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II-4-30. Review of Cosmic Ray Daily Variation and Geomagnetic Effects

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§1. Introduction

In discussing the daily variation of cosmic rays we shall consider local time effects. These are not only diurnal, but often involve a semidiurnal variation as well, particularly at low latitudes.

The meteorological effects which cause variations of intensity of local neutrons or of mu meson or of the soft component are now reasonably well understood and I will not discuss these. The correction of the daily variation of meson intensity for temperature effects nevertheless posses some problems, since the experimental determination of the daily variation of air temperature at different levels in the atmosphere is beset with many difficulties. Most workers would agree that the total temperature correction is not likely to exceed 0.2% and this introduces some ambiguity when the true daily variation is of the same order of magnitude. Rao and Sarabhai[1] have recently suggested a method which uses ground temperature and the altitude dependence of the daily variation of temperature derived by meteorologists. This appears to provide a good approximation. But, in any case, the daily variation of cosmic ray intensity on individual days has often an amplitude exceeding 0.5% and residual errors due to meteorological effects are then quite negligible.

The main interest in the daily variation of cosmic rays is to study anisotropies and local time dependent periodic changes of the geomagnetic field or of electric fields in the exosphere which may affect cosmic rays. Some evidence for processes of the latter type following geomagnetic storms has recently been obtained from east-west directional studies at low latitudes.

We have heard in the plenary session on particles of the great importance from the standpoint of interpretation of measurements of energy spectrum and of initial anisotropy in the arrival of solar particles. For the modulation of galactic cosmic rays this is equally so. Most processes involve the outward transport of energy and magnetic fields in interplanetary space. In general we should expect strong anisotropy of the galactic radiation as these sweep past the earth. But the anisotropy would be transient, so that characteristically it could be expected to last from a few hours to perhaps a few days. One might expect that these transient anisotropies would be distributed in a most complicated manner. The surprising feature is that there is a distinct pattern. Hence even when time averaged data is examined we can discern a story. If, in the past, this has not excited the interest of many experimenters and theoreticians in this field, it is perhaps because time averaging kills in a most drastic way many interesting features such as the magnitude of the effect.

§2. Local Time Effects and Anisotropy of Cosmic Rays

A major experimental difficulty in studying the daily variation of cosmic rays is in separating local time (L.T.) effects from universal time (U.T.) effects due to the isotropic modulation of intensity observed simultaneously on a world-wide basis. The problem has been tackled in two ways:

(a) Sekido and his coworkers have suggested the estimation of the U.T. effect by combining the results from three comparable stations situated meridianally 120° apart. The L.T. effect at each station can then be estimated by correcting for the U.T. effect.

(b) Anisotropy can be detected by the occurrence of a characteristic phase difference in the pattern of variation of intensity in east and west pointing telescopes as these telescopes scan interplanetary space with the spinning of the earth.

At this Conference evidence derived from both methods has been presented.

Using triplets of stations appropriately situated, one in middle latitude and another near the equator, Kane[2] has estimated data for the I.G.Y. period to seek confirmation of many earlier reported features of the daily variation and its solar and terrestrial relationships. Using a rigorous technique, he confirms the world-wide occurrence of daily variation of large amplitude on groups of days with a 27 day recurrence tendency. On the other hand, he does not find significant relationships with solar features or geomagnetic disturbance.

A new result of great interest has been reported by Regener[3], who has conducted experiments with telescopes pointing to east and west directions, underground at the geomagnetic equator. Regener finds that, even for intensity of primaries with average energy of about 2×10^{11} e.v. arriving along the plane of the ecliptic, there is a solar anisotropy which shows itself in daily variation with characteristic phase shift for the two inclined telescopes.

§ 3. Solar Anisotropy and Declination

A number of interesting communications have been presented concerning the change in the magnitude of the anisotropy with declination in the celestial sphere. From world-wide data averaged over many years Dorman had pointed out that the anisotropy is strongest along the plane of the ecliptic. Sandström *et al*[4] have given a very convincing demonstration of this by conducting simultaneous studies with directional telescopes at three stations covering the latitude belt 60° to 89°N. They find that the east telescope at Uppsala, which looks into the plane of the ecliptic, has a very much larger daily variation than telescopes at Murchison Bay, which look at asymptotic directions almost perpendicular to the ecliptic.

Using telescopes pointing to south and to north directions inclined at 45° to the zenith, Sarabhai and Gottlieb[5] have conducted an investigation at 10°N geomagnetic latitude. They have reported at this Conference that south pointing telescopes, which look along the plane of the ecliptic, exhibit a higher amplitude of the daily variation than north pointing telescopes, which look at asymptotic directions inclined at about 30° with the plane of the ecliptic. Thus they confirm for time averaged data and on a day-to-day basis that the anisotropy is strongest along the plane of the ecliptic.

Two papers relate to the latitude effect of characteristics of the daily variation observed by the I.G.Y. network of neutron monitors. The results presented by Pomerantz *et al*[6] are consistent with the decrease of anisotropy for asymptotic directions with high declination in the celestial sphere. Kanno and Murakami[7] have derived a world map showing lines of constant time of maximum of the average diurnal component. The significance of their approach is that it can perhaps indicate the shear or deformation westwards of the geomagnetic field by the solar emissions in interplanetary space which envelope the earth. However, the I.G.Y. data which has been used is not adequate either with regard to coverage or accuracy to furnish positive evidence in this regard.

§ 4. Solar and Terrestrial Relationships of the Daily Variation

A group of papers presented at this Conference are concerned with a re-examination of many of the earlier reported solar and terrestrial relationships of the daily variation of cosmic ray intensity, which mainly relate to data prior to 1955. The communications of Kane[2] and of Sandström[8] make it clear that during the period of the I.G.Y. and the years following it, the relationship between the characteristics of the daily variation and the degree of geomagnetic disturbance, for example, is not clearly established. Crowden and Marsden[9] also report a relationship between daily variation and cosmic ray storms which differs from earlier studies. The more rigorous statistical techniques of analysis which are now used may have something to do with this; but it is more than likely that there is a real difference between the conditions during the present solar cycle and the preceding one.

§ 5. Geomagnetic Effects

In the interpretation of the daily variation in terms of anisotropy of primary radiation, it is important to be able to make appropriate allowance for geomagnetic effects. The experiments of Brunberg and Dattner have provided an invaluable basis for making these corrections. These are now being refined and extended by using analogue methods and numerical calculations with computers. A representation of the geomagnetic field involving 6 terms of harmonic expansion of the surface field is being used in place of the dipole field. Elliot has reported the early results from a terella set up by Bland[10] at London. This has permitted the examination of penumbra effects in an elegant way. Further work involving imposed external fields will be very eagerly awaited by the many workers in the field of cosmic ray variations. Quenby and Wenk[10] as well as McCracken and Fréon[11] have made numerical calculations which are of great value. Komori[12] has considered the energy balance of the cosmic ray secondary components in the atmosphere to provide further confirmation of the calculations of cut offs by Quenby and Webber.

§ 6. The Lunar Daily Variation

The lunar daily variation of cosmic ray intensity is of considerable interest since it can throw light on the lunar oscillations of the atmosphere as well as on the meteorological corrections to be applied to cosmic ray intensity. Bagge[13] has reported at this Conference a study of the lunar tide in cosmic rays. The effect as yet cannot be followed clearly and consistently; but I hope that he will continue interest in this important field of geophysics.

§ 7. Summary of Present Position

I believe that the following summary of position in this field would be widely acceptable:

(a) The solar daily variation of cosmic ray intensity can generally be attributed to an anisotropy of primary radiation. The anisotropy is of a variable character and is quite marked on groups of days which occur with a 27 day recurrence tendency.

(b) The degree of anisotropy is dependent on the declination of the asymptotic direction of cosmic ray primaries. The anisotropy is strongest for primaries along the plane of the ecliptic.

(c) There are undoubted relationships between the daily variation of cosmic rays and solar and geomagnetic activity, and with the isotropic changes of intensity, such as occur in cosmic ray storms. These relationships however appear to be time dependent and their precise nature is somewhat obscure.

(d) There is a suspicion that daily variation of cosmic ray intensity on some days following geomagnetic storms cannot be attributed to an anisotropy of primary radiation. A confirmation of the local non-meteorological source of daily variation is required.

§ 8. The Future

(a) There is great need to improve the I.G.Y. network of stations, both with regard to coverage and in regard to experimental technique. It is now necessary to have instruments with really high counting rates to permit us to follow the changes of anisotropy which are constantly occuring and which can give very valuable information on movements of plasma in interplanetary space. We require more neutron monitors appropriately situated to study the directions of arrival of solar particles. Data from these in conjunction with data from meson telescopes would permit reliable spectrum determination of cosmic ray variations. The establishment of instruments very close to the geomagnetic poles and in the equatorial belt are of particular significance. High counting rate meson telescopes pointing to inclined directions east, west, north and south furnish very important data concerning the modulation of galactic intensity. Moreover, the east-west asymetry, which is derived from studies in inclined directions, is an important tool for continuously following the changes of energy spectrum of the primary radiation.

(b) There is today a great lacuna in the theoretical interpretation of anisotropy. Dorman has worked out in detail the implications of his model which is based on basic ideas originally put forward by Alfvén. However, in view of the reservation entertained by some theoretical workers concerning the plausibility of electric field effects in the context of the conductivity of interplanetary space it is important that alternative theories of anisotropy be worked out in some detail. Experimental workers in this field would, I am sure, welcome an elaboration of the models proposed by Parker and by Gold to predict the anisotropy, that would be expected.

(c) Further advance in the reliability of interpretation of experiments on daily variation depend vitally on a more accurate understanding of geomagnetic and atmospheric transition effects. The coupling coefficients and the multiplicity functions which are applied to interpret measurements at mountain elevations and at equatorial stations are mainly derived from extrapolation, and experimental verification wherever possible is necessary.

(d) We have listened at this Conference to experiments being conducted to determine the anisotropy in the arrival of gamma rays and very high energy cosmic ray primaries. Another challenging experimental task is to observe neutrons from the Sun, which are expected from charge exchange following the production of high energy protons. In India an approach is now being undertaken through collaboration between the Tata Institute of Fundamental Research and the Physical Research Laboratory for the detection with photographic plates at balloon elevations. At all events it is pretty clear that we shall be quite busy for many years to come.

References

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3) V. H. Regener: Kyoto Conference, MO II-4-26.
4) A. E. Sandstörm, E. Drying and S. Lindgren: Kyoto Conference MO II-4-24.
5) V. Sarabhai and Gottlieb: Kyoto Conference, MO II-4-3.
6) M. A. Promerantz, S. P. Duggal and K. Nagashima: Kyoto Conference, MO II-4-22.
7) T. Kanno and K. Murakami: Kyoto Conference, MO II-4-21.
8) A.E. Sandström: Kyoto Conference, MO II-4-25.
9) J. B. Crowden and P. L. Marsden: Kyoto Conference, MO II-4-27.
10) C. G. Bland, J. J. Quenby and C. J. Wenk: Kyoto Conference, MO II-4-18.
11) K. G. McCracken and A. Fréon, Kyoto Conference, MO II-4-19.
12) H. Komori: Kyoto Conference, MO II-4-20.
13) E. Bagge: Kyoto Conference, Mo II-4-28.

Discussion

McCracken, K.G.: Dr. Sarabhai has made a very good point regarding the necessity for study of the diurnal variation on a day to day basis. I would go one step further, and suggest that it should be studied on an hour to hour basis. We know that the phase of the diurnal variation can change markedly within a day, and this means that the anisotropic nature of the radiation is changing rapidly with time. These changes in anisotropy are undoubtedly due to changes in the interplanetary electromagnetic field, presumably induced by the motion of plasma from the sun, and we know that such plasma travels a distance of about 1AU in 24 hours. A clear understanding of the process producing the diurnal variation needs establishment of the experimental correlations between the position of the plasma cloud and the phase of the diurnal wave. The nature of the anisotropy can be studied by employing the data observed simultaneously by a number of detectors situated at different longitudes.

Elliot, H.: With regard to Dr. McCracken's remarks, I want to say following. The interplanetary magnetic field configurations responsible for the cosmic ray modulation are certainly very complicated. It is essential to try to establish broad general patterns in the first instance and this is what we do in investigation the time averaged behaviour of the daily variation. When the general pattern has been established then of course we should look at progressively finest detail.

Korff, S.A.: In considering relation from great distances, a proton at 10^{14} e.v. in a field of 0.1 gamma is bent into a curve of less than a light-year in radius, so that radiation from distant sources will have arrival directions scrambled.

Do the searches for galactic sources take account of this effect? If there seems to be a higher counting rate from the galactic plane, how should this be interpreted in view of these curvatures?

Sarabhai, V.A.: I was only referring to the modulation of a galactic intensity which for the reasons stated by you should be nearly isotropic till it interacts with plasma and magnetic fields in interplanetary space.

I suggest that experimental evidence indicates day to day processes of modulation being more effective along the plane of the ecliptic.