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WILD CABLES IN TOKAMAK PLASMAS (EXPERIMENT)

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1. Introduction.

Recently two phenomena have been suggested [1,2] in analyzing available databases with the help of the method [1,2(a)] of multilevel dynamical contrasting (MDC) of the images, namely: (i) self-similarity of the filaments, and their networks, in a very broad range of length scales (and macroscopic densities of electric current) in various laboratory plasmas, namely: gaseous Z-pinches [1,2(b),3,4,5(a)], plasma foci [7], laser-produced plasmas [4], tokamaks [2(c),5(b),6] and cosmic space [1,2(a),3,4,5(a)]; (ii) unbelievably high survivability of some filaments, and their networks, in laboratory plasmas. The latter point was illustrated [4,5(a)] with tracing the history of a typical long straight rigid-body block in a Z-pinch (the pictures were taken in the visible light at different time moments from different positions, during about half a microsecond, that is comparable with the entire duration of the Z-pinch discharge, see Fig.1 in [4,5(a)]).

However, a question about the presence of similar structures in tokamak plasmas, i.e. under conditions of a strong static magnetic field, was not answered yet. The present paper (which is essentially a part of the preprint [8]) is aimed at presenting the evidences for the tubular structuring of an anomalously regular form in tokamak plasmas. A theoretical view on the observed phenomenon is addressed in the accompanying paper (see paper P2.028 of this conference).

2. Rigid-body structures in tokamak plasmas

An analysis of available databases carried out with the help of the MDC method [1,2(a)], shows the presence of tubular structures of an anomalously regular form (sometimes the large scale structuring may be seen even without MDC processing). The reliability of the results is based on the rich statistics, considerable similarity of the structures observed in various regimes and various facilities, as well as on the insensitivity to specific way of imaging.

The typical examples for a number of small and moderate size tokamaks are shown in Figures 1-7. The major parameters of these tokamaks (TM-2, T-4, T-6, T-10) are as follows: R (m) = 0.4, 0.9, 0.7, 1.5; a (cm) = 8, 20, 20, 33; B_T (T) = 2, 4.5, 0.9, 3; I_p (kA) = 25, 200, 100, 300; $T_e(0)$ (keV) = 0.6, 3, 0.4, 2; $n_e(0)$ (10^{13} cm^{-3}) = 2, 3, 2, 3.

The pictures 1-7 are taken in the visible light with the help of a strick camera (Figs. 1-4, 6-8) and high-speed camera (Fig. 5). Everywhere the toroidal direction is the horizontal one. The effective time exposure is about 10 microseconds. All the images correspond to plasma self-emission, except for Figure 5 where the light emitted by an injected pellet, illuminates the LLFs in a rather broad region.

The major features of the structuring are as follows:

(a) the length scale of the regular structuring varies in a broad range, from comparable with the minor radius of a tokamak to smallest resolvable lengths, i.e. less than millimeter scale (significantly, the presence of the large-scale structures proves the structuring to be present in the hot plasma interior, see Fig. 7(a));

(b) the typical tubule seems to be a cage assembled from the (much) thinner, long rectilinear rigid-body structures which look like a solid thin-walled cylinders; often the cage takes the form of a few nested cages;

(c) the (almost rectilinear) tubules form a network which starts at the farthest periphery and is assembled by the tubules of various directions (e.g., toroidally directed tubules interconnected by those of radial and poloidal directions);

(d) a radial sectioning of the above network is resolved which looks like a distinct heterogeneity at a certain magnetic flux surface(s) (such a sectioning was suggested [2(c),6] to cause the observed internal transport barriers in tokamaks).

3. Conclusions

(i) The observed structures could be responsible for the nonlocal (non-diffusion) component of heat transport (and observed phenomena of fast nonlocal responses) in tokamaks. The resemblance of the resolved internal structuring (Fig. 7(b)) of the observed large filament in Fig. 7(a) to the structure of a cable, and especially the theoretical analysis of the accompanying paper P2.028, make it worth to call such a structure a ***wild cable.***

(ii) This phenomenon seem to be a universal one in the well-done laboratory plasmas and space. In particular, similar wild cables may form in gaseous and wire-array Z-pinches and be responsible for the fast nonlocal transport of EM energy toward Z-pinch axis (see paper P2.051 of this conference).

(iii) The similarity of the observed structuring to the rigid-body long-living filaments of anomalously high survivability found [3,4,5(a)] in a Z-pinch (cf. Fig.1 in [4,5(a)]), gives some support to the hypothesis [3,4,5(a)] about the presence of a microsolid skeleton in the observable long-living filaments in plasmas. More arguments in favor of such an approach come from the evidences for tubular structures in the range from few nanometers to few micrometers in diameter, which were very recently found [9] in various dust deposits in tokamak T-10. Here, the similarity of the structures of an easily distinguishable topology (namely, a tubule with a cartwheel in the edge cross-section) in a broad range of length scales, as shown in [9] for tokamak dust and tokamak plasma (cf. Figures in [9] and also Figs. 4,7(b) below), is compatible with suggested [3,4,5(a)] self-similarity of blocks assembled in the above-mentioned hypothetical skeletons (see P2.028 for more detail).

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REFERENCES

[1]-[6], and [8]: Kukushkin A.B., Rantsev-Kartinov V.A.:

[1] Laser and Part. Beams, **16** (1998) 445.

[2] Rev. Sci. Instrum., (a) **70** (1999) 1387; (b) Ibid, p. 1421; (c) Ibid., p. 1392.

[3] Proc. 17th IAEA Fusion Energy Conf., Yokohama, Japan, October 1998, IFP/17.

[4] Proc. 3rd Symposium "Current Trends in Int. Fusion Research: Review and Assessment", Washington D.C., March 1999, Ed. E.Panarella, NRC Research Press, Ottawa, Canada (to appear), 33 pp.

[5] Proc. 26-th Eur. Phys. Soc. conf. on Plasma Phys. and Contr.Fusion, Maastricht, Netherlands, June 1999, (a) p. 873, (b) p. 1737.

[6] Preprint of Kurchatov Institute, IAE 6095/6, Moscow, May 1998, 48 pp.

[7] Kukushkin A.B., Rantsev-Kartinov V.A., Terentiev A.R., Fusion Technology, **32**, (1997) 83.

[8] Preprint of Kurchatov Institute, IAE 6157/6, Moscow, October, 1999, 20 pp.

[9] Kolbasov B.N., Kukushkin A.B., Rantsev-Kartinov V.A., Romanov P.V., Phys. Lett., **A269** (2000) 363.

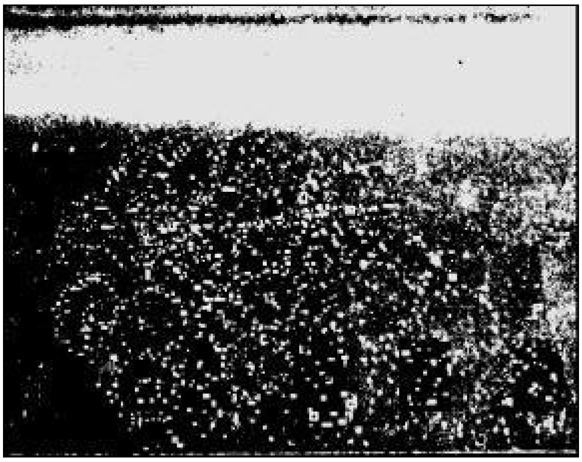


Fig. 1. Scrape-off layer of tokamak T-6. Positive, height 10 cm. Diameter D of circles is ~1-1.5 cm, diameter d of the central spot inside circles is ~2-3 mm. It looks like these structures, on the one hand, are linked to the plasma column (seen on the top) and, on the other hand, may not be a purely plasma formation.

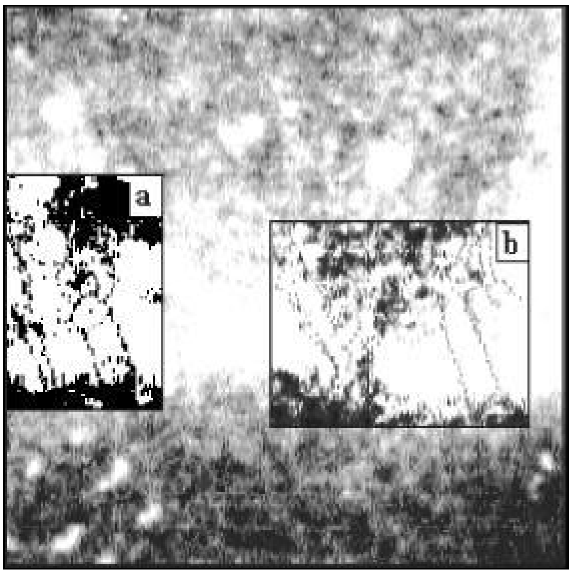


Fig. 2. Periphery of tokamak T-6. Positive, height 20 cm. A radially directed tubule (D ~ 1 cm, d~ 2 mm) is seen in the window (a) of the enhanced contrasting, and the networking of similar formations is seen in the window (b).

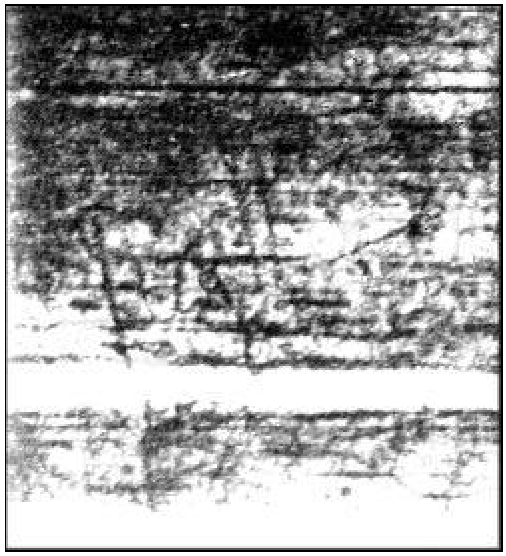


Fig. 3. Long tubular filaments (D ~1-2.5 cm) in tokamak T-4, directed nearly radially. Negative, height 20 cm. (Thick horizontal white band in the lower part of the Figure is a shadow of the reference wire located outside the chamber.)

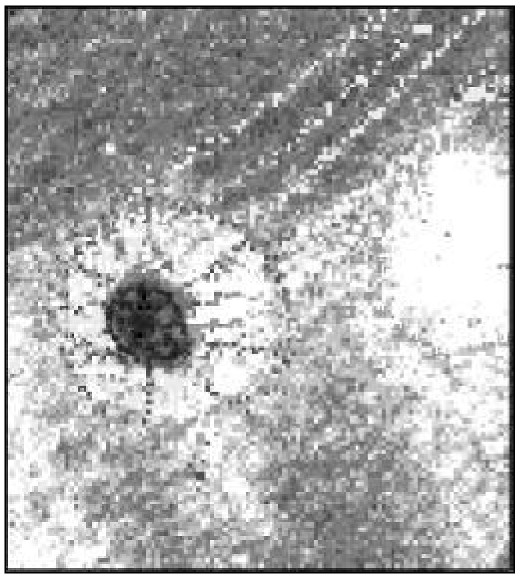


Fig. 4. Periphery of tokamak TM-2. Positive, height 6.4 cm. For the entire tubular structure, D ~ 2.5 cm, while diameter of the inner dark circle is ~1 cm and the darker spot inside it is of ~3 mm diameter.

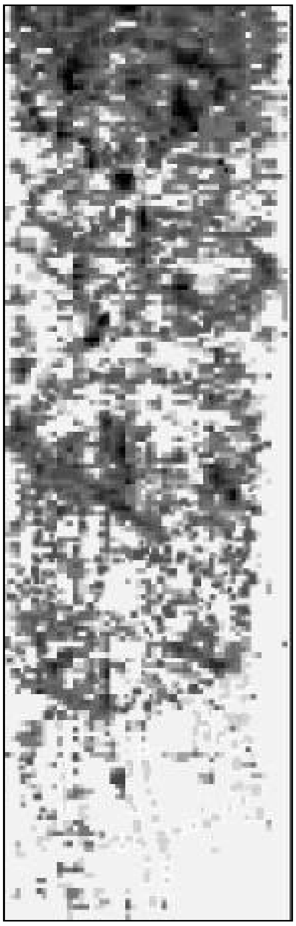


Fig. 5. Periphery of tokamak T-10 illuminated by the carbon pellet emission (the pellet track is outside the picture). Negative, height 14 cm. The system of concentric circles with the inner tubule forms a sort of the squirrel's wheel, ~5 cm long, of ~4-4.5 cm diameter, with central and boundary vertical sticks of diameter 4-5 mm.

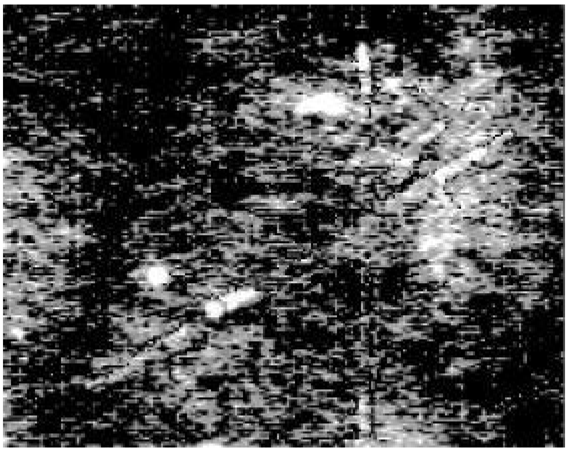
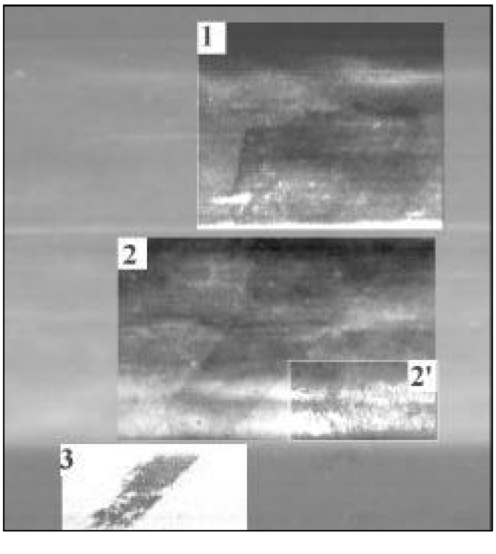
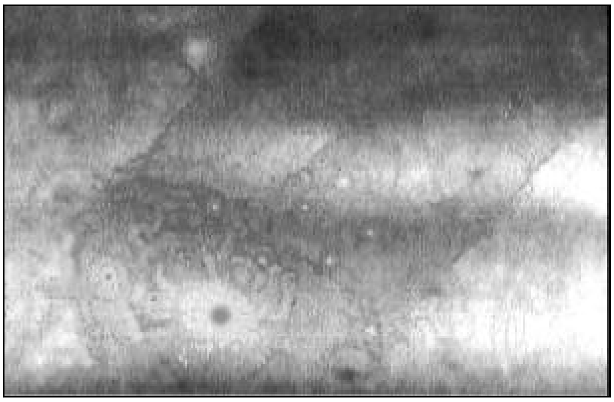


Fig. 6. A rigid-body cross made of tubular filaments of D ~3-4 mm in tokamak TM-2. Positive, height 6 cm.



(a)



(b)

Fig. 7. Tubular formation in tokamak TM-2 (Figure (a), positive, height 20 cm) which goes from the limiter-shadow region at the one side of the plasma column (i.e. outside plasma, window 3) to similar region at its opposite side (dark horizontal band on the top of the window 1). The windows correspond to different levels (maps) of contrasting of the images, in order to show the continuity of the structuring. The tubular block seen on the bottom of the window 2 (namely, to the left from the window 2') is shown in Figure (b). Here, diameters of the tubule and central dark spot are ~2.5 cm and ~1.5 mm, respectively (figure height 2.8 cm). The tubules of ~1 mm diameter, which belong to this structure, may also be seen when the picture is magnified.