The Three-Dimensional Hydrocode *DEC3D* with Multigroup Radiation Transport

K. M. WOO, R. EPSTEIN, J. A. DELETTREZ, A. BOSE, R. BETTI, AND K. S. ANDERSON

University of Rochester, Laboratory for Laser Energetics

Summary

The 3-D hydrocode *DEC3D* has been developed to study the deceleration phase of inertial confinement fusion (ICF) implosions

- The 2-D Eulerian hydrocode *DEC2D** has been extended to 3-D and is integrated with a multigroup radiation-transport package
- Numerical results from the multigroup radiation-transport package show good agreement with 1-D *LILAC* simulations
- The parallel multigroup radiation transport integrated in *DEC2D* shows efficient computation
- The *DEC3D* simulates Rayleigh–Taylor (RT) instability in the deceleration phase

*K. S. Anderson, R. Betti, and T. A. Gardiner, Bull. Am. Phys. Soc. 46, 280 (2001).

TC11616

The diffusion equation is solved implicitly to maintain stability

- Equations of radiation transport and radiation-material coupling

$$\partial_t \phi_g + \vec{\nabla}\cdot(\vec{U}\phi_g) + P_g \vec{\nabla}\cdot\vec{U} = c\kappa_g\left(b_g T_e^4 - \phi_g\right) + \vec{\nabla}\cdot D_g \vec{\nabla}\phi_g$$

$$\rho C_V \partial_t T_e = \sum_g c\kappa_g\left(\phi_g - b_g T_e^4\right)$$

- The advection and radiation-pressure terms are operator-splitted from the radiation equation; the remaining diffusion equation is solved implicitly

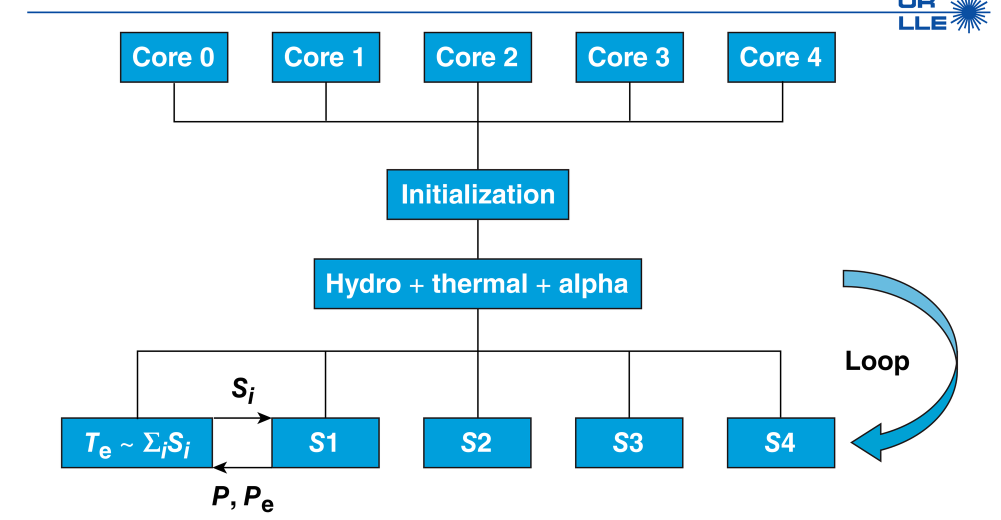
$$\frac{\phi_g^{n+1}-\phi_g^n}{\Delta t} = c\kappa_g^n\left[b_g\left(T_e^n\right)^4 - \phi_g^{n+1}\right] + \vec{\nabla}\cdot D_g^n \vec{\nabla}\phi_g^{n+1}$$

- The electron temperature is solved explicitly by summing the contribution from all the groups

$$\rho^n C_V\left(\frac{T_e^{n+1}-T_e^n}{\Delta t}\right) = \sum_{g=1}^{G} c\kappa_g^n\left[\phi_g^{n+1} - b_g\left(T_e^n\right)^4\right]$$

TC11627

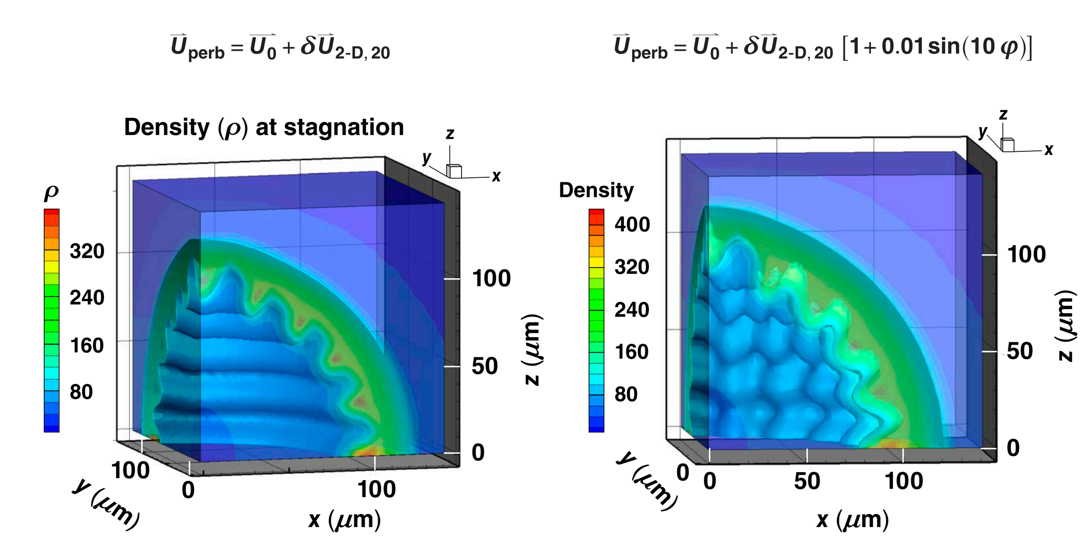
Multigroup radiation transport is integrated with parallel computation architecture



- Features of efficient parallelization
  - use the minimum communication of data during a time step
  - use nonblock communication

TC11619

DEC3D simulates the RT instability with axisymmetric and axial-varying perturbations



TC11623

Hydro equations are solved in terms of moving-mesh variables

- *DEC3D* is constructed on a moving mesh

$$\xi_i(x_i,t) = \frac{x_i}{R(t)} \quad \text{and} \quad \partial_t = \partial_t - \sum_{i=1}^{3}\frac{x_i}{R^2}\dot{R}\partial_{\xi_i} \quad \text{and} \quad \partial_{x_i} = \frac{1}{R}\partial_{\xi_i}$$

- Hydrodynamic equations expressed in terms of moving-mesh variables

$$R^2\partial_t(\rho) - x_i\dot{R}\partial_{\xi_i}(\rho) + R\partial_{\xi_i}(\rho U_i) = 0$$
$$R^2\partial_t(\rho U_j) - x_i\dot{R}\partial_{\xi_i}(\rho U_j) + R\partial_{\xi_i}(\rho U_i U_j + \delta_{ij}P) = 0$$
$$R^2\partial_t(\varepsilon) - x_i\dot{R}\partial_{\xi_i}(\varepsilon) + R\partial_{\xi_i}\left[U_i(\varepsilon + P)\right] = 0$$

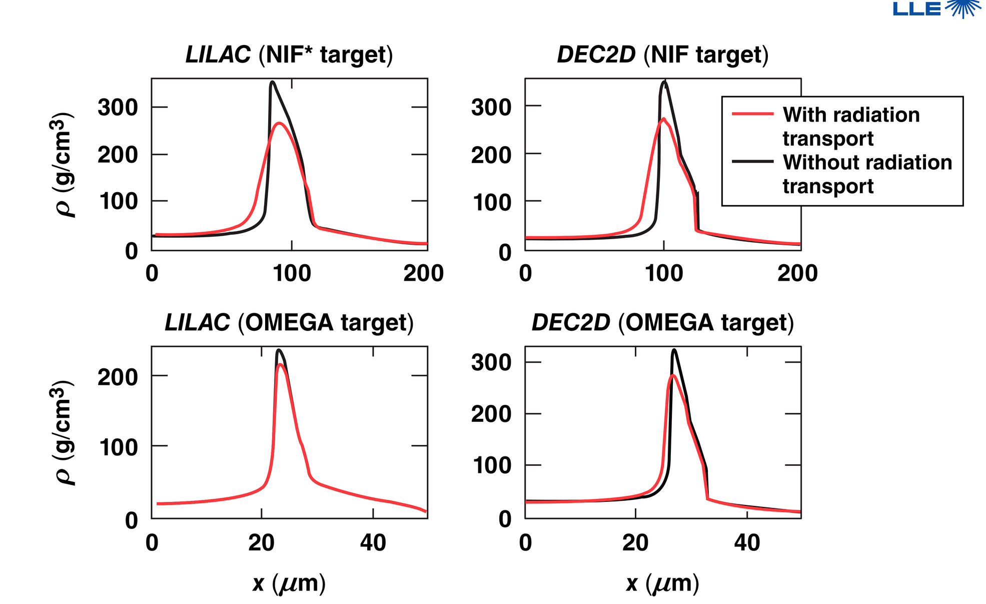
+

$$R^2\partial_t(P_e^{3/5}) - x_i\dot{R}\partial_{\xi_i}(P_e^{3/5}) + R\partial_{\xi_i}(P_e^{3/5}U_i) = 0$$
$$R^2\partial_t(\varepsilon_\alpha^{3/5}) - x_i\dot{R}\partial_{\xi_i}(\varepsilon_\alpha^{3/5}) + R\partial_{\xi_i}(\varepsilon_\alpha^{3/5}U_i) = 0$$

Hydrodynamics → Radiation transport → Thermal conduction → Alpha transport

TC11624

Numerical results of the 48-group radiation-transport package are consistent with *LILAC* simulations



*National Ignition Facility

TC11622

The parallel multigroup radiation transport shows significant improvement in computation efficiency

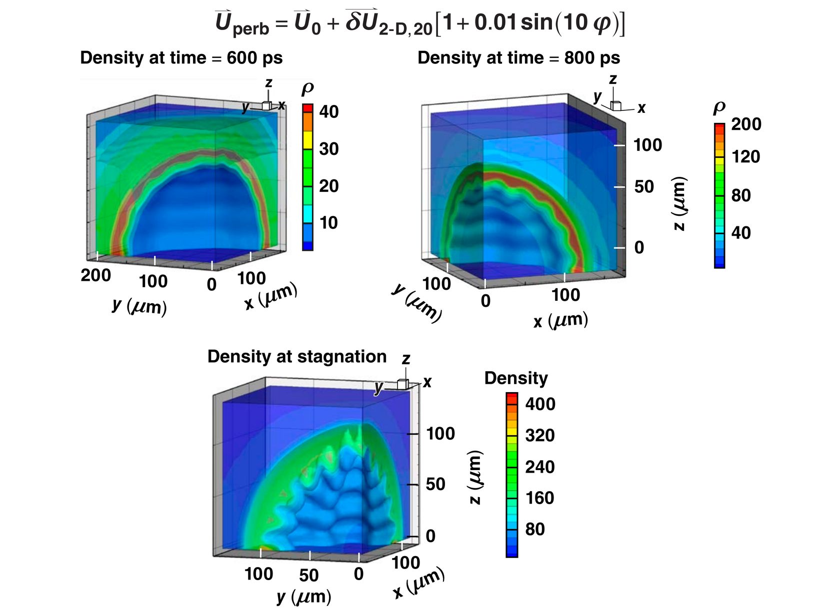
Single time-step run time (s)	Grid number ($N \times N$)	$N = 200$	$N = 400$	$N = 600$	$N = 800$
Parallel code	Four-group in parallel	0.075	0.19	0.39	0.67
	Other (hydro, thermal, and alpha)	0.100	0.46	1.00	1.80
	Other + four-group in parallel	0.175	0.65	1.39	2.47
Serial code	Four-group in serial	0.130	0.63	1.4	2.6
	Other (hydro, thermal, and alpha)	0.092	0.40	0.94	1.7
	Other + four-group in serial	0.222	1.03	2.34	4.3

TC11620

DEC3D simulates the growth of RT instability during the deceleration phase

Initial velocity perturbations

$$U_{perb} = U_0 + \delta U_{2\text{-D},20}\left[1+0.01\sin(10\varphi)\right]$$



TC11625

The radiation transport is operator-splitted from the hydrodynamics, thermal, and alpha transport

Hydrodynamics → Radiation transport → Thermal conduction → Alpha transport

- Hydro equations are solved by the MacCormack scheme; the ideal gas equation of state (EOS) is used
- Group opacity is taken astrophysical opacity table; The radiation diffusion is solved implicitly using the flux-limited diffusion coefficient
- Thermal and alpha diffusions are solved by the Crank–Nicolson scheme
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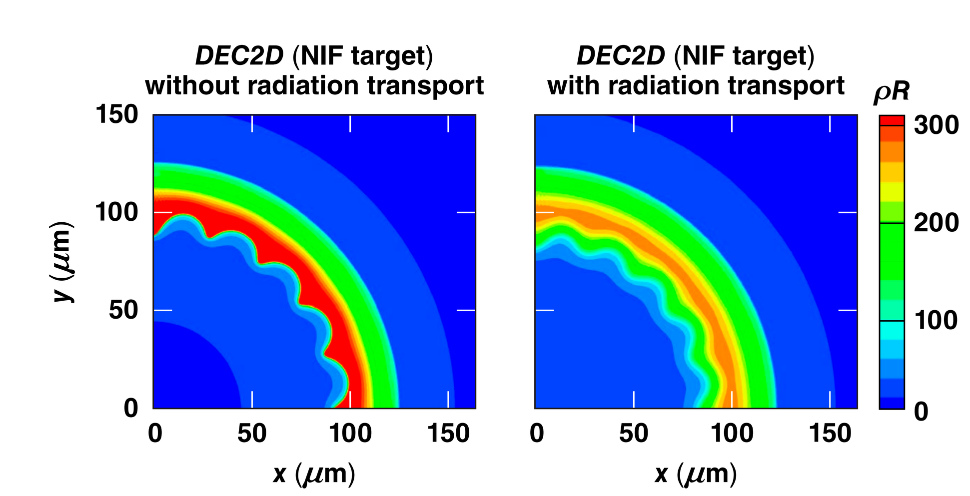
TC11618

RT instability is mitigated by the ablative effect because of the absorption of photons on the inner shell surface



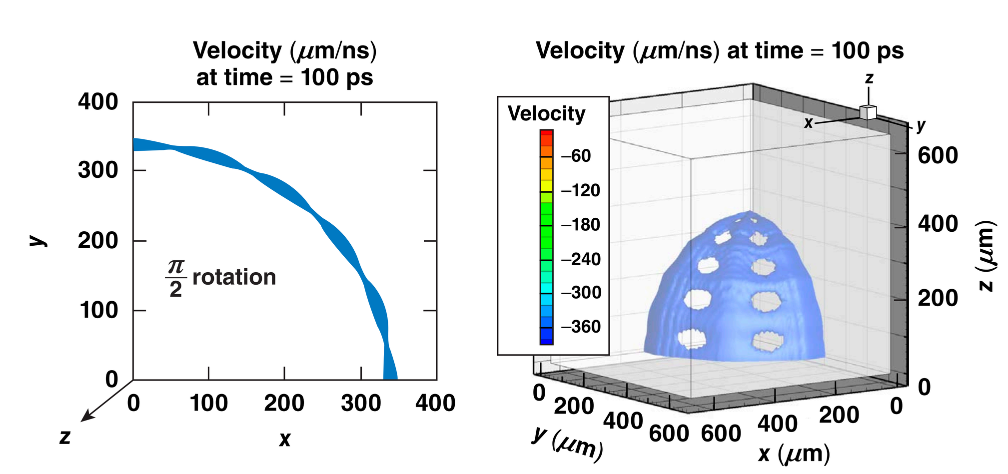
A. Bose *et al.*, GO5.00006, this conference.

TC11617

The 3-D initial velocity perturbation is set up by rotating the 2-D perturbation with sinusoidal axial variation

- Define initial velocity perturbation

$$U_{perb} = U_0 + \delta U_{2\text{-D},m}\left[1+\delta\sin(n\varphi)\right] \quad \text{or} \quad U_{perb} = U_0 + \delta U_{2\text{-D},m}\left[1+\delta\sin(n\varphi)\,e^{-z/R_{hs}}\right]$$



TC11621

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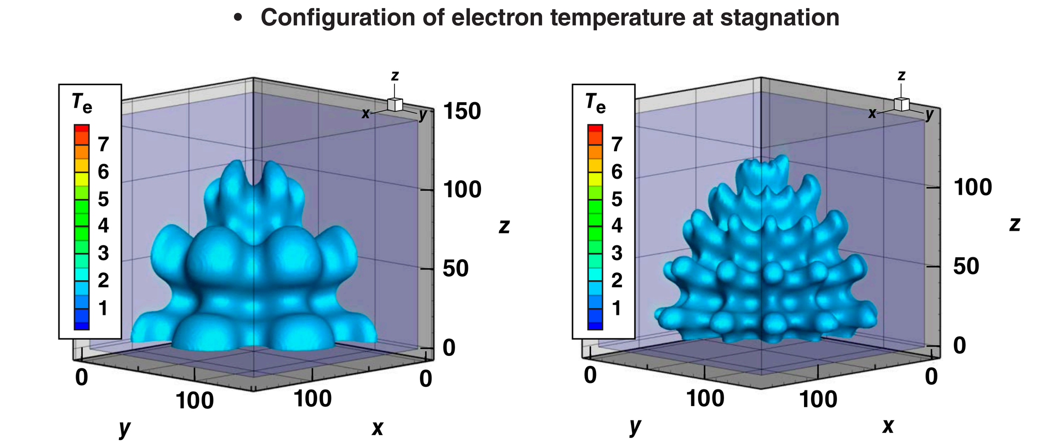
- Configuration of electron temperature at stagnation



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TC11626

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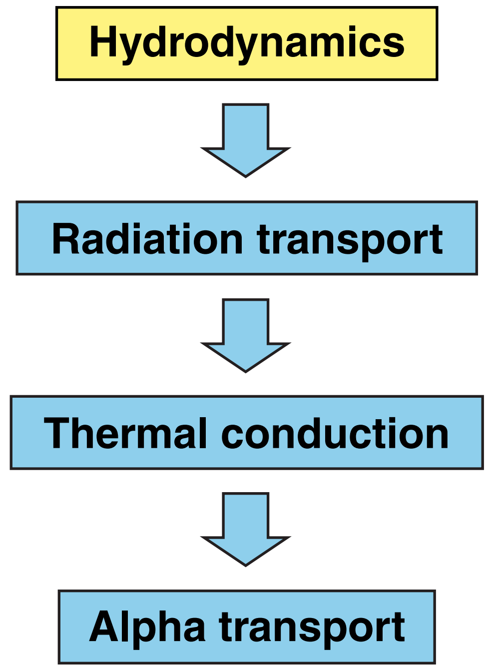

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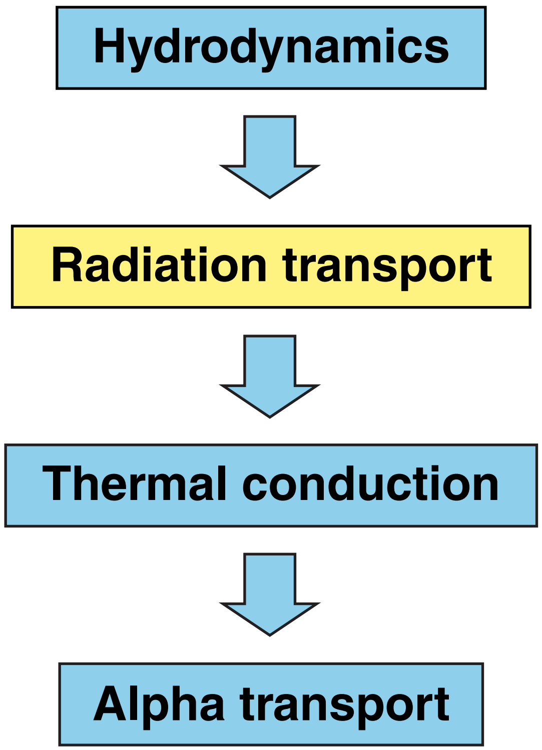

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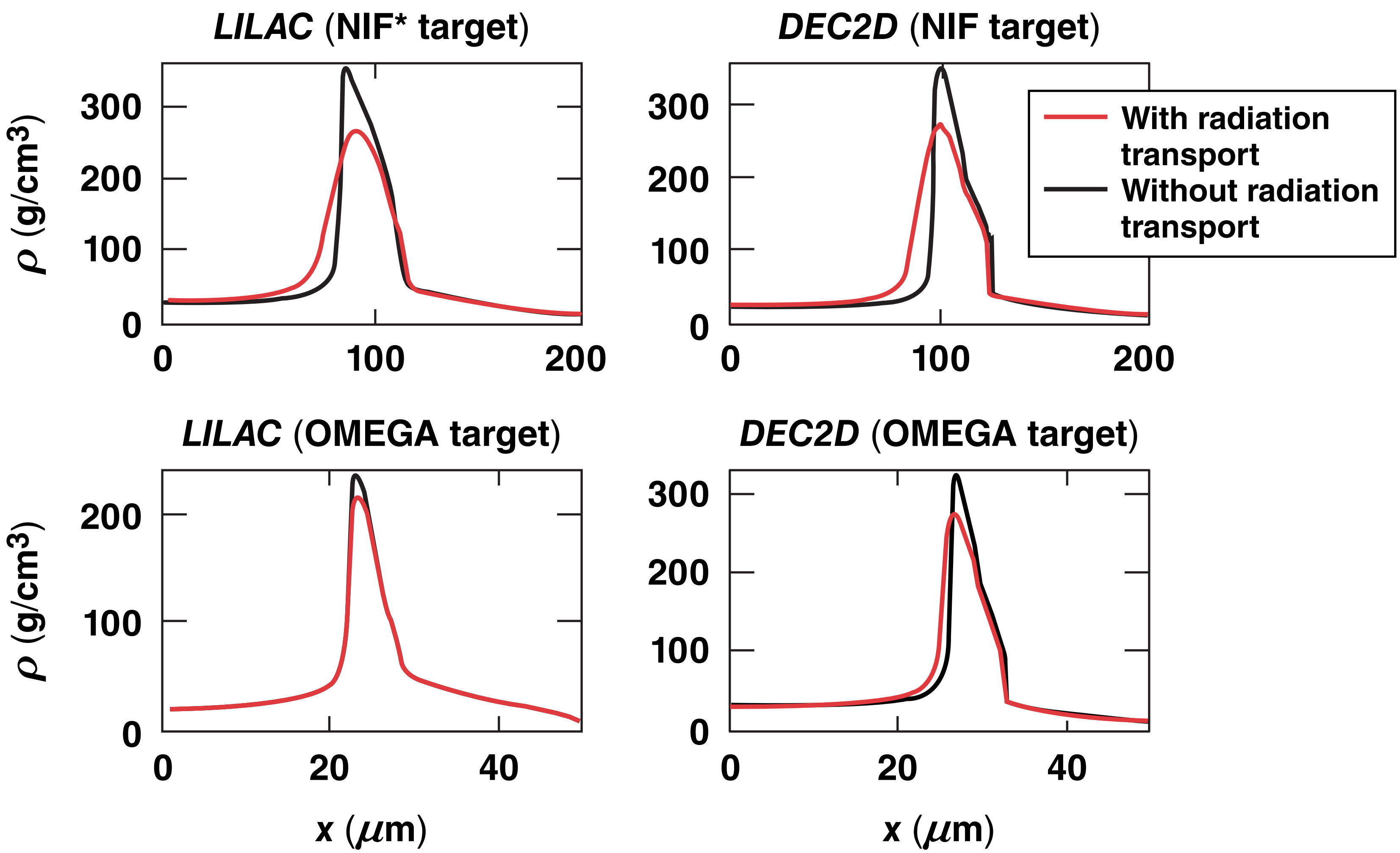

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TC11622

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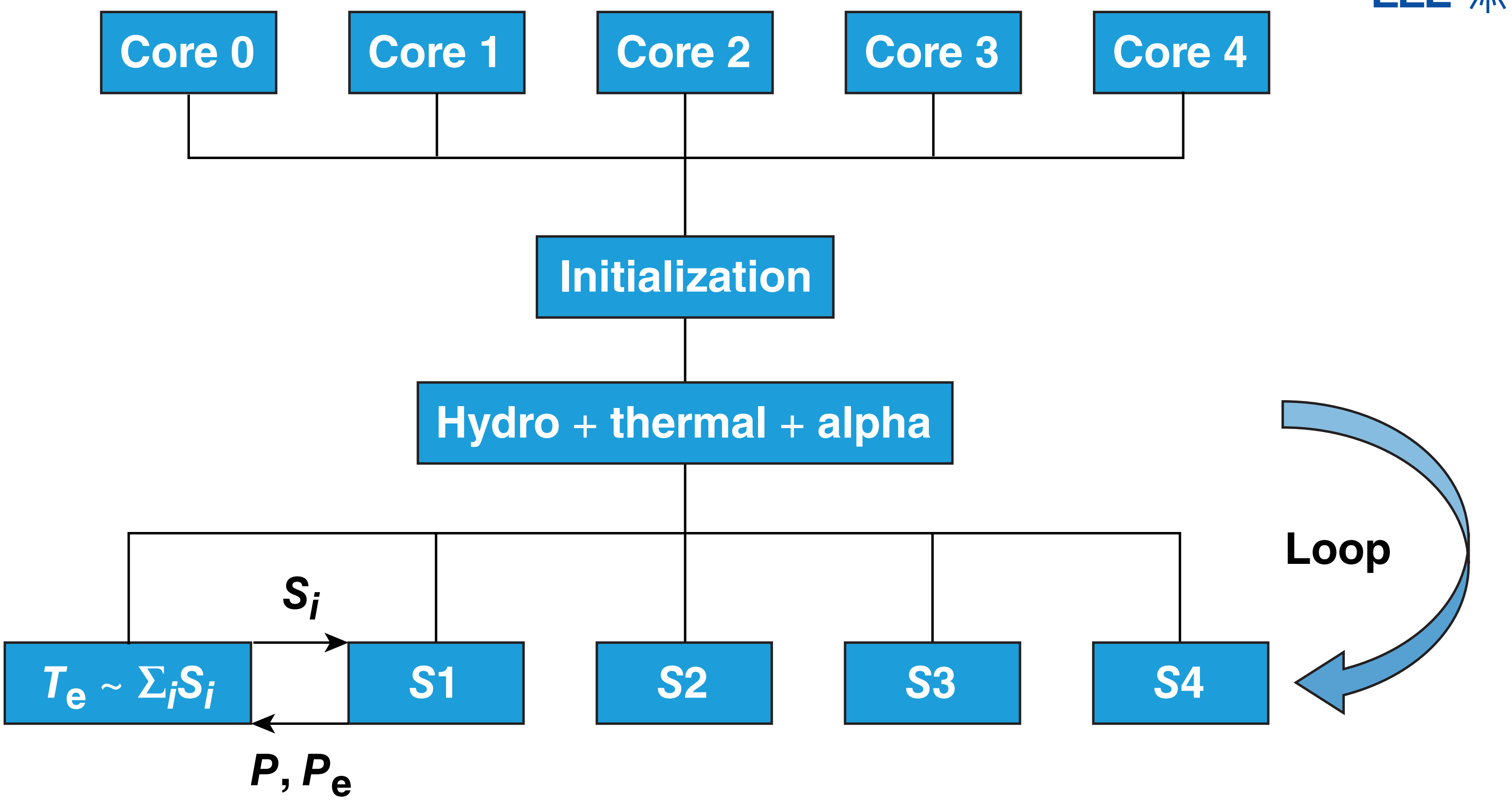

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TC11619

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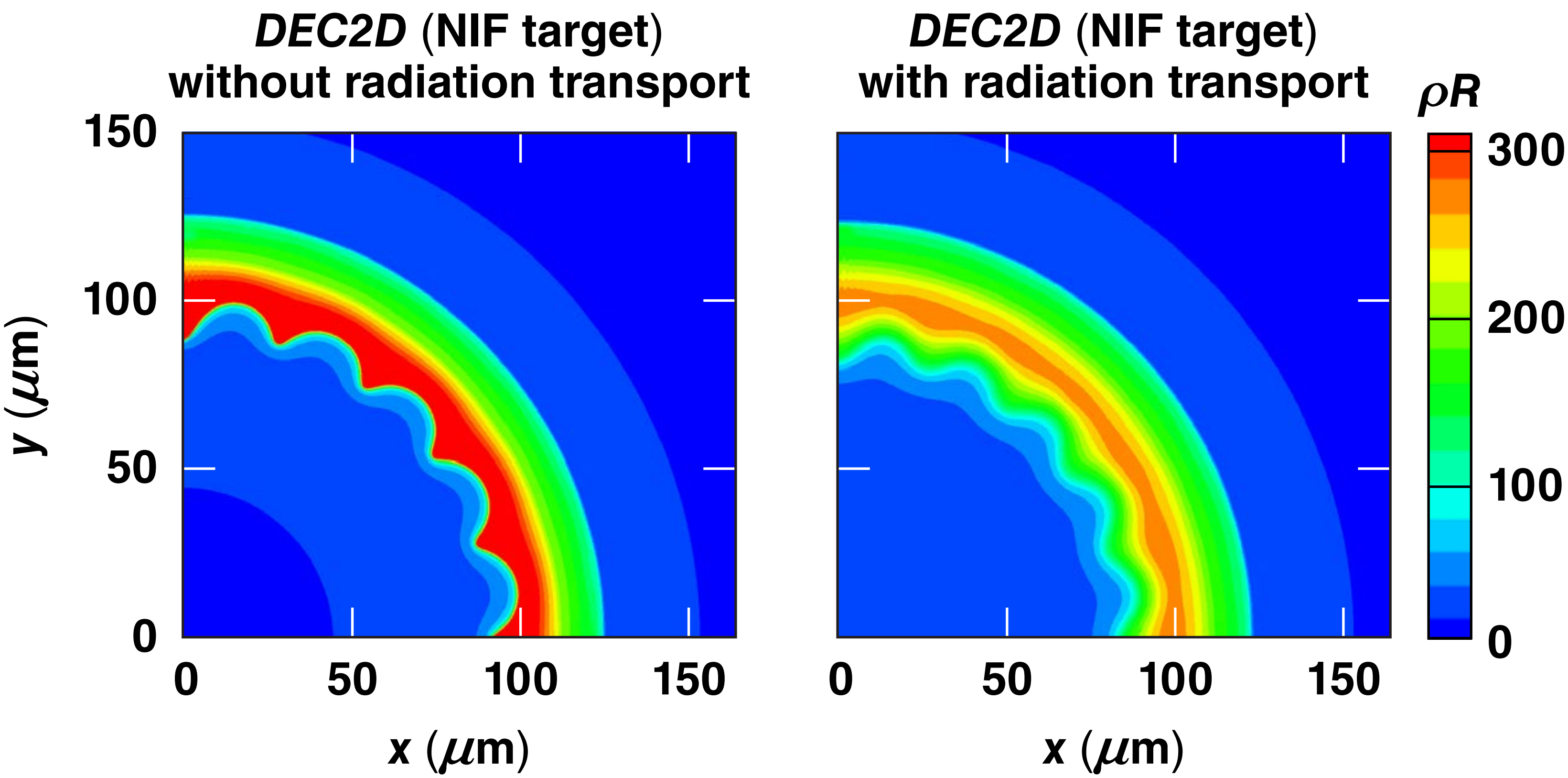

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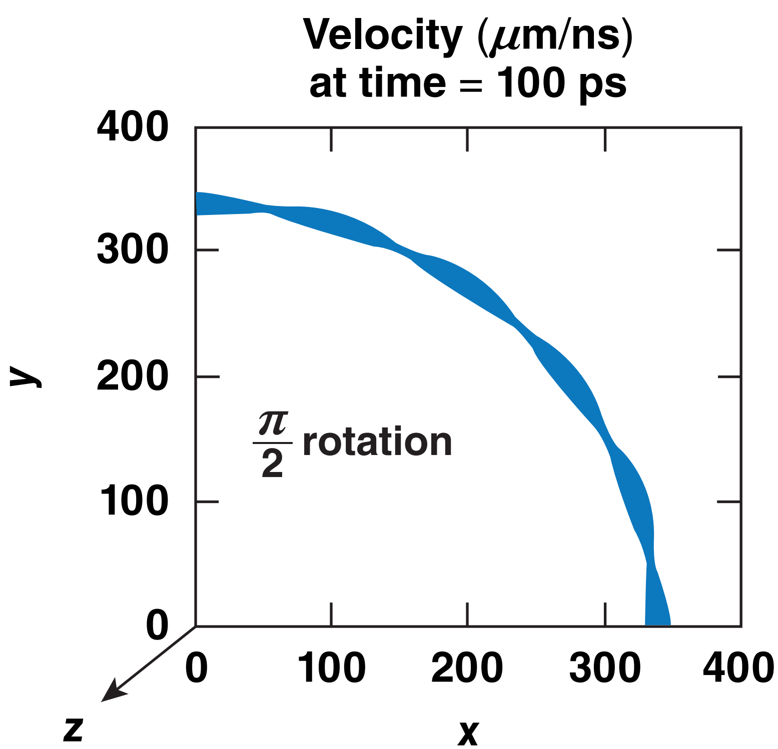

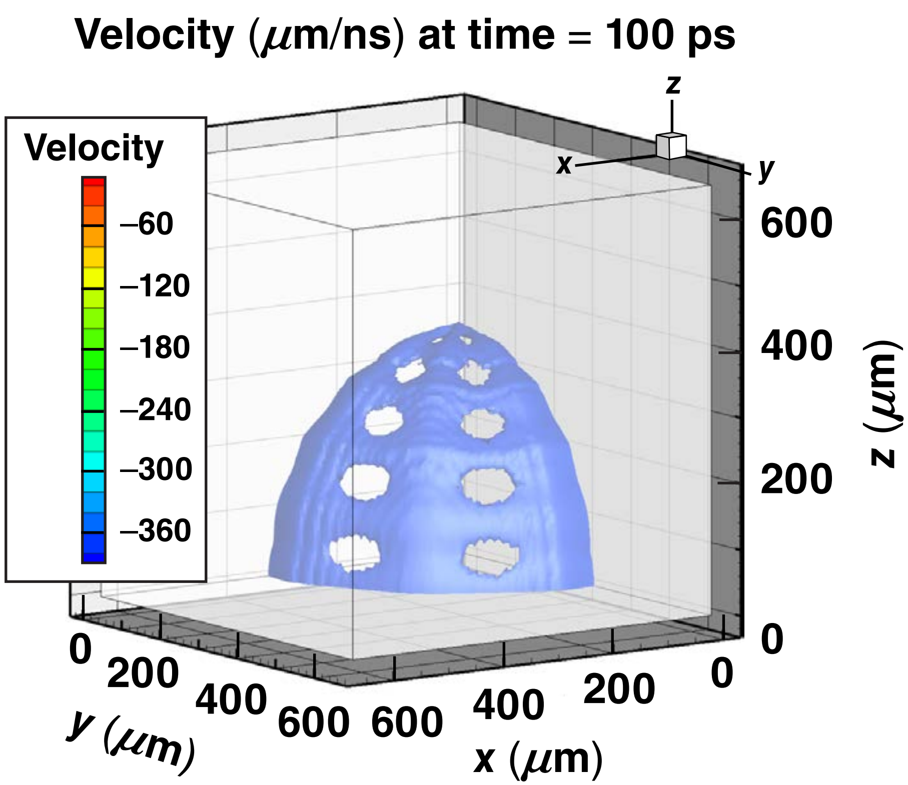

TC11621

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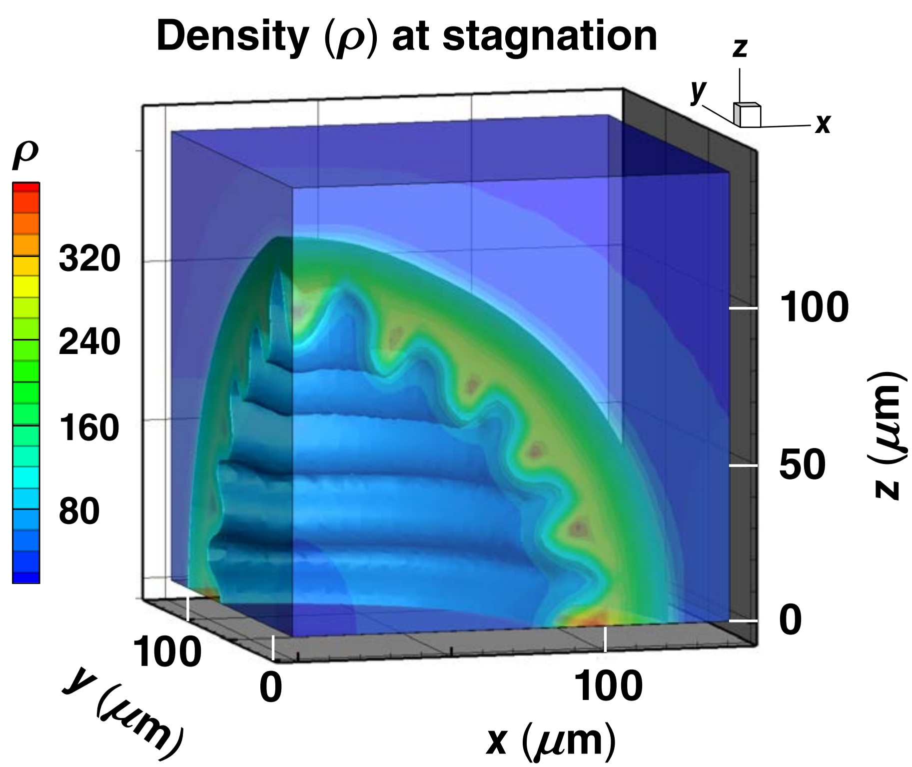

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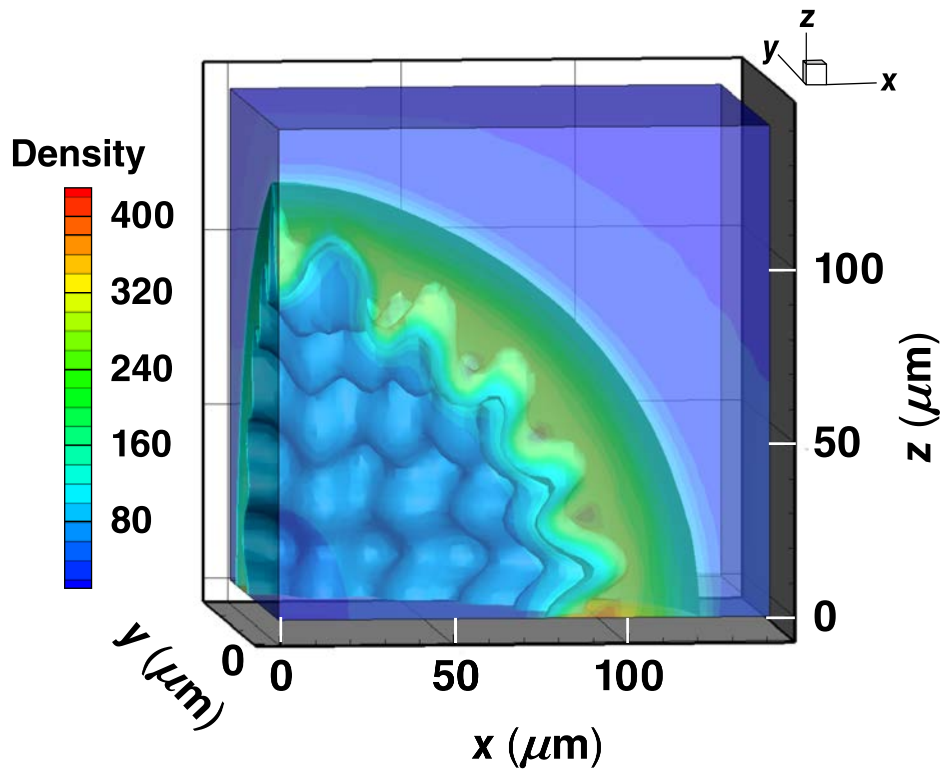

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Initial velocity perturbations

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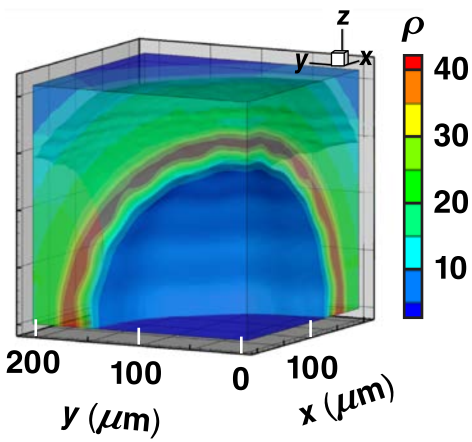
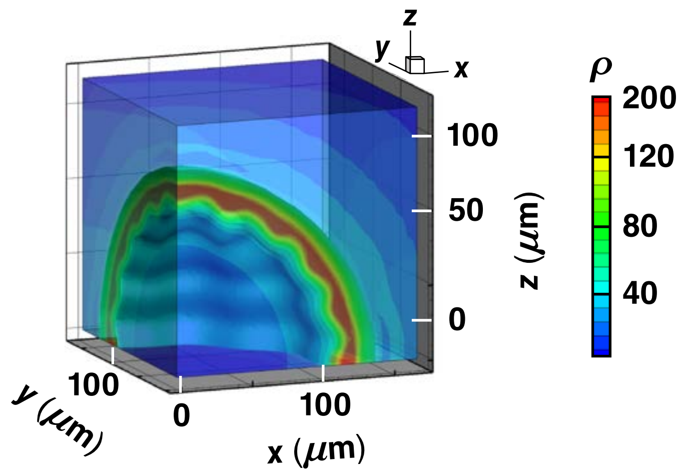
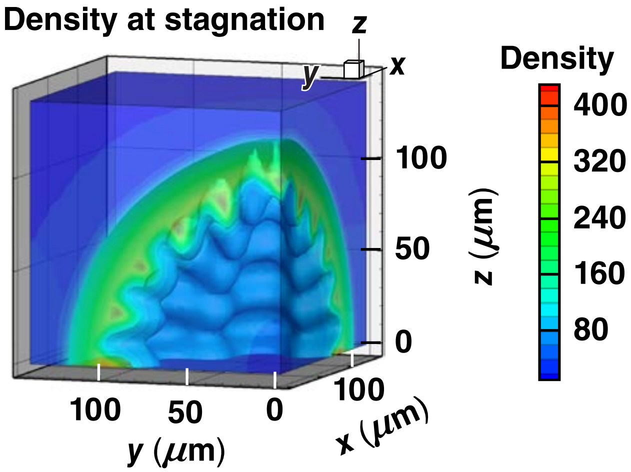
Density at time = 600 ps



Density at time = 800 ps



Density at stagnation



TC11625

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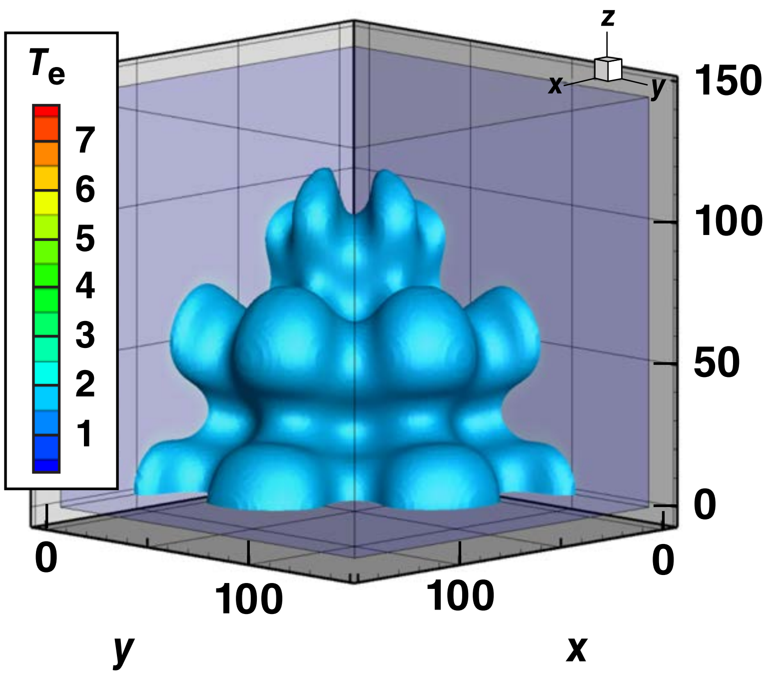
- Configuration of electron temperature at stagnation



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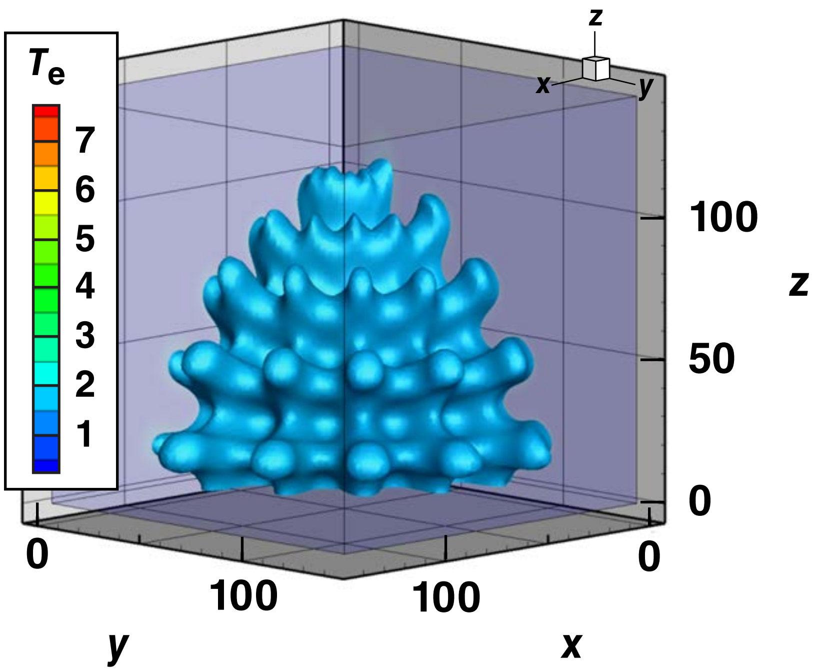

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