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TRANSPORT OF COSMIC RAYS IN THE SOLAR CORONA

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This work was undertaken in collaboration with Len Fisk of Goddard Space Flight Center.

Solar cosmic rays produced by flares, such as Werner Neupert was showing, can gain access to the interplanetary magnetic field near Earth from flares located almost anywhere on the Sun. In fact, there is evidence that at least one flare located near central meridian on the invisible solar hemisphere produced detectable increases in the intensity of picojoule (few-MeV) protons at Earth.

The diffusion of energetic particles in the interplanetary medium cannot account for the observations; therefore, there must exist an efficient mechanism for the transport of cosmic rays in the solar corona.

We are suggesting a method by which these energetic particles can diffuse in solar longitude. The method consists of particle motion occurring along current sheets separating discontinuous field structures in the corona. These sheets can serve as pathways along which energetic particles drift at nearly their propagation speed.

First, let us look at a model of the coronal magnetic field and see how the large-scale field behaves. Figure 1 shows a model for the coronal magnetic field. As you can see, the Sun's magnetic field is much more complicated than the Earth's dipole field. There are all sorts of fields associated with active regions: bipolar magnetic regions and unipolar magnetic regions, which give rise to the coronal magnetic loops and arches seen here.

Energetic particles can travel very easily along the magnetic field but only with great difficulty across the magnetic field. Although the field is very complex, there are some regions that are connected by field lines to others at distant longitudes. Most locations are not connected so that flare particles could travel along the field and arrive at Earth. Hence we require a mechanism by which particles can travel across the coronal magnetic field and arrive at Earth.

Figure 2 shows one such mechanism. The magnetic field in the upper portion of the figure, above the current sheet J, is directed inward; below the current sheet it is directed outward. If current sheets exist in the solar corona such that there are discontinuities in the

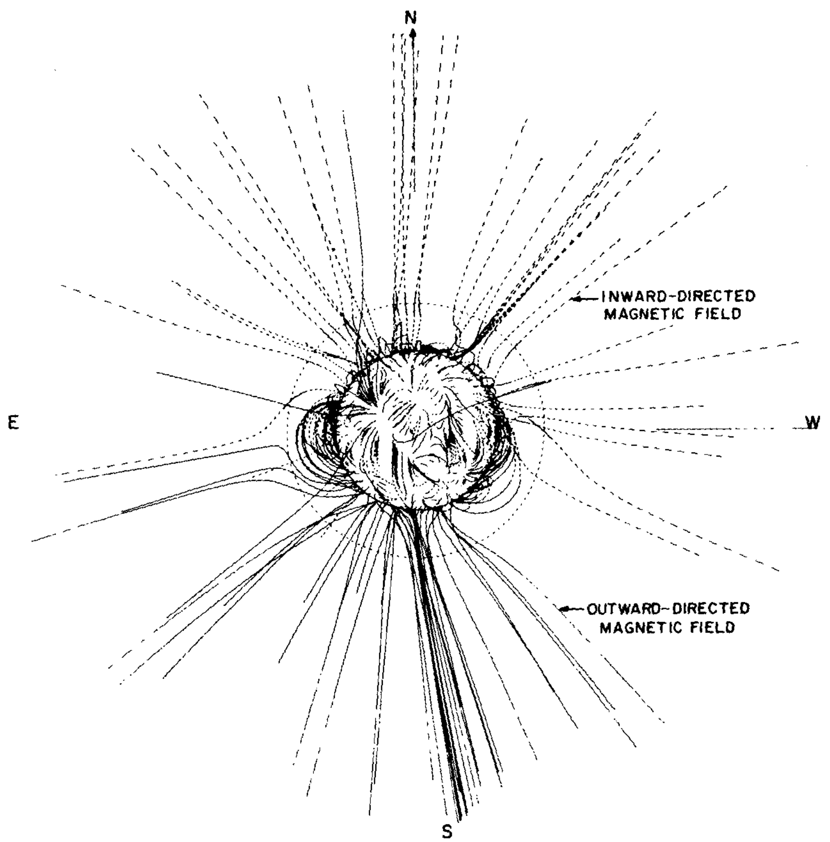

Figure 1–Model of the coronal magnetic field.

coronal field on a very small scale, a particle can travel along these discontinuities and thus across the field by undergoing a zigzag motion on either side of the current sheet, as shown in the lower portion of the figure. It is a little bit like a sailboat tacking upwind insofar as the particle is making progress it could not make directly by choosing alternate advantageous pathways.

It is important to note that the particle can travel across the field in this way at nearly its propagation speed, thus the particle can diffuse across the Sun in a very short time.

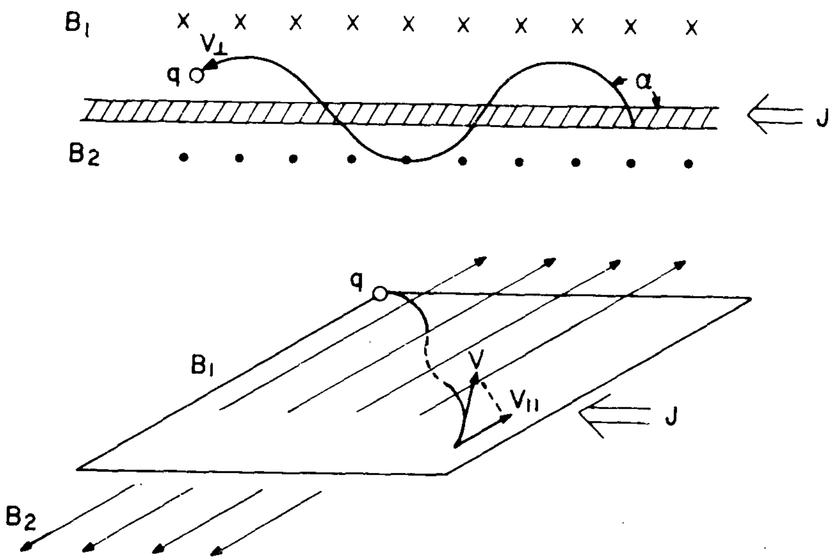

Figure 2–Mechanism by which particles can travel across the coronal magnetic field and arrive at Earth.

Although Figure 2 shows oppositely directed fields on either side of the current sheet, the process occurs nearly as efficiently with alined fields having differing field strengths.

It should be pointed out that this mechanism is not really a new phenomenon but rather an enhanced type of gradient field drift. In addition, Michel and Dessler (Ref. 1) suggested a similar mechanism for particle motion in the Earth's magnetic tail field. Let us take a larger scale look at the diffusion process where many current sheets occur in the coronal field.

Figure 3 shows how an energetic particle would behave in a filamentary coronal field. Each of these cells or filaments might be the extensions of the boundaries of the granules and the supergranules found on the Sun. As one can see, the energetic particle can weave its way along the boundaries of these cells in a sort of random-walk fashion.

We have put this model to a quantitative test by fitting the mechanism to a diffusion equation, choosing reasonable values for the current sheet dimensions. We find that our model can be fit very well to the observations of

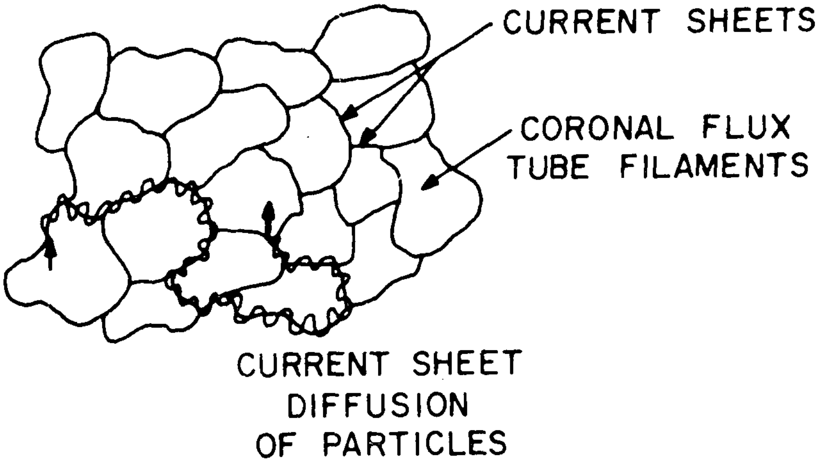

Figure 3–Behavior of an energetic particle in a filamentary coronal field.

McCracken et al. (Ref. 2) that 1.6-pJ (10-MeV) protons decrease in intensity as a function of heliocentric longitude with an *e*-folding angle of 30°. That is, if one is 30° removed from a flare event, one sees only about one-third as many energetic protons. Our model also fits the spectral index variation that McCracken observed.

In conclusion, we are suggesting that the transport of cosmic rays in the solar corona may take place along thin current sheets. In addition, this general type of transport of particles may be important in other astrophysical plasmas.

CHAIRMAN:

Are there any questions on this paper?

MEMBER OF THE AUDIENCE:

Can the mechanism work if the fields on either side of the current sheet are parallel?

DR. SCHATTEN:

Yes, even if the fields are completely parallel as long as the field strengths are different. If the field strengths are the same and they are completely parallel, then there is no current separating the fields. The particle would just stay there in orbit about a single position. But with different field strengths, the particle would undergo a cycloidal type of motion, and therefore it would still travel along the discontinuity.

REFERENCES

1. Michel, F. C.; and Dessler, A. J.: J. Geophys. Res., vol. 75, 1970, p. 6061.

2. McCracken, K. G.; Rao, U. R.; Bukata, R. P.; and Keath, E. P.: Solar Phys., 1972, in press.