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Similarity of skeletal objects in the range 10^{-5} cm to 10^{23} cm

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Abstract

The similarity of distinctive skeletal structures (namely, cartwheels and tubules) in the range 10^{-5}–10^{23} cm is found. The former analysis of dust deposits in tokamak (10^{-6}–10^{-3} cm) and of electric discharges in tokamaks, Z-pinches, plasma focus and vacuum spark (10^{-2}–10 cm) is extended here to hail particles (1–10 cm), tornado (10^{3}–10^{5} cm), and various objects in space (10^{11}–10^{23} cm). The similarity and the observed trend toward self-similarity within above skeletal structures suggest all of them, similarly to skeletons in the particles of dust and hail, to be basically a fractal condensed matter which, similarly to submicron dust skeletons, is assembled from nanotubular blocks.

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1. Introduction

Observations of transverse-to-electric current, few-centimeters long straight filaments [1,2] of an anomalously long lifetime [3] in the plasma of gaseous electric discharge, a Z-pinch, lead to a hypothesis [3,4] that such filaments possess a microsolid skeleton which might be assembled during electric breakdown from wildly formed carbon nanotubes (or similar nanostructures of other chemical elements). Subsequent analysis [5] of electron micrographs of various types of dust deposits in the tokamak T-10 showed (i) the presence of tubular structures in the range several nanometers to several micrometers, (ii) the predicted [3,4] trend of assembling bigger tubules from smaller ones (i.e., the self-similarity of such tubules), and (iii) topological identity of cartwheel-like structures (often located in the edge cross-section of a tubule) in the above dust and in few-centimeters sized structures found [6,7] in the plasma images in small tokamaks, Z-pinch and plasma focus. Further, the skeletons (tubules and cartwheels of millimeter-centimeter size) were found [7] at electric breakdown stage of discharge in tokamak, plasma focus, and vacuum spark. Thus, the hypotheses [3,4] appeared to have some predictive force. In the present Letter, we show that the phenomenon of such skeletons may likely extend up to length scale of large galaxies.

2. Cartwheel-like structures in the range 10^{-5}–10^{23} cm

We try to draw a bridge between laboratory experiments and space with presenting a short gallery of

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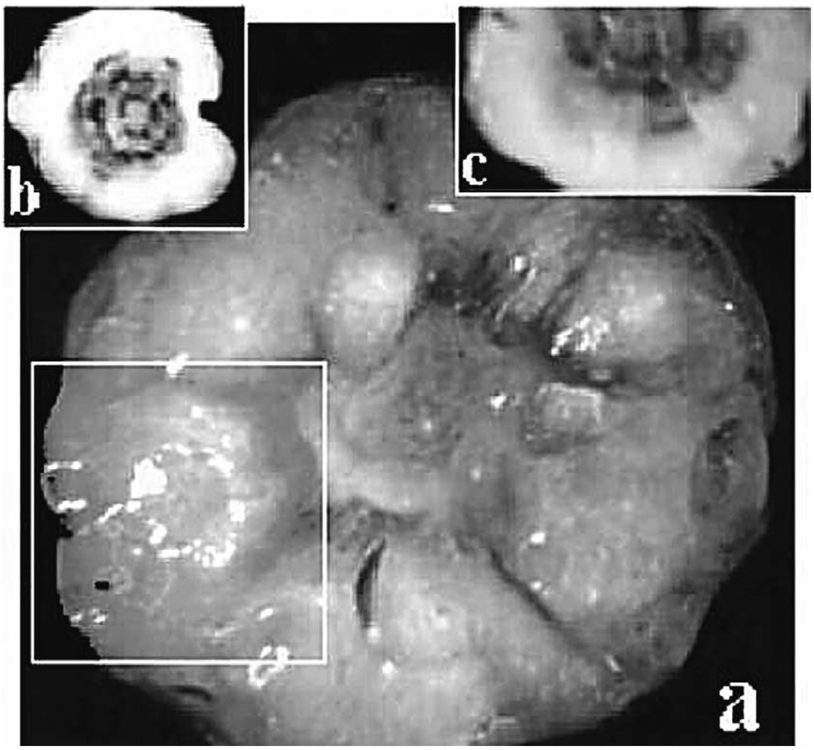

Fig. 1. The photographs [8] of big icy particles of a hail of diameter 4.5 cm (a), 5 cm (b), and 5 cm (c). The frame in the left lower part of the image (a) has a higher contrast to show an elliptic image of the edge of a radially directed tubular structure. The entire structure seems to contain a number of similar radial blocks. A distinct coaxial structure of the cartwheel type is seen in the central part of image (b). Image (c) shows strong radial bonds between the central point and the wheel.

cartwheel-like structures—probably the most inconvenient objects for being described universally for the *entire* range of length scales under consideration. In laboratory electric discharges [6,7] and respective dust deposits [5], the cartwheels are located either in the edge cross-section of a tubule or on an "axle-tree" filament, or as a separate block (the smallest cartwheels are of diameter less than 100 nm, see Figs. 2 and 3 in [5]). Similar structuring of dramatically different size may be seen in the following examples of (i) big icy particles of a hail of several centimeters in diameter (Fig. 1), (ii) a fragment of tornado of estimated diameter of some hundred meters (Fig. 2), and (iii) a fragment of solar coronal mass ejection of estimated diameter $\sim 5 \times 10^{11}$ cm (Fig. 3) (iv) supernova remnant, "a flaming cosmic wheel" forty light-years across, i.e., $\sim 4 \times 10^{19}$ cm (Fig. 4).

We may add to the last item of this list the wheel-like supernova remnant G11.2-0.3 which is also 40 light years across (see [11] http://chandra.harvard.edu/photo/cycle1/1227/1227_xray.tif), and a two-ring coaxial structure, with the inner ring of one light year in diameter, in the centre of the Crab nebula (see [11] http://chandra.harvard.edu/photo/cycle1/0052/0052_x-ray_lg, where radial structures are less distinct though). The gallery of cosmic wheels is obviously to be finished with the Cartwheel galaxy, 150,000 light years across, i.e., $\sim 1.4 \times 10^{23}$ cm (see [12] http://oposite.stsci.edu/pubinfo/gif/cartknot.gif).

Significantly, most distinct example of cosmic wheel's skeleton (Fig. 4) tends to repeat the structure of the cartwheel, coated with ice (Fig. 1), up to details of its constituent blocks. For instance, some of radially directed spokes are ended with a tubular structure seen on the outer edge of the cartwheel. Moreover, there are evidences for the trend toward self-similarity because, e.g., the cartwheel structure of the icy particle contains a smaller cartwheel as a constituent block (see the edge

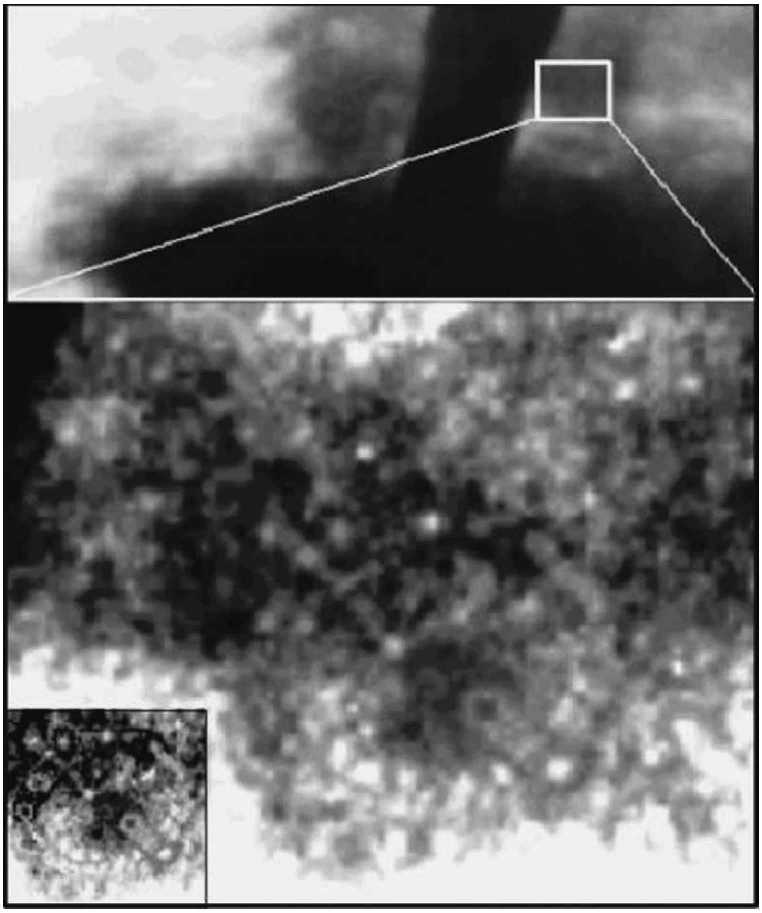

Fig. 2. Top: A fragment of the photograph [9] of a massive tornado of estimated diameter of some hundred meters. Bottom: A fragment of the top image shows the cartwheel whose slightly elliptic image is seen in the centre. The cartwheel seems to be located on a long axle-tree directed down to the right and ended with a bright spot on the axle's edge (see its additionally contrasted image in the left corner insert).

cross-section of the tubule in the left lower window in Fig. 1). This fact extends to larger length scales the evidences for such a trend in tubular skeletons in the dust deposits [5].

The ring-shaped structure of supernova remnant may be reproduced within the frame of hydrodynamic description of an expanding magnetized plasma-gaseous medium (see, e.g., [13] for the formation of the three-ring structure around supernova 1987A). However, we did not find in the literature an attempt to model a ring-shaped system with radial bonds, i.e., the cartwheel.

Note that the images of all the figures in this Letter are obtained via processing of original electronic images (most of them are available at the web sites [8–12]) with the method of multilevel dynamical contrasting (MDC) [1] (some of originals are processed only a little). As a rule, the structuring revealed with the help of MDC may then be easily recognized in the original, non-processed images (especially, for properly magnified high-resolution electronic images).

3. Electric torch-like structures and self-illumination of skeletons

Besides the distinctive topology (e.g., the cartwheels) of general layout of bright spots within skeletal structures, another evidence for the phenomenon of skeletons comes from the resolution of fine structure

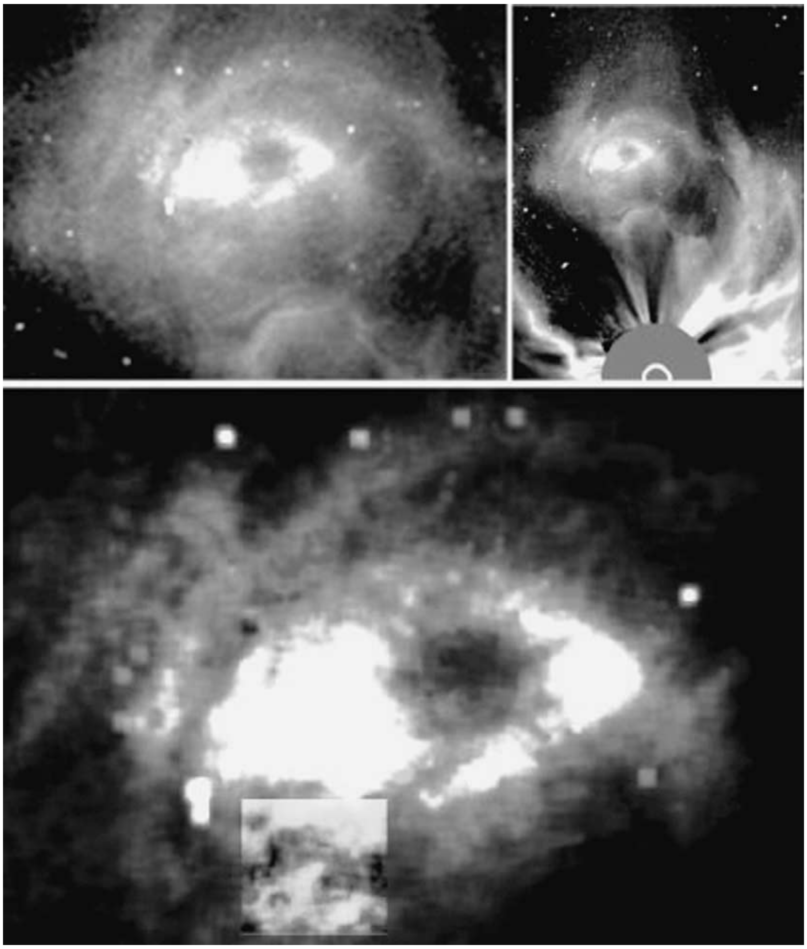

Fig. 3. Top right: the image of solar coronal mass ejection (see image [10], rotated 90° clockwise) with the solar disk overshadowed and indicated with a white circle. Top left: the magnified image of the front of the jet reveals a wheel-like structure with straight radial bonds between thick central point and circular/toroidal formation. Bottom: magnified and additionally contrasted image of the wheel-like structure; the window (seen on the bottom) differs by contrast and colour to show the continuity of radial spoke of the wheel. The elliptic images with the small central point (which are seen on the front edge of this spoke and in the central point of the wheel, and in the right-hand radial spoke) suggest all these formations to posses a tubular (and even coaxial) structure.

of luminosity around, at first glance, solitary bright spots. Here, the best evidence is the shining edge of a truncated straight filament which belongs to a skeletal network. The similarity of an electric torch-like structure of bright spots at different length scales is shown in Figs. 5–7. They give, respectively, examples of bright spots of size (i) ~ 1 mm, in Z-pinch electric discharge, (ii) ~ 100 m, in tornado, and (iii) ~ 0.1 light year, in the Crab nebula. Note that Fig. 6 illustrates the documented phenomenon of an internal illumination inside tornado's funnel (see, e.g., a short survey of published witnesses to luminous tornadoes in a paper by E. Lewis at http://www.padrak.com/ine/ELEWIS3.html).

Such a similarity suggests that the blocks of skeletons may work as a guiding system for (and/or a conductor of) electromagnetic signals. Therefore, the open end of a dendritic electric circuit or a local disruption of such a circuit (e.g., its sparkling, fractures, etc.) may self-illuminate it to make it observable (see, e.g., the "Southern Crab Nebula", which looks like a sparkling in the fracture of a tubular structure, [12]

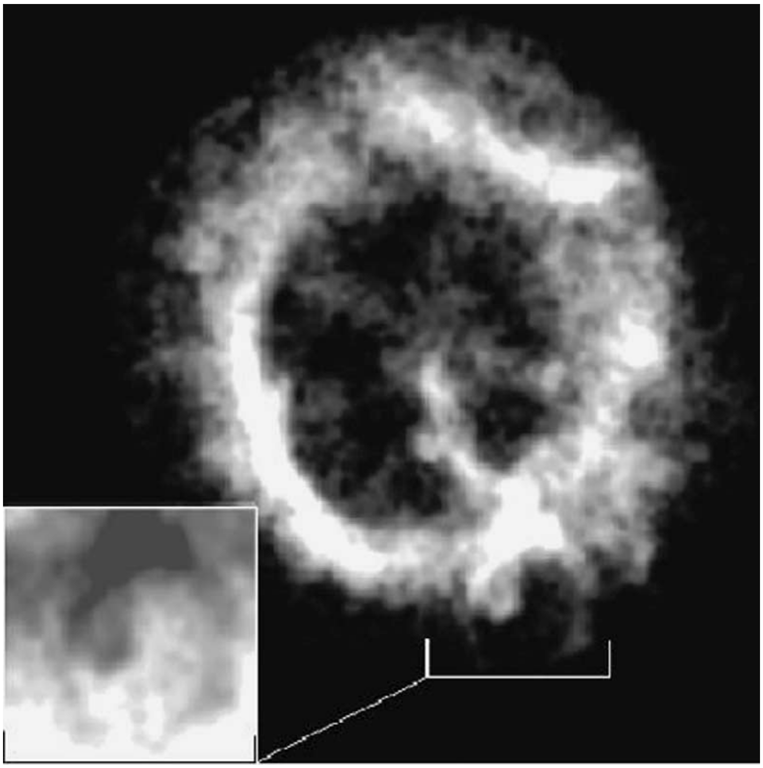

Fig. 4. “A flaming cosmic wheel” of the supernova remnant E0102-72, with “puzzling spoke-like structures in its interior”, which is stretched across forty light years in Small Magellanic Cloud (see http://chandra.harvard.edu/photo/snrg/e0102electricbluet.tif in [11]). The radially directed spokes are ended with tubular structures seen on the outer edge of the cartwheel. The inverted (and additionally contrasted) image of the edge of such a tubule (marked with a horizontal square bracket) is given in the left corner insert. Note that the cosmic wheel’s skeleton tends to repeat the structure of the cartwheel, coated with ice (Fig. 1), up to details of its constituent blocks.

http://oposite.stsci.edu/pubinfo/PR/1999/32/, and some other butterfly-shaped nebulae in [12]).

4. Discussion and conclusions

The most important implication of bringing all the above skeletons under one roof is that they, similarly to skeletons in the particles of dust [5,14] and hail [8] (Fig. 1), may be composed basically of a fractal condensed matter which, similarly to submicron dust skeletons [5,14], is assembled from nanotubular blocks. This conclusion is supported not only by the similarity of skeletal structuring but also by the trend toward self-similarity within these structures: just the ability of the blocks of one or few topological types, like the tubule and the cartwheel, to assemble a larger (or much larger) block of the same topology allows to draw a bridge between the dust-deposit cartwheels $\sim 10^{-5}$ cm in diameter and the Cartwheel galaxy $\sim 10^{23}$ cm in diameter. Note that, as a rule, the skeleton may be coated with various media, namely: amorphous (e.g., hydrocarbon) component, in dust deposits; the ice, in hail particles; plasma/gaseous component, in laboratory electric discharges, Earth atmosphere and space.

The above approach obviously requires to resolve somehow the difficulties with (i) conservation of topology in a growing/expanding skeleton, like that, e.g., in Figs. 3 and 4, and (ii) survivability of skeleton in a hot ambient plasma. Below we briefly discuss the status of our former hypotheses suggested to treat the above problems.

The prediction [3,4] of the phenomenon of skeletons in a wide range of lengths, starting from nanoscale structures, was based on appealing to exceptional elec-

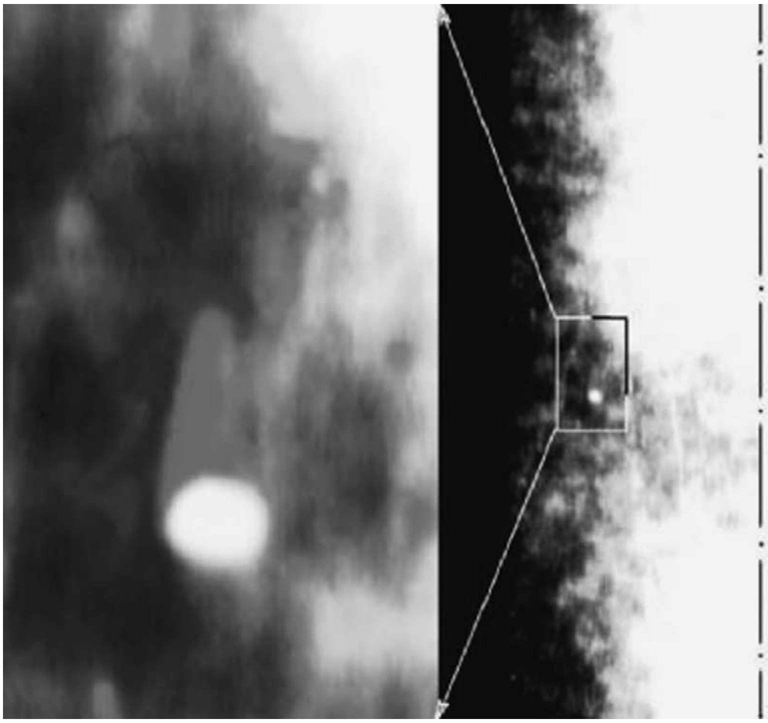

Fig. 5. Right: The visible light image (positive, width 17.5 mm) of the left-hand side of the denser and hotter core of the vertically aligned long plasma column in the electric discharge [1,2] of Z-pinch type (Z-pinch axis is shown with a dashed-and-dotted line). The image is taken with time exposure 2 ns nearly at the moment when discharge's magnetic field squeezes the hot plasma column and partly strips a skeletal network from ambient luminous plasma (for an example of a strongly stripped skeleton in the same Z-pinch see Fig. 3 in P2_051 in [6]). Left: The magnified, 3.6 mm wide window reveals the "hot spot" to be the edge of the filament (cf. also similar structure in tokamak in Fig. 2 in P2_029 in [6]).

trodynamic properties of their hypothetical building blocks—first of all, the ability of these blocks to facilitate the electric breakdown in laboratory discharges and to assemble the micro- and macroskeletons. The carbon nanotube (CNT) [15] or similar nanostructures of other chemical elements have been suggested [3, 4] to be such blocks. The self-assembling of skeletons was suggested to be based dominantly on *magnetic* phenomena. This, in fact, assumes the following simultaneous processes, namely (α) externally driven expansion/inflation of a self-assembling network (in laboratory discharges, there is an inflow of magnetic field from the external electric circuit, which is especially intense at initial stage of discharge; in space, an expansion may result, e.g., from nuclear energy release produced by gravitational instability and collapse), (β) sticking of the blocks together—due to trapping of magnetic flux by CNTs, and/or their assemblies, and respective mutual magnetic dipole attraction; at macroscopic scales this mechanism agrees with the experimentally verified trend [16] in magnetically confined plasmas to form the so-called force-free configuration which sustains a balance between longitudinal and transverse magnetic confinement, and thus always produces a longitudinal attraction both in the entire plasma column and individual electric current filament, and (γ) *partial* solidification due to welding of blocks by the passing electric current. We believe that the mechanisms (α), (β), and (γ) may give a parachute-like expansion of a dendritic network (namely, a parachute with the "liquid" strops and the localized explosive sources of dendricity), which selects the structures of a matter-saving and survivable geometry (first of all, tubules and cartwheels, and their combinations) regardless of specific source of expansion/inflation.

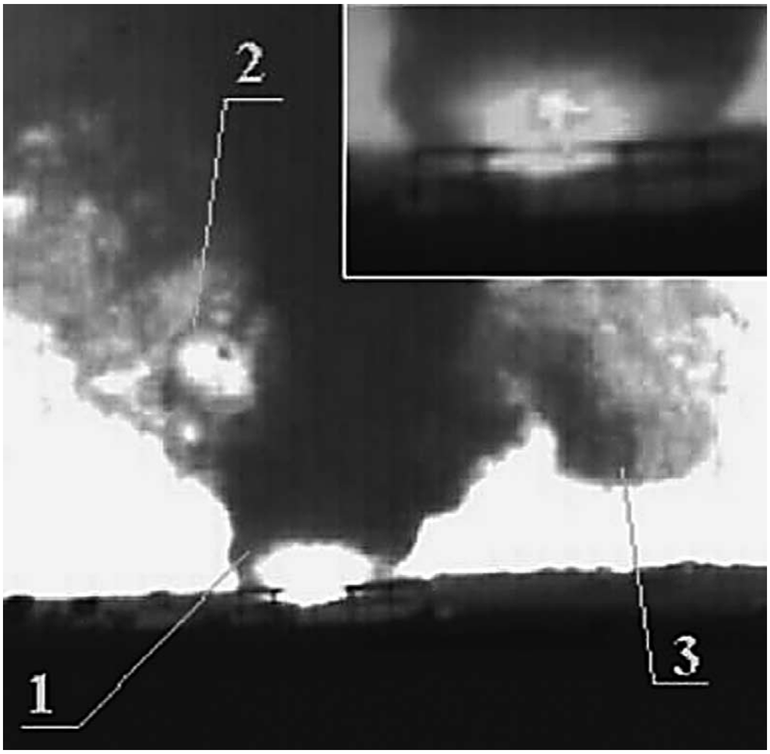

Fig. 6. A fragment of the photograph of tornado (cf. http://www.tornadochaser.net/) of estimated diameter ~ 100 m (see label 1 and an insert in the right upper corner), which shows internal illumination inside tornado's funnel and suggests that similar funnel which does not contact the Earth's surface may be seen either as the bright edge of a light-guiding branch (label 2) resolvable on the background of the opaque main body of tornado or as its dark branch (label 3) directed opposite to the observer.

The indications on plausibility of the anomalous magnetism and, in particular, on the ability of CNTs, and/or their assemblies, to trap and almost dissipationlessly hold a magnetic flux, with the specific magnetization high enough to stick the CNTs together, come from observations of superconductor-like diamagnetism in the assemblies of CNTs at high enough temperatures. Such evidences are obtained for the self-assemblies of CNTs (which contain, in particular, the ring-shaped structures of few tens of microns in diameter) inside *non-processed* fragments of cathode deposits, at room temperatures [17], and for the artificial assemblies, at 400 K [18].

The indications on the conservation of topology in a growing/expanding skeletal structure (i.e., on the compatibility of rigidity of certain blocks with the global/local expansion) come from the available data—at this point, unfortunately, rare ones—on tracing the *dynamics* of a cosmic explosion, namely in the young star system XZ Tauri, ~ 0.01 light years across (http://oposite.stsci.edu/pubinfo/PR/2000/32/ [12]). Here, we found the signs of a two-dimensional expansion (it's worth to call this a "planar explosion"). This example seems to be an inflationary production of the cartwheel-like structures on the common axle and is compatible with the interplay of the mechanisms (α) and (β). Another example (though, a static one) of a distinct planar structuring is the "large thin equatorial disk" (http://oposite.stsci.edu/pubinfo/PRC96-23a [12]) less than one light year across around the star Eta Carinae (http://oposite.stsci.edu/pubinfo/EtaCarC.jpg [12]) which has been released as a supernova explosion.

At this point, the signs of the saturation of the growth/expansion of a dendritic network are only implicit ones. For instance, the open, "shining" ends of the network (see Figs. 5–7) could result not only from local disruption of the network but also from local termination of a dendritic growth because of lo-

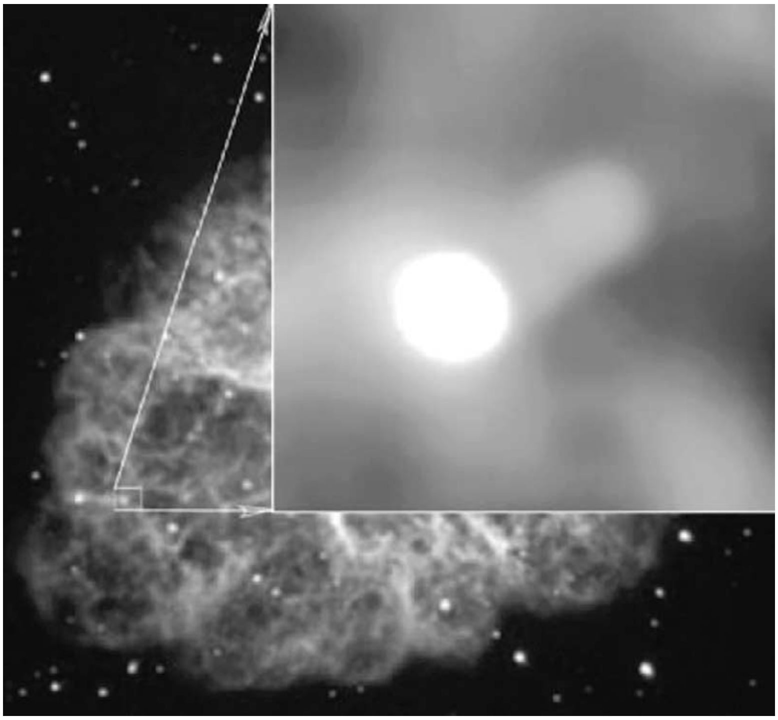

Fig. 7. A fragment of optical image of the Crab nebula (see [11] http://chandra.harvard.edu/photo/0052/0052_optical.tif) shows an electric torch-like structure of the filament of ~ 0.1 light year in diameter. The light from the filament's edge anisotropically illuminates the ambient gas.

cal exhaust of the proper material. Another argument in favour of saturation is the presence [19] of typical skeletal structures in the *time-integrated* X-ray images of one of the most bursty phenomenon in the laboratory, namely plasma corona produced by the irradiation of a solid target with a short laser pulse.

Regarding all the above-mentioned evidences for the dendricity of skeletal structures, we have to note that the typical block of skeletons, namely the cartwheel on an axle and the tubule with the central rod and the cartwheel in the edge cross-section, are the dendrites. An example of simultaneous dendricity and tubularity of the skeleton composed of tubular nanofibers is found in the submicron dust particle (see Section 4 in [14]).

The solution to the problem of survivability of skeleton in hot plasmas has been suggested within the framework of the problem of nonlocal (nondiffusive) transport of heat observed in high-temperature plasmas for controlled thermonuclear fusion. The microsolid skeletons were suggested [6] to be self-protected from an ambient high-temperature plasma by thin vacuum channels self-consistently sustained around the skeletons by the pressure of high-frequency (HF) electromagnetic waves, thanks to the skeleton-induced conversion of a small part of the incoming slow, quasi-static magnetic field (poloidal, in tokamaks, or azimuthal, in Z-pinches) into HF waves of the TEM type (a "wild cable" model, see P2_028 in Ref. [6]). This model allows to evaluate the width and length of vacuum channels around straight blocks of skeletons from the measurements of HF electric fields, both inside and outside the plasma column. The respective results [6] for the case of tokamak T-10 and gaseous Z-pinch reasonably agree with visible dimensions of observed straight blocks of skeletons.

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