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Title: An Overview of the Los Alamos Inertial Confinement Fusion and High-Energy-Density Physics Research Programs

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An Overview of the Los Alamos Inertial Confinement Fusion and High-Energy-Density Physics Research Programs

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Abstract

- **The Los Alamos Inertial Confinement Fusion and Science Programs engage in a vigorous array of experiments, theory, and modeling. We use the three major High Energy Density facilities, NIF, Omega, and Z to perform experiments. These include opacity, radiation transport, hydrodynamics, ignition science, and burn experiments to aid the ICF and Science campaigns in reaching their stewardship goals. The ICF program operates two nuclear diagnostics at NIF, the neutron imaging system and the gamma reaction history instruments. Both systems are being expanded with significant capability enhancements.**

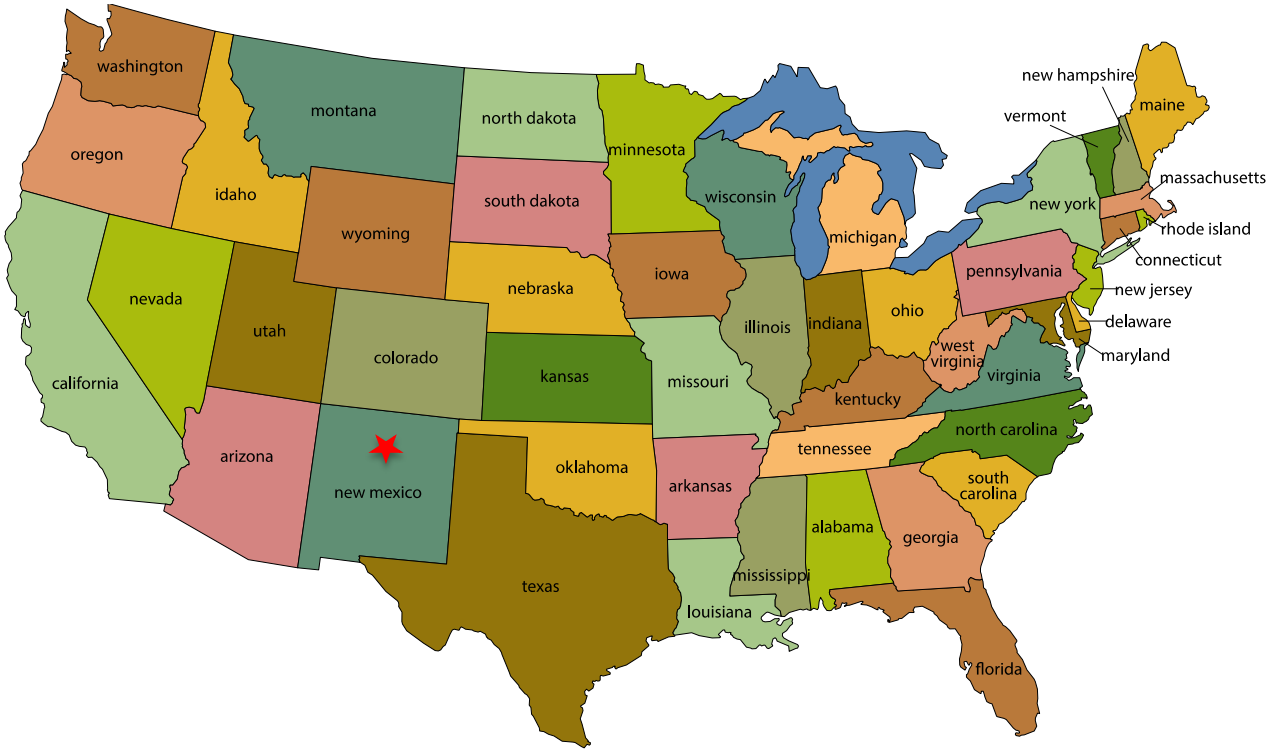
Los Alamos National Laboratory is the United States senior National Security Laboratory

- **We have four core missions:**
  - Provide a safe, secure, effective stockpile
  - Protect against the nuclear threat
  - Counter emerging threats and create new opportunities
  - Provide solutions to strengthen energy security

- **To meet these goals, LANL employs specialists in a wide range of disciplines**
  - Physics, Math, Chemistry, ….
  - Archeology, Biology, Earth Science, ….

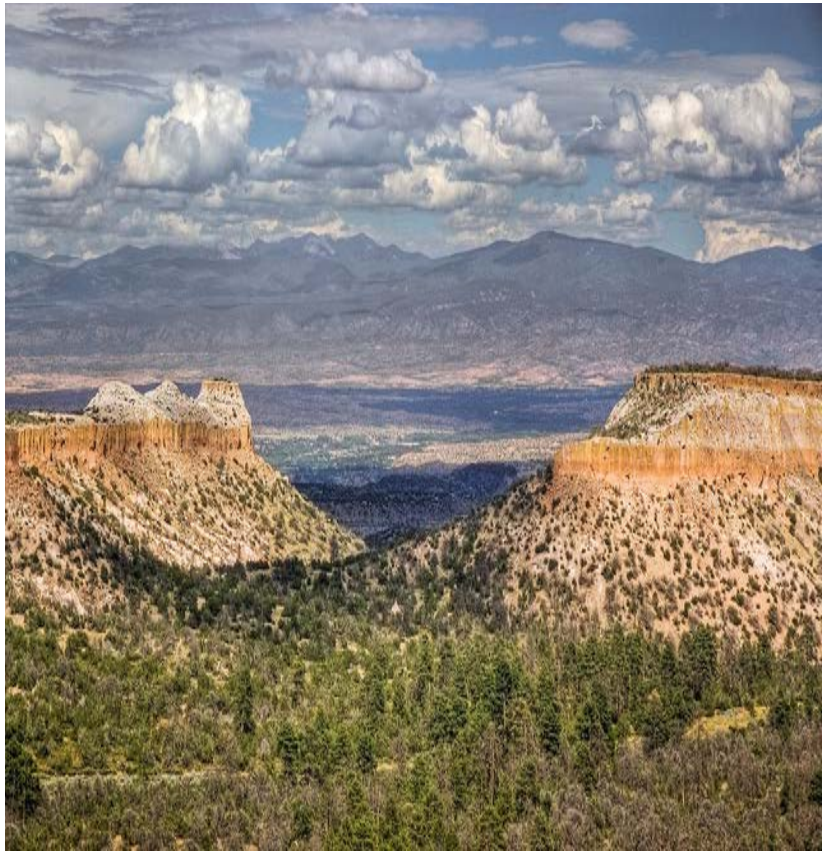
- **High Energy Density Physics and Inertial Confinement Fusion programs support and steward important capabilities**

LANL encompasses 43 square miles in New Mexico



Lab Factoids

- **10,500 employees**
  - 3,600 technical staff
  - 1,100 students
  - 390 post docs
  - ≈800 foreign nationals
- **$2.45B budget**
- **1,000 buildings with 8.2M sq. ft.**
- **13 nuclear facilities**
- **Los Alamos Nuclear Science Center**
- **Very fast supercomputers**



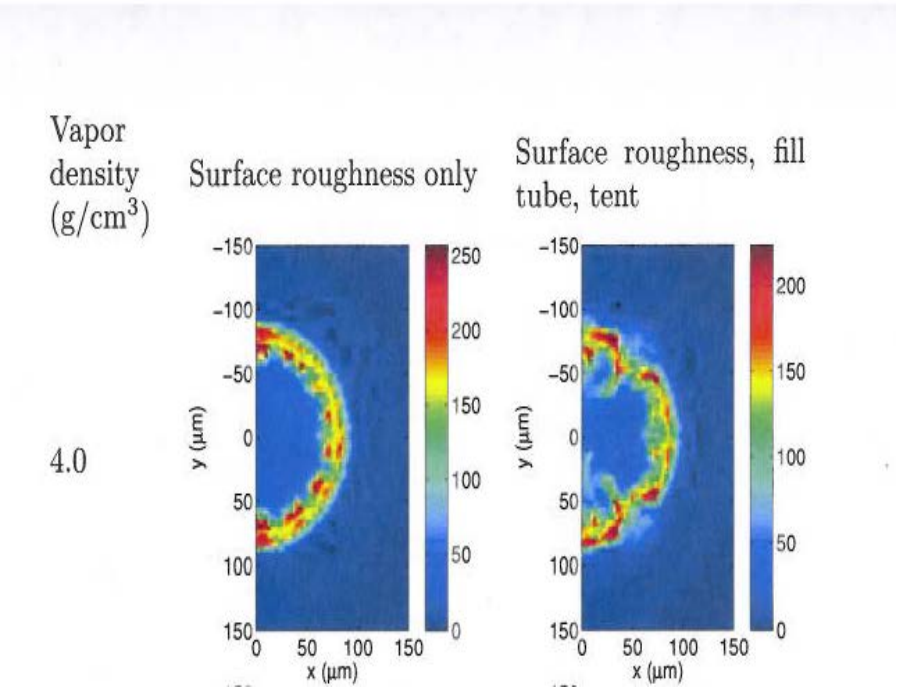
Inertial Confinement Fusion at LANL

LANL ICF Uses 3 Threads to Support Stewardship

- **Burning Plasma Platforms**
  - Create a burning plasma platform, or
  - Understand why not
  - *Use innovative platforms and approaches*
- **HED Physics**
  - Hydrodynamics
  - Mixing & models
- **Diagnostics**
  - Gamma-ray measurements
  - Neutron Imaging
  - *25% of the Transformative Diagnostics*
- **Infrastructure important to executing program**
  - Target fabrication and operations

LANL RAGE Code Now Used Routinely After Long Investment by ICF and Science

- **Laser Ray-Trace package added in collaboration with U. Rochester**
  - Working well for direct drive, hohlraum capability imminent
- **First Omega experiment completely designed & analyzed using RAGE**
- **Indirect drive capsule implosions now routine (need link from HYDRA)**
- **Provides a second look at ignition since code architecture and models very different**



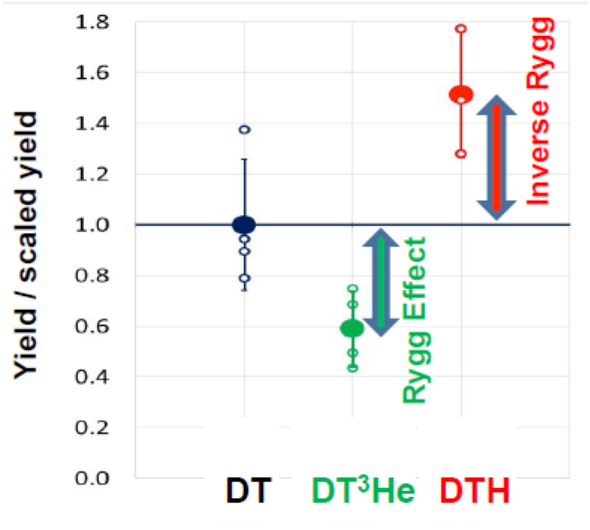
Our Ignition Science Research Theme Is To Achieve "1D Performance" Using 3 Platforms

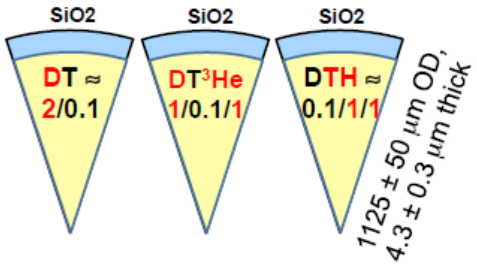
- **Hypothesis:**
  - Codes are not complete and not predictive
  - Move to regimes where 1D codes are predictive, *i.e.* "1D Performance"
    - Example: Predict Radius(t), Tion, density, shape, hot-spot pressure, ….
  - Intentional perturbations will identify incomplete models
- **LANL is addressing two issues identified in indirect-drive reviews**
  - Symmetry (& capsule support)
  - Convergence
- **We are using three platforms**
  - High case to capsule ratio experiments
  - Wetted Foam capsules
  - Double shell capsules

We Demonstrated the Existence of Kinetic Plasma Effects In HED Regimes

DTRat

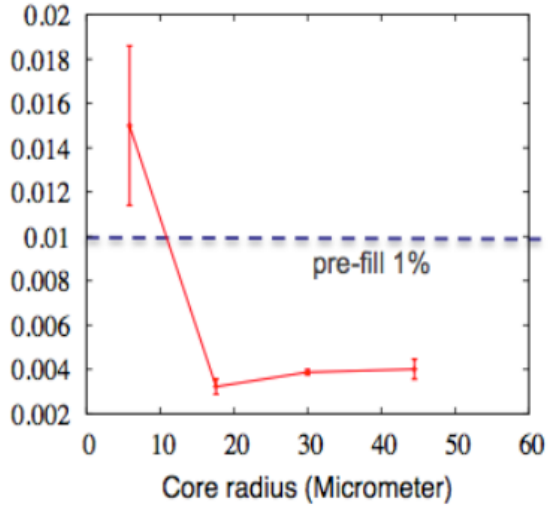
Yield / scaled yield [Herrmann]

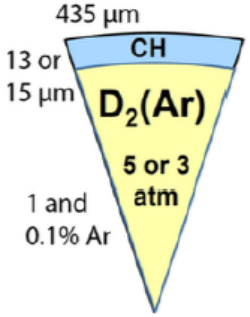




IonSepMMI

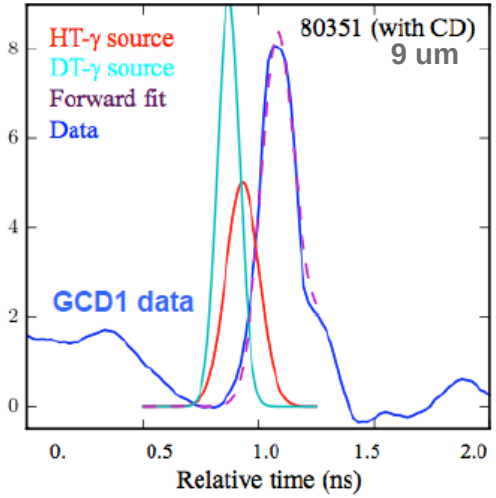
Argon concentration [Hsu]

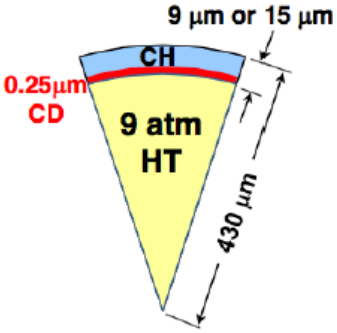




HKMix

Shell/gas mix γ's [Schmitt]

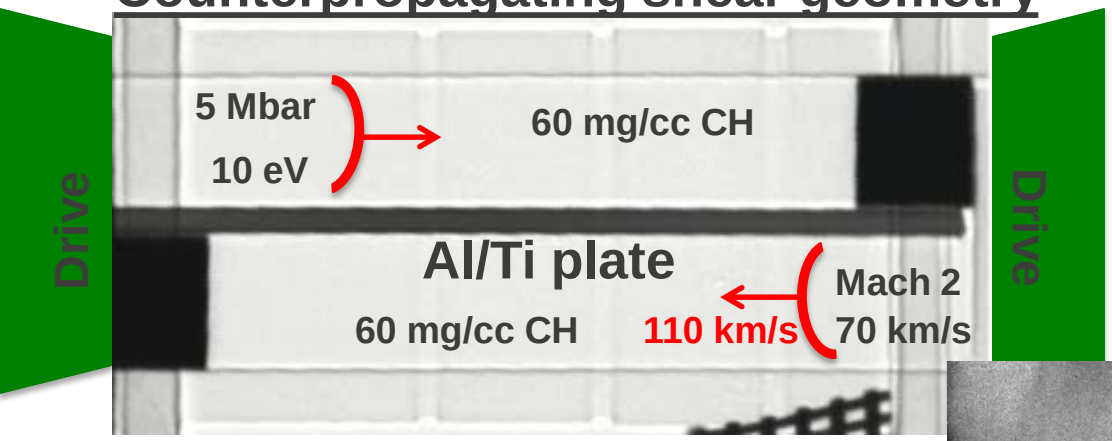




Slide 10

Shock/Shear experiment generates extreme KH shear instability for model validation

Counterpropagating shear geometry



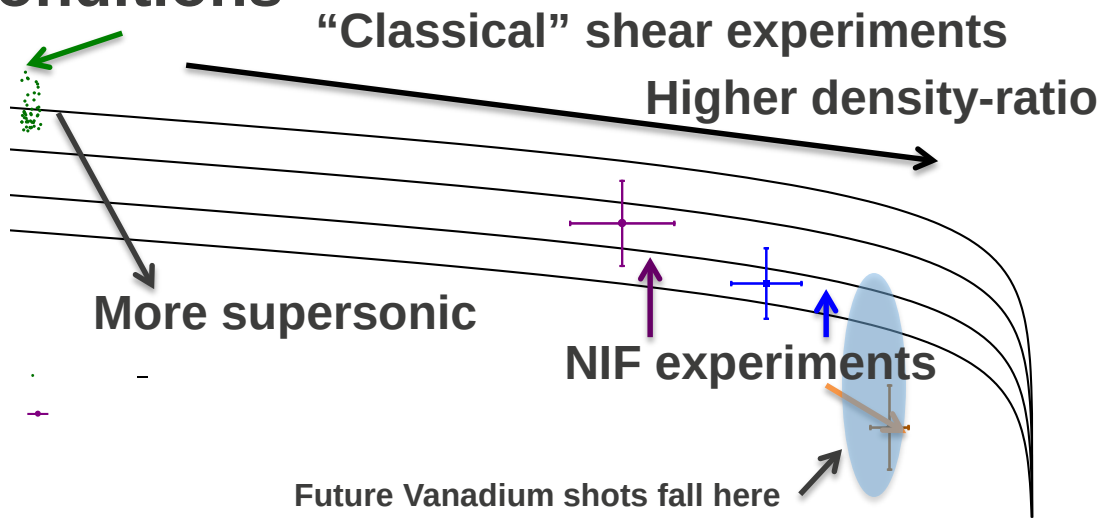
- Edge-on view measures tracer mix width, will be compared with turbulence model predictions.

Mix width measured along line

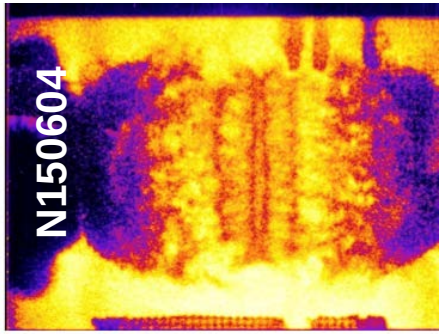
- **Experiment originally developed at Ω, then taken to NIF to extend to long (10 ns) sustained indirect drive.**

Shock/Shear's high-Atwood dataset looks for mixing anomalies in HED conditions

- Observed coherent KH structures
- Can use the methods and context of traditional mixing layer work



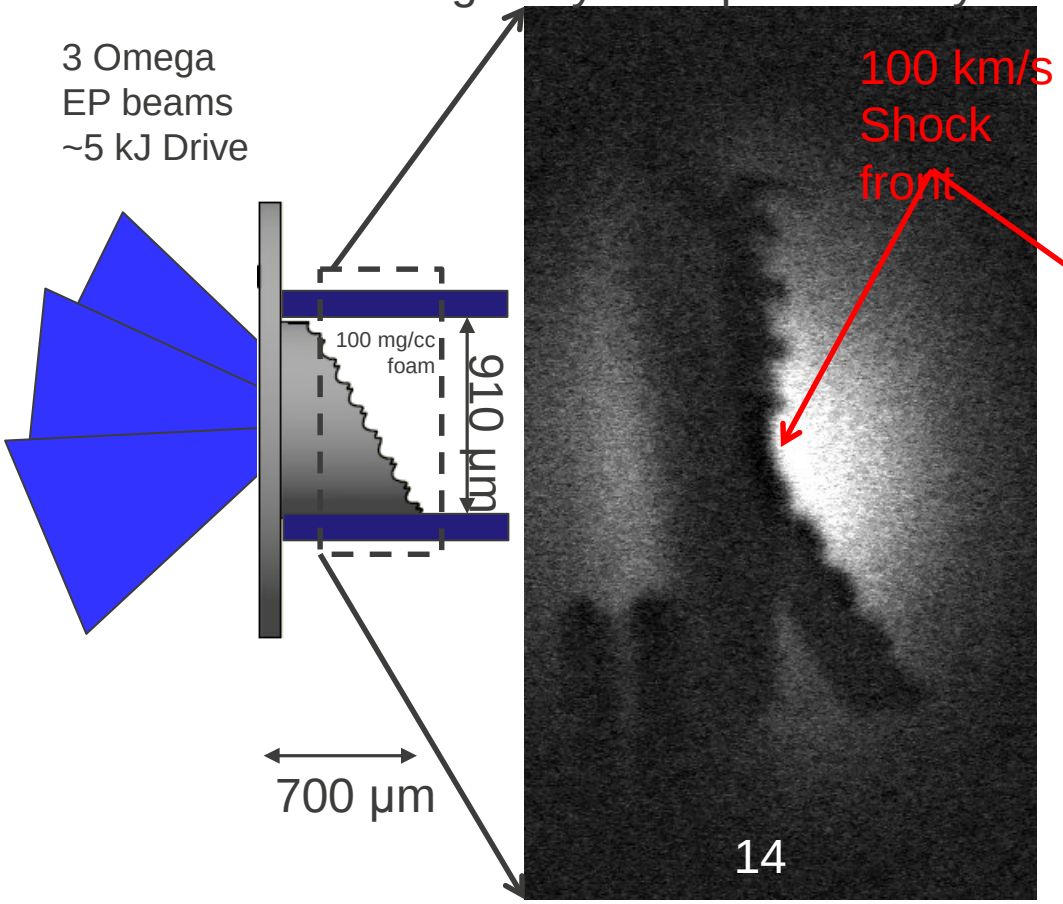
- Turbulent flow energy is estimated by comparing the primary and secondary instabilities
- NIF takes data in the high-density ratio, supersonic-flow regime where existing aerodynamic data from wind tunnels is sparse Deviations may indicate mixing anomalies in the HED regime.



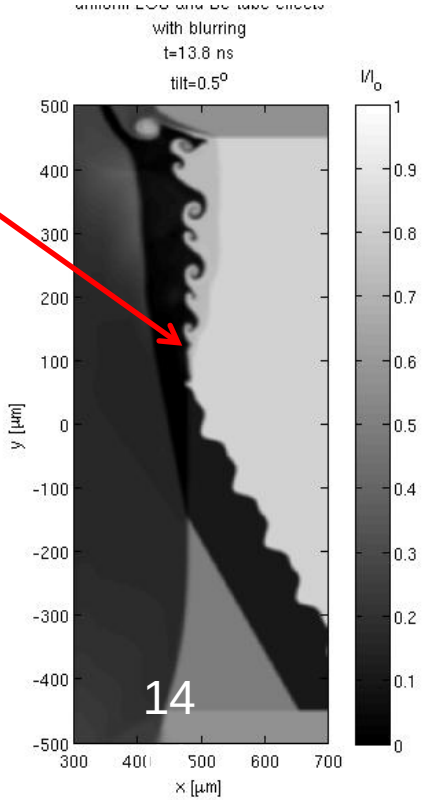
Titanium shear data

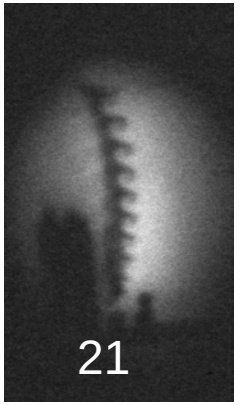
The Omega EP Oblique Shock Campaign seeks to understand the interplay between Kelvin-Helmholtz, Richtmyer-Meshkov and Rayleigh-Taylor instabilities on mixing in an HED environment

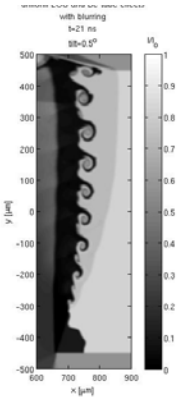
Area imaged by the Spherical Crystal Imager (at 8 keV)



Simulations in RAGE





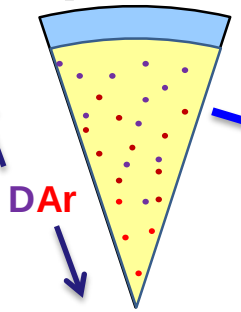


LANL Made the First Direct Observation of Ion Separation Using X-Ray Imaging Spectroscopy

First-principles interspecies-ion-diffusion theory

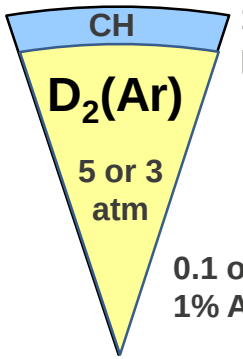
$$\mathbf{i} = -\rho D(\nabla c + k_p \nabla \log p_i + \frac{e k_E}{T_i}\nabla\Phi + k_T^{(i)}\nabla \log T_i + k_T^{(e)}\nabla \log T_e)$$

Concept: Strong ion thermo-diffusion between D/Ar observed via Ar K-shell spectroscopy

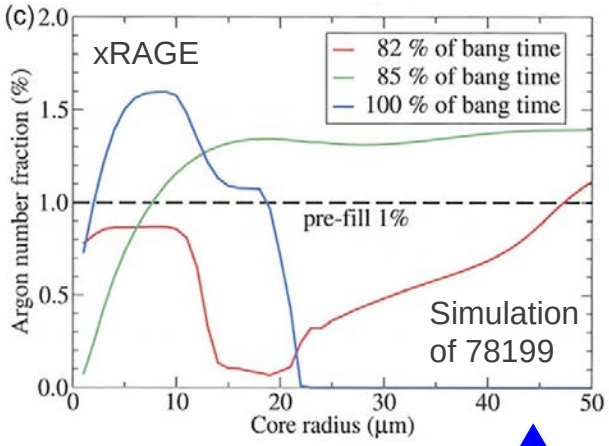


60-beam symmetric direct drive on OMEGA

435-μm radius

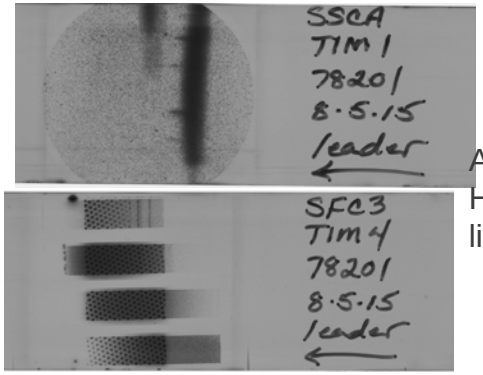


13 or 15 μm thick

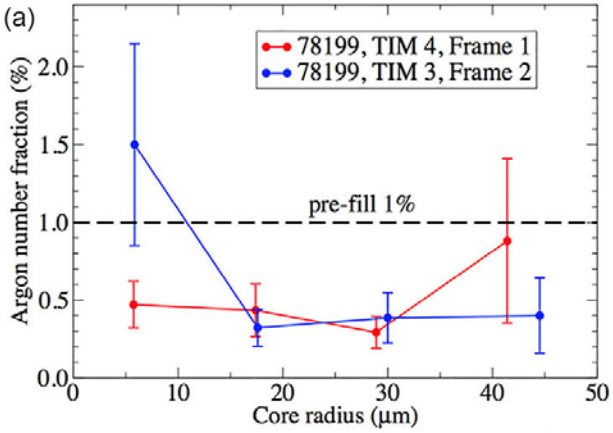


Good qualitative agreement (compare blue with blue and red with red curves) with xRAGE simulations including the MSV multi-ion-species transport model. Ar enhancement/depletion around incoming shock is dominated by ion thermo-diffusion in the simulation.

Obtained good SSCA and MMI data (8/5/15)



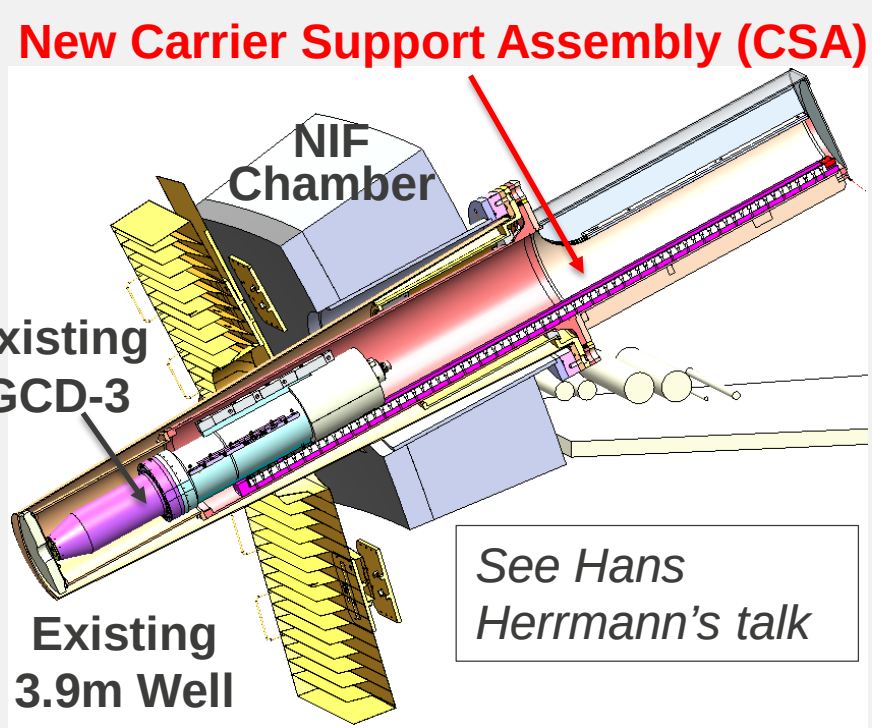
Ar H- and He-like lines



Detailed analysis to extract radial profiles of argon number fraction

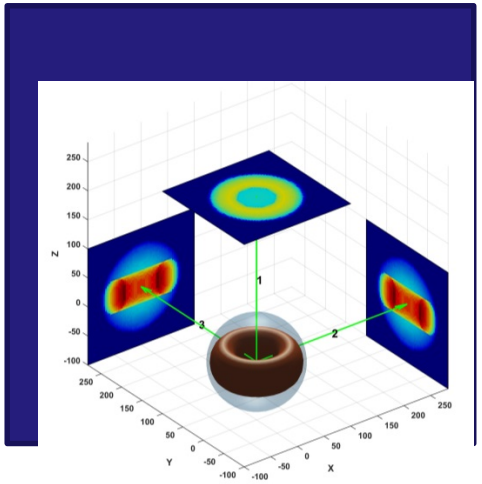
LANL is Building 2 of 8 Transformative Diagnostics To Understanding of Stagnation & Burn

Bringing GCD-3 from OMEGA to NIF



Goal: Enhanced Gamma-Ray Sensitivity, Temporal & Spectral Response relative to GRH-6m

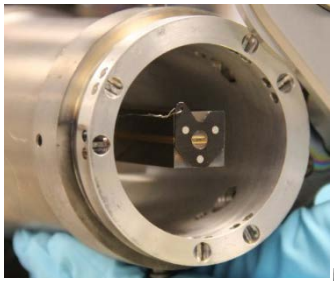
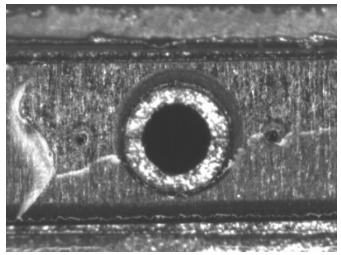
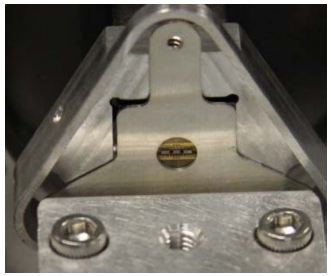
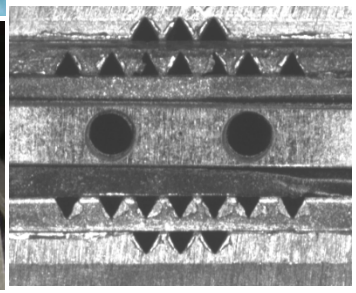
3D Neutron Imaging Polar, primary image only installed in Q2FY17



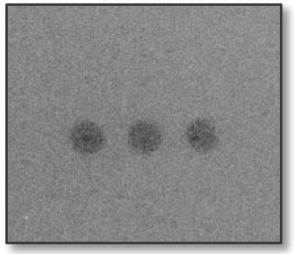
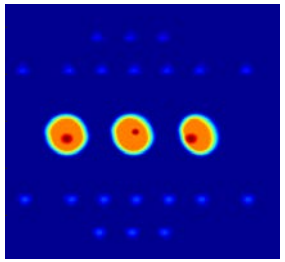
Three views give tomographic imaging Significant changes to present NIS to meet constraints

Neutrons and X-Rays Give Different Information
Non-Azimuthal Symmetry Requires Single Line of Sight

X-ray pinholes were placed on the existing neutron pinhole array

First Data in August on N150820

Simulation

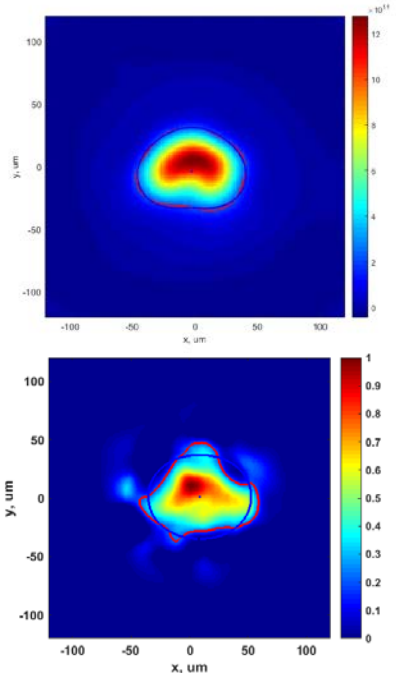
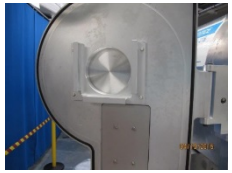
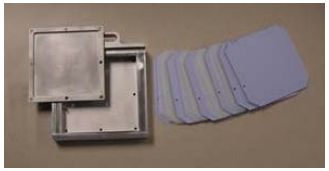


Image plate based detector at back of DIM

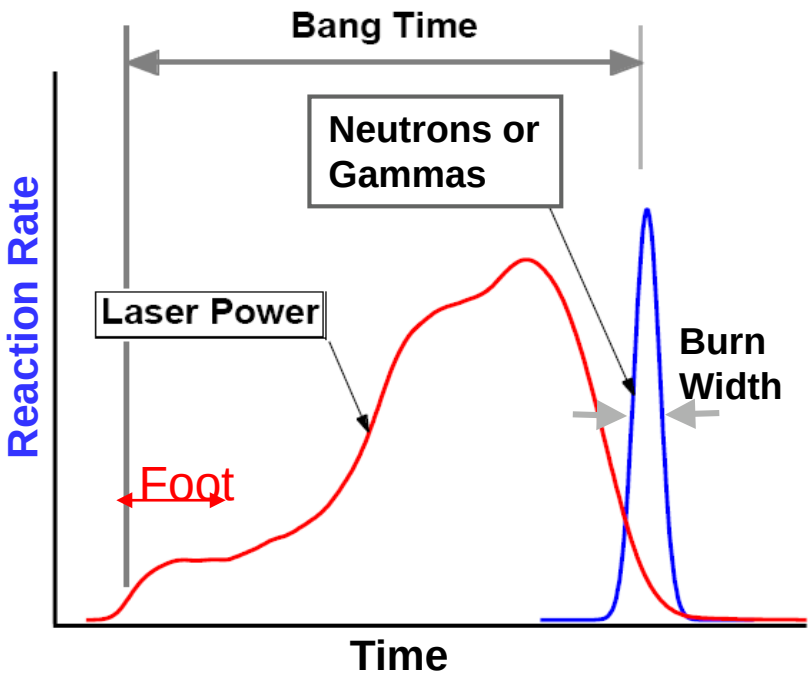



Gamma-rays provide the most un-perturbed nuclear signature of ICF performance

$$D + T \rightarrow {}^{5}He^{*} \begin{cases} \xrightarrow{\sim 1} n\,(14.1\ MeV) + \alpha\,(3.5\ MeV) \\ \xrightarrow{\sim 4e{-}5} {}^{5}He + \gamma\,(16.75 MeV) \rightarrow n + \alpha \end{cases}$$

Doppler Broadened (T_i)

no escape (hopefully)

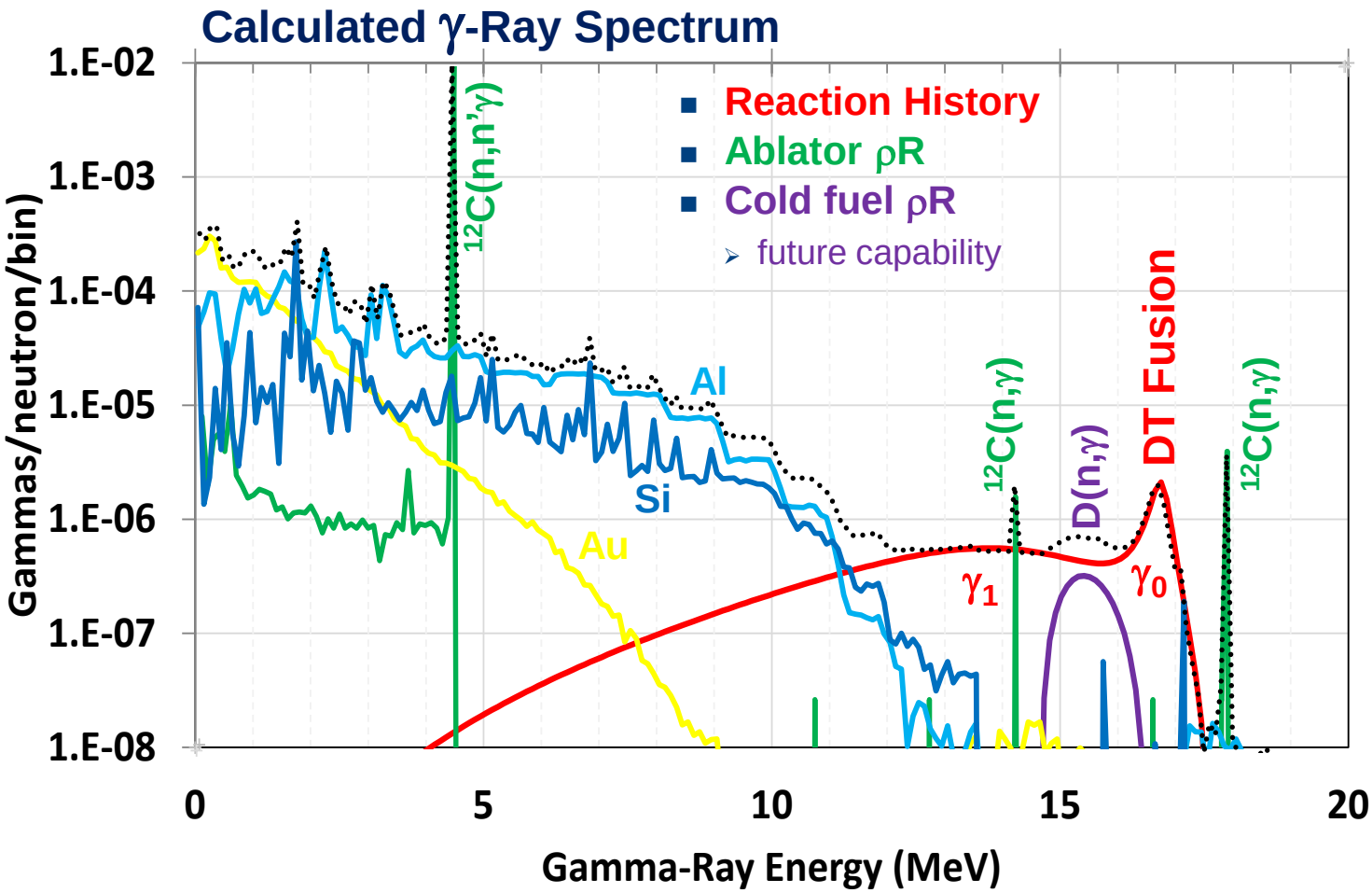


- **Bang Time** - used to establish laser energy coupling to target (shell velocity)

$$ITF = I_0 S^3 \left(\frac{v}{v_0}\right)^8 \left(\frac{\alpha}{\alpha_0}\right)^{-4} \left(1 - 1.2\frac{\Delta R_{hotspot}^{K-wtd}}{R_{hotspot}}\right)^{4+\varepsilon} \left(\frac{M_{clean}}{M_{DT}}\right)^{0.5}$$

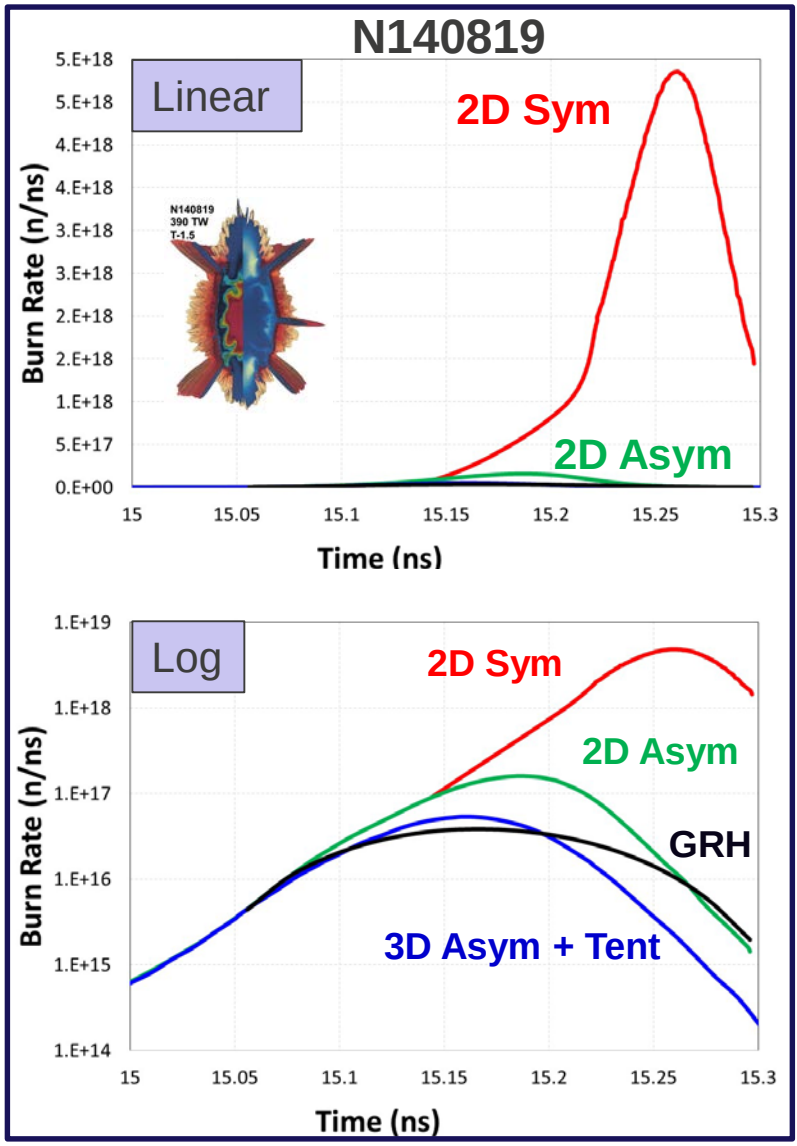
- **Burn Width & other RH features** - used for failure mode correlation

The Prompt γ-Ray Energy Spectrum from Indirect-Drive, Cryo-Layered Implosions is full of information!



Comparison with Simulated NIF Reaction Histories Reveals "Truncated" & "Prolonged" Burn

Source	Y_{DTn}	BW (ps)	Comments
2D Sym.	3.7e17	60	~1D, ignites
2D Asym.	1.5e16	100	P2 tuned
3D Asym. + Tent Pertur.	5.5e15	110	~BT tuned
Data (GRH)	5.5e15	147	RT-driven B?



Conclusions

- **LANL has a small dynamic program**
- **Using innovative platforms to resolve ignition science questions**
- **Fundamental HED experiments clarify the way hydrodynamics work at extreme conditions**
- **Addressing the existnece and role of kinetic plasma effects**
- **New diagnostics will improve our understanding of hot-spot formation**