Plasma-based soft x-ray lasers : amplification of high order harmonic beams carrying an orbital angular momentum.

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Light is carrying angular momentum. In atomic physics, angular momentum exchange is observed during the interaction of circularly polarized light with a quantum system. This intrinsic property of the optical field is also called Spin Angular Momentum (SAM). However, an optical beam may also transport Orbital Angular Momentum (OAM). An example of this is the optical vortex beam, a wave presenting an helical wavefront, with an azimutal dependence of its phase $\phi = l\,\theta$, where θ is the azimutal angle and l is an integer called the topological charge.

A vortex beam is presenting a phase singularity on its propagation axis, leading to a null intensity in this region. Singularity in optics are also observed wherever the polarization state of light is not defined. Radially and azimutally polarized laser beams are some examples of such a situation. Both type of structured optical beams are actively investigated in microscopy, optical communication, or atomic and molecular physics.

Recently, these properties have been successfully transferred in the soft x-ray range, through the conversion of intense structured beams in high order harmonics. However, precise characterization of their optical properties is challenging. Moreover, this conversion is often coming with a drop in conversion efficiency.

In this presentation, we will present recent results achieved in the LASERIX facility in Paris-Saclay. We will show that OAM beam harmonic up-conversion (25^{th} harmonic) can lead to OAM beams with a topological charge as high as l=100. Besides, wavefront reconstruction of such a soft x-ray vortex beam was successfully achieved, enabling an assessment of its mode purity. We extend this nonlinear up-conversion of optical property to azimutally and radially polarized vortex beam, demonstrating for the first time soft x-ray vector-vortex beams and their detailed characterization.

Finally we will present first experimental investigations of amplification of such beams by a plasma-based soft x-ray laser. If spatial coupling still needs to be improved, we show that the phase gradient of the incident beam is conserved, despite the important density gradient of the plasma amplifier.