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REVIEW OF OBSERVATIONAL RESULTS ON GAMMA RAY BACKGROUND *

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ABSTRACT

Recent observations in the x and gamma ray region of the electromagnetic spectrum have given strong evidence for the existence of an extragalactic intensity with a slowly steepening power law spectrum in the region 10^3 to 10^8 eV. Improved data from the OSO-III high energy gamma ray detector are in agreement with earlier published reports, and suggest that the gamma rays from high galactic latitudes have a softer spectrum than those from the galactic plane.

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Code - 1
CR-105310
Category - 29

The previous paper by Dr. Oda of the University of Tokyo has reviewed the status of measurements of the diffuse radiation in the region below 100 KeV. We shall be concerned here with the region of the electromagnetic spectrum above that energy.

Measurements of the diffuse radiation are difficult in this energy region. Gamma rays are produced in collimators, in nearby pieces of apparatus, and in the

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Earth's atmosphere by the ever-present charged particle cosmic radiation. In the region of a few MeV, in fact, Peterson (1967, 1969) has shown that the albedo from the Earth is just equal to the apparent diffuse radiation. At higher energies, as will be discussed presently, the albedo is enormously greater than the diffuse radiation. Because gamma ray production in matter is such an important phenomena, the use of shutters, inactive collimators and background evaluation by viewing the Earth – all important and useful devices in the lower energy region – are quite impossible in the energy region under discussion.

Figure 1, taken in part from a similar figure prepared by Gorenstein, Kellogg and Gursky (1969), summarizes representative measurements of the diffuse gamma radiation. Up to 1 MeV, at least, all measurements above 20 KeV fall with reasonable consistency on a straight line of slope – 2, indicating a photon number spectrum of the form dE/E^2. In the region 1-10 MeV, there are only the measurements of Vette, Matteson, Gruber and Peterson (1969) indicated by "Peterson et al (1969-ERS)" on Figure 1. As with the measurement of Metzger et al (1964) the observations were carried out far from the Earth where albedo effects are small. The apparent deviation from a power law, if real, has possible cosmological indications as discussed by Stecker (1969).

The highest energy measurement labeled "OSO-III" at 100 MeV refers to the published results of Clark, Garmire and Kraushaar (1968). Since that initial report, more observations have been reduced and while the earlier conclusions are unchanged, the statistical evidence is now appreciably improved.

Figure 2 shows the detected rate of gamma rays referred to a satellite-centered coordinate system with polar axis at the instantaneous zenith. The data have been separated into two parts; one in which the satellite was within 20° of the geomagnetic equator, the other in which the satellite was more than 20° from the geomagnetic equator. The horizon of the earth is brighter when the satellite is far from the equator because the Earth's magnetic field permits a larger portion of the

galactic cosmic ray flux to enter there. The counting rate for angles more than 40° above the horizon is statistically the same for both parts of the data. This is to be expected, of course, if these gamma rays are of celestial not terrestial origin.

The next several figures describe in various ways the anisotropic character of the detected high energy gamma radiation. Each point on the upper map of Figure 3 corresponds to the arrival direction in galactic coordinates of a gamma ray. In itself this map has little significance because the exposure of the instrument to various parts of the sky was not uniform. Correspondingly, each point on the lower map of Figure 3 corresponds to a certain time that the instrument spent viewing in the indicated direction. In other words, the density of points in a given region on the upper map divided by the density of points in the same region on the lower map is proportional to the directional gamma ray intensity. Once the data are available in the form described by Figure 3, variation of the intensity with galactic latitude, galactic longitude, etc. can be investigated conveniently.

Figure 4 shows the variation with galactic latitude, data from all galactic longitudes having been summed. We see a pronounced intensity peak at the galactic equator, and a definite non-zero intensity at all galactic latitudes. The shape of the pronounced rise near $\underline{b} = 0$ essentially reproduces the response of the instrument to a line source. The "line" could be several degrees wide, of course. The data are sufficient to allow division into six regions of galactic longitude, as shown in Figure 5. The most pronounced peak at the galactic equator occurs near the galactic center, although significant peaks towards the equator but of lesser intensity are apparent elsewhere.

Figure 6 shows the galactic longitude distribution for all those gamma rays that arrived within 15° of the galactic equator. The strongest emission, as was evident from Figure 5, is from regions near the galactic center. The distribution in $\underline{\ell}$, however, is much broader than the distribution to be expected from a point source at the galactic center.

One of the frequently discussed mechanisms for high energy gamma ray production is the collision of cosmic ray protons with nuclei of the interstellar gas. If the cosmic ray proton flux is the same everywhere in the galactic disc, the gamma ray intensity should be proportional to the columnar hydrogen density. In Figure 7 is shown the columnar hydrogen density averaged over the 5°, 10°, and 15° closest to the galactic equator plotted versus ℓ. The dependence on ℓ is surprisingly weak. This is because when one averages over several degrees in galactic latitude, much of the gas included is, in fact, relatively local. We conclude on these grounds alone that our data are not consistent with the nuclear collision production mechanism unless there are large amounts of molecular or cool gas undetected in the 21 cm surveys and concentrated in the galactic plane near the galactic center. In addition, as was pointed out in our initial paper announcing the OSO-III results, the observed intensity is more than 10 times that expected from the nuclear collision mechanism.

It is possible, of course, that cosmic rays are themselves concentrated towards the galactic center. The non-thermal radio noise distribution in galactic longitude, as indicated in Figure 7, may in fact be taken to indicate that this is likely. The radio noise and high energy gamma ray intensities are distributed rather similarly in galactic longitude.

The cumulative flux from discrete x-ray sources located within 15° of the galactic plane has a distribution in galactic longitude similar to that of the high energy gamma rays. This has also been pointed out by Ogelman (1969), who in addition has suggested that when a power law spectrum of index 2 is assumed, the extrapolated x-ray intensity falls near the measured gamma ray intensity. It is interesting to point out that when extrapolating over 3 decades, an uncertainty of 20% in the index, results in a dynamic range of 16 to 1 within which "agreement" may be claimed. Table I summarizes the predictions of some of the frequently discussed high energy galactic gamma ray production mechanisms.

The existence of gamma rays of galactic origin can hardly be questioned in view of the highly directional properties of the measured intensity. No such convincing evidence exists to prove the reality of the measured high galactic latitude and presumably isotropic component. All conceivable forms of background are related to the charged cosmic ray flux incident on the orbiting instrument or on the atmosphere beneath it. Since the orbit of OSO-III traverses a range of geomagnetic latitudes between +40° and -40°, and since the charged cosmic ray flux varies significantly over this range, any background should vary also with geomagnetic latitude. We have therefore examined our data for this type of dependence and the results are shown in Figure 8. Certainly neither the total gamma ray intensity nor the gamma ray intensity from high galactic latitudes have any obvious tendency to increase with geomagnetic latitude. In order to investigate the question quantitatively, we have computed, for the high galactic latitude component, the ratio of measured intensity for $|\lambda| > 20°$ to that for $|\lambda| < 20°$. We have

$$R = \frac{I\ (|\lambda| > 20°)}{I\ (|\lambda| < 20°)} = 1.14 \pm 0.18$$

The corresponding ratio for charged cosmic rays is 1.8, so the independence is established to about a 3.5σ level.

The instrument is equipped with a rather poor resolution gamma ray energy calorimeter. The results of the approximate energy measurements are still being studied but such preliminary results as are available are shown in Figure 9. The upper and lower dashed curves show pulse height distributions for gamma rays from the horizon of the Earth and from the Earth's disc, respectively. As is to be expected from simple kinematic arguments, gamma rays from the horizon, having followed the direction of the primary cosmic rays, have higher average energies. Gamma rays from high galactic latitudes have a pulse height distribution similar to those from the Earth's disc, while gamma rays from the galactic plane have a pulse

height distribution similar to those from the horizon. We conclude that gamma rays from the galactic plane are on the average more energetic than those from high galactic latitudes. This qualitative statement is in agreement with the hypothesis that gamma rays from the galactic plane have a π°-decay (nuclear interaction) origin while those from high galactic latitudes have an electromagnetic origin. Our results cannot be taken to prove this, of course.

The values of the high energy gamma ray intensity are unchanged since our initial report. Fichtel, Kniffen and Ogelman (1969) have recently flown their balloon-borne spark chamber instrument upside down so as to measure the upward moving gamma ray albedo intensity from the Earth's disc. Their value for this intensity is about 1/3 as large as ours. We feel it unlikely that our efficiency - solid angle calibration could be off by a factor as large as three, but the possibility has been recognized in preparing Figure 1. We and the G.S.F.C. group are currently planning a recalibration of both instruments in the same tagged gamma ray beam at the California Institute of Technology electron synchrotron.

In recent months a number of groups have provided supporting evidence, though at a marginal statistical level, for a narrow line of high energy gamma ray emission from the galactic plane. These measurements are summarized in Table III. In addition, as reported in these Proceedings, Hutchinson, Ramsden and Wills (1969) have detected a somewhat enhanced emission from the galactic plane with their spark chamber aboard OGO-5.

TABLE I

Gamma Rays From Galactic Center Region

Observed Intensity 3×10^{-4} $cm^{-2}sec^{-1}rad^{-1}$

Mechanism	Responsible Momentum	Predicted / Observed
π° production by nominal*C.R. protons on known gas	$P_p > 2$ GeV/c	0.07
Bremsstrahlung by nominal*C.R. electrons on known gas	$P_e > 0.1$ GeV/c	0.01
Inverse Compton by nominal C.R. electrons on known stellar photons	$P_e > 5$ GeV/c	0.02
Inverse Compton by nominal C.R. electrons on enhanced Becklin and Neugebauer (1968) Galactic Center stellar photons	$P_e > 5$ GeV/c	0.04
Inverse Compton by nominal C.R. electrons (on Shivandan et al (1968) infra-red 8°K photons. Cowsik and Pal (1969), Shen (1969)	$P_e > 50$ GeV/c	~1
Extrapolated (3 decades) discrete x-ray sources Ogelman (1969)		~1

* By nominal cosmic ray protons and electrons we mean the measured intensity near the Earth at solar minimum.

TABLE II

Recent Reports of High Energy Gamma Ray Detection via Balloon-Borne Instruments

Cornell:	Delvaille, Albats, Greisen and Ogelman (1968) Spark Chamber; $E > 1$ GeV, $-1 < b^{II} < 1$; $\ell^{II} \approx$ A.C. to Cygnus $I = (6 \pm 3) \times 10^{-4}$ $(cm^2\text{-sec-sr})^{-1}$
Minnesota:	Valdez and Waddington (1969) Emulsion-Spark Chamber, $E > 100$ Mev. $b^{II} \approx 0$, $\ell^{II} \approx 65°$ 2σ
G.S.F.C.	Fichtel, Kniffen and Ogelman (1969) Spark Chamber; $E > 50$ Mev, $-3 < b^{II} < 3$, $\ell^{II} \sim -10$ to 25 $J = (2.2 \pm 1.1) \times 10^{-4}$ $(cm^2\text{-sec-rad})^{-1}$
Case-Western Reserve:	Frye and Wang (preprint) Spark Chamber; $E > 100$ MeV, $-3 < b^{II} < 3$, $\ell^{II} \approx 55$ to 85 $J = (4 \pm 2) \times 10^{-5}$ $(cm^2\text{-sec-rad})^{-1}$
Imperial College	Sood (preprint) Cerenkov Counters, $E > 50$ MeV, $b^{II} \approx 0$, $\ell^{II} \approx 30$ $J = (1.5 \pm .5) \times 10^{-4}$ $(cm^2\text{-sec-rad})^{-1}$ (estimated)

FIGURE CAPTIONS

Figure 1 Representative measurements of the apparently diffuse cosmic x and gamma ray spectrum. Interstellar absorption is an important effect below 1 MeV and the meaning of measurements in this range is unclear at present.

Figure 2 Distribution of high energy gamma rays relative to the Earth.

Figure 3 Distribution of detected gamma rays in galactic coordinates (upper map). Each point on the lower map is proportional to a fixed amount of time that the instrument viewed in the indicated direction.

Figure 4 Dependence of gamma ray intensity on galactic latitude. Here the data have been summed over all galactic latitudes.

Figure 5 Galactic latitude distribution for six regions of galactic longitude.

Figure 6 Dependence of gamma ray intensity near the galactic disc on galactic longitude.

Figure 7 Galactic longitude dependence of gamma rays, cumulative x-ray flux, 1.5 meter non-thermal radio noise and columnar hydrogen density.

Figure 8 Variation of gamma ray intensity with geomagnetic latitude of the satellite.

Figure 9 Pulse height distribution of gamma rays from the Earth's disc, from the Earth's horizon, from the galactic plane and from high galactic latitudes.

REFERENCES

1. Becklin E. E. and Neugebauer, G., Ap. J. 151, 145 (1968).
2. Bleeker, J. A. M., Burger, J. J., Deerenberg, A. J. M., Scheepmaker, A., Swanenburg, B. N., Tanaka, Y., Hayakawa, S., Makino, F., and Ogawa, H., Canadian Journal of Physics 46, S461 (1968).
3. Clark, G. W., Garmire, G. P., Kraushaar W. L., Ap. J. Letters 153, L203 (1968).
4. Cowsik, R. and Pal, Y., Phys. Rev. Letters 22, 550 (1969).
5. De Jager, C., and De Loore, C., Proceedings of I.A.U. Symposium #37, Rome, May 8-10, 1969.
6. Delvaille, J. P., Albats, P., Greisen, K. I., and Ogelman, H. B., Canadian Journal of Physics 46, S425 (1968).
7. Fichtel, C. E., Kniffen, D. A., and Ogelman H. B., Proceedings of I.A.U. Symposium #37, Rome, May 8-10, 1969.
8. Gorenstein, P., Kellogg, E. M., and Gursky, H., Ap. J. 156, 315 (1969).
9. Hoffman, W. F. and Frederick, C. L., Ap. J. Letters 155, L9 (1969).
10. Hutchinson, G. W., Ramsden, D., and Wills, R. D., Proceedings of I.A.U. Symposium #37, Rome, May 8-10, 1969.
11. Metzger, A. E., Anderson, E. C., Van Dil'a, M. A., and Arnold, J. R., Nature 204, 766 (1964).
12. Ogelman, H., Nature 221, 753 (1969), "Discrete Source Interpretation of Recent High Energy Cosmic Gamma Ray Measurements".
13. Peterson, L. E., Private Communication (1969).
14. Peterson, L. E., University of California at San Diego report SP68-1, July, 1967.
15. Rocchia, R., Rothenflug, R., Boclet, D., Ducros, G. and Labeyrie, J., Space Research VII (North Holland Publishing Co., Amsterdam 1967). Vol. 1, pp. 1327-1333.
16. Shen, C. S., Phys. Rev. Letters 22, 568 (1969).

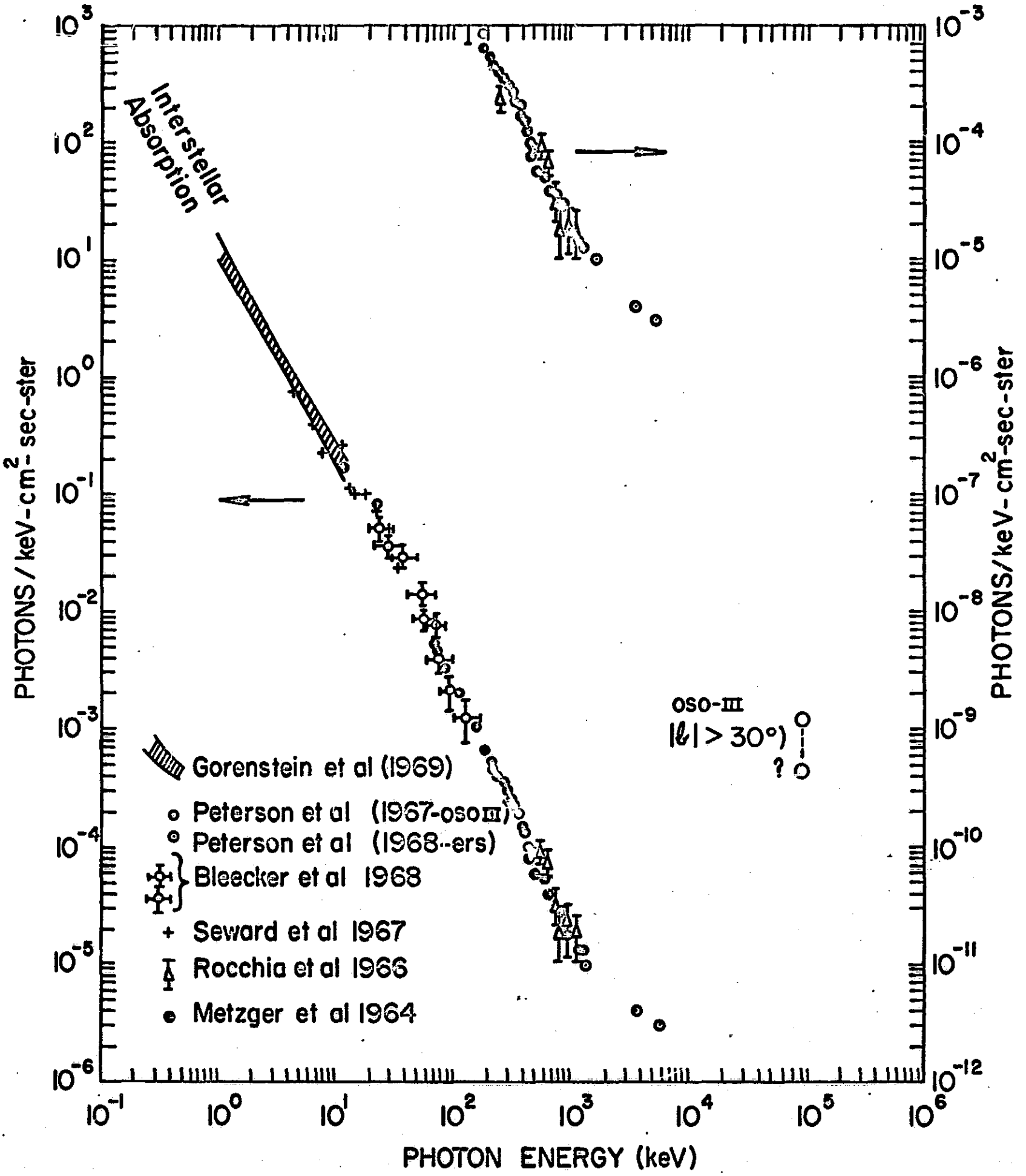
REFERENCES cont'd

17. Shivanandan, K., Houck, J. R., and Harwit, M. O., Phys. Rev. Letters 21, 1460 (1968).

18. Stecker, F. W., Proceedings of I.A.U. Symposium #37, Rome, May 8-10, 1969.

19. Valdez, J. V. and Waddington, C. J., Ap. J. (Letters) 156, L85.

20. Vetter, J., Matteson, J. L., Gruber, D., and Peterson, L. E., Proceedings of I.A.U. Symposium #37, Rome, May 8-10, 1969.


Interstellar Absorption
OSO-III
|b| > 30°)
?
Gorenstein et al (1969)
Peterson et al (1967-oso III)
Peterson et al (1968--ers)
Bleecker et al 1968
Seward et al 1967
Rocchia et al 1966
Metzger et al 1964
PHOTONS / keV-cm²-sec-ster
PHOTONS/keV-cm²-sec-ster
PHOTON ENERGY (keV)

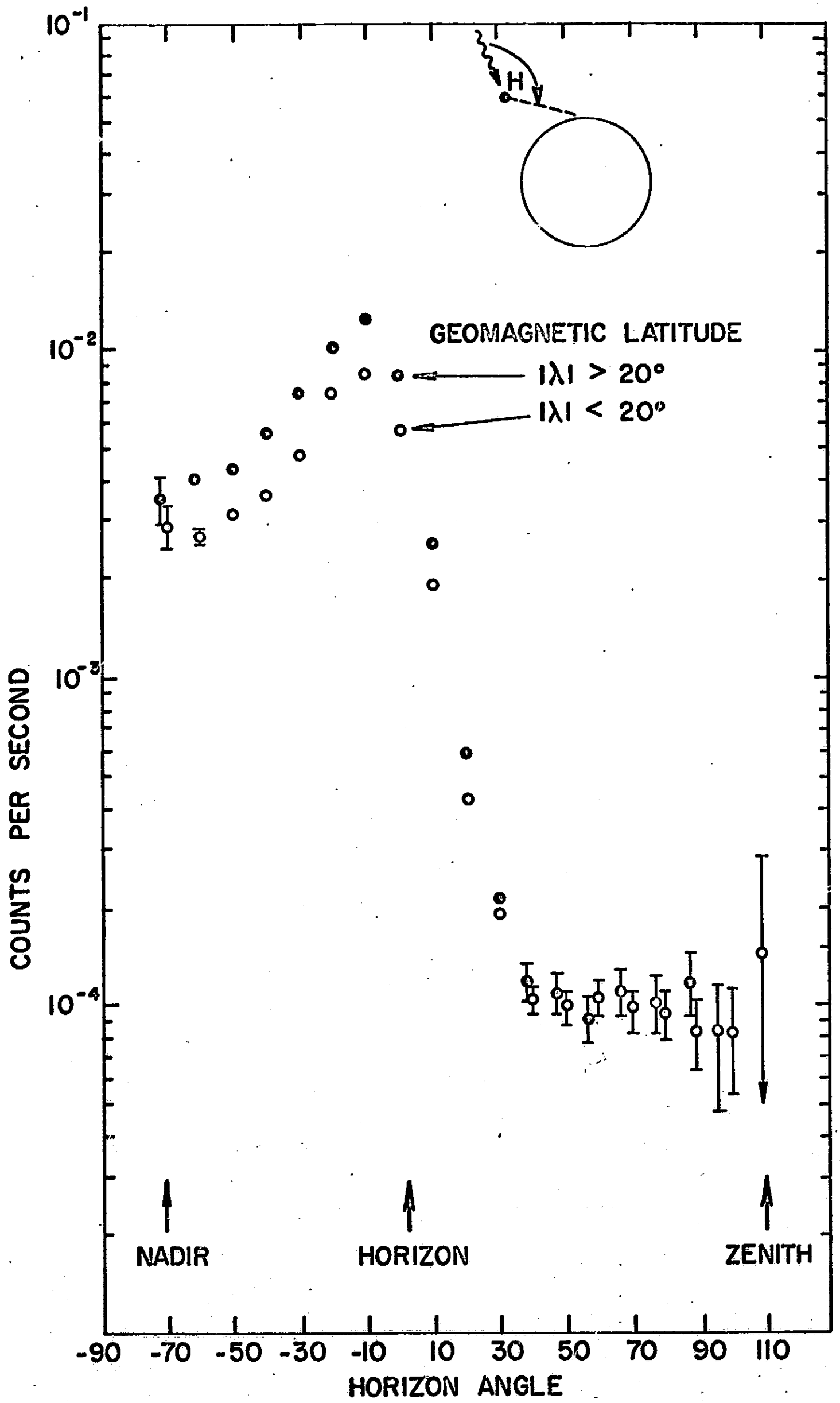
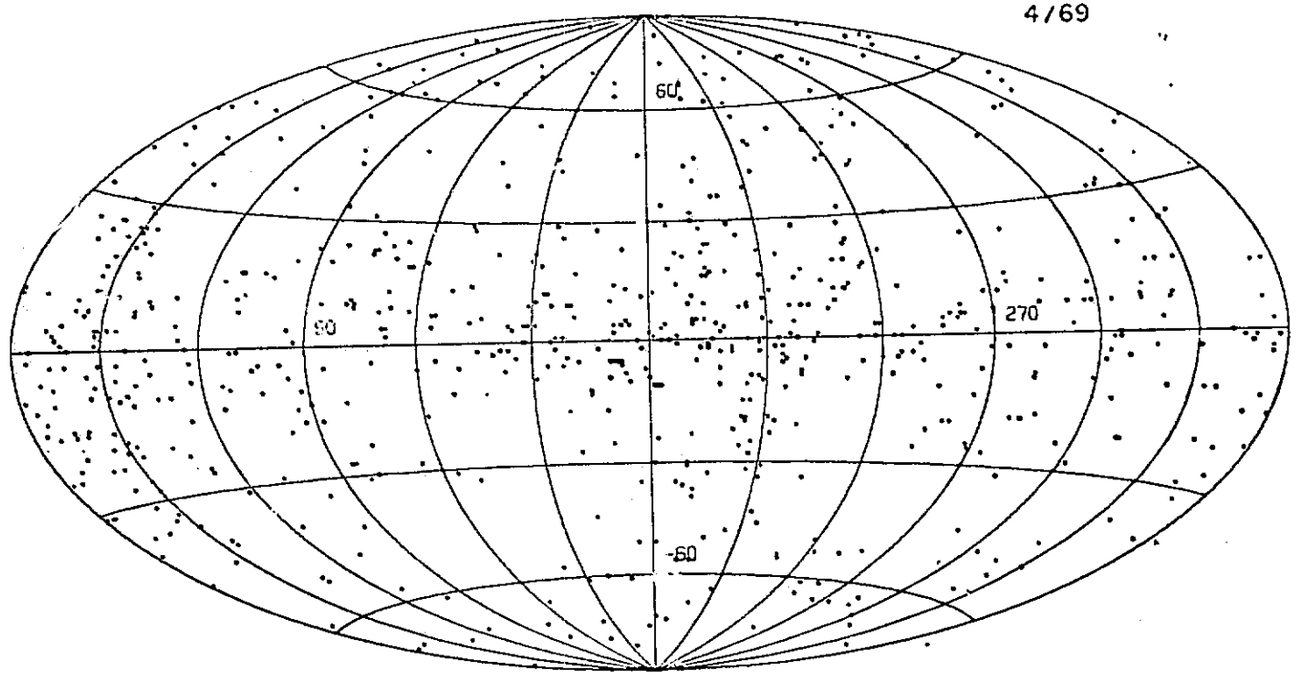
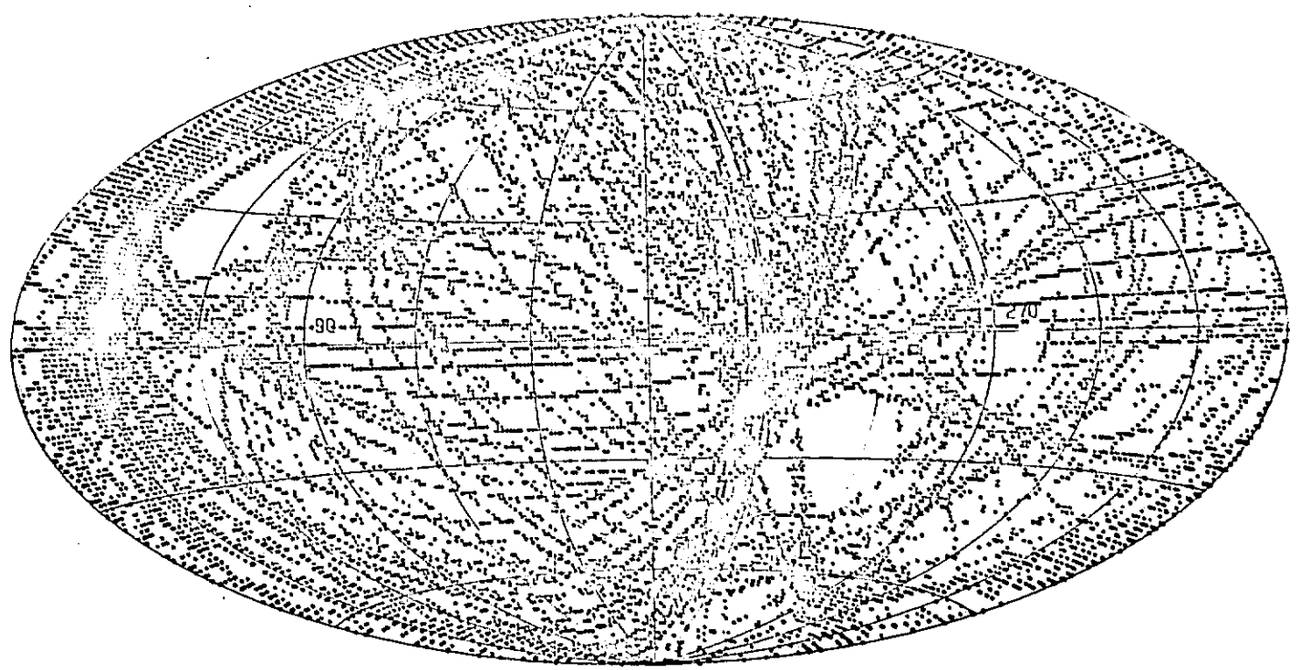

H
GEOMAGNETIC LATITUDE
|λ| > 20°
|λ| < 20°
COUNTS PER SECOND
10^-1
10^-2
10^-3
10^-4
NADIR
HORIZON
ZENITH
-90 -70 -50 -30 -10 10 30 50 70 90 110
HORIZON ANGLE

Fig 2

GALACTIC COORDINATES



Cosmic Gamma-ray Events



Exposure Events

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

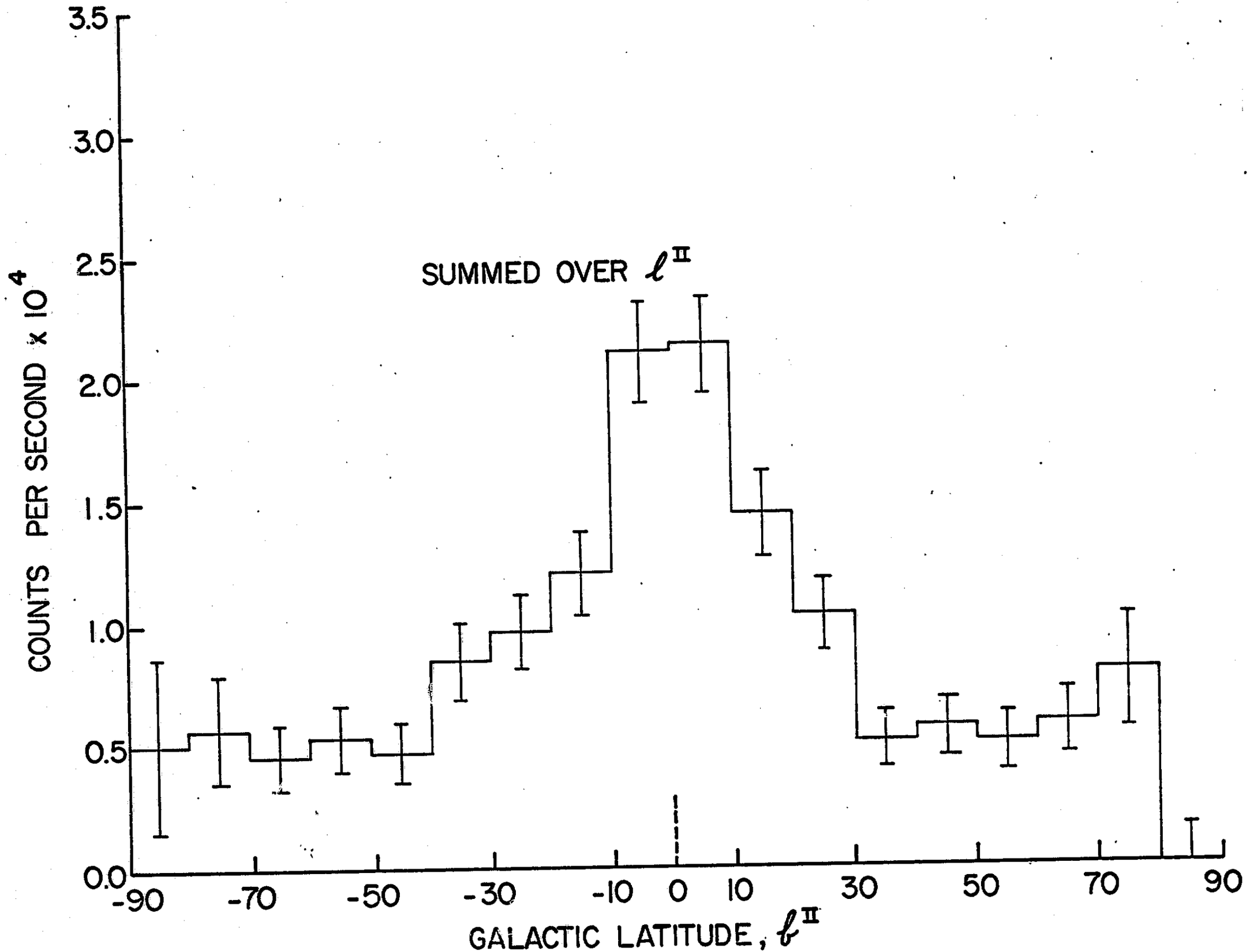
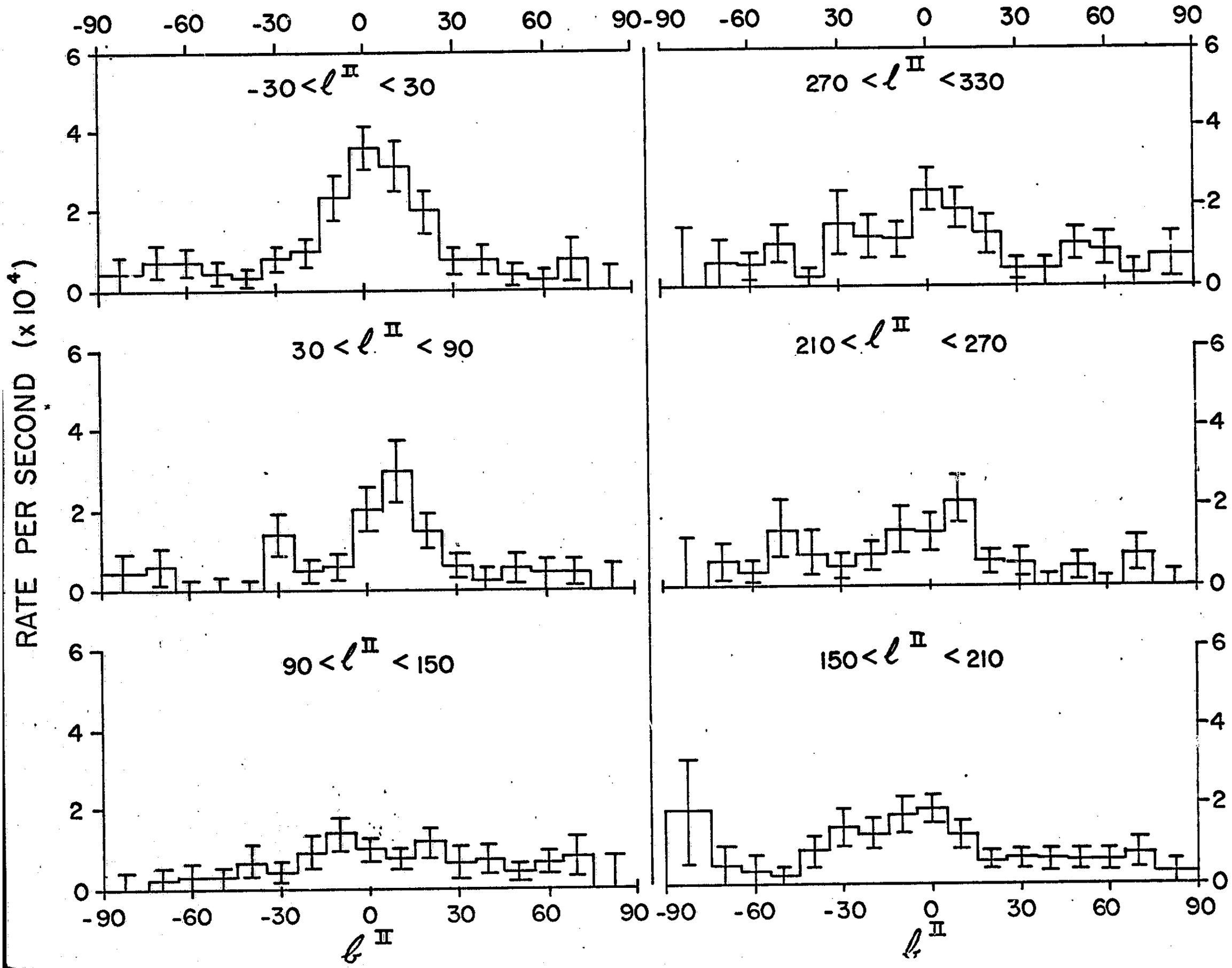

SUMMED OVER ℓ^{II}
COUNTS PER SECOND x 10^4
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-90
-70
-50
-30
-10
0
10
30
50
70
90
GALACTIC LATITUDE, b^{II}

Fig. 4


RATE PER SECOND (x 10⁴)
-30 < ℓ^II < 30
270 < ℓ^II < 330
30 < ℓ^II < 90
210 < ℓ^II < 270
90 < ℓ^II < 150
150 < ℓ^II < 210
ℓ^II
ℓ^II

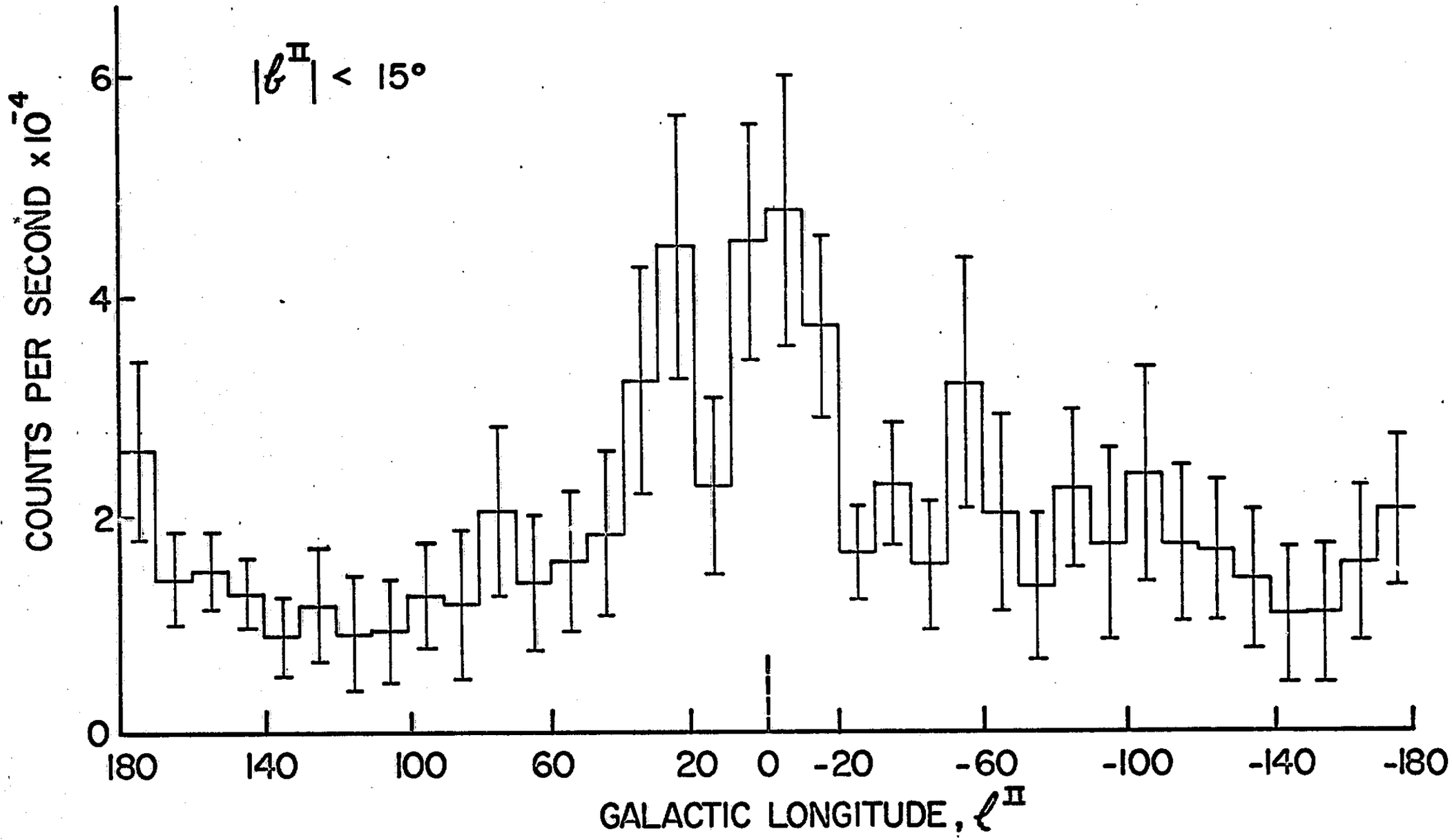
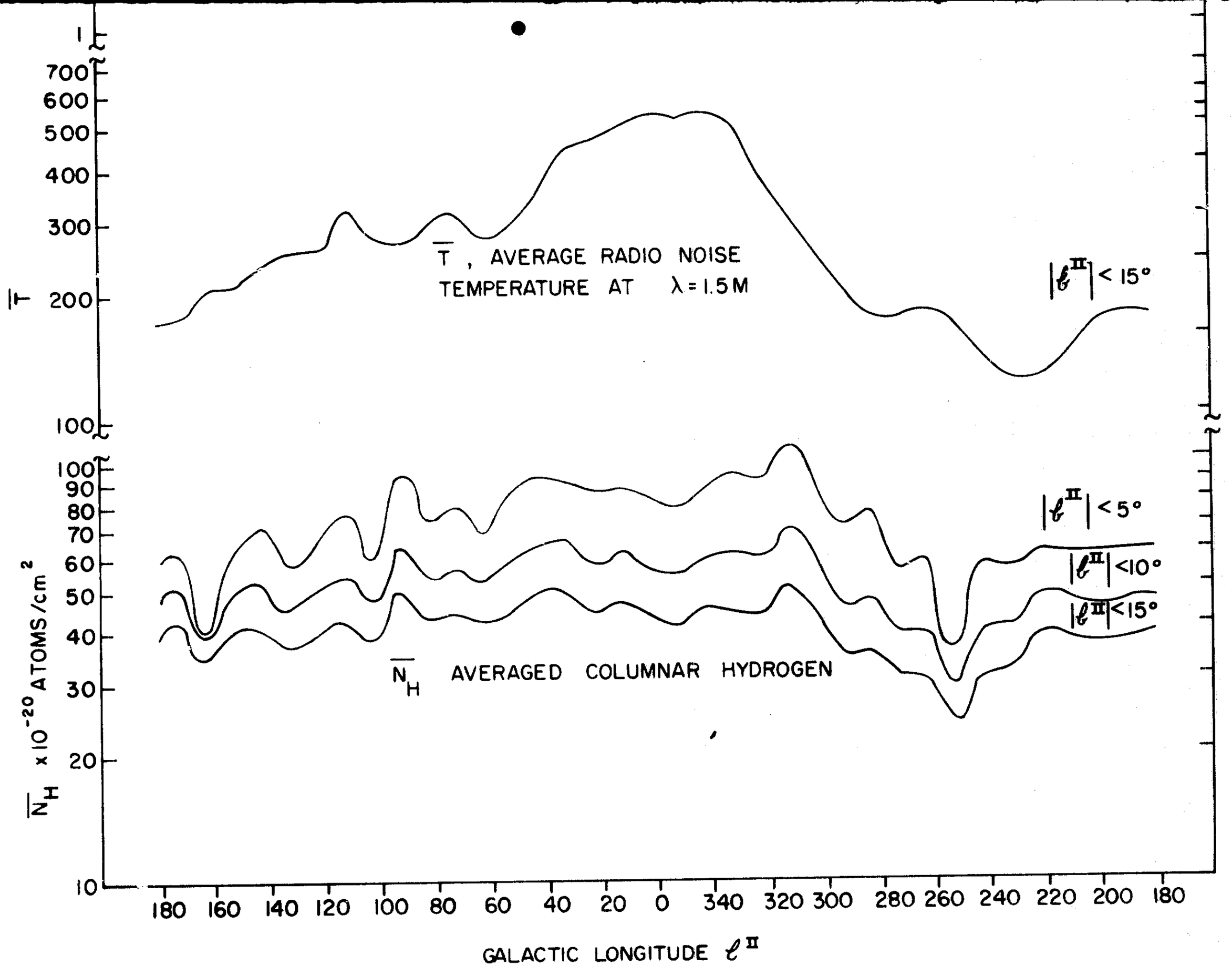
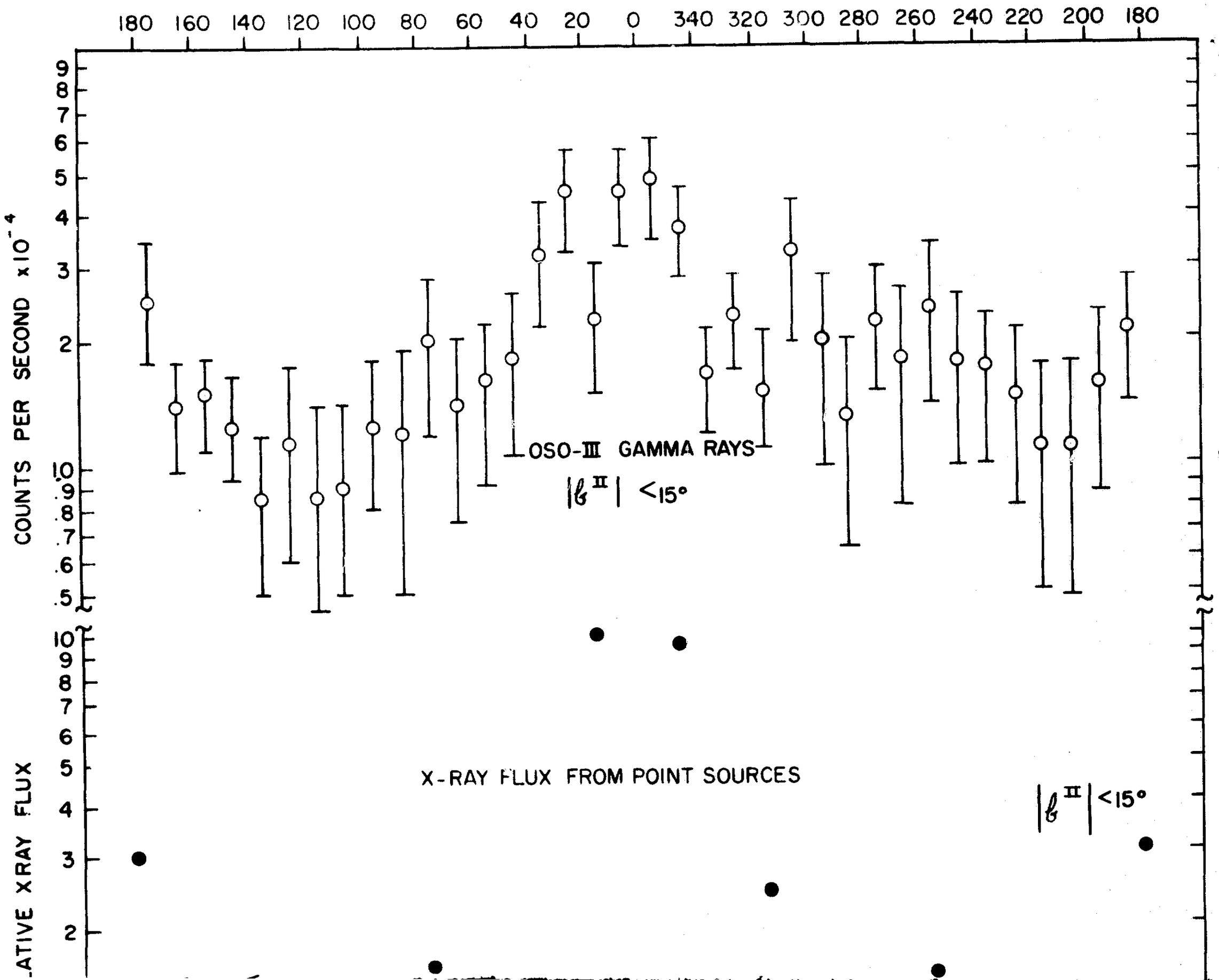

$|b^{II}| < 15°$
COUNTS PER SECOND x 10^{-4}
0
2
4
6
180
140
100
60
20
0
-20
-60
-100
-140
-180
GALACTIC LONGITUDE, ℓ^{II}

Fig. 6


$\overline{T}$, AVERAGE RADIO NOISE TEMPERATURE AT λ = 1.5 M
$|\ell^{II}| < 15°$
$|\ell^{II}| < 5°$
$|\ell^{II}| < 10°$
$|\ell^{II}| < 15°$
$\overline{N}_H$ AVERAGED COLUMNAR HYDROGEN
$\overline{N}_H \times 10^{-20}$ ATOMS/cm^2
GALACTIC LONGITUDE ℓ^{II}
1
700
600
500
400
300
200
100
100
90
80
70
60
50
40
30
20
10
180 160 140 120 100 80 60 40 20 0 340 320 300 280 260 240 220 200 180


180 160 140 120 100 80 60 40 20 0 340 320 300 280 260 240 220 200 180
COUNTS PER SECOND x10^-4
OSO-III GAMMA RAYS
|b^II| <15°
RELATIVE XRAY FLUX
X-RAY FLUX FROM POINT SOURCES
|b^II| <15°

8

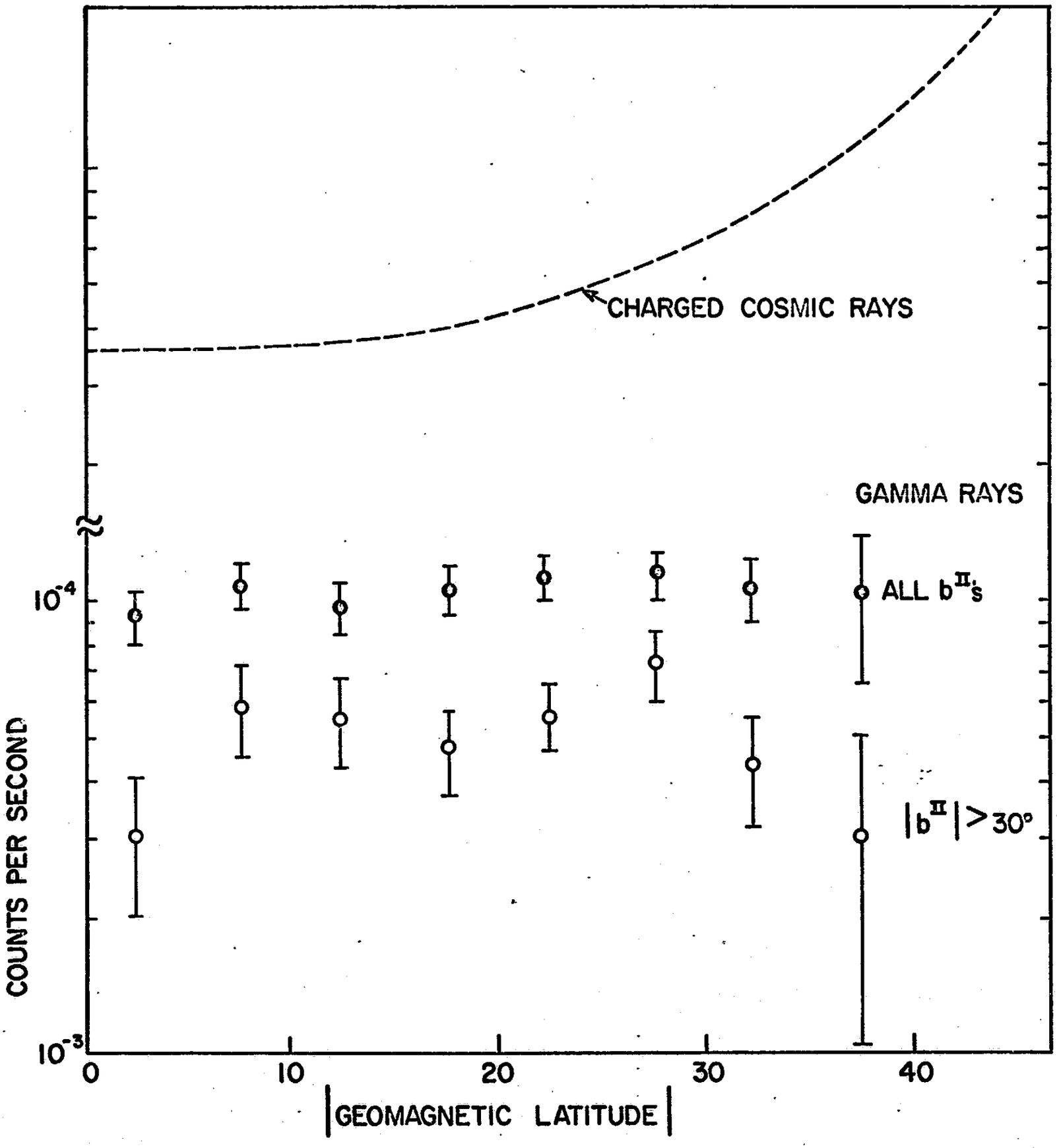

CHARGED COSMIC RAYS
GAMMA RAYS
ALL b^{II}'s
$|b^{II}| > 30°$
COUNTS PER SECOND
10^{-4}
10^{-3}
0
10
20
30
40
|GEOMAGNETIC LATITUDE|

Fig 8

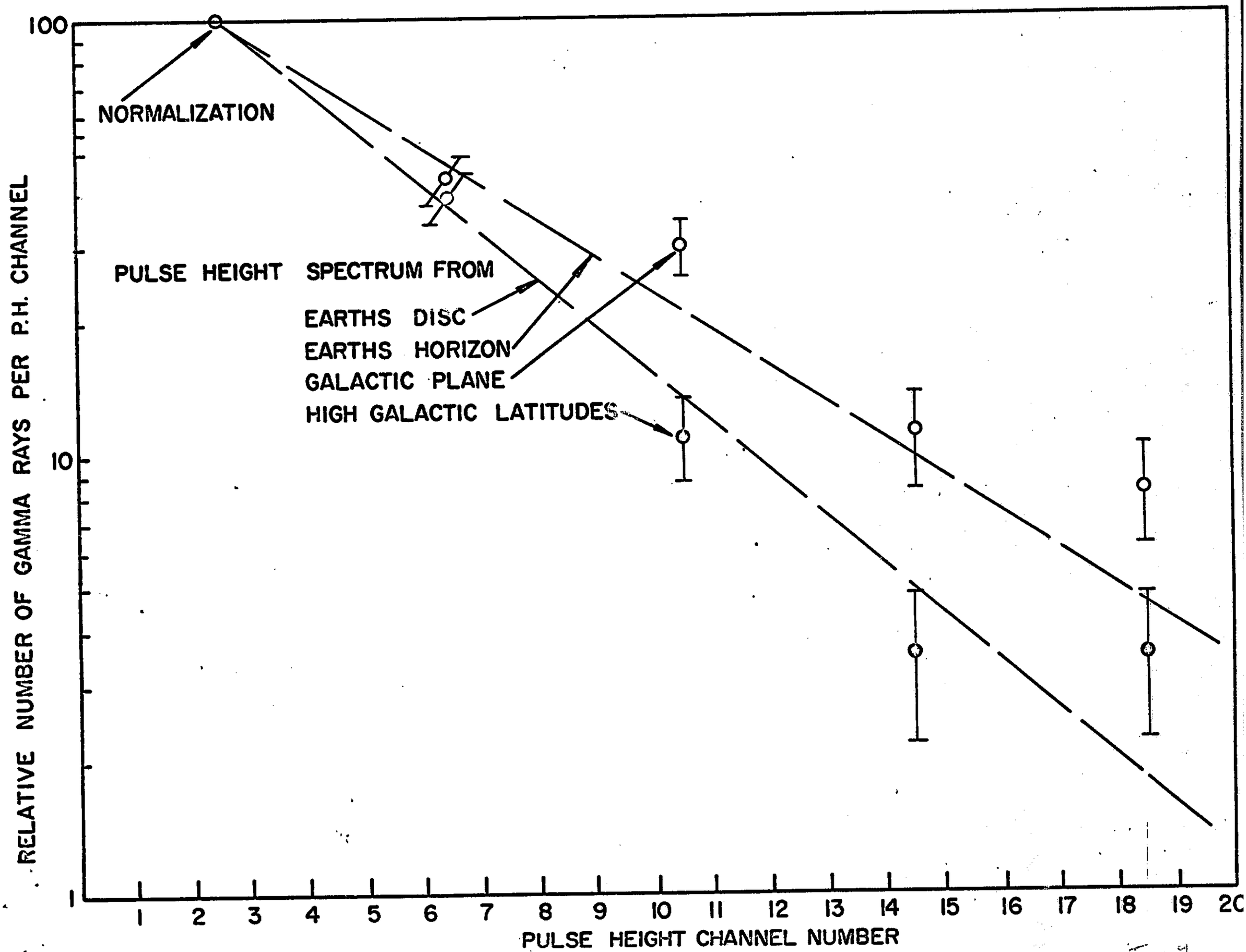

100
10
1
NORMALIZATION
PULSE HEIGHT SPECTRUM FROM
EARTHS DISC
EARTHS HORIZON
GALACTIC PLANE
HIGH GALACTIC LATITUDES
RELATIVE NUMBER OF GAMMA RAYS PER P.H. CHANNEL
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
PULSE HEIGHT CHANNEL NUMBER

Fig 9