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Distribution of Trapped Particles at an Altitude of 900-km near the South Atlantic Geomagnetic Anomaly

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ABSTRACT

Energetic particle responses on x-ray photometers from the NRL 1964-O1-D Satellite experiment have been analyzed in order to describe the zone where this effect is observed in the Southern Hemisphere. The particles are identified as protons from the inner Van Allen belt, and their flux is determined approximately by using data recorded at Lima, Peru. A description of the particle signals and their geographic distribution in the South Atlantic geomagnetic anomaly is presented. Contours are established for constant fluxes of 10^3, 2.2×10^3, and 2.7×10^3 protons/cm^2 sec, and a discussion concerning their peculiarities near the orbital altitude of 900 km is presented.

PROBLEM STATUS

This report is on one phase of a continuing problem.

AUTHORIZATION

NRL Problem A01-20.301
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DISTRIBUTION OF TRAPPED PARTICLES AT AN ALTITUDE OF 900 Km NEAR THE SOUTH ATLANTIC GEOMAGNETIC ANOMALY

INTRODUCTION AND DESCRIPTION OF THE DATA

This report has been written following a suggestion from one of the authors (Robert W. Kreplin), who made available data from 1964-01-D Satellite passes over Lima, Peru. Interest in particle interferences over the South American continent arose from the investigation of São Paulo, Brazil, as a suitable site for an x-ray monitoring station. The results in this sense were negative; however a broad picture of the region was drawn, together with approximate values of particle fluxes.

It has been noted by Acton and others (1) and by Kreplin (2) that one of the main interference effects experienced by the NRL Solar Radiation Monitoring Satellite is caused by high-energy trapped particles found at some regions crossed by the satellite. Although its x-ray photometers were shielded against the detection of electrons with energies up to 1.0 MeV, this protection proved to be ineffective, especially in two zones, (a) in the horns of the Van Allen belts, and (b) over the South American continent.

A qualitative analysis of these zones where higher fluxes of particles are present was conducted by Hook and Parthasarathy (3). However, they considered only the interference in northern latitudes. The strong interferences in the southern hemisphere—verified on Lima and Quito records—were noted, but no analysis was made.

The data available for this study consisted of 16 records from the Lima Station of the NASA STADAN network. In these records particle interferences are clearly observed on the satellite's x-ray detectors. Eight other records from February were also used for characterizing the effects.

The satellite's orbit had a varying altitude from 915 km over the region of interest, giving an area of "visibility" for the Lima tracking antennas consisting of a circle with a radius of about 3000 km, and a maximum pass time of 15 min.

Kreplin (2) presented various examples of records illustrating particle interferences on the x-ray detectors. At northern latitudes the region of interference was localized around McIlwain coordinates $L = 4.5\ R_e$ and $B = 0.39$ gauss, and it was suggested that electrons from the outer Van Allen belts were responsible for the effect. Further, it was observed that the particle responses have a frequency which is twice the spin frequency of the satellite. This observation is understood to be due to the anisotropic distribution of high-energy electrons near their mirror points in the geomagnetic field. Concerning the intensity of the interferences, the records obtained at College, Alaska, showed that the particle fluxes seldom produced photometer currents capable of driving the electrometer amplifiers into saturation, but in the Lima records saturated signals were normally present for prolonged periods.

Analyzing the x-ray detector response to charged particles constitutes a rather complex problem, since they were not designed for this purpose and no calibrations were made with particle excitation. The x-ray photometers normally produce signals of the order of 10^{-12} to 10^{-11} ampere under excitation by Van Allen belt particles or by solar x-rays. It has been observed that a modulation of this current can be produced by the earth's magnetic field, but the effect is small and can be neglected in the present work.

As the satellite spins within a region in which particle interference is experienced, one observes a "roll modulation" of the photometer current as mentioned by Acton and others (1) and by Kreplin (4). The character of the modulated signal depends on the orientation of the spin axis with respect to the magnetic field as well as particle species, energy, and pitch-angle distribution.

Figure 1 shows three typical sample records where the photometers experienced particle interference. Detailed examinations of these records permit a classification of the sources of particle interference in the South Atlantic anomaly in the following categories:

1. Simple roll modulation of the particle flux, probably due to shielding of the photometer by the satellite structure in the region where particle velocities are somewhat nonisotropic.

2. Double frequency roll modulation of the particle flux, due to detection of trapped particles near their mirror points.

The sudden changes in signal level from saturation to on-scale values are due to the characteristics of the feedback circuit (5) of the electrometer amplifiers under conditions of signal saturation.

With either type 1 or 2 modulation, the electrometer is usually driven into a saturated condition as the satellite passes through the anomaly. These "particle" signals can be attributed to proton fluxes from the inner Van Allen belt. The shape of the modulation appearing in the particle signal depends on the pitch-angle distribution of the charged particles and on the relation of the spin axis to the magnetic field vector as the satellite moves along its orbital trajectory.

This report is mainly concerned with a determination of the order of magnitude of proton fluxes and their distribution in terms of McIlwain coordinates in the region of the South Atlantic anomaly.

RESPONSE OF X-RAY PHOTOMETERS TO PROTON FLUXES

Satellite NRL 1964-01-D carried photometers for the x-ray regions 44 to 60 Å, 2 to 8 Å and 8 to 14 Å. Their characteristics were fully described by Kreplin and others (6), Chubb and others (7) and by Kreplin (2). No data on their response for particles was published—but a recent private communication by Kreplin (8) on some measurements made with the photometers exposed to monoenergetic fluxes of electrons in a Van de Graaff accelerator permitted rough calculations of their expected response to high-energy proton fluxes. The method used to calculate the particle responses is presented in the Appendix. Figure 2 shows the response of the Mylar (44 to 60 Å) and beryllium (2 to 8 Å) detectors to 1-MeV protons. The laboratory data on the aluminum window photometer (8 to 14 Å) was not adequate for such a calculation, and therefore its response to protons is not considered here.

Finally, it must be understood that the quantitative data presented below refer to proton fluxes with energies E greater than 1 MeV and less than 10 MeV, since ion production is not appreciable for higher energy particles, as is shown in the Appendix.

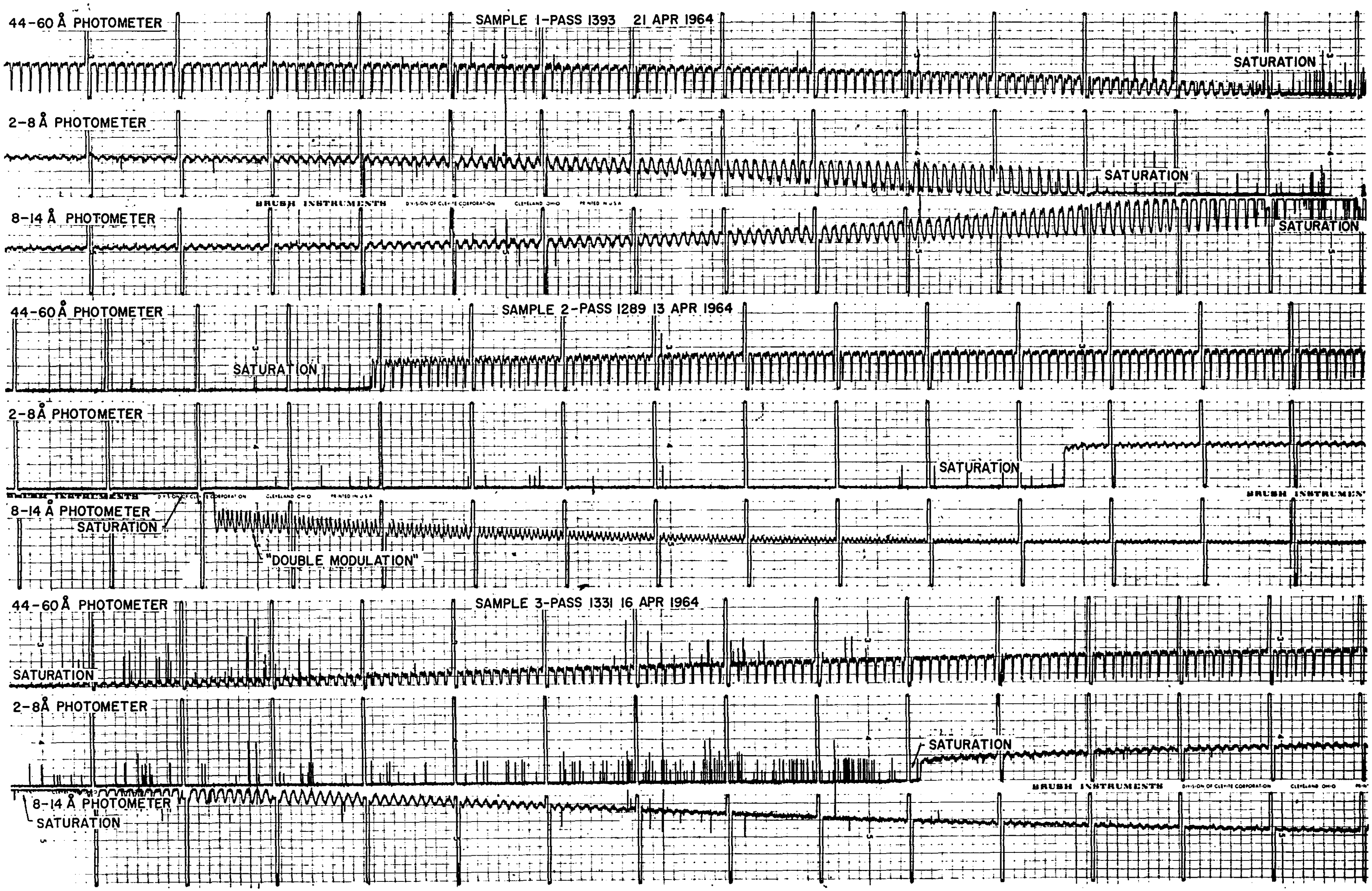

Fig. 1 - Three examples of typical particle interference experienced by the x-ray photometers. Sample 1 shows the type 1 interference mentioned in the text. It is the most frequently observed particle signal. Sample 2 illustrates the abrupt return of the saturated signal to normal on-scale operation. Also illustrated is the type 2 interference mentioned in the text. Sample 3 shows a type 1 interference, with "roll modulation" appearing only very near saturation. The peaks observed on the 44 to 60 Å channel are due to solar x-ray radiation. Time increases from left to right.

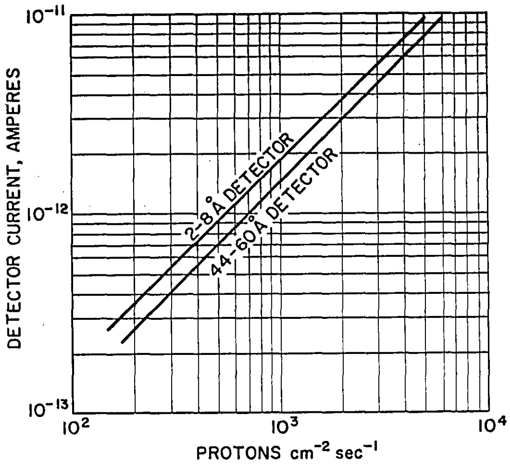

Fig. 2 - The response of the 2 to 8 Å and 44 to 60 Å photometer to proton fluxes

DISCUSSION OF THE REDUCED DATA

The electrometer amplifiers used with the x-ray photometers saturate when the input current exceeds 4×10^{-12} ampere. This corresponds to a flux of 2.7×10^3 protons/cm^2 sec for the 44 to 60 Å detector, and to 2.2×10^3 protons/cm^2 sec for the 2 to 8 Å detector. Points of saturation for each pass were joined to form a contour line, and the results are shown in Fig. 3 (44 to 60 Å) and Fig. 4 (2 to 8 Å). These contours were derived from 16 passes acquired during April 1964.

The most important considerations concern the main contour trace (i.e., when the satellite's detectors are brought into saturation). Very often, satellite tracking started or ended when the photometers were still suffering particle interferences. This was especially true for the southern limit of the contour. Consequently, it is not well defined. On the other hand, the northern boundary was very well established.

The main contour points are located at McIlwain coordinates (Ref. 9) B = 0.20 to 0.22 gauss and L = 1.2 to 1.5 R_e. It can be stated immediately that in the region of the center of the South Atlantic geomagnetic anomaly, where $B < 0.20$ gauss and $1.4 \geq L \geq 1.2\ R_e$, proton fluxes surely are greater than 2.7×10^3 protons/cm^2 sec.

The values found here are in rather good agreement with observations made by Pieper and others (10). At $L \approx 1.2\ R_e$ and $0.17 \leq B \leq 0.19$ gauss, they found omnidirectional fluxes of the order of 10^3 protons/cm^2 sec with energy $1 \leq E \leq 15$ MeV.

It can be noticed that the contour lines have a similar shape for both detectors. They surround the geomagnetic anomaly but do not follow the constant-B line as calculated by Roederer and others (9) for a 900-km altitude. The dashed contour running roughly parallel to the saturation contour in Figs. 3 and 4 represents a flux level of 10^3 protons/cm^2 sec.

CONCLUSIONS

Although the 1964-O1D experiment was not designed to study the distribution of trapped particles, it has been possible to derive some interesting information concerning protons found at an altitude of about 900 km in the southern hemisphere. Definitely, it can be concluded that solar x-ray monitoring is not possible from tracking stations situated inside the South Atlantic geomagnetic anomaly. The inner proton belt is observed at low altitudes in this region, and strong interfering fluxes will be experienced at 900 km wherever $B \approx 0.20$ gauss and L lies between 1.2 R_e and 1.4 R_e.

In the middle of the South Atlantic geomagnetic anomaly, the proton fluxes should be higher as has been confirmed by Fillius (11). He indicates that at 900 km over São Paulo where B = 0.165 gauss and L = 1.29 R_e, a flux of 5×10^4 protons/cm^2 sec, in the range of 4 to 13 MeV, can be expected. These estimates are based on the Explorer XV experiment.

The constant-flux contours found for 10^3, 2.2×10^3, and 2.7×10^3 protons/cm^2 sec have a very similar shape. However, they don't follow exactly the calculated constant-B

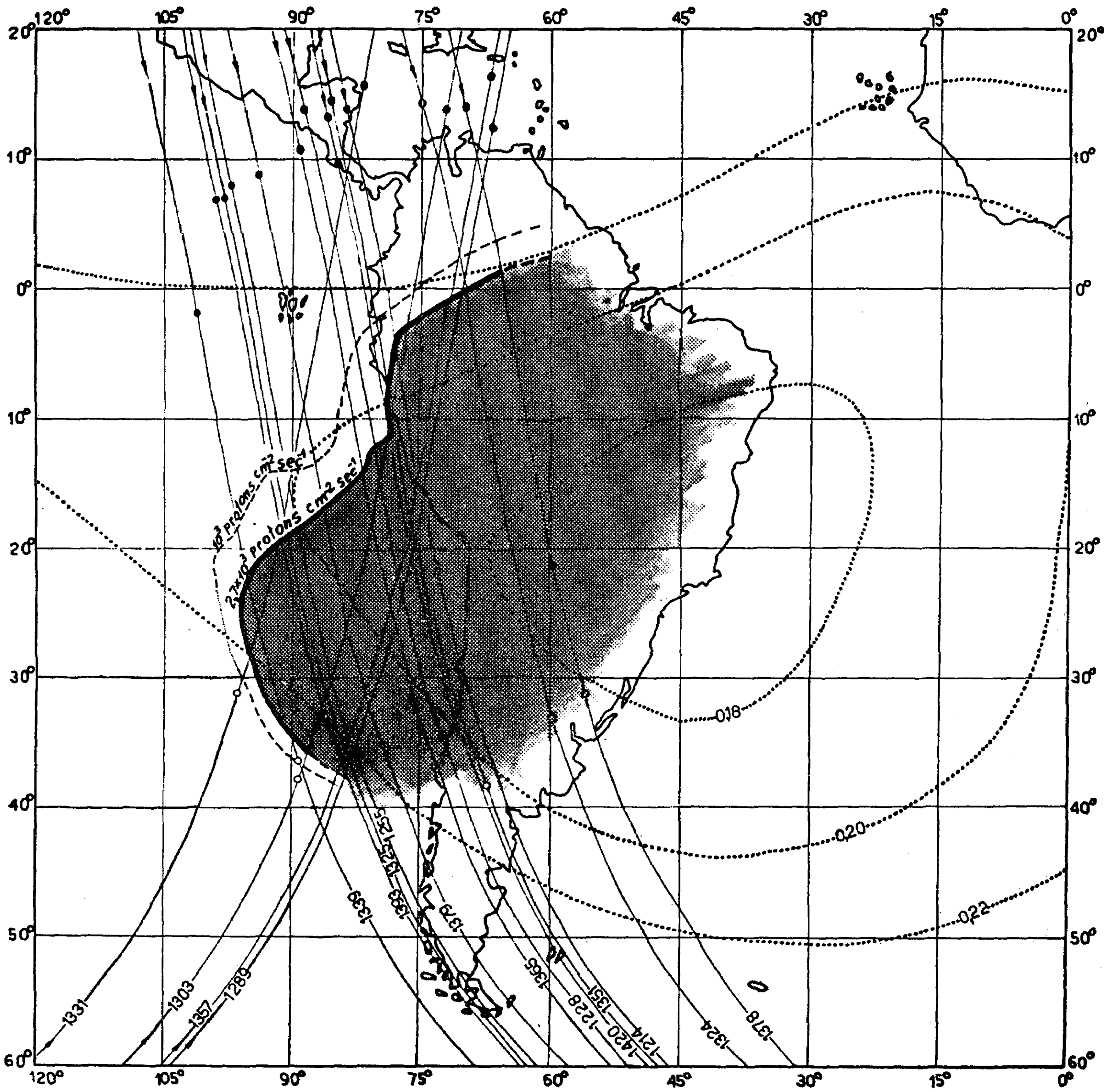

Fig. 3 - A description of the zone of proton interference as determined from 44 to 60 Å photometer response. The passes used to construct this contour are designated by the orbit numbers. The dashed contour represents a flux of 10^3 protons/cm^2 sec and the full line a flux of 2.7×10^3 protons/cm^2 sec. Calculated contours of constant B are also shown.

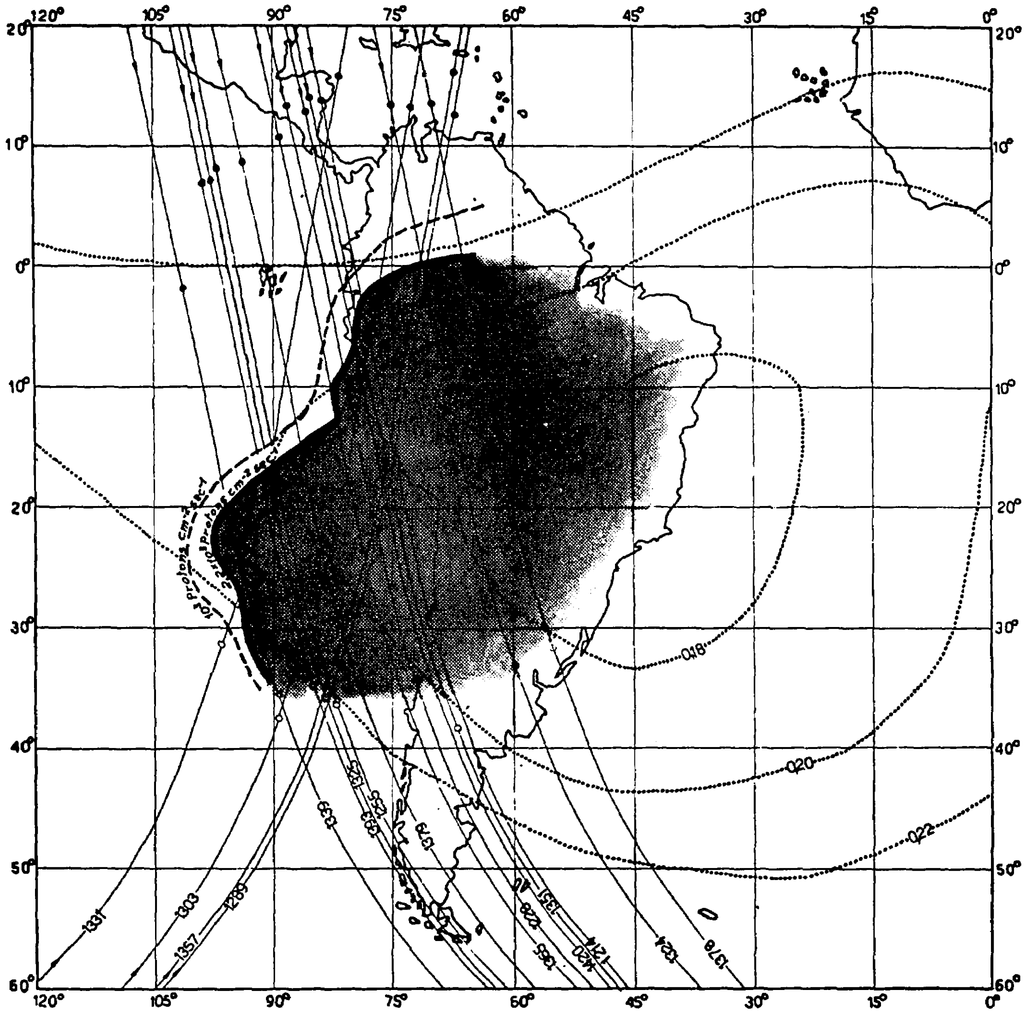

Fig. 4 - A description of the zone of proton interference as determined from the 2 to 8 Å photometer response. The dashed line represents a flux of 10^3 protons/cm^2 sec, and the full line indicates a flux of 2.2×10^3 protons cm^2 sec.

contours. This suggests that over this region of the earth irregularities in the geomagnetic field influence the shape of the trapped particle zone. On the other hand, it is of interest to observe that the contours follow approximately a contour of constant elevation lying on the earth's geoid in relation to its theoretical ellipsoidal form, as determined by Kaula (12). This would mean that, apart from the dependence on geographic distribution of deposits of ferromagnetic materials, the anomalies in the earth's form have possibly a noticeable influence on the constant-B contours, at a given altitude.

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Appendix

CALCULATION OF CONVERSION FACTOR FOR PROTON RESPONSE

From the data received in Kreplin's private communication, a conversion factor for proton detection was calculated, based on the detector's geometry and window materials, and on laboratory calibrations for electrons performed at NRL.

If a flux ϕ of monoenergetic electrons with energy E penetrates an ion chamber through a window of area ΔS, then the number of electrons N entering the volume of the chamber per unit time will be

$$N = \phi \, \Delta S \ . \tag{1}$$

One electron with energy E can produce n_0 ion pairs after penetrating a length Δl in a given medium; thus

$$n_0 = k_t(E) \, \Delta l \ , \tag{2}$$

where $k_t(E)$ is the number of ion pairs produced per unit length of path. The total number of ion pairs produced n can be expressed as

$$n = \phi \, \Delta S \, k_t(E) \, \Delta l \ . \tag{3}$$

Assuming the existence of a direct proportionality between the current collected and the number of ion pairs produced, the current I can be expressed by the relation

$$I = \epsilon K n = \epsilon K \phi \Delta S \, k_t(E) \, \Delta l \ , \tag{4}$$

where ϵ is the ion-collection efficiency (assumed to be unity as a first approximation) and K is a proportionality coefficient. From Eq. (4) it is possible to determine the proportionality coefficient, but actually the product $K \Delta S \Delta l$ is obtained, since ΔS and Δl are characteristics derived from the geometry of the ion chamber.

For the 44 to 60 Å photometer (Mylar window, filled with nitrogen at 400 mm Hg), fluxes of 1.0 MeV electrons of 6.8×10^8 electrons/cm^2 sec produced a current of 1.3×10^{-8} ampere. Following Whaling (A1), $k_t(E) \approx 50$ for nitrogen at the specified pressure for electrons of this energy range; thus,

$$K \Delta S \Delta l = 1/[\phi \, k_t(E)] \approx 4.3 \times 10^{-19} \text{ amp cm}^3 \text{ sec} \ .$$

For other energy ranges this figure varies somewhat, but not more than one order of magnitude. Considering that the measurements performed with the Van de Graaff accelerator contained uncertainties perhaps as large as 50%, the following value was adopted:

$$K \Delta S \Delta l = 3 \times 10^{-19} \text{ amp cm}^3 \text{ sec} \ .$$

Using this proportionality coefficient, an expression for the current response for monoenergetic fluxes of protons can be written in the same form as Eq. (4);

$$I_p = 3 \times 10^{-19} [k_t(E)]_p \, \phi_p$$

The ion production coefficients $k_t(E)$ for electrons and $[k_t(E)]_p$ for protons, at various energies for nitrogen and argon were derived from Whaling (A1), the "American Institute of Physics Handbook" (A2) and Glendenin (A3). The results of these calculations are plotted in Fig. 2.

One final important observation concerns the decrease in production rates with increasing proton energies. By calculating the ratio M defined by the equation:

$$M = \frac{[k_t(E)]_{1\ \mathrm{MeV}}}{[k_t(E)]_{E\ \mathrm{MeV}}} = \frac{\text{number of ions pairs produced by 1 MeV protons}}{\text{number of ions pairs produced by } E \text{ MeV protons}}$$

These calculated results, tabulated below, show quantitatively that the contour data presented in this study refer to protons with energies between 1 and 10 MeV, since the ion production by protons with $E > 10$ MeV can be neglected.

E	M (44-60 Å)	M (2-8 Å)
5 MeV	3	2
10 MeV	5.5	3
20 MeV	10	6

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