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December 12, 1962

East-West Asymmetry in the Flux of Mirroring Geomagnetically Trapped Protons*

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We report here on the visual detection of geomagnetically trapped protons in the region of the South Atlantic magnetic anomaly. Protons with energies ≥57 MeV were recorded in electron-insensitive Ilford K·2 nuclear emulsions during a 65 orbit, oriented satellite flight recovered on September 1, 1962. More than 90% of all the particles recorded by the emulsions were confined to a well-defined plane. We detected, therefore, protons from the inner radiation belt near their mirror planes in a highly localized region in space. We observe an east-west asymmetry in the flux of geomagnetically trapped protons, confirming an effect predicted by Lenchek and Singer.[1,2] Using measurements of the east-west asymmetry we obtain a value of 62.0±5.0 km for the scale height of the atmosphere at 364 km altitude. From our data we also have determined the location and approximate area of this region over the South Atlantic.

Parameters of the orbit relevant to this experiment are inclination, 65.2 deg; apogee, 407 km; and perigee, 178 km.

GEOMETRY

Four emulsion stacks were mounted with a known orientation beneath the ablative shield of the recoverable section of the satellite. Three stacks (Nos. 1, 3, and 4) were selected for analysis. The fourth was used for test processing and background measurement.

The projected angular distribution of protons that entered stack 4 with dip angle of ≤ 15 deg. and came to rest within 3 mm of the edge of the emulsion is shown in Fig. 1a. The distribution is characteristic of mirroring particles. The insert in Fig. 1a illustrates how the mirror plane intersects the plane of emulsions in this stack--fortuitously at 90±1 deg. The normal to the mirror plane is $\hat{\underline{B}}$, the unit vector of the geomagnetic field. The $\hat{\underline{B}}$ vectors deduced from stacks 1, 3, and 4 are identical within errors of measurement. The average values of the direction of cosines of $\hat{\underline{B}} = \hat{\underline{i}} \cos\epsilon + \hat{\underline{j}} \cos\eta + \hat{\underline{k}} \cos\mu$ in a coordinate system fixed in the satellite are $\cos\epsilon = 0.668 \pm 0.029$, $\cos\eta = 0.516 \pm 0.056$, and $\cos\mu = -0.537 \pm 0.026$. The vector $\hat{\underline{i}}$ is normal to the earth's surface, i.e., the zenith direction, and the axis of symmetry of the satellite, $\hat{\underline{k}}$, is in the orbital plane.

GEOGRAPHIC LOCATION

The direction of cosines of $\hat{\underline{B}}$ given above are used to evaluate the magnetic inclination, I, and the magnetic declination, D, in the mirroring region: I = 41.9±2.2 deg and D = 11.1±3.0 deg W. Considering altitudes, magnetic-field intensities, and L values, and using the Jensen and Cain (1962) harmonic expansion[3] of the geomagnetic field at 400-km altitude, we deduced a unique location for the mirroring region: 39 deg S, 41 deg W (Fig. 2). At this point the satellite was approaching apogee at an altitude of 364 km. This location is near the center of one of the regions of high counting rates that have been observed by counter techniques.[4-7]

EAST-WEST ASYMMETRY

Briefly, the east-west asymmetry arises because, at the point of observation, protons traveling toward the east have guiding centers at higher altitudes than those traveling toward the west. Because of the diminution of atmospheric density with altitude, the eastward flux is expected to be larger than the westward flux.[8]

Assuming that the unidirectional proton flux $\underline{j}$ is inversely proportional to the atomospheric density averaged over the circle of gyration, Lenchek and Singer give for the east-west ratio:

$$\frac{j_E}{j_W} = \exp\left[\underline{a}(\cos\theta_E - \cos\theta_W)/h\right] \qquad (1)$$

where $\underline{a}$ is the gyroradius, $\underline{a}(\cos\theta_E - \cos\theta_W)$ is the difference in altitudes of the guiding centers of flux j_E and j_W, and h is the scale height of the atmosphere.

The east-west asymmetry is manifest in Fig. 1a, where the ratio of the number of protons entering the west (270 deg) edge of stack 4 to the number entering the east edge is 2.30±0.25. Data on the east-west effect are summarized in Table I. We obtain from these data a measurement of the scale height of the atmosphere

$$h = 62.0 \pm 5.0 \text{ km} \; .$$

This result is in satisfactory agreement with measurements of h deduced from observations of satellite drag.[9, 10]

PITCH-ANGLE DISTRIBUTION

We are able to show that a Gaussian pitch-angle distribution is expected at low altitudes under the assumption that the mirror point density is inversely proportional to the atmospheric density at the mirror point of the guiding center[11] when the atmospheric density is of the form $\rho \propto \exp[-r/h]$. The variance of the derived Gaussian is

$$\sigma^2_{calc} = \frac{3h}{4r}(2 + \cos^2 I) , \qquad (2)$$

where r is the dipolar radius and I is the magnetic dip. If we take h = 62.0±5.0 km obtained from the east-west asymmetry as the scale height of the atmosphere, the value of σ_{calc} is 7.36±0.30 deg.

For the observed pitch-angle distributions, Figs. 1(b) and (c), the σ are necessarily larger than σ_{calc} primarily because of variations in the direction of the magnetic field in the mirroring region. From the pitch-angle distribution for protons traveling normal to the magnetic meridian, i. e., in the direction $\hat{\underline{I}} \times \hat{\underline{B}}$, Fig. 1b, the deviation of the magnetic declination in the mirroring region is σ_D = 2.5±0.9 deg. The width of the pitch-angle distribution observed in the magnetic meridian, Fig. 1(c), is attributable to a deviaation in magnetic inclination of σ_I = 10.7±0.2 deg.

ABSOLUTE PARTICLE FLUX

The "wobble" of the magnetic declination σ_D and inclination σ_I given above enables us to roughly estimate the size of the geographic area where the mirroring particles were detected. The shaded area in Fig. 2 is delineated by the isogonic lines 8.6 and 13.6 deg and isoclinic lines 31.2 and 52.6 deg. The flight time in this region was about 720 sec. Preliminary measurements of the energy spectrum give an omnidirectional flux N = 2.0±0.2 $\times 10^4$ protons cm^{-2} MeV^{-1} at 65 MeV. This flux corresponds to a peak counting rate of about 15 cm^{-2} MeV^{-1} sec^{-1} if we assume that the counting-rate contours are Gaussian.

The authors wish to thank the members of the Lawrence Radiation Laboratory visual-measurements group for their assistance in analyzing the emulsion data, and Dr. Walter H. Barkas for his helpful comments. We also appreciate the cooperation of Dr. Alan Andrews, Mr. G. Minalga and Mr. B. Schlaff, of the Lockheed Missiles and Space Company.

FOOTNOTES AND REFERENCES

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1. A. M. Lenchek and F. S. Singer, J. Geophys. Res. 67, 4073 (1962).
2. G. Haerendel, J. Geophys. Res. 67, 1173 (1962).
3. D. C. Jensen and J. C. Cain, Harmonic Expansion, 1960 (1962), private communication from Lester L. Newkirk, Lockheed Missiles and Space Company, Palo Alto, California.
4. S. N. Vernov, I. A. Savenko, P. I. Shavrin, and N. F. Pisarenko, Dokl. Akad. Nauk SSSR 140, 1041 (1961) [Translation: Soviet Phys. Dokl. 6, 893 (1962).]
5. L. V. Kurnosova, T.N.Kolobyanina, V.I. Logachev, L. A. Razorenov, I. A. Sirotkin, and M. I. Fradkin, Planetary Space Sci. 9, 513 (1962).
6. L. G. Mann, S. D. Bloom, and H. I. West, Jr., University of California Radiation Laboratory Report UCRL-6902-T, 1962.
7. Frederick D. Seward, Lawrence Radiation Laboratory, Livermore, private communication.
8. Lenchek and Singer inadvertently reversed the effect and predicted a larger flux from the east. That the opposite may be expected is evident from their Fig. 1.
9. Francis S. Johnson, Satellite Environment Handbook (Stanford University Press, Stanford, California 1961), pp. 9-24.
10. L. G. Jacchia and J. Slowey, Smithsonian Astrophysical Observatory Special Report No. 100, 1962.
11. S. Yoshida, G. H. Ludwig, and J. A. Van Allen, J. Geophys. Res. 65, 807 (1960).

Table I. Observed east-west ratios and calculated scale-heights of the atmosphere at an altitude of 364 km and field B of 0.222 Gauss.

Proton energy (MeV)	$\cos\theta_E - \cos\theta_W$	j_E/j_W	h (km)
116	1.466	5.49 ± 0.77	62.2 ± 6699
107	0.714	2.30 ± 0.25	59.5 ± 8811
60	0.620	1.57 ± 0.16	69.6 ± 15.0
		Average:	62.0 ± 5.0

FIGURE LEGENDS

Fig. 1. (a) Angular distribution of stopping protons in stack 4. The insert illustrates orientation of the mirror and emulsion planes. The unequal number of protons in the two peaks is due to an east-west asymmetry. Cosmic-ray secondaries account for the isotropic background. (b) Observed pitch-angle distribution of proton flux normal to the magnetic meridian. (c) Observed pitch-angle distribution of proton flux in the plane of the magnetic meridian; δ is the angle between the direction of the incident proton and the mirror plane.

Fig. 2. Geographic location of the mirroring protons. The mean coordinate of the region--39 deg S, 41 deg W--is shown as an open circle with accompanying error bars. Isogonic lines are solid, isoclinic lines are dashed. Satellite trajectories (near apogee) are heavy solid lines with arrows. The approximate area of the mirroring region as deduced in this experiment is shaded.

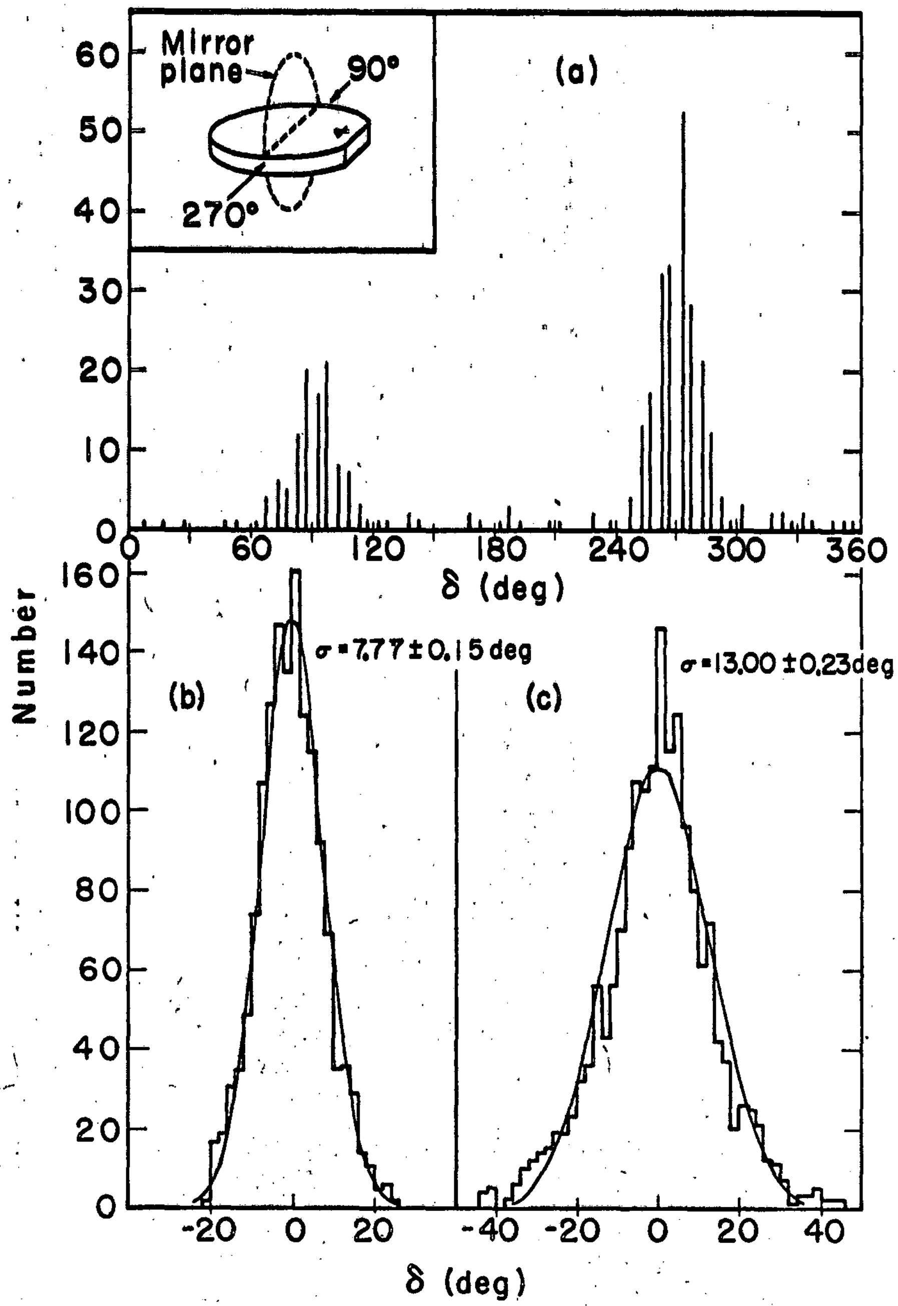
Mirror plane
90°
270°
(a)
60
50
40
30
20
10
0
0 60 120 180 240 300 360
δ (deg)
Number
160
140
120
100
80
60
40
20
0
σ = 7.77 ± 0.15 deg
(b)
(c)
σ = 13.00 ± 0.23 deg
-20 0 20 -40 -20 0 20 40
δ (deg)
MUB-1513

Fig. 1.

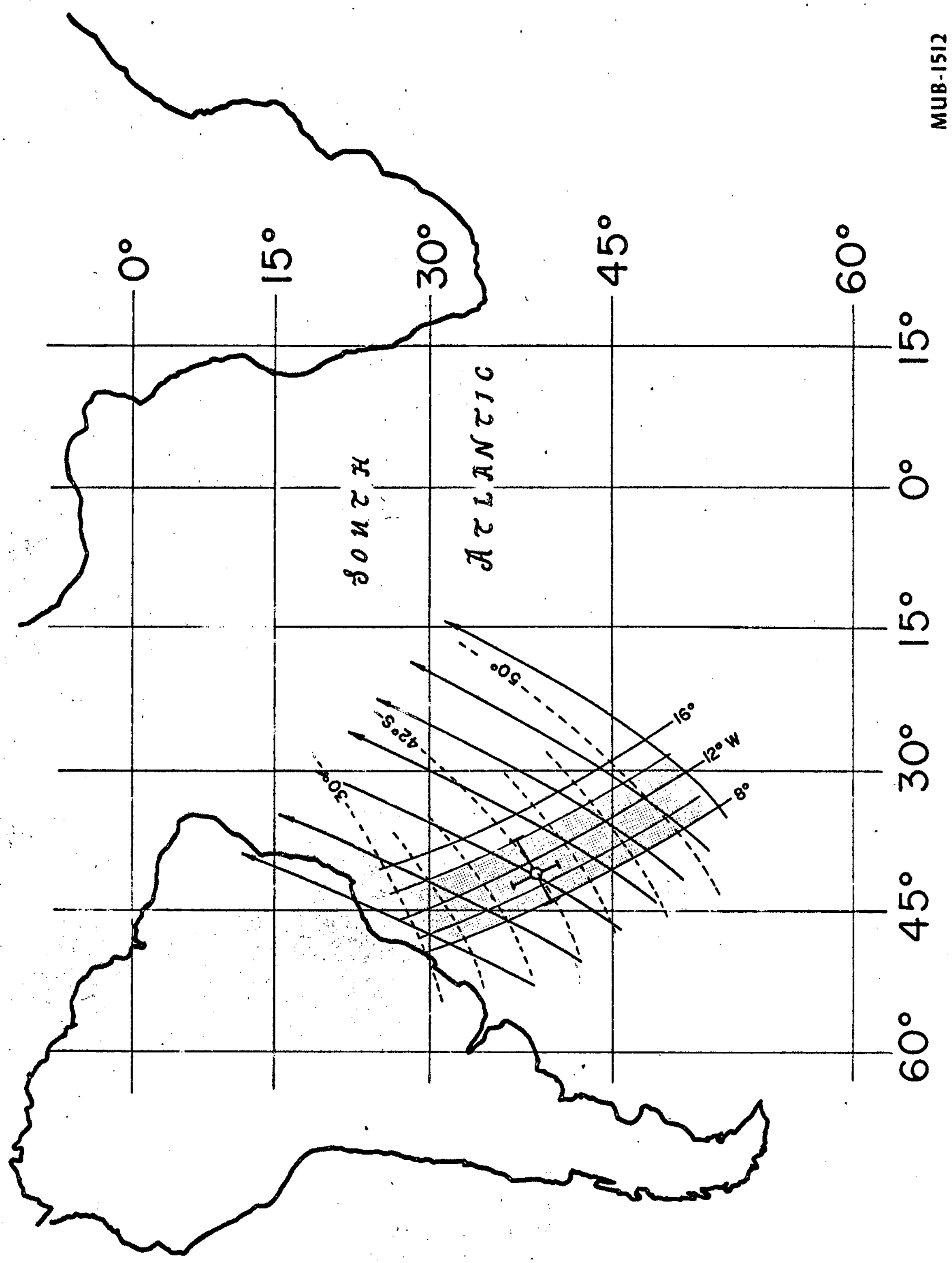
0°
15°
30°
45°
60°
15°
0°
15°
30°
45°
60°
SOUTH
ATLANTIC
50°
42°S
30°
16°
12°W
8°
MUB-1512

Fig. 2.