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EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

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Data from an Aerobee rocket carrying a payload consisting of three large area Geiger counters have revealed a considerable flux of radiation in the night sky that has been identified as consisting of soft x rays.

The entrance aperture of each Geiger counter consisted of seven individual mica windows comprising 20 cm^2 of area placed into one face of the counter. Two of the counters had windows of about 0.2-mil mica, and one counter had windows of 1.0-mil mica. The sensitivity of these detectors for x rays was between 2 and 8 Å, falling sharply at the extremes due to the transmission of the filling gas and the opacity of the windows, respectively. The mica was coated with lampblack to prevent ultraviolet light transmission. The three detectors were disposed symmetrically around the longitudinal axis of the rocket, the normal to each detector making an angle of 55° to that axis. Thus, during flight, the normal to the detectors swept through the sky, at a rate determined by the rotation of the rocket, forming a cone of 55° with respect to the longitudinal axis. No mechanical collimation was used to limit the field of view of the detectors. Also included in the payload was an optical aspect system similar to one developed by Kupperian and Kreplin.[1] The axes of the optical sensors were normal to the longitudinal axis of the rocket. Each Geiger counter was placed in a well formed by an anticoincidence scintillation counter designed to reduce the cosmic-ray background. The experiment was intended to study fluorescence x rays produced on the lunar surface by x rays from the sun and to explore the night sky for other possible sources. On the basis of the known flux of solar x rays, we had estimated a flux from the moon of about 0.1 to 1 photon $\text{cm}^{-2}\ \text{sec}^{-1}$ in the region of sensitivity of the counter.

The rocket launching took place at the White Sands Missile Range, New Mexico, at 2359 MST on June 18, 1962. The moon was one day past full and was in the sky about 20° east of south and 35° above the horizon. The rocket reached a maximum altitude of 225 km and was above 80 km for a total of 350 seconds. The vehicle traveled almost due north for a distance of 120 km. Two of the Geiger counters functioned properly during the flight; the third counter apparently arced sporadically and was disregarded in the analysis. The optical aspect system functioned correctly. The rocket was spinning at 2.0 rps around the longitudinal axis. From the optical sensor data it is known that the spin axis of the rocket did not deviate from the vertical by more than 3°; for purposes of analysis, the spin axis is taken as pointing to zenith. The angle of rotation of the rocket corresponds with the azimuth

Φ and is measured from north as zero and increasing to the east. The data were reduced by using the optical aspect information to determine the azimuth as a function of time. Each complete rotation of the rocket was divided into sixty equal intervals, and the number of counts in each of these intervals was recorded separately.

The total data accumulated in this manner during the entire flight are shown in Fig. 1 for the operating Geiger counters. The observed region of the sky is shown in Fig. 2. The counting rates show an altitude dependence on both the ascending and descending portions of the flight. These are shown in Fig. 3, the numbers representing three-second sums. The rocket had begun tumbling during descent. The data in that portion of the flight are difficult to interpret and have not been included in the analysis.

The residual cosmic-ray background could not be determined directly. However, the strong angular dependence of the counting rate and the large difference between the counting rates of the counters provided with windows of different thickness clearly show that most of the recorded counts are due to a strongly anisotropic and very soft radiation. Thus, the possible existence of a small cosmic-ray effect is not an essential element in the discussion of the results.

The large peak that appears at about 195° in both counters shows that part of the recorded radiation is in the form of a well collimated beam. The fact that the counting rate does not go to zero on either side of the peak shows that this beam is superimposed on a diffuse background radiation. The background radiation itself is not isotropic, but appears to have a higher intensity in directions to the east of the peak than in the direction to the west of the peak, suggesting a secondary maximum centered around 60°. The statistical significance of this conclusion may be evaluated by comparing the total number of counts recorded by counter No. 2 in an angular interval east of the maximum (from $\Phi = 102°$ to $\Phi = 18°$) with that recorded in an equivalent angular interval west of the maximum ($\Phi = 282°$ to

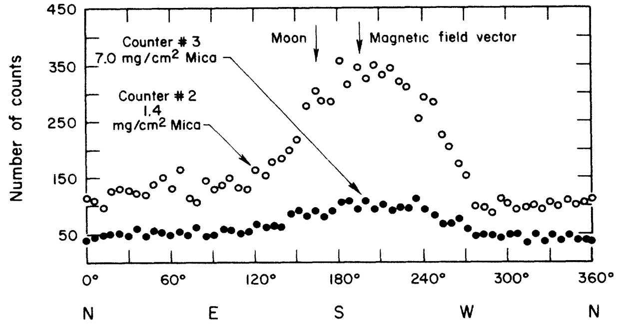

FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

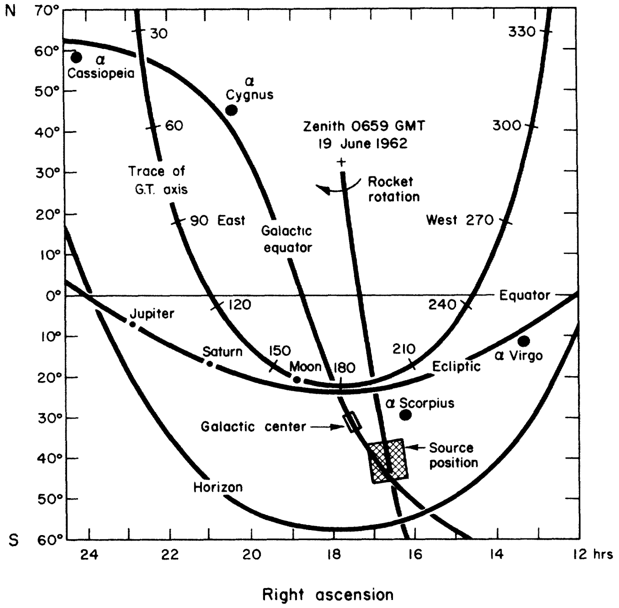

FIG. 2. Chart showing the portion of sky explored by the counters.

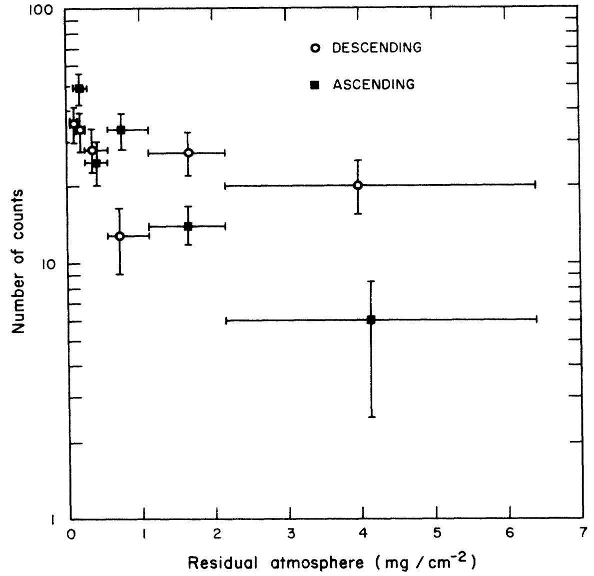

FIG. 3. Counting rate versus residual atmosphere. The numbers represent counts accumulated in counter No. 2 in three-second intervals for azimuth angles from 102° to 282°.

$\Phi = 6°$). The two numbers are 2005 and 1582, respectively, yielding a difference of 423 ± 60 counts. A similar excess, although statistically less significant, appears in counter No. 3 and is 90 ± 40 counts.

At the location where the measurements were obtained, the magnetic field has an inclination of 63° and a declination of 13° east of north. Thus, the field lines are at an azimuth of 193°, which is about the same as the azimuth of the observed radiation peak. This coincidence makes one wonder whether the radiation might not consist of charged particles spiraling along the field lines. On the basis of the minimum energy necessary for the penetration of the thin- and thick-window counters, the radiation would have to consist of electrons with energies of the order of several tens of keV, or protons with energies of the order of one MeV. On the other hand, it would be unlikely that protons form the main component of the observed radiation, considering that they must possess a much higher energy than electrons in order to penetrate the windows. In any event, both protons and electrons are strongly deflected by the earth's magnetic field and must exhibit axial symmetry with respect to the magnetic field; i.e., at a given pitch angle the flux of particles must be independent of azimuth around the field. The magnetic field makes an angle of 27° with the spin axis of the rocket and the detector axis makes an angle of 55° with the spin axis. Hence, particles moving with pitch angles between 28° and 82° would be normal to the detector axis at two different roll angles and would tend to give a double peaked distribution of counts. Particles with a 90° pitch angle would be detected with maximum efficiency from the north. Thus, the sharpness and azimuth of the observed peak requires that the pitch angles of these particles be very small. It is hard to find a resonable source for particles with the required small pitch angles at the location of our measurements. In particular, particles spilling out of the inner radiation belt ought to have a broad pitch-angle distribution. One may add that it is not easy to account for the sharpness of the observed peak even under the extreme assumption that all particles had a zero pitch angle, i.e., came as a parallel beam in the direction of the field lines. The shape of the peak depends on the absorption curve of this radiation. The curve in Fig. 4 represents the counting rate as a function of roll angle for a beam of particles with zero pitch angle computed under the assumption of an exponential absorption, with an absorption coefficient consistent with the relative responses of the thick-window and thin-window counters. The observed angular dependence is not consistent with the calculated curve, and it is difficult to ascribe the discrepancy to the arbitrary assumption of an exponential absorption. Moreover, it is clear that the presence of particles with finite pitch angles would broaden the predicted distribution.

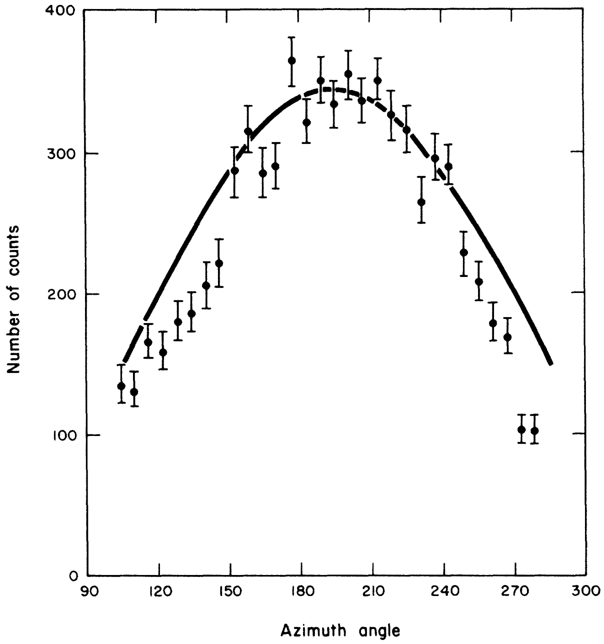

FIG. 4. Comparison of experimental results with the computed angular dependence for a unidirectional beam of electrons exhibiting exponential absorption in the counter window.

It is also clear that the radiation responsible for the asymmetry of the background cannot consist of charged particles. Thus, we conclude that the bulk of the observed radiation is not corpuscular, but electromagnetic in nature.

The counters were so constructed as to be insensitive to visible or ultraviolet light. The data themselves provide a definite test on this point since a strong visible light source, the moon, and two comparatively strong ultraviolet light sources, Virgo and presumably the moon, went through the field of view of the counters, and yet were not detected. Thus, if the radiation is electromagnetic, it must consist of soft x rays.

Consider first the radiation responsible for the peak and assume that it originates from a point source, and that it is monochromatic with a wavelength λ. The difference in counting rates observed in the two counters with the two different mica windows depends on the absorption coefficient $\mu_{\text{mica}}(\lambda)$ for the given radiation and on the minimum angle θ formed during the rotation of the rocket by the normal to each counter with the direction of the source. The experimental data give the product $\mu_{\text{mica}}(\lambda)\sec\theta$. The variation of the counting rate with altitude depends on the absorption coefficient $\mu_{\text{air}}(\lambda)$ for the given radiation and on the angle ψ between the horizon and the source (ψ and θ are related by a numerical constant), and yields the product $\mu_{\text{air}}(\lambda)\sec\psi$. By comparing these two pieces of information it is possible to determine values of λ and ψ for which both relations are satisfied. One obtains a λ of about 3 Å and a ψ of about 10°.

The shape of the peak also depends on $\mu_{\text{mica}}(\lambda)$ and ψ. Use of the previously determined λ, under the assumption of a point source, allows a semi-independent determination of ψ which yields a value of 20°. The difference between the two values of ψ can be accounted for by a source width of approximately 10°. Thus, the peak appears to be due to a source emitting x rays of a 3Å wavelength whose origin is about 10° above the horizon. The location of this source is shown as "source position" on the sky map in Fig. 2. The measured flux from this source is 5.0 photons $\text{cm}^{-2}\ \text{sec}^{-1}$

The diffuse character of the observed background radiation does not permit a positive determination of its nature and origin. However, the apparent absorption coefficient in mica and the altitude dependence is consistent with radiation of about the same wavelength as that responsible for the peak. Assuming the source lies close to the axis of the detectors, one obtains the intensity of the x-ray background as 1.7 photons $\text{cm}^{-2}\ \text{sec}^{-1}\ \text{sr}^{-1}$ and of the secondary maximum (between 102° and 18°) as 0.6 photon $\text{cm}^{-2}\ \text{sec}^{-1}$. In addition, there seems to be a hard component to the background of about 0.5 $\text{cm}^{-2}\ \text{sec}^{-1}\ \text{sr}^{-1}$ which does not show an altitude dependence and which is not eliminated by the anticoincidence.

The question arises whether the source of the observed x radiation could be associated with the earth's atmosphere and ascribed to some form of auroral activity. The rarity of occurrence of auroras of the magnitude required to account for the observed intensities at the latitude of the measurement makes this possibility very unlikely.

In addition, the following comments are apropos. The bulk of the measurements were obtained between altitudes of 100 to 225 km and over a range of distances from the firing point of the rocket of 15 to 100 km. The variation of the measured intensity within these limits is consistent with a source at infinity. A lower limit on the position of the source places it at a distance greater than 1000 km. This number, combined with the measured elevation angle of 10°, places a lower limit on the altitude of the source which is about 400 km above the earth's surface. Auroral electrons of energy sufficient to produce the observed radiation would, on the other hand, penetrate down to an altitude of about 100 km and would expend the bulk of their energy at altitudes lower than 200 km. We conclude that the hypothesis of an auroral source for the observed radiation is not consistent with the data.

From Fig. 2, showing the locations of the source as well as of the moon and planets, it is clear that the observed source does not coincide with any obvious scattering body belonging to our solar system. Further, the intensity of solar x radiation at the observed wavelength is much too low in this period of the solar cycle to account for the observed intensities of the peak or of the background on the basis of back-scattered solar radiation. It would thus appear that the radiation does not originate in our solar system.

From Fig. 2 we see that the main apparent source is in the vicinity of the galactic center at a G.T. azimuthal angle of about 195°. We also see that the trace of the G.T. axis lies close to the galactic equator for a value of the azimuthal angle near 40°, which is the region where the background radiation is recorded with greater intensity. This apparent maximum of the background radiation is the general region of the sky where two peculiar objects—Cassiopeia *A* and Cygnus *A*—are located. It is perhaps significant that both the center of the galaxy where the main apparent source of x rays lies, and the region of Cassiopeia *A* and Cygnus *A* where there appears to be a secondary x-ray source, are also regions of strong radio emission. Clark[2] has pointed out that the probable mechanism for the production of the nonthermal component of the radio noise, namely, synchrotron radiation from cosmic electrons in the galactic magnetic fields, can also give rise to the x rays we observe.

In the cosmic-ray air shower experiment presently being carried out in Bolivia,[3] tentative evidence has been obtained for the existence of cosmic γ rays in the energy region of 10^{14} eV at a rate of 10^{-3}-10^{-4} of the charged cosmic-ray flux at the same energy with an indication of enhanced emission in the galactic plane. Clark has shown that cosmic electrons must be produced along with

γ-rays by the decay of mesons that arise in the interactions of cosmic rays with interstellar matter. Since electrons at these energies lose their energy predominantly via synchrotron radiation in the galactic magnetic field, one should observe roughly the same total energy in synchrotron radiation at the earth as in γ-ray energy. For electrons of 2×10^{14} eV in a field of 3×10^{-6} gauss, the peak of the synchrotron emission is at 3 Å; in a stronger field this will happen at lower electron energies. It has been shown[4] that x rays in this wavelength region are not appreciably absorbed over interstellar distances.

With this one experiment it is impossible to completely define the nature and origin of the radiation we have observed. Even though the statistical precision of the measurement is high, the numerical values for the derived quantities and angles are subject to large variation depending on the choice of assumptions. However, we believe that the data can best be explained by identifying the bulk of the radiation as soft x rays from sources outside the solar system. Synchrotron radiation by cosmic electrons is a possible mechanism for the production of these x rays. Ordinary stellar sources could also contribute a considerable fraction of the observed radiation.

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[1] J. E. Kupperian and R. W. Kreplin, Rev. Sci. Instr. 28, 19 (1957).

[2] G. W. Clark (to be published).

[3] Joint Program, MIT, University of Tokyo, University of Michigan, and University at La Paz. The MIT Cosmic Ray Group has graciously made available to us the preliminary results of the air shower experiment. We have also profited considerably from discussions with Professor M. Oda of the University of Tokyo and with Professor G. W. Clark of MIT.

[4] S. E. Strom and K. M. Strom, Publs. Astron. Soc. Pacific 73, 43 (1961).

STRONG ACOUSTOELECTRIC EFFECT IN CdS

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When a sinusoidal acoustic wave propagates through a semiconductor, it gives rise to an ac electric field traveling through the crystal with the velocity of the acoustic wave. A dc field, under the action of the traveling ac field, is generated across the crystal while the wave traverses the crystal. This was defined as an acoustoelectric effect by R. H. Parmenter.[1] We have observed the effect in CdS.

The dc acoustoelectric field generated in CdS is about six orders of magnitude larger than that in n-type germanium crystals,[2,3] because an ac field much larger than that due to the deformation potential is produced in CdS by piezoelectric coupling with the acoustic wave. Illumination and dc voltage applied to a CdS crystal affect the magnitude and polarity of the observed acoustoelectric voltage across the crystal. This will be explained by consideration of acoustic-wave amplification in the crystal.[4]

A shear-wave piezoelectric amplifier was built in the configuration described by Hutson, McFee, and White.[4] Fused quartz buffers one-inch long provided time delay and electrical insulation between the ferroelectric ceramic transducers and the CdS crystal. The crystal, obtained from the Eagle-Picher Co. with a dark resistivity of 10^7 ohm-cm, was oriented for k_{15} electromechanical coupling, and cut to the dimensions 0.2 cm^2 by 0.3 cm. Pulsed rf signals applied to the input transducer at 33 Mc/sec were used to generate the applied acoustic waves. Control of the crystal conductivity was provided by varying the intensity of a mercury vapor lamp.

First we will consider the case with no external dc field applied. Under the assumption of the conservation of momentum, Weinreich[5] has derived a relationship between the absorption coefficient of acoustic waves and the acoustoelectric field[6]:

$$\alpha = \delta n e V_s E_{\mathrm{ae}} / Q, \qquad (1)$$