# SELF-SIMILARITY OF PLASMA NETWORKING IN A BROAD RANGE OF LENGTH SCALES: FROM LABORATORY TO COSMIC PLASMAS

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## 1. Introduction

The filaments of electric current are known to be able to sustain their integrity as long as the plasma itself exists [1,2]. However, the role of filamentation in global plasma dynamics seems to be not recognized in full. Really, existing numeric hydrocodes for modeling the most of plasmas consider the plasma as a non-filamentary medium. There was a number of attempts to treat the plasma as a set of topologically one-dimensional filaments (fibers) of electric current interacting with each other; however, this appeared to be still insufficient for overcoming existing difficulties in predicting global behavior of plasmas.

The present paper is based on the results of a high-resolution processing, called a method of multilevel dynamical contrasting [3], of numerous data from laboratory electric discharges and observations of cosmic plasmas to demonstrate the networking of electric currents in plasmas in a very broad range of length scales.

## 2. Hierarchy of plasma networking

This includes the following levels of self-organization in plasmas.

**(1) Filamentation of electric current.** The lowest level pertains to the well-known fact of the filamentation of electric currents [1,2]. It follows that as far as the filaments are formed at the very birth of plasma, there is no sense to treat filamentation as a self-organization of the originally non-filamentary plasma: vice versa, one may treat conventional, non-structured plasmas as a limiting case of the microscopically filamented plasmas.

The interpretation of the filament(s) of emissivity is a complicated task. However, in what follows we will associate the term «filament» with a fiber of electric current. Fortunately, major conclusions about plasma structuring appear to be rather insensitive to rigorous mathematical definition(s) of the filament. Indeed, the data suggest that each individual filament is formed by at least a couple of the mutually wound sub-filaments to make the filament stable and elastic both in transverse and longitudinal directions. The interchanging of sub-filaments within the filament (Fig. 1, left) makes them identical and substantially increases the stability of the filament. The thinnest filaments resolved in laboratory plasmas produce a damage of the micrometer size scale at the surface of the electrodes. It was found [2] that with increasing electric current the projection of the interior of the electron beam filament gives a circle with a spot in the center. This is compatible with the transverse projection of the two mutually wound sub-filaments (Fig. 1, left). Tracing the dynamics of filaments in Z-pinch discharges, from the very early stage of implosion up to compression of filaments at stagnation stage, clearly shows that the strongest filaments may retain their integrity during all the time of electric discharge [3].

**(2) Fractality of individual filament.** The filament tends to make its internal electric currents (i.e. its sub-filaments) magnetic-field-aligned (Fig. 1, left) and, regardless of internal structure of sub-filaments, possesses magnetic torsion which is acquired at filament's birth and evolves in time. The accumulation, above some threshold, of the energy of filament's local torsion releases in forming a compact, twisted loop which branches off the filament's main line, roughly in perpendicular direction (Fig. 2, center). This forms an almost-closed helical heterogeneous magnetoplasma configuration (we called this configuration a *heteromac* [3]). Such a branching off makes single, originally one-dimensional filament (Fig. 2, left) a fractal, *tree-like* structure (Fig. 2, right). Significantly, the observed branching suggest that the elasticity of the filament is, to a large extent, similar to that of the ordinary elastic thread with relatively free end points because the thread, if being enough twisted, produces the same structure. Figure 3 (of size 0.8×0.6 cm) shows formation of distinct heteromacs on the individual filament (cf. Fig. 2, center) resolved in its visible-light self-emission at initial stage of Z-pinch discharge (for Z-pinch experimental conditions see [3,4]).

The filament, and its internal structure, of much larger length scale, and observed in other frequency range, can be found in a processed image [3] (Fig. 4) of the ultraviolet picture of the Sun taken from [5]. This is to illustrate the hypothesis of *dark filaments* in cosmic space

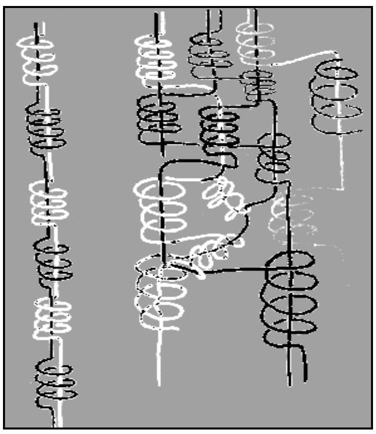

**Fig. 1**

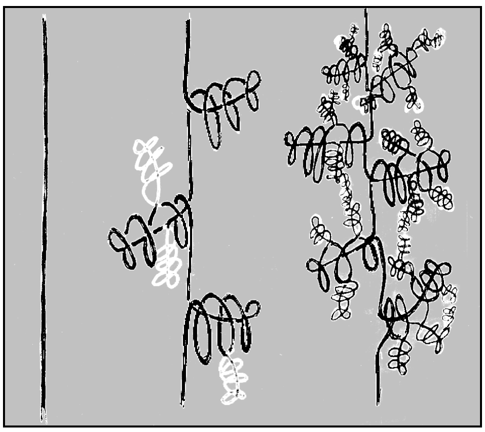

**Fig. 2.**

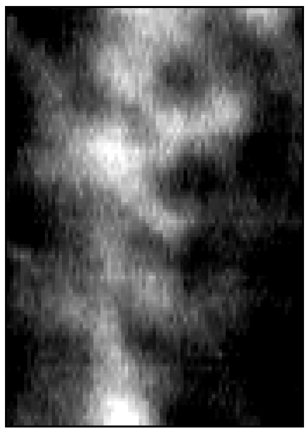

**Fig. 3.**

suggested by the extending the approach [3], formulated originally for laboratory plasma, up to maximal identified length scale in the universe, thus extending the pioneering approach by H. Alfvén [6] (see Sec. 6 in [3]). The matter is that the stellar objects look like being incorporated into a unified network and, thus, either belong to a local thick filament or are entered by the thin filaments (see also Fig. 20 in [3]). Very often the sequence of stars indicates their mother (dark) filament quite similar to the layout of hot spots at individual electric current filament in laboratory plasmas (see [3,4]).

**(3) Networking of filaments.** In laboratory plasmas the networking of filaments starts from the very beginning of discharge and very often leads to formation of the stocking(s) which is/are *regularly* woven by the individual filaments (see Fig. 1 in [4]). The interchanging of sub-filaments inside the filament (Fig. 1, left) looks like merely an internal networking of the filament. Numerous exciting examples of networking may be found in cosmic space. For instance, the arm of spiral galaxy usually looks like a branch of a tree with the stars being the «fruits» illuminating the fine structuring of the arm. Unlike purely gravitational picture, there may be seen the sequences of stars directed roughly perpendicular to galaxy's arm (i.e. the heteromacs): see an arrow on the upper boundary of Figure 5 which shows a processed image of the spiral galaxy M100 (the original is taken from the Hubble Space Telescope gallery [7]). At the periphery of the galaxy (on the right-hand side marked with lines on the top and bottom) the image is inverted to show the integrity of networking inside and outside the galaxy's core . Also a number of unexpectedly long, almost rectilinear formations («needles») may be seen (e.g. along the direction marked on the left- and right-hand sides; see [3,4] for more details).

**(4) Fractality of the entire plasma.** This implies the self-similarity of the building blocks of the network at essentially different length scales. For instance, the entire plasma formation may have the form of few filaments only or even of a single one (the well-formed Z-pinch at stagnation stage often resembles a single filament). And vice versa, the individual filament has a complicated internal structure which tends to take the form of a fractal force-free-like configuration. It is the fractality and the strong deviation from the LTE that make the filaments visible in a broad spectroscopic range of emitted radiation.

**(5) Percolatory networking and plasma synergism.** And, finally, the long-range bonds provided by the filaments make the network of electric currents in the plasma a *percolating network*. The strongest filaments form a backbone component of the entire network (this works like a *central* nerves system of the plasma body) whereas the weaker filaments form a local order within the entire network (this works like a *peripheral* nerves system). The percolation in plasmas is based mostly on the long-living structures rather than the fluctuative, essentially chaotic formations so that the interpretation of structuring in plasmas in terms of the turbulence in the fluid-like plasmas should allow for the anomalous survivability of filaments. Thus, the self-organization goes far beyond the fractality as itself. The above sequence of processes -- from forming the proto-filaments to networking of filaments to give the filament-made stocking(s) -- may be considered as a self-organization cascade in a wide range of length scales. The resulting synergism may be illustrated with the fact that sometimes plasma formations resemble biological structures.

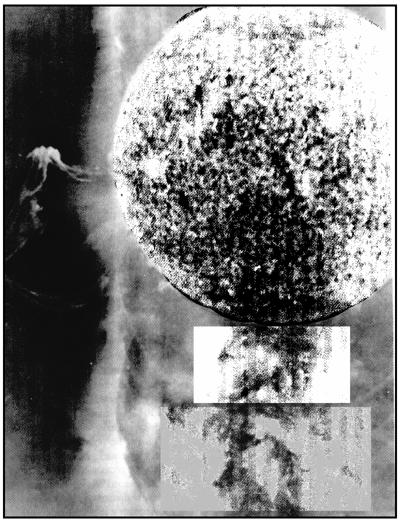

**Fig. 4.**

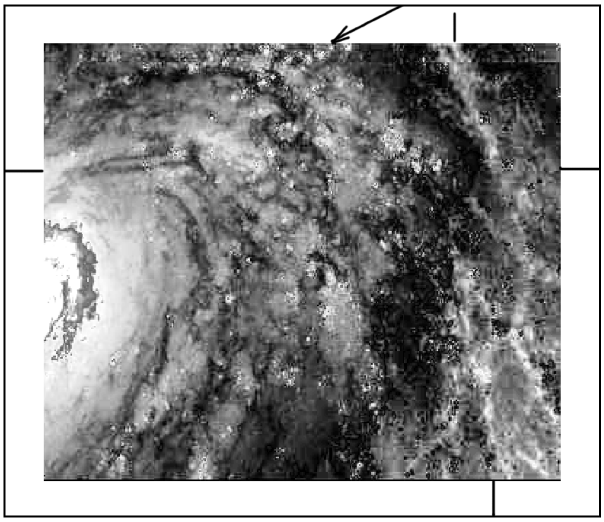

**Fig. 5.**

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