What is Inertial Confinement Fusion?
Inertial Confinement Fusion: dense & short-lived plasma

Fusing D and T requires
- temperature – to overcome Coulomb repulsion
- density & confinement time – to maximize number of reactions

MCF: low density plasma confined by B fields over minutes or more
ICF: high density plasma confined – very briefly – by its own inertia
→ ICF is a *pulsed* process

Areal density \( (\rho R) \) is a key parameter
- for efficient burn (fuel burns before it deconfines)
- for reasonable driver & yield energies

Hot spot ignition needed to make up for low laser and hydrodynamic efficiencies: fusion reactions start in heated fuel and spread to neighboring cold fuel
Laser-driven ICF uses intense laser beams to compress and heat a small pellet of DT fuel.

The obvious way: direct drive

The mainstream way: indirect drive
Physics issues associated with indirect-drive ICF

Capsule shape and stability
- Control low-mode symmetry & high-mode hydrodynamic instabilities

Capsule compression
- Implode fuel with proper timing and strength of shocks

Ignition and Burn
- Trigger and propagate burn wave

Laser-Plasma Interaction
- Propagate intense beams in long, low-density plasma

X-ray conversion
- Absorb laser energy and re-emitt as x-rays

Design relies heavily on complex, multiphysics, radiative hydrodynamics codes
ICF research status
the National Ignition Facility (USA)
The National Ignition Facility (NIF) was designed and built to demonstrate ignition and net energy gain.

NIF has delivered 1.86 MJ at 525 TW to target in an ignition pulseshape, — Exceeding its design goal.
NIF has made good progress towards demonstrating target and laser performance required for ignition.

The latest shot had a total yield of $6.2 \times 10^{15}$ at a $T_{\text{ion}} = 4.9$ keV.

The $\alpha$ (or self heating) yield equaled the compression yield.

This “$\alpha$-doubling” is an important step towards achieving fusion ignition.
The National Ignition Campaign on NIF had to face two major difficulties: velocity and mix

- Radiation drive produced in the hohlraum is in reasonable agreement with predictions, but implosion velocity of capsule systematically below prediction

- Pressure in hot spot and yield remain low, suggesting more mix of ablator in fuel than expected, quenching fusion

- Changing the pulse shape has improved mix control, and enabled record neutron yields, but scheme does not extrapolate to ignition target
- Clear experimental progress, but offset with simulation still holds
M. J. Edwards (LLNL), IFSA 2013:

We are pursuing 2 paths to improved performance

<table>
<thead>
<tr>
<th>Gas-filled design</th>
<th>Near vacuum design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Challenge</strong></td>
<td><strong>Challenge</strong></td>
</tr>
<tr>
<td>Inner beam propagation for symmetric drive</td>
<td>Implosion before hohlraum fills</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lower density plasma</td>
<td></td>
</tr>
<tr>
<td>• Hohlraum geometry eg “Rugby”</td>
<td></td>
</tr>
<tr>
<td>• Higher temperature plasma</td>
<td></td>
</tr>
<tr>
<td>• Higher Z fill</td>
<td></td>
</tr>
<tr>
<td>• B-fields</td>
<td></td>
</tr>
<tr>
<td>• Higher density ablators</td>
<td></td>
</tr>
<tr>
<td>• HDC</td>
<td></td>
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<tr>
<td>• Be</td>
<td></td>
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<tr>
<td>• Optimal drive with shorter laser pulses</td>
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</tbody>
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ICF research status
the Laser Mégajoule (France)
Laser Mégajoule main characteristics

4 Laser bays
- Glass Neodymium laser, frequency tripled: $\lambda = 0.35 \mu m$
- Pulse duration: from 0.3 ns to 25 ns
- Designed for 240 beams, 176 will be installed
- Laser energy > 1.3 MJ, Power > 400 TW

Target area
- Biological protection: 2 m thick concrete
- Target chamber $\varnothing 10$ m

Ignition target
- 2 X 2 cones irradiation: 33° & 49°
- Hohlraum length ~ cm
- Capsule $\varnothing$ ~ 2 mm

DT cryogenic layer
The four laser bays are (nearly) complete

Bay South-East
7 bundles+ PETAL completed end 2011

Bay North-East
5 bundles completed end 2011

Bay North-West
5 bundles completed end 2012

Bay South-West
6 bundles will be completed end 2013
LMJ is a key component of the CEA «Simulation Program» to guarantee a safe and reliable French Deterrent w/o testing

- Design and Guarantee of nuclear warheads now relies on numerical simulation codes
- Progress in physical models and numerical tools is obtained through prediction and comparison with dedicated experimental results
- This experimental program is executed on
  - LIL - a prototype LMJ quad delivering 15 kJ (CEA, Cesta, France), shut down 2014
  - Omega - a 60 beam, 30 kJ facility at LLE (U. Rochester, USA),
  - uses NIC results as much as possible
  - will benefit from initial LMJ experiments starting at the end of 2014

- Gain demonstration on LMJ is a long term objective - simulation codes must first be improved to be consistent with NIF results
20% of LMJ time will be open to academic access

The « Institut Laser et Plasmas » brings together the French academic community on laser plasmas, and will organize access to LMJ for civilian research.
ICF research effort worldwide

Location of the major High Energy Density laser facilities worldwide
Compactness of fast ignition will accelerate inertial fusion energy development.