Ptychographic measurements of ultrahigh intensity laser-plasma interactions

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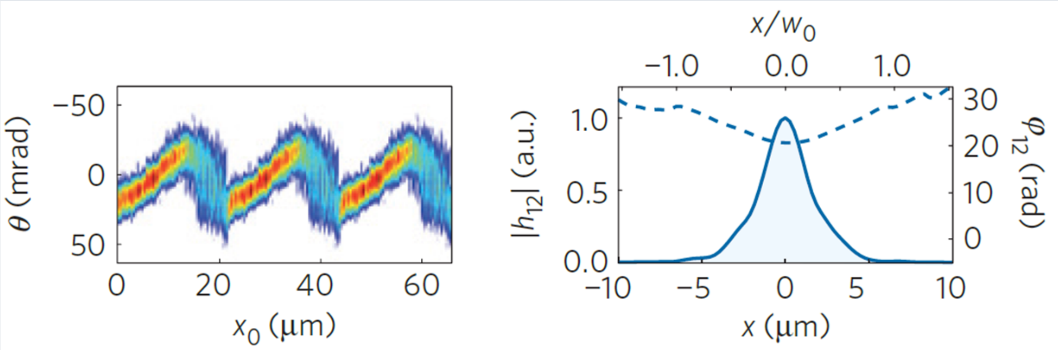
The extreme intensities now delivered by femtosecond lasers make it possible to drive and control relativistic motion of charged particles with light, opening a path to compact particle accelerators and coherent X-ray sources. Accurately characterizing the dynamics of ultrahigh-intensity laser–plasma interactions as well as the resulting light and particle emissionsis an essential step towards such achievements. This remains a challenge, as the relevant scales typically rangefrom picoseconds to attoseconds in time, and from micrometresto nanometres in space. In these experiments, owing to the extreme physical conditions, measurements can be performed only at macroscopic distances from the targets, yielding only partial information at these microscopic scales. In this project, we have applied the concepts of ptychography to such measurements, and thus retrieved microscopic information hardly accessible until now.



Left: ptychographic trace of the 12th harmonic generated on a transient plasma grating. Right: spatial amplitude and phase profiles of the 12th harmonic source in the plasma mirror plane, obtained by appying a phase retrieval algorithm to the ptychographic trace.

Ptychography is a general lensless imaging technique, used to reconstruct images with simultaneous amplitude and phase contrast. It consists in measuring the intensity of the diffraction pattern produced by a probe beam diffracted out by an object to be imaged, typically placed at or around the beam focus, for different relative positions between the probe and object. We have adapted this technique to the spatial characterization of harmonics beams produced on plasma mirrors, by generating these harmonics on a spatially modulated plasma mirror surface that acts as the object. This harmonic beam thus constitutes the probe which is here directly generated on the object, instead of being provided by an external source as in usual ptychography. The modulated plasma mirror surface can be obtained in situ by optically microstructuring an initially flat solid target, using a combination of two interfering prepulse beams to trigger a spatially modulated plasma expansion.

We have used this new and flexible measurement scheme to carry out a thorough study of the spatial properties of harmonic beams produced from plasma mirrorr irradiated by ultraintense laser beams. These spatial properties carry rich information on the physics of the generation process, and their detailed understanding is essential for applications of these light beams.For instance, the curvature of the harmonic spatial phase observed on the figure above (right graph) is due to the curvature of the plasma mirror surface induced by the considerable laser radiation pressure. Such measurements have been used to validate analytical models of the harmonic spatial phase in different interaction regimes, and to benchmark ultrahigh-order Maxwell solvers of particle-in-cell simulation codes.

A.Leblanc, S. Monchocé, C. Bourassin-Bouchet, S. Kahaly and F. Quéré, "*Ptychographic measurements of ultra-high intensity laser plasma interactions*", Nature Physics 12, 301–305 (2016)

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