JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-5-12. Propagation of Solar Particles and the Interplanetary Magnetic Field*,**

Constance WARWICK

National Bureau of Standards
Boulder, Colorado, U.S.A.

Careful study of solar activity near the time of PCA (polar cap absorption) events reveals peculiarities in the propagation characteristics of the 30 to 100 Mev solar protons responsible for the absorption. Delay time of onset of absorption from the solar flare or radio burst presumed to occur simultaneously with particle emission varies from a value of several minutes, appropriate to the proton energy, up to many hours. In the period near maximum solar activity, all delay times are long. Other characteristics of solar cosmic-ray increases, PCA events and geomagnetic storms may be summarized by noting that the propagation of particles of low individual energy is less affected than that of higher energy particles. This relation is to be expected if the particles encounter in interplanetary space regions of enhanced magnetic field such that magnetic energy density is comparable to kinetic energy density of the group of particles, and such that gyroradius of the particles is small compared to path length in the field. Direct observations of the energy spectrum of solar protons show that energy density increases steeply as particle energy decreases. With magnetic field of 10^{-5} to 10^{-4} gauss, solar particle clouds that cause geomagnetic disturbance have sufficient kinetic energy density to overcome the field; PCA protons have comparable energy density and may be delayed, solar cosmic-ray particles will be stopped.

Characteristics of solar cosmic-ray increases and PCA events near solar minimum may be explained if the interplanetary field then consists of a regular field, nearly normal to the ecliptic plane, with intensity less than 10^{-6} gauss. Such a field may be identified with the general galactic field, directed along the galactic arm. Particle clouds of the sort associated with geomagnetic disturbance compress this weak, regular field as they move outward from the sun, and form regions with field strength up to 10^{-4} gauss at distances 1/2 to 10 A.U. from the sun. Probably many relatively weak irregularities are created between 1/2 and 1 A.U. by solar particle clouds with insufficient energy to reach the earth. These clouds must be so numerous at maximum solar activity that PCA particles will almost certainly encounter at least one between the sun and the earth. When solar activity is lower, the number of irregularities must be very much smaller. When a stream of solar protons encounters such a region of high magnetic field, the most energetic particles will be stopped. More numerous particles with lower velocities will have enough energy density to control the field and to carry it along their original path. Thus protons will arrive at the earth with a delay appropriate to the velocity of particles with energy density high enough to balance the field. Such a model is consistent with propagation characteristics of solar particles, and also with observations of the interplanetary field made from the space vehicle Pioneer V.

Regions of high magnetic field, moving outward from the sun with a velocity of about 10^8 cm/sec, will impart to the velocity distribution of galactic cosmic-rays in the vicinity of the sun a small systematic component of velocity. If, at a time near maximum solar activity, one-fifth of the cosmic ray particles near the earth have encountered an irregularity, this velocity will be 2×10^7 cm/sec. Although this is very small compared to the total velocity of a cosmic-ray particle, the fact that it is systematically outward can explain the main effects of solar modulation of galactic cosmic-rays. The 11-year variation is explained as a change in density over a period of years in a region within several A.U. of the sun. The Forbush decrease may

* No manuscript has been received and the preprint is reprinted.

** This paper was read by R. W. Knecht.

also be due to a lowering of density, in a region of dimensions of about 1/3 A.U. and with a time scale of the order of hours or days. The diurnal variation can be explained by the addition of the small outward component to the velocity of particles coming from the direction of the sun, and the subtraction of the same small component from the velocity of particles moving toward the sun. Rough computations indicate that this effect will explain quantitatively these three manifestations of solar modulation. If the radial dimension of an irregularity is of the order of 10^{11} cm, cosmic-rays with energies of the order of 100 Bev will be affected considerably less by an encounter with an irregularity than will comic-ray particles of lower energy, so that energy dependence of the solar modulation is to be expected.

Discussion

Hines, C. O.: A great deal of information is given us here, which will require some time for assimilation. For the moment, though, I would like to point out that the conclusion "there is no statistically significant asymmetry in the position of those solar flares that produce PCA's" is quite different from the conclusion "it is statistically highly probable that no asymmetry exist." The available data are concerning too few to permit the second conclusion to be drawn, even though this same paucity of data may justify the first. But unless and until the second conclusion can be drawn, it seems to be too early to accept further conclusions based on it. Specially, I see no compelling reason for believing that the PCA particles are free from the control of a previously exciting solar magnetic field.

Knecht, R. W.: It would seem to me that the burden of proof should rest with those trying to show that an asymmetry exists rather than vice-versa.

Gold, T.: The propagation "as a cloud" of the PCA particles cannot be contemplated as for too much energy and momentum would be implied if the magnetic field and the interplanetary gas locked in it were all accepted to the speed appropriate to the transit times.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-II, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part II

II-5-13. Propagation of Solar Particles through Interplanetary Magnetic Fields*

Tatsuzo OBAYASHI

Radio Research Laboratories, Japan

A model of interplanetary magnetic fields, which is formed by the outward streaming of solar plasma clouds, can account for various characteristics of solar particles observed on the earth. All available information of solar flares including radio emissions, polar cap absorptions, geomagnetic and cosmic ray storms during the period from July 1957 to December 1960 has been examined. Summarizing the results obtained, following experimental facts have been found:

1. There is an intimate relation between major solar radio outbursts of continuum radiation (type IV) and solar cosmic ray events. Large cosmic ray storms are also associated with this type of solar outbursts.

2. The time variation of polar cap absorptions caused by the flares originating from

* No manuscript has been received and the preprint is reprinted.