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Diffuse Galactic Gamma-Ray Continuum

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Abstract. Coordinated observations of the galactic center region using the imaging SIGMA instrument and the high-sensitivity OSSE instrument were performed to separate the compact source contributions from the diffuse component. The resulting compact-source corrected spectrum of the galactic center region is found to be similar in both intensity and spectral index to the spectra obtained from OSSE observations of the galactic plane at $l = 25°$ and $339°$, suggesting that the spatial distribution of the emission is broad and nearly flat in galactic longitude. At energies below ~ 100 keV, the observed spectrum is found to be softer and more intense than predicted by theoretical models. The observed low energy continuum may be either diffuse in origin, or due to unresolved X-ray sources below the SIGMA detection threshold.

Key words: Gamma rays: observations – ISM: cosmic rays – Galaxies: Milky Way – Galaxy: center

1. Introduction

Historically, observations of low energy diffuse galactic gamma-ray emission from the direction of the galactic center have been complicated by the large number of hard X-ray sources in the region. Non-imaging low energy gamma ray instruments typically have large fields-of-view ($\gtrsim 15°$ FWHM) and are sensitive to both diffuse and compact sources of emission, while imaging instruments have smaller fields-of-view and are generally sensitive only to compact sources of emission. Coordinated observations of the galactic center region using the imaging SIGMA instrument and the high-sensitivity OSSE instrument were performed to separate the compact source contributions from the diffuse component. These observations were designed to provide a measurement of the low energy (50 – 600 keV) diffuse galactic gamma-ray spectrum from the inner galactic plane.

In addition to the coordinated OSSE/SIGMA observation of the galactic center region, OSSE has also performed several observations of the galactic plane away from the galactic center. Observations of the galactic plane at $l = 25°$ and $339°$ were selected since these fields contain fewer known X-ray binaries than observations of the inner galactic plane. The continuum spectra for these observations are found to be similar to the compact source corrected galactic center spectrum in both intensity and spectral index, suggesting that the spatial distribution of the low energy continuum emission is broad and nearly flat in galactic longitude. Latitude scans through the galactic plane at $l = 0°$ and $l = 25°$ indicate that the continuum is extended in latitude with a FWHM of $\sim 5.5°$.

At energies below ~ 100 keV the observed spectrum is found to be softer and more intense than predicted by theoretical models (Skibo et al. 1996). If the observed emission is diffuse in origin the most likely source is electron bremsstrahlung, in which case a power of $\sim 10^{43}$ erg s^{-1} is required to keep the electrons in equilibrium against energy losses in the interstellar medium (Skibo et al. 1996). The observed low energy emission may be due to unresolved X-ray sources below the SIGMA detection threshold, however. Given the relative OSSE and SIGMA sensitivities, this would suggest that there are ~ 10 weak ($\lesssim 5 \times 10^{-3}$ photons cm^{-2} s^{-1} MeV^{-1} at 100 keV) X-ray sources in each of the OSSE fields-of-view, and that the galactic distribution of such sources is broad and relatively flat in longitude.

2. Observation Descriptions

The coded aperture telescope SIGMA provides high angular resolution images of the gamma-ray sky in the 35 keV – 1.3 MeV energy band. The detector consists of a NaI(Tl) crystal optically coupled to an array of 61 photomultiplier

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tubes and has an effective area of $\sim$ 800 cm^2. A tungsten coded mask aperture, based on a URA pattern, is located 2.5 m above the detector plane. The angular resolution is about 15′ over a total field of view of 18° × 16.7° . Compact source positioning accuracy is $\sim$ 1′– 5′, depending on the signal-to-noise ratio. The sensitivity is about 25 mCrab (2σ) for a typical 24 hour observation. Sky images are reconstructed by standard decoding procedures (e.g., Fenimore & Canon 1981). With its large field of view and imaging capabilities, SIGMA provides the ability to map and monitor compact sources in the galactic center region. A detailed description of the SIGMA instrument is given in Paul et al. (1991).

The OSSE instrument consists of four separate, nearly identical detectors. The primary detecting element of each detector is a large area NaI(Tl)-CsI(Na) phoswich crystal which provides spectral information over the energy range 50 keV – 10 MeV. Each detector has a photopeak effective area of $\sim$ 500 cm^2 at 100 keV. The tungsten slat collimators provide a field-of-view which is 3.8° × 11.4° full-width at half-maximum (FWHM). Each detector has a separate elevation control system which provides independent positioning of the detectors about an axis parallel to the long axis of the collimators. During source observations, periodic background measurements are performed by offset-pointing the detectors from the target. Source and background observations are each typically 131 seconds in length, with the observations alternating between source and background measurements. A detailed description of the OSSE instrument and its operation is given in Johnson et al. (1993).

There were four viewing periods during which coordinated OSSE/SIGMA observations of the galactic center region were performed. For two of these viewing periods (viewing periods 21 and 24) the OSSE field-of-view was oriented with the long direction of the collimator nearly aligned with the galactic plane – maximizing the response to galactic diffuse emission. Two additional observations of the galactic plane at l = 25° and 339° also had the long direction of the collimator aligned with the galactic plane. These observations were included in this analysis since their fields contained fewer known X-ray binaries than observations of the inner plane. All of these observations had offset-pointed backgrounds at $b = \pm 10°$. In addition, the l = 25° and the viewing period 24 observation of the galactic center region both included several source pointings above and below the galactic plane.

3. Data Analysis

The SIGMA data accumulated during the coordinated observations were analyzed using the standard methods (e.g., Fenimore & Canon 1981). Maps generated from this analysis indicated that the sources 1E 1740.7-2942, GX 354-0, 1E 1724-3045 (Terzan 2), SLX 1735-269, 1E 1743-288, and GX 3+1 were active during these periods at levels above the SIGMA sensitivity. The spectra from these sources were each fitted separately by a thermal bremsstrahlung function.

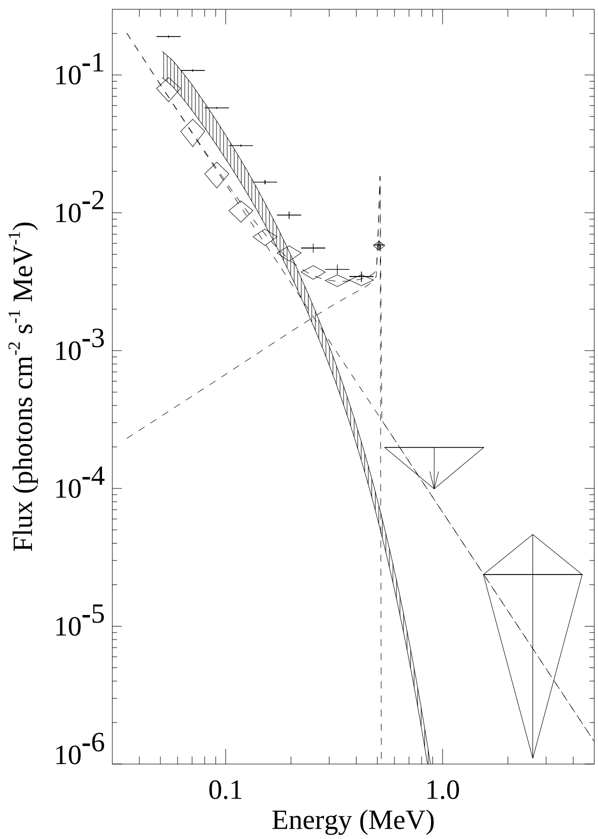

Fig. 1. The galactic center spectrum from the OSSE viewing period 21 observation (20 Feb – 5 Mar, 1992). The hatched region represents the estimated compact-source contribution, based on the SIGMA model parameters and folded through the OSSE instrument response. The diamonds represent the estimated diffuse galactic spectrum. The dashed curves represent a fit to the diffuse spectrum.

The OSSE data were analyzed using the standard methods described in Johnson et al. (1993). The resulting OSSE spectrum for one of the coordinated observations of the galactic center (viewing period 21; 20 Feb – 5 Mar, 1992) is shown in Figure 1. Also shown is the expected compact-source contribution for this observation. The compact source contribution was estimated by folding the known source locations and SIGMA spectral models through the OSSE instrument response. The range of the compact source contribution given in Figure 1 represents the uncertainties in the compact source spectra. The difference between the observed OSSE spectrum and the estimated compact source contribution is also shown in Figure 1 and represents an estimate of the diffuse galactic spectrum from the direction of the galactic center. The uncertainties in the compact source corrected spectrum represent the combined uncertainties in the observed spectrum and in the contributions from the compact sources. The spectrum shown in Figure 1 was fitted over the energy range 50 keV – 4.5 MeV with a function consisting of a single power law, a photopeak line fixed in energy and width at 511 keV and 2.5 keV, respectively, and a positronium continuum component. The fitted power law spectral index was -2.4 ± 0.1, with a continuum flux of $1.61 \pm 0.08 \times 10^{-2}$ photons cm^{-2} s^{-1} MeV^{-1} at 100 keV. Because there may still be contributions from compact sources below the SIGMA detection threshold, however, this difference spectrum may represent an upper limit to the diffuse galactic emission.

The analysis described above was also applied to the OSSE viewing period 24 data, which had a viewing configuration very similar to viewing period 21. The resulting compact source corrected spectrum was found to be consistent with the viewing period 21 result, indicating the stability of the correction technique. The average of the compact source corrected spectra from viewing periods 21 and 24 is shown in Figure 2. This spectrum was fitted with the same function described above; the fitted power law spectral index was -2.5 ± 0.1, with a continuum flux of $1.66 \pm 0.07 \times 10^{-2}$ photons cm^{-2} s^{-1} MeV^{-1} at 100 keV.

Figure 2 also shows the average spectrum from the OSSE observations of the galactic plane at $l = 25°$ and 339°. With the exception of the positron annihilation line and positronium continuum in the galactic center spectrum, this spectrum is seen to be remarkably similar in both shape and intensity. This spectrum was also fitted with the same function described above; the fitted power law spectral index was -2.71 ± 0.03, with a continuum flux of $1.71 \pm 0.02 \times 10^{-2}$ photons cm^{-2} s^{-1} MeV^{-1} at 100 keV. Note that the quoted errors represent the statistical uncertainies only.

The latitude scans performed during the $l = 25°$ observation and viewing period 24 observation of the galactic center region were used to study the latitude extent of the continuum emission. These observations were analyzed separately by comparing the data with the expected response for various distribution models. The distribution models were assumed to be symmetric about the galactic plane and to have a gaussian latitude profile. Models having galactic latitude extents between 0° and 15° FWHM were investigated. Following previous work (e.g., Gehrels & Tueller 1993), the distribution models were assumed to be flat in longitude over the range $-40° < l < +40°$ and zero outside of this range. Because the scanning observations during these viewing periods were nearly orthogonal to the galactic plane, however, the results are nearly independent of the longitude extent of the emission.

For the viewing periods containing latitude scans, the distribution models were folded through the instrument response for each of the scan positions. The resulting model responses were then fitted to the data, with only

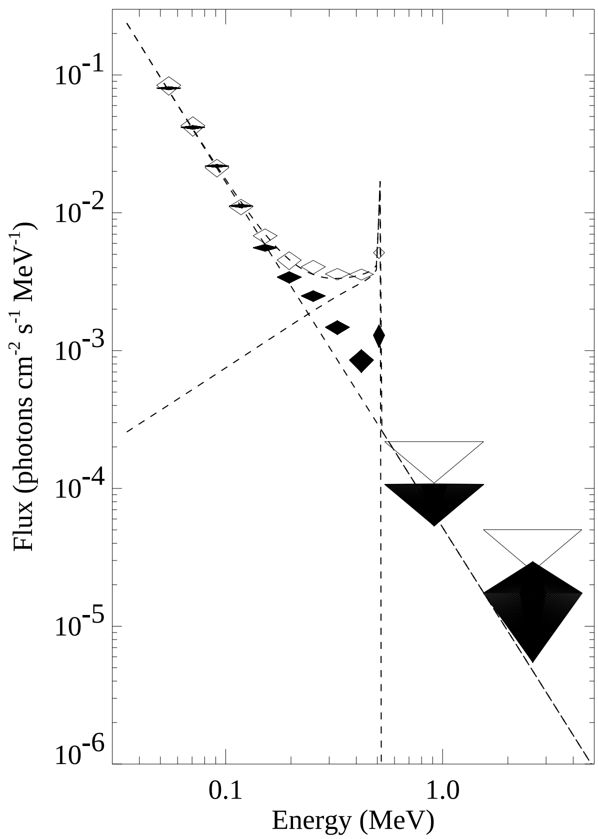

Fig. 2. OSSE spectra of the diffuse galactic continuum at $l = 0°$ (open diamonds) and at $l = 25°$ and 339° (filled diamonds). The dashed curves represent a fit to the galactic center diffuse spectrum.

the amplitude a free parameter. The fitting was performed for several energy bands covering the range 50 – 600 keV. The mean latitude extent was found to be $5.4° \pm 0.5°$, with no significant evidence of an energy dependence.

The OSSE diffuse spectra can also be compared with observations at other energies. Figure 3 shows a broadband spectrum of the diffuse galactic emission, including the OSSE $l = 0°$ and $l = 25°$ and 339° spectra from Figure 2. The OSSE spectra were converted into flux per radian by calculating the energy-dependent angular response for each of the observation configurations. Because OSSE has a relatively small field-of-view (3.8° × 11.4°), a model for the distribution of the emission was also required. The distribution model used for the conversion to flux per radian was the same as described above. Based on the results of the latitude extent of the emission discussed above, the latitude distribution was assumed to be 5.4° FWHM. This model was folded through the OSSE energy-dependent angular response to determine the conversion factors for the $l = 0°$ and $l = 25°$ and 339° spectra.

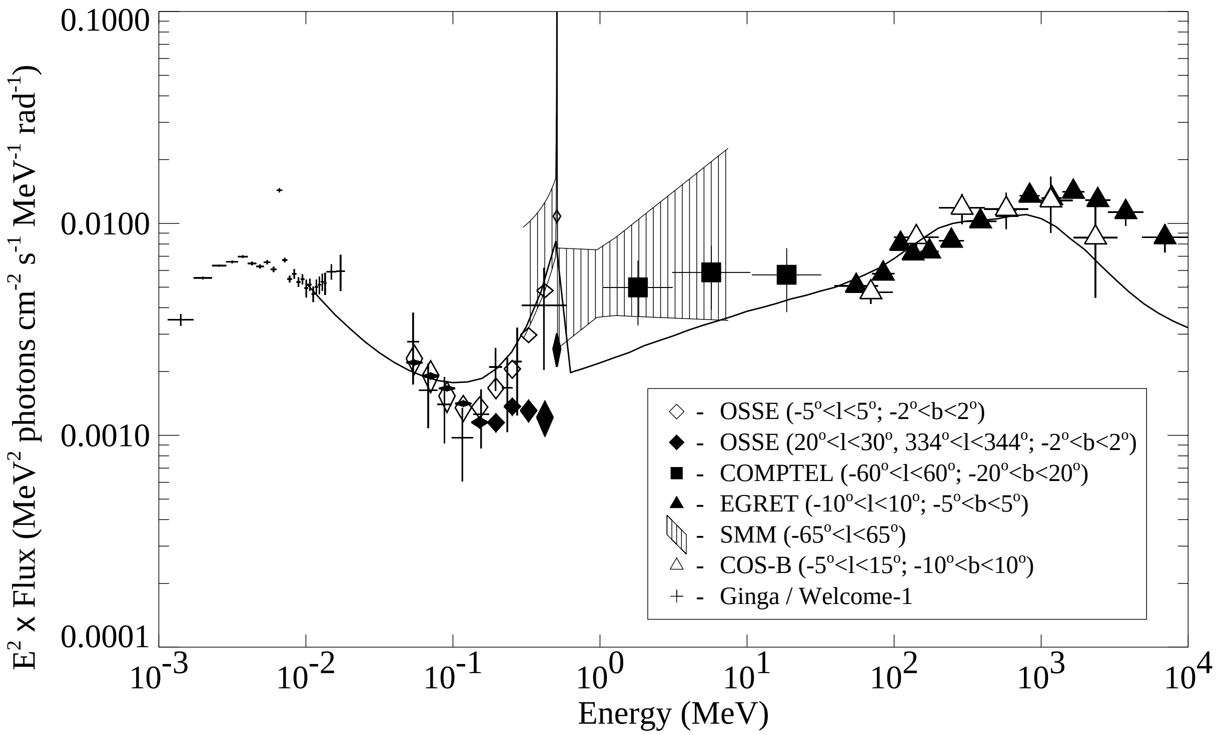

Fig. 3. Broad-band gamma ray spectrum of the diffuse galactic emission. The thick solid curve represents the model of Skibo et al. 1996. Data references: OSSE – this work; COMPTEL – Bloemen et al. (1994), Strong et al. (1994); EGRET – Fichtel et al. (1993); SMM – Harris et al. (1990); COS-B – Paul et al. (1978); Ginga/Welcome-1 – Yamasaki et al. (1996a, 1996b).

A change in the latitude extent of $\pm 2°$ changes the OSSE flux per radian by only $\pm 25\%$.

4. Summary and Conclusions

Coordinated observations of the galactic center region using the imaging SIGMA instrument and the high-sensitivity OSSE instrument were performed to separate the compact source contributions from the diffuse component. The resulting compact-source corrected spectrum from the galactic center region is found to be very similar in both intensity and spectral index to the spectra obtained from observations of the galactic plane at $l = 25°$ and $339°$. This suggests that the spatial distribution of the low energy continuum emission is broad and nearly flat in galactic longitude. In addition, latitude scans through the galactic plane at $l = 0°$ and $l = 25°$ indicate that the continuum is extended in latitude with a FWHM of $\sim 5.5°$.

At energies below $\sim$ 100 keV the observed spectrum is found to be softer and more intense than predicted by theoretical models. The observed low energy spectrum may be either diffuse in origin, or due to unresolved X-ray sources below the SIGMA detection threshold. If the observed emission is diffuse the most likely source is electron bremsstrahlung, which would require a power of $\sim 10^{43}$ erg s^{-1} to keep the electrons in equilibrium against energy losses in the interstellar medium. If the observed emission is due to unresolved X-ray sources, the galactic distribution of these sources must be broad and relatively flat in longitude. Furthermore, given the SIGMA sensitivity threshold of $\sim 5 \times 10^{-3}$ photons cm^{-2} s^{-1} MeV^{-1} at 100 keV and the average OSSE response of $\sim$ 25% over its $3.8° \times 11.4°$ field of view, $\sim$ 10 such sources would be required in each OSSE field of view to produce a significant fraction of the observed emission.

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