DPP12-2012-001677

Abstract for an Invited Paper
for the DPP12 Meeting of
the American Physical Society

Marshall N. Rosenbluth Outstanding Doctoral Thesis Award Talk: The Ultrafast Nonlinear Response of Air Molecules and its Effect on Femtosecond Laser Plasma Filaments in Atmosphere[1]

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When exceeding the critical power P_{cr}, an intense laser pulse propagating in a gas collapses into one or multiple "filaments," which can extend meters in length with weakly ionized plasma and local intensity $\sim 10^{13}$ W/cm^2 radially confined in a diameter of < 100 μm [1]. While it has been generally accepted the nonlinear self-focusing of the laser pulse leading to beam collapse is stabilized by plasma generation [2], neither the field-induced nonlinearity nor the plasma generation had been directly measured. This uncertainty has given rise to recent controversy about whether plasma generation does indeed counteract the positive nonlinearity [3, 4]. For even a basic understanding of femtosecond filamentation and for applications, the focusing and defocusing mechanisms—nonlinear self-focusing and ionization—must be understood. By employing a single-shot, time-resolved technique based on spectral interferometry [5] to study the constituents of air, it is found that the rotational responses in O_2 and N_2 are the dominant nonlinear effect in filamentary propagation when the laser pulse duration is longer than $\sim$ 100fs. Furthermore, we find that the instantaneous nonlinearity scales linearly up to the ionization threshold [6], eliminating any possibility of an ionization-free negative stabilization [3] of filamentation. This is confirmed by space-resolved electron density measurements in meter-long filaments produced with different pulse durations, using optical interferometry with a grazing-incidence, ps-delayed probe [7].

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