

SHOCK AND STATISTICAL ACCELERATION OF ENERGETIC PARTICLES
IN THE INTERPLANETARY MEDIUM

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1. Introduction. Definite evidence for particle acceleration in the solar wind came around a decade ago (Mc Donald et al, 1976, Barnes et al, 1976). Since then a considerable amount of data have been taken at different distances from the sun confirming and extending the first findings and it is now widely accepted that particles are accelerated in the Solar Wind (Quenby, 1983). Two likely sources are known to exist: particles may be accelerated by the turbulence resulting from the superposition of Alfvén and Magnetosonic waves (Statistical Acceleration) or they may be accelerated directly at shock fronts formed by the interaction of fast and slow solar wind (CIR's) or by traveling shocks due to sporadic coronal mass ejections. Naturally both mechanisms may be operative.

Shock acceleration has been widely investigated theoretically (Axford, 1981 and references therein) and there is substantial evidence of this as an operative mechanism in the Heliosphere (Scholer, 1984). However there are also experimental observations not obviously consistent with shock acceleration v.g. (Van Ness et al, 1984) and some ion enhancements only explained in terms of statistical acceleration (Richardson, 1984).

Previous treatments of statistical acceleration involved theoretical methods based on power spectral representations of the electromagnetic field (see Quenby, 1983 and references therein).

In this work the acceleration problem was tackled numerically using Helios 1 and 2 data to create a realistic representation of the Heliospheric plasma as will be described in the next section. Two 24 hour samples were used: one where there are only wave like fluctuations of the field (Day 90 Helios 1) and another with a shock present in it (Day 92 of Helios 2) both in 1976 during the STIP II interval. Transport coefficients in energy space have been calculated for particles injected in each sample and the effect of the shock studied in detail.

2. Interplanetary Medium Model. The magnetic field used is defined from \underline{B}_i three dimensional vectors where each one corresponds to the 8 sec. measurements of Helios 1 or 2. Every point in space is also furnished with a solar wind velocity vector \underline{V}_i where these are the corresponding velocities in the solar wind frame. Consequently because all parts of the solar wind are moving there is an electric field $\underline{E}_i = -\underline{V}_i \times \underline{B}_i$ associated to every point in space. For every sample we have divided the space in a series of layers where both the electric and magnetic fields are constant. Trajectories are integrated based on analytical

solutions of the equations of motion for each layer. For more details see Moussas et al, (1982).

Because we require layers of roughly 1/20 of a cyclotron radius only 100 MeV protons have been used in this work, lower energies require smaller IMF sampling time to keep a reasonable number of layers per gyroradius.

3. Calculation of Transport Coefficients in Energy Space. First and second order coefficients (D_T and D_{TT}) were calculated in energy space by two different techniques. One is based upon the construction of a steady state distribution by injecting particles with a single energy T_0 (100 MeV in this case) and removing them when they reach any of the two preset boundaries "above" and "below" the injection point (see Moussas et al, 1982 for details).

Another method is based upon the time evolution of the energy distribution. D_T is calculated via a least square fit of successive distributions first order momenta vs. time. If we take the diffusion equation in energy, integrate for injection at $T=T_0$, assume a first order Taylor expansion in energy for D_{TT} , and make a determination of the spread $\langle(T-\langle T \rangle)^2\rangle$ we arrive at

$$\langle(T-\langle T \rangle)^2\rangle = 2D_{TT}(T_0)t + 2(D_T)^2$$

from where D_{TT} can be calculated.

Both methods are generalizations of those initially developed by Jones et al (1978) to study pitch angle scattering on a randomly generated IMF.

The effect of the shock is traced by counting every particle encounter with it and recording the resulting energy change. The average energy change is given by the ratio of the total gain and the number of shock encounters. Transport coefficients can be calculated using the time an average particle takes to get back to the shock $t_B = 2\lambda/v$ where λ = mean free path = 0.03 AU (see Valdés-Galicia et al, 1984) and v = particle velocity.

4. Shock Characteristics. The shock used in this study passed through Helios 2 on day 92 of 1976 when the spacecraft was at 0.45 AU from the Sun. It is a perpendicular shock $\Theta_{B\hat{n}} = 89^\circ$ (Lepping et al, 1971) with a high Alfvén Mach number $M_A = 7.5$. The magnetic field overshoot is some 24 Gammas which is around 50% of the downstream field.

It was assumed to be a plane shock and data were transformed to a frame where the $Y-Z$ plane coincides with that of the shock so that it is parallel to our layer planes.

5. Results and Discussion. In figure 1 we present a result of a time stationary distribution of particles for an experiment carried out using data from day 90/Helios 1. It can be easily appreciated the asymetry of the distribution towards the "right" of the injection energy T_0 , showing strong acceleration by waves. Boundaries were put at + 2 MeV from $T_0 = 100$ MeV. It should be noted that the mean free path these particles is very small ($\lambda = 0.006$ AU, Valdés-Galicia et al, 1984).

Figure 2 shows an evolution diagram of the distribution function of particles in energy and time. Contours are drawn for different density levels. Areas with zero density within the distribution are shown black. Injection energy is at the middle of the figure and energy increases downwards. Full extension from top to bottom is 6 MeV. The horizontal scale covers 2000 sec. Black diamonds represent first order momenta of particle distributions every 100 secs.

In table 1 we show the main results of this work. Transport coefficients are average values of the calculations done by the two different methods. Although not shown individually both values agree within 15%. The second row of table 1 shows results for all particles (85) used with Helios 2 day 92 sample including 79 shock crossings so they are representative of the two processes involved (shock and statistical acceleration),

We can appreciate that even though average energy changes corresponding to statistical and statistical plus shock acceleration are greater than the shock produced average, transport coefficients for this process are greater by an order of magnitude. In the last column of the table we have calculated the the e-folding times (τ) corresponding to every experiment (Wibberenz et al, 1972). If we calculate the time for adiabatic deceleration at 0.45 assuming $V_{sw} = 400$ Km/sec and radial expansion we get $\tau_{ad} = 35.3$ hours. Thus although statistical acceleration can have an effect in reducing the adiabatic cooling only the shock accelerated particles are able to overcome it at these energies.

Unfortunately we were limited by the time resolution of the data and could not explore lower energies in a similar manner.

6. Conclusions.

- a) The time evolution and time stationary methods to calculate transport coefficients agree quite well.
- b) Statistical acceleration at particle energies of 100 MeV in the inner Heliosphere is not able to overcome the effects of adiabatic cooling.
- c) Shock acceleration as opposed to statistical acceleration may be a source of particles at these places and energies.

- d) Statistical acceleration may be a more efficient process at lower energies.

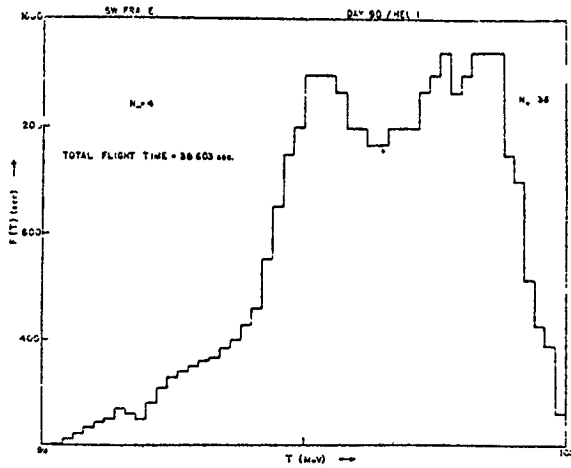


FIG 1

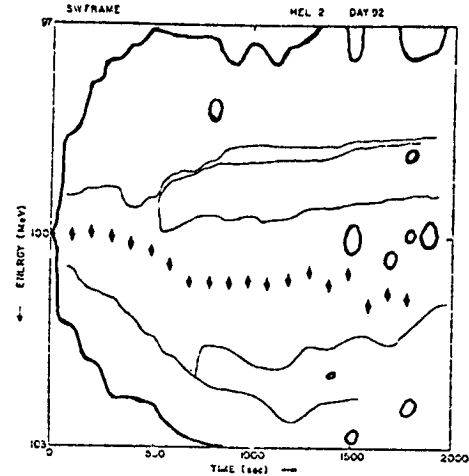


FIG 2

TABLE I

LOY/SC	POSITION (AU)	ACCELERATION PROCESS	$\langle \Delta T \rangle$ (μeV)	D_T (MeVs^{-1})	D_{TT} (MeVs^{-2})	τ (Hrs)
90/HEL 1	0.31	STATISTICAL	0.76	$(3.6 \pm 2.1) \times 10^{-4}$	$(4 \pm 3) \times 10^{-4}$	76.5
92/HEL 2	0.45	SHOCK+STATISTICAL	0.83	$(5.2 \pm 2) \times 10^{-4}$	$(5 \pm 3.5) \times 10^{-4}$	53.
92/HEL 2	0.45	SHOCK	0.26	$(3.4 \pm 1.5) \times 10^{-3}$	$(1 \pm 9) \times 10^{-4}$	10.9

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