ON THE POSSIBILITY OF LOCAL MAGNETIC FIELD INTENSIFICATION IN EVAPORATING CHROMOSPHERIC SOLAR FLARE PLASMA

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The investigations of plasma motions at the initial phases of solar flares (Antonucci and Dennis, 1983; Doschek, 1983; Watanabe, 1987) suggest evaporation from the chromospheric flaring area. According to de Jager (1983) when seen at the limb the evaporated plasma will look like a "convective plume" and it can be seen separated from heated footpoint areas.

The subject of this work is the study of the possibility of forming hydrodynamic structures of thermal and starting plume's kind at the time of evaporation of the upper chromosphere in a flaring area. Also the possibility of increasing an initial magnetic field by a periodically moving vortex in a plume structure is investigated.

Doschek (1983) points out that both random mass motions and upflowing plasma are evident during the rise phase of many flares. According to Antonucci and Dennis (1983) the soft X-ray plasma at the fla e onset consists of two basic components: a dynamic component that later disappears, and a stationary component that is present throughout the event. They come to the conclusion that dynamic component is due to a chromosphere evaporation resulting from the energy deposition during the impulsive phase. From analysis of hard X-ray spectra they obtain plasma upward velocity of 310 km s^{-1} at temperature of 1.4×10^{7}K and turbulent motions in the coronal plasma at 130 km s^{-1}, and draw the conclusion that chromospheric evaporation lasts throughout the impulsive hard X-ray burst.

Velocity of 200 km s^{-1} for temperature pulse $\Delta T=4\times10^{6}$ K can be derived on the base of simple theoretical considerations (de Jager, 1983).

It is well known from hydrodynamics that when a volume of fluid is forcibly ejected into a quiet homogeneous medium a vortex ring is formed in which the vorticity is concentrated within a sharp core. Hydrodynamics provides some interesting results associated with the buoyant vortex structures, such as plumes, thermals and starting plumes generated by a finite source which emits flu of mass and momentum at a steady rate, as well as buoyancy (see for example Turner, 1973).

These observational and theoretical considerations lead to the idea that it is possible, in definite initial conditions, the heated footpoint areas of a flare to be treated as sources of momentum and buoyancy and the moving upward evaporated chromospheric plasma as a forced plume, or "convective plume" as de Jager (1983) proposed to call them. Then from such point of view we can define some of the physical characteristics of these hydrodynamic structures.

If the vorticity is assumed to be uniformly distributed over the cross-section of the vortex the isolate vortex ring moves forward in axial direction at velocity (Lamb, 1945)

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(1) $\dot{z}=\Gamma(4\pi R)^{-1}[\ln(8R/\delta)-1/4]$

where Γ is the circulation around the vortex ring, δ is the size of the vortical core, and R is the radius of the ring. The center of the vortex will perform a periodic motion immediately after its release at the moment t_1, with the following velocity components (Tung and Ting, 1965).

$$\dot{x}=U_0[1-\cos\omega(t-t_1)]+V_0\sin\omega(t-t_1)$$
(2)
$$\dot{y}=V_0[1-\cos\omega(t-t_1)]+U_0\sin\omega(t-t_1)$$

with the frequency of oscillations $\omega = \Gamma/(8\pi\nu t_1)$. U_0 and V_0 represent, respectively, x and y components of the local mean velocity at the instant $t=t_1$.

The effective size of the core is

(3) $\delta=2(\nu\tau)^{1/2}$ where

(4) $\tau=\int_0^t R^{\circ}(t')dt'/R^{\circ}(t)$ and ν is the kinetic viscosity.

In the case of source's dimension $L_0=3\times10^3$ km and plasma velocity $V=200$ km s^{-1} we compute dz/dt, δ, ω at three different temperatures of evaporation, respectively $T=10^6$, 1.4×10^6 and 10^7 K. The results obtained are shown on Fig. 1a, b, c. From these figures may be drawn the conclusion that by increasing the source's temperature the characteristic size of the vortex core δ increases while the vortex raise velocity dz/dt and the period of its oscillations decrease. It is curious to note that at $T=10^7$ K in 60 s the characteristic size δ is about 2500 km. The dimensions and the duration of such a structure are near to those of the so called magnetic transients first mentioned by Patterson and Zirin (1981) and Zirin and Tanaka (1981).

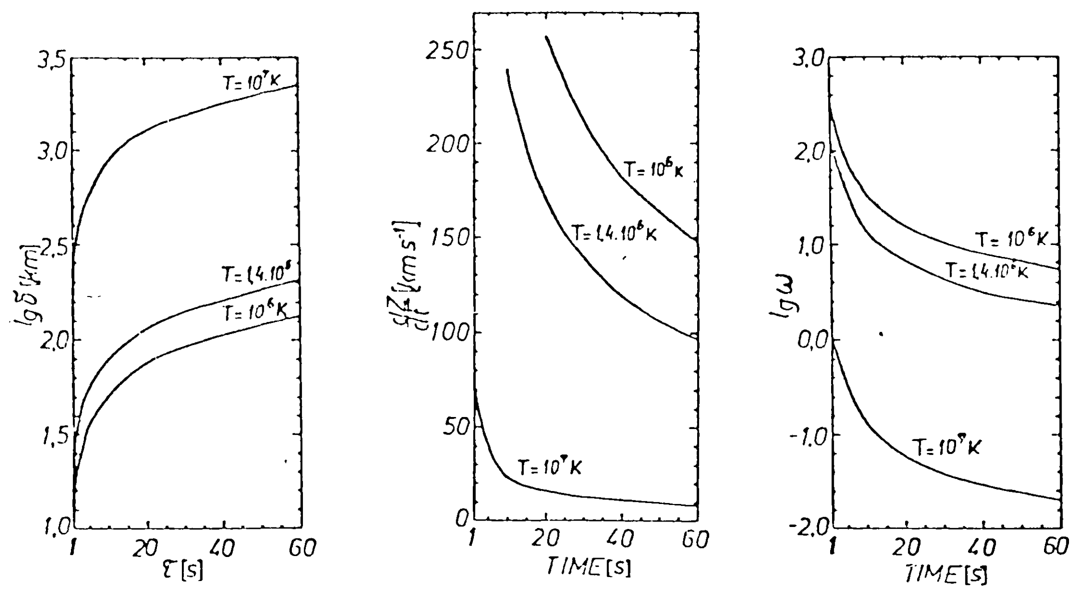

Fig. 1

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We restrict the problem to the study of a plume structure with a characteristic dimension L=3000 km and time of existing of about 60 s. We suppose that the time for forming the structure is equal to its duration. Later we suppose the possibility of forming toroidal vortexes whose core's characteristic dimensions considerably depend on the temperature of chromospheric evaporation (see Fig.1a). For example at $T=10^7$ K some seconds after the vortex is formed its characteristic dimension is already 500 km, its velocity is of the order of 60 km s^{-1} and the oscillation period is about 5 s.

We are starting from the equation of generation of a magnetic field in a given moving media for which the correlation time of the velocity field's components is small (Molchanov et al., 1983). In the case of an isotropic symmetric flow it is reduced to the well-known equation of Steenbeck-Krause-Raedler

$$\frac{\partial \vec{B}(t,\vec{x})}{\partial t}=\alpha \, rot\vec{B}+\beta\Delta\vec{B} \tag{6}$$

$$\alpha=-\frac{\tau}{3}\langle\vec{v}\, rot\vec{v}\rangle , \quad \beta=\nu_m+\frac{\tau}{2}V_o^2$$

where τ is the correlation time, v is the characteristic velocity of the short correlative velocity field, and ν_m is the magnetic diffusion coefficient which is considered to be constant.

In the case of an isotropic mirror-unsymmetric flow the characteristic time for the increase of the magnetic field is proportional to $\tau V_o/\alpha$, i.e.

$$t_G=\frac{k\tau V_o}{\alpha} \tag{7}$$

where k is constant. In order to eliminate the necessity of a detailed description of the media's motion from (7) we define

$$\alpha=k\frac{\tau}{t_G}V_o \tag{8}$$

For an initial magnetic field B=0.002 T located in an initial motionless atmosphere, similar to the upper chromosphere, at fixed boundary conditions (2) the velocity field is defined by solving the equation for conservation of momentum and the equation for conservation of mass on a two-dimensional network with a step $\Delta x=\Delta y=10$ km. Two- steps Lax-Wendroff scheme is chosen. Afterwards, on a three- dimensional network with step $\Delta x=\Delta y=\Delta z=10$ km the equation (9) was numerically solved. A modified scheme, in which the terms describing the diffusion are approximated by the method of Dufort-Frankel, was used.

We simulate a short-time correlated velocity field (τ=5 s) with a period of oscillation Π=0.1 s, varying the initial velocity components from 60 to 200 km s^{-1}. The coefficient k and the time for the increase of the magnetic field t_G have been selected so that the first term's coefficient on the right of equation (6) exceeds the second term's coefficient. The characteristic velocity $V_o(\vec{x})$ has been computed as a mean square of the velocity components for every junction of the network.

All variants of the numerical experiment produced the similar result: the initial magnetic field does not change. In the case of an initial magnetic field decreasing in height an effect of bringing-out stronger magnetic field to areas of weaker field can be observed.

Probably, the problem of the behaviour of a small scale

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magnetic field will find its solution when a way for a detailed study of plasma dynamics in small-scale eddy structures is found. Suggestive in this respect are the results from some laboratory plasma experiments carried out during the 60's and 70's. For instance, lab experiments described by Komelkov et al. (1960), Vasiliev et al. (1960) and Komelkov et al. (1962) show that in different plasma configurations comparatively stable plasma structures are formed. The authors described them as dynamic stable current filament coaxially surrounded by plasma. In the most general case such structures originate in toroidal votexes. They exhibit a proper longitudinal and azimuthal magnetic field of approximately equal value of the order of 10^2 to 10^4 Gauss.

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