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Progress in X-ray Thomson Scattering of Warm Dense Matter on Z-Accelerator

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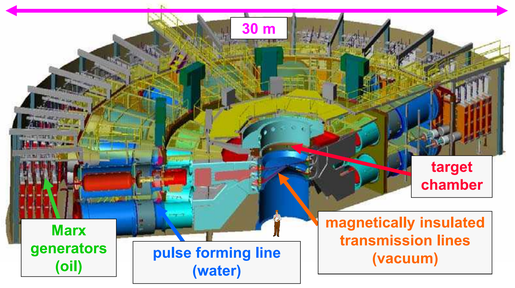
Accurate measurements of warm dense matter (WDM) physical properties, such as temperature, density, and ionization state, are important for understanding and modeling high-energy density physics. X-ray Thomson scattering has recently been used to probe WDM states generated with high-power lasers. The Z-Accelerator has the capability to create WDM states with greater uniformity, larger size, and longer duration than that achievable on laser-driven experiments. Magnetically launched flyers experiments on the Z-Accelerator utilizing the Z-Backlighter Laser to generate x-rays for scattering of shock-compressed samples are in preparation. Alternatively, experiments are being designed to use x-ray radiation from a z-pinch implosion to isochorically heat and probe samples. A new spherically bent focusing spectrometer has been built to measure scattered x-rays with high spatial and spectral resolution, and high sensitivity. Initial calibration measurements and plans for future Z experiments will be discussed.

Z-Accelerator

- Pulsed power generator: 26 MA, 100-700 ns
- Magnetic compression: coaxial and strip-line configurations
  - Ramp (isentrope) loading: 20-400 GPa,
  - Shock loading: flyer plate velocity > 40 km/s
- Z-pinch x-ray source: 1-2 MJ, > 200 TW

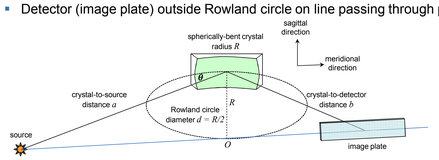


X-ray scattering spherical spectrometer (XRS^3)

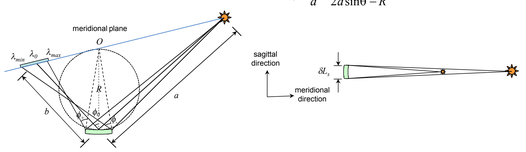
- Focusing spectrometer with spatial resolution
  - Simultaneously obtain high spectral and high spatial resolution
  - X-rays from source dispersed from spherically-bent crystal according to Bragg equation:

$$n\lambda = 2d\sin\theta$$

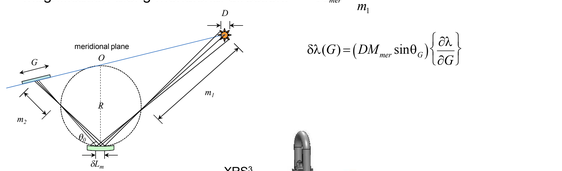
- Source-crystal-detector setup
  - Source located outside Rowland circle
  - Detector (image plate) outside Rowland circle on line passing through point O and source



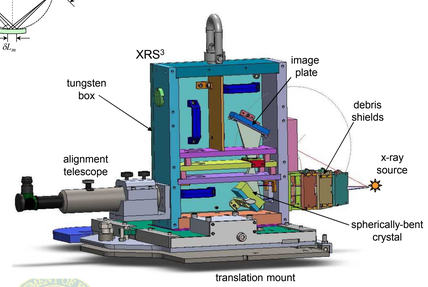
- Magnification along sagittal direction: $M_{sag} = \frac{b}{a} = \frac{R}{2a\sin\theta - R}$



- Magnification along meridional direction: $M_{mer} = \frac{m_2}{m_1}$



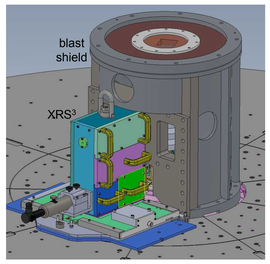
$$\delta\lambda(G) = \left(DM_{mer}\sin\theta_G\right)\left\{\frac{\partial\lambda}{\partial G}\right\}$$



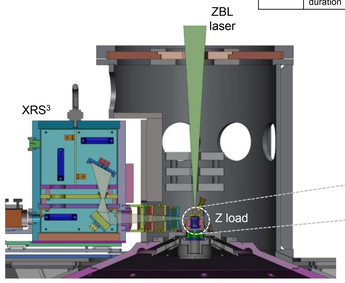
Magnetically launched flyer experiment

- Z Warm Dense Matter samples are unique: uniform, large, & long duration
- Z-Backlighter (ZBL) laser generates intense x-rays to penetrate compressed matter

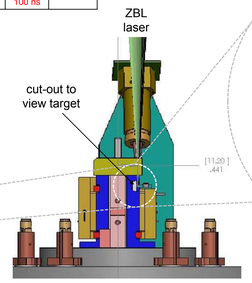
		Z	laser
target	thickness	1 mm	0.25 mm
	diameter	10 mm	1 mm
steady state	spatial extent	200 – 400 um	25 um
	temporal duration	10 – 100 ns	1 ns



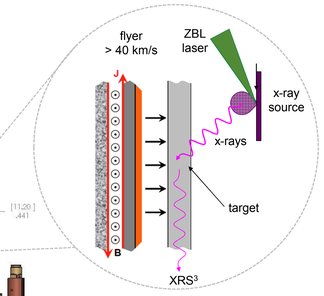
Z load isometric view



Z load side view

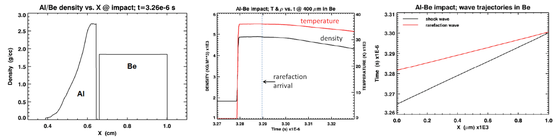


XRS^3 line-of-sight view

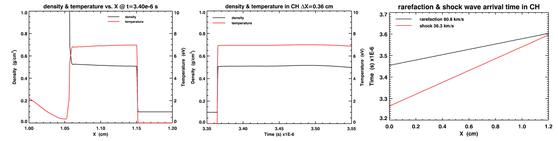


Z load top view

- ALEGRA calculations with Al flyer (40 km/s)
  - 14 Mbar, 3 eV in Be target
  - Large spatial extent: > 200 μm
  - Long time duration: > 10 ns

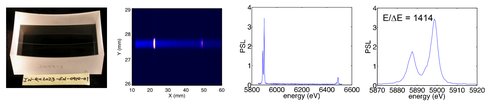


- ALEGRA calculations with Al flyer (30 km/s)
  - 0.8 Mbar, 7 eV in CH foam target
  - Very large spatial extent: > 400 μm
  - Very long time duration: > 100 ns

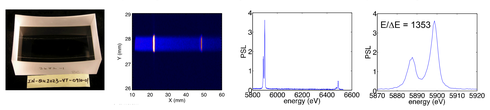


Spherically bent crystal characterizations

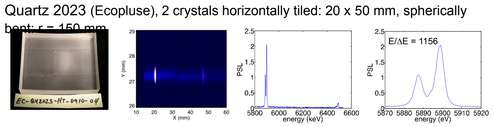
- Manson x-ray source calibrations, Mn anode: K-α (5.899 keV) & K-β (6.491 keV)
- Quartz 2023 (Inrad), 1 crystal: 18 x 60 mm, spherically bent: r = 150 mm



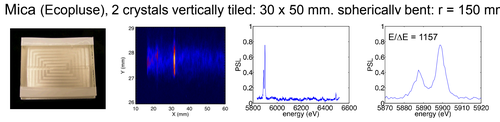
- Quartz 2023 (Inrad), 2 crystals vertically tiled: 36 x 60 mm, spherically bent: r = 150 mm



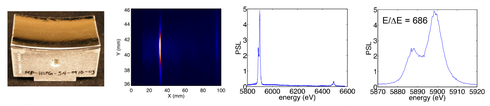
- Quartz 2023 (Ecopluse), 2 crystals horizontally tiled: 20 x 50 mm, spherically bent: r = 150 mm



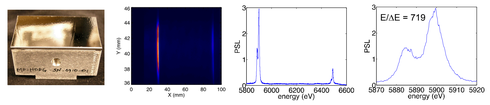
- Mica (Ecopluse), 2 crystals vertically tiled: 30 x 50 mm, spherically bent: r = 150 mm



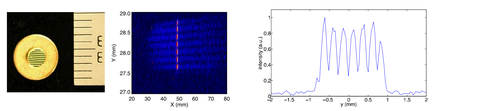
- HOPG (Momentive Performance), spherically bent: r = 150 mm, mosaic focusing



- HOPG (Momentive Performance), cylindrically-bent: r = 150 mm, mosaic focusing



- Spatial calibration: 65 μm Au wires, 180 μm spaces

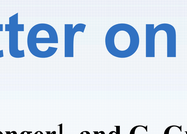


Radiatively heated experiment

- Immense radiation from Z-pinch
  - Isochoric heat sample with broad band x-rays
  - Probe warm dense matter with intense spectral line: Ti-He-α (2 kJ)
- Sample located far from x-ray source
  - Highly collimated x-rays allow small angle forward scattering

Wire array

Z-pinch of wire array

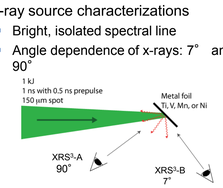


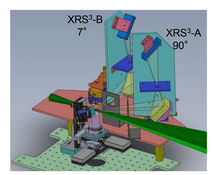
Z load isometric view

Z load top view

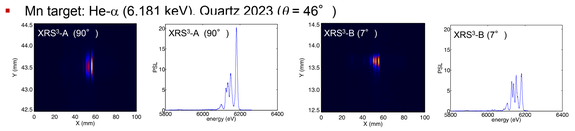
ZBL x-ray source development and x-ray scattering experiments

- X-ray source characterizations
  - Bright, isolated spectral line
  - Angle dependence of x-rays: 7° and 90°

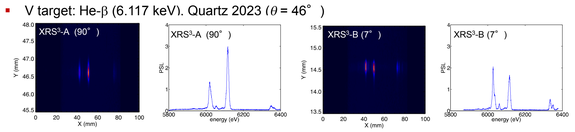




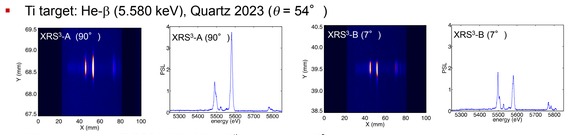
- Mn target: He-α (6.181 keV), Quartz 2023 ($\theta = 46^\circ$)



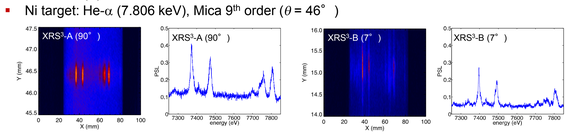
- V target: He-β (6.117 keV), Quartz 2023 ($\theta = 46^\circ$)



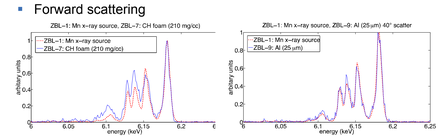
- Ti target: He-β (5.580 keV), Quartz 2023 ($\theta = 54^\circ$)



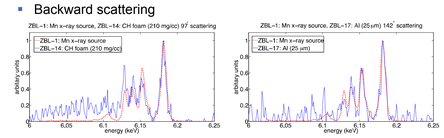
- Ni target: He-α (7.806 keV), Mica 9th order ($\theta = 46^\circ$)



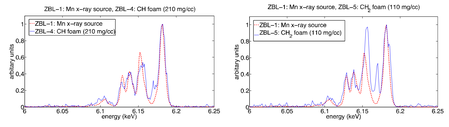
- X-ray scattering of cold targets: CH foam (210 mg/cm^3), Al (2.7 g/cm^3)
  - Forward scattering



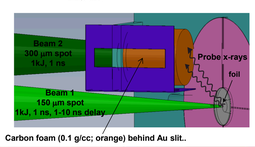
  - Backward scattering



- X-ray scattering of "unintentionally" heated targets: CH foam (210 mg/cm^3), CH_2 foam (110 mg/cm^3), forward scattering



- Future x-ray scattering of heated target
  - CRF (carbon resorcinol formaldehyde) foam (100 mg/cm^3)



Carbon foam (0.1 g/cc; orange) behind Au slit..

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