ON STOCHASTIC DYNAMICS OF PROTONS IN SOLAR MAGNETIC LOOPS

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ABSTRACT. It is shown that stochastization of particles due to Alfven waves is accompanied by their effective acceleration in loop structures of solar magnetic fields.

This report is devoted to the study of ion acceleration in solar coronal loops during a resonance interaction of energetic particles (protons) with Alfven waves in terms of a theory presented by Zaslavsky and Sagdeev (1988). The particle stochastization condition in a plane-wave field (Chirikov's criterion) (Zaslavsky and Sagdeev, 1988) in our problem can be written as: $K = 1/\tau^2\Omega^2 \gg 1$, where $\tau = (m/eEk_z)^{1/2}$ is the period of phase oscillations of a particle with mass m and charge e in the wave's potential well, E is the wave's electric field, and $\Omega \sim |\omega - \omega_{Hi}A/v_z|$. Here ω and A are the frequency and velocity of Alfven waves, respectively, and ω_{Hi} and v_z are the gyrofrequency and the proton velocity projected onto an external magnetic field, respectively. The boundary of the stochasticity region can be determined from the relationship $K \sim 1$. The largest width of the stochastic layer is formed near the separatrix separating trapped and transient particles in the MHD wave field (Chirikov, 1978).

The physics behind the appearance of the stochasticity effect is associated with the presence of special points on the phase plane such as points of self-intersection of the separatrix, near which the integrals of motion are violated. A particle, trapped into a potential well, is subjected to a stochastic instability under the action of any other wave that plays the role of a disturbance. The motion of the particle in a stochastic layer of the wave becomes similar to Brownian motion, which leads to the fact that the particle's energy, on the average, grows with the time as:

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$$\mathcal{E} \sim \delta\mathcal{E}_0 (T/\tau)^{2/3} \quad (1)$$

where $\delta\mathcal{E}_0$ is the variation of the particle's energy during a period τ, and T is acceleration time (Zaslavsky and Sagdeev, 1988).

Qualitatively, the physics of the acceleration mechanism is thus: the variation in energy of the particle associated with the wave's electric field, is $\delta\mathcal{E}_0 \sim eE\ell_{eff}$, where ℓ_{eff} is the effective length of resonance interaction between the particle and the wave. It is clear that ℓ_{eff}, in the case of the usual Landau resonance and in the presence of stochastization, are different, and ℓ_{eff} in the latter case is significantly larger, which leads, accordingly, to a greater growth of the particle energy.

Based on formula (1) we shall make an estimate of the proton energy gain for the solar flare of 7 June 1980 described by Smith (1989), who, as in our case, treats the flare coronal magnetic loop as a semicircular magnetic trap filled with MeV-ions and MHD waves with the wave energy density $W_A \sim 1.5$ erg·cm^{-3} comparable with the thermal plasma energy density for $n \sim 5 \cdot 10^{10}$ cm^{-3} and $T_i \sim 1.6 \cdot 10^6$K. The Alfven wavelength $\lambda \sim 10^7$ cm, $\omega_{Hi} \gg 10^4$ s^{-1}, $A \sim 10^8$ cm·s^{-1}, and $v_z \sim 10^9$ cm·s^{-1}. By taking for estimations the Alfven wave amplitude of $\sim 10^{-1} - 10^{-2}$G and the ratio $T/\tau \sim$ $\sim 5 - 30$, we find that the growth of the MeV-ion energy makes up from 3 to 10 MeV. (The value of the T/τ -ratio was obtained by estimating τ and the lifetime of protons in the coronal loop). The share of the particles heated during stochastization in the coronal loop usually is $\lesssim 10\%$.

Unlike Smith (1989), the more effective proton acceleration discussed here is connected mainly with stochastic dynamics of protons (the mean energy and the share of accelerated protons is greater, owing to the contribution of transient particles). Therefore, this acceleration mechanism is of interest for interpretation of the gamma-radiation of solar flares.

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