HiPER: laser fusion in Europe

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UK Central Laser Facility

- Provides world leading facilities – state of the art laser systems
- Performs and supports UK and International research
- Provides access for Industrial users
- Investigates and develops new technologies

Principal Technical Areas

- Clean energy
- Bioscience & medical applications
- Fundamental science
- Environmental science

Tabletop to international scale laser systems
Laser science impacts many fields

- **Ultra-high Intensity interaction physics**
  *Why?* Frontier science - access to conditions otherwise unobtainable on Earth

- **Time resolved Vibrational Spectroscopy**
  *Why?* To provide unique tools for medical, biological and fundamental chemistry applications

- **Bioscience at the cellular and DNA level**
  *Why?* To understand how cells function, and thus the basic processes controlling cancer

- **Nano-scale control and imaging**
  *Why?* Next-generation capability to enable nano and molecular manipulation

- **Plasma-based particle accelerator development**
  *Why?* To provide international scale accelerator performance in a small lab

- **Ultrafast (<10fs) science**
  *Why?* Frontier science – understanding the fundamental mechanics of matter

- **Fusion Energy research**
  *Why?* This offers a route to inexhaustible, clean energy

- **Next generation laser development**
  *Why?* To keep the CLF in an internationally leading position
Pushing the boundaries: new CLF projects

- Ultra fast
  - Artemis (<10fs)
- Ultra small
  - Nanoprobes (nm, pN)
- Ultra sensitive
  - Ultra (10kHz spectroscopy)
- Ultra intense
  - $10^{15}$ and $10^{16}$ Watt projects
- Ultra broad
  - Combined laser + accelerator sources (prototype + proposal)
- Ultra energetic
  - HiPER fusion facility (proposal)
- Ultra spacious!
  - New research building (proposal)
Putting laser numbers into perspective

- **Energy**: pitifully small
  - Vulcan ~ 500 Joules
  - 4 finger KitKat…. 973,000 J

- **Timescale**: very short
  - Astra ~ 40 fs (0.000000000000004 s)
    (equivalent fraction to 1 second in 1 million years)

- **Power**: staggering large
  - Lightbulb ~ 100 W
  - 1 Petawatt > 10,000x National Grid
    ( 1,000,000,000,000,000,000 Watts )

Imagine this power focussed to a spot 10x smaller than the width of a human hair….
The UK is a world leader

Vulcan laser facility, CLF, Rutherford Appleton Lab
High Power Lasers: continued leadership

CLF: home to the world’s most intense lasers

Science
- The hottest, densest matter on Earth; the highest magnetic field
- Future: fundamental studies of the quantum vacuum

Exploitation
- Miniature accelerators (“dream beam”) for science, medicine and security
- Alternative routes to fusion energy (“HiPER”)
18 European Laser Laboratories

• Trans-national access
• Joint technology development
• Coordinated strategic goals
plus:
European training programs
Laser Fusion Energy – why bother?

• Plentiful fuel source
• No carbon emissions, and no long-lived radioactivity
• Intrinsically safe reactor (no stored energy)
• Complements the magnetic fusion approach (ITER): multiple solutions

• Would provide a source of Hydrogen (high temperature environment)
• Advanced H₂ cycles do not suffer from CO₂ by-product

H₂ via water decomposition (electrolysis + chemical cycle)
The route to Fusion Energy with lasers...

**The Sun:**
A natural fusion reactor

**Terrestrial fusion fuel is plentiful**

Core $\sim 15$ MK
$\sim 150$ g/cc

Terrestrial fusion fuel is plentiful

$E = mc^2$

Mass difference between initial & final particles

This energy is $\sim$ a million times greater than in chemical reactions

$D + T \rightarrow \alpha + n$

3.5 MeV  14.1 MeV

Total energy of world oil reserve
Inertial (Laser) Fusion Power Plant

- Inertial fusion has been proven to work (1980s)
- What now remains is to achieve this in the laboratory and design a commercially viable power plant
NIF (USA) and LMJ (France) due to demonstrate laser fusion “ignition” within the next 5 years

How will we respond to this transformational event?
IFE “Fast Ignition” approach

Ignite the fuel directly using a “spark plug” of electrons or protons from the laser interaction

- Allows an affordable commercial route to be pursued
  - Smaller infrastructure for the same energy output
  - Potentially cheaper electricity (estimate 5 c/kWh)
- Allows European academia & industry to take a lead role
- Will have unique capabilities for a broad science programme

Compress  Prepare  Heat  Energy output
Fast Ignition – attractive but uncertain

If successful, FI offers:

- High energy gain
- Smaller infrastructure
- Cheaper electricity
  (5 ¢/kWh vs 7 - 8)
- Unique science facility

Fast Ignition performance is uncertain at this time: coordinated research programme is needed
Countries involved to date:

UK, France, Spain, Italy, Germany, Poland, Portugal, Czech Republic, Greece, Canada

- UK is leading this international process
- 18 month conceptual design completed
- 10 plenary workshops, >50 participants

Next step:
- Detailed design and risk reduction project (3 years)

UK leadership announced (Jan 07)

HiPER accepted onto the European large facilities roadmap (ESFRI) – October 2006
1. Implosion laser
   200 kJ 10ns
   10 m (NIF) chamber

2. “Sparkplug” laser
   70kJ 10ps

3. Exawatt options
   (1 EW = 1000 Petawatt)

High repetition rate source development

Future reactor technology and design

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Flexibility for a broad science programme

- **Material Properties under Extreme Conditions**
  Unique sample conditions & diagnosis
  Non-equilibrium atomic physics tests

- **Laboratory Astrophysics**
  Viable non-Euler scaling & diagnosis

- **Nuclear Physics**
  Access to transient & obscure nuclear states

- **Neutron Scattering?**
  IFE based neutron scattering source?

- **Turbulence**
  Onset and evolution in non-ideal fluids

- **Radiation transfer and HED physics**
  Unique sample conditions & diagnosis

- **Development of new particle beam sources**

- **Fundamental Physics**
Focusing the high power laser beams

Propose to use a similar approach to the large area optical telescope community
Technology development requirements

- Detector and diagnostic technology
  - Optical to gamma rays; Electrons, protons, ions; neutrons
  - Single shot to MHz, high sensitivity, novel

- Large area (metre scale) optics: production, coating, handling

- Adaptive Optics and Active Control (Phase Locking)

- Micro-fabrication of (cryogenic) fuel pellets
  (and future bulk manufacture methods)

- Micro-scale characterisation (SEM, AFM, tomography, …)

- High efficiency, high repetition rate laser designs

- Materials to withstand harsh environments

- Systems Engineering

Many DTI / EC sponsored mechanisms to coordinate academia & industry in this type of activity
eg. Knowledge Transfer Networks
www.sensorsktn.org
Conclusions

• UK has an internationally competitive laser programme
• Many ongoing projects requiring new technology:
  • large area optics and advanced mirrors
  • micro fabrication and characterisation
  • cryogenic and remote handling
• UK is leading a major European fusion energy laser project
  • HiPER: Accepted onto the European roadmap
    Detailed design phase due to start 2007
• Coordination of UK industry & academia is essential

www.clf.rl.ac.uk www.hiper-laser.eu