SAND2016-10868C

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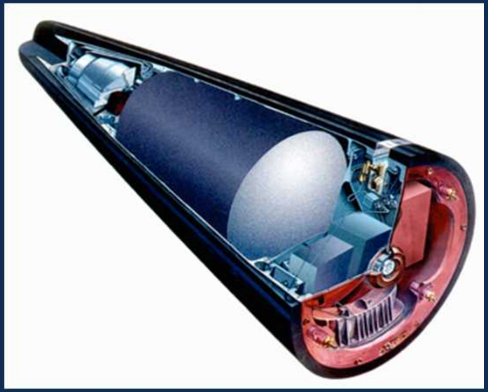

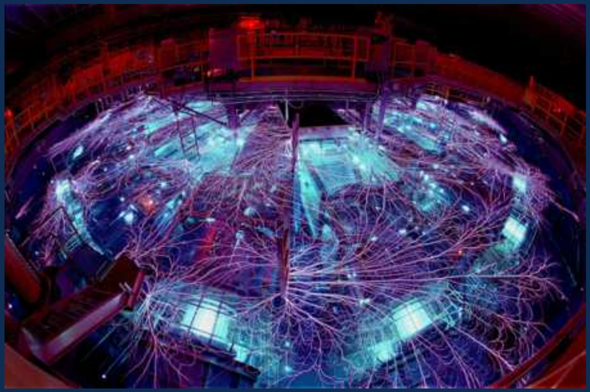

HEDSA with Pulsed Power

Keith Matzen

Pulsed Power Sciences Center

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10/29/2016

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

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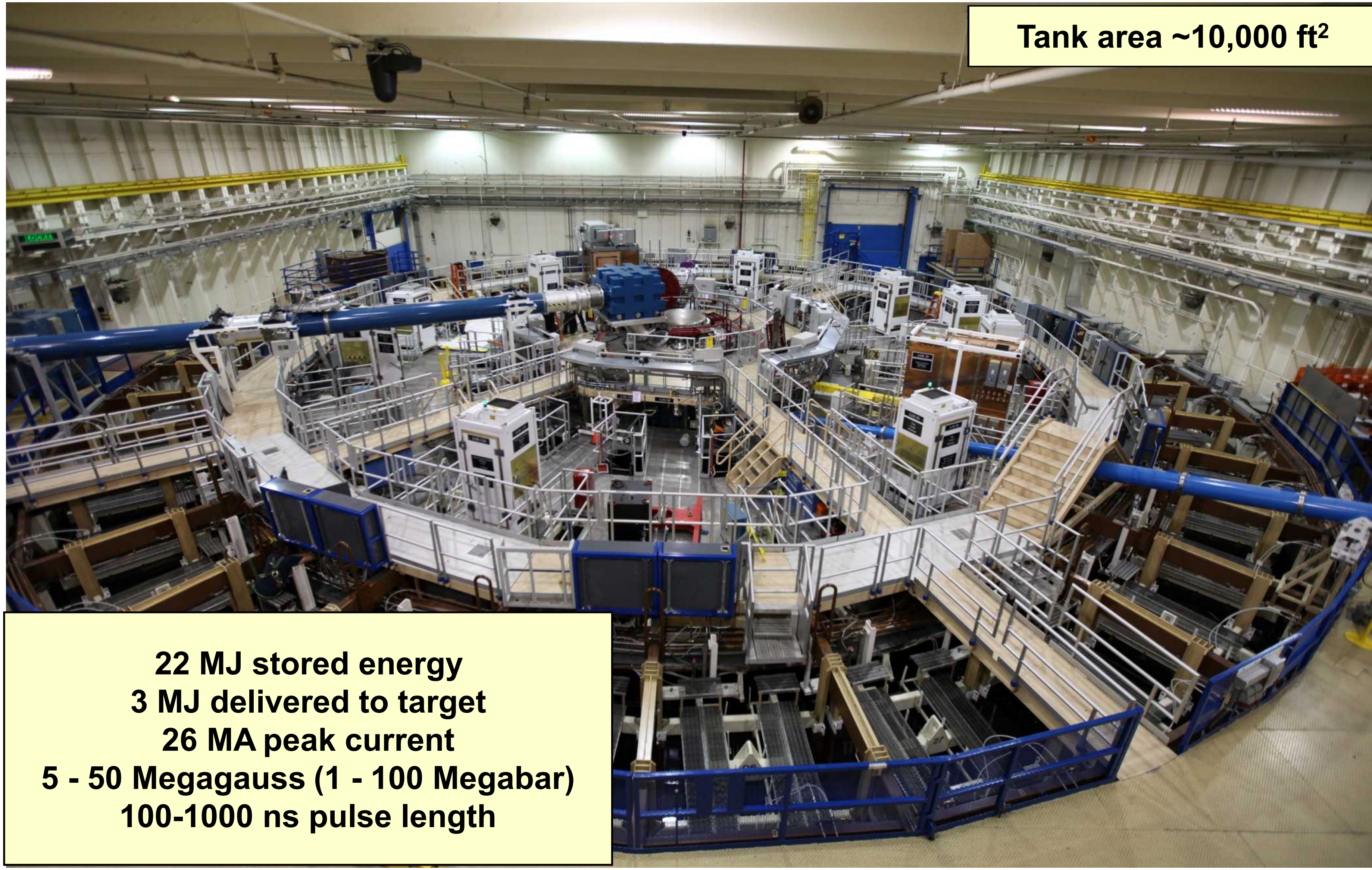
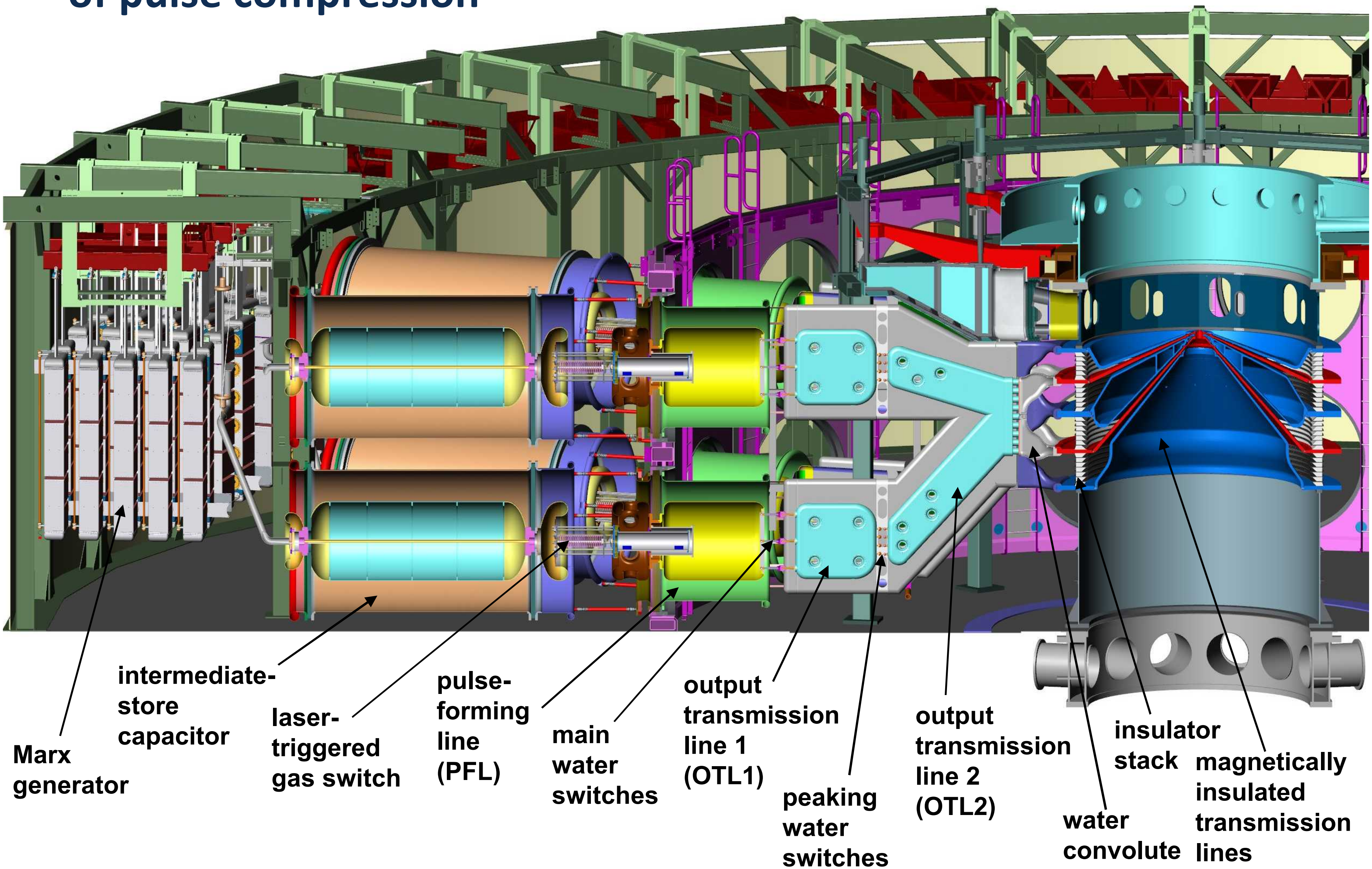
The Z pulsed power facility generates HED conditions by generating large magnetic fields



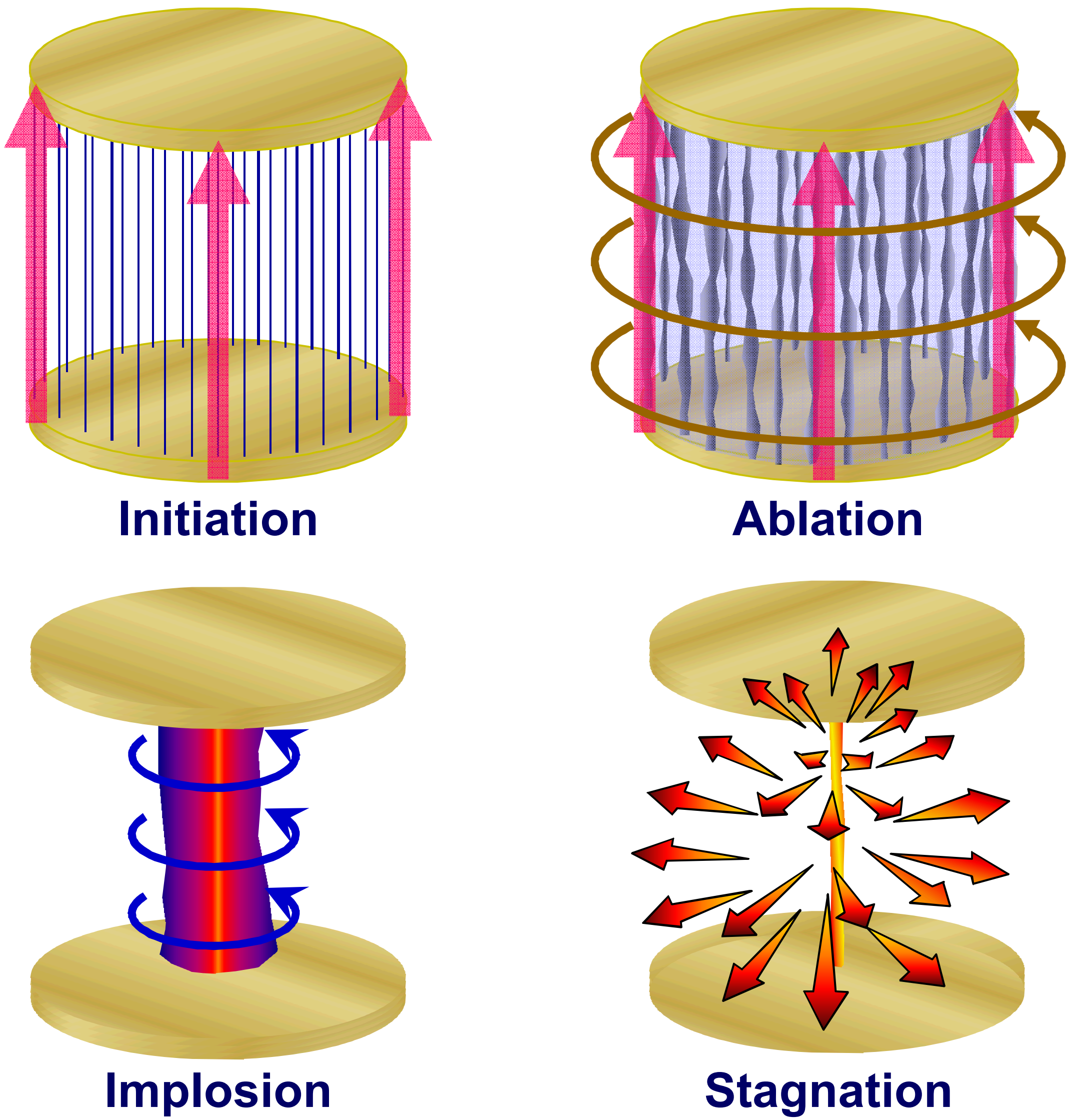
Tank area ~10,000 ft^2

22 MJ stored energy
3 MJ delivered to target
26 MA peak current
5 - 50 Megagauss (1 - 100 Megabar)
100-1000 ns pulse length

Each of Z's 36 modules perform several stages of pulse compression

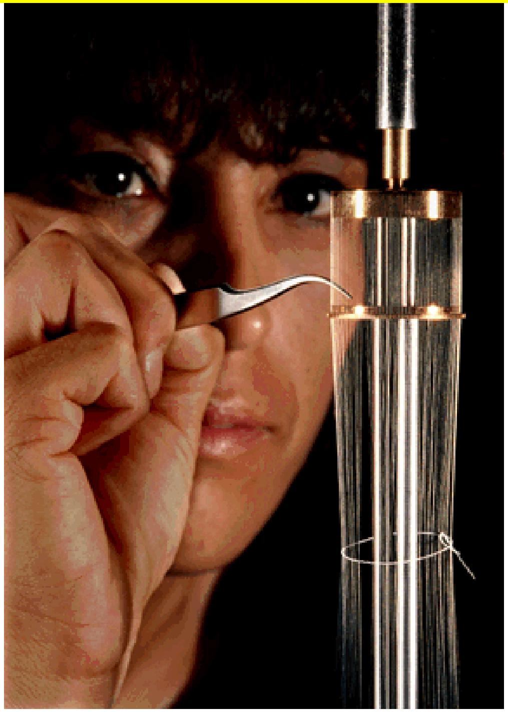


Magnetically-driven z-pinch implosions efficiently convert electrical energy into radiation



On Z:

- **Energy: x-ray ≈15% of stored electrical**
- **Power: x-ray ≈2- 4 times electrical**



High current pulsed power accelerators drive many different load configurations

High Current

Z-pinch x-ray source

High Z

Hohlraum source (Planckian)

- ICF
  - Ignition & high yield
- Shock physics
- Fundamental science

Low to mid Z

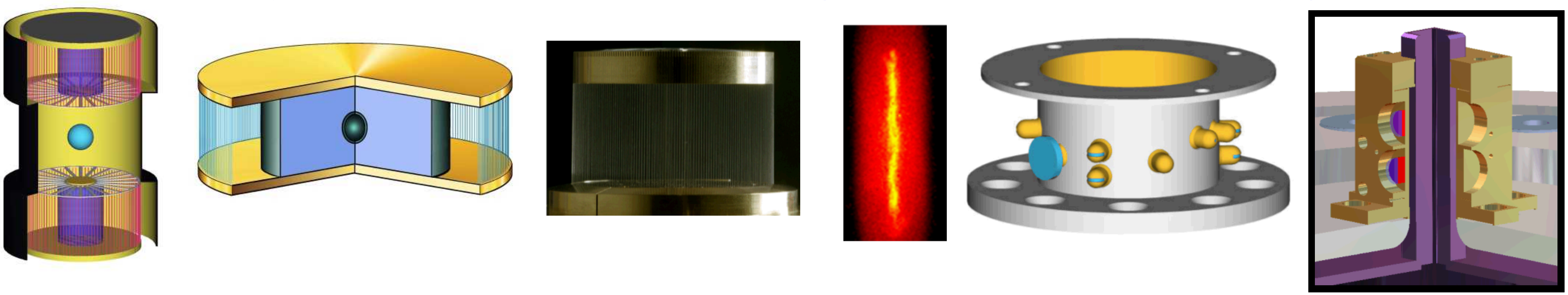
K-shell source (Non-Planckian)

- Radiation-material interactions
- Fundamental science

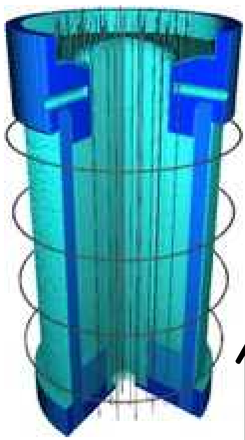
Magnetic pressure

- Isentropic Compression Experiments (ICE)
- Flyer Plates
- Fundamental science

ICF ⟷ RES ⟷ EOS

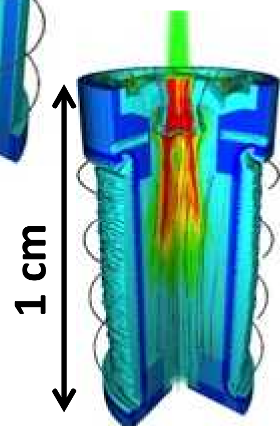


MagLIF (Magnetized Liner Inertial Fusion) is our principal approach to pulsed power fusion



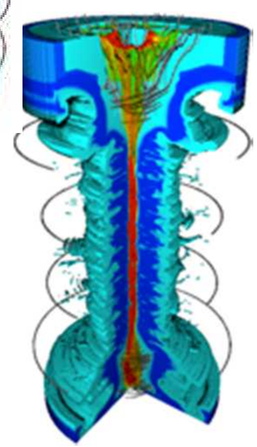
Axial Magnetic Field (10 T initially; 30 T available)

- Inhibits thermal losses from fuel to liner
- May help stabilize liner during compression
- Fusion products magnetized



Laser heated fuel (2 kJ initially; 6-10 kJ planned)

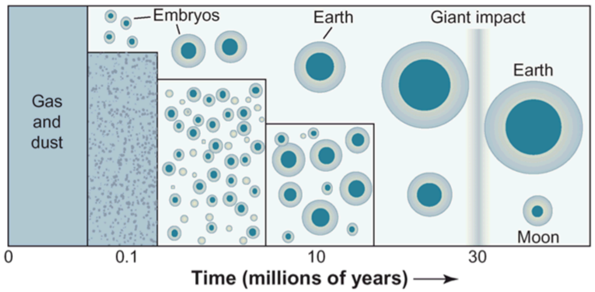
- Initial average fuel temperature 150-200 eV
- Reduces compression requirements (R_0/R_f ~ 25)
- Coupling of laser to plasma in an important issue



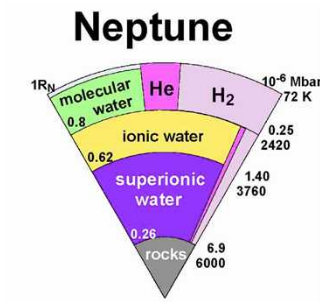
Magnetic compression of fuel (~100 kJ into fuel)

- ~70-100 km/s, quasi-adiabatic fuel compression
- Low aspect ratio liners ($R/\Delta R$~6) are robust to hydrodynamic (MRT) instabilities
- Significantly lower pressure/density

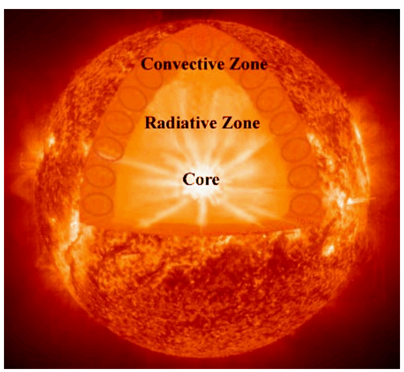
The Z Fundamental Science Program engages a broad community and has advanced HED science



Earth and super earths
Properties of minerals and metals
Nature Geoscience 2015



Jovian Planets
Water and hydrogen
PRL 2012 and SCIENCE 2015



Stellar physics
Fe opacity and H spectra
Nature 2015

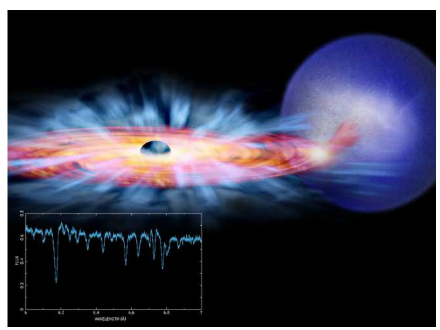


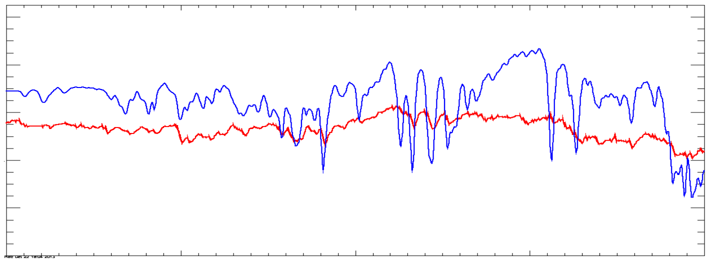
Photo-ionized plasmas
Ionization, temperature, and emergent spectra

- Resources/shots on Z since 2010
  - 60+ dedicated ZFS shots (~5% of all Z shots)
- Science with far-reaching impact
  - 1 Nature, 1 Nature Geoscience, 1 Science
  - Dozens of peer-reviewed papers published
- Popular outreach
  - National Public Radio, "All things considered", Joe Palca 3/6/2014
  - MIT Technology review, 10/4/2012
  - Discover Magazine, 9/16/2012
- Many institutions
  - UT Austin, Harvard, UC Davis, Ohio State, UWV, WSU, Carnegie, UN Reno, and more
- Students and postdocs
  - 4 M.Sc. Exam, 2 Ph.D. exams
  - 5 postdocs
- Workshops most years since 2009
  - Next workshop 7/16-19, 2017

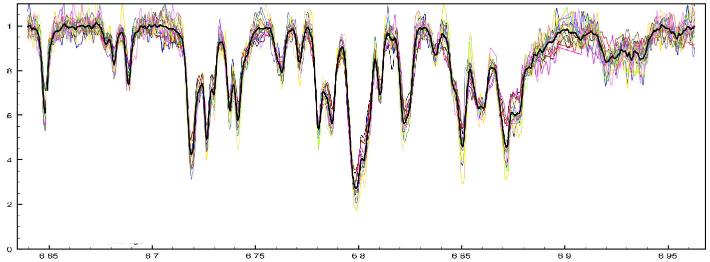
Z Astrophysical Plasma Properties (ZAPP) measures fundamental properties of atoms in plasmas to help solve astrophysical puzzles

- **Why can't we predict the location of the convection zone boundary in the Sun?**
  - ➢ **Opacity of Fe at ~200 eV**
- **How does ionization and line formation occur in accreting objects and warm absorbers?**
  - ➢ **Ionization distribution and spectral properties of photoionized Ne and Si**
- **Why doesn't spectral fitting provide the correct properties for White Dwarfs?**
  - ➢ **Stark-broadened H-Balmer line profiles**

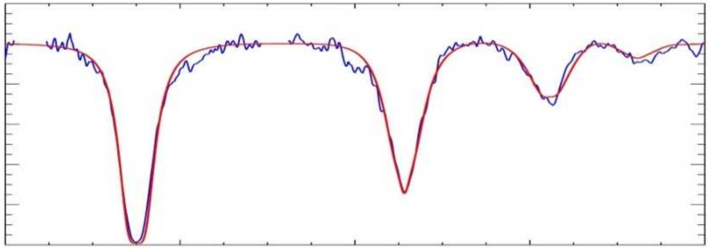
Fe Opacity



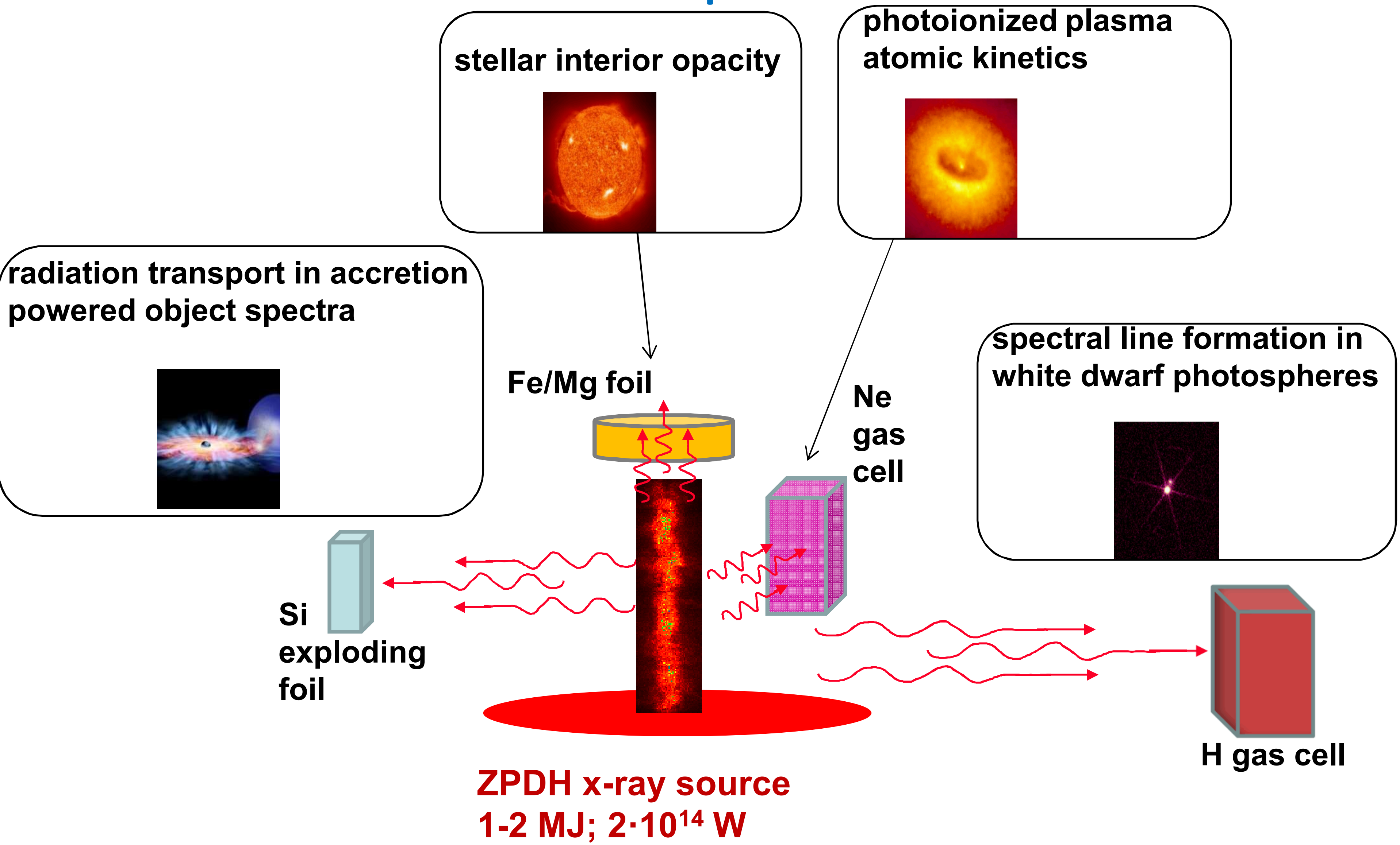
Si Photoionization



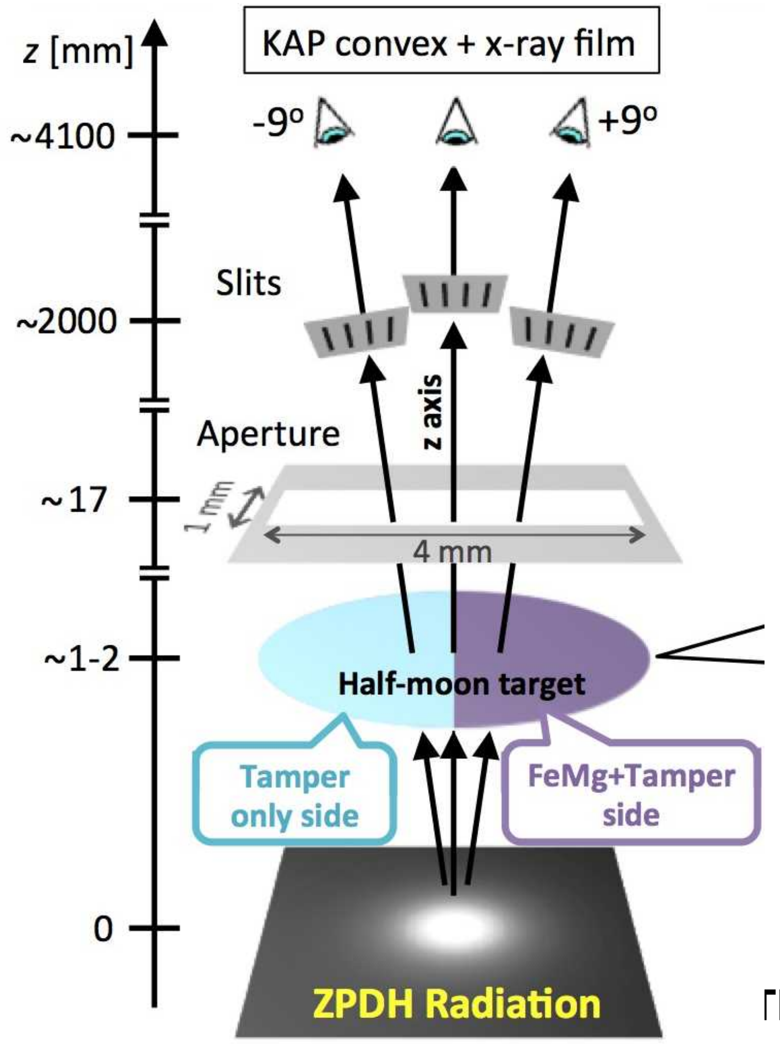
H-Balmer Line shapes



Four topics are simultaneously investigated by the ZAPP collaboration on each Z experiment



ZPDH opacity science platform satisfies challenging requirements for reliable opacity measurements



- **Heat Fe to uniform conditions**
  - **Powerful ZPDH radiation**
- **Measure Fe conditions independently**
  - **Mg K-shell spectroscopy**
- **Overcome Fe self-emission**
  - **350 eV Planckian at stagnation of the Z-pinch is stronger than sample radiation**
- **Measure transmission spectra accurately**
  - **Multiple Convex KAP spectrometers with x-ray films**
  - **Measure tamper-only simultaneously for accurate calibration**

The radiation source is the highly reproducible Z pinch dynamic hohlraum (ZPDH)

Properties of materials are measured along different paths in T, P, and rho by employing shock, ramp, and most recently, shock-ramp compression

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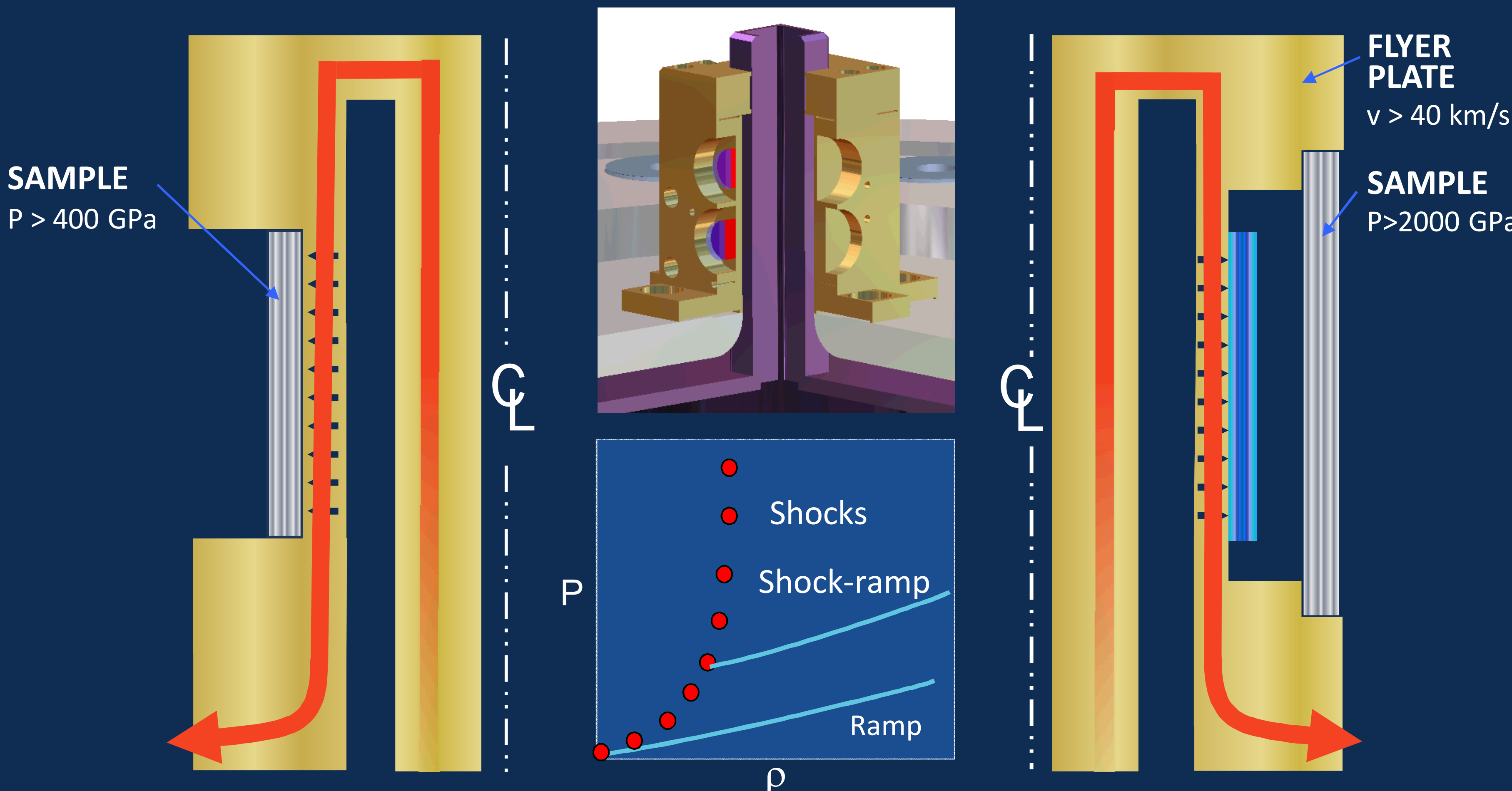
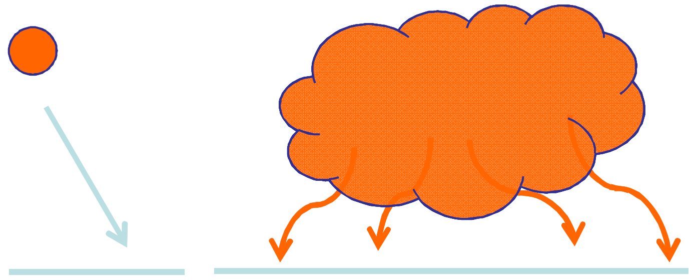


Isentropic Compression Experiments:
Gradual pressure rise in sample

Shock Hugoniot Experiments:
Shock wave in sample on impact

Discoveries in Planetary Science within the Z Fundamental Science Program

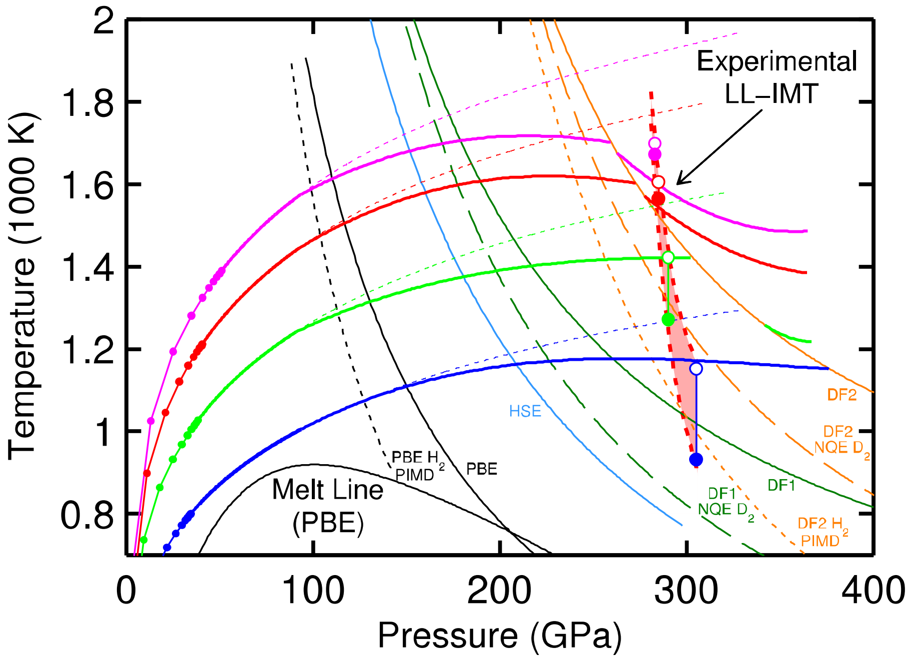


Iron rain following a meteor impact explains the iron-enriched mantle of the earth and a key earth/moon difference

Impact vaporization of planetesimal cores in the late stages of planet formation

- **Richard D. Kraus, Seth Root, et. al., Nature Geoscience, DOI:10.1038/NGEO2369 (2015)**
- **Sandia, Harvard, UC Davis, and LLNL**
- **Multi-Mbar dynamical material experiments to measure properties of vaporized iron at conditions of planetary impacts**

Discoveries in Planetary Science within the Z Fundamental Science Program



Measured the predicted pressure-driven insulator-metallization transition in deuterium

Direct observation of an abrupt insulator-to-metal transition in dense liquid deuterium

Marcus Knudson, Michael Desjarlais, et. al., SCIENCE 348, 1455 (2015).

- **Sandia and University of Rostock, Germany**
- **Experiments above ~250 GPa show clear evidence of metallization of deuterium**
- **Pressure is well above numerous first principles predictions**
- **Implications for understanding Jupiter, Saturn, and thousands of exoplanets**
- **Insensitivity to T suggests this is a density-driven transition**

A foundation of the research on Z is the close integration of experiments and simulations – resulting in deep understanding and faster progress

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- A broad range of theoretical expertise is needed
  - State of the art MHD algorithms and codes
  - High-fidelity material models – often based on quantum mechanics (QMC, DFT, and TDDFT)
  - Leading atomic physics to extract conditions from advanced diagnostics
  - Expertise in design of the load/machine electrical circuit system
- Changing code and HPC landscape
  - Existing codes are evolving
    - ALEGRA/EMPHASIS/SIERRA (SNL)
    - Ares, Hydra, Kull, and Lasnex (LLNL)
    - Research codes to investigate key physics phenomena
  - New (exascale) computer architectures drive major changes:
    - EMPIRE particle code at SNL
    - KOKKOS interfacing to hardware
    - QMCPack ECP and CMS project
    - Partnering with LANL, LLNL, vendors, and academia

High quality simulations accelerate experimental progress

The Z Fundamental Science Program (ZFSP) started in 2009; the program remains strong going into 2017 and beyond

- **Workshops on fundamental science using pulsed power**
  - 2009 Hilton, Santa Fe
  - 2010 Eldorado, Santa Fe
  - 2011 Eldorado, Santa Fe
  - 2012 Andaluz, Albuquerque
  - 2014 Andaluz, Albuquerque
  - 2015 Hyatt, Albuquerque
  - 2016 Andaluz, Albuquerque
- **Liner Fusion workshop**
  - 2012 Marriott, Albuquerque
- **ZFSP**
  - 2010 – call for proposals and review by an external committee
  - 2011 – 2015 around 50 dedicated Z shots
  - 2014 – External review of projects
  - 2015 – Call for proposals for 2016-17 and evaluation by an external committee
  - 2016 – 2017 almost 30 dedicated Z shots
- **Future**
  - 2017 - *Call for proposal opens June 15 and closes on September 15, 2017 for experiments in 2018 and 2019.*

2017 ZFSP workshop

Sunday 7/16/17 (eve.) to Wednesday 7/19/16 (all day)

Albuquerque, NM. Venue TBD