Simulation of Inertial Confinement Fusion at UW

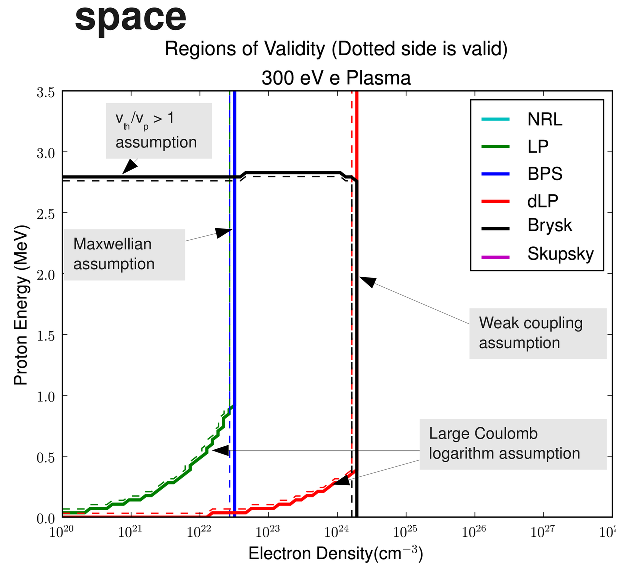
Gregory Moses, Milad Fatenejad, Matthew Terry, Thad Heltemes, Alex Prochaska
Fusion Technology Institute, University of Wisconsin-Madison

Overview of Inertial Confinement Fusion

Heating Deuterium and Tritium (DT) to ignition temperatures is the easiest approach to fusion energy. ICF involves compressing a ~1 mm capsule ("target") to hight densities (~400 g/cm3) in ~10 ns. The target is spherically imploded using a high power (~100 TW) driver, high power lasers being the most common driver. Ablation of the outer surface of the target drives a series of radial shock waves into the target. These shock waves compress the target and heat it to thermonuclear temperatures. High energy alpha particles created from the fusion of Deuterium and Tritium propagate out through cold DT fuel and deposit energy. This energy leads to a propagating burn wave which ignites the remaining fuel and cause the release of significant amounts of energy.

Stopping power models have complicated consistency regions

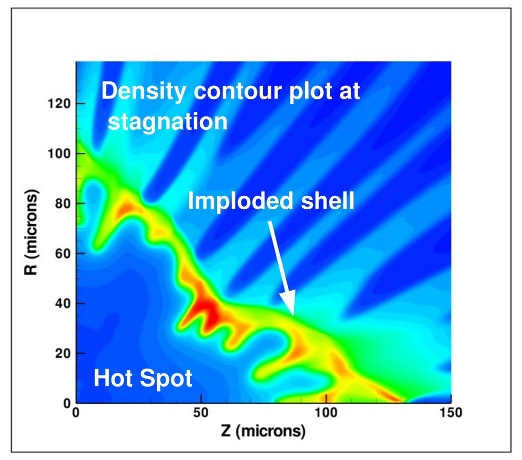
- Each models contains assumptions of plasma conditions
- These assumptions lead to complicated validity regions in temperature-density-particle energy phase space

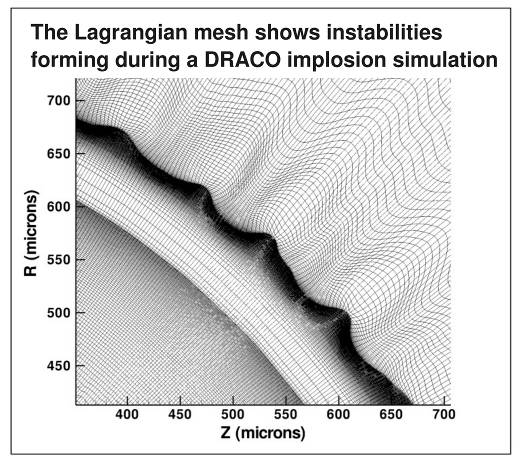


- Common assumptions:
- Collisional behavior
- Dielectric behavior
- Femi-Dirac statistics
- Maxwell-Boltzmann statistics

Significant capabilities have been added to the radiation-hydrodynamics code, *DRACO*

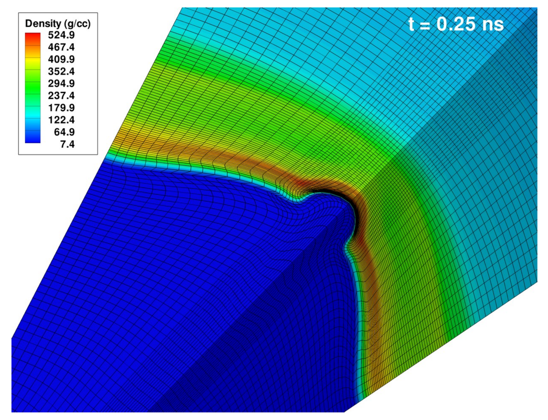
- *DRACO* is a production code used to perform multidimensional simulations of experiments on the OMEGA laser facility
- This work was performed in collaboration with the University of Rochester – Laboratory for Laser Energetics





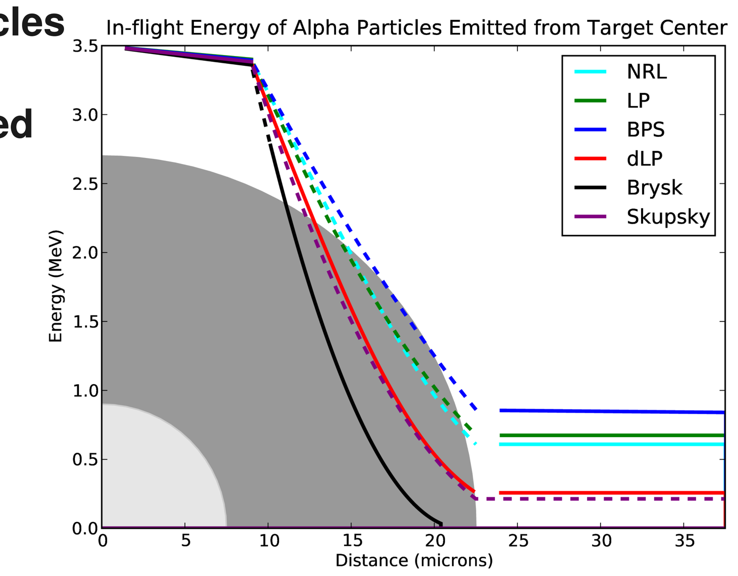
Cooper is being developed as an open platform for modeling ICF relevant physics in three dimensions

- Cooper is parallelized using domain decomposition to run on large meshes
- The code uses the compatible hydrodynamics frame work which allows it to conserve energy to round of error levels
- Cooper is able to preserve spherical symmetry although the methods operate in Cartesian geometry
- Two-temperature thermal conduction and radiative transfer are also being modeled



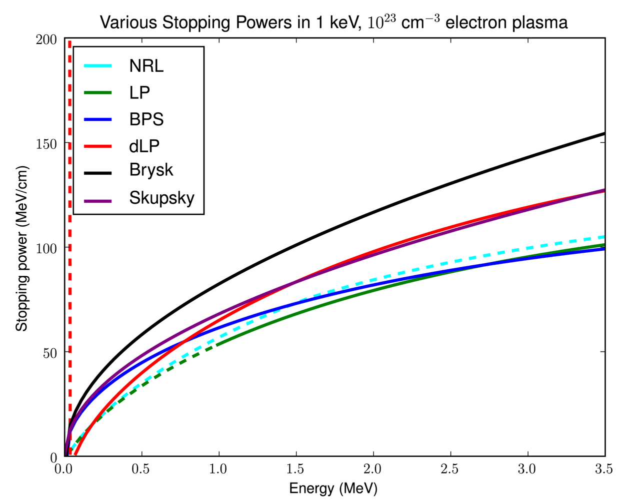
Alpha particle transport is important for modeling ICF ignition

- Alpha particle energy deposition is the mechanism for bootstrap heating
- Alpha particle heating raises plasma temperature, increasing thermonuclear reaction rates, creating more alpha particles
- Alpha particle heating is required for sustained fusion burn
- Many models for alpha particle transport exist



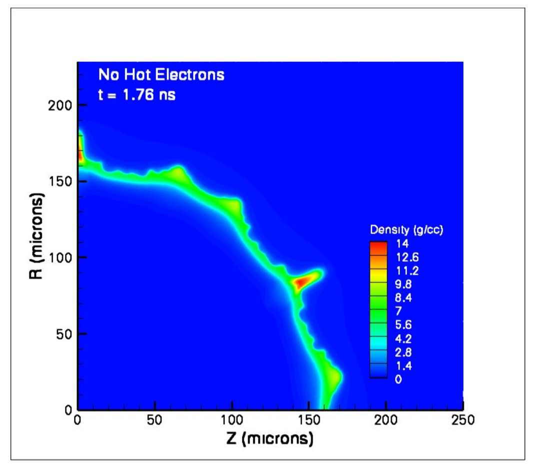
Mutually consistent models calculate different stopping power values

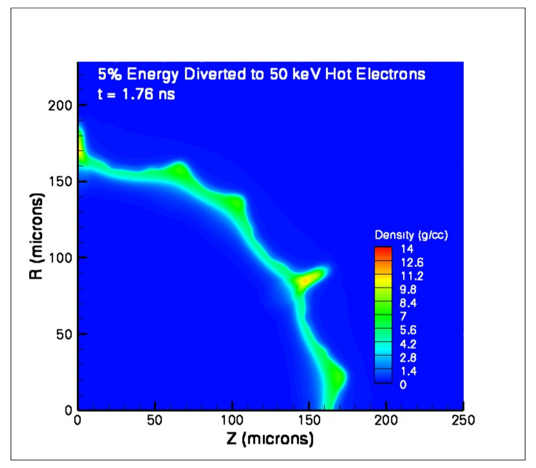
- Implemented a library (Deeks) of 12 different models, with extensive consistency checks
- Incorporated Deeks into UW-developed 1D multi-physics code BUCKY
- Performing integrated target simulations with different stopping power models
- Use BUCKY for hydrodynamics, laser absorption, radiation transport
- Deeks for alpha particle transport



New models have been incorporated into two-dimensional simulations

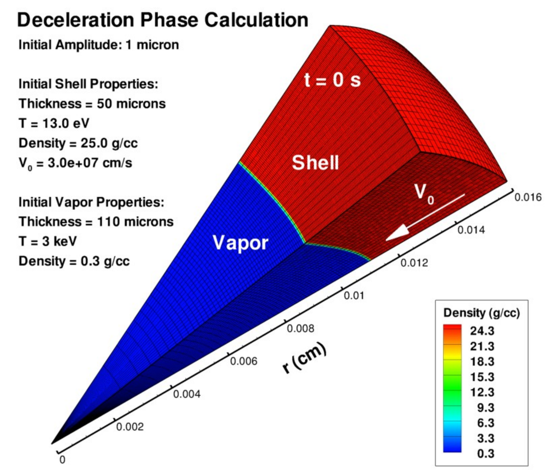
- *DRACO* can now model radiative transfer using both Monte Carlo and diffusion based methods
- Recently, the ability to directly model energetic electrons has been added to the code
- Below, *DRACO* simulations show the effect of energetic electrons and target density and instability growth

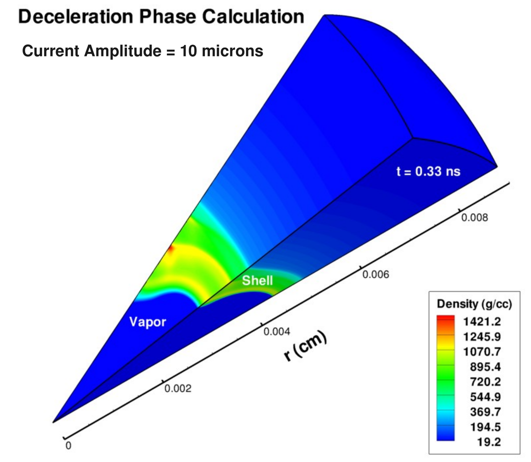




Stopping power measurement brainstorming

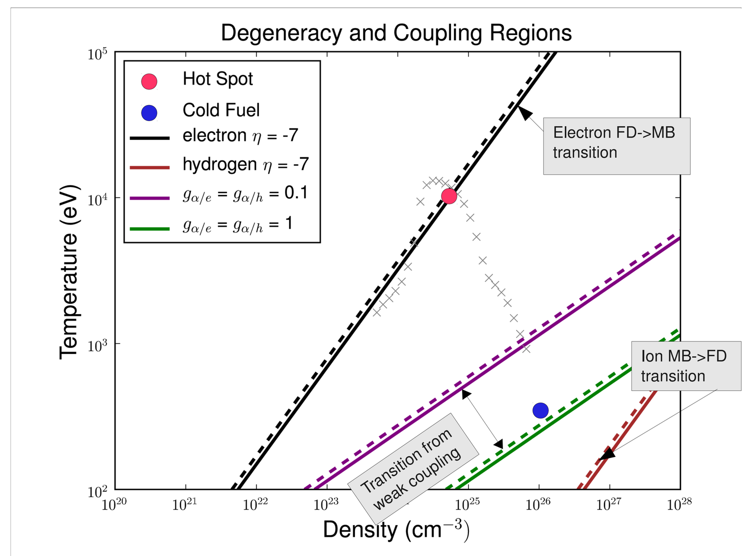
- Cooper is being used to model the deceleration phase of target implosions
- Instability growth during this phase can effect target performance



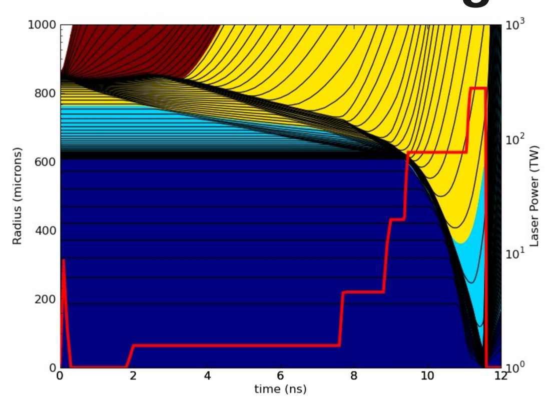


ICF simulations have large ranges of plasma temperatures and densities

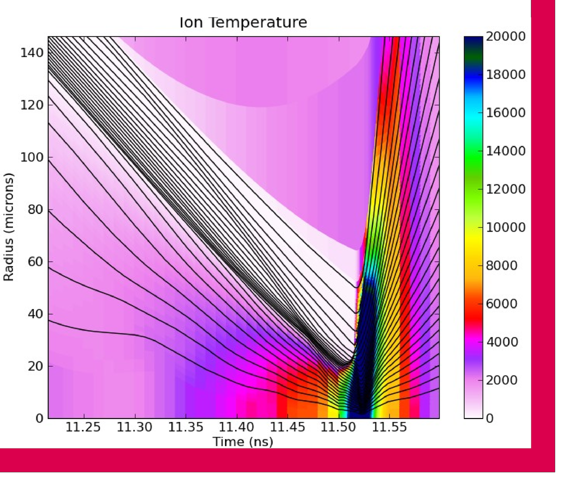
- Large range of conditions makes choice of stopping power model ambiguous
- Plasma transitions from regimes dominated by different physics



We are performing integrated simulations of Shock Ignition ICF targets

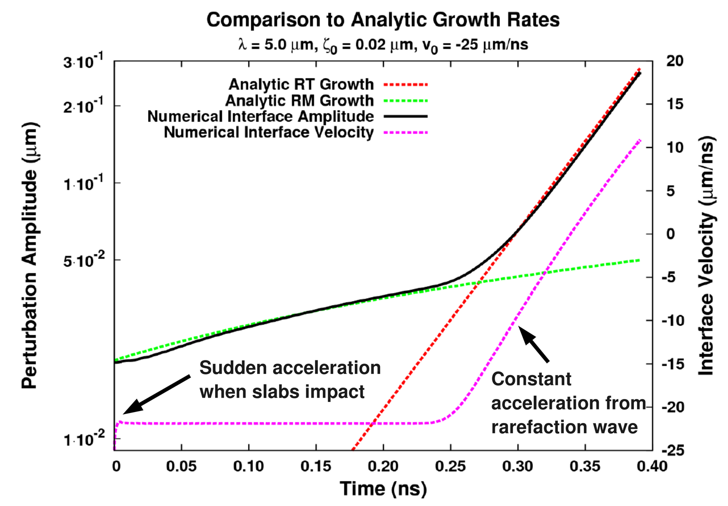


- Targets imploded slowly with lessened laser power requirements
- Strong shock launched to arrive at center at stagnation
- Shock raises temperature above 4 keV, initiating thermonuclear burn
- Above: R-T plot shows shock timing and laser power
- Right: Ion temperature during fusion burn



DRACO has been extended to function in 3D Cartesian Geometry

- This code has been verified using comparisons to analytic instability growth rates



- 3D thermal conduction and radiative transfer are also available

Cooper is currently being used to model the aftermath of a target implosion for a fusion reactor design

- After a target explodes, debris will expand into the target chamber
- Previously, we modeled this expansion using a one dimensional code
- Recently, we've learned that multidimensional effects are important, and cooper is being used to model instabilities in this system