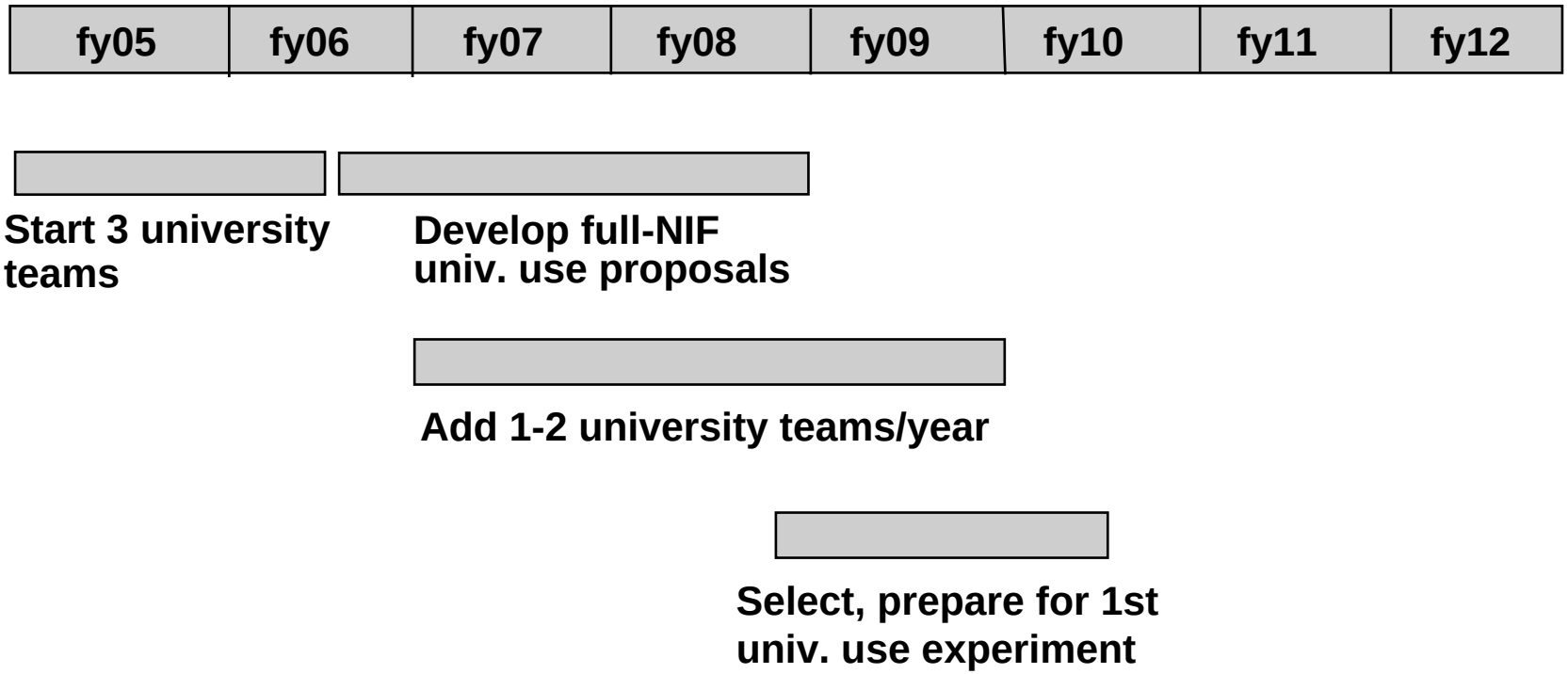
Science outreach on NIF: possibilities for astrophysics experiments

Presentation to the SABER workshop,
Stanford Linear Accelerator Center,
March 15-16, 2006

Bruce A. Remington
Group Leader, HED Program
Lawrence Livermore National Laboratory

We are implementing a plan for university use of NIF

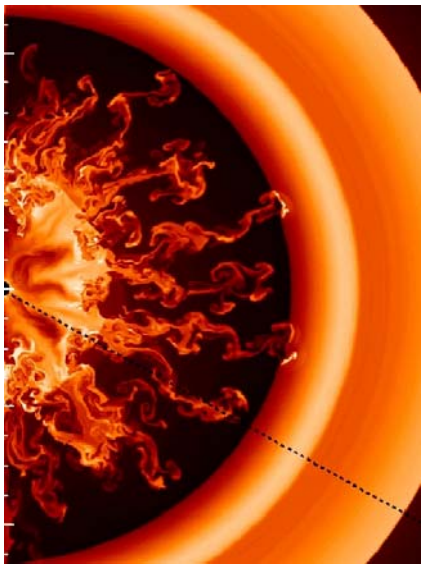


Issues:

- funding for the universities
- targets
- coordination with the other facilities
  - Omega/NLUF, Z/ZR, Jupiter, Trident, …
- proposal review committee
  - assess science impact, facility capability, readiness

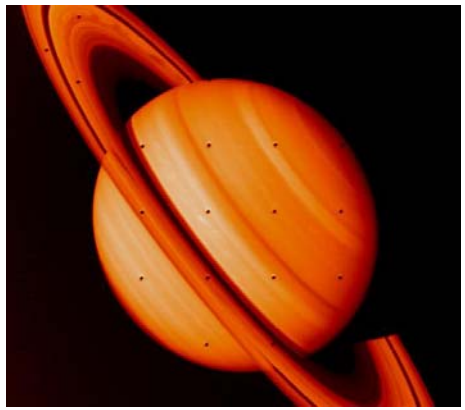
Three university teams are starting to prepare for NIF shots in unique regimes of HED physics

Astrophysics - hydrodynamics



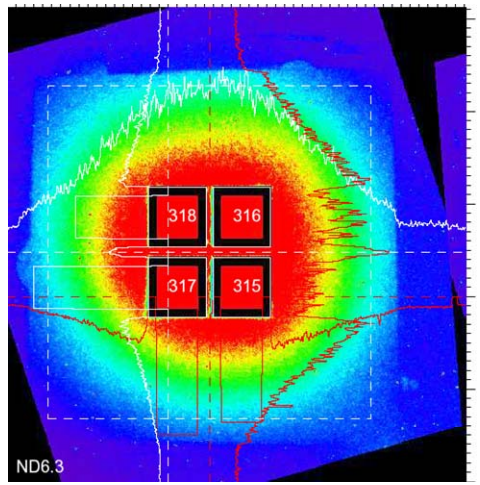
Paul Drake, PI, U. of Mich.
David Arnett, U. of Arizona,
Adam Frank, U. of Rochester,
Tomek Plewa, U. of Chicago,
Todd Ditmire, U. Texas-Austin
LLNL hydrodynamics team

Planetary physics - EOS



Raymond Jeanloz, PI, UC Berkeley
Thomas Duffy, Princeton U.
Russell Hemley, Carnegie Inst.
Yogendra Gupta, Wash. State U.
Paul Loubeyre, U. Pierre & Marie Curie, and CEA
LLNL EOS team

Nonlinear optical physics - LPI

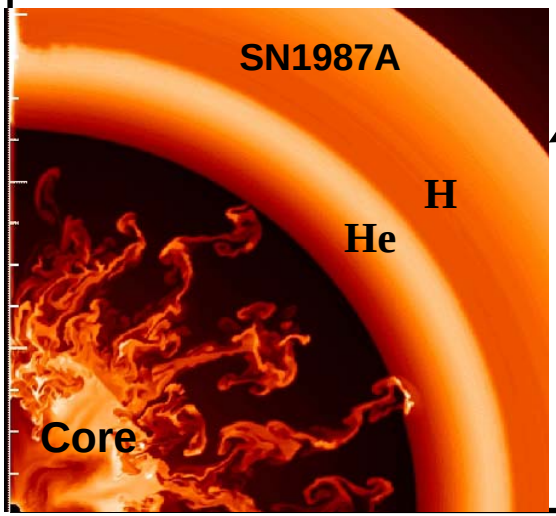


Chan Joshi, PI, UCLA
Warren Mori, UCLA
Christoph Niemann, UCLA NIF Prof.
Bedros Afeyan, Polymath
David Montgomery, LANL
Andrew Schmitt, NRL
LLNL LPI team

Supernova experiments on NIF will address the core penetration discrepancy in SN1987A

- Simulations do not reproduce observed core penetration velocities

Spherical shock model

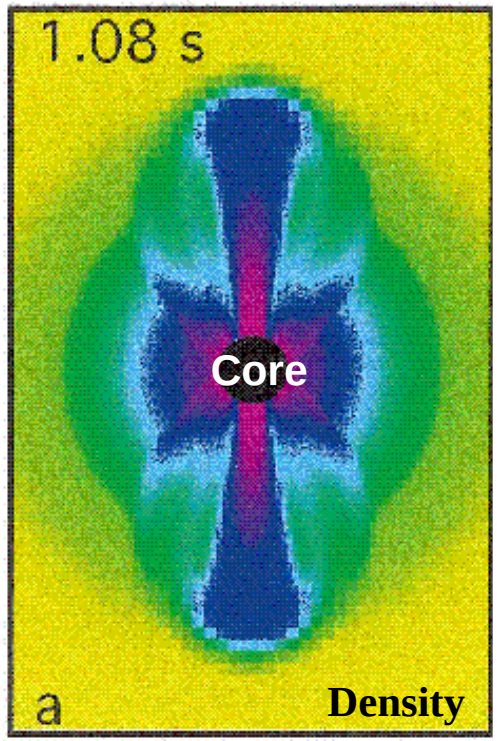


Shock front

Kifonidis, Ap. J. Lett 531, L123 (2000)

5×10^{11}cm

Jet model



Khokhlov, Ap. J. 524, L107 (1999)

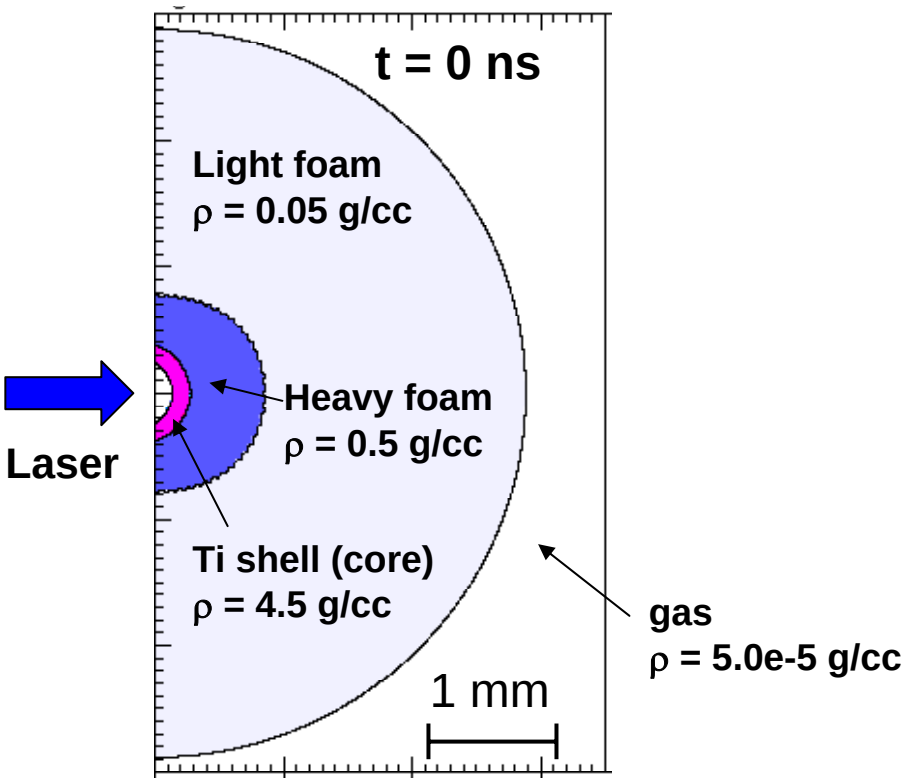
9×10^{9}cm

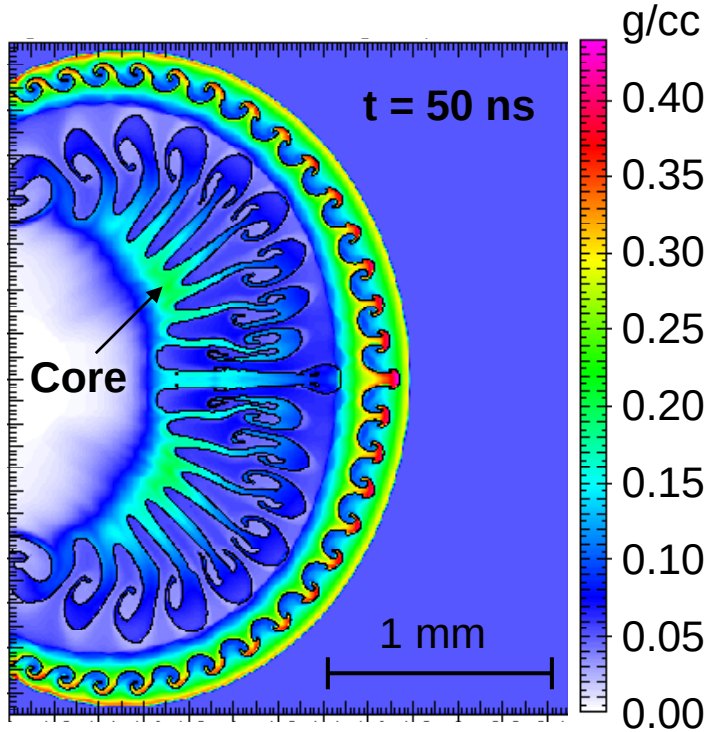
6×10^{9}cm

- Does He shell breakup allow core spikes to escape?
- Are differences in 3D vs 2D spike velocities important?
- How do 3D perturbations on multiple interfaces interact?
- How does the initial perturbation spectrum affect the late-time evolution?

[Courtesy of R. Paul Drake et al.]

The SN team is designing a divergent RT experiment for NIF to address these SN issues





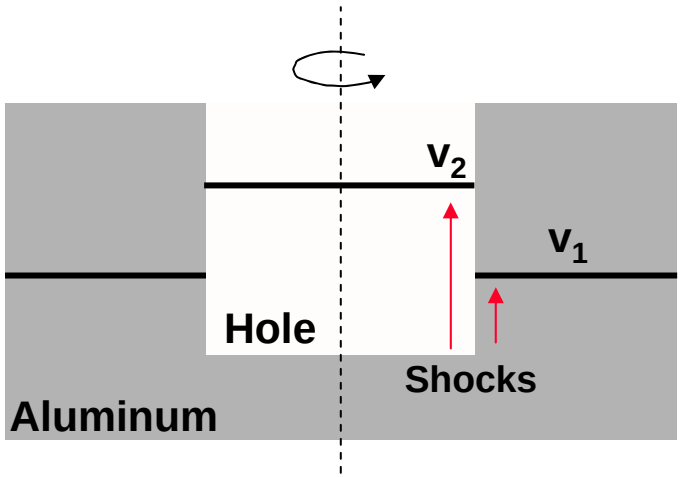
[Simulations by Aaron Miles (2004)]

- **Mass-scaled to SN with representative Core/He, He/H, and H/ISM interfaces**
- **Designed to address issues of: multi-interface interaction, divergence, initial conditions, 3D vs 2D, turbulent vs non-turbulent instability evolution, code validation**
- **Can be scaled up in size, energy, and complexity, as NIF evolves**

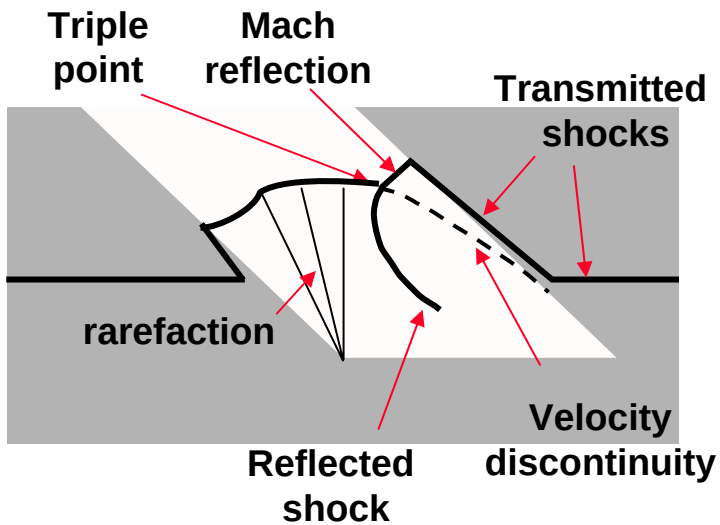
[Courtesy of R. Paul Drake et al.]

NIF has already demonstrated nonlinear, shock driven, 3D hydrodynamics experiments

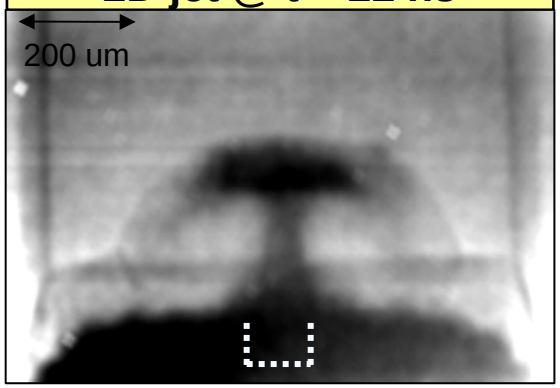
2D perturbation



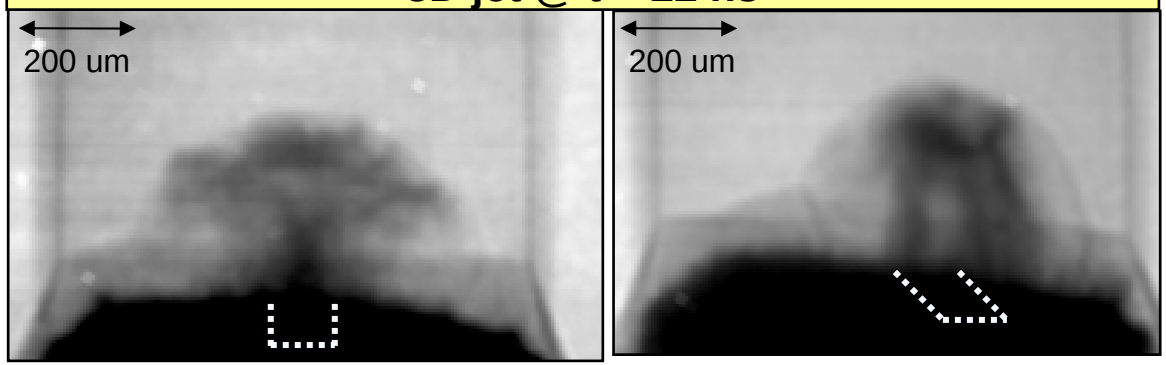
3D perturbation



2D jet @ t = 22 ns

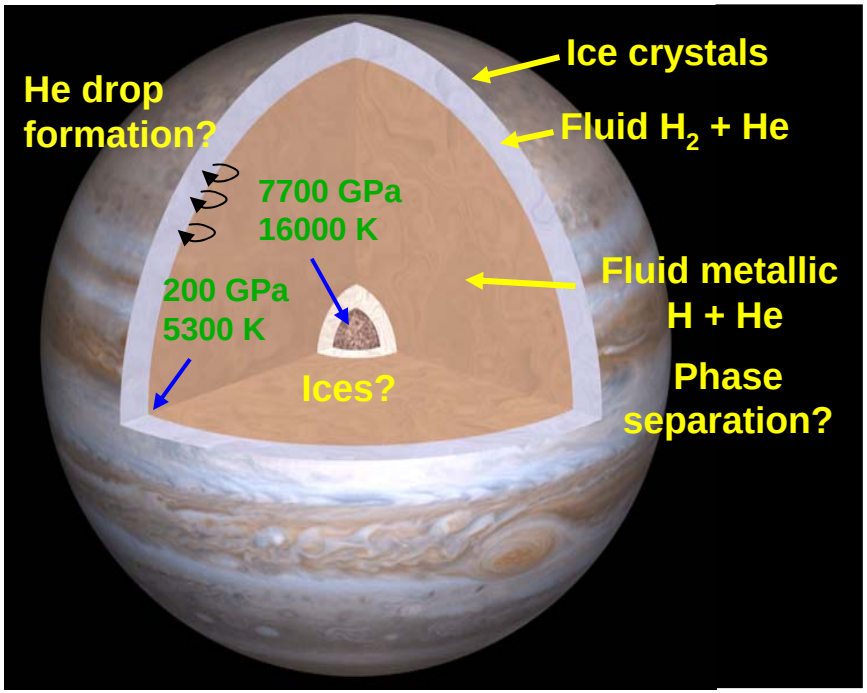


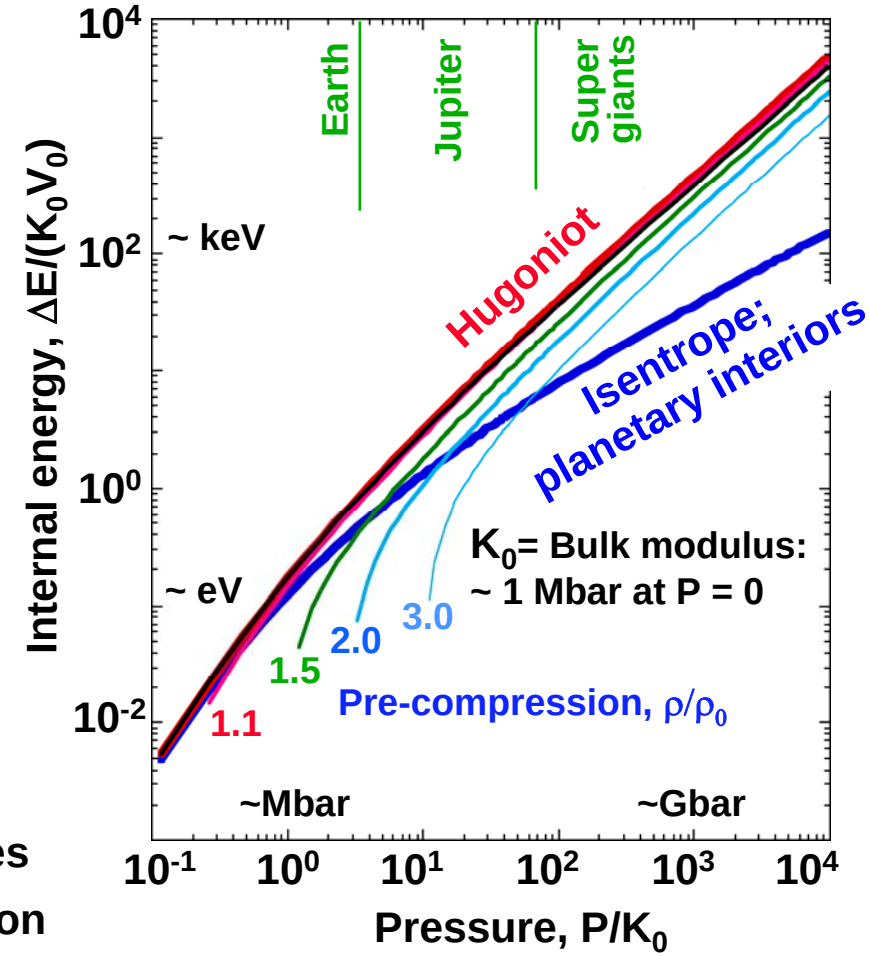
3D jet @ t = 22 ns



[Brent Blue et al., PRL 94, 095005 (2005); PoP 12, 056313(2005)]

High pressure experiments on NIF will address key questions regarding the internal structure of Jupiter



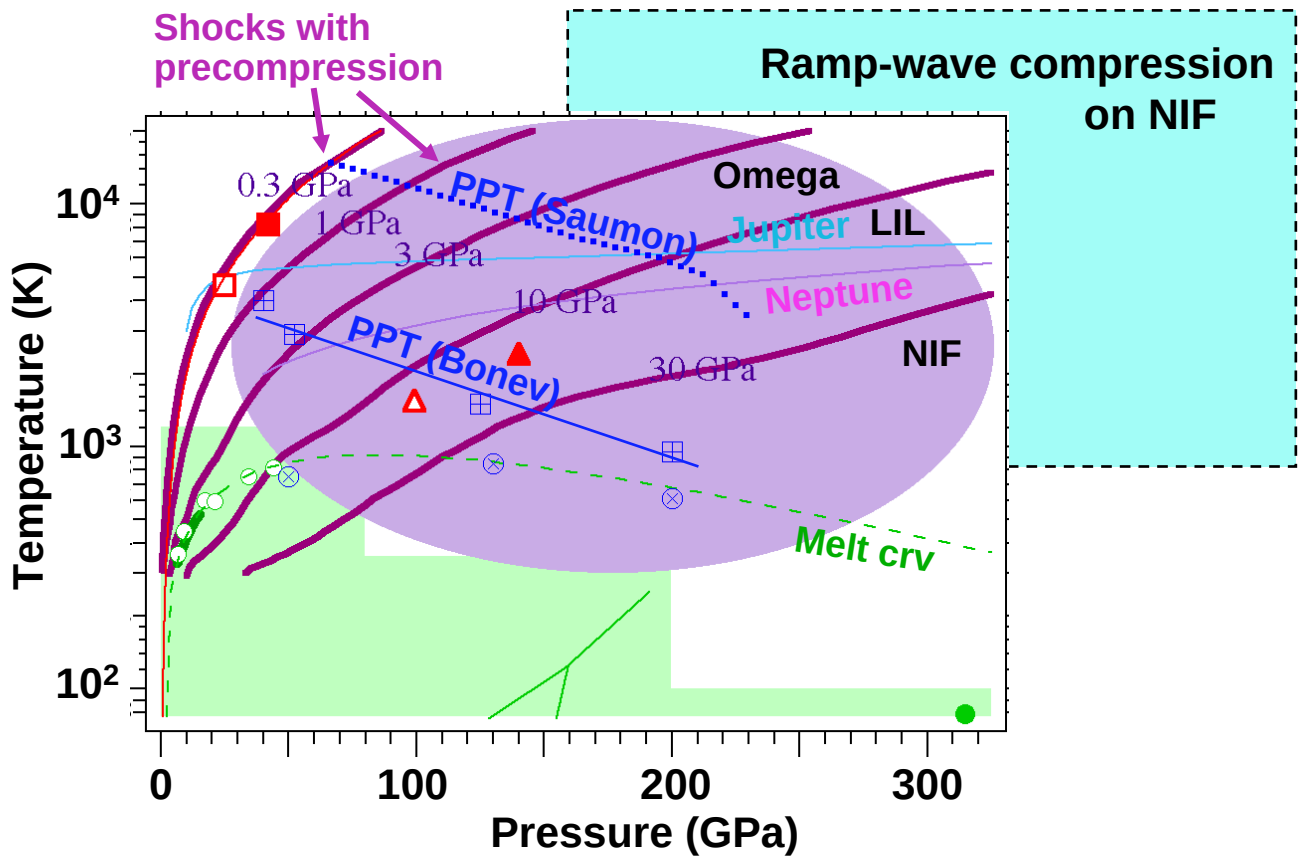


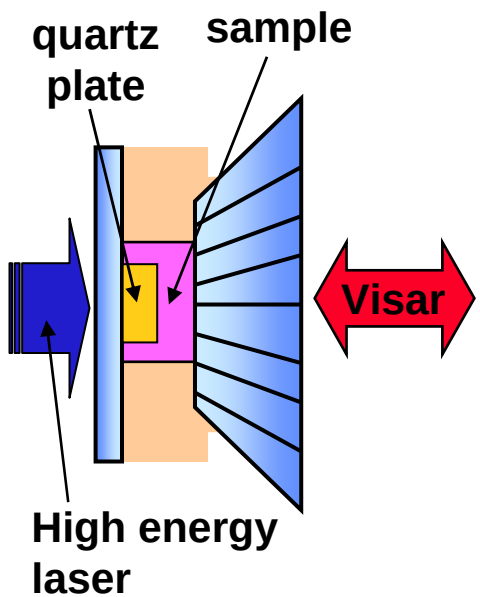
Key Questions:

- Equation of state near the planetary isentropes
- Location of the insulating-conducting transition
- Melt line at high pressure
- Existence of a plasma phase transition (PPT)
- Does He and H_2 phase separate in Jupiter/Saturn

[Courtesy of Raymond Jeanloz et al.]

Coupling NIF with DAC targets will enable key measurements of planetary interior states

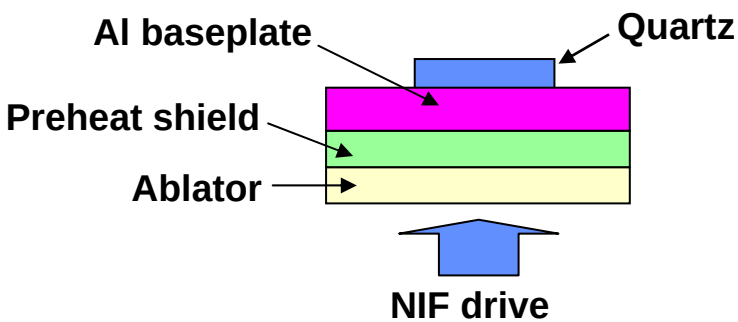


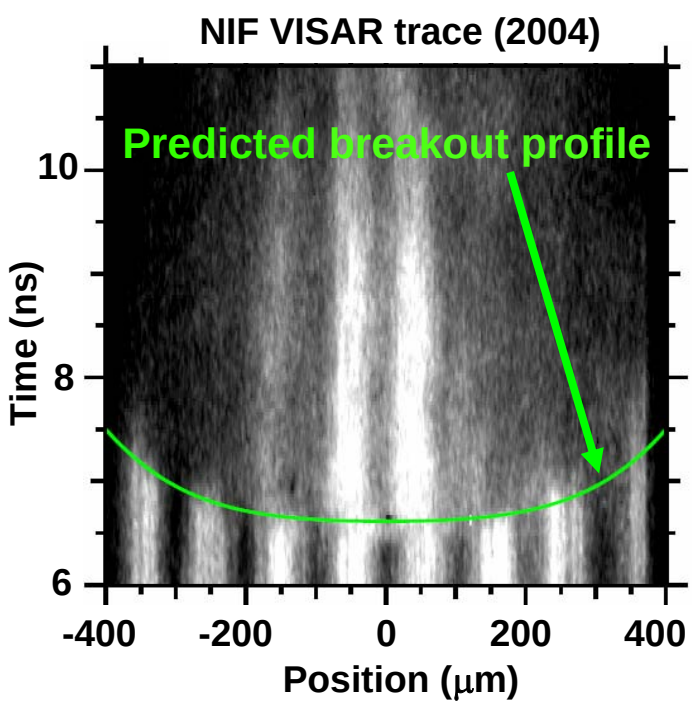


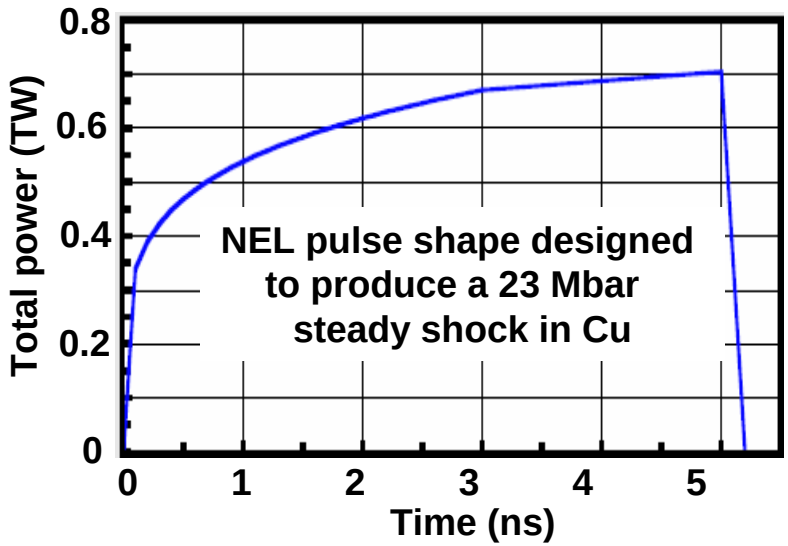
- Pre-compression is the only way to study dense He+H_2 mixtures
- The PPT accessed with pre-compressions > 1 GPa
- Melt curve maximum accessed with pre-compressions ~ 30 GPa
- Ramp wave compression may allow planetary core conditions to be accessed

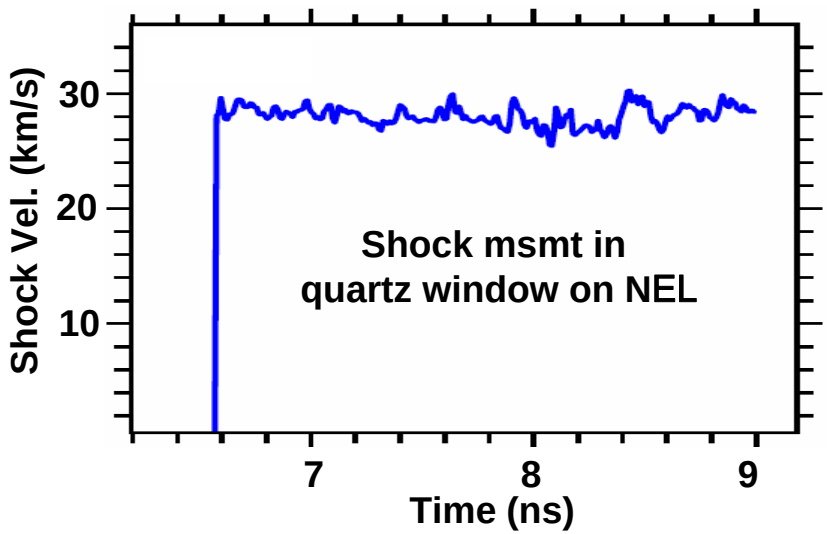
[Courtesy of Raymond Jeanloz et al.]

The NIF VISAR diagnostic and pulse shape have been demonstrated for possible shock EOS experiments





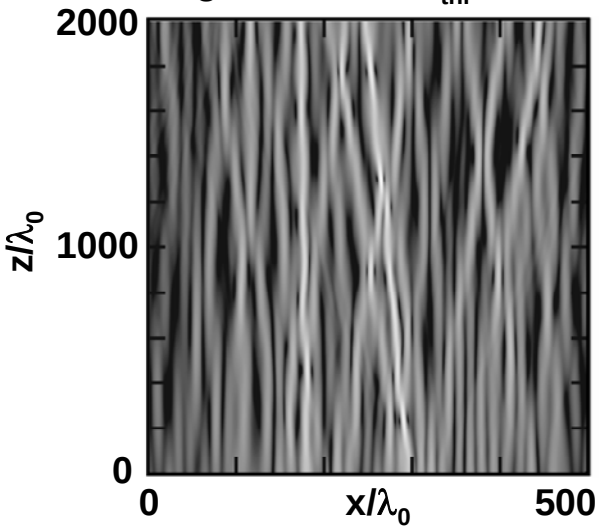




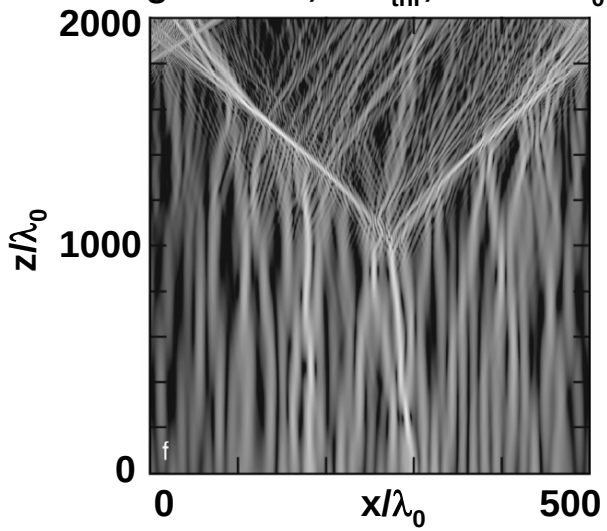
[Courtesy of Raymond Jeanloz et al.]

Nonlinear interactions of intense laser beams in large scale plasmas is a scientific challenge of considerable importance

Single beam, $I > I_{thr}$, $t = 0$

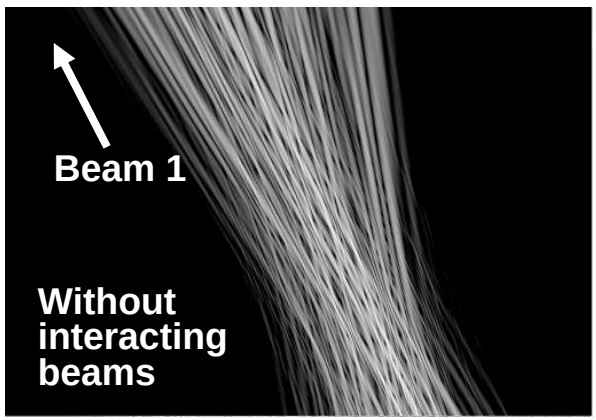


Single beam, $I > I_{thr}$, $t = 312\ \lambda_0/c_s$

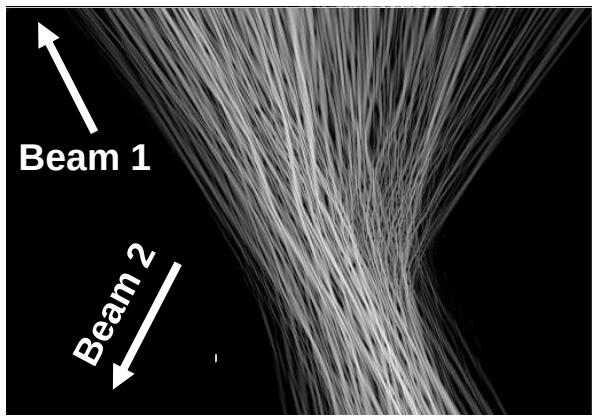


[Schmitt & Afeyan, PoP 5, 503 (1998)]

$I < I_{thr}$, single-beam simulation, no filamentation



$I < I_{thr}$, sub-thresh. crossing beams can filament, due to interactions with IAW fluctutions

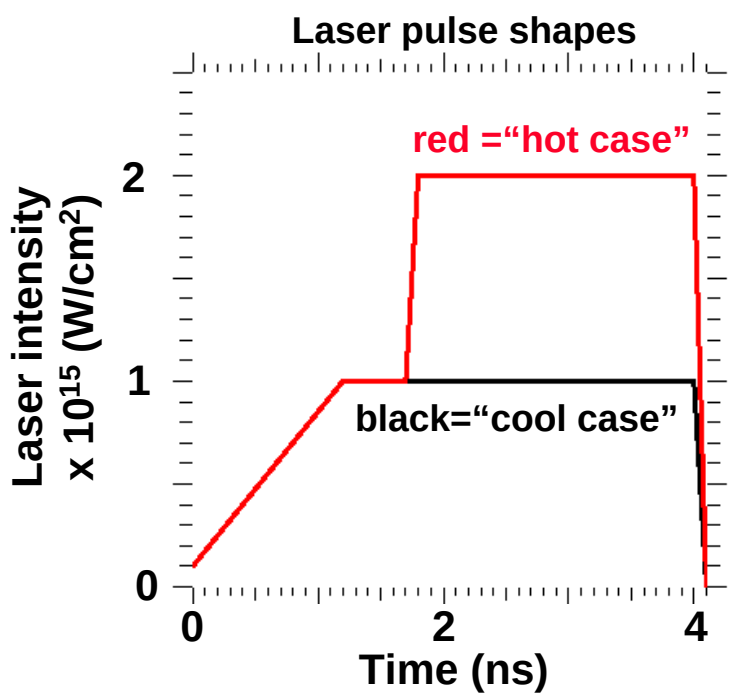


[Courtesy of Andy Schmitt & Bedros Afeyan

- **Filamentation strongly affects the initiation and evolution of SRS and SBS backscatter, as well as beam pointing**

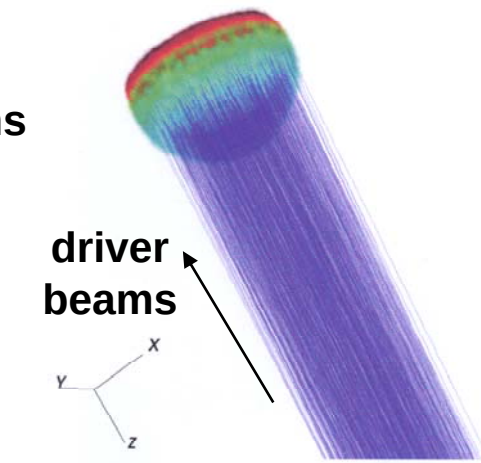
NIF will allow experiments probing the interaction of multiple beams in large scale plasmas over a wide range of (n_e,T_e)

- HYDRA simul's show that high plasma temperatures (T_e = 3-6 keV) and densities (n_e =0.1 critical) can be achieved
- Crossing beams will allow non-resonant effects on SRS backscatter to be studied with good speckle statistics
- NIF's versatile pulse-shaping will greatly expand the design space for exploding foil targets



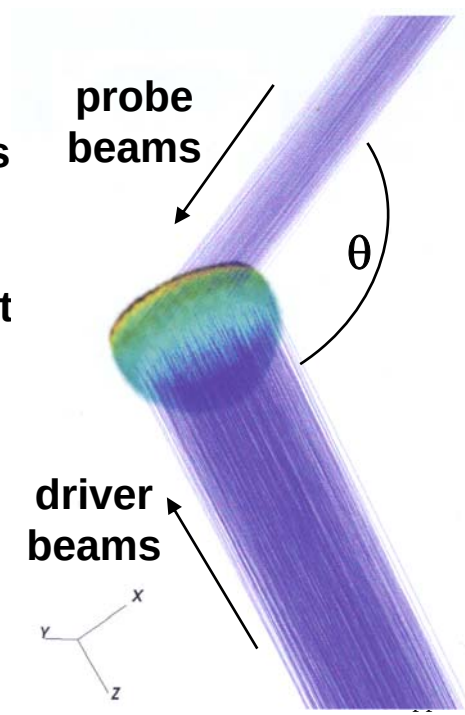
Early time:

driver beams explode foil



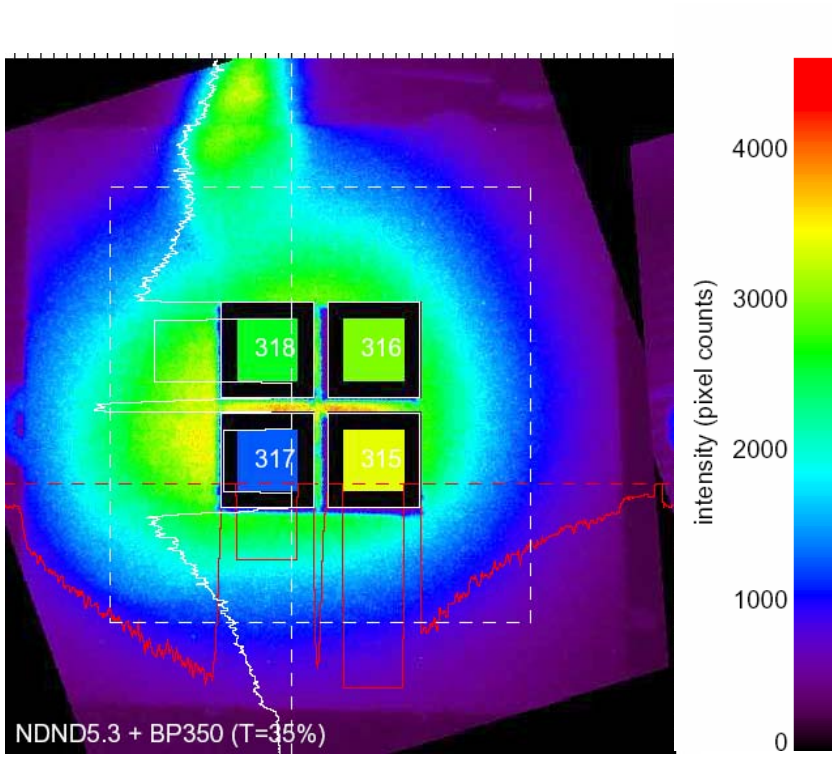
Late time:

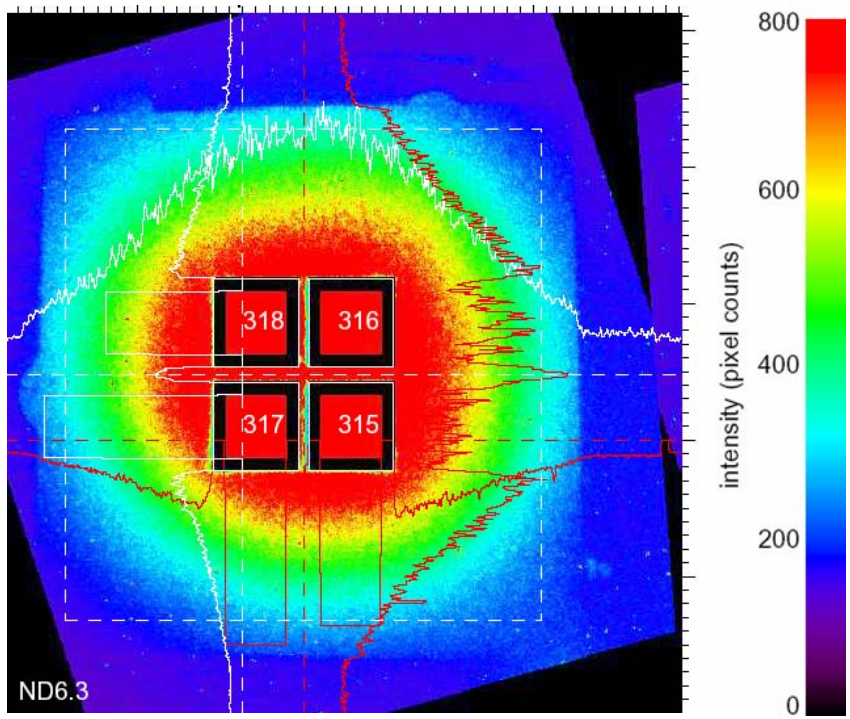
probe beams interact with drive beams and long, hot plasma.



[Courtesy of Chan Joshi et al.]

The FABs and NBI diagnostics have already measured angularly resolved scattered energy with high precision on NIF





1.2 kJ SBS out side lenses
153 J in lenses

130 J SRS out side lenses
38 J SRS in lenses

(High temperature hohlraum target experiment)

[Glenzer et al., Nucl. Fusion 44, S185 (2004)]

[Courtesy of Chan Joshi et al.]

Summary

Our vision for university use of NIF is to coordinate with the other HED facilities in a staged approach

- Test out new ideas, develop new techniques, on smaller facilities, such as Janus, Trident, Titan, Vulcan, Helen, Cornell X-pinch, Nevada Terawatt Facility, Magpie, …

  Example: Collins, Jeanloz et al., laser-DAC experiments on Vulcan

- Promising ideas move to major HED facilities, such as Omega, Z/ZR, Saturn, LIL, … for demonstration on "big machines":

  Examples of Omega / NLUF:

  "Optical Mixing Controlled Stimulated Scattering Instabilities," Bedros B. Afeyan et al.

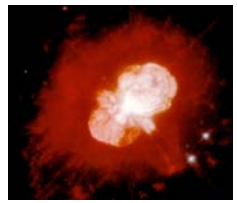
  "Recreating Planetary Core Conditions on Omega," Raymond Jeanloz et al.

  "Experimental Astrophysics on the Omega Laser," R. Paul Drake et al.

- Those experiments requiring high energy "conclusion points" then propose to NIF

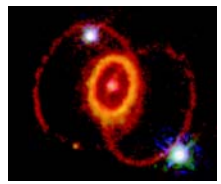
- Informal coordination between the facilities appears possible

HED laboratory astrophysics allows unique, scaled testing of models of some of the most extreme conditions in the universe



- **Stellar evolution: opacities (eg., Fe) relevant to stellar envelopes; Cepheid variables; sellar evolution models; OPAL opacities**

- **Planetary interiors: EOS of relevant materials (H_2, H-He, H_20, Fe) under relevant conditions; planetary structure - and planetary formation - models sensitive to these EOS data**



- **Core-collapse supernovae: scaled hydrodynamics demonstrated; turbulent hydrodynamics within reach; aspects of the "standard model" being tested**

- **Supernova remnants: scaled tests of shock processing of the ISM; scalable radiative shocks within reach**

- **Protostellar jets: relevant high-M-# hydrodynamic jets; scalable radiative jets, radiative MHD jets; collimation quite robust in strongly cooled jets**

- **Black hole/neutron star accretion disks: scaled photoionized plasmas within reach**

- **Our goal: to be *citius, altius, fortius, sapientius* for laboratory astrophysics**

[Roger Blandford, keynote address, HEDLA-04]