PARTICLES AND ENERGY TRANSPORT IN THE SOLAR ATMOSPHERE DURING SOLAR FLARES

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Abstract :

The proposed model of particles transport in the solar atmosphere during flares consists in a low density plasmoid originating deep in the atmosphere and rising under magnetic and buoyancy forces. Confined particles are selectively released during the ascent and their interaction with the solar atmosphere produces X and γ bremsstrahlung. The characteristics of high energy particles released in the interplanetary medium are found to agree with observations.

I. INTRODUCTION

It is generally accepted that particles accelerated during solar flares interact with the solar atmosphere and escape and diffuse in the interplanetary medium (i.m.). Such interacting particles are believed to be the primary source of energy in the flare process. In most models (Svestka 1976, Ramaty and Murphy 1987), particles are accelerated high in the atmosphere, and some of them impinge on the low atmosphere while others are ejected in the i.m. But such models fail to explain **both** properties of energetic particles recorded in the i.m. : chemical and isotopic composition and energy spectra. We discuss here the possibility of a very different model where particles are transported upwards in an isolated structure.

II. CHARACTERISTICS OF FLARES PARTICLES IN THE I. M.

We concentrate here on some major characteristics of energetic particles recorded in the i.m.

1. Chemical and isotopic composition.

The ratio ^{3}He / ^{4}He is far larger than the cosmic value and depends on the events with a range of 10^4 (Kocharov and Kocharov 1984). The same is true for Fe. There is also evidence for the existence of partially ionized atoms ($He^+ \approx 10\%$, Fan *et al* 1984, Hovestadt *et al* 1981). These two features are hard to explain if acceleration occurs high in the atmosphere.

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2. Energy Spectra.

Energy spectra of energetic particles recorded in the i.m. follow a power law that varies with time (as the result of scattering in the i. m.). The source spectra of particles are generally derived from the different energy-band maximal intensities, whatever their times (Bryant *et al* 1964). These spectra must be corrected : for instance, for isotropic diffusion, we have :

$$I = \frac{N v}{32\pi(\pi\lambda v t/3)^{1.5}} exp(-\frac{3r^2}{4\lambda v t})$$

where N is the total number of particles in a given energy band, *t* the time, *v* the velocity, λ the mean free path, r the distance from the source, and I the intensity).

With this formula, if λ is the same for all energies, the above profiles are the same as functions of the travelled distance *vt* within the factor *Nv*. So the spectrum formed with maximal intensities must be corrected by a *1/v* factor. Then the source spectra of the i.m. particles often follow a power law and indicate, in all cases, **a small traversed material.**

We conclude that in the i. m., energetic particles have the characteristics of both : the HIGH atmosphere (spectrum) and the LOW atmosphere (composition). Moreover, the very existence of partially ionized He requires a low origin on one hand, and the absence of any interaction with the atmosphere on the other hand.

III. THE PROPOSED MODEL

As a solution of the above problems, we propose a plasmoid (magnetically isolated structure) that originates deep in the solar atmosphere and rises under magnetic and buoyancy forces (Heristchi *et al* 1988 and Figure 1).

a/ Basic Features :

It confines particles (mostly electrons) but releases high energy protons which interact with the atmosphere and produce X and γ bremsstrahlung.

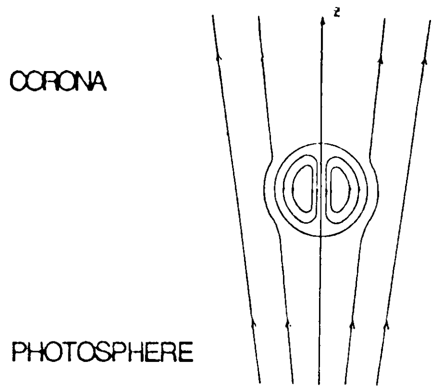

FIG. 1. : Schematic representation of the plasmoid in the solar magnetic field lines.

At the top of the atmosphere, the plasmoid explodes and releases the particles recorded in the i.m. Because of the low average density of the plasmoid, confined particles have weakly interacted with matter. With "reasonable" physical parameters (size and density of the plasmoid, internal and external magnetic fields) the ascent time is comparable with the impulsive phase duration (a few 10s). The average density is estimated as 10^7-10^8 cm^{-3}, the instantaneous density decreasing from

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bottom to top of the atmosphere, because of the volume increase.

b/ Dynamics of the plasmoid :

The dynamics of the plasmoid (Raadu *et al* 1987) can be written as :

$$M_{eff} f = D\, grad \mid B \mid - MnVg + M_i n_i V g$$

where M_{eff} is the effective mass of the plasmoid, MnV the mass of volume V with ambient density n and $M_i n_i V$ the plasmoid mass; *f* is the acceleration term. The first term on the right-hand side is the magnetic force (D is the equivalent dipole), the second and third ones are the buoyancy and gravity forces respectively. Neglecting the gravity term (see above) and assuming an exponential law for the field opening (with scale height H), we arrive at a simple equation relating the velocity of the plasmoid with the initial Alfven velocity and H. Figure 2 shows that an ascent time of about 30s can be reached with an Alfven initial velocity of a few 100 km/s and a scale height less than 10000 km.

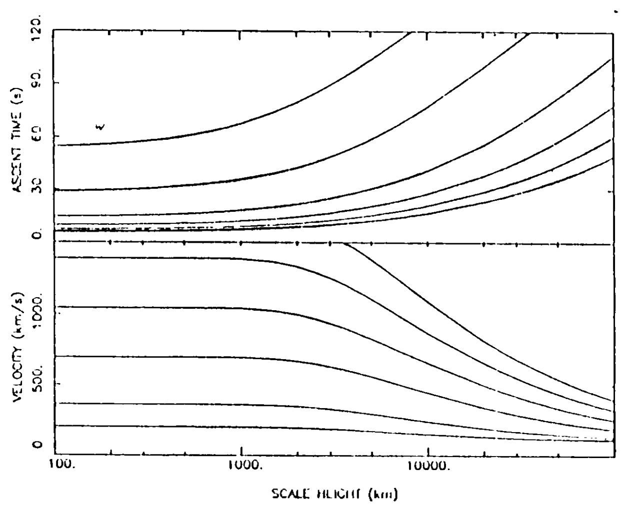

FIG. 2. Variations of the ascent time and the terminal velocity, taken at a height of 10^4 km, versus the magnetic scale height for different initial Alfven velocities. Alfven velocities have values of 50, 100, 200, 300, 400, 500 km/s for decreasing times (increasing velocities).

IV. CONSEQUENCES OF THE MODEL

The properties of the plasmoid in relation to the particle transport and release in the solar atmosphere can be summarized as follows :

1/ **Protons**, nuclei (e. g. ^{3}He, partially ionized particles) are extracted in the low atmosphere. 2/ They are stored in the magnetic bubble. 3/ They can partially -but gradually- escape in the atmosphere. 4/ Interacting with the atmosphere, particles (especially protons) create γ and X rays bremsstrahlung (proton-electron) . 5/ Electrons are confined. 6/ Particles left are ejected in the i. m. 7/ Particles have stayed a constant time in the plasmoid. 8/ Microwave emission results from knock-on electrons. 9/ The p/e ratio may be very variable, as observed (Lin 1973).

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V. CONCLUSION

As far as energetic particles in the i. m. are concerned, the proposed model solves the problem of : ° **the chemical and isotopic composition** and ° **the energy spectra.** As a result of the constant time spent by energetic particles in a low density medium, the traversed material is small. The spectra of energetic particles differ only slightly from a power law. Figure 3 compares the spectra of electron and proton which have traversed a constant thickness of material or have stayed a constant time in a given medium (plasmoid).

Fig. 3a.

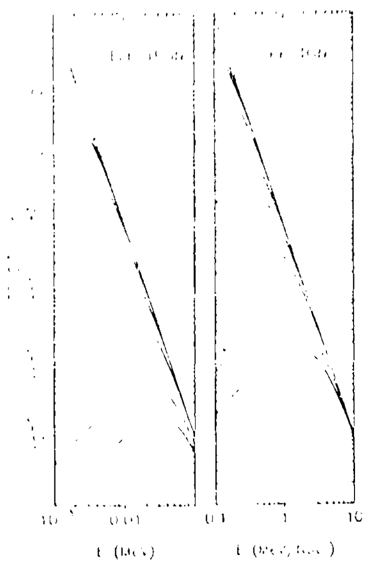

Fig. 3b.

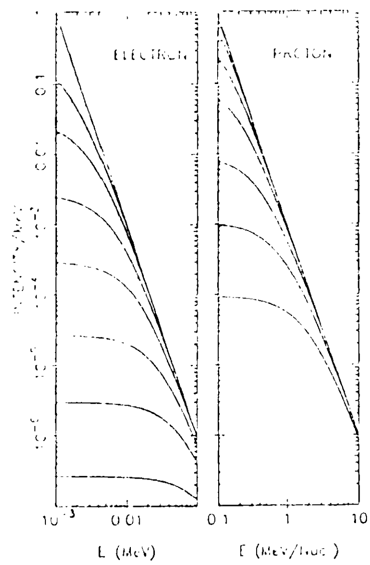

FIG. 3. Computed spectra of electrons and protons having traversed a medium of constant thickness x (Fig. 3a) or having stayed a constant time, given here by the column mass traversed y (Fig. 3b). From top to bottom, x increases from 0 to 10^{-3} ($5\ 10^{-7}$, 10^{-6}, $3\ 10^{-6}$, 10^{-5}, $3\ 10^{-5}$, 10^{-4}, $5\ 10^{-4}$) and y from 0 to 10^{-2} (10^{-5}, $3\ 10^{-5}$, 10^{-4}, $3\ 10^{-4}$, 10^{-3}, $3\ 10^{-3}$) $g\ cm^{-2}$.

In the second case (plasmoid), the importance of the traversed material is significantly reduced. This result is a basic feature of our model.

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