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Rapporteur Paper for Session MG1, MG3, and MG4 Modulation Theory, Interplanetary Propagation, and Interplanetary Acceleration

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RAPPORTEUR PAPER FOR SESSIONS MG1, MG3, AND MG4 MODULATION THEORY, INTERPLANETARY PROPAGATION, AND INTERPLANETARY ACCELERATION

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This report is a summary of three sessions, MG1, MG3, and MG4. Although the formal session titles were Modulation Theory, Interplanetary Propagation, and Interplanetary Acceleration, respectively, I have chosen to divide MG1 and MG3 along slightly different lines. This change reflects no more than my own, rather personal way of looking at the subject.

There were over fifty papers and confirming abstracts submitted to these three sessions indicating a lively interest in the subject. However, only twenty were actually presented at the conference; this fact can be viewed as either deplorable or a relief depending upon ones particular responsibilities in the matter.

1. Microscopic or Fundamental Theory

This group of papers started off with a bit of controversy; in a pair of papers (MG1-2,3) K. Nagashima and K. Munakata presented results showing the effect of adding a term to the usual convection-diffusion (modulation) equation. The term that they added was called by them a "Joule heating" term and was given by the expression

$$\frac{\partial}{\partial p}\left(\frac{1}{3}\, p\, \underline{V}\cdot\underline{\nabla}U\right) \qquad (1)$$

This term represented the energy loss undergone by particles moving against the electric field induced by the motion of the solar wind in the interplanetary magnetic field. This field also induced a potential on the outer boundary of the heliosphere further distorting the distribution of galactic cosmic rays in the solar cavity. Although the effect of this additional term was considerable over the entire solar cavity it turned out to be small at one A.U. radius.

To understand the controversial nature of this result let us turn to the next paper in this category which happens to be my own. In this paper (MG1-3) the convection-diffusion equation was once again derived from the Boltzmann Equation with the additional complication of allowing the velocity of the scattering centers, V_s, to differ from the velocity of the plasma, V_p, that produces the induction electric field.

$$\underline{E} = \underline{V}_p \times \underline{B}/c \qquad (2)$$

The results showed that in the limit of a small collision frequency compared to the gyrofrequency it is the plasma flow velocity, V_p, that convects the particles in the direction perpendicular to the magnetic field. Since the only effect of the plasma flow is to produce the induced electric field it is clear that it is the "E cross B" drift velocity that sweeps charged particles out of the solar cavity with the solar wind speed.

The controversy is contained in the fact that in this derivation the electric field never appears in the final equation although it was included in the initial Boltzmann Equation. By the time the final convection-diffusion equation is derived the total effect of the electric field is contained in the plasma flow velocity. In fact Kota (1979) showed that the part of the adiabatic cooling term caused by the perpendicular (to B) component of the solar wind velocity was due to gradient and curvature drifts in the induced electric field. The contention is, therefore, that the effects inserted into the modulation by Nagashima and Munakata are already there in the form of the plasma flow velocity.

There has been some discussion between the concerned parties over this issue and at the present writing one must say that the issue remains controversial. It is hoped that a resolution will come about in the near future.

I also include in this section a paper by R. Gall, B. Thomas, and H. Durand (MG3-18). This paper belongs in this section because nothing is more fundamental than F=ma and this is the basis of the research described here. These authors have investigated the effect of a shock wave traveling from the sun out through the heliosphere on the flux of galactic cosmic rays. They integrate the equations of motion of a charged particle moving in a Parker spiral magnetic field upon which has been superimposed a narrow region of increased magnetic field strength, simulating a shock wave. A typical trajectory obtained by them is shown in Figure 1.

The authors find by this method that they can reproduce the phenomenon of a Forbush decrease. The cosmic ray flux is reduced because the particles become trapped behind the outward moving shock and are therefore cooled by adiabatic deceleration more than typical cosmic-ray particles. This method requires a careful use of Liouville's Theorem to obtain fluxes from trajectory calculations and while the authors do not discuss the matter in this paper I have been assured that all such matters have been properly taken care of.

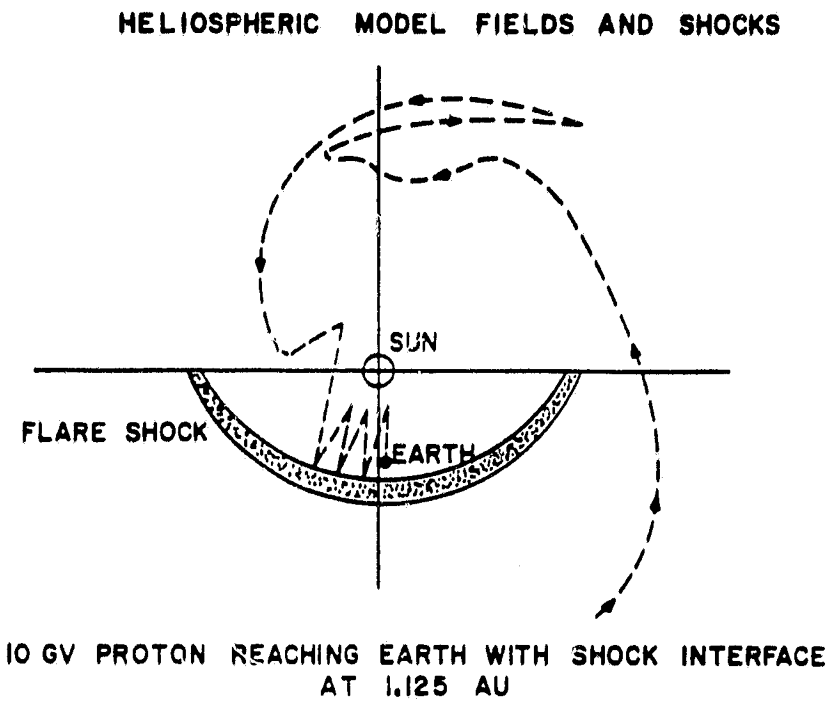

Fig. 1: Trajectory of 10 GV proton from behind a shock. From MG3-18.

S. Yasue, I. Morishita, and K. Nagashima (MG9-9) investigated the effect of cosmic-ray scattering by magnetic irregularities on the siderial daily variation. They performed their study by means of a Monte Carlo calculation following particle trajectories in the Parker spiral field with and without scattering. They noted that scattering reduced the daily variation and that the higher order variations were reduced more than the lower orders. This is in keeping with the general wisdom that scattering or diffusion degrades fine detail before it does gross outline.

As an extra I would like to discuss a paper that is not properly in my area of responsibility; it is the paper by J. W. Bieber and M. A. Pomerantz (MG8-1). The authors of this paper have analyzed twelve years of data from the Swarthmore neutron monitor (hence the placement of the paper in an experimental session.) In their analysis Bieber and Pomerantz show that the higher harmonics (n=2,3) of the cosmic-ray diurnal variation can be explained as manifestations of the same physical process that produces the basic n=1 variation. They are able to fit the data to the first focusing eigenfunction introduced by Earl (1976). The first focusing eigenfunction is completely determined by the parameters λ/L and q where λ is the scattering mean free path of the cosmic rays in the interplanetary field , L is the scale length of variation of the field and q is related to the scattering function of the cosmic rays (q = 1.0 is equivalent to isotropic scattering). They are able to obtain a good fit with the values $\lambda/L = 0.6$ and $q = 1.1$ or if one accepts the nominal value of $L = 0.9$ AU then $\lambda = 0.5$ AU. It is pleasing for a theoretician to see a bit of abstract theory manifest itself by offering a simple explanation for a complicated observational fact.

2. Gradient and Curvature Drifts in Modulation

There did not seem to be as many papers at this conference as at past ones dealing directly with curvature and gradient drifts of cosmic-ray particles. Only one dealt directly with calculating modulation due to such drifts, the paper by M. S. Potgieter and H. Moraal (MG1-9). These calculations included spatially varying solar wind speed and diffusion coefficients, which the authors say produce results that differ only quantitatively from previous work; the real difference is produced by a finite thickness neutral sheet in the equatorial plane which give anisotropies at the position of the Earth's orbit that are more realistic than those produced by the Jokipii and Davila model (1981).

G. K. Ustinova presented evidence (MG3-8) that the North-South asymmetry in the cosmic-ray flux, while reversing on a roughly 22 year cycle, has persisted when averaged over a million year period. This evidence comes from a study of cosmogenic radionuclides in meteorites that have fallen during the years 1955-1976, practically two complete solar cycles. It is not clear to me just what level of certainty one should place on such a result; studies of cosmic-ray gradients from meteorite data is well out of my personal area expertise but I have been led to understand that such studies are extremely difficult and should be approached with great caution.

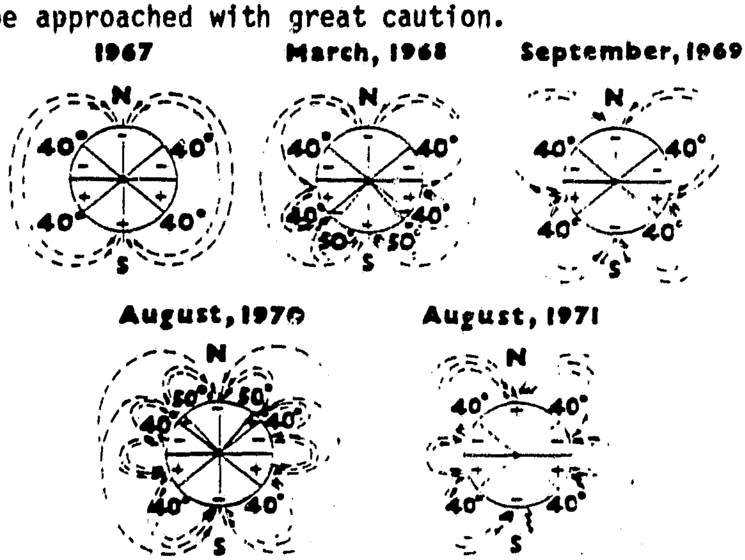

Fig. 2: Evolution of solar magnetic field over a four year period showing development of neutral cones at ± 40° solar latitude. From MG 3-8.

However, one particular point raised by Prof. Ustinova does, I feel, call for some further comment on my part. In discussing how complicated solar field configurations can significantly effect the entry of cosmic rays into the heliosphere via drifts she presented a diagram showing data taken from Howard (1974). This diagram is shown below.

Here we see that the field evolves into a configuration where instead of one neutral sheet there is a neutral sheet and two neutral cones at ± 40 degrees solar latitude. I can not help but believe that such configurations would have a profound effect on cosmic-ray modulation if drifts dominate and until modulation theorists (such as myself) can handle such non typical though probably common cases we can not understand what the full implications of drift theory really are.

Two papers by Alania and his co-workers (MG3-16, M. V. Alania, R. G. Aslamazashvili, T. V. Djapiashvili, and V. S. Tkemaladze and MG3-21, M. V. Alania, R. T. Guschina, and L. I. Dorman) were presented together as one. In this paper the authors present the results of studying cosmic ray anisotropies as measured by 11 neutron monitor stations. The data were separated according to whether the earth was in a "+" or"-" sector of the IMF at the time of measurement. They presented evidence (Figure 3) to show that the anisotropy does indeed depend on the sector structure of the local magnetic field.

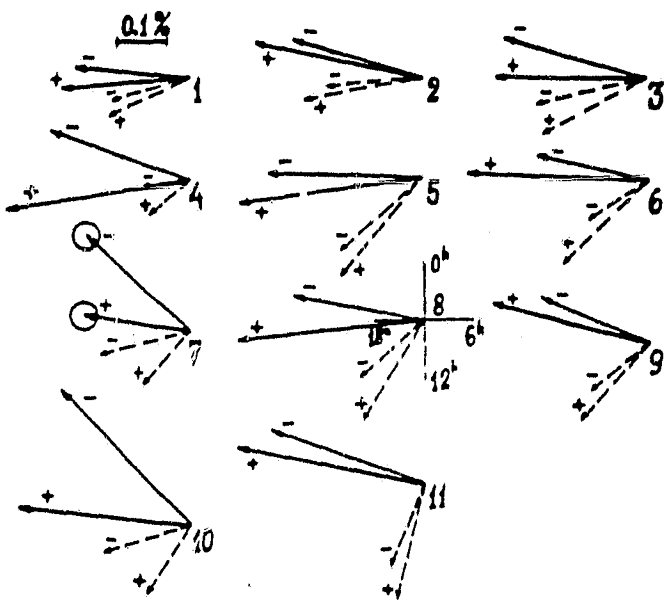

Fig. 3: Anistropy vectors for eleven different stations grouped by sector sign. From MG3-16.

They also presented the results obtained when the harmonically anylized data from one neutron monitor station was combined to form yearly averages. They showed how the phase of the cosmic ray anisotropy changes over a 22 year period. It was shown that there is a definite correlation between the local anisotropy and the sign of the average local IMF.

I believe that this would be an appropriate place to make an observation on what might really be only an issue of terminolgy but should be mentioned nevertheless. The paper that I have just discussed (and many others, I should point out) discuss the measurement of anisotropies as though they were directly related to the drift motion of cosmic rays. In fact the truth is quite the opposite; gradient and curvature drifts have no direct relation to local anisotropies. Although both phenomena are produced by the off-diagonal components of the diffusion tensor their properties are quite different. Gradient and curvature drift arise from gradients of the magnetic field, do not requyire gradients in particle density, transport particles from one region of space to another, but produce no fluxes or anisotropy. On the other hand, fluxes and anisotropies are produced by gradients in particle density, do not require gradients of the magnetisc field, and do not necessarily transport particles from one place to another. This may seem a trifling matter to some but I believe that a great deal of confusion has arisen over just these points.

3. Interplanetary Acceleration

There were more papers by far in this section than in the other two combined. If such facts are indicative of anything it is clear that acceleration processes are of prime interest at this time. M. Lee presented a paper (MG4-12) in which he extended his general self-consistent theory of bow shock acceleration to the case of interplanetary travelling shocks and ESP events. In the case of interplanetary travelling shocks the theoretical results were compared with recent ISEE results which we shall discuss in more detail shortly.

M. Forman (MG4-10) discussed some further details of the features observed in particle populations that have been accelerated by interplanetary shocks. She showed that the slow (5 hr) decrease in particle flux observed behind a shock could be explained by the process of adiabatic cooling of the particles in the expanding solar wind. The sharp drop in intensity that follows the shock by several hours was explained as due to the arrival of unshocked material at the point of observation.

A series of papers (MG4-1,13,15,16,17) was presented by K. -P. Wenzel and T. R. Sanderson that represented the efforts of many authors from a number of institutions: ESTEC, TRW, UCLA, U. of Washington, JPL, and Los Alamos. These papers reported on an extensive study of interplanetary shocks using data from the ISEE 1, 2, and 3 satellites. This study made use of measurements of 35-56 keV protons, solar wind plasma, magnetic field, and waves associated with these shocks. In particular a detailed study of a quasi-parallel shock observed on Nov. 11/12, 1978 revealed the following structure of the event:

UPSTREAM: waves in association with energetic particles, particles flowing away from the shock (in the solar-wind frame), and a gradual rise of particle intensities as the shock approaches.

DOWNSTREAM: few waves, particles isotropic in solar-wind frame, slow drop off in particle intensity, spectrum is cut off in agreement with Forman (1981).

The general conclusion of the authors is that their observations are in excellent agreement with the self-consistent theory of shock acceleration as presented by Lee(1983). Furthermore a table presented in one of the papers (MG4-16) comparing the properties of two observed shocks, one quasi parallel and one quasi perpendicular, could well have come from a textbook on the theory of particle acceleration by the various types of shocks found in interplanetary space.

Possibly the most valuable bit of information resulting from this study comes from a statistical observation. Of the forty some odd shocks that were observed quasi perpendicular ones were considerably more common but the quasi parallel ones are far more effective in accelerating particles. This is valuable in that it tells us which types of shocks are the most interesting ones to study if we are trying to understand particle acceleration.

Lest one think that all differences between theory and observation have been settled once and for all, a couple of papers helped to show that there is still much to understand about interplanetary shocks and particle acceleration. G. Wibberenz, W. Scholz, and H. Kunow (MG4-5) studied 3 - 30 MeV/nucleon particles accompanying solar-flare produced shocks on Sept. 24, 1977, Jan. 1, 1978, and April 10, 1981. They found that the intensity of these energetic particles began to increase up to twelve hours before the shock arrival. The streaming was highly anisotropic (approximately unity), directed away from the approaching shock yielding a mean free path equivalent to "scatter free" events or longer. They asserted that such results were incompatible with the model of acceleration by diffusive shocks, prefering a process such as second order Fermi acceleration in the immediate vicinity of or behind the shock. It would appear to me that such long mean free paths present a problem no matter what process is responsible for the acceleration.

T. von Rosenvinge and C. Paizis (MG4-19) reported on anisotropies that were observed from IMP-8 during Energetic Storm Particle Events. They usually saw particle flows away from the shock shortly before the arrival of the shock indicating particle acceleration at the shock front. On occasion flows back towards the shock were seen several hours prior to the shock arrival but since these events were produced by solar flares these particles could not be unambigously associated with the shock. However, on many occasions particles were seen flowing away from the shock after the shock had passed, an observation not in accord with the simple model of diffusive shock acceleration. These particles do seem to be produced in the shock nevertheless, and it is likely that including effects such as adiabatic cooling (Forman MG4-10) could produce a better agreement between observation and theory.

Theories of shock acceleration were also applied to the solar wind termination shock in papers by L. Fisk and M. Lee (MG4-2) and by J. R. Jokipii (MG4-11). Fisk and Lee applied a sphericaly symmetric model of diffusive shock acceleration to obtain "anomalous" fluxes of He, N, O, Ne, and <100 MeV protons. The shock strength was the only adjustable parameter in there model, the position of the termination shock (50 AU) being given by equating the pressure of the accelerated protons to the solar wind ram pressure. Rather good agreement with observed fluxes was obtained as can be seen in Figure 4.

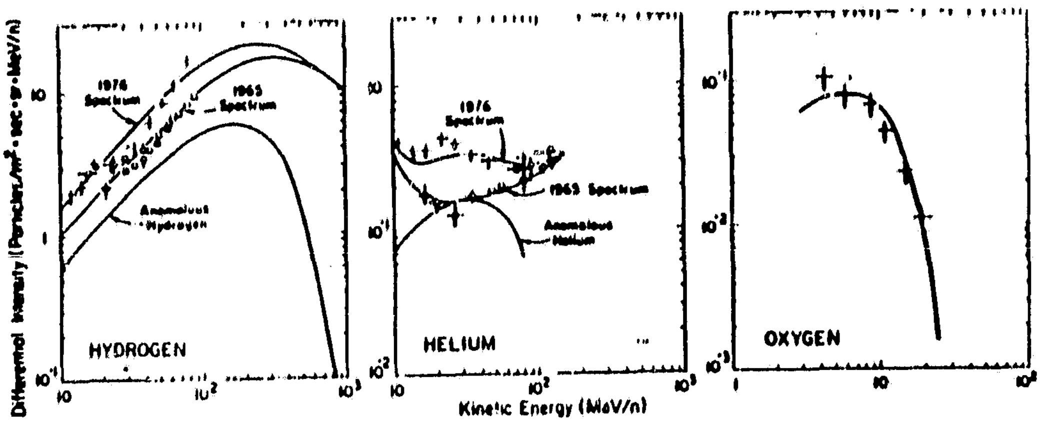

Fig. 4: Fit of sphericaly symmetric model to anomalous component. From MG4-2.

Jokipii, on the other hand, included drift energization in the shock front and the full drift equations in his calculation. Due to the presence of energy gains as well as losses the usual method of numerical solution of the equations was not applicable so he was forced to employ a Monte Carlo type of technique to obtain solutions. His results are shown in Figure 5 but it should be born in mind that this work is just beginning and Monte Carlo calculations take a lot of computing time to produce results with good statistical accuracy.

Indirect evidence for shock acceleration was obtained from neutron monitor data by P. J. Ankiewicz, P. H. Stoker, and H. Moraal (MG4-21). In plotting regression curves between two neutron monitors with differing cut-off rigidities they were able to see the stepwise depression of the cosmic-ray flux during Forbush decreases. They also

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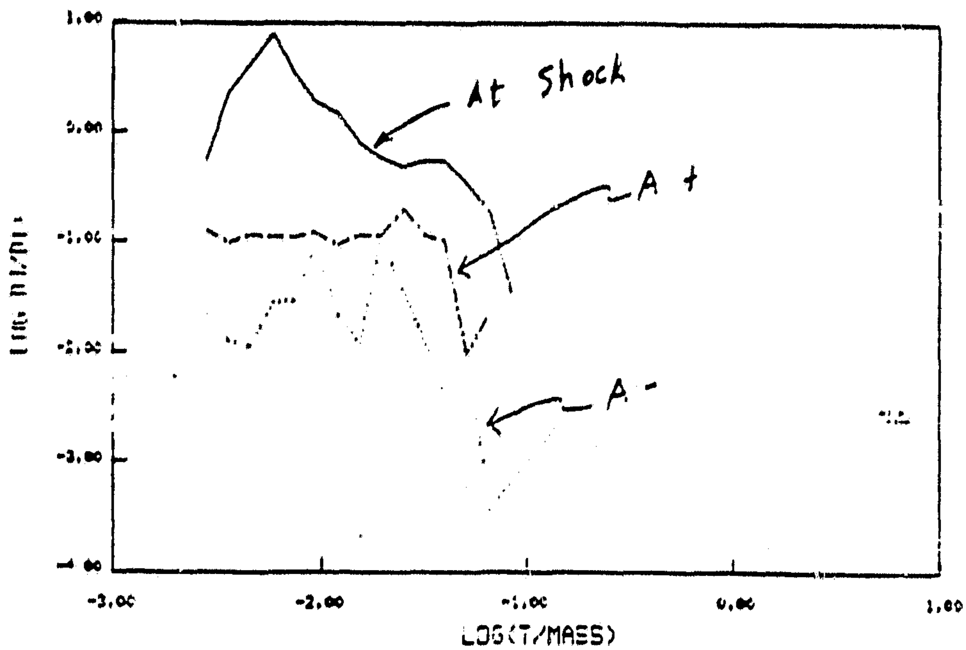

Fig. 5: Fit of drift model to anomalous component. From MG4-11.

noted that after a decrease the spectrum of the cosmic rays often hardened a bit. They proposed that this could be due to an acceleration of the particles by the same shock that caused the Forbush decrease.

4. Conclusions, Recommendations, Etc.

At this point it is customary to summarize the sessions with a few well chosen observations on the general health of the various fields that have been reviewed. I am happy to report that I believe the health of cosmic-ray acceleration by shocks to be excellent. A wealth of complete, pertinent, information is coming in from the experimentalists and it indicates that the theorists are on the right track. I am sure that during the next few years what we learn here at home in the solar system about diffusive, quasi-parallel shocks (and these seem to be the ones that are interesting for cosmic-ray folks) will be readily applied to the wider problems of galactic cosmic-ray acceleration.

I am afraid that cosmic-ray modulation, on the other hand, is in one of those turbulent eddies that we hear of from time to time; the circulation velocity is greater than the linear velocity. Before I am accused of being harsh let me add that I believe that this is because the problem is very hard. Many years ago, flushed with the success of the original diffusion-convection equation in describing the general form of modulation, one eminent scientist predicted the field's imminent demise from sheer boredom. That prediction turned out to be premature for the subject is far more complicated than was originally believed. The introduction of the ideas of gradient and curvature drifts while, I believe, quite correct has had the unfortunate effect of making solutions very difficult to obtain. Furthermore the solutions seem to be unreasonably sensitive to boundary conditions; if the solar-system field structure is changed a bit the solutions can look very different. And we have seen that actual field structures can differ greatly from the simple spiral that describes the average field.

Furthermore, over the last few years the results of experiments on the Pioneer and Voyager spacecraft have shown that cosmic-ray modulation is both spatialy as well as temporaly complex. Modulation proceeds outward from the sun in discreet events and these events move with the solar wind speed. So it is probably no wonder that our understanding of the suns effect on cosmic rays is temporarily stymied. There is a lot to be done in developing ways of modeling these phenomena in forms that are computable <u>and</u> understandable, a formidable but interesting job.

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