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Dense Electron-Positron Plasmas Generated by 10PW Lasers in the QED-Plasma Regime

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Electron-positron plasmas are a prominent feature of the high-energy Universe. In the relativistic winds from pulsars and black holes it is thought that non-linear quantum electrodynamics (QED) processes cause electromagnetic energy to cascade into an e^-e^+ plasma [1]. We show that next-generation 10PW lasers, available in the next few years, will generate such a high density of pairs that they create a micro-laboratory for the first experimental study of a similarly generated e^-e^+ plasma [2]. In the first simulations of a 10PW laser striking a solid we demonstrate the production of a pure electron-positron plasma of density $10^{26}\mathrm{m}^{-3}$. This is seven orders of magnitude denser than currently achievable in the laboratory [3] and is comparable to the critical density for commonly used lasers, marking a step change to collective e^-e^+ plasma behavior. Furthermore, a new ultra-efficient laser-absorption mechanism converts 35% of the laser energy to a burst of gamma-rays of intensity $10^{22}\mathrm{Wcm}^{-2}$, potentially the most intense gamma-ray source available in the laboratory. This absorption results in a strong feedback between both pair and γ-ray production and classical plasma physics leading to a new physical regime of QED-plasma physics [2]. In this new regime the standard particle-in-cell (PIC) simulation approach, which has been one of the most important kinetic simulation tools in plasma physics for 50 years, is inadequate. We have developed a new approach (QED-PIC) which will provide a powerful new modeling tool essential to the future advancement of the field of high intensity laser-plasma interactions.

[1] P. Goldreich & W.H. Julian, Astrophys. J. 157, 869 (1969)
[2] C.P. Ridgers et al, Phys. Rev. Lett. 108, 165006 (2012)
[3] H. Chen et al, Phys. Rev. Lett. 105, 015003 (2010)