PARTICLE ACCELERATION DUE TO SHOCKS IN THE INTERPLANETARY FIELD: HIGH TIME RESOLUTION DATA AND SIMULATION RESULTS.

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INTRODUCTION

In this study, data is examined from two experiments aboard the Explorer 50 (IMP 8) spacecraft. The Johns Hopkins University/Applied Physics Lab Charged Particle Measurement Experiment (CPME) provides 10.12 second resolution ion and electron count rates as well as 5.5 minute or longer averages of the same, with data sampled in the ecliptic plane. The Goddard Space Flight Center Magnetic Field Experiment provides the high time resolution magnetic field data (15.36 sec). IMP 8 spends about half its nearly circular (32 to 38 Re) orbit in the interplanetary field. The high time resolution of the data allows for an explicit, point by point, merging of the magnetic field and particle data and thus a close examination of the pre- and post-shock conditions and particle fluxes associated with large angle oblique shocks in the interplanetary field. A computer simulation has been developed wherein sample particle trajectories, taken from observed fluxes, are allowed to interact with a planar shock either forward or backward in time. Shock normals are determined from the single spacecraft method of Lepping and Argentiero (1) using the Imp 8 magnetic field data and OMNI plasma data (J.W. King, NSSDC). One event, the 1974 Day 312 shock, is examined in detail.

DETERMINATION OF THE SHOCK NORMAL

The method of Lepping and Argentiero is based on the coplanarity theorem (2) in which the normal is determined by the magnetic fields:

$$\hat{n} = \frac{\left(\vec{B}_2-\vec{B}_1\right)\times\left(\vec{B}_1\times\vec{B}_2\right)}{\left|\left(\vec{B}_2-\vec{B}_1\right)\times\left(\vec{B}_1\times\vec{B}_2\right)\right|}$$

Instead of using the average values calculated from the data, "best estimate" values are determined in a manner to be explained below. Two assumptions are necessary to use this method: first, that the Rankine-Hugoniot equations are valid for interplanetary shocks; second, that the shock is a step-function increase in all parameters, with superimposed noise. Figure 1 lends credibility to the second assumption. The first assumption is necessary because certain of the

Rankine-Hugoniot equations are used as a constraint on the shock normal. The equations in the shock rest frame are:

$$[\rho V_n]_1^2 = 0$$
$$\left[\rho V_n V_t - \frac{B_n B_t}{4\pi}\right]_1^2 = 0$$
$$[V_n B_t - V_t B_n]_1^2 = 0$$
$$[B_n]_1^2 = 0$$

Eleven variables can be identified from these equations:

$$\rho_1, \rho_2, \vec{W}\left(\vec{V_2} - \vec{V_1}\right), \vec{B_1}, \vec{B_2}$$

Three of these variables are isolated in terms of the other eight. In the Lepping and Argentiero study any three variables could be isolated. Their data consisted of 30 sec averaged magnetic field data and approximately 90 sec averaged plasma data. In this study 15 sec averaged magnetic field data was used along with 5 min averaged plasma data. Because of the large standard deviations associated with the solar wind data (Wx,Wy,Wz), partly due to the low resolution of the data, it was necessary to isolate these three variables. To use them in the Rankine-Hugoniot equations to solve for the other variables produced inconsistent results or no convergence.

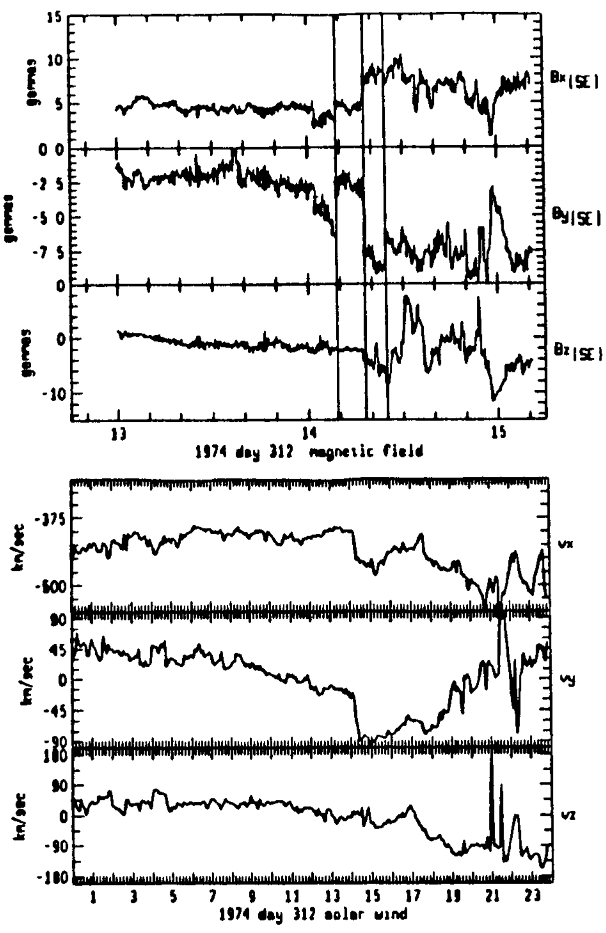

Fig 1 a) Magnetic field in solar ecliptic coordinates Vertical lines separate field into pre- and post- shock regions which were used in the shock normal determination b) Solar wind in solar ecliptic coordinates Shock occurs at 14 30 hours

The method uses the eight "known" variables and the three variables calculated from the Rankine-Hugoniot equations in a type of least squares fit which is minimized by use of an iteration process. The solution should converge to the "best estimate" values relatively quickly. Many starting values should be used and these compared to assure convergence to the same minimum.

This normal determination method was tested in several ways. Multiple runs were made with different starting values (particularly, different numbers of plasma points were used from 15 min to 40 min of data), and these were checked against each other. Three events were used; one, the 1974 day 312 shock to be used in the remainder of this work, and two others which were checked against thetabn angles supplied by Tsurutani (private comm.)--thetabn being the angle between the magnetic field and the shock normal. The 1979 day 93 thetabn was calculated at 39° which is within 4° of that calculated by Tsurutani, and the 1979 day 95 thetabn is within 6° of the Tsurutani value. The 1974 day 312 shock was not included in the Tsurutani study. It was further checked by calculating the time of propagation of the shock from the spacecraft along the shock normal to the Earth and comparing against the reported SSC time. For a calculated thetabn of 60° and a shock speed of 470 km/sec, the time of arrival at Earth was 14.29 hours compared to the reported 14.23 hours.

DESCRIPTION OF THE COMPUTER SIMULATION

The computer simulation is a further development of the work of Chen (3). The frame of reference is as follows. A plane shock is assumed moving in the direction of the shock normal (x direction). The magnetic field is in the x-z plane (By=0 upstream forces By=0 downstream). The upstream plasma moves in the -x direction, the downstream plasma in the x-z plane. The electric field is in the y direction and constant across the shock. Data for a particular shock can be made to fit these conditions by suitable rotations and galilean transformations. The best estimate values from the previous section provide a consistent set for this work since they obey the Rankine-Hugoniot equations (as they must since they were determined from these equations). With this framework established, individual particles are allowed to spiral in along magnetic field lines and be reflected upstream or transmitted downstream due to the change in magnetic field at the shock surface and the initial conditions. The particles move according to the Lorentz force; each time a particle crosses the shock the final conditions at the crossing point become the new initial conditions, and the appropriate magnetic field is inserted into the force equation. The gain or loss in energy is monitored, along with the number of times the particle crosses the shock before being reflected or transmitted. Particles can be inserted either upstream or downstream from the shock and can move either forward or backward in time.

DISCUSSION

Figure 2 shows the CPME data used in the study. This is the 290 keV to 500 keV sectored proton data. It is highly structured on a short time scale particularly in the post shock region. Associated with each of the eight data channels is a direction consistent with the midpoint in the ecliptic plane of the 45 degree sampling angle. Plasma flow collected for each of these channels will be in the opposite direction. Magnetic field data is also available on this high resolution time scale. For several of the peaks the magnetic field is identified, and associated pitch angles are determined for each of the eight channels. Then, using a linear distribution of phase angles for each pitch, an ensemble of particles is sent backward in time to the shock surface.

The objective of this study is a quantitative determination of the particle kinematics in the vicinity of interplanetary shocks, in particular the 1974 day 312 shock. The anisotropy of the particle data at certain peaks together with the phase averaged energy changes, and comparisons, will be presented.

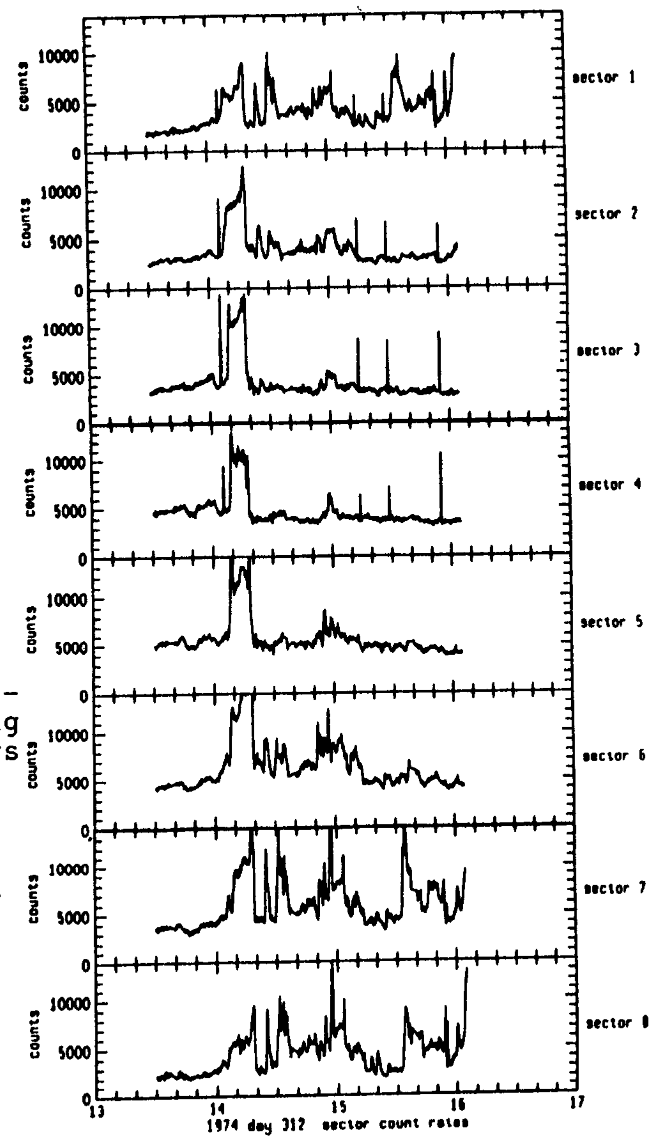

Fig 2 8 sectors in the ecliptic plane of 290 keV to 500 keV proton data from the JHU/APL Charged Particle Measurement Experiment (CPME) Shock occurs at 14 30 hrs

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