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OSSE Observations of Galactic 511 keV Annihilation Radiation

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ABSTRACT

The Oriented Scintillation Spectrometer Experiment (OSSE) on the *Compton Gamma-Ray Observatory* has performed several observations of the Galactic plane and Galactic center region to measure the distribution of Galactic 511 keV positron annihilation radiation. Preliminary analysis of data collected during the observation of the Galactic center region over the period July 13–24, 1991, indicates the presence of a 511 keV line and positronium continuum superimposed on a power-law continuum. The line flux was found to be $(2.7 \pm 0.5) \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$, with a positronium fraction of (0.9 ± 0.2). The 3σ upper limit to daily variations in the 511 keV line flux from the mean during the observation interval is $3 \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$. If all of the observed annihilation radiation is assumed to originate from the X-ray source 1E 1740.7–2942, the corresponding 511 keV line flux would be $(3.0 \pm 0.6) \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$. The 3σ upper limit for 511 keV line emission from the X-ray binary GX1+4 is $6 \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$. Results from the Galactic plane observations at Galactic longitudes of 25° (August 16–21, 1991) and 339° (September 6–11, 1991) suggest that the emission is concentrated near the Galactic center. The observations and the preliminary results are described.

INTRODUCTION

While positron annihilation radiation has been observed from the Galactic center region by numerous balloon and satellite-borne experiments since the 1970s, the location and distribution of the emission has not yet been identified (see Lingenfelter and Ramaty 1989 for a recent review). The situation is further complicated by the possibility that the 511 keV annihilation line may vary in intensity by as much as $\sim 10^{-3}\ \gamma\ cm^{-2}\ sec^{-1}$, leading to the suggestion that the observed emission is composed of two separate sources: a steady state diffuse Galactic component and a time variable point source near the Galactic center (Lingenfelter and Ramaty 1989). The source of the diffuse Galactic component is thought

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Table 1: OSSE Galactic Center / Galactic Plane Observations

Galactic Longitude	Position Angle	Background Offset Angle	Observation Interval	On-Source Time (sec)
0°	90°	±10°	13–24 July	10^5 / 10^5
25°	90°	±10°	16–21 Aug	5×10^4
339°	90°	+4.3/−8.5	6–11 Sept	5×10^4

to be the β^+-decay products from radioactive nuclides produced by supernovae, novae or Wolf-Rayet stars (Clayton 1973), while γ-γ interactions in the vicinity of an accreting black hole has been suggested as a possible source of time variable annihilation emission (Lingenfelter and Ramaty 1982). At this time, however, few details about of the source(s) of the positrons is known. One of the scientific goals of the OSSE team is to map the distribution of positron annihilation radiation and to search for time variability from the Galactic center region.

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, providing an effective area of 450 cm^2 at 0.5 MeV. The phoswich is actively shielded and passively collimated. Tungsten collimators provide a field-of-view which is 3.8° × 11.4° (FWHM), with the long direction of the collimators oriented parallel to the spacecraft Y-axis. Each detector has a separate elevation control system which provides independent positioning of the detectors about an axis parallel to the spacecraft Y-axis. During source observations, periodic background measurements are performed by offset-pointing the detectors from the target. A detailed description of the OSSE instrument and its operation can be found in Johnson *et al.* (1989).

ANALYSIS METHOD

Table 1 provides a description of the OSSE observations of the Galactic center and Galactic plane used to generate the preliminary results reported here. The position angle represents the angle between the long direction of the OSSE field-of-view and Galactic North. For the observations described here, the long direction of the OSSE collimator was oriented parallel to the Galactic plane to maximize the response to a diffuse Galactic distribution. The background offset angle represents the Galactic latitude at which the background observations were performed. The Galactic center observation included additional source pointings at Galactic latitudes of $b = \pm1.5°$ and $\pm3.0°$. The on-source time for the Galactic center observation indicates the total on-source time for both the $b = 0°$ and the $b = \pm1.5°$, $\pm3.0°$ observations. The Galactic plane observation at $l = 339°$ included an

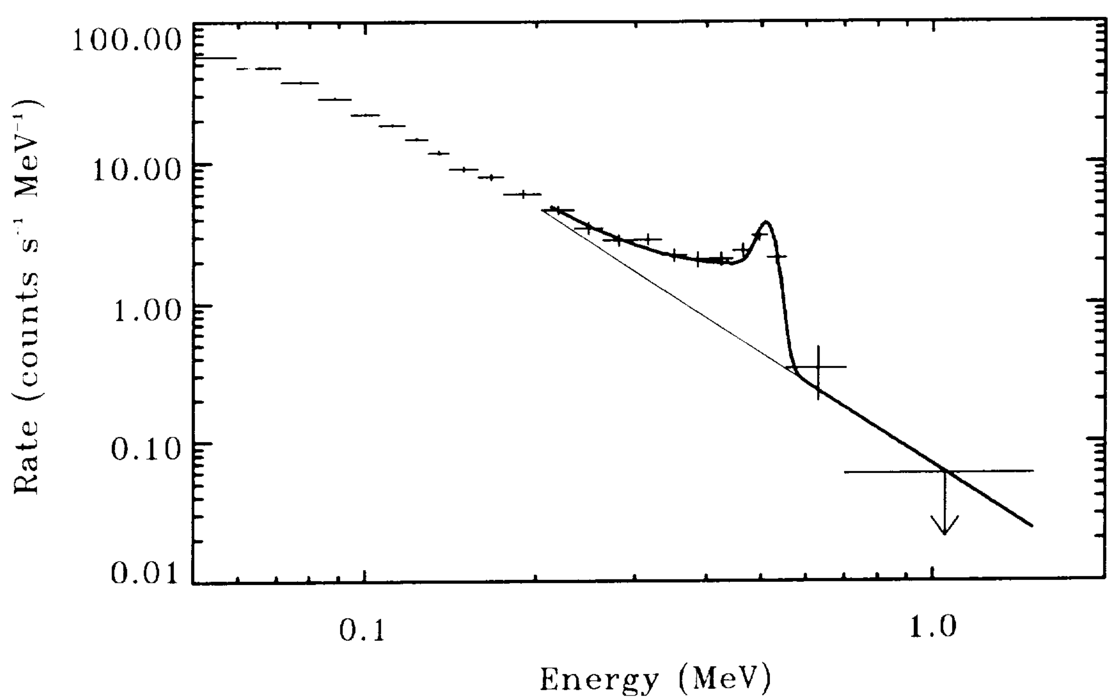

Figure 1: The OSSE Galactic center ($b = 0°$) spectrum summed from all four detectors over the period 13–24 July, 1991. The fitted function consists of a power law, a photopeak line and a term approximating the positronium continuum. See text for details.

additional source pointing at the target GX339–4.

The instrumental background is measured by offset-pointing the OSSE detectors from the source position. Source and background measurements are typically alternated at two minute intervals, with backgrounds being sampled on each side of the source position along the instrument scan plane. The background offset angles for the Galactic center and Galactic plane observations were selected to minimize possible residual response to a diffuse latitude distribution. For the analysis described here, data having low live-times, telemetry errors or in which the detector zenith angle was greater than 100° were excluded. Background estimation and subtraction was performed for each detector separately. In order for a source observation to have been included in the analysis two background measurements were required, one before and one after the source observation. For these source observations, the background spectrum was estimated by linearly interpolating in time, channel-by-channel, between the two background spectra. The individual background-subtracted spectra were then summed by detector and by day to perform the spectral analysis.

The summed background-subtracted spectra for the Galactic center $b = 0°$ observation is shown in Figure 1. This spectrum shows strong evidence for a 511 keV line and positron-

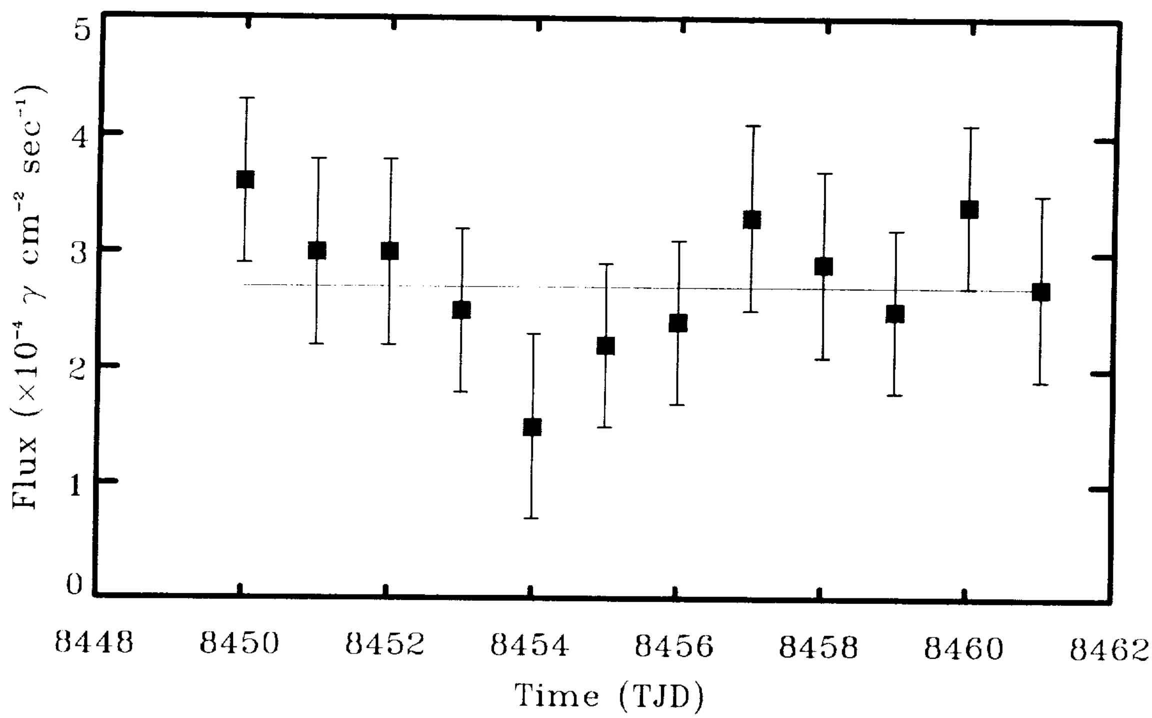

Figure 2: The fitted daily 511 keV line flux for the Galactic center $b = 0°$ observations.

ium continuum. The position of the line is consistent with an energy of 511 keV, and the line width is consistent with the instrumental resolution. For the spectral studies reported here, the spectral fits were performed in count space over the energy range 0.2 - 1.5 MeV. The fitting model consisted of a power law, a photopeak line fixed in energy at 511 keV and in width at the instrumental resolution, and a term approximating the positronium continuum. The positronium continuum component consisted of a triangle having a maximum at 511 keV and decreasing linearly with energy and which was smoothed by the instrumental resolution. The intensity of the positronium continuum component was a free parameter in the spectral fits. The spectral fits were performed in count space and did *not* include folding the model through the instrument response.

PRELIMINARY RESULTS

Using the fitting model described above, the summed background-subtracted spectra for the Galactic center $b = 0°$ observation results in a fitted 511 keV line flux of $(2.7 \pm 0.5) \times 10^{-4}$ γ cm^{-2} s^{-1} and a positronium fraction of (0.9 ± 0.2). The spectral fit is shown in Figure 1. Time variability of the 511 keV line flux was investigated by summing the background-subtracted spectra for each day of the observation interval separately. The resulting line fluxes are shown in Figure 2. No significant time variability of the line flux is observed. The 3σ upper limit to daily variations from the mean is 3×10^{-4} γ cm^{-2} s^{-1}.

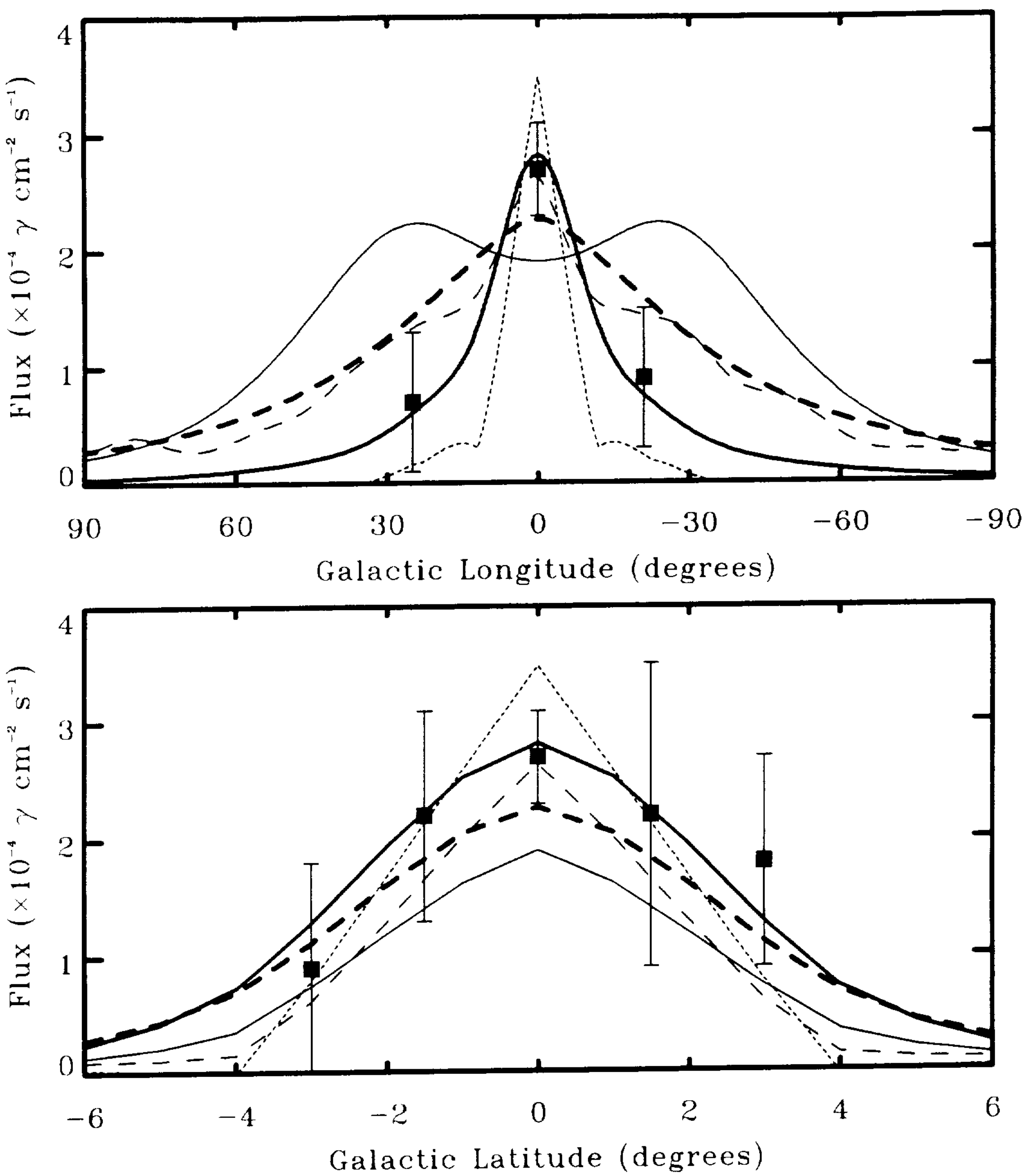

Figure 3: The fitted 511 keV line flux for the Galactic plane (top) and Galactic center latitude scan (bottom) observations. The curves represent the expected OSSE responses for several Galactic distribution models, fitted simultaneously to the observed longitude and latitude data shown. The thin solid line represents the CO model of Leising and Clayton (1985), the thick solid line represents the Nova model of Leising and Clayton (1985), the thin dashed line represents the observed CO distribution (Dame *et al.* 1987), the thick dashed line represents a model following the Galactic visual luminosity (Bahcall and Soneira 1980), and the dotted line represents the response for a point-source located at $l = 0°$, $b = 0°$.

The results of fitting the summed background-subtracted spectra for the Galactic plane ($l = 0°, 25°$ and $339°$) and the Galactic center latitude scan ($b = 0°, \pm 1.5°$ and $\pm 3.0°$) are shown in Figure 3. Also shown in this figure is the expected OSSE responses for several Galactic distribution models, fitted simultaneously to the observed latitude and longitude data. As can be seen, the data are sharply peaked in longitude near the Galactic center, consistent with the reported GRIS observations (Gehrels *et al.* 1991). The Galactic center latitude scan suggests that the emission is centered near the plane and may be slightly broadened compared with the expected point source response.

From the Galactic center latitude scan shown in Figure 3, it can be seen that the bulk of the emission can not be from the X-ray binary GX1+4. If the $\sim 1\sigma$ excess observed for the $b = +3°$ observation is assumed to be due to emission from GX1+4, the 3σ upper limit to the 511 keV flux is $6 \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$. If the observed Galactic center flux of $(2.7 \pm 0.5) \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$ is assumed to originate entirely from the X-ray source 1E 1740.7–2942, the corresponding 511 keV line flux would be $(3.0 \pm 0.6) \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$. If a point source of annihilation radiation with a 511 keV line flux of $2 \times 10^{-3}\ \gamma\ cm^{-2}\ s^{-1}$ was active during the Galactic center observation interval, its position (1σ) must be outside of the region bounded by $l = \pm 8°$, $b = \pm 4°$.

If all of the observed emission is assumed to originate from a diffuse Galactic source, the OSSE data are inconsistent ($> 2.5\sigma$) with a distribution following the CO model of Leising and Clayton (1985). Further, the fitted OSSE intensities for the models following the observed CO distribution (Dame *et al.* 1987) and the Novae model of Leising and Clayton (1985) are only $\sim 50\%$ of the 511 keV intensity reported by SMM (Share *et al.* 1990), suggesting either that the distribution does not follow these models, or that the SMM observations included a time-variable component which was not active during the OSSE observations. The latter is not yet required, however; the fitted OSSE intensity for a model following the Galactic visual luminosity is consistent with the reported SMM flux.

CONCLUSION

The preliminary results described here are based on four weeks of OSSE observations of the inner Galactic plane. The observation of the Galactic center region over the period July 13–24, 1991, indicates the presence of a 511 keV line and positronium continuum superimposed on a power-law continuum, with a line flux of $(2.7 \pm 0.5) \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$ and a positronium fraction of (0.9 ± 0.2). No evidence for daily variations in the line flux was observed during this period, with a 3σ upper limit to daily variations from the mean of $3 \times 10^{-4}\ \gamma\ cm^{-2}\ s^{-1}$. The Galactic longitude observations at $l = 25°$ and $339°$ suggest that the 511 keV line emission is concentrated near the Galactic center.

Five further OSSE observations of the Galactic center with various collimator position angles are scheduled for the remainder of the GRO Phase 1 viewing plan which will provide an additional 10 weeks of data. These observations will allow OSSE to monitor the Galactic center for variability of the annihilation radiation and to measure the distribution of the emission within $\sim 5^\circ - 10^\circ$ of the Galactic center. Simultaneous observations of the Galactic center region with SIGMA are scheduled which will aid in separating point source contributions from the diffuse component. Ten additional weeks of Galactic plane observations are also scheduled which will further aid in measuring the diffuse distribution.

REFERENCES

Bahcall, J. N., and Soneira, R. M., 1980, *Ap. J. Suppl.*, **44**, 73.

Clayton, D. D., 1973, *Nature Phys. Sci.*, **244**, 137.

Dame, T. M., *et al.*, 1987, *Ap. J.*, **322**, 706.

Gehrels, N., *et al.*, 1991, *Ap. J. (Letters)*, **375**, L13.

Johnson, W. N., *et al.*, 1989, in *Proc. of the GRO Science Workshop*, ed. W. N. Johnson, p. 2–22.

Leising, M. D., and Clayton, D. D., 1985, *Ap. J.*, **294**, 591.

Lingenfelter, R. E., and Ramaty, R., 1989, *Ap. J.*, **343**, 686.

Lingenfelter, R. E., and Ramaty, R., 1982, in *The Galactic Center*, ed. G. R. Riegler and R. D. Blandford (New York:AIP), p. 148.

Share, G. H., *et al.*, 1990, *Ap. J. (Letters)*, **358**, L45.