High Energy Density Physics In National Security, Energy Research and Basic Science

National Nuclear Security Administration

Presented to:
Stockpile Stewardship Graduate Fellowship Annual Conference

Presented by:
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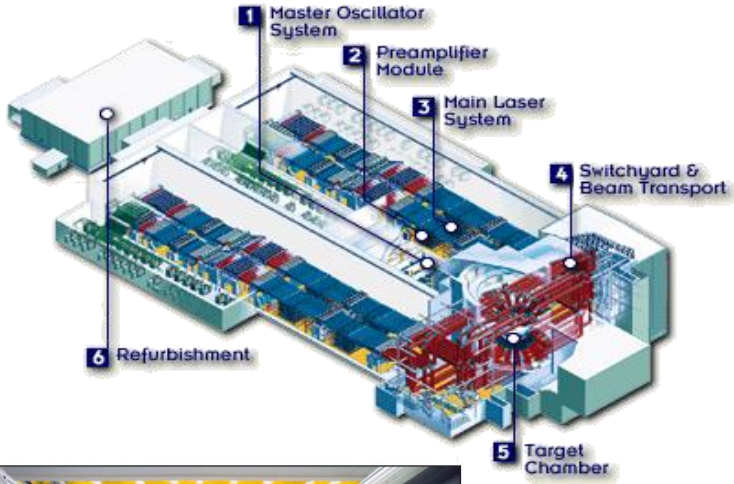
High Energy Density Physics is the central discipline underpinning Stockpile Stewardship

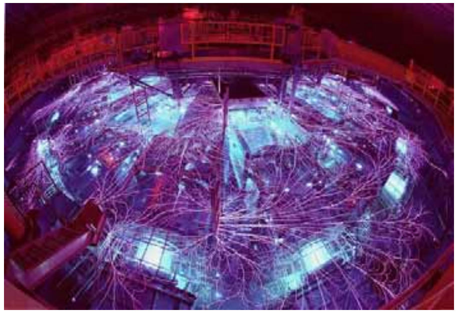
- Extreme conditions in temperature, density, pressure allow investigation of a large span of physical states.
- These extreme conditions are required to meet national security needs but also enable contributions to astrophysics, general
- Stewardship of HED and plasma science benefits NNSA

Extraordinary new HED capabilities are now in place



- **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**

Questions that the young researcher might ask

- What is the scientific research potential for this sub-discipline called High Energy Density Physics?
- What are the prospects for getting a good job based on the training I will receive ?
- What contributions can I make to the needs of the country and the world ?
- Is the field receptive to new ideas and radical thinking **?**

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

One of the teams recently Received the Schawlow Prize

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

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

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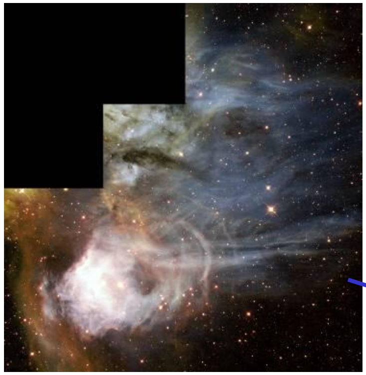
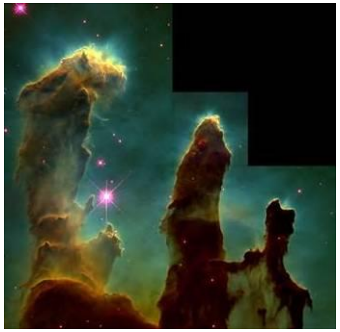
High Mach Number unstable flows

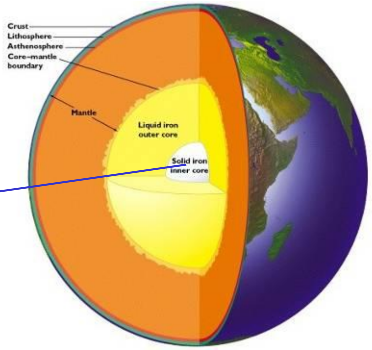


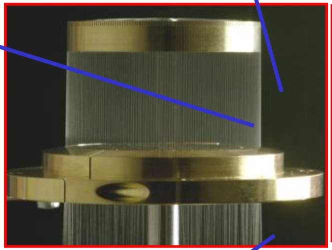
Jets

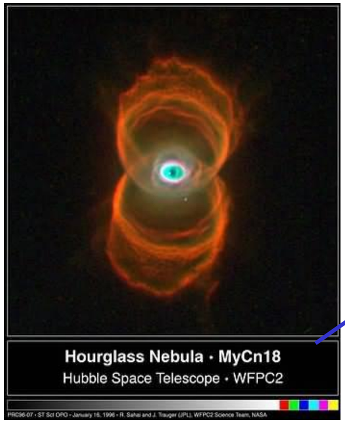
Rayleigh Taylor Instabilities



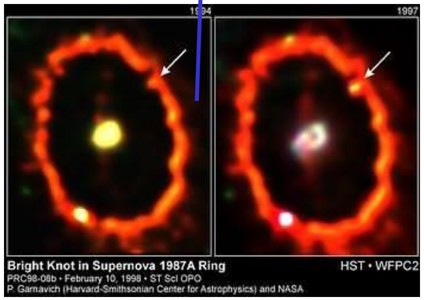
Materials in the Extreme







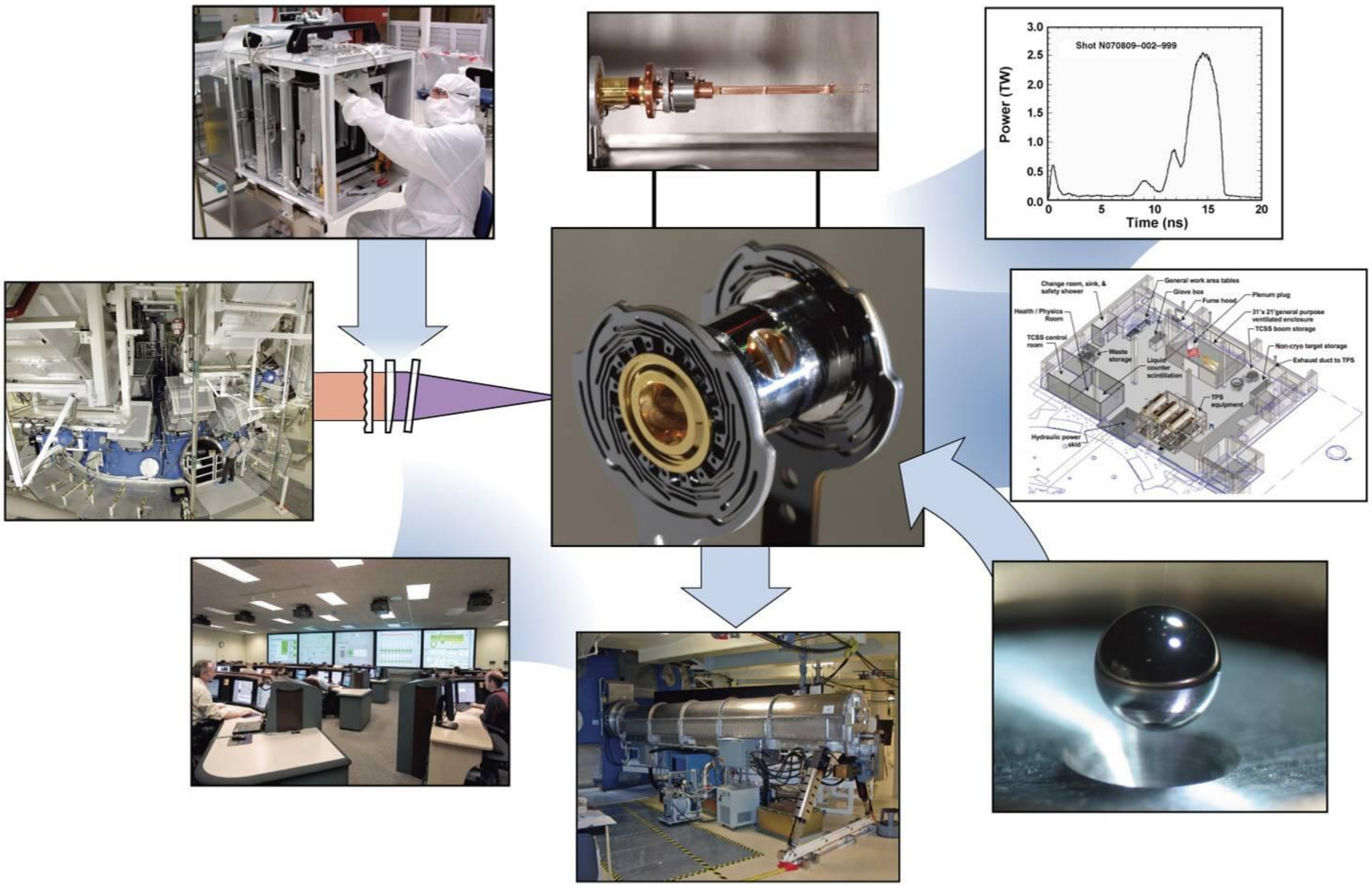
Mass Outflow



Shocks and radiation transport

MHD, thermo-electric, and "anomalous" heating

Ignition will be the start of a new scientific era for NNSA and the Nation



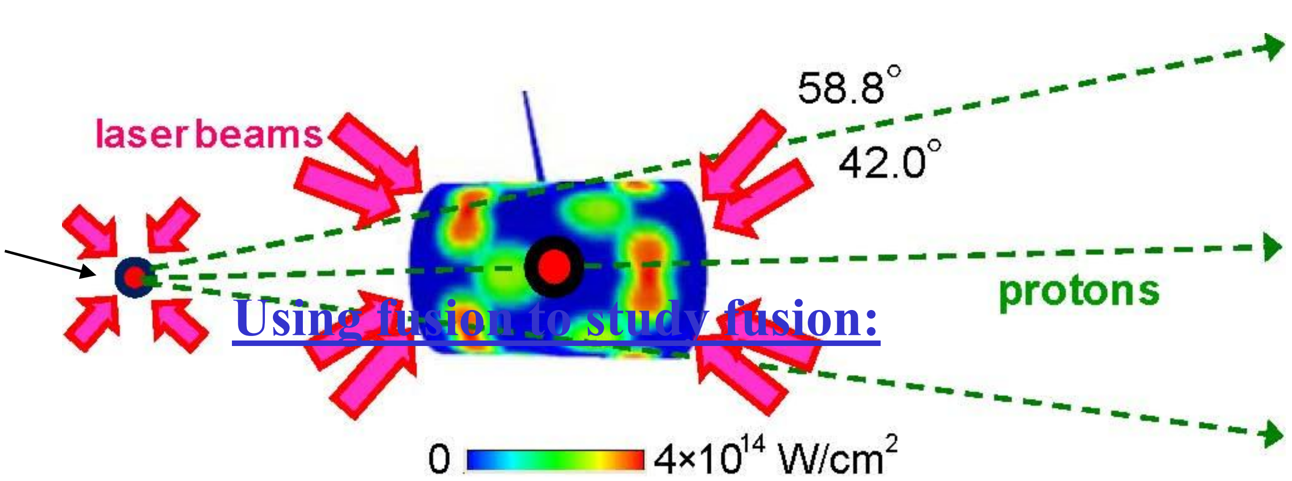
Ignition on NIF will be a defining moment for inertial confinement fusion energy

The achievement of igniting conditions will open new frontiers in plasma research

- Plasma temperatures > 20 keV ; compressed densities > 1000 gm / cm^2 ; pressures ~ 1 Tbar
- The high performance implosions needed for ignition can also be employed in a variety of non-ignition basic science investigations.
  - Planetary and astro- physics
  - Materials under extreme conditions
- Performing detailed measurements under igniting conditions will present a considerable diagnostic challenge.

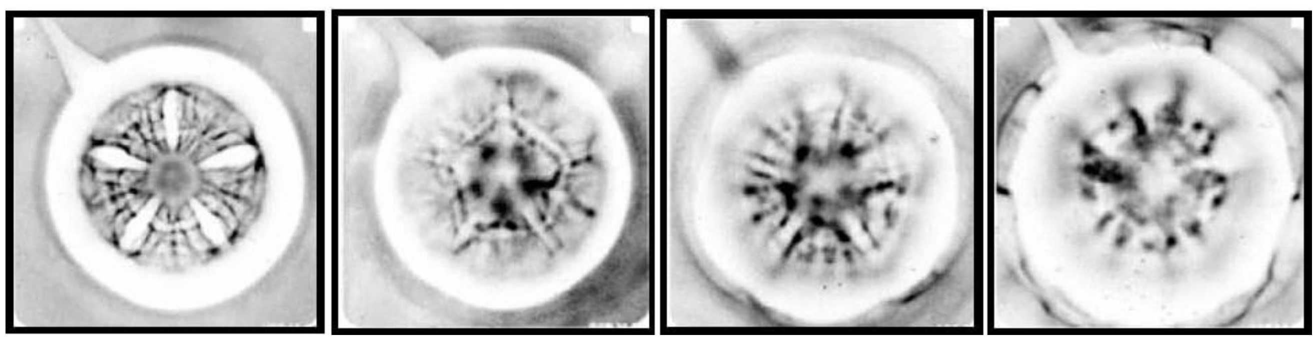
Using fusion products to study hohlraum physics

$D + {}^3He \rightarrow \alpha\ (3.6\ MeV) + p\ (14.7\ MeV)$



Using fusion to study fusion:

Proton radiographs

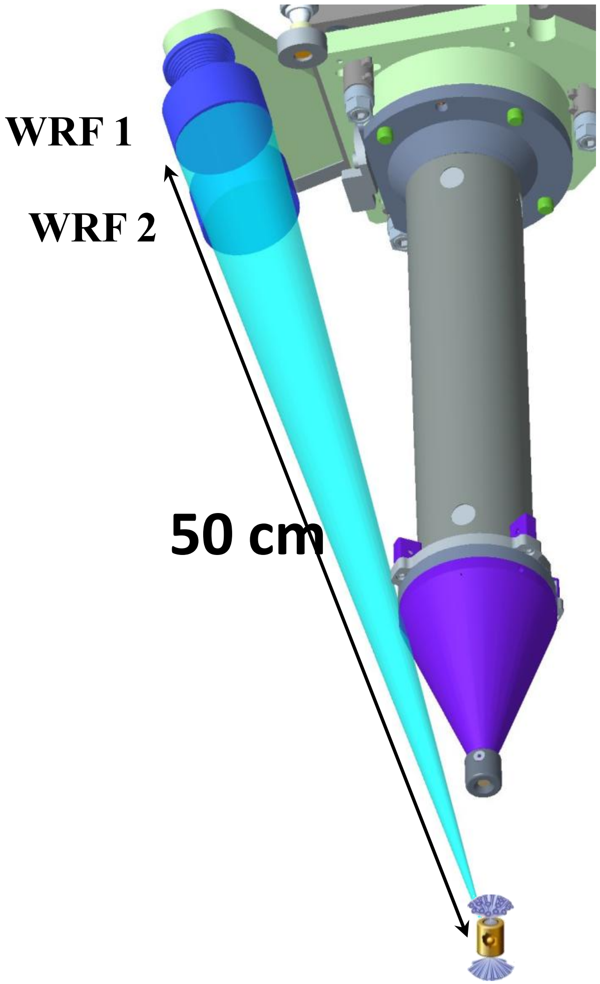


0.9 ns 1.6 ns 2.2 ns 2.8 ns

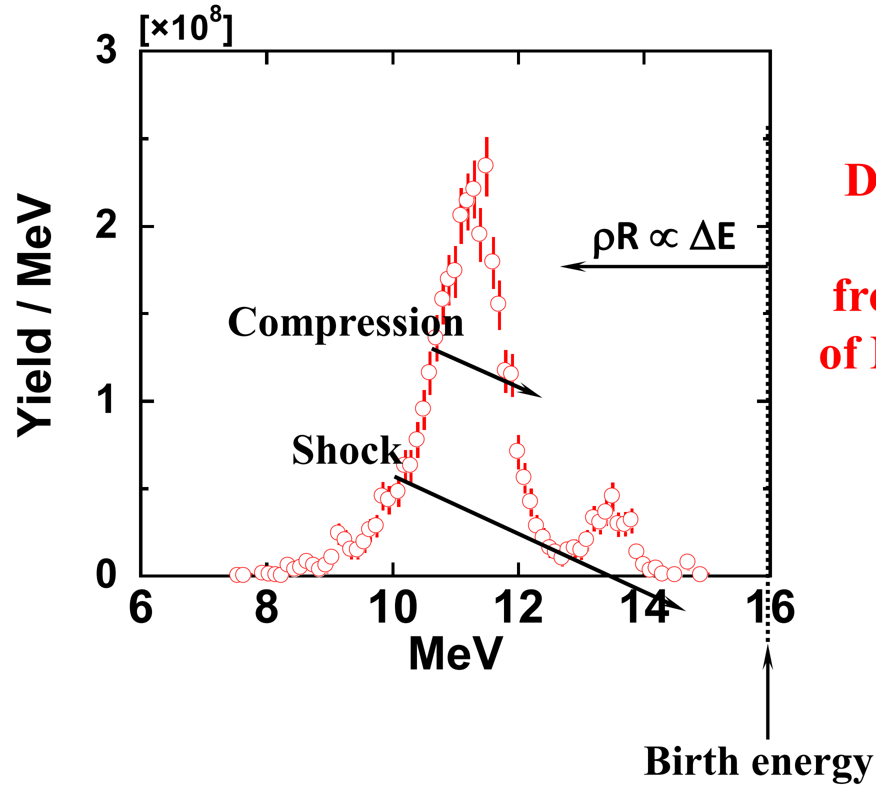
Using fusion to study fusion: Fusion protons have been used for backlighting and characterizing x-ray drive and capsule implosions in indirectly-driven ICF experiments

C.K Li *et al.*, *Science* 327 1231

Two proton spectrometers (WRFs) were fielded on the NIF



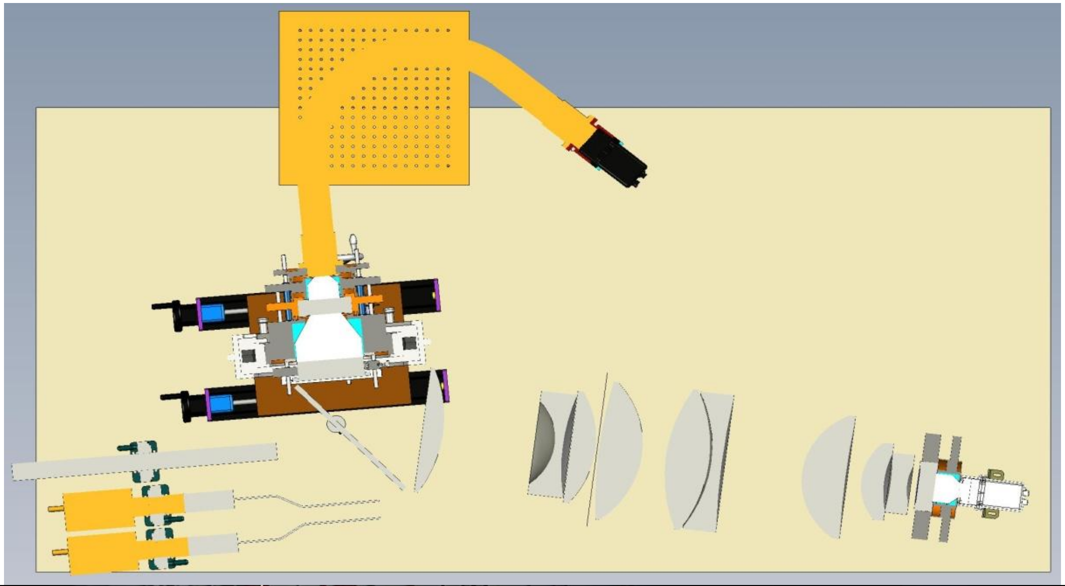
D + ^{3}He → ^{4}He + p (14.7 MeV)

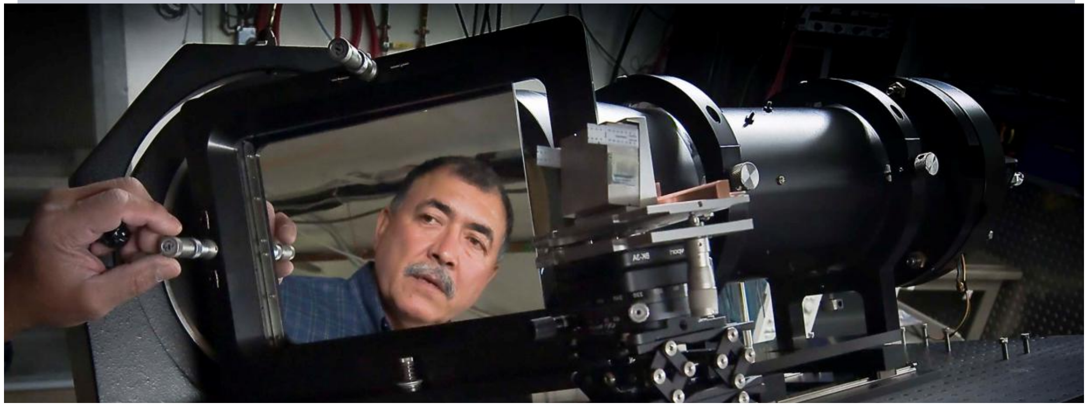


D^{3}He-proton spectrum from NIF Shot of Nov 23, 2009

measurements of the D^{3}He-proton spectrum for shock and compression areal density (ρR) determination

Los Alamos NIF Neutron imager is tested and calibrated on Omega

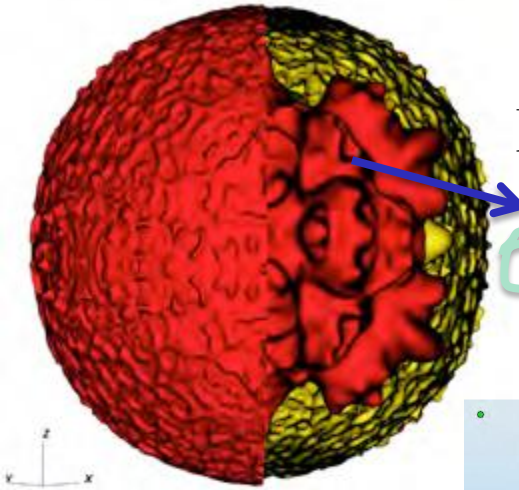




2 axis / 2 image system will allow simultaneous primary(14-MeV) and downscattered (10-12 MeV) imaging.

Future testing of NI will likely involve polar direct drive capsules thus advancing both basic science and diagnostic development

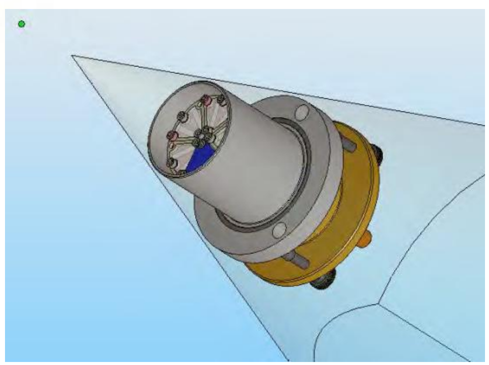
Nuclear diagnostics are being developed to enable precision measurements of capsule conditions



Mix region

t+ 9Be

Ignited DT fuel



Debris collector
& β counter.

A double reaction is used to diagnose mix:

$n + t \rightarrow t^*$

t + shell -> mix β

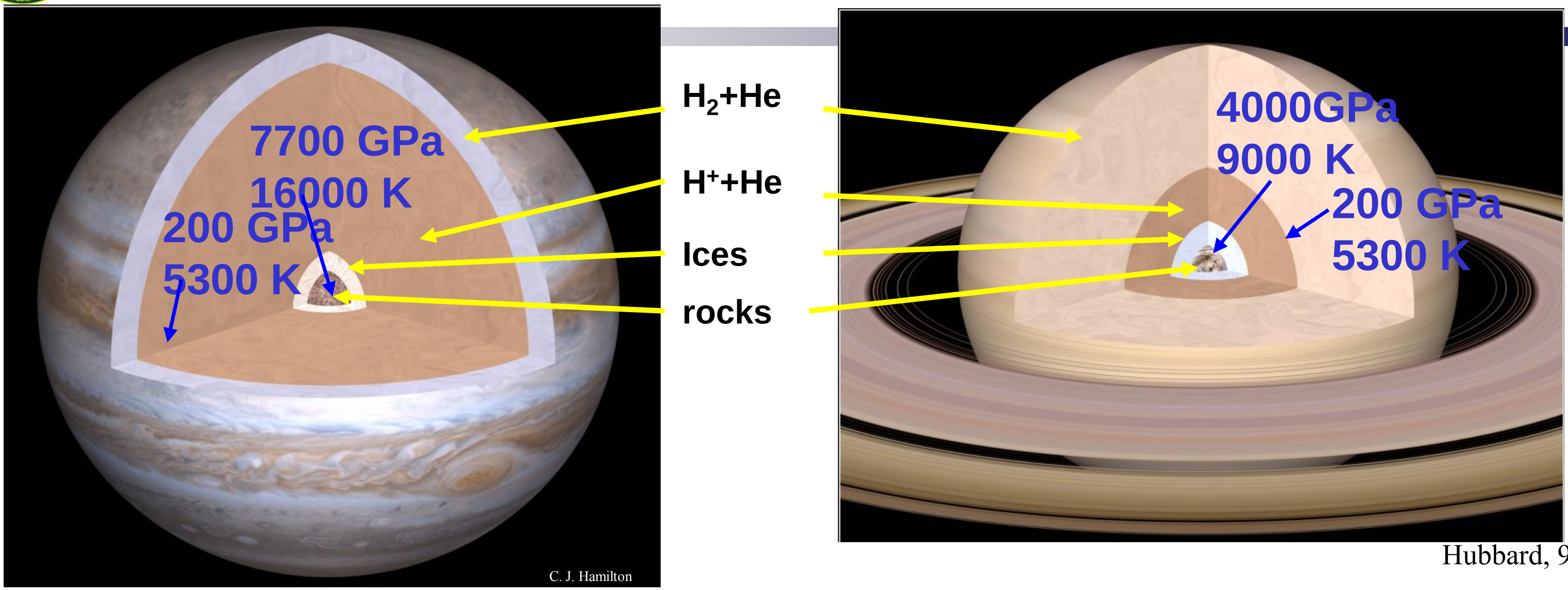
Triton + 9Be ablator (t,α) reactions distinguish different types of mix.

NIF full Yield - 8Li production

No Mix	Chunk Mix	Atomic Mix
1E12	3E12	1E14

t+ 9Be -> α + 8Li + β (13 MeV, 840 ms)

Emerging capabilities will allow us to solve fundamental questions in planetary and condensed matter physics



Hubbard, 98

- **FOR EXAMPLE:**
- **Jupiter: luminosity data + EOS models + evolutionary=>calculated age = 4.7 GYr Age of our solar system = 4.6 Gyr**
- **Saturn: Using the same models + luminosity data from Saturn, it "looks" to be only 2.1 GYr old!**
- **The difference may be due to inhomogeneous mixing of He/H!**

NIF allows access most of these states for the first time

Properties of dense He are key for understanding white dwarfs (which determine gallaxy age) and Giant planets

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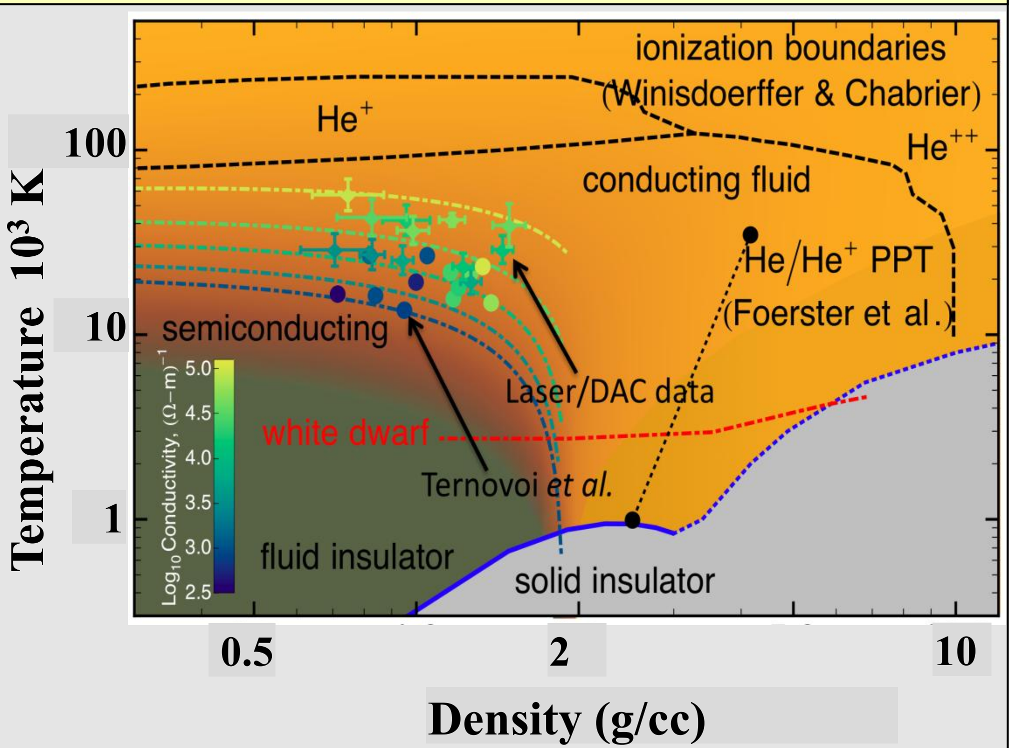
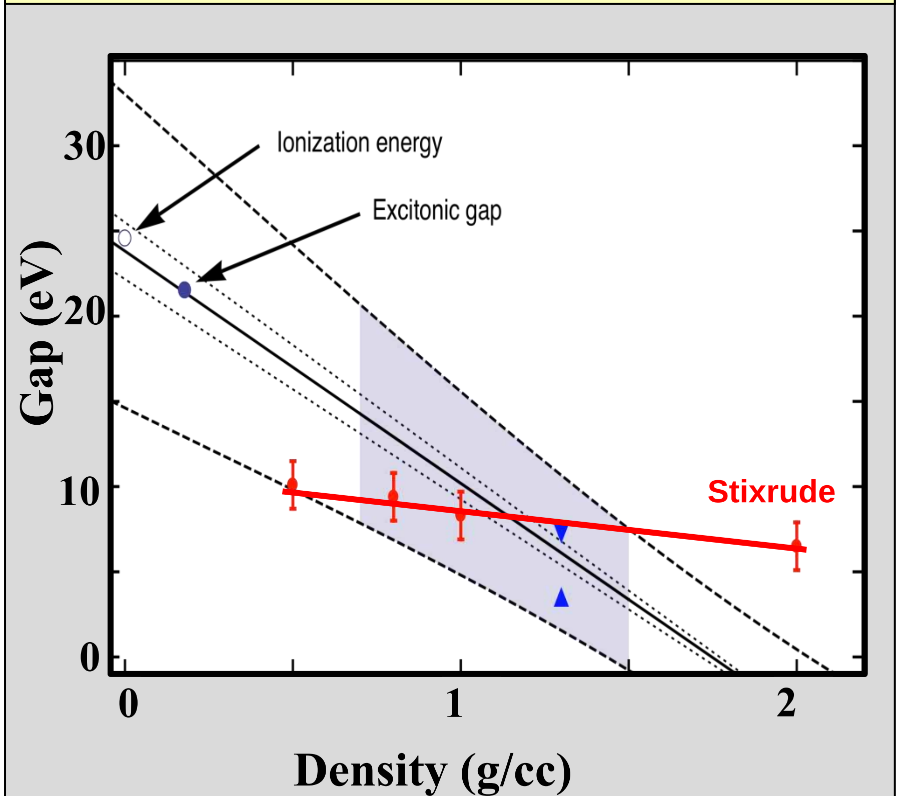
He becomes conducting near Mbar and 10,000 K consistent with models used to understand white



He bandgap closes near 1.8 g/cc



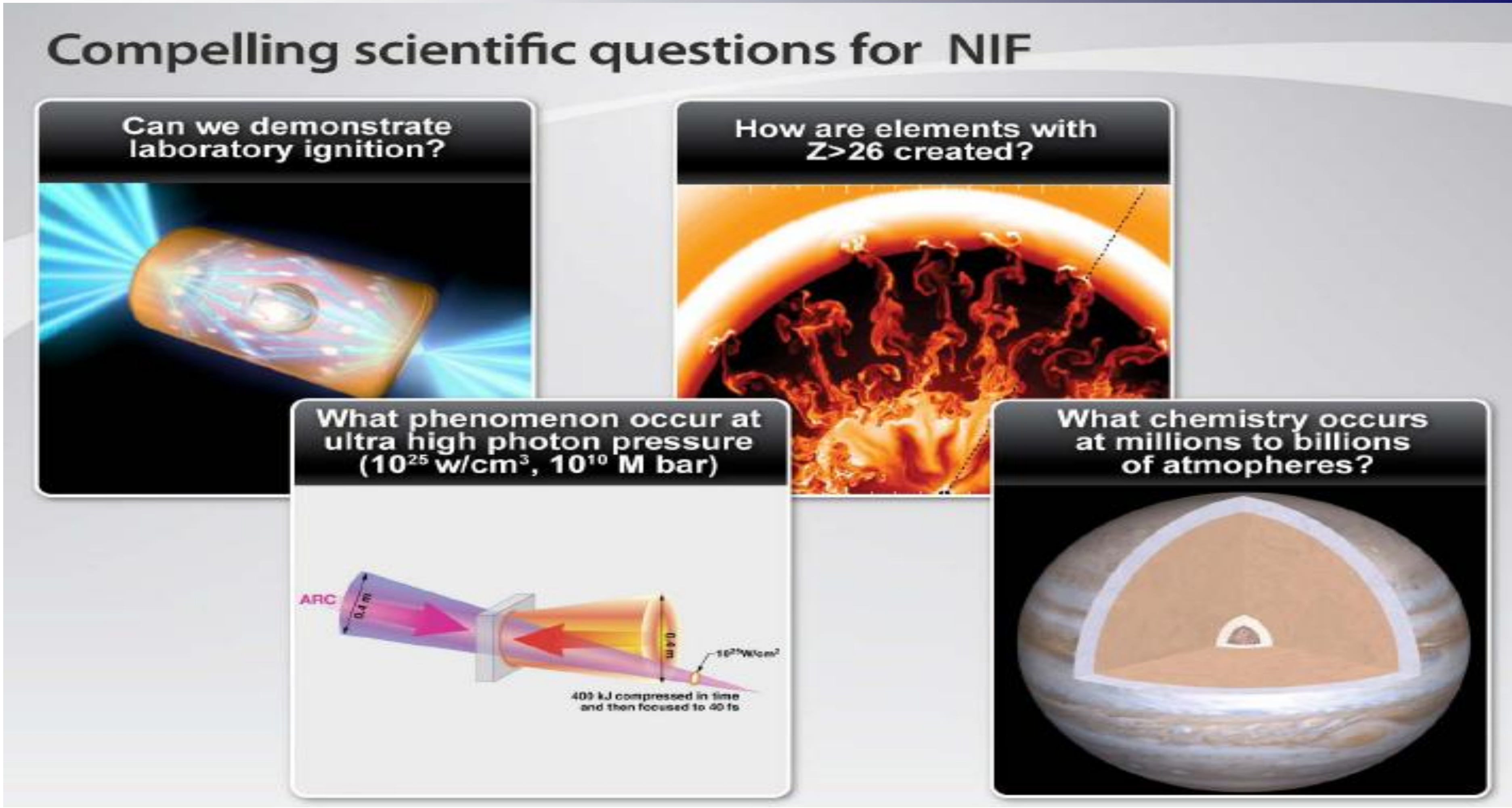
Recent data and theory suggest
He/H2 likely miscible at 1 Mbar/30kK

Results comparable to Ternovoi

- Gap appears to have strong density dependence and not dependent on T
- LDA predicts closure at ~14g/cc
- DFT also predicts closure at much higher ρ

Celliers PRL, 2010

Compelling scientific questions for NIF

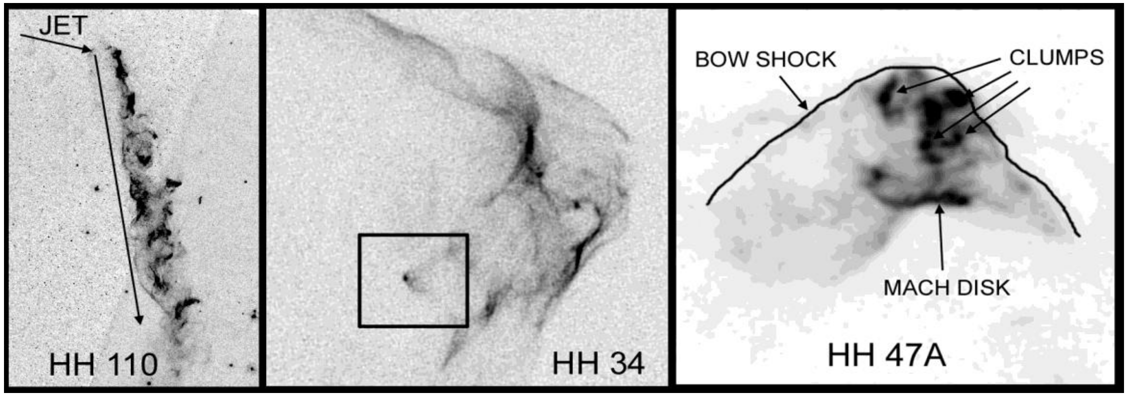


Omega will play a key role in preparing for all of this work

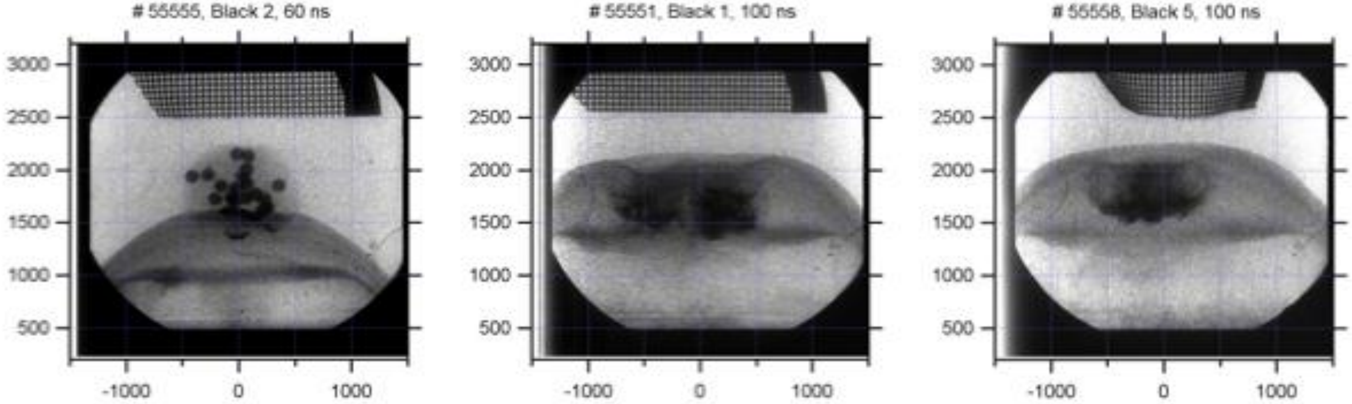
Data from an NLUF experiment on OMEGA was used to obtain observational time on the Hubble Space Telescope (HST)

- P. Hartigan (Rice) and collaborators study the interaction of astrophysical jets with clumps in the interstellar medium with the HST and the same physics on OMEGA

Examples of shocked clumps from jets in young stars (HST images)

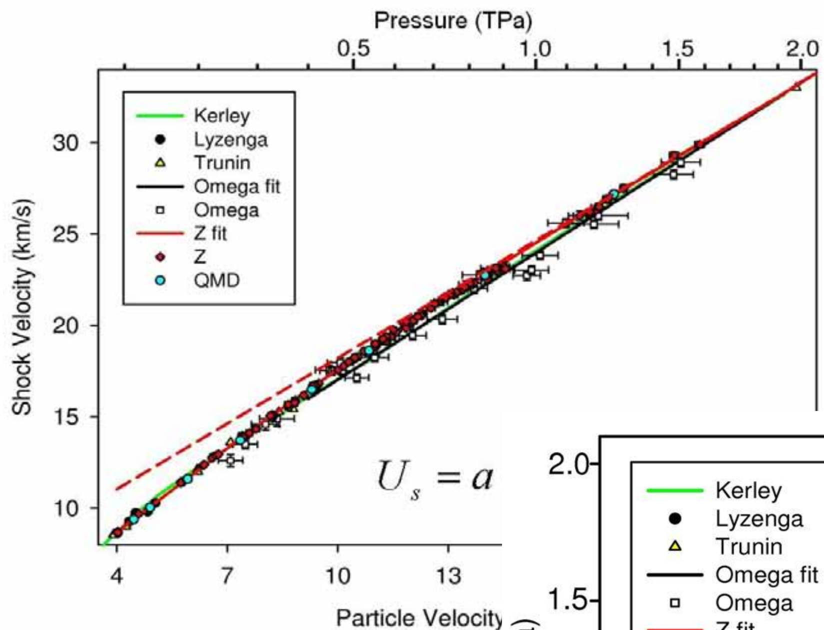


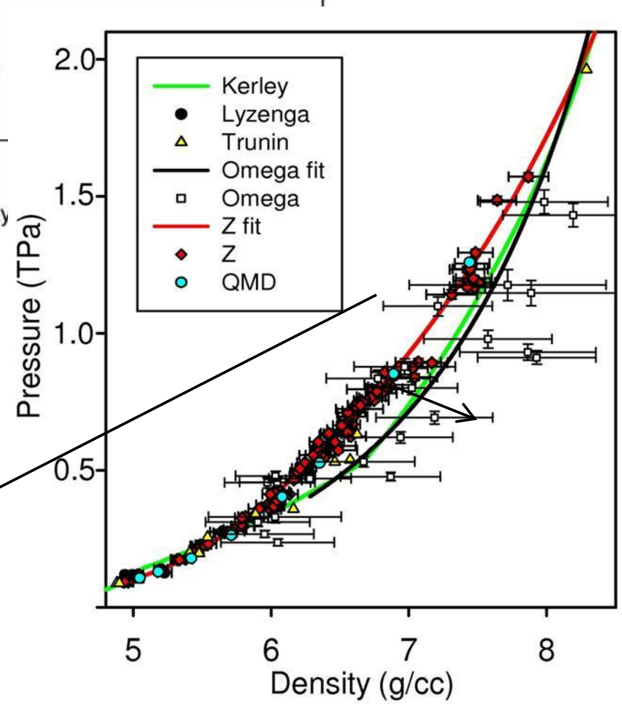
OMEGA data showing a shock overrunning a region of clumps

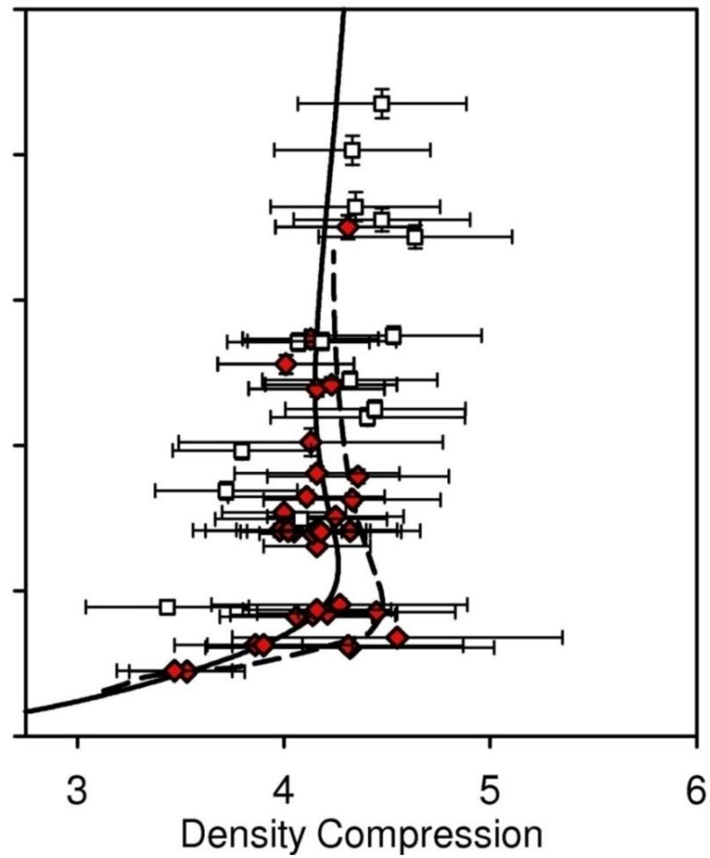


Builds on Hartigan et al., Astrophysical Journal, 705, (2009) 1073-1094

The effect of a more accurate α-Quartz on Omega deuterium hugoniot is profound





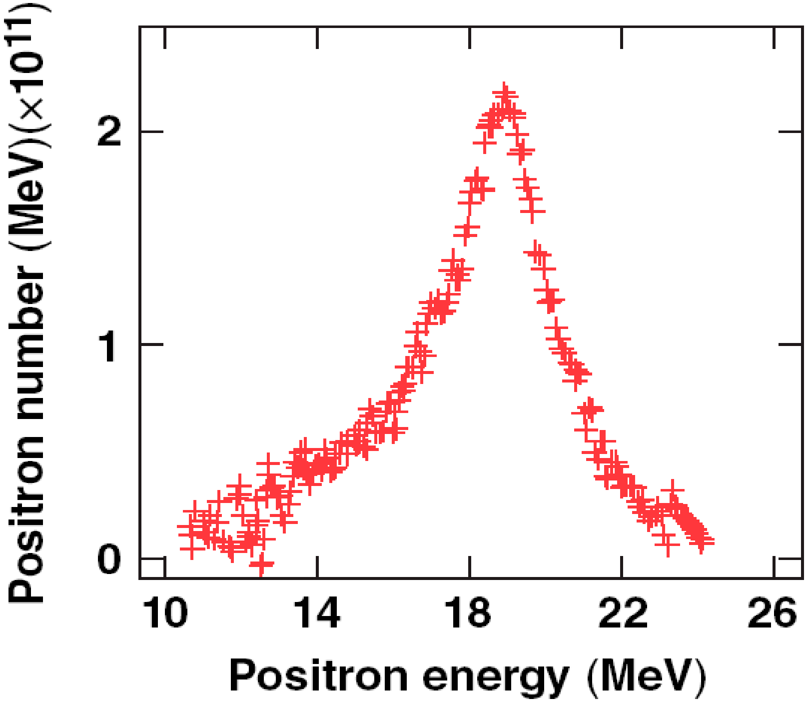


Data with larger error bars measured only transit time. More recent data measured transit time and shock velocity directly

An OMEGA EP experiment resulted in the highest positron production rate achieved in the laboratory

- A jet of relativistic positrons is emitted from the rear surface of the mm-thick Au target – beam temperature ~1 MeV
- LLNL-LLE collaboration, H. Chen, PI

- **1 kJ, 10 ps OMEGA EP laser pulse**
- **~ 10^{12} positrons produced**
- **~ 0.3% conversion efficiency from laser to positrons**
- **No magnetic field in the initial experiments**



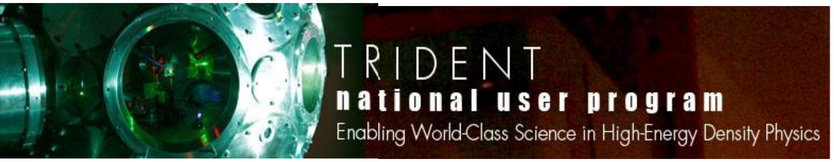
*H. Chen *et al.*, Phys. Rev. Lett. 102, 105001 (2009).

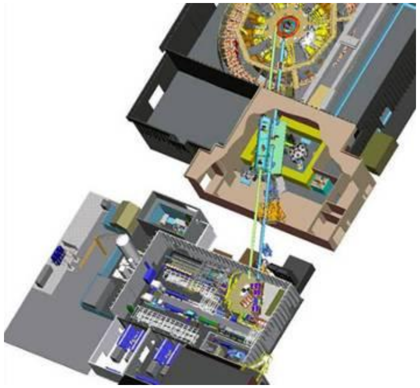
The challenge is to confine them into an electron-positron plasma

NNSA relies on intermediate scale plasma science facilities for basic science support

Examples of intermediate size plasma facilities:

- **Jupiter at LLNL (lasers): support of NIC and NIF; mission; users**
- **Trident at LANL (laser): support of NIF and NIC; mission; users**
- **Texas Petawatt at UTX (laser): discovery-driven research; users**
- **Z-Beamlet / Z Petawatt at SNL (laser): diagnostic for ZR; users**
- **Nevada Terawatt at UNR: pulsed power**





Intermediate-size plasma facilities provide both direct and indirect mission support, and we are encouraging user access at our intermediate facilities

2nd OMEGA Users Workshop, 28-30 April 2010

Security Administration

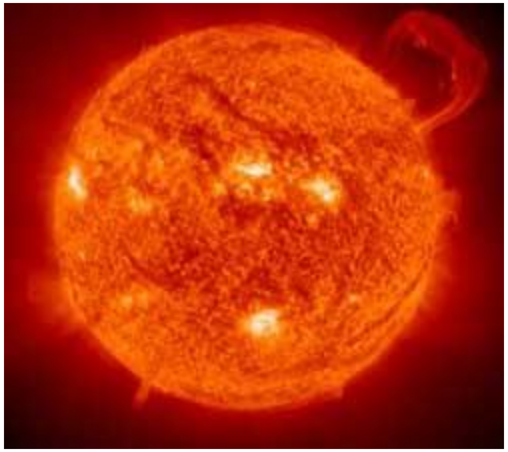
115 researchers from around the world (5 countries, 19 universities, 20 laboratories) focused on ways to improve research and facility capabilities at OMEGA for frontier high-energy-density laboratory physics.

76 outstanding talks and posters were presented, including 45 by students and young researchers.

Plans for the 3rd OMEGA Users Workshop (27-29 April 2011) are underway. Financial assistance for student/young researchers is already allocated by NNSA.

Inertial Fusion Energy 2010

- Fusion Energy – no carbon dioxide, modest nuclear waste,
- 50 years of exploration – ignition imminent at NIF
- NAS to provide recommendations on IFE priorities
- Timeline and demonstration potentially similar to ITER

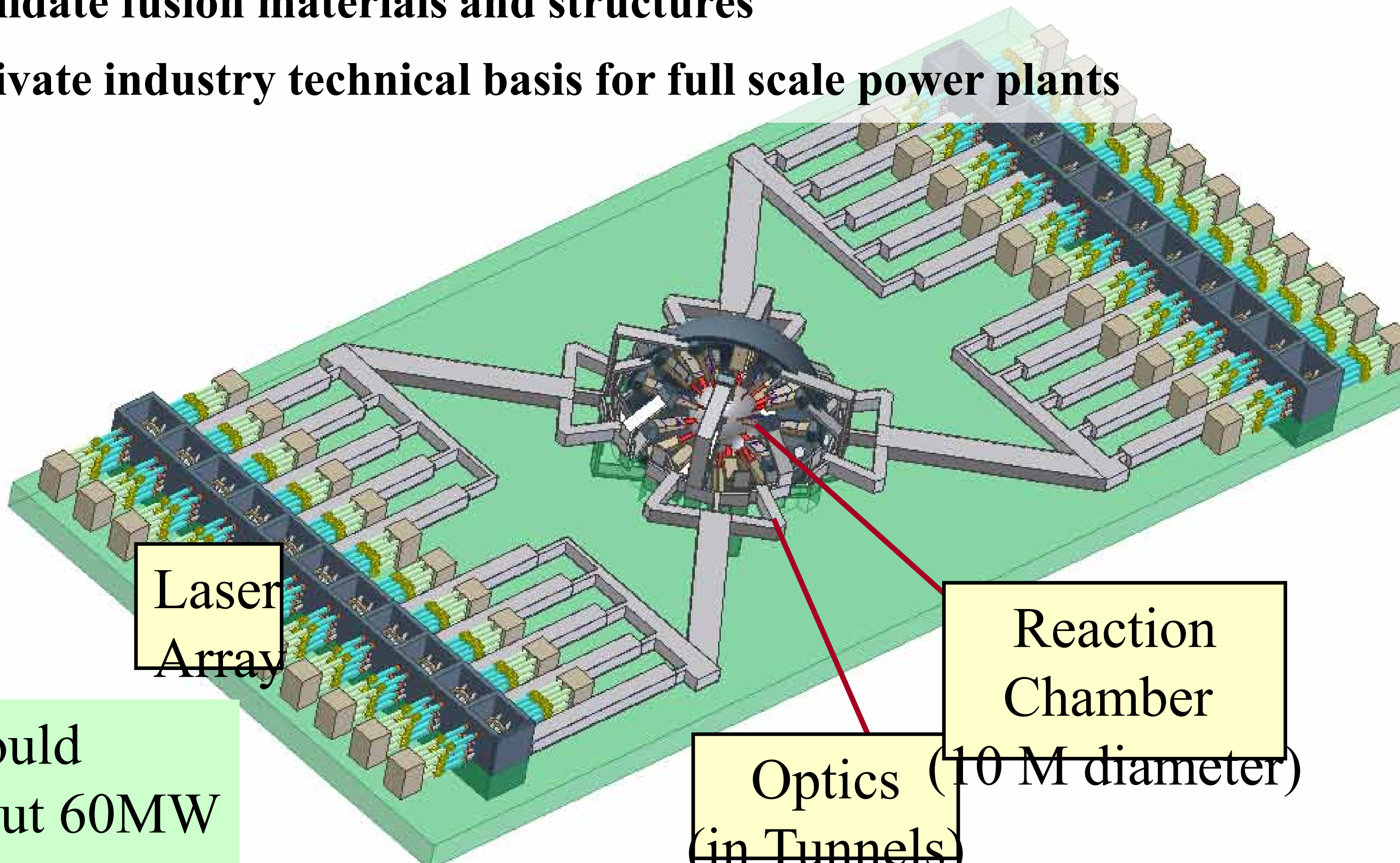


Inertial Fusion Energy 2010
Principles applied by Working Group

- Focus on IFE specific program that relies on ICF and FES but does not replace them
- Look at fastest route to demonstrate most critical elements
  - Rapid repeated ignition (once per second for hours)
  - Using technology applicable for steady and affordable energy source
- Flexible management and budget with risks
- Driver technology and specific ignition approach identified as critical components
  - 5 years to down select,
  - Use existing facilities including NIF

A Fusion Test Facility (FTF)

- Demonstrate reliable continuous power from laser inertial fusion *
- Develop/ validate fusion materials and structures
- Provides private industry technical basis for full scale power plants



*The FTF could generate about 60MW of electric power

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.
- A broader constituency for our facilities is attractive to substantial segments of **congress**.

Careers in HED

- The Nuclear Posture Review (NPR) and the Administration's strongly stated position place considerable emphasis on nuclear based national security
  - CTBT ?
- A strong academic community has grown from HED-based research
  - it is still modest compared to more mature fields
- Strong directions in IFE-based energy research will emerge in 1-2 years.

Conclusions

- High Energy Density Science evolved from the National Security mission continues to be vital and exciting discipline

- Career opportunities in National Nuclear Security are good

- HED based Academic opportunities are good and may grow considerably in the next few years.