SMM DETECTION OF INTERSTELLAR ^{26}AL GAMMA RADIATION

G.H. Share, R.L. Kinzer
E.O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, D.C. 20375
USA

E.L. Chupp, D.J. Forrest
Physics Department
University of New Hampshire
Durham, New Hampshire 03824
USA

E. Rieger
Max Planck Institut fur Physik und Astrophysik
Institut fur Extraterrestriche Physik
Garching, FRG

ABSTRACT

The gamma-ray spectrometer on the Solar Maximum Mission Satellite has detected the interstellar ^{26}Al line when the Galactic center traversed its aperture in 1980, 1981, 1982, and 1984. The center of the emission is consistent with the location of the Galactic center, but the spatial distribution is presently not well defined. The total flux in the direction of the Galactic center is $(4.3 \pm 0.4) \times 10^{-4}$ γ/cm^2-s-rad for an assumed population I distribution.

1. Introduction. Gamma-ray line emission at 1.809 MeV from the decay of Galactic ^{26}Al has been detected by both the HEAO-C spectrometer in 1979 (1) and by the SMM spectrometer in 1980, 1981 and 1982 (2). ^{26}Al can be synthesized in novae, supernovae, red giants, and massive stars (3-9) and accumulates in the interstellar medium due to its 0.72×10^6 yr half life (10).

The gamma-ray spectrometer on the Solar Maximum Mission satellite has been in operation since February 1980. Although it was not designed for Galactic studies, the spectrometer's excellent stability, good sensitivity and long observing period have enabled it to detect the interstellar ^{26}Al line at a high level of significance, $>5\sigma$, each year as the Galactic center passed through its field of view. In this paper we summarize the earlier SMM observations (2) and report on the detection of the line in 1984.

2. Observations. We obtained the data base for the Galactic studies by accumulating 1 minute spectra along with the satellite's location and orientation. Three-day accumulations of these spectra were then sorted according to three parameters: 1) the time from the last significant transit of the radiation belts (SAA), 2) the zenith angle of the detector axis, and 3) the vertical geomagnetic cutoff rigidity for cosmic rays. Data were only included in these summations for ~8 orbits each day which were free from significant exposure to the SAA. Both computerized and visual screening of all the data prior to the 3-day summations allowed us to remove contributions from solar

flares, gamma-ray bursts, geomagnetic disturbances, and times with poor telemetry transmissions.

We have used the fact that SMM follows the Sun along the ecliptic to search for an annual increase in the intensity of 1.81 MeV gamma-rays as the Galactic center passes through its 130° (FWHM) aperture. Our ability to uniquely separate the interstellar line from background lines is limited by the 95 keV (FWHM) energy resolution of the spectrometer near 1.81 MeV. However, the > 3 year data base permits us to resolve the different components. Details of this analysis are presented in reference 2. The overall background spectrum in the 1.6 to 2.0 MeV region can be represented by a power-law continuum and a line feature near 1.78 MeV whose width exceeds the instrumental resolution. This feature is dominated by unresolved lines at ~1.75 MeV, ~1.79 MeV and ~1.81 MeV. A likely source of the 1.75 MeV feature is ^{119}Te which is produced in the instrument's CsI shield. The component near 1.79 MeV is due in large part to ^{22}Na produced from aluminum in the instrument's housing. The observed line is produced by the simultaneous detection of a 1.275 MeV gamma ray with a 0.511 MeV photon from the annihilation of the emitted positron. Another contributer to this feature is the ^{27}Al(n,γ) ^{28}Al reaction which produces a line near 1.78 MeV. In addition to interstellar ^{26}Al gamma rays, the feature near 1.81 MeV appears to contain background contributions from a radioactive decay sequence and from the excited state of ^{26}Mg produced by (n,np) reactions on aluminum (1).

Shown in Figure 1 is the measured rate of the composite line feature between ~1.79 and 1.81 MeV plotted as a function of time following the launch of SMM. Only data accumulated with the detector axis within 72° of zenith are included. The data have been summed to 24 days to remove most of the systematic variations due to SMM's 48-day precession. The gradual increase is due to the growth of the ^{22}Na background line (2.6 yr half life). Superimposed is a striking increase which occurred in each of four years centered in the latter part of December. This is the time when the detector axis was pointed near the center of the Galaxy. The dashed curve represents a model having three terms: 1) a constant, 2) the increased activation in the ^{22}Na line produced by the incident radiation (SAA and cosmic), and 3) the calculated response of the instrument to a diffuse Galactic source which follows the longitude distribution of >100 MeV gamma rays (11). The average amplitude of the Galactic modulation is 0.033 ± 0.0025 cts/s; the rate does not appear to vary from year to year.

We have obtained a spectrum of the Galactic line emission near 1.81 MeV by separately summing data within 45 days of Galactic center and Galactic anti-center transits during the first 3 1/2 year observing period shown in Figure 1. We then normalized the spectra by live time and subtracted the Galactic anti-center exposures from the Galactic center exposures. A clear line feature is observed with an energy = 1.804 ± 0.004 MeV and width = 102 ± 10 keV FWHM (includes instrumental broadening of 95 keV FWHM). The fitted energy and intrinsic line width (38^{+21}_{-38} keV FWHM) are consistent with a narrow line at 1.809 MeV from ^{26}Al.

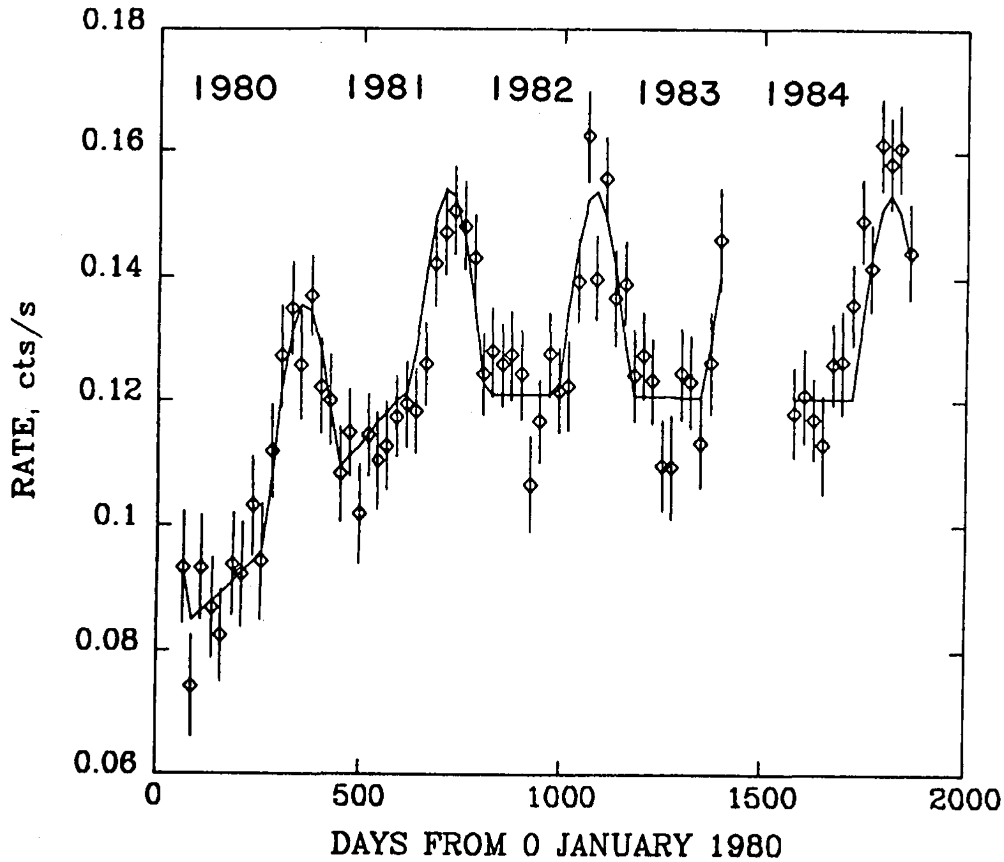

Figure 1 Variation in the intensity of a composite line near 1.81 MeV obtained when data for times >10,000 s from the last SAA passage in the 1.6-2.0 MeV range are fit by a power-law continuum and lines at 1.75 and 1.81 MeV. Only data accumulated <72^{o} of zenith are plotted. The gradual increase in the 1.81 MeV intensity is due to the nearby ^{22}Na line which is not resolved in this fit. No data are available from late 1983 to early 1984 when SMM's tape recorders were turned off.

3. Discussion and Summary. We have analyzed 4 years of data from the gamma-ray spectrometer on SMM and have observed a >10σ increase in the intensity of line radiation near 1.81 MeV when the Galactic center region traversed its aperture. Restricting data samples in order to reduce the effects of background in the instrument has no significant effect on the measured intensity of the line. All of our tests point to a celestial origin of the radiation. The measurement is consistent with the detection of a narrow line at 1.809 MeV from interstellar ^{26}Al. Unambiguous identification of this line with ^{26}Al comes from the high resolution HEAO-3 measurements of its energy, 1808.49 $\pm$ 0.41 MeV, and width, <3 keV (1).

The detection of interstellar 1.81 MeV line gamma-radiation by both the SMM and HEAO-3 spectrometers is convincing evidence for nucleosynthesis of ^{26}Al during the past million years. It was initially believed that the integrated emission from Galactic supernovae could account for the observed gamma-ray flux (10), however, recent work indicates that this may not be the case (12,13). Alternative sources are novae, red giant stars, and massive stars(6-8). One of the keys to determining the origin of the observed emission is its angular distribution (14). The Galactic longitude distribution for novae is strongly peaked toward the Galactic center (>50% are within 10° of the center; see ref. 14). The distribution of CO, which monitors star formation and supernovae in the Galaxy, is broader and drops off in intensity only for longitudes more than 30° from the Galactic center.

The SMM results require a strong concentration in the direction of the Galactic center, as evidenced by the striking annual modulation shown in Fig. 1. We have compared this modulation with calculations of the instrument's response to source distributions which either lie along the Galactic plane or are asymmetric in Galactic latitude. The centers of these distributions fall in an error box defined by 345° and 25° in Galactic longitude and -15° and $+10^{\circ}$ in latitude (99% confidence). This is consistent with a source centered at the Galactic center. Due to the large aperture of the spectrometer, the distribution of the radiation is not well defined. However we are hopeful that by using the Earth as an occulting disk for the source, we can obtain more information on its distribution.

The intensity of the ^{26}Al line averaged over four SMM observations in 1980, 1981, 1982 and 1984 is $0.033 \pm .0025$ cts/s. There is no evidence for any year-to-year variation in intensity. If we assume that the line emission follows the >100 MeV Galactic gamma-ray distribution (11), this corresponds to a total flux of $(4.3 \pm 0.4) \times 10^{-4}$ γ/cm^2-s-rad. This is consistent with the flux of $(4.8 \pm 1.0) \times 10^{-4}$ γ/cm^2-s-rad observed by HEAO-3 in 1979/1980 (1).

4. Acknowledgements. This work was supported by NASA contract S-14513D at NRL and NAS5-28609 at UNH, and by BFFT contract 010k 017-ZA/WS/WRK 0275.4 at MPE.

References

1. Mahoney, W.A., et al. (1984), Ap. J., 286, 578.
2. Share, G.H., et al. (1985), Ap. J. (Lett), 292, L61.
3. Clayton, D.D. and Hoyle, F. (1976), Ap. J., 203, 490.
4. Arnett, W.D. (1969), Ap. J., 157, 1369.
5. Woosley, S.E. and Weaver, T.A. (1980), Ap. J., 238, 1017.
6. Arnould M., et al. (1980), Ap. J., 237, 931.
7. Norgaard, H. (1980), Ap. J., 236, 895.
8. Cameron, A.G.W. (1984), Icarus, 60, 416.
9. Dearborn, D.S., and Blake, J.B. (1985), Ap. J. (Lett), 288, L21.
10. Ramaty, R., and Lingenfelter, R.E. (1977), Ap. J. (Lett), 213, L5.
11. Mayer-Hasselwander, H.A. (1983), Space Sci. Rev., 36, 223.
12. Clayton, D.D. (1984), Ap. J., 280, 144.
13. Fowler, W.A. (1984), Science, 226, 922.
14. Leising, M.D. and Clayton, D.D. (1984), Ap. J., submitted.