Diffuse Galactic Continuum Radiation

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Abstract. The diffuse gamma-ray continuum emission, which arises from cosmic-ray protons and electrons interacting with the interstellar matter and low energy photons, is the dominant feature of the gamma-ray sky. This emission has been studied from 0.05 MeV to over 50 GeV using the observations from OSSE, COMPTEL, and EGRET on the Compton Gamma-Ray Observatory. The OSSE observations show the diffuse continuum to be a composite of three independent components: e^+e^- anihilation line plus continuum, a soft low-energy component, and a dominant, hard component. The COMPTEL results are the first measurement of the diffuse emission at intermediate energies and the EGRET results have provided a much clearer image of the spatial and spectral distribution of this emission at higher energies. Although significant contributions from unresolved distributions of point sources cannot be excluded, particularly from the COMPTEL and OSSE data, the spectra from the three instruments, from 1 MeV to about 1 GeV, can be explained with the sum of bremsstrahlung, nucleon-nucleon (π^0 decay), and inverse Compton components. However, above about 1 GeV, the EGRET spectrum is harder than expected from the nucleon-nucleon spectrum derived from an $E_{\mathrm{P}}^{-2.7}$ cosmic-ray proton spectrum observed in the Solar neighborhood.

These observations and results are discussed in terms of the correctness of our interpretations of the observations, what does and what does not conform to the standard picture, the significance of these observations for cosmic-ray physics, and how much of the observed flux is due to point sources.

INTRODUCTION

Prior to the launch of the *Compton Gamma-Ray Observatory* (CGRO) on April 5th 1991, a number of non-simultaneous observations of the Galactic diffuse emission were made with a variety of instruments covering various and generally non-overlapping energy ranges. These include observations in the 0.3–8.5 MeV energy range with the Gamma-Ray Spectrometer on the *Solar Maximum Mission* [1], at higher energies (35 MeV – 150 MeV) with SAS 2 [2,3] and with COS B (50 MeV – 6 GeV) [4,5]. There were no observations

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made in the intermediate (10 – 50 MeV) energy range. A detailed review of the analyses of these observations above about 1 MeV is given by Bloemen [6].

This paper provides an overview of the recent observations made with the OSSE, COMPTEL, and EGRET instruments on CGRO, covering over six decades in gamma-ray energy (50 keV – > 50 GeV). The BATSE instrument is also sensitive to the diffuse gamma radiation over its energy range from 0.02 MeV to 100 MeV. However, the results of a long term project to extract the diffuse emission from the BATSE observations [7] are not yet available.

The OSSE, COMPTEL, and EGRET observations are providing us with a much clearer understanding of the spectrum and spatial distribution of the Galactic diffuse gamma radiation. This review examines the scientific results from these observations and examines our interpretations: how these results conform, or fail to conform, with the standard picture; the significance for cosmic-ray physics; and the significance of the contribution from point sources.

CGRO OBSERVATIONS AND RESULTS

OSSE – Orientated Scintillation Spectrometer Experiment

The OSSE instrument consists of four identical phoswich spectrometers which are sensitive to gamma rays from about 50 keV to 10 MeV. Passive tungsten slat collimators define a $3.8° \times 11.4°$ FWHM aperture for each detector. A detailed description of the OSSE instrument is given by Johnson et al. [8].

Purcell et al. [9] and Kinzer et al. [10] describe OSSE observations of the central region of the Galactic plane ($b = 0°$) for which the large angle dimension of the OSSE collimator was aligned with the plane of the Galaxy. This alignment maximizes the signal from the extended Galactic ridge emisison while minimizing contamination of plane emission in the background measurements, at $|b| = 10°$.

The high statistical quality of the OSSE observations of the Galactic center allows detailed investigations of various spectral components over the 0.050 to 10 MeV energy range. Kinzer et al. [10] fit various photon models to the spectra by folding the model through the instrument response function, on the assumption of a 5° FWHM width for the Galactic plane emission, and comparing the resultant count spectrum to the observed spectra. The model spectra contained at least four components: a hard cosmic-ray induced component, a soft low-energy component which includes a discrete source contribution, a positron annihilation line at 0.511 MeV, and a positronium continuum annihilation component. The 1.809 MeV ^{26}Al line has an intensity below the sensitivity of a single two-week observation and was not included.

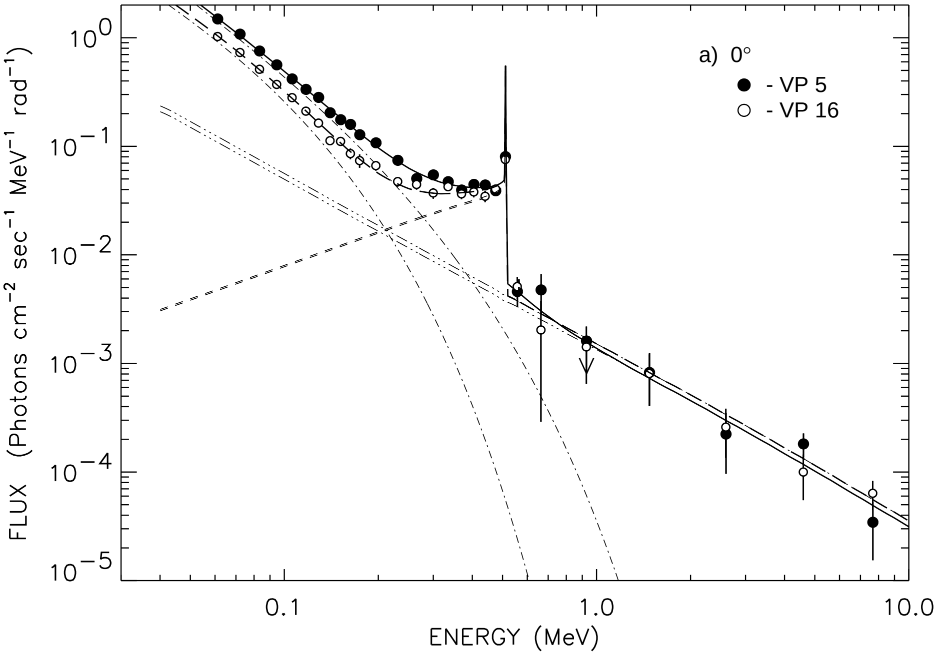

FIGURE 1. OSSE spectra of the diffuse emission from the Galactic center region (l = 0°, b = 0°, VP 5 and VP 16). The best fit four component model of Kinzer et al. [10] is shown as a solid line. The model components are: exponentially absorbed power-law, dash-doted line; positronium continuum and 2.5 keV wide narrow line at 0.511 MeV, dashed line; and cosmic-ray interaction continuum model of Skibo [11], dash-triple dotted line.

The best fit to the OSSE spectrum from the Galactic center region of the plane (Fig. 1) was obtained by combining the high-energy continuum model of Skibo [11] with an exponentially absorbed power-law model for the low-energy component and models for positron 511 keV annihilation line and the positronium continuum. In the two Galactic center spectra shown in Figure 1, the soft low-energy component fluxes differ by a factor of about 1.7. This strong variation below 0.2 MeV is attributed to one or more bright and highly variable point sources near the Galactic center.

Since the OSSE instrument is non-imaging, it is sensitive to both the diffuse emission and compact sources in the aperture. Purcell et al. [9] used coordinated observations of the Galactic center region made with the imaging SIGMA instrument [12] to separate the discrete source contribution from the diffuse emission observed with OSSE over the energy range 50 keV – 4.5 MeV. Purcell et al. [9] fit a similar model (consisting of a single power law, a photopeak line fixed in energy at 511 keV with a width of 2.5 keV, and a positronium continuum component) to this source subtracted spectrum. The fitted power law spectral index was -2.4 ± 0.1, with a continuum flux of

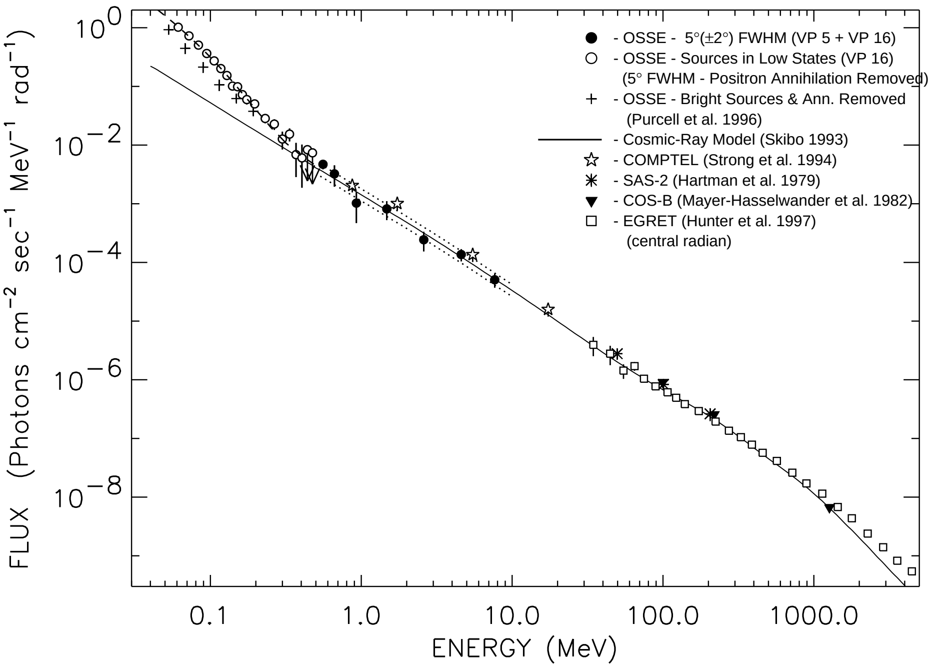

FIGURE 2. Comparison of the OSSE, COMPTEL, and EGRET estimates of the diffuse emission from the Galactic center region without the positron annihilation components and bright source component. The solid line shows the cosmic-ray interaction continuum model of Skibo [11] fit to the OSSE observations for a 5° FWHM Galactic latitude width.

$(1.61 \pm 0.08) \times 10^{-2}$ cm^{-2} s^{-1} MeV^{-1} at 100 keV. This analysis showed that the spectrum below 0.3 MeV towards the Galactic center has roughly the same intensity as the emission at $l = 25°$ and $l = 339°$ after correcting for the discrete sources resolved by SIGMA. This suggests that the residual soft low-energy component of the Galactic diffuse emission is broadly distributed in Galactic longitude and that bright discrete sources contribute significantly to the Galactic center spectrum below 500 keV.

The OSSE spectrum of the plane toward the Galactic center, unfolded on the assumption of a latitude width of 5° FWHM and corrected for the discrete source component, with the positron-annihilation components removed, is shown in Figure 2. Also included are recent results from COMPTEL and EGRET, described below, and earlier findings. The figure shows the best fit model for the soft low-energy component and the cosmic-ray continuum model of Skibo [11]. The Skibo model, as fit to the OSSE data, is shown over the entire energy range. The good agrement between the model and the OSSE, COMPTEL, and EGRET data, up to 1 GeV, lends support to the leaky-box model of Skibo. The discrepancy above 1 GeV is discussed below.

COMPTEL – Imaging Compton Telescope

The COMPTEL instrument is the first medium-energy imaging gamma-ray telescope ever flown on a satellite. It is sensitive to gamma rays in the energy range from 0.75 – 30 MeV, which overlaps the high end of the OSSE energy range and adjoins the low end of the EGRET energy range. Gamma rays in this energy range are produced by cosmic-ray electrons interacting via electron bremsstrahlung and inverse Compton scattering of low-energy photons. Photons in this energy range are difficult to detect; the double Compton scattering detection technique used in the COMPTEL instrument and its large size [13] make it about 20 times more sensitive than prior detectors in this energy range [14].

Derivation of the Galactic diffuse emission spectrum using the COMPTEL data requires fitting a model to the data and is hence sensitive to the handling of the instrumental responce and background. The Galactic center spectrum recently derived by Bloemen et al. [16] is compared with earlier results of Strong et al.; in Figure 3a, the early results of Strong et al. [17] are in agreement, but the more recent estimates [20,18] are too high at 1–10 MeV. The most recent values by Strong et al. [19] (Fig. 3b) are lower again at 1–10 MeV. These variations are due to inadequate handlings of the instrumental background, in particular in [20,18].

Interpretation of the diffuse emission spectrum in the medium-energy range has evolved considerably since the launch of CGRO. In 1994 electron bremsstrahlung was assumed to be the dominant production mechanism [15,17]. Later work [18] showed that inverse Compton emission is an important component. The current picture [19] indicates that there may be much less bremsstrahlung and that inverse Compton emission may be the dominant component of the continuum emission below about 10 MeV, although a contribution from nuclear deexcitation lines can't be ruled out.

The bremsstrahlung component of the medium-energy (1 – 50 MeV) diffuse emission, combined with observations of the diffuse radio synchrotron emission which traces electrons with energies of typically 100 MeV – 10 GeV, can be used to derive the shape of the cosmic-ray electron spectrum below 10 GeV, which is highly uncertain due to Solar modulation. Strong & Moskalenko [22] conclude that if the bremsstrahlung emission is less significant then the electron injection spectrum must be harder than previously thought, $E^{-2.1}$, rather than $E^{-2.4}$ based on radio data [21].

The latitude distribution of the diffuse emission in the 1 – 3 MeV range has been derived by Strong et al. [20]. The latitude distribution in the 10 – 30 MeV range is shown in Figure 4. The profile is fairly well described by the sum of a narrow (2° FWHM) bremstrahlung component plus a broader (8° FWHM) inverse Compton component [20]. Within about ±10° of the plane this model agrees fairly well with the observations although there are moderately significant discrepancies at about $b = -6°$, $-14°$, and $14°$.

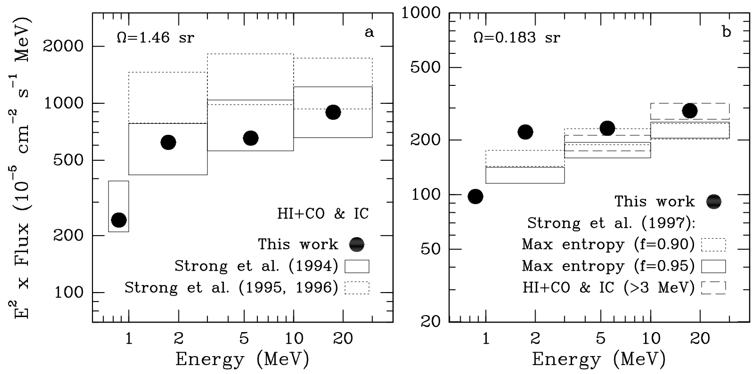

FIGURE 3. *a* COMPTEL broad-band spectra of the inner Galaxy ($300° < l < 60°$, $|b| < 20°$), as recently determined by Bloemen et al. [16] (black dots), compared to preveious results of Strong et al. [17,20,18], fitting the same H I and CO observations and IC intensity model (IC not used in [17]. *b* Comparison witht he most recent results of Strong et al. [19] ($330° < l < 30°$, $|b| < 5°$).

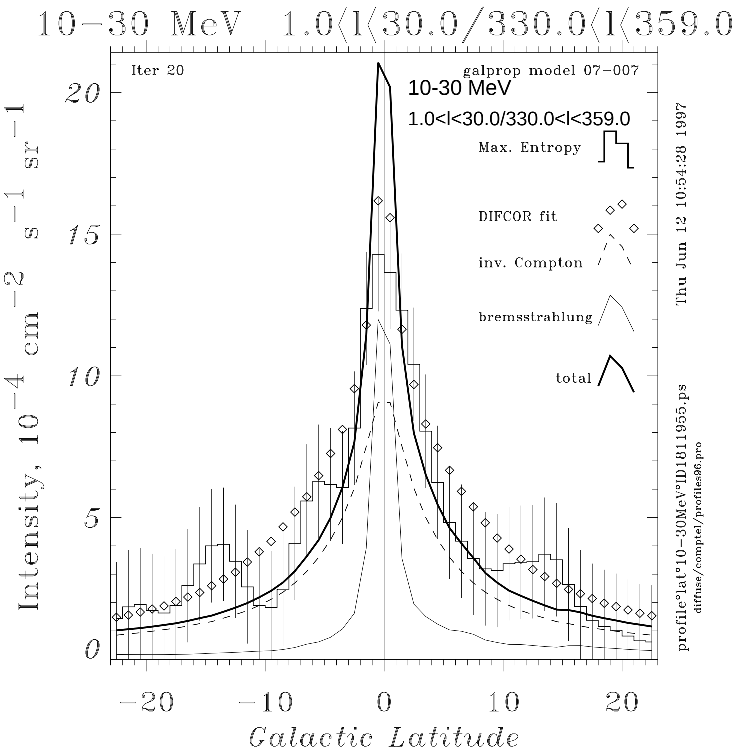

FIGURE 4. COMPTEL latitude profile of the diffuse emission in the Galactic center region compared to a prediction for a cosmic-ray interaction model [19].

The first attempts to determine the gamma-ray emissivity and the intensity of the diffuse emission from these data by Strong et al. and Strong [23–25] showed that the COMPTEL results were consistent with previous measurements, and with calculations of the bremsstrahlung emissivity using a "leaky box" propagation model for the cosmic-ray electrons. Further analysis of the COMPTEL data (Phase I) was presented at the Second Compton Science Symposium [25]. The point source contribution is unknown, and has generally been presumed rather small; however, quantitative estimates are very difficult.

EGRET – Energetic Gamma Ray Experiment Telescope

The EGRET instrument is sensitive to gamma rays with energy from about 30 MeV to over 30 GeV, adjoining the COMPTEL energy range. These photons are produced by the interactions of cosmic rays with the interstellar medium via electron bremsstrahlung, nucleon-nucleon processes (π^0 decay), and, to a lesser extent, inverse Compton scattering of low-energy photons.

The greater sensitivity and spatial and energy resolution of the EGRET instrument [26] compared to SAS 2 [27] and COS B [28] has enabled much more detailed spatial and spectral analyses of the diffuse emission to be performed than were possible with these earlier instruments.

The EGRET observations of the diffuse emission from the Galactic plane from the first fifteen months (1991 May 15 – 1992 Nov 17, Phase 1) and the following ten months (1992 Nov 17 – 1993 Sep 14, Phase 2) of EGRET operation have been analyzed by Hunter et al. [29]. These observations provide fairly uniform exposure to the Galactic plane (average exposure = 1×10^9 cm^2 s). They determined the longitude and latitude distributions for 4 broad energy intervals (30–100 MeV, 100–300 MeV, 300–1000 MeV, and 1000–30,000 MeV) averaged, respectively, over $1° \times 4°$ and $20° \times 0.5°$ ($l \times b$) bins (see Figures 2 and 3 of [29]). Spatially resolved, average spectra of the diffuse emission were also determined for 11 energy intervals covering the range from 30 MeV to 30 GeV for $10° \times 4°$ ($l \times b$) bins (see Figure 5 of [29]). The average diffuse gamma-ray spectrum of the inner Galaxy, $300° < l < 60°$, $|b| \leq 10°$, is shown in Figure 5. Spatially resolved spectra have also been determined by Dixon & Samimi [30] using a model independent, wavelet-based analysis technique.

The components of the diffuse emission, electron Bremsstrahlung, nucleon-nucleon, inverse Compton, and the extragalactic (isotropic) diffuse, shown in Figure 5 were derived from a 3-dimensional model of the Galactic interstellar matter distribution on the assumption that the cosmic-rays are coupled to the matter [31]. This model has only two parameters that are considered to be adjustable, the molecular hydrogen mass calibrating ratio (the X-ratio), and the scale of the cosmic-ray coupling to the matter. The spectral components calculated using these parameter values are shown in Figure 5. The

TABLE 1. The $W_{CO}/N(H_2)$ Calibration Factor (X-ratio)

Region	X-ratio/10^{20} cm^{-2}(K km s^{-1})$^{-1}$	Authors & References
Whole Galaxy	1.56 ± 0.05	Hunter et al. 1997 [29]
Whole Galaxy	1.9 ± 0.2	Strong & Matttox 1996 [36]
Whole Galaxy	1.9 ± 0.3	Strong et al. 1988 [37]
Outer Galaxy	2.7 ± 0.1	Hunter et al. 1997 [29]
Perseus Arm	2.5 ± 0.9	Digel et al. 1996 [38]
Ophiuchus	1.1 ± 0.2	Hunter et al. 1994 [39]
Orion	1.06 ± 0.14	Digel et al. 1995 [40]
Local	0.9 ± 0.14	Digel et al. 1996 [38]

best-fit value for the coupling scale was found to be 1.76 ± 0.2 kpc and the value for the X-ratio is given in Table 1 along with other values determined from the EGRET gamma-ray data on several spatial scales, local, individual molecular clouds, Galactic arms, and the Galaxy as a whole. These results, summarized in Table 1, are consistent with a trend for higher values of the X-ratio in the outer Galaxy suggested by non-gamma-ray determinations of the X-ratio, such as Sowdrowski et al. [32]. Increasing values of the X-ratio in the outer Galaxy would be consistant with the metalicity gradient. There is also an indication of a smaller than average value for the X-ratio locally. The energy dependence of the X-ratio over the EGRET energy range has also been investigated [39,40,36,38]. An apparent energy dependence would indicate cosmic-ray exclussion of enhancment in molecular clouds. Above 100 MeV there does not appear to be any significant variation with energy. Below 100 MeV the errors are much larger, but are also consistent with no variation.

In general, the spatial agreement between the Hunter et al. model and observation is very good, particularly in the directions of the Galactic arm tangents. There are, however, a few areas where the fit is not as good which provide interesting insights into the diffuse emission. At medium latitudes ($3° < |b| < 10°$) toward the Galactic center (Fig. 3 of [29]) the model under-predicts the observed emission. This deficit may be due to underestimation of the inverse Compton intensity in the Galactic center, perhaps owing to undetestimating the density of cosmic-ray electrons or low-energy photons. The longitude profile (Fig. 2 of [29]) shows a general overprediction near the outer Galaxy in the Galactic plane and in isolated longitude regions near the Galactic center. This may indicate a that the assumption of dynamic balance between the cosmic-rays and the intersteller matter density.

The diffuse emission excess above 1 GeV relative to the expected π^0-decay emission (Fig. 5) [41,36,29] can not be explained by a spectral variation in the X-ratio. The model of Strong & Mattox [36] alowed for a spectral variation of the X-ratio, but found no significant variation (Fig. 6). Comparison of the Hunter et al. model [29], based on the assumption of an energy independent

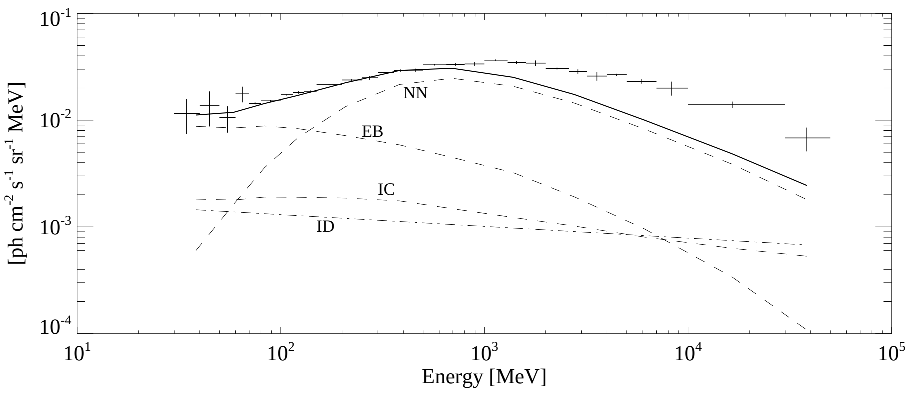

FIGURE 5. The average diffuse gamma-ray spectrum of the inner Galaxy region, $300° < l < 60°$, $|b| \leq 10°$ (0.73 sr) observed with EGRET [29]. The contributions from point sources detected with more than 5σ significance [33,34] have been removed. The data are plotted as crosses where the horizontal line indicates the width of the energy interval and the vertical line the $\pm 1\sigma$ statistical error. The best-fit model calculation (see [29]) plus the isotropic diffuse emission [35] is shown as the solid line. The individual components, nucleon-nucleon (NN), electron-bremsstrahlung (EB), and inverse Compton (IC) of this calculation are shown as dashed lines. The isotropic diffuse emission (ID) is shown as a dash-dot line.

value for the X-ratio, with the observation found the discrepancy to be uniformly proportional to the modeled intensity indicating that the source of the excess emission comes equally from both the atomic and molecular hydrogen and must have a common origin.

Hunter et al. suggest four possible explanations for the excess above 1 GeV: 1) there may be a possible error in the EGRET calibration, 2) the theory of $p + p \rightarrow \pi^0 + X \rightarrow \gamma + \gamma$ production may not be adequately understood, 3) there may be a distribution of unresolved point sources, and 4) the shape of the cosmic-ray spectrum that is measured near the Sun may not be representative of the Galactic average spectral shape. Of these, the first is considered unlikely for various reasons and the second, although also unlikely, is being re-examined by Barring & Stecker (private communication).

The third possibility, a distribution of unresolved point sources has been examined by several authors. These studies include: gamma rays and cosmic rays from supernova explosions and young pulsars [42] and gamma-rays from pulsars [43]. Pulsars, however, are not likely to be the explanation of the high energy excess also appears in high latitude spectra.

The fourth possibility, if correct, would require significant alteration to our understanding of the Galactic cosmic-ray distribution. The consequences of an average Galactic cosmic-ray spectrum different from the locally observed spectrum have been investigated by several authors. Mori [44] determined

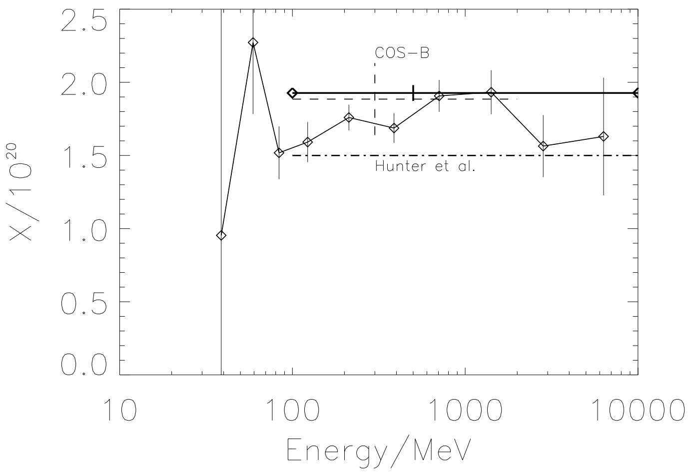

FIGURE 6. Energy dependence of the $N(H_2)/W_{CO}$ calibration factor (X-ratio) in units of mol cm^{-2} (K km $s^{-1})^{-1}$ derived by Strong & Mattox [36] for the whole Galaxy in ten energy ranges and for 100–10000 MeV (solid line). The Galactic average values from EGRET [41] (dash-dot line), and COS B [37] (dashed line) are shown for comparison.

that the $E_\gamma > 100$ GeV excess can be fairly well explained if the average cosmic-ray proton spectrum is $E_p^{-2.45}$, which is very much flatter than the locally observed $E_p^{-2.75}$ spectrum. Mori's "best-fit" spectrum shown in Figure 7 agrees fairly well with the EGRET spectrum above about 500 MeV, however, below this energy the model of Hunter et al. [29], shown in Figure 5, agrees better with the data.

An enhanced inverse Compton component is another possible explanation of the gamma-ray excess above 1 GeV. Chen, Dwyer, & Kaaret [45] found that the high latitude ($29.5° < |b| < 74°$) gamma-ray emission has two components; one is correlated with H I and the other, correlated with the 408 MHz radio emission, was identified as the inverse Compton emission. Chen et al. determined a power-law spectral index of -1.88 ± 0.14 for this emission over the energy range 30–5000 MeV. The spectral index of the inverse Compton emission corresponds to a cosmic-ray electron spectral index of $\alpha_e = 2\alpha_\gamma + 1 = -2.76 \pm 0.28$. This spectrum is harder than expected from electrons. A harder inverse Compton spectrum was also found by Strong & Mattox [36]. Although this may be due to detection of emission other than pure inverse Compton, it may indicate a harder cosmic-ray spectrum locally. This could be possible if the locally measured electron spectrum is dominated by local supernova remnants, and is not typical of the Galactic average spectrum [46].

Other possibilities include: flattening of the extragalactic diffuse spectrum

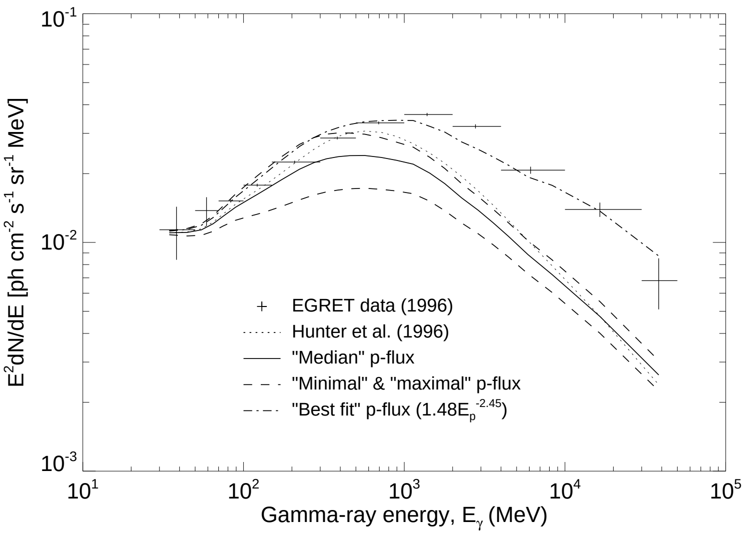

FIGURE 7. Model predictions of the diffuse gamma-ray spectrum based on gamma-ray emissivities from cosmic-ray nuclear interactions based on various assumptions of the proton spectrum [44] compared to the EGRET spectrum [41].

above 1 GeV [47]; hardening of the Galactic diffuse spectrum above 1 GeV by cosmic-ray transport effects in dense molecular clouds [48]; and enhanced cosmic-ray electron bremsstrahlung [46].

Weak evidence of spectral variations of the diffuse emission with Galactic longitude were observed in the EGRET data in the direction of the Galactic anti-center and only at low latitudes ($-2° < b < 2°$) [29]. In this direction the spectrum appears to be steeper above about 4 GeV than at other longitudes or higher latitudes (see Fig. 7 of [29]). This variation of the diffuse gamma-ray emission hints at a possible variation of the cosmic-ray proton spectrum with Galactic radius which might be expected if cosmic-rays are accelerated primarily in the inner Galaxy and diffuse to the outer Galaxy or if the high-energy cosmic rays are confined less well in the outer Galaxy.

The spectral shape of the diffuse emission between about 30 MeV and a few hundred MeV can be used to study the cosmic-ray electron-to-proton (e/p) ratio. In this energy range the dominant production mechanism of the diffuse emission shifts at about 100 MeV from electron (electron bremsstrahlung and inverse Compton) to proton (nucleon-nucleon, π^0-decay) processes. Zhang et al. [49] examined the the COS B data for variation in the spectral ratio I($E_\gamma >$ 300MeV)/I(70MeV $< E_\gamma <$ 300MeV) as a function of Galactic longitude. They suggest that variations in this ratio, typically less than 1 sigma, are most likely due to variations in the e/p ratio. The Spatially resolved spectra ($10° \times 4°$, $l \times b$) derived from the EGRET data [29] do not show any evidence for significant variation in the shape of the diffuse emission spectrum with Galactic longitude below about 4 GeV.

The spectra and distribution of cosmic-ray electrons and protons in the Galaxy have been investigated by several authors and the results compared with the OSSE, COMPTEL, and EGRET data. The electron spectrum derived from a propagation model by Skibo [11] was used by Kinzer et al. [10] and Hunter et al. [29] to derive models of the diffuse emission for analysis of the OSSE and EGRET data, Figures 1 and 5, respectively. The diffuse emission model of Skibo is shown in Figure 2. Strong & Moskalenko [22] have developed a 3-dimensional model, which includs diffusion/convection and transport effects, of the cosmic rays and gamma rays in the Galaxy. This program offers simultaneous predictions of many observable parameters of the cosmic-ray distribution and places significant constraints on their values. A main result of this study is an improved cosmic-ray electron spectrum.

The distribution of cosmic rays in the Galaxy has likewise been examined by several authors using different techniques. Strong & Mattox [36] determined the cosmic-ray emissivity using a radially symetric model of the Galaxy (Figure 8). The emissivity in the outer Galaxy has been determined by Digel et al. [38] from a study of the diffuse emission in Cepheus ($100° < l < 130°, -5° < b < +32°$) including the emission from the prominant local molecular clouds in the Cepheus and Polaris flares and the cloud complex associated with Cas A and NGC 7538 in the Perseus arm. Hunter et al. determined the 2-dimensional Galactic cosmic-ray surface density on the assumption that the cosmic-rays are coupled to the interstellar matter. The radial cosmic-ray distribution, derived from this study, for each Galactocentric quadrant is compared in Figure 9 with the radial gradient derived by Strong et al. from the COS B data. The Strong & Mattox emissivity gradient (Fig. 8) shows an indication of a lower cosmic-ray density at the Galactic center and a general decrease in the outer Galaxy. The Hunter et al. distribution (Fig. 9) also shows this general decrease. In addition, there is a slight density increase in quadrants II and III in the Perseus arm at 13 – 16 kpc from the Galactic center.

CONCLUSIONS

Studies of the Galactic diffuse gamma-ray continuum emission using the instruments on the Compton Gamma Ray Observatory have addressed several important questions about the structure of our Galaxy and the distribution of cosmic rays. Earlier basic interpretations seem now to be confirmed and we have a fairly solid picture of the interstellar matter distribution and the Galactic cosmic-ray density [9,10,17,20,19,29]. The main points of this interpretation include:

- The diffuse Galactic gamma-ray emission has its origin in cosmic-ray electron and proton interactions with the interstellar medium (high energy electron bremsstrahlung and nucleon-nucleon interations leading to π^0

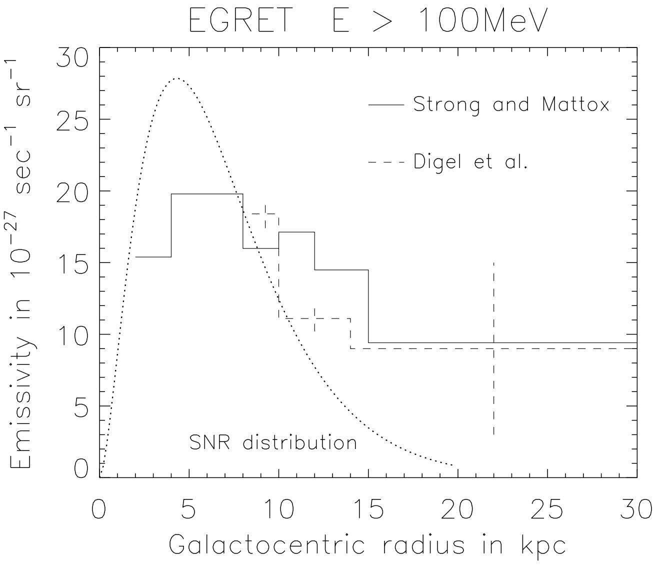

FIGURE 8. Emissivity gradient determined from EGRET data by Strong & Mattox [36] for the whole galaxy, and by Digel et al. [38] for the outer Galaxy in the direction of Cepheus ($100° < l < 130°, -5° < b < +32°$). The supernova remnant distribution of Case & Bhattacharya [50], dotted line, is more centrally peaked and falls off faster than the cosmic-ray gradient.

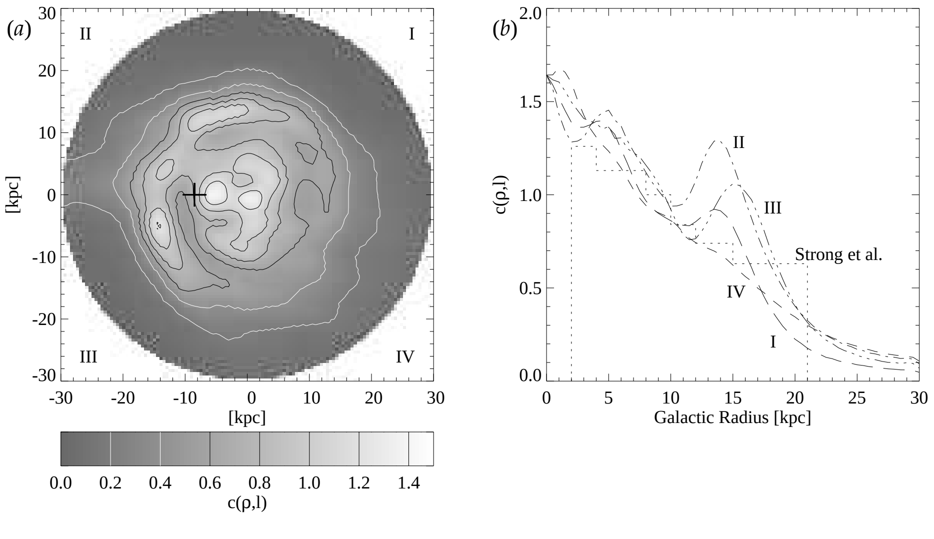

FIGURE 9. (a) The cosmic-ray density relative to the local density, derived on the assumption that the cosmic rays are coupled to the matter [29]. (b) The azimuthal average of the enhancement factor for each Galactocentric quadrant shown in (a). The Galactic average cosmic-ray gradient determined by Strong et al. [37] using the COS-B data is shown as the dotted line.

decay) and with low-energy photons (inverse Compton). The Galactic diffuse emission at these energies has a narrow latitude extent along the Galactic plane, with enhancements towards the Galactic center and at the tangent points of the spiral arms.

- The molecular component of the interstellar medium has been clearly shown and the mass calibrating factor (X-ratio) has been fairly well established (Table 1). It appears that the value of the X-ratio is independent of energy (EGRET range), but may vary across the Galaxy.

- The cosmic-ray electron spectrum below about 10 GeV, which is strongly affected by Solar modulation, is tightly constrained by the gamma-ray observations between 10 and 100 MeV where bremsstrahlung is the dominant process. Below 10 MeV, the contribution from inverse Compton emission relative to bremsstrahlung, although somewhat uncertain, offers further constraints on the cosmic-ray electron spectrum. Observations from OSSE and COMPTEL provide evidence that the Galactic diffuse contiuum extends down to energies below 100 keV. The spectrum steepens below a few hundred keV (see Figure 2) but this is likely a point source contribution rather than an indication that the source electron spectrum turns up below a few MeV.

- The density of cosmic-ray electrons and protons in the Galaxy has a general Galactic gradient decreasing towards the outer Galaxy and perhaps peaking at the Galactic center.

- The shape of the diffuse spectrum in the EGRET energy range does not appear to vary with Galactic longitude and/or latitude except near the plane in the Galactic anticenter, where there is weak evidence for steepening.

The instruments on CGRO have, however, also revealed several surprising new aspects of the Galacticemission which show that we don't understand the diffuse emission as well as we might. We may have to rethink some of the basics.

- The high-energy excess above about 1 GeV may indicate that the cosmic-ray proton and/or electron spectrum observed in the local neighborhood is not representative of the Galactic average. A very flat proton spectrum, $E^{-2.45}$, is required to explain the excess if it is due to π^0 decay. A higher density and/or scale height of low-energy photons could explain the excess in terms of increased inverse Compton emission. A unresolved distribution of point sources is another, although unlikely, possibility.

- The cosmic-ray electron spectrum below about 6 GeV can, in principle, be derived from the spectrum of the diffuse emission. This determination is, however, complicated by the uncertainty in the relative contribution of bremstrahlung and inverse Compton emission below about 100 MeV.

- Supernova remnants have been proposed as the source of the cosmic rays, although this has not been confirmed. The cosmic-ray distribution is much flatter than the supernova distribution although there are large uncertainties in the supernova distribution. The flatter cosmic-ray distribution may, however, simply reflect the effects of cosmic-ray propagation.
- The contribution from bright, resolved point sources to the diffuse emission has been accounted for in the EGRET analyses described above. However, the contribution from a distribution of weaker, and hence unresolved, point sources to the diffuse emission observed with all three instruments is not as readily determined. In fact, the distinction between an unresolved distribution of point sources and the diffuse emission is unclear.

These issues present challenges for future work.

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