SAND2011-5472C

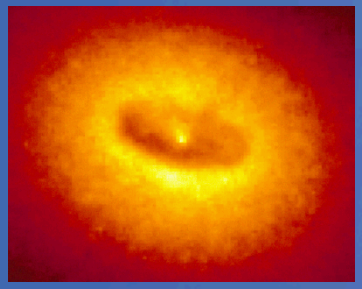
Sandia National Laboratories

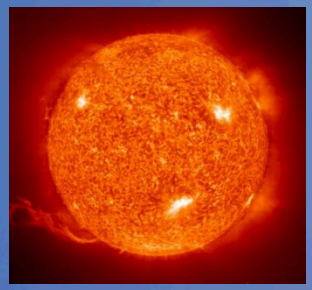
28 July 2011

Z Sources and Diagnostics for Fundamental Science

Gregory A. Rochau

Workshop on Science with High-Power Lasers and Pulsed Power

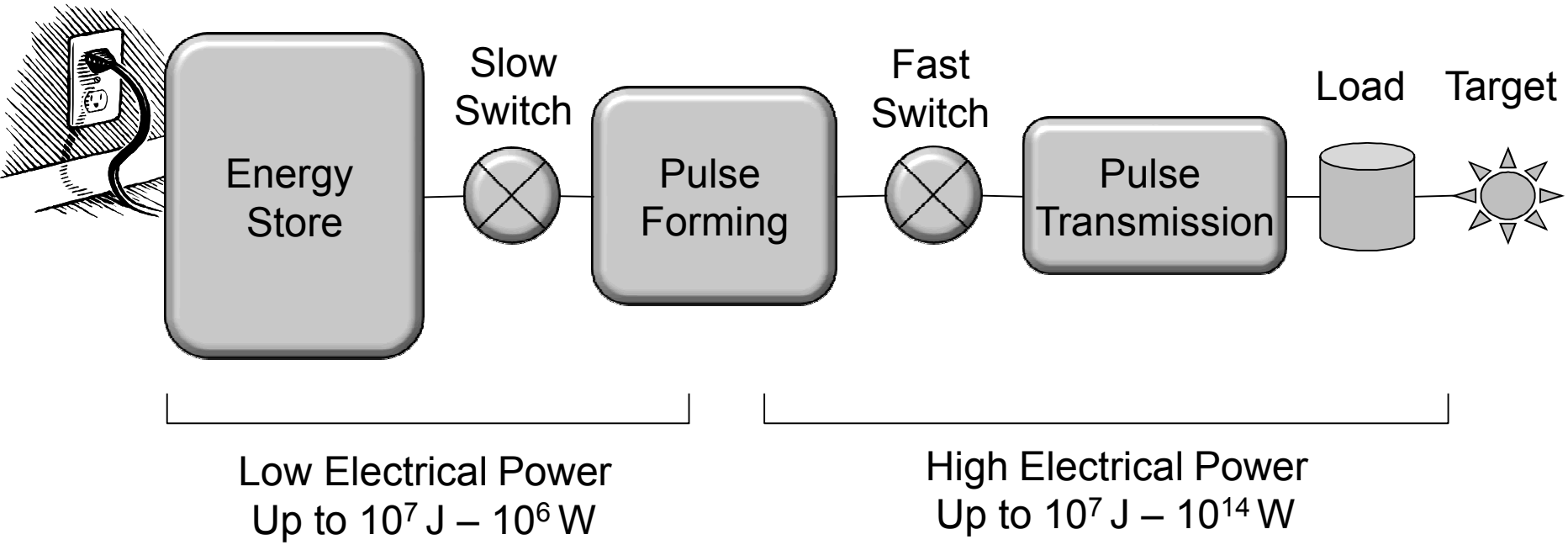




Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Pulsed power: The temporal compression of electrical energy to produce short bursts of high power.

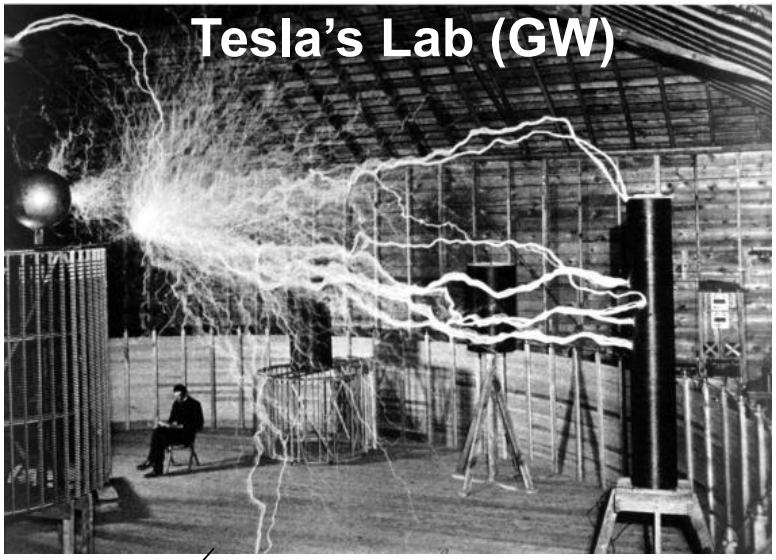


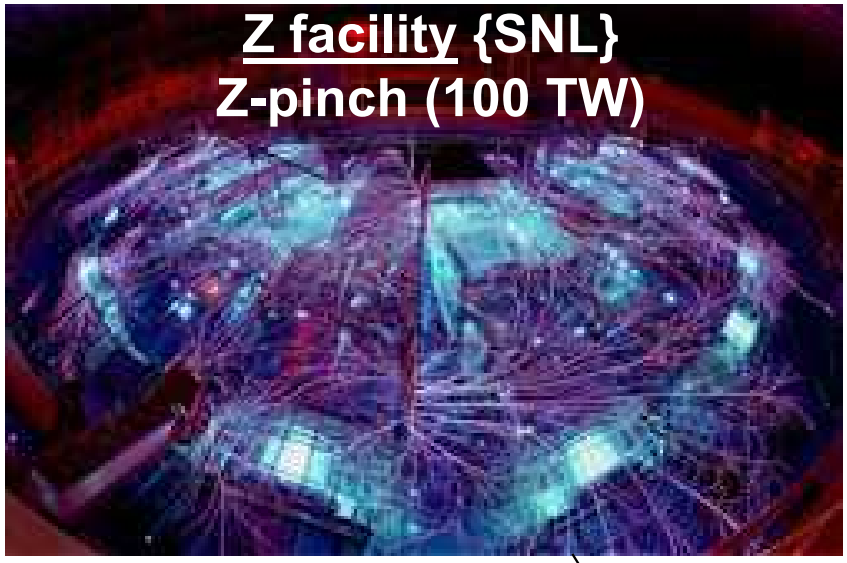
Take the equivalent electrical energy consumption in one evening's operation of a TV set (a few MJ) and compress it into more electrical power than provided by all the power plants in the world combined (~15 TW).

…S T Pai & Qi Zhang, "Introduction to High Power Pulse Technology," World Scientific Publishing Co., Singapore, 1995.

Sandia National Laboratories

Pulsed power has been investigated for over a century.





1900 1920 1940 1960 1980 2000

WWII

Hermes - II {SNL}
e-beam (TW)

PBFA - II {SNL}
Ion Beams (20 TW)

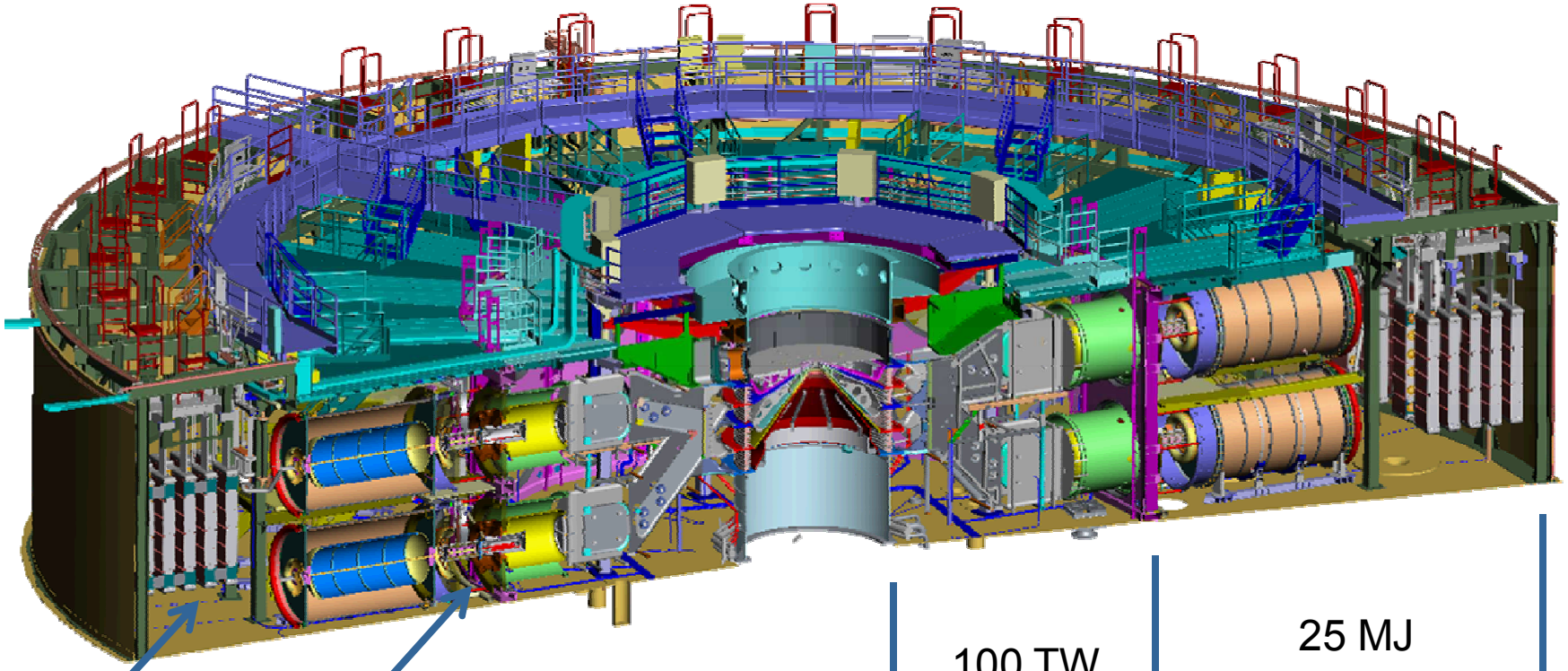
Radar (MW)
- Germany
- US
- Russia
- Great Brittain

Angara - II {Russia}
Simulator (TW)

DARHT {LANL}
Radiography (10 GW)

Sandia National Laboratories

The Z facility at Sandia National Laboratories is the most powerful pulsed power machine in the world.



Marx Generator

Laser-triggered Gas Switch

> 26 MA Current

100 TW Electrical

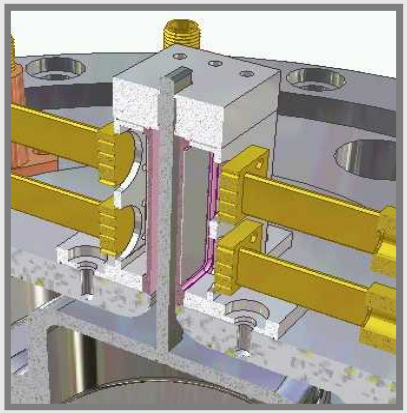
25 MJ Electrical

Sandia National Laboratories

Multiple ways to use the current on Z

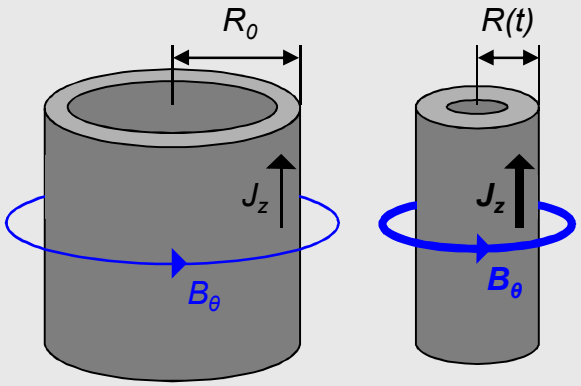
Flyer plates

Velocities > 40 km/s



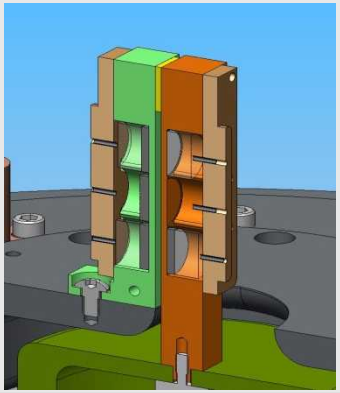
Cylindrical compression

-Fusion -EOS up to 6.5 Mbar



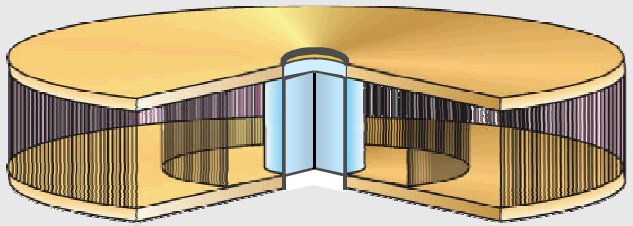
Planar ramp-compression

Isentropic compression up to ~4 Mbar

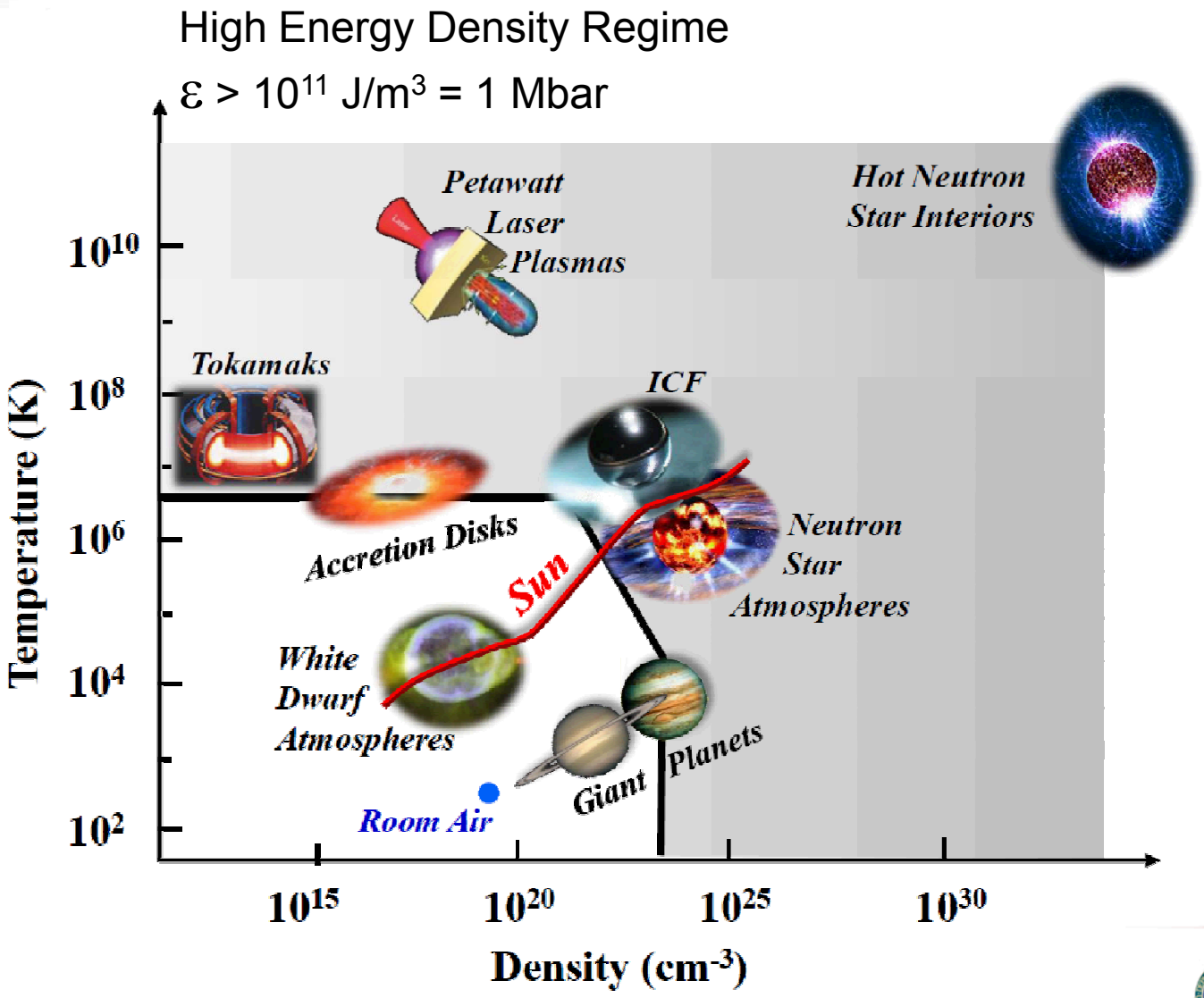


Z-pinch x-ray sources

X-ray power up to 330 TW, 2.2 MJ

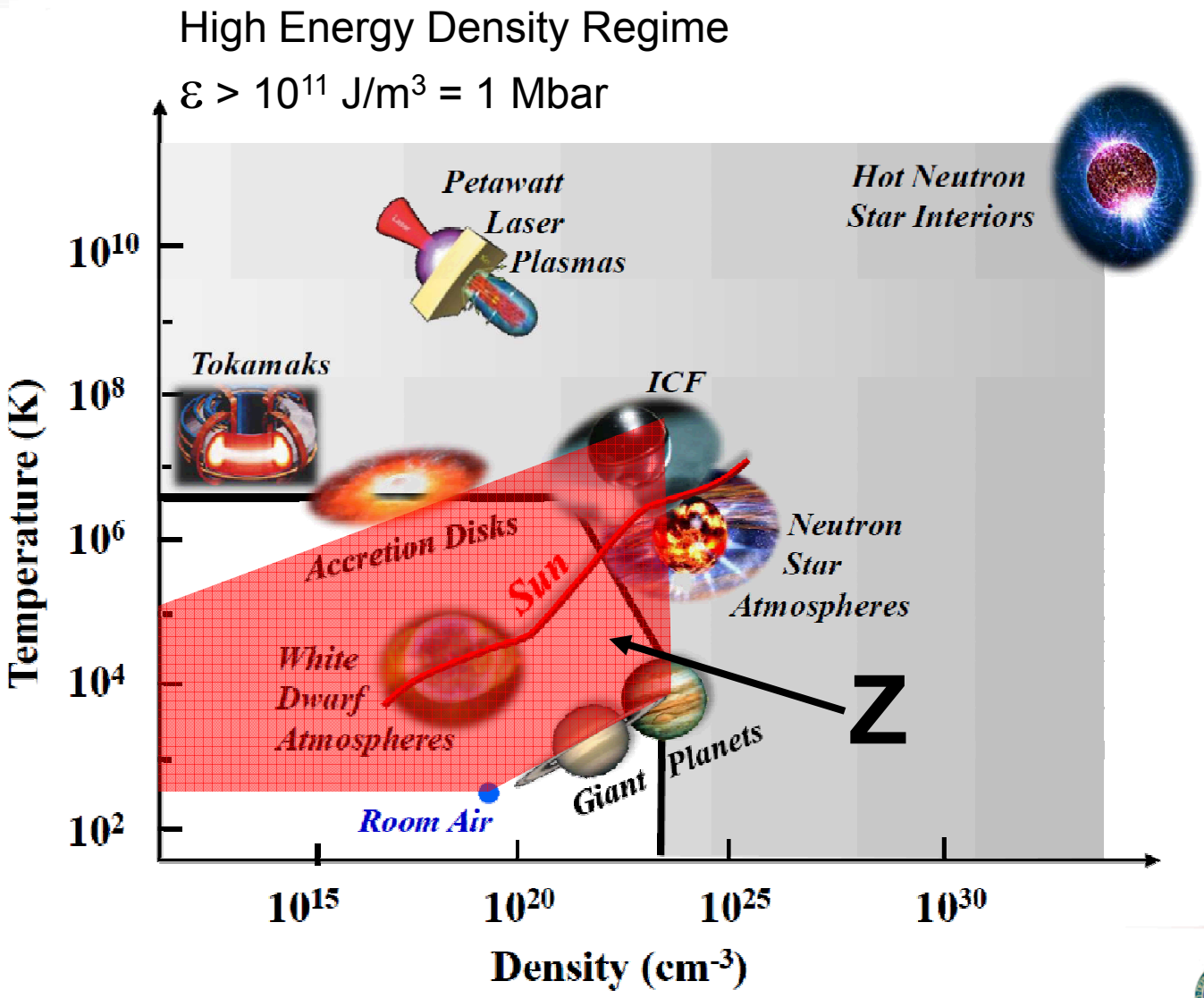


Experiments on Z access a large region of the energy density phase-space



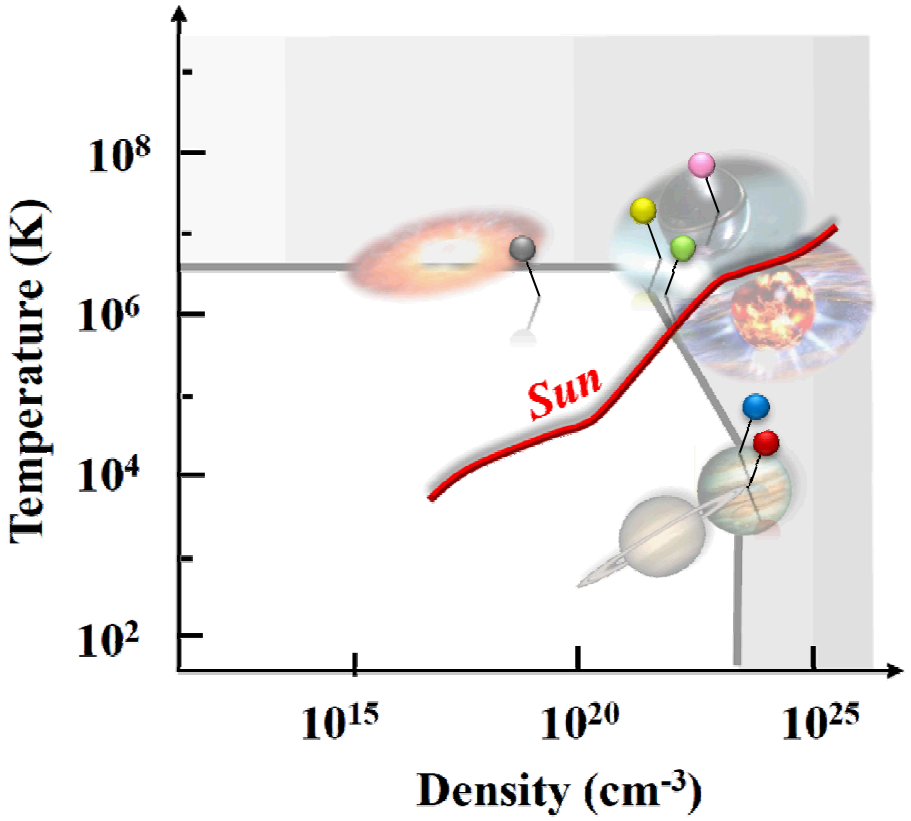
Sandia National Laboratories

Experiments on Z access a large region of the energy density phase-space



Sandia National Laboratories

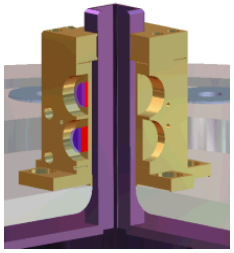
HED experiments on the Z facility address issues of fundamental importance



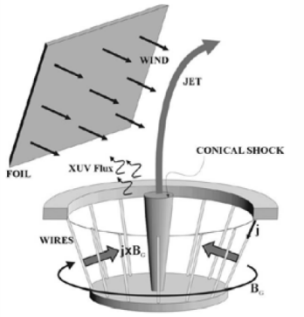
- **Diamond at 10 Mbar**
  Knudson et al., Science 322 (2008)
- **D_2 EOS at 1 Mbar**
  Knudson et al., PRL 87 (2001)
- **Photoionized Plasmas**
  Foord et al., PRL 94 (2004)
- **Radiating Shocks**
  Rochau et al., PRL 100 (2008)
- **Opacity at T_e > 150 eV**
  Bailey et al., PRL 99 (2007)
- **Fusing Plasmas**
  Bailey et al., PRL 93 (2004)

Sandia National Laboratories

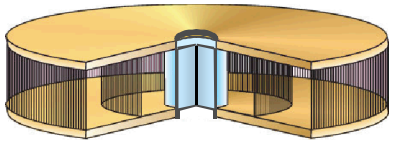
Three ways to use Z for fundamental science



Use the current and associated B-field to compress a sample or launch shocks.



Use the current to drive a specialized Z-pinch implosion



Use the x-rays from a previously established z-pinch source to radiatively heat and/or ionize a sample

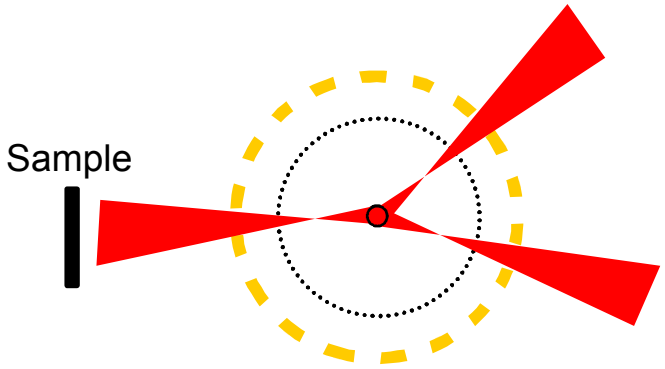
Sandia National Laboratories

A 'Beamline' model for x-ray driven fundamental science on Z

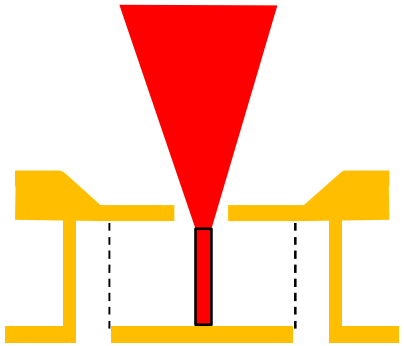
- Use a previously established z-pinch x-ray source.
  - Z-pinch dynamic hohlraum
    - near black-body x-ray source with an axial LOS
  - K-shell x-ray source
    - high energy K-shell line emission (Al, SS, Cu)

- Utilize radial (and axial) x-ray emission to conduct multiple experiments on a single shot.

Typically 9 or 18 Radial Beamlines



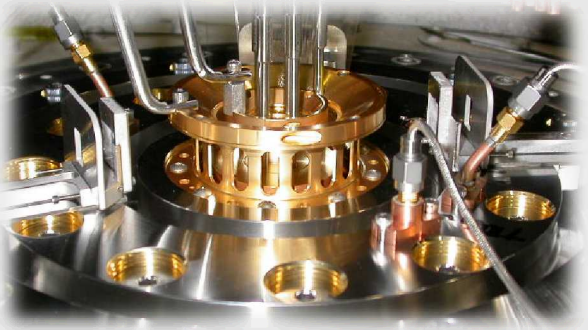
1 Axial Beamline



Sandia National Laboratories

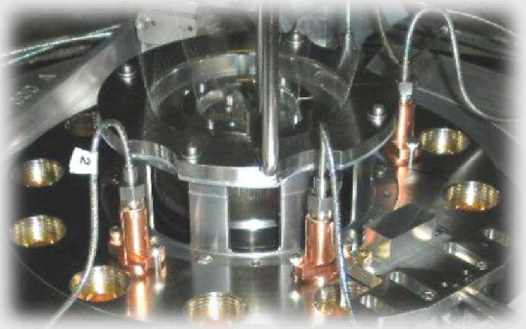
Two types of routine, established z-pinch sources

Z-pinch dynamic hohlraum



- Diameter: 4 cm
- Height: 1.2 cm
- Radial Beamlines: 9 or 18
- Axial Beamlines: 1
- Near-Planckian emission spectrum
- Broadband Energy Emission: 1 MJ
- Peak Power: 170 TW
- Power FWHM: 3 ns

Large-diameter K-shell sources



- Diameter: 4-8 cm
- Height: 2 cm
- Radial Beamlines: 9
- Axial Beamlines: 1
- Optimized for K-shell emission
- Spectrum/Power/Energy depends on wire material

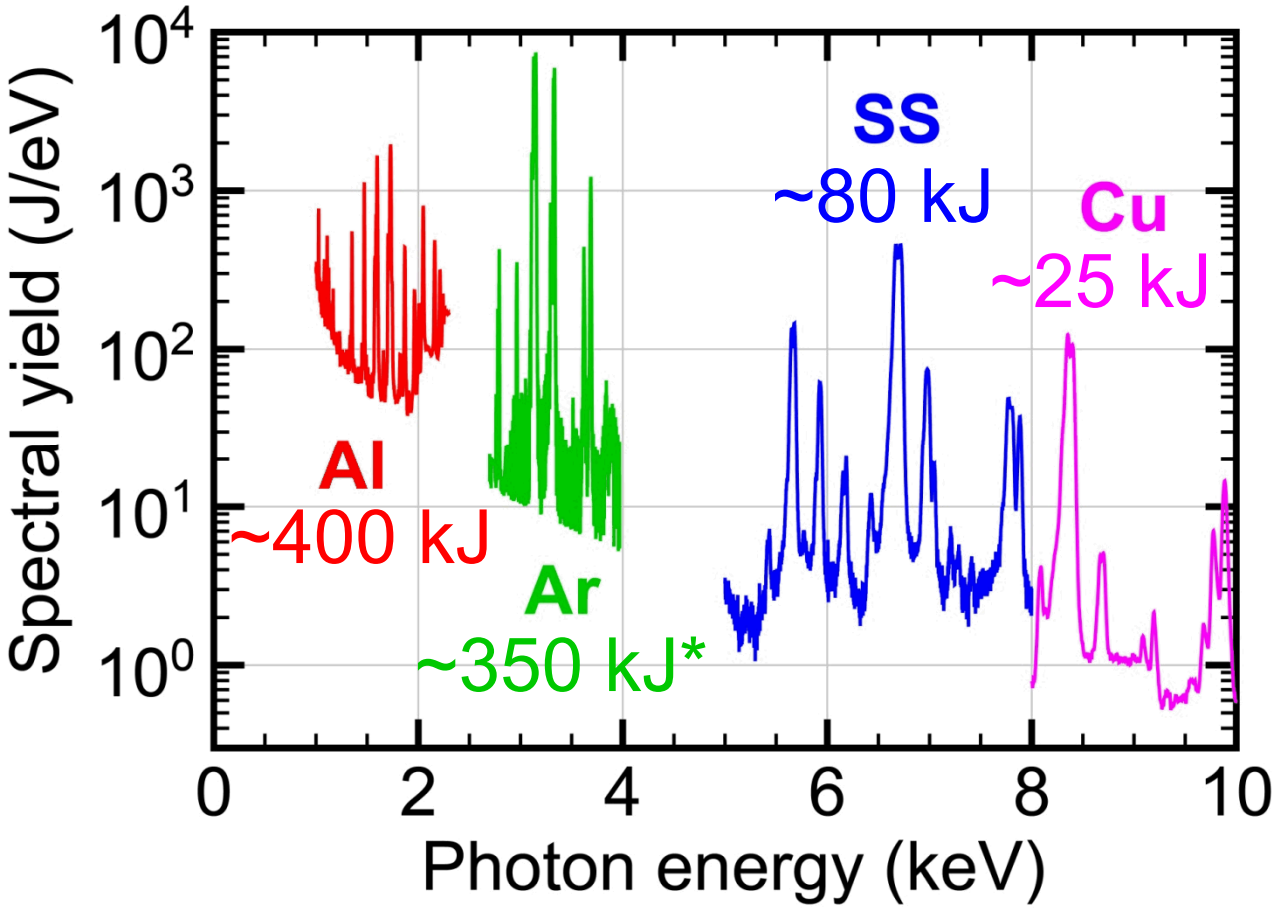
Sandia National Laboratories

Z provides extremely intense x-ray environments at 1-10 keV photon energy

Source	K-shell FWHM (ns)	K-shell power (TW)
Al	7.1	31
Ar	8.4*	30
SS	2.4	28
Cu	3.0	5.4

*Z data pre-refurbishment

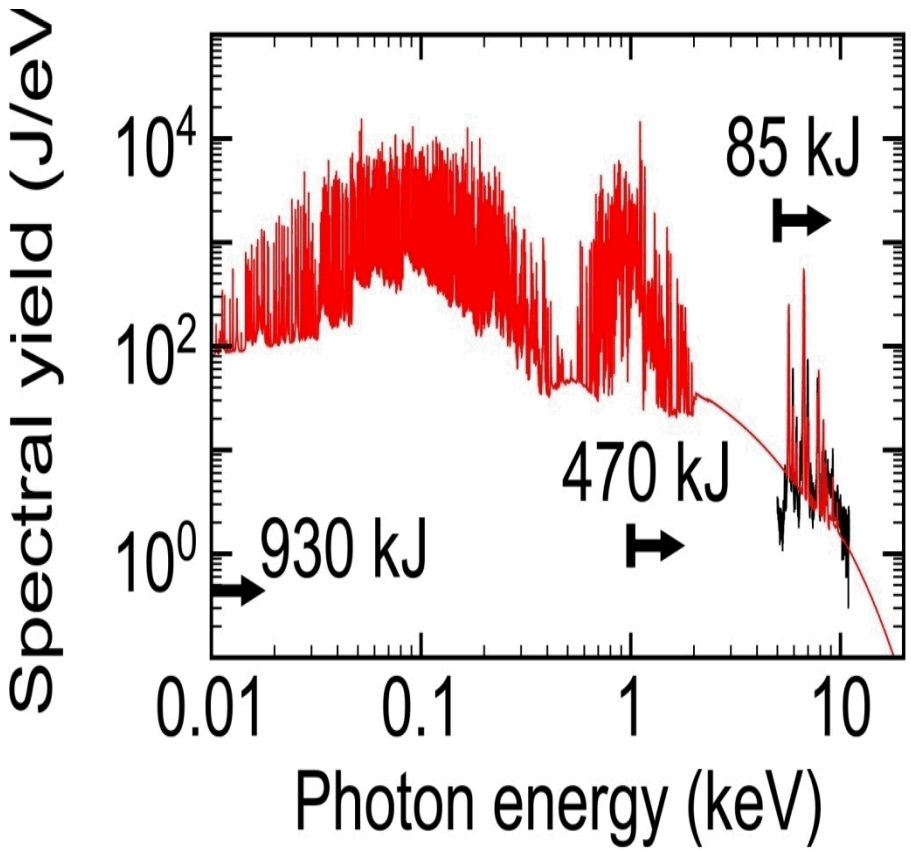
Shot-to-shot yield variability ±10-20%

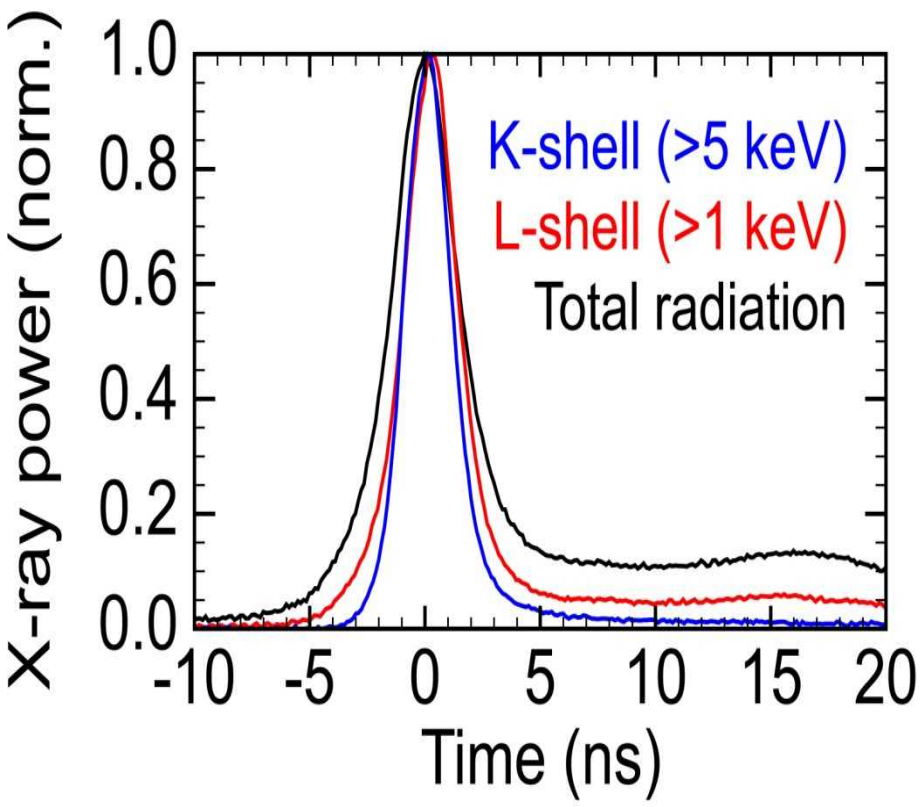


Contact D.J. Ampleford (damplef@sandia.gov) for more information

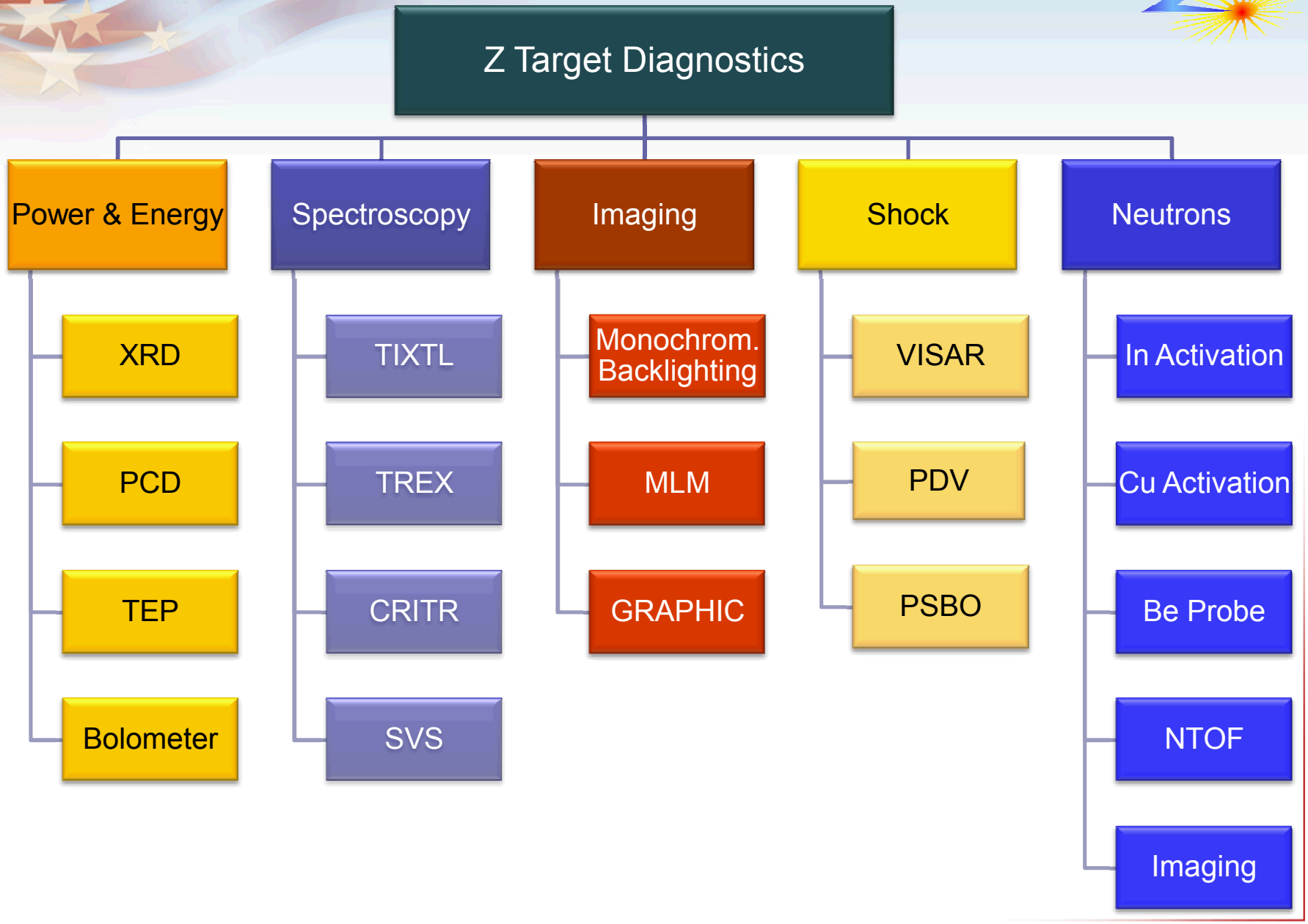
Sandia National Laboratories

Stainless steel wire arrays provide a broad spectrum with a strong high-energy component





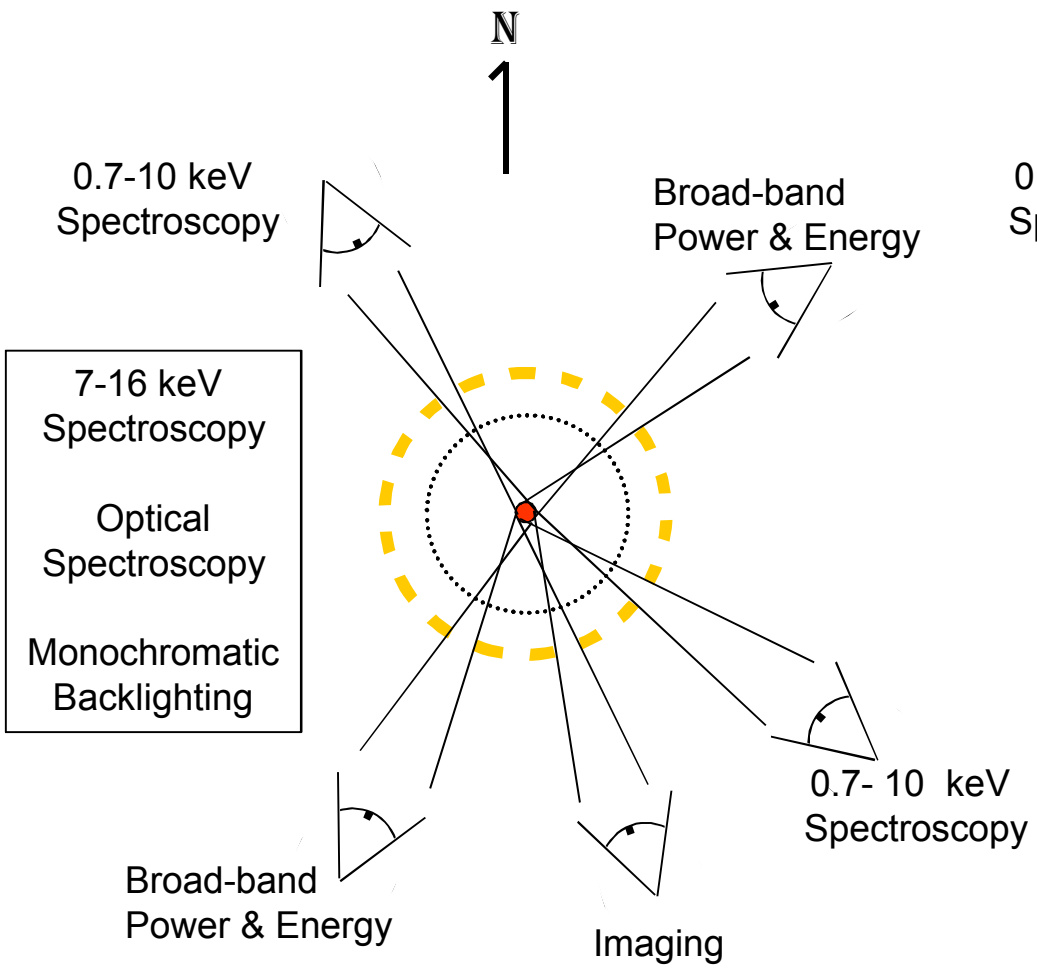
Sandia National Laboratories



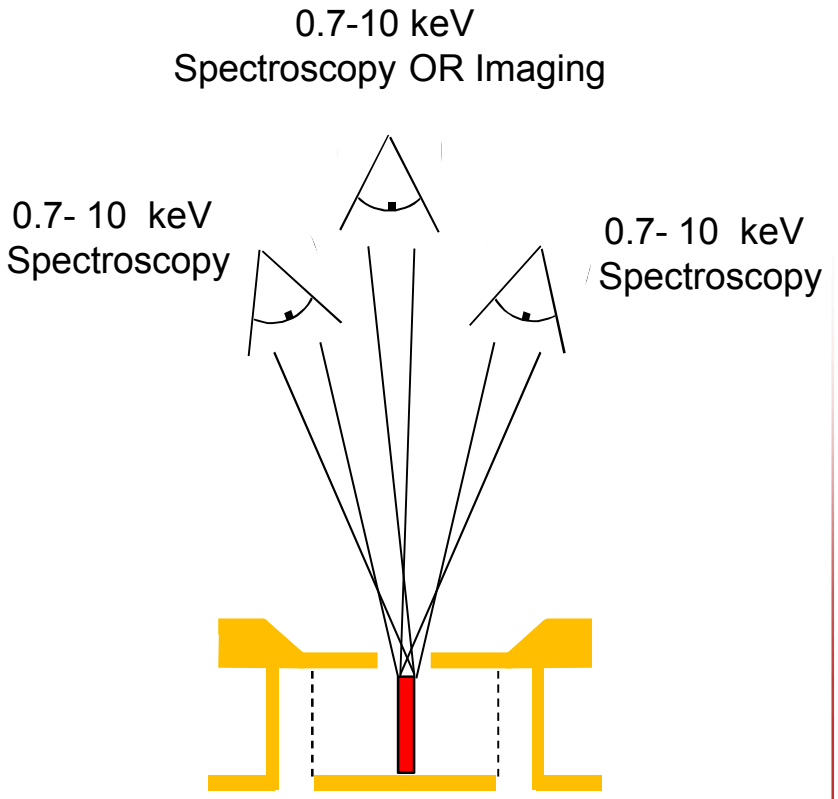
Sandia National Laboratories

X-ray diagnostic positions on Z

Radial Diagnostics



Axial Diagnostics



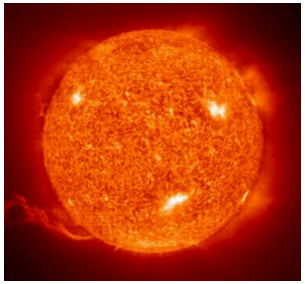
Sandia National Laboratories

Typical measurement requirements for an x-ray driven fundamental science experiment

- Machine Performance (How much current was delivered?)
  - Timing
  - Load Current
- Z-pinch x-ray output (How many x-rays were emitted and when?)
  - Power
  - Energy
  - Spectrum
- Z-pinch source size (Where did the x-rays come from?)
  - X-ray Imaging
- Beamline specific measurement
  - X-ray Imaging
  - Backlighting
  - X-ray Spectroscopy
  - Optical Spectroscopy
  - Monochromatic Backlighting

Example: Fundamental Properties of Astrophysical Plasmas (FPAP)

Solar Opacity



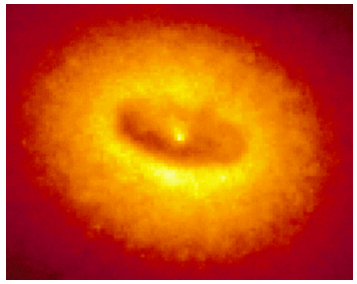
Collaborator:
Anil Pradhan et al.,
Ohio State University

SNL POC:
Jim Bailey

Purpose:
Test Fe opacity models at conditions relevant to the convection zone boundary in the Sun.

Required Conditions:
T_e ~ 180 eV, n_e ~ 10^{23} cm^{-3}

Photoionized Plasma



Collaborators:
Roberto Mancini et al.,
University of Nevada - Reno

SNL POC:
Jim Bailey

Purpose:
Test photo-ionization models of Ne at conditions relevant to black hole accretion disks.

Required Conditions:
T_e ~ 15 eV, n_e ~ 10^{18} cm^{-3}

White Dwarf Spectra

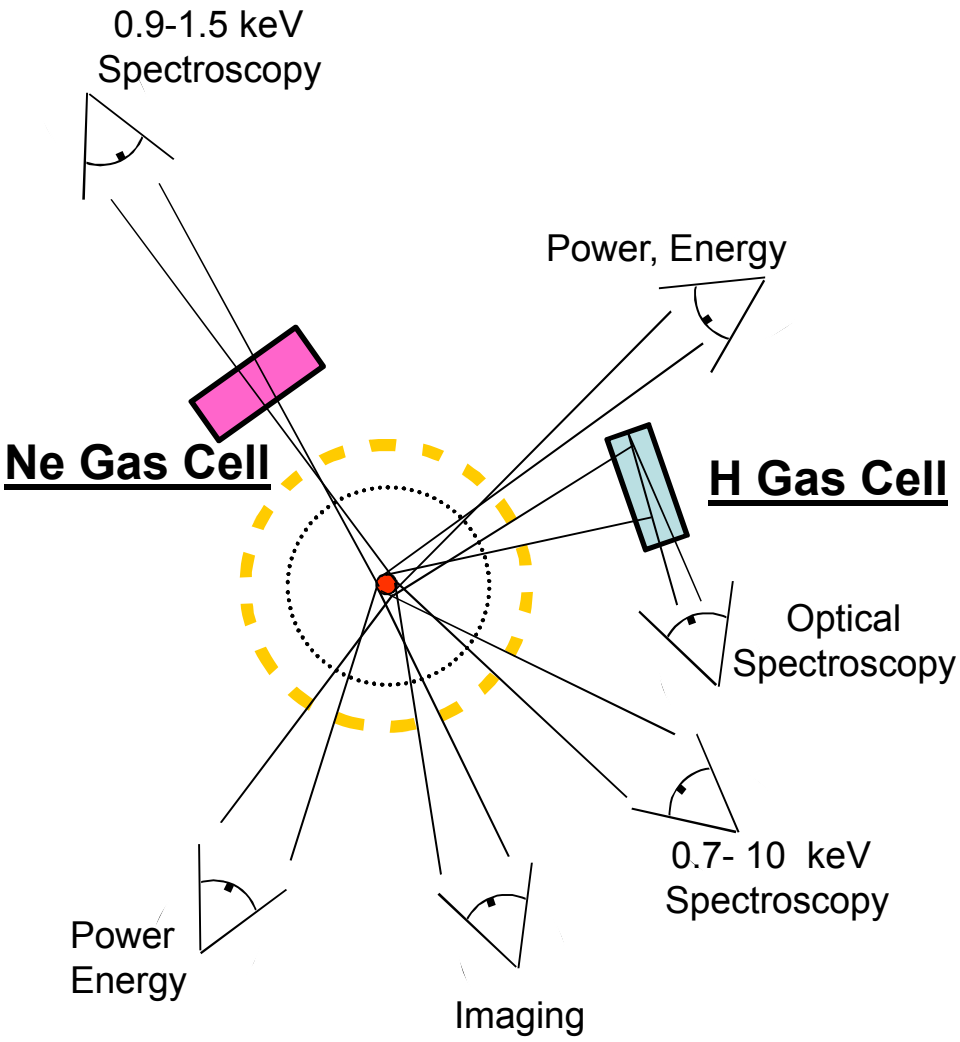
Collaborator:
Don Winget et al.,
University of Texas

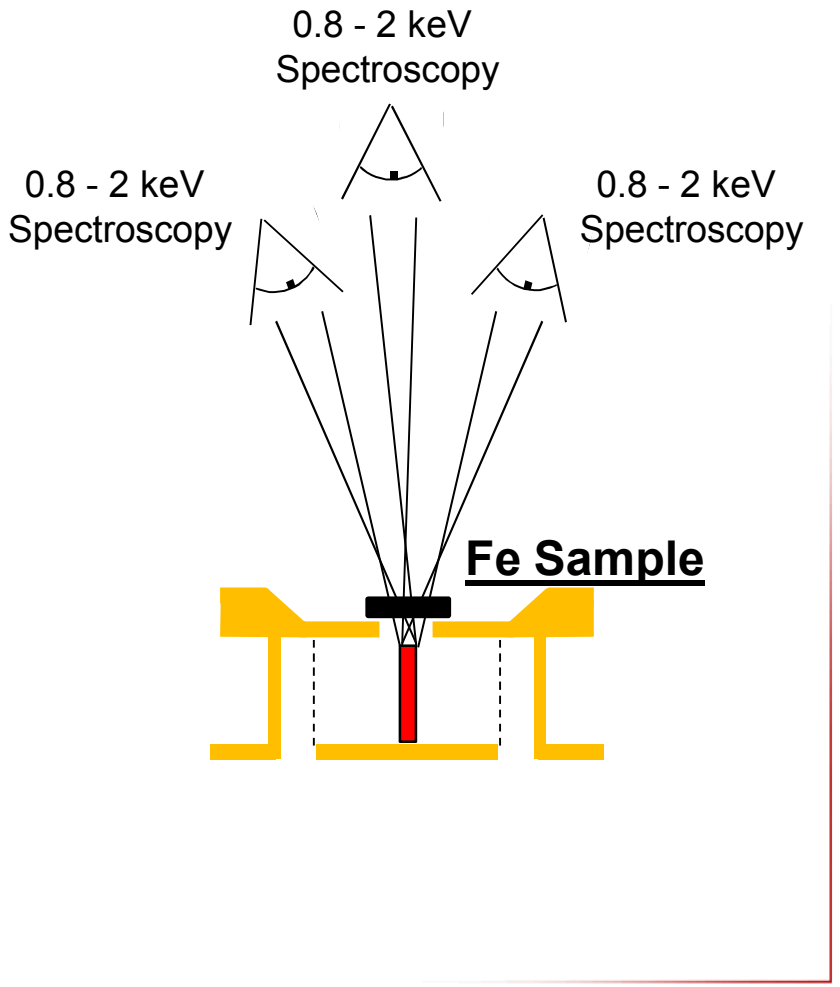
SNL POC:
Greg Rochau

Purpose:
Test line-broadening theory of H at conditions relevant to White Dwarf photospheres.

Required Conditions:
T_e ~ 1 eV, n_e ~ 10^{17} cm^{-3}

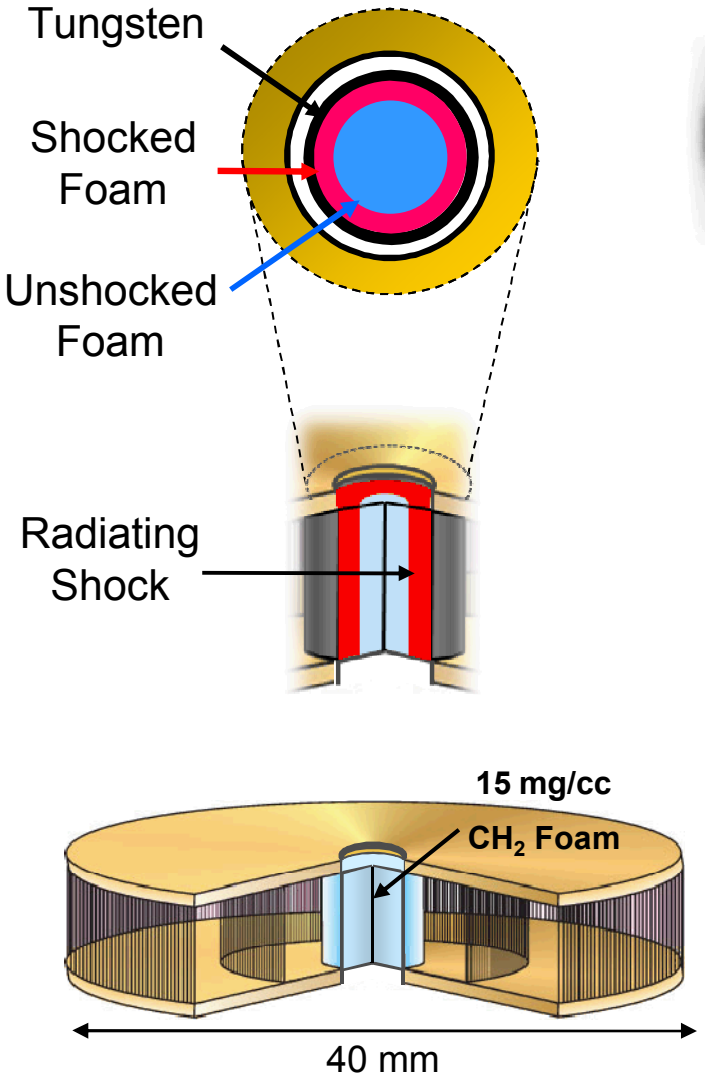
FPAP Sample and Diagnostic Configuration



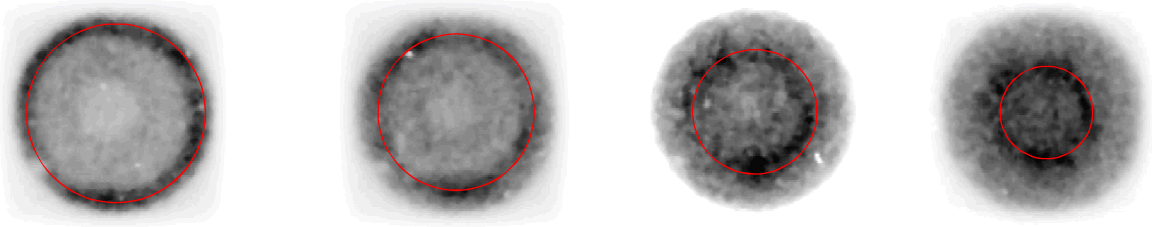


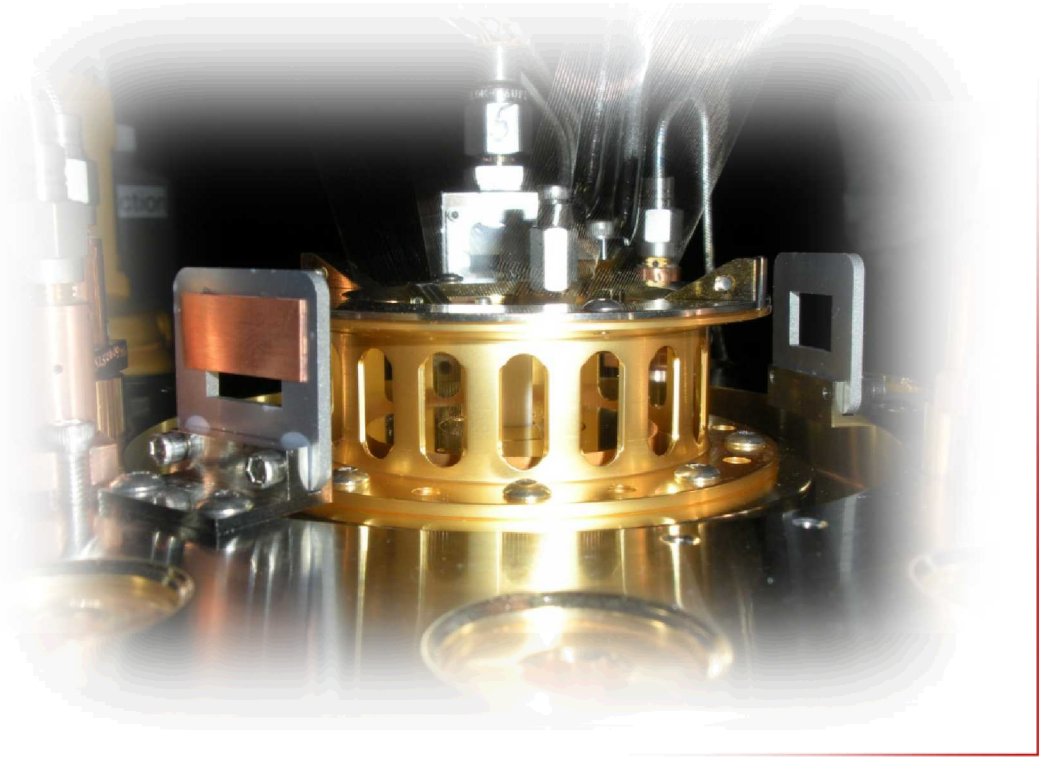
Sandia National Laboratories

The Z-pinch dynamic hohlraum (ZPDH) forms a radiating shock in CH_2 foam.



Framing Pinhole Camera Images



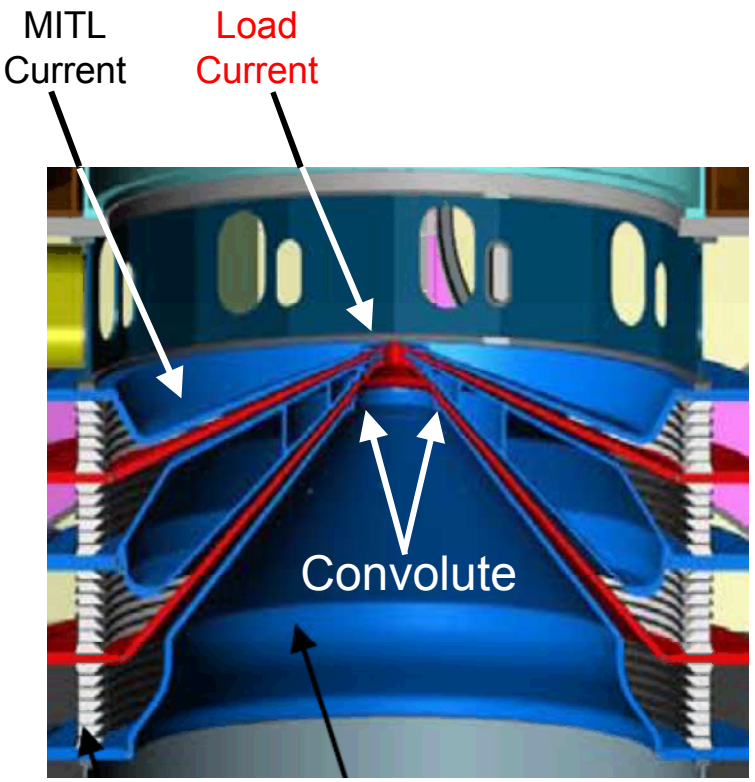


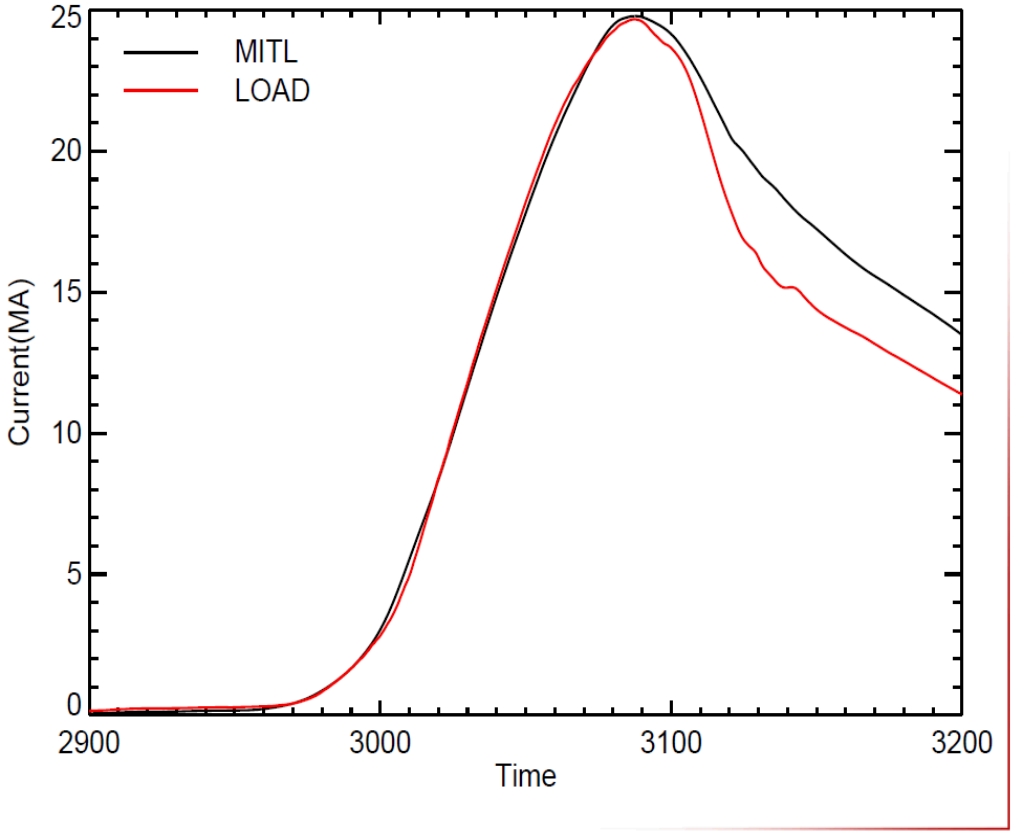
Sandia National Laboratories

Measuring machine performance

Relevant Diagnostics

- > 400 recorded pulsed power monitors
- B-dots near the load are the most direct measure of delivered current



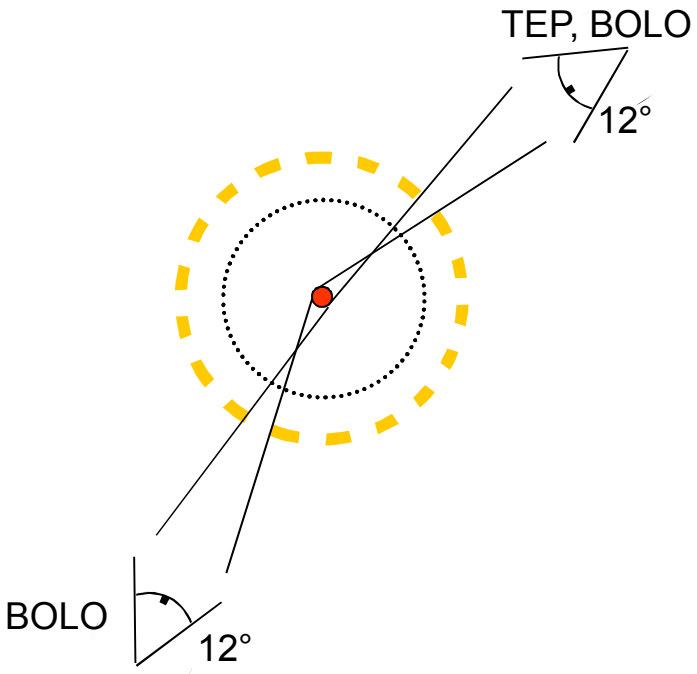


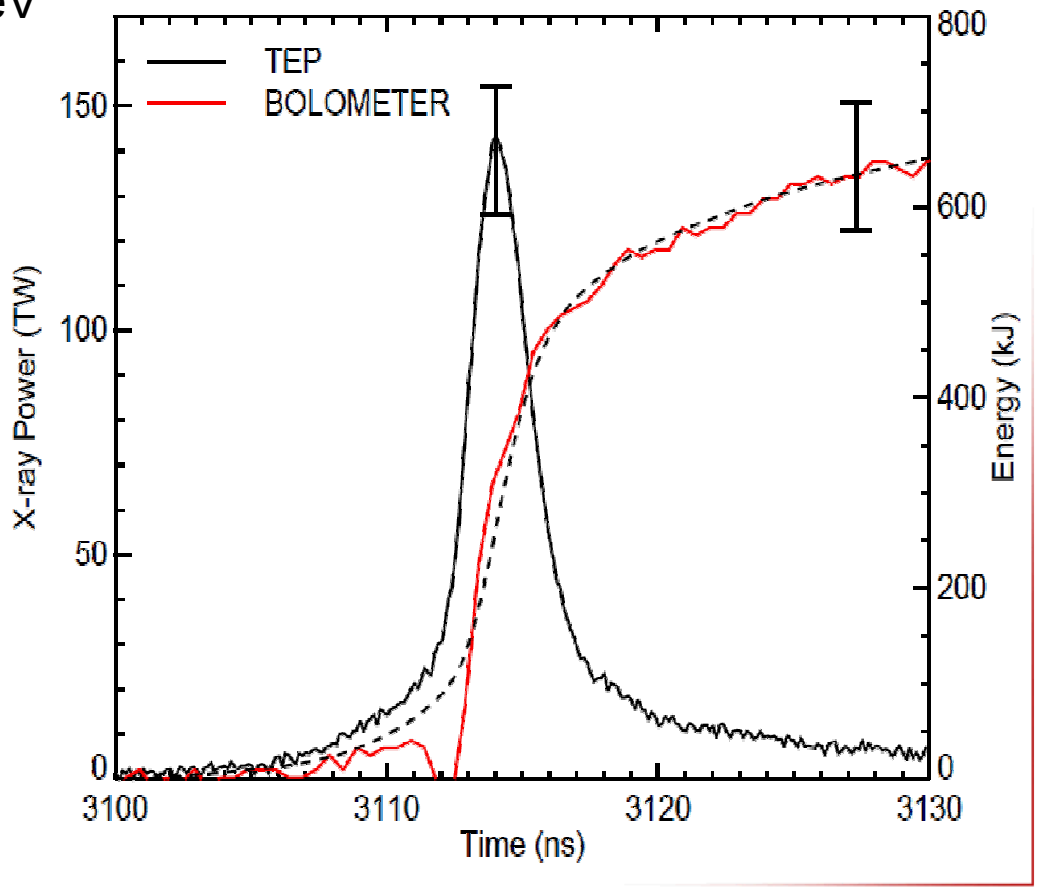
Sandia National Laboratories

Measuring total z-pinch x-ray output

Relevant Diagnostics

- Total Energy Power (TEP)
  - flat response over 0.1 – 4 keV
- Fast Resistive Bolometer
  - intrinsic response



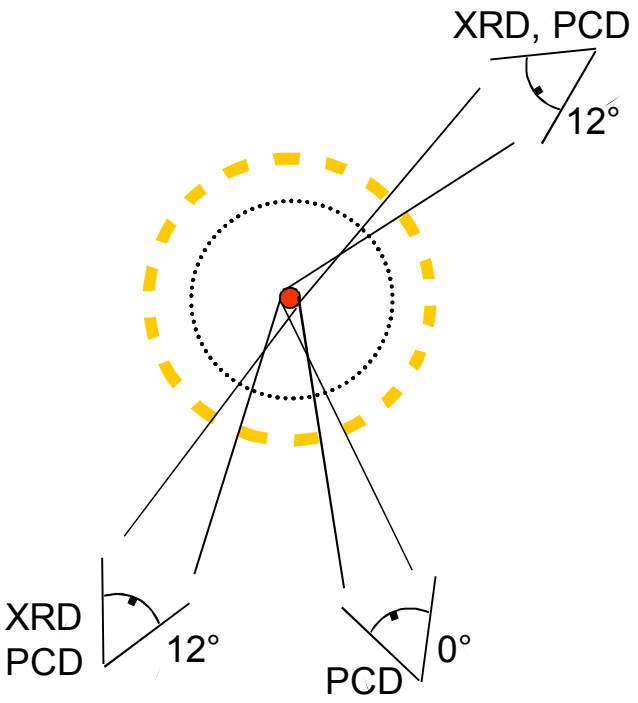


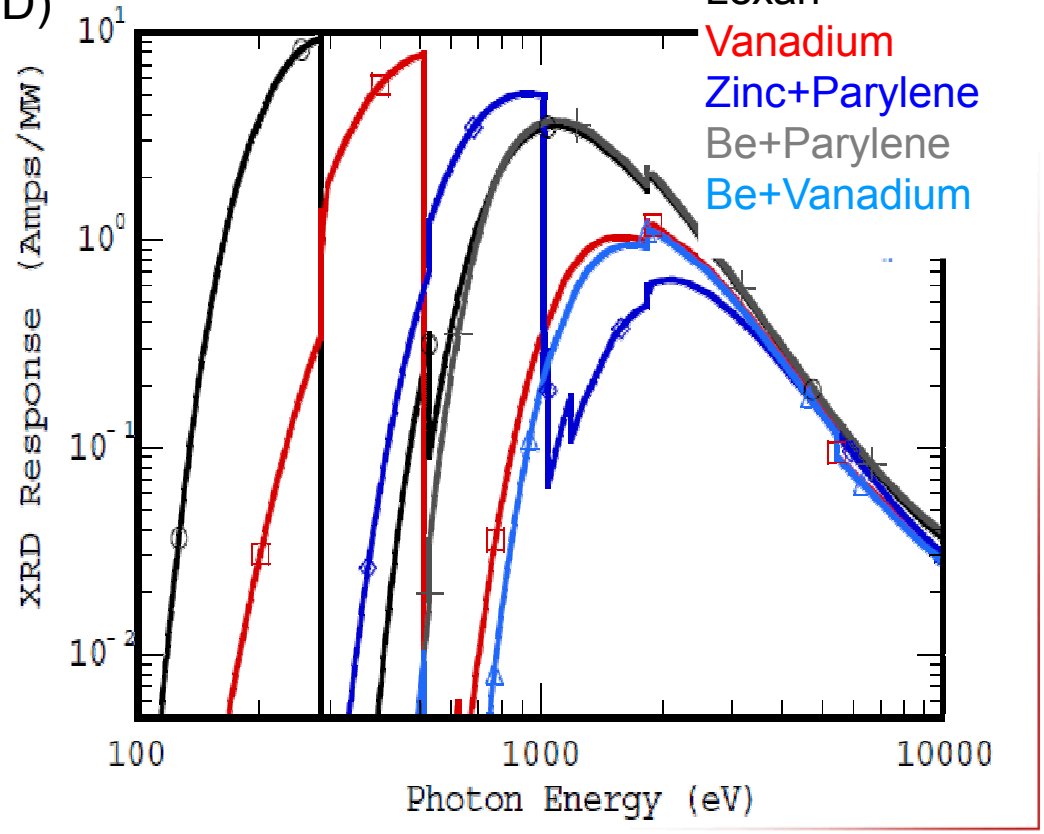
Sandia National Laboratories

Measuring broad-band x-ray spectral content

Relevant Diagnostics

- X-ray Diodes (XRD)
  - absolutely calibrated
- Photo-conducting diamonds (PCD)
  - intrinsic response



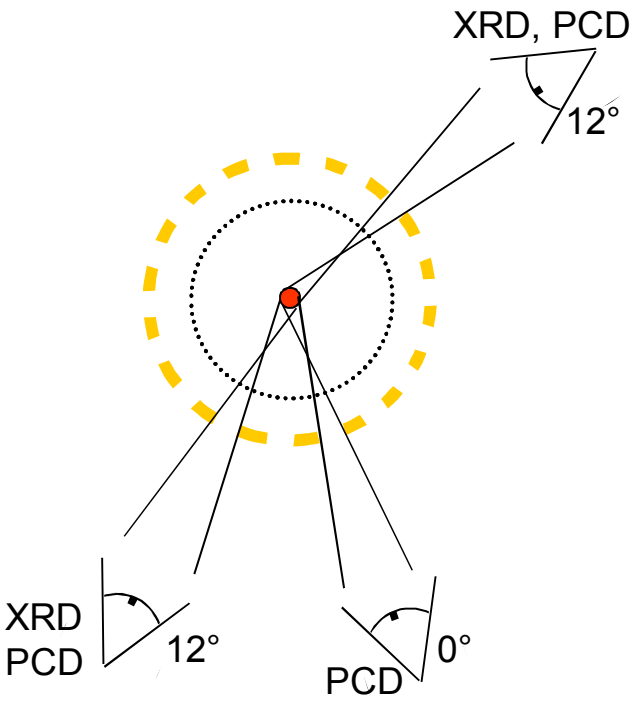


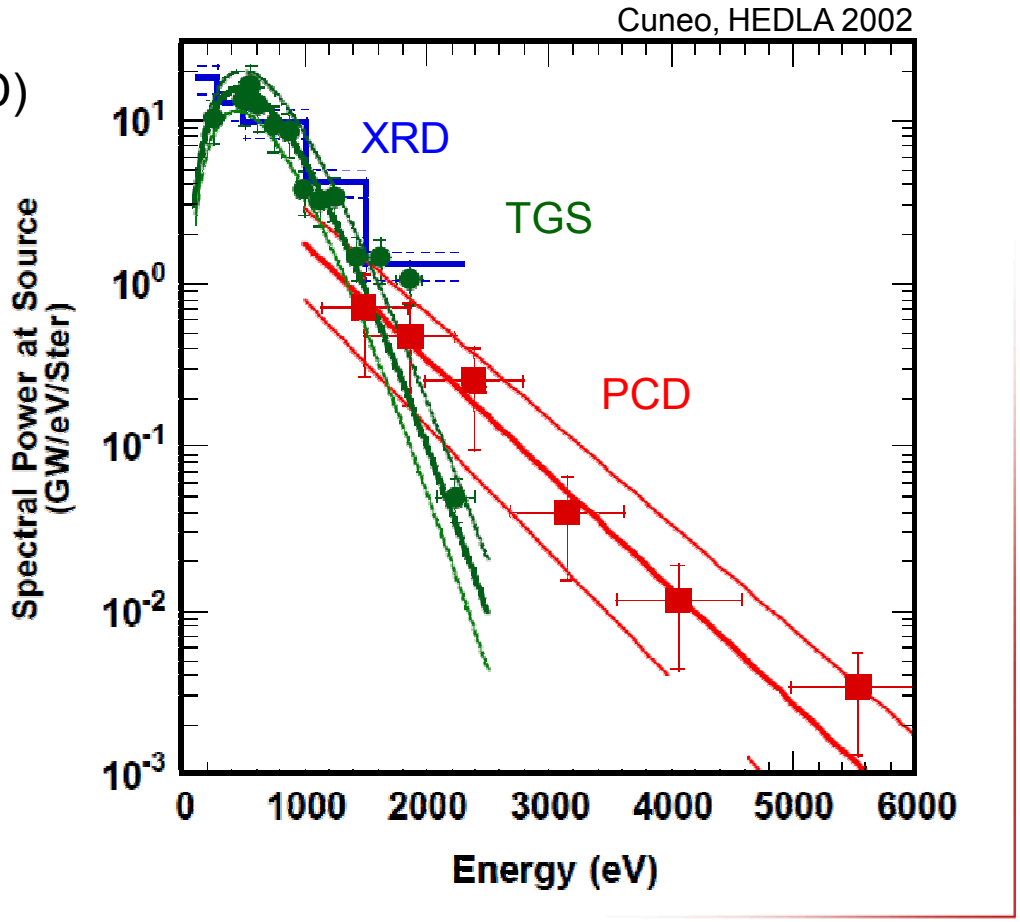
Sandia National Laboratories

Measuring broad-band x-ray spectral content

Relevant Diagnostics

- X-ray Diodes (XRD)
  - absolutely calibrated
- Photo-conducting diamonds (PCD)
  - intrinsic response



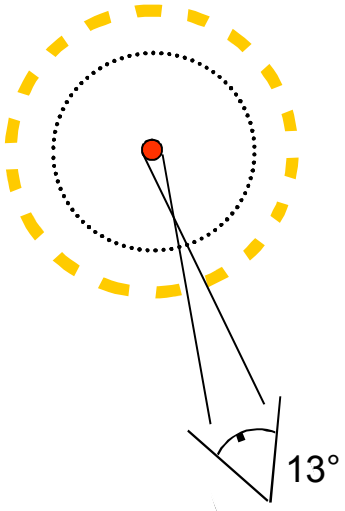


Sandia National Laboratories

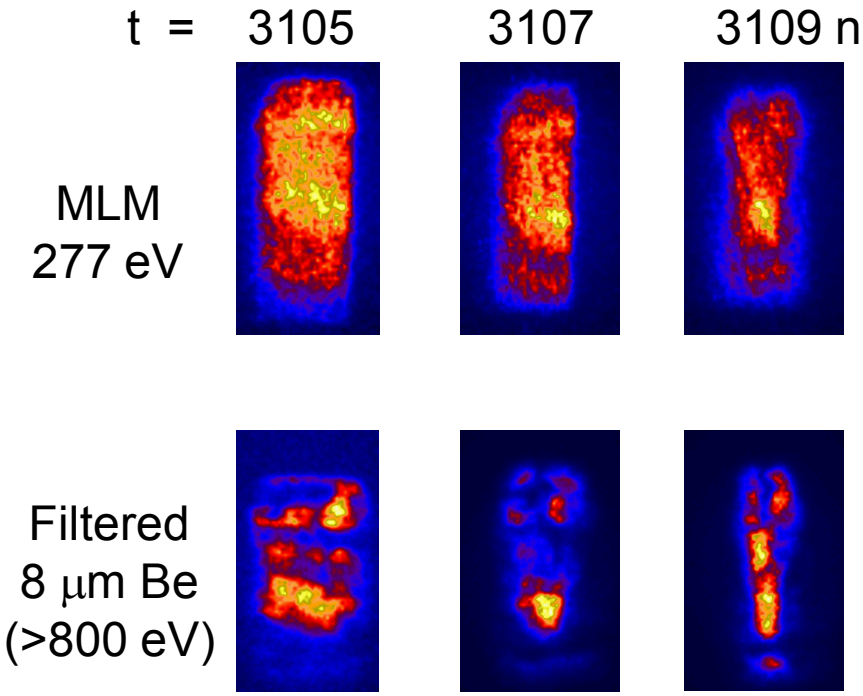
Measuring radial x-ray source size

Relevant Diagnostics

- Multi-Layer Mirror (MLM) Pinhole Camera
  - 277 ± 1.5 eV imaging -14 frames
- Filtered Pinhole Camera
  - Broadband imaging – 8 frames



MLM
Filtered Pinhole Camera

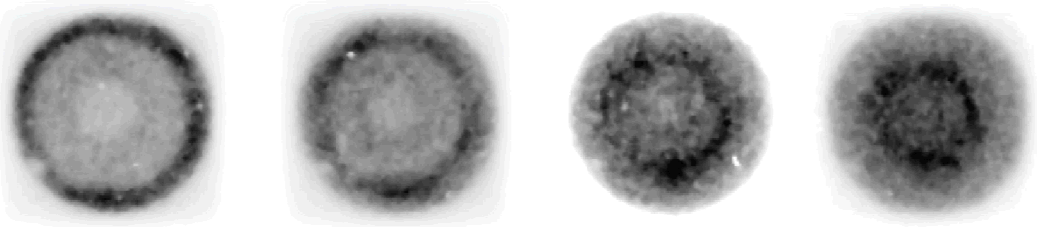


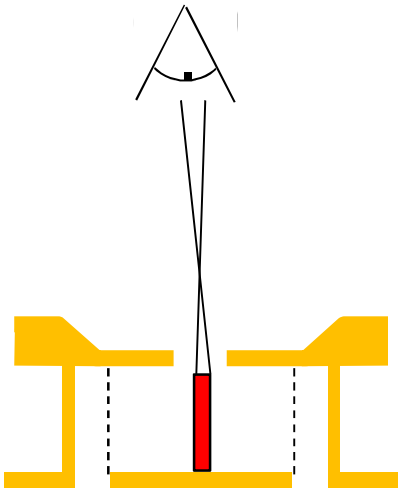
Sandia National Laboratories

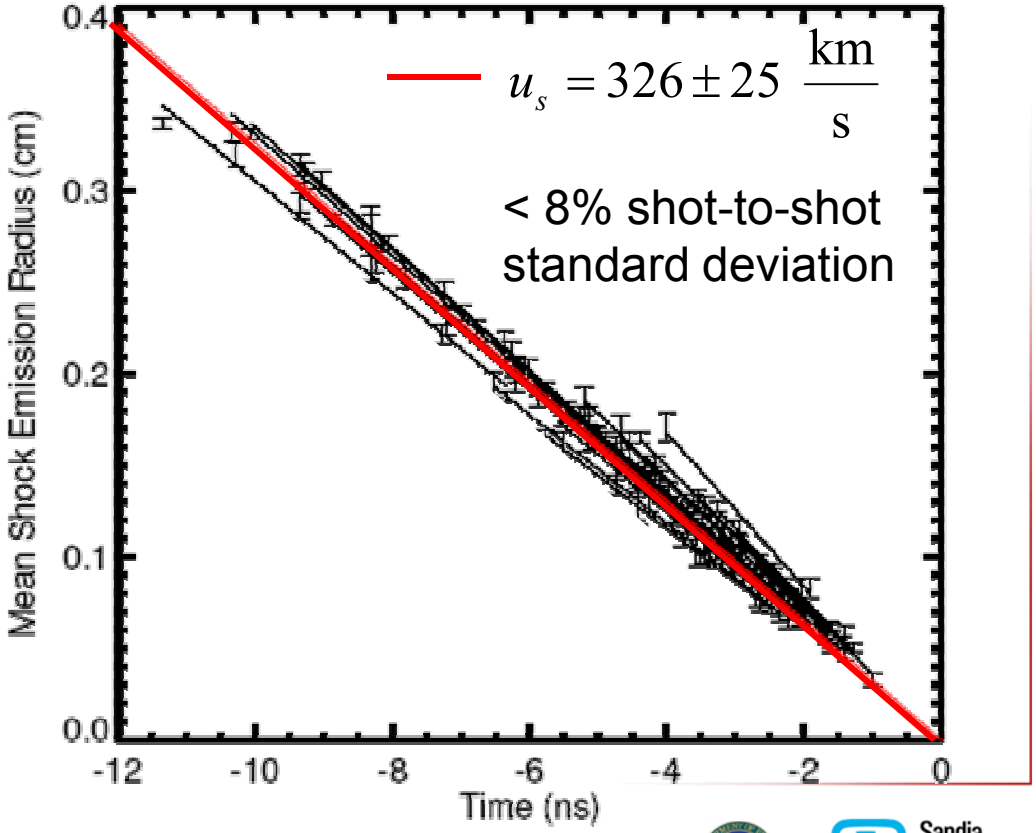
Measuring axial x-ray source size

Relevant Diagnostics

- Filtered Pinhole Camera
  - Broadband imaging
    - 8 frames





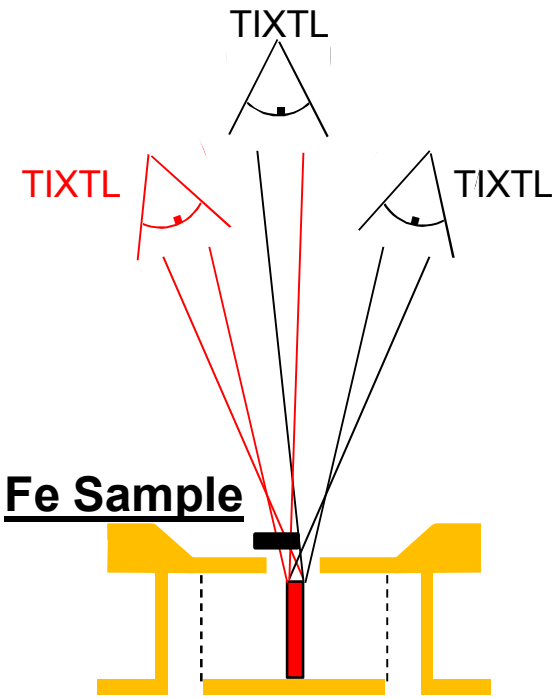


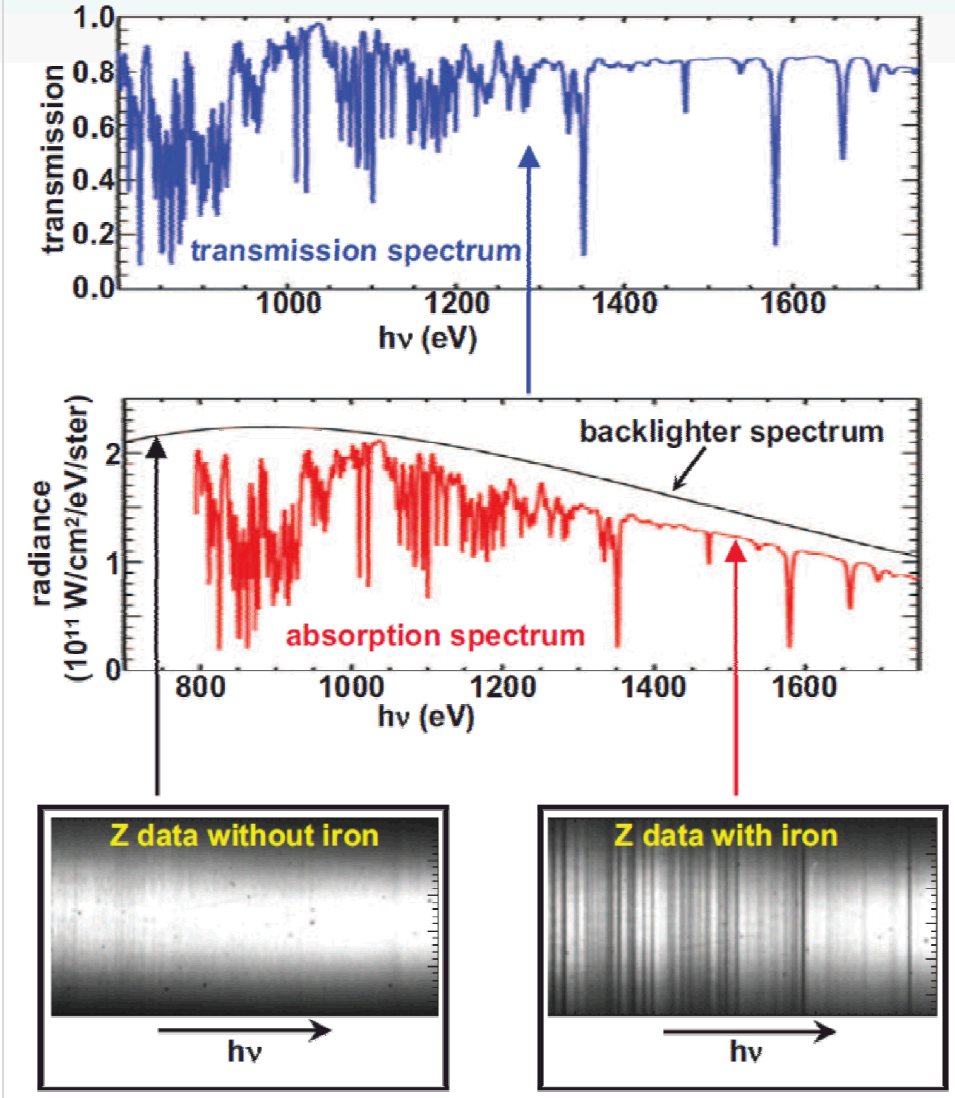
Sandia National Laboratories

Measuring Fe Transmission

Relevant Diagnostics

- Time-Integrated Convex Crystal Spectrometers (TIXTLs)
  - 0.8 - 2 keV at R>700





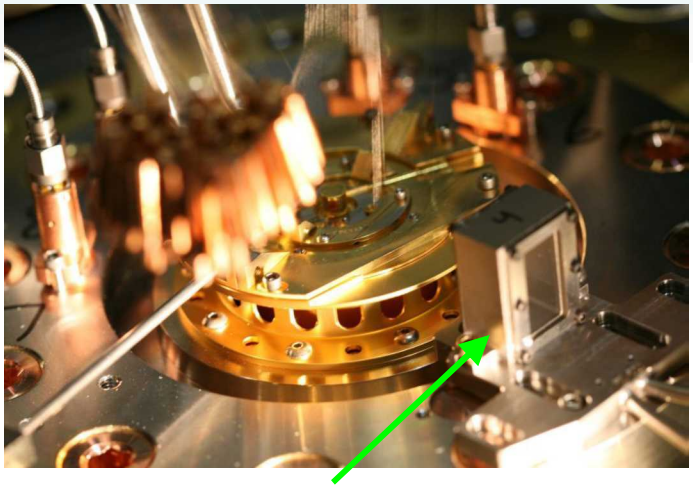
Sandia National Laboratories

Measuring Photo-ionized Neon

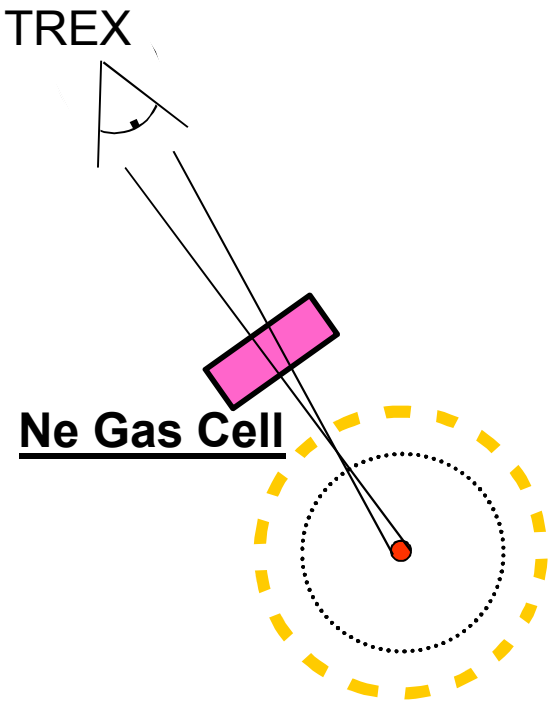
Relevant Diagnostics

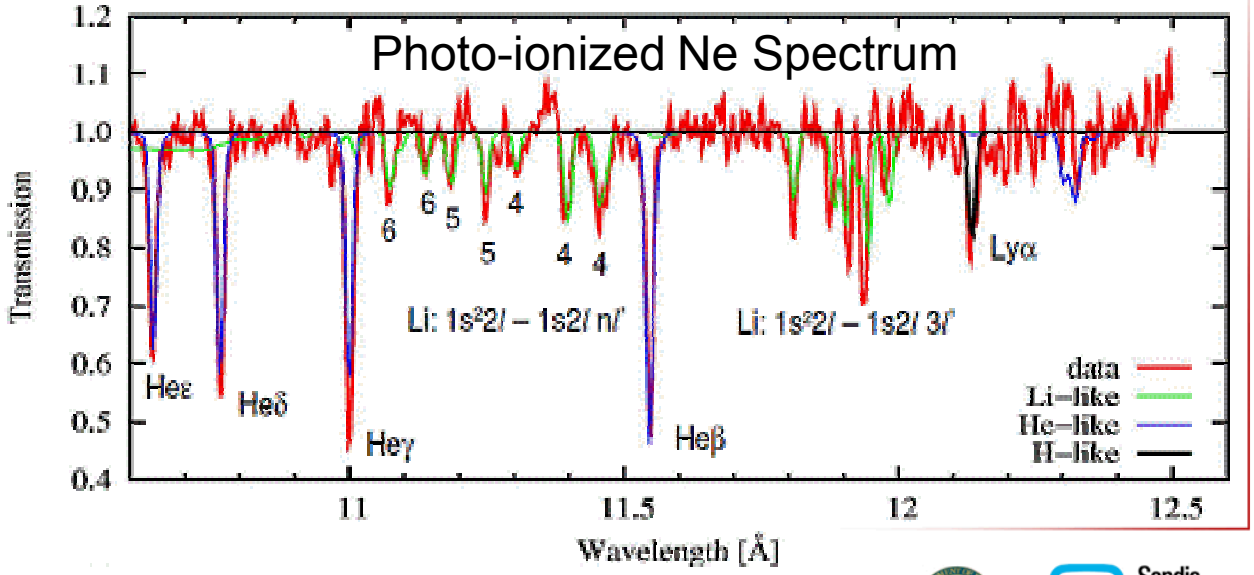
- Time-Integrated &Time-Resolved Elliptical Crystal Spectrometers (TREXs)
  - 0.8 - 2 keV at R>700

Fielded by UNR Post-doc Ian Hall



Neon Gas Cell





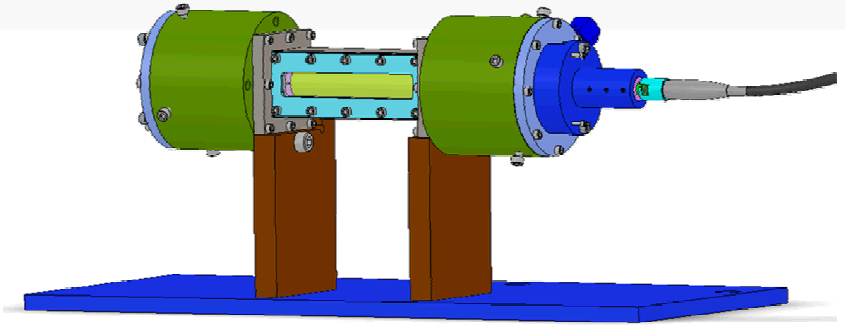
Sandia National Laboratories

Measuring Hydrogen line-shapes

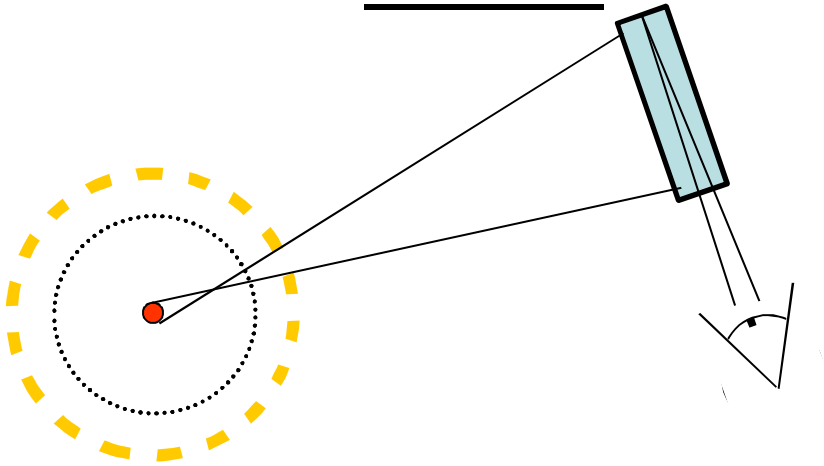
Relevant Diagnostics

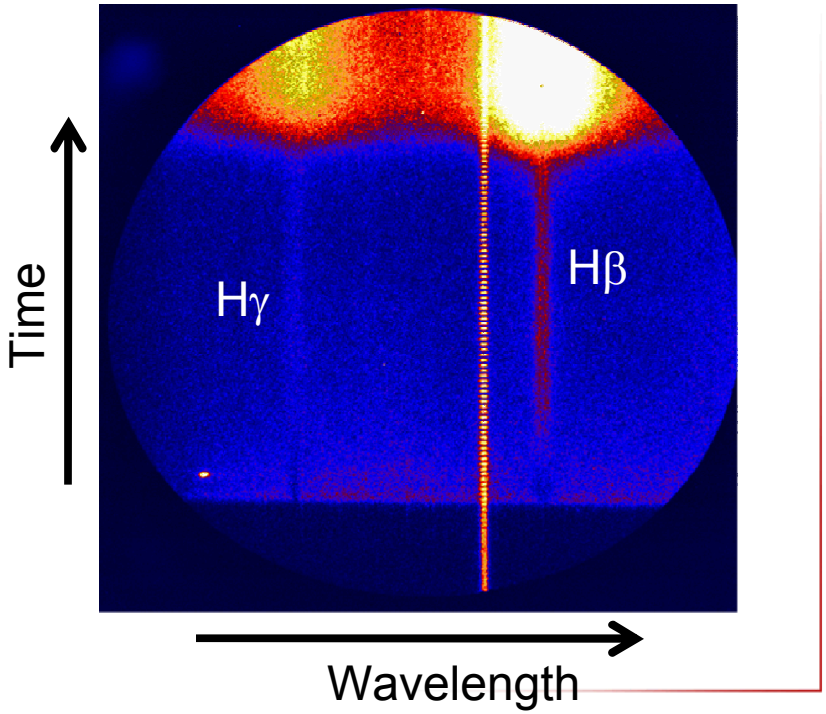
- Streaked Visible Spectrometer
  - 2.3 – 3.0 eV

Established by UM grad-student Matt Gomez
Fielded by UT students Ross Falcon, Thomas Gomez and Jennifer Ellis.



H Gas Cell





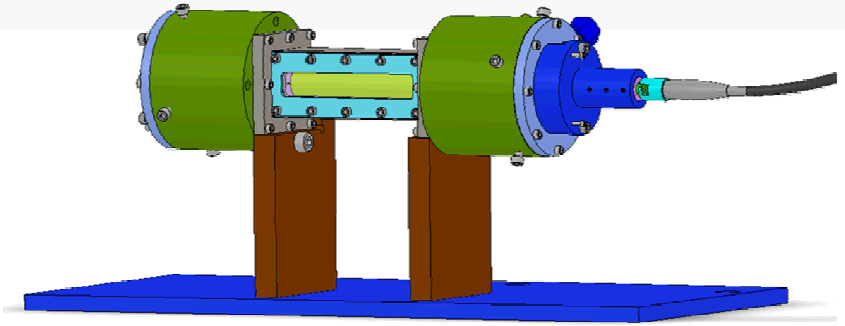
Sandia National Laboratories

Measuring Hydrogen line-shapes

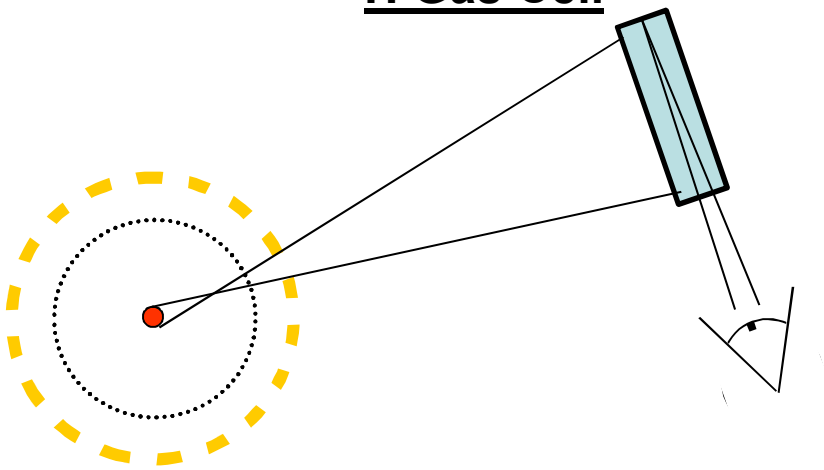
Relevant Diagnostics

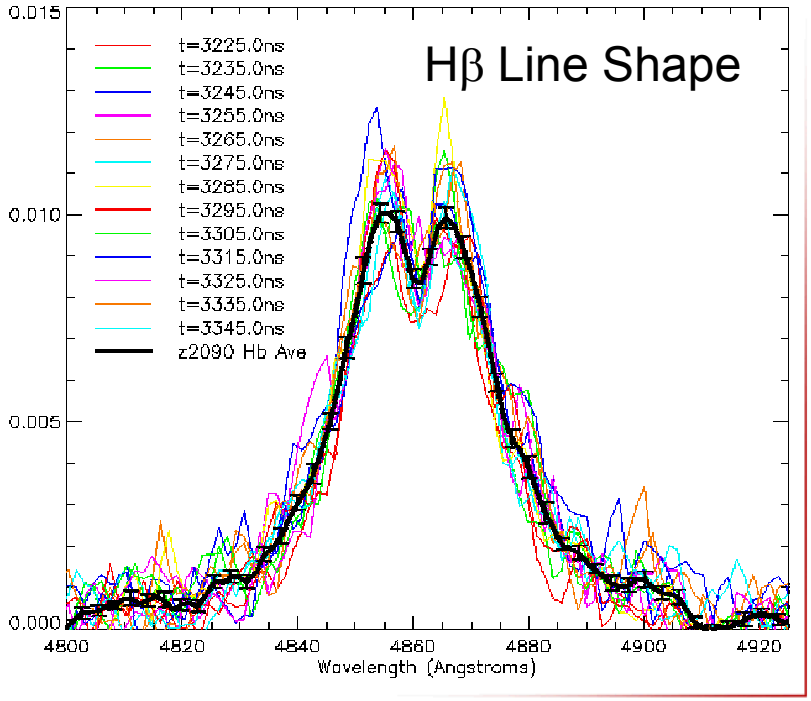
- Streaked Visible Spectrometer
  - 2.3 – 3.0 eV

Established by UM grad-student Matt Gomez
Fielded by UT students Ross Falcon, Thomas Gomez and Jennifer Ellis.



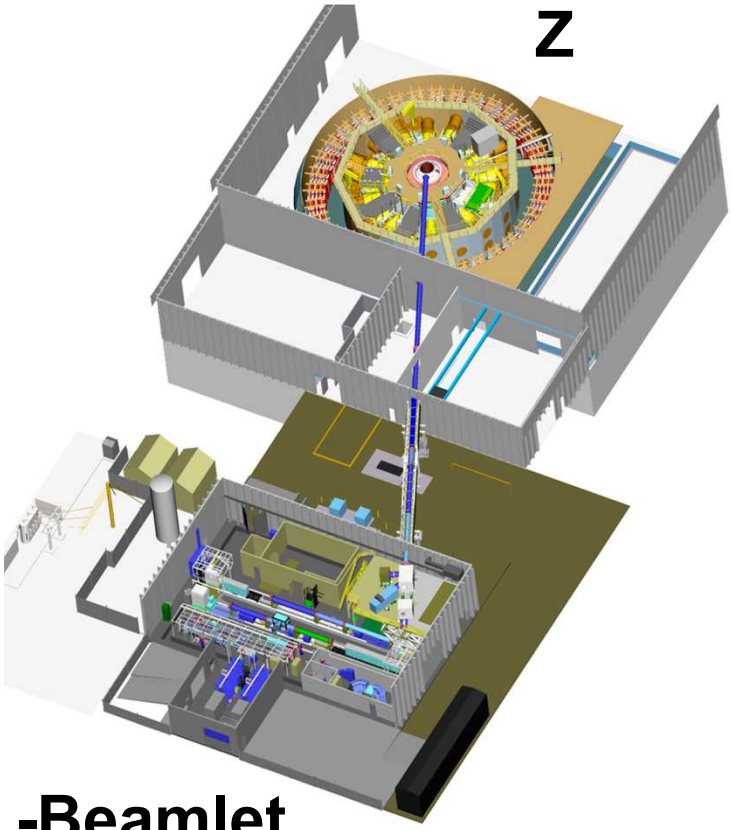
H Gas Cell



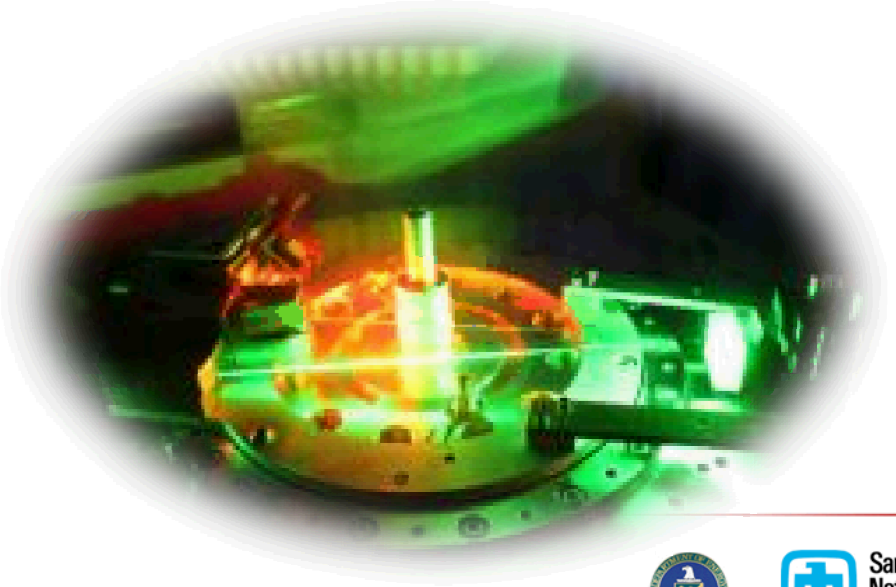


Sandia National Laboratories

Z has a unique backlighting capability



- ~2 kJ at 2ω in up to a four-post picket at ≤ 2 TW peak power.
- > 80% of the 2ω energy into a focal spot of 50-μm-diam
- 1 or 2-frame Monochromatic Radiography
  - -1.865 keV
  - -6.151 keV
- 2-color Monochromatic Radiography
  - -1.865 and 6.151 keV



Sandia National Laboratories

Summary

- Z experiments address fundamental issues in HED science.

- Multiple established sources and platforms are available for use.

- The ‘Beamline’ model of collaborative experiments on Z is an efficient way to do fundamental radiation driven science.

- Z has a large x-ray diagnostic infrastructure for making multiple types of measurements on both the z-pinch performance and the radiation driven experiment.

- University collaborators with the appropriate safety training and access privileges on Z are actively participating in the development, characterization, and fielding of diagnostics on Z.

- Experiments should be designed around existing diagnostic capabilities on Z or integrated in with programmatic diagnostic development projects.