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Intense Laser-Driven Ion Beams: the Science of How They're Made and Their Applications

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Abstract

Laser-plasma interactions in the novel regime of relativistically-induced transparency have been harnessed to generate efficiently intense ion beams with average energies exceeding 10 MeV/nucleon (> 100 MeV for protons) at 'table-top' scales. High-intensity is possible because these beams are neutralized and therefore immune to the space-charge and current limits of conventional beams. We have discovered and utilized a self-organizing scheme that exploits persisting self-generated plasma electric (~ 0.1 TV/m) and magnetic (~10^4 Tesla) fields to reduce the ion-energy (E_i) spread after the laser exits the plasma [1], thus separating acceleration from spread reduction. In this way we routinely generate aluminum and carbon beams with narrow spectral peaks at E_i up to 310 MeV and 220 MeV, respectively, with high efficiency (~5%), which at present represents the worldwide state of the art. The experimental demonstration has been done at the LANL Trident laser, irradiating planar foils up to 250 nm thick. Our progress is enabled by massive high-fidelity computer simulations of the experiments. This work advances next-generation compact accelerators suitable for new applications. *E.g.*, a E_i ~400 MeV carbon beam with ~10% energy spread is suitable for fast ignition (FI) of compressed DT [2]. The observed scaling suggests a FI-class ion beam is feasible with existing tar-

get fabrication and PW-laser technologies, using a sub-ps laser pulse with $I \sim 2.5 \times 10^{21}$ W/cm^2. More near term, these beams have been used on Trident to generate warm-dense matter at solid-densities [3]. They also drive an intense neutron-beam source [4] with great promise for important applications such as bulk thermometry of dynamic materials, active interrogation of shielded nuclear materials, neutron imaging and weapons physics. In addition, these beams have been used to drive an intense point-like, directed source of ~ 1 MeV gamma-rays, which has been used for imaging thick objects.

[1] S. Palaniyappan, C. Huang, *et al.,* Nature Comm. **6**, 10170 (2015)

[2] J. C. Fernandez, *et al.,* Nucl. Fus. **54**, 054006 (2014)

[3] W. Bang, *et al.*, Sci. Rep. **5**, 14318 (2015)

[4] M. Roth, *et al.*, PRL **110**, 044802 (2013)