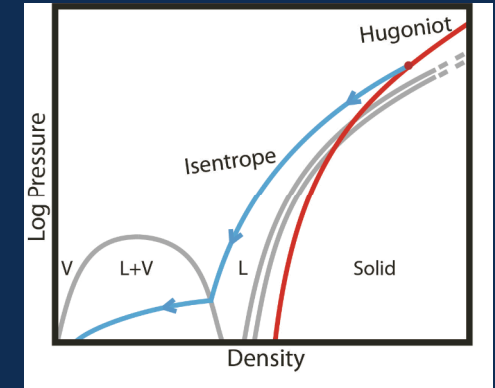
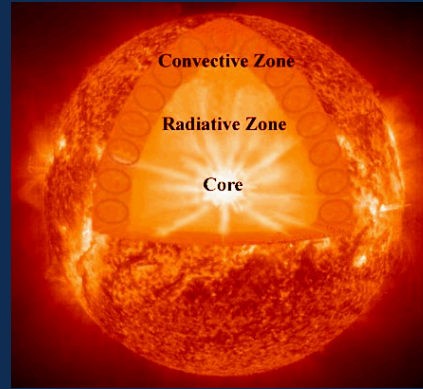
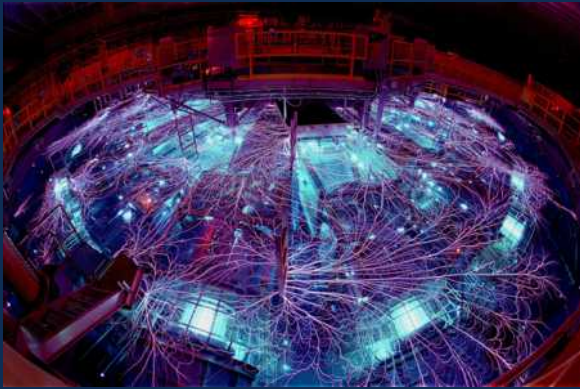


*Exceptional service in the national interest*



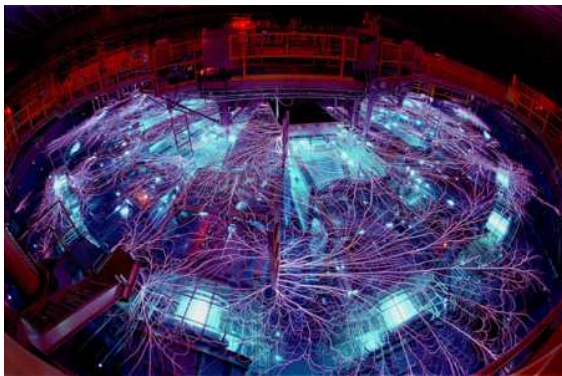
## HED Science at Sandia and the Z Fundamental Science Program (ZFSP)

**Mark Herrmann**

**Director, Pulsed Power Sciences Center  
Fundamental Science with Pulsed Power:  
Research Opportunities and User Meeting  
Albuquerque, NM July 20-23**

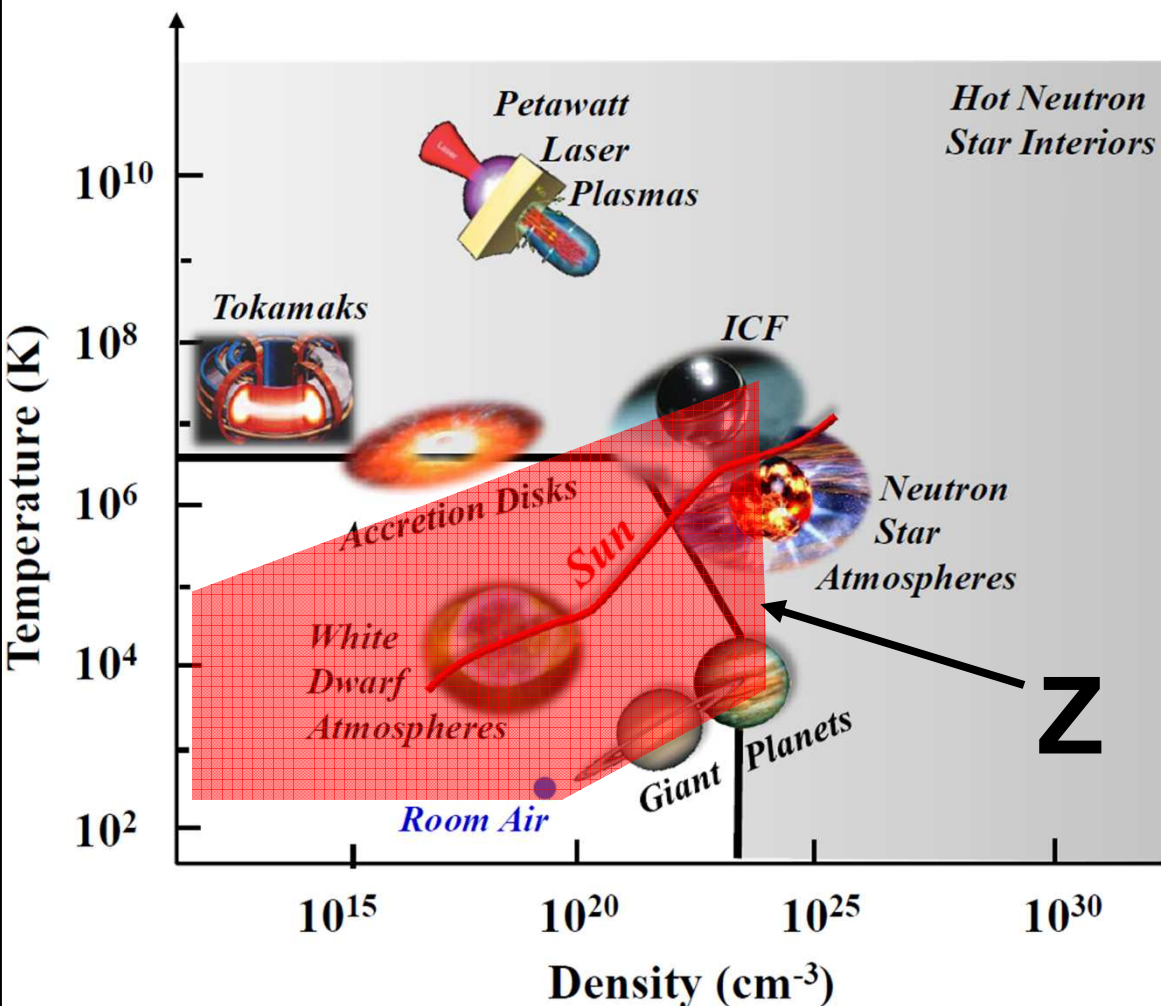
# HED Science and the Z Fundamental Science Program (ZFSP)

- **HED Science is a field with challenges that are of highest importance for the Nation**
  - Ensure a safe, secure, and reliable stockpile
  - Lead development in multiple research fields to avoid technological surprise
  - We depend on scientists that are capable of meeting these challenges



- **The ZFSP plays a key role in our strategy for the future**
  - Collaborate with leading scientists across the nation to solve grand-challenge problems
  - Provide access to a national flagship research facility
  - Engage our scientific staff in research with broad impact and importance for the general scientific community
  - Develop new innovative research methods and experimental platforms
  - Build relationships for recruiting the very best students and postdocs to Sandia and/or other NNSA labs

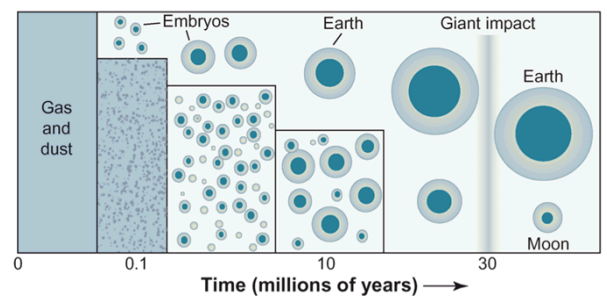
# The Z machine is the focal point of HED research at Sandia



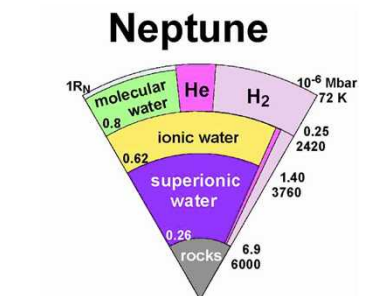
ZFPS performs exciting science in active fields

- Astrophysics
  - Age of white dwarfs
  - Structure of the sun
- Planetary science
  - Formation of star systems
  - Structure of Jupiter
- ICF
  - Magnetic fields change the game for fusion in the lab
- Materials at HED
  - Solids at multi-Mbar
  - Phase transitions

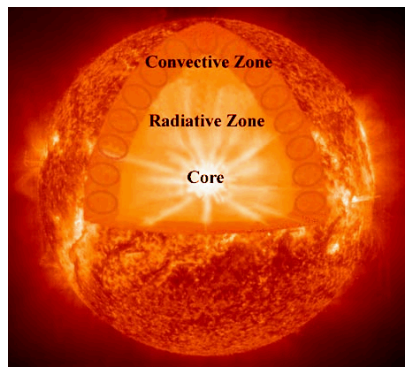
# The Z Fundamental Science Program engages a broad community and has advanced HED science



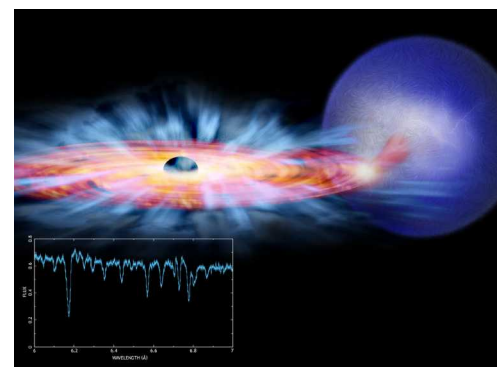
**Earth and super earths**  
Properties of minerals and metals



**Jovian Planets**  
Water and hydrogen



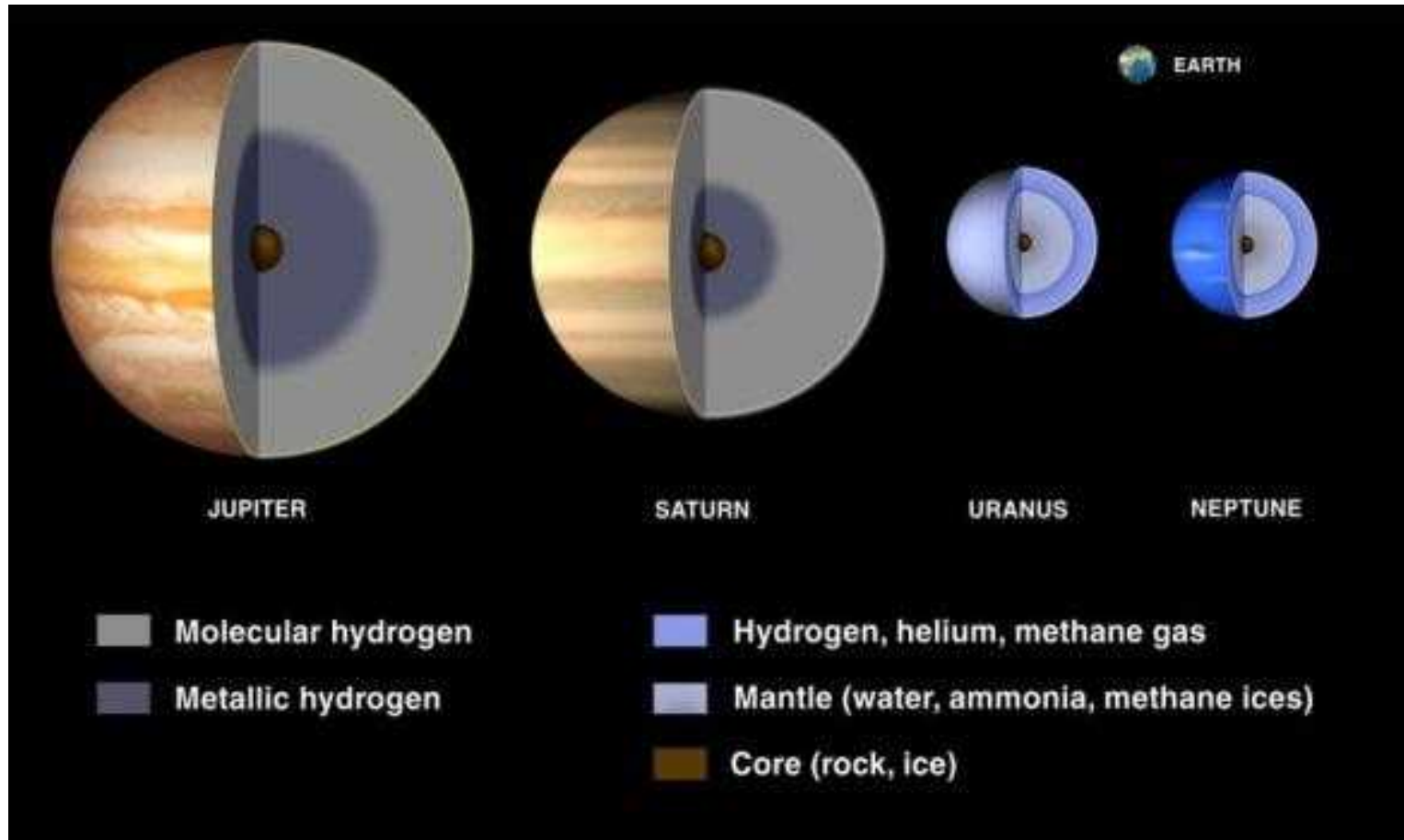
**Stellar physics**  
Fe opacity and H spectra



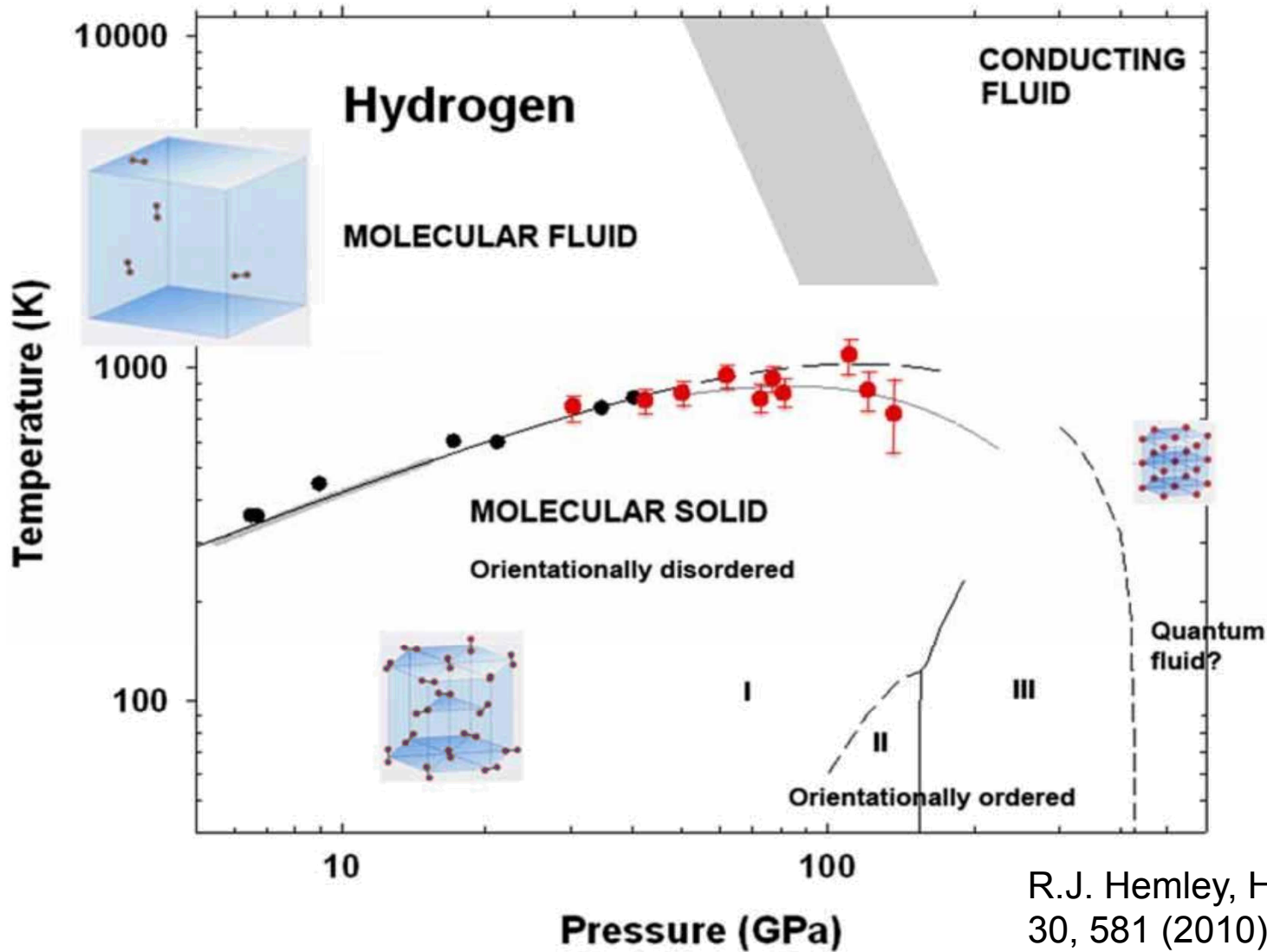
**Photo-ionized plasmas**  
Range of ionization param.  $\xi$

- **Resources/shots on Z**
  - 40 dedicated ZFS shots
  - 40 ride-along shots
- **Science with impact**
  - 1 Phys. Rev. Lett.
  - 3 Physics of Plasmas
  - 2 Phys. Rev. A / B
  - 8 other peer-reviewed publications
  - Very interesting manuscripts in progress
- **Popular outreach**
  - National Public Radio, “All things considered”, Joe Palca 3/6/2014
  - MIT Technology review, 10/4/2012
  - Discover Magazine, 9/16/2012
- **New external funding**
  - HEDLP for UT Austin, Harvard
- **Students and postdocs**
  - 4 M.Sc. Exam, 2 Ph.D. exams (May)
  - 5 postdocs
- **Review of the program in April**

# The properties of hydrogen are of key importance for the structure of giant gas planets



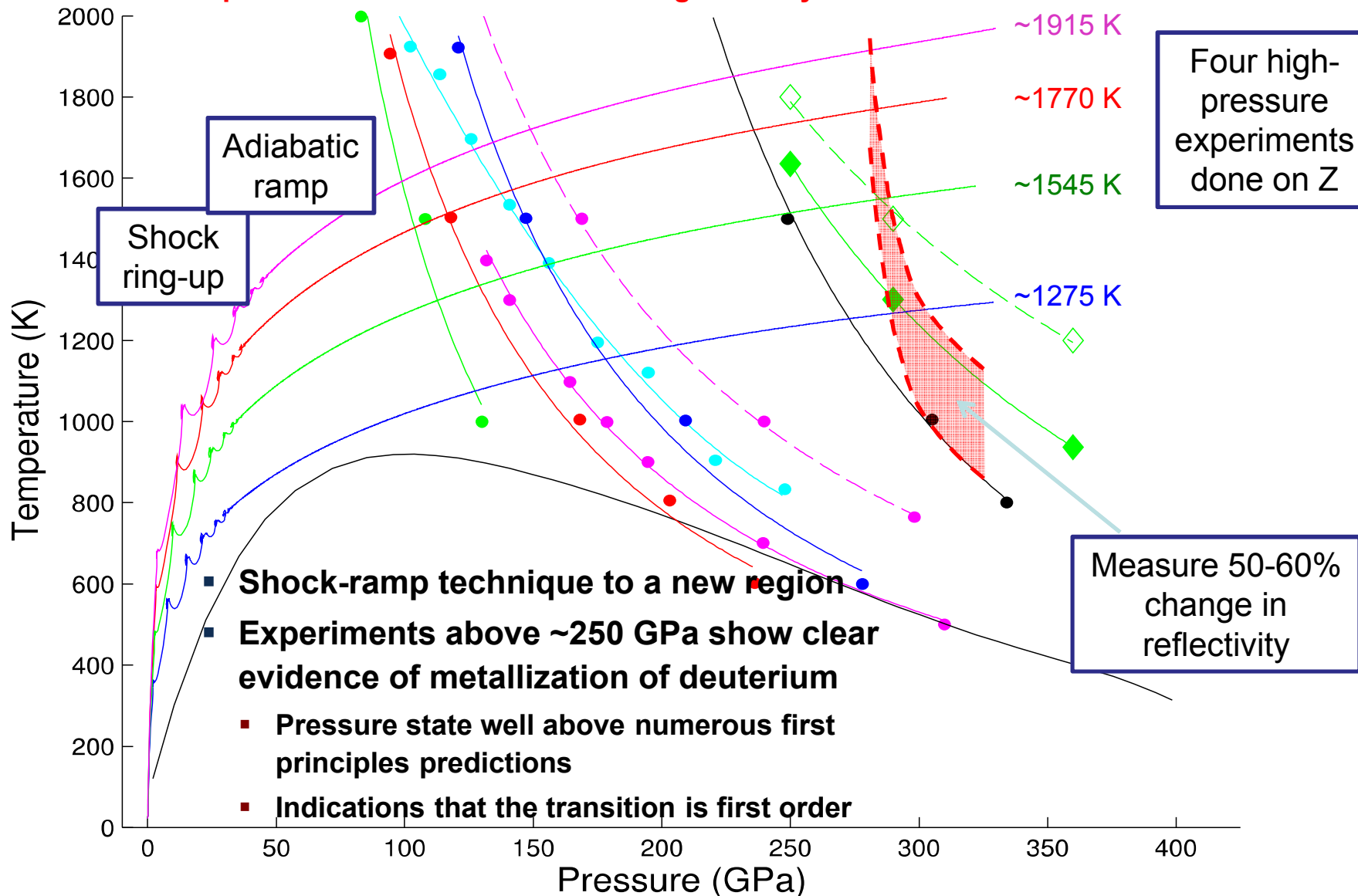
# A key region of the phase diagram of importance to planets has not been experimentally explored



R.J. Hemley, High Press Res. 30, 581 (2010)

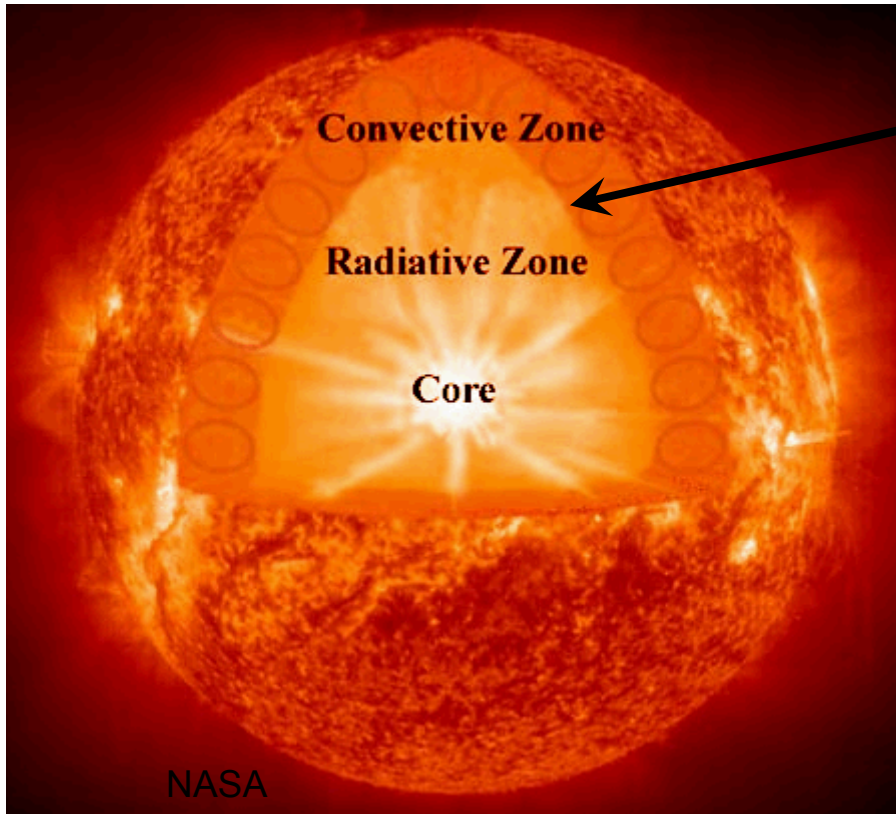
# Possible location of the LL-IMT in deuterium

Theoretical predictions of transition varies significantly between models



# Models for solar interior structure disagree with helioseismology observations.

## Convection-Zone (CZ) Boundary Models are qualitatively off



### Models depend on:

- Composition (revised in 2005\*)
- EOS as a function of radius
- The solar matter *opacity*
- Nuclear cross sections

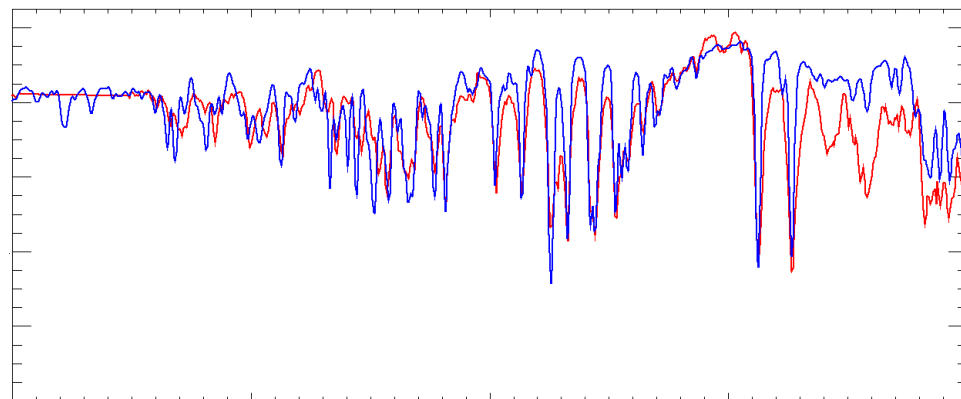
\*M. Asplund *et al*, Annu. Rev. Astro. Astrophys. **43**, 481 (2005).

**Question: Is opacity uncertainty the cause of the disagreement?**

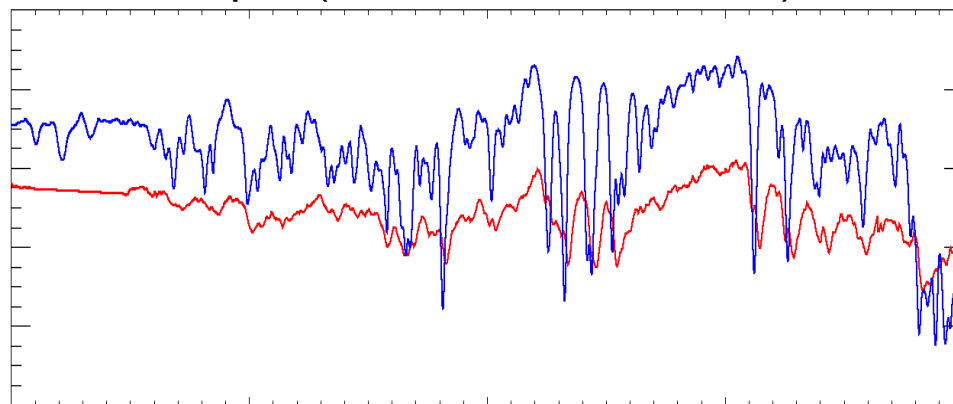
**Objective: Measure Fe opacity at CZ base conditions.**

# Modern computations of Fe opacity show large disagreements with data at CZ base conditions

Thin Tamper\* ( $156 \text{ eV}$ ,  $6.9 \times 10^{21} \text{ cm}^{-3}$ )



Thick Tamper ( $182 \text{ eV}$ ,  $31 \times 10^{21} \text{ cm}^{-3}$ )



Wavelength (Å)

## Present Status

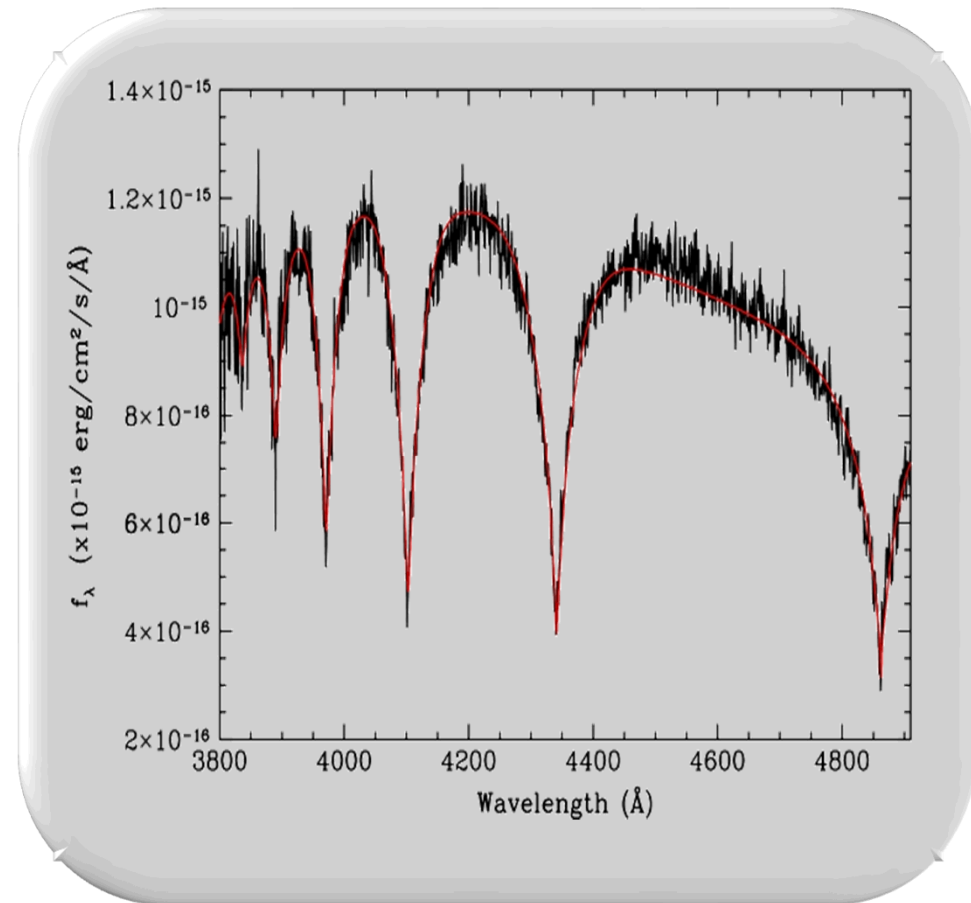
- Agreement between data and computation becomes worse at increasing temp. and dens.
- Disagreements at CZ base conditions can partially explain the CZ boundary problem.
- The differences are probably not unique to Fe

# The properties of White Dwarfs are determined by spectral fitting, but disagrees with other methods

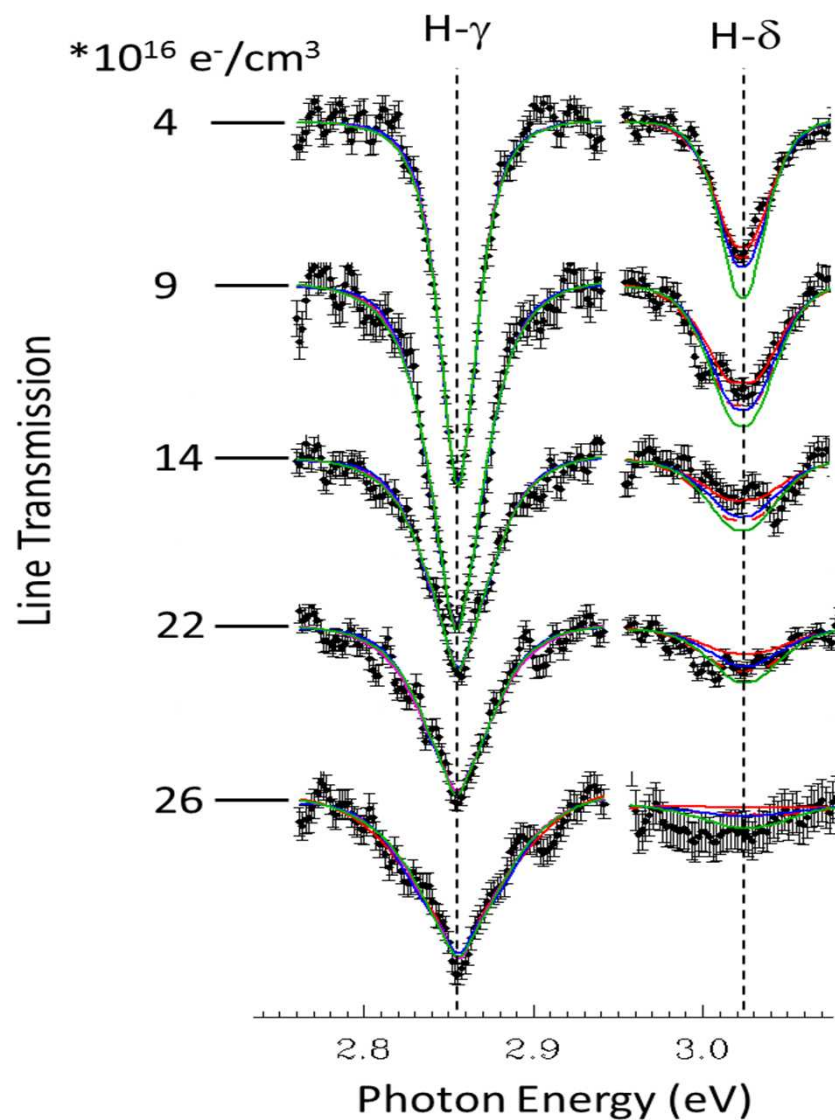


- **White Dwarfs are fundamentally important**
  - Evolutionary endpoint for ~98% of stars
  - Simple in structure and evolution
  - Cosmic laboratories (cosmochronology)
- **WD surface temperature and total mass are usually determined by fitting the observed spectra**
- **The spectroscopic method and gravitational redshift disagree by >10% in the stellar mass**

Spectral fit of WD J1916+3938\*



# The measured evolution of H-Balmer line shapes provides tight constraints on models



## Present Status

- Measurement of relative line-shapes up to  $n=7$  provides a strong constraint on models
- Additional measurements at higher density may be required to fully address the WD problem
- Continued scrutiny on the data is prudent:
  - Reproducibility of the result
  - Plasma uniformity

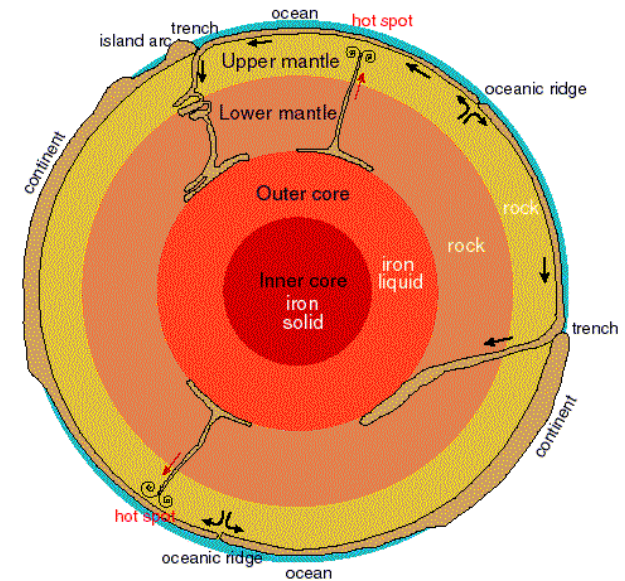
# The structure of rocky planets is complex

## Rocky exoplanet observations

- Mass, radius, & atmosphere
  - interior structure & composition
- Collision products (gas & dust)
  - recent giant impacts

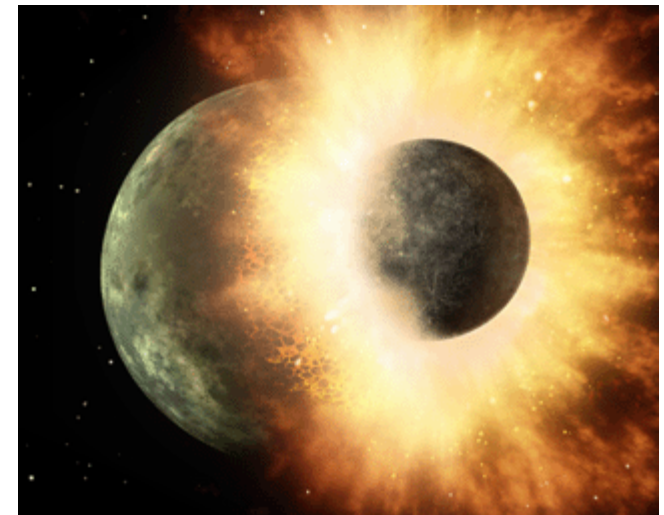
## Formation and evolution of rocky planets

- Coupled to surface conditions and habitability
- High pressure and temperature phases, thermophysical properties, and chemistry
- Earth's initial condition after formation by giant impacts and the origin of the Moon

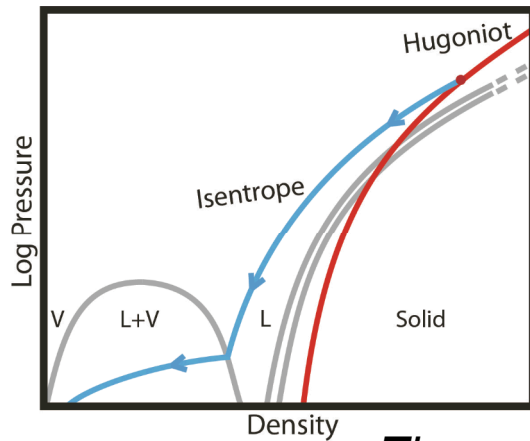


## Using Z brought a lot of advantages

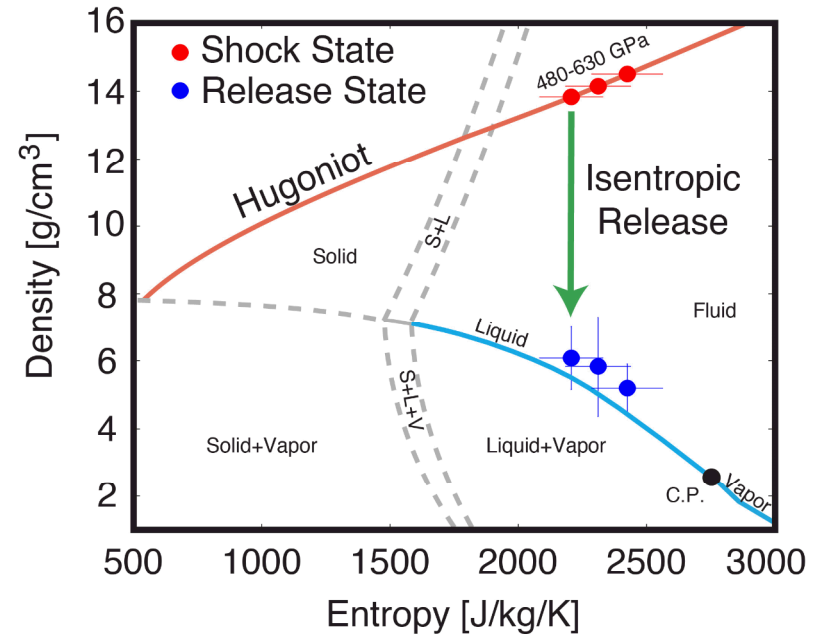
- Pressure-temperature range not achievable on gas guns and smaller laser platforms
- Experimental technique requires long durations and target sizes



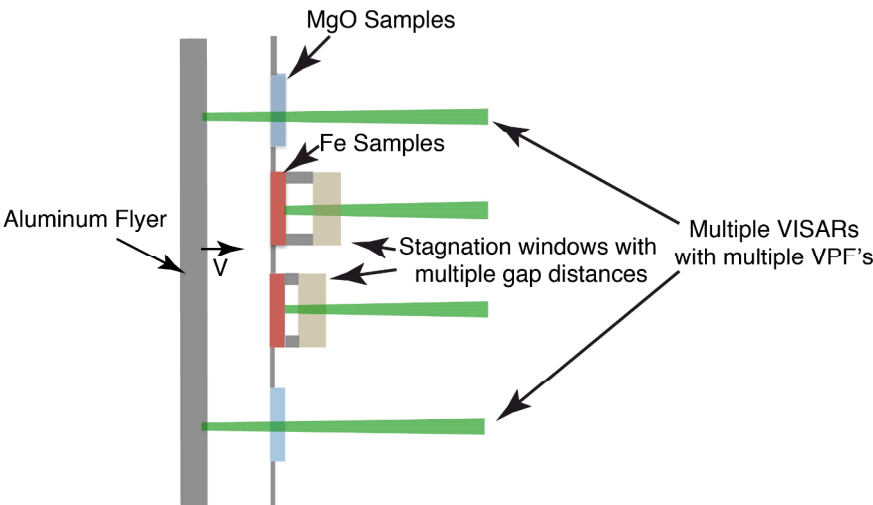
# Shock-vaporization of iron – a reverse impact experiment stagnating iron vapor-liquid onto a window



*Thermodynamics of the experiment*



We find that the shock-pressure required to vaporize iron upon release is 507 (+67,-90) GPa  
Submitted to Nature Geoscience



*Design of the target assembly*

# ZFSP has played a big role in Z reaching a broader audience in academic research and the public

## Research on Z featured in

- NPR
  - All Things Considered
  - STARDATE
- Nature news article MagLIF results
- Multiple press interactions
- Physics Today article in June, 2014



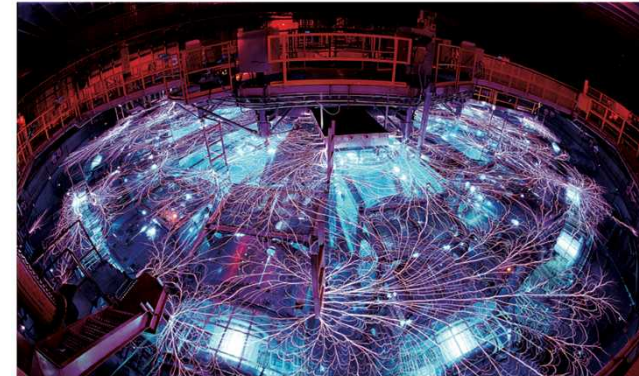
## NEWS IN FOCUS

**CLIMATE** Water will be scarce in warmer world, huge study says [p.10](#)

**PHYSICS** With \$50 million spent, X-ray source is now out in the cold [p.11](#)

**2014** Transgenic monkeys, comets and more will make the news this year [p.13](#)

**EPIDEMIOLOGY** A scientist's bid to track down the roots of aggression [p.14](#)



The intense electrical discharge of the Z machine at Sandia National Laboratories in New Mexico is used in attempts to trigger nuclear fusion.

PLASMA PHYSICS

## Triple-threat method sparks hope for fusion

*The secrets to its success are lasers, magnets and a big pinch.*

BY W. WAYT GIBBS

The Z machine at Sandia National Laboratories in New Mexico discharges the most intense pulses of electrical current on Earth. Millions of amperes can be sent towards a metallic cylinder the size of a pencil eraser, inducing a magnetic field that creates a force — called a Z pinch — that crushes the cylinder in a fraction of a second.

Since 2012, scientists have used the Z pinch to implode cylinders filled with hydrogen isotopes in the hope of achieving the extreme temperatures and pressures needed for energy-generating nuclear fusion. Despite their efforts, they have never succeeded in reaching ignition — the point at which the energy gained from fusion is greater than the energy put in.

But after tacking on two more components, physicists think they are at last on the right path.

Researchers working on Sandia's Magnetized Liner Inertial Fusion (MagLIF) experiment added a secondary magnetic field to thermally insulate the hydrogen fuel, and a laser to pre-heat it (see "Feeling the pinch"). In late November, they tested the system for the first time, using 16 million amperes of current, a 10-tesla magnetic field and 2 kilojoules of energy from a green laser.

"We were excited by the results," says ▶

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## **The ZFSP plays a key role in our research strategy**

- This workshop an opportunity for furthering research directions
- Continue with present projects for experiments in CY15
- Issue a call for proposals for experiments in CY16
- Pursue collaborations at Universities and other facilities

## **Challenges**

- **National ICF review in FY15**
  - Key moment for the national ICF program
  - This review could significantly reshape NNSA's High Energy Density Science efforts.
- **NNSA/Congress priorities**
  - Future role of fundamental science in the stockpile stewardship program
- **Shot days on Z are precious**
  - Intermediate scale facility
  - Collaborations at Universities and other HED facilities