Radiation Dominated Implosion with Flat Target

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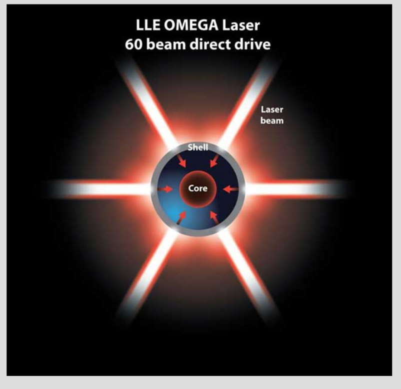
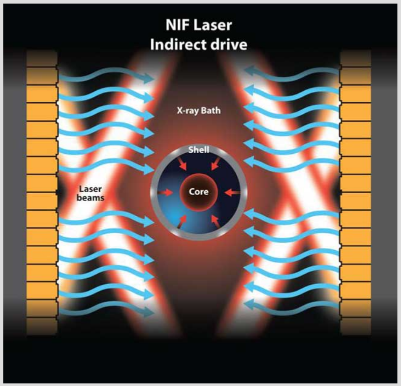
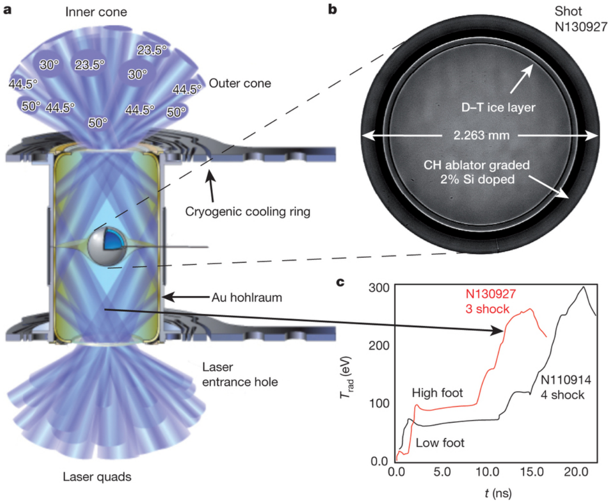
Direct vs Indirect drive





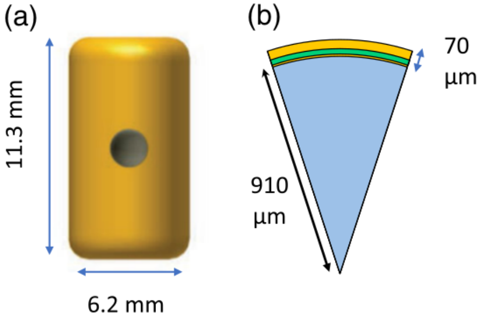
PHOTONICS MEDIA photonics.com

Hohlraum



[O.A. Hurricane et al., Nature, 506, 343 (2014)]

NIF older | newer target



- thin plastic ablator | tungsten-doped diamond-like high density carbon
- gold hohlraum | depleted uranium hohlraum

OMEGA Experiment

ARTICLES
NATURE PHYSICS DOI: 10.1038/NPHYS3614

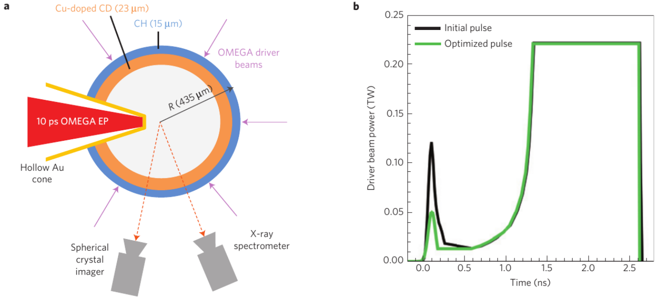


Figure 1 | Configuration of the target, experimental layout, and laser parameters. a, Schematics of the cone-in-shell target, laser beams and main diagnostics. **b**, OMEGA ultraviolet driver beam pulse shape.

Objective

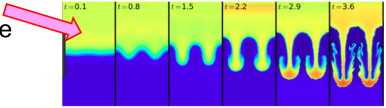
Achieve fusion reaction conditions taking into consideration:

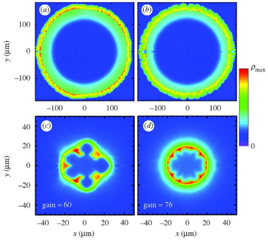
- $D + T \rightarrow n(14.1\mathrm{MeV}) + {}^4He(3.5\mathrm{MeV})$
- Rapid, volume ignition in Inertial Confinement Fusion (ICF), to avoid **Rayleigh-Taylor** instabilities.
- Achieve **simultaneous ignition** by increasing absorption with **Au nano-spheres**.
- If the density of D and T are n_1, n_2 then the rate of DT reactions are proportional with $n_1 n_2 \langle \sigma \mathbf{v} \rangle$

Rayleigh-Taylor Instability

Rayleigh – Taylor Instability

High pressure





Spherical compression [LLNL]

3

RFD

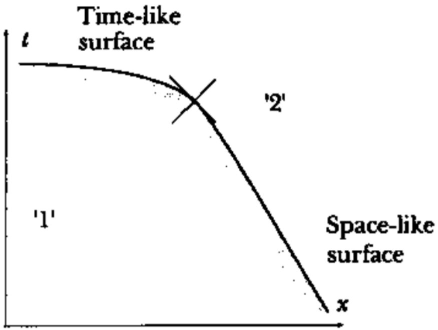
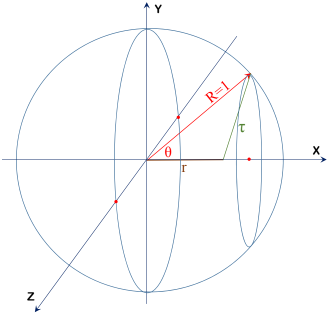


Figure 5.10: Smooth change from spacelike to timelike detonation

[Csernai, L.P. (1987). Detonation on a time-like front for relativistic systems. Zh. Eksp. Teor. Fiz. 92, 379-386.]

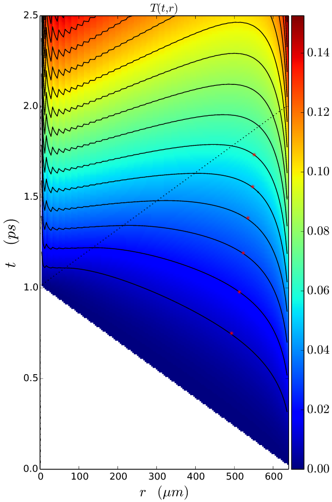
Old spherical target configuration

Let us chose a point on the sphere, and the angle of this point from the x-axis is denoted by Θ. Then the length between this surface point and the point at r is $\tau = (R^2 + r^2 - 2Rr\cos\Theta)^{1/2}$. If the speed of light is $c = 1$ then the propagation time from the surface point to the point at r equals τ.



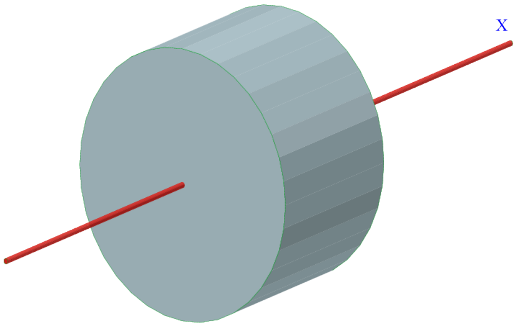
[Csernai, L.P., Kroo, N. and Papp, I. (2018). Radiation dominated implo- sion with nano-plasmonics, Laser and Particle Beams 36, 171-178. DOI: 10.1017/S0263034618000149]

Changing absorptivity



[Csernai, L.P., Kroo, N. and Papp, I. (2017). Procedure to improve the stability and efficiency of laser-fusion by nano-plasmonics method. Patent P1700278/3 of the Hungarian Intellectual Property Office.]

Flat target



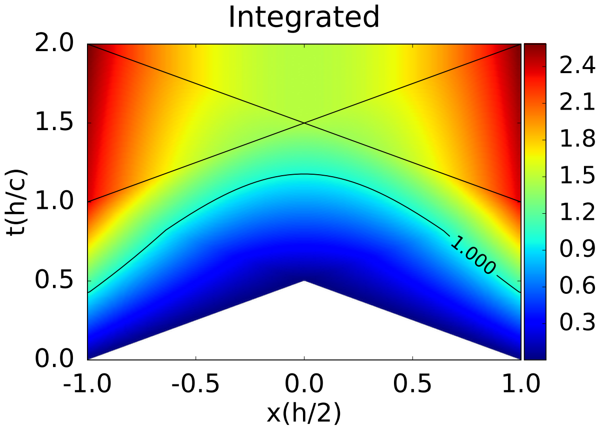
Schematic view of the cylindrical, flat target of radius, R, and thickness, h. [L.P. Csernai, M. Csete, I.N. Mishustin, A. Motornenko, I. Papp, L.M. Satarov, H. Stcker & N. Kro, Radiation- Dominated Implosion with Flat Target, *Physics and Wave Phenomena*, **28** (3) 187-199 (2020)]

Flat target

$$V = 2\pi R^3, \qquad R = \sqrt[3]{V/(2\pi)}, \qquad h = \sqrt[3]{4V/\pi}.$$

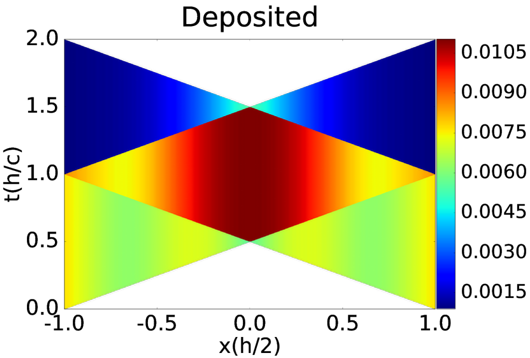
- Based on the NIF results the necessary ignition energy of the DT target is $Q/m = 207.7$ kJ/mg.
- Assuming $Q_0 = 100$ J laser pulse energy we can ignite a DT target $m = 0.481\ \mu$g.
- Density of DT ice $\rho = 0.225$ g/cm^3, with volume of $V = 0.00214$ mm^3.
- For a minimal target surface, $2R = h = 0.111$ mm, and its cross section is $A = 0.0153$ mm^2.
- The critical energy density for ignition is: $\epsilon = \rho \cdot Q/m = 46.47$ MJ/cm^3 (kJ/mm^3), while the required pulse duration is $t_{pulse} = h/c_{DT} = 0.526$ ps.

Constant absorption



The **integrated energy** up to a given time in the space-time across the **depth**, h, of the flat target. The color strip indicates the energy density, in units of the critical energy density (T_c).

Varying absorptivity

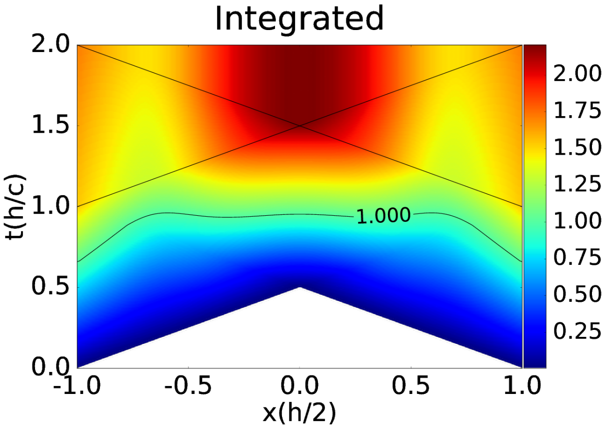


Deposited energy per unit time in the space-time plane across the depth, h, of the flat target.

To increase central absorption we used the following distribution:

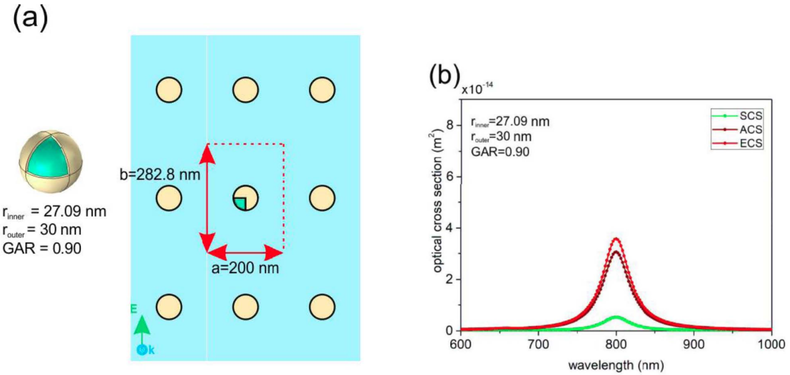
$$\alpha_{ns}(s) = \alpha_{ns}^{C} + \alpha_{ns}(0) \cdot \exp\left[4 \times \frac{\left(\frac{s}{100}\right)^2}{\left(\frac{s}{100} - 1\right)\left(\frac{s}{100} + 1\right)}\right].$$

Varying absorptivity



The contour line $T = 1$, indicates the critical energy density, T_c where the phase transition or ignition in the target is reached. This contour line is almost at a constant time, indicating **simultaneous ignition** in the whole target volume.

Doping with gold



(a) Left: Single core-shell nano-sphere. Right: Rectangular lattice of nano-spheres in a transverse layer of the target.
(b) Optical cross-section of an individual core-shell nano-sphere optimized to absorb light at 800 nm wavelength and optical response of the same core-shell nano-spheres composing a rectangular lattice.

Conclusions

- Mechanical, pressure driven processes are subject to RT instability, while shorter and more energetic irradiation can prevent the possibility of all mechanical instabilities.
- In our model, we see that the critical ignition energy density is reached in about 80% of the target volume simultaneously.
- For more realistic estimates we need relativistic fluid dynamical, PICR analysis of the dynamics of the compression and expansion of the system.
- More results will be shown in the presentations of **L.P. Csernai** and **A. Bonyár** on the workshop in **September 11th**.