NASA
Technical Memorandum **79651**

Galactic Plane Gamma Radiation

(NASA-TM-79651) GALACTIC PLANE GAMMA RADIATION (NASA) 39 p HC A03/MF A01 CSCL 03B
N79-18877
Unclas
G3/93 17934

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September 1978

National Aeronautics and
Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

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ABSTRACT

Analysis of the complete data from SAS-2 accentuates the fact that the distribution of galactic γ radiation has several similarities to that of other large-scale tracers of galactic structure. The radiation is primarily confined to a thin disk, which exhibits offsets from b=0° similar to the warping of the galactic disk seen at radio frequencies. Enhancements in the γ radiation are seen in the galactic center and in regions deduced from 21 cm radio data to be associated with spiral arms. The principal distinction of the γ-ray distribution is a stronger contrast in intensity between the region $310° < \ell < 45°$ and regions away from the center than can be explained on the basis of the best current estimates of the total interstellar matter and a uniform cosmic ray density. This result is attributed to a variation in the cosmic ray density as a function of position in the Galaxy. The distribution of γ-rays in both latitude and longitude is consistent with a model in which the galactic cosmic rays have a density in the plane which is correlated with the matter density on the scale of galactic arms and have a scale height of about 1 kpc.

The diffuse galactic γ-ray energy spectrum shows no statistically significant variation with direction, and the spectrum seen along the plane is the same as that derived for the galactic component of the γ radiation at high latitudes. In terms of a power law fit, the differential photon spectral index is 1.70 ± 0.14 between 35 MeV and about 200 MeV. Within the experimental uncertainties, this spectrum is consistent with the γ radiation resulting from the combination of cosmic

ray nucleon interactions with interstellar matter, cosmic ray electron bremsstrahlung, and Compton collisions of photons with cosmic ray electrons. The electron contribution is estimated to represent about one third of the total radiation above 100 MeV.

The uniformity of the galactic γ-ray energy spectrum, the smooth decrease in intensity as a function of galactic latitude, and the absence of any galactic γ-ray sources at high latitudes argue in favor of a diffuse origin for most of the galactic γ radiation, rather than a collection of localized sources. The contribution of discrete sources is, however, very uncertain, primarily because of the limited angular resolution of the SAS-2 and COS-B instruments.

All the localized sources identified in the SAS-2 data are associated with known compact objects on the basis of observed periodicities, except γ195+5. Excluding those SAS-2 sources observed by COS-B and two other excesses (CG312-1 and CG333+0) visible in the SAS-2 data associated with tangential directions of spiral arms, there are eight remaining new sources in the COS-B catalog (Hermsen et al. 1977). The SAS-2 upper limits are consistent with all of these except CG176-7, for which the SAS 2 95% confidence limit of 0.8×10^{-6} photons cm^{-2} s^{-1} above 100 MeV is a factor of 2 below the flux reported by COS-B.

Subject headings: gamma rays: general -- cosmic rays: general -- galaxies: structure -- gamma rays: sources -- galaxies: Milky Way

I. INTRODUCTION

The most intense celestial high energy γ radiation observed is that from the galactic plane (Kraushaar et al. 1972; Kniffen et al. 1973; Fichtel et al. 1975; Bennett et al. 1977b). The γ-ray intensity is particularly strong over a band of about 90° in longitude in the general direction of the galactic center with variations in intensity clearly associated with galactic features (Fichtel, et al. 1975). There has been great interest in interpreting the γ radiation because of its potential signficance in understanding galactic structure and dynamics. The radiation itself is believed to come largely from cosmic ray interactions with interstellar matter (Bignami and Fichtel 1974; Paul et al. 1974; Schlickeiser and Thielheim 1974; Bignami et al. 1975; Stecker et al. 1975; Stecker 1976; Puget et al. 1976; Paul et al. 1976; Kniffen, Fichtel and Thompson 1977), but with contributions from cosmic ray electron interactions with interstellar photons (Cowsik and Voges 1974; Stecker, 1977; Fichtel, Simpson and Thompson 1978) and from discrete sources (Ögelman et al. 1976; Hermsen et al. 1977; Paul et al. 1978; Bignami et al. 1978; Strong et al. 1977; Higdon and Lingenfelter 1976).

In an earlier paper (Fichtel et al. 1975), the preliminary γ-ray results for the galactic plane deduced from the SAS-2 data were presented, and the intensity as a function of longitude has subsequently been presented in more detail by Kniffen, Fichtel and Thompson (1977). Here the final SAS-2 γ-ray results for the galactic plane will be presented, including longitude and latitude distributions and energy spectral information as a function of position. It will be seen that the results related to the galactic plane as well as those on the galactic component at high latitudes are consistent with the majority of the radiation coming from cosmic ray interactions, although the experimental results from SAS-2 and COS-B do not permit a definitive estimate of the point source contribution.

The enhancement seen in the γ radiation between longitudes 310° and 45° is larger than would be expected from a uniform cosmic ray density interacting with the interstellar matter distribution as currently estimated (Kniffen, Fichtel and Thompson 1977), thus supporting the concept of a cosmic ray density which varies with position in the Galaxy.

II. EXPERIMENT AND DATA ANALYSIS

The present work is based largely on data obtained with a γ-ray telescope flown on the Second Small Astronomy Satellite (SAS-2) during the period from November 1972 to June 1973. The γ-ray instrument is a 32-level magnetic core spark chamber system surrounded by an anticoincidence scintillator and triggered by a set of directional scintillator-Cerenkov counter telescopes in anticoincidence with the outer scintillator. A discussion of the instrument is given by Fichtel et al. (1975) along with a description of the satellite characteristics. A more detailed description of the detector alone is given by Derdeyn et al. (1972) and of the spacecraft by Townsend (1969).

The data have been analyzed in accordance with procedures described by Fichtel et al. (1975). The analysis used the detailed sensitivity calculation procedures, the angular response function, the accuracy of the measurement of the γ-ray arrival direction, and the energy resolution determined in the calibration outlined in that paper, as well as extensive (>80%) rescans of the γ-ray events to search for possible inefficiencies, and selected Earth albedo measurements during the satellite's lifetime to check for possible changes in detector performance. Small changes were found and appropriate correction factors included. For purposes of orientation, Fig. 1 shows the region of the sky covered by the SAS-2 γ-ray observations.

Energy estimates of the individual γ-rays are based on measurements of the multiple Coulomb scattering of the two secondary electrons in the tungsten plates between the spark chambers. Meaningful information on the γ-ray energy can be obtained from the threshold (about 30 MeV) to about 200 MeV, above which this method of energy determination is no longer useful because of the predominance of the "reading error" in the scattering measurement. The limited statistics available here do not permit the least squares method (e.g. Trombka and Schmadebeck, 1968) to be used to deduce an energy spectrum. The primary spectrum may, however, be assumed to be represented by a simple smooth curve or the sum of two simple smooth curves over the relevant energy range, and the most likely parameters for the assumed spectral shape can be calculated using the experimental data and the measured energy and angle dependent distribution functions. This method was used here with the spectra being assumed to either a power law of the form

$$\frac{dJ}{dE} = KE^{-a}$$

or a combination of this spectrum and a cosmic-ray nucleon-nucleon interaction γ-ray spectrum (e.g. Stecker 1970).

The uncertainty in the measured energy is sufficiently large that the energy resolution function can play a role in the intensity determination, depending on the exact spectral shape. For example, the intensity above some energy such as 100 MeV, cannot be determined directly from the number of γ-rays with measured energies above that energy, but the distribution in energy of the γ-rays must also be taken into account.

III. RESULTS AND DISCUSSION

a) Spatial Distribution

The distribution in galactic longitude of γ-rays with energies above 100 MeV is given in Figure 2. These data are accumulated in 2.5 degree longitude bins and are summed over the latitude interval from -10° to 10°. The essential features of this distribution are very similar to those presented previously by Kniffen, Fichtel and Thompson (1977). The most obvious features, excluding strong discrete sources, are the large overall enhancement extending from 310° to 45° of galactic longitude and the intensity peaks near longitudes 312°, 332°, 342°, 37° and the galactic center. An overall increase in the estimated intensity relative to earlier presentations (Fichtel et al., 1975; Kniffen, Fichtel and Thompson 1977), as well as some minor changes in the details of the distribution, have resulted from a more precise determination of the galactic energy spectrum and a more thorough knowledge of the detector response, as discussed in the previous section.

The longitude distribution for data summed over the latitude interval from -4° to 4° is presented in Figure 3. The intensities shown have been corrected for the detector angular resolution. Although essential features of the distribution in Figure 2 remain, some details are different because of fluctuations resulting from the reduced statistics and the reduced influence of sources, especially γ195+5 and PSR0531+21, which do not lie directly on the galactic equator. The features near galactic longitudes of 312°, 332°, 342°, 37° and the galactic center, remain with similar relative intensities, within statistics, implying the sources of the emission lie within the galactic matter disk. The directions correspond approximately to the tangential directions of galactic spiral arms and the the galactic center.

Figure 4 shows the longitude distribution for γ-rays with energies from 35 to 100 MeV summed over the latitude interval from -10° to +10°. Between longitudes 300° and 30° around the galactic center, the distribution is consistent with that observed for energies above 100 MeV. Individual peaks are less visible due to the reduced angular resolution at these lower energies. Between longitudes 30° and 60°, the 35<E<100 MeV distribution falls off more slowly than the E>100 MeV distribution. This difference is of marginal statistical significance, but does suggest that this region may not be characteristic of the rest of the galactic plane.

The distributions in galactic latitude for γ-rays above 100 MeV and in the interval from 35 to 100 MeV are given in Figures 5 and 6. The boundaries of the longitude intervals have been chosen to elimate the influence of the stronger discrete sources. In the range $320°<\ell<40°$, a 3.4 standard deviation enhancement is visible in Figure 5 in the latitude range $6°<b<20°$ relative to the range $-20°<b<-6°$. Taken together with the excess seen at negative latitudes in the galactic anticenter, this enhancement has been interpreted as γ-ray emission produced in the local concentration of clouds known as Gould's Belt (Fichtel et al. 1975; Thompson et al. 1977). A similar excess at positive latitudes near the galactic center has been reported based on the COS-B data (Bennett et al. 1977b; Lebrun and Paul 1978).

The latitude distributons for $90°<\ell<175°$ have a pronounced peak at about $b=2°$, while the E>100 MeV distribution for $205°<\ell<250°$ has an excess at negative latitudes (the 35<E<100 MeV distribution for this range showsno clear peak, but within statistical uncertainties is consistent with the high energy distribution). These offsets are qualitatively similar to the "hat brim" effect visible in the radio observations and due to the large-scale warping of the galactic disk (see, for example, the summary of Burton (1976), based on the data of Weaver and Williams, 1973). Using a Gaussian fit to the latitude distributions as an approximation provides a quantitative estimate of the effect. A χ^2 analysis yields centroids of the two distributions of $+2°\pm0.5°$ for $90°<\ell<175°$ and $-2°\pm0.5°$ for $205°<\ell<250°$, values which are consistent with those obtained from radio observations. This agreement is a further indication that the γ-ray emission is related to the large-scale structure of the Galaxy.

The broad distribution in galactic latitude for the longitude intervals away from the galactic center gives strong evidence that the observed γ-rays are largely produced locally (within a few kiloparsecs) whereas the narrower distribution seen toward the inner parts of the Galaxy implies that a large part of the emission comes from more distant (>3 kpc) features. Fichtel, Simpson and Thompson (1978) have shown that a more detailed study of the high latitude distribution also shows an important contribution from local regions which must be considered in the interpretation of the all sky diffuse radiation.

b) Energy Spectrum

The galactic γ radiation is believed to result mostly from the interactions of cosmic rays, including cosmic ray nucleon interactions with matter, cosmic ray electron bremsstrahlung, and cosmic ray electron Compton interactions (e.g. Kniffen, Fichtel and Thompson 1977). Theoretical spectra calculated for bremsstrahlung and Compton interactions are well represented by power laws. The recent work of Fichtel, Simpson and Thompson (1978), together with data at higher energies (Paul et al. 1978) and lower energies (Kniffen et al. 1978), has shown that the bremsstrahlung and Compton components appear to be sufficiently large that the combined spectrum, including both nucleonic and electromagnetic components, cannot be distinguished from a power law with the energy resolution of this experiment. Therefore, in the analysis here, the power law form is assumed and the exponent determined.

Table 1 gives the power law exponents deduced for seven different regions of the galactic plane and for all of these regions combined.

The uncertainties associated with the exponents for individual regions are dominated by statistics; however, the uncertainty in the exponent for the combined data also reflects the systematic effects. The major systematic uncertainties are related to the accuracy to which the energy resolution functions and the absolute average energy could be determined.

Excluding the four strong sources identified in Figure 2, there is no significant evidence for a variation of the energy spectrum along the galactic plane. Similar conclusions for parts of the galactic plane were based on preliminary results from SAS 2 (Fichtel et al. 1977) and COS-B (Paul et al. 1978). The overall spectral index of 1.70 ± 0.14 is consistent with the value of 1.5 ± 0.3 deduced for the galactic component of the high latitude ($|b|>10°$) radiation (Fichtel, Simpson and Thompson 1978). This agreement, although of limited statistical weight, is important because there are no known local galactic sources contributing to the high latitude radiation. If galactic sources make a major contribution to the galactic plane radiation, their combined spectra must be similar to that of the high latitude diffuse galactic radiation. A more likely explanation may be that point sources are not a major contributor to the galactic plane emission after subtraction of the strong sources identified in Figure 2.

Figure 7 shows the spectrum of the galactic γ radiation for a region near the galactic center ($355° < \ell < 15°$). The experimental results are in agreement in both shape and absolute intensity. These results indicate that the contribution from cosmic ray electron interactions is higher by about a factor of 2 than expected from the interstellar electron intensities obtained by correcting the intensity observed near the earth for the effects of solar modulation (Daugherty, Hartman and Schmidt 1975). The interstellar electron spectrum required lies within the range of allowable values, considering the large demodulation uncertainties (Shukla and Cesarsky 1977; Schlickeiser and Thielheim, 1978), but is near the high side of this range. The calculated curve (Kniffen et al. 1978) shown on this figure takes this relatively high electron density into account and is seen to be consistent with the data.

c) Diffuse Galactic Component

It has been known for over two decades (e.g. Hayakawa 1952; Hutchinson 1952) that the interaction of cosmic rays with interstellar matter would lead to diffuse galactic γ-ray emission which could be used in the study of the galactic matter distribution and the cosmic ray gas, responsible for what is believed to be the most dynamic of the expansive pressures in the Galaxy. More recently it has been more fully realized that, in addition to the cosmic ray nucleon matter interactions and the electron bremsstrahlung, Compton emission is also a small but not negligible contributor.

Interpretation of the diffuse component of the galactic γ radiation clearly requires a knowledge of the galactic matter and cosmic ray distributions. Information about the matter distribution is drawn largely from radio observations, particularly the 21 cm emission of neutral atomic hydrogen and the 2.6 mm emission from carbon monoxide, which is considered to be a tracer of molecular hydrogen in the Galaxy. On the basis of the interpretation of the γ-ray data (e.g. Bignami and Fichtel 1974; Paul et al. 1974; Schlickeiser and Thielheim 1974; Bignami et al. 1975; Stecker et al. 1975; Schlickeiser 1976; Puget et al. 1976; Paul et al. 1976), there appear to be good reasons for believing that the cosmic ray density is enhanced where the matter density is greatest, and this concept of coupling is supported by theoretical considerations (Parker 1966, 1969).

One recent theoretical treatment of the diffuse galactic γ-ray emission is that of Kniffen, Fichtel and Thompson (1977), who also reviewed the earlier work. These authors assume that the cosmic rays are correlated with the galactic matter on the scale of galactic arms, the matter is preferentially concentrated in spiral arms (using the model of Simonson (1976) based on 21 cm observations and the density wave theory), and the radial distribution of both atomic and molecular hydrogen is that given by Gordon and Burton (1976), modulated to correspond to the spiral arm pattern. The scale height of the cosmic rays is taken to be about 1 kpc based on the equivalent disk thickness of the nonthermal continuum radio emission estimated by Baldwin (1967, 1976) and on the assumption that the scale heights for the cosmic rays and magnetic fields are the same. The exact arm to interarm matter density ratio is not critical as long as it is about 2:1 or greater. Figure 8 shows the γ-ray intensities predicted by this model, using updated parameters for the γ-ray production source function and the local interstellar matter density as indicated by Fichtel, Simpson and Thompson (1978). Also shown is the component due to Compton Scattering. The electron interactions account for about one-third of the total γ-ray emission above 100 MeV. There seems to be quite reasonable agreement with the experimental data, especially in view of the uncertainties in the knowledge of the mass distribution, particularly in the galactic center region, and the uncertain contribution of point sources. Notice in particular that the individual maxima observed in the γ radiation from the central region are correlated with those predicted to result from spiral arm tangents. Further, the intensity at the cent is reproduced, and the general ratio between the anticenter region and the central (320°<ℓ<40°) region of the Galaxy is well explained. There may be a small additional component at the galactic center, such as Compton scattering from a high photon density, but there is not a compelling need for such a component from the γ-ray data. In Figure 8, there are regions between longitudes 100°-140°, 35°-55°, and 275°-285° in which the model does not reproduce the intensities observed. Statistical fluctuations might account for the apparent features in the ranges 100°-140° and 275°-295°, but not the excess between longitudes 35° and 55°. Two dimensional histograms do not indicate single point sources in this region, although groups of sources are a possible explanantion. Regions of enhanced cosmic ray density could also produce the observed distributions.

A constant cosmic ray density, as might be predicted in the simplest concept of a universal cosmic ray model, gives too small a ratio between the γ-ray intensity from the central region and that from the outer parts of the Galaxy, and does not give rise to the significant peaks seen along galactic spiral arm features in the γ-ray data. The failure of the constant cosmic ray model in this way supports the concept of a cosmic ray gradient in the Galaxy.

Instead of the approach discussed here, one might consider "turning the problem around" and using the existicg γ-ray data to deduce the galactic structure (e.g. Puget and Stecker 1974; Strong 1975; Caraveo and Paul 1978). Whereas this method is a potentially powerful means of determining galactic structure, for the present several difficulties exist, These are: (1) the large statistical uncertainty in the points which cause the deduced distribution to be far from unique in the sense of principal features, (2) the limited angular accuracy which makes it impossible to see the fine features of a distribution and difficult to see the principal ones even with a larger number of photons, and (3) the remaining point source contributions which cannot be removed because the angular accuracy is not sufficient to resolve the individual point sources. A proper analysis of this type must, therefore, await data of better angular accuracy and statistical weight.

d) Localized Galactic Sources

SAS-2 observed four strong localized sources along the galactic plane: the Crab pulsar, PSR0531+21 (Kniffen et al. 1974); the Vela pulsar, PSR0833-45 (Thompson et al. 1975); Cygnus X-3 (Lamb et al. 1977); and the still-unidentified γ195+5 (Thompson et al., 1977). In addition, two other radio pulsars were tentatively identified in the SAS-2 data (Ögelman et al. 1976). On the basis of selected regions of the galactic plane, the COS-B collaboration has reported a total of 13 localized excesses (Hermsen et al. 1977). Two of these are the Crab and Vela pulsars and two others match closely the positions of the other strong sources seen by SAS-2. Of the nine remaining excesses in the COS-B catalog, CG312-1 and CG333+0 are visible in the SAS-2 data (see Figure 2) and have been associated with tangential directions to galactic spiral arm features (Bignami et al., 1975). For the other seven, there is no evidence for enhancements in the SAS-2 data at the COS-B positions, but the upper limits to localized source emission do not conflict with the fluxes reported by Hermsen et al., (1977), with one exception. That is CG176-7, for which the 95% confidence upper limit deduced from SAS-2 data is 0.8×10^{-6} photons $cm^{-2}s^{-1}$ for γ-rays above 100 MeV compared to the reported COS-B flux of about twice this value. The strongest case for a long term time variation is that associated with Cygnus X-3, seen in the data from the SAS-2 γ-ray telescope (Lamb et al. 1977) during March 1973 with the characteristic 4.8 h periodicity observed at other wavelengths. This periodicity was not seen by COS-B for the position of Cygnus X-3 or for the slightly displaced source CG78+1 (Bennett et al. 1977c) during November and December 1975 when the 2-6 keV x-ray emission was observed to be in a very low state (Parsignault et al. 1977).

With regard to short-term time variations, the existence of γ-ray counterparts to some radio pulsars is well-estiblished. In addition, a 59 s periodicity has been suggested by data from both SAS-2 (Thompson et al. 1977) and COS-B (Masnou et al. 1977), but it should be emphasized that the statistical significance of this periodicity is not sufficiently strong for it to be considered established.

Of all the possible γ-ray sources, only the pulsars and Cygnus X-3 have identifications with objects seen at other wavelengths.

Evidence of possible correlations with other observed galactic features (Strong 1977; Maraschi et al. 1978; Julien and Helmken 1978; Gregory and Taylor 1978; Lamb 1978; Coe et al. 1978; Massaro and Scarsi 1978) is not yet sufficiently compelling to add any insight. Considering the absence of proven time variations and the limited angular resolution of the SAS-2 and COS-B instruments, it is not known whether the other enhancements are point sources or extended features. Nevertheless, the question of the possible contributions of discrete sources affects the interpretation of the observed galactic γ-ray emission.

Ogelman et al. (1976); Strong et al. (1977), and Kniffen et al. (1977) have shown that γ-ray counterparts of pulsars are unlikely to account for more than five to ten percent of the observed galactic γ-ray intensity. Little is known of other possible classes of sources. Bignami et al. (1978) have shown that under the assumption that all of the suggested sources are discrete, the implied luminosity distribution over the entire Galaxy can account for 40% or more of the observed γ-ray emission above 100 MeV. Some limitations to discrete source contributions can be inferred from the existing γ-ray data. As shown in the data given here and in the COS-B data (Paul et al. 1978) there is no compelling evidence for any spectral variation in the galactic γ-ray emission as a function of position in the galaxy. Furthermore, the spectrum matches that of the more local high latitude galactic γ radiation (Fichtel, Simpson and Thompson 1978). In contrast to the large-scale uniformity of the galactic γ-ray energy spectrum, significant differences from this spectrum have been reported for some known localized sources (Thompson et al. 1977; Bennett et al. 1977; Masnou et al. 1977).

In light of the above discussion, it is too early to make definitive statements concerning the relative contributions of discrete sources and diffuse emission to the observed galactic γ-radiation. From theoretical and experimental considerations, it is likely there is a considerable emission from γ-rays produced in cosmic ray interactions with the interstellar gas and with photons. Some contributions from discrete sources are clearly present, but the extent of their influence on the total galactic γ-ray emissivity is still highly uncertain and will remain so until improved observations are available.

IV. SUMMARY AND CONCLUSIONS

Refinements and extensions of the SAS-2 data, together with the COS-B results, give an improved picture of the high energy γ radiation from the galactic plane. The principal results may be summarized as follows:

On a large scale, the distribution of γ radiation from the galactic plane has several similarities to that of other tracers of galactic structure. The radiation is primarily confined to a thin disk. This disk exhibits offsets from b=0° similar to the "hat brim" effect seen in the radio frequency measurements. Enhancements in the γ radiation are seen in the galactic center and regions deduced from 21 cm radio data to be associated with spiral arms. The principal distinction of the γ radiation is a stronger contrast in intensity between the region from 310° to 45° in longitude and the regions away from the center than can be explained on the basis of the best current estimates of the total interstellar matter (atomic and molecular) and a uniform cosmic ray density. This feature is, therefore, attributed to a variation in the cosmic ray density as a function of position in the Galaxy. The distribution of γ-rays in both latitude and longitude is consistent with a model in which the galactic cosmic rays have a density in the plane which is correlated with the matter density on the scale of galactic arms and have a scale height of about 1 kpc.

The diffuse galactic γ-ray energy spectrum shows no statistically significant variation with direction. Further, the spectrum seen along the galactic plane is the same as the spectrum derived for the galactic component of the γ radiation at high latitudes. In terms of a power law fit, the differential photon spectral index is 1.70±0.14 between 35 MeV and about 200 MeV. Within the uncertainties of the measurements this spectrum is consistent with the combination of cosmic ray electron bremsstrahlung, radiation from Compton scattering of photons by cosmic ray electrons, and γ radiation resulting from collisions of cosmic ray nucleons with interstellar matter in the proportions which would result from the above model. The electron contribution is estimated to represent about a third of the total radiation above 100 MeV.

The uniformity of the galactic γ-ray energy spectrum, the smooth decrease in intensity as a function of galactic latitude, and the absence of any galactic γ-ray sources at high latitudes argue in favor of a diffuse origin for the bulk of the galactic γ radiation, rather than a collection of localized sources. The net contribution of localized sources is, however, very uncertain, primarily because of the limited angular resolution of the SAS-2 instrument and other current experiments.

All the localized sources identified in the SAS 2 date are associated with known compact objects on the basis of observed periodicities, except for γ195+5. After eliminating those SAS-2 sources observed by COS-B, and two other excesses (CG312-1 and CG 333+0) visible in the SAS-2 data associated with tangential directions of spiral arms, there are eight remaining new sources identified from the γ-ray data of COS-B (Hermsen et al., 1977). The SAS-2 upper limits are consistent with all but one. The exception is CG176-7, for which the SAS-2 upper limit of 0.8×10^{-6} photons $cm^{-2} s^{-1}$ above 100 MeV is a factor of 2 below the intensity reported by COS-B.

In conclusion, at present the majority of observed γ radiation above 35 MeV seems best explained in terms of diffuse emission with a cosmic ray interaction origin. The cosmic rays would appear to be correlated with matter on a large scale and probably have a scale height much larger than the matter. Future γ-ray studies, particularly those with improved energy and angular resolution as well as greater sensitivity should be able to add greatly to the study of high energy processes in the Galaxy.

Details of the analyzed γ-ray data from the entire SAS-2 data base exist in the form of tables (Fichtel et al., 1978). This compilation presents the numbers of detected photons and the exposure factors (sensitivity) for all points in the sky observed by the instrument, together with a description of the conversion of these values into absolute γ-ray intensities. Copies of this document are available from the authors.

TABLE 1

Galactic Longitude Range	Spectral Index
350°-10°	1.74±0.15
10°-40°	1.72±0.15
40°-70°*	1.79±0.15
*90°-175°+	1.68±0.16
+205°-255°★	1.62±0.17
★275°-320°	1.84±0.22
320°-350°	1.55±0.15
All of Above	1.70±0.14

*Cygnus X-3 region was omitted.

+Anticenter region near (PSR0531+21) and (195,5) was omitted.

★(PSR0833-45) region was omitted.

FIGURE CAPTIONS

Fig. 1 -- Regions of the sky observed by SAS-2 shown in galactic coordinates. The exposure factor (sensitivity) is given in units of effective area x live time, for an energy of 100 MeV. The sensitivity contour 1.9×10^{6} $cm^{2}s$ represents the effective boundary of the SAS-2 exposure. Variations in the sensitivity are caused by the detector's angular response function coupled with overlapping exposures.

Fig. 2 -- Distribution in galactic longitude of γ-rays with energies above 100 MeV. The data are summed between b=-+10° and b=+10° and given in bins with a width of 2.5° in longitude, except near the edges of the exposure, where the bin width is 5° (shown as diamonds). Positions of the strong γ-ray sources observed by SAS-2 are indicated by arrows. The uncertainties shown are statistical only. An additional uncertainty of about 13% should be attached to the overall normalization, reflecting limiations in the calibration and the spectral resolution correction.

Fig. 3 -- Distribution in galactic longitude of γ-rays with energies above 100 MeV. The data are summed between b=-4° and b=+4° and given in bins with a width of 2.5° in longitude, except near the edges of the SAS-2 exposure, where the bin width is 5° (shown as diamonds). The uncertainties shown are statistical only. An additional uncertainty of about 14% should be attached to the overall normalization.

Fig. 4 -- Distribution in galactic longitude of γ-rays with energies between 35 MeV and 100 MeV. The data are summed between b=-10° and b=+10° and given in bins with a width of 5° in longitude. The uncertainties shown are statistical only. An additional uncertainty of about 14% should be attached to the overall normalization.

Fig. 5 -- Distribution of γ-ray (E>100 MeV) intensities as a function of galactic latitude for three longitude intervals which exclude strong discrete sources. Latitude division boundaries are not necessarily integers, because the regions represent sums of smaller areas formed from dividing the sky into equal-area regions formed by fixed longitude intervals and 144 latitude intervals. The uncertainties shown are statistical only. An addition uncertainty of about 13% should be attached to the overall normalization. No correction has been made for the angular resolution of the detector.

Fig. 6 -- Distribution of γ-ray (35 MeV <E<100 MeV) intensities as a function of galactic latitude for three longitude intervals which exclude strong discrete sources. The uncertainties shown are statistical only. An additional uncertainty of about 14% should be attached to the overall normalization. See also the comments in the legend to Fig. 2 regarding non-integer latitude boundaries. No correction has been made for the angular resolution of the detector.

Fig. 7 -- Energy spectrum of the galactic γ radiation for a region near the galactic center. The SAS-2 data are represented by a power law, because the energy resolution of the detector cannot distinguish the small deviation from a power law which is predicted by the calculated spectrum over the SAS-2 energy range. The calculated spectrum shown in the figure is based on the work of Fichtel et al., (1976), but with an increase of a factor of two in the primary electron spectrum as suggested by the work of Fichtel, Simpson and Thompson (1978) and Kniffen et al., (1978).

Fig. 8 -- Comparison of the calculated longitude distribution of γ-rays with energy above 100 MeV with the SAS-2 results. The calculation is based on the model of Kniffen, Fichtel and Thompson (1977), using updated values for the γ-ray source function and the local interstellar matter density as indicated by Fichtel, Simpson and Thompson (1978) and Kniffen et al., (1978).

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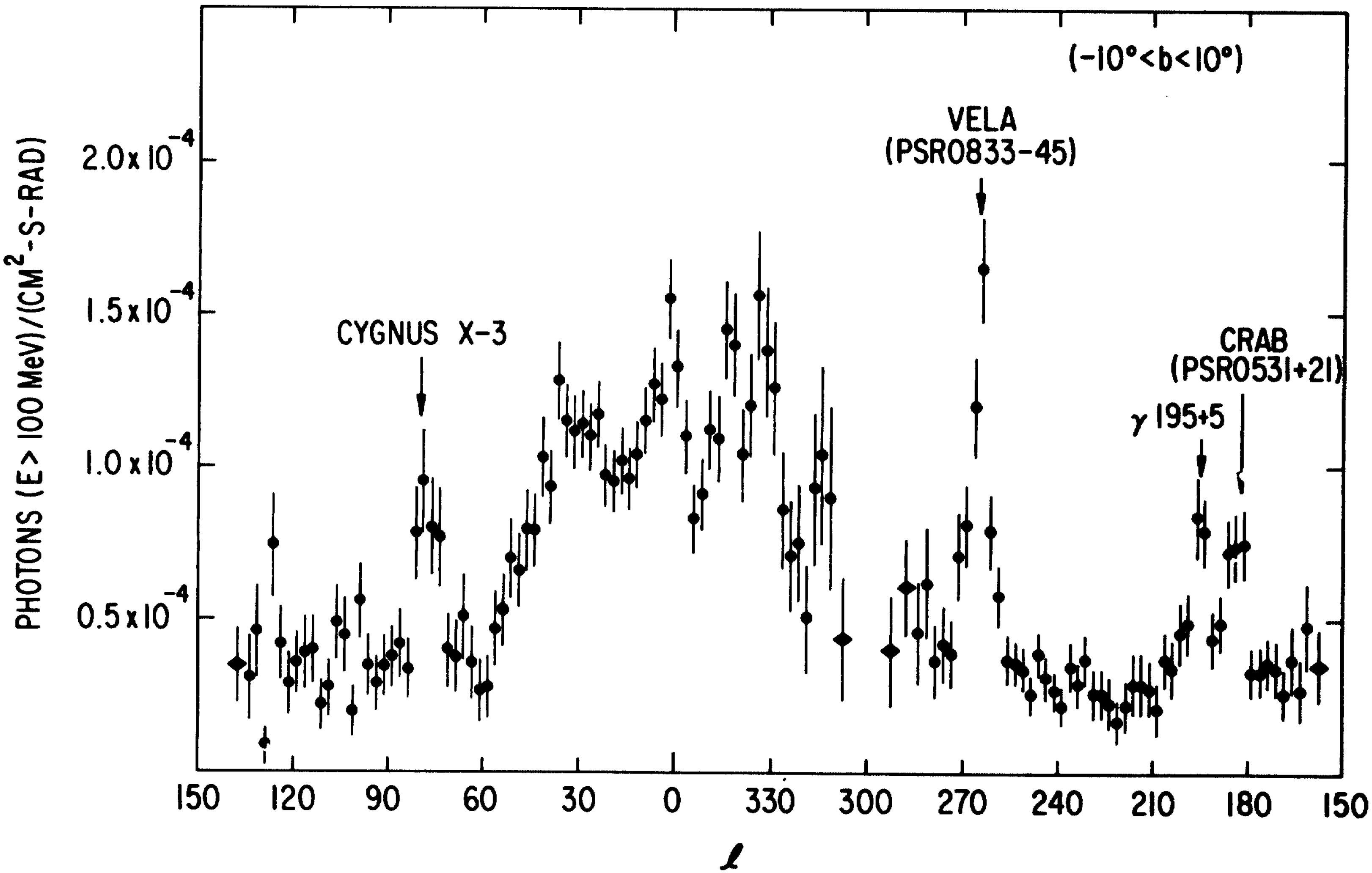

(-10°<b<10°)
VELA
(PSR0833-45)
CYGNUS X-3
CRAB
(PSR0531+21)
γ 195+5
2.0x10^-4
1.5x10^-4
1.0x10^-4
0.5x10^-4
PHOTONS (E> 100 MeV)/(CM^2-S-RAD)
150
120
90
60
30
0
330
300
270
240
210
180
150
ℓ

Fig. 1

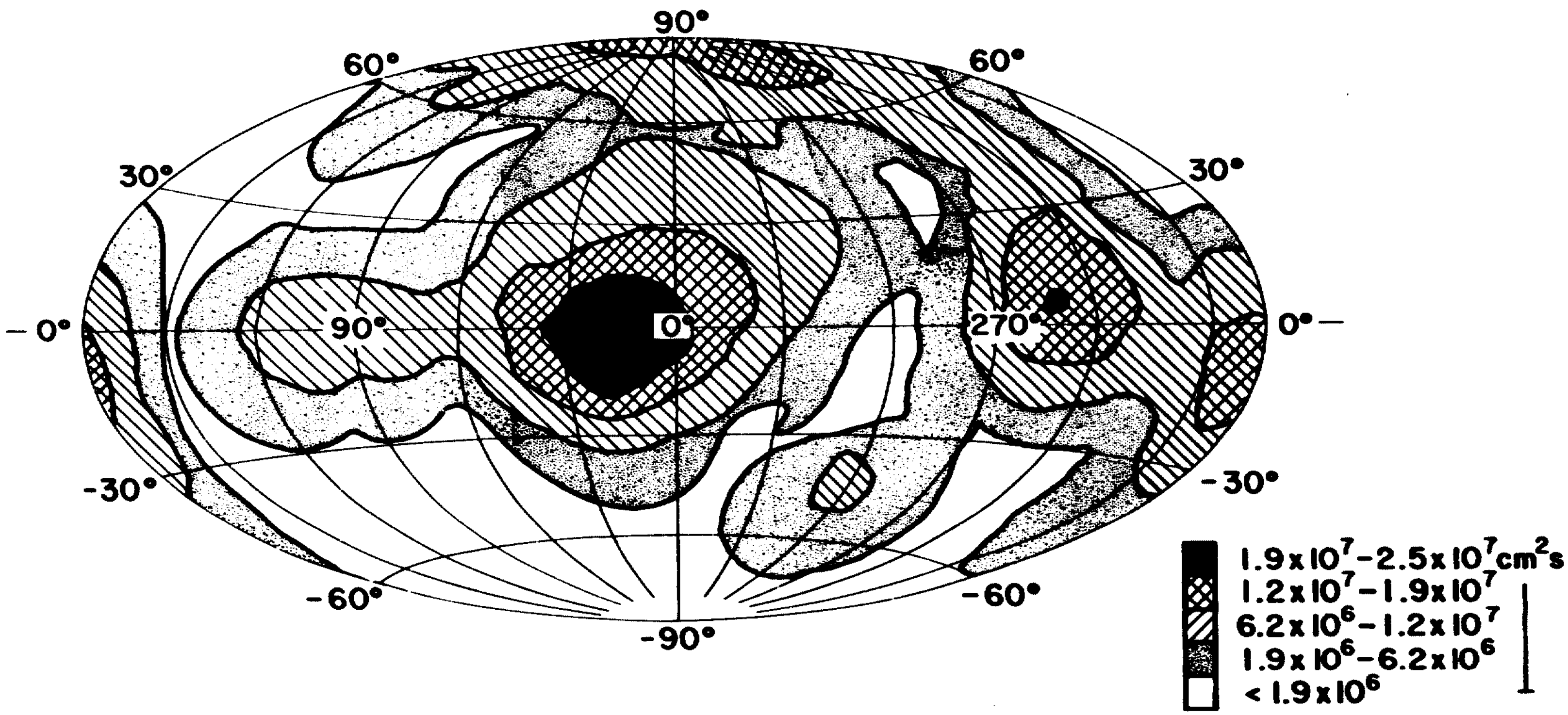

90°
60°
60°
30°
30°
0°
90°
0°
270°
0°
-30°
-30°
-60°
-60°
-90°
$1.9 \times 10^7 - 2.5 \times 10^7 cm^2 s$
$1.2 \times 10^7 - 1.9 \times 10^7$
$6.2 \times 10^6 - 1.2 \times 10^7$
$1.9 \times 10^6 - 6.2 \times 10^6$
$< 1.9 \times 10^6$

Fig. 2

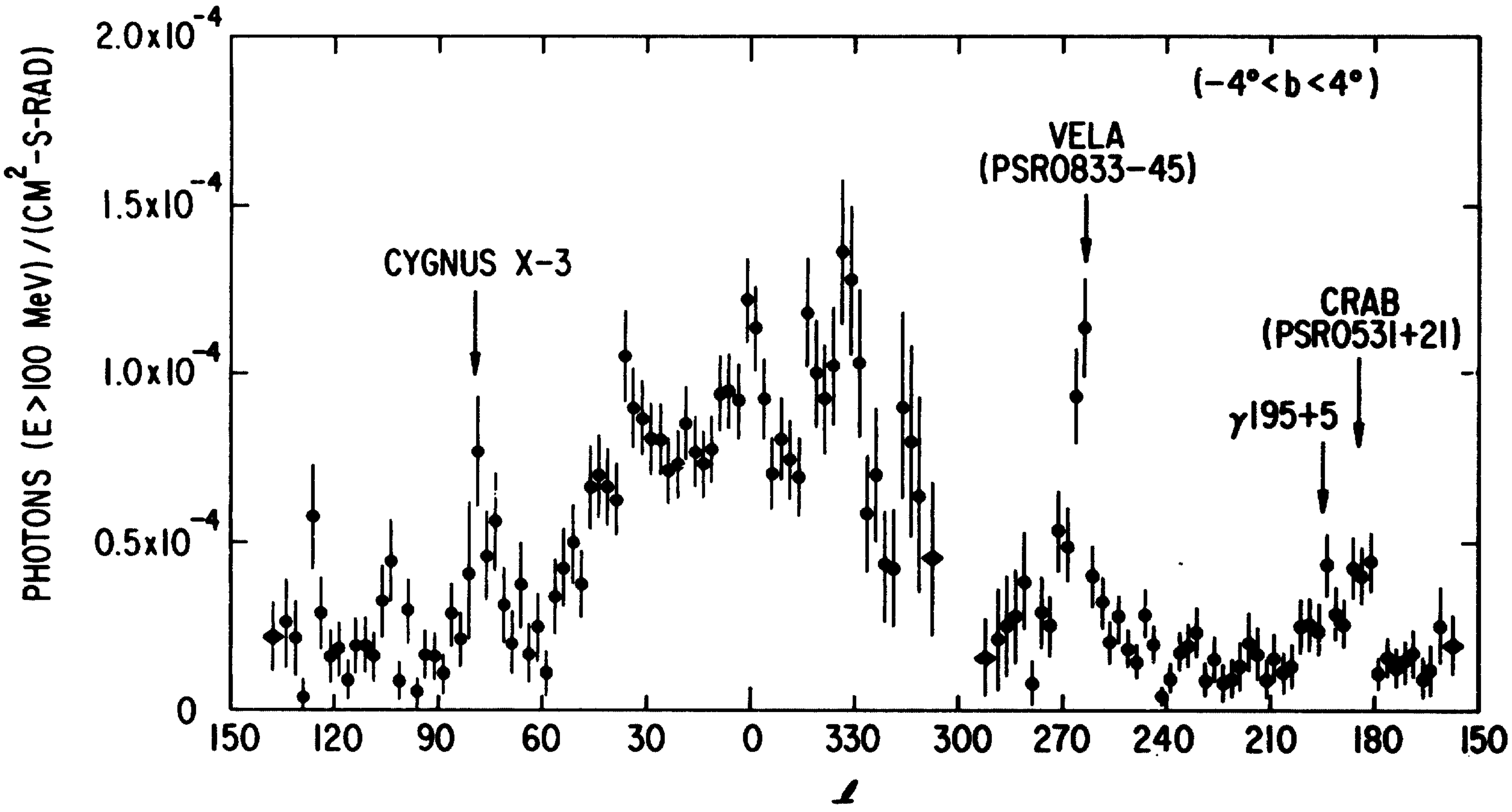
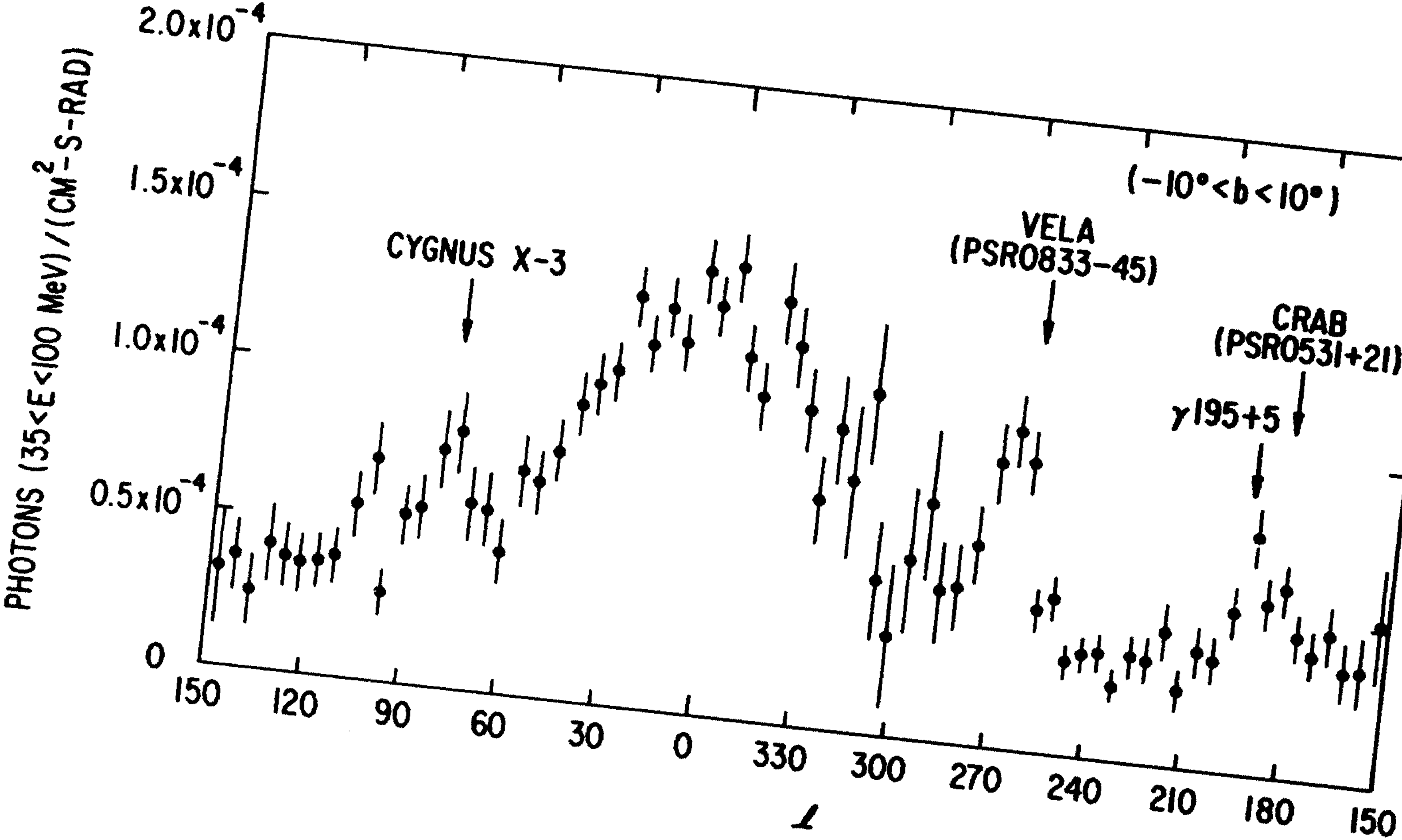

PHOTONS (E>100 MeV)/(CM^2-S-RAD)
2.0x10^{-4}
1.5x10^{-4}
1.0x10^{-4}
0.5x10^{-4}
0
(-4°<b<4°)
VELA
(PSR0833-45)
CYGNUS X-3
CRAB
(PSR0531+21)
γ195+5
150
120
90
60
30
0
330
300
270
240
210
180
150
ℓ

Fig. 3



PHOTONS (35<E<100 MeV)/(CM²-S-RAD)
2.0x10⁻⁴
1.5x10⁻⁴
1.0x10⁻⁴
0.5x10⁻⁴
0
(−10°<b<10°)
CYGNUS X-3
VELA
(PSR0833-45)
CRAB
(PSR0531+21)
γ195+5
150
120
90
60
30
0
330
300
270
240
210
180
150
l

Fig. 4

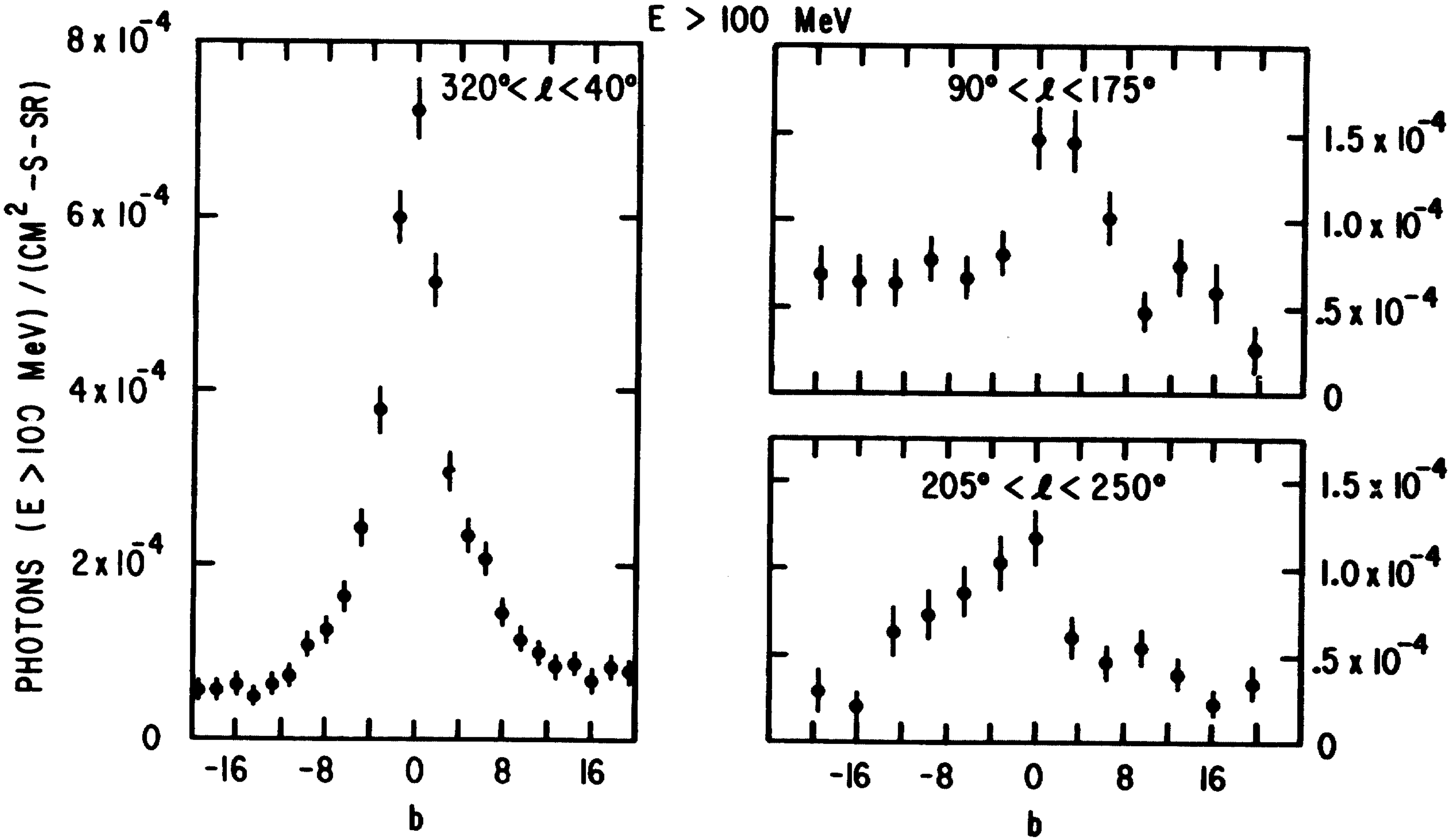
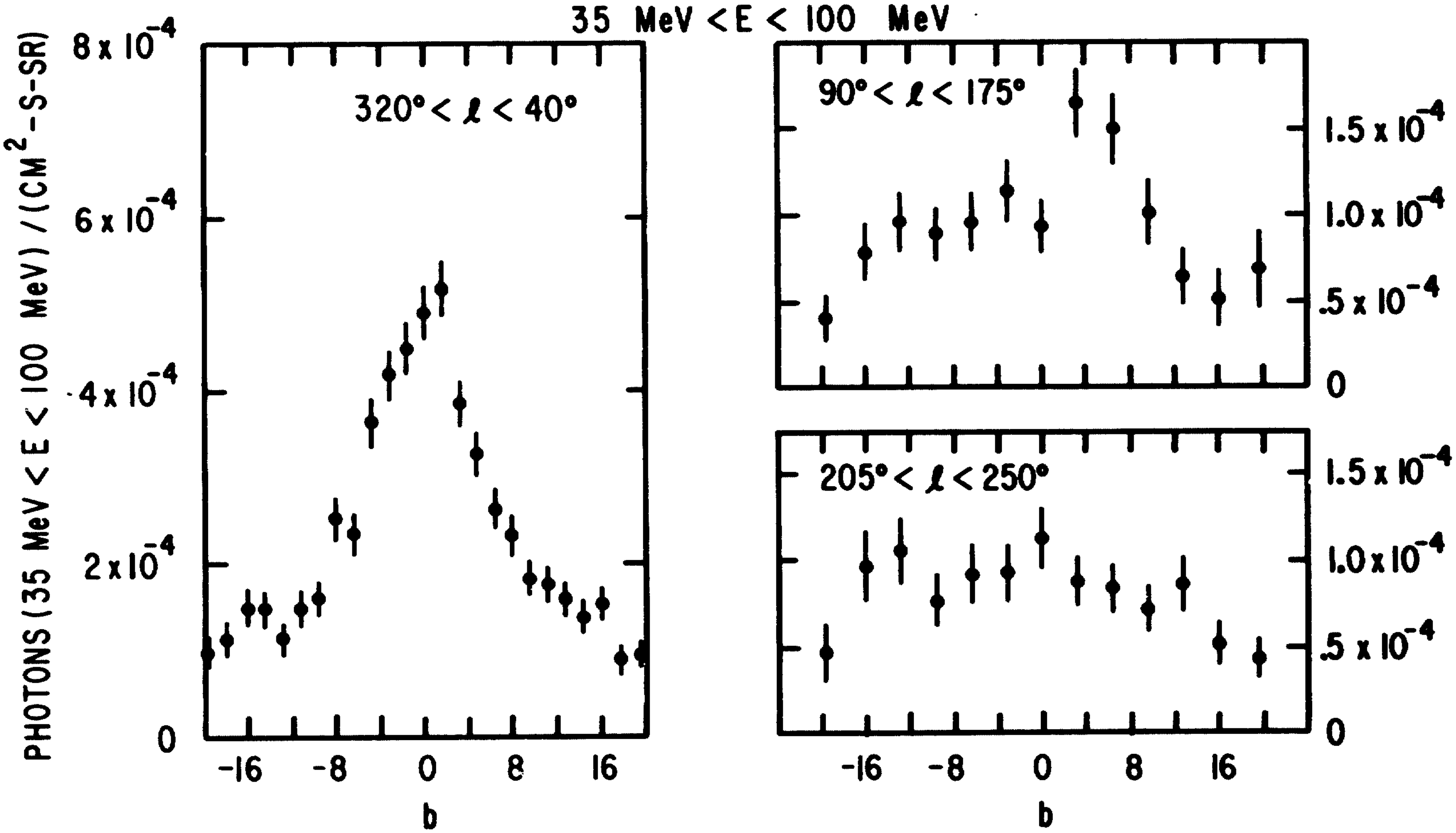
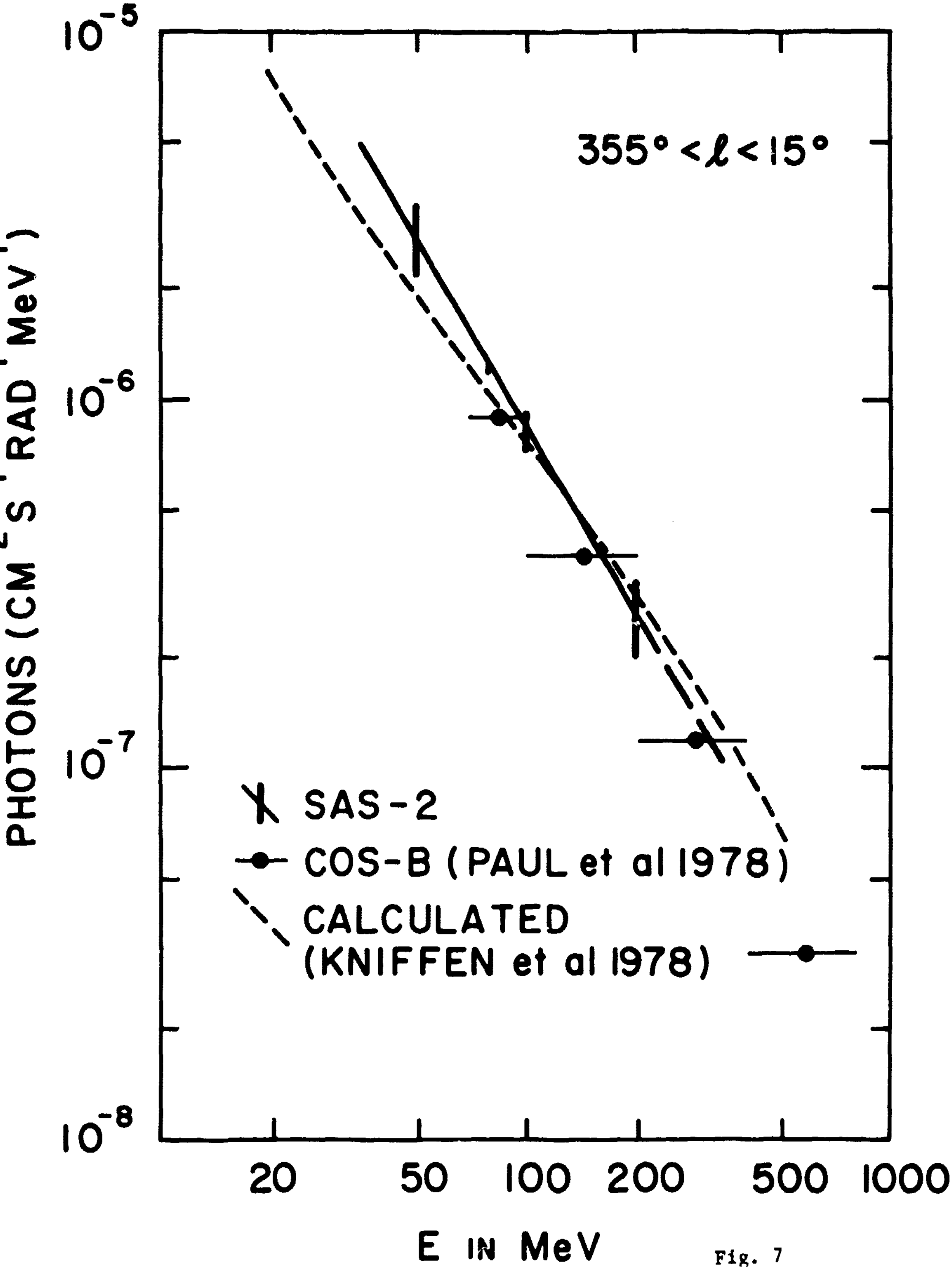

E > 100 MeV
PHOTONS (E > 100 MeV) / (CM^2-S-SR)
8 x 10^{-4}
6 x 10^{-4}
4 x 10^{-4}
2 x 10^{-4}
0
320° < ℓ < 40°
-16
-8
0
8
16
b
90° < ℓ < 175°
1.5 x 10^{-4}
1.0 x 10^{-4}
.5 x 10^{-4}
0
205° < ℓ < 250°
1.5 x 10^{-4}
1.0 x 10^{-4}
.5 x 10^{-4}
0
-16
-8
0
8
16
b

Fig. 5



35 MeV < E < 100 MeV
PHOTONS (35 MeV < E < 100 MeV) / (CM^2-S-SR)
8 x 10^{-4}
6 x 10^{-4}
4 x 10^{-4}
2 x 10^{-4}
0
320° < ℓ < 40°
-16
-8
0
8
16
b
90° < ℓ < 175°
1.5 x 10^{-4}
1.0 x 10^{-4}
.5 x 10^{-4}
0
205° < ℓ < 250°
1.5 x 10^{-4}
1.0 x 10^{-4}
.5 x 10^{-4}
0
-16
-8
0
8
16
b

Fig. 6



10^{-5}
10^{-6}
10^{-7}
10^{-8}
PHOTONS ($CM^{-2}S^{-1}RAD^{-1}MeV^{-1}$)
$355° < \ell < 15°$
SAS-2
COS-B (PAUL et al 1978)
CALCULATED
(KNIFFEN et al 1978)
20
50
100
200
500
1000
E IN MeV

Fig. 7

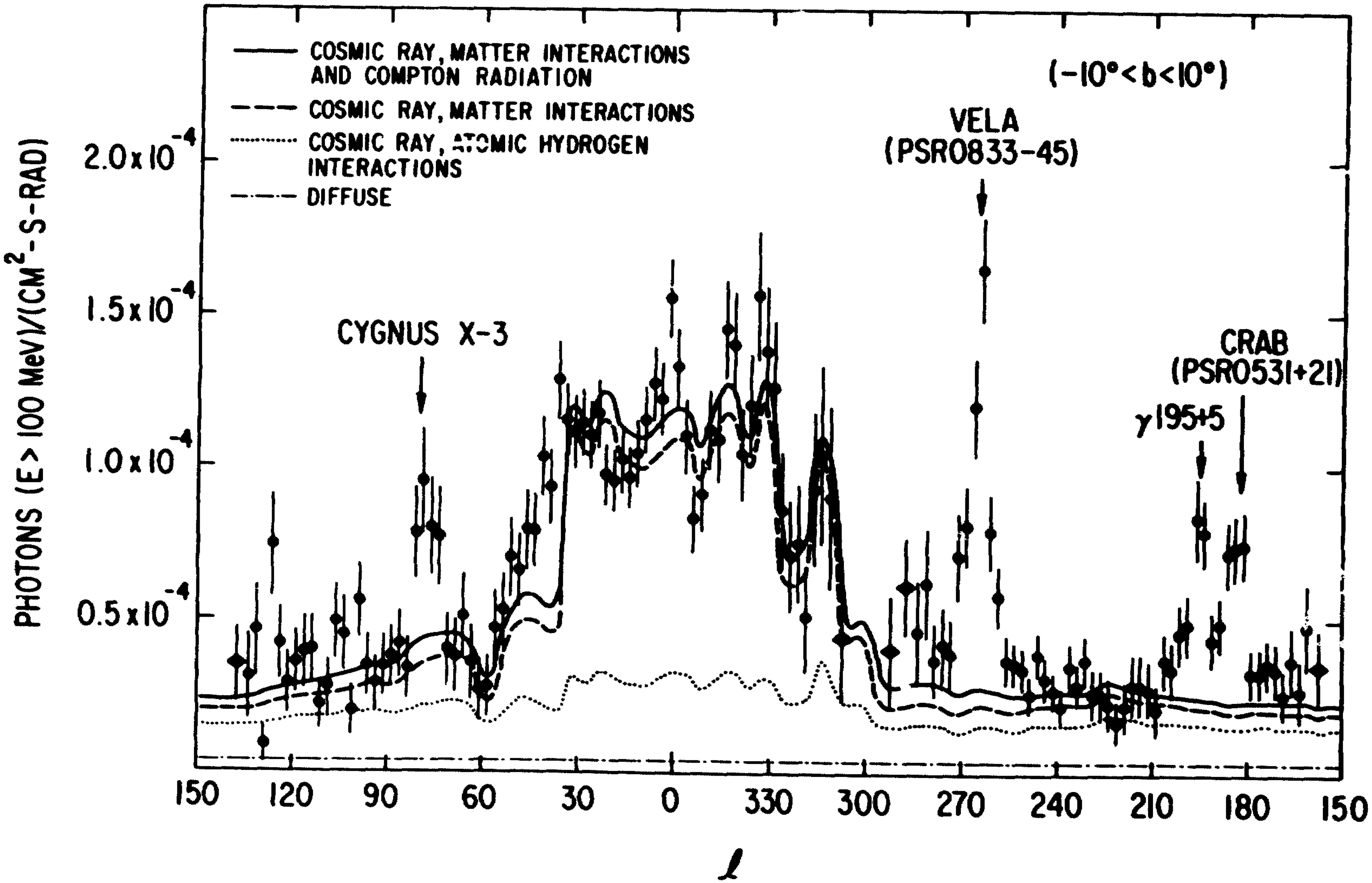

COSMIC RAY, MATTER INTERACTIONS AND COMPTON RADIATION
COSMIC RAY, MATTER INTERACTIONS
COSMIC RAY, ATOMIC HYDROGEN INTERACTIONS
DIFFUSE
(-10°<b<10°)
VELA (PSR0833-45)
CYGNUS X-3
CRAB (PSR0531+21)
γ195+5
PHOTONS (E> 100 MeV)/(CM²-S-RAD)
2.0x10⁻⁴
1.5x10⁻⁴
1.0x10⁻⁴
0.5x10⁻⁴
150 120 90 60 30 0 330 300 270 240 210 180 150
ℓ

Fig. 8