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GRIS OBSERVATIONS OF ^{26}Al GAMMA-RAY LINE EMISSION FROM TWO POINTS IN THE GALACTIC PLANE

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ABSTRACT

The GRIS (Gamma-Ray Imaging Spectrometer) experiment observed the Galactic center region during a balloon flight over Alice Springs, Australia, on 1988 October 28–30. Two observations of the Galactic plane were made at $l = 0°$ and 335°, respectively. ^{26}Al gamma-ray line emission (1809 keV) was detected during both observations, although that in the latter was statistically marginal. For an assumed Galactic longitude distribution similar to high-energy gamma rays, the inferred fluxes at $l = 0°$ are 4.2 (+1.9, −1.7) × 10^{-4} cm^{-1} s^{-1} rad^{-1} (2.5 σ) and 5.4 (+2.9, −3.1) × 10^{-4} cm^{-1} s^{-1} rad^{-1} (1.7 σ) for the two observations. For the combined $l = 0°$ and 335° data sets, we calculate a flux of 4.5 (+1.5, −1.6) × 10^{-4} cm^{-1} s^{-1} rad^{-1} (2.8 σ). These observations are consistent with the assumed high-energy gamma-ray distribution, but they are consistent with other distributions as well. The marginal statistics of the observations combined with the broad field of view (40° effective FWHM) do not permit meaningful tests of the model distributions to be made. The data do, however, suggest that the ^{26}Al emission is distributed over Galactic longitude rather than confined to a point source. The GRIS data hint that the 1809 keV line is broadened. The measured FWHM of the 1809 keV line for the combined data set is 5.1 (+2.1, −2.3) keV, which differs from zero by 2.3 σ.

Subject headings: galaxies: The Galaxy — gamma rays: general

1. INTRODUCTION

^{26}Al with its 10^6 yr mean life is a valuable tracer of nucleosynthetic processes in our galaxy. Ramaty & Lingenfelter (1977) first suggested that the 1809 keV ^{26}Al line might be detectable in the Galactic plane. Such emission was subsequently discovered by *HEAO 3* (1984) and confirmed by Share et al. (1985), von Ballmoos, Diehl, & Schonfelder (1987), and MacCallum et al. (1987). Supernovae, novae, AGB stars, and Wolf-Rayet stars have been suggested as possible sources for the radioactive ^{26}Al. Most of these models produce flux distributions that are concentrated in the Galactic plane. Blake & Dearborn (1989), however, have proposed a model wherein the ^{26}Al comes from a nearby concentration of OB stars centered on the Sco-Cen association. This model can produce distributions that are extended in Galactic latitude. In general, the Galactic longitude distributions for these various models are different. Hence, the shape of this distribution is one of the most important clues as to the origin of the emission. Thus far our knowledge of the distribution is meager. The results reported herein from the GRIS experiment are a first step toward mapping this Galactic longitude distribution, but, as will be seen later, more powerful instruments are required to make meaningful distinctions between the various candidate models.

2. OBSERVATIONS

The GRIS experiment (Tueller et al. 1988) is a balloon-borne high-resolution gamma-ray spectrometer. It consists of an array of seven germanium detectors surrounded by a thick active NaI anticoincidence shield. The results reported herein are from the second flight of the GRIS experiment over Alice Springs, Australia on 1988 October 28–30. The total duration at float of the flight was 44 hr at a typical atmospheric depth of 5 g cm^{-2}. The Galactic center ($l = 0°$, $b = 0°$) was observed for 9.9 hr on October 29. On the following day, a point in the Galactic plane 25° off the center ($l = 335°$, $b = 0°$) was observed for 6.9 hr. During both observations the normal observing mode was to alternate between target and background pointings every 20 minutes. Background was taken by rotating the experiment in azimuth to that point at which the Galactic latitude is a maximum while holding the elevation constant. The one exception to this was when the Galactic center was at high elevation near transit. During this period (~1.5 hr) the Galactic center was continuously tracked, and extended background pointings were made before and after.

In deriving the source flux, it is important to take into account the effects of collimator sidelobes and shield leakage, particularly if the ^{26}Al emission is distributed over a broad range in Galactic longitude. Detailed Monte Carlo calculations were performed and verified with radioactive source calibrations. The nominal field of view of the GRIS instrument at 1809 keV is 24° FWHM. The typical shield leakage at 1809 keV is 5%. For the distributions under consideration, the contribution to the flux outside the main field of view is typically 10%–25% of the flux in the main field of view. Strong sidelobes due to collimator cross-hole trajectories significantly broaden the effective width of the aperture. The effective width at 1809 keV (defined as the width of the equivalent triangular aperture

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that would give the same number of detected counts for a flat longitude distribution) is 40°.

Differences were taken between the 20 minute target pointings and the two adjacent 10 minute background intervals. The final flux values were derived by taking weighted sums of these difference spectra. The analysis was performed under the assumption of different forms for the distribution of the incident ^{26}Al flux in Galactic longitude. The assumed distributions were: high-energy cosmic-ray (*COS B* [Mayer-Hasselwander et al. 1982; Mahoney et al. 1984]), CO (Dame et al. 1987), nova (Higdon & Fowler 1989), and point source. The number of counts keV^{-1} in the ^{26}Al line is given by

$$\frac{dN}{dE} = \left\{\int_0^{2\pi} \lambda(E) f(l) R[\alpha(l), \beta(l)] T[h, \epsilon(l)] dl + B\right\} t$$
$$= [\lambda(E) I + B] t \,, \qquad (1)$$

where

l = Galactic longitude,
$\lambda(E)$ = flux at $l = 0°$ (photons cm^{-2} s^{-1} keV^{-1} rad^{-1})
(Note: $\lambda(E)$ is broadened by the instrumental energy resolution),

$f(l)$ = flux distribution (normalized to unity at $l = 0$),
α, β = angles in GRIS coordinate frame,
$R[\alpha(l), \beta(l)]$ = instrument response function (effective area vs. angle),
$T[h, \epsilon(l)]$ = atmospheric transmission,
h = atmospheric depth,
ϵ = elevation angle,
t = duration of observation,
B = instrument background (counts keV^{-1} s^{-1}), and
$I \equiv \int_0^{2\pi} f(l) R[\alpha(l), \beta(l)] T[h, \epsilon(l)] dl$.

Note: Because this analysis is done over a narrow energy window, all quantities other than $\lambda(E)$ are taken to be energy independent.

Then we can write for a target pointing

$$(dN/dE)_T = [\lambda(E) I_T + B] t_T \,, \qquad (2)$$

and similarly for a background pointing,

$$(dN/dE)_B = [\lambda(E) I_B + B] t_B \,. \qquad (3)$$

TABLE 1

1809 keV LINE MEASUREMENTS[a]

Measurement	Flux at $l = 0°$ (10^{-4} cm^{-1} s^{-1} rad^{-1})
GRIS	
$l = 0°$	$4.2^{+1.9}_{-1.7}$ (2.5 σ)
$l = 335°$	$5.4^{+2.9}_{-3.1}$ (1.7 σ)
($l = 0°$) + ($l = 335°$)	$4.5^{+1.5}_{-1.6}$ (2.8 σ)
HEAO 3 (Mahoney et al. 1984)	4.8 ± 1.0
SMM (Share et al. 1985)	4.0 ± 0.4
AT&T/Bell Labs[b]	
(MacCallum et al. 1987)	$3.9^{+2.0}_{-1.7}$

[a] Assuming *COS B* distribution.
[b] Model-independent analysis.

Taking the difference between equations (2) and (3) and solving for λ gives

$$\lambda(E) = \frac{(dN/dE)_T/t_T - (dN/dE)_T/t_B}{I_T - I_B} \,. \qquad (4)$$

$\lambda(E)$ is calculated for each target-background pair, and a weighted sum is taken to give the final flux at $l = 0°$. This distribution is then fitted with a Gaussian folded through the experimental response function to give the total line flux.

The flux spectra, as derived above, are plotted in Figure 1 for the $l = 0°$ and 335° pointings. Note that what is plotted is the flux at $l = 0°$ for both the $l = 0°$ and 335° pointings. The assumed distribution is *COS B* (a smoothed version used by Mahoney et al. 1984 and Share et al. 1985). The solid line is the best-fit Gaussian folded through the GRIS response function (instrumental resolution = 2.8 keV FWHM at 1809 keV). The values for the integrated 1809 keV line fluxes are given in Table 1. Positive detections of the 1809 keV line were made for both pointings (2.5 σ and 1.7 σ, respectively), although the latter was statistically marginal. The GRIS Galactic center flux values from the $l = 0°$ and 335° observations agree within errors, which means that the data are consistent with the assumed *COS B* distribution. The combined significance of the two GRIS measurements is (see Table 1) is 2.8 σ. Also given are $l = 0°$ flux values from several other experiments. These all appear to be in mutual agreement.

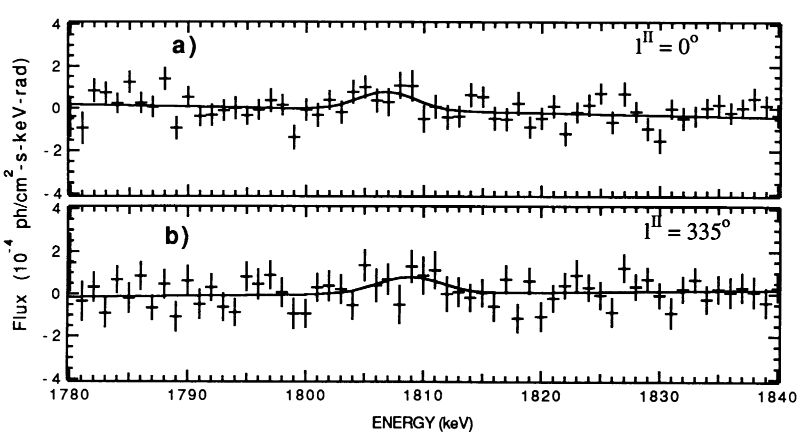

FIG. 1.—GRIS spectra (derived at $l = 0°$) of the ^{26}Al line. A high-energy gamma-ray distribution (*COS B* [Mahoney et al. 1984; Mayer-Hasselwander et al. 1982]) is assumed for the flux calculation. Solid lines are best-fit Gaussians folded through the GRIS instrumental response function. (*a*) $l = 0°$ observation; (*b*) $l = 335°$ observation.

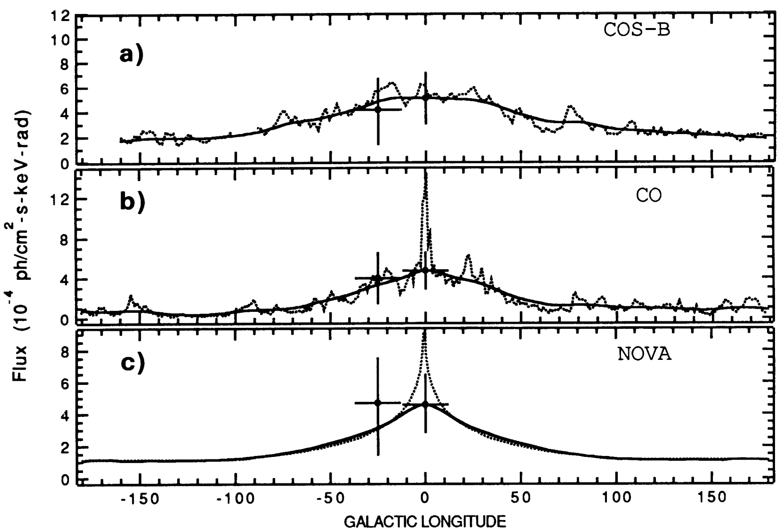

FIG. 2.—Comparison of GRIS results with various assumed Galactic plane distributions. Dotted line is measured data. Solid line is measured data folded through GRIS aperture response function. (*a*) *COS B* distribution (Mahoney et al. 1984; Mayer-Hasselwander et al. 1982); (*b*) CO distribution (Dame et al. 1987); (*c*) nova distribution (Higdon & Fowler 1989).

Figures 2*a*–2*c* show the two GRIS data points calculated for various assumptions about the Galactic longitude distribution and compared with each of the assumed distributions. In each case the original distribution has been folded through the GRIS aperture response function. It is evident from Figure 2 that no meaningful discrimination can be made between the various assumed distributions. This is due to the combination of poor statistics and the broad sidelobe pattern of the GRIS aperture response function. Also, the 25° separation in pointings was optimized for 511 keV (see Gehrels et al. 1991) and is far from ideal for the 1809 keV observation. A definitive determination of the shape of this distribution must await observation with an instrument such as the NAE/INTEGRAL which has a narrower field of view (10° FWHM) and two orders of magnitude greater sensitivity (Matteson 1989).

A similar analysis was carried out assuming a point source at the Galactic center. The results are given in Table 2 and compared with other measurements. In a previous analysis of the balloon flight data of the MPI Compton telescope (von Ballmoos et al. 1987), most of the ^{26}Al emission was found to come from the Galactic center region. The data were best fitted by a narrow source with an extension smaller than or equal to the angular resolution of the telescope (10° FWHM), but wider distributions could not totally be excluded. For example, a flat Galactic longitude distribution could be excluded only at the 2 σ level. For a point source origin, a flux of $(6.4 \pm 2.6) \times 10^{-4}$ cm^{-2} s^{-1} was obtained. A recent reanalysis of these data (Schoenfelder & Varendorff 1991) has reduced the flux to $(4.6 \pm 2.3) \times 10^{-4}$ cm^{-2} s^{-1}. The derived image of the line emission, however, was found to be very similar to the one obtained earlier: the data are better matched by distributions with an enhanced emission toward the Galactic center than with wide, flat longitude distributions. However, the two GRIS measurements, taken by themselves, favor a distributed source at the 1.5 σ level.

The GRIS line-fit results for the 1809 keV line are given in Table 3. The quoted errors for the peak energies include 0.3 keV estimated systematic uncertainty in the energy calibration at 1809 keV. The peak energy for $l = 0°$ lies 1.7 σ below the laboratory value. Both values for the FWHM suggest a broadened line, but the $l = 335°$ measurement is also consistent with zero line width. To explore further the question of whether our 1809 keV line results are significantly different from the laboratory values, we have calculated the best-fit line

TABLE 2

1809 keV LINE MEASUREMENTS[a]

Measurement	Flux (10^{-4} cm^{-2} s^{-1})	Field of View (FWHM)
GRIS		
$l = 0°$	1.9 ± 0.8	24°[b]
$l = 335°$	$2.1^{+1.1}_{-1.2}$	24°[b]
AT&T/Bell Labs (MacCallum et al. 1987)	1.3 ± 0.9	15°
UC/France (Malet et al. 1991)	1.9 ± 0.9	22.5°
SMM (Harris et al. 1990)	4.0 ± 0.4	130°
MPI (Schoenfelder & Varendorff 1991)	4.6 ± 2.3	60°[c]

[a] Assuming point source.
[b] Effective FOV = 40°.
[c] Compton telescope.

TABLE 3

1809 keV Line Fit Parameters[a]

Parameter	Flux at $l = 0$ (10^{-4} cm^{-2} s^{-1} rad^{-1})	Peak Energy (keV)	FWHM (keV)
$l = 0°$	$4.2^{+1.9}_{-1.7}$	$1806.3^{+1.4}_{-1.6}$	4.2 ± 2.4
$l = 335°$	$5.4^{+2.9}_{-3.1}$	$1808.5^{+2.1}_{-2.0}$	$5.5^{+4.5}_{-5.5}$
$(l = 0°) + (l = 335°)$	$4.5^{+1.5}_{-1.6}$	1806.8 ± 1.1	$5.1^{+2.1}_{-2.3}$

[a] Assuming *COS B* distribution.

parameters for the combined $l = 0°$ and 335° data sets. These are given in Table 3. We find, again, that the measured peak energy is 1.7 σ below the laboratory value and that the FWHM is 2.3 σ larger than zero. We note, however, that some broadening is expected due to Galactic rotation. A velocity spread of ± 200 km s^{-1} (typical of the inner few kpc of the Galaxy) would give a ^{26}Al line width of 2.4 keV (full width). Our measured value is larger than this by only 1.2 σ.

3. SUMMARY AND CONCLUSIONS

The GRIS experiment has detected the ^{26}Al line at two points in the Galactic plane ($l = 0°$ and 335°). The results are suggestive of a distributed source, but poor statistics (due to abbreviated observing time) do not permit a definitive statement to be made on the shape of the distribution. Assuming a distributed source that follows the high-energy gamma rays, the derived GRIS results at $l = 0°$ are consistent with most other similar measurements (Mahoney et al. 1984; Share et al. 1985; MacCallum et al. 1987; Malet et al. 1991). The GRIS data hint at a possible broadening of the 1809 keV line (FWHM = 5.1 [+2.1, −2.3] keV for the combined data set), which is significant at the 2.3 σ level. However, further measurements, with either longer duration or a more powerful instrument, are required to firmly establish whether or not this broadening is real.

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