Monograph:

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LDRD ER Final Report Recreating Planetary Cores in the Laboratory

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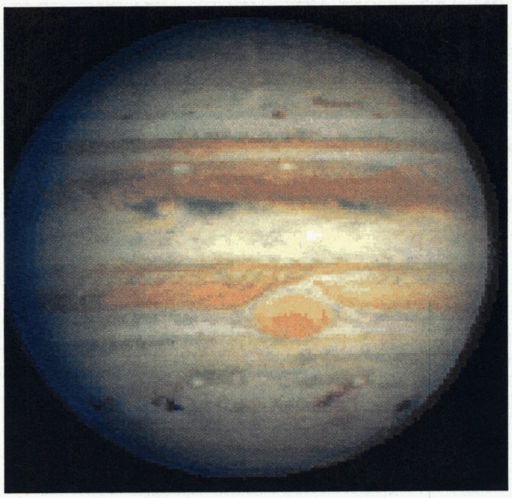
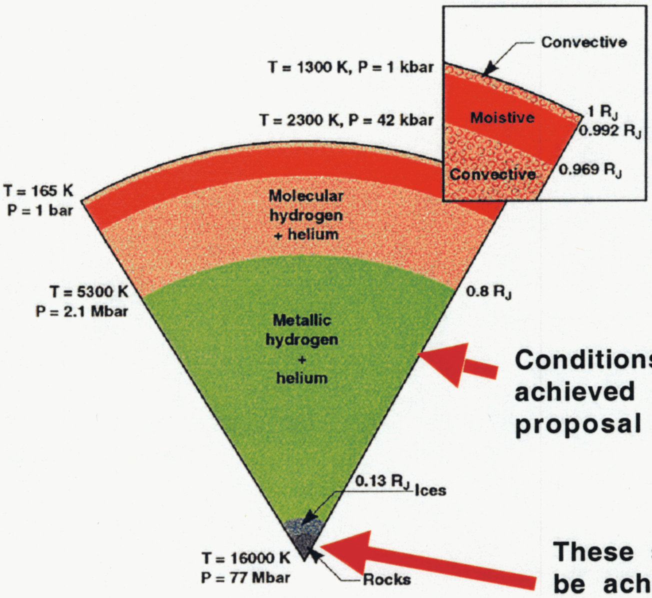
LDRD ER Final Report

Recreating Planetary Cores in the Laboratory





Conditions to be achieved in this proposal

These states will be achievable on NIF with techniques developed in this proposal

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Recreating Planetary Cores in the Laboratory

New techniques to extremely high density states

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An accurate equation of state (EOS) for planetary constituents at extreme conditions is the key to any credible model of planets or low mass stars. However, very few materials have their high pressure (>few Mbar) EOS experimentally validated, and even then, only on the principal Hugoniot. For planetary and stellar interiors, compression occurs from gravitational force so that material states follow a line of isentropic compression (ignoring phase separation) to ultra-high densities[1]. An example of the hydrogen phase space composing Jupiter and one particular Brown Dwarf are shown in Fig. 1.[2]

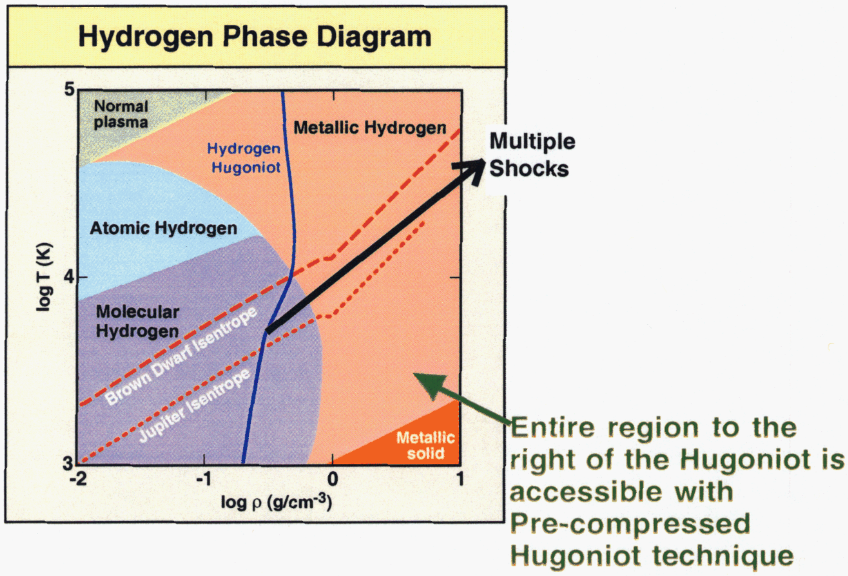

Fig. 1. Equation of state diagram for hydrogen and experimental design that will allow us to follow isentrope of Jupiter, brown dwarfs, or warm solid phase.

At extreme densities, material states are predicted to have quite unearthly properties such as high temperature superconductivity[3] and low temperature fusion[4]. High density experiments on Earth are achieved with either static compression techniques (i.e.diamond anvil cells) or dynamic compression techniques using large laser facilities, gas guns, or explosives. The ultimate goal of this multi-directorate and multi-institutional proposal was to develop techniques that will enable us to understand material states that previously only existed at the core of giant planets, stars, or speculative theories. Our effort was a complete success, meeting all of the objectives set out in our proposals.

First we focused on developing accurate Hugoniot techniques to be used for constraining the equation of state at high pressure/temperature. We mapped out an accurate water EOS and measured that the ionic->electronic conduction transition occurs at lower pressures than models predict. These data and their impact are fully described in the first enclosed paper "The Equation of State and Optical Properties of Water Compressed by Strong Shock Waves." Currently models used to construct planetary isentropes are constrained by only the planet radius, outer atmospheric spectroscopy, and space probe gravitational moment and magnetic field data. Thus these data, which provide rigid constraints to these models, will have a significant impact on a broad community of planetary and condensed matter scientists, as well as our fundamental understanding of the giant planets.

We then developed and tested precompressed and multiple shock techniques on water. Scientists around the world have teamed with us to conduct these complex and seminal high density experiments which allow access to the extreme core states of giant plants. Double shock experiments using a variety of anvils to compress water to densities higher and temperatures lower than accessible by single shock Hugoniot techniques. First a clear determination of the EOS and optical properties of the anvils needed to be measured. These properties for LiF and Al2O3 are written up in the second attached article,"Shock-Induced Transformation of Sapphire and Lithium Flouride into Semiconducting Liquids." An example double shock data record for water is shown in Fig. 1a. These data are being written up for publication.

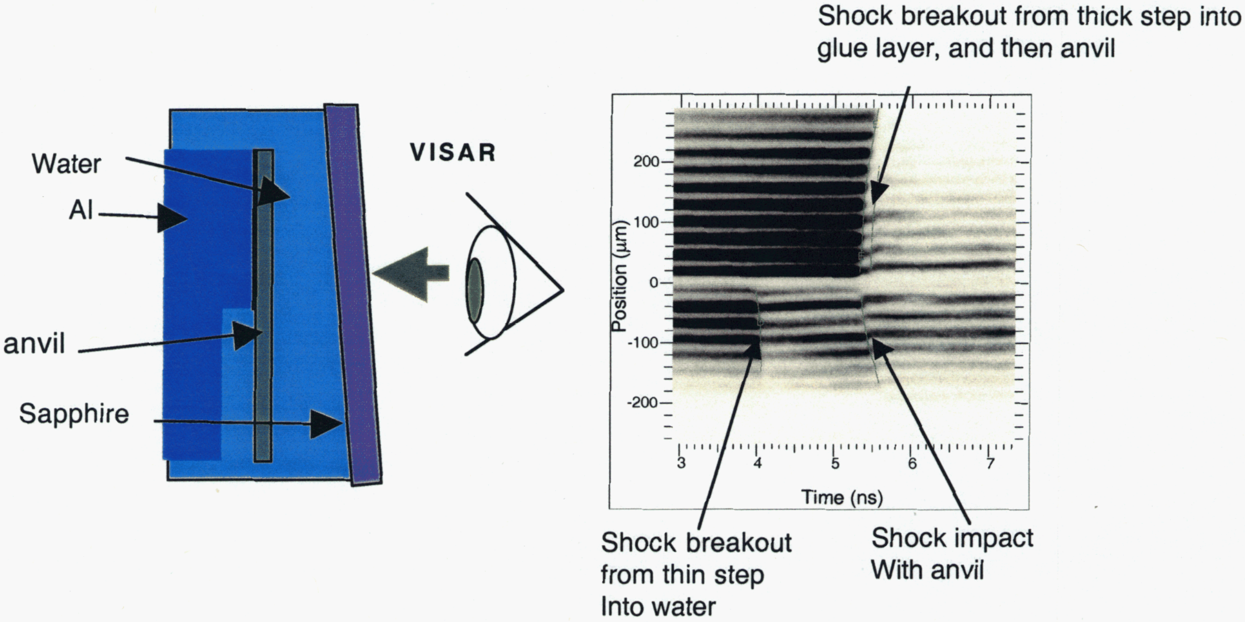

Fig. 1a. Image on right shows sample VISAR data record from the target design shown on the left. In the VISAR record, time goes to the right and distance across the target is up down. The fringe position (fringes are the horizontal lines) are directly proportional to velocity. In this record we measure shock velocity in the aluminum from the step breakout times and known step thickness, the shock velocity in the anvil, and the shock velocity in the water. Using impedance matching techniques we obtain the double shock EOS.

In parallel with reshock experiments, we successfully completed our first set of precompressed experiments where a single shock Hugoiot measurement was performed on water initially squeezed to high initial density in a diamond anvil cell. These experiments were described in the third attached paper, "Using Vulcan to Recreate Planetary Cores ." Even modest precompression provides a large change in shock densities and significantly lower shock temperatures for constant laser drive.

Finally, this new technique for accessing extreme pressures and densities was applied to Hydrogen. This work and corresponding implications are described in the final enclosed document "Coupling static and dynamic compressions with a laser shock in a diamond anvil cell and the properties of dense fluid hydrogen." This novel experimental technique has opened a new class of high gamma and finite temperatures experiments critical for understanding planetary and astrophysical objects. Armed with these techniques and data we are ready to use NIF to measure the core state of Jupiter.

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[1] Hubbard, W. B. Science 214, 145(1981). Hubbard, W. B. Guillot, T., Lunine, J. I., Burrows, A. Saumon, D., Marley, M. S., & Freedman, R. S. 1997, Phys. Plasmas 4, 2011

[2] G.W. Collins, L.B. Da Silva, P. Celliers, D.M. Gold, M.E. Ford, R.J. Wallace, A. Ng, S.V. Weber, K.S. Budil, and R. Cauble, Science **281**, 1179(1998).

[3] N. W. Ashcroft, *Phys. World* **8**, 43 (July, 1995).

[4] S. Ishimaru, Rev. Mod. Phys. **65**, 255 (1993).