Adv. Space Res. Vol. 13, No. 12, pp. (12)723–(12)726, 1993
Printed in Great Britain.

0273–1177/93 $6.00 + 0.00

COMPTEL RESULTS ON THE 1.809 MeV GAMMA-RAY LINE FROM THE GALACTIC-CENTER REGION

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ABSTRACT

The COMPTEL experiment on the Compton Gamma-Ray Observatory is designed to image celestial gamma radiation in the energy range from 0.75-30 MeV within a field of view of 1 steradian. It can locate stronger point sources with an accuracy better than 0.5°and is capable of mapping diffuse emission as well. The Galactic-center region was observed by COMPTEL for several 2-week periods in 1991/1992. These observations show evidence for 1.8 MeV line emission along the Galactic disk (attributed to radioactive ^{26}Al), extending over at least 40 degrees in longitude.

INTRODUCTION

The 1.809 MeV gamma-ray line originating from the decay of radioactive ^{26}Al (decay time 1 million years) was predicted by Ramaty and Lingenfelter in 1977 and first detected by the HEAO-C instrument /8/. Many other measurements have been made since then (see review /17/), and the existence of the line was firmly established by the SMM measurement in 1985. The line width, as determined from Ge detector measurements, appears to be not (or very little) broadened /8,16/, which indicates that the ^{26}Al decay takes place in the interstellar medium. The formation of ^{26}Al occurs in nucleosynthesis sites such as novae, supernovae, and the interior of massive stars /1,10,20/. The Galactic distribution of these stellar populations is established to some extent from optical measurements. Imaging of the 1.8 MeV emission can help to identify the potential ^{26}Al sources.

Spatial distributions of the 1.8 MeV line emission have been reported by different groups: von Ballmoos, Diehl, Schönfelder (1987, MPE's imaging Compton telescope) /19/, Purcell et al. (1990, SMM, exploiting earth occultation)/11/, and Teegarden et al. (1991, GRIS on-off-source pointed telescope)/16/. Limitations in sky exposure or instrumental capabilities have prevented a conclusive result sofar, although the data indicate that the emission region is extended rather than 'pointlike'. The COMPTEL imaging telescope aboard the Compton Gamma-Ray Observatory /14/ has adequate sensitivity and spatial resolution to provide a new insight into the origin of ^{26}Al. First results from spectral and coarse COMPTEL imaging analyses have been reported /3/; this paper presents a more refined imaging analysis.

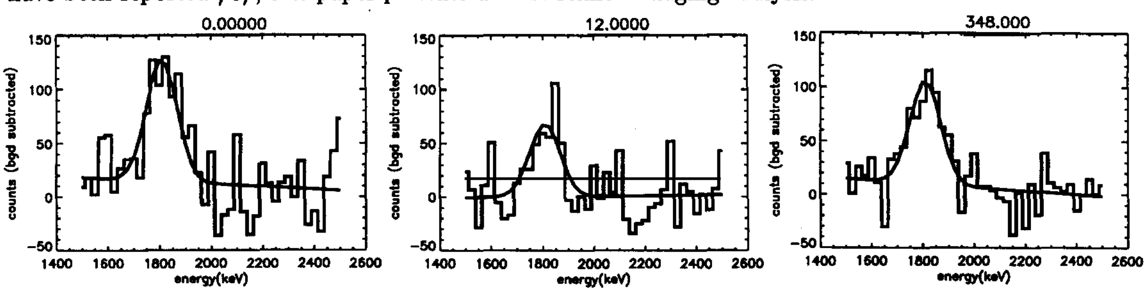

Figure 1. Background corrected energy spectra for 10 °wide regions near l=0°/b=0 °(a), l=12°/b=0°(b), and l=-12°/b=0°(c). Fits with the instrumental line width are shown.

ANALYSIS AND RESULTS

The Galactic-center region was observed during the GRO sky survey in observation 5 (2-week pointing in July 1991 at l=0°/b=-4°), observations 7.5 and 13.0 (two 1-week pointings in August/November 1991 at l=25°/b=-14°), observation 16 (2-week pointing in December 1991 at l=0°/b=2°), and observation 27 in April/May 1992 (l=-28°/b=3°). This paper presents results from a combination of these observations.
With an instrumental energy resolution of 8.5% FWHM at 1.8 MeV and a high photopeak fraction at MeV energies, the 1.8 MeV ^{26}Al gamma-ray line can already be seen in the raw data. Using the imaging information of COMPTEL, such spectra have been generated for selected sky areas along the Galactic plane, about 10 degrees wide. Similary, an average background spectrum was derived from observations at high Galactic latitudes (l=-55°, l=68°).

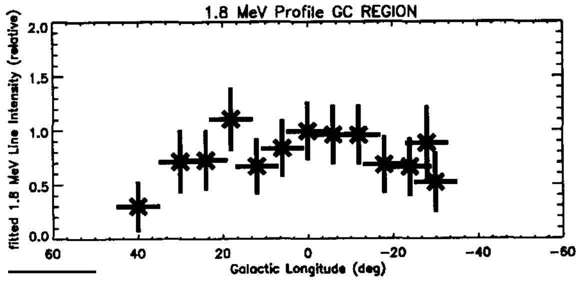

Figure 2. Profile of the 1.8 MeV gamma-ray intensity distribution along the Galactic plane, as derived from energy spectra for selected regions (normalized to the 0/0 measurement). The horizontal bars indicate the effective beam width of the spatial selection; the vertical bars indicate uncertainties in the intensity values (dominated by the residual background uncertainty).

Figure 1 shows background subtracted energy spectra for three regions near the Galactic center (the high-latitude averaged spectrum was scaled by normalizing to the 2.2 MeV background line). The residual broadband features in the background subtracted spectra indicate the variation of the overall background continuum with selected region in the field of view and observation period. Figure 1 also shows Gaussian fits to the 1.8 MeV line on top of a linear background (position and width were fixed according to prior knowledge /3/). Figure 2 shows a longitude profile of the 1.8 MeV intensity distribution along the Galactic plane, determined from the Gaussian fits. The distribution is not smoothly centered on the Galactic center, rather somewhat irregular with e.g. a dip near l=12°. This (non-deconvolved) profile is consistent with the (non-deconvolved) profile derived from SMM measurements via earth occultation analysis /11/, which also shows non-symmetric irregularities.
In order to utilize the full imaging capability of the telescope, events in the energy interval of interest (1.7-1.9 MeV) were binned in the 3-dimensional dataspace of measured scatter direction and scatter angle. (Strong background lines at 1.5 and 2.2 MeV must be excluded from the analysis, therefore the narrow 1.7-1.9 MeV band was chosen, at the expense of tails of the 1.8 MeV peak.) The background in this dataspace was derived by a similar binning of events from adjacent energy bands (1.5-1.7 and 1.9-2.1 MeV) of the same observation, thus subtracting continuum emission and instrumental background. Using appropriate response and exposure matrices a sky image can be constructed through maximum entropy deconvolution, which is shown in Figure 3. We emphasize that only the brightest structures in this map are statistically significant. Bootstrap analyses are being applied to assess statistical uncertainties of structural details, and maximum likehood techniques are used for model fitting, and flux and significance determinations; both these will be discussed in a future paper.

DISCUSSION AND CONCLUSIONS

The combined COMPTEL data from four observations of the central region of the Galaxy show evidence for 1.8 MeV line emission (attributed to radioactive ^{26}Al) along the Galactic disk, extending over at least 40° in longitude. The data show some evidence for hot spots in the intensity distribution, with a particularly prominent peak at l=1.5°, b=-2.0°. Although our findings sofar should be regarded as preliminary, there seems no noubt that COMPTEL will be able to set stringent constraints on the origin of ^{26}Al.

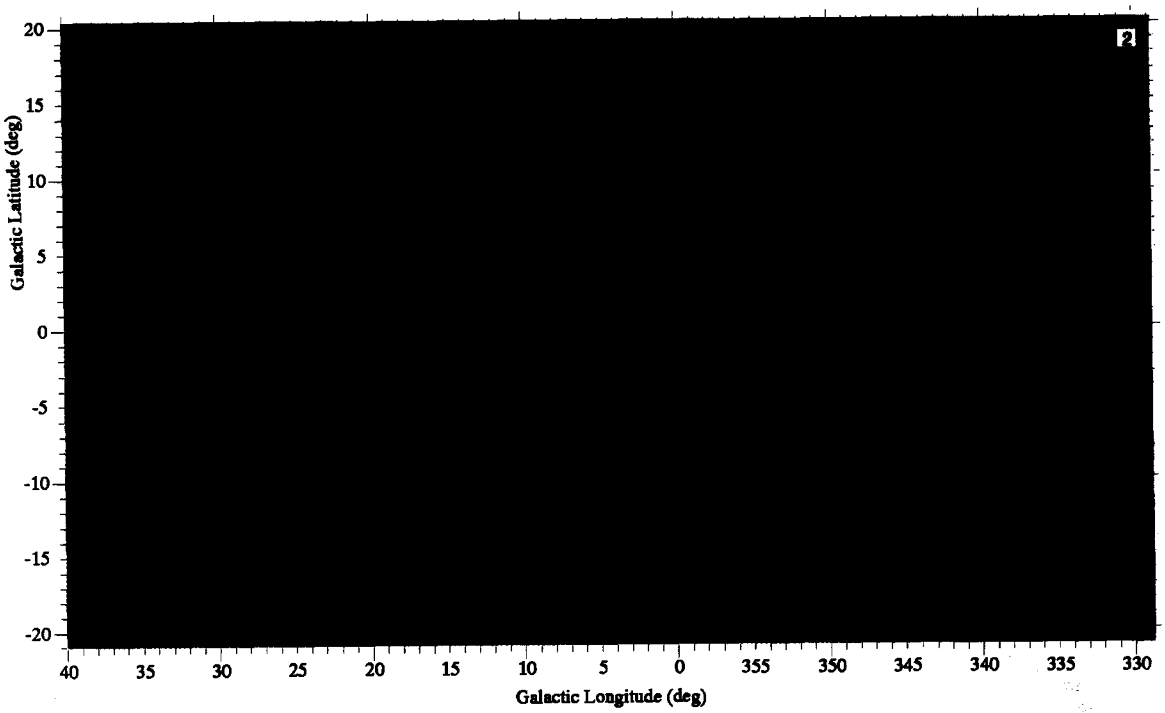

Figure 3. Image of the Galactic-center region in the 1.8 MeV gamma-ray line, derived from the combination of four COMPTEL observations, using maximum entropy deconvolution.

The nucleosynthesis sites of ^{26}Al (such as novae, type II supernovae, and massive stars) are required to be sufficiently hot and sufficiently enriched in ^{26}Al seed nuclei such that the ^{26}Al production can be effective. On the other hand, the destruction of ^{26}Al due to photodisintegration in such hot environments should be sufficiently small for significant residual yield in ^{26}Al. These constraints favour non-equilibrium nuclear burning scenarios, such as explosive nucleosynthesis on the surface of metal enriched O-Ne-Mg novae or nucleosynthesis in supernovae type II (core collapse supernovae), where rapid propagation of a nuclear burning zone through the seed matter ensures that the ^{26}Al generated in the burning zone survives and is diluted in the interstellar medium. An alternative is core nuclear burning in massive stars with convective stellar atmospheres, where the synthesized ^{26}Al can be convected away from the hot inner burning region sufficiently fast. Because of the delicate balance of the nuclear reactions in these scenarios, depending critically on temperatures and convection, precise yield calculations are very difficult and require adequate treatment of the hydrodynamics of the nucleosynthesis region in 3 dimensions. Also, the nuclear reaction rates at these (lower than nuclear statistical equilibrium) temperatures are quite uncertain.

The most direct constraints on the origin of ^{26}Al can probably be obtained from correlation studies of the 1.8 MeV intensity distribution and the Galactic distributions of potential sources. For instance, if the yields of a few individual nucleosynthesis events are substantial fractions of the total ^{26}Al emission, or if the Galactic nucleosynthesis history includes regions of local enhanced activity, a clumpy intensity distribution can be expected. On the other hand, for low individual yields, as expected for novae and massive stars, the intensity distribution should be fairly smooth. Hence the COMPTEL observations already tend to exclude the smooth and centrally peaked novae model /5,6/, as well as models that attribute all observed ^{26}Al to a single point source. As a next step, in order to study the role of frequent explosive nucleosynthesis events (metal enriched novae, supernovae, or Wolf-Rayet stars), global comparisons with catalogues of Wolf-Rayet stars and supernova remnants can provide important insight. Such correlation studies are in progress. The observed emission peak near the Galactic center coincides with the peak of the Galactic gas distribution as measured in CO (also slightly offset from the Galactic center /2/), which might suggest a correlation to young massive stellar populations, provided the CO intensity traces regions of massive star formation. It should be emphasized that the COMPTEL observations do not exclude a (partly) local ^{26}Al origin, which could imply that the ^{26}Al mass derived from the 1.8 MeV line intensity may be well below the canonical 1-3 $M_{\odot}$. Further observations in other regimes of the Galaxy are needed to set stringent constraints.

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