An introduction to laser wakefield acceleration and x-ray generation

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This lecture will introduce some important topics and concepts needed to understand laser wakefield acceleration and the production of high-quality, high-energy electron beams and bright x-rays using intense short pulse lasers. Since the seminal work of Tajima and Dawson in 1979 [1] introducing the concept of the laser wakefield accelerator, there has been much international effort in this field to produce compact (university laboratory sized) particle accelerators and more recently the development of techniques to produce bright x-rays. I will discuss some of the key concepts required to understand many of the most recent results in the field.

In laser wakefield acceleration an ultra-short (~ 30 fs), intense (~ 10^{19} Wcm^{-2}) laser pulse is focused into a moderate density plasma (~ 10^{18} electrons per cc). The ponderomotive force of the laser pulse sets up a plasma wave that travels through the plasma , trailing the laser pulse at a phase velocity close to the speed of light. The electric field of this wave can accelerate electrons injected into the wave to very high energies (~ 1 GeV) in very short distances (~ 1 cm), this is due to the orders of magnitude higher electric fields that can be supported in a plasma compared to those in a conventional accelerator. The main limit to the acceleration is due to dephasing of the electrons from the wave due to the subluminal phase velocity of the plasma wave.

If the wave amplitude is high enough, the plasma wave can trap electrons from the background plasma. Under certain conditions the self-trapped electron bunch can be of very high quality, having narrow energy spread (~ 5 %), low divergence (~ 5 mrad) and high charge (~ 0.5 nC). The non-linear refractive index of the plasma wave can lead to a significant enhancement of the laser intensity through the processes of photon acceleration/deceleration, pulse compression and self-focusing. This means that even a moderately intense laser pulse can evolve so that it can drive the plasma wave to breaking point.

As well as the strong accelerating field the plasma wave, which at large amplitude looks like a plasma “bubble”, has strong focusing forces. These forces lead to transverse, or “betatron” oscillations of the electron beam in the plasma wave, leading to the production of very bright , ultra-short x-rays. These x-rays may well be suitable for a wide range of applications in science and technology.

[1] “Laser Electron Accelerator” T. Tajima & J. Dawson, Phys. Rev. Lett .,**43**, 267, (1979)