Upper limit power for self-guided propagation of intense lasers in plasma

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Abstract: It is broadly recognized that ponderomotive force can help laser self-focusing in plasma by forming a channel-like density profile. Based on the prediction of self-focused guiding of high power lasers, many laser wakefield acceleration (LWFA) experiments are designed to use hundreds of TW to PW lasers. Preformed channel-like plasma is also planning to use for further improvement of guiding of such high power lasers, which has been proved to be valid in LWFA experiments with lasers of below or at 100 TW. However, our work shows that it is not necessarily favorable to use the lasers with powers of hundreds of TW to PW for LWFA; and channel-like plasma is not favorable any longer for guiding of such lasers.

It is shown that there is an upper-limit laser power *Pu* for self-focusing of a laser pulse in plasma in addition to the well-known lower-limit critical power *Pc* set by the relativistic effect. This upper limit is caused by the transverse ponderomotive force of the laser, which tends to expel plasma electrons from the laser propagating area. Above *Pu*, a defocusing effect will dominate, which is called ponderomotive defocusing by us. Furthermore, there is a lower-limit plasma density for a given laser spot size, below which self-focusing does not occur for any laser power. Both the lower-limit density and the upper-limit power are derived theoretically and verified by 2D and 3D particle-in-cell simulations. We also find that a plasma channel can reinforce ponderomotive defocusing at high laser power above *Pu* which is unfavorable for stable laser guiding. The present theory shall provide guidance for future experimental designs when the self-guided propagation of laser pulses over a long distance is required, such as in LWFA with the laser power at of hundreds of TW to PW.