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II-4-26. Solar Diurnal Variation of Cosmic Rays Underground Near the Geomagnetic Equator*

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In an earlier experiment[1] it was shown that the vertical flux of mu-mesons at a depth of 30 meters water quivalent has a 24-hr. diurnal variation with an amplitude of about 0.3% and with a maximum at about 15^h mean solar time. This work was done in 1959 at Chacaltaya Laboratory** in Bolivia.

In 1960 and 1961, two large transistorized plastic-scintillator telescopes were operated at the same place. One of these was inclined toward the east, the other toward the west, for the purpose of checking upon the terrestrial or extraterrestrial origin of the diurnal variation. As a result of the earth's rotation, an extraterrestrial anisotropy of the cosmic-ray flux would cause the maximum of the diurnal variation to come at an earlier time in the east-pointing telescope, and at a later time in the west-pointing telescope. Fig. 1 shows the geometry of the location. Due to the slope of the ground, the two telescopes gave equal counts of about 5000 counts per hour at zenith angles of 28° for the east-pointing telescope and 62° for the west-pointing telescopes, respectively. The equivalent depth below the top of the atmosphere amounts to 40 meters of water for the east telescope, and somewhat less for the west telescope. The average energy of the primaries which cause our counting rate is estimated to be on the order of 200 BeV; it is smaller for the west telescope in relation to that of the east telescope because the counting rates in the two telescopes is equal in spite of the additional loss of mu-mesons by decay at the larger zenith angle of the west telescope. At a primary energy of 100 BeV, the deflection in the earth's magnetic field is only about 10°. Thus, the time of maximum of the diurnal variation can be expected to correspond quite well to the time at which the telescopes face the direction of the increased flux in the primary cosmic radiation, if indeed the diurnal variation is the result of an extraterrestrial anisotropy.

Since the vertical telescope furnished a maximum at 15^h, the east-pointing telescope should give a maximum at about 13^h, and the west-pointing telescope should show it at about 19^h. The amplitudes of the diurnal vari-

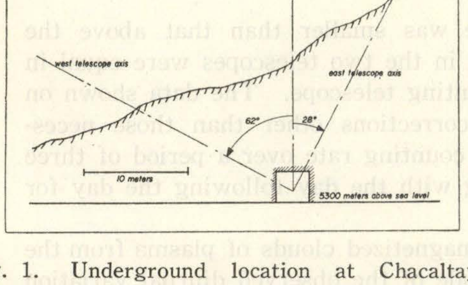

Fig. 1. Underground location at Chacaltaya Observatory.

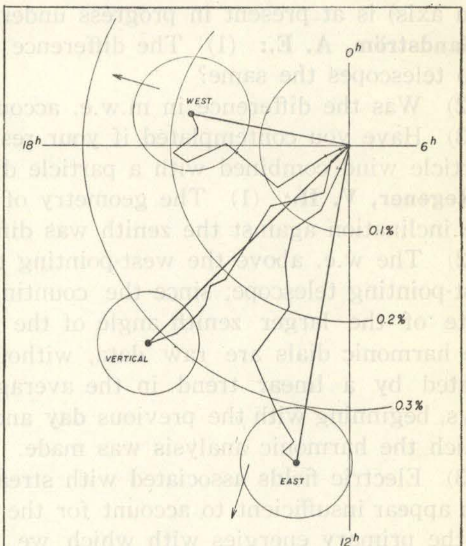

Fig. 2. Harmonic dial of the 24-hr diurnal variation of cosmic rays underground at Chacaltaya.

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** Elevation 5300 meters, geomagnetic latitude −3.6°.

ations should be the same in the three telescopes, except for a possible dependence of the anisotropy upon the energy of the primaries.

Fig. 2 is a harmonic dial which shows the diurnal variations as measured by the three telescopes. The vertical telescope gives an amplitude of $(0.32\pm0.06)\%$ with a maximum at 15^h; the east-pointing telescope gives an amplitude of $(0.36\pm0.06)\%$. at $12^h\ 38^m$, the west-pointing telescope gives an amplitude of $(0.18\pm0.06)\%$ at $18^h\ 48^m$. The times of occurrence of the maxima are in agreement with what one would expect for an extraterrestrial anisotropy. Fig. 2 shows, by means of two arrows, the times at which the maxima in the east and west telescopes are expected, based upon the time of the maximum in the earlier, vertical, experiment. The average vectors for the diurnal variation are shown with standard error circles obtained from the scatter of the harmonic coefficients evaluated for each day.

The vertical data were obtained during 110 days. Ten measurement periods of 11 days each are shown on a reduced scale in the manner of a summation dial, to indicate the consistency with which the average vector was arrived at. The east and west data were obtained during 140 days, and ten measurement periods of 14 days each are shown in a similar manner. No pressure or temperature corrections were applied.

Elliot[2] has proposed a model which might account for this diurnal variation in terms of a mechanism which modulates the galactic cosmic-ray flux by means of a general dipole-like interplanetary magnetic field. Further work is planned at other depths and other zenith angles.

This work was done with the collaboration of Ismael Escober, Raoul Weil, and Abelardo Alarcon, of Chacaltaya Laboratory, and with that of Charles Hyder and James Kenney of the University of New Mexico. Support by the National Science Foundation is gratefully acknowledged.

References

1) V. H. Regener and J. F. Kenney: Proceedings of the Moscow Conference, I. U. P. A. P., Vol. IV, (1960) 216.
2) H. Elliot: Phil. Mag. **5** (1960) 601.

Discussion

Parsons, N. R.: I would like to mention here that an experiment with inclined telescopes (one pointing in the equatorial plane and the other along the earth's rotation axis) is at present in progress underground at Hobart.

Sandström, A. E.: (1) The difference in zenith angle, was the geometry of your two telescopes the same?

(2) Was the difference in m.w.e. accounted for?

(3) Have you contemplated if your results are consistent with a particle wind or a particle wind combined with a particle diffusion from the sun?

Regener, V. H.: (1) The geometry of the individual telescopes was the same, only the inclination against the zenith was different.

(2) The w.e. above the west-pointing telescope was smaller than that above the east-pointing telescope, since the counting rates in the two telescopes were equal in spite of the larger zenith angle of the west-pointing telescope. The data shown on the harmonic dials are raw data, without any corrections other than those necessitated by a linear trend in the average daily counting rate over a period of three days, beginning with the previous day and ending with the day following the day for which the harmonic analysis was made.

(3) Electric fields associated with streams of magnetized clouds of plasma from the sun appear insufficient to account for the magnitude of the observed diurnal variation at the primary energies with which we are dealing here. The minimum energy of the primaries is estimated to be about 100 Bev. Fluctuations in the multiplicity of the π-meson production process may lead to a contribution to our counting rate from primaries below that energy; nevertheless, we do not know a modulation mechanism other than one operating with electric fields.

Sarabhai, V. A.: (1) Did you study the changes in daily mean intensity in the two directions?

(2) Have you studied the scatter of diurnal time of maximum on individual days?

Regener: (1) The daily mean values of the counting rate of the scintillator telescopes did not seem to have the necessary long-term stability for such a study.

(2) A preliminary study of the cloud of end points of the daily vectors on the harmonic dial did not yet reveal anything but a general scatter about the centroid. There is an indication that the diurnal variation is well developed during magnetically quiet periods, and that it becomes confused on magnetically disturbed occasions, but the evidence is not conclusive.

Miyazaki, Y.: (1) Were the temperature and pressure corrections applied to the data?

(2) Do you expect to continue the observation?

(3) Do you expect a secular variation to exist or not?

Regener: (1) No temperature or pressure corrections were applied to the data. The temperature of the equipment at the underground location was constant. The vertical distribution of temperature and pressure in the atmosphere was unknown but, except for the difference in the zenith angles of the two telescopes, atmospheric effects would have shown up simultaneously in the two telescopes, not with the observed phase shift.

(2) We expect to continue the observations under level ground and at various depths, as well as at some additional locations.

(3) There is no clear indication of a secular trend in the data. If anything, the amplitude seems to decrease with increasing distance from the solar maximum.

Kane, R. P.: I am rather surprised that the barometric pressure amplitude is so small as 0.5 mm. In our experience, sometimes friction on the barometric chart reduces the genuine pressure amplitude. I hope this is not playing any role in your case.

Regener: The planetary barometric pressure variation with a period of 12 hours is known to have an amplitude of about 1 mb at the latitude at which we measured. The amplitude of the 24-hour diurnal pressure variation, which would enter into our results, is much smaller, of the order of 0.1 mb at the Chacaltaya location. The counting rate at our depth may show a diurnal variation with an amplitude of 0.01% due to this pressure wave, which is three per cent of the observed amplitude.