ICF & High Energy Density (HED) Research Future Directions and Plans

Fusion Power Associates Symposium
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Washington, DC

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Office of Defense Science and Inertial Fusion

National Nuclear Security Administration
US Dept. of Energy

Extraordinary new HED capabilities are now in place

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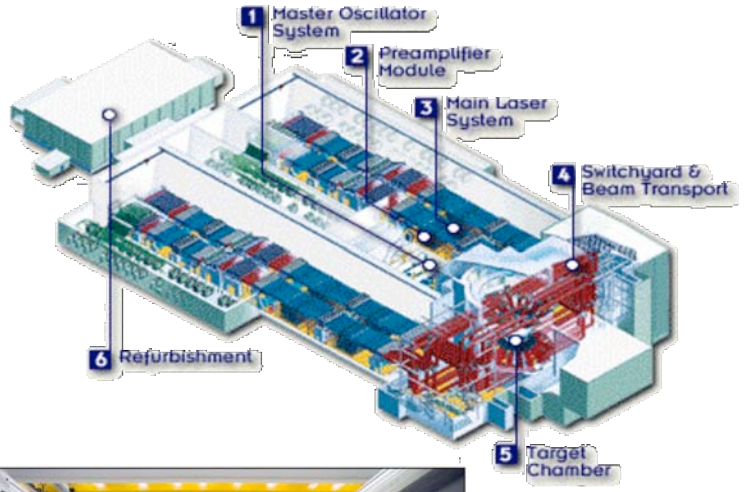
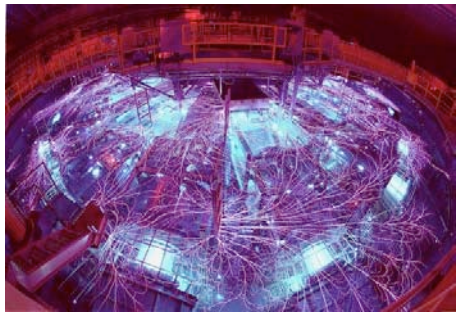
- **National Ignition Facility (NIF)**
  - Only access to burning plasma conditions
  - Important mission experiments have already been performed



- **Omega EP**
  - Sophisticated high irradiance capabilities
  - Important venue for advanced fusion research

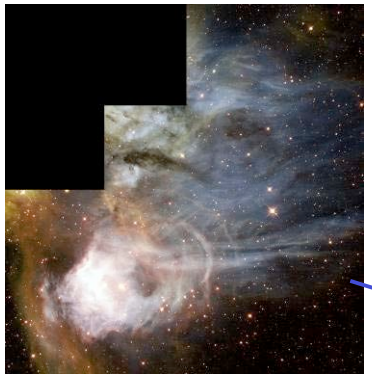
- **Z Machine**
  - Key venue for materials science measurements
  - Outstanding new results at 4 Mbar.



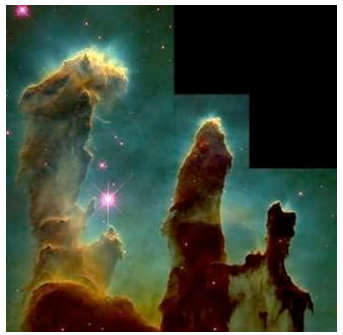
- **Enormous increase in computational power**

NNSA mission needs have driven the creation of HEDP environments that are ideal to study complex HED plasmas and materials

High Mach Number unstable flows

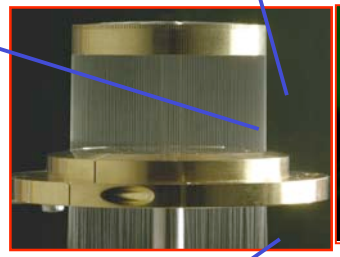


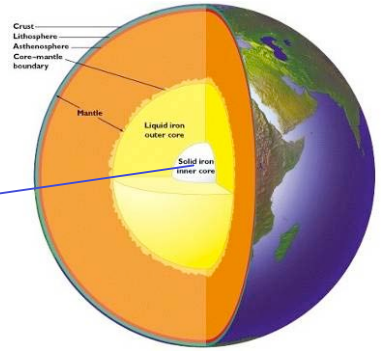
Jets

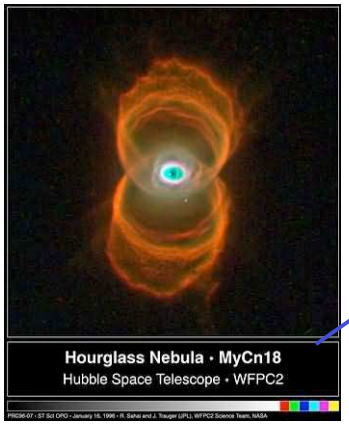


Rayleigh Taylor Instabilities

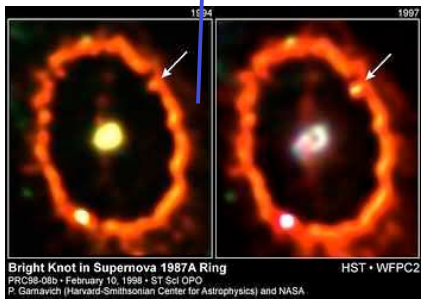
Materials in the Extreme







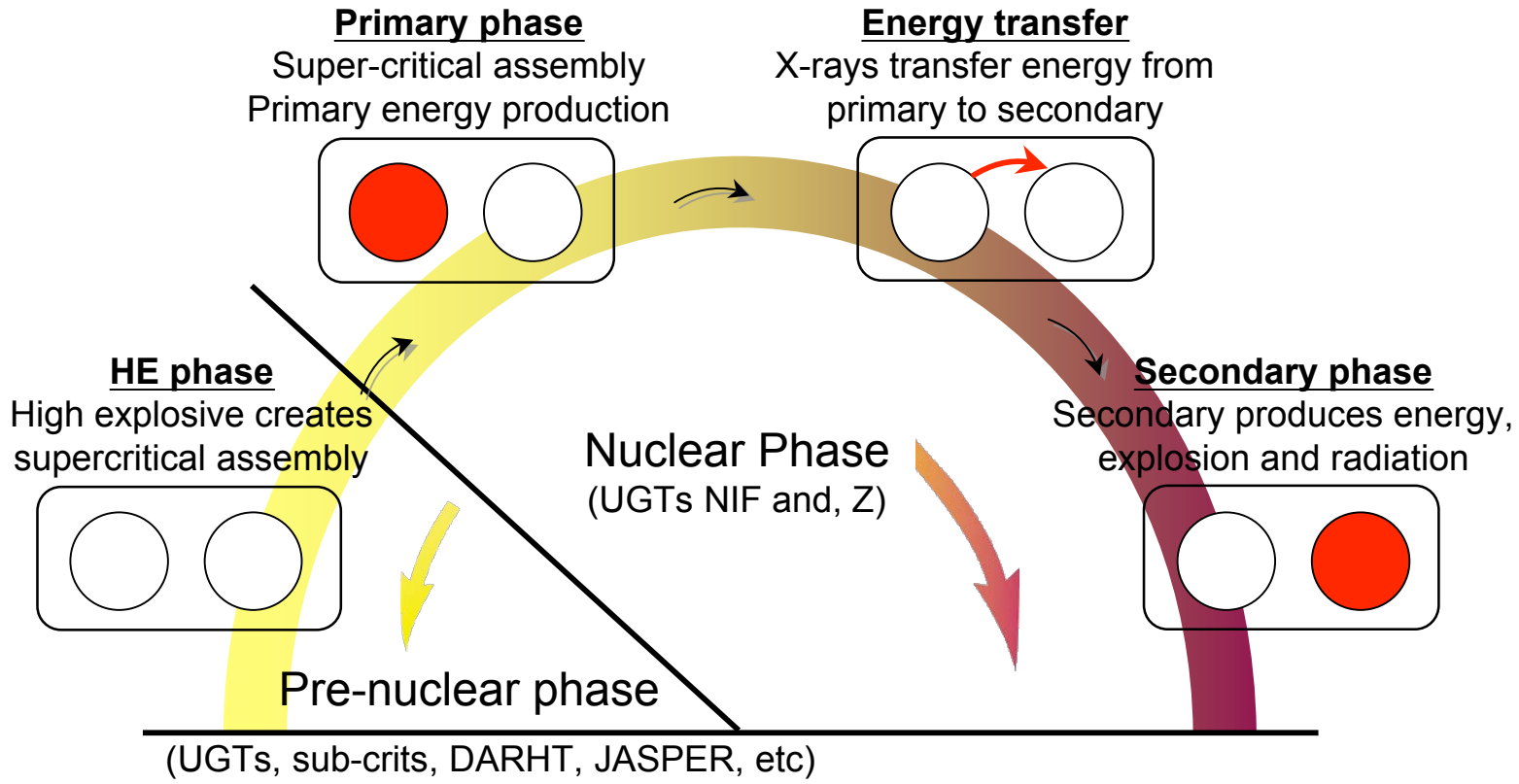
Mass Outflow



Shocks and radiation transport

MHD, thermo-electric, and "anomalous" heating

After the explosive phase, weapons rapidly evolve into the HED and plasma regimes



Weapons operation proceeds through the conditions of planetary interiors, to stellar interiors

The pursuit of ignition will dominate the agenda at NIF through 2012

- **3 major series of ignition experiments are planned for 2010-2012.**
  - The plan is to transition to development of an "ignition weapons physics platform"
  - **This "platform" development shares many common goals with energy research**
    - **Robust operation, moderate to high gain**

- **The diagnostic suite will be rapidly evolving during this period.**
  - Neutron imaging will installed in 2011
  - Several beam lines of the ARC backlighting system will be available in late 11.
  - **Diagnostics that may be unique to the energy mission should be under consideration now.**

- **Detailed diagnostics that operate during an ignition shot remain a major challenge.**

- **A successful ignition shot will mandate a 1-2 week suspension of experimental operations at NIF.**

The Predictive Capability Framework (PCF) is our principal tool for planning the weapons Science and Technology agenda

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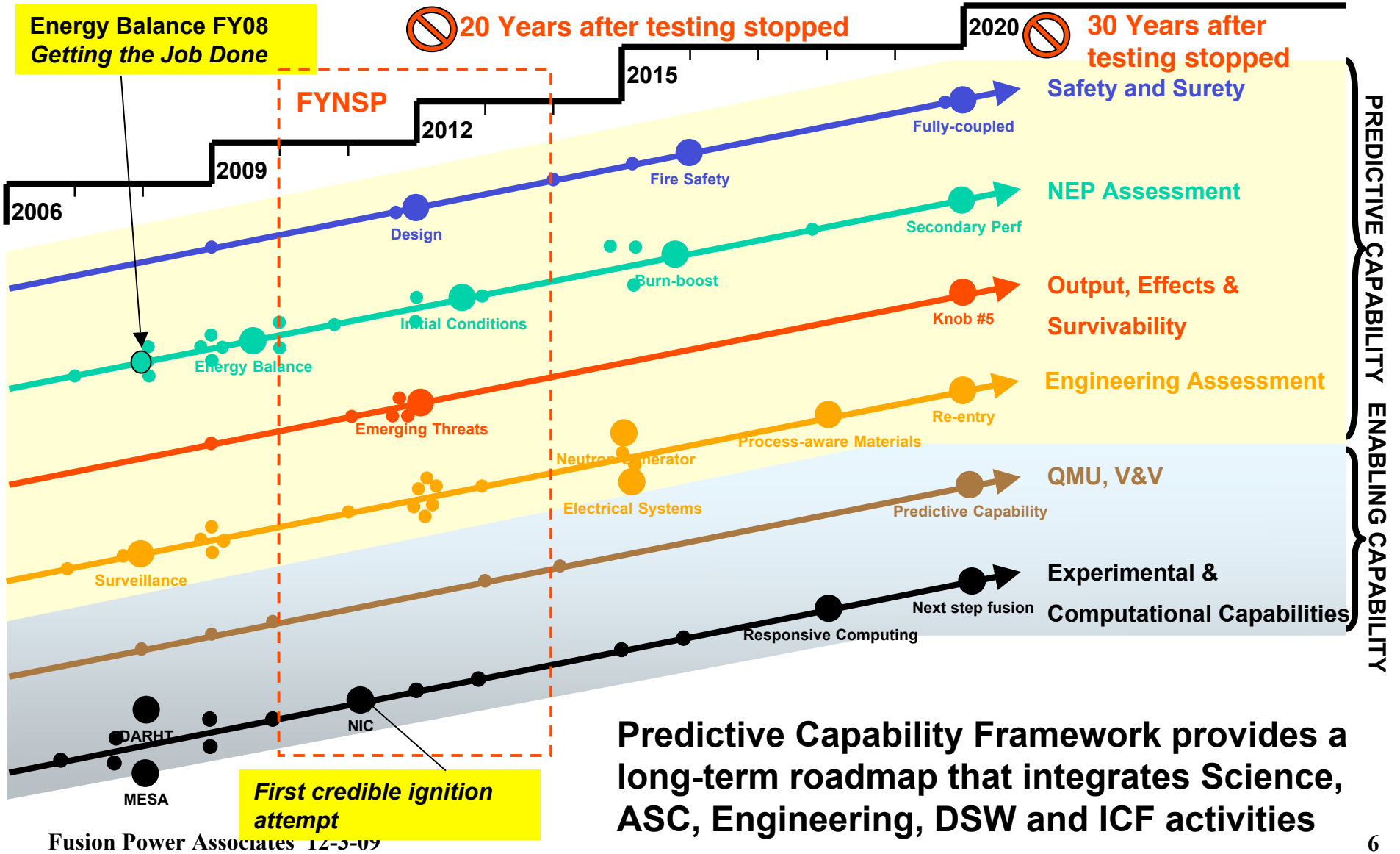

Predictive Capability Framework provides a long-term roadmap that integrates Science, ASC, Engineering, DSW and ICF activities

There is active work in coupling the PCF with HED planning

Fundamental Source Documents – set weapons requirements

- Primary and secondary certification plans
- SNM Plans

PCF – produces an integrated picture of the linkage and schedule of tasks required for certification and assessment on a continuing basis

Major emphasis areas (e.g. HED) – utilize the PCF linkages And schedules to analyze **resource requirements**

This same methodology can be used to outline the key Directions for IFE research

High Energy Density Physics is the Cornerstone of Science at NIF, Omega and Z

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HEDS — An important emerging discipline

NIF-0208-14452
24EM/cls

Advanced Materials Science has proved to be a fruitful application for ICF facilities

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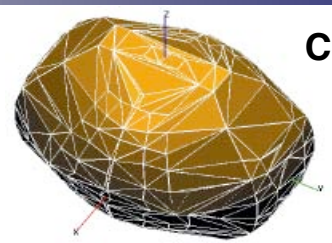
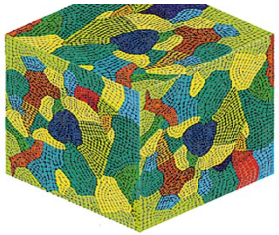
Computational science and experimental science must be integrated from the atomic- to the continuum-level to predict the properties of materials under extreme conditions

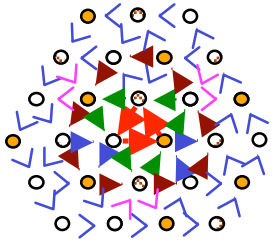


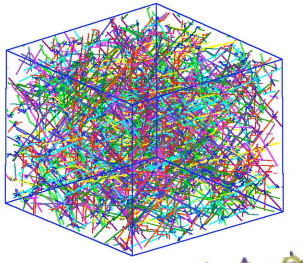
Continuum

Microscale



Atomic Scale



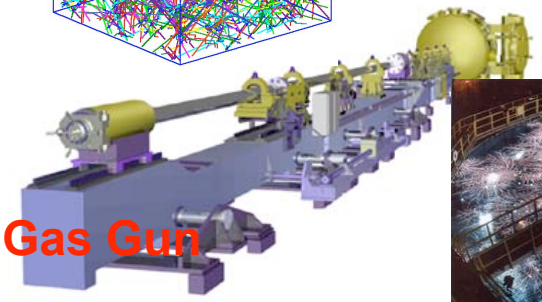


Length scales

m

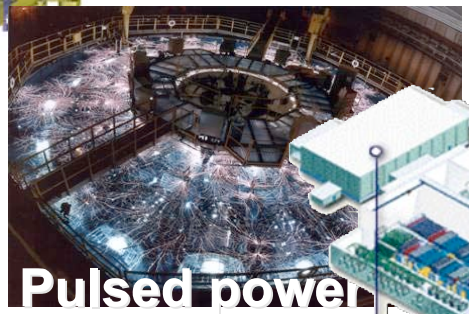
μm

nm

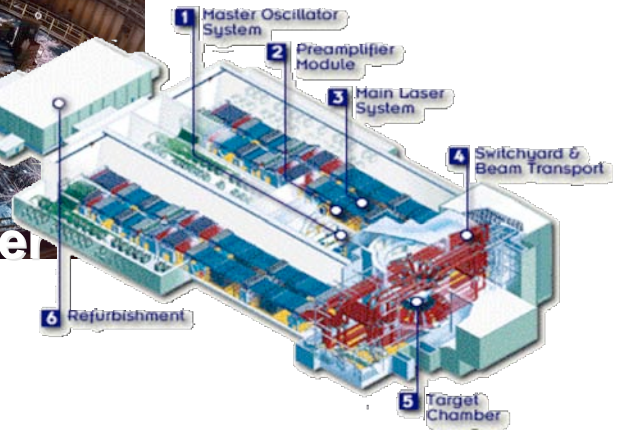


Gas Gun

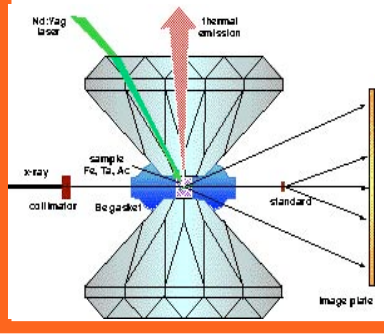
Lasers



Pulsed power



DAC



Experimental platforms

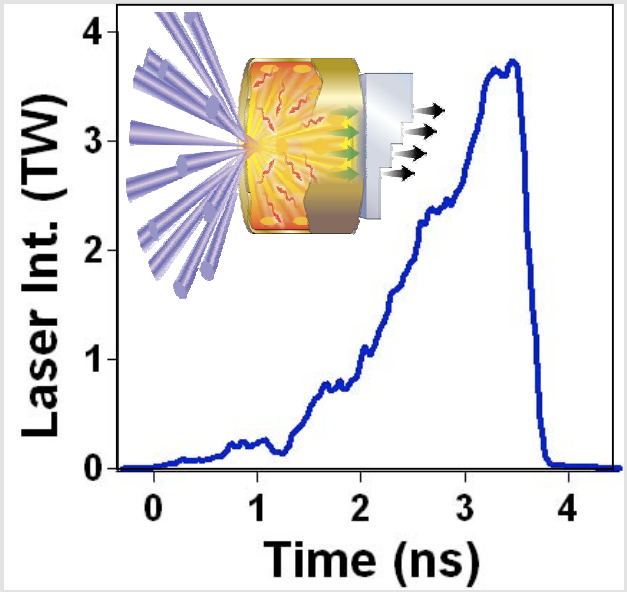
Static | $10^{-4} – 10^{2}$ s^{-1} | $10^{2} – 10^{5}$ s^{-1} | $10^{5} – 10^{9}$ s^{-1}

Strain Rates

Pressure →

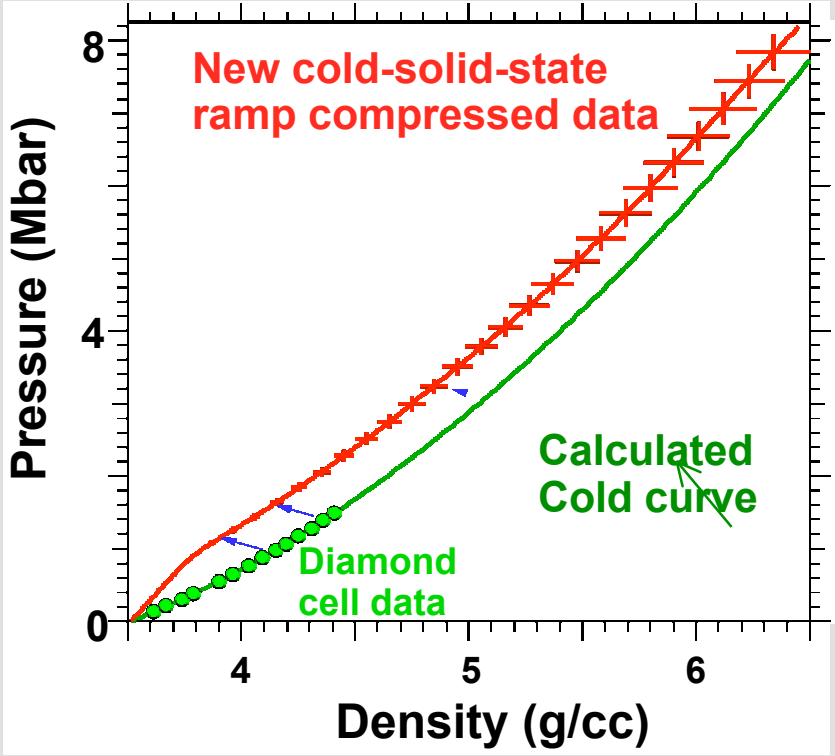
High energy lasers have been used to extend solid state physics to the 10 Mbar regime

Ramp laser intensity to produce shockless compression



- Edwards, et al. (PRL 04)
- Smith, et al. (PRL 06)
- Bradley, et al. (PRL 08)
- Eggert et al. (SCCM 07)

Ramp compression shows diamond is stable and strong to 8Mbar



NIF designs use the same technique to study solids to many >30 Mbar

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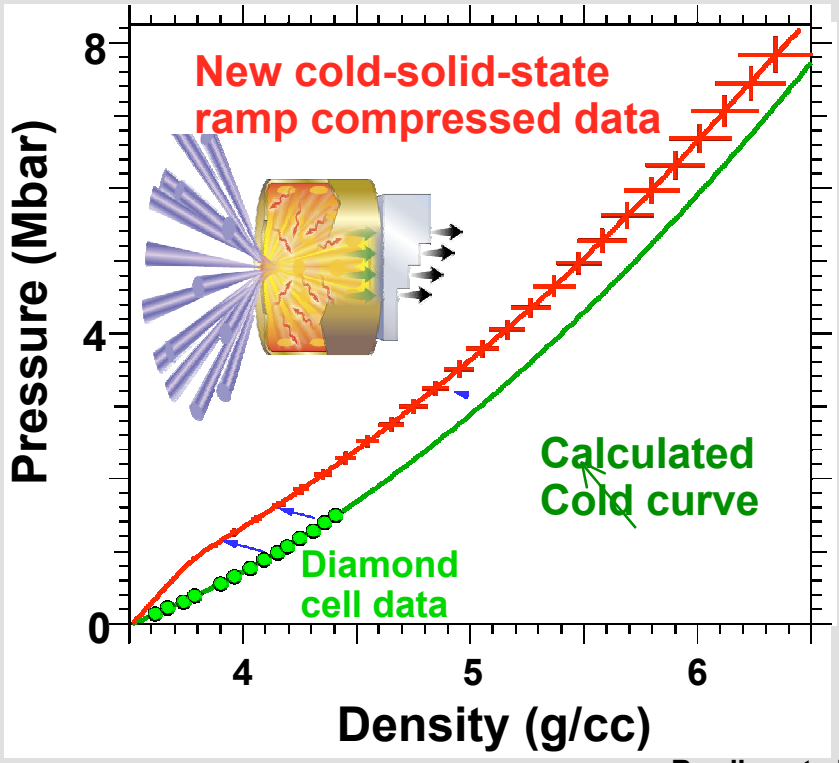
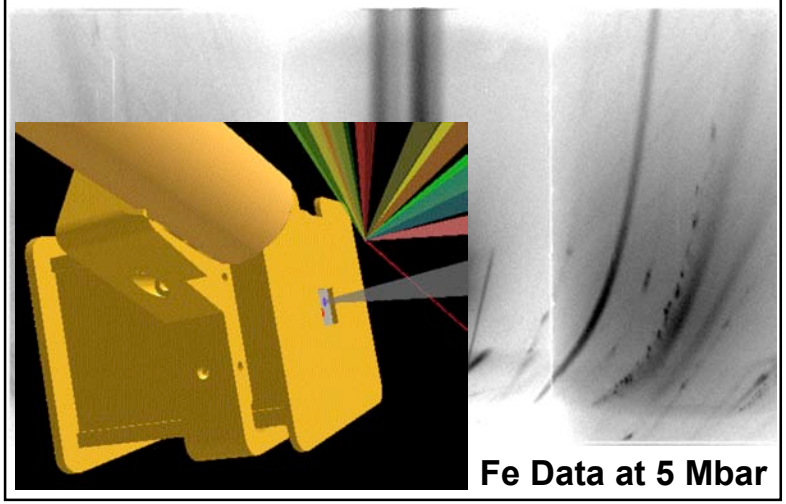


Bradley et al

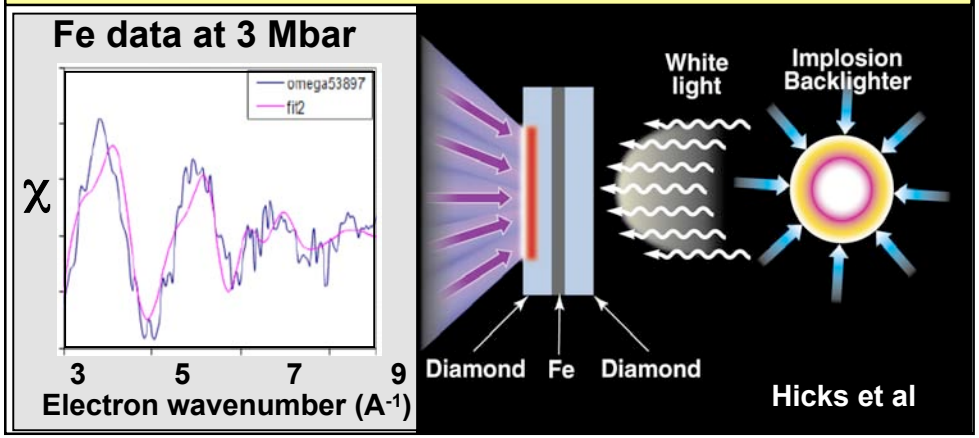
NIF designs use the same technique to study solids to many >30 Mbar

Diffraction for structure & strength =>Fe is HCP to 5 Mbar



Eggert et al

EXAFS is being used to measure T & structure in Fe to 3 Mbar



User Facilities and Shared National Resources – an important component of the future of NNSA facilities

- **Strengthening the HED science base** is an essential part of the NNSA mission and a responsibility to the nation.
- **15% of facility time** devoted to basic science is a goal.
- **Mission oriented work** will still dominate the agenda for the foreseeable future.
- **Uniform policies and procedures** will give a clear picture to the international science community and to our sponsors
- A broader constituency for our facilities is attractive to substantial segments of **congress**.

Thus far, consideration of basic science (beyond the weapons mission) has been in the general realm of HED

A joint NNSA / OFES Program in HED has been an important exercise in cooperative interaction

- 23 proposals were funded with an average award of $300K
- 3 Centers were supported
  - Fusion Science
  - Lab. Astrophysics
  - Advanced diagnostics for laser-plasma / ICF experiments.
- 2 large team awards ~ $1M
- 4 awards involved some aspects of laboratory astrophysics
- *3 awards involved Inertial Fusion Energy research*
- 3 awards involved analysis and control of laser-plasma instabilities

The response to the Joint HED Solicitation is promising for the future

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PI	Institution	Title
B. Afeyan	Polymath Research	Optical Mixing Techniques for Taming Laser Plasma Instabilities in High Energy Density Laboratory Plasmas
J. Bailey	Sandia National Laboratories	Laboratory Tests of Stellar Interior Opacity Models*
R. Betti	University of Rochester	Fusion Science Center for Extreme States of Matter

The response to the Joint HED Solicitation is promising for the future

R. Davidson	Princeton Plasma Physics Laboratory	Advanced Plasma Source Development and Ion-Ion Plasma Studies in a 100 Kilovolt Test Stand
T. Ditmire	University of Texas at Austin	Experimental Study of the Equation-of-State in Dense, Strongly-Coupled Plasma
P. Drake	University of Michigan	Center for Laser Experimental Astrophysics Research (CLEAR)
J. Fernandez, M. Foord, R. Stephens	Los Alamos National Laboratory, General Atomics, Lawrence Livermore National Laboratory	Ion-Fast Ignition – Establishing a Scientific Basis for Inertial Fusion Energy

The response to the Joint HED Solicitation is promising for the future

A. Frank	University of Rochester	Resolving the Issue: The Dynamics of Magnetized Astrophysical Jets Through Pulsed Power HEDP Laboratory Studies
D. Hammer	Cornell University	Spectroscopic Determination of the Magnetic Fields in Exploding Wire and X Pinch Plasmas
S. Hsu, D. Witherspoon, M. Gilmore, J. Cassibry	Los Alamos National Laboratory, HyperV, University of New Mexico, University of Alabama	Formation of Imploding Plasma Liners for HEDP and MIF Applications

Organizing and planning principles beyond the ignition demonstration

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- Formulating the national agenda for HED weapons physics will begin with a white paper – first draft Dec. 2009
  - This will evolve to one of the key source documents for the PCF
- Weapons requirements will continue to dominate the agenda at the major NNSA facilities
  - **A close collaboration and cooperation will be formed between NNSA and the DOE Office of Science to formulate the broader scientific agenda (~15% of facility time).**
- **NNSA will provide help to the Office of Science in Preparing for the NAS review of IFE.**
- Utilization of the major NNSA facilities will be guided by a uniform national policy
- A long term (10 year) national plan for HED research (weapons + wider agenda) is under way.

After robust ignition is demonstrated, advanced fusion concepts will be considered

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- **Double shell ignition**
  - Many desirable characteristics
- **Fast ignition**
  - Potentially higher gain
- **Shock ignition**
- **Direct Drive**
  - Potentially higher gain
  - Potentially greater physical access to the burning plasma
- **Operation at 2 ω**
  - Potentially > 3 MJ available

Uniform policies and methods will present a clear picture to the scientific community

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- The basic outline for user facilities is contained in a “Business Operating Procedure” or BOP – available at **nnsa.doe.gov**
  - http://nnsa.energy.gov/news/documents/SDM452_3_final_w_signature.pdf
- The next step in this process will be formulating an implementation plan for user facilities and shared national resources. – *in process*.
- A national HED planning document will also aid in the planning process. – *in process*
- NLUF on OMEGA provides an example for facility access.

User Facilities and Shared National Resources – an important component of the future of NNSA facilities

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Carefully addressing the needs of the mission-oriented agendas while promoting a level of peer review that will grow to be consistent with Office of Science standards

NNSA supports HED facilities of varying scale

- Large facilities – NIF, OMEGA, Z
  - Most extreme conditions, complex experimental setups, large operations crews, few hands-on opportunities
- Intermediate Scale – Trident, Jupiter, Zebra, …
  - Modest operations crew, hands-on opportunities
- University Scale – Texas Petawatt, OSU high rep. rate, …
  - Small operations crew, serve as a basic training ground for new students, many hands-on opportunities

In many cases, experiments will progress from small to intermediate to large scale facilities

Smaller scale work will also continue to play a role in IFE

IFE / interaction points between NNSA and OFES

- As **data on ignition** comes in it will be utilized to guide some aspects of IFE planning
  - NNSA responsibilty to make this information readily available as soon as feasible
- **OFES will take the lead** in some aspects of "advanced ICF"
  - Shock ignition
  - Fast ignition
- As IFE plans solidify **more NNSA facility time** for this work may be justified.

Conclusions

- The achievement of ignition will provide a significant catalyst to all of HED and IFE in particular
- It will also present specific challenges – the specific constraints of reliable ignition production
- Current collaborative interactions between OFES and NNSA are very promising precursors to even stronger collaborations on national challenges such as energy

The National Ignition Facility provides the only access to thermonuclear burn conditions

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NIF is Operational !

Uniform policies and methods (cont.)

- A general call for time on all NNSA facilities would be a complicated undertaking.
  - Consistently (uniformly) fair processes for choice
  - A process for “channeling” proposals to the most appropriate facility.
  - Plan for partitioning resources based on a number of national factors
    - Facility availability based on mission needs
    - Quality of proposals for various scale work

Newly formed user groups have provided outstanding input for future planning

- **The Omega Users Group** met for several days
  - Provided independent perspective on the use of the facility – closer to the prevalent models at Office of Science Facilities
  - Provided valuable example scenarios of the genesis and execution of complex research projects
  - Provided some sampling of the breadth and depth of work that can be envisioned on NNSA facilities
- **The Texas Petawatt Facility** also had an extensive users meeting.
  - Provided an outstanding sampling of the breadth of interest in laboratory astrophysics
  - Also identified a large potential body of work in beams and particles

The role of intermediate scale facilities is a crucial planning issue

- A consistent picture of the value of intermediate facilities has emerged from the academic community
  - Value of "hands on" experience in training and education
  - The need for staging, prototyping and calibration for work at the large facilities.
- Finding a funding pattern will be a challenge but a preliminary effort will be attempted

The response to the Joint HED Solicitation is promising for the future

H. Strauss	HRS Fusion	Hall MHD Stability and Turbulence in Magnetically-Accelerated Plasmas
H. Vu	University of California, San Diego	Study of Laser Plasma Instabilities Generation of Hot Electrons that Adversely Affect Fusion Target Compression

A number of important activities are contributing to HED planning

- **Upcoming OFES/NNSA HED workshop**
  - Bob Rosner, Chairman *and* Dave Hammer, Co-Chair
- **FESAC Sub-committee on HED**
  - Riccardo Betti, Chair
- **10 Year HED Planning Document**
  - Kirk Levedahl, Federal Coordinator

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Nov 15-18 Rockville, Md.

Chairs: Bob Rosner, David Hammer

Panel	Co-Chair	Co-Chair
HED hydrodynamics	**Betti**	**Giuliani**
Nonlinear optics of plasmas	**Montgomery**	**Kruer**
Relativistic plasma and intense beams	**Stephens**	**Fisch**
Magnetized HED plasma physics	**Ryutov**	**Chittenden**
Rad-dominated dynamics and materials	**Bailey**	**Libby**
Warm dense matter	**Desjarlais**	**Jeanloz**
Crosscut: Overall	**Drake**	**Fernadez**
Diagnostics	**McLean**	**Leeper**
Computing	**Douglas**	**Lamb**
Research infrastructure	**Petrasso**	**Wootton**
High-Z multiply-ionized atomic	**Mancini**	**Apruzese**

Fusion-Fission Hybrid Workshop

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September 30 - October 2, 2009 Gaithersburg Hilton

Chairs: Jeremy Freidburg / Philip Finck

Sponsored by NE, SC/OFES, NNSA

Purpose-assess areas in which FF devices might be useful such as:

- **electricity generation**
- **closing the fuel cycle by transmuting waste**
- **breeding fission fuel**