

HEDS: The study of matter under extreme conditions



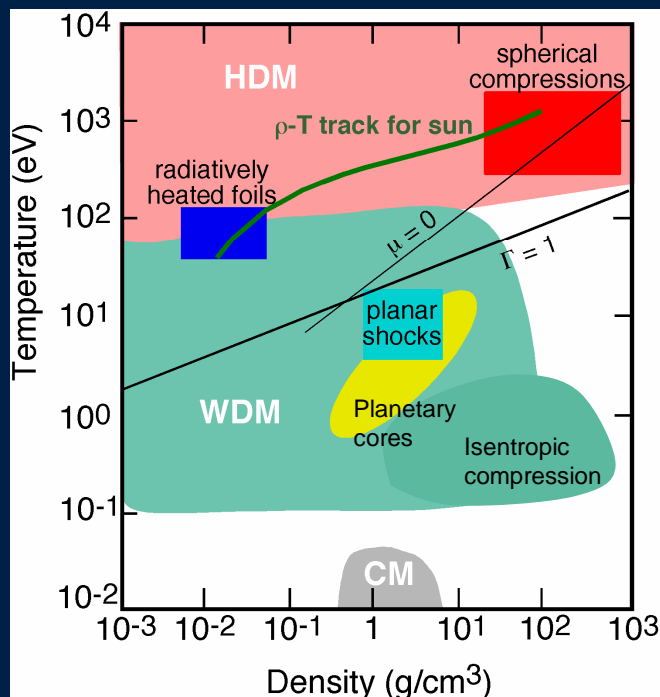
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Why is HEDS important ?

Hydrogen phase diagram



HEDS provides the unifying platform for the understanding of a new class of materials at the boundary between the solid state and the ideal gas regimes

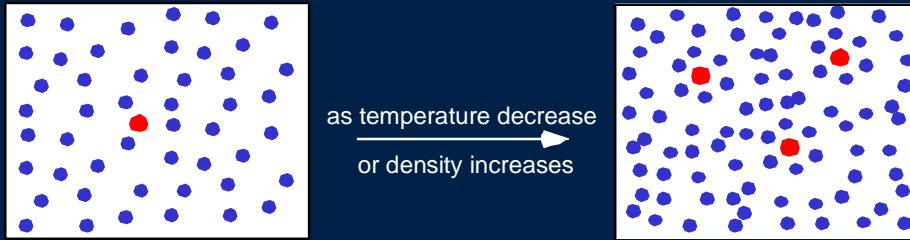
- **Laboratory analogues of astrophysical objects:** can directly measure equation-of-state (EOS), thermodynamic and optical properties
- **Warm dense matter:** experimental benchmark of a partially degenerate, strongly correlated many-body system
- **Energy security:** the success of inertial fusion energy relies on the proper understanding of the physics of HEDS



Modeling of extreme matter requires a finite-temperature multi-million particle simulations

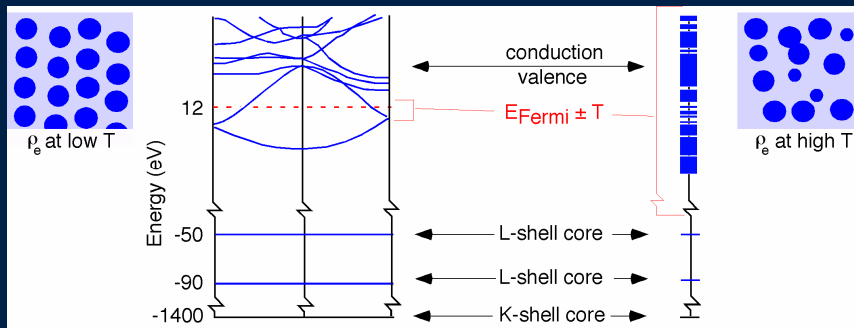
In WDM particle correlations become important: ion- e^- and ion-ion give rise to both short and long range order

- depression and shifts of the ionization potentials

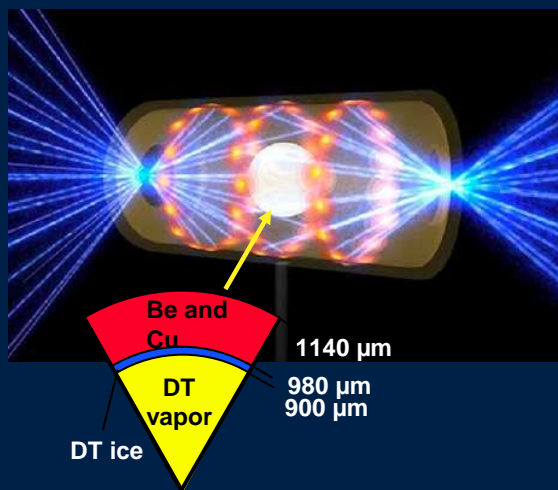


The kinetic energy is comparable to the Fermi energy:

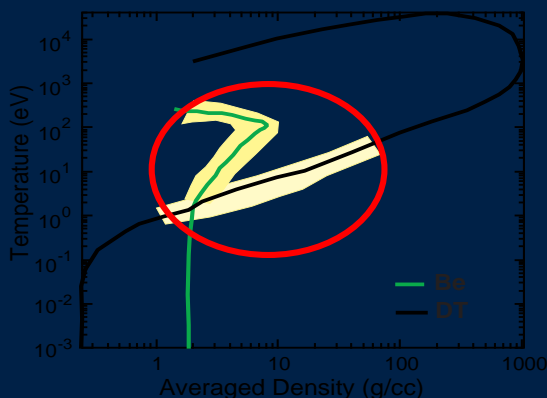
- excitations of the core levels
- internal structure must be accounted explicitly



HEDS matter is produced in laser experiments



- Laser is focused through holes inside a cavity (hohlraum): the cavity radiates energy and heats a capsule in the center
- A compression shock wave is launched inside the heated material
- The compressed matter reaches the WDM regime: many body effects, correlations, pressure ionization



- Knowledge of EOS to constraint evolutionary models of giant planets in the solar system
- Determines efficiency of compression in fusion energy experiments

UK community has been at the forefront of HEDS research



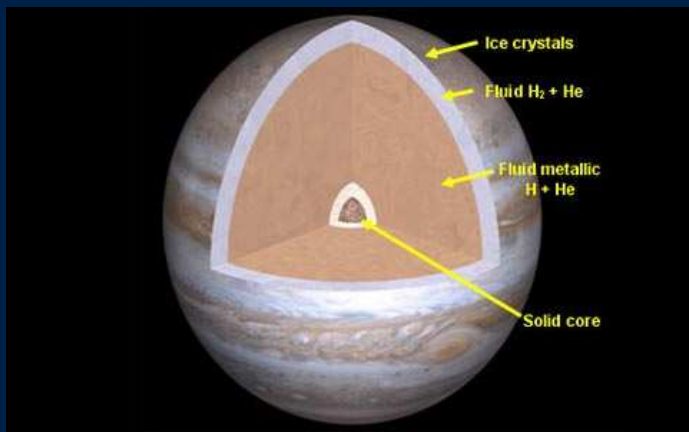
UK Universities and National Laboratories are leading HEDS research in many areas:

- Laboratory astrophysics of jets and supernova remnants
- Nuclear astrophysics
- Structure and EOS of dense matter
- Ultrafast phase transitions
- Electron and proton transport
- X-ray spectroscopy
- Plasma electron accelerators
- Strongly coupled plasma theory

...and we invite to any other interested group to join us

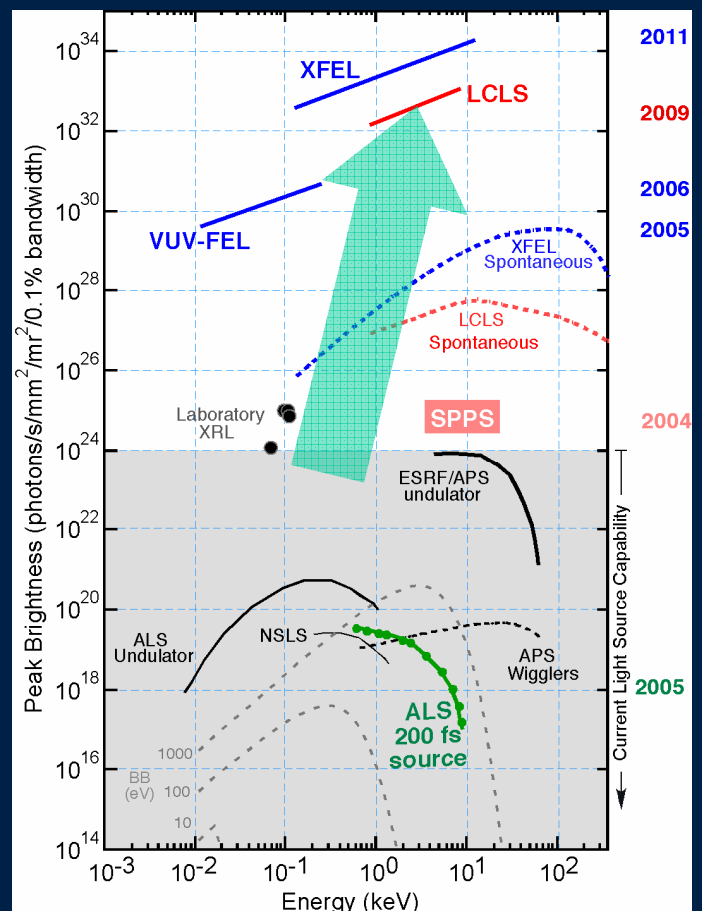
The New Light Source will enable the UK community to stay ahead in the international arena

NLS will provide the required tool for HEDS studies



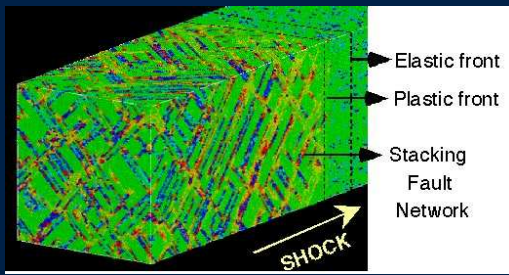
HEDS vision for the NLS:

- source of high-flux keV photons for diffraction and scattering experiments
- coupled to high-power optical laser for the generation of HEDS "extreme" states
- coupled to electron beam for electric and magnetic fields, and stopping power measurements



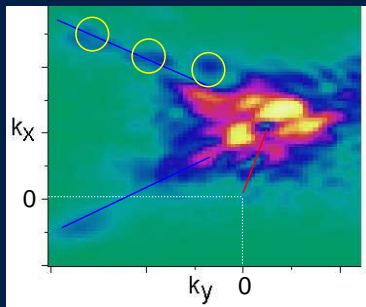


Current Status Simulation of x-ray diffraction



• MD simulation of FCC Cu (Bringa)

Periodic features
⇒
average distance between faults



Diffuse scattering from stacking fault

Peak diffraction moves from 0,0 due to relaxation of lattice under pressure

• X-ray diffraction image using LCLS probe of the (002) shows *in situ* stacking fault information (Wark)

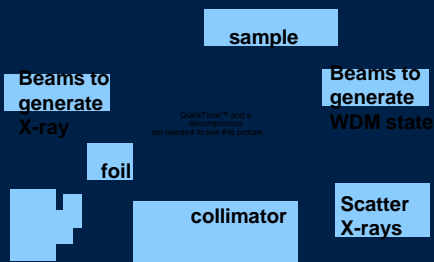
Future with X-FEL Unique capabilities

- Imaging capability
 - Point projection imaging
 - Phase contrast
 - High resolution (sub- μm)
- Direct determination of density contrast
- Diffraction from WDM samples
 - Detection of high pressure phase transitions
 - Lattice structure, including dislocation & defects
 - Liquid structure

These complement the standard instruments, e.g., VISAR and other optical diagnostics



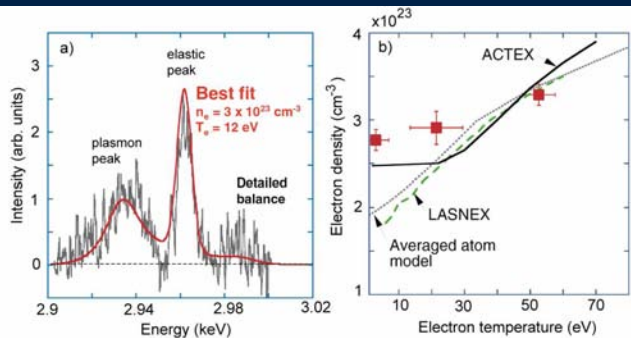
Current Status Simulation of x-ray scattering



• Laser sources used to generate WDM states and x-ray probe radiation

Future with X-FEL Time-resolved dynamics

- Significant improvement in signal-to-noise ratio
 - Accurate temperature measurements
 - Electron velocity distribution function
- Space and time resolved structure factors
 - Sub-picosecond time resolution to study microscopic energy relaxation processes
 - Minimize effects from gradients in sample volume



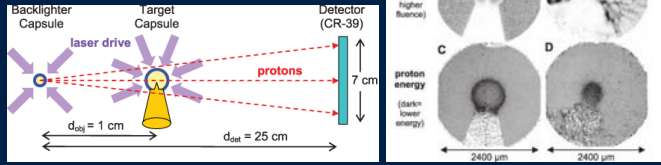
• Inelastic x-ray scattering provides information on the ionization balance and microscopic structure (Glenzer)



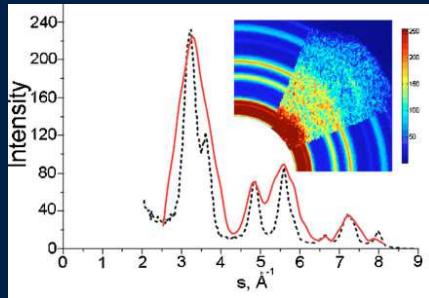
Current Status

Probing and energy loss spectroscopy

- Use of monochromatic proton beams requires large laser facilities and/or complex geometries



- Charged particle radiography provides a tool to map fields under extreme matter conditions (Borghesi, Zepf, Mackinnon, Petrasso and others)



- Ultrafast diffraction on cold solids using e^- from Linac (Hastings)

Future with X-FEL

Ultrafast field dynamics in WDM

- Electron beam (1-10 MeV) coupled to NLS and high power laser could provide novel techniques to study HEDS
 - Ultra-short and monochromatic bunches for E and B field radiography
 - Time-resolved energy loss spectroscopy
 - Stopping power measurements for conditions relevant to inertial fusion energy
- Additional electron source could also provide ultra-intense THz radiation to resonantly drive non-linear lattice oscillations and melting



Research in HEDS will benefit from a "combined" light source infrastructure

