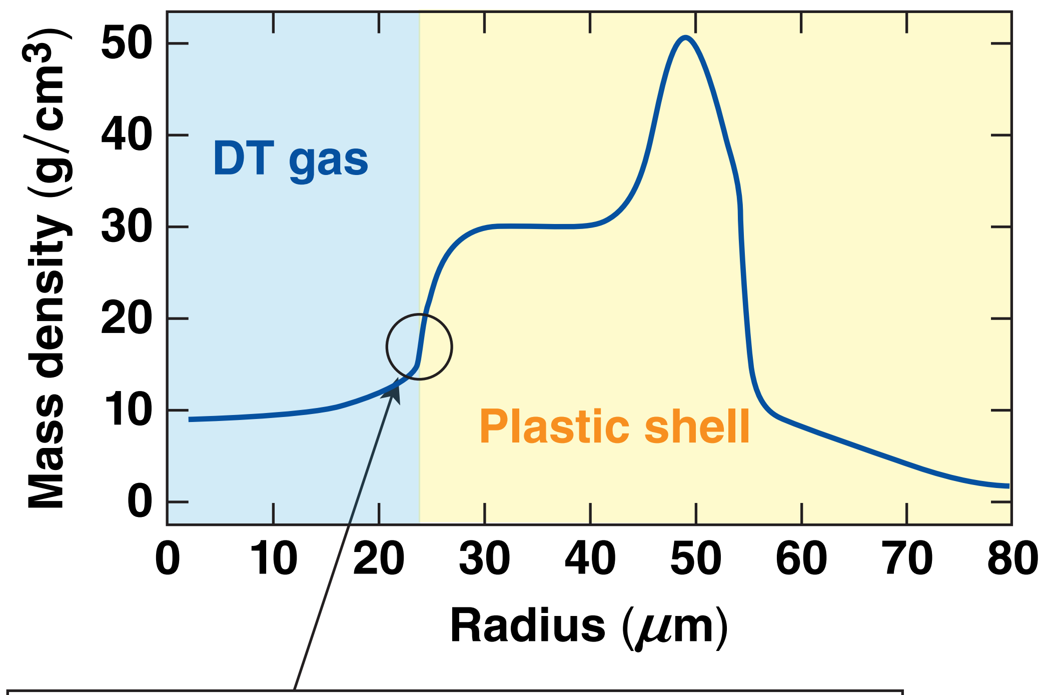
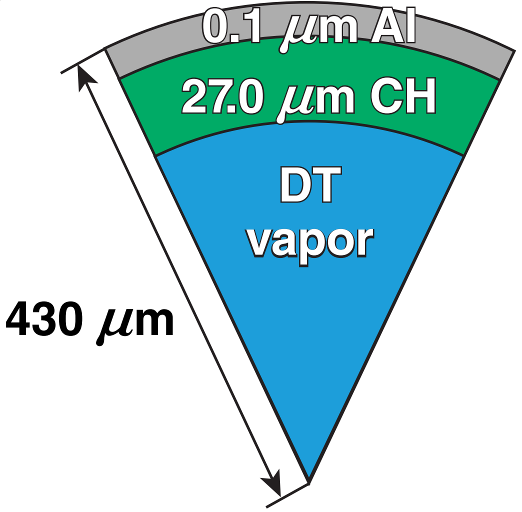
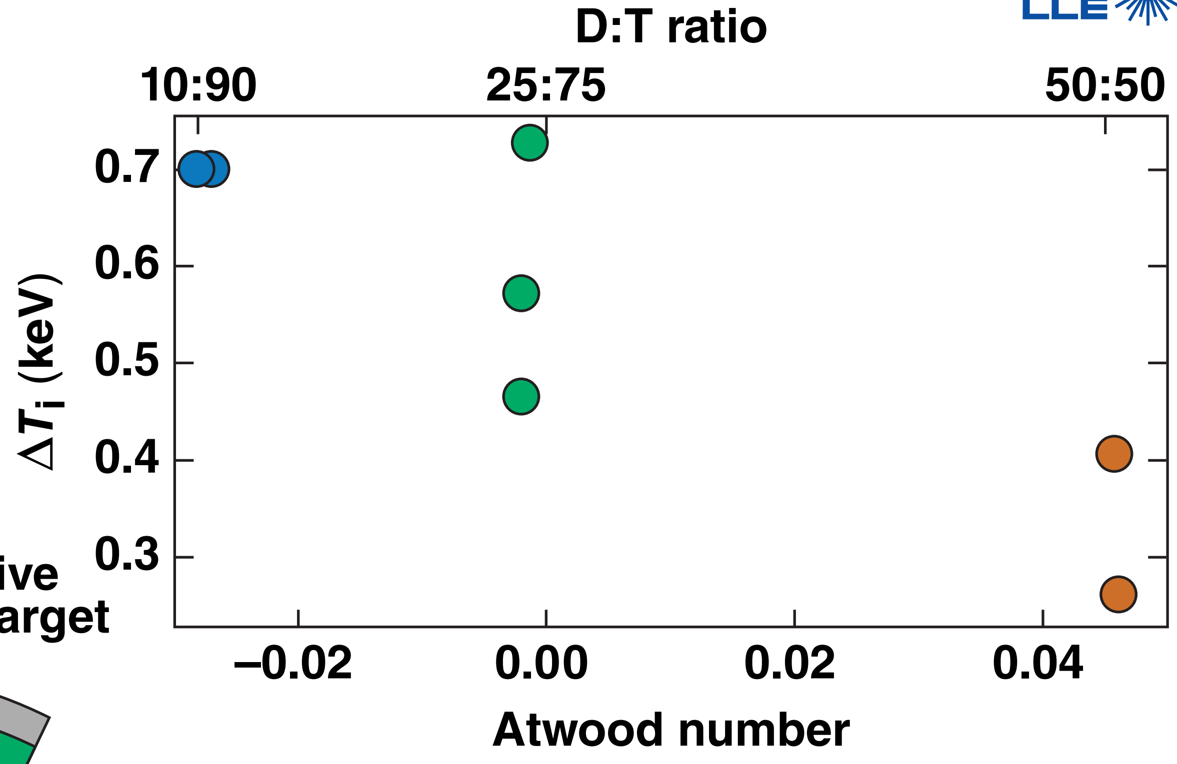
Finite Atwood Number Effects on Deceleration-Phase Instability in Room-Temperature Direct-Drive Implosions



Classically unstable material interface

OMEGA direct-drive room-temperature target





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Summary

Observed T_i variation decreases with increasing Atwood number in room-temperature implosions

- Room-temperature implosions have a finite Atwood number at the fuel–pusher interface that creates short-scale Rayleigh–Taylor (RT) growth during the deceleration phase
- Simulations indicate residual kinetic energy in the core contributes to ion-temperature variation*,**
- Increasing the Atwood number (by changing the D:T ratio) results in increased short-scale growth and reduced bulk-fluid motion
- Low Atwood number room-temperature targets, with reduced short-scale RT growth, have large ΔT_i similar to cryogenic targets

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*B. Appelbe and J. Chittenden, Plasma Phys. Control. Fusion 53, 045002 (2011).

**T. J. Murphy, Phys. Plasmas 21, 072701 (2014).

Collaborators

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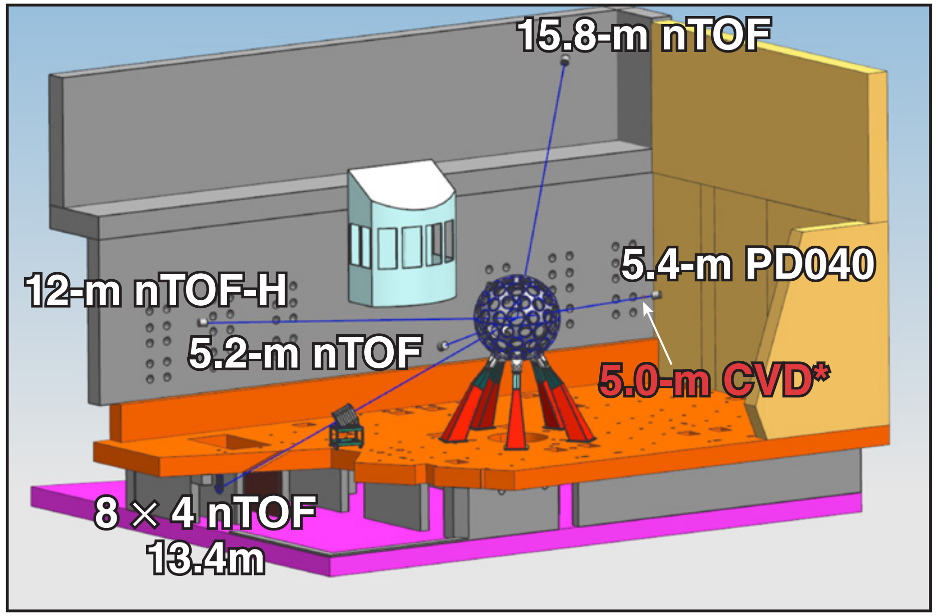
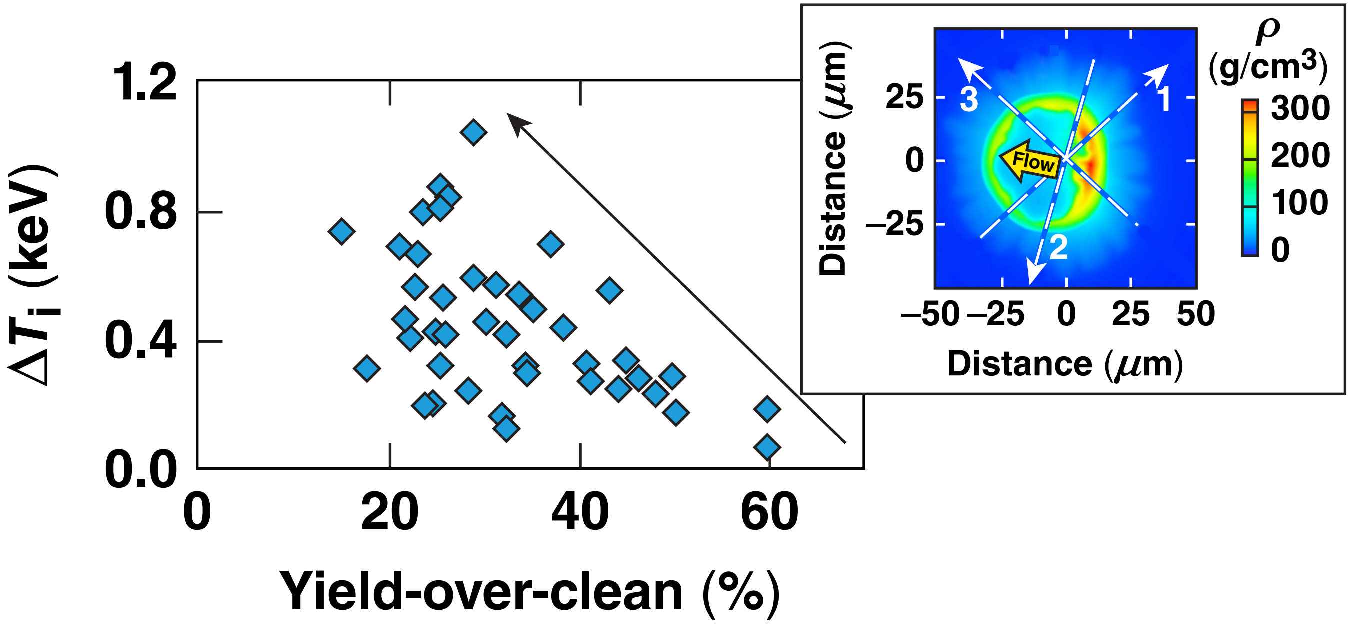
Significant variations in DT ion temperature are observed in cryogenic implosions on OMEGA

Multiple lines of sight within the OMEGA target chamber



No classically unstable material interface in cryogenic targets



- Ion temperature is observed from multiple lines of sight on OMEGA → ΔT_i
- Significant variation is caused by long-wavelength nonuniformities*
  - – no classically unstable material interface in cryogenic targets

Room-temperature D–T and D–D implosions show much smaller ΔT_i.**

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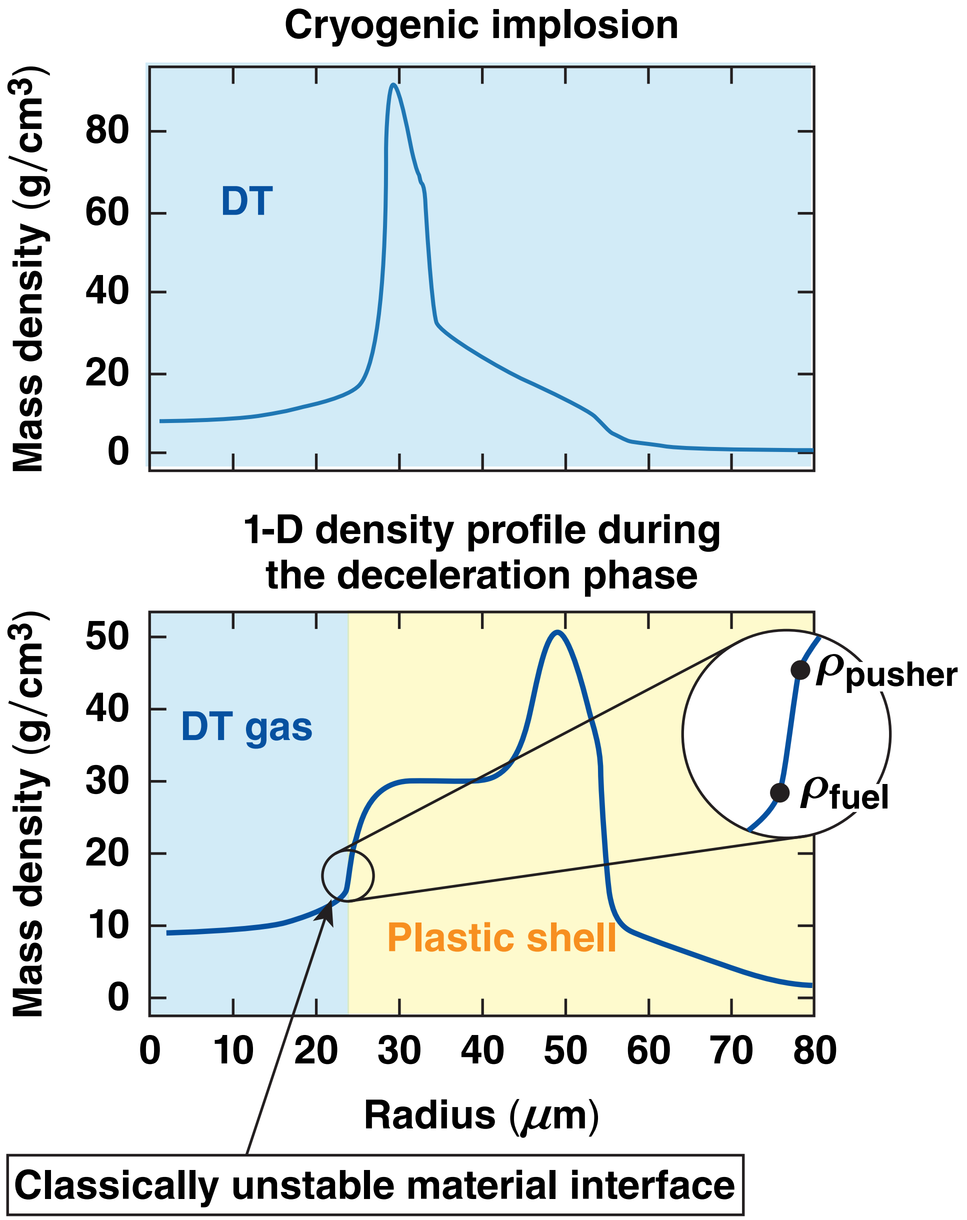
*I. V. Igumenshchev *et al.*, Phys. Plasmas 23, 052702 (2016).
**M. Gatu Johnson *et al.*, Phys. Rev. E 94, 021202(R) (2016).

One hypothesis is that deceleration-phase short-scale RT growth in room-temperature implosions reduces ΔT_i



Classical Rayleigh–Taylor growth rate

$$\gamma = \sqrt{A_T k g}$$

$$A_T = \frac{\rho_{\text{pusher}}/\rho_{\text{fuel}} - 1}{\rho_{\text{pusher}}/\rho_{\text{fuel}} + 1}$$

$$\frac{\rho_{\text{pusher}}}{\rho_{\text{fuel}}} = \frac{m_i^{\text{pusher}}}{m_i^{\text{fuel}}}\,\frac{1 + Z_{\text{fuel}}}{1 + Z_{\text{pusher}}}$$

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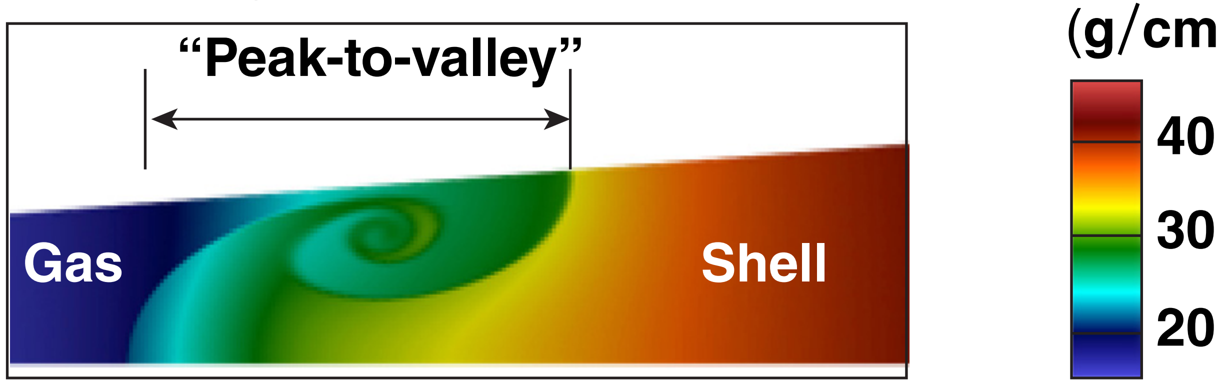
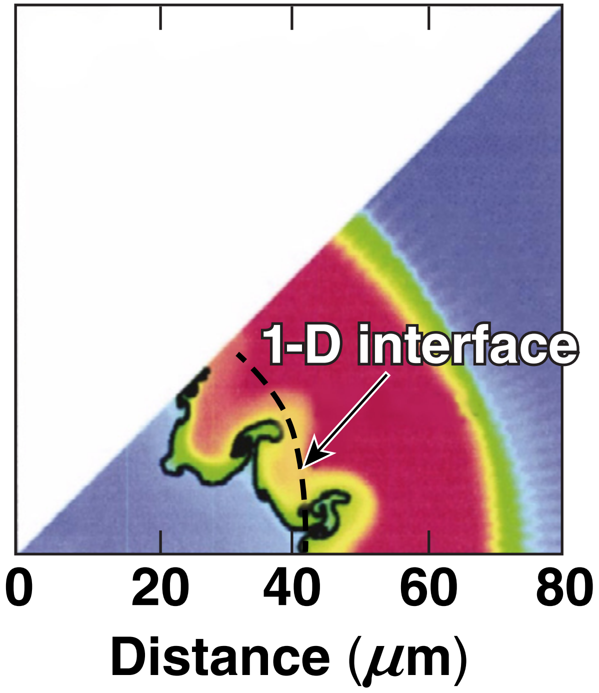
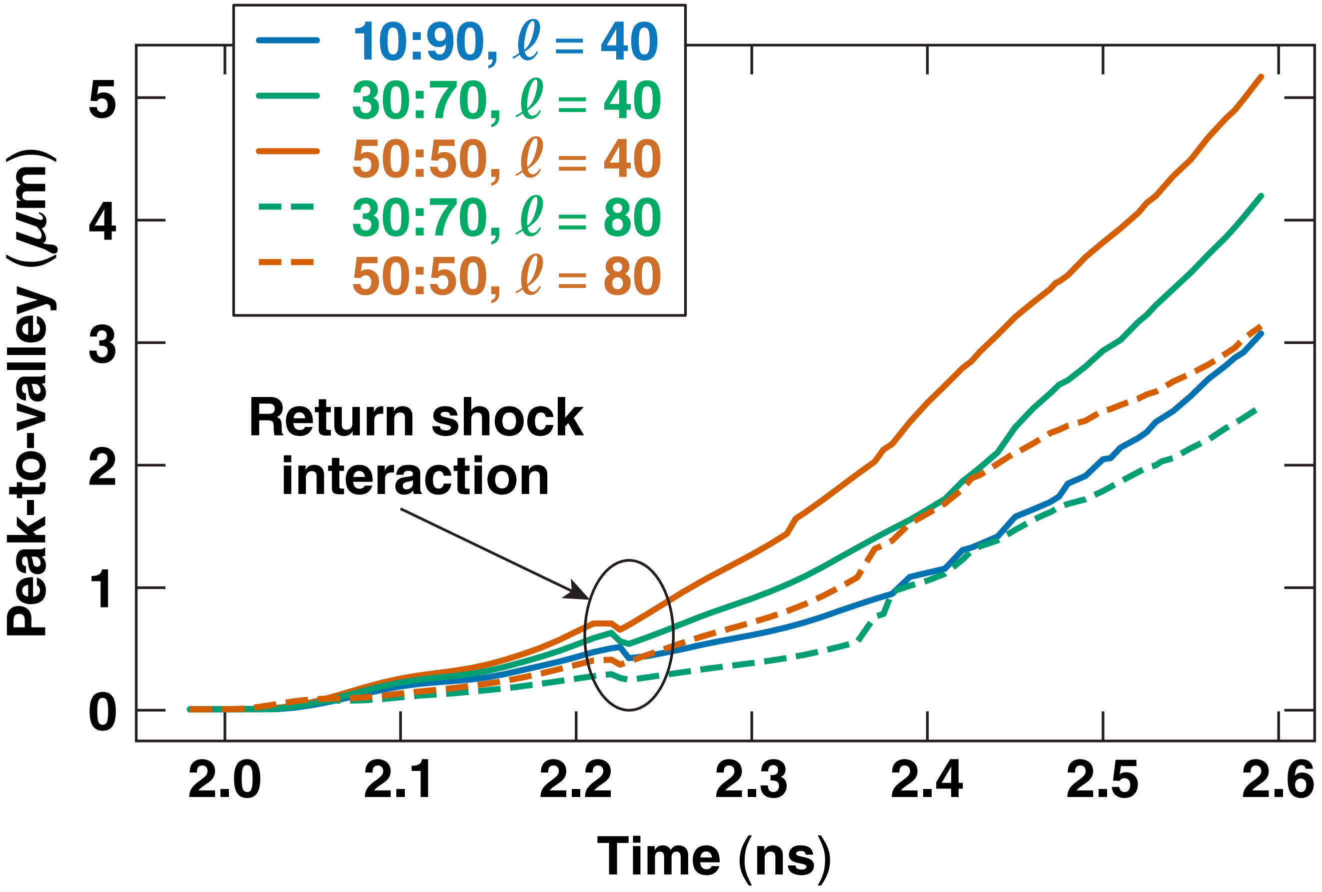
Higher Atwood numbers result in larger single-mode growth rates

DRACO **single-mode ($\ell = 40$) simulation**



DRACO **multimode**
($\ell = 4, 20, 200$) simulation*





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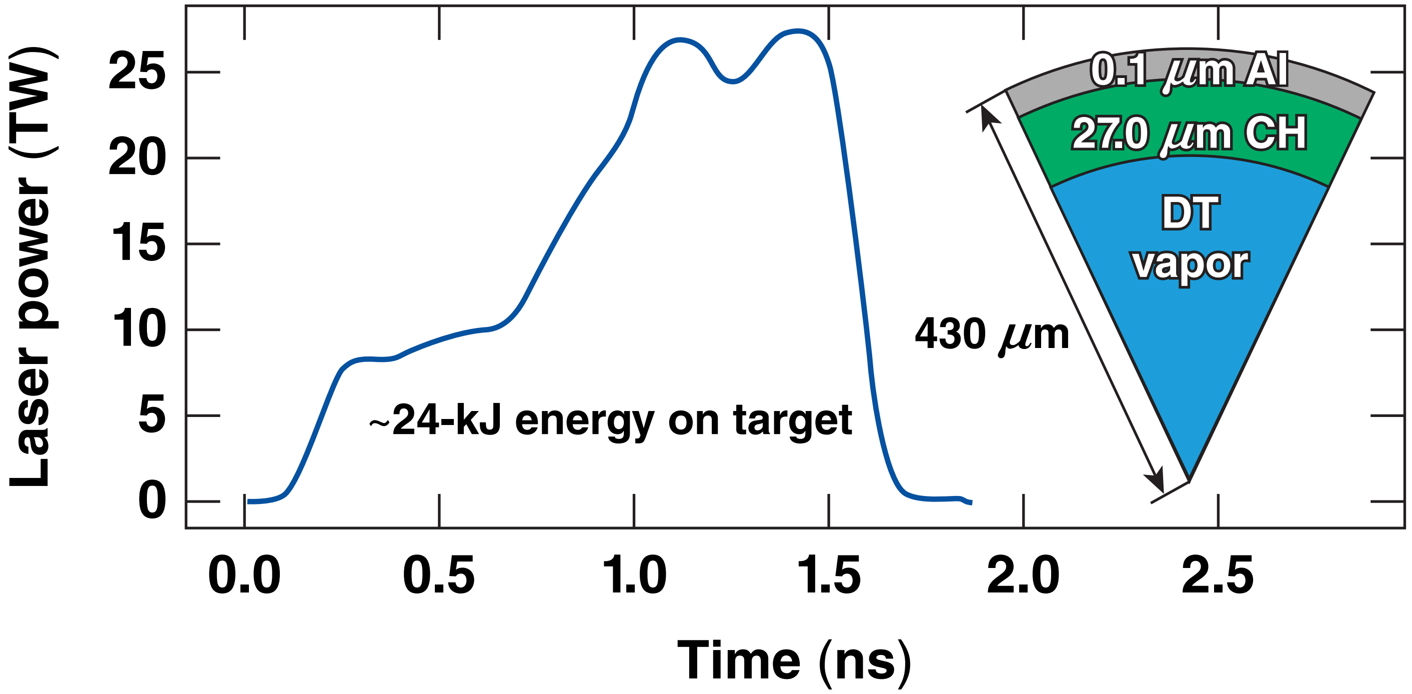
*P. B. Radha *et al.*, Phys. Plasmas 12, 056307 (2005).

Experiments to systematically change the Atwood number at the fuel–pusher interface were conducted on OMEGA

- Systematically vary D:T ratio for the same target and pulse shape
  - 860-μm-diam, 27-μm-thick CH, 10-atm DT fill

Pulse shape



Target configurations

D (%)	T (%)	Atwood number*	
50	50	0.05	Unstable
25	75	0.00	Neutral
10	90	–0.03	Stable

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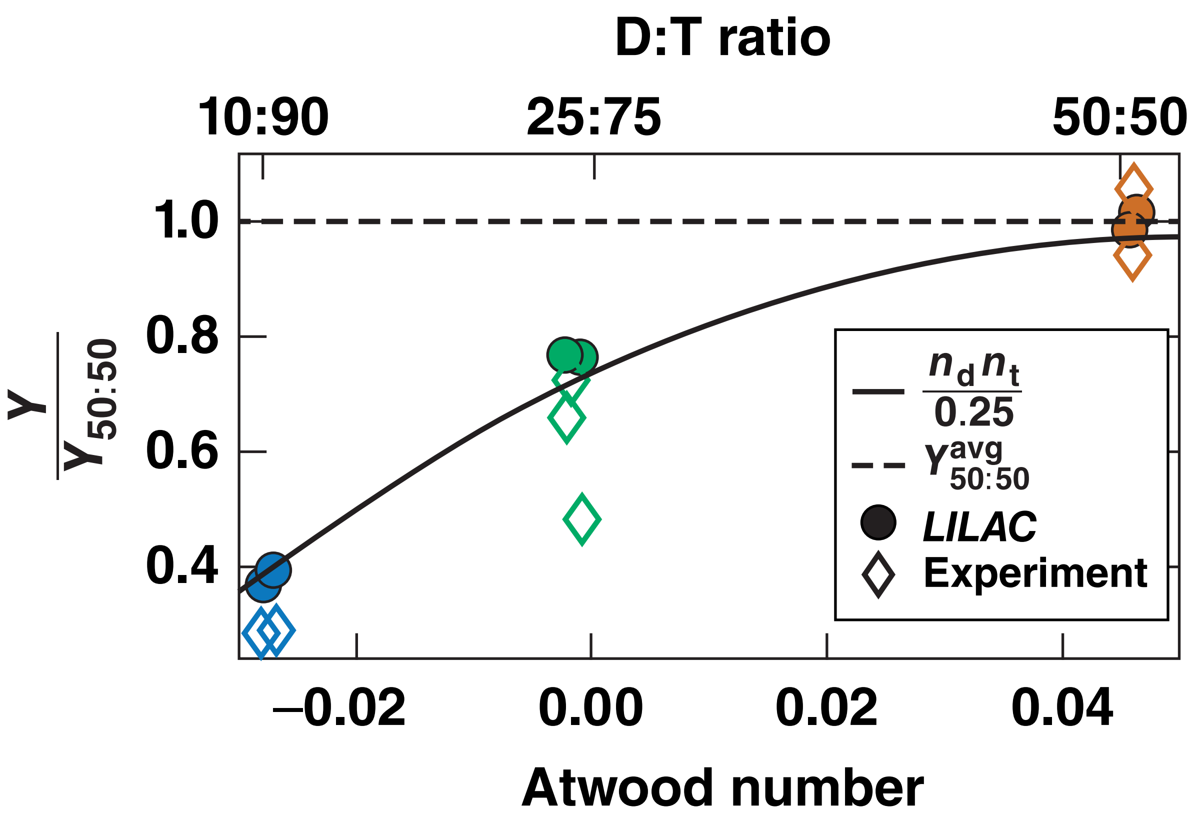
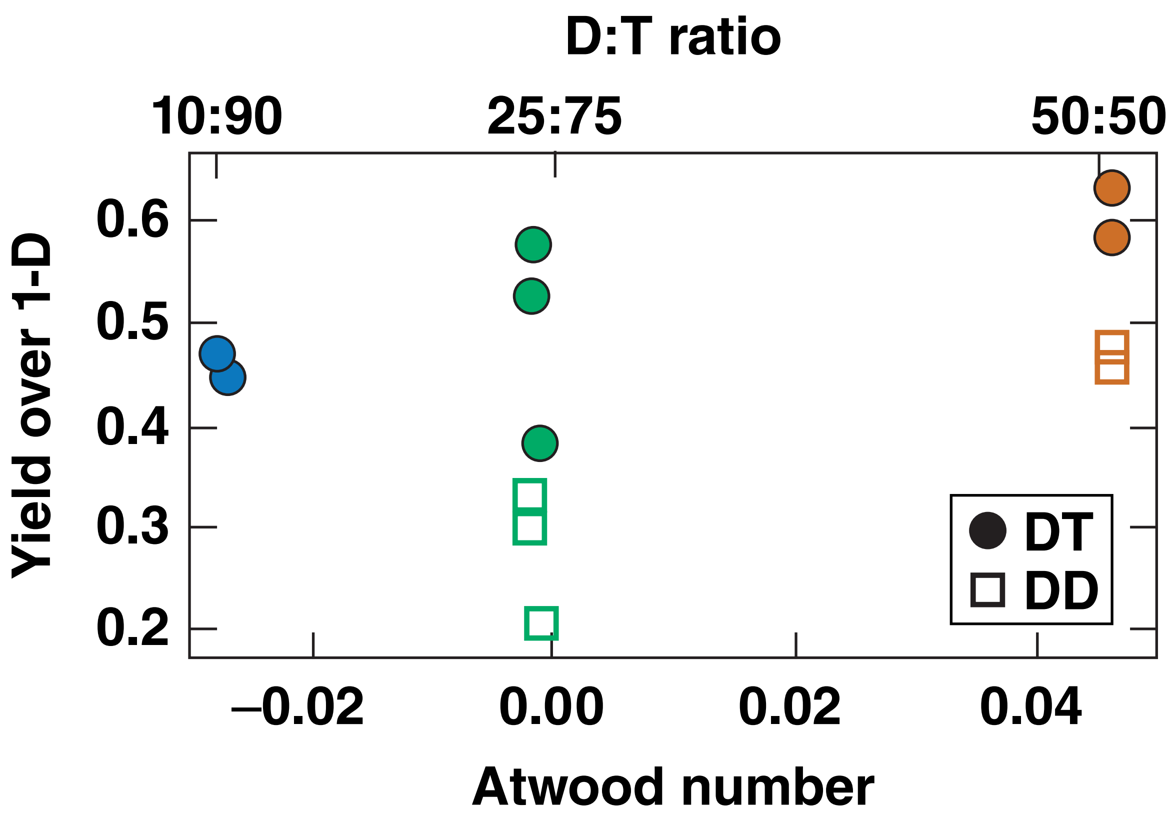
*Atwood number at the start of the deceleration phase

Target performance improves relative to predictions with increasing Atwood number





- Contrary to intuition, yield-over-clean improves with increasing Atwood number (more short-scale growth)

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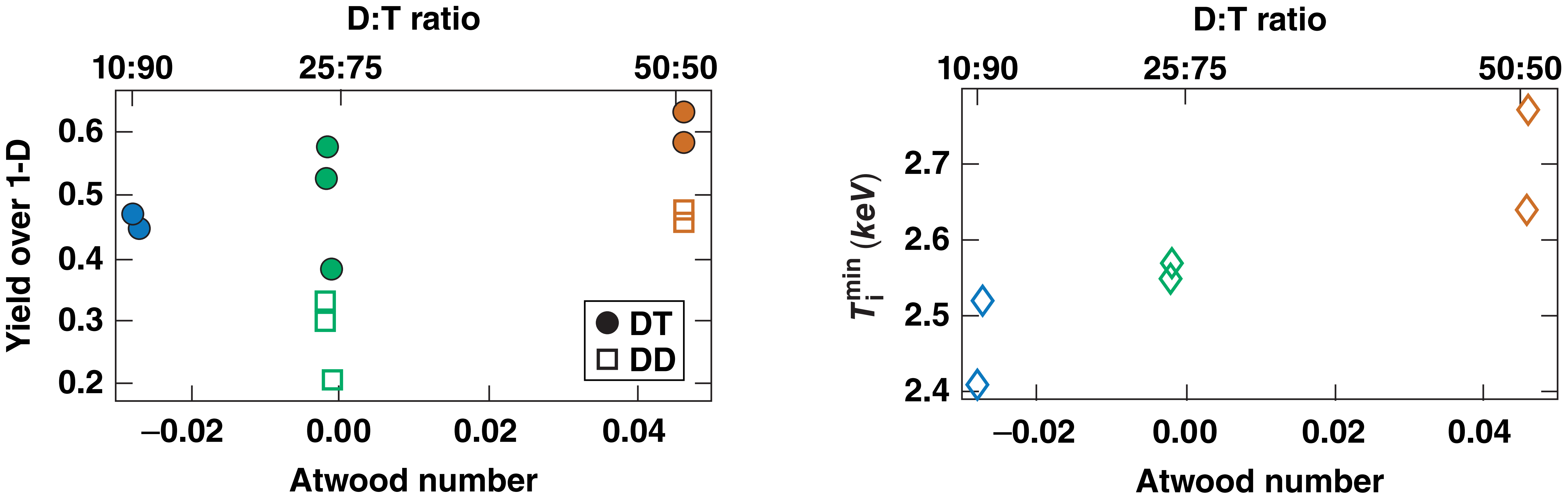
Increased yield correlates with higher ion temperatures



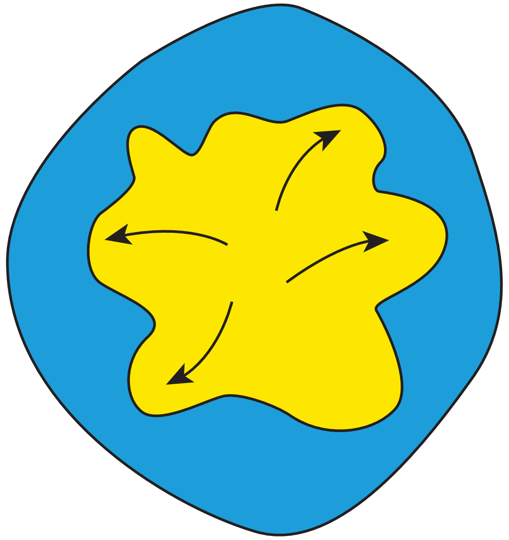
$$\frac{Y_{10:90}}{Y_{50:50}} \sim \left(\frac{T_{i\,avg}^{10:90}}{T_{i\,avg}^{50:50}}\right)^{4.5} \longrightarrow \left(\frac{2.45}{2.7}\right)^{4.5} = 0.65$$

E26783

Higher inferred T_i is a result of short-scale RT growth preventing the fuel from penetrating into the cold bubbles

Low Atwood number

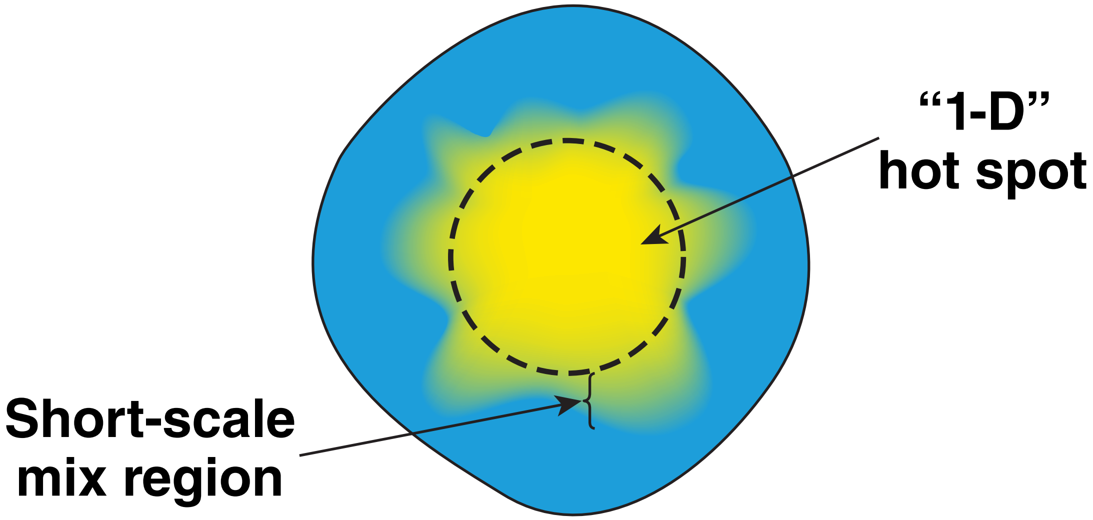
- Low-mode asymmetries only
- Larger ΔT_i along different lines of sight
- Fuel flows into cold bubbles because of bulk-fluid motion



Larger ΔT_i, similar to cryogenic implosions

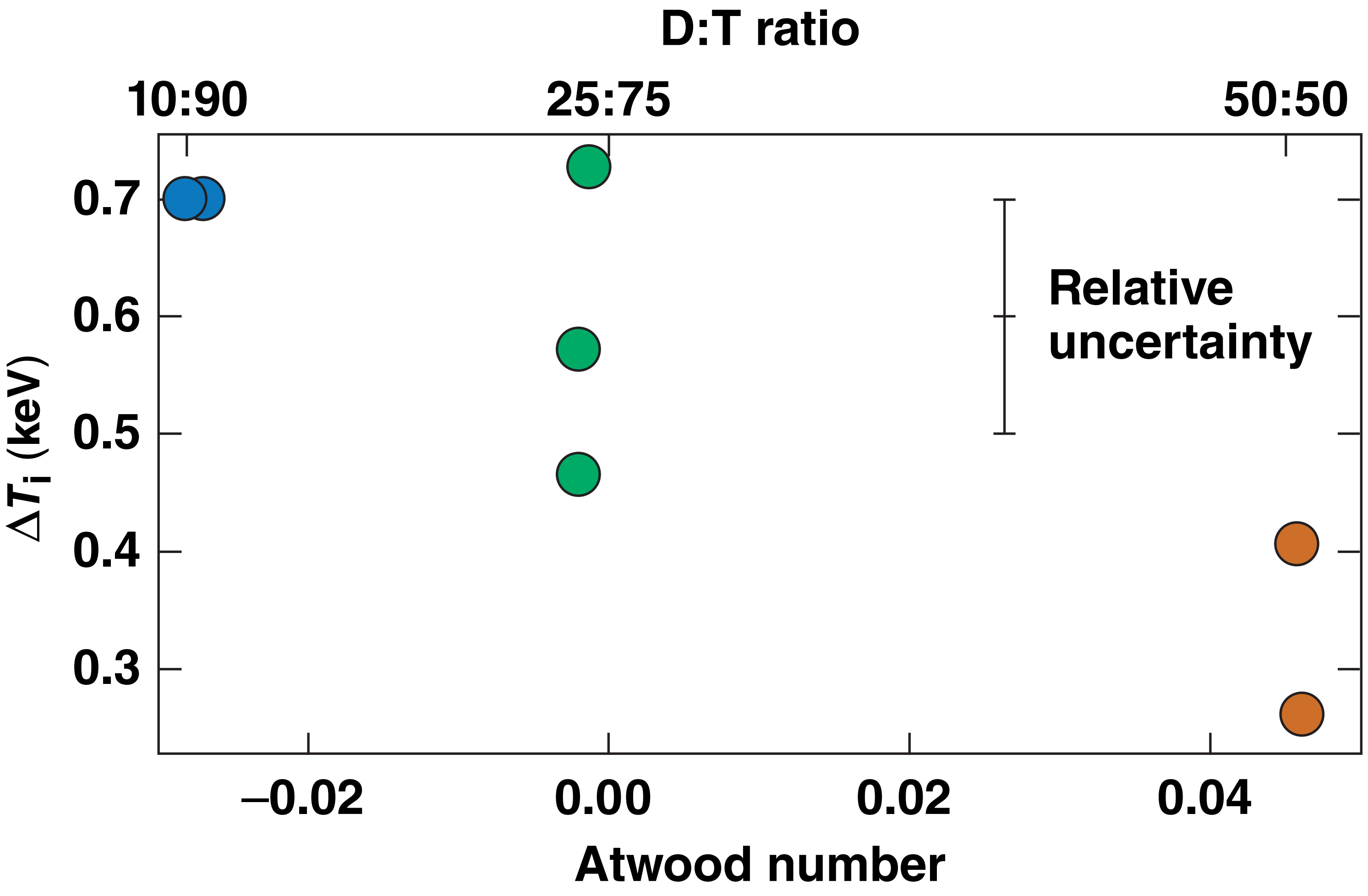
High Atwood number

- Smaller hot spot, but more "1-D" → improved yield-over-clean
- Short-scale growth prevents fuel from flowing into cold bubbles



Less ΔT_i

Larger ion-temperature variation is observed for lower Atwood numbers similar to cryogenic implosions



- Simulations indicate that higher bulk flows lead to higher ΔT_i

E26841

Summary/Conclusions

Short-scale Rayleigh–Taylor growth reduces the effects of bulk fluid motion in room-temperature implosions

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- Simulations indicate residual kinetic energy in the core contributes to ion-temperature variation*,**
- Increasing the Atwood number (by changing the D:T ratio) results in increased short-scale growth and reduced bulk-fluid motion
- Low Atwood number room temperature targets, with reduced short-scale RT growth, have large ΔT_i similar to cryogenic targets

Future multimode simulations are the next step to demonstrate short-scale growth effects on ion-temperature variation.

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*B. Appelbe and J. Chittenden, Plasma Phys. Control. Fusion 53, 045002 (2011).

**T. J. Murphy, Phys. Plasmas 21, 072701 (2014).