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-5-6. The Effect of Solar Disturbances and the Galactic Magnetic Field on the Interplanetary Gas*

Leverett DAVIS, Jr.
*California Institute of Technology, California, U.S.A.*

It is suggested that a model of interplanetary storms be considered in which the gas emitted from the sun is added to a basic, previously flowing solar wind whose velocity varies from week to week, depending on previous solar activity. Thus the shock produced by the added gas can be weaker, the continuous supply of pressure on the back side of the shock can be smaller, and there will be less tendency to spread to the back side of the sun than if the shock were in a stationary medium. It is suggested that the solar plasma may produce a cavity of radius 5–20 A.U. in the galactic magnetic field; this radius being deduced with relatively few assumptions from the observed effect of the solar plasma on the geomagnetic field. The boundary of this cavity should be unstable, allowing bubbles of gas to escape into the galactic field and exciting Alfvén waves that run along the galactic field away from the cavity. Thus galactic cosmic rays trapped inside the cavity are pumped out and the diffusion in is impeded. It seems possible that this mechanism may account for the 11 year cycle in cosmic ray intensity.

I wish to discuss briefly two different sets of ideas concerning the boundary and initial conditions for the interplanetary plasma. One set is concerned with the boundary conditions at the sun and the initial conditions for an interplanetary storm; the other set is concerned with the outer boundary where one encounters galactic spiral arm gas and magnetic field. Quantitative treatments are not yet available, but the qualitative ideas seem worth a brief discussion.

We are all familiar with the fact that geomagnetic disturbances occur of the order of a day after flares and other disturbances on the visible side of the sun. Chapman and Ferraro gave the classic explanation of this in terms of clouds of gas shot out from the sun through an interplanetary region whose contents were ignored or perhaps tacitly assumed to be a vacuum. Later Biermann and Parker introduced the concept of a more or less continuously flowing solar wind. Not long ago, Gold emphasized that the sudden commencement must be due to a shock wave in the interplanetary gas. My only point in this connection is that if the shocks, which are observed to have velocities of the order of 500 to 3000 km/sec, were in a stationary gas or a breeze that goes only a few tens of kilometers per second, the shocks must be highly supersonic and hence very strong. If, in the spherical geometry, they are not to fade away before they get here, there must be a continual push behind them; that is a continual supply of hot, high pressure gas from the sun for a period of a day or so. This seems unlikely. Also a source on the back side of the sun would be expected to push around to our side as soon as the shock got out to 5 to 10 solar radii; but this is not observed.

Many of these difficulties would be alleviated by a model in which there was a basic, low density solar wind whose velocity was of the order of 250—1000 km/sec, perhaps varying from week to week depending on recent solar activity. Puffs of greater gas density and temperature are deposited in this wind from time to time by flares or other sources of disturbance. Partly these expand as weak shocks, but partly they are convected out by the wind and thus do not have to come the whole distance on their own. It is suggested that this model be explored to see whether or not its consequences fit the observations better than do those of the more usual models.

Second, consider the outer boundary of the

* Supported by a grant from the National Aeronautical and Space Administration.

interplanetary plasma, the interface between it and the galactic plasma[1]. At Guanajuato it was suggested that the plasma from the sun might make a large cavity or bubble in the galactic magnetic field. I would like to suggest that this bubble is smaller and its boundary more irregular than previously suggested. It is now possible to arrive at a zeroth order estimate of the radius of the cavity, making relatively few assumptions. Space probe observations have shown that at solar maximum in the direction of the sun the geomagnetic field is not drastically affected by the solar plasma until the fields strength drops to about 10—20 $\gamma$, but that at somewhat smaller fields it is completely pushed aside. Thus we would expect a galactic field of 10—20 $\gamma$ to be pushed back to about 1 A. U. from the sun. It seems plausible that the velocity of the solar wind would be nearly independent of distance from the sun and that its density would be inversely proportional to the square of the radius. Since the pressure of the galactic magnetic field is $B^2/8\pi$, the radius of the cavity should be inversely proportional to the strength of the galactic field. If the latter is 1—2 $\gamma$, the radius of the bubble should be 5—20 A.U.. Note that nothing has been assumed as to the mechanism by which the solar plasma interacts with the magnetic fields, except that it is the same in both instances. It may be either the conventional balance of momentum flux against magnetic field pressure, or, as suggested by Sonett[2], the momentum of waves in the magnetic field could be important.

Because the interface between the geomagnetic field and the plasma is convex toward the plasma, it is stable; but the interface between the galactic field and the plasma is concave toward the plasma and hence subject to interchange instabilities. Thus in the next approximation it seems plausible that the galactic field might be pushed back relatively less far than the geomagnetic field and hence that the cavity might be smaller than the above argument would indicate. Hence it would not be surprising if a space probe sent to the neighborhood of Jupiter, particularly at solar minimum, should discover evidence of the galactic magnetic field and plasma; on the other hand, it may be necessary to go beyond Uranus, particularly if the galactic field should be weaker than 1 $\gamma$ in the neighborhood of the sun.

Some of the features of this model may help to explain the 11 year cycle of galactic cosmic ray intensity. The interchange instability will allow bubbles of interplanetary gas to escape from the main cavity into the galactic field. This process must be fairly efficient or the solar wind would be blocked and would back up toward the source. Each small bubble will pump out some of the galactic cosmic rays trapped inside the main cavity. In addition, the disturbance of the galactic magnetic field due both to the instabilities at the surface of the cavity and to the motion of the sun and the interplanetary region through the galactic plasma and field will excite Alfvén waves which will run along the galactic field away from the cavity. The cosmic rays that enter the cavity will be spiraling along the galactic field lines toward the cavity and will have to diffuse through these wave trains. They will make a random walk on a moving escallator and hence will tend to be pumped out of the cavity, thus lowering the cosmic ray density inside. These mechanisms should be more effective for low energy particles with their small radii of curvature and should be more active at sun spot maximum. Thus it seems worth exploring this mechanism further to see if it can explain some of the slow variations in cosmic ray intensity.


### References

1) L. Davis, Jr.: Phys. Rev. **100** (1955) 1440.
2) C. P. Sonett: Phys. Rev. Lett. **5** (1960) 46.


### *Discussion*

**Elliot, H.:** There is a close connection between the 11 year variation and the Forbush decrease in that quite frequently a part of the 11 year variation apparently arises as a result of incomplete recovery from a Forbush decrease. The energy dependence of the two modulation process is also very similar. Is it not remarkable that these two apparently similar and related processes should arise from quite different causes?

**Davis, Jr., L.:** Presumably the Forbush decrease depends on large scale structures inside the main cavity. No attempt has been made to relate the behavior of these large scale structures and their interaction with the boundaries of the cavity, but it would not be surprising if there were some such effect.

**Alfvén, H.:** If you go from the qualitative model you have proposed to a quantitative theory, I think you will meet insuperable difficulties. It is unlikely that the galactic intensity is higher than the cosmic ray intensity during any part of the 11-year period. It should be observed that we have no real information about the cosmic ray intensity at large distance from the solar system, but it seems reasonable (from arguments I have given elsewhere) that it is much smaller than the intensity measured at and near the earth.

**Davis:** The more usual model is that the cosmic ray intensity near the earth is less than or equal to that in this region of the galaxy.

**Kellogg, P. J.:** I have two remarks to make about Dr. Davis' picture of shocks from the sun. I believe that it is possible that a shock can propagate out from the sun (1) without spreading around to the other side, and (2) to remain strong without a continual supply of driver gas. To take the second first, as a shock progresses into a medium of decreasing density or sonic (probably Alfvén) velocity, it will have to increase in Mach number to carry the same energy, and this may compensate for, or even overcome the $1/r^2$ decrease due to spherical expansion. If the shock remains strong, then it must be nearly spherical, for if regions of sharper curvature develops, then the shock tends to weaken there because the energy propagates normal to the shock front. The region of sharp curvature then slows down and the curvature is smoothed out. A strong shock remains nearly spherical therefore, but not necessarily centered at the sun. In fact, if the shock travels fast at large radii, the shock may take the form of a spherical bubble with one surface touching the sun. The shock front thus might stretch over a region of about 90° of solar longitude, as is required by observations.

**Gold, T.:** A shock wave going out into space from the sun will be quite different depending on the density that existed in space beforehand and the compression with the density of the driving gas. If the pre-existing density is small enough then the expansion occurs almost like into a medium, with only the very first part of the flow affected. A sudden but small wave would then result and then corresponds to the sudden commencement appearance where usually the following disturbances are much larger than the S.C. itself. In this case there are no difficulties with attenuation, and no continuous supply of driving gas has to be assumed.

**Davis:** With a very low density this will certainly be the case, but I do not feel confident that I know what the density is. I do urge that it is worthwhile to work out a variety of plausible models and I feel that one such model in this case where the outward velocity of the solar wind is important.

**Parker, E. N.:** I would like to remark that the question of blast wave acceleration, driving etc. has been computed and will be discussed tomorrow. Professor Davis' presentation has been correct for blast wave far from the sun.

**Biermann, L.:** Regarding the occurrence of shocks in interplanetary space, I would like to point out that certain events in the comet's tails—the sudden disruption of the tail observed occasionally—do suggest the action of strong shocks. These events, however, are rarer than one would expect, if they were a normal feature of a magnetic storms; thus, in a qualitative sense, it looks, as though the comet's observations support the picture developed in Dr. Davis' paper. I suggest, however, to defer further discussion of this point to tomorrow's session.