SAND2016-5730C

Exceptional service in the national interest

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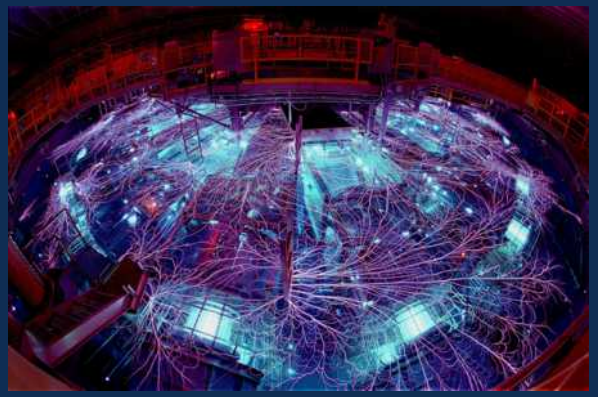

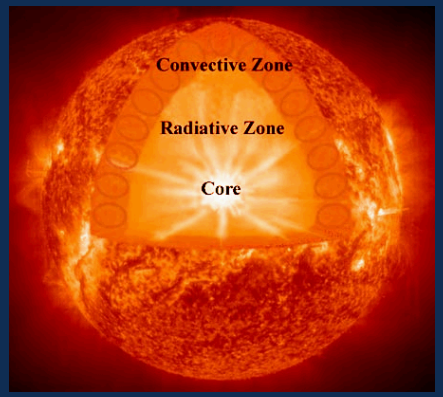

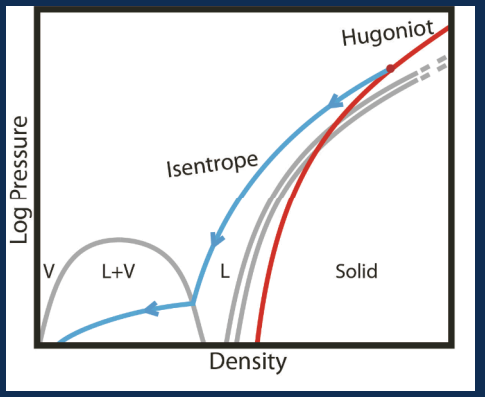

Dynamic High Pressure Materials Research on Sandia's Z-Machine

SAND2016- C

Thomas Mattsson

Manager, HEDP Theory

NNSA/CEA Workshop on Materials Science Collaborations, APS/Argonne, June 14-15, 2016.

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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MHD: currents and the corresponding magnetic fields can create high energy density matter

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Current x magnetic field

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t}+(\mathbf{u}\cdot\nabla)\mathbf{u}\right)=\frac{\mathbf{J}\times\mathbf{B}}{c}-\nabla P\approx\frac{1}{4\pi}\mathbf{B}\bullet\nabla\mathbf{B}-\nabla\left(P+\frac{B^2}{8\pi}\right)$$

velocity field

Pressure

Magnetic field as scalar pressure

- Using pulsed power (current) as a source has advantages
  - *Can create high pressures without making material hot*
  - Generated over long time scales with control over the time history
  - Large samples and energetic sources (2 MJ to load of 20 MJ stored)
  - Low price - $4/Joule stored for refurbishment in 2007
- Integrated projects with theory/simulations/experiment
  - Develop, design, analyze, and optimize experiments

Isentropic compression and shock wave experiments map different regions of phase space

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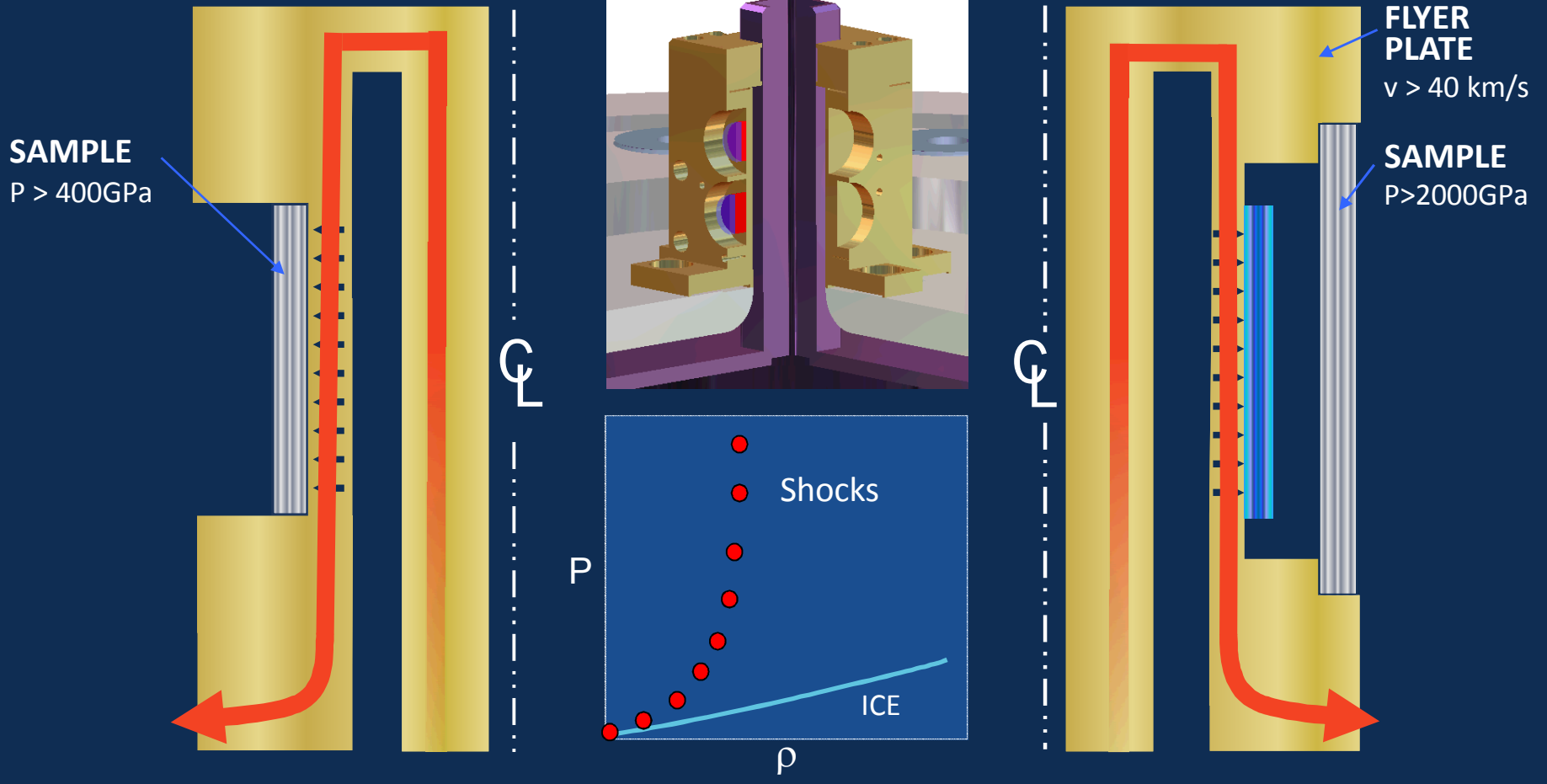
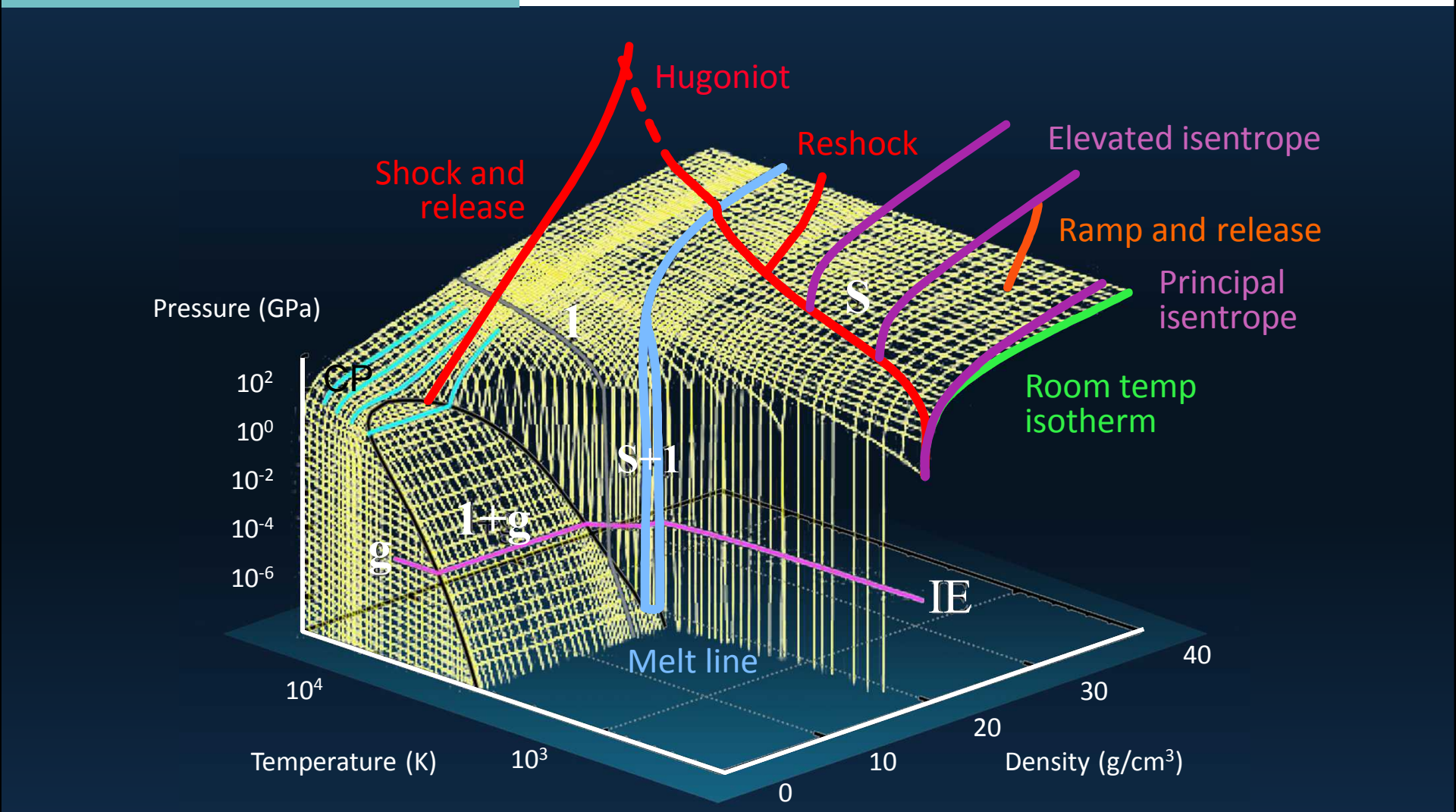


Isentropic Compression Experiments:
Gradual pressure rise in sample

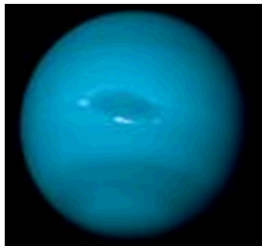
Shock Hugoniot Experiments:
Shock wave in sample on impact

Dynamic compression experiments on Z can probe large regions of a material's equation-of-state surface

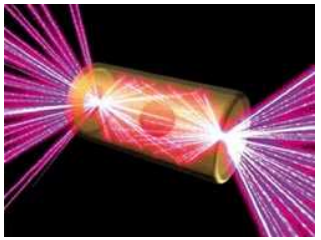


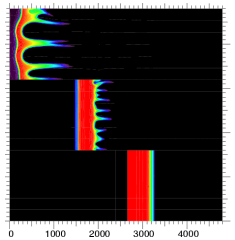
Properties of matter under HED (High Energy Density) conditions are important to many physical problems

- **Planetary science – Jupiter, Saturn, Uranus, Neptune, and exo planets [e.g. hot Neptunes]**
  - Water in 2005-2012: 2 Phys Rev Letts and 2 Phys Rev B
  - Metallization of hydrogen/deuterium: Science 2015
- **Planetary science – earths and super-earths**
  - Silicates, MgO (Phys. Rev. Lett. 2015), and iron/iron alloys
  - Determining the vaporization threshold for iron – and implications for planetary formation, Nature Geoscience 2015.
- **Materials for Stockpile Stewardship, HED and inertial confinement fusion (ICF)**
  - Investigating the periodic table from Aluminum to Zirconium: a broad range of materials are of interest - a talk in itself
  - *The programmatic work drives precision – we rely on the data!*



We aim to turn planetary science *quantitative* by high fidelity modeling and high-precision experiments





ICF concepts: laser driven Hohlraum and MagLIF

The Z Fundamental Science Program has created strategic partnerships with dozens of leading institutions

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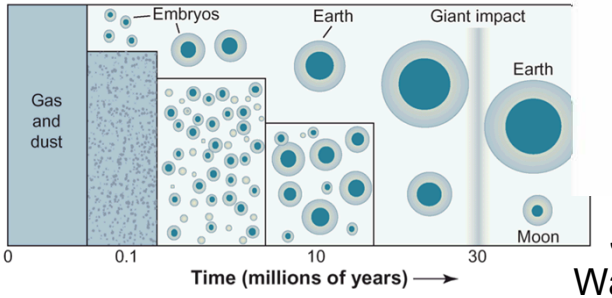
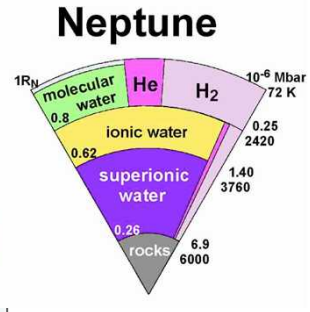
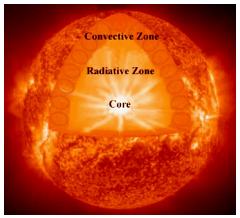


Earth and super earths
Properties of minerals and metals



Jovian Planets
Water and hydrogen



Stellar physics
Fe opacity

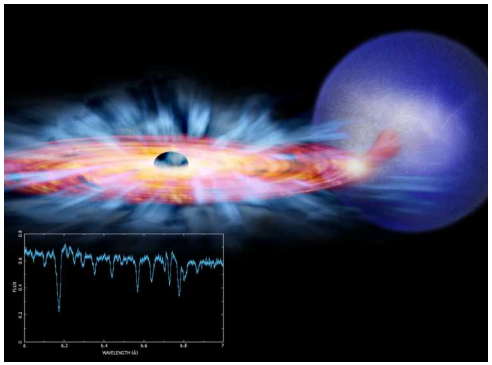


Photo-ionized plasmas
Range of ionization param. ξ

- **Opportunities for collaboration and access to Z**
- **Competitive proposal process**
- **Science with significant impact**
  - Bailey et al, Nature (2015)
  - Kraus et al, Nature Geoscience (2015)
  - Knudson et al, SCIENCE (2015)
  - 1 PRL, 3 PoP, 1 PRA, 1 PRB, and 8 other peer-reviewed publications
- **Workshops most years since 2009!**

2016 ZFSP workshop

Sunday 7/31/16 (eve.) to Wednesday 8/3/16,

Hotel Andaluz,

Albuquerque, NM.

Future directions - build on our strengths and develop new capabilities for diagnostics, drive, and analysis

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- Strengths in dynamic research on Z
  - *Can create high pressures without making material hot*
  - Generated over long time scales with control over the time history
  - Large samples that allow a range of material conditions – variations of grain sizes and other meso-scale phenomena
  - Cross-platform comparisons between Z, guns, HE, and lasers as a possible area of collaboration
    - *Equilibrium properties and phase transitions*
    - *Effect of time scales*
    - *Effect of length scales*

Backup slides

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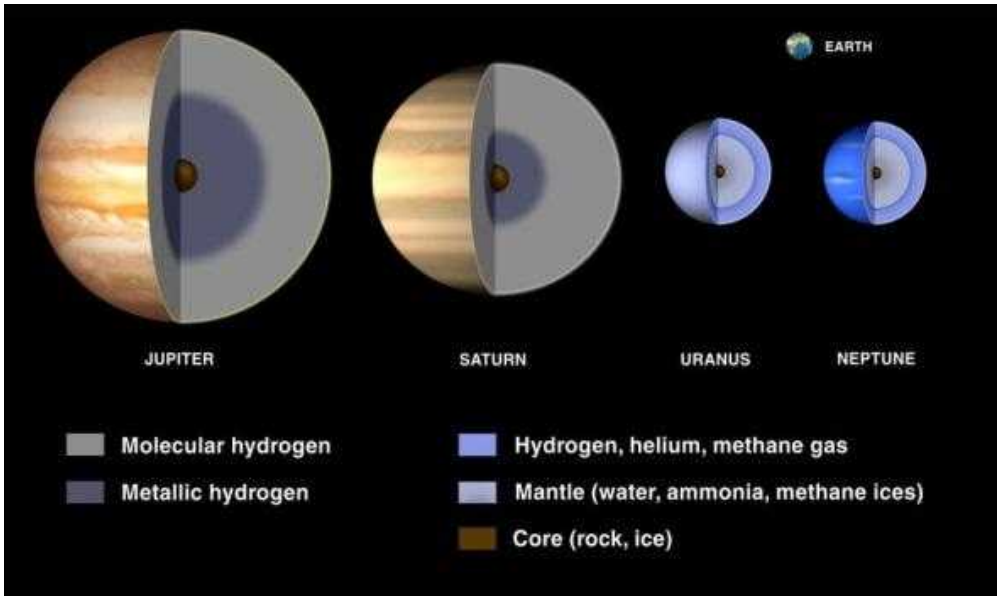
Understanding the properties of hydrogen is crucial for understanding giant planets



- **Present structure**
  - Layers of different composition while fulfilling observational constraints
- **Evolution**
  - Discrepancies in modeling the evolution of Jupiter and Saturn – the “Saturn age problem”
  - Why is Saturn so luminous?
- **Magnetic fields**
  - Origin of multi-polar fields in Neptune and Uranus

We have located the Liquid-Liquid Insulator-to-Metal Transition in deuterium to be a steep curve at 300 GPa

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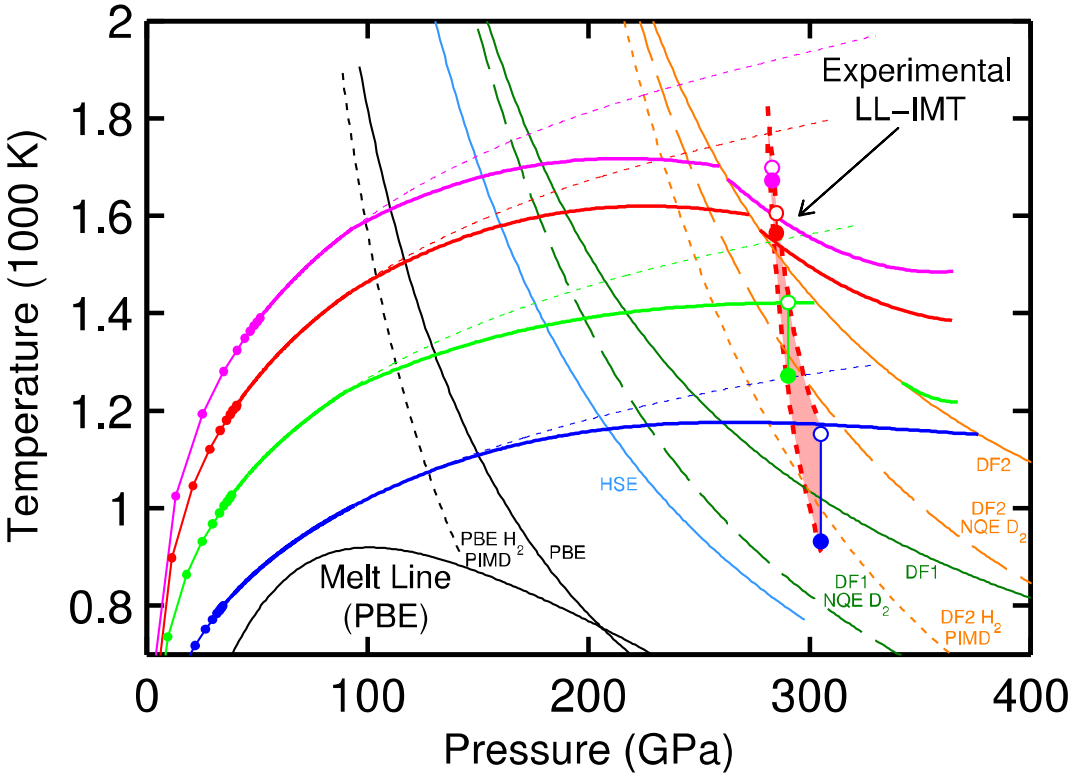

M.D. Knudson, M.P. Desjarlais, A. Becker, R.W. Lemke, K.R. Cochrane, M.E. Savage, D.E. Bliss, T.R. Mattsson, and R. Redmer, Science **348** 1455, 26 June 2015.

- **Experiments used a new shock + ramp drive to scan this space**
- ***Insensitivity to T suggests this is a ρ-driven transition***
  - ρ at the transition is inferred to be ~2-2.1 g/cc in deuterium
  - Qualitatively different transition than in shock experiments (T driven)
- **Broad team with expertise in diagnostics, pulse-shaping, experimental design, and first-principles simulations**
- **A project within the Z Fundamental Science Program**
  - Professor Ronald Redmer's group at University of Rostock

Although impacts come in all speeds and sizes – we have focused on giant impacts

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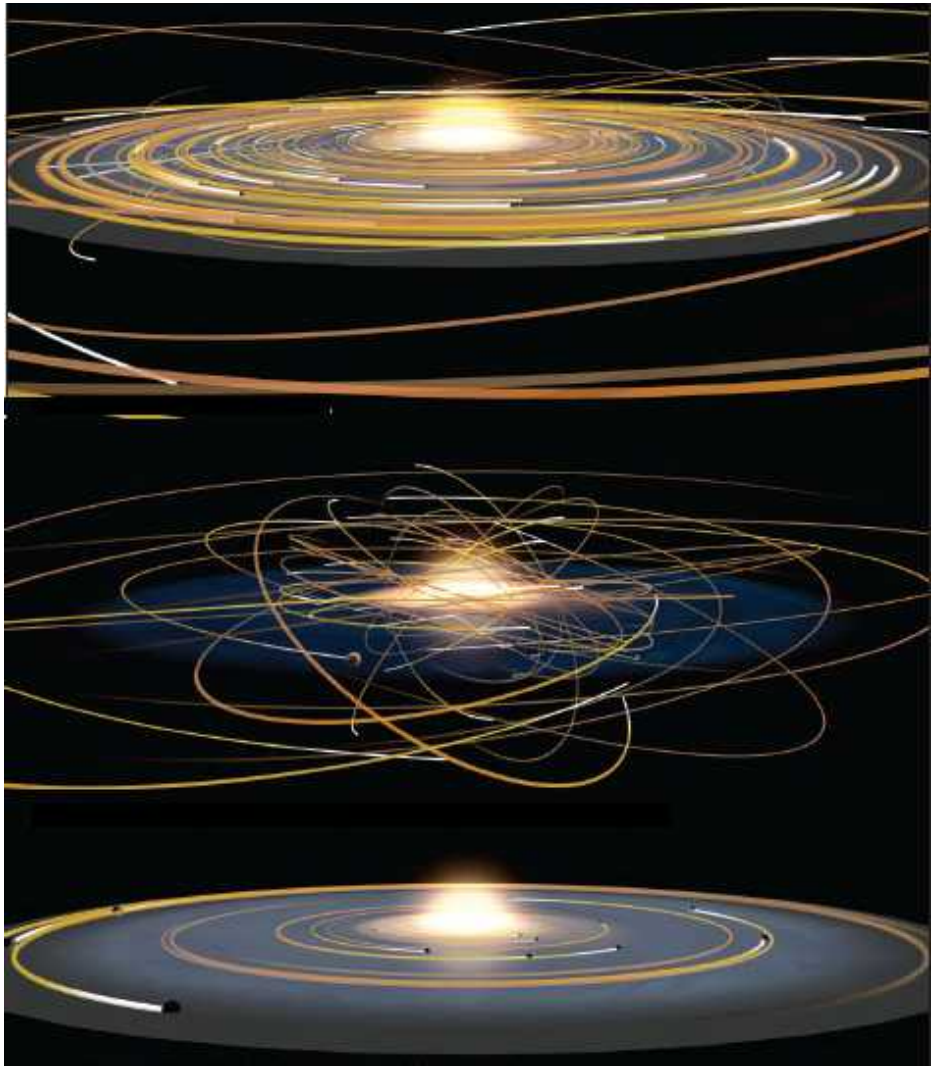


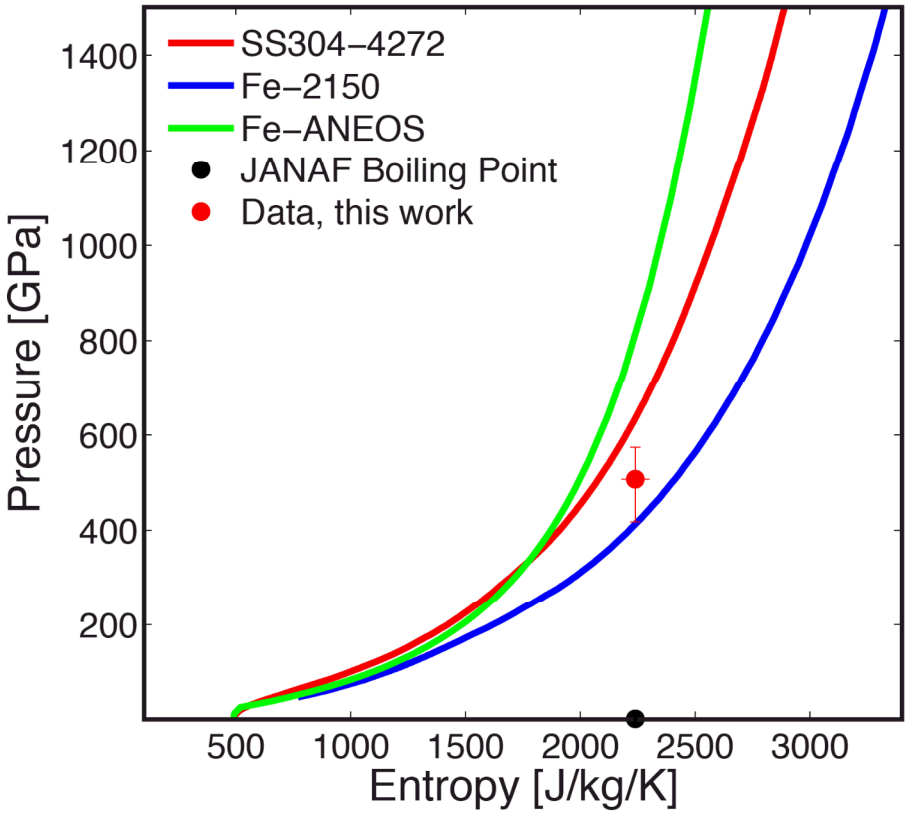
Dust particles impacting at fractions of miles per hour

Boulders colliding at a few miles per hour

City sized planetesimal collisions

Moon sized giant impacts

One of the first determinations of the thermal state of an opaque material on the Hugoniot



- ***Vaporization is significantly easier than ANEOS suggests-the most broadly used model***
- **A project within the Z Fundamental Science Program**
  - **Stein Jacobsen, Harvard**
  - **Sarah Stewart at UC Davis**
  - **Rick Kraus, LLNL**

Impact vaporization of planetesimal cores in the late stages of planet formation, R.G. Kraus, S. Root, R.W. Lemke, S.T. Stewart, S.B. Jacobsen, and T.R. Mattsson, Nature Geoscience 2015 DOI: 10.1038/NGEO2369

The Z Fundamental Science Program engages a broad international community and has advanced HED science

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- **Resources/shots on Z over 5 years**
  - 50+ dedicated ZFSP shots (~5% of all Z shots)
  - Ride-along experiments on program shots
- **Science with far-reaching impact**
  - 1 Nature, 1 Nature Geoscience, 1 SCIENCE
  - 1 Phys. Rev. Lett, 3 Physics of Plasmas, 2 Physical Review (A,B) , 9 others
- **Popular outreach**
  - National Public Radio, “All things considered”, Joe Palca 3/6/2014
  - MIT Technology review, 10/4/2012
  - Discover Magazine
    - Reportage 9/16/2012
    - *Iron rain #62 in top 100 Science stories in 2015*
  - Local TV coverage (7-KOAT, 13-KRQE) in early 2015
- **New external funding won**
  - DOE/OFES/HEDLP
- **Students and postdocs**
  - 4 M.Sc. Exam, 2 Ph.D. exams
  - 5 postdocs

The ZFSP and collaborations with academic groups greatly benefits Sandia's and NNSA's mission on both short- and long term

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- **Supporting HED science**
  - Students and groups active in topics of importance to the national laboratories
- **Growth in the HED science community**
  - New funding won by teams
  - Active participation in the academic community of HED science – attracting new academic partners
  - Scientific discoveries make the field attractive
- **Direct methods development**
  - The platform for shock- and vaporization experiments developed jointly with Harvard/UC Davis is now our standard load for science campaign experiments
  - The work on Fe opacity has served an important role for platform development and provides international peer review
- **Development of technical staff**
  - An opportunity for Sandia staff to do leading research and participate fully in the international research community

A future Sandia machine at 40-50 MA creates a capability gap - an opportunity for mid-scale facilities

The Z Fundamental Science Program has grown over the last few years

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ZFSP past and present

- IHEDS 2009-2010 workshops in SF
- 2010 – call for proposals and review
- 2011 – 15 dedicated shots on Z
- 2012 – 20 dedicated shots on Z
- 2013 – NNSA/NA-11 pause
- 2014 – Restart of ZFSP
- 2014 – External review of the program and extension for CY15 shots
- 2015 – 18 shots on the schedule
- 2016 – 12 shots planned (FY16 is tight)
- 2017 – TBD with a goal of 20 shots

- **Workshops**
  - 2009 Hilton, Santa Fe
  - 2010 Eldorado, Santa Fe
  - 2011 Eldorado, Santa Fe
  - 2012 Andaluz, Albuquerque
  - 2014 Andaluz, Albuquerque
  - 2015 Hyatt, Albuquerque

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