§25. Simulations of Shock Wave Acceleration of High Energy Particles Associated with Coronal Mass Ejections

Den, M. (National Inst. Information Comm. Technology), Ogawa, T. (Kitazato Univ.), Yamashita, K. (Yamanashi Univ.)

We studied time evolution of an energy spectrum of a proton flux in the range of 47 – 4750 keV for the energetic particle event occurred on 314 DOY in 2000. It is believed that coronal mass ejection (CME) driven shock waves can produce energetic particles by diffusive shock acceleration. We modeled the process by the following two steps: a study of the shock propagation and a study of acceleration at the shock. The shock wave is realized by a three-dimensional hydrodynamic simulation with an Adaptive Mesh Refinement (AMR) scheme. The acceleration of particles is simulated by Stochastic Differential Equation (SDE) method.[1] Figure 1 is a snap shot of the solar wind velocity on the sun-earth line. It shows that the shock wave is formed and the coupling of AMR-TVD sheme is proper for the shock capturing.

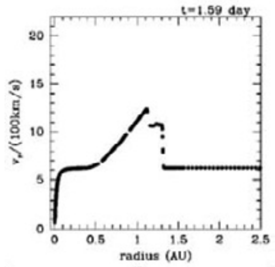

Fig. 1. A snap shot of the solar wind velocity on the sun-earth line.

Figure 2 presents time evolution of energetic particles observed by ACE satellite. It indicates that energetic particles were injected before shock wave passage, in other words, there existed pre-accerelated particles without a shock wave. In our previous works, we assumed that a diffusion coefficient was constant in time and space. Here we adopt the diffusion coefficient model as follows:

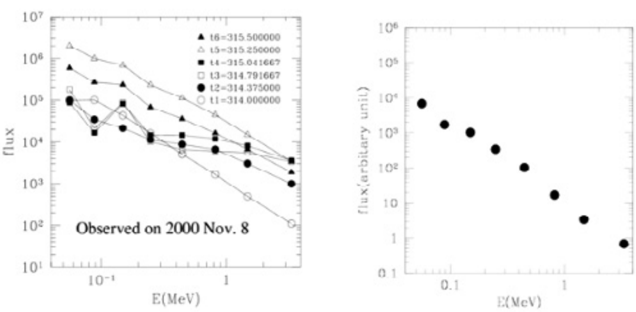

Fig. 2. Time evolution of energy spectrum for observed energetic particles (left). Energy spectrum of ambient solar wind (right).

$$\kappa(p) = \frac{\kappa_o}{A(k)}\frac{B_o}{B}\frac{(p/p_o)^2}{\sqrt{(m_p c/p_o)^2 + (p/p_o)^2}}$$

where κ, p, B, $A(k)$ are the spatial diffusion coefficient, a particle momentum, the interplanetary magnetic field intensity, and wave energy density, respectively [2]. For simplicity, we assume that B is expressed by Parker model and κ is determined by Bohm form, which indicates strong shock limit is assumed and $A(k)$ =1 [3]. As for seed particle distribution, models are same as the previous works and summary for models is presented in Table 1.

Table 1: Model parameter

	κ	Seed particle:	
		Ambient solar wind	150keV , impulsive 0.45day
Model C-C	Const.	100%	0%
Model C-K	$\kappa(p)$	100%	0%
Model I-C	Const.	2%	98%
Model I-K	$\kappa(p)$	2%	98%

Figure 3 presents spectrum of simulation results. The squares indicate the energy range which the ACE satellite observed. Model I-C may be similar as the observed spectrum, so the results show that there exist pre-accelerated particles before the shock propagation and the diffusion coefficient does not so depend on the particle energy.

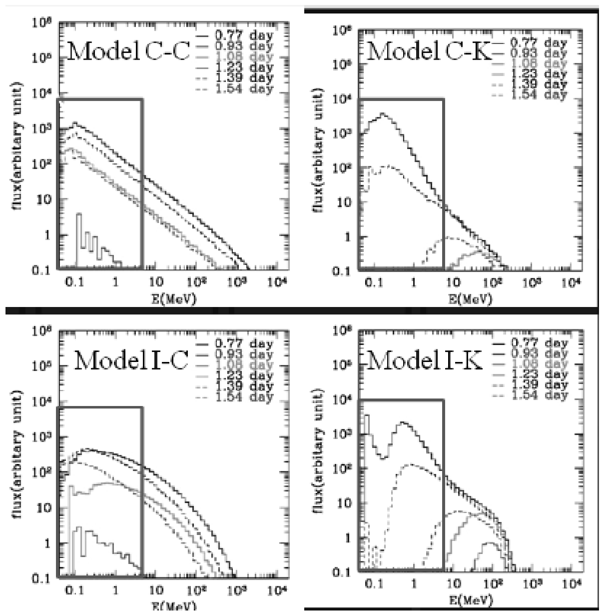

Fig. 3 Spectrum of simulated accelerated particles

1) Yoshida, T. and Yanagita, S. : Prog. of Theor. Phys. **92** (1994) 1217.
2) Bell, A.R., Mon. Not. Astron. Soc., **182** (1978) 147.
3) Zank, G.P., Rice, W.K.M, and Wu, C.C., J. of Geophys. Res., **105** (2000) 25,079.