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Observation of Skeletal Filamentary Structures in Plasma of a Fast Z-Pinch

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The investigation of the fine structure of fast Z-pinches is one of major trends in physics of plasma x-ray radiation sources. Here we present here the results of analysis, with the help of formerly designed method of multilevel dynamical contrasting (MDC) [1], of the plasma images taken in the facility C-300 under condition of 1-3 MA electric currents for current growth front of ~ 100 ns duration. The load was a tailored cylinder (8 mm long, 3-5 mm in diameter, with a neck of ~ 1 mm diameter), made of agar-agar with various heavy-element filling. The analyzed images were taken with the help of electronic optical converters (exposure 3 ns, interframe interval 15 ns, spatial resolution 50-100 mcm). In a single discharge, from 3 to 5 images were successively taken in the visible light and/or soft x-rays (SXR), with covering a part of vacuum ultraviolet (VUV) spectral range. This enabled us to (i) observe the long-lived skeletal structures (SSs) in plasma, (ii) reveal the continuity of SS in the core and periphery, (iii) roughly trace dynamics of SS during the entire discharge, (iv) resolve the fine structure of SS.

The results of analyzing the plasma images suggest the presence of filamenatry structures in the plasma of a fast Z-pinch, with the properties of these structures being much different from chaotic filaments. The major properties of these filamentary structures are (i) longevity and (ii) their skeletal structuring.

The first feature, longevity, means that the skeletal structures observed in the plasma images may exist during the time period which much exceeds the lifetimes predicted by the MHD approach and plasma kinetics description (for a slow Z-pinch [1] the longevity was shown to exceed the respective predictions by the orders of magnitude, see Fig. 1 in [2(c)]). The phenomenon of longevity for the case of a fast Z-pinch is illustrated with Figure 1.

The second feature, the skeletal structuring, means that the observed structures are composed of building blocks of a distinctive topology typical for the rigid-body structures. These blocks are (a) a straight block of tubular and/or coaxial tubular structure (Figs. 2, 3), and (b) a cartwheel-like structure (Figs. 3,4). The straight cylindrical block are of diameter in the sub-millimeter range and of length in the range from few millimeters up to the radius of the plasma column in the neck of the Z-pinch. In the coaxial structure, the ratio of outer diameter (of few millimeters) to diameter of the inner rod (which may itself possess a tubular structure) is in the range ~ 3-5.

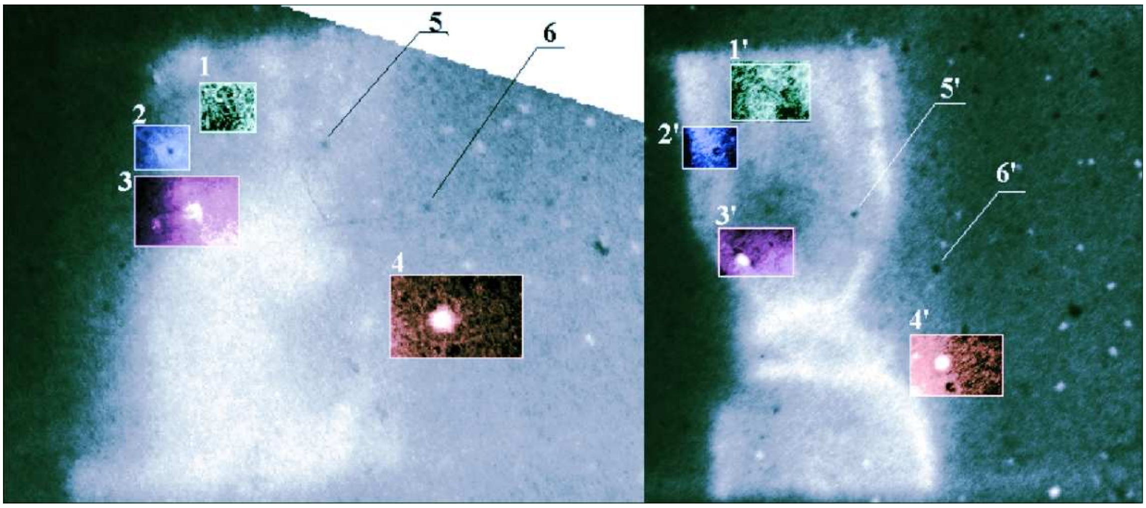

Fig. 1. Two successive images (positives) taken with the help of an electronic optical converter in soft x-rays with interframe time ~ 15 ns. Both images are analyzed with respect to probable existence of objects which conserve their structure during the interframe (note that the relative layout of such objects may differ due to internal restructuring or global rotation of the entire structure). Such structures are found in the windows 1-4 where the original image is processed with the MDC method [1]. Also, typical recognizable dark spots are marked (see labels 5 and 6). All the windows 1-4 (and respectively 1'-4') exhibit the presence of the same, conservative and quite distinctive structuring that indicates on the longevity of these structures. The distance between the spots in the windows 3-5 is changed by ~ (15-20)%.

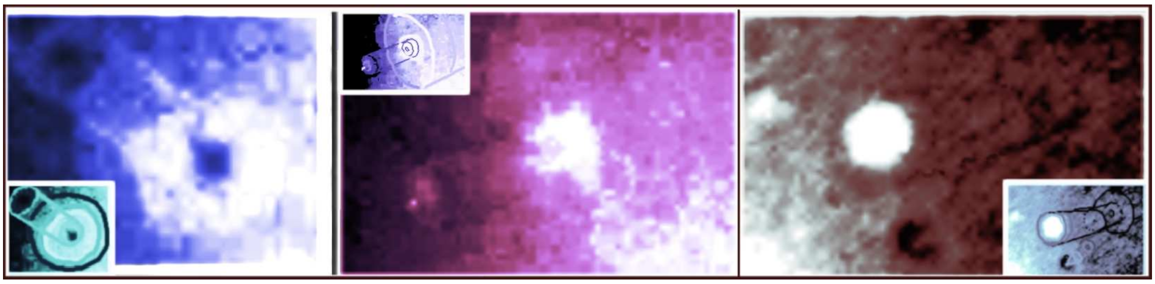

Fig. 2. The fragments of Fig. 1 are shown as a magnified image of the windows 2, 3 and 4'. The width of the images are ~1 mm, 1.75 mm, and 1.6 mm, respectively. The windows show tubular structures of various diameter d and declination. The tubules in the left and central windows seem to have a thick bright region in the base of presumably a larger coaxial structure. The central tubule has a small bright point on the front edge. For each image, we give a schematic drawing of the structuring, which is obtained with the help of mosaic MDC method (see Sec. 2 in [3] for more details about this method).

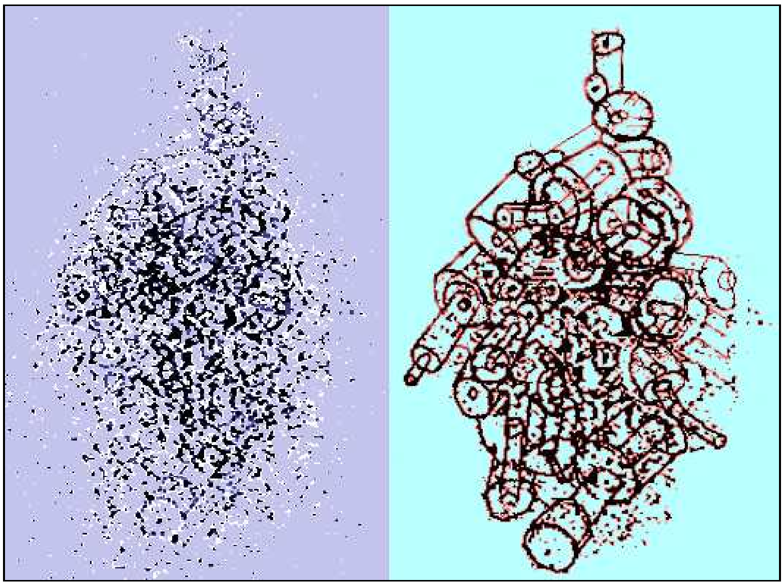

Fig. 3. The fine structure of the typical filtered (3 μm thick mylar) pinhole image (negative) of the entire Z-pinch (height is 8 mm). The right hand image gives a schematic drawing obtained similarly to that in Fig. 2. The cartwheel-like structure are found as a separate block or as a edge of the tubular structure (see right upper part of the image). Diameters of cartwheels are about 1 mm. The minimal diameter of tubules is ~ 150 μm.

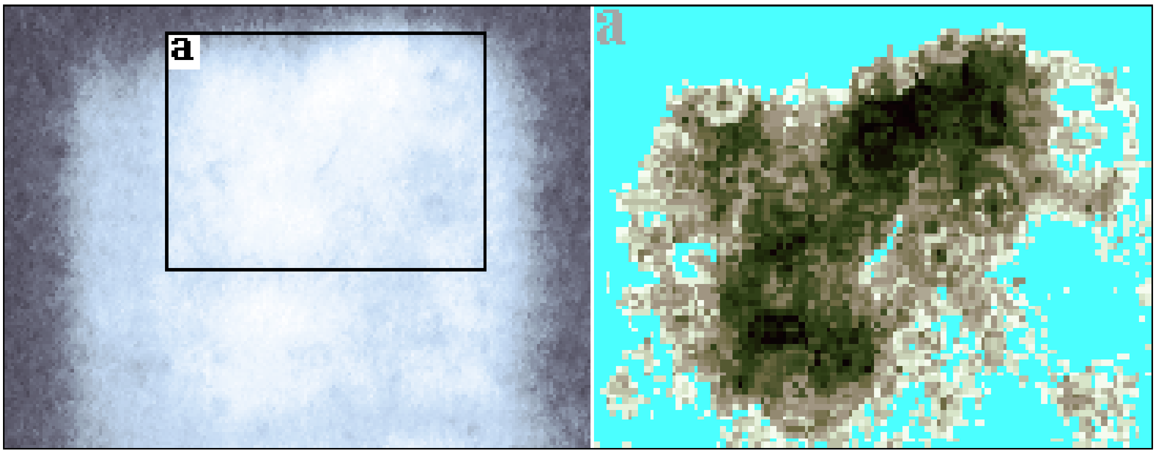

Fig. 4. The electronic optical converter image in soft x-rays. The left: a part of the 4mm thick plasma column. The right: the image of the 2.2 mm high window in the left image. It shows the cartwheel-like structures in the right upper corner and elliptical images of the edges of cylindrical (presumably, tubular) structures (e.g., in the right upper corner).

Besides the skeletal structuring as itself, there is also a trend toward the phenomenon of self-similarity, i.e. when some filamentary formation (e.g. tubular one) may assemble the similar formation of a bigger size. However, a higher resolution is needed to reliable identification of this phenomenon in a fast Z-pinch. The best example here is the fine structure of hot spots. It shows that the individual hot spot often looks like a cluster made of a complex intersection of tubular blocks and resembles a tangle with the radially directed spokes (see Fig. 5).

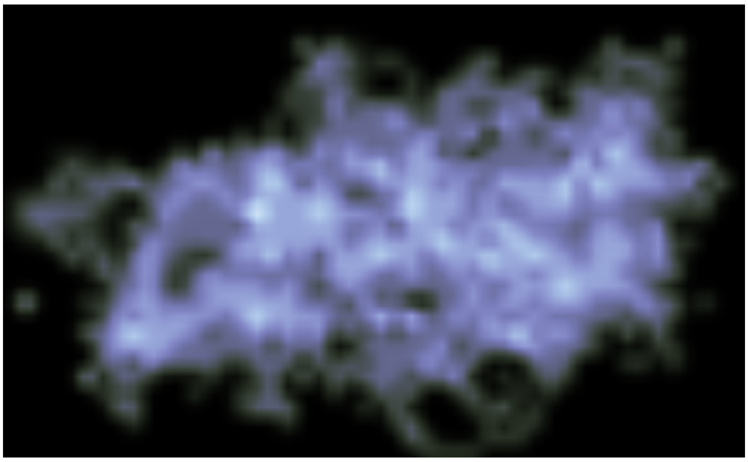

Fig. 5. The image taken in the visible light with the help of an electronic optical converter (positive, spatial resolution is ~ 50 µm). The width of the image ~ 0.7 mm. One may see coaxial tubular formations of diameter ~ 0.2 mm, with the central part up to 50 µm. In the right hand side of the figure there is a cart-wheel-like structure of diameter ~ 0.3 mm whose central part is of diameter ~ 50 µm.

Conclusions. The present analysis allows to extend the former conclusions, which claimed [2] the probable presence of long-lived skeletal structures in a classical gaseous straight Z-pinch plasma [2], to the case of a fast Z-pinch as well. This is because we see similar skeletal structures which are composed of straight tubular blocks of diameter 0.1-1 mm and of length comparable with plasma radius in the neck.

References

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