Long range horizontal propagation of femtosecond self-channelled laser pulses in air

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Abstract: Using a multiterawatt femtosecond laser, we have studied long distance (~ 2 km) filamentation in air as a function of initial pulse chirp. Ionized channels are observed over several hundred meters.

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Several applications, such as remote multi-component pollutant detection, lightning protection, long range propagation of light bullets and production of secondary sources rely on femtosecond filamentation in air [1]. This phenomenon was discovered in the late nineties with ultrashort lasers emitting at infrared wavelengths. For an input power close to the critical power for self-focusing P_{cr}~ 5GW, a single filament with a diameter around 100 μm and a peak intensity around 10^{13}-10^{14} W/cm^2 is formed over several tens of meters. At such intensities, air ionization occurs via multiphoton processes, so that the self-channelled laser pulse leaves in its wake a plasma string with an initial density around 10^{16} cm^{-3}. The physics of filamentation in this intensity regime is well understood and can be closely reproduced numerically

Much less information is available concerning the propagation of ultrashort pulses with much higher incident power ($P \gg P_{cr}$). We report on experimental results with multiterawatt short laser pulses along a long horizontal path d > 500 m. We use a mobile laser system, called Teramobile, which delivers up to 200 mJ per pulse, with a pulse duration of 100 fs. The intensity profile of the pulse and the occurrence of air ionization have been investigated as a function of propagation distance for different initial values of the laser chirp.

For small chirps (short initial pulse), a bright broad band continuum is created over the first 50 meters. The beam then propagates within a diverging cone of 1 mrad, with no marked high intensity spots (see Fig. 1a). For larger initial negative chirp, the beam breaks into a multifilamentation pattern which persist over several hundred meters (see Fig. 1b). Ionization could be detected over a distance of 300 meters (see Fig. 2). These results are well reproduced by numerical simulations using a 3d+1 dimensional propagation code with the proper initial laser conditions. Finally, for even longer negative chirps, bright light tubes, without significant ionization, propagate over at least 2 km (Fig.1c). Thus, depending on the initial chirp conditions, one can maximise either a) white continuum generation, b) the electron density at fixed location, or c) the length of intense light strings.

[1] Kasparian, J., M. Rodriguez, G. Méjean, J. Yu, E. Salmon, H. Wille, R. Bourayou, S. Frey, Y.-B. André, A. Mysyrowicz, R. Sauerbrey, J.-P. Wolf et L. Wöste, *Femtosecond white light filaments: a new tool in atmospheric research*, Science page 61, vol. 301 (2003).

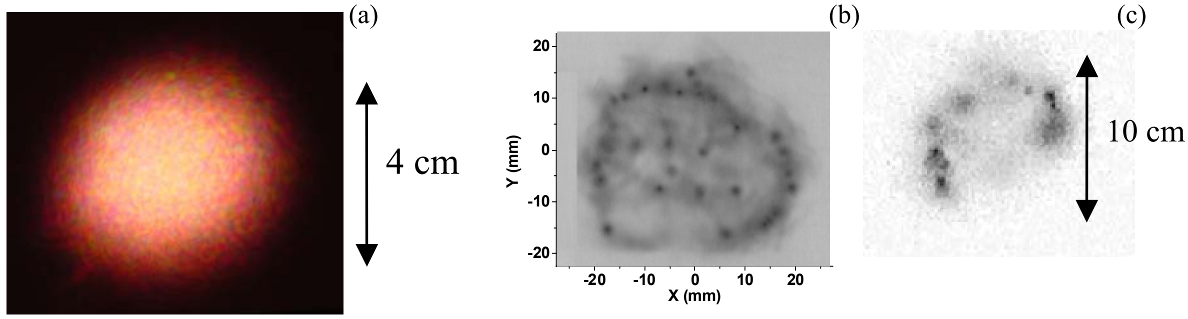

Figure 1. Characteristic laser beam profiles recorded with different initial negative chirps: a) small negative chirp; b) intermediate chirp; c) large negative chirp. The beam profile is recorded at a distance of respectively 50 m (a), 70 m (b); 860 m (c).

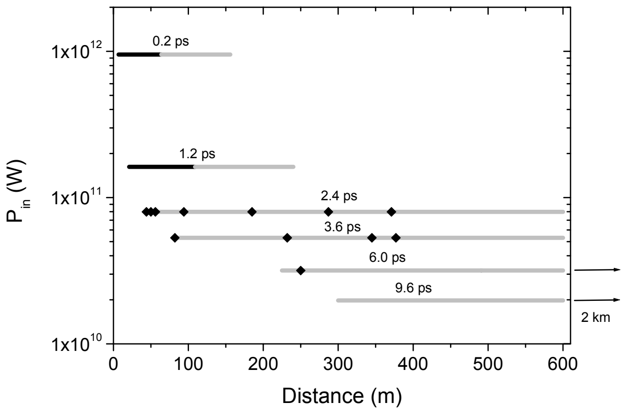

Figure 2: Distance of filamentation for different values of the negative initial chirp, expressed in terms of pulse stretching. The pulse without chirp has a duration of 100 fs. The black lines and black points refer to locations where air ionization could be detected, grey lines to distances where bright light channels are observed.