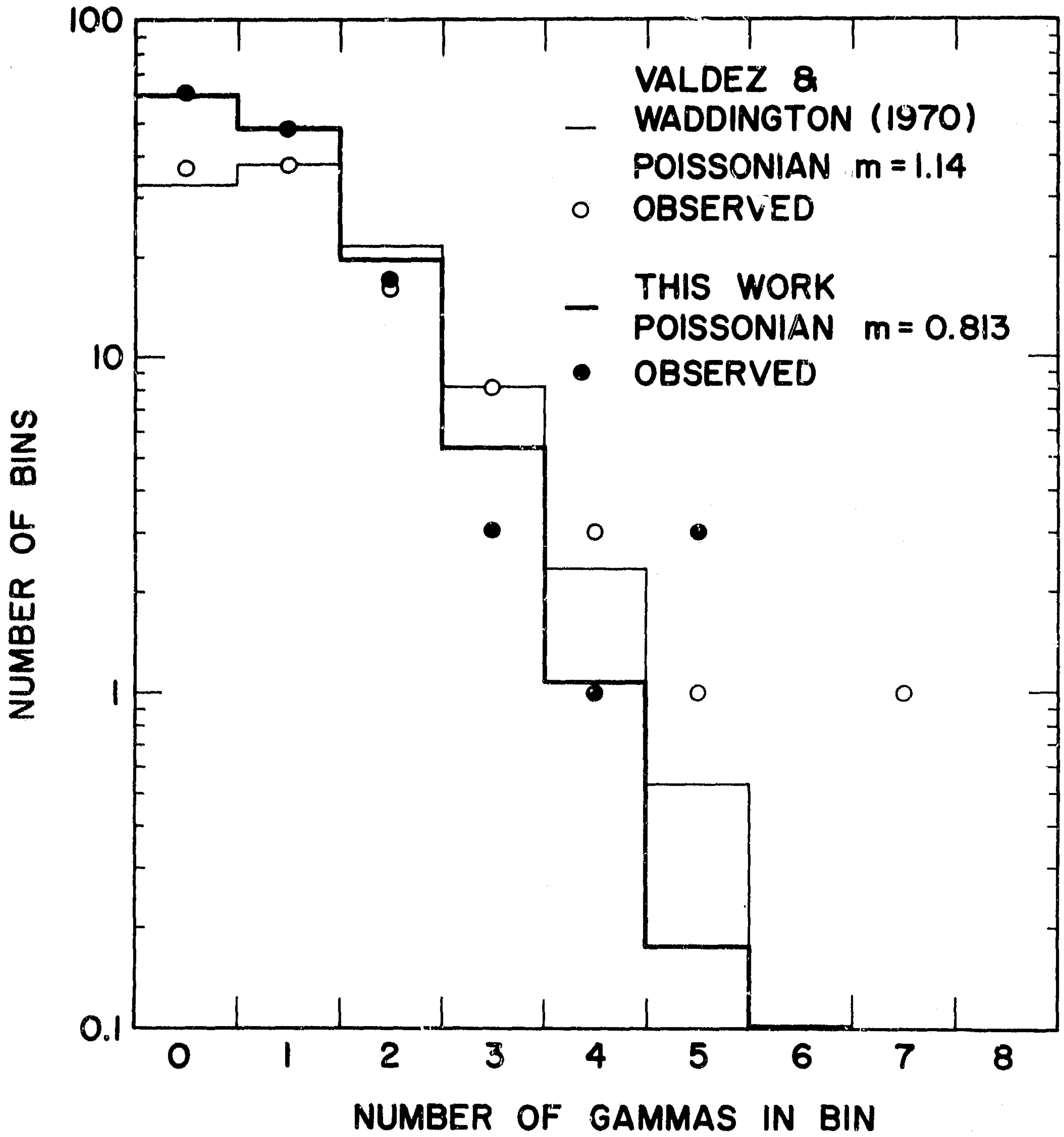
100
10
1
0.1
NUMBER OF BINS
0
1
2
3
4
5
6
7
8
NUMBER OF GAMMAS IN BIN
VALDEZ &
WADDINGTON (1970)
POISSONIAN m = 1.14
OBSERVED
THIS WORK
POISSONIAN m = 0.813
OBSERVED

Figure 5

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