ALPHA PARTICLE TRANSPORT IN INERTIAL CONFINEMENT FUSION

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ALPHA TRANSPORT – MOTIVATION AND MODEL

Hotspot self-heating condition: $W_{dep} > W_{brems} + W_{conduction} + W_{work}$

Alpha particle transport is a loss term: $\chi W_{\alpha} > W_{brems} + W_{conduction} + W_{work}$

χ is the fraction of produced alpha energy deposited in the hotspot.

We model alpha transport kinetically [1]. Computational macroparticles interact with the fluid using Chandrasekhar drag and scatter rates [2].

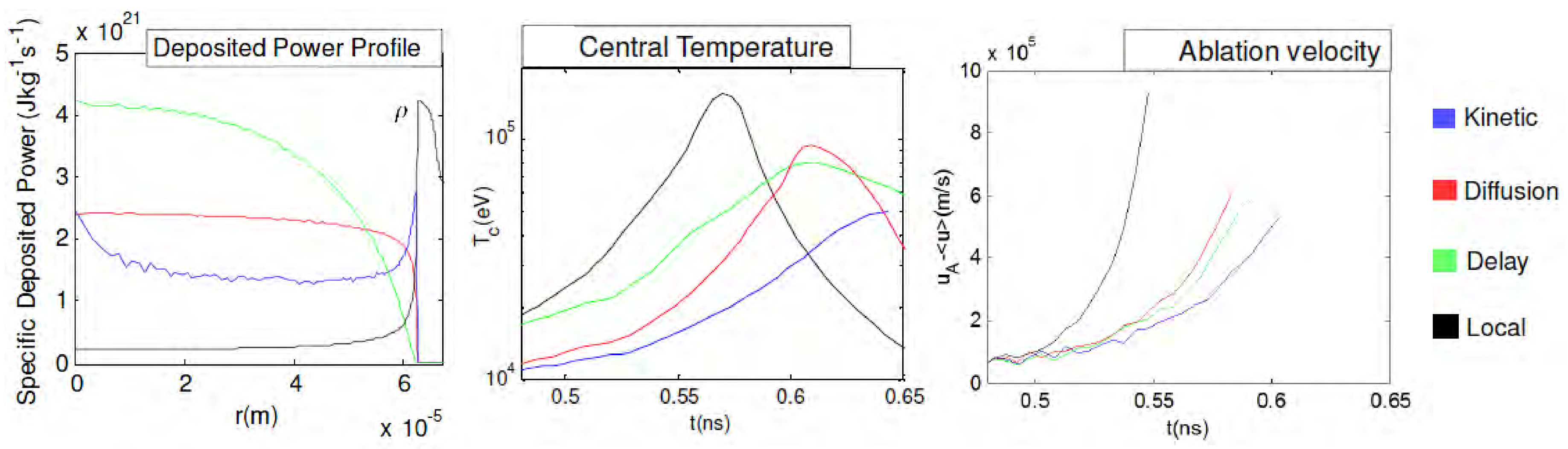


Figure 1: Kinetic model vs. other alpha transport models

Kinetic model gives peak central temperature ~50% that of the diffusion model. In ablation region, alpha heating rate ~ electron heating rate.

ALPHA ENERGY LOST BY SPHERICALLY SYMMETRIC HOTSPOTS

Figure 2 shows how χ depends on the hotspot parameters. We ran the alpha transport model on a static background plasma typical of the start of the burn phase. The plasma density, temperature and size (hotspot radius) were rescaled separately.

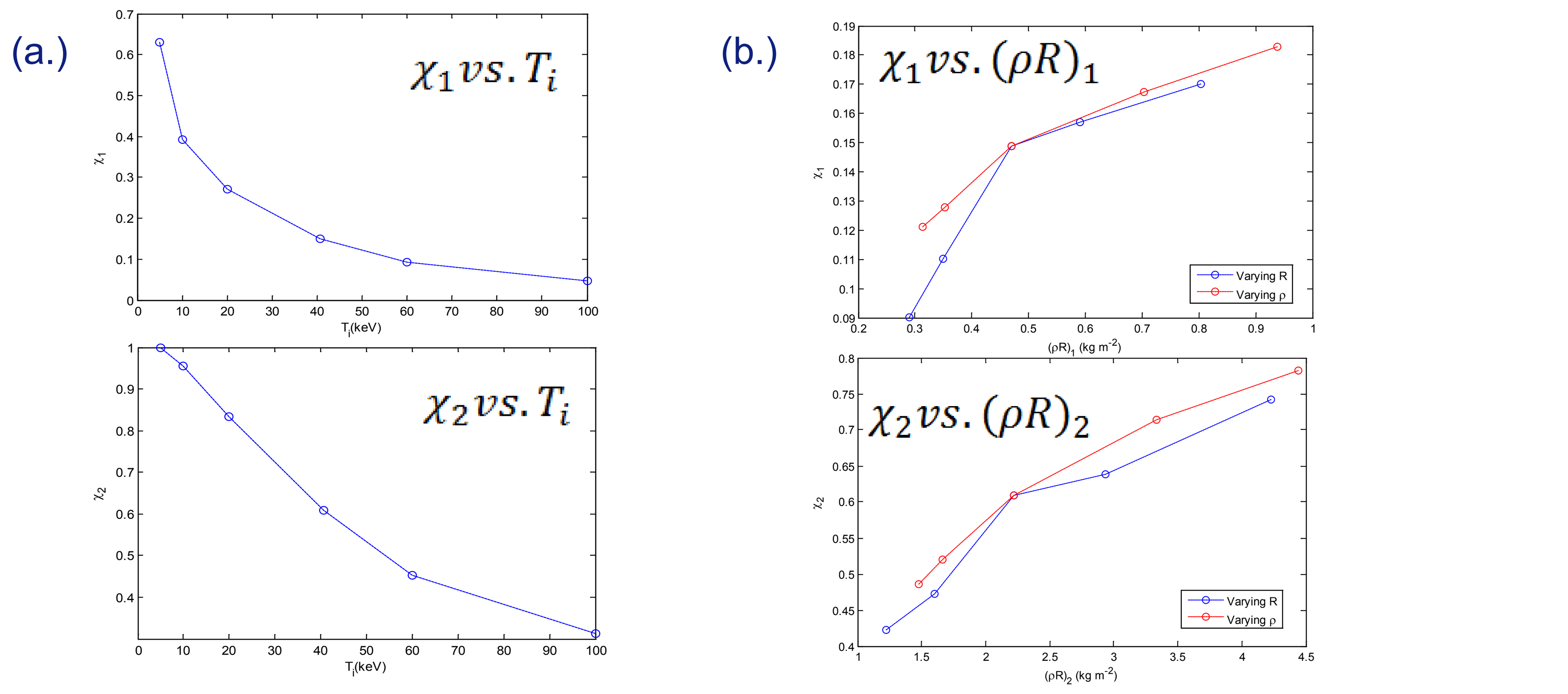


Figure 2: Fraction of alpha energy confined vs. (a.) Central ion temperature (b.) Areal density

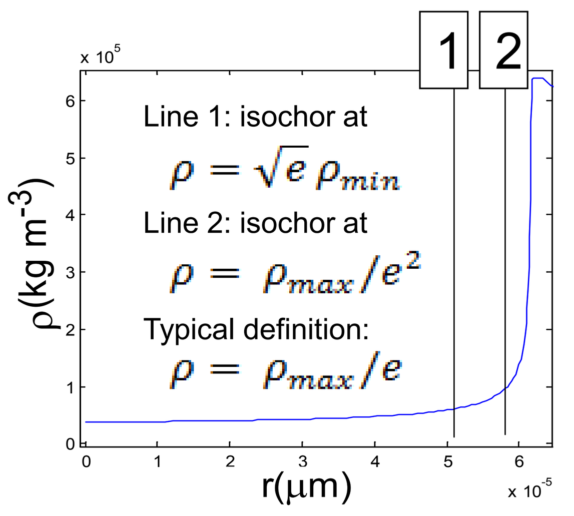


Figure 3: Definition of 'hotspot'

χ is sensitive to how the hotspot is defined: χ_1 and χ_2 are the fraction of alpha energy deposited before lines 1 and 2 (figure 3). A large amount of alpha energy is deposited in the region between the lines, and it is debatable to what extent this is recycled.

Typically $\chi_1 \sim 0.2$ and $\chi_2 \sim 0.6$.

BURN WAVES

In the deflagration regime of the burn phase an ablation front (A) driven by thermal conduction and alpha deposition heats and ablates the shell (figure 4a). The pressure peak in this region compresses the remaining shell, accelerating the accretion shock (B) (figure 4b). When the ablation front meets the accretion shock, a detonation is formed (figure 4c).

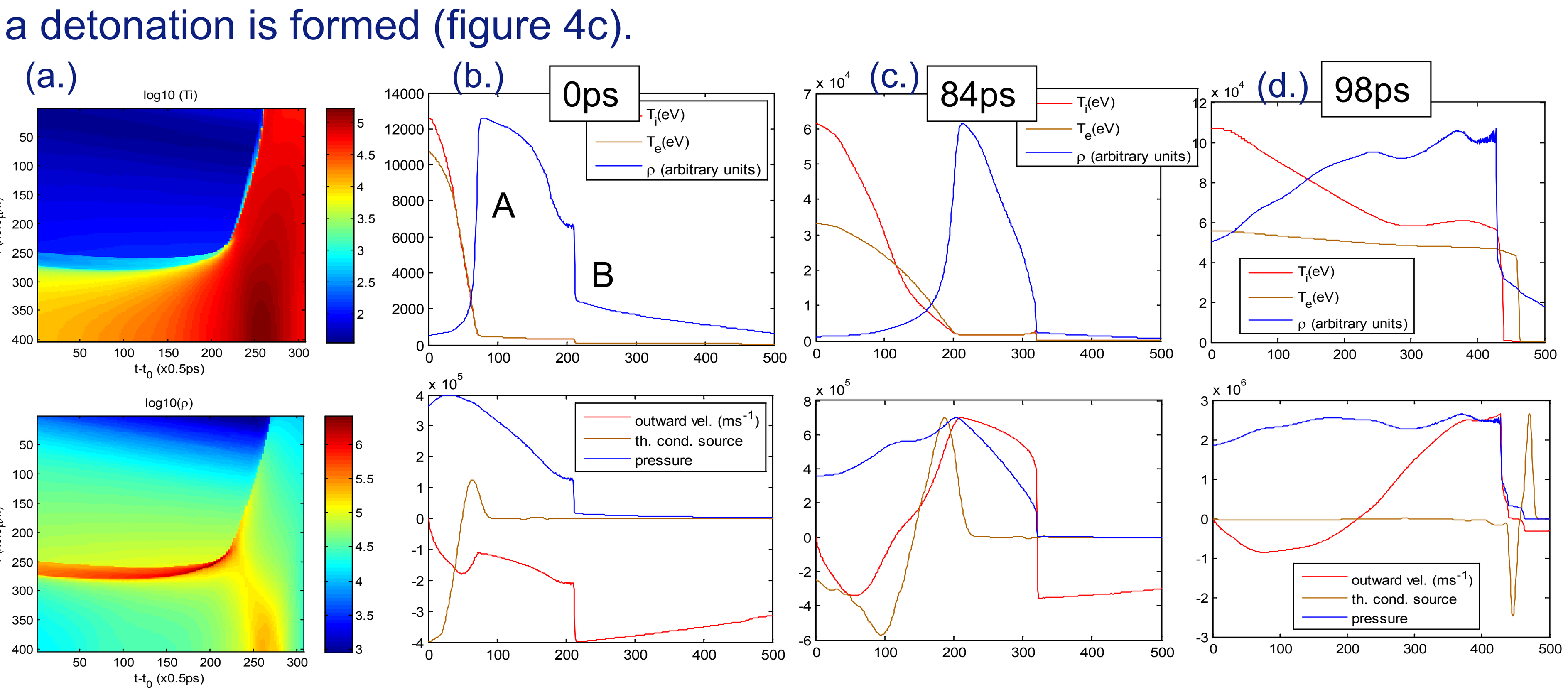


Figure 4: (a.) r-t diagrams of burn wave propagation (b.-d.) radial profiles of burn wave. Top: Ion Temperature (red), electron temperature (brown), density (blue). Bottom: Outward velocity (red), thermal conduction source term (brown), pressure (blue).

PERTURBATIONS

Kinetic model implemented in a 3D hydrocode. Initial condition is a spherically symmetric ρ and T distribution with a perturbed velocity field. The velocity field is an analytic solution of the Rayleigh-Taylor Instability in a cylinder [3] (figure 5c). This field is placed at each node of a tessellated icosahedron (figure 5a). Several orders of tessellation can be superimposed to create a 'multimode' perturbation (figure 5d).

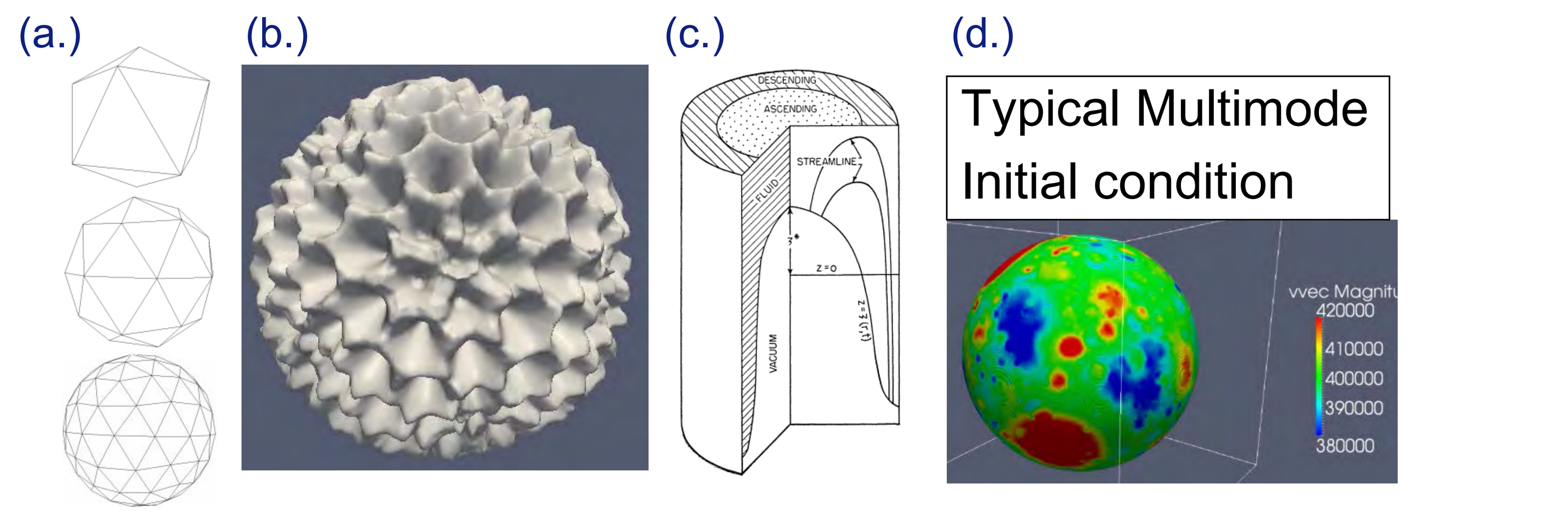
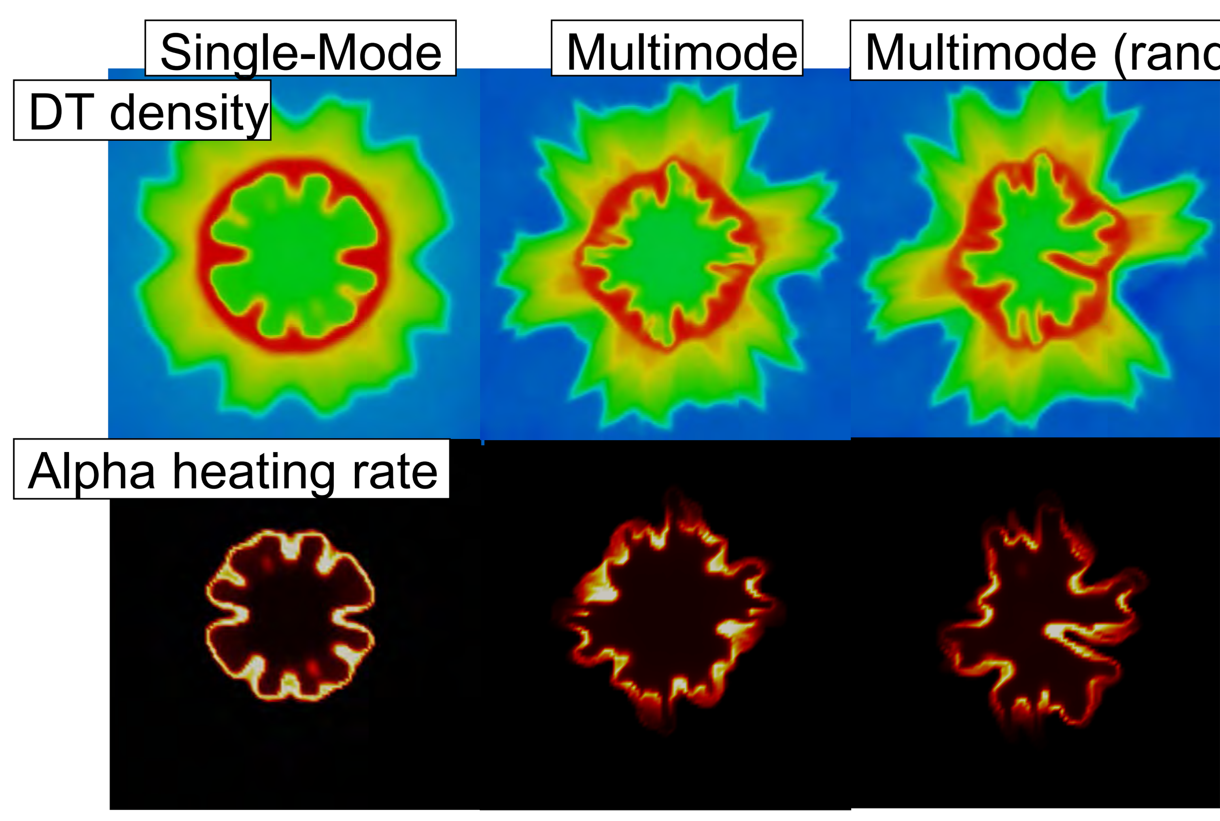


Figure 5: Initialisation of perturbations

Alpha particle confinement is reduced by ~15% in the first-order single-mode case; this did not vary strongly with perturbation amplitude.

Setting random node amplitudes caused confinement to drop significantly. This may relate to the artificially-imposed symmetry of the non-randomised case, which leads to smaller perturbations. When diagnosed the randomised case may give the false impression of being oblate or prolate, though no such low-wavelength perturbation was explcitly imposed.

The alpha heating rate is higher on the tips of the spikes. The hotspot areal density is lower in the spike regions. This may lead to a 'fire polishing' effect.

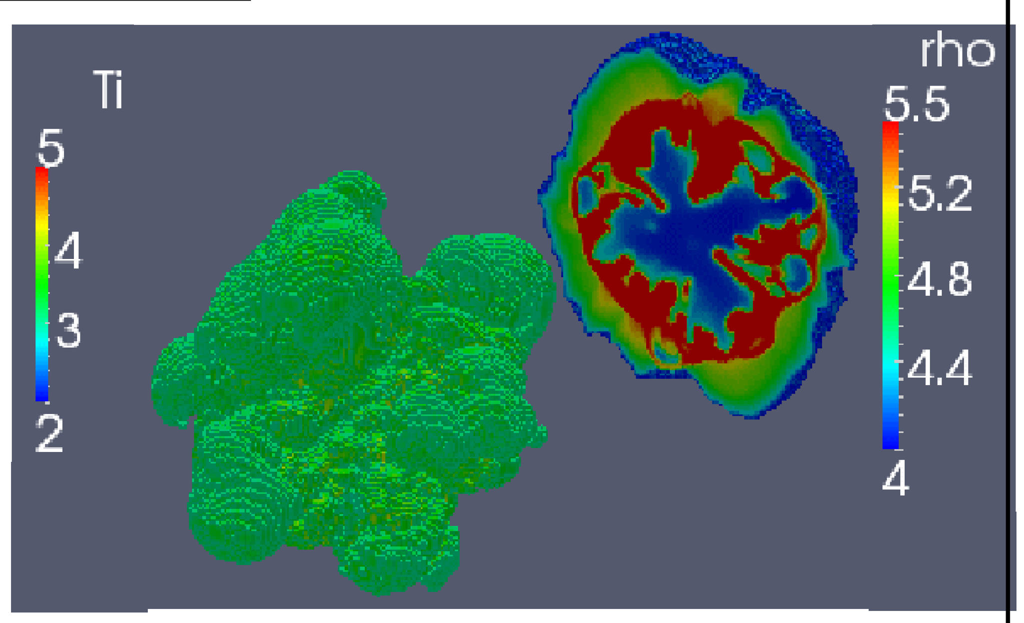


$$\frac{\chi_{pert}}{\chi_{symm}} \approx 0.86$$

$$\frac{\chi_2^{nonrand}}{\chi_2^{rand}} = 1.16$$

$$\frac{\chi_1^{nonrand}}{\chi_1^{rand}} = 1.66$$

Spherical thermal waves propagate from points where the RTI bubbles burst through the decelerated region. This loss mechanism may also exist for alpha particles.

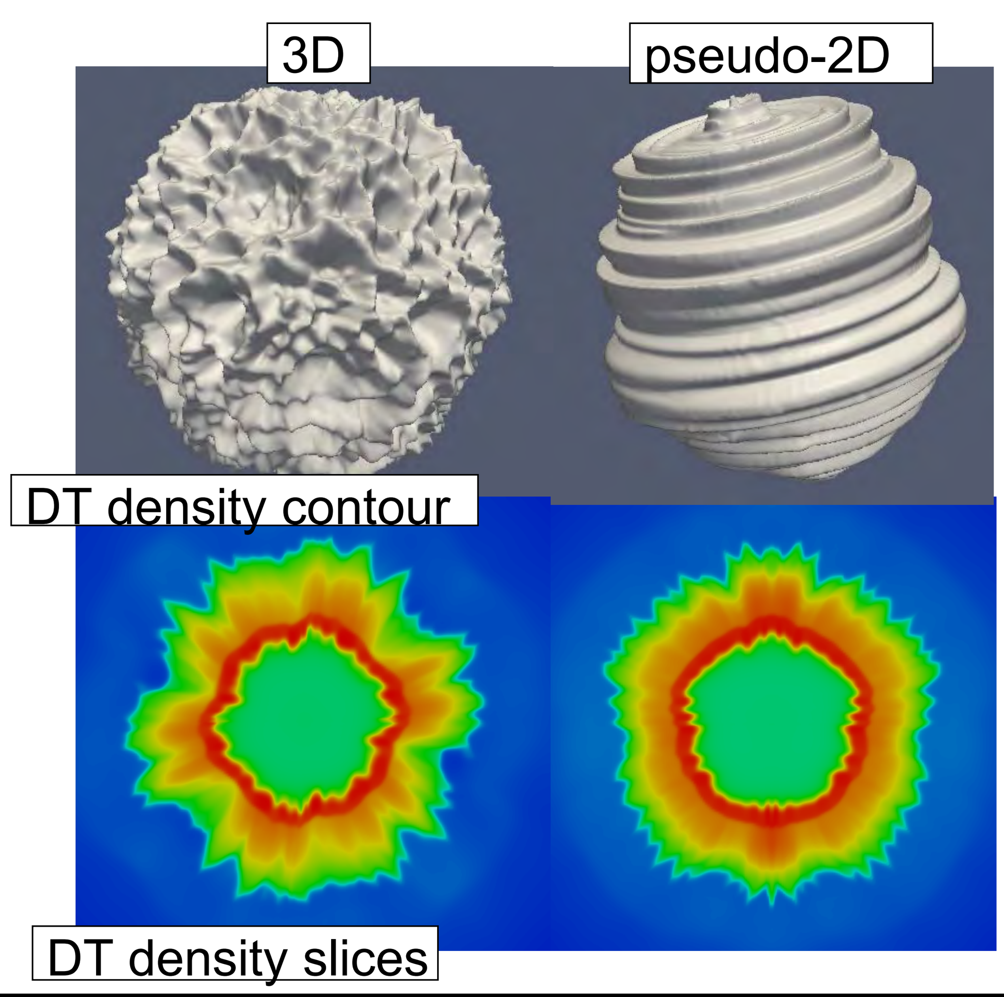


2D vs. 3D

ICF simulations are usually 2D, with the plasma properties assumed constant in the φ direction. We find a 20% overestimation of alpha particle confinement in the 2D case:

$$\frac{\chi_1^{2D}}{\chi_1^{3D}} = 1.20$$

$$\frac{\chi_2^{2D}}{\chi_2^{3D}} = 1.27$$



REFERENCES
[1] M. Sherlock, *J. Comput. Phys.* **227, 2286-2292 (2008)**
[2] S. Chandrasekhar, *Astrophysical J.* **97, 255-262 (1943)**
[3] D. Layzer, *Astrophysical J.* **122, 1 (1955)**