MAX PLANCK INSTITUTE
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MPQ

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Press Release

Plasma hotter than expected

Scientists at MPQ discover unexpected properties of laser-induced plasmas using new method of electron deflectometry

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Laser-induced plasmas are of great interest because they are suitable for a variety of applications such as nuclear fusion, acceleration of electrons and ions, and the generation of X-Ray sources and attosecond pulses in the extreme ultraviolet. A detailed knowledge of the temporal evolution of this state is critical for optimizing the parameters of a given application. With the help of a new pump-probe technique Dr. Martin Centurion, Peter Reckenthäler, and Dr. Ernst Fill of the Attosecond and High-Field Physics Division (Director: Prof. Ferenc Krausz) at Max Planck Institute of Quantum Optics (MPQ) in Garching have now succeeded in observing plasma dynamics in real time (Nature Photonics, DOI 10.1038/nphoton.2008.77). They discovered that against all expectations OFI (optical-field induced) plasmas build up high electric and magnetic fields. This knowledge may have a significant impact on a range of applications of laser-induced plasmas.

A plasma is a state of very hot and dense matter in which the bonds between the electrons of the atomic shell and the nucleus are broken apart such that positively charged ions and negatively charged electrons coexist independently. According to standard theory the charges balance each other out, and as a consequence the interior of the plasma is free of electric fields. Charge fluctuations are supposed to occur only over very small distances that are of the order of the Debye length (0.1 micrometer). In contrast to these expectations the MPQ experiments have revealed a positively charged core and a cloud of electrons expanding far beyond the Debye length.

At MPQ the OFI plasma is generated by intense laser pulses with duration of 50 femtoseconds (1 fs=10^{-15} sec) that are directed onto nitrogen streaming from a nozzle. Due to the high electric fields of the laser pulse the atoms get ionized and a plasma forms in the region of the focus of the laser beam. Now pulses of monoenergetic 20 keV electrons are sent through the plasma. Thereafter the electrons are detected on a screen. The influence of the plasma on the probe-beam of electrons is reflected in their spatial distribution. If the plasma were free of electric fields the electrons would be distributed homogenously and only be blocked by the gas nozzle. The experiments, however, show a very interesting and fast changing pattern on the screen.

In order to observe the temporal evolution of the plasma the time delay between laser pulse and probe pulse is varied. The images taken in a distance of a few picoseconds show the following behavior (see the figure below from left to right): In the very beginning – after about a few picoseconds – a “hole” appears in the electron beam in the area of the laser focus. The electrons missing in the depleted region have obviously wandered into two bright “lobes” on each side of the plasma region, which move away along the line of laser propagation in opposite directions. This goes on for about 80 picoseconds, then the electrons accumulate in the central region to a density higher than in the original beam.

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After about 300 picoseconds this pattern gets washed out.

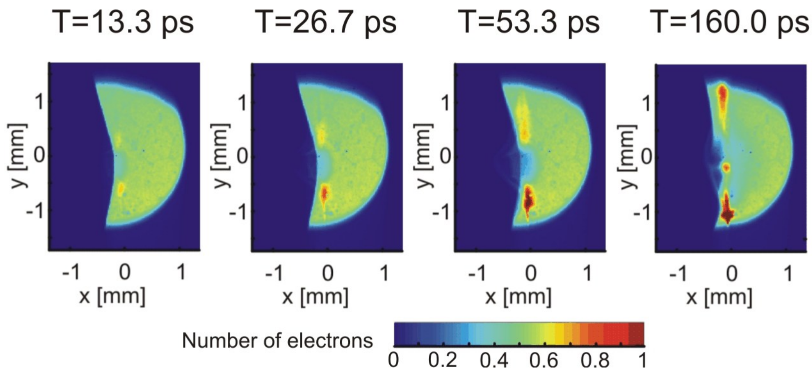

Figure: Pump-probe images of plasma evolution. The figure shows the changes in the electron distribution of the probe-beam as a function of the time delay between the electron and the laser pulses. The time T is measured in picoseconds.

The scientists explain these observations with the following mechanisms: Shortly after the plasma is generated by a laser pulse a positively charged core is formed which is surrounded by a cloud of hot electrons. Due to this charge-separation electric and magnetic fields build up that deflect the electrons resulting in the distribution described above. After about 100 picoseconds the electron cloud expands beyond the original plasma region reaching a radius that is a thousand times larger than the Debye length. Under these conditions the probe beam now becomes focused onto the centre of the detector screen resulting in a bright spot.

Numerical simulations based on these assumptions are in very good agreement with the experimental data. The relevant physical parameters, such as the fields, the number of charges and the electron temperature can be deduced. The calculations also show that such a charge distribution is only possible if a small fraction of the electrons heats up to temperatures higher than the plasma temperature itself. This could possibly be caused by frequent recollisions of the electrons with the atomic nuclei.

This new technique of electron deflectometry is able to capture changes in the plasma evolution with a spatial resolution of 30 microns on a picosecond scale. The sensitivity is due to the fact that even small charge imbalances within the plasma are observable as distortions in the spatial profile of the electron beam. The new method will lead to a better understanding of laser plasmas and may have the potential to improve electron and ion acceleration techniques that are based on plasmas. [O.M.]

Original publication:

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