# HYDROMAGNETIC INTERPRETATION OF SHORT TIME SCALE STRUCTURES IN SOLAR FLARES

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**ABSTRACT. Hydromagnetic interpretation of the solar flare short time scale structure indicated in microwave and hard X-ray emission during the impulsive phase is presented. The main assumption is that the plasma ejection from the current sheet may be considered as a forced convection by an isolated source. From this point of view some analogies with small scale short lasting hydrodynamic and laboratory plasma structures are drawn.**

ГИДРОМАГНИТНАЯ ИНТЕРПРЕТАЦИЯ КРАТКОВРЕМЕННЫХ СТРУКТУР В СОЛНЕЧНЫХ ВСПЫШКАХ: Представлена гидромагнитная интерпретация кратковременных структур в солнечных вспышках, которые наблюдаются во вреня импульсивной фазы в микроволновом и жестком рентгеновском излучении. Главное предположение состоится в том, что выброс плазмы можно рассматривать как вынужденную конвекцию изолированным источником. С такой точки зрения делаются аналогии с некоторыми мелкомасштабными кратковременными структурами в гидродинамике и лабораторной плазме.

**HYDROMAGNETICKÁ INTERPRETÁCIA KRÁTKOTRVAJÚCICH ŠTRUKTÚR V SLNEČNÝCH ERUPCIÁCH. Krátkotrvajúce štruktúry v slnečných erupciách sú indikované emisiou v mikrovlnnom a tvrdom rontgenovom žiarení počas impulznej fázy erupcie. V príspevku je uvedená hydromagnetická interpretácia týchto krátkotrvajúcich erupčných štruktúr. Hlavný predpoklad zavedený v práci pre výron plazmy z prúdovej vrstvy je predpoklad o vynútenej konvekcii, ktorá je spôsobená izolovaným zdrojom. Uvedené sú analógie s niektorými rozmerovo malými a krátkotrvajúcimi štruktúrami v hydrodynamike a v laboratórnej plazme.**

## 1. INTRODUCTION

**Already the early analysis of the hard X-ray emission (Frost, 1969; Van**

Beek et al., 1974; De Jager et al., 1976) has shown that the impulsive phase of solar flares involves a great number of events of a relatively short duration. The term "elementary flare burst" (Van Beek et al., 1974) was introduced in order to make a difference between the individual and similar in form "spikes" of a duration from 5 to 20 sec, measured in hard X-ray fluxes.

Later on, the rapid variations in the millimeter-wave radio-flux were interpreted (Kaufman et al., 1980) as effects of subsequent superposition of individual "sub-bursts" of time scales of about 50 ms. The same time scale was determined also for the fluctuations in the hard X-ray flux, measured during the experiments on the Solar Maximum Mission (Kiplinger et al., 1983).

Recently, Sturrock et al. (1984) have identified four phases of different time scales of the energy release in solar flares. According to them, each of these phases is characterised by the action of specific physical processes. They suppose that the energy release of the elementary magnetic tube produces an elementary burst, lasting about several seconds. The formation of magnetic "islands" during this process is considered to be the reason for the generation of sub-bursts, generally lasting parts of the second.

This work refers to short time scale structures, observed during the impulsive phase of solar flares. In the following sections we make an attempt to show that, from the point of view of hydrodynamics and laboratory plasma physics, the formation of small scale magnetic structures of short duration is possible during this phase.

## 2. HYDROMAGNETIC INTERPRETATION

The large scale magnetohydrodynamic interchange instability (Pikel'ner and Tzitovich, 1973; Parker, 1973) can be considered as the basic mechanism of plasma ejection from the current sheet of a solar flare. The hot and dense plasma outflows with a velocity close to the Alfvén velocity $V_A$ in the cooler and less dense surrounding medium. Due to the limited thickness of the current sheet this ejection can be viewed as a forced convection by isolated source. From such a point of view the problem of formation of small scale short lasting structures in solar flares is reduced to the problem of the "onset of turbulence", i.e. to the study of the way in which a flow "jumps" from a quiet stable laminar state into a turbulent state.

Numerical computations have shown that the onset of turbulence in the Lorenz system (Lorenz, 1963) is characterized by the fact that the trajectory of the chaotic motion, after some transients, rapidly reaches an "attractor" which does not depend on the initial conditions and is structurally stable. However, even a simple phenomenological consideration of the properties of a fully-developed turbulence, in particular the question of intermittence, or in other words the spottiness of small scales, is a rather complicated task.

Without going into details we can consider the ejected plasma as a turbulent flow, generated by a finite source which emits fluxes of mass and momentum at a steady rate, as well as buoyancy. Morton (1959) has shown that such

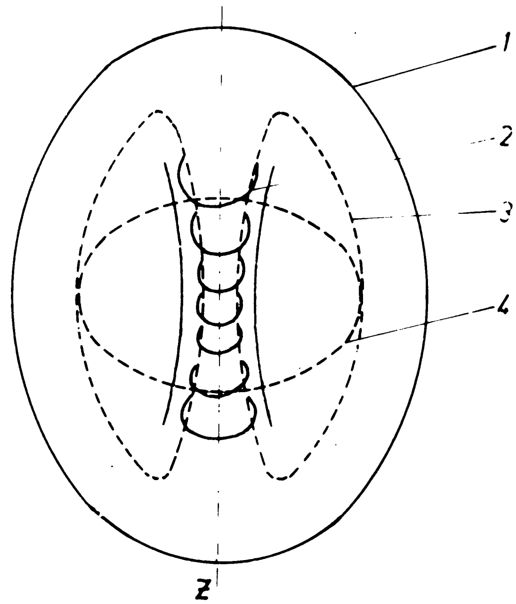


Fig. 1: Structure of the electric currents and magnetic fields in a plasmoid, cut off from the plasma jet. 1 - plasmoid, 2 - internal current helix, 3 - longitudinal magnetic field, 4 - azimuthal magnetic field (according to Komelkov et al., 1962)

a general flow, called by him a forced plume, can be considered as a flow from a virtual point source of momentum and buoyancy only. These turbulence flows in fluids are rather well studied theoretically and experimentally (see Turner, 1973 and the references there).

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. It can be turbulent and in this case the radius of its cross-section increases, remaining nearly proportional to the radius of the ring. The core is carrying along with it a spheroidal region of nonbuoyant fluid which is very similar in shape to the thermal.

The impulse in vortex rings and Hill's spherical vortexes in ideal fluid depends only on the full vorticity and the radius (Lamb, 1932; Turner, 1957), while the energy depends mostly on the vorticity distribution in the moving region. The form of this region strongly depends on the ratio R/A, where R is the radius of the region where the vorticity is concentrated, and A is the radius of the circular-shaped section of the region where the vorticity is uniformly distributed. For small values of R/A the shape is like an oblate

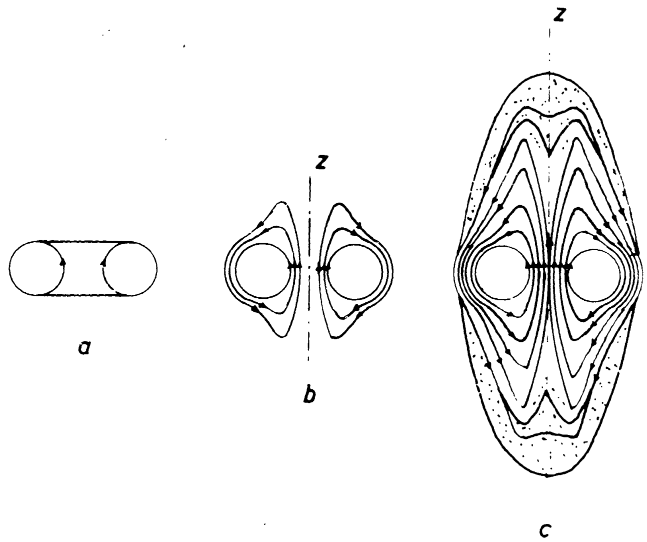


Fig. 2: The possible development of a toroidal vortex structure

spheroid and the vorticity is concentrated in the core of the vortex structure. According to Turner (1957) these regularities do not obviously depend on the physical properties of the medium. They are equally valid for gaseous as well as liquid media, but they depend essentially on the way of ring formation and the subsequent vorticity distribution.

The matter ejected at a velosity $V \sim V_A$ from the current sheet is hotter and denser than that in the magnetic tube outside the sheet. In this case, from the point of view of hydrodynamics of convective flows from isolated sources, it is possible, in definite initial conditions, gradually decelerating turbulent vortex structures to be formed, which resemble a flat spheroid with vorticity concentrated in the core.

On the other hand, the laboratory plasma experiments also show that relatively sta ble plasma structures, called dynamic stable current filaments, are formed in different plasma devices (see for example Komelkov et al.,1960). In the most general case such structures originate in toroidal vortexes. They exhibit a proper longitudinal and azimuthal magnetic field of approximately equal value of the order of $10^2$ to $10^4$ gs. The longitudinal field is recorded from 2 to 3 $\mu$s after the generation of the discharge in the chamber. The source of this magnetic field is a dynamically stable current filament with a helix-shape cord, located along its axis. The latter is observed as a source of hard X-ray emission reaching 200 - 250 keV. These current filaments are stable over a wide time range (5 - 200 $\mu$s), pressure ($10^2$ - $10^6$ dyn/cm$^2$) and

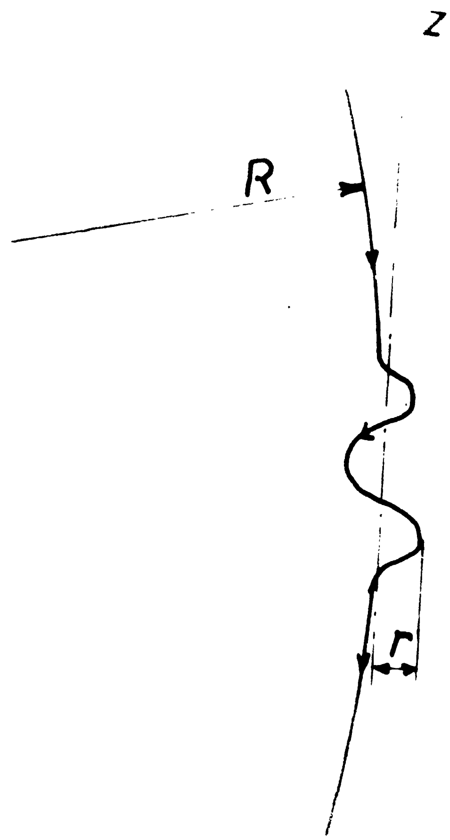


Fig. 3: Curving of a current line.

density ($10^{-10}$ - $10^{-3}$ $g/sm^3$) of the plasma; the geometric size of the chamber has a slight influence only. Figure 1 shows the structure of currents and magnetic fields in a plasmoid, cut off from the plasma jet, according to Komelkov et al. (1962).

From the point of view of hydrodynamics and laboratory plasma physics it is possible to explain qualitatively the mechanism of formation of similar plasmoids during the impulsive phase of a solar flare. The energy release in the elementary magnetic tube may lead to the formation of toroidal vortex structures. In the case when $R/A$ is small enough, the vorticity will be concentrated in the core of the structure. The possible development of such a vortex is illustrated in Figure 2.

The concentration of the vorticity in the core creates conditions for the curving of the current lines, as a result of which a helix cord is formed in the direction of the axis of the plasma structure. This is very important for the further evolution of the vortex structure. Since the direction of the centrofugal force does not coincide with the direction of the magnetic field, a drift motion of velocity $\vec{U} = \vec{f} \times \vec{B}/m\omega B$ (Pikel'ner, 1969) will arise. The sign of the angular frequency of the circular motion $\omega$ is different for electrons and ions, so that the electrons will drift in a direction opposite to that of ions. As a result, electric current along the cord will flow, which causes the induction of a longitudinal magnetic field. In the most general case it can be assumed that when such a vortex is deformed and lengthened along the axis Z /see Fig. 2), its induction increases.

The general magnetic field can be expressed by the formula $B = B_\varphi - \mu B_z/R$, where $B_\varphi$ and $B_z$ are the azimuthal and longitudinal magnetic fields respectively. The sense of the quantities R and $\mu$ is illustrated on Figure 3.

## 3. DISCUSSION AND CONCLUSIONS

In this investigation we do not propose any model for the small scale short lasting structures of the solar flares. We only make an attempt to show one possible connection between the process of interchange instability in current sheet, which is probably going on in the solar flares, and the small scale short lasting accompanying events, which are observed in hard X-ray and microwave emission.

Recently, some discrete structures, observed in the resonance line Ca XIX during the impulsive phase (Doyle and Bentley, 1986) have been interpreted as random plasma flows of a velocity from 50 to 200 km/sec. The way in which such a plasma flow "jumps" from a laminar into a turbulent state has not been studied yet, but from numerical experiments it is known that during the onset of turbulence in Lorenz system (Lorenz, 1963) the trajectories of the chaotic movement rapidly reach an "attractor", which does not depend on the initial conditions and is structurally stable.

We try to draw an analogy of the development of turbulence in a random flow, ejected during the impulsive phase of the solar flares, with the formation of the forced plumes or the oblate spheroid-shaped vortexes. The small scale hydrodynamic structures usually transport a very small quantity of energy. However, in the hydromagnetic case the small scale velocity gradients can intensify the magnetic fields, which can result in a drastic change of the properties of these structures.

A number of laboratory plasma experiments on the development of a stable pinch effect imply the possibility relatively stable short-lived small scale plasma structures to be formed, in which a proper magnetic field is generated. In particular, such structures can be observed when a plasma "cluster" is aqueezed through a slit, more stable filaments are formed when an external longitudinal magnetic field is applied (Coltage et al., 1958; Bezbatchenko et al., 1956).

One may expect by analogy that the solar flare plasma would exhibit similar properties during the impulsive phase. Similarly, in the region of current conducting turbulence a significant electric field of short duration is possible to be maintained, which suggests a possible particles acceleration mechanism. However, in order to completely elucidate the problem, a detailed theoretical investigation on the subject would be necessary.

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