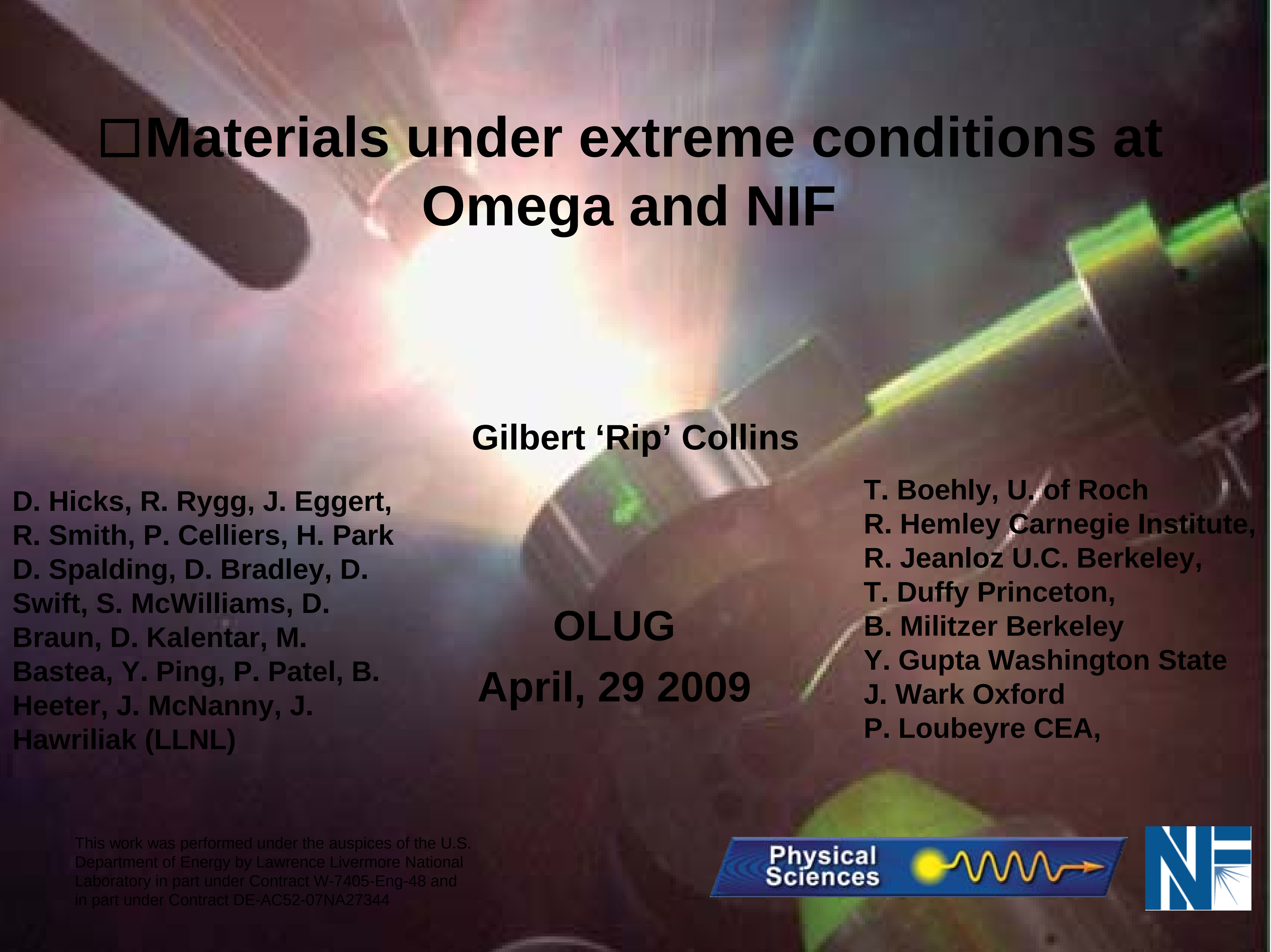


□Materials under extreme conditions at Omega and NIF

Gilbert ‘Rip’ Collins

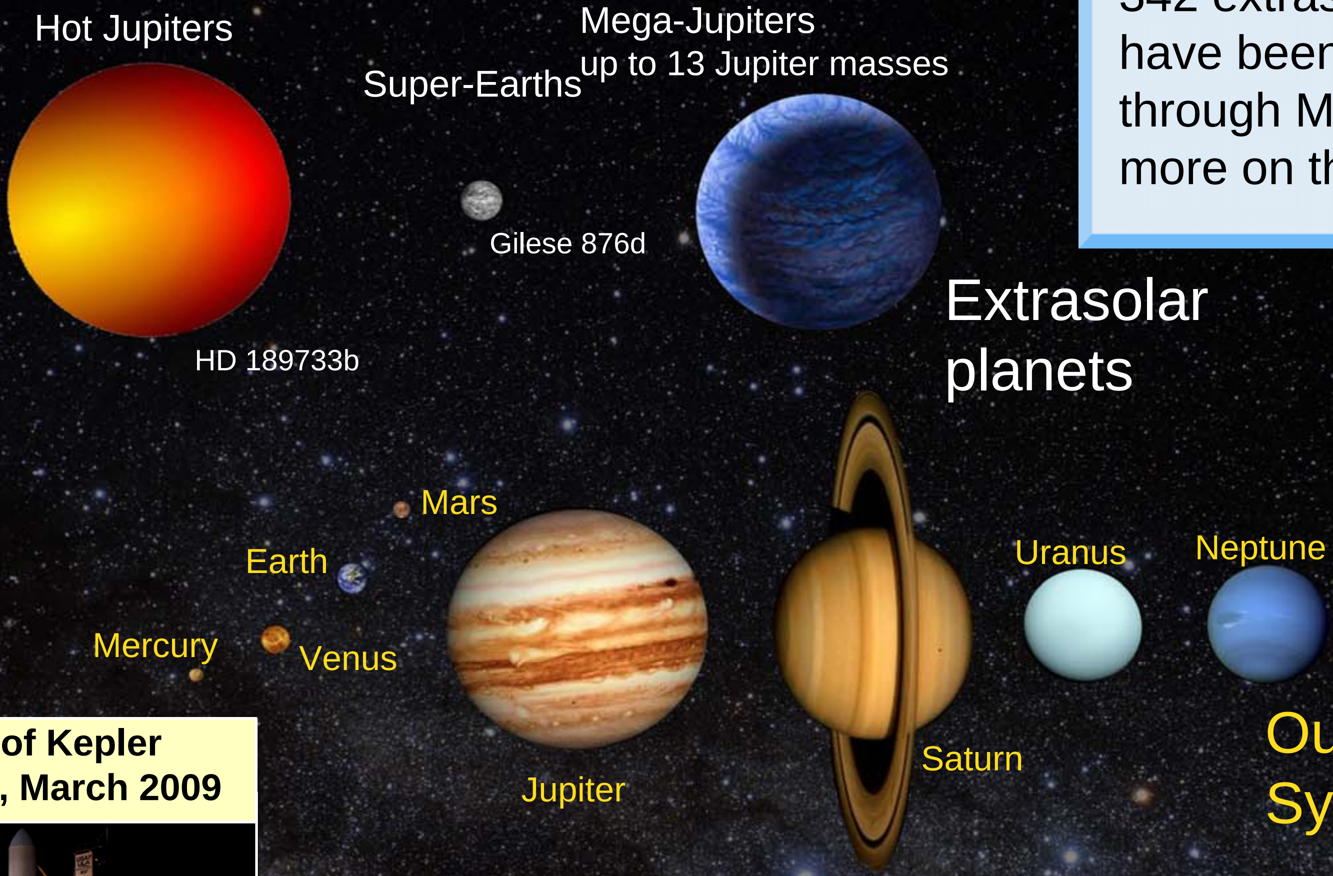
D. Hicks, R. Rygg, J. Eggert, R. Smith, P. Celliers, H. Park D. Spalding, D. Bradley, D. Swift, S. McWilliams, D. Braun, D. Kalentar, M. Bastea, Y. Ping, P. Patel, B. Heeter, J. McNanny, J. Hawriliak (LLNL)

T. Boehly, U. of Roch
R. Hemley Carnegie Institute,
R. Jeanloz U.C. Berkeley,
T. Duffy Princeton,
B. Militzer Berkeley
Y. Gupta Washington State
J. Wark Oxford
P. Loubeyre CEA,

OLUG
April, 29 2009

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory in part under Contract W-7405-Eng-48 and in part under Contract DE-AC52-07NA27344

342 extrasolar planets have been discovered through March 2009, more on the way



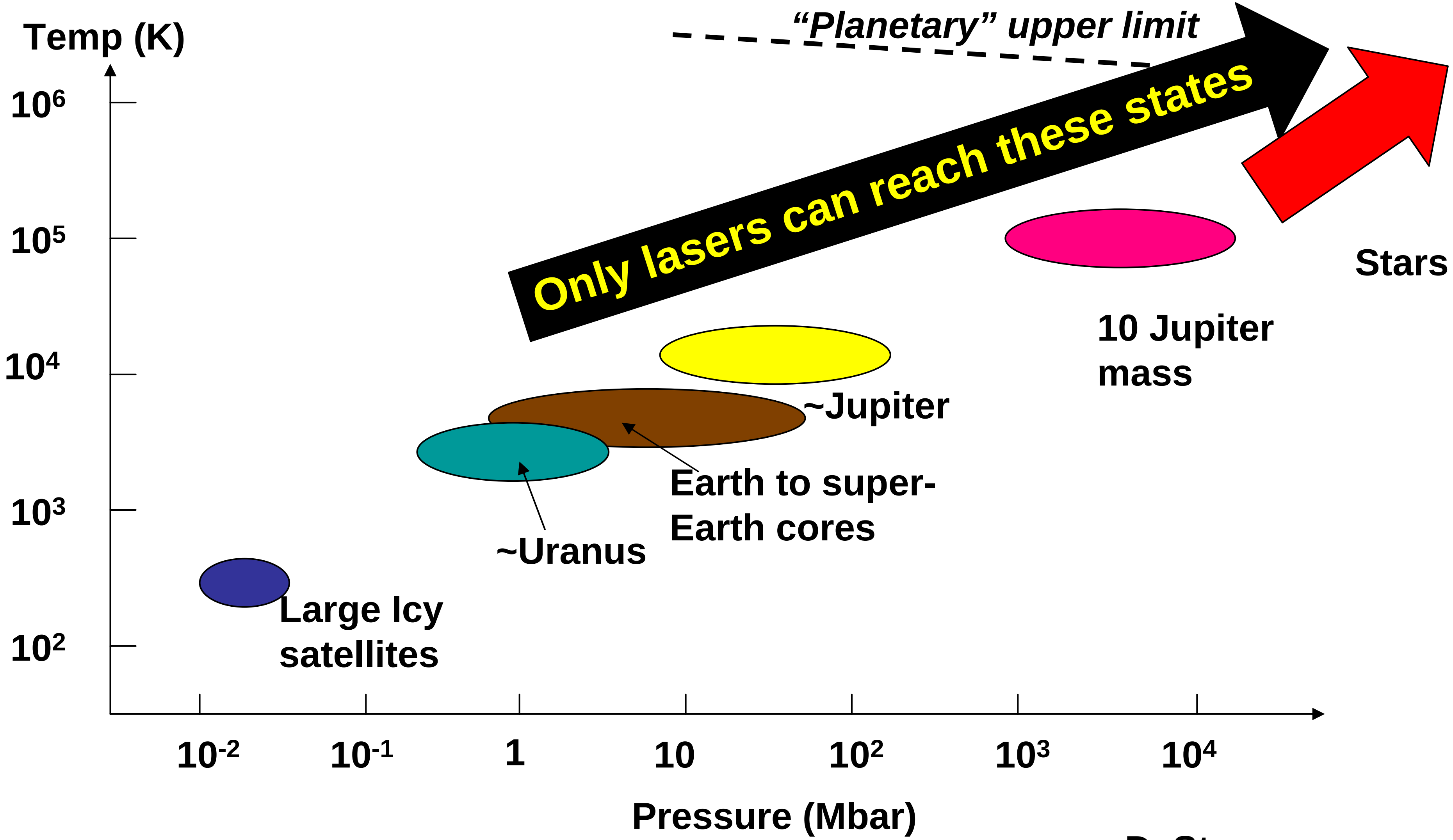
Extrasolar planets

Our Solar System

Brown Dwarfs:
80 to 13 Jupiter Masses

Launch of Kepler mission, March 2009

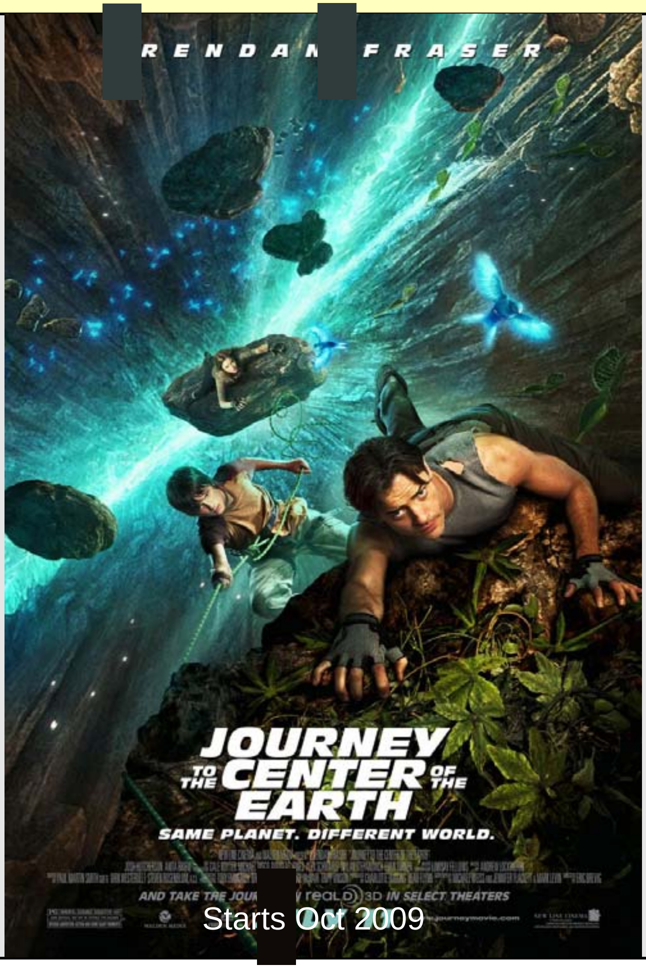
Understanding planetary evolution requires knowledge of the material properties at extreme conditions



D. Stevenson

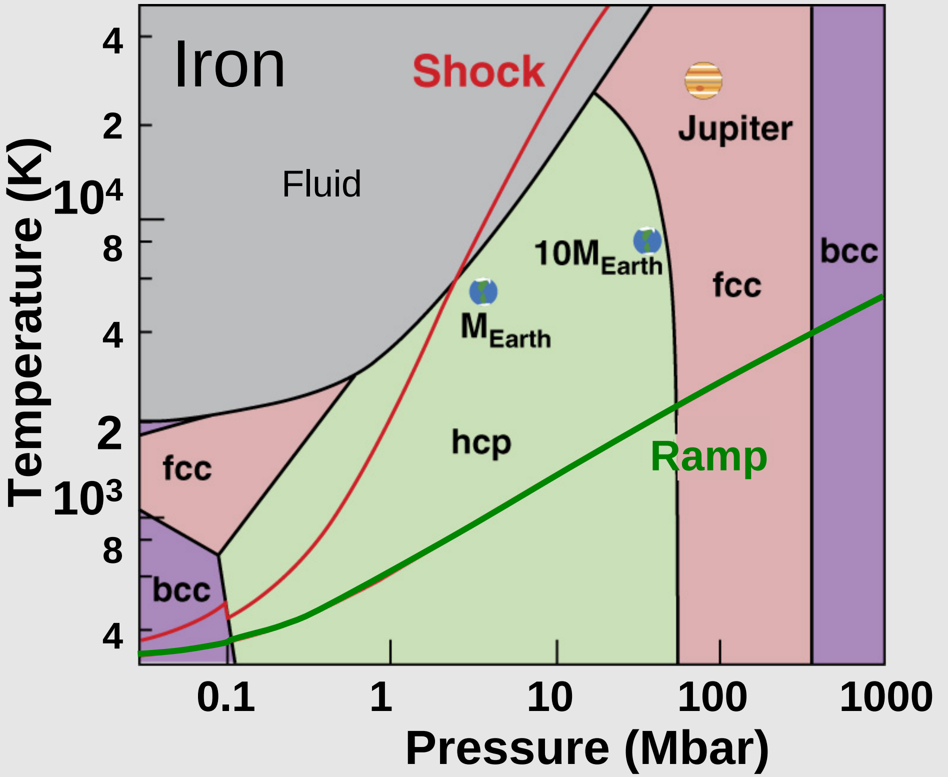
Lasers are redefining condensed matter, chemistry, plasma, and nuclear science

Omega and NIF allow us to explore the most extreme conditions in planets and low mass stars



Starts Oct 2009

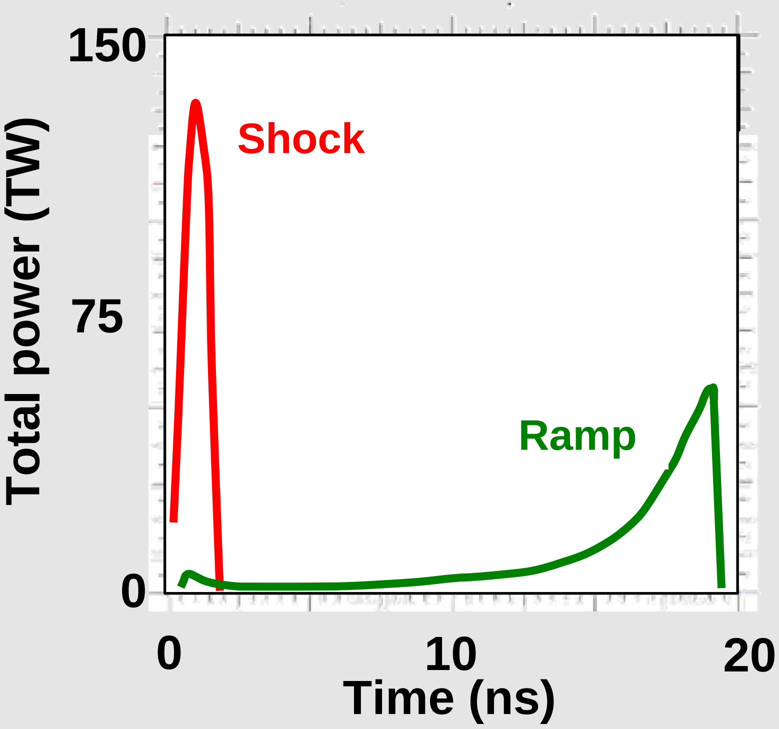
Soon we will study P > 1 Gbar shocks, P> 10's Mbar for Ramp compression



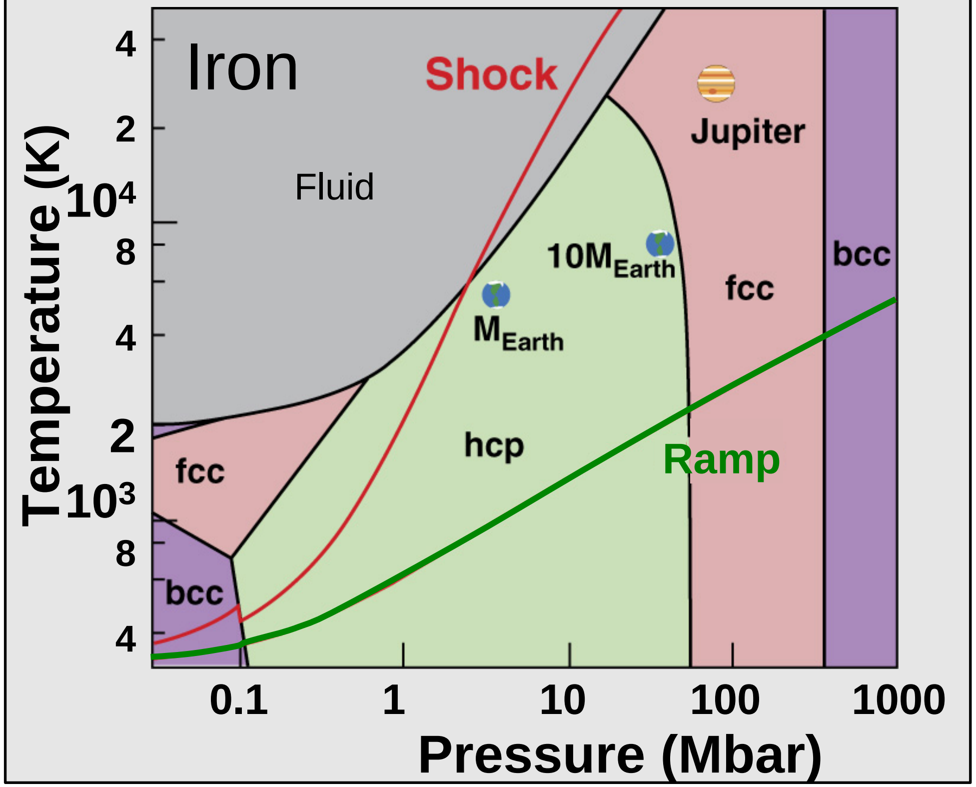
Stixrude, 2008

Lasers are redefining condensed matter, chemistry, plasma, and nuclear science

Pulse shape =>ultra-high pressure plasma and solid-state experiments

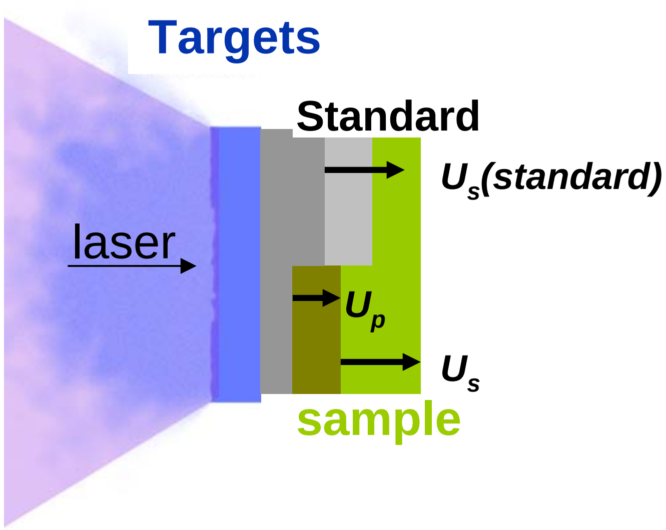


Soon we will study P > 1 Gbar shocks, P> 10's Mbar for Ramp compression



Stixrude, 2008

We determine shock and particle speed with a shock speedometer (VISAR), temperature with pyrometer



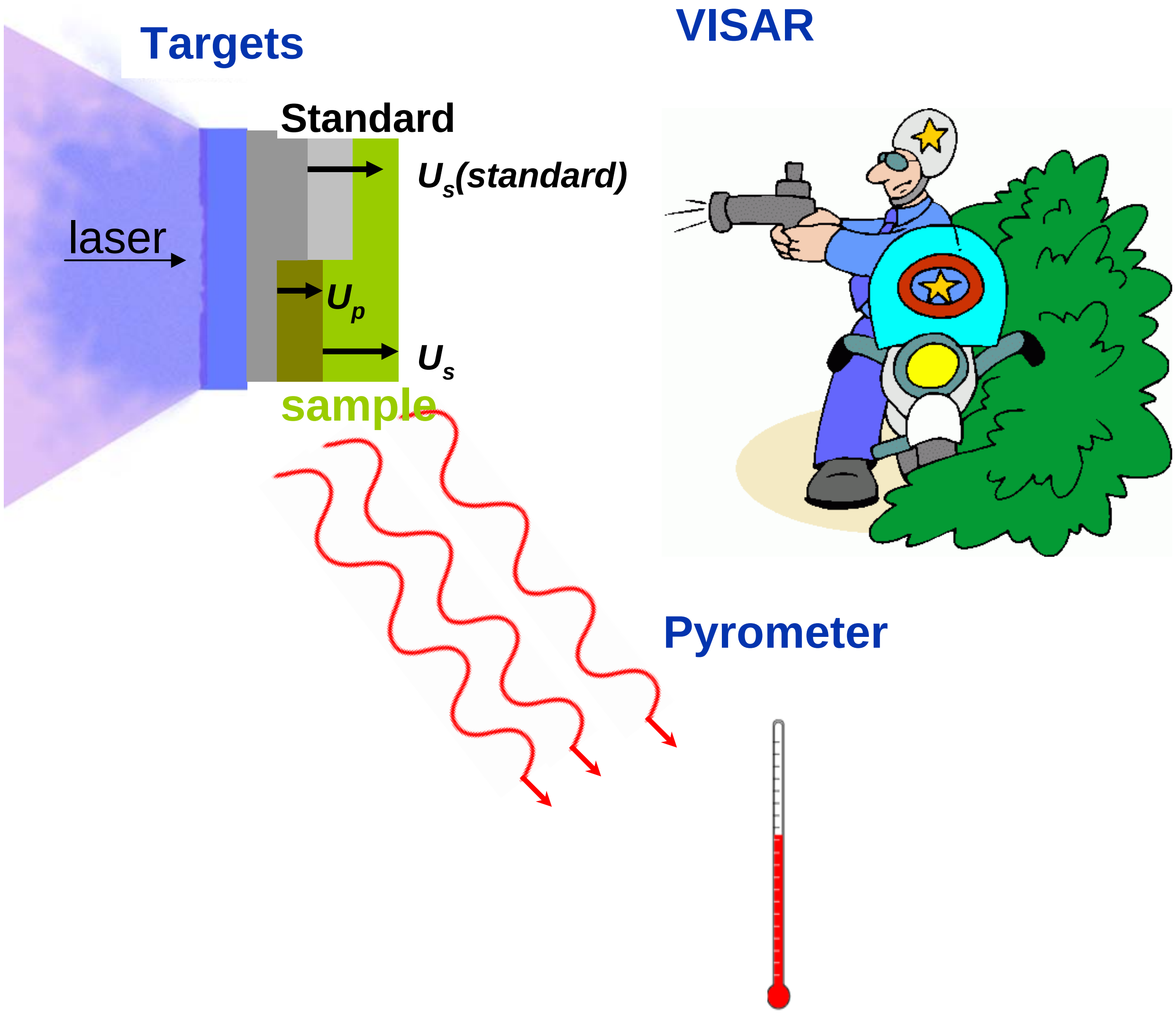
$$\rho_o(U_s) = \rho(U_s - U_P)$$

$$P = \rho_0 U_s U_P$$

$$E = \frac{1}{2} P(1/\rho_o - 1/\rho)$$

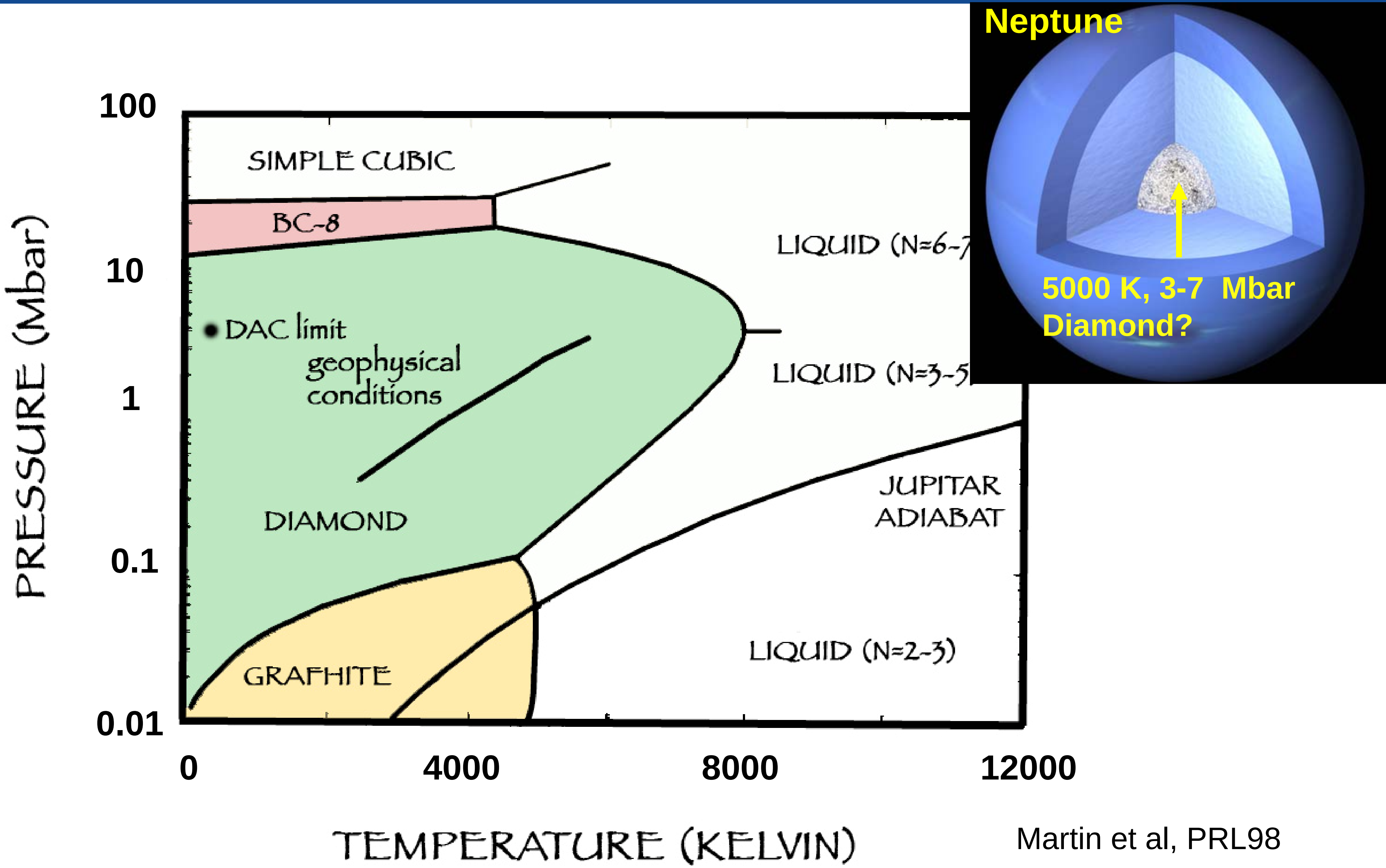
- **3 equations, 5 unknowns (*Us, Up, P,* ρ*, E*) -> need to Measure 2 of these**

We determine shock and particle speed with a shock speedometer (VISAR), temperature with pyrometer



- **Temperature is measured separately from pressure, density….**

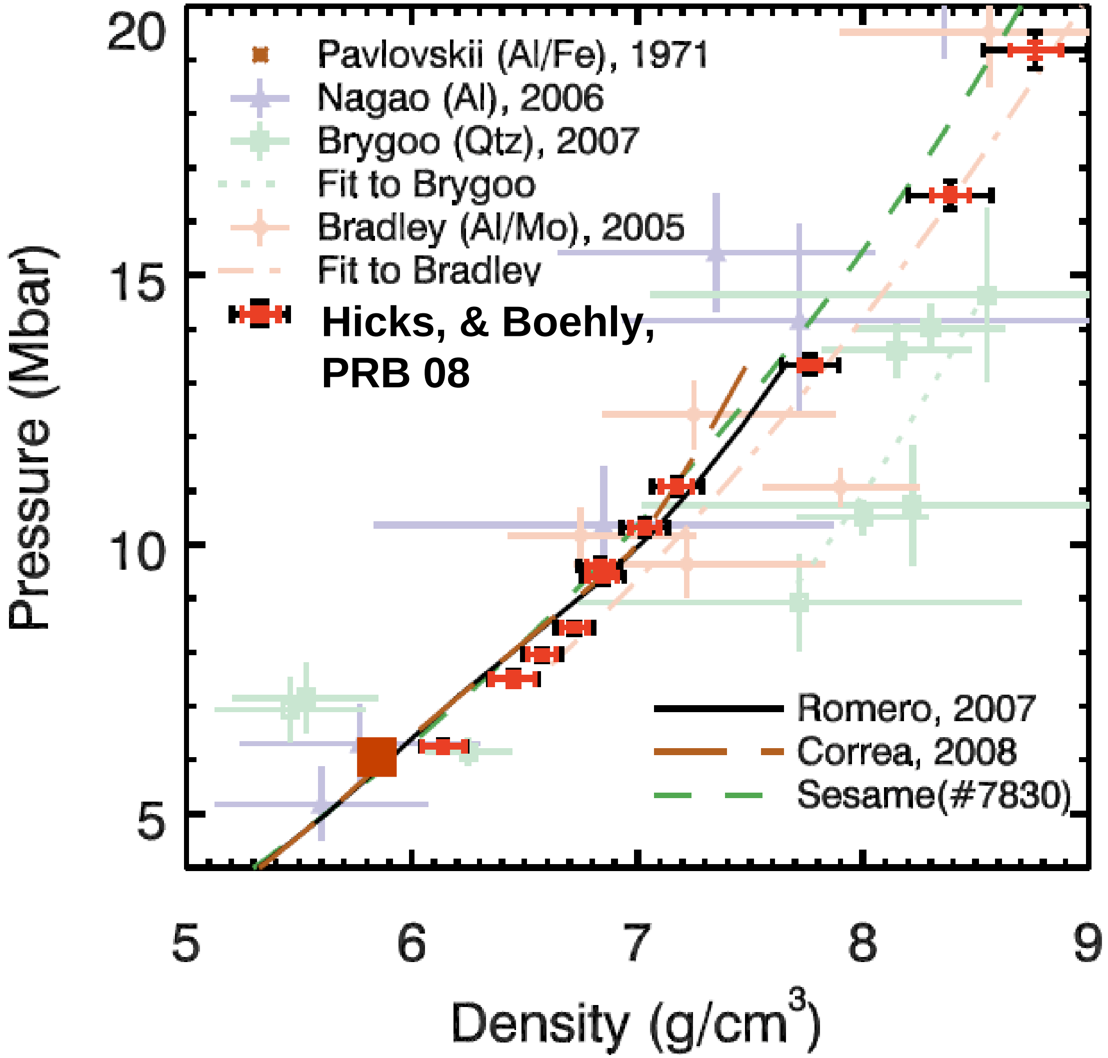
Carbon, a principal constituent of Neptune, is thought to have a complicated solid and liquid structure



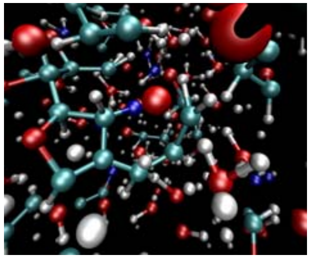
Martin et al, PRL98

By measuring shock velocities very accurately we determine pressure and density to a few percent

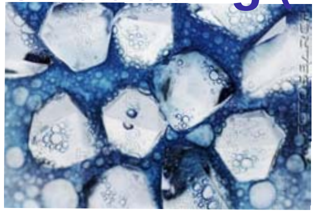
We have compressed diamond by ~ 3x



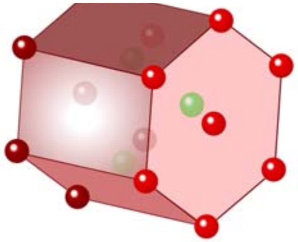
Polymeric fluid
To plasma



Liquid-solid mix & conducting (Bradley)

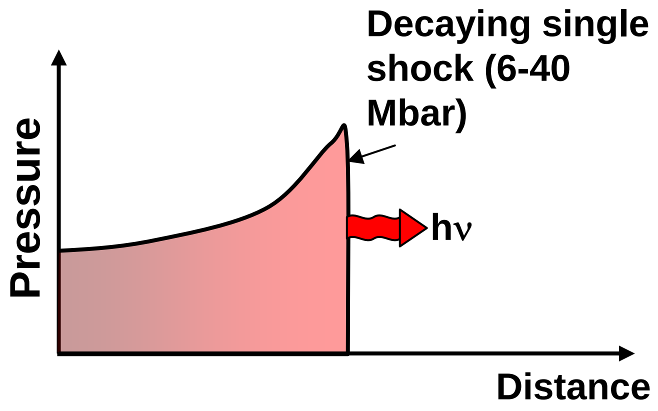


Solid insulator

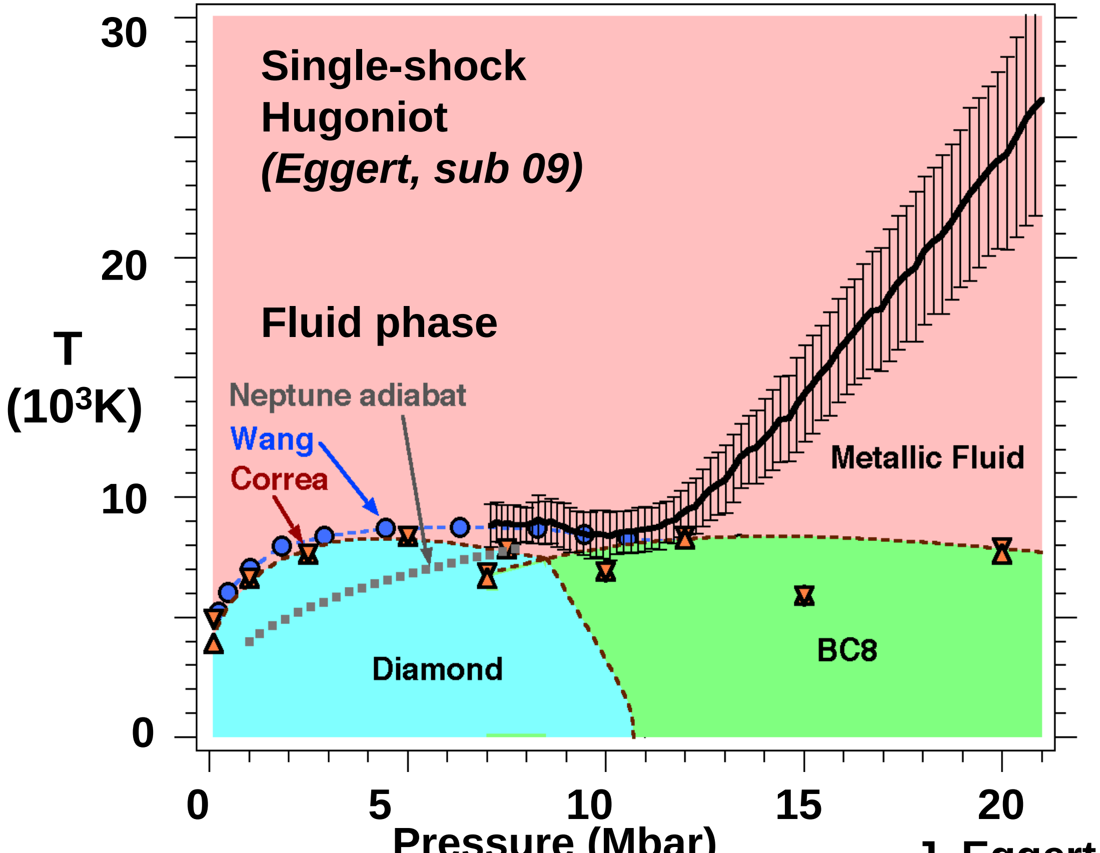


Temperature was measured on decaying shocks
This unveiled the melt curve from 6 to 11 Mbar

Use decaying shock to Map high P-melt curve



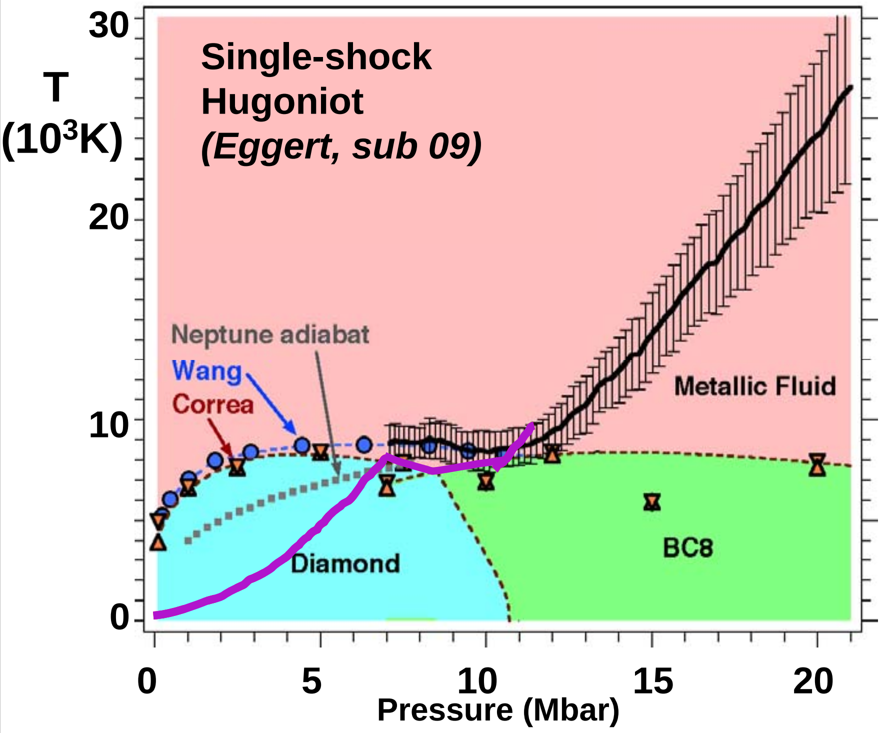
Melt curve stays nearly flat from 6-11 Mbar



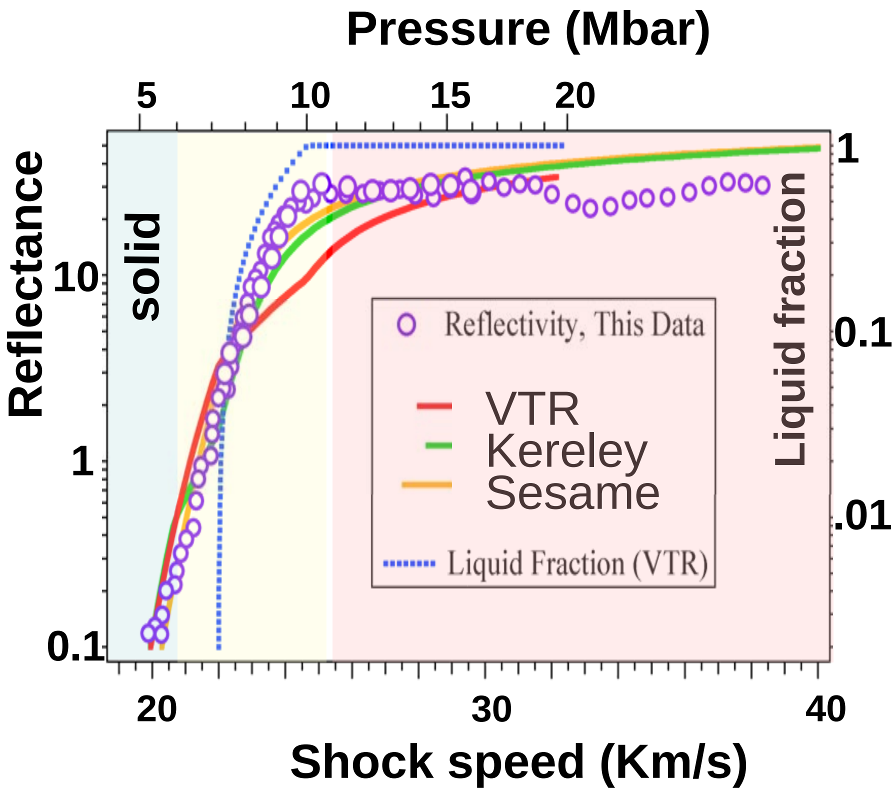
J. Eggert

Reflectivity measurements show Carbon melts from the diamond phase to a liquid metal

Melt along 1-shock Hugoniot



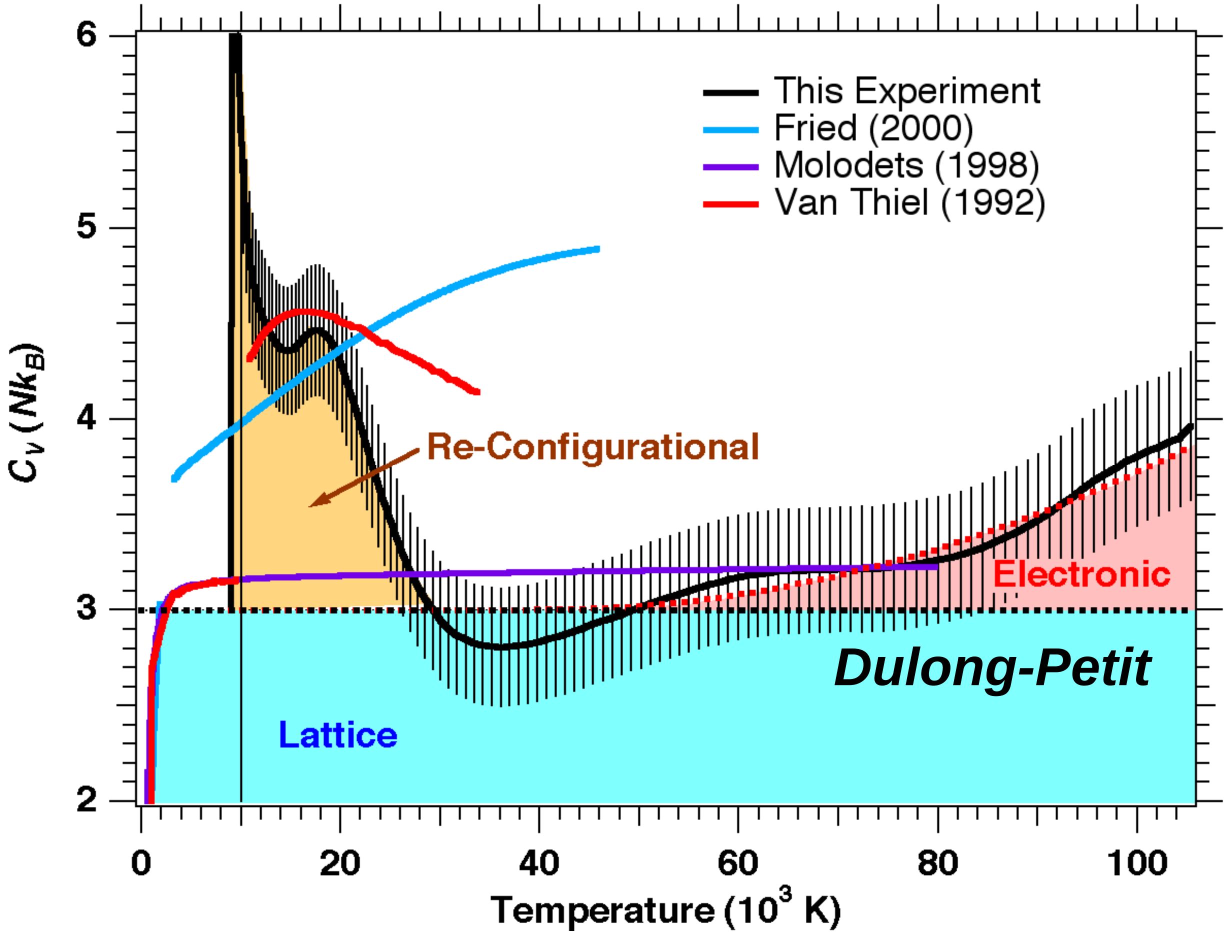
Diamond melts to a liquid conductor



Bradley, 05

- **In fact several materials become conducting upon melt (MgO, SiO2, LiF, ..) This is not what one would expect from simple condensed matter theory**

Finally this carbon metallic fluid phase is also polymeric up to 20 Mbar and 30kK



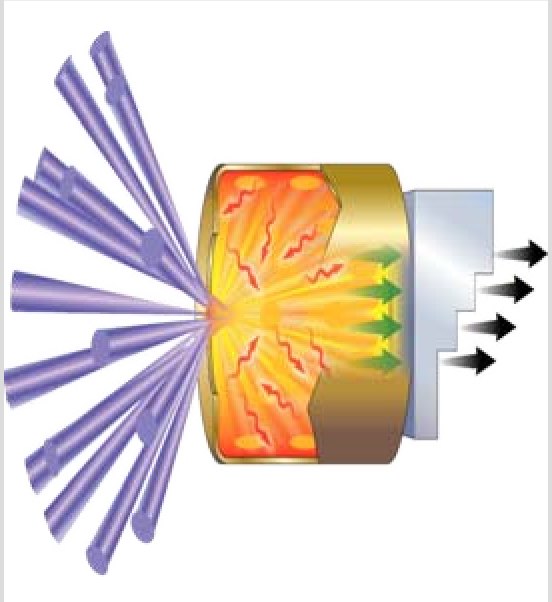
Hicks PRL 06
Eggert sub. to Nature 09

Both SiO_2 and C exhibit a high heat capacity due to dissociation and bonding reconfiguration up to 20 Mbar

This is not predicted by Ab-initio models

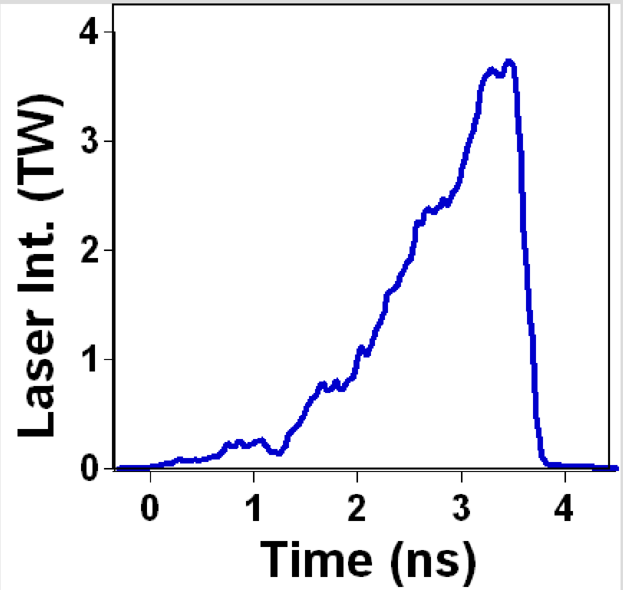
To generate colder dense states with lasers, just tune laser intensity versus time

Laser ramps use x-ray drive stepped samples



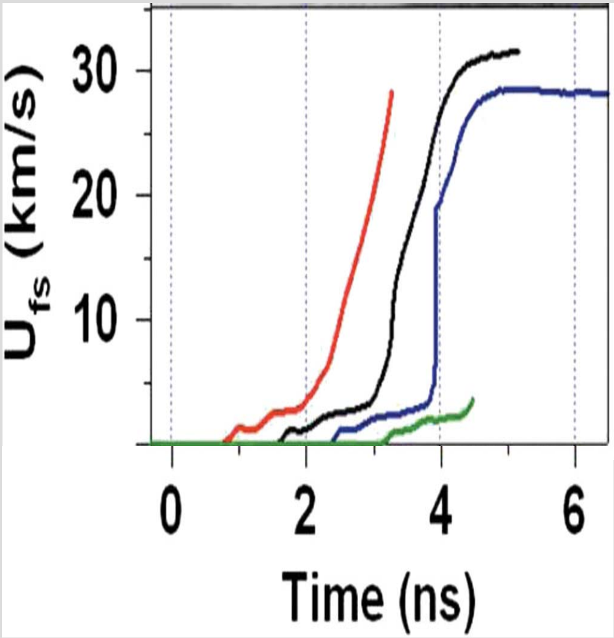
- •Edwards, et al. (PRL 04)
- •Smith, et al. (PRL 06)
- •Bradley, et al. 08
- •Eggert et al. (SCCM 07)

Ramp laser intensity to produce shockless compression



Velocity histories are used to determine P-rho

Free surface velocity vs time

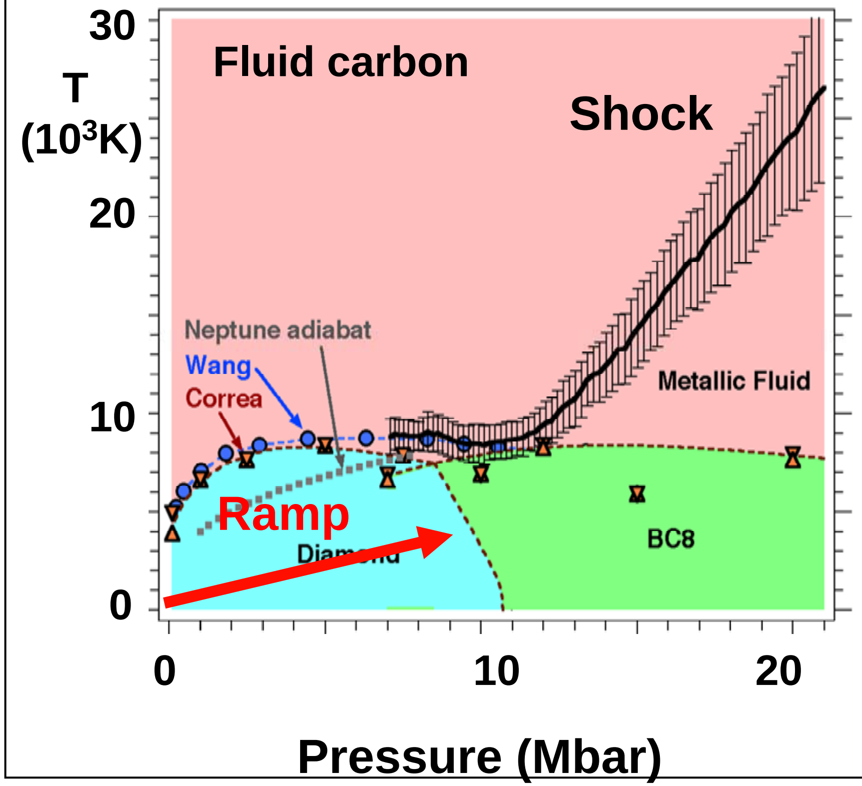


Wave-profile analysis is used to determine C_l,stress,rho (Maw,Rothman,05, Eggert 06)

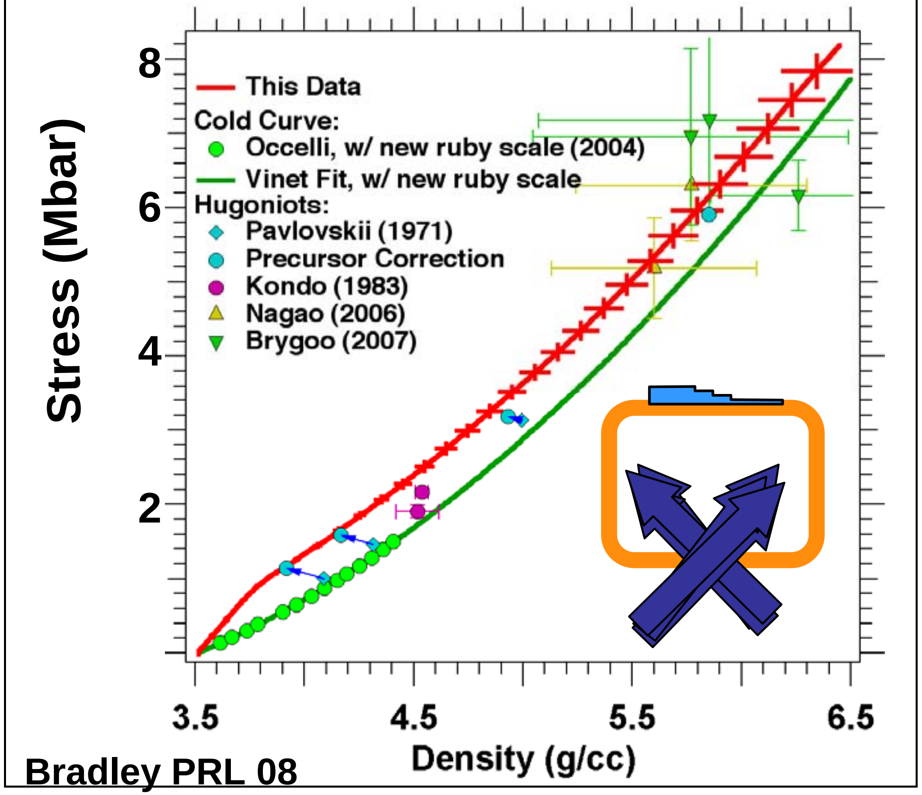
R. Smith 2005

We measured the stress-density of diamond to 8 Mbar with ramp compression

Ramp waves keep the sample ~cool and solid (until plastic heating ↑)



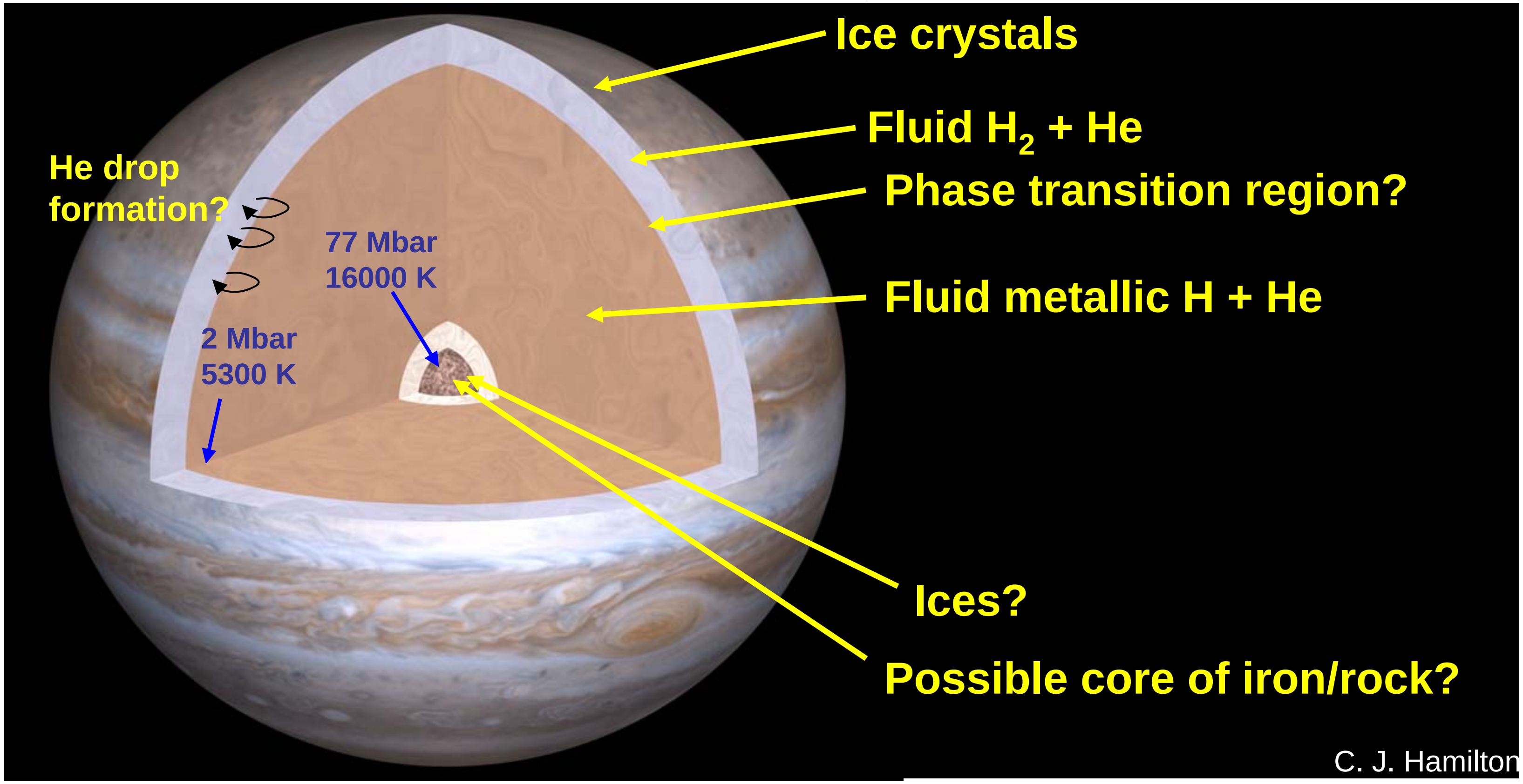
Ramp compression shows diamond is stable and strong to 8Mbar



Bradley PRL 08

This allows us to measure the properties of many solids to ~ TPa pressures

Jupiter is thought to contain H and He at 10's of Mbar, what happens to H or He at those conditions?

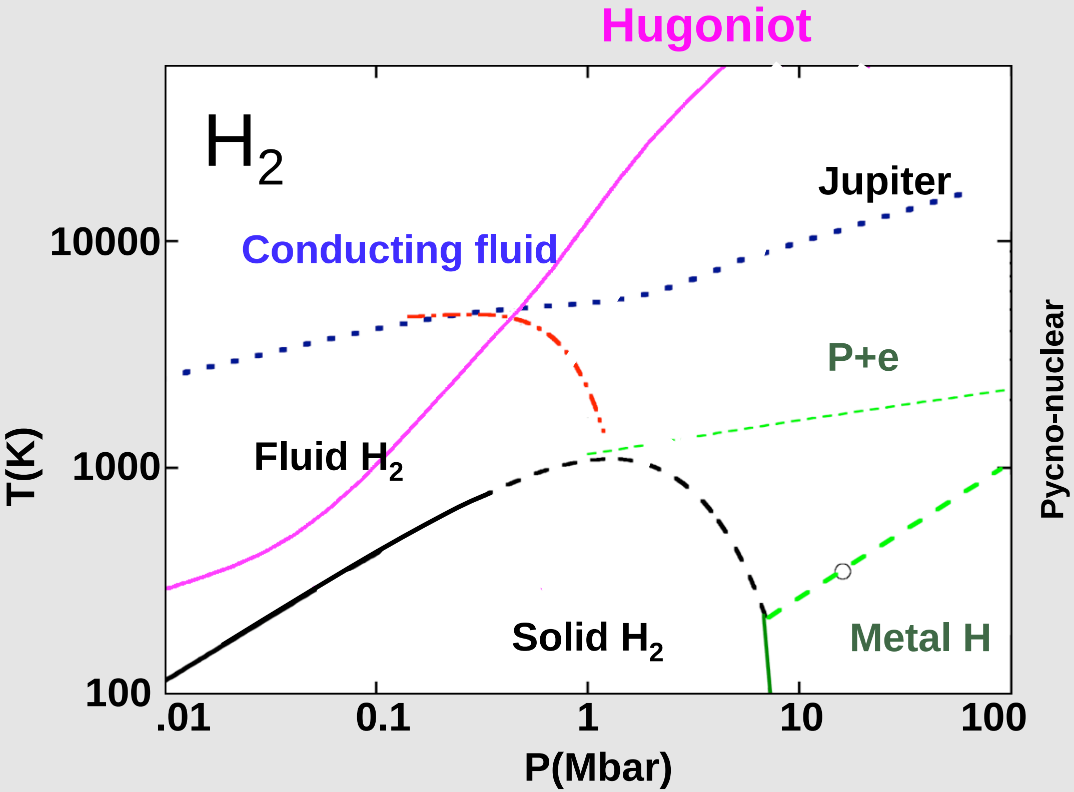


C. J. Hamilton

How do we study these light fluids at such high density?

Most previous high pressure-temperature experiments on hydrogen focused on the Hugoniot

Particular attention on H due to its importance in astrophysics and ICF



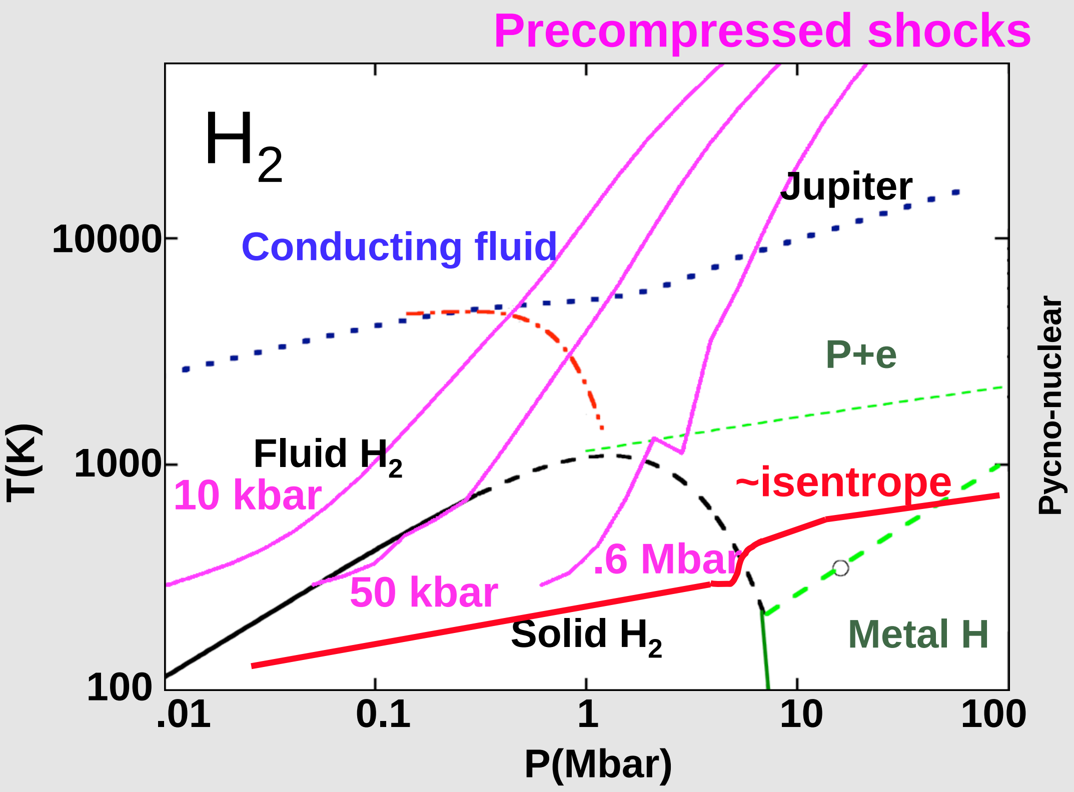
Hugoniot:
Nellis et al
DaSilva et al
Knudson et al
Boehly, et al
Hicks et al
Glenzer et al

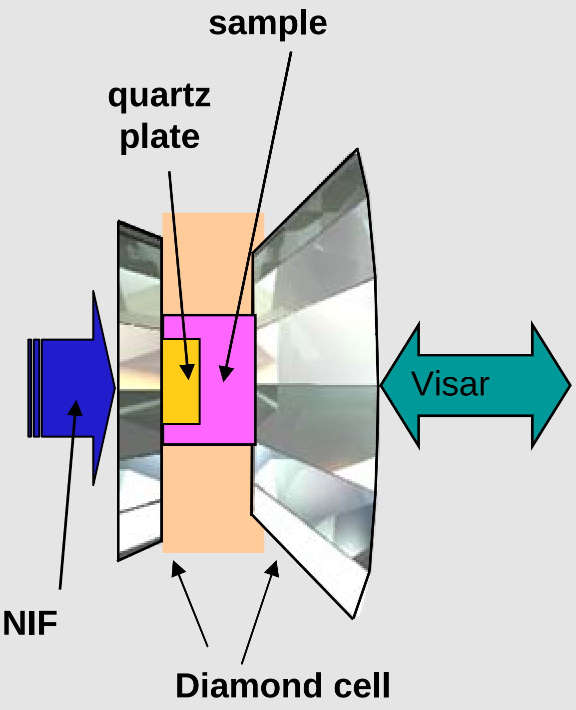
Loubeyre, 06

Scientists have measured P, rho, T and the insulating to conducting transition in the WDM regime to ~ Mbar pressures on the Hugoniot

Coupling diamond cells to laser shocks enables access to ultra-high density states for He, H_2, He+H_2

Particular attention on H due to its importance in astrophysics and ICF



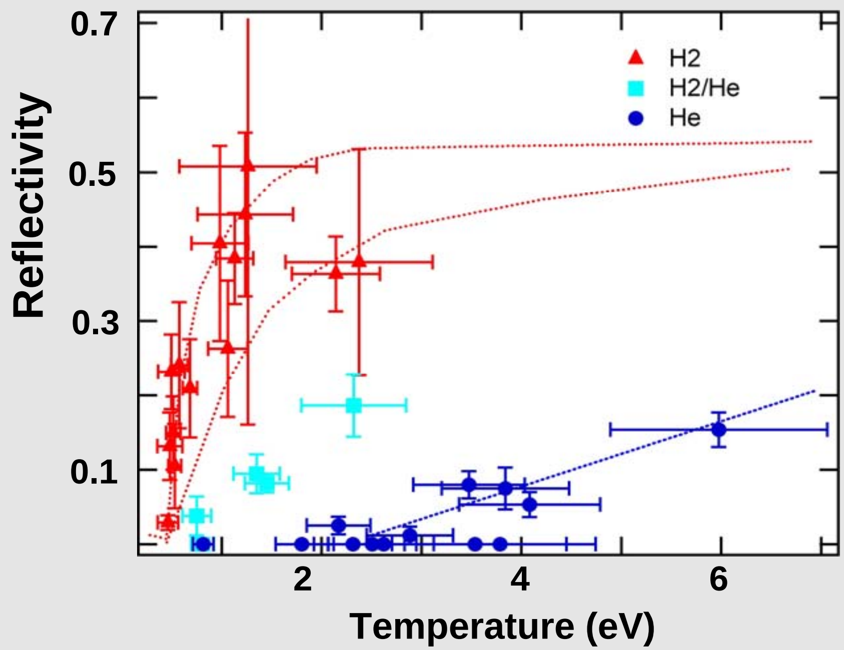


Loubeyre 06

The technique has been demonstrated on Omega to 200 GPa, and is expected to scale to 10+ TPa on NIF (Eggert PRL 08, Jeanloz PNAS 07, Lee JCP 06, Loubeyre JHP 06)

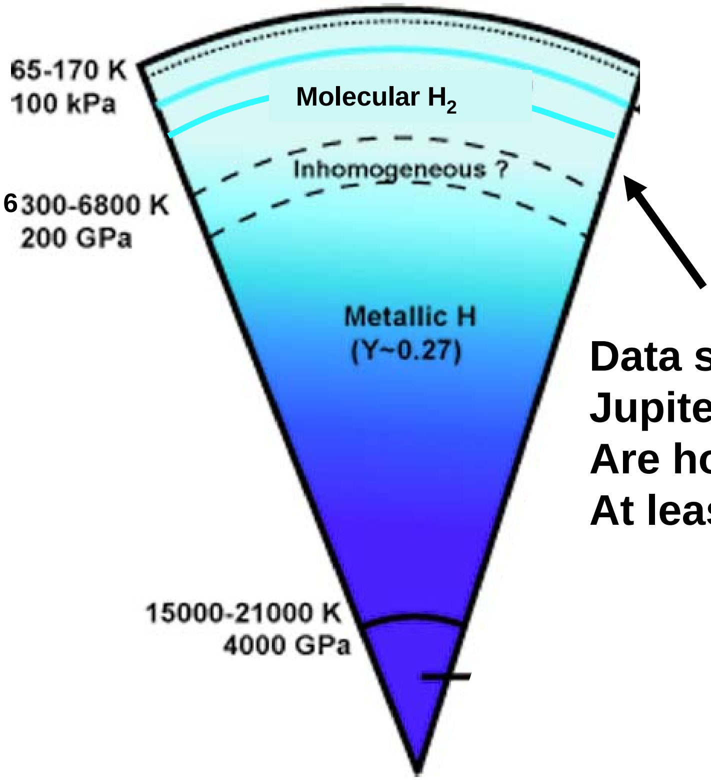
He/H2 data give insight to the insulator-conductor transition of the mixture

Reflectivity and T for He/H_2 Mix is Between He and H_2



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

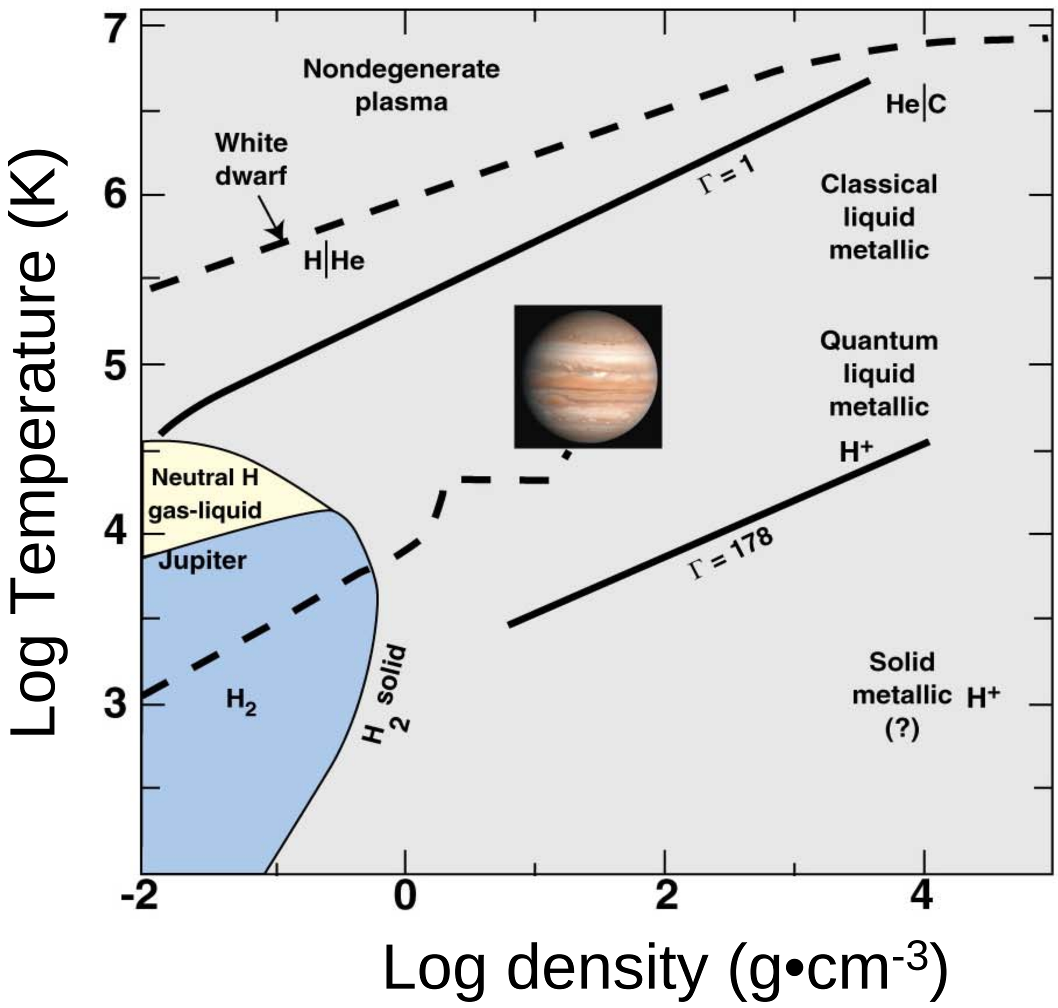
This may have important implications for ICF



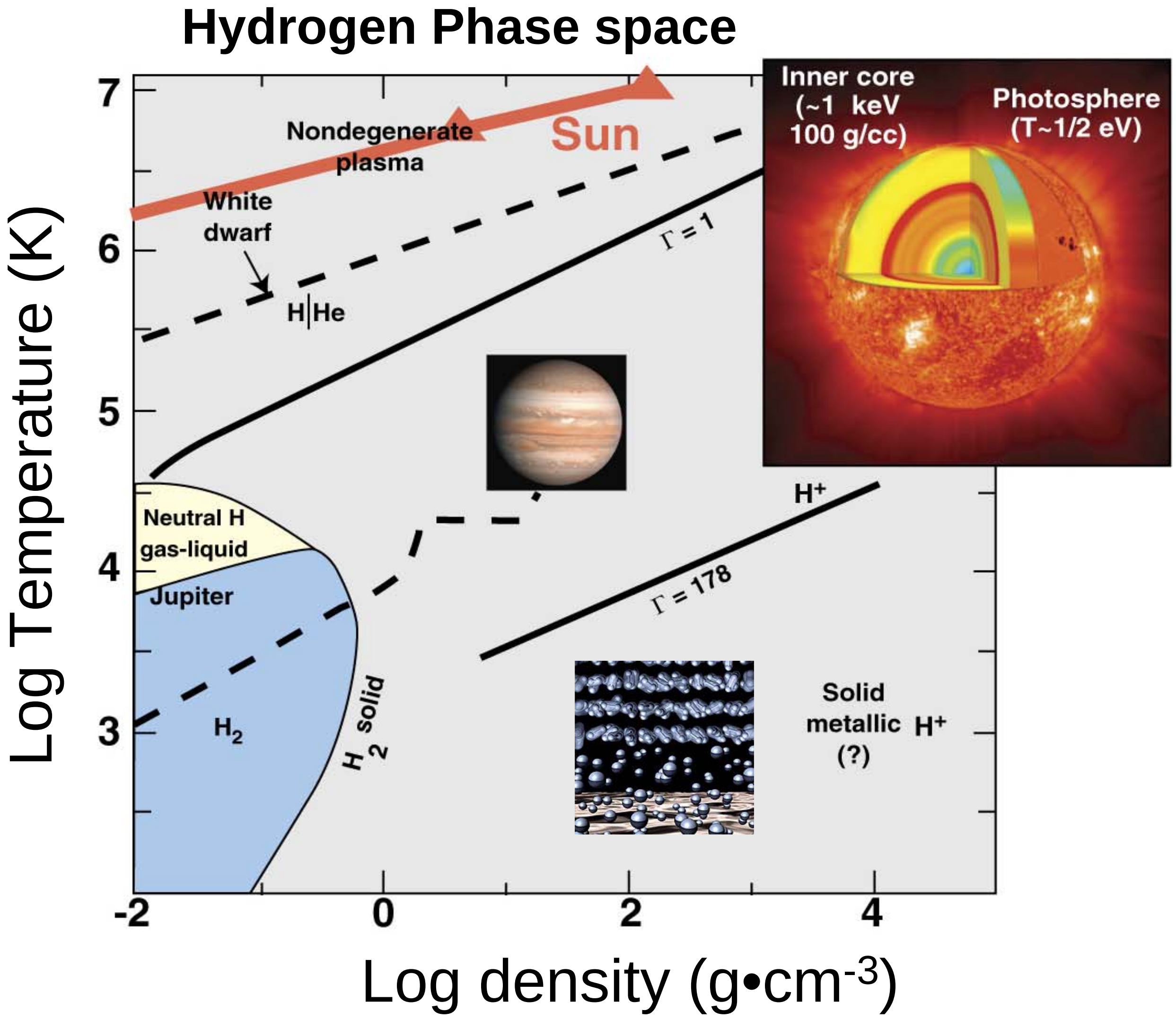
Data shows
Jupiter/Saturn
Are homogeneous
At least to here

What next?

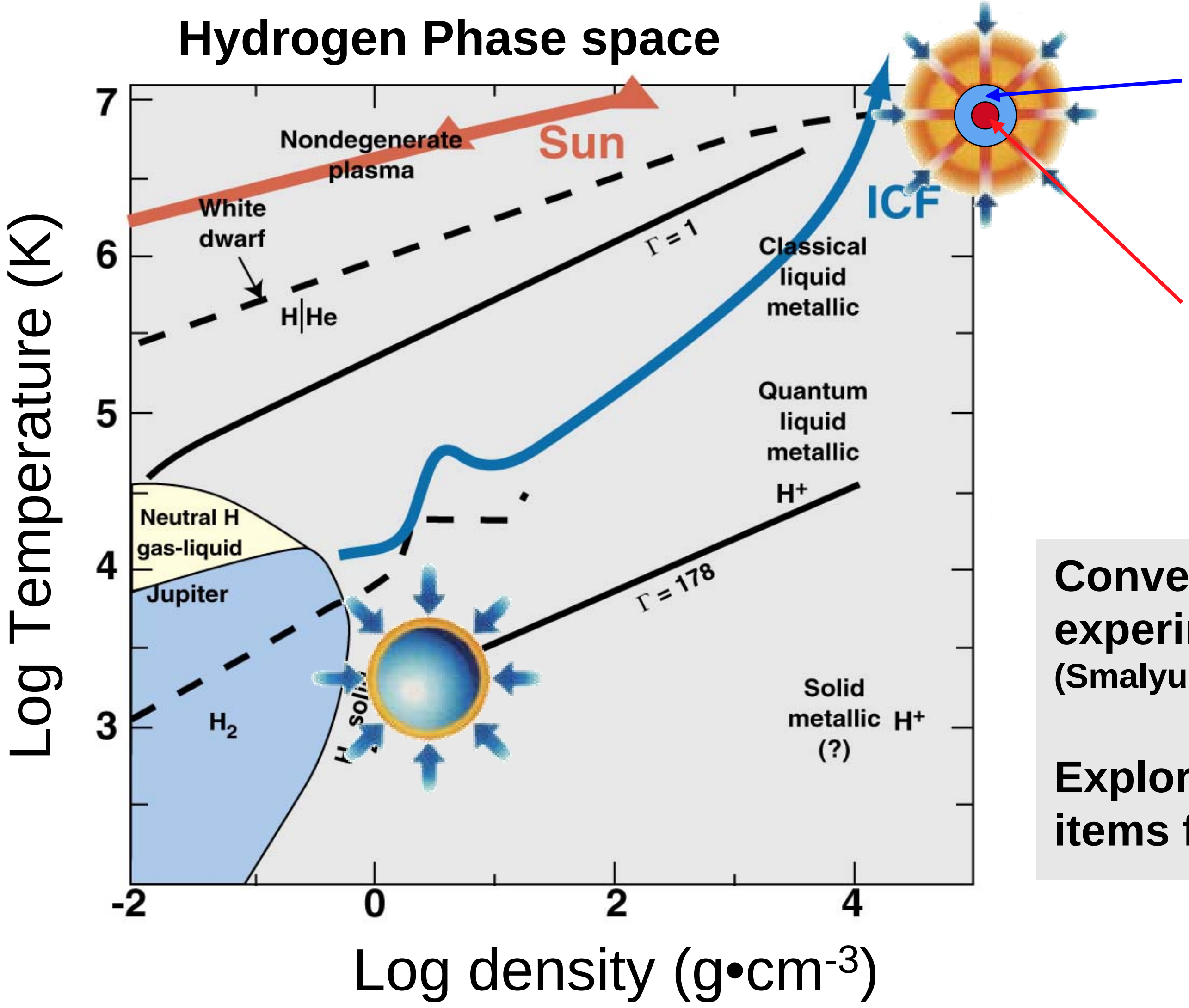
Hydrogen Phase space



What next?


Hydrogen Phase space
Log Temperature (K)
Log density (g•cm-3)
7
6
5
4
3
-2
0
2
4
Nondegenerate plasma
Sun
White dwarf
H|He
Γ = 1
Neutral H gas-liquid
Jupiter
H2
H2 solid
H+
Γ = 178
Solid metallic H+ (?)
Inner core (~1 keV 100 g/cc)
Photosphere (T~1/2 eV)

What next?



Hydrogen Phase space

Cold fuel
1 Kg/cc

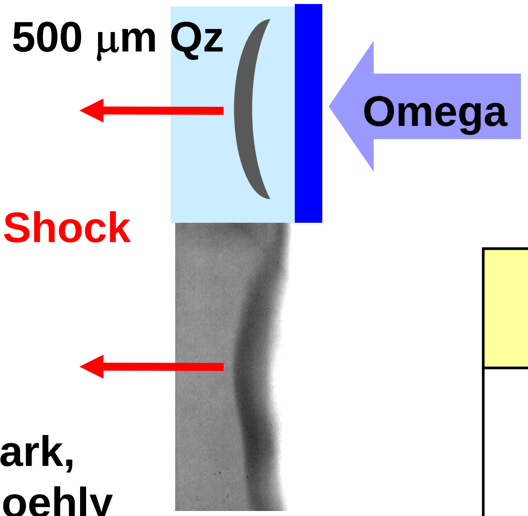
Hot spot
10^8 K

Convergent experiments
(Smalyuk, Rygg)

Explore key items for ignition

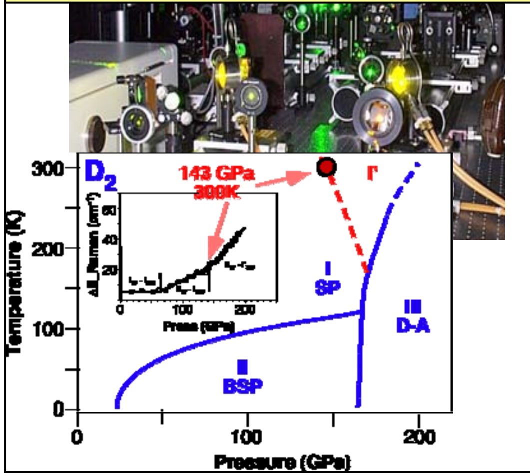
Advanced diagnostics are key for the next generation experiments dynamics, chemistry, band structure…..

High resolution imaging 17.5 KeV image of shock in Quartz



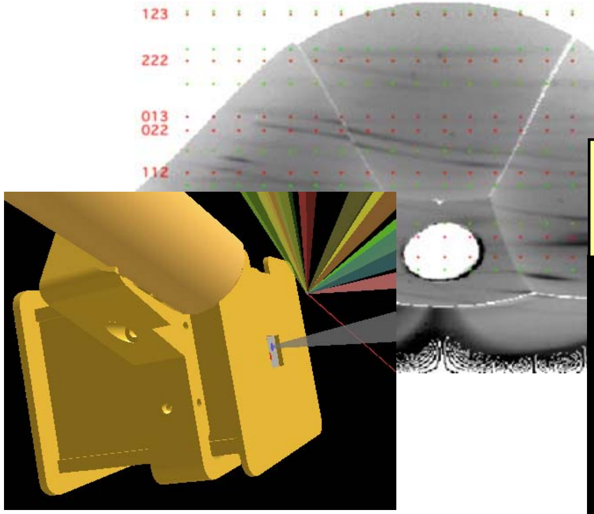
Park, Boehly

CARS to determine bonding (Bolme)

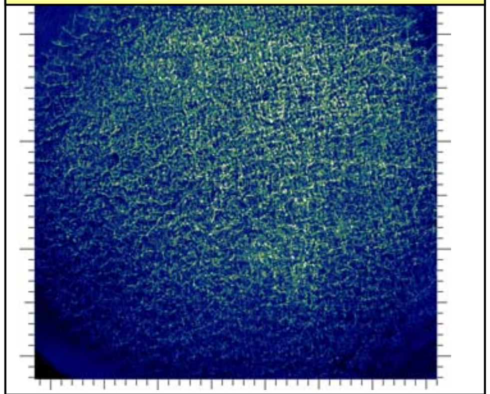


Diffraction to determine structure

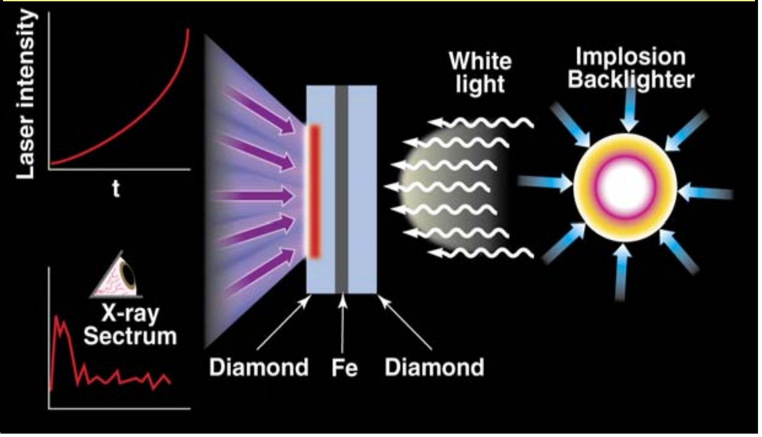
(Eggert, Hawriliak, Wark, Lorenzana…)



Hi-res interferometry (Celliers)



X-ray Scattering/absorption for Melt, Chemistry (Yaakobi, Hicks)



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