

Microsolid Tubular Skeleton of Long-Living Filaments of Electric Current in Laboratory and Space Plasmas

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1. Introduction

Recently the self-similarity of plasma structuring, in a very broad range of length scales and macroscopic densities of electric current, and the unexpectedly high survivability of long-living filaments (LLFs) of electric current have been revealed [1,2] in analyzing laboratory and cosmic plasmas with the help of the method [1,2] of the multilevel dynamical contrasting (MDC) of images. This enabled us to come to a conclusion [3,4(a)] that only the quantum (molecular) long-range bonds inside LLFs may be responsible for their observed survivability, rather than the mechanisms of a classical particles plasma. Specifically, the carbon nanotubes have been proposed to be the major microscopic building blocks of the respective microsolid component of LLFs, and the probable mechanisms of assembling a number of self-similar structures have been described [3,4(a)]. The special role of the tubular structures for the successive buildup of generations of self-similar structures and the probable mechanisms of survivability of quantum-long range bonds in a high-temperature plasma environment have been discussed briefly in [4(b),5]. The above hypothesis is supported by the numerous examples of tubular and fullerene-like structures in a broad range of length scales, including cosmic length scales (e.g. in the NASA Hubble Space Telescope database [6]), that have been found with the help of the MDC method (see [3-5]).

The present paper gives typical example of an LLF in the laboratory Z-pinch discharge and an example of the structure of a regular geometric form of cosmic length scales. Also, an estimate is given of the particle number (and mass) of the skeleton of the observed LLFs, which is based on the concept of generations of self-similar tubules [3-5].

2. Long-living rigid-body blocks of LLFs: evidence for anomalous survivability

The strongest evidences for the anomalously high survivability of LLFs come tracing the history, within reasonably long time, of a formation which can not be cast into the frames of conventional MHD picture. This appears to be the case when the filamentary formation contains a long-living rigid-body block(s). Figure 1 shows a short movie composed of the visible light pictures of a part of the gaseous Z-pinch, taken at four different time moments and different observation angles (for experimental conditions see [1,2(b)]). Note that the stick which is seen at all the pictures is located roughly perpendicular to the major direction of the Z-pinch electric current (Fig. 1(c) coincides with Fig. 7 in [2(b)]). Similar sticks may also be seen in Figures 5(a), 6, 10, and 11(a) in [1]. The lifetime of the sticks which are directed roughly perpendicular to the major current, normally amounts to the entire time of observation (in given case, 500 ns; in general, about one microsecond and more). As to those LLFs which are directed roughly along major current, they appear to be destroyed in the Z-pinch's neck during disruption of the neck (cf. Fig. 9 in [1] and Fig. 8 in [2(b)]).

3. Generations of self-similar tubules and the mass of skeletons

An analysis of self-similarity of the long-living structures of a *regular geometric form*, in a very broad range of length scales, suggests that the self-sustainment of these and other long-

living structures in laboratory and cosmic plasmas is based on the assembling of *self-similar tubules*. The self-similarity of assembling the tubules is based, in turn, on the universal nature of the tendency toward a force-free magnetic configuration that involves not only the classical electric currents in the plasma component of a filament but also the quantum current on the tubular microsolid skeleton of a filament. In laboratory discharges, such a self-organization process starts at the nanometer length scales (i.e. from individual nanotubes) and proceeds with the appropriate alignment and sticking of the nanotubes captured by the electric current at the breakdown stage of the discharge [3-5].

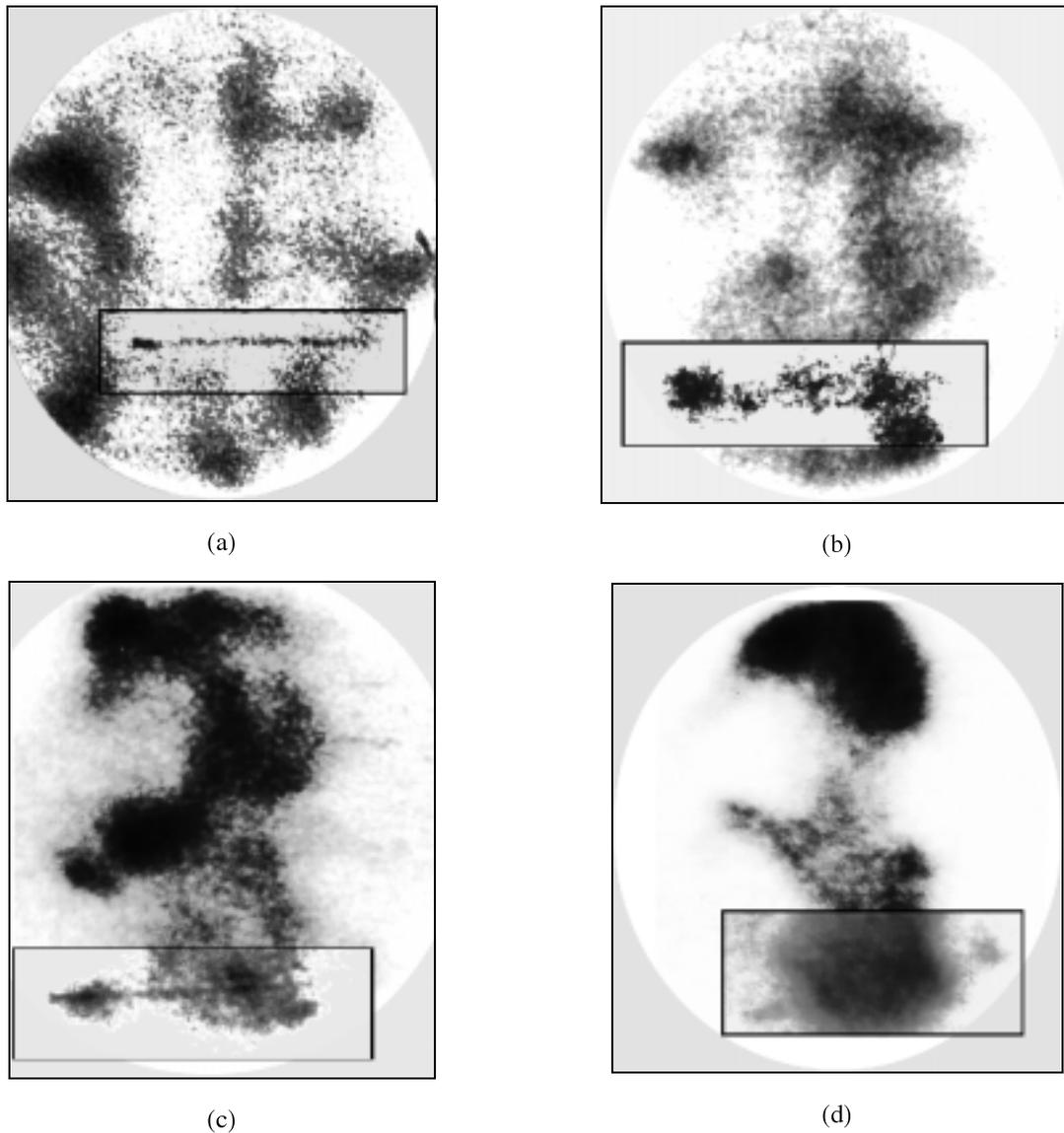


Figure 1. The images of a Z-pinch, taken in visible light and MDC processed. The images are taken at different time moments and different observation angles θ in the plane orthogonal to Z-pinch axis (the circle is produced by the geometry of the optics collecting the light; Z-pinch axis is directed vertically; time t is counted from the major singularity of electric current derivative; circle's diameter ≈ 3 cm; time exposure 60 ns; initial pressure of deuterium gas 1.2 Torr) : (a) $t = -900$ ns, $\theta = 0^\circ$, (b) $t = -750$ ns, $\theta = 60^\circ$, (c) $t = -550$ ns, $\theta = 90^\circ$, (d) $t = -400$ ns, $\theta = 180^\circ$. The windows of the enhanced (a,b,c) and diminished (d) contrasting show the evolution of the rigid-body formation of a needle-like form.

An analysis of the combination of the two following properties, namely (i) mechanical stability of tubular formations and (ii) an ability to assemble larger self-similar tubules (i.e. certain electro-chemical property), suggests that there should be a distinct peaking of the distribution of tubules in their space dimensions, specifically, in tubule's diameter. The respective peaks could be interpreted as a *generations* of self-similar tubules. The fine structure of the peaks around certain generation corresponds to the distinguishable types of structuring. The generations overlap in the «wings» of the respective peaks because the deviations from assembling of a perfect structure (i.e. from what we called a «peak») may produce various «byproduct» structures. Nevertheless, the spectrum of typical structuring around the peak can roughly be divided into three groups.

(A) If tubular structuring produces a tubule which simultaneously possesses the high enough mechanical stability and the open ends (the latter makes the tubule "macro-chemically" active), one has the optimal building blocks for extending the buildup of long-living structures to the larger length scales. We would call such a structure *an optimal tubule*.

(B) The tubular structuring, which starts from smaller diameter of the rolled up layers, as compared to that for optimal tubules, produces quasi-spherical structures. Such a structure takes the form of a closed cage of the fullerene-like topology of the links. These structures possess highest mechanical stability, however they have smaller macro-chemical activity, as compared to optimal tubules. We would call such a structure *a macro-fullerene*.

(C) The tubular structuring which starts from larger diameter of the rolled up layers, as compared to that for optimal tubules, gives elastic, non-rigid formations. We would call such a structure *an elastic tubule*. These tubules may produce elastic filaments and be the basic blocks for more amorphous structures (the latter structures could be, at microscopic level, fragile enough, in order to sustain very high macroscopic elasticity).

The 2-D densities, $n^{(2)}$, of atoms in the walls of self-similar tubules of two neighboring generations, g -th and $(g+1)$ -th, obey a recurrent relation which, for assembling the tubule's wall from hexagons, takes the form ($g > 1$):

$$n_{g+1}^{(2)} = \frac{2\pi}{\sqrt{3}} \frac{N_w}{A_g} n_g^{(2)}, \quad A_g \equiv \frac{L_g}{D_g}, \quad n_1^{(2)} = \frac{4}{3\sqrt{3}L_0^2} \quad (1)$$

where D_g and L_g are, respectively, diameter and length of the tubule of g -th generation, A_g , respective aspect ratio, N_w , the number of the walls in the tubule, and L_0 is the distance between neighboring atoms within the atomic monolayer of the 1-st generation tubules (for graphitic sheets $L_0 = 1.42 \text{ \AA}$).

For the multiplication factor F , which is defined as a step between neighboring generations, one has

$$F_{g,(g+1)} \equiv \frac{D_{g+1}}{D_g} \equiv \frac{L_{g+1}}{L_g} = \frac{A_{g+1}}{\pi} N_{g+1}^{(b)} l^{(b)} \quad (2)$$

where $N_{g+1}^{(b)}$ is the number of blocks (e.g. hexagons) which are intersected by the transverse plane on the surface of the $(g+1)$ -th generation tubule, and $l^{(b)}$ is a reduced transverse length of the block, i.e. the (average) length of the above intersection taken in the units of the length of tubules of previous generation. The value $l^{(b)}$ depends on the geometrical chirality of the tubule and, e.g., for zero chiral angle, is equal to $3^{1/2}$.

Preliminary analysis shows that for the most survivable types of self-similar tubules the value $lg(F)$ lies in the range of two-three units, and the universal behavior of multiplication factor may be true throughout the entire range of length scales, up to galactic (and much

larger) length scales. Though the very mechanism of producing the tubules at largest length scales in cosmic space seems to differ from that in laboratory discharges (as it depends, in particular, on various cosmological issues of the problem), the geometrical similarity of generations may have a universal nature because the latter is determined, to a large extent, by the purely mechanical properties of tubules.

Such an approach suggests that the needle which is seen in Fig. 1, belongs to third generation. Correspondingly, the minimal number (and mass) of carbon atoms needed to assemble the skeleton of this tubule is estimated (see Eq. (1)) to be $\sim 10^{14} \div 10^{15}$ atoms, or equivalently, $\sim 10^{-9} \div 10^{-8}$ g.

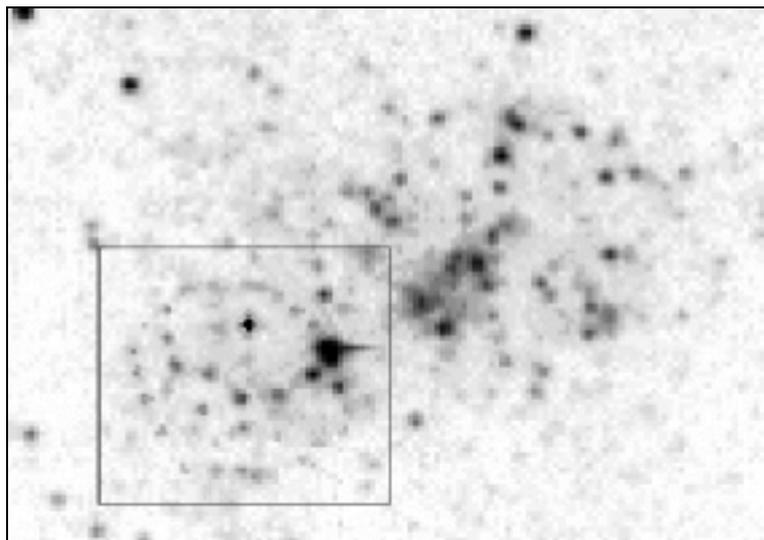


Figure 2. The (MDC processed) image of a cluster of stars in a giant star-forming region, NGC 2363, in the Magellanic galaxy NGC 2366, taken from the image <http://oposite.stsci.edu/pubinfo/pr/96/31.html> in the NASA Hubble Space Telescope Gallery. The formation of interest is marked with a frame (and is located lower the bright starbirth region not shown here).

The most reliable identification of the suggested "quantization" of structuring could be achieved by focusing oneself at observations of spherical cages (i.e. macrofullerenes) as they should have the smallest dispersion of their distribution in diameters. An example of the typical structure which forms in gaseous Z-pinch discharges [1] and resembles a spherical cage is given in Fig. 7 in [5]. However, the most exciting examples of a «quantized» structuring and distinct resemblance to the hexagonal structuring come from the cosmic length scale database. Figures 2 shows typical example of the structure of a regular geometric form with the stars in its vertices.

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