WILD CABLES IN FUSION PLASMAS (EXPERIMENT)

A.B. Kukushkin, V.A. Rantsev-Kartinov
INF RRC "Kurchatov Institute", Moscow 123182 Russia
rank@nfi.kiae.ru

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 taken from [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. Also, a couple of examples of a tubular structure is given for the case of a Z-pinch.

A theoretical view on the observed phenomenon is addressed in the accompanying paper (see next poster).

2. Rigid-body structures in fusion 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 2-9. The major parameters of these tokamaks are as follows.

	TM-2	T-4	T-6	T-10
Major radii R (m)	0.4	0.9	0.7	1.5
Minor radii a (cm)	8	20	20	33
Toroidal field B_T (T)	2	4.5	0.9	3
Total current I_p (kA)	25	200	100	300
Electron temperature $T_e(0)$ (keV)	0.6	3	0.4	2
Electron density $n_e(0)$ (10^{13} cm^{-3})	2	3	2	3

The pictures 2-9 taken in the visible light with the help of a strick camera (Figs. 2-5, 7-9) and high-speed camera (Fig. 6). Everywhere the toroidal direction is horizontal one. The effective time exposure is about 10 microseconds.

The images correspond to the self-emission of the plasma (for Figure 6, this is the light emitted by an injected pellet and reflected by the LLFs).

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. 9(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

It follows from the above data that the observed structures could be:

(i) responsible for the nonlocal (non-difusion) component of heat transport (and observed phenomena of fast nonlocal responses) in tokamaks;
(The resemblance of the resolved internal structuring, Fig. 9(b), of the observed large filament seen in Fig. 9(a) to the structure of a cable and especially the theoretical analysis of the accompanying paper make it worth to call such a structure a ***wild cable***.)
(ii) a universal phenomenon in well-done laboratory plasmas and space (for Z-pinch case, see Fig. 1 and especially Fig. 10). (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.)

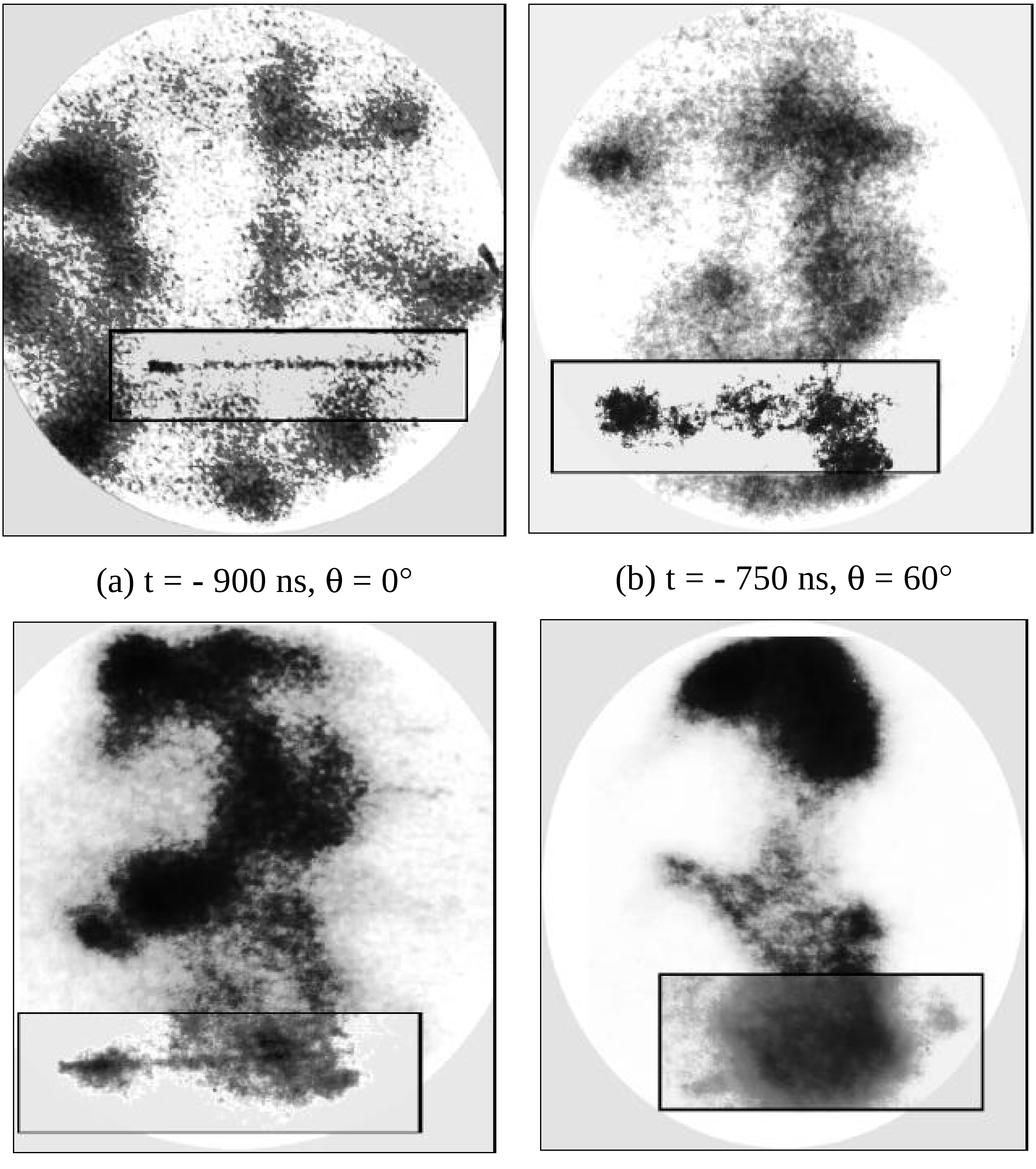
Also, the similarity of the observed structuring to the rigid-body long-living filaments of anomalously high survivability found [3,4,5(a)] in a Z-pinch (see Fig.1), gives some support to the hypothesis [3,4,5(a)] about the presence of a microsolid skeleton in the observable long-living filaments in plasmas.

One could expect that the recognition and controlling of the phenomenon of long-living filaments may open new opportunities for confining the fusion plasmas in the facilities for both conventional and innovative confinement.

Acknowledgments. The authors are indebted to V.M. Leonov, S.V. Mirnov and I.B. Semenov, K.A. Razumova, and V.Yu. Sergeev for presenting the originals of the data from tokamaks T-6, T-4, TM-2, and T-10, respectively.

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) pp. 873 (http://epsppd.epfl.ch/cross/p2087.htm), (b) pp. 1737 (p4096.htm)
[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**, 83 (1997); Kukushkin A.B., Rantsev-Kartinov V.A., Terentiev A.R., Cherepanov K.V., AIP Conference Proceedings vol. 409, Dense Z-pinches 4th Int. Conf., Vancouver, Canada, May 1997, Eds. N.R.Pereira, J.Davis, and P.E.Pulsifer, AIP Press, New York (1997), p. 381.
[8] Preprint of Kurchatov Institute, IAE 6157/6, Moscow, October, 1999, 20 pp.



(a) t = - 900 ns, θ = 0°

(b) t = - 750 ns, θ = 60°

(c) t = - 550 ns, θ =90°

(d) t = - 400 ns, θ =180°

Figure 1. The MDC processed images, taken in visible-light, of a Z-pinch. The circle is produced by the geometry of the optics collecting the light. The images are taken at different time moments and different observation angles θ in the plane orthogonal to Z-pinch axis (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, θ = 0, (b) t = - 750 ns, θ = 60°, (c) t = - 550 ns, θ = 90°, (d) t = - 400 ns, θ = 180°. 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.

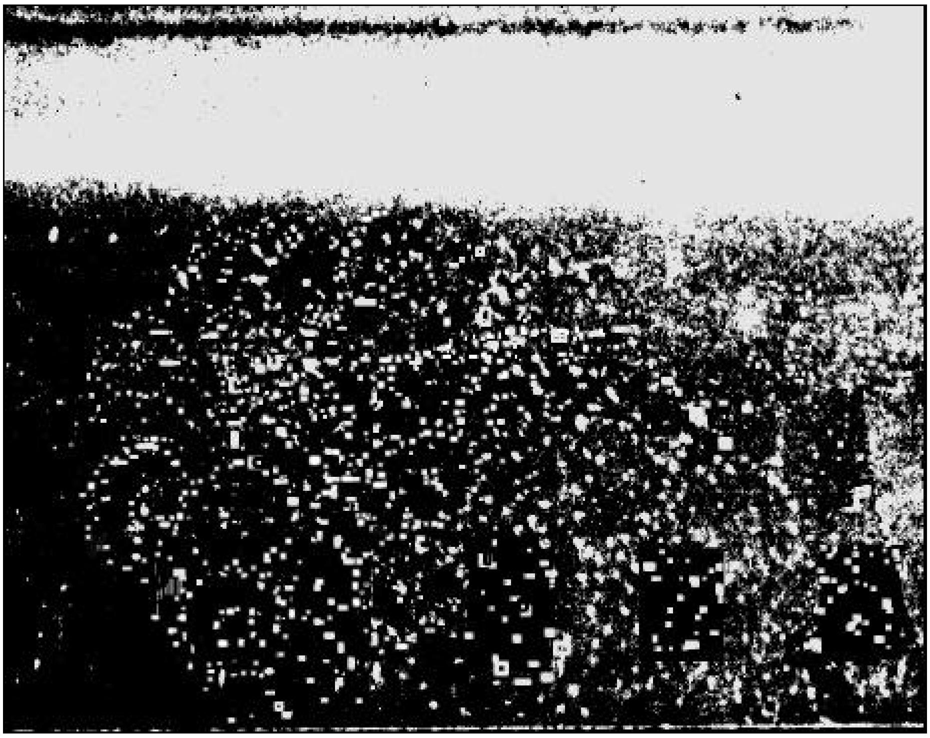


Fig. 2. Scrape-off layer of tokamak T-6. Positive, height 10 cm. Diameter D of circles is ~1-1.5 cm, diameter d of the central spot inside circles is ~2-3 mm.

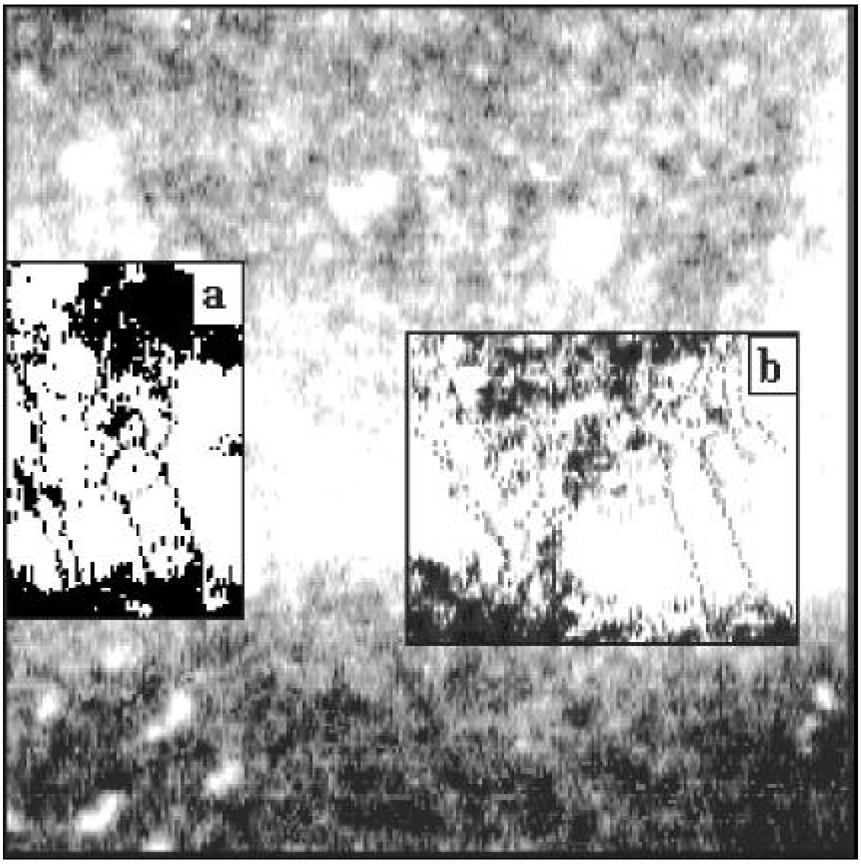


Fig. 3. Periphery of tokamak T-6. Positive, height 20 cm. A radially directed tubule (D ~ 1 cm, d~ 2 mm) is seen in the window (a) of the enhanced contrasting, and the networking of similar formations is seen in the window (b).

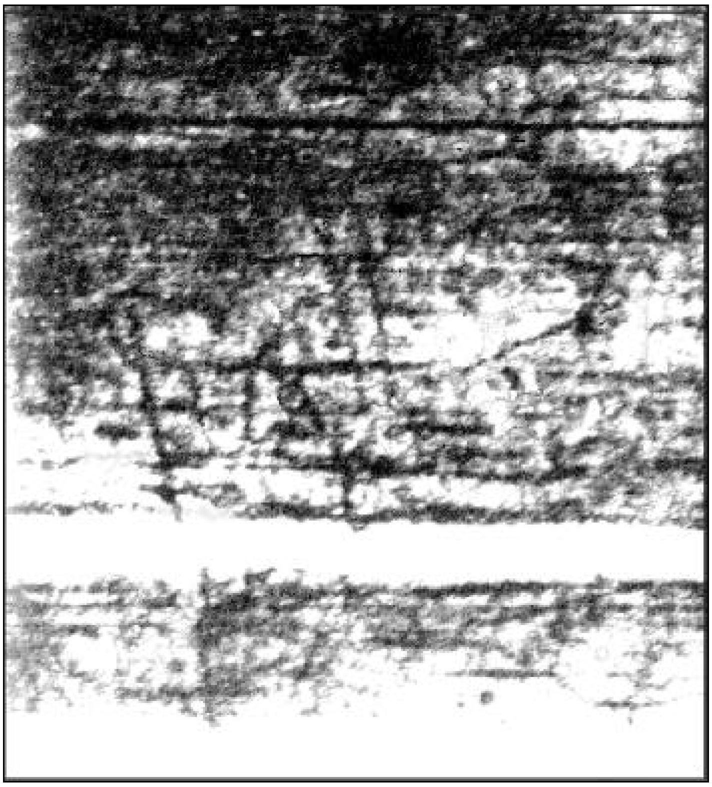


Fig. 4. Long tubular filaments (D ~1-2.5 cm) in tokamak T-4, directed nearly radially. Negative, height 20 cm. (Thick horizontal white band in the lower part of the Figure is a shadow of the reference wire located outside the chamber.)

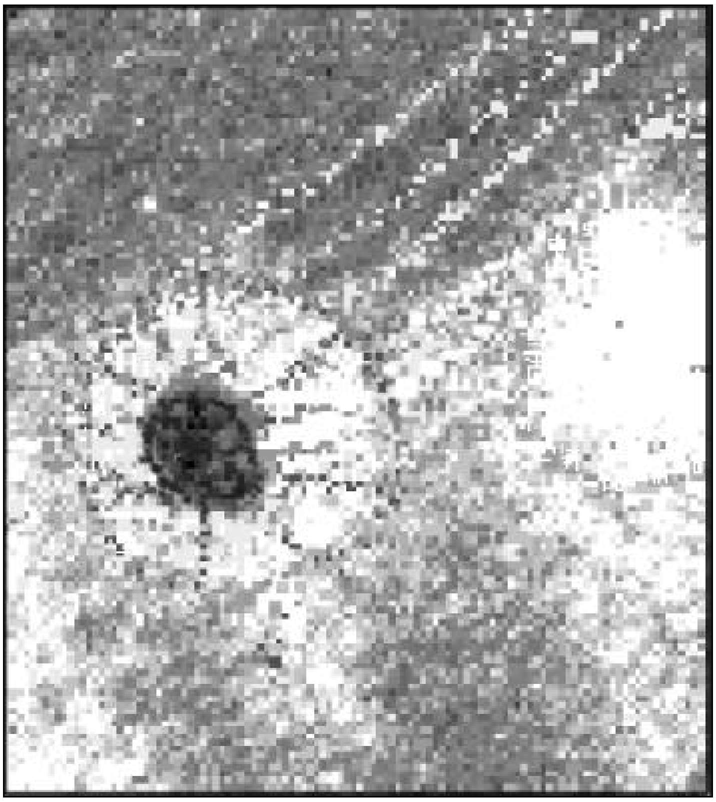


Fig. 5. Periphery of tokamak TM-2. Positive, height 6.4 cm. For the entire tubular structure, D ~ 2.5 cm, while diameter of the inner dark circle is ~1 cm and the darker spot inside it is of ~3 mm diameter.

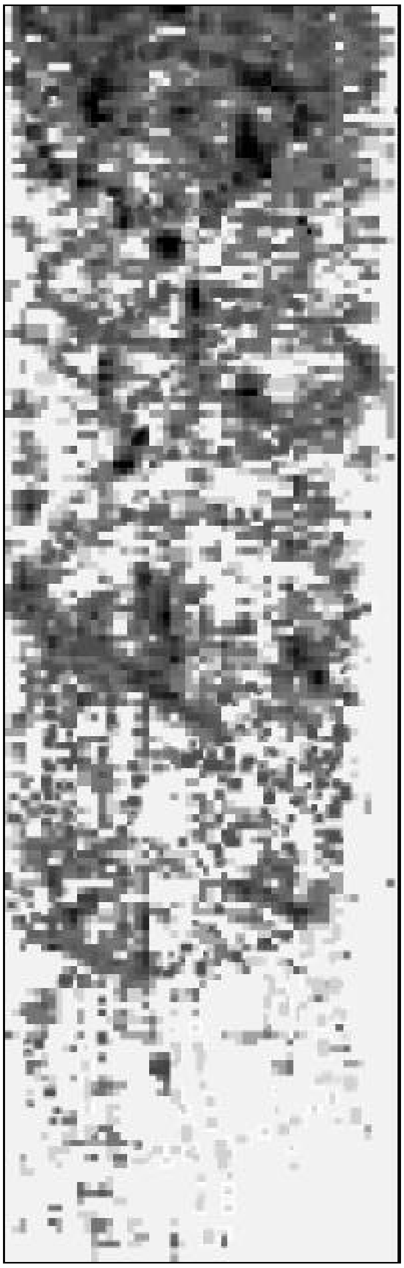


Fig. 6. Periphery of tokamak T-10 illuminated by the carbon pellet emission (the pellet track is outside the picture). Negative, height 14 cm. The system of concentric circles with the inner tubule forms a sort of the squirrel's wheel, ~5 cm long, of ~4-4.5 cm diameter, with central and boundary vertical sticks of diameter 4-5 mm.

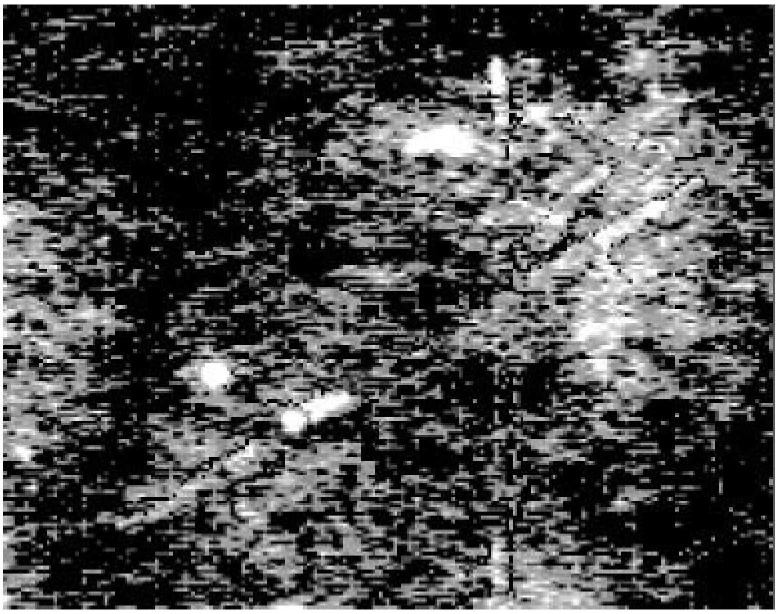


Fig. 7. A rigid-body cross made of tubular filaments of D ~3-4 mm in tokamak TM-2. Positive, height 6 cm.

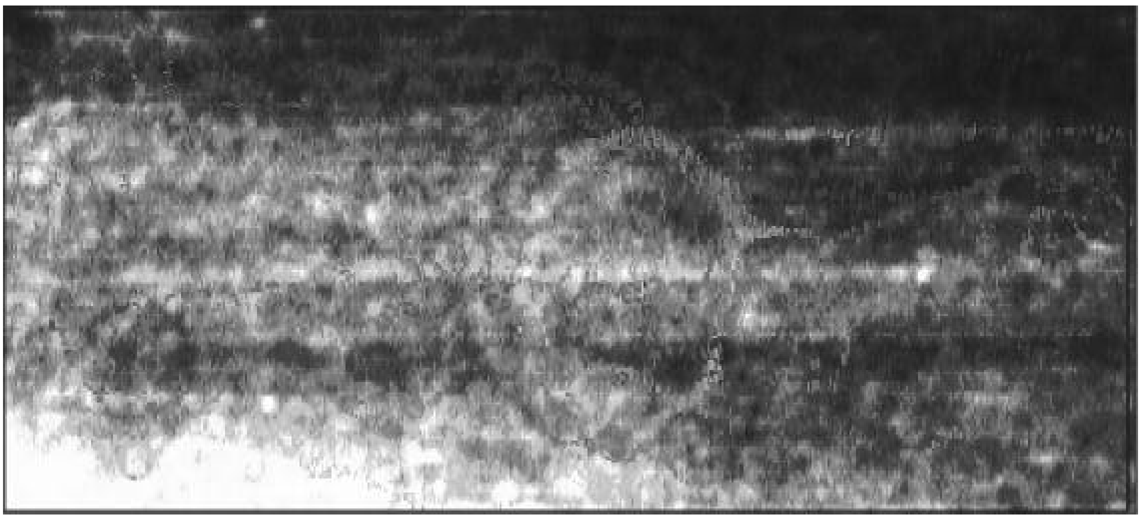
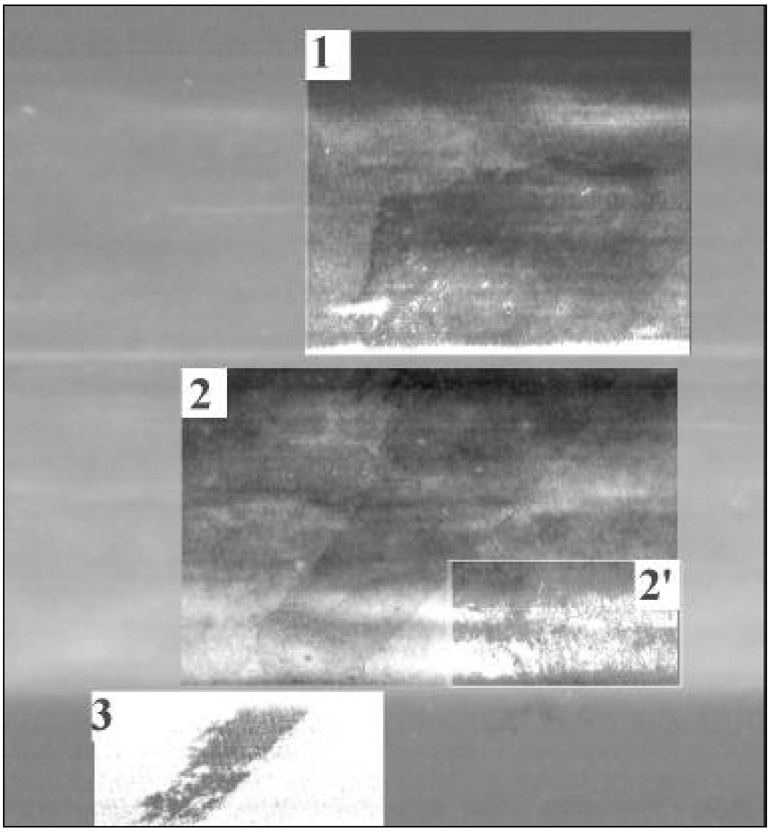
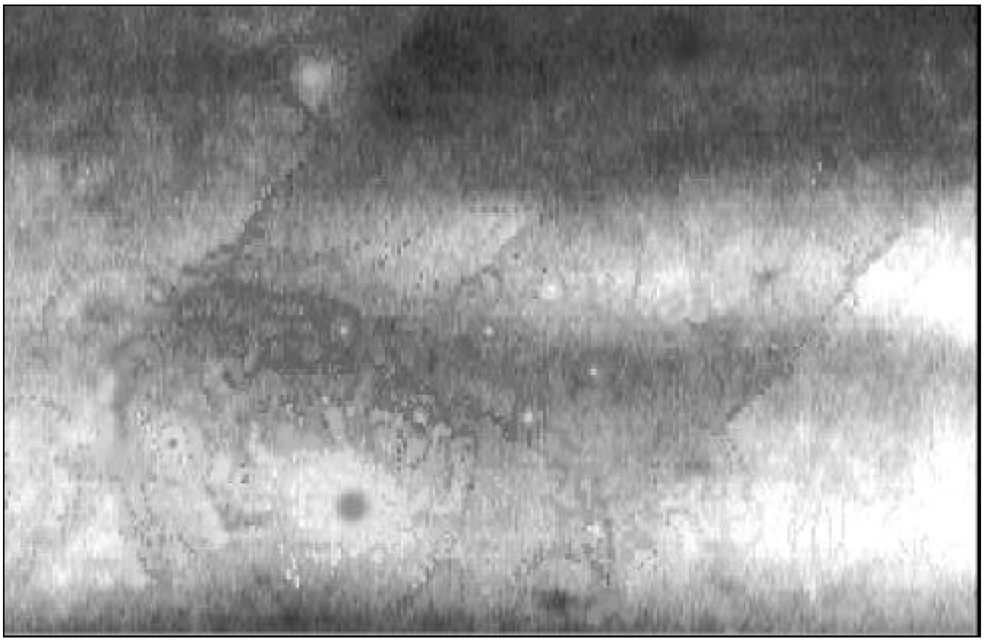


Fig. 8. A tubular formation of D ~ 2 cm, 6-7 cm long, in the central part of tokamak TM-2. Diameter of inner tubule is ~6 mm. Positive, height 3.2 cm.



(a)



(b)

Fig. 9. 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.

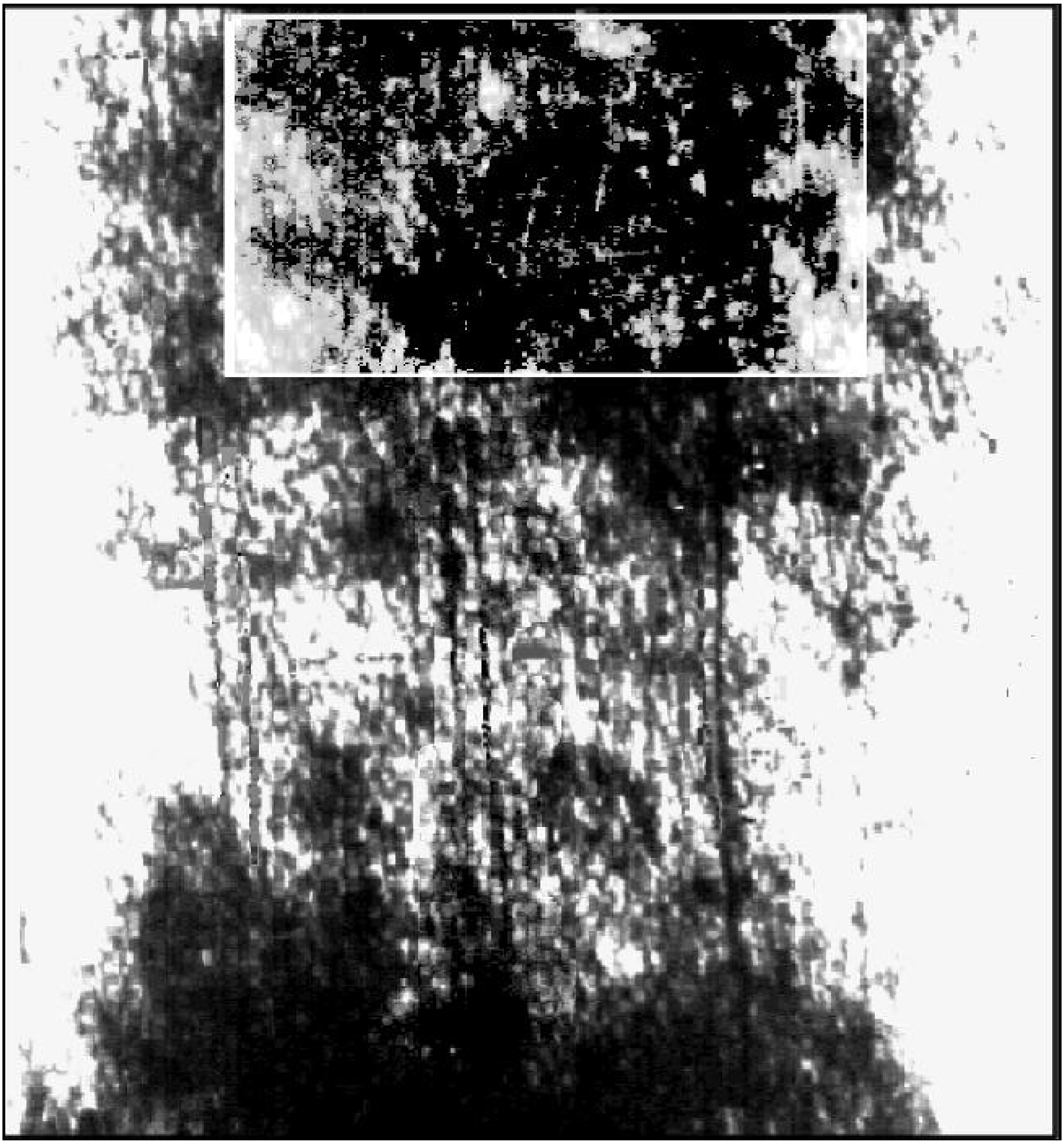


Fig. 10. The neck of a Z-pinch (chamber 60 cm long and 20 cm diam., major axis is directed vertically, 360 kA, deuterium, visible light picture, time exposure 2 ns; for other experimental conditions see Refs. [1,2(b)]). Negative, height 1.65 cm. Diameter D of vertical tubules is ~0.3 mm, while for thinner tubules of various directions, including horizontal ones, D~ 0.1-0.2 mm. The picture illustrates the presence of the network(s) built up by the tubular rigid-body filaments which are hidden in the ambient plasma but appear to be stripped by the magnetic field when it pushes the plasma out of the Z-pinch's neck (such an event leads to a singularity of the total electric current through the Z-pinch).