Single Plasma Cord from Geometrically Focused 5-cm-Wide Terawatt Peak Power Beam

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The current needs of ionizing channels provided by femtosecond terawatt level pulses over hundred-meter range distances in air [1] as well as precise modification of the bulk transparent dielectrics with high numerical aperture optics [2] and generation of internal crack-free voids [3] encourage the study of merging multiple plasma channels created before the geometrical focus [4-6]. Geometrically focused femtosecond laser pulses that we are going to consider have the peak power at least several times larger than the critical power for self-focusing in air. Formation of filaments takes place from the modulational instabilities on the initial beam profile. These multiple filaments form individual plasma strings well before the geometrical focus and merge together in the vicinity of the focus, providing for a plasma cord, the transverse width and the electron density of which exceeds the ones of an individual channel. Up to date, the time-resolved simulations were able to resolve the small-scale representation of the filament fusion [5], but the multi-TW problem was out of computational capabilities.

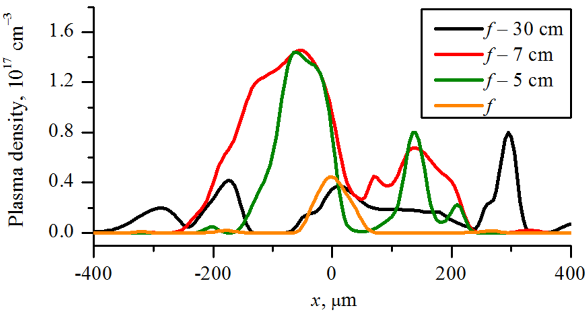

Figure 1: The simulated transverse slices of the plasma density at the end of the pulse. Note the appearance of the high density and wide plasma cord at 7 cm before the focus and its persistence till the geometrical focus

In this work, we take a step forward and simulate the propagation and filamentation of 800-nm, 20-mJ, 50-fs pulse with the beam diameter of about 5 cm. The geometrical focusing distance is $f = 7$ m, the initial beam distribution is cordially supplied by the authors of [4]. Handling of such challenging propagation task is technically affordable if we omit the temporal dynamics of the pulse over the majority of the path to the geometrical focus, namely, the propagation over first 6.3 m is considered in (x, y, z) geometry. At this point, the intensity reaches 12 TW/cm^2, so further on the plasma may affect the pulse temporal shape. Therefore, for $z > 6.3$ m the simulations are performed with the time included (t, x, y, z) on the moderate size spatial grid thanks to the shrinked beam size due to focusing.

The plasma density slices are shown in Fig. 1 at distances $z = f - 30$ cm, where multiple filaments converge but do not interact yet, at $z = f - 5 \div 7$ cm, where the superfilament is established with a transverse size of $\sim$200 μm, elongation of $\sim$10 cm, peak plasma density exceeding 10^{17}, *i.e.* a factor of 2 larger than in the individual filament.

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