HiPER:
the science of extreme conditions and the route to IFE in Europe

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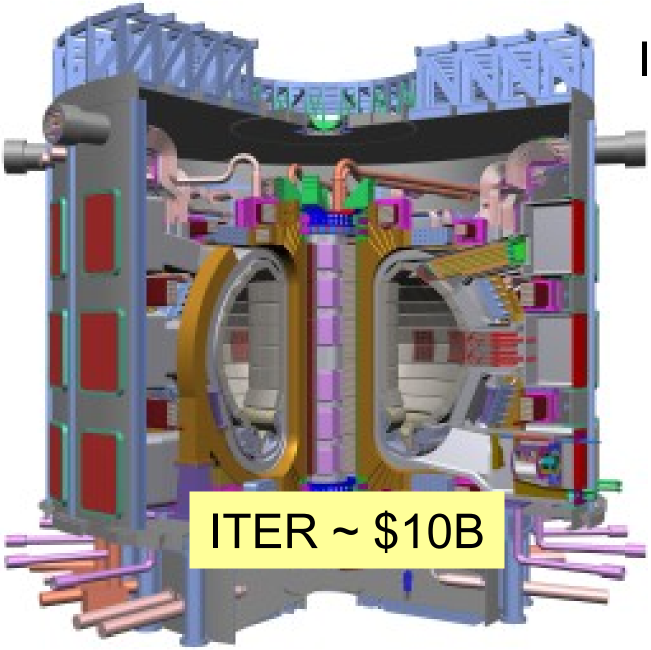
Fusion: We are entering a new era

- Commitment to fusion via ITER, NIF, LMJ (multi-$B investment)
- Demonstration of net energy production from laser fusion predicted within **3 to 5 years**
- **These are fundamental step-changes in our field**
- **Huge implications for our science and energy programmes**

- **A strategic way forward in Europe has been defined**



A European project: HiPER

Project partners (at the ministerial / national funding agency level):

UK, France, Spain, Italy, Portugal, Czech Republic, Greece

Other partners (at the institutional level):

Germany, Poland, Russia

International links:

Japan, China, South Korea, USA, Canada

HiPER

The facility

HiPER will be a large scale laser system designed to demonstrate significant energy production from inertial fusion, whilst supporting a broad base of high power laser interaction science. This is made feasible by the advent of a revolutionary approach to laser-driven fusion known as "Fast Ignition". HiPER will make use of existing laser technology in a unique configuration, with a 200 kJ long pulse laser combined with a 70 kJ short pulse laser.

Background

High power lasers enable the physics of matter at extreme densities and temperatures to be studied in the laboratory, with applications ranging from fundamental science, to new technological opportunities (e.g. compact particle accelerators and laboratory based astrophysics) and high impact industrial exploitation (e.g. inertial fusion energy).

Energy production from Inertial Fusion was proven in the 1980s, with laser driven inertial fusion due to be demonstrated in the laboratory in the period 2009-2012. To date, however, research in inertial fusion has been limited to the defence sector due to the scale of the laser facilities needed to initiate the process. The advent of Fast Ignition completely changes the landscape, removing the dependence on defence programmes, using a method which breaks the scientific link of radiation driven implosions. Construction of HiPER would allow Europe to lead the world in this field, taking advantage of these transformational events.

What's new? Impact foreseen?

The technique of "Fast Ignition" is a revolutionary approach to inertial fusion, calculated to lead to an order-of-magnitude reduction in the scale (and thus cost) of the laser facility. Recent demonstration experiments have been published in a series of articles in Nature and have led to the 2006 American Physical Society award for Excellence in Plasma Physics. The unique laser configuration creates the opportunity to provide a world-leading, broad-based research infrastructure in Europe. This type of laser fusion facility will open up a wide range of applications in laboratory astrophysics, nuclear physics, atomic physics, plasma science and material studies under extreme conditions.

Timeline and estimated costs

Based on the ongoing conceptual design work and experience with LIL-PETAL, the construction cost of the facility is estimated at ~800 M€, with a preparatory cost of ~55 M€ (including completion of PETAL), and an annual operating cost of ~80 M€. The present scientific and technological basis of the facility allows a 3-year detailed design phase to start immediately, with construction envisaged

2-year conceptual design phase (2005,6)

Included on European roadmap (Oct 06)

UK endorsement – coordinators (Jan 07)

Bid for next phase (May 07)

Passed assessment (Jul 07)

Project start (Apr 08)

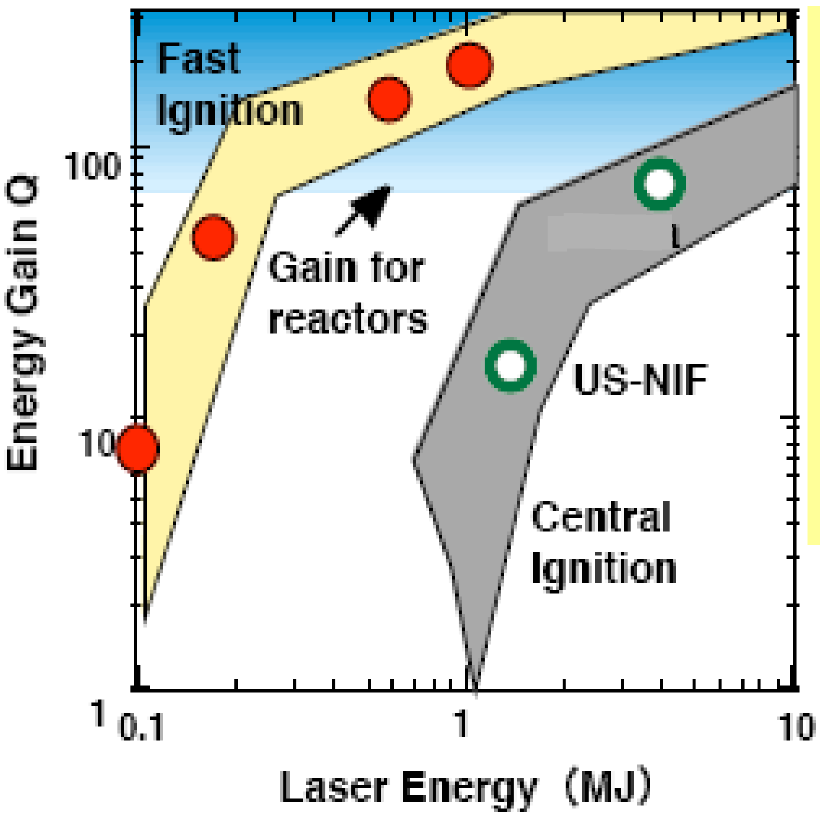
Community progress is needed

4 key goals need to be met:

- Ignition demonstration [NIF / LMJ]
- Evidence for advanced ignition path [EP, FIREX, …]
- **Robust, costed facility design for the next step (HiPER)**
- **Political and financial commitment**

Fast Ignition approach to laser fusion

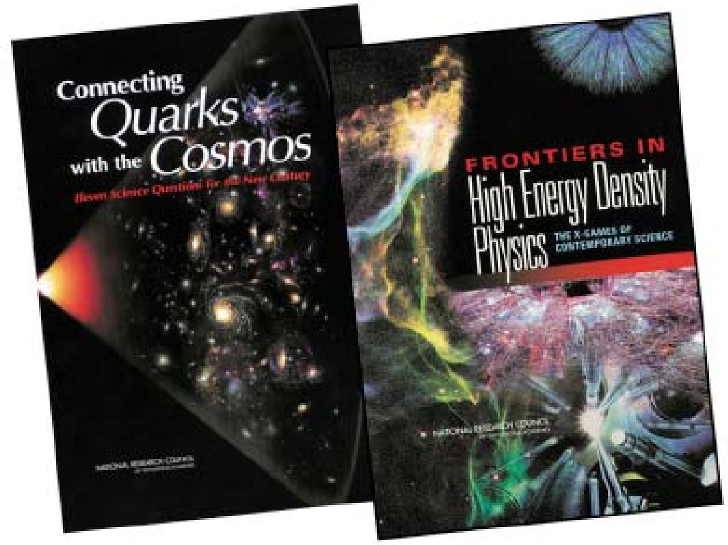
"Fast Ignition" approach of HiPER provides the bridge between laser fusion demonstration (NIF, 2010-2012) and an affordable route to power production



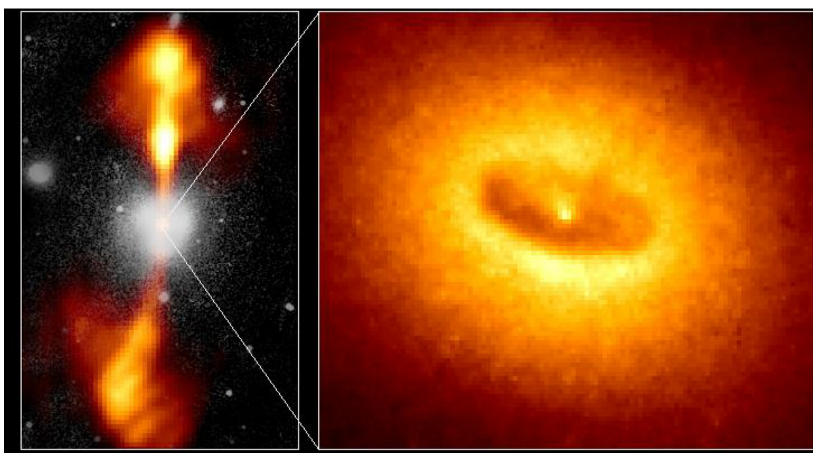
- Significantly smaller (cheaper) capital plant investment
- System model predicts cheaper electricity
- Allows European academia & industry to take a lead role
- Will have unique capabilities for a broad science programme

HiPER

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 nuclear states
- **Neutron Scattering**
  - Potential for 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 strong field science**



Options for the next step

Guiding theme to date has been a civilian facility, pulling together European and International expertise

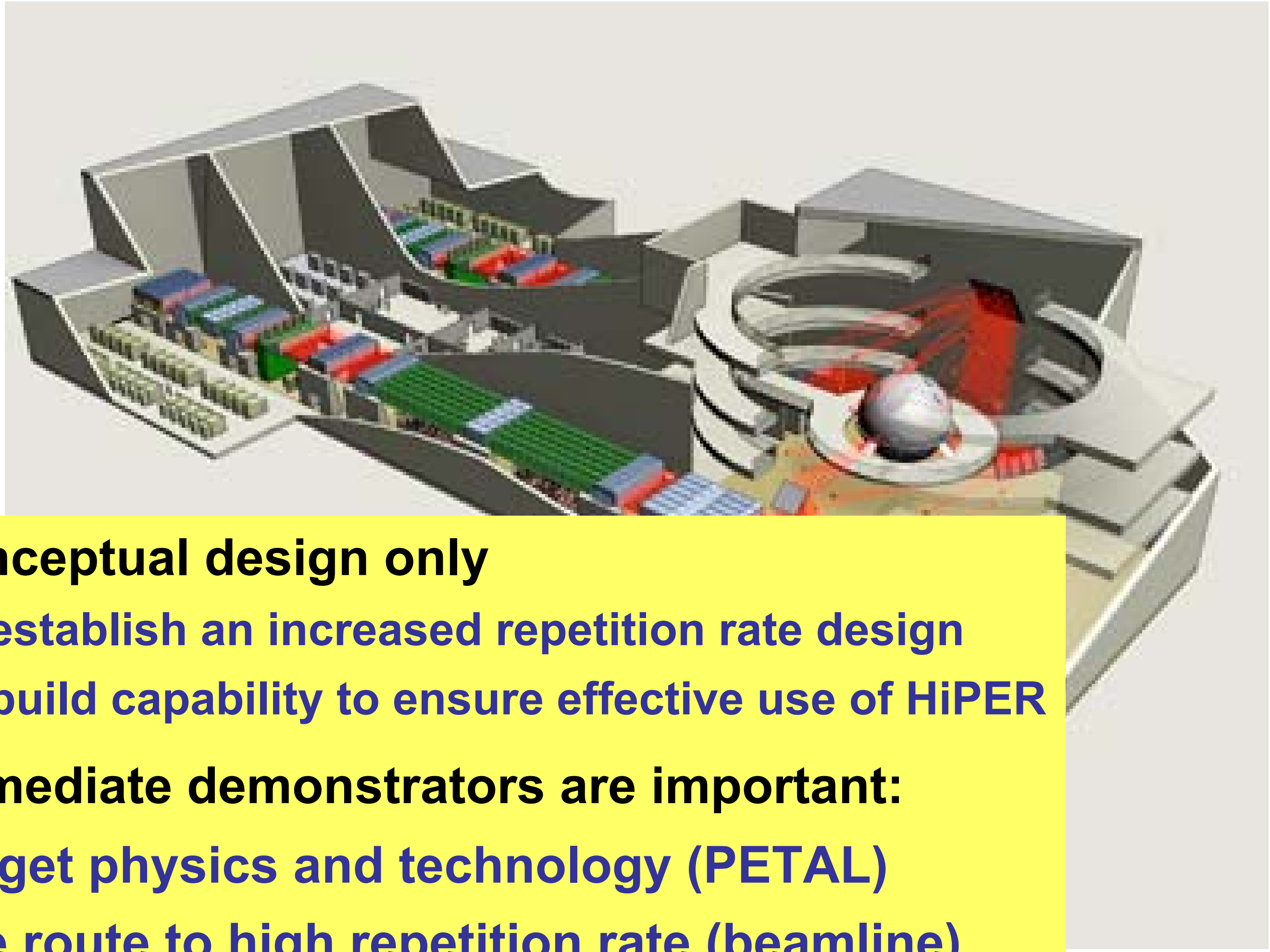
2 options:

- High yield (fast ignitor) demonstrator based on optimised NIF/LMJ technology
- Full scale, high rep-rate fusion facility

Both options to be analysed to allow an informed decision

Baseline specifications

1. **Implosion energy:**
   200 kJ in 5ns
   10 m chamber



2. **PW beamlines:**
   >70kJ in 10ps
   2ω

3. Paralle
of IFE bui
- **Target n**
- **High rep**
- **Reactor**

This is a conceptual design only
- **We need to establish an increased repetition rate design**
- **We need to build capability to ensure effective use of HiPER**

→ Intermediate demonstrators are important:
- **Target physics and technology (PETAL)**
- **The route to high repetition rate (beamline)**

Preparatory phase project

3 main deliverables:

1. Design of the HiPER facility (for the 2 principal options)
2. Establish sufficient level of capability
   - Point designs from self-consistent simulations
   - Integrated experimental validation programme
   - Technology readiness
   - Coordination with international partners
   - **Confidence in the Fast Ignition route**
3. Legal, financial and governance framework

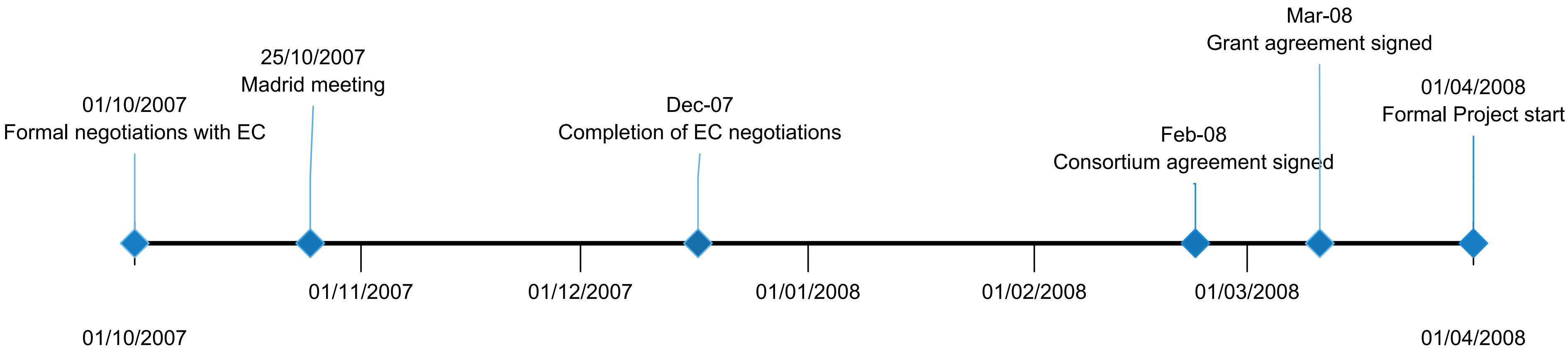
HiPER Funding

- We have completed 2-years of planning for the next phase [300 page document available on request!]

- Integrated plan developed: 15 M€ required over first 3 years
  - Underlying R&D
  - Project specific technical planning
  - Financial, legal, governance development
- Funding is from EC and member states

- **Current expectation: this funding is likely**
- **Detailed allocation of money & responsibilities**
  - **Madrid, 25-26 Oct 2007**
  - **Contract signatures in early 2008**

Project Timeline



HiPER

Required technical developments

- Laser design
  - 2ω CPA solution, OPCPA (for high power beam)
  - Flexibility for a range of ignition options
  - High repetition rate, high efficiency drivers
- Improved understanding of the target performance
  - Needs coordinated research programs on international laser facilities
  - Point design assessment, and key physics issues
- Micro-fabrication & delivery of fuel pellets (and future bulk manufacture methods)
- Integrated reactor designs

International cooperation in these areas is essential

Staged approach towards HiPER agreed

ESFRI

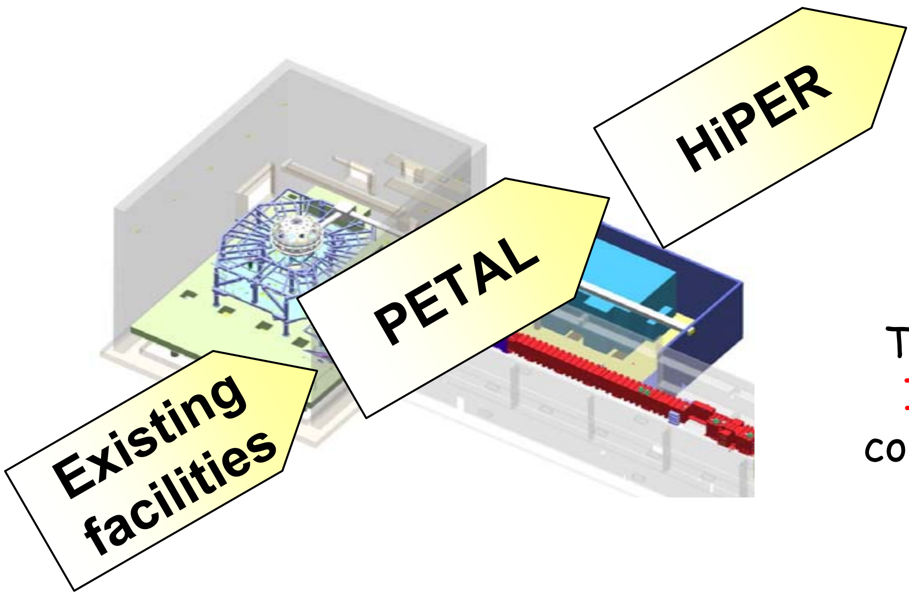
A single approach to IFE within Europe has been defined

Common strategic theme, with phased facility development:

- PETAL: Integration of PW and high energy beamlines
- HiPER: High yield facility

Coordinated scientific and technology development between the major European laser laboratories (e.g. Vulcan, LULI, PALS, …)

ILP



3.5 kJ	60 kJ
0,5 – 10 ps	8 beams
Up to 7 PW	ns , 3ω

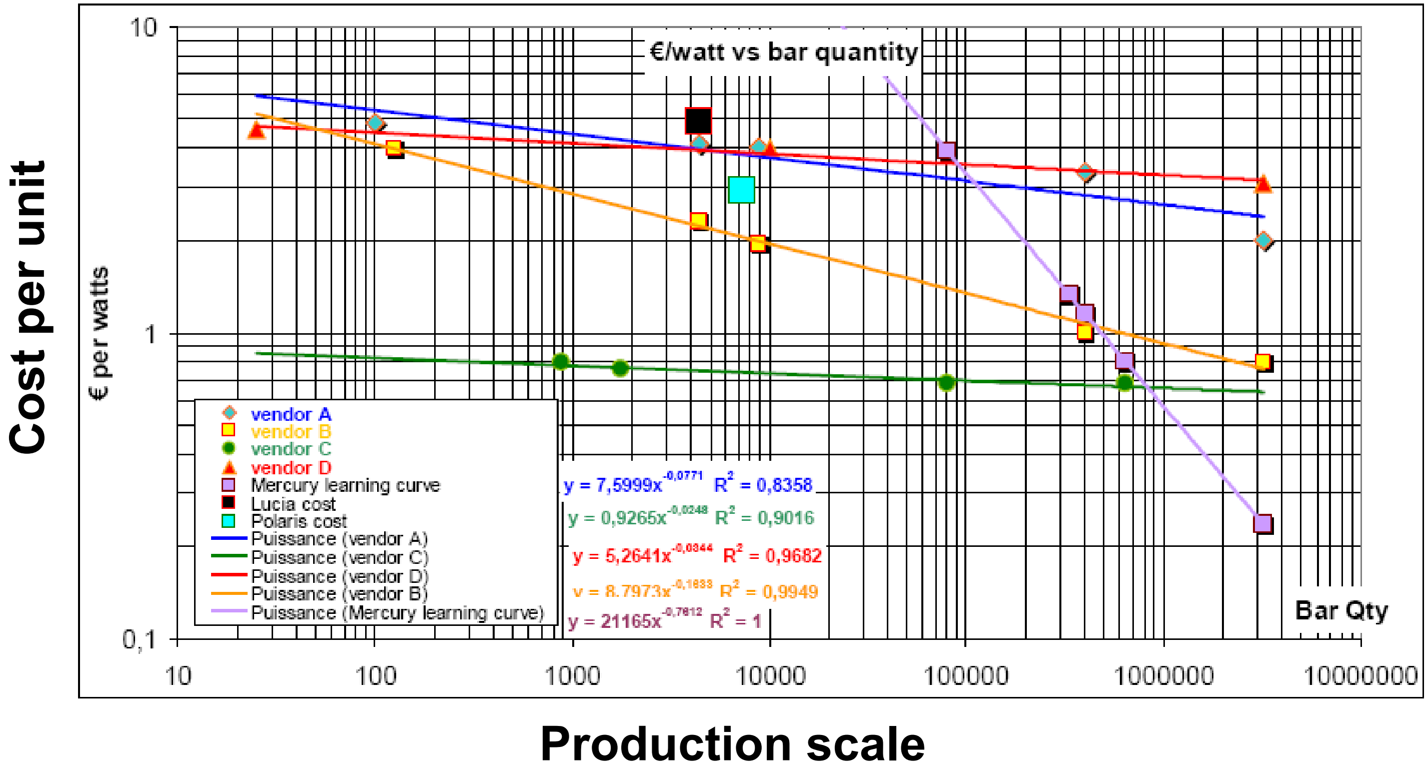
The PETAL scientific program is under the Institute Lasers and Plasmas (ILP) which coordinates high intensity lasers activities in France

HiPER Laser technology demonstrator

Progress is needed prior to the decision to "skip a generation"

- few-kJ, few-Hz demonstrator beamline assessed (Chanteloup et al)
- Workshops with research groups + industry held
- ~80 M€ beamline estimate (based on recent soft quotes at today's prices)

→ Market survey and international coordination planned



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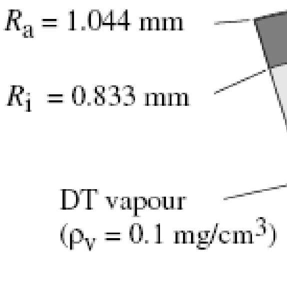
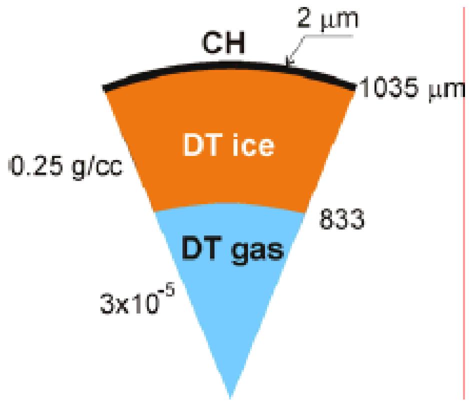
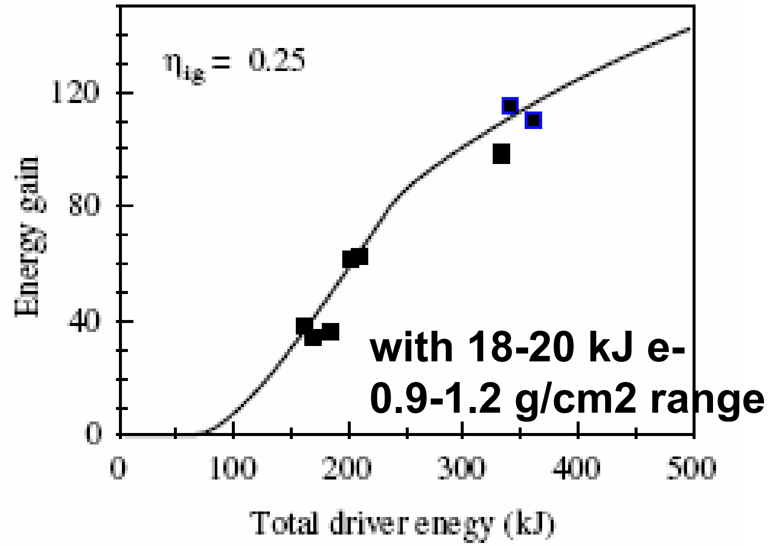
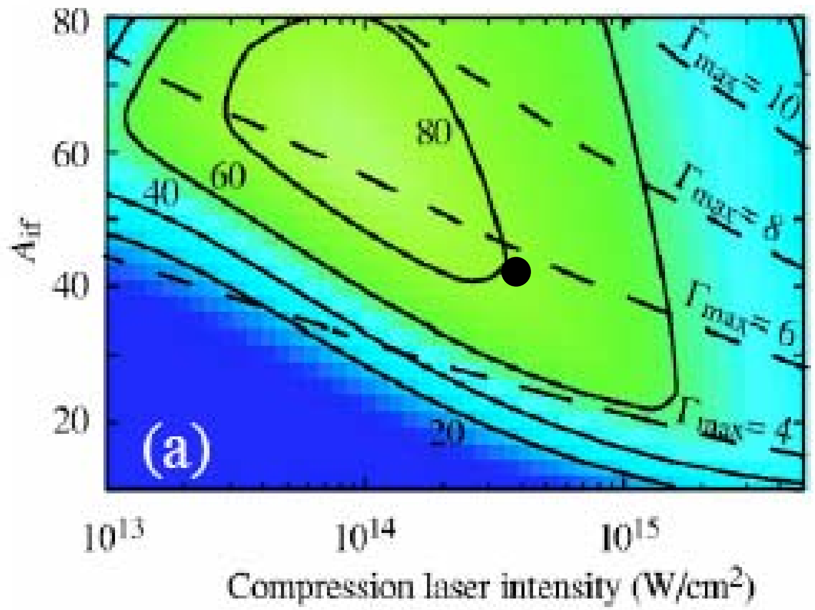
Recent sensitivity modelling (Atzeni, Honrubia et al)



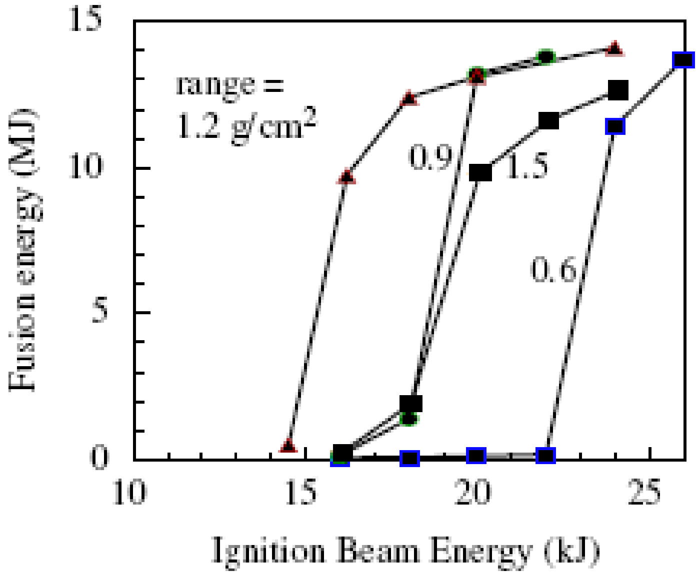


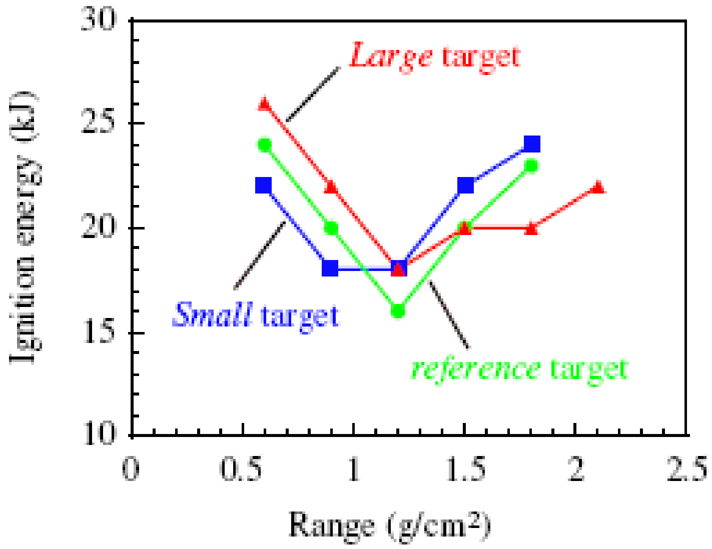


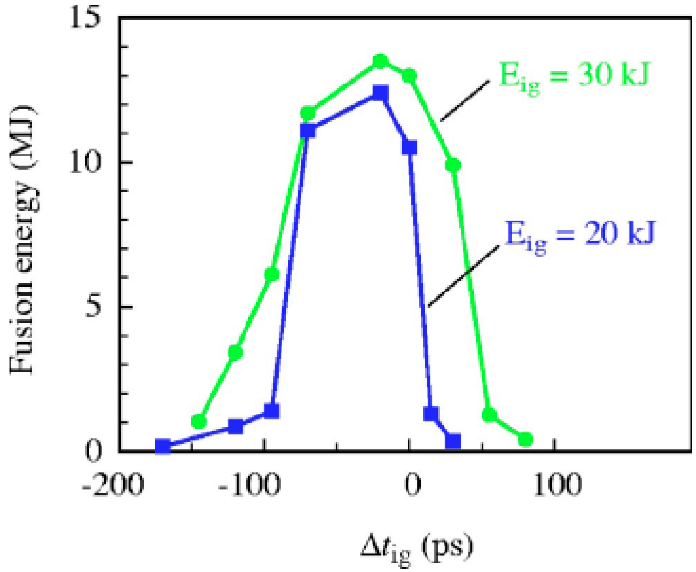
	small	reference	*large*
outer radius (mm)	0.912	1.044	1.316
inner radius (mm)	0.728	0.833	1.050
total mass (mg)	0.39	0.587	1.17
E_c^{laser} (kJ)	89	132	263
max $<\rho R>$ (g/cm^2)	1.33	1.58	1.99
max fusion yield (MJ)	6.5	13	38
max $<\rho R>$ (g/cm^2) (3T model)	1.06	1.28	1.62



Sensitivity (Honrubia & Atzeni studies) …







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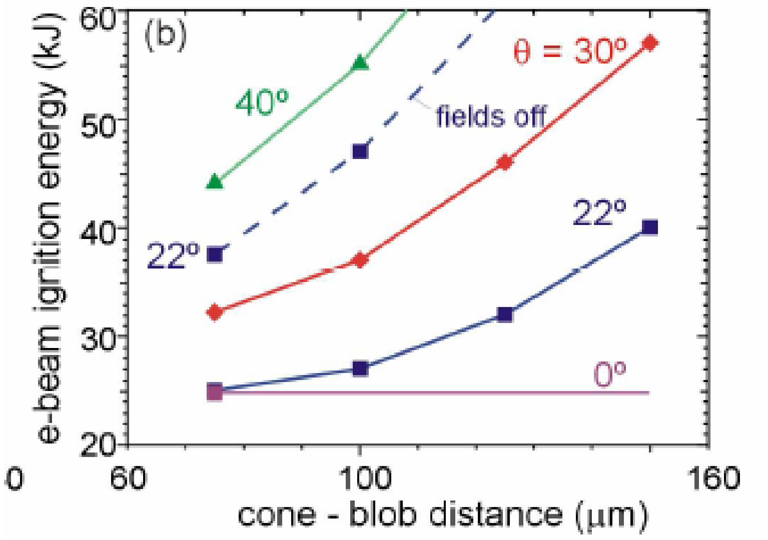
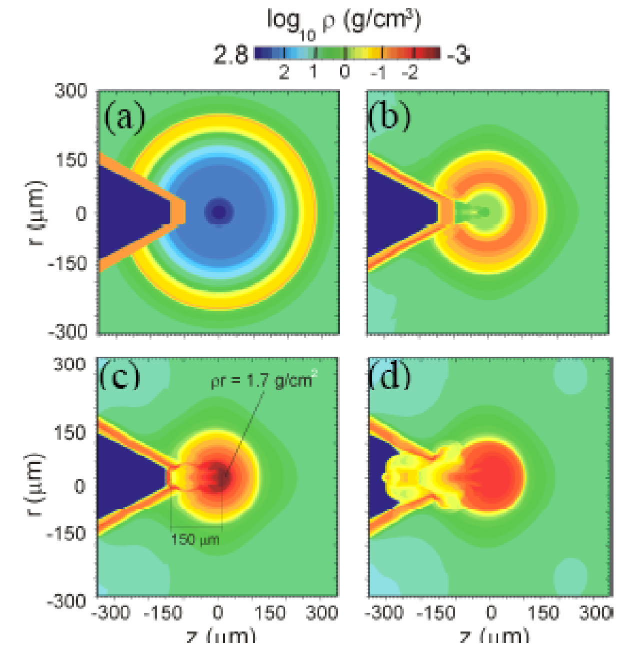


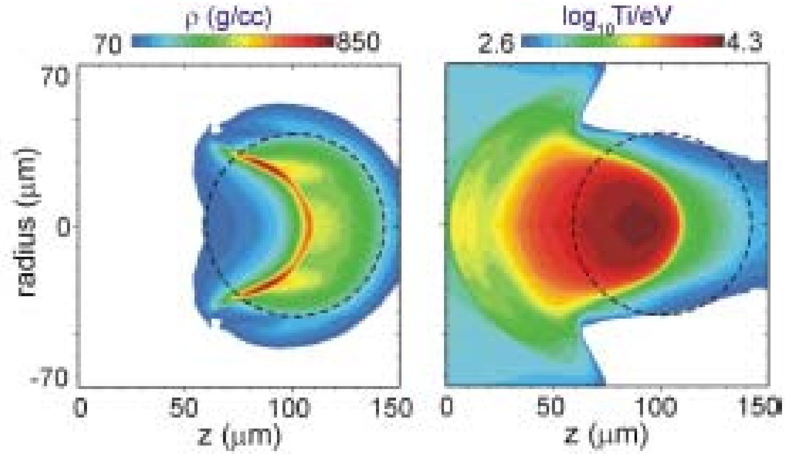
Indicates:

- **200 kJ implosion laser**
- **70 – 100 kJ ignition laser**

Assuming

- **cone to blob ~ 100 μm**
- **divergence ~ 30º half-angle**
- **fλ ~ 0.4 μm**
- **we can believe these codes**





HiPER Experimental validation programme needed

- Absorption and energy transfer to the fast electron beam
- Divergence and collimation – novel techniques
- Phase control
-
-
-
-
-
- Proton / ion driven FI scaling experiments
- Two stream instability – ion heating
- Hole boring
- Alternative geometries (get rid of the cone!!!)

Coordinated experimental programme being planned to address these issues

Note: significant target requirements over the next 3-5 years!

Required technical developments

- Laser design
  - 2ω CPA solution, OPCPA (for high power beam)
  - Flexibility for a range of ignition options
  - High repetition rate, high efficiency drivers
- Improved understanding of the target performance
  - Needs coordinated research programs on international laser facilities
  - Point design assessment, and key physics issues
- **Micro-fabrication & delivery of fuel pellets (and future bulk manufacture methods)**
- Integrated reactor designs

International cooperation in these areas is essential

HiPER Target Fabrication – planned work (1 / 2)

<u>Self-consistent target design</u>

- **Iterate design to produce a practical, robust target:**
  - manufacture & fielding constraints
  - plasma modelling specifications
  - overall facility design constraints
- **Technical analysis of key target production issues:**
  - Cone/capsule seal at cryo temperatures
  - Thermal and structural analysis of target assembly
  - Layering for wicked foam and high density shell targets with cone
  - Baseline cryo insertion for direct drive fast ignition target
  - Experimental validation plan for the proposed design

To produce : Conceptual Design for FI target assembly and fielding

: Assessment of European capability in this area

: Future plans for required target production

HiPER Target Fabrication – planned work (2 / 2)

Target production for experimental validation

- For experiments on PETAL (and other international facilities)

Investigate mass production techniques and capability

- Determine credible, large scale target production route
  - for target manufacture, assembly, and preferred filling method
  - propose experimental validation plans where required
- Cost study for high repetition production
- Assess high rep-rate injection and tracking techniques
- Assess cryogenic infrastructure requirements & costs
- Analyse Tritium handling procedures

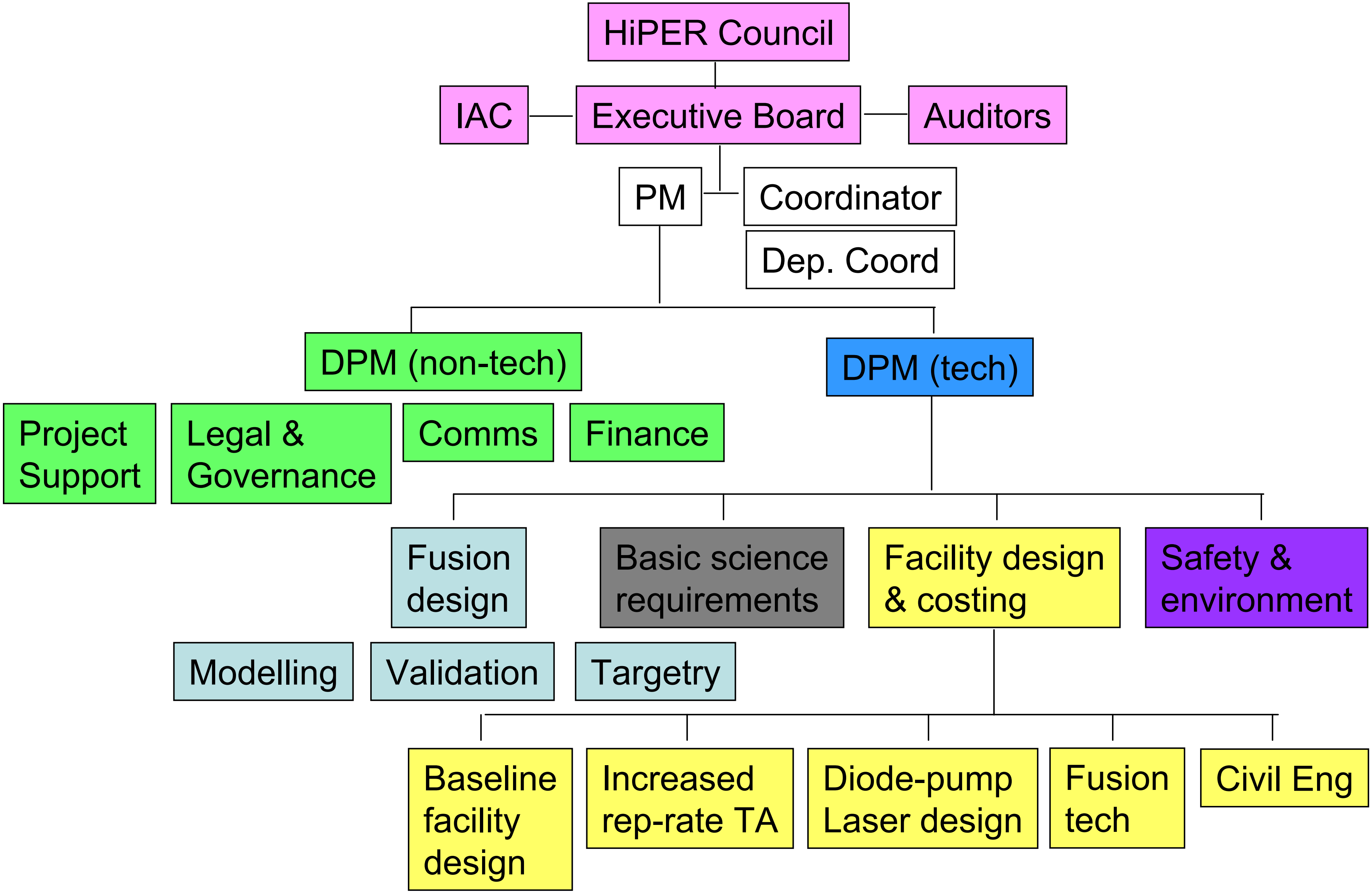
Conclusions

- Fusion ignition is fast approaching
- A concept for a next-generation UK/European facility has been proposed
- The transition from concept to technical and political reality is now underway
- Target technology is one of the key issues to be addressed over the next 3 years
- We must work together in an internationally coordinated programme

HiPER Funding – details (DRAFT)

		Cost (kE)
WP1	Management of the Preparatory Phase Project	1,737
WP2	Coordination activities	681
WP3	Legal and Governance Frameworks	251
WP4	Strategy for International, Industrial and Academic Partnerships	501
WP5	Finance, cost engineering and through life analysis	803
WP6	Safety and Environmental analysis	322
WP7	Cost-benefit and impact analysis	231
WP8	Public Relations and Communications	653
WP9	Requirements specification for fusion programme	2,172
WP10	R&D validation of fusion design	1,568
WP11	Targetry assessment, prototyping and long-term R&D	3,224
WP12	Requirements specification for science programme	1,858
WP13	Baseline facility costing and design	1,003
WP14	R&D for high repetition rate laser	1,977
WP15	R&D for high repetition rate experimental area	2,197
		19,178

Draft management structure



Choosing the best option

- NIF/LMJ laser architecture is a straightforward option, but both the science and energy programmes would benefit from higher repetition rate
  - Facility optimisation (the laser is not the limiting factor)
  - Long term: ~Hertz repetition rate demonstrator for reactor programme
  - What is the appropriate stage for HiPER?
- Repetition rate technically desirable, but it adds:
  - Cost
  - Complexity
  - Delay
- However, the HiPER project is not about securing a new facility for a particular lab, it is about driving forwards our field
- Which approach is acceptable to our funding agencies?
  - We shall see …

HiPER

Progress towards a coordinated programme

- **Re-direction** of existing people & programmes for the successful realisation of HiPER
- **Identification** of new resources to this project at the EU, national and regional government level
- **Coordination** of user access to the three highest energy European laser laboratories (CLF, LULI, PALS)
- **Merger** with PETAL on a common strategic path
- **Alignment** of the major high power laser groups within Europe
- **Cooperation** with International partners being pursued:
  - Concepts, experiments, training, component supply, …

HiPER will address some of the most fundamental questions in science

- How does matter behave under conditions of extreme temperature, pressure, density and electromagnetic fields ?
- What are the new states of matter at enormous temperature and pressure ?

- What is the nature of matter in the early universe ?
- How do photons and matter interact in extreme conditions ?
- How do planetary cores form and evolve ?
- How are the elements from Iron to Uranium made ?
- Can we create nuclear flames in the laboratory ?
- Is it possible to produce meaningful scaled astrophysical events (eg Jets, Supernova Remnants) in the laboratory ?
- Can turbulence be understood ?
- Are current models of star and planet structure and dynamics correct ?

- Can fully degenerate “quantum plasmas” be created in the laboratory ?
- Can lasers boil the vacuum ?
- Is it possible to recreate the atmosphere of a neutron star ?
- When does the vacuum become opaque ?

- When do solids become transparent ?
- Can lasers be accelerators ?
- Can we change the refractive index of the vacuum
- Does metallic Hydrogen exist in the solid state ?
- Can pure electron-positron plasma be produced ?
- Can the Radiative Hydrodynamics of many astrophysical events (Colliding galaxies, supernovae..) be reproduced ?
- Can Unruh Radiation (E-M equivalent to Hawking Radiation) be detected ?
- Can relativistic physics on the attosecond timescale be achieved ?

HiPER

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