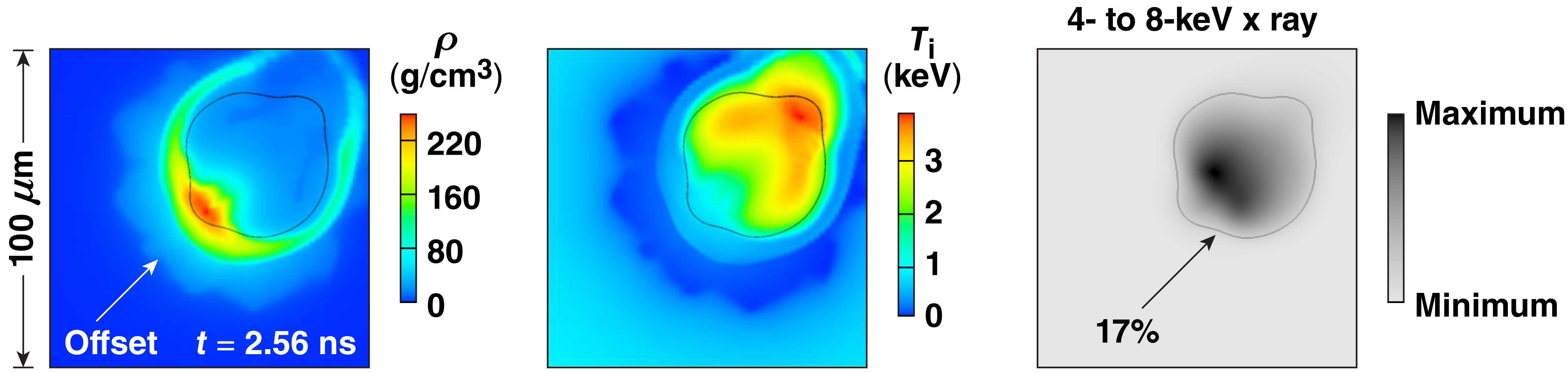
Numerical Study of Large-Scale, Laser-Induced Nonuniformities in Cryogenic OMEGA Implosions

3-D *ASTER* simulations of shot 78378



I. V. Igumenshchev
University of Rochester
Laboratory for Laser Energetics

57th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Savannah, GA
16–20 November 2015

Summary

Large-scale, laser-induced nonuniformities can explain performance degradation of cryogenic implosions on OMEGA

- The 3-D hydrodynamic code *ASTER* was developed to study direct-drive implosions
- Simulations consider the OMEGA laser's configuration and include typical target offsets and measured beam imbalance, mispointing, and mistiming
- The effects of the stalk mount were mimicked by applying surrogate perturbations
- Simulations suggest that the implosions are mostly affected by target offset and beam imbalance

Collaborators

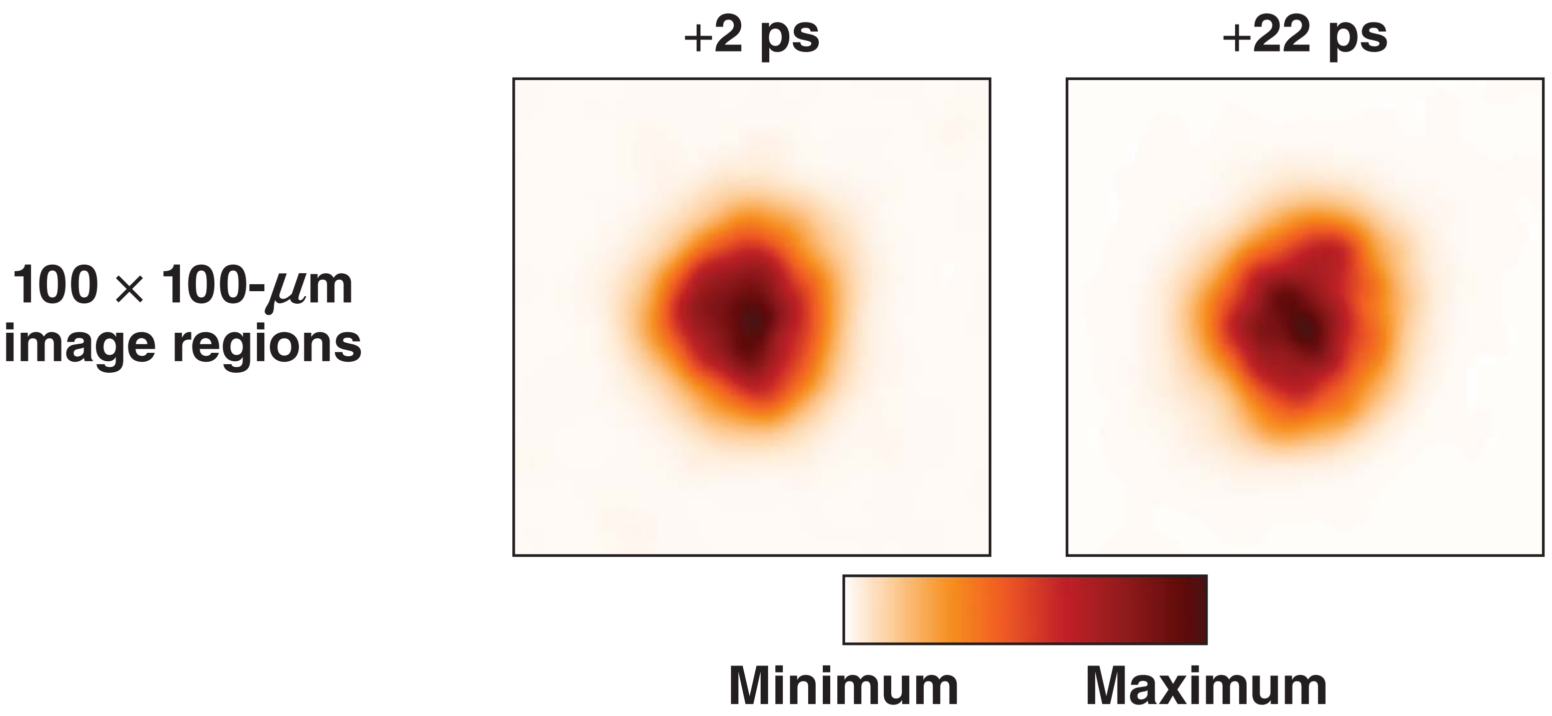
**V. N. Goncharov, F. J. Marshall, K. Silverstein,
J. P. Knauer, D. H. Froula, and S. P. Regan**

**University of Rochester
Laboratory for Laser Energetics**

Short-scale perturbations alone cannot explain the performance of cryogenic implosions on OMEGA

- Implosions with $\alpha \gtrsim 3.5$ and in-flight aspect ratio (IFAR) $\lesssim 22$ underperform
- Images of implosion cores evidence the evolution of low-ℓ-mode structures

X-ray images in the 4- to 8-keV range (shown in shot 77064)*



- T_i measurements suggest significant bulk motions in the hot spot**

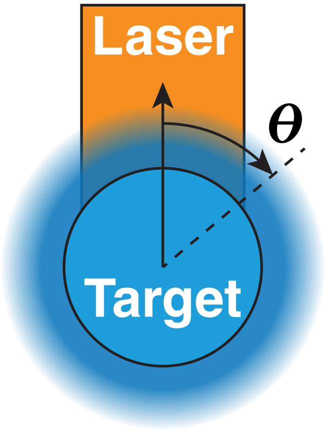
*F. J. Marshall *et al*., UO4.00004, this conference.
**T. J. Murphy, Phys. Plasmas 21, 072701 (2014).

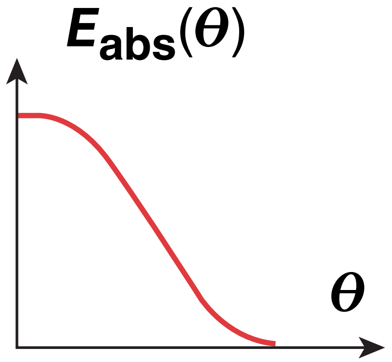
The 3-D code *ASTER* studies the effects of large-scale nonuniformities in OMEGA implosions

- Based on the Eulerian piecewise-parabolic method (PPM)*
- Utilizes a two-temperature (ion and electron) fluid model of plasma, which can consist of multiple materials (DT, CH, etc.)
- Implemented on a 3-D orthogonal spherical grid (R, θ, φ)
- Parallelized using the domain-decomposition approach
- A nominal-resolution ($700 \times 60 \times 120$) implosion simulation takes less than 48 h
- Current physical options
  - tabulated Z and equation of states (EOS's)
  - Spitzer thermal conduction (with optional flux limitation)
  - simplified 3-D laser-deposition model

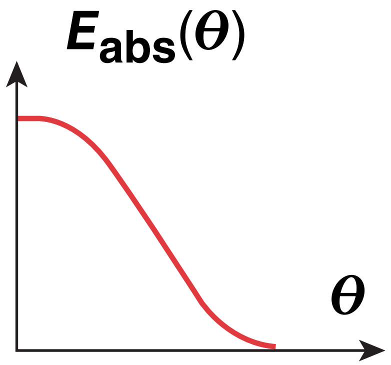
*P. Colella and P. R. Woodward, J. Comput. Phys. 54, 174 (1984).

ASTER uses a simplified 3-D laser deposition model

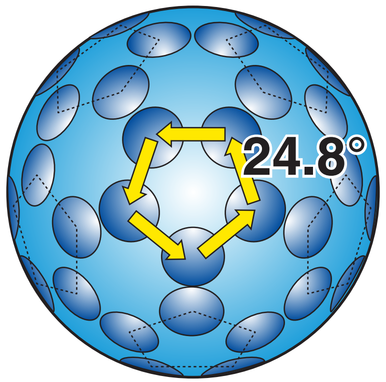




- The assumption of a spherical corona
- Adopts a ray-tracing routine with cross-beam energy transfer (CBET)* from the 1-D code *LILAC***



+



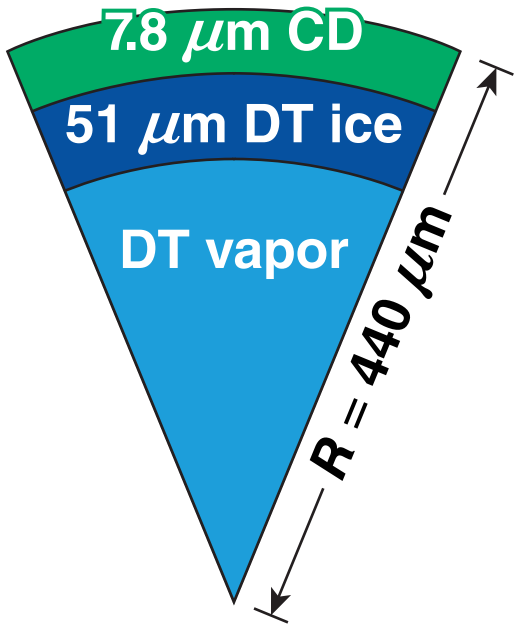
+ Perturbations of individual beams → 3-D laser deposition

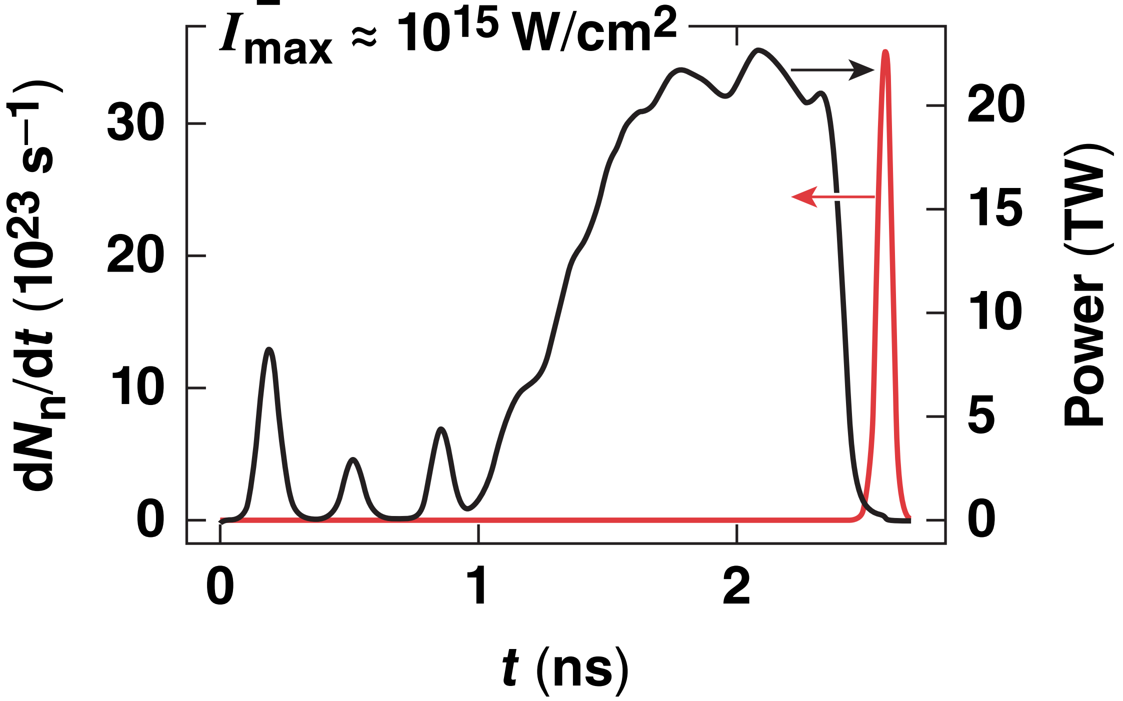
Simulated effects:
- OMEGA beam overlap
- beam-energy imbalance
- beam mispointing
- beam mistiming
- target offset

*I. V. Igumenshchev *et al*., Phys. Plasmas 17, 122708 (2010).
**J. Delettrez *et al*., Phys. Rev. A 36, 3926 (1987).

OMEGA shot 78378 was simulated assuming measured 3-D laser-imposed perturbations

$\alpha = 4$
IFAR = 22

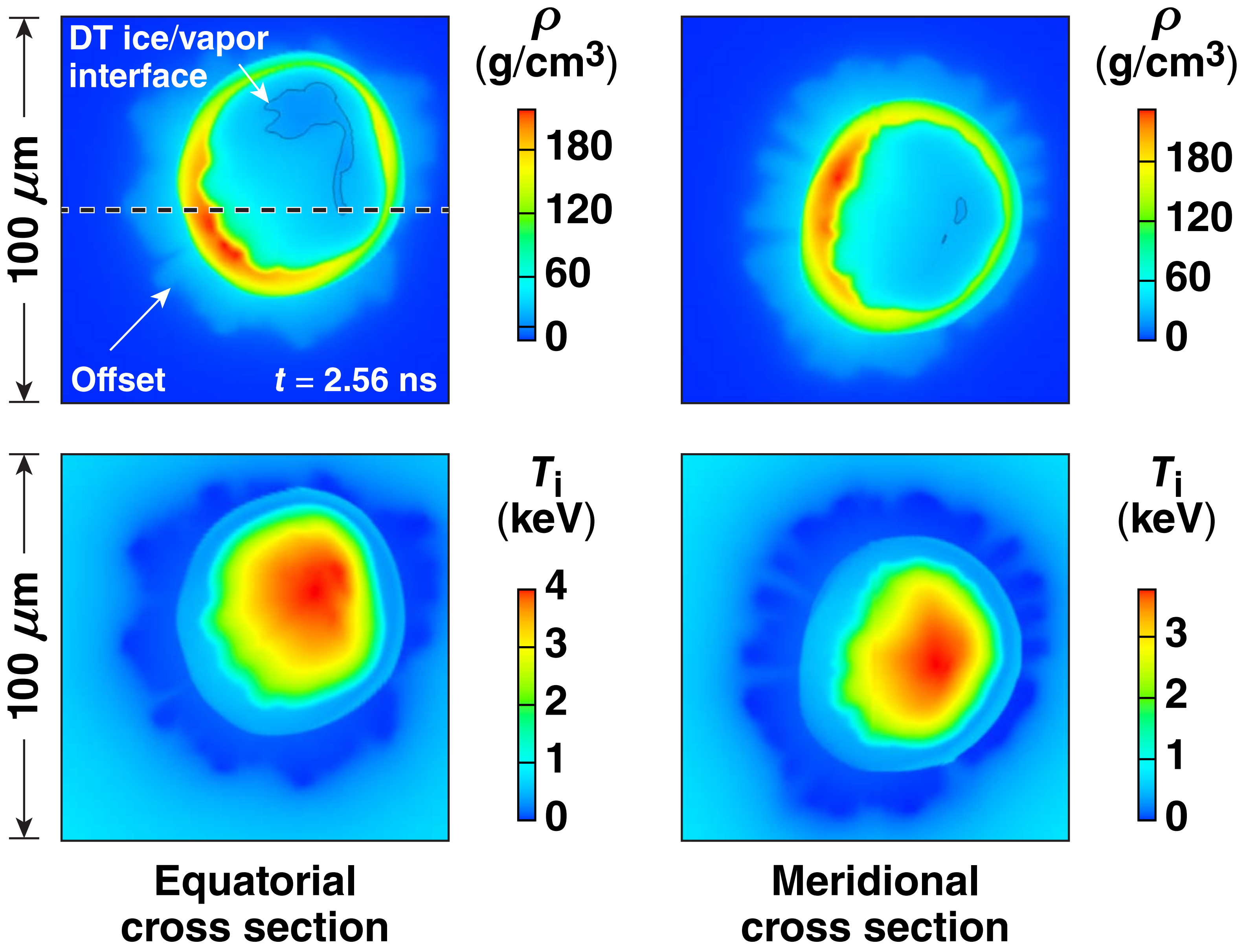




- Nominal model:
  - Beam overlap
  - 10% σ_{rms} imbalance
  - 10-μm σ_{rms} mispointing
  - 5-ps σ_{rms} mistiming
- Typical target offset ~10 to 20 μm

TC12510

Simulations of a nominal model with a 10-μm offset suggest that offset and beam imbalance have the largest effect



YOU = 0.51

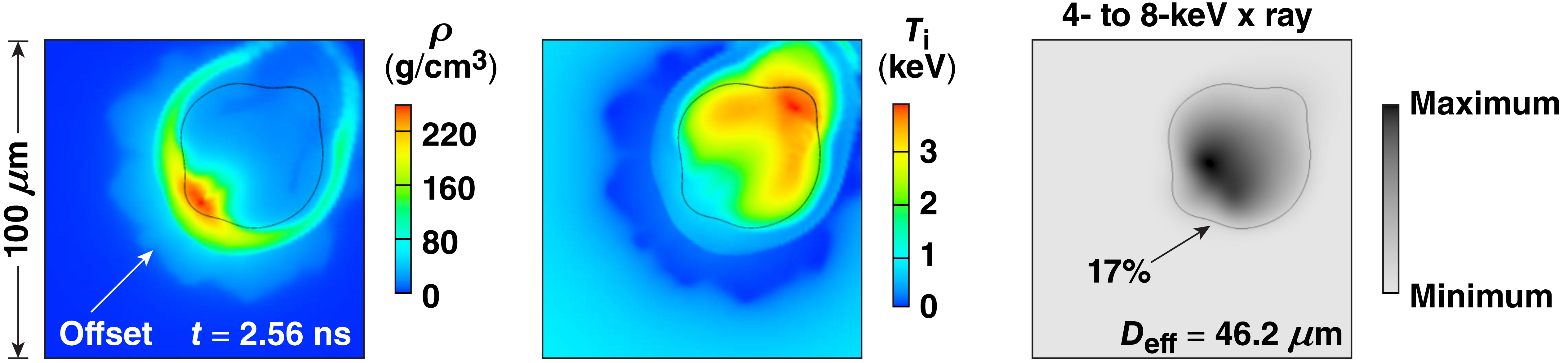
- Larger perturbations are needed to explain OMEGA implosions (YOC ~ 30)

YOU: yield over uniform
YOC: yield over clean

TC12605

A nominal model with a 20-μm offset shows the typical performance of OMEGA α = 4 cryogenic implosions

3-D *ASTER* simulations of shot 78378



YOU = 0.22
P_n = 47 Gbar (versus 45±6 Gbar for shot 78378)

17% contour defines the hot spot size

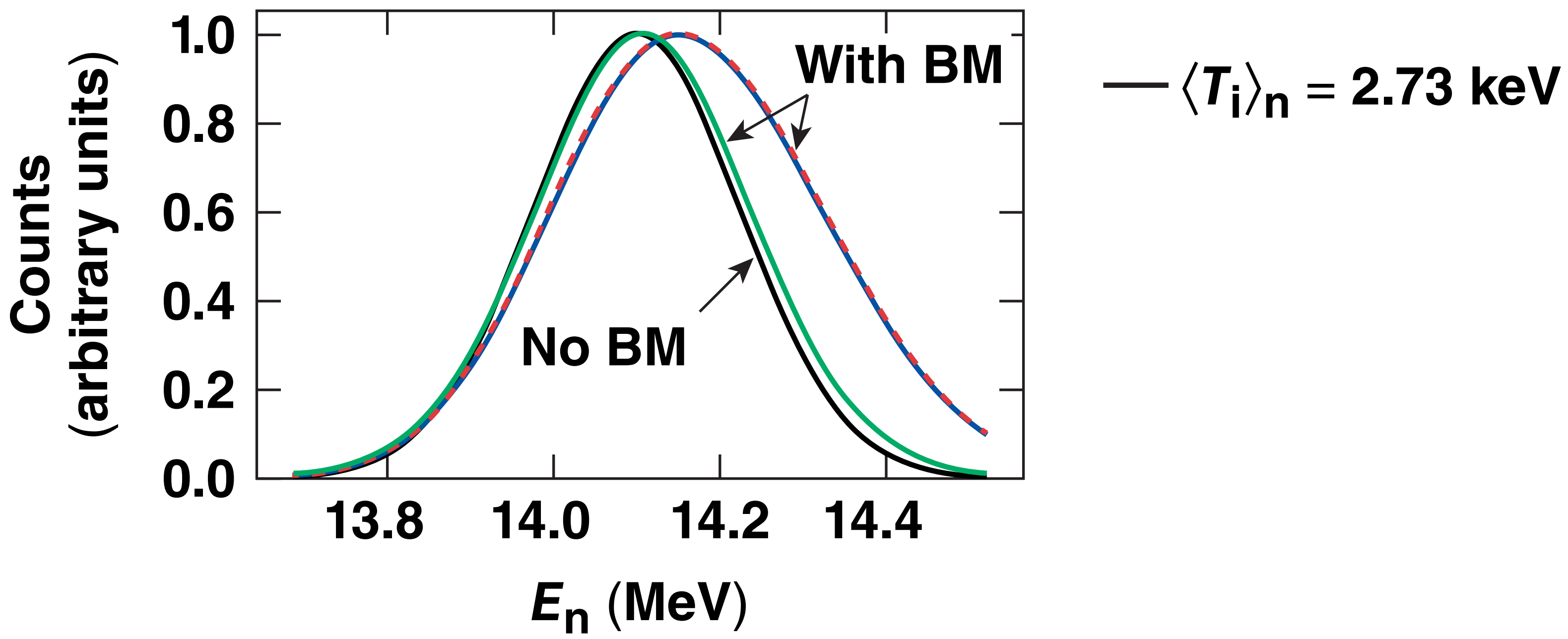
- Self-emission x-ray images loosely reproduce the hot-spot shape
- The cold shell must be imaged

TC12513

Large-scale perturbations increase the variation of inferred T_i, which is in good agreement with measurements

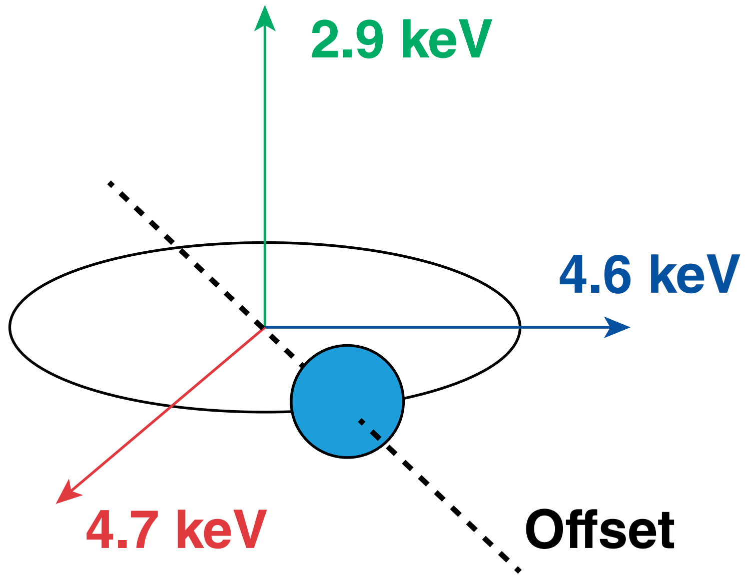
Nominal model with 20-μm offset

Normalized neutron spectra* with and without the effects of plasma bulk motion (BM)



Shot 78378
Inferred T_i: 3.6, 3.7, and 4.6 keV

The directions of measurements and inferred T_i

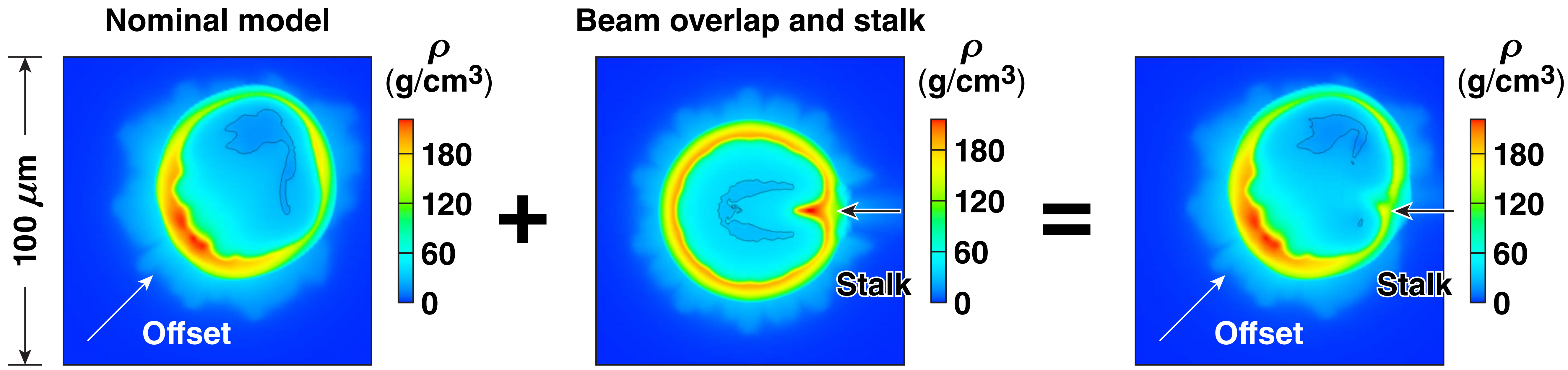


TC12606

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

Perturbations from a mount stalk and other sources interact, reducing the implosion performance

Equatorial density map at neutron peak (t = 2.56 ns)



YOU = 0.51

Perturbations in laser deposition mimic the effects of a stalk mount

YOU = 0.48

TC12550

Large-scale, laser-induced nonuniformities can explain performance degradation of cryogenic implosions on OMEGA

- The 3-D hydrodynamic code *ASTER* was developed to study direct-drive implosions
- Simulations consider the OMEGA laser's configuration and include typical target offsets and measured beam imbalance, mispointing, and mistiming
- The effects of the stalk mount were mimicked by applying surrogate perturbations
- Simulations suggest that the implosions are mostly affected by target offset and beam imbalance