Limits on Nuclear Gamma-Ray Emission from Orion

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ABSTRACT

The discovery of γ-ray line emission in the 3 – 7 MeV range from the Orion complex was recently reported (Bloemen et al. 1994). The observed Compton Telescope (COMPTEL) spectrum suggested that the emission results from the de-excitation of excited states of ^{12}C and ^{16}O. We report on a search for these lines using the Oriented Scintillation Spectrometer Experiment (OSSE) on the *Compton Gamma Ray Observatory (CGRO)* during a 5-week observation from April to June in 1995. The OSSE detectors were pointed midway between the Orion A and B radio sources in three different viewing configurations. We find no compelling evidence for line emission near 4.4 or 6.1 MeV. The sensitivity of the OSSE measurements is dependent on the widths of the reported C and O lines and on the source location and spatial extent. A point source at the flux level reported by COMPTEL and located on-axis would have been detected by OSSE at $\sim 7\ \sigma$ and $\sim 5\ \sigma$ levels of confidence for narrow and broad lines, respectively. A spatially-distributed source of the same strength with a distribution following the intense CO emission localized around Orion A and Orion B (see Maddalena et al. 1986) would have been detected by OSSE at $\sim 3.5\ \sigma$ and $\sim 2.5\ \sigma$, respectively. Thus, these OSSE observations require that any γ-ray line source must be even more extended to be consistent with the reported COMPTEL intensity.

Subject headings: gamma rays: observations – acceleration of particles – stars: abundances

Report Documentation Page

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1. REPORT DATE **1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**
4. TITLE AND SUBTITLE **Limits on Nuclear Gamma-Ray Emission from Orion**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Code 7650,4555 Overlook Avenue, SW,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**20**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1. INTRODUCTION

A startling detection of 3 – 7 MeV γ-ray emission from the Orion complex was reported by Bloemen et al. (1994) from observations made using the COMPTEL experiment on the Compton Gamma Ray Observatory (*CGRO*). The measurements were made over a period of 18 months during 1991 – 92 and revealed what appeared to be lines at 4.4 and 6.1 MeV arising in a region close to the Orion A and B radio sources. The total observed flux in the 3 – 7 MeV energy band was $(1.0 \pm 0.15) \times 10^{-4}$ γ cm^{-2} s^{-1}. Bloemen et al. (1994) suggested that the emission could arise from interactions of $\sim$10 MeV nucleon^{-1} C and O with interstellar hydrogen and helium rather than from interactions of accelerated protons and α particles with interstellar C and O. Although the data do not rule out the latter possibility (Ramaty et al. 1995a; Cowsik and Friedlander 1995), such an origin appears to be inconsistent with the lack of detection of line emission from 1 to 3 MeV expected from Ne, Mg, Si and Fe (Ramaty et al. 1995a). If the emission is due to accelerated heavy nuclei, this lack of emission in the 1 – 3 MeV region requires suppression of abundances of nuclei heavier than C and O.

Using data from the SMM spectrometer, Harris, Share, and Messina (1995) have derived upper limits on broadened line emission at 4.4 and 6.1 MeV from the direction of the Galactic Center in comparison with Orion. These upper limits indicate that the galactic distribution of the emissivity in these lines does not follow the square of the known ambient galactic CO distribution. This requires that the gas and dust in Orion are irradiated by an unexpectedly large flux of low-energy cosmic rays. This intense irradiation, however, cannot extend to higher energies (Nath & Biermann 1994; Cowsik & Friedlander 1995) because the resultant pion-decay emission would exceed the high-energy γ-ray flux observed from Orion with EGRET (Digel, Hunter & Mukherjee 1995). To keep the power deposited in Coulomb interactions by these accelerated particles from exceeding the IR emission from Orion, they must have energies in the range of several tens of MeV nucleon^{-1} (Ramaty et al. 1995a,b; 1996). These constraints suggest that Orion is a unique source and that additional measurements are necessary to understand the COMPTEL observation.

The COMPTEL observation has also generated considerable interest and speculation concerning the origin of the accelerated particles responsible for the observed γ-ray emission. Suggested sources for particles with enhanced abundances of C and O are 1) the winds of Wolf-Rayet stars (Ramaty et al. 1995a), 2) the ejecta of supernovae from massive-star progenitors (Bykov & Bloemen 1994; Cassé, Lehoucq & Vangioni-Flam 1995; Ramaty, Kozlovsky & Lingenfelter 1995b; 1996; Cameron et al. 1995), and 3) pickup ions resulting from the breakup of interstellar dust (Ramaty et al. 1995b; 1996; Ip 1995).

These particles need to be accelerated to higher energy in order to produce γ rays. Both shock acceleration and stochastic acceleration have been proposed. Shock acceleration can occur in the strong stellar winds from O and B stars (Nath & Biermann 1994) and from young stars (Ip 1995), or from winds colliding with supernova ejecta (Bykov & Bloemen 1994). The latter may be associated with the Orion-Eridanus bubble (Cameron et al. 1995; Ramaty et al. 1996), which may have been created by a supernova that occurred $\sim$ 80,000 years ago (Burrows et al. 1993). Stochastic acceleration, which can occur via gyroresonance with cascading Alfvén turbulence in the accretion disk of a black hole, was proposed by Miller & Dermer (1995) and explains the enhancement of C and O nuclei relative to protons and α particles. This mechanism does not, however, explain the suppression of Ne and heavier elements inferred from the COMPTEL limits on 1 – 3 MeV radiation. This suppression can be accounted for by models with Wolf-Rayet stars of spectral type WC or those involving interstellar dust (see Ramaty et al. 1996).

High-energy ions produced by shocks can propagate tens of parsecs or more (depending on the magnetic fields), leading to a spatially-extended emission region. On the other hand, γ rays produced in the accretion disk of black holes would yield a highly-localized region of emission.

The Orion observations have also motivated studies relating to the origin of light elements and the extinct radioisotopes existing at the time of the formation of the solar system (Clayton 1994; Cassé et al. 1995; Ramaty et al. 1995b; 1996; Cameron et al. 1995; Clayton & Jin 1995). It is interesting that the linear growth of the Be and B abundances observed with time is more naturally explained by a low-energy accelerated particle population depleted in protons and α particles (Cassé et al. 1995) than by the abundances reflected in galactic cosmic rays (e.g., Reeves 1994).

In order to confirm the COMPTEL result and to learn more about this unexpected emission from Orion, *CGRO* observed this region for five weeks from April to June in 1995. The COMPTEL and OSSE instruments made simultaneous measurements during this time period. In this paper we discuss the results of the analysis of data from OSSE. We find no convincing evidence for narrow or broad γ-ray emission at 4.4 and 6.1 MeV from Orion. We discuss constraints these measurements suggest for either the extension or the location of the source observed by COMPTEL.

2. OBSERVATIONS

The OSSE instrument consists of four independent large-area NaI detectors covering the energy range from 0.05 – 200 MeV in a well-shielded geometry (Johnson et al. 1993).

The $3.8^\circ \times 11.4^\circ$ (FWHM) aperture of each detector is defined by a tungsten collimator and observations consist of a sequence of alternating 2-minute source and background pointings. Backgrounds are typically accumulated by offsetting the detector 4.5° on either side of the source position. Quadratic interpolation of the rates in time is used to estimate the background during the source observation. Each detector has a photopeak area of ~ 200 cm^2 near 5 MeV.

Due to constraints on the *CGRO* viewing plan, the Orion observations had to be separated into three *CGRO* Viewing Periods (VP 419.1, 419.5 and 420) over a two-month time span beginning in early April of 1995. Since the location of the Orion source is uncertain, the OSSE detectors were aimed at a point midway between Orion A and B at a Right Ascension of 84.7° and Declination of -3.6° (J2000) throughout all of the observations. This assumed source direction is close to the centers of the CO and γ-ray intensity profiles plotted in Figure 4 of Bloemen et al. (1994). (We discuss the impact that an off-axis source would have on the OSSE measurements in §4.) A map of the Orion region is shown in Figure 1. Plotted along with the brightest stars in the complex are lowest-level contours of CO emission measured by Maddalena et al. (1986) and the maximum likelihood contours of the 3 – 7 MeV emission observed in 1991/2 by COMPTEL (Bloemen et al. 1994). Bloemen et al. do not indicate whether there is evidence that the source is extended.

Three distinct background-pointing configurations were used during the observations. Because of the possibility of background contamination by an extended source, the data from each background-pointing configuration were analyzed separately. The configurations, designated A, B, and C, are displayed in Figure 2 a, b, and c, respectively. The ovals represent the 10% level of response of the OSSE detectors to 50 keV photons and are plotted superimposed on the COMPTEL contours. During VP 419.1 (one week, Apr 4 – 11), all four of the detectors used Configuration A ($\sim \pm 7.5^\circ$ background offsets). There is some evidence in the COMPTEL maps for emission in the OSSE background accumulation near Monoceros. If the γ-ray emission is extended significantly in that direction, the OSSE sensitivity for Configuration A would be reduced (see §4). During VP 419.5 (two weeks, May 9 – 23; the most sensitive observation), all four of the detectors used Configuration B ($\sim \pm 12^\circ$ background offsets) so that no source region was contained in the background accumulations. During VP 420 (two weeks, May 23 – June 6), the spacecraft was re-oriented to accommodate the observation of supernova remnant Cas A. As a result of this maneuver, Detectors 3 and 4 had to use Configuration C (one-sided background offsets of $+4.5^\circ$ and $+7^\circ$). If the Orion source is extended in this direction, these relatively-close backgrounds would contain source emission and thus reduce the OSSE sensitivity for Configuration C (see §4). During this viewing period, Detectors 1 and 2 again used the large $\sim \pm 12^\circ$ background offsets of Configuration B but, because of the reorientation, the source angle relative to

the spacecraft was different for VP 420 than for VP 419.5. Since there is a background systematic which is dependent on this angle (discussed below), the Configuration B data of VP 420 (designated B2) had to be analyzed separately from the Configuration B data of VP 419.5 (designated B1).

Table 1 provides details of the OSSE source and background-offset configurations for the Orion observations. The Table lists the inclusive dates, the background-offset configuration, the on-source live times per detector, and the locations of the detector axes for the source and background observations. Two live times are provided; the primary time is for the medium-energy range of the spectrometer (1.5 – 10 MeV) and the time in parenthesis is for the low-energy range (0.05 – 1.5 MeV). The differences were caused by the priority assigned to on-board storage of medium-range spectra. On-board storage was required due to the loss of real-time telemetry that occurred while the TDRS 3 satellite was activated to replace TDRS 1.

The background offsets used for all the Orion measurements are larger than the typical 4.5° used for most observations made by OSSE. These large offsets are known to produce a systematic effect noticeable in the continuum emission above 1 MeV. This effect arises because the background continuum varies non-linearly with detector pointing angle relative to the massive *CGRO* spacecraft. As a result, systematic effects are observed in source-free fields when background offsets have significantly exceeded the nominal $\pm 4.5°$ value or when they are asymmetric or one-sided. We use a detailed study of mapping observations at high galactic latitudes (Kurfess et al. 1996) to provide energy-dependent corrections to the count spectra for each configuration. (These corrections will be made available on the OSSE home page of the World Wide Web.) As the absolute level of this correction is dependent on the overall background of a specific observation, we only use the shape of the predicted correction and determine its amplitude by a fit to the data. Adjacent Detectors 1 and 2 are physically located above adjacent Detectors 3 and 4 on the *CGRO* spacecraft; the corrections for Detectors 1 and 2 are therefore similar to one another but are different from the corrections for Detectors 3 and 4. For this reason, we first analyze the spectra of Detectors 1 and 2 separately from those of Detectors 3 and 4 for each of the three background-pointing configurations and then combine the results for each configuration.

3. RESULTS

Shown in Figure 3 are six count spectra after correction for the systematic due to large or asymmetric background offsets. For purposes of display, we have separately summed spectra from Detectors 1 and 2 and from Detectors 3 and 4 for each of the three viewing

periods and plotted the data in channels of 250 keV width. The moderate scatters in data plotted in 3b and 3f are reflected in the lower probabilities, P_{χ^2}, that the data come from randomly-distributed sets. The dotted lines show the systematic continua that were removed from the original spectra. We note that the magnitude of these continua are on the order of the total flux measured by COMPTEL in the 3 – 7 MeV band from Orion. This highlights the reason why we are not confident in reporting broad-band measurements of the flux from Orion in the MeV range at this time. We instead focus our efforts on studying the 4.4 and 6.1 MeV line emission reported by Bloemen et al. (1994). It is clear from inspection of Figure 3 that there is no evidence for any feature near 6.1 MeV in any of the observations. There is some structure in a few of the spectra (e.g., Figure 3d and 3e) near 4.4 MeV which suggests the possible presence of a weak line feature at the threshold for detection by OSSE; however, spectra accumulated at the same times by the other pairs of detectors do not show such features.

We used a forward-folding technique and the OSSE response function to fit an incident photon spectrum to the 2 – 9 MeV data from each pair of detectors simultaneously. The incident photon models were comprised of either narrow or broad Gaussian-shaped lines at 4.44 and 6.13 MeV. Narrow lines of widths 95 and 110 keV FWHM, respectively, are expected at 4.44 and 6.13 MeV from isotropic interactions of $\sim$ 10 MeV nucleon^{-1} protons and α particles. Broad lines of width $\sim$700 keV FWHM at these energies are expected from isotropic interactions of $\sim$ 10 MeV nucleon^{-1} C and O ions. Best fits for the narrow- and broad-line intensities were obtained using a χ^2-minimization algorithm. For clarity, we show only the broad-line fits to the spectra in Figure 3. The line fluxes derived from the fits are given in Table 2. The uncertainties were obtained by mapping the χ^2 statistic to obtain a 68% confidence level. We have assumed that there is no significant correlation between the intensities of the two lines (i.e., $\Delta\chi^2 = 1$ for a 1-σ uncertainty). The typical 1-σ uncertainties for the lines are $\sim 3 \times 10^{-5}$ γ cm^{-2} s^{-1} for each pair of detectors. This is about 60% of the flux expected in each line based on the COMPTEL observation. These individual OSSE measurements are therefore at the limit of detectability for such a source. We have studied the distribution of the narrow- and broad-line intensities listed in Table 2 about their mean values and conclude that they are consistent with a randomly-distributed set of data.

Table 2 confirms that there is no evidence for any feature at 6.1 MeV. The significances of a broad feature near 4.4 MeV in Detector 3 and 4 data of Configuration B1 and Detector 1 and 2 data of Configuration B2 are each less than 2 σ. There is also a suggestion for a narrow feature near 4.4 MeV in the data from the last viewing period (VP 420, Configurations B2 and C). However, the combined significance of this feature is only 2.6 σ and there is no evidence for it in data from the two earlier viewing periods. If the VP 420

measurement were to represent an actual change in the flux level, a variability time scale of <2 weeks would be implied. Of the suggested models for line emission from Orion, such variability would only be consistent with the black-hole accretion scenario of Miller and Dermer (1995), but the line would then be expected to be broad and accompanied by the 6.1 MeV O line. Such a line at 6.1 MeV is not detected.

The individual OSSE measurements shown in Table 2 are at the limit of detectability for a source at the level reported by COMPTEL. We can improve the sensitivity of the OSSE search for line features by summing the spectra accumulated during each of the three background-pointing configurations. The narrow- and broad-line fluxes derived from fits to these summed spectra are given in columns 2 through 4 of Table 3. It is clear once again that there is no evidence for either broad or narrow line emission near 6.1 MeV in any of the viewing configurations. Narrow and broad line features near 4.4 MeV observed in Viewing Configurations B and C are significant at less than 2 σ and no evidence for a 4.4 MeV line is found in spectra accumulated during Configuration A.

Ramaty et al. (1995) have predicted a flux of 2×10^{-5} γ cm^{-2} s^{-1} in the 511 keV positron annihilation line based on the COMPTEL 3 – 7 MeV measurement. Because the OSSE sensitivity for this line has been reduced by the limited live time available at this energy (see Table 1), we do not expect to be able to detect this line at this flux level. Nevertheless, we searched for the line by fitting the spectra with a model consisting of (1) a narrow (10 keV) line at 0.511 MeV, (2) a positronium continuum, and (3) a flat, energy-independent continuum. The fitted 511 keV line fluxes for the three background-pointing configurations are (1.3 ± 4.1), (-4.0 ± 4.4) and $(-15.1 \pm 7.3) \times 10^{-5}$ γ cm^{-2} s^{-1}, respectively. Thus we see no evidence for line emission at 0.511 MeV. Because of difficulties distinguishing the positronium continuum from the flat, energy-independent continuum, meaningful upper limits could not be obtained for these components.

4. DISCUSSION

We have divided the OSSE observations of Orion into three viewing configurations with differing background-pointing choices. We find no compelling evidence for line emission near 4.4 or 6.1 MeV in the spectra from any of these viewing configurations. If the Orion source is point-like and lies within a few degrees of the center of the OSSE field of view (RA = 84.8°, Dec = −3.6°), the differences of the background pointings are not important and the data from the three configurations may be added and fit. Under this supposition we see from the summed spectrum in Figure 4 and the last column of Table 3 that there still is no evidence for a line near 6.1 MeV and that any line feature near 4.4 MeV is significant at

less than 2 σ. A point-like, on-axis source at the 1.0×10^{-4} γ cm^{-2} s^{-1} level reported by COMPTEL would have been observed by OSSE with a significance of 7 or 5 σ depending on whether the lines are narrow or broad, respectively.

Due to its small $3.8^\circ \times 11.4^\circ$ aperture, OSSE would detect only a fraction of the flux from a point-like source located off axis or a spatially-extended source. We have calculated factors for correcting the derived fluxes at MeV energies for such sources, and they are plotted in Figure 5 for observing Configurations A, B and C. Panels a, c and e provide contour plots of relative sensitivity for sources offset from the detector axis. Panels b, d and f display relative sensitivities for Gaussian distributions of varying FWHM widths co-aligned with the instrument axis. We have combined Panels a, c and e, weighted by their appropriate livetimes, to provide a sensitivity plot for the total OSSE observation of Orion shown in Figure 6. For example, if the source is point-like but located 3° from the center of the FoV, Figure 6 shows that the inferred total narrow- or broad-line fluxes for the sum of the three configurations (column 5 of Table 3) increase by a factor of 1.5 to 5 depending on its orientation in the FoV; i.e., to as much as (9.6 ± 7.1) or $(12.0 \pm 10.0) \times 10^{-5}$ γ cm^{-2} s^{-1}, respectively. If the source is spatially extended by 10° FWHM, the inferred fluxes increase by a factor of five to (9.5 ± 7.0) or $(12.1 \pm 10.0) \times 10^{-5}$ γ cm^{-2} s^{-1}, respectively. Thus, the OSSE limits presented here would be consistent with the existence of a source at the level reported by COMPTEL if the source is sufficiently off-axis or extended.

Figure 6 can also be used to calculate the relative total OSSE response to any desired spatial distribution. We first use a distribution whose outline (shown in Figure 1) is given by the intense CO emission contours of Maddalena et al. (1986) that are localized around the Orion A and B radio sources. Within this outline we assume the emission is uniform. By combining this distribution with the contours of Figure 6, the inferred OSSE total narrow- and broad-line fluxes would increase by a factor of two to (3.8 ± 2.8) or $(4.8 \pm 4.0) \times 10^{-5}$ γ cm^{-2} s^{-1}, respectively. Therefore, such a source at the COMPTEL-reported level should still have been detected by OSSE at 3.5 σ or 2.5 σ for narrow or broad lines. However, if we assume the very extended distribution whose outline (shown in Figure 1) is given by the least-intense contours of CO emission and is uniform within, the inferred OSSE fluxes increase by a factor of five to (9.6 ± 7.1) or $(12.0 \pm 10.0) \times 10^{-5}$ γ cm^{-2} s^{-1}, respectively. Thus, the OSSE limits presented here are consistent with the existence of a source at the level reported by COMPTEL only if the source is sufficiently extended. Recent analysis of additional observations with COMPTEL (Bloeman, priv. comm. 1996) suggests that the source is present at the originally-reported flux level but is distributed over the entire Orion Cloud complex; this would be consistent with the limits set in this work.

Bykov, Bozhikin, and Bloemen (1996) have recently suggested that the line shapes

from interactions of accelerated C and O may be more complicated than the Gaussian shape used in this analysis. Specifically they show that line splitting is expected. Such shapes do not appear to be reflected in the COMPTEL spectra shown by Bloemen et al. (1994), on which our current study is based. If additional analysis of the COMPTEL data provides a better definition of the line shape, we will consider reanalyzing the OSSE spectra. However, with such a weak source, introducing more complicated line shapes in the analysis does not appear to be a fruitful endeavor, especially as there is no compelling evidence for features in the OSSE spectra from Orion above 2 MeV.

We wish to thank the other members of the OSSE team for their assistance with this analysis. We also acknowledge the useful discussions we have had with Hans Bloemen. This work is supported by NASA grant DPR S-10987C.

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This preprint was prepared with the AAS LaTeX macros v3.0.

Viewing Period and Dates (1995)	Background-offset Configuration	Live Time[1] (10^5 s)	Source RA	Source Dec	Backgrounds RA	Backgrounds Dec	Backgrounds RA	Backgrounds Dec
VP 419.1 (Apr 4 – 11)	A	1.0 (1.0)	84.8	−3.6	92.8	−2.3	77.7	−4.8
VP 419.5 (May 9 – 23)	B1	1.5 (0.7)	84.6	−3.6	91.0	−13.9	78.4	6.6
VP 420, Dets 1 & 2 (May 23 – June 6)	B2	1.5 (0.5)	84.6	−3.6	91.0	−13.9	78.4	6.6
VP 420, Dets 3 & 4 (May 23 – June 6)	C	1.5 (0.5)	84.6	−3.6	82.3	0.2	81.0	2.3

Table 1: Summary of OSSE Observations of Orion

[1]The primary live times listed are for the 1.5 – 10 MeV range; the times in parentheses are for the 0.05 – 1.5 MeV range, some of which were limited as discussed in the text

	Configuration					
	A		B1		B2	C
	Det 1,2	Det 3,4	Det 1,2	Det 3,4	Det 1,2	Det 3,4
4.4 MeV narrow	-3.1 ± 3.2	1.8 ± 3.3	0.0 ± 2.6	1.6 ± 2.7	4.9 ± 2.5	4.7 ± 2.7
6.1 MeV narrow	-2.2 ± 2.4	1.6 ± 2.4	2.4 ± 1.9	-1.8 ± 2.0	-0.5 ± 1.9	0.1 ± 1.9
4.4 MeV broad	-6.6 ± 4.8	0.8 ± 4.8	-0.3 ± 3.8	5.3 ± 3.9	6.7 ± 3.8	4.0 ± 3.8
6.1 MeV broad	-2.7 ± 3.2	1.7 ± 3.1	2.1 ± 2.6	-2.8 ± 2.5	-0.5 ± 2.5	1.0 ± 2.5

Table 2: Line fluxes[1] Measured by OSSE for a Discrete Source on Axis

[1]Fluxes are all in units (10^{-5} γ cm^{-2} s^{-1})

	Configuration A	Configuration B	Configuration C	Sum of All Three Configurations
4.4 MeV narrow	-0.7 ± 2.3	2.2 ± 1.5	4.7 ± 2.7	2.0 ± 1.1
6.1 MeV narrow	-0.4 ± 1.7	0.1 ± 1.1	0.1 ± 1.9	0.0 ± 0.8
Total narrow	-1.1 ± 2.9	2.3 ± 1.9	4.9 ± 3.3	1.9 ± 1.4
4.4 MeV broad	-2.9 ± 3.4	3.9 ± 2.2	4.0 ± 3.8	2.3 ± 1.7
6.1 MeV broad	-0.4 ± 2.2	-0.4 ± 1.5	1.0 ± 2.5	-0.1 ± 1.1
Total broad	-3.4 ± 4.1	3.5 ± 2.7	5.0 ± 4.6	2.4 ± 2.0

Table 3: Line fluxes[1] Measured by OSSE for a Discrete Source on Axis

[1]Fluxes are all in units (10^{-5} γ cm^{-2} s^{-1})

Fig. 1.— Map of the Orion Complex showing bright stars, the COMPTEL maximum likelihood map (dotted contours), and the regions of CO emission (grey areas) and the most intense CO emission (dark areas) observed by Maddalena et al. (1986).

Fig. 2.— OSSE detector configurations for the Orion observations. Light solid lines: COMPTEL maximum likelihood contours; solid oval: OSSE source aperture (10% response @ 50 keV); dotted ovals: OSSE background apertures. Solid heavy lines: source regions accessible to all four OSSE detectors using standard background subtractions; dashed heavy lines: regions accessible only to two detectors.

Fig. 3.— OSSE background-subtracted count spectra for the 3 viewing periods separated by detector pairs and corrected for the background systematic. For each pair, the spectrum from each detector has been rebinned into 250-keV channels before summing. The dotted line shows the background systematic which was removed from the count spectrum. The solid curve is the fit of two broad lines at 4.44 and 6.13 MeV. P_{χ^2} is the quality of the fit.

Fig. 4.— Summed count spectrum from all data obtained during the OSSE observations rebinned into 250 keV channels. The solid curve is the fit of two broad lines at 4.44 and 6.13 MeV.

Fig. 5.— OSSE sensitivity factors for offset point sources and for extended sources relative to an on-axis point source. Panels a, c and e present sensitivity contours for point sources located off-axis for Configuration A, B and C (the dotted contours represent negative sensitivity). Panels b, d and f plot the corresponding sensitivities for extended Gaussian-shaped distributions centered on axis.

Fig. 6.— Sensitivity contours for point sources located off-axis for the total combined OSSE observation of Orion (the dotted contours represent negative sensitivity).