NASA/CR-97-

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To: Mr. John Chiappe

Re: Final Report for NAG 5-2883

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Final Report – Grant NAG 5-2883

NASA grant NAG 5-2883 was provided to Northwestern University (PI – Dr. William Purcell) to support scientific research relating to the Oriented Scintillation Spectrometer Experiment (OSSE) on NASA's Gamma Ray Observatory. This work was to be coordinated with scientists from the COMPTEL instrument team and others. The Northwestern University team for this effort consisted of Dr. Purcell and Dr. Melville Ulmer, who are members of the OSSE Diffuse Galactic Science Team. The primary role of the NU team was to act as consultants with the COMPTEL team members, perform and analyze data from OSSE observations, and present the scientific results.

During the grant period (February 1995 - February 1996), the NU team members worked to analyze the available data. Results of this analysis were presented at the *24th International Cosmic Ray Conference* held in Rome, Italy, August 28 - September 8, 1995, and at the 1996 meeting of the AAS/High Energy Astrophysics Division held in San Diego, California, April 30 - May 3, 1996 (see attached abstracts). The results were also published in the conference proceedings of the Cosmic Ray Conference (Purcell, W. R., et al., 1995, *Proceedings of the 24th International Cosmic Ray Conference*, **2**, 211). A copy of this paper is also attached.

As a result of this work, subsequent proposals have been submitted to continue this effort and to develop enhanced capabilities for OSSE observations of high energy emission. Accepted proposals for this work include NAG 5-3125 ("CGRO Maps of ^{26}Al Using New, Improved Techniques", PI - Dr. Ulmer) and NAG 5-3490 ("Improved CGRO Maps of ^{26}Al", PI - Dr. Ulmer).

Abstract from Presentation at the 24th International Cosmic Ray Conference

Diffuse Galactic Gamma-Ray Emission

W. R. Purcell[1], D. A. Grabelsky[1], M. P. Ulmer[1], W. N. Johnson[2], R. L. Kinzer[2], J. D. Kurfess[2], M. S. Strickman[2], G. Jung[2,3], J. G. Skibo[2], M. D. Leising[4], L. Bouchet[5], P. Mandrou[5], J. P. Roques[5], and G. Vedrenne[5]

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Observations with the Oriented Scintillation Spectrometer Experiment (OSSE) onboard NASA's Compton Gamma ray Observatory have provided spectra of the low-energy diffuse galactic gamma-ray emission. Strong 511 keV line and positronium continuum emission, produced by positron annihilation, is detected within ~10o of the Galactic center. A significant line at 1.809 MeV from the nuclear decay of 26Al is also observed when multiple observations of the galactic plane are combined. Coordinated observations of the Galactic center region by the SIGMA and OSSE instruments provide the ability to separate the compact and diffuse sources of emission. The resulting diffuse galactic gamma-ray spectrum is shown and compared with observations by other instruments.

Abstract from Presentation at the 1996 Meeting of the AAS/High Energy Astrophysics Division

CGRO Maps of ^{26}Al Using New, Improved Techniques

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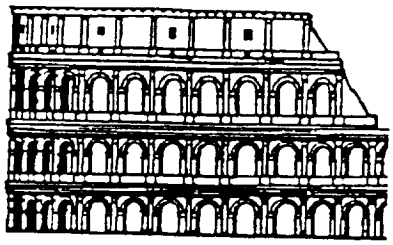
Currently the standard background subtraction technique produces an about 5.5 sigma result for *all* the OSSE galactic plane observations combined. Due to the diffuse nature of the ^{26}Al emission and the wings of the OSSE field of view at 1.8 MeV, the standard offset background subtraction measurement includes a ^{26}Al 1.809 MeV signal that is about 75% for the "source pointing." This effect results in reducing the measured ^{26}Al flux by approximately a factor of 4 over the optimally possible signal. We are, therefore, working on techniques to improve the background subtraction with the goal of producing a signal nearly 4 times higher than with the standard background subtraction. These techniques use both the Earth as an occulting disk and sophisticated modeling of the detector background. The goal of this project is to produce an improved and more reliable map of ^{26}Al emission in the Galactic plane so that we can associate the emission with known objects, e.g., SNRs, Wolf-Rayet stars, etc. With this information in hand, we will be much closer to understanding the origin of recent nucleosynthesis in the Galaxy.



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Under the auspices of the
INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS

Diffuse Galactic Gamma-Ray Emission

W.R. Purcell[1], D.A. Grabelsky[1], M.P. Ulmer[1], W.N. Johnson[2], R.L. Kinzer[2], J.D. Kurfess[2], M.S. Strickman[2], G. Jung[2,3], J.G. Skibo[2], M.D. Leising[4], L. Bouchet[5], P. Mandrou[5], J.P. Roques[5], and G. Vedrenne[5]

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Abstract

Observations with the Oriented Scintillation Spectrometer Experiment (OSSE) onboard NASA's Compton Gamma Ray Observatory have provided spectra of the low-energy diffuse galactic gamma-ray emission. Strong 511 keV line and positronium continuum emission, produced by positron annihilation, is detected within $\sim 10^\circ$ of the galactic center. A significant line at 1.809 MeV from the nuclear decay of ^{26}Al is also observed when multiple observations of the galactic plane are combined. Coordinated observations of the galactic center region by the SIGMA and OSSE instruments provide the ability to separate the compact and diffuse sources of emission. The resulting diffuse galactic gamma-ray spectrum is shown and compared with observations by other instruments.

1 Introduction

Observations of low energy diffuse galactic gamma-ray emission provides information about: 1) the distribution and spectrum of cosmic rays in the Galaxy; 2) the distribution of positrons and properties of the annihilation medium, and; 3) the distribution and flux of gamma-ray lines from the decay of radioactive nuclei in the interstellar medium. Coordinated OSSE and SIGMA observations of the galactic center region have provided the ability to separate the compact source contributions from the diffuse component. The resulting diffuse spectrum is found to be softer at lower energies than at higher energies, and to have a distribution which is relatively flat in longitude within $\sim 25^\circ$ of the galactic center. In contrast, the 511 keV line and positronium continuum is observed primarily within $\sim 10^\circ$ of the galactic center. OSSE has also detected significant emission in the 1.809 MeV decay line of radioactive ^{26}Al. When compared with observations by other instruments, the observed flux suggests the ^{26}Al distribution is either patchy or has a latitude extent $\gtrsim 5^\circ$ full-width at half-maximum (FWHM).

2 Observations and Analysis

The OSSE instrument[8] consists of four separate, nearly identical detectors which provide spectral information over the energy range 50 keV – 10 MeV. Tungsten slat collimators provide a field-of-view which is $3.8^\circ \times 11.4^\circ$ FWHM.

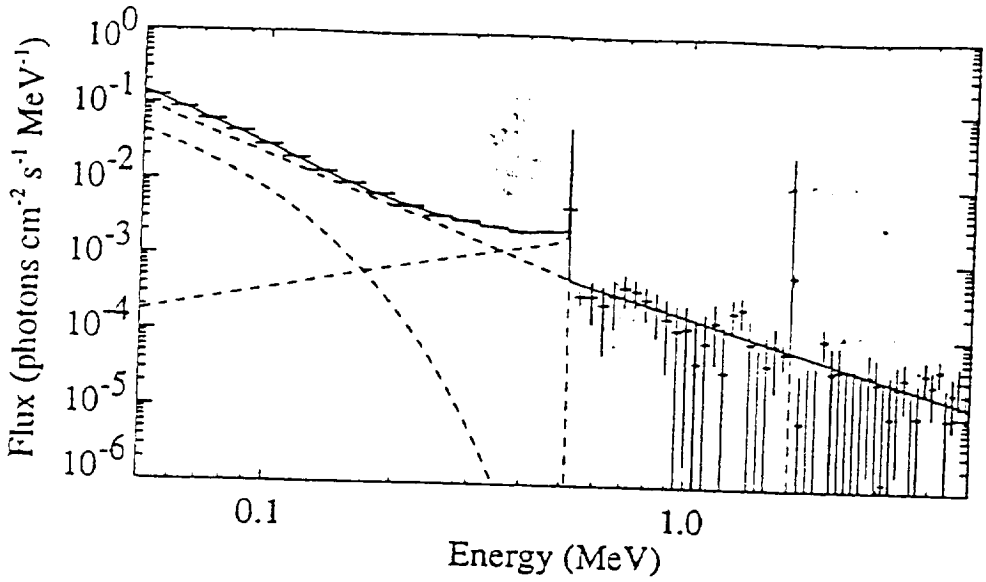

Figure 1: *Average spectrum of the inner galactic plane ($l \approx -50° - +40°$) generated by combining multiple OSSE observations. The spectrum is well fitted with a model consisting of a broken power-law, an exponential, a 511 keV line and positronium continuum component, and a narrow line at 1.809 MeV. The dashed curves show the individual components to the fit.*

Each detector can be positioned independently 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.

The OSSE observations of the galactic plane were performed with the long direction of the collimator aligned approximately parallel to the galactic plane and with background positions at $b \approx \pm 10°$ in order to maximize the sensitivity to diffuse galactic emission. Since the launch of GRO in April 1991, OSSE has performed 22 observations of the galactic plane covering the longitude range $-50° - +40°$. The resulting average spectrum, which corresponds to over 200 days of accumulation time, is shown in Figure 1.

The spectrum in Figure 1 shows significant evidence for a strong 511 keV line and positronium continuum emission produced by positron annihilation. The spectrum also shows evidence for a narrow line at 1.809 MeV from the radioactive decay of ^{26}Al. The spectrum is well fitted by a model consisting of a broken power-law, an exponential, a 511 keV line and positronium continuum component, and a line at 1.809 MeV. The average 511 keV line flux from the inner galactic plane ($l \approx -50° - +40°$) is $(1.37 \pm 0.09) \times 10^{-4}$ γ cm^{-2} s^{-1}, and the positronium fraction is (0.96 ± 0.03). The 1.809 MeV line is found to have a flux of $(5.8 \pm 0.9) \times 10^{-5}$ γ cm^{-2} s^{-1}.

Many of the OSSE observations included emission from both compact sources and diffuse galactic emission in the fields-of-view. Using simultaneous observations of the galactic center region by the OSSE and SIGMA instruments, it has been possible to remove the compact-source contribution in the

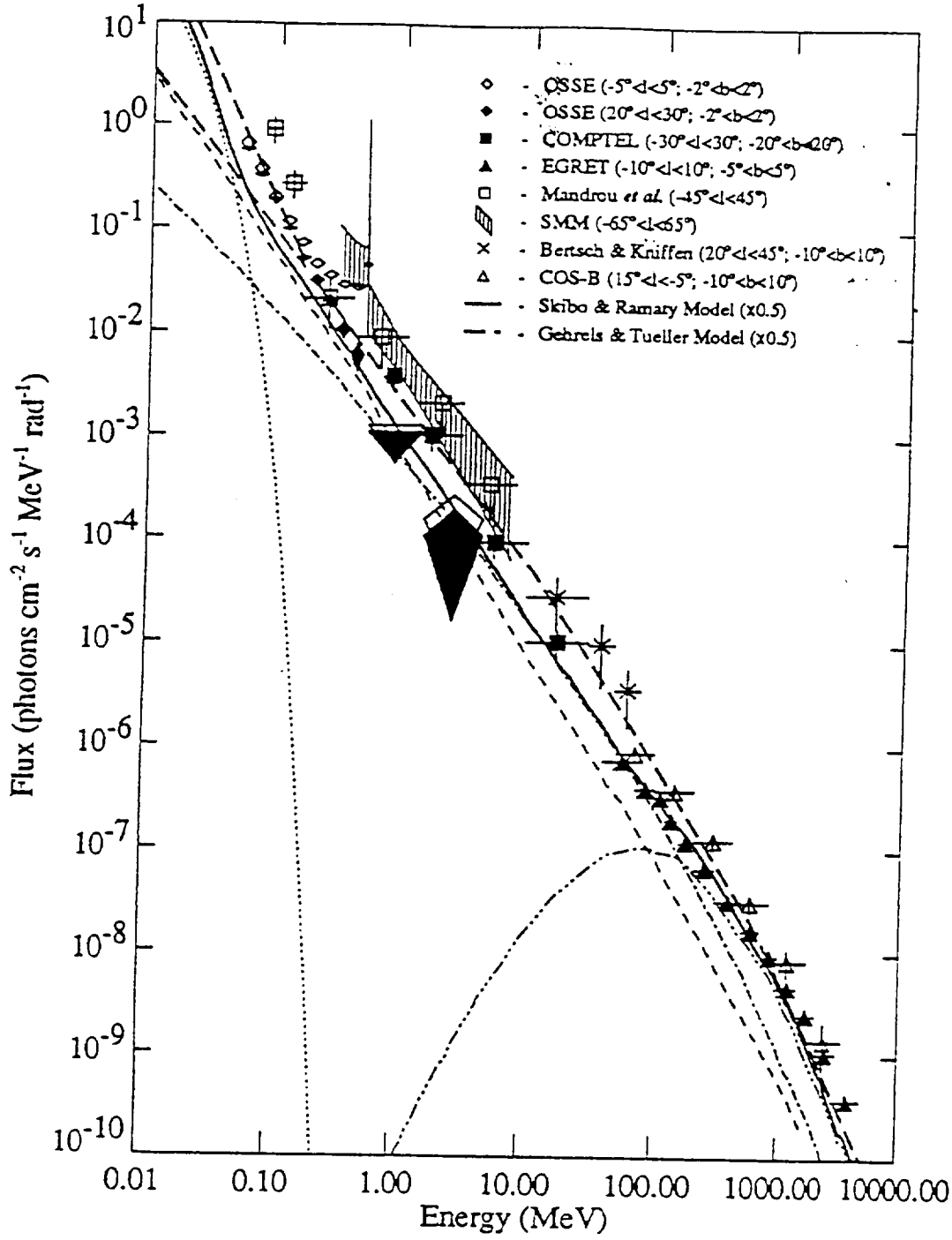

Figure 2: *Broad-band gamma-ray spectrum of the diffuse galactic emission. The thick solid curve represents the model of Skibo & Ramaty[11], reduced in intensity by a factor of 2 to provide better agreement with the EGRET data. The thin broken curves represent the separate components (10 keV thermal bremsstrahlung, inverse-Compton, non-thermal bremsstrahlung and π^0-decay) of the Skibo & Ramaty model. The thick broken curve represents the best-guess spectrum of the diffuse galactic emission from Gehrels & Tueller[6]; the upper and lower curves at low energies represent the uncertainty in the best-guess spectrum. Data references: COMPTEL - [2], [13]; EGRET - [5]; COS-B - [10]; SMM - [7]; Balloons - [9], [1]*

OSSE spectra. The resulting compact source corrected spectrum of the galactic center region, which represents an estimate of the diffuse galactic emission, is shown in Figure 2. Also shown in Figure 2 is the OSSE spectrum from $l = 25°$, in which there is no evidence of a compact source contribution.

3 Results and Discussion

The ^{26}Al flux from Figure 1 can be used to estimate the total flux from the inner radian. For typical galactic distribution models (e.g., galactic CO[3]), the observed OSSE flux of $(5.8 \pm 0.9) \times 10^{-5}$ γ cm^{-2} s^{-1} corresponds to a flux of $(2.0 \pm 0.3) \times 10^{-4}$ γ cm^{-2} s^{-1} rad^{-1}. The implied flux is roughly a factor of two smaller than the value measured by SMM for these model distributions[7], implying that they are not good approximations to the actual galactic ^{26}Al distribution. The true distribution could be 1) patchy, with significant excesses where the current OSSE coverage is poor (see the COMPTEL ^{26}Al map[4]); or 2) somewhat extended in latitude so that some emission falls outside of the OSSE source fields of view or is subtracted off in the difference spectra.

As shown in Figure 2, the strong 511 keV line and positronium continuum present in the $l = 0°$ spectrum is nearly absent from the $l = 25°$ spectrum, indicating the annihilation radiation is concentrated within $\lesssim 20°$ of the galactic center. Below ~ 150 keV there is good agreement between the $l = 0°$ and $l = 25°$ spectra, consistent with a relatively flat longitude distribution of this emission. At these energies, the observed spectrum is steeper and more intense than models predict[11]. If this emission is produced by bremsstrahlung of cosmic-ray electrons, the observed gamma-ray spectrum suggests that the cosmic-ray electron spectrum must turn up at energies below a few MeV[12].

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