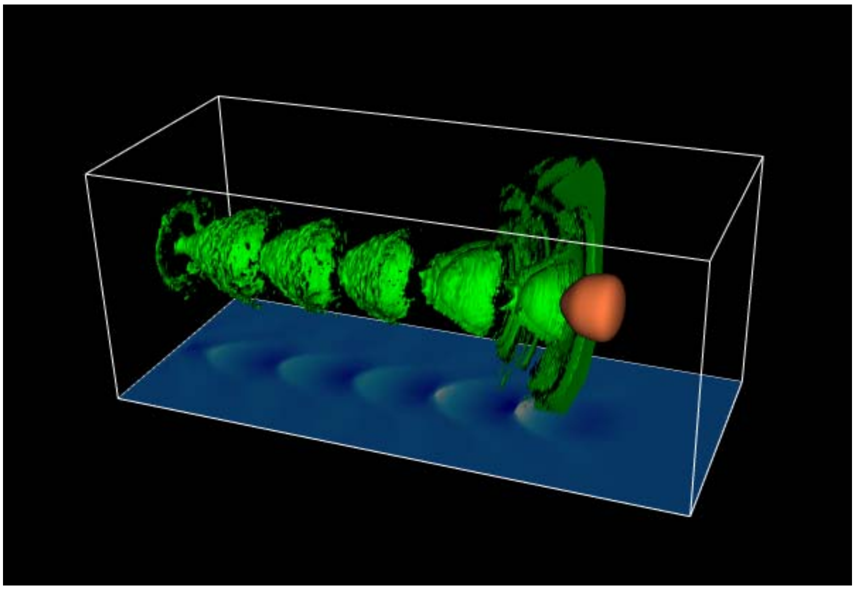
Simulating laser acceleration of electrons

In conventional particle accelerators, the electric fields are limited to several tens of megavolts per metre to avoid breakdown of the accelerating structures. Producing beams of high-energy particles therefore requires very long durations of acceleration. The rapidly developing technology of plasma accelerators could overcome this constraint, since in this case the particles are accelerated in a plasma, an already ionised environment which can support electric fields several orders of magnitude greater.

In these new generation accelerators, the electric fields are excited by passage of an extremely short - several tens of femtoseconds - and extremely intense laser pulse. In the wake of this pulse, the electrons in the plasma can become "trapped" by the accelerating structure and are accelerated to energies on the order of a billion electron-volts in just a few centimetres, rather than over the several metres which would be minimally required in conventional machines.



Modulation of the electron density (in green) excited by the wake of the laser pulse (in orange).
In blue, a horizontal projection of the associated longitudinal electrostatic field.

The physical and numerical challenge

To well understand this method of acceleration, and to optimise it, the interaction between the laser radiation and the electrons of the plasma needs to be modelled in great detail. This can be achieved using a "particulate" method, in which the plasma is described by a collection of several hundred million numeric particles and the electromagnetic fields are discretised at the nodes of a three-dimensional mesh containing several hundred million elements. Such a computational task can only be achieved using massively parallel codes, such as the CALDER code from DAM/DPTA. Over the last few years, numerical simulation has hence become an indispensable tool for exploring laser-plasma interaction mechanisms, which occur on such a small scale in both time and space that they often defy measurement. And so simulation now accompanies, or perhaps even runs ahead of, experimental progress.

The outlook

Acceleration of electrons by plasma will lead naturally to the production of beams with higher and higher energy, obtained over larger acceleration distances, which will present an increasing challenge to the numerical simulations. New numerical models need to be developed to accompany these experiments and current tools need to be adapted to gain as much benefit as possible from future designs of machine.