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D. A. Kniffen and C. E. Fichtel

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**Goddard Space Flight Center**
Greenbelt, Maryland 20771

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D.A. Kniffen and C.E. Fichtel
NASA/Goddard Space Flight Center, Greenbelt, MD 20771

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D.A. Kniffen and C.E. Fichtel
NASA/Goddard Space Flight Center, Greenbelt, MD 20771

## ABSTRACT

The diffuse high energy galactic γ radiation to be expected from cosmic-ray interactions with matter and photons is examined. Particular emphasis is placed on the Compton emission since work in this area is hindered by the limited knowledge of the galactic photon densities. Both the photon density in and near the visible region and that in the infrared region are deduced from the estimates of the emission functions throughout the Galaxy. The blackbody radiation is also included in the estimate of the total Compton emission. The result suggests that the γ-ray Compton radiation from cosmic ray interactions with galactic visible and infrared photons is substantially larger than previously believed. The analysis of the energy spectra and latitude dependence shows further that the Compton radiation, the bremsstrahlung, and the nuclear cosmic ray, matter interaction radiation should be separable by the study of appropriate energy intervals and latitude regions, where there are no major point source contributions. The experimental results, even though limited, give encouragement that the basic concepts and assumptions are likely to be correct and the future γ-ray results will be very helpful in defining galactic structure, determining the relative importance of cosmic-ray electrons in the galaxy, estimating the intensity and pressure effects of cosmic rays in other parts of the galaxy, and aid, in conjunction with radio data, in determining the galactic photon density at least within a few kiloparsec, as well as setting limits in the galactic center region.

Subject Headings: cosmic rays: general - galaxies: Milky Way - galaxies: structure - gamma rays: general

# I. INTRODUCTION

The diffuse high energy galactic γ-radiation is generally believed to come largely from cosmic-ray interactions with matter and photons. This radiation should thus have the potential of being a valuable probe of the nature of the galaxy, particularly in view of the high penetrating power of these photons. A high energy γ-ray may pass through the galactic plane from one side to the other with less than a 1% chance of interacting. Even at present the limited γ-ray data on the galactic diffuse radiation provide useful information for the study of the galaxy. The cosmic ray, matter interactions have been studied in some depth theoretically, but calculations of the Compton radiation from cosmic ray electrons have been hampered by the limited knowledge of the galactic photon densities. It is the latter which shall receive the primary attention of this paper, although some improvements in the calculation of γ-ray production in cosmic ray, matter interactions, will also be considered.

With the launch of the high energy ($E \gtrsim 35$ MeV) γ-ray satellites SAS-2 in 1972 and COS-B in 1975, γ-ray data (e.g. Fichtel et al., 1975; Mayer-Hasselwander et al., 1980; Hartman, et al., 1979) on the galactic plane became available in sufficient detail to stimulate attempts to understand their implications in terms of current concepts of the galactic structure and cosmic ray dynamics. Although information on the distribution of interstellar atomic hydrogen had existed for some time, it was also in the 1970's that the 2.6 mm observations of carbon monoxide (e.g. Scoville and Solomon, 1975, and Gordon and Burton, 1976) became available as a tracer of interstellar molecular hydrogen and indicated the importance of this constituent in the interstellar medium of the inner galaxy and, hence, in the production of the galactic γ-radiation. There have been several attempts to predict the γ-ray distribution to be expected from the cosmic ray electrons and nucleons interacting with interstellar galactic atomic and molecular hydrogen (e.g. Bignami and Fichtel, 1974; Paul Cassé, and Cesarsky, 1974; Schlickeiser and Thielheim, 1974; Bignami et al., 1975; Paul, Cassé, and Cesarsky, 1975; Stecker et al., 1975; Stecker, 1977; Puget et al., 1976; Paul, Cassé, and Cesarsky, 1976). These calculations have generally shown that the relative intensity distribution along the plane is about what would be expected and that the absolute intensity is not unreasonable, although the observed intensity seems to be near the high side of the allowed range. The concept of cosmic-ray, matter coupling on the scale of galactic arms, as originally proposed by Bignami and Fichtel (1974) based on concepts developed earlier by Parker (1966 and 1969), in particular seems, generally, to give good agreement.

Compton radiation may result from galactic cosmic ray electrons interacting with the 3°K blackbody radiation, photons in the optical range, and infrared photons. The Compton γ-radiation due to the interaction of the cosmic ray electrons and the blackbody radiation can be computed in a straightforward manner, but is relatively small. For some time it has been recognized that there are contributions to the Compton radiation from galactic starlight and infrared photons (e.g. Feenberg and Primakoff, 1949; Piccinotti and Bignami, 1976; Fichtel, Simpson, and Thompson, 1977; Stecker, 1977), but the past estimates have been very uncertain, and probably too small. An attempt is made in this paper to develop models for the infrared and visible photon distributions and use them to produce a better estimate of the Compton radiation. The results of these calculations indicate that these components are probably substantially more significant than previously believed.

With regard to the photon distributions, Boissé et al. (1981) have used results from a far-infrared survey of the milky way together with other information to deduce galactic infrared photon emission functions and a spectrum. The same data and somewhat different assumptions to unfold the observed infrared spectrum are used here in part to demonstrate the sensitivity of the final result to the assumptions. From the emission functions galactic photon density distributions are calculated. Finally, the distribution of the expected γ-ray emission and the γ-radiation expected to be observed are calculated. A similar approach is used for the starlight photon density based on the stellar distribution models of Bahcall and Soneira (1980) for the distribution of galactic stellar populations. From these, the Compton emission is then determined.

Ultimately, it would be very desireable to be able to use γ-ray measurements directly to aid in the determination of the cosmic ray and photon distributions in the inner galaxy. Unfortunately, at present γ-ray observations of sufficient statistical significance, angular accuracy, and energy resolution to allow a meaningful analysis of this type do not exist. However, the existing measurements are adequate to provide a useful guide when compared to the predictions of theory. It should also be mentioned that point sources make some contribution to the observed γ radiation, but they are probably not a major contributor (See for example Cesarsky, 1980).

The results of the calculations to be presented here predict not only the relative contributions to the γ-radiation, but also the marked variations of the different components with energy and spatial distribution, especially latitude. As will be shown, these variations should ultimately permit the separation of Compton radiation from cosmic ray, matter interaction induced γ-radiation, and, separately, cosmic ray nucleon, matter interactions from bremsstrahlung.

## II. THE MODEL AND CALCULATIONS

In order to estimate the intensity and spectrum of the expected high energy galactic γ-radiation, models for the matter, cosmic ray, and photon distributions must be chosen since bremsstrahlung, high energy cosmic ray nucleon interstellar matter interactions, and Compton interactions all make significant contributions. Since the cosmic ray electron intensity and spectrum are needed to perform the Compton radiation calculations and since the cosmic ray density is believed to be related to the galactic matter density on a broad scale, the cosmic ray and matter distributions will be discussed first.

### a) Cosmic Ray and Matter Distributions

With regard to the matter distribution the relevant concern is the galactic diffuse matter in the form of atoms, molecules, ions, and dust with which cosmic rays interact. The difficult translation of the observations into a galactic spatial distribution has been studied extensively; however, a general spiral pattern on a broad scale (or at least spiral arm segments) does appear to emerge. The distribution of atomic hydrogen (e.g. Simonson, 1976), continuum radio emission (Landecker and Wielebinski, 1970; Price, 1974), HII regions (Georgelin and Georgelin, 1976), supernova remnants (Clark and Caswell, 1976), γ-radiation (Bignami et al., 1975), pulsars (Seiradakis, 1976), and infrared emission (Hayakawa et al., 1976) are all consistent with the existence of spiral structure in the galaxy. Although the atomic hydrogen density is thought to be reasonably well known from 21 cm measurements, the absolute intensity of molecular hydrogen is still quite uncertain. Gordon and Burton (1976) have estimated that the molecular hydrogen is dominant in the inner galaxy, and Solomon and Sanders (1980) have shown that it is largely contained in giant clouds. From the Copernicus satellite data, Savage et al. (1977) estimate the fraction of the gas in molecular form locally to be about 0.25 and possibly higher. Because of the difficulty in the interpretation of the observations and because CO observations for the southern half of the galactic center region (the fourth quadrant) where the spiral arms appear most strongly in the 21 cm data do not yet exist, it has not been clear whether molecular clouds are associated with spiral structure. However, on the basis of a very high sample survey and observations in both the first and second quadrants of the galactic plane, Cohen et al. (1980) appear to have shown the existence of the molecular counterparts of the five 21 cm spiral arm segments in these regions of the galaxy, namely the Perseus arm, the Local arm, the Sagittarius arm, the Scutum arm, and the 4 kpc arm.

The spiral model of Simonson (1976) used previously (Hartman et al., 1979) will be used here also for consistency for both atomic and molecular hydrogen, but the characteristic arm width will be assumed to be 0.5 kpc rather than the larger one used previously and a 3:1 ratio for the arm to inner arm density will be used. This ratio implies that as much molecular hydrogen exists in the interarm region as in the arm segment, since the arms are typically 2 kpc apart. The densities are chosen so that the average molecular hydrogen density as a function of galactic radius is consistent with the estimates of Gordon and Burton (1976) in the outer galaxy and two thirds of their estimate in the inner galaxy. The scale height of molecular hydrogen was taken to be 50 pc (Gordon and Burton, 1976), as compared to 120 pc for atomic hydrogen in the inner galaxy.

The remaining relevant material in the interstellar medium is relatively small. Whereas ionized matter, grains, and dust are negligible from the standpoint of $\gamma$-ray production, except for the possibility of $\gamma$-ray lines from interstellar grains, helium and heavier nuclei do make significant additions to the diffuse γ-ray intensity. Although they represent only about 10% and 1% of the hydrogen content respectively, the cross sections for γ-ray production are large. These factors are included in the production functions.

Combining the confinement lifetime of the cosmic ray nuclei, their velocity, and the average amount of matter traversed shows that the average density of matter seen by the nuclear cosmic rays is about 0.1 $cm^{-3}$. Hence, they do not spend most of their time in the thin matter disk where the density is about 1 $cm^{-3}$, but rather they must have a broader distribution relative to the galactic plane. The nonthermal continuum radio emission, which is generally attributed to the synchrotron radiation from cosmic ray electrons interacting with the galactic magnetic fields (see for example Ginzburg and Syrovatskii, 1964, 1965), provides information about the high-energy cosmic ray electrons. Baldwin (1967, 1976) estimates the equivalent disk thickness for synchrotron emission to be about 750 pc, and some analyses have suggested that it is even larger. Both of these results are consistent with a cosmic ray scale height of about 1.0 kpc, and this value is adopted for this work.

Little is known experimentally about the cosmic ray distribution in the plane of the galaxy. However, the high-energy γ-ray data suggest that the cosmic ray density distribution is similar to that of the matter on a coarse scale in terms of the distribution in the galactic plane (see for example Fichtel et al., 1975 and Hartman et al., 1979), and even support the concept of the cosmic ray density being greater in arm segments, including the strong interstellar matter feature about 5 kpc from the center. As noted earlier, the continuum radio emission, generally agreed to result from synchrotron radiation of cosmic ray electrons, appears to reflect the galactic spiral pattern.

Several fundamental theoretical considerations place constraints on the cosmic ray distribution. Under the now generally accepted assumption that the cosmic rays and magnetic fields are primarily galactic and not universal, these fields and cosmic rays can only be constrained to the galactic disk by the gravitional attraction of the matter (Bierman and Davis, 1960 and Parker 1966, and 1969). Further, assuming the solar system is not at an unusual position in the galaxy, the cosmic ray density throughout the galaxy may be as large as could be contained under near-equilibrium conditions. These considerations and others lead to the hypothesis that the energy density of the cosmic rays is larger where the matter density is larger on a coarse scale such as that of the galactic arms. For a more detailed discussion of these considerations and the γ-rays production from cosmic ray, matter interactions, see, for example, Kniffen, Fichtel, and Thompson (1977) or Fichtel and Trombka (1981). It will be assumed here that the cosmic ray column density in the plane is proportional to that of the matter on the scale of galactic arms; however, the cosmic ray scale height is much larger, as noted earlier.

### (b) Galactic Photon Distributions

There are three relevant photon distributions with which the cosmic ray electrons interact. These are those of the black body radiation, the interstellar starlight in and near the visible region, and the interstellar infrared region. The source function for the Compton radiation is given by the equation

$$q_c(E_\gamma) = \frac{8\pi}{3} \sigma_T \rho_{ph} (m_e c^2)^{1-\Gamma} \left(\frac{4}{3} \langle\epsilon\rangle\right)^{\frac{\Gamma-3}{2}} K E_\gamma^{-\frac{\Gamma+1}{2}} \qquad (1)$$

for an electron spectrum of the form

$$I_e = K\, E_e^{-\Gamma} \tag{2}$$

where q is in γ-rays $cm^{-3}\ s^{-1}\ MeV^{-1}$, $\sigma_T = 6.65\times10^{-25}\ cm^2$, $\rho_{ph}$ is the low energy photon density, ε is the photon energy, $E_e$ is the electron energy, $I_e$ is in electrons $cm^{-2}\ s^{-1}\ ster^{-1}\ MeV^{-1}$, and $E_\gamma$ is the γ-ray energy. Following the work of Cane (1977) and Webber, Simpson, and Cane (1980) based on radio continuum and local cosmic ray measurments, K=25 and Γ=2.14 for $E_e$<2.5 GeV and $K=4.3\times10^3$ and Γ =2.8 for $E_e$>2.5 GeV. Particularly because of solar modulation, there is some uncertainty in these parameters (e.g. Cesarsky, 1980), especially in the electron energy region most relevant for bremsstrahlung (E≲300 MeV), and to a much less extent in the region relevant for the stellar Compton emission ($E_e$≳1 GeV). For the electrons in the energy region relevant for blackbody radiation (i.e., $\gtrsim 0.6\times10^2$ GeV), the electron energy spectrum itself is less well measured because of the lower intensity, but there is no solar modulation

For the blackbody radiation, the temperature was taken to be 2.7°K, and the photon density to be 0.25 $eV/cm^3$. Defining Q as,

$$Q_b = \int_{E_1}^{E_2} q_b\,(E_\gamma)dE, \tag{3}$$

and performing this integration gives values of Q for the blackbody radiation of $0.2\times10^{-26}$ γ-rays $cm^{-3}\ s^{-1}$ for $E_\gamma$>100 MeV and $0.33\times10^{-26}$ γ-rays $cm^{-3}\ s^{-1}$ for 35 MeV<$E_\gamma$<100 MeV.

In order to obtain the Compton emission function over the galaxy, it is necessary to know the visible and infrared photon density distributions and spectra. Boisse et al. (1981) have used results of a homogeneous far-infrared survey of a portion of the galactic plane to deduce the volume emissivity for two different wavelength bands. They have also noted that one of these bands appears to have a distribution representative of the total infrared intensity where comparisons can be made and, therefore, allows them to deduce a total infrared volume emissivity. Their calculation was done by dividing the plane into one kiloparsec rings. After repeating their calculation to verify the computation, calculations have been performed for this work in which the plane was divided into a spiral pattern using the model of Simonson (1976). With these results for the galactic plane and assuming a scale height for the emission function of 0.25 kiloparsecs, both of these functions were then integrated over the galaxy to obtain the infrared photon density as a function of position in the galaxy. The absorption effect in this instance is small. The results for both solutions in the galactic plane are shown in Figure 1, and the agreement between the two approaches is seen to be close. The farther from the plane, the closer the agreement between the two approaches, as expected; therefore, only a set of values for one distribution, the one corresponding to the first quadrant assuming the existence of spiral arms, is shown in Table 1. That distribution for the photon density will be used henceforth, although the results are not sensitive to the choice.

Notice that the photon densities in the inner galaxy are found to be substantially larger than locally and that the calculated local density agrees with the observed local value, although the model based on simple rings gives a value a bit on the high side. No attempt was made to give an estimate for R<0.5 kpc because of the uncertainties in the observations and models in this

R<0.5 kpc because of the uncertainties in the observations and models in this region. It will be seen that the high energy γ-ray data can set a limit on the product of the infrared photon density and the cosmic ray electron density in that region. Notice in Table I also that the photon density near the central part of the galaxy remains relatively high even at some distance away from the galactic plane; hence, it will be the cosmic ray distribution which will predominately determine the scale height for γ-ray emission.

It is difficult to determine the visible starlight distribution in the galaxy observationally because of the high rate of absorption. In this work, the model adopted by Bahcall and Soneira (1980) is used. This model is based in part on the observations in the solar neighborhood. Although there are three components in this model, the disk, a spheroid, and a massive halo, the disk component dominates for γ-ray production. As a result, the luminosity function decreases with height above the plane approximately exponentially with a scale height of 250 pc and with galactocentric radius from the center exponentially with a scale length of 3.5 kpc. The local value of the emission is $0.60 \times 10^{-11}$ eV $cm^{-3}$ $s^{-1}$, or 0.067 $L_{\odot}$ $pc^{-3}$. The photon density was then obtained as in the case of the galactic IR emission and the distribution is given in Table 2.

## III. Results and Discussion

As the results of the calculations to be presented below will show, the relative contribution of the predicted Compton component varies markedly with latitude and energy, and somewhat less markedly with longitude. Although the parameters are at present uncertain, the Compton radiation from the inner galaxy could account for a significant part of the total γ-radiation. Inversely, the observed level of γ-radiation can be viewed as setting a significant constraint on the product of the photon density and the cosmic ray electron density in the inner galaxy.

a) The Latitude Distribution

The calculated contributions for the different γ-ray Compton components and the cosmic ray, matter interaction γ-radiation are shown in Figure 2a and 2b for the energy intervals of 35 to 100 MeV and >100 MeV, and for the latitude interval of 0° to 15°. Beyond 10° the relative contributions remain about the same, or vary slowly. The dramatic difference between the cosmic ray, matter interaction radiation and the Compton radiation is due to the narrow width of the galactic matter distribution relative to the photon distribution in conjunction with the radial dimensions of the galaxy. For example, at a distance of 10 kpc, a line of site vector reaches the $e^{-1}$ point relative to the galactic plane for Compton radiation production at a galactic latitude of about 5° or 6°, whereas for cosmic ray, matter interactions the γ-ray production function falls to the $e^{-1}$ point at about 1/2°. Thus, whereas the latter dominates very strongly for very low galactic latitudes in both energy ranges shown in Figure 2, the Compton radiation dominates for all latitudes beyond several degrees in the lower of the two energy ranges. The exact spectra, of course, depend on the specific parameters which have been used, as well as the longitude.

It has already been noted by Fichtel et al. (1975) that the experimental data related to the inner galaxy appear to be the sum of two distributions, one being broad and the other being similar to the detector resolution or less, as the model being discussed here would require. The existing experimental data from the SAS-2 and COS-B experiments do not have sufficient angular resolution to allow an immediate comparison; rather, the results shown in Figure 2 must be multiplied by the resolution function, for E>100 MeV, and integrated. Unfortunately, this means that much of the significance of the distribution in terms of what the experimental data might reveal will have to wait for future experimental results. Nonetheless, the comparison is given in Figure 3 to shown there is reasonable agreement. The excess observed in the 6° to 20° range in latitude is thought to be due to Gould's belt, a local galactic feature not included in the general galactic model being discussed here.

The latitude distributions of Figures 2a and 2b shows that, in the future, γ-ray data with improved angular resolution may be used to study the cosmic ray, matter, and cosmic ray, photon distributions independently. For $|b|<1°$ where the cosmic ray matter interaction strongy dominates, the high energy γ radiation clearly provides another approach to studying the galactic structure. At high latitudes it may be possible to obtain another independent estimate of the galactic photon density assuming a good estimate of the cosmic ray electron spectrum in the relevant energy region has been obtained from radio observation of the synchrotron radiation.

### b) The Energy Spectrum

Figures 4a and 4b show the energy spectrum calculated for $b=1/2°$ and $b=10°$. Above $b=10°$, the spectrum will remain about the same. In Figure 5, the spectrum is shown for the integral from $b=-10°$ to $b=+10°$ averaged over the region $320° < \ell < 40°$ and compared to the experimental data from SAS-2 and COS-B. Clearly, the agreement between the theoretical curve and the data is good. However, it must also be noted that if the calculated γ-ray bremsstrahlung to cosmic ray nucleon, matter interaction γ-radiation ratio is correct, the three energy spectra shown in Figures 4a, 4b, and 5 are very similar.

The variation of the relative contributions of the different components with energy is apparent. Notice the marked difference of the cosmic ray nucleon spectrum from the others. The variation with latitude is dramatically illustrated in the comparison of figures 4a and 4b which shows that whereas the cosmic ray matter interactions dominate strongly at b=1/2 in this picture, at b=10° the Compton component is strong. As noted earlier, for this model at all latitudes beyond 10°, the Compton components dominate at low energies. Also, since the γ-radiation from cosmic ray matter interactions will dominate strongly near b=0, these two components are separable in that region.

In future γ-ray investigations it will be valuable to examine carefully the energy spectrum for -1°<b<+1° to determine the spectral structure and, thereby, determine the relative contributions of the two cosmic ray matter components. This is an important measurement, since the energy spectrum of the galactic electrons in the relevant energy range for bremsstrahlung (10 MeV to ~ 300 MeV) is not well known because of the need to correct for solar modulation. It appears that only an unexpectedly strong point source contribution could effect a definitive answer from these measurements.

### c) The Longitude Distribution

The contributions of the three different Compton components as a function of longitude for the central region of the galaxy are shown in Figures 6a and 6b for 35 MeV<E<100 MeV and E>100 MeV. The inner galaxy is clearly seen, as has been noted before. Beyond the central longitude region, the Compton contributions are small. These intensities are shown together with the cosmic ray, matter contributions in Figure 7 and compared to the experimental data above 100 MeV. The contribution of the Compton radiation is relatively greater for the 35-100 MeV region; otherwise the distributions are similar, and the experimental data are less significant. The SAS-2 data were used rather than the COS-B data because, although they have less statistical significance, a normalized COS-B distribution has not yet been published. The published COS-B distribution when normalized to SAS-2, in general, shows a very good correspondence. The agreement of the calculations with the data in Figure 7 is generally good, reproducing most of the major features. The minor deviations, although not surprising in view of the uncertainties, are possibly interesting in terms of future study. For example, the observed excesses between 120° and 135° and 270° and 290° in galactic longitude may represent sources. Swanenburg et al. (1981) have reported two localized excesses in each of these regions in the data of COS-B.

## IV. Summary

The results presented here based on the calculation of the photon densities deduced from current knowledge of galactic emission suggest that the γ-ray Compton radiation from cosmic ray interactions with galactic visible and infrared photons is substantially larger than previously believed. An analysis of the energy spectra and latitude dependence shows further that the Compton radiation, the bremsstrahlung, and the nuclear cosmic ray, matter interaction radiation should be separable. The Compton radiation should dominate at energies in the 10 to $10^2$ MeV range at galactic latitudes greater than several degrees. The relative contributions of bremsstrahlung and nuclear cosmic ray matter interactions should be determinable free of major Compton contribution by studying the γ-radiation for $|b|<1°$, in regions where there are no major point source contributions. The experimental results, even though limited, give encouragement that the basic concepts and assumptions are likely to be correct and that the future $\gamma$-ray results will be very helpful in defining galactic structure, determining the relative importance of cosmic ray electrons in the galaxy, estimating the intensity and pressure effects of cosmic rays in other parts of the galaxy, and aid, in conjuction with radio data, in determining the galactic photon density at least within a few kiloparsec, as well as setting limits in the galactic center region.

TABLE 1

INFRARED PHOTON DENSITY IN EV $CM^{-3}$

| R (Kiloparsec) | Z=0.0 | Z=0.25 | Z=0.50 | Z=0.75 | Z=1.00 | Z=1.25 | Z=1.50 |
|---|---|---|---|---|---|---|---|
| 0.50 | 7.06 | 4.82 | 2.60 | 1.81 | 1.40 | 1.16 | 0.99 |
| 1.50 | 1.67 | 1.47 | 1.33 | 1.19 | 1.06 | 0.96 | 0.87 |
| 2.50 | 1.50 | 1.23 | 1.13 | 1.03 | 0.94 | 0.87 | 0.80 |
| 3.50 | 2.33 | 1.82 | 1.29 | 1.09 | 0.96 | 0.87 | 0.79 |
| 4.50 | 2.01 | 1.56 | 1.34 | 1.15 | 1.00 | 0.88 | 0.79 |
| 5.50 | 3.60 | 1.82 | 1.42 | 1.15 | 0.97 | 0.84 | 0.74 |
| 6.50 | 1.71 | 1.17 | 1.02 | 0.89 | 0.78 | 0.70 | 0.53 |
| 7.50 | 1.84 | 0.90 | 0.78 | 0.68 | 0.61 | 0.55 | 0.51 |
| 8.50 | 0.61 | 0.51 | 0.50 | 0.48 | 0.45 | 0.43 | 0.40 |
| 9.50 | 0.47 | 0.68 | 0.53 | 0.45 | 0.40 | 0.36 | 0.34 |
| 10.50 | 0.41 | 0.40 | 0.37 | 0.34 | 0.31 | 0.29 | 0.27 |
| 11.50 | 0.37 | 0.23 | 0.23 | 0.22 | 0.22 | 0.21 | 0.20 |
| 12.50 | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.16 | 0.16 |
| 13.50 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| 14.50 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| 15.50 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |

TABLE 2

OPTICAL PHOTON DENSITY IN EV $CM^{-3}$

| R (Kiloparsec) | Z=0.0 | Z=0.25 | Z=0.50 | Z=0.75 | Z-1.00 | Z-1.25 | Z=1.50 |
|---|---|---|---|---|---|---|---|
| 0.50 | 4.67 | 3.44 | 2.18 | 1.67 | 1.37 | 1.16 | 1.00 |
| 1.50 | 3.64 | 2.75 | 1.83 | 1.46 | 1.23 | 1.06 | 0.93 |
| 2.50 | 2.88 | 2.22 | 1.53 | 1.24 | 1.06 | 0.93 | 0.82 |
| 3.50 | 2.30 | 1.80 | 1.26 | 1.04 | 0.90 | 0.80 | 0.72 |
| 4.50 | 1.80 | 1.42 | 1.03 | 0.86 | 0.75 | 0.67 | 0.61 |
| 5.50 | 1.42 | 1.13 | 0.83 | 0.70 | 0.62 | 0.56 | 0.51 |
| 6.50 | 1.09 | 0.88 | 0.66 | 0.57 | 0.51 | 0.47 | 0.43 |
| 7.50 | 0.86 | 0.70 | 0.53 | 0.46 | 0.42 | 0.38 | 0.36 |
| 8.50 | 0.67 | 0.55 | 0.43 | 0.38 | 0.34 | 0.32 | 0.30 |
| 9.50 | 0.53 | 0.44 | 0.35 | 0.31 | 0.28 | 0.26 | 0.24 |
| 10.50 | 0.41 | 0.34 | 0.27 | 0.24 | 0.22 | 0.21 | 0.20 |
| 11.50 | 0.32 | 0.26 | 0.21 | 0.19 | 0.18 | 0.17 | 0.16 |
| 12.50 | 0.14 | 0.14 | 0.14 | 0.14 | 0.13 | 0.13 | 0.13 |
| 13.50 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| 14.50 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| 15.50 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |

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D.A. KNIFFEN and C.E. FICHTEL
NASA Goddard Space Flight Center, Greenbelt, MD 20771

# FIGURE CAPTIONS

Figure 1. Infrared photon energy density as a function of galactic radius in the galactic plane based on the calculations decribed in the text.

Figure 2a. Gamma ray photon intensity for 35 MeV<$E_\gamma$<100 MeV as a function of galactic latitude predicted by the model described in the text at the galactic longitude of 330°.

Figure 2b. Gamma ray photon intensity for $E_\gamma$>100 MeV as a function of galactic latitude predicted by the model described in the text at the galactic longitude of 330°.

Figure 3. Comparison of experimental and predicated γ-ray (E>100 MeV) latitude dependence for -20°<b<20°. The theoretical calculation includes the finite resolution of the observing instrument, and hence, the distribution appears less narrow then those in Figures 2a and 2b.

Figure 4a. The calculated γ-ray energy spectra at b=0.5°, ℓ=330° for bremsstrahlung, nuclear interactions, and Compton radiation.

Figure 4b. The calculated γ-ray energy spectra at b=10°, ℓ=330° for Compton, nuclear interactions, and bremsstrahlung.

Figure 5. A comparison of the observed γ-ray spectrum to the calculated one for -10°<b<10°, 320°<ℓ<40°.

Figure 6a. Calculated Compton γ-ray intensity (35 MeV<$E_\gamma$<100 MeV) for blackbody, optical, and infrared photons as a function of galactic longitude for -10°<b<10°.

Figure 6b. Calculated Compton γ-ray intensity ($E_\gamma$>100 MeV) for blackbody, optical, and infrared photons as a function of longitude for -10°<b<10°.

Figure 7. Comparison of the total calculated γ-ray intensity as a function of galactic longitude compared to the experimental data for -10° < b < 10° and $E_\gamma$ > 100 MeV.

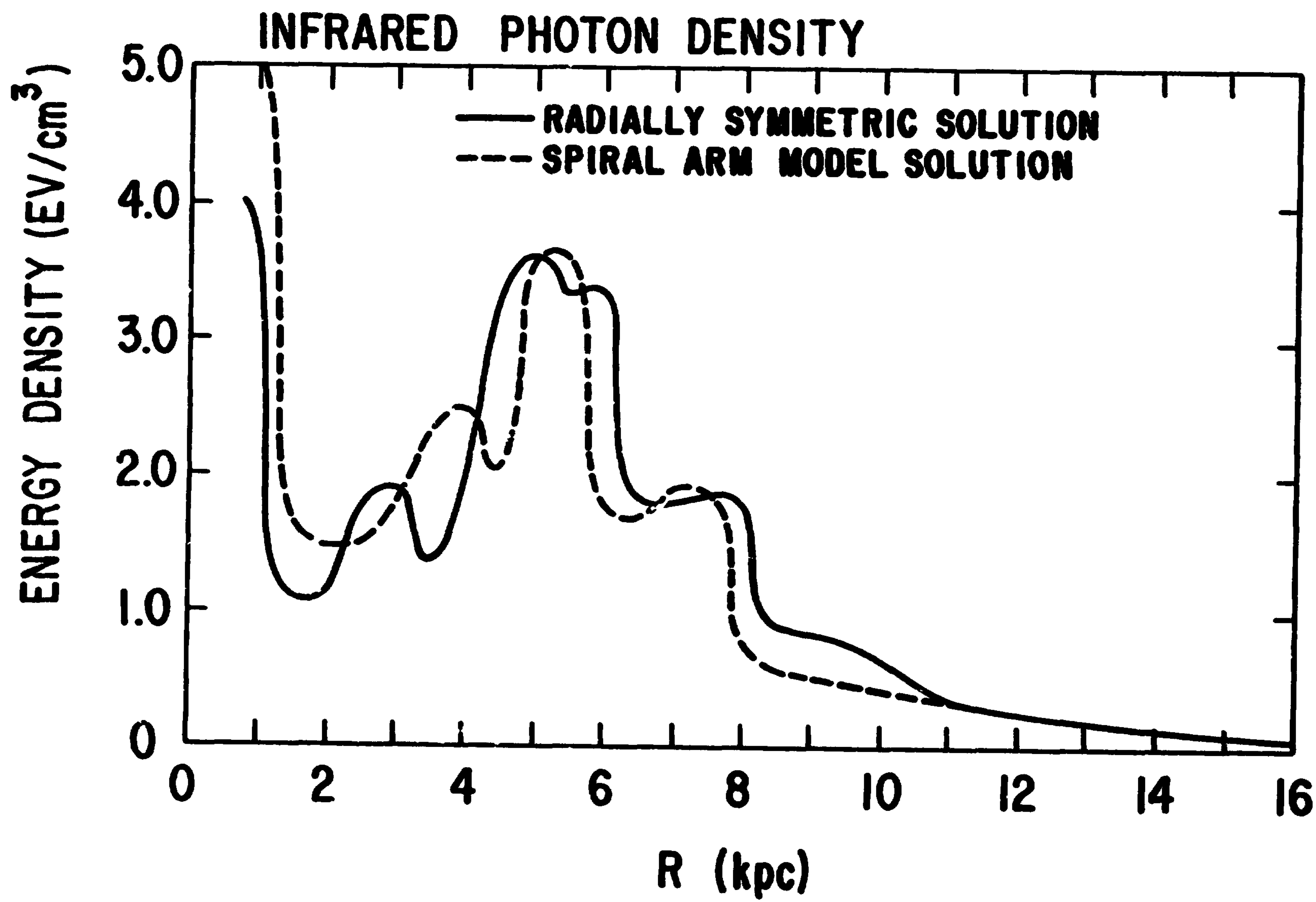
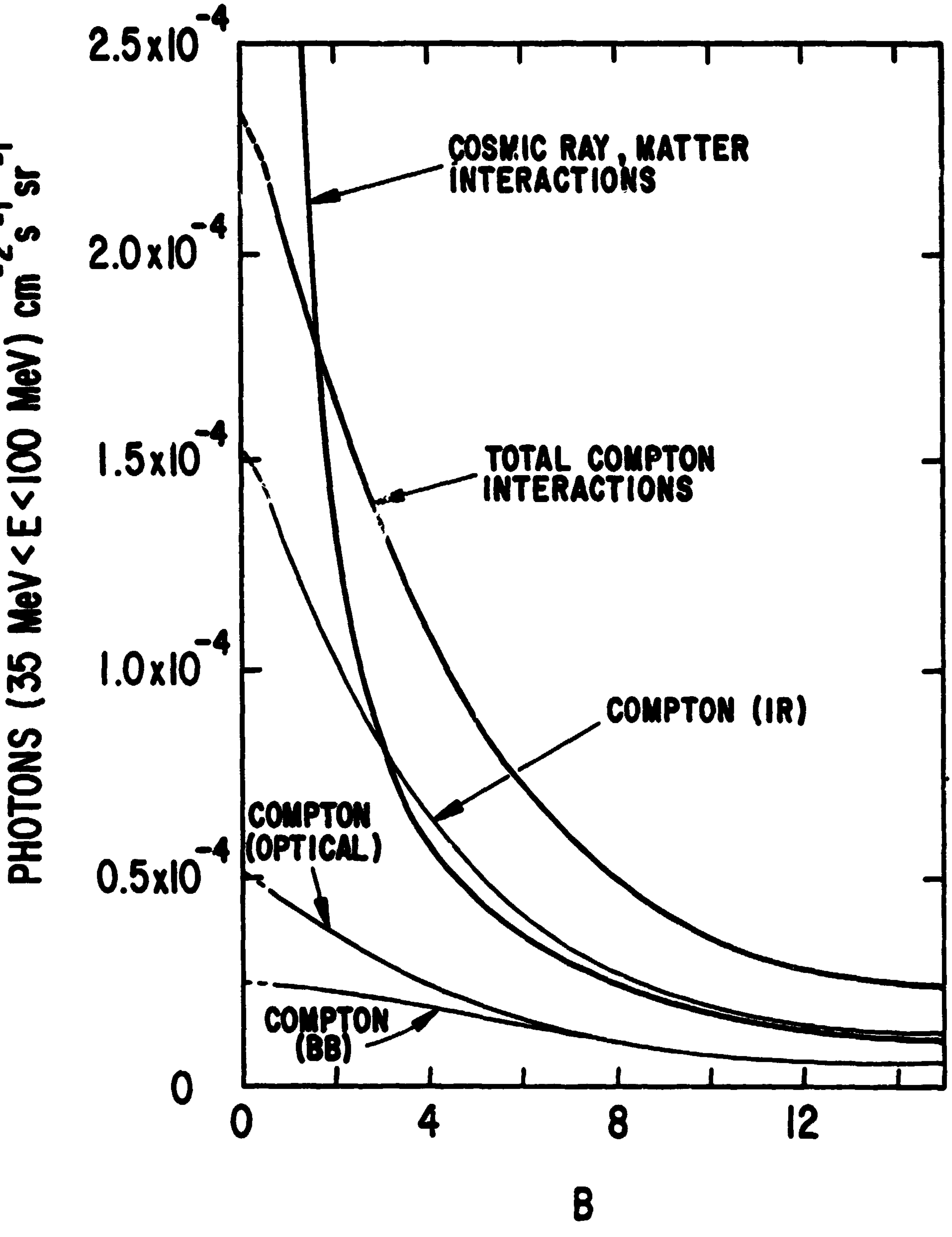

INFRARED PHOTON DENSITY
RADIALLY SYMMETRIC SOLUTION
SPIRAL ARM MODEL SOLUTION
ENERGY DENSITY (EV/cm³)
5.0
4.0
3.0
2.0
1.0
0
0
2
4
6
8
10
12
14
16
R (kpc)

FIGURE 1



2.5x10^-4
2.0x10^-4
1.5x10^-4
1.0x10^-4
0.5x10^-4
0
PHOTONS (35 MeV< E <100 MeV) cm^-2 s^-1 sr^-1
COSMIC RAY, MATTER INTERACTIONS
TOTAL COMPTON INTERACTIONS
COMPTON (IR)
COMPTON (OPTICAL)
COMPTON (BB)
0
4
8
12
B


FIGURE 2A

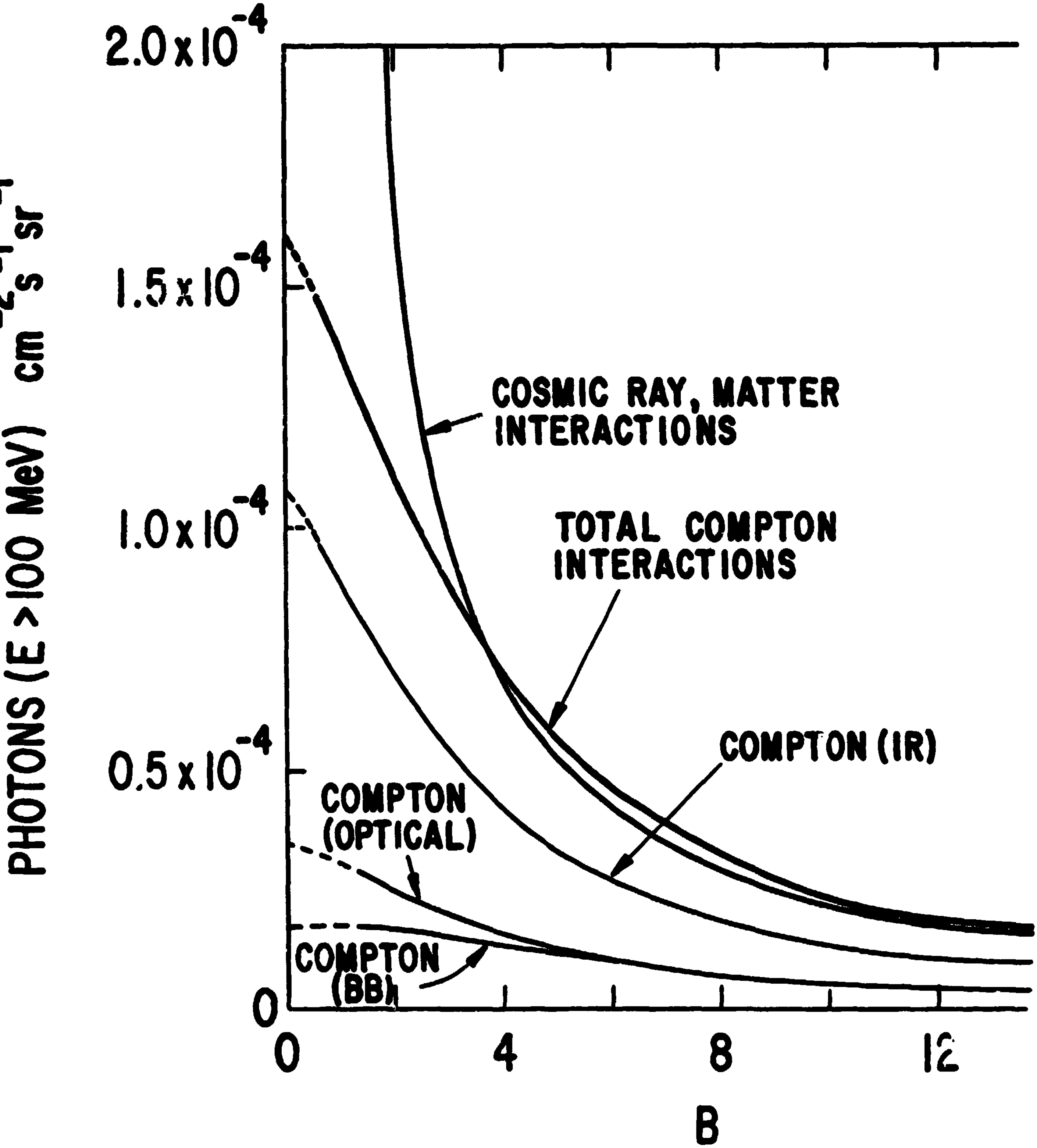

2.0 x 10^-4
1.5 x 10^-4
1.0 x 10^-4
0.5 x 10^-4
0
PHOTONS (E >100 MeV) cm^-2 s^-1 sr^-1
COSMIC RAY, MATTER INTERACTIONS
TOTAL COMPTON INTERACTIONS
COMPTON (IR)
COMPTON (OPTICAL)
COMPTON (BB)
0
4
8
12
B

FIGURE 2B

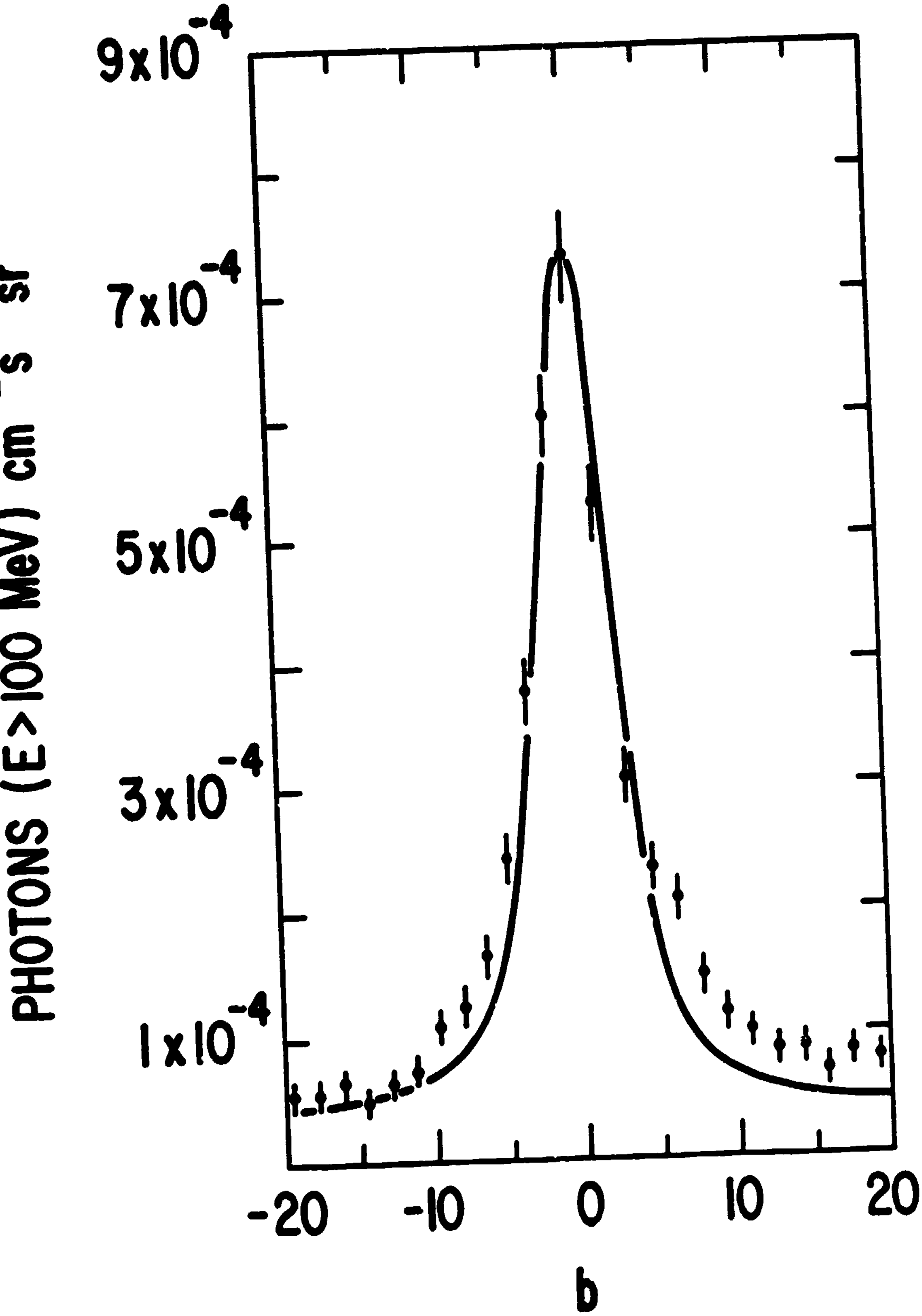
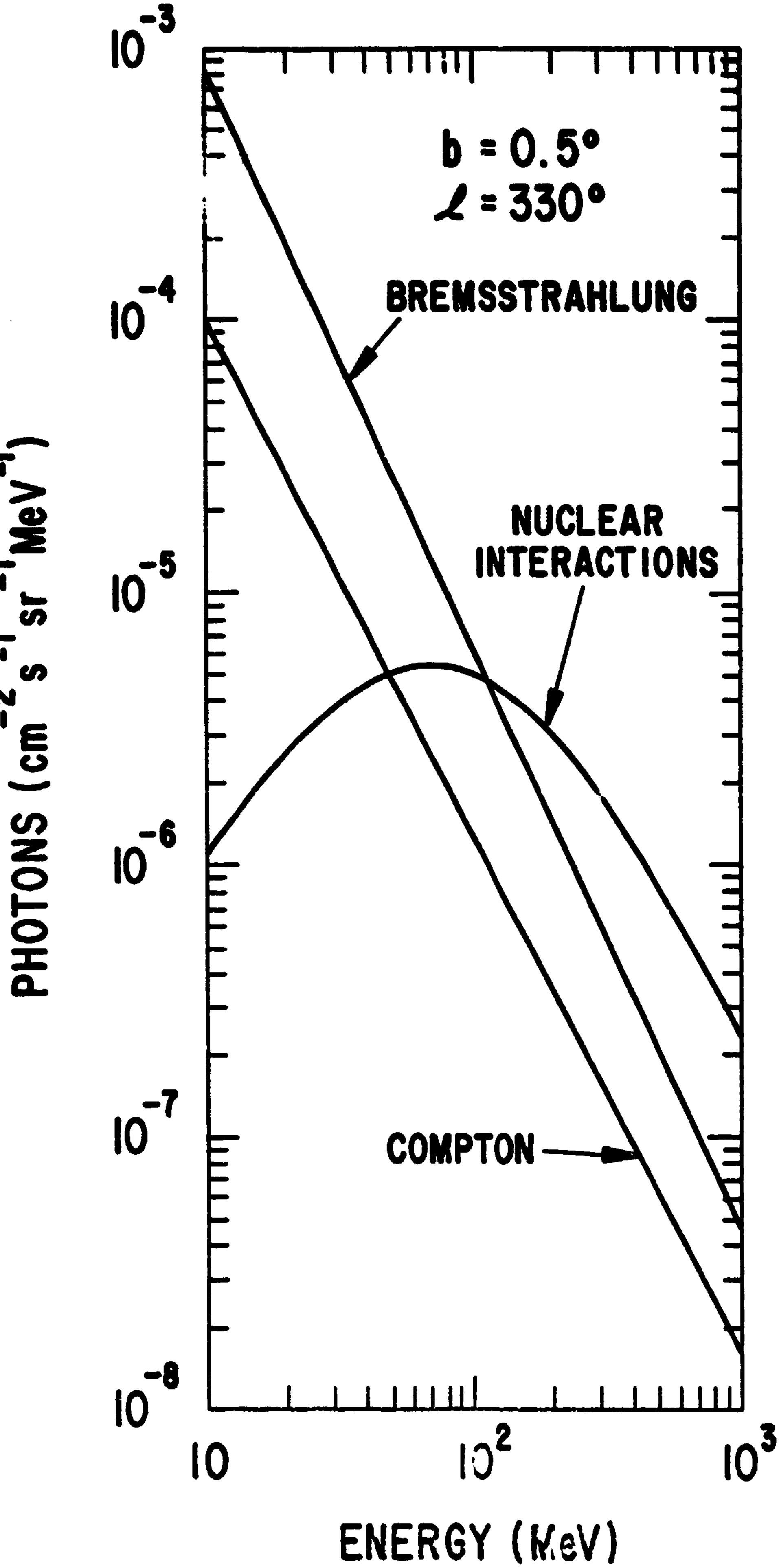
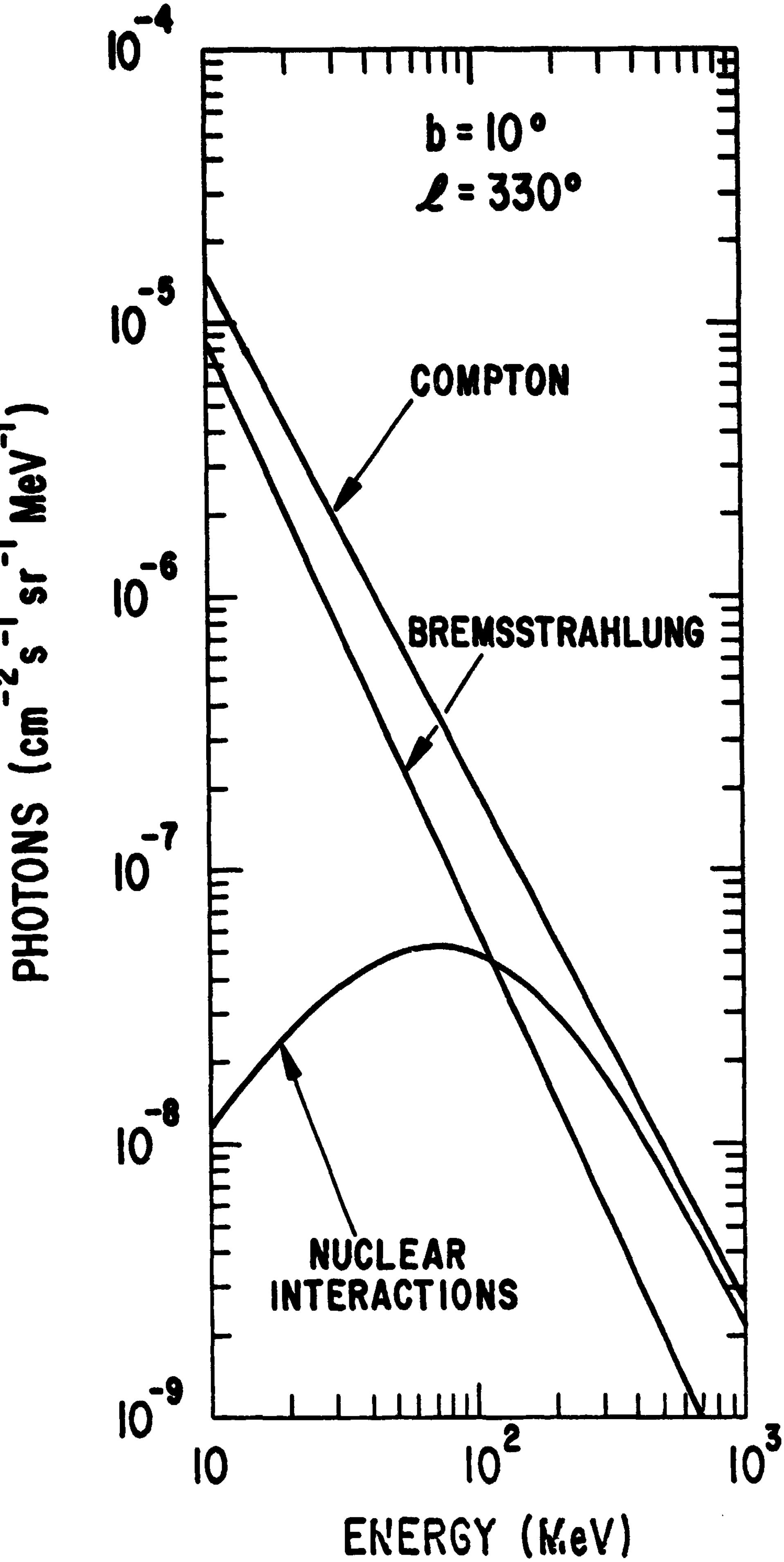

9x10-4
7x10-4
5x10-4
3x10-4
1x10-4
PHOTONS (E>100 MeV) cm-2s-1sr-1
-20
-10
0
10
20
b

FIGURE 3



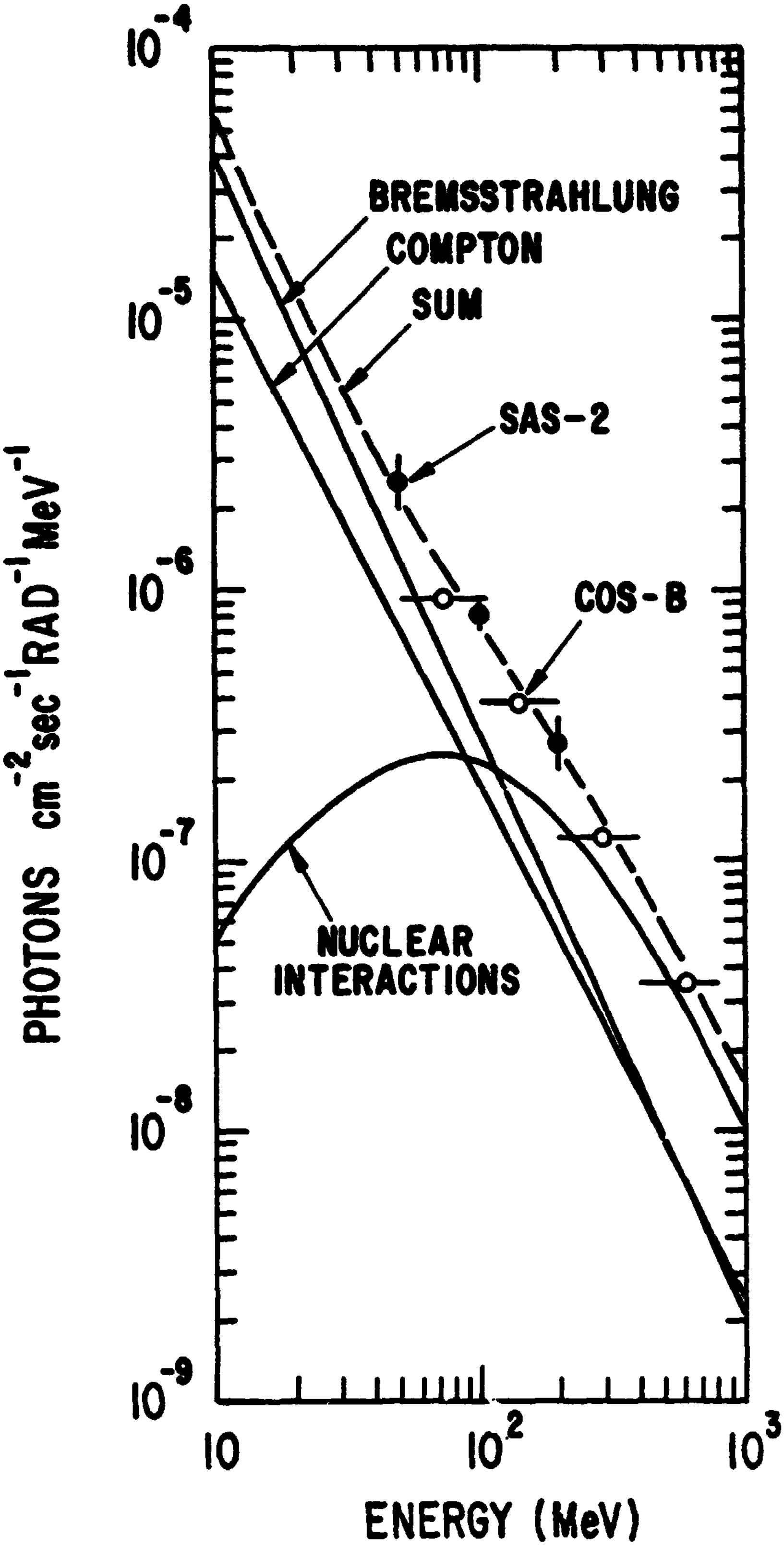
b = 0.5°
ℓ = 330°
BREMSSTRAHLUNG
NUCLEAR INTERACTIONS
COMPTON
PHOTONS (cm⁻² s⁻¹ sr⁻¹ MeV⁻¹)
ENERGY (MeV)


FIGURE 4A



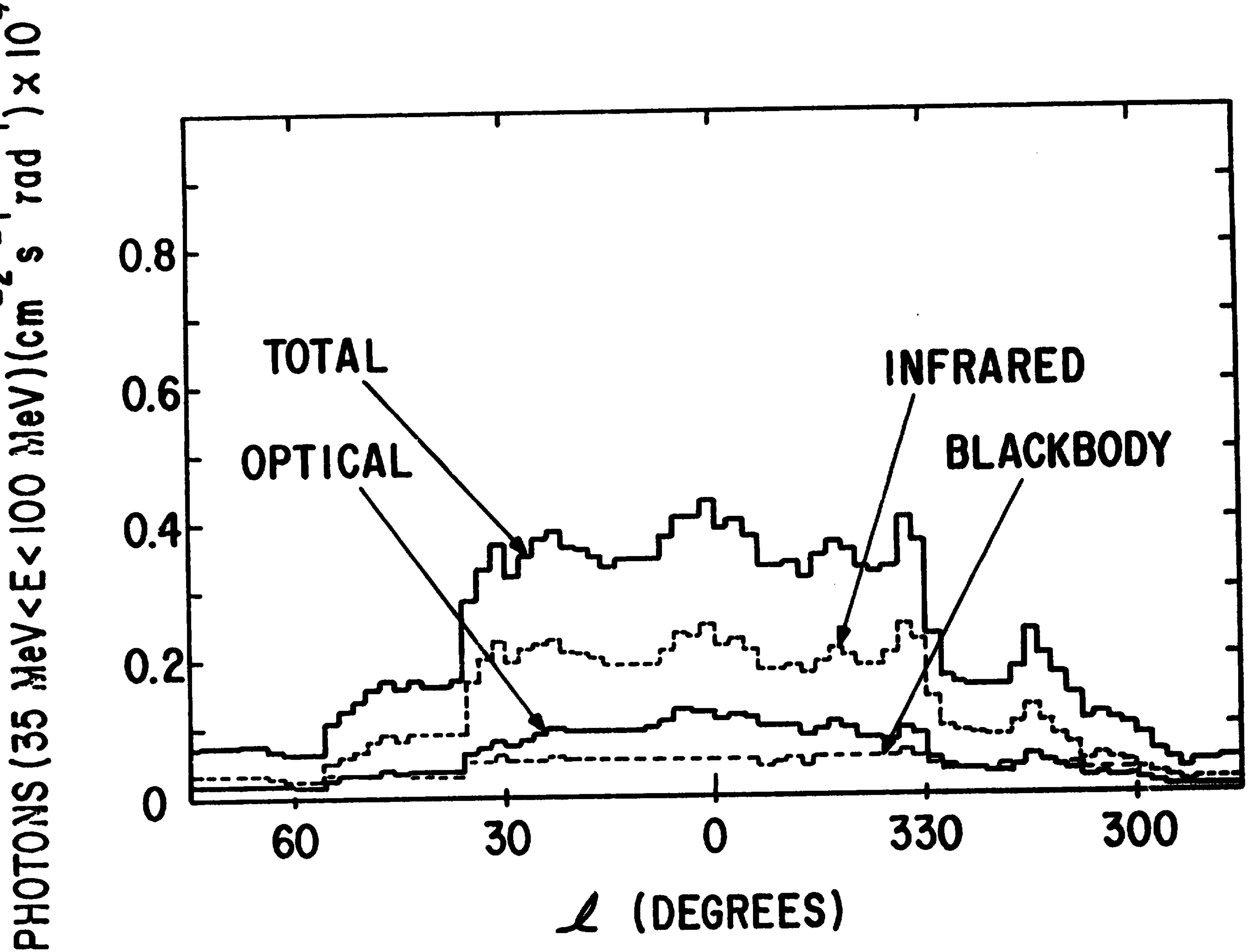
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
PHOTONS $(cm^{-2} s^{-1} sr^{-1} MeV^{-1})$
b = 10°
ℓ = 330°
COMPTON
BREMSSTRAHLUNG
NUCLEAR INTERACTIONS
10
$10^{2}$
$10^{3}$
ENERGY (MeV)


FIGURE 4B



PHOTONS cm$^{-2}$sec$^{-1}$RAD$^{-1}$MeV$^{-1}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
BREMSSTRAHLUNG
COMPTON
SUM
SAS-2
COS-B
NUCLEAR
INTERACTIONS
10
$10^2$
$10^3$
ENERGY (MeV)


FIGURE 5



PHOTONS (35 MeV<E<100 MeV)(cm$^{-2}$ s$^{-1}$ rad$^{-1}$) x 10$^{4}$
0.8
0.6
0.4
0.2
0
TOTAL
OPTICAL
INFRARED
BLACKBODY
60
30
0
330
300
$\ell$ (DEGREES)

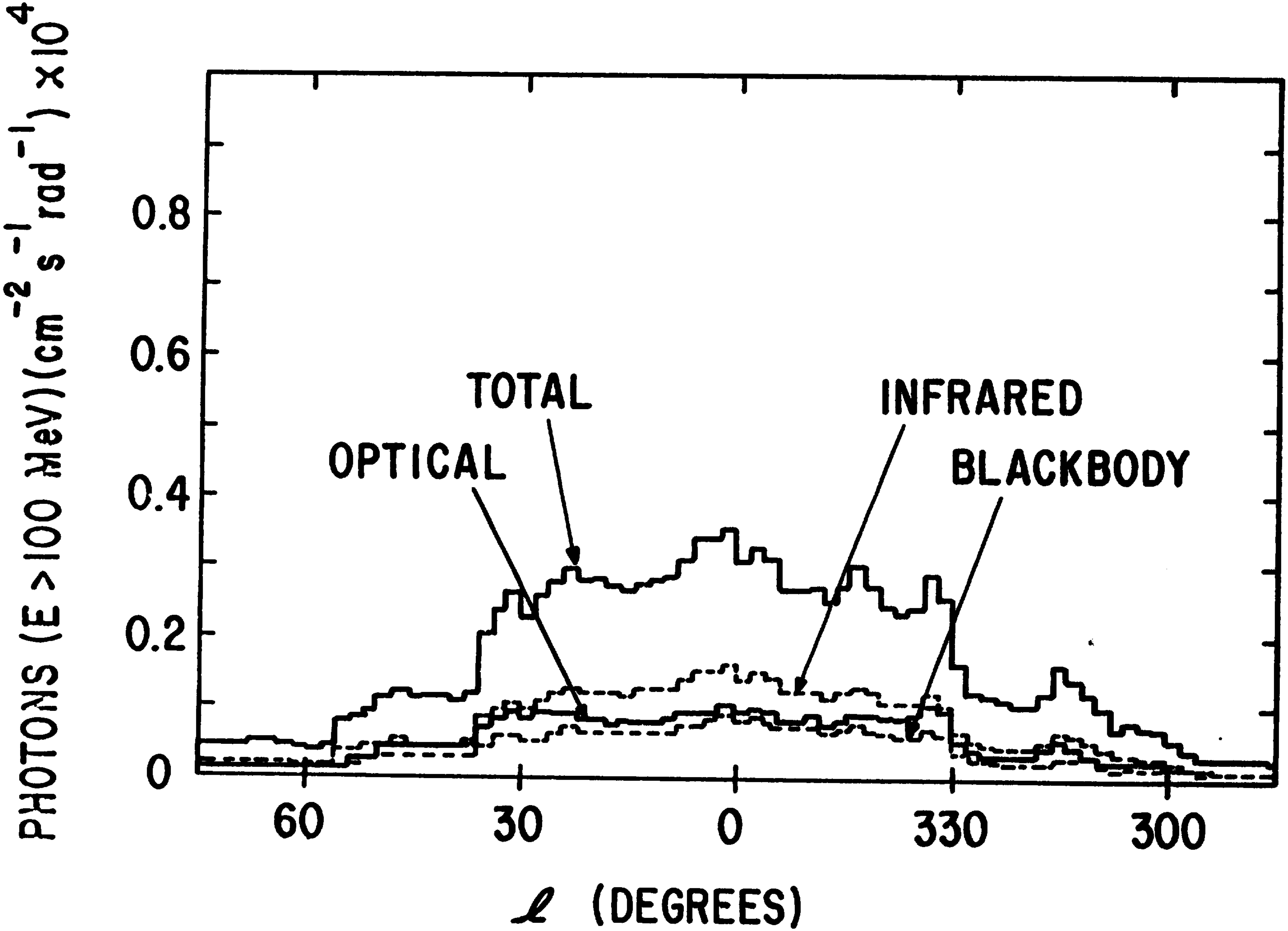

PHOTONS (E > 100 MeV)(cm$^{-2}$ s$^{-1}$ rad$^{-1}$) ×10$^4$
0.8
0.6
0.4
0.2
0
TOTAL
OPTICAL
INFRARED
BLACKBODY
60
30
0
330
300
$\ell$ (DEGREES)

FIGURE 6B

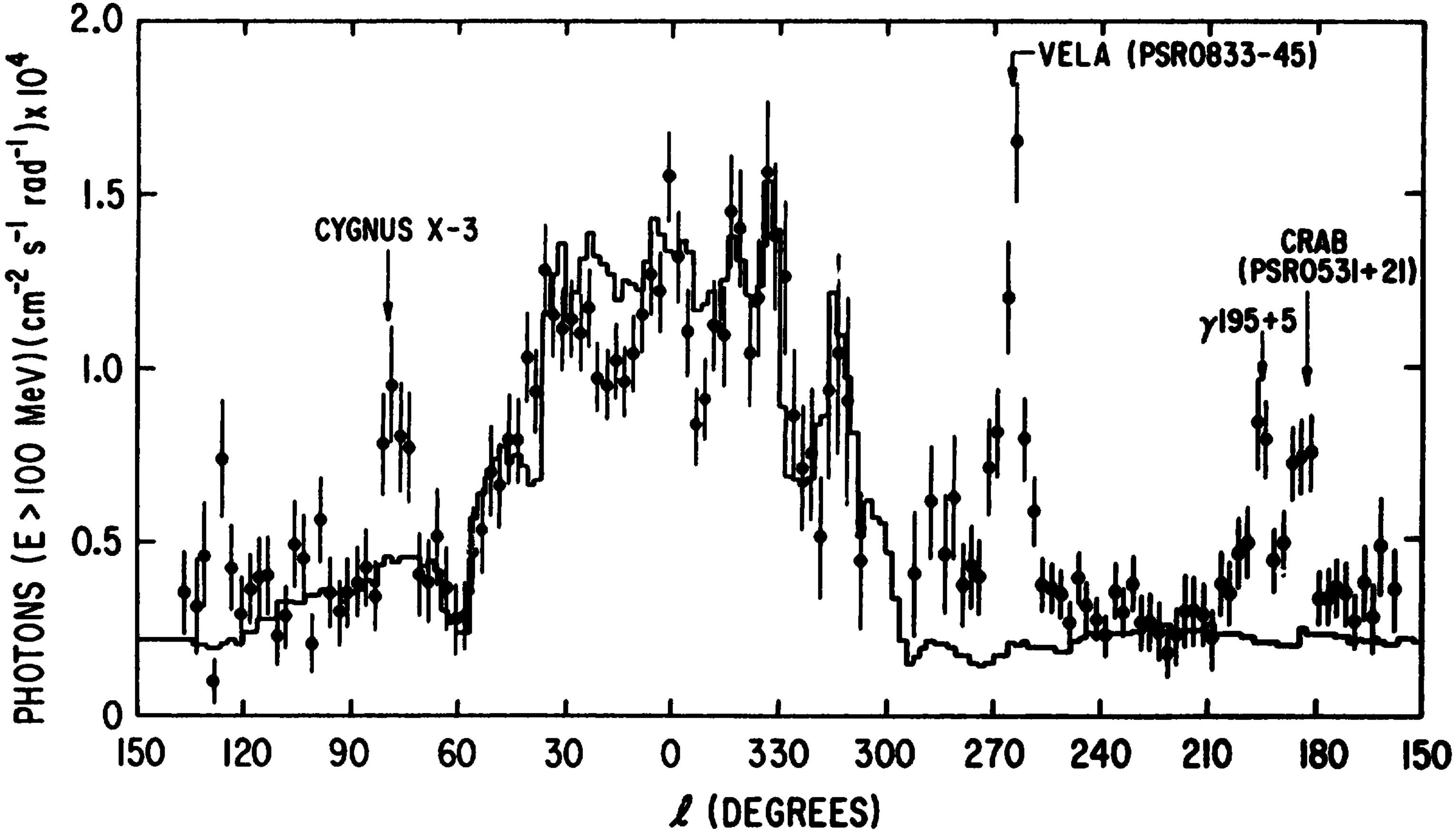

PHOTONS (E > 100 MeV)(cm$^{-2}$ s$^{-1}$ rad$^{-1}$) x 10$^{4}$
2.0
1.5
1.0
0.5
0
150
120
90
60
30
0
330
300
270
240
210
180
150
$\ell$ (DEGREES)
CYGNUS X-3
VELA (PSR0833-45)
CRAB
(PSR0531+21)
$\gamma$195+5

FIGURE 7