

# X-Ray Scattering from Warm Dense Matter at Vulcan

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Warm dense matter (WDM) is a state of matter that lies between the physical regimes of condensed matter and weakly coupled plasmas. Density ranges from 0.1-10 times solid density and temperatures are from 0.1 to 100eV <sup>[1]</sup>. WDM is important in astrophysics; it is the most likely state of matter for the cores of Jovian planets (figure 1), brown dwarfs and could also be similar to the Earth's own core. Indeed closer to home WDM is a phase that a D-T fuel pellet goes through during the initial stages of compression in any inertial confinement experiment. During this stage the compression must be extremely uniform, keeping instabilities to a minimum. A greater understanding of WDM could greatly improve the chances of success with Inertial Confinement Fusion (ICF).

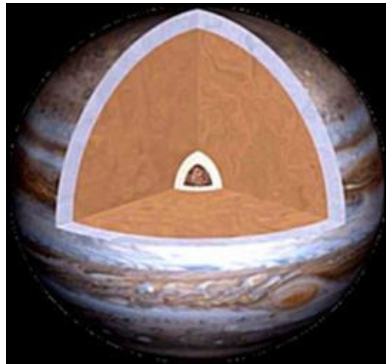


Figure 1. The core of Jovian planets is theoretically predicted to be in the WDM state. The interiors of these planets can experience pressures of up to 40Mbar and temperatures of 15000-21000K. <sup>[2,3]</sup>

Matter in this exotic state exhibits both long and short range order, due to correlation effects between atoms and ions, dependent upon the ratio of the Coulomb and kinetic energies of the ions. Just as the structure of crystalline materials may be investigated through X-ray diffraction, the structure and dynamics of WDM may be investigated by angularly resolving the scatter of X-rays through this matter.

Creating uniform WDM samples in the laboratory is not a trivial task and diagnosis of the plasma conditions requires a bright, monochromatic, kilovolt X-ray source; which in itself is not easy to produce but Vulcan has proved to be capable of just that.

Target area west (TAW) at the Vulcan laser facility potentially offers 6 long pulse beams, frequency doubled to green 527nm light with a total energy of

approximately 1kJ. Coupled with this is the option to utilize two, 100TW short pulse beams (1-10ps).

This makes the TAW area a versatile laboratory for experiments on WDM. Counter propagating long pulse beams simultaneously irradiate a plastic coated aluminium target (targets are produced on site, allowing user flexibility on their design). As the plastic ablates, the rocket like expansion drives shock waves through the target. Careful selection of the pulse duration, focal spot size and laser intensity allows one to tailor these shocks to produce the conditions characteristic of WDM in aluminium. This technique can be adapted for studying other materials such as iron. A much more intense short pulse beam, at the fundamental infra-red frequency (with the option to also convert to 2w green as well) produces a bright X-ray source such as 4.75Kev He-alpha radiation from thin Ti foils. A schematic of a typical experiment is shown below;

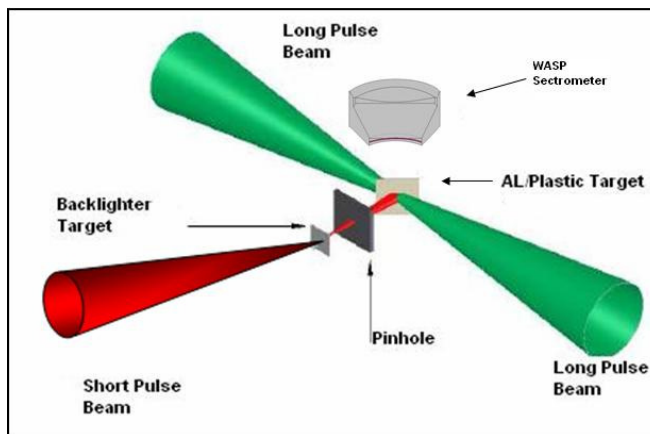


Figure 2. Typical X-ray scattering from WDM set-up. The pinhole is used to collimate the probing X-rays, increasing angular resolution. Detectors are not shown. Target designs can be complicated, however are produced on site at Vulcan, affording many benefits to users.

Scatter from the target can be spectrally and angularly resolved, giving information about the structure, density and temperature of the shocked material. In Figure two a recently developed diagnostic is shown. The wide angle spectrometer (WASP) can collect scatter data from multiple angles simultaneously. This diagnostic has had initial success at Vulcan. [4]

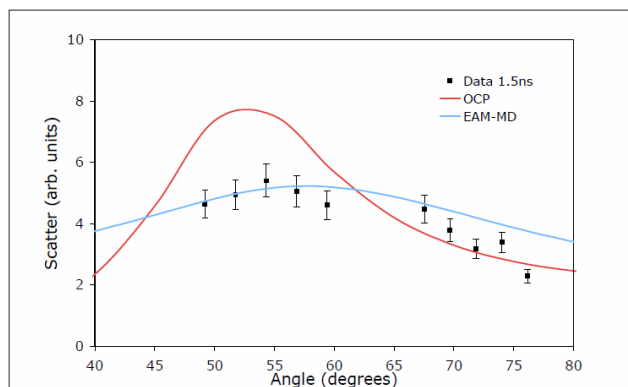


Figure 3. Plot of intensity of scatter radiation as a function of angle for aluminium at solid density and approximately 8000K.

Figure 3 displays data from a previous experiment at Vulcan. The experimental points are plotted together with theoretical curves for the scatter intensity. The red curve represents the one component plasma (OCP) model while the blue curve is an embedded atom model molecular dynamics code

(EAM-OD). One can clearly see the differences between the two models and understand the need for comparative experimental data.

Vulcan can provide a world class facility capable of performing these difficult and demanding experiments, and indeed has proven so in the past <sup>[5,6,7]</sup>. It is crucial that sound experimental data is acquired as it essential for the validation of new theoretical models which attempt to describe the incredibly complicated dynamics of WDM.

#### References

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