Activities of the High Energy Density Laboratory Plasmas Panel

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R. Betti

on behalf of the HEDLP FESAC subpanel

Meeting of the Fusion Energy Science Advisory Committee
November 6-7, 2008
Gaithersburg MD

The charge to FESAC

- →“joint program [OFES+NNSA] budget is expected to be .. $30-50M”
- →“identify the compelling scientific opportunities for research in fundamental HEDLP”
- →”identify the scientific issues of implosion and target design that need to be addressed to make the case for inertial fusion energy”
- →”provide background for a specific plan for energy related HEDLP studies”
- →“Identify the gaps in knowledge and opportunities for energy related HEDLP”

The HEDLP FESAC subpanel

F. Beg (UCSD)
B. Remington (LLNL)
R. Betti (UR) (chair)
R. Davidson (Princeton)
P. Drake (U. Michigan)
R. Falcone (U. Berkeley)
D. Hammer (Cornell)
M. Knudson (SNL)
G. Logan (LBNL)
D. Meyerhofer (UR)
D. Montgomery (LANL)
W. Mori (UCLA)
M. Murnane (U.Colorado)
R. Petrasso (MIT)
D. Ryutov (LLNL)
J. Sethian (NRL)
R. Siemon (UNR)

IFE Subcommittee (second part of charge)

R. Betti (UR) (chair)

D. Hammer (Cornell) Z-pinch fusion

G. Logan (LBNL) Heavy ion fusion

D. Meyerhofer (UR) Fast Ignition

J. Sethian (NRL) Laser direct drive

R. Siemon (UNR) Magnetized Target Fusion

The Panel Process

- →Breakdown of the field into IFE-related and fundamental science, areas and issues
- → HEDLP panel web site http://fsc.lle.rochester.edu/hedlp/hedlp.php
- →Input to the panel: HEDLP workshop, August 25-27, Washington DC, 82 attendees
- →Preliminary prioritization/assessment: ranking criteria and e-mail vote
- →Prioritization and assessment: Panel meeting, September 17-19, Los Angeles, and weekly follow-up conference calls (September-December)

Two categories of scientific issues are identified: IFE-related and Fundamental HEDLP issues

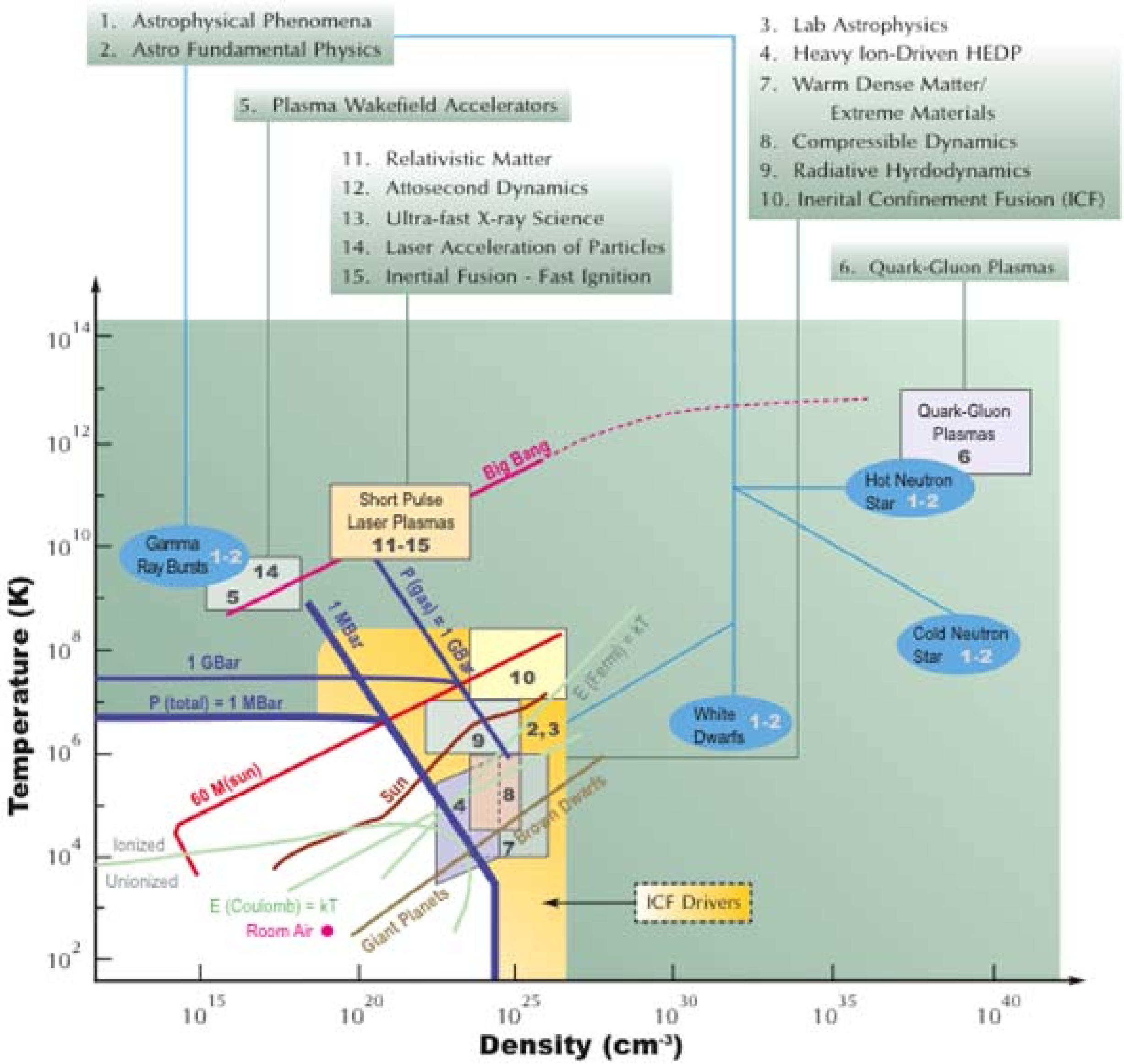
Fundamental HEDLP science

- **Identification** of the compelling scientific opportunities in fundamental HEDLP science
- **Assessment** of the scientific opportunities

IFE-related HEDLP science

- **Identification** of the compelling scientific issues in IFE-related HEDLP science
- **Prioritization** of the issues

The HED universe spans a large parameter space in density and temperature



Organizing the field for assessment and prioritization: areas, issues, questions, descriptions

Example:

Area: relativistic HED plasma and intense beam physics
Issue: *Intense particle beam acceleration by intense lasers*
Question: *How are particles accelerated by intense lasers?*
Description. Energetic charged particles are generated in high intensity laser matter interactions via a number of physical mechanisms such as resonance absorption, vacuum heating and ponderomotive (JxB) accelerations etc. Also protons and ions in short pulse high intensity laser matter interactions are accelerated via the Target Normal Sheath Acceleration (TNSA) mechanism. The general idea is that the when the laser irradiates a target, its energy is transferred efficiently to the hot electrons via above described mechanisms, which consequently accelerate protons/ions due to TNSA. The knowledge and understanding of mechanisms causing acceleration of energetic charged particles is important to fast ignition. In full-scale **fast ignition** experiments, one would expect inherent laser prepulse (with an energy contrast ~ 10-5) due to the amplified spontaneous emission (ASE) in the range of 0.5-1 J. This ASE prepulse can significantly affect the mechanism accelerating the charged particles (electron, proton or ions) as a result modifying the hot electron distribution and temperature. Both hot electron spectrum and temperature are crucial to the success of fast ignition. The requirement for hot electron temperature is 1-2 MeV for an efficient electron energy coupling to the compressed core. The temperature prediction from some of the above-mentioned mechanisms (e.g., ponderomotive scaling) is significantly higher than the required values at the intensities of 1020 Wcm-2. However, recent analytical models and simulations suggest that the lower hot electron temperature could be achieved with the density steepening. These effects are not tested yet due to the lack of facilities for full scale fast ignition experiments. Now, it is becoming possible to perform such experiments on OMEGA-EP and also on NIF ARC in a couple of year time. Furthermore, direct measurements of the electron source at the point of generation are not physically possible; indirect methods (Kalpha x-rays, bremsstrhalung and escaping electrons) are routinely used. The conversion efficiency measurements assume Monte Carlo transport for the electrons and photon production. Complex transport issues such as electric and magnetic fields within the target are ignored.

HEDLP science is organized into 6+1 areas

- HED hydrodynamics
- Warm dense matter physics
- Nonlinear optics of plasmas and laser-matter interactions
- Radiation-dominated dynamics and material properties
- Magnetized HED plasma physics
- Relativistic HED plasma and intense beam physics
- Integrated HEDLP physics (for IFE sciences)

The HEDLP workshop provided input to the panel. 14 invited and 28 contributed talks

M. Donovan (NNSA) NNSA perspective
G. Nardella (OFES) OFES perspective

HEDLP for Inertial Fusion Energy (invited speakers)

- J. Perkins (LLNL) *High Gain Target Physics and Advanced Target Design*
- J. Banard (LBL) *Heavy-Ion Fusion*
- B. Bauer (UNR) *Magneto-Inertial Fusion*
- M. Key (LLNL) *Fast Ignition*
- A. Schmitt (NRL) *Laser IFE*
- K. Matzen (SNL) *Z-pinch IFE*

Fundamental HEDLP (invited speakers)

- G. Dimonte *(LANL) Nonlinear Hydrodynamics, Instabilities and Turbulent Mix*
- D. Arnett *(U. Arizona) HEDLP Applications to Astrophysics*
- M. Herrmann *(SNL) Radiation and Magneto Hydrodynamics of HED Plasmas*
- R. Collins *(LLNL) Material Properties at High Pressures*
- B. Afeyan *(Polymath Research) Nonlinear Optics of HED Plasmas*
- C. Ren *(UR) High Intensity Laser and Energetic Particle-Matter Interaction*

HEDLP science issues relevant to IFE (part 1)

- **HED hydrodynamics**

→ **Hydrodynamic instabilities and turbulent mix**
→ **Implosion hydrodynamics for high gains**

- **Warm dense matter physics**

→**Properties of strongly coupled plasmas**

- **Nonlinear optics of plasmas and laser-matter interactions**

→ **Laser-plasma instabilities and hot electron generation**
→ **Nonlocal transport of energy**
→ **Laser/particle beam x-ray conversion**

- **Magnetized HED plasma physics**

→**Magnetically driven implosions**
→**Influence of magnetic field on HED fusion plasmas**

HEDLP science issues relevant to IFE (part 2)

- **Radiation-dominated dynamics and material properties**
  - → Opacities of HED plasmas and materials at high pressure
  - → Radiation hydrodynamics
  - → Equation of state of HED plasma and materials at high pressures

- **Relativistic HED plasma and intense beam physics**
  - →Charged particle generation by intense lasers
  - →Transport and energy coupling of intense particle beams in HED plasmas

- **Integrated HEDLP physics**
  - → Integrated target physics for inertial fusion energy
  - → Integrated science for IFE systems

Fundamental HEDLP science issues (part 1)

HED hydrodynamics
→ Turbulent mix
→ Probing properties of HED matter through hydrodynamics
→ Solid-state hydrodynamics at high pressures
→ New hydrodynamic instabilities
→ Hydrodynamic scaling
→ Hydrodynamic simulations of HED systems

Warm dense matter physics
→ Phase transitions in and around the WDM regime
→ Comprehensive theory connecting different WDM regimes
→ Equation-of-state dependence on formation history
→ Transport properties of warm dense matter
→ Quark-gluon plasma similarities to warm dense matter

Fundamental HEDLP science issues (part 2)

Nonlinear optics of plasmas and laser-matter interactions

→ Interplay between coherent radiation and nonlinear states in plasmas
→ Nonlinear wave-particle interactions
→ Multiple coexisting instabilities
→ Broad band radiation in plasmas
→ Quantum phenomena in HED plasmas
→ Multi-scale predictive simulation tools

Magnetized HED plasma physics

→Basic properties of magnetized HED plasmas
→Coupled dynamics and atomic kinetics
→Phase transitions in the presence of high magnetic fields
→Ultra high magnetic fields and their measurements
→Radiation dominated HED dynamo
→Radiation dominated reconnection

Fundamental HEDLP science issues (part 3)

Radiation-dominated dynamics and material properties

→ Radiative shocks
→ Radiation waves
→ Radiative cooling
→ Equation of state and opacities
→ Radiative instabilities
→ Radiation pressure

Relativistic HED plasma and intense beam physics

→Relativistic wake fields
→Relativistic particle beam propagation
→Relativistic laser-solid interaction
→Generating laser field at the QED limit
→Relativistic thermal plasmas
→Relativistic shocks

<u>Assessment</u> of fundamental HEDLP science

Importance, potentials and readiness of Fundamental HEDLP areas are assessed

<u>Assessment criteria</u> for <u>areas</u> of Fundamental HEDLP

- **IMPORTANCE to the fundamental understanding and development of high energy density science**
- **POTENTIAL for important practical applications**
- **POTENTIAL for resolving major issues in other fields of science**
- **POTENTIAL for stimulating interest in graduate students and scientists from other fields**
- **READINESS: what progress is expected in next 5/10 years?**

Prioritization of IFE-related HEDLP science

IFE-related science issues are prioritized

Ranking criteria for issues of IFE-related HEDLP science

- **IMPORTANCE to the advancement of fusion energy sciences**
- **DISTINCTIVENESS: degree to which the issue is NOT addressed in the NNSA-funded conventional ICF ignition program**
- **READINESS: what progress is expected in the next five/ten years?**
- **GENERALITY: degree to which the solution of the issue impacts multiple IFE concepts**
- **COST: level of resources required to address the issue**

TIMELINE

→ **November 11: Final assessment of Fundamental HEDLP**

→ **December 5: Address second part of the charge**

→ **December 20: Final report**

→ **January 4: Report to FESAC**