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Coherent Laser-Plasma Acceleration: Examples and Recent Results

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Laser-Plasma based schemes for particle acceleration are to a large extent a realization of the "coherent acceleration" paradigm proposed by Veksler in 1957 [1]. The basic idea is that in a many-particle system with collective behavior the energy attainable by the particles is proportional to their number, making the approach attractive for applications requiring high particle fluxes. The basic consequences are the important role of self-organized dynamics and the need to control instabilities and nonlinear effects which are often detrimental.

Amongst the schemes under investigation, the "Light Sail" (LS) concept for laser-driven ion acceleration is the closest to Veksler's idea of a nanoparticle pushed by the radiation pressure resulting from coherent scattering [1,2]. Besides the simplest textbook model of a laser-driven mirror, for ultrahigh laser intensities the LS exhibits a complex behavior. The momentum of laser light is transferred first to electrons and then to ions via a dynamic charge separation field, which produces the well-known LS motion on the average and under proper conditions, such as use of a circularly polarized driver and a single ion species target [3]. The multi-dimensional behavior is affected by Rayleigh-Taylor-like instabilities coupled with plasmonic surface modes which produce structured patterns observed in 3D simulations (Fig.1) [4]. These features will be briefly reviewed and recent experimental results, promising for radiobiology studies, will be also presented [5].

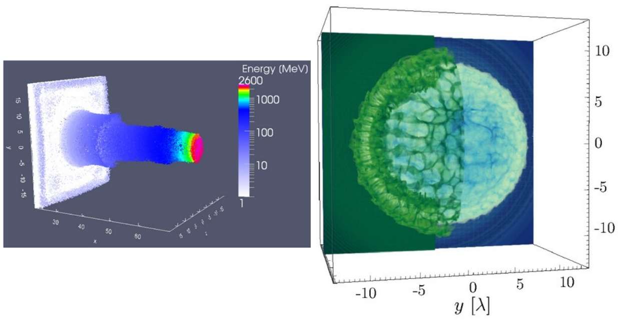

Fig.1: 3D simulation of Light Sail acceleration. Left: spatial-energy ion distribution . Right:hexagonal structures generated by a RT-like instability [4].

Results on the recently demonstrated approach of electron acceleration by intense laser-excited surface plasma waves (SPW) will be also presented. The acceleration process in a surface plasma wave is analogous to that occurring in a bulk plasma wave and exploited for laser/plasma wakefield acceleration; however the SPW, being localized at the interface berween vacuum and a solid-density plasma, can lead to very high numbers of electrons.

Simulations reproduce the experimental results accurately and show how electrons are trapped in the surface wave field forming dense bunches. In turn, these bunches scatter the laser pulse coherently, leading to emission of high harmonics correlated in space and time with the electrons (Fig.2) as experimentally observed [6]. This effect is reminiscent of the collective instability in a free electron lasers. Finally, a perspective to exploit surface waves for proton acceleration will be also described [7,8]: by exploiting the high number of electrons and a novel target arrangement, such that the space-charge field generated by electrons will be homogeneous over the target layer region containing hydrogen, high energy monocromatic proton beams may be generated.

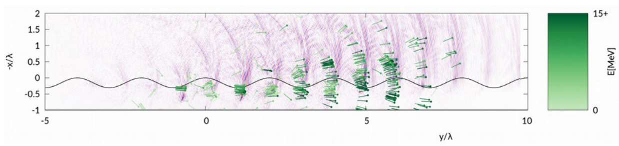

Fig.2: 2D simulations of acceleration of electrons (green arrows) and generation of high harmonics (purple) by an intense laser-driven surface plasma wave [6].

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