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Towards Extreme Field Physics: Relativistic Optics and Particle Acceleration in the Transparent-Overdense Regime[1]

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A steady increase of on-target laser intensity with also increasing pulse contrast is leading to light-matter interactions of extreme laser fields with matter in new physics regimes which in turn enable a host of applications. A first example is the realization of interactions in the transperent-overdense regime (TOR), which is reached by interacting a highly relativistic (a0>10), ultra high contrast laser pulse [1] with a solid density target, turning it transparent to the laser by the relativistic mass increase of the electrons. Thus, the interactions becomes volumetric, increasing the energy coupling from laser to plasma, facilitating a range of effects, including relativistic optics and pulse shaping, mono-energetic electron acceleration [3], highly efficient ion acceleration in the break-out afterburner regime [4], and the generation of relativistic and forward directed surface harmonics. Experiments at the LANL 130TW Trident laser facility successfully reached the TOR, and show relativistic pulse shaping beyond the Fourier limit, the acceleration of mono-energetic ∼40 MeV electron bunches from solid targets, forward directed coherent relativistic high harmonic generation >1 keV Break-Out Afterburner (BOA) ion acceleration of Carbon to >1 GeV and Protons to >100 MeV. Carbon ions were accelerated with a conversion efficiency of >10% for ions >20 MeV and monoenergetic carbon ions with an energy spread of <20%, have been accelerated at up to ∼500 MeV, demonstrating 3 out of 4 for key requirements for ion fast ignition. The shown results now approach or exceed the limits set by many applications from ICF diagnostics over ion fast ignition to medical physics. Furthermore, TOR targets traverse a wide range of HEDP parameter space during the interaction ranging from WDM conditions (e.g. brown dwarfs) to energy densities of $\sim 10^{11}$ J/cm^3 at peak, then dropping back to the underdense but extremely hot parameter range of gamma-ray bursts. Whereas today this regime can only be accessed on very few dedicated facilities, employing special targets and pulse cleaning technology, the next generation of laser facilities will operate in this regime by default, turning its understanding in a necessity rather than a curiosity.

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