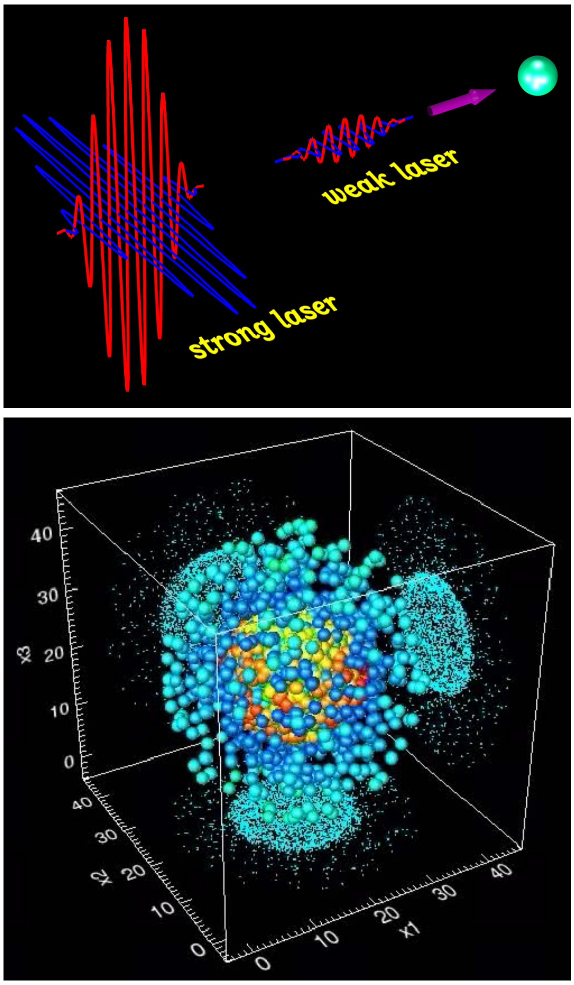
Shock-driven nuclear fusion reactions from nanoplasma explosions

The laser-induced explosion of tiny spheres of solid deuterium can be controlled by appropriately shaping the laser pulses: a "double-pump" irradiation scheme causes the formation of particular shock structures, capable of driving nuclear fusion reactions.

Nowadays laser technology discloses new realms of investigation in the field of laser-matter interactions. One of the most spectacular experimental outcomes of these researches is tabletop nuclear fusion [1]. This is achieved by shooting extremely intense lasers against a jet of deuterium clusters (tiny spheres of solid deuterium a few tens of nanometers across): the laser strips each cluster of its electrons, leaving highly charged ion balls, which suddenly explode because of the electrostatic repulsion (such process is named a Coulomb explosion). After a while, different exploding clusters start overlapping with one another (like colored fireworks exploding together in the sky) and the violent collisions among ions from neighboring clusters drive fusion reactions.

Recently, a research team from IST, Lisbon (Portugal), discovered that nuclear fusion can occur even within a single exploding cluster (just one firework in the sky) [2]. With the aid of computer-based simulations, the researchers showed that the very explosion process can be manipulated so as to force the cluster to overlap with itself (technically, a "shock shell" is said to form, i.e., a spherical shell in which fast expanding ions overtake slowly expanding ones [3]). Amazingly, this can be obtained very simply by firing two laser pulses, instead of a single one. The first pulse is weak and does not expel the electrons from the cluster; rather, it simply heats them up, creating a "nanoplasma", composed of cold ions and hot electrons [4]. In this conditions, the ions in the outer part of the plasma sphere get involved in a slow expansion, driven by the thermal motion of the electrons, while the inner ions stay still. After a proper time delay, a second, extremely strong laser is fired, driving the violent Coulomb explosion of the ion core: the exploding inner ions soon catch up with the slowly expanding outer ions and start to overtake them, forming the shock shell. Collisions between ions overtaking each other can drive nuclear fusion (a well-tuned double-pump experiment would provide a clear signature for the occurrence of intracluster, shock-driven fusion reactions, in the form of a time-resolved burst of fusion neutrons). In a sense, the first pulse prepares a target of slow ions and the second pulse shoots fast ions against it.



The "double-pump" technique: *the combined effects of weak and strong lasers drive a nonuniform explosion where the inner ions (red and yellow spheres) overrun the outer ions (blue and cyan spheres).*

The features of the shock shell can be tailored by varying the intensities of the two lasers and the delay between them, thus providing a unique way to control the explosion of nanometer-sized plasmas. In the future, even more intense lasers will allow to control the explosion of micrometer-sized spheres of solid deuterium (or deuterium/tritium mixtures), thus opening the way toward the production of ultraprompt, ultralocalized neutron sources.

References:
[1] T. Ditmire *et al.*, Nature **386**, 54 (1997); Nature **398**, 489 (1999).
[2] F. Peano *et al.*, Phys. Rev. Lett. **94**, 033401 (2005); Phys. Rev. A, **73** (2006).
[3] A. E. Kaplan *et al.*, Phys. Rev. Lett. **91**, 143401 (2003).
[4] F. Peano *et al.*, Phys. Rev. Lett. **96**, 175002 (2006).

During this meeting:
Invited talk:
9:30 AM–12:30 PM, Friday, November 3, 2006
Philadelphia Marriott Downtown - Grand Salon CDE
[ZI2.00005]
(http://meetings.aps.org/Meeting/DPP06/Event/53270)

Poster session:
2:00 PM–5:00 PM, Tuesday, October 31, 2006
Philadelphia Marriott Downtown - Franklin Hall AB
[JP1.00077]
(http://meetings.aps.org/Meeting/DPP06/Event/52357)

9:30 AM–12:30 AM, Thursday, November 2, 2006
Philadelphia Marriott Downtown - Franklin Hall AB
[UP1.00090]
(http://meetings.aps.org/Meeting/DPP06/Event/53000)

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