Laser-matter interactions and WDM physics at Warwick

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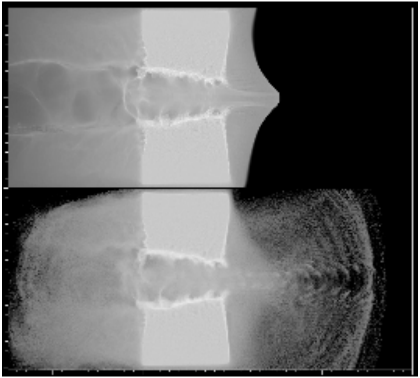
ICF Relevant Code Development at Warwick

- **People involved**: Warwick has one staff (Arber), two PDRAs and three PhD students actively involved in major code development of relevance to ICF.
- **EPOCH**: a 3D, relativistic EM-PIC code developed in Warwick; (new support via a four year grant for 3 additional PDRA to increase capabilities in collaboration with Oxford (Bell) and Imperial (Evans)
- **Valis**: a (2d,2p) relativistic direct EM-Vlasov solver developed in collaboration with AWE (Sircombe)
- **Lare3d**: a 3D Lagragian-remap code for MHD simulations developed at Warwick (plans to extend to (r-z) ALE + multi-material versions)
- **CCPP – Collaborative Computational Project in Plasma physics**: UK wide collaborative effort in code development and staff training funded by a 3 yr EPSRC network grant (since Oct. 2009, PI is Arber)

EPOCH - an Extendible Pic Open Collaboration

Laser burns through foil



Interaction of a $10^{20}\,\mathrm{Wcm}^{-2}$ laser with 1μ of hydrogen ($n=2n_c$). Top: ion density; bottom: electrons.

Current status:

- 3D, explicit, relativistic PIC code
- Parallelised on problems using up to $\sim$ 1024 cores
- Easy setup through maths parser in input deck
- Visualisation through VisIt plugin

Development plans:

- QED effects relevant for ultra-high fields and pair production (Bell)
- Collisions, radiation, time filtering and implicit schemes (Evans)
- Load balancing and HECToR scaling optimisation, user interface,... (Arber)

Valis - a Relativistic (2d,2p) EM Direct Vlasov Solver

General aim:

- Development of a high fidelity, noise free kinetic code for short pulse LPI.
- Work is a collaboration between AWE (Sircombe) and Warwick (Arber)

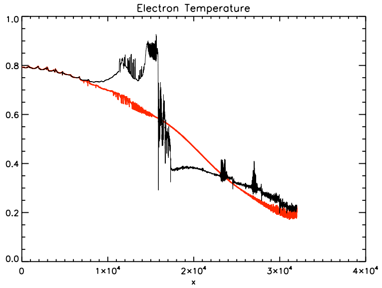
Current status:

- Core: relativistic (2d,2p) EM direct Vlasov solver
- Parallelised/tested up to 1024 cores

Development plans:

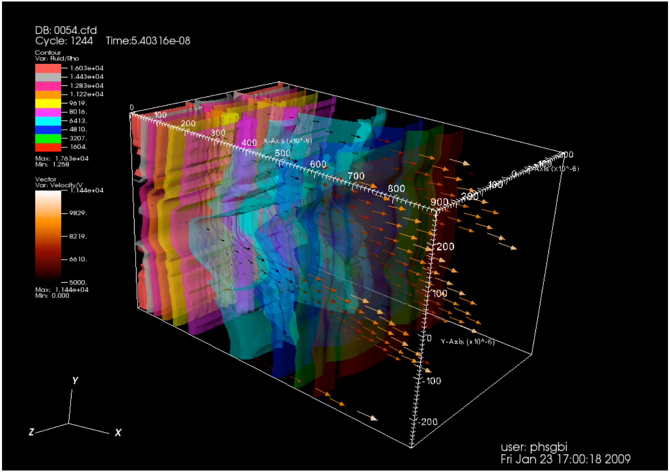
- Include options for collision terms
- Extend to AMR
- (1d, 3p) mainly for space plasmas
- More accurate advection schemes to reduce number of grid points

Standard test: transport driven by temperature profile

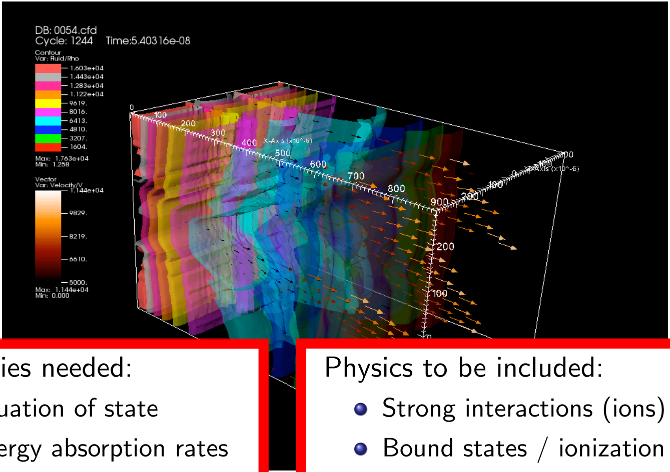


Nonlocal electron transport including mobile ions (red line: immobile ions). Initially, $T_e(x) \sim \tanh(x)$ ranging 300 keV to 3 keV ($n_e = 10^{23}\,\mathrm{cm}^{-3}$).

Lare3D - Hydro-Simlations of Dense Plasmas and WDM



Lare3D - Hydro-Simlations of Dense Plasmas and WDM



Properties needed:

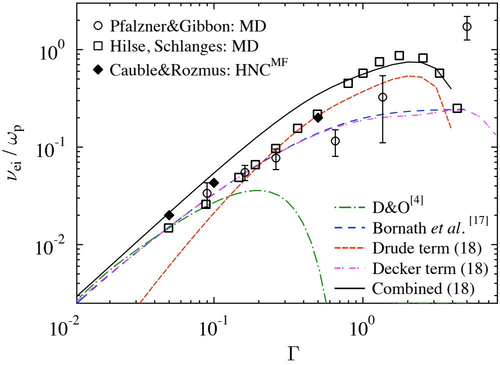
- Equation of state
- Energy absorption rates
- Relaxation rates
- Properties tested

Physics to be included:

- Strong interactions (ions)
- Bound states / ionization balance
- Quantum degeneracy
- Structural information

Collisional Absorption: Strong Electron-Ion Collisions

Electron-ion collision frequency



Collisional absorption of laser energy in dense hydrogen versus coupling strength.
Grinenko & Gericke (PRL 2009)

General aim:

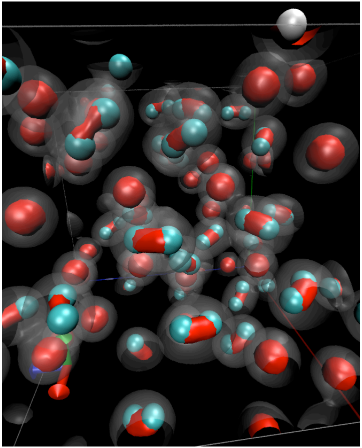
- Analytic (fast) approach to laser absorption for intermediate laser intensities
- Good description of target

Insights gained:

- Quantum treatment absolutely necessary; otherwise break-down at strong coupling
- Quantum theories with weak coupling not sufficient
- Frame of the electrons depends on strong collisions
- Nonlinear behaviour of absorption for heavier elements

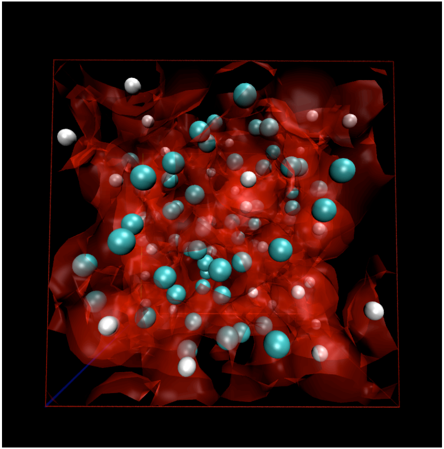
Ab initio Quantum Simulation (DFT-MD using VASP, ...)

Molecular Hydrogen



$\varrho = 0.2\,\mathrm{g cm^{-3}}$ and $T = 4 \times 10^3\,\mathrm{K}$.

Metallic Hydrogen



$\varrho = 3.7\,\mathrm{g cm^{-3}}$ and $T = 4 \times 10^3\,\mathrm{K}$.

Results from DFT-MD: EOS for Fully Ionized Hydrogen

General aim:

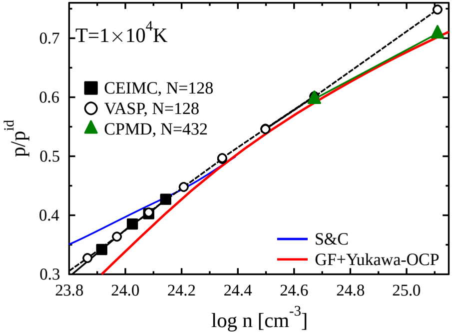
- Highly accurate EOS for H, D and H-He mixtures needed for ICF (and planetary) modeling
- Smooth results to allow for determination of other thermodynamic functions

Refinements needed to obtain limiting law:

- High particle numbers
- Extremely hard pseudo-potential $\longrightarrow$ Coulomb-potential
- *k*-point average (fluids?)

$\Rightarrow$ **DFT-MD works, but needs attention!**

Hydrogen EOS at high densities/pressures



Comparison of different models for the EOS of hydrogen at high densities.

(quasi)-Analytical Work related ICF Research at Warwick

- **Hydro-dynamics**: Extensions of the Lare3D code to multi-materials and to include better EOS, transport and absorption data
- **Energy absorption**: Laser-plasma interaction and ion stopping
- **Equation of state**: Bridging the gap between limiting results and simulation data valid for low and high electron degeneracy
- **Structure in warm dense matter**: Ionic and electronic structure in systems with strongly coupled ions and degenerate electrons
- **Application to x-ray Thomson scattering**: Using the structural information to predict spectra of x-rays scattered on WDM
  $\rightarrow$ use this method as plasma diagnostics (see talk of Wark)
- **Relaxation in dense plasmas**: Apply advanced collision integrals to describe relaxation and properties of nonequilibrium systems