European Cooperation in the field of Scientific and Technical Research - COST -

Brussels, 21 November 2012

MP1208

MEMORANDUM OF UNDERSTANDING

Subject :	Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action MP1208: Developing the Physics and the Scientific community for Inertial Confinement Fusion at the time of NIF ignition

Delegations will find attached the Memorandum of Understanding for COST Action as approved by the COST Committee of Senior Officials (CSO) at its 186th meeting on 20 - 21 November 2012.

MEMORANDUM OF UNDERSTANDING
For the implementation of a European Concerted Research Action designated as

COST Action MP1208
DEVELOPING THE PHYSICS AND THE SCIENTIFIC COMMUNITY FOR INERTIAL CONFINEMENT FUSION AT THE TIME OF NIF IGNITION

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 4154/11 “Rules and Procedures for Implementing COST Actions”, or in any new document amending or replacing it, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to develop the physics and the scientific community for Inertial Confinement Fusion at the time of NIF (National Ignition Facility) ignition.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 64 million in 2012 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of 4 years, calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter V of the document referred to in Point 1 above.

A. ABSTRACT AND KEYWORDS

The present Action aims at directly contributing to develop a scientific community in Europe working in Inertial Confinement Fusion and High Energy Density Physics. This will be complementary and synergic to several initiatives going on in Europe at the moment, in particular the construction of the lasers Megajoule (LMJ) and PETAL (Petawatt Aquitaine Laser) in France (LMJ/PETAL facility), the upgrade of high-energy laser facilities already working, the HiPER (European High Power laser Energy Research facility) and ELI (Extreme Light Infrastructure) projects. At the same time, the physics related to the development of high-energy laser facilities is very interesting and fascinating in itself, opening new perspectives and new fields of research. The objectives of the present Action address Networking on one side and the Study of relevant physics on the other. In particular, LMJ/PETAL will be open the European academic community for civilian research in 2015. This will be a unique system in the world (comparable only to NIF, the National Ignition Facility, in US, United States of America) and this Action will contribute to the elaboration of the scientific program for such a facility over the next 10 years. No other European research program is at the moment directly covering such topics and all mentioned programs are related to "facility development" rather than "community building". Therefore this Action will fill an "empty slot" in a way, which is synergic to running programs.

A.2 Keywords: Inertial Confinement Fusion, High-energy lasers, Laser-produced Plasmas, Diagnostics, Laboratory Astrophysics, Extreme states of matter, Advance Schemes for Ignition, Hydrodynamics

B. BACKGROUND

B.1 General background

The research topic addressed in this Action concerns a state of the art subject nowadays, such as the study of the physics of Inertial Confinement Fusion with lasers and related topics of laser-matter interactions. This is an open field of research, which is currently expanding, thanks also to the progress in laser technology.

The relevance of this Action, and the fact that it is desirable to launch it, comes from 3 closely correlated facts:

1) The innovative new physics, which can be studied with high-energy laser-systems. This includes several topics which will be discussed further in the following, i.e., the physics of inertial confinement fusion (ICF); extreme states of matter; realization of "laboratory astrophysics" experiments; progress in particle and radiation sources obtained by irradiating targets with such lasers. These fields are rapidly evolving both for their intrinsic interest and for the growing possibilities offered by more numerous and more advanced laser systems (for a detailed report see for instance the chapter on science in "HiPER, Technical background and conceptual design" Rutherford Appleton Laboratory (RAL) Report RAL-TR-2007-008, 2007; and R.W. Lee "Science on the NIF" https://www.llnl.gov/etr/pdfs/12_94.5.pdf)

2) The growing activity in the field of high-energy laser systems in Europe, including the construction of LMJ and PETAL in France, the upgrade of already-working facilities Vulcan in the UK, Laboratoire pour l'Utilisation des Lasers Intenses (LULI) in France, Prague Asterix Laser System (PALS) in the Czech republic, Phelix at GSI, Germany, the design phases of HiPER, but also the recently approved Extreme Light Infrastructure (ELI) projects with installations in Romania, Hungary, France and the Czech Republic.

3) In the US, the largest laser in the world, National Ignition Facility (NIF) at Livermore, has started the "National Ignition Campaign" (NIC, see https://lasers.llnl.gov/programs/nic/). Although NIC is meeting serious difficulties, it is probable that US scientists will finally be able to demonstrate ignition, even if with a very low gain. It seems therefore very important that the European scientific community is, at this time, able to maintain and strengthen a close collaboration with the US.

At the same time, one must notice the striking contrast between the growing activities in Europe in the field of high-energy lasers and the reduced size, and dispersion, of the community, which in Europe is using such systems. Not only, but until now, European scientists have never worked with laser facilities which are really "big" (the size of Omega, NIF, Gekko/Firex) and which require a different approach to the design and realization of experiments. This is particularly important in view of the fact that, starting in 2015, the LMJ/PETAL Facility will be opened for a significant part of the laser time (up to 30%) to civilian academic research. This unique facility (comparable only to NIF in the US) will allow for unique experiments to be performed in the domains of physics of inertial fusion and high energy density physics. But before 2015, a credible "academic scientific program", covering the next 10 years to come must be elaborated, and to assemble the European scientific community around such an installation.

This explains why COST, which funds only networking and capacity-building activities is the best mechanism for support. Indeed networking will allow building and expanding the community in a synergetic way with other programs (both at the national and European level) more directly aimed at funding research.
This Action will work both at a qualitative and quantitative level. Networking and formation actions will be undertaken (e.g. training courses, summer schools, etc.) but it is also essential that researchers in the field perform “real” advanced work (experiments, simulation, etc.) thereby assuring a qualitative growth too.

B.2 Current state of knowledge

Inertial Confinement Fusion (ICF) has a quite long history being practically born simultaneously with high-power lasers. From initial too-optimistic estimates, which predicted achievement of nuclear ignition using kJ-class lasers (J. Nuckolls, et al, Nature 239 (1972), p. 139), the community has moved to the current state-of-the-art MJ-class lasers, like NIF in the US and the twin “Laser Megajoule” under construction in France.
However, demonstration of nuclear ignition by NIF in the next couple of years will not stop the need for a continuation of research in this field. Indeed, on one side NIF will only achieve a very modest gain (ratio of the output energy from fusion to the input laser energy), which is certainly not scalable to energy production, and on the other side the laser technology itself is not scalable, not allowing for high-repetition operation.
At the physical level, the low gain, which will be achieved on NIF, is partly due to the “indirect drive” approach, which requires very high laser energies due to the intermediate step of conversion to soft thermal X-rays. New approaches seem to allow for higher gains using direct drive compression of fusion targets coupled to novel ignition schemes, namely the so-called “Fast ignition” (FI) and “Shock Ignition” (SI). In particular, shock ignition seems to allow for simpler targets and irradiation schemes and therefore, unlike indirect-drive, seem to meet the requirements for the development of future commercial fusion reactors. The study of such approaches, described in more detail in sec. D (Scientific Program), is indeed the core business of this Action from the scientific point of view, **and provides the innovation character** of the Action.
It is important to notice that over the last 10 years, the European community has provided important contributions to fast ignition, and it is going to play a similar role for shock ignition, mainly by realizing smaller scale experiments in European laser facilities, aimed at understanding and mastering the underlying physics. Preliminary experiments in this field have been performed at

LULI (S. Baton, et al., Phys. Rev. Lett. 108, 195002, 2012) and at PALS (L. Antonelli, et al., Acta Tecnica, **56**, T57, 2011) in the framework of large European collaborations with many of the groups which are involved in the present Action).
Nevertheless, this Action is not limited to the study of such approaches. There are a number of subjects, which may be studied with high-energy lasers (again outlined in Section D), in particular related to the study of High Energy Density (HED) Physics. These provide interesting physics other than ICF (thereby allowing to attract more research groups to the use of high-energy lasers) but, above all, provide relevant physics: performing experiments in these domains allows to acquire experimental capabilities which are also common to and useful for ICF, to develop laser and plasma diagnostics, to get useful experimental data on the behavior of materials, and finally allows a detailed benchmark for the development of simulations codes.

Two important points need to be underlined:

1) This program is highly innovative. No other research program is at the moment clearly addressing the study of advanced ignition schemes for direct drive, no other research program is addressing development of ICF as a future source of energy or its scientific applications such as “Laboratory Astrophysics”. Even the UK and France, the two leading European countries in ICF, do not have programs related to energy production by ICF, fusion programs for energy production being still limited to the magnetic confinement approach. Therefore this Action is completely innovative in approaching the already-existing problem of achieving nuclear fusion.

2) The presence of other European programs does not reduce the need for networking, represented by this Action. On the contrary it makes the need for collaboration larger. The “Preparatory phase” of HiPER is going to conclude in April 2013 and the other programs are clearly related to facility building and not to networking and community building. Instead, a much larger and stronger community is needed in view of the challenges represented by Inertial Fusion Research. Also a much larger community is needed in order to allow the best use of existing and developing laser facilities in Europe, and in particular for exploiting the “academic access” offered on the LMJ/PETAL Facility

B.3 Reasons for the Action

The main reason for launching the Action is the need to develop and strengthen the scientific community working in Europe of the physics of ICF and HED. This is related in the long term to the need for developing new sources of energy, clean and practically inexhaustible. ICF is definitively one of such possibilities, and the development of megajoule-class lasers (NIF, LMJ) should allow demonstration of ignition soon. Indeed although energy production by ICF may not be practical within 30 years, nevertheless the demonstration of shock ignition on LMJ can take place within the next 10 years and a scientific program for reaching such an ambitious goal should be started NOW. In this respect, this Action, in the long-term, aims at contributing to the solution of the energy problem, certainly one of the most important for Europe now and in the next decades to come. Therefore, on a long time scale, the Action can be considered as mainly aimed at addressing European economic/societal needs.

On a shorter time scale, several objectives and applications justify the Action on the basis of scientific/technological advances. Concrete outcomes will include:

1) The Action will allow a larger community to get expertise and profitably use the many high-energy laser facilities already present or developing in Europe.
2) Indirectly, this will produce measurable effects on laser industry in Europe not only in terms of a larger market, but also in terms of positive synergies and formation of competent personnel, which may be hired in research or by companies. Let's recall that several European industries (e.g. Amplitude, Quantel, Thales, etc.) already play a world-leading role in laser technologies and are market leaders especially for high-intensity lasers.
3) The Action will contribute to developments in plasma diagnostics and the study of materials for future fusion reactors (in synergy with other important projects, e.g. the International Thermonuclear Experimental Reactor (ITER), project on magnetic confinement fusion). Again such highly-advanced technological developments will have a positive synergy with European industry in fields like electronics, detectors, software, etc.
4) A series of high-level scientific and technological results will be obtained (outlined in section D).

Concerning points (2) and (3) such benefits, although indirect, will be clear. However this Action is clearly addressed towards basic research. Nevertheless plans for implication of industrial or energy sectors stakeholders are already under elaboration and preliminary contacts with stakeholders have already been established. .

To obtain the goals of this Action, a network of experts in the area is needed. The added value of such networking will be establishing a larger and stronger European scientific community in the field, as well as creating the basis for pan-European research studying advanced schemes (fast ignition, shock ignition) for direct drive with the goal of developing a purely civilian academic-based program on Inertial Fusion as a future source of Energy. One important goal of such a program will be the demonstration of Polar Direct drive and Shock Ignition on the LMJ laser in France in the next decade (see section D).

B.4 Complementarity with other research programmes

This Action will be complementary to several other European programs:

- The first is obviously HiPER. However, the preparatory phase of HiPER is going to be completed in April 2013. In addition HiPER does not involve all European countries and /or the academic community from Universities.
- The already-existing high-energy laser facilities (LULI2000, LIL, PALS, Phelix, RAL Vulcan), all part of LASERLAB EUROPE (the Integrated Initiative of European Laser Research Infrastructures II - web site: http://www.laserlab-europe.net/). The benefits will consist of the scientific community in Europe acquiring new capabilities and being able to really use the existing facilities at their best.
- The ELI (Extreme Light Infrastructure) European project with its branches in Romania, Hungary, the Czech Republic and in France (Apollon). ELI aims at realizing a European facility for ultra-short timescales ultra-high-intensities dedicated to: i) Investigation of laser-matter interactions in the ultra-relativistic regime; and ii) Development of intense ultra-short particle and radiation sources (web site: http://www.extreme-light-infrastructure.eu/) Although not addressed to ICF, it will however allow significant studies on specific topics (related, for instance to fast ignition or diagnostics development).
- The Research Networking Program SILMI (Super-intense laser-matter interactions) of the European Science Foundation and the COST program MP0601: Short Wavelength Laboratory Sources (web site: http://www.shortwavelengthsources.net/html/cost_mp0601.html). Again this will terminate in May 2014.
- Finally one should recall the politics of the Academic Opening of CEA (Commissariat à l'énergie atomique et aux énergies alternatives), making LMJ/PETAL available for scientific civilian research. Several programs have already started in France under the umbrella of ILP (Institut Laser Plasmas), including the PETAL+ project for developing diagnostics for LMJ/PETAL. These are and will be even more open to the European community. Already several participants of this Action are involved in these activities including at coordination level. This Action will establish a European framework for such activities.

2. Again, it is important to note that the existence of all such programs does not reduce the need for networking, represented by this Action. On the contrary, it makes the need for collaboration bigger, especially if one considers the dimension of the scientific and technological challenges and the reduced size of the European scientific community working in the field.

C. OBJECTIVES AND BENEFITS

C.1 Aim

Developing the physics and the scientific community for Inertial Confinement Fusion at the time of NIF ignition, via networking activities

C.2 Objectives

The Action aim, to be achieved through networking activities, is indeed in line with the main aims of a COST Action, which is to promote excellence and to contribute strongly to European Society economic growth. Networking is the best strategy to strengthen the plasma physics scientific community and to develop new scientific knowledge and technical know-how in various fields such as in high-energy lasers, physics of laser plasmas, inertial fusion, astrophysical plasmas, earth science, biology and medicine.
Specifically, in addition to the links between different groups working in the field through networking, this implies also several goals including:

1) To allow the realization of common experiments (in particular using the mechanism of STSMs) both in Europe and overseas (Japan, US).

2) To catalyze the formation of new scientists competent in this field. In particular, this Action will use a significant part of the budget for the realization of summer schools for Ph.D. and Post Docs.

3) To study important physical problems related to ICF.

New scientific knowledge will be acquired in other fields such as:

i) “Astrophysics in the laboratory.”

ii) Study of matter in extreme conditions (equation of state in the Multimegabar pressure range, radiative properties (opacities), etc.).

iii) Development of so-called “secondary” sources of radiation (X-rays) and particles (energetic electrons and proton beams) and applications in medicine and biology (i.e. tumor therapy by protons etc.).

iv) Development of novel diagnostics techniques for plasma physics experiments and for laser systems.

The monitoring of the activities will be based on annual reports from the 5 Working Groups (WGs), which will be deliverables from the project. The results of experiments will also serve as evaluation criteria /milestones. Also, the Action will prepare two documents addressing the problems of "Science with High Energy Lasers" and "A pathway to demonstration of Polar Direct drive and Shock Ignition on LMJ/PETAL". Such documents are intended to be an arrival / starting point for the European Scientific Community in order to prepare future experiments on LMJ/PETAL and to serve as a starting point for collaboration with overseas scientific communities.

C.3 How networking within the Action will yield the objectives?

It will allow to bring together European researchers allowing them to work on "intermediate" laser facilities (LULI, Vulcan, PALS, etc.), to propose common experiments to be realized in US and Japan, to start the elaboration of a scientific program to be realized on LMJ/PETAL and finally to organize training actions for young researchers (i.e. Erasmus IP, i.e. intensive programs, Erasmus Mundus, etc.).

In addition to the coordinated experimental program, some documents will be written and addressed to the public, the governments and to the European leadership for a better visibility. The necessary manpower (which can indeed be provided through networking activities) for the realization of such an effort (especially the experimental one) will come from the participating laboratories and groups.

C.4 Potential impact of the Action

The intention of this Action is to bring together high-level scientists, researchers and students and to combine expertise in the fields of HED and ICF physics. While more and more laser facilities allow studying such domains, there is currently no European program directly addressing such topics. Also, there is no research program worldwide addressed at developing the shock ignition and direct drive approach for achieving nuclear burn using existing lasers like LMJ/PETAL. Therefore a high

impact from this Action is anticipated.
Within the framework of this Action, the collaborations between European teams and the access to the high-energy laser facilities will facilitate, for the first time, opening a dedicated route to fusion energy using lasers. Young scientists will have the opportunity to be trained in an innovative area of research, which will help them in the continuation of their careers in research, academia and even into the private sector.
Production of scientific reports addressed to politicians and the general public about the benefits and the impact of nuclear fusion research should sustain the crucial debate concerning new sources of energy

C.5 Target groups/end users

The scientific end users of this Action will be a broad scientific and technology audience, including plasma and matter physicists, biologists, engineers (i.e. optoelectronics), radioprotection officers, etc.
There will also be industrial end users of this Action. In particular, this Action refers to the European laser industry and to high-technology industry in general (optoelectronics, nanotechnologies, advanced materials resisting to high radiation fluxes, etc.) i.e. all the components, which are needed to develop a technologically advanced laser facility. Also the improvements and the industrial development in laser technology will be able to generate some spin-off in medicine and biology.
The political end users of this Action will be the general public as well as several European governments. The Action will produce reports addressed at showing how research on nuclear fusion is beneficial both in the long terms (contributing to the solution of the energetic problem) and in short-term, thanks to the several spin-offs and economic benefits which it can bring to the European research, technology, industry.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

This Action aims at directly contributing to the development of a European Inertial Confinement Fusion (ICF) scientific community. This is a timely Action since the National Ignition Facility

(NIF) is currently working in the US to provide the proof of scientific feasibility of laser driven thermonuclear ignition of deuterium/tritium (DT) targets. At the same time, several initiatives are already going on in Europe, in particular the construction of the Laser Megajoule in France, which, together with the high-energy short-pulse laser system PETAL, will be a unique facility in the world to study HED and ICF physics. Up to 30 % of laser time will be provided to the European Scientific Community for academic civilian research starting in 2015 (i.e. well within the Action life time).

The physics related to high-energy laser facilities is very interesting and fascinating, opening new perspectives and new fields of research. The objectives of the present Action are linked to these programs and are specifically addressed to Networking the community on one side and to the Study of relevant physical problems on the other side. In particular:

1) Networking

Despite the before-mentioned initiatives, the European ICF scientific community is limited and dispersed in several nations / research institutions. The number of employees at LLNL (Lawrence Livermore National Laboratory, US) is largely exceeding the size of the European community, which this Action aims at strengthening through the COST support, by: realization of common experiments, organization of dedicated summer schools, general knowledge exchange. Networking is indeed essential to involve and link universities and research centers from entire Europe in order to efficiently exploit the facilities and to reach a critical mass of scientists and engineers, required for such large projects.

2) Study of relevant physics (achieved mainly through networking, not requiring direct research funding).

The European scientific community leads the World in the study of ultra-high-intensity laser-matter interaction and such leadership must be consolidated, while in other fields (implosion experiments, hydrodynamics) a gap with other communities needs to be filled.

The Action's main scientific goal is to study new ICF approaches, Fast Ignition (Tabak et al, Phys. Plasmas 1, 1626, 1994) and Shock Ignition (Perkins, et al, Phys. Rev. Lett. 103, 045004, 2009), promising higher gains than the "classical" approach followed by NIF. Also, they allow for simpler targets and irradiation schemes, more compatible with the constraints of future fusion reactors. Fast ignition and shock ignition, essential ingredients of HiPER, are based on the idea of decoupling the DT fuel compression and ignition phases.

The ignition in fact requires the creation of such a "hot spark", a small portion of the fuel, which, at the time of maximum compression, reaches the DT fusion temperature.

Fast ignition proposes to trigger ignition by the external addition of energy through a beam of relativistic electrons created irradiating the fuel pellet by a short-pulse ultra-intense laser beam. The required laser intensity falls in the range of 1e19 – 1e20 W/cm2 against a typical 1e14 W/cm2 of the compression (ns) beams. Several key aspects of this scheme require investigation: laser interaction with the compressed target, fast electrons generation, propagation and energy deposition in dense matter. Fast ignition has rapidly grown in the last 10 years and, being more academic in nature and (for the present, preliminary, stage) less related to the use of very-large-energy lasers, many European groups have played a key role in this field. The present Action will contribute to consolidate such a role, while allowing the European community to prepare for the next step, i.e. a feasibility demonstration of fast ignition on the available high-energy lasers.

At the same time in the last three years the so-called "Shock Ignition" approach has emerged. In SI, the ignition spark is created by a high-intensity (1e16 W/cm2) laser spike generating a strong shock through the compressed fuel. The advantages of shock ignition over fast ignition consist in: first, the laser-plasma interaction physics (although largely unknown) seems to be more manageable, and second, the requirements are certainly more compatible with present-day "LMJ-like" technology. European researchers have already contributed substantially in the newborn shock ignition research. In particular two preliminary experiments to study laser-plasma interaction physics in the relevant intensity range have been performed in 2010 and 2011 at PALS and LULI (by research teams taking part in the present Action). However, a solid network is required in order to strengthen and coordinate the collaboration between European groups, and allow for a more productive collaboration with US.

The main important point is that shock ignition can in principle be demonstrated on LMJ (operational in 2015) within the next decade. CEA, which manages the installation, has officially opened it to French and European Academic communities, making up to 30% of laser shots available for Academic civilian research. Moreover, LMJ will be coupled to the high-energy short-pulse PETAL laser (funded by the Region Aquitaine for civilian academic research), both to provide a backlighting facility for implosion experiments and to allow exotic states of matter and laboratory astrophysics studies. Moreover, the coupling of such advanced laser systems makes possible the development of an ICF Energy Production research program in Europe.

To support such an ambitious scientific program, it is thus crucial to connect the European Academic Community through networking activities and joint effort experiments and research.

An important step before the actual demonstration of shock ignition will be the achievement of relevant target compression on LMJ, using the so-called "Polar Direct Drive" (PDD) approach.

Indeed, being designed for indirect-drive, LMJ does not allow for a simple spherical irradiation of targets, implying that laser beams must be defocused and redirected on the target (impinging at oblique angles). Presently numerical simulations supported the feasibility of PDD, while experimental demonstration is needed.

The study of such ICF approaches (Fast Ignition and Shock Ignition) alone justifies the innovative character of the Action. Nevertheless, this Action is also addressed to a number of subjects beyond the ICF domain, which may be studied through high-energy lasers, possibly attracting different research branches to cooperate.

In particular, this Action aims at addressing the following scientific issues:

i) Study of Diagnostics for ICF experiments. Especially in the field of neutron diagnostics (neutron spectrometry, neutron imaging, etc.) there is a lack of specific competence in Europe (at least outside CEA, whose partially defense-oriented purposes lie far from the goal of this Action, related to purely civilian research). See for instance “Neutron Imaging Development for MegaJoule Scale Inertial Confinement Fusion Experiments” G. P. Grim, et al. Journal of Physics, 112 (2008) 032078.

ii) Study of Hydrodynamics and hydro instabilities (in particular Rayleigh-Taylor instability). These, especially when coupled to radiative phenomena (e.g. radiative shocks, etc.), are important for ICF but also for basic physics and astrophysics. Despite that much progress has been made in recent years (mainly thanks to US and Japanese groups) still many aspects are not understood. 3D numerical codes coupling hydro and radiation transport need to be developed (as a recent example see “Rayleigh-Taylor Growth Measurements in the Acceleration Phase of Spherical Implosions on OMEGA” V. A. Smalyuk, et al., PRL 103, 105001, 2009).

iii) Study smoothing of laser irradiation non-uniformities. Approaches such as optical smoothing, radiation smoothing, foam-buffered smoothing or novel gas-jet smoothing need to be reviewed in the context of shock ignition and fast ignition. Non-uniformities in irradiation seed Rayleigh Taylor instability and prevent a uniform compression of fuel, which is essential in ICF (e.g. see D. Batani et al. “Foam smoothing studied through laser produced shocks” Phys. Rev. E, 62, 8573 (2000) and R. Benocci et al. “Gas-induced smoothing of laser beams studied by interaction with thin foils” Plasma Physics Contr. Fusion, 50, 115007, 2008).

iv) Extreme states of matter. The equation of state of matter at large densities and temperatures needs to be understood. This is useful for detailed ICF target design and for astrophysics and planetology (allowing the modellization of the interior of giant planets, of brown and white dwarfs). See for instance D. Batani, et al. “Hugoniot Data for Carbon at Megabar Pressures” PRL, 92, 065503 (2004).

v) Study of the Radiative properties of Matter (Opacities), again a common subject for ICF and astrophysics. Experimental data will provide a validation of theoretical opacity models (still not compatible) allowing a better definition of radiation transport in hydro-codes. See R.W. Lee “Science on the NIF” https://www.llnl.gov/etr/pdfs/12_94.5.pdf

vi) Study of matter subject to high-irradiation fluxes and of activation of chamber components (also interesting for nuclear scientists and for MCF community). Irradiation of targets with lasers in near-ignition conditions (where high neutron fluxes are produced) or with short-pulse ultra-high-intensity lasers, produces high radiation fluxes, which require a proper radioprotection plan (useful as basis of radioprotection in future fusion facilities), also allowing irradiation of materials. See for instance J. M. Perlado and J. Sanz “Neutronics on inertial fusion reactors” Fusion Engineering and Design, 48 (2000) 355.

vii) Study of Laboratory Astrophysics. High-energy laser facilities offer a unique possibilities to realize astrophysical-relevant experiments aiming either at characterizing matter (equations of state, opacities) or at simulating on a small scale hydro phenomena like astrophysical jets, radiative shocks dynamics, hydro instabilities development, etc. See for instance E. Falize et al. “Scaling laws for radiating fluids: the pillar of laboratory astrophysics” Astrophysics and Space Science 322, 107 (2009).

viii) Study of “secondary” sources of particles (electrons, protons) and radiation, obtained by focusing high-intensity lasers. These can be useful for applications in imaging, biology, solid-state physics, etc., but also for the development of advanced ICF diagnostics. For instance, see F. Lindau et al. “Laser-Accelerated Protons with Energy Dependent Beam Direction“ PRL 95, 175002 (2005); A. Flacco et al. “Dependence on pulse duration and foil thickness in high-contrast-laser proton acceleration” Phys. Rev. E 81, 036405 (2010).

D.2 Scientific work plan methods and means

The Scientific Work Plan of the Action consists in addressing the previously-listed physical problems by performing experiments (and related theoretical / numerical work) in European and overseas laser facilities. In order to perform such experiments, the groups belonging to the Action will apply for Laser time through the usual European channels (national and international access programs). As for the collaboration with US and Japan, the Action will use the bilateral collaboration channels, which have been recently opened, as well as the calls for proposals for Omega and NIF (such facilities providing the essential technology for the Action purposes). STSMs will be used to allow for the participation of European researchers to such experiments. The Action is articulated into 5 Working Groups, each of them taking care of the needed access organization and of international research teams coordination. The WGs will also direct experimental work in European laser facilities related to their respective domain and promptly communicate the relevant results.

The milestones of the Action will consist in:
1) Organization of a kick-off meeting at the beginning of the Action, bringing together all the involved groups and trying to involve the media for sake of visibility (in a location where low cost flights are available).
2) Each of the 5 WGs will hold a periodic (annual) meeting (although several WGs may decide to hold their meeting together or simultaneously to other events like sponsored workshops or summer schools for PhD students).
3) A mid-term report will be prepared, which will also serve for dissemination purposes, i.e. to spread information about the Action goals and results.
4) A final meeting (and conference) will be organized just around the end of the Action again bringing together all of the involved groups (in a location where low cost flights are available).

The deliverables of the Action which will allow monitoring how well the Action achieves its goals will be:
1) Each of the 5 WGs will issue an annual report on its activity including in particular 3 sections on the work done for proposing, preparing and realizing experiments in i) "intermediate" European laser facilities, ii) facilities in US and Japan, iii) future experiments on LMJ/PETAL. (ii) and (iii) are essential for the Action, providing the suitable technology for unprecedented experiments in the domain of this Action.
2) The proposals for experiments (officially submitted through Laserlab or other channels) as well as specific reports to be produced once each of such experiments has been performed. In addition to published articles and presentations at international scientific conferences, these will also serve for

evaluation criteria.
3) Two documents addressing the problems of “Science with High Energy Lasers” and of “Polar Direct drive and Shock Ignition on LMJ/PETAL” which will include the scientific achievements of the Action will be prepared. The goal of such documents is intended to be a starting point as well for the European Scientific Community in order to prepare future experiments on LMJ/PETAL and to promote collaboration with overseas scientific communities.
4) Other scientific deliverables will be the annual WG and Action meetings, the sponsored workshops, and the organization of summer schools for PhDs and young researchers. Due to the high impact of training for developing the European community working in ICF, this last point is particularly important.

In addition, in order to promote gender balance and Early Stage Researchers (ESR), the Action will organize specific events including i) a special day for women researchers and one for young researchers during one or more of the main events organized by the Action (in particular, but not only, the closing meeting), and ii) two annual prizes for the best achievements obtained by a female researcher and a young researcher, respectively.

E. ORGANISATION

E.1 Coordination and organisation

The Action Chair will chair the Management Committee (MC); it is the ultimate decision-making structure within this Action, in charge of all scientific aspects, project progress, administrative and financial matters. The MC will meet on a yearly basis (in a location where low cost flights are available) and in addition by teleconference whenever it is needed.
All governing bodies and the composition of the MC will reflect: i) a gender balance, ii) the presence of young researchers, and iii) synergies with other European programs.
The research will be carried out and financed through a concerted action by the participating countries, while the Action provides the necessary co-ordination and support for networking activities. The MC will also set up a specific website that will not duplicate general information already available from the COST website and will keep it updated with information on STSMs, upcoming (and past) events organized by the Action, but also main scientific achievements and preparation of experimental proposals.
Many practical actions will be taken by the 5 Working Groups in which the Action is organized. In

fact the WGs will implement the coordination of national research in a single pan-European research Program. In particular, the WGs will take care of coordinating experimental proposals to be realized both within Europe (through Access programs to European large scale laser facilities, like Laserlab and national access programs) and overseas (in collaboration with researchers from US and Japan).

Practical items, which do not require the meeting of the full Management Committee (MC) e.g. assignment of STSMs, will be managed by a core group the MC including the MC Chair and Vice-Chair, and the leaders of the 5 WGs. This will meet regularly (at least once per 6 months), or consult through teleconference when necessary.

The milestones and deliverables are represented by the organization of events (annual WG meetings, Summer Schools), by the preparation of experimental proposals for Large Scale Laser Facilities, by the preparation of the two already-cited documents on “Science with High Energy Lasers” and “A pathway to demonstration of Polar Direct drive and Shock Ignition on LMJ/PETAL” respectively due for mid-term of the Action (end of year 2) and for the end of the Action (6 months before end of year 4).

E.2 Working Groups

This Action will be articulated into 5 Working Groups directed at addressing specific problems:

WG 1: Study of fast ignition and fast electron transport

WG 2: Study of the shock ignition Approach to ICF

WG 3: Study of Plasma and Laser Diagnostics

WG 4: Complementary aspects: Secondary sources of particles and radiation

WG 5: Complementary aspects: Astrophysics in the laboratory

Each Working Group will have a scientific responsible chosen among the members of the Management Committee of the Action. At least 2 of the 5 WGs will be coordinated by female researchers.

No specific "theoretical / numerical" WG has been established. Indeed this Action strongly believes that the advancement of a field in physics needs the direct and close cooperation of theoreticians and experimentalists.

The advances of the Working Groups will be constantly monitored by the previously-cited restricted scientific coordination panel.

For more details on the organization of the dissemination plan, please refer to section H.

E.3 Liaison and interaction with other research programmes

This Action is obviously related to several other European initiatives:

- The HiPER project, which is currently supported by the EU and by various national funding agencies (STFC in UK, CEA in France, the Academy of Science in the Czech Republic), going to finish by April 2013.

- LASERLAB EUROPE, the Integrated Initiative of European Laser Research Infrastructures, web site: http://www.laserlab-europe.net/. This infrastructure actually includes all already-existing high-energy laser facilities (LULI2000, PALS, RAL Vulcan, Phelix at GSI, all part of the LASERLAB consortium).

- The ELI European project with its several branches in Romania, Hungary and the Czech Republic and in France (Apollon). The ELI project (Extreme Light Infrastructure) aims at realizing a European laser facility working on ultra-short time scales (web site: http://www.extreme-light-infrastructure.eu/) the availability of such high-energy systems will also allow significant studies to be performed on specific topics (related, for instance to fast ignition or diagnostics development)

- the ESF Research Networking Program SILMI (Super-intense laser-matter interactions).

Several of the Action's participants are also deeply involved in Laserlab, SILMI, ELI. Collaboration with such programs will take place at various levels:

- Exchange of information,

- Realization of common initiatives (workshop and summer schools), as said elsewhere, the politics of this Action will not be to organize completely new events, (there are already too many workshops and conferences) but rather to strengthen already-existing events,

- If needed, inviting representatives of such programs to WG meetings or MC meetings (in open sessions).

Finally, this Action also considers the initiative going on in Europe in MCF (i.e. the JET, Joint European Torus, facility and the ITER project) as possible and interesting partners. A new era in fusion is being entered (via NIF, LMJ, and ITER). The board of the Plasma Physics Division of the European Physical Society has been operating in this direction in the last 10 years.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance and considerable involvement of

early stage researchers (ESR) in all its activities and the Management Committee (MC) will place this as a standard item on all its MC agendas.
The Action will strongly promote the participation of early-stage researchers (and Ph.D. students) not just as a “quantitative" effort, but also in qualitative terms. Whenever possible, this Action will directly charge young researchers of designing, proposing and realizing experiments in Large Laser Facilities. This will allow young researchers to rapidly acquire considerable experience and be able to form the bone of tomorrow’s European ICF community. Also, one of the main activities of the Action will be the realization of summer schools, which will be realized not only through the direct support of the Action but also through Intensive Erasmus Programs and/or by promoting Erasmus agreements between participating universities.
As for gender balance, this is an important issue, and one must not be limited to a “declaratory policy” but specific and concrete solutions should be investigated and implemented. In the MC composition, the gender issue will be addressed as far as possible, as well as the inclusion of young researchers.
In order to meet such issues, the Action will organize specific events including i) a special day for female researchers and one for young researchers during the main events organized by the Action (in particular, but not only, the closing meeting), and ii) two annual prizes for the best achievements obtained by a female researcher and a young researcher, respectively (where the «young» researcher may also be female).

F. TIMETABLE

	Year 1		Year 2		Year 3		Year 4	
Activities	1st sem.	2nd sem.	1st sem.	2nd sem.	1st sem.	2nd sem.	1st sem.	2nd sem.
Action (common)	Kick-Off Meeting	Summer school		Summer school		Summer school		Summer school
	web site Preparation		Release of pedagogical material (text book, e-learning) on ICF and related physics	Mid Term Meeting (and mid-term report)	Release of document “Science with High Energy Laser”		Release of document “A pathway to demonstration of PDD and SI on LMJ/ PETAL”	Closing Meeting of the Action

	Dissemination activities			
Experi-mental activity	Proposals for experiments on European Lasers	Proposals for experiments on LMJ/PETAL	Preparation of Experiments on LMJ/ PETAL	First experiments on LMJ / PETAL
	Strengthening relations with US /Japan scientific community	Preparation of European proposals on Omega / Gekko	First "European" experiments on Omega / Gekko	"European" experiments on Omega / Gekko
	Experiments in European Lasers			
WG1, …, WG 4	WG meeting	WG meeting	WG meeting	WG meeting

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: BE, BG, CH, CZ, DK, EL, ES, FR, HU, IL, IT, PL, PT, RO, RS, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 64 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

It is of the main aims of a COST Action to fulfill some fundamental characteristics and criteria, one of these is the successful dissemination of the actions and the results described in the Action. Among others, the main aims of a COST Action are a) to promote excellence via networking activities, b) to contribute strongly to European Society economic growth, c) to identify and support research and development actions supported by other funding schemes, d) to encourage capacity building and mobility of researchers and e) to help the young scientist supporting them with high level education. All the aforementioned criteria can be successfully reached only if a "state of the art" Dissemination Plan is "designed".

The Dissemination Plan in this Action is based on two components strongly coupled: “traditional” dissemination actions and that of “modern” dissemination actions. Bellow both these group of dissemination actions will be presented.
This Action has the goal to involve different areas of science and engineering with a particular regard for plasma science (Inertial Confinement physics) with its “open problems” related the high-level of the technology required and questions still open. In this sense this field is of interest for **private sectors** (optoelectronics, optics, automation systems etc.). Not only Fusion science and technology but also medicine, biology and material science can be developed as a consequence of this kind of research.
In line with the above the first target, the audience for the dissemination actions are the **scientists and engineers of various fields** including plasma physics, material science, astrophysics, medicine, biology, earth science, optoelectronics engineering, optics, laser technology etc.
This Action has also the aim, via networking, to establish the foundations for top quality training of young scientists in the proposed field. The collaboration of scientists from leading European Institutions and other groups from Europe (and through their links with US, Japan, Russia etc.) in the area of ICF will generate a pole of high quality research in Europe in the field. **Young scientists** are therefore a very important target group for the dissemination actions of this Action.
This implies important socio-economic benefits for Europe and an added value to community. This an important point and the Action will take care that it reaches the appropriate target groups for the dissemination actions (such as the **European level policy makers**, the **Government policy makers** and finally the **public).**

H.2 What?

The way to coordinate and to organize has to be based on the experience of the past involving also new methods and possibilities. In this sense **“traditional”** dissemination actions involve:
- Publications in scientific journals, publications in workshop proceedings, state of the art reports, publications in popular public journals for science, newspapers etc.
- Organization of events such as, workshops, satellite meetings within large conferences (i.e. EPS, European Physical Society, APS, American Physical Society), public open days, open days for industry.
- Special meetings and workshops for the European level policy makers and the Government policy makers.

- Organization of summer schools. This is an important action for the training of young scientists. This is an important target group for dissemination. Furthermore, during the summer school the local governmental authorities such as municipality, periphery etc. are involved, which are first-degree governmental policy makers. During the summer school (usually lasts for two weeks) simplified lectures for wide audience will be organized.
- Introduction of the research and its results in the educational process of the participating Higher Education Institutions. This is a very effective dissemination action and is in line with the necessary modernization of the curriculum of the University departments.
- A series of presentations about ICF energy production and its importance for the future of our planet will be given to the young pupils and their teachers. For this purpose visits to schools (primary and high schools) will be organized in each of the countries, which participate in this Action. Discussions with the pupils will have a creative role and one goal: to pass onto them enthusiasm for plasma physics and clean energy production via fusion with lasers and promote European policy for the training, science and technology integration for the benefit of the community.

A so-called **“modern”** dissemination action involves novel electronic tools:

a) e-learning platforms of the participating higher education institutions. The networking activities and the results of the research will be disseminated via this powerful learning tool. The university authorities will be informed about this Action and if necessary memorandums will be signed.

b) A website will be developed for the public dissemination of the activities of this Action. In the same website a password protected part will be developed for internal communication and dissemination of the Action participants. In addition, a part of the web will include more advanced scientific and technical information for the experienced scientists worldwide.

c) Radio and TV broadcast in terms of public understanding of science, e-newsletters, and video-clips productions will be initiated. Indeed this is very effective for the dissemination of the activities of the present Action and it includes all the target groups described above.

d) Electronic book development. In this book all the results and activities of this Action will be included and uploaded into the main web pages of the participating institutions.

H.3 How?

All the participants of this Action are committed to the best possible dissemination of the produced knowledge to the academic community, the public, industry and stakeholders. All the tools described above will be intensively used.

In particular, in order to ensure effectiveness for implementing the Dissemination Plan described above a “Dissemination Committee” consisting of the Action Chair plus two more scientists of the participating institutions and one administrative person (from the coordinating institution) will be responsible for the a) coordination of the Dissemination Plan and b) monitoring the quality and the progress of the Dissemination Plan. This Dissemination Committee will define one of the 4 persons described above as **“Dissemination Manager”** for the whole dissemination program of the Action. The Dissemination Manager in collaboration with the MC will have the responsibility for the implementation of the dissemination plan described above. A questionnaire monitoring the quality control of the dissemination plan will be developed and distributed to the participating institutions. This questionnaire will address and check all the necessary activities that the participating institutions will have to follow for the dissemination plan. The Dissemination Committee and the Dissemination Manager will be responsible for developing this questionnaire and for distributing it, collecting it and analyzing the results. The results of the analysis of the questionnaires will be disseminated using the methods described in H.2.