Systematic Fuel Cavity Asymmetries in Directly Driven ICF Implosions

Rahul Shah

Los Alamos National Laboratory

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F. J. Wysocki, B. M. Haines, P. Hakel, G. Kagan, T. J. Murphy
Los Alamos National Laboratory

J. F. Benage
Sandia National Laboratories

R. C. Mancini
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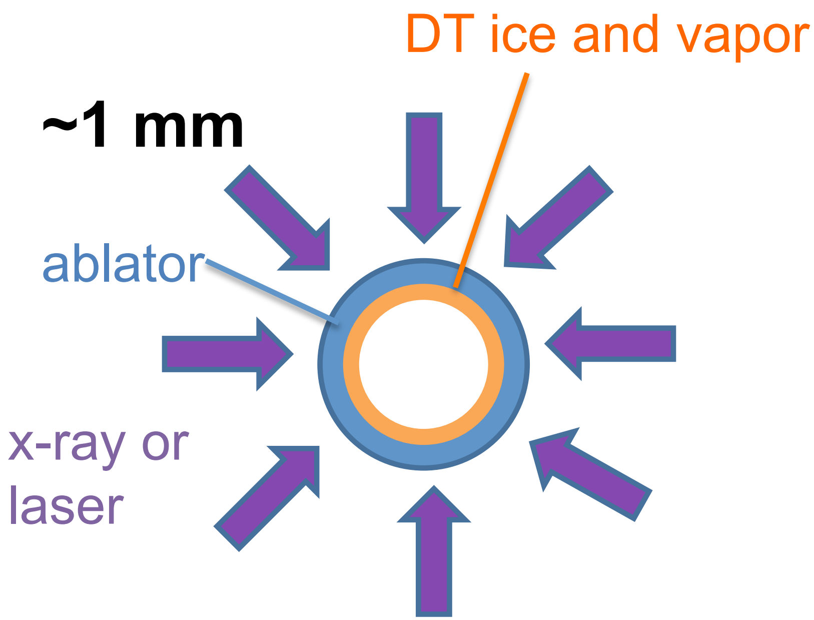
An ICF capsule is a pressure amplifier – what's going wrong?



- High pressure (>> driving pressure) requires energy concentration
- We're **not** getting the necessary pressures
- We're making trade-offs for mix, but **is the symmetry sufficient**?

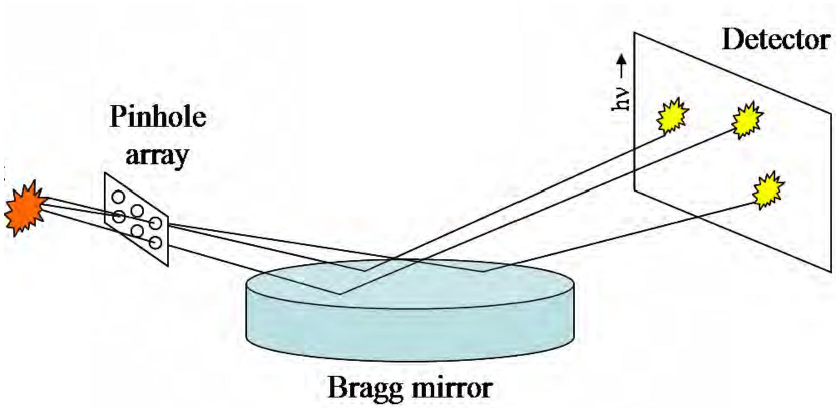
A tracer highlights shape and gives us reason to suggest it's mattering[1]

- Ti tracer layer provides specificity to the imaging
- We identify systematic asymmetries as caused by capsule mounting and low-mode in the laser drive
- **<u>We infer that laser-drive asymmetry imposes an important limit on the achieved hot-spot pressure.</u>**

[1] R.C. Shah *et al. Phys. Rev. Lett.* **118**, 135001 (2017)

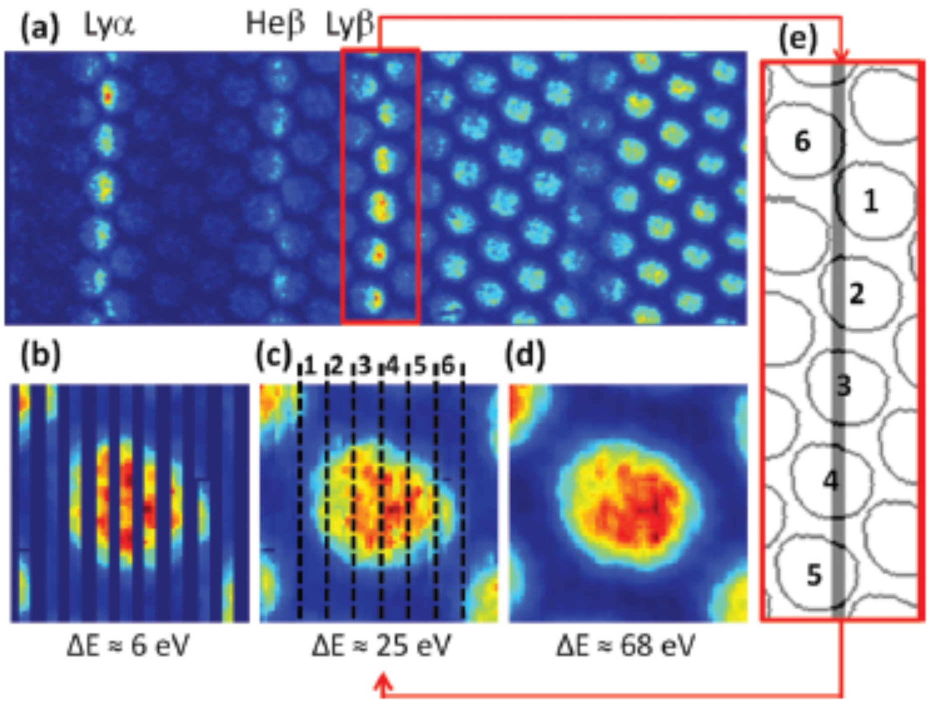
Dopants provide probes (for various purposes) – the MMI let's us image this data

Concept of MMI



L. Welser, PhD Thesis. Univ. Nevada Reno (2006), RSI (2003)

Narrow-band image



T. Nagayama, PhD Thesis. Univ. Nevada Reno (2011), JAP (2011), RSI (2015)

MMI has been enabling exploration of what really happens inside an ICF capsule

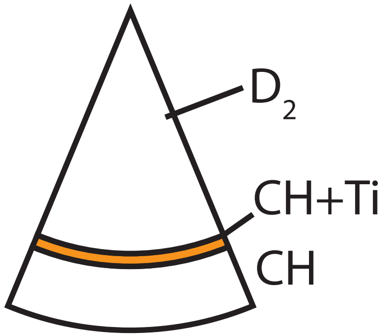
Tracer in gas

- **Inferences of mixing**
  - Leslie Welser-Sherrill *et. al.*, PRE (2007), POP (2008), HEDP (2009)
- **3-D reconstruction**
  - Taisuke Nagayama et al POP (2012), POP (2014)
- **Investigation of ion-thermo-diffusion**
  - Scott Hsu *et. al.* EPL (2016), Tirtha Joshi et al POP (2017)

Tracer in shell

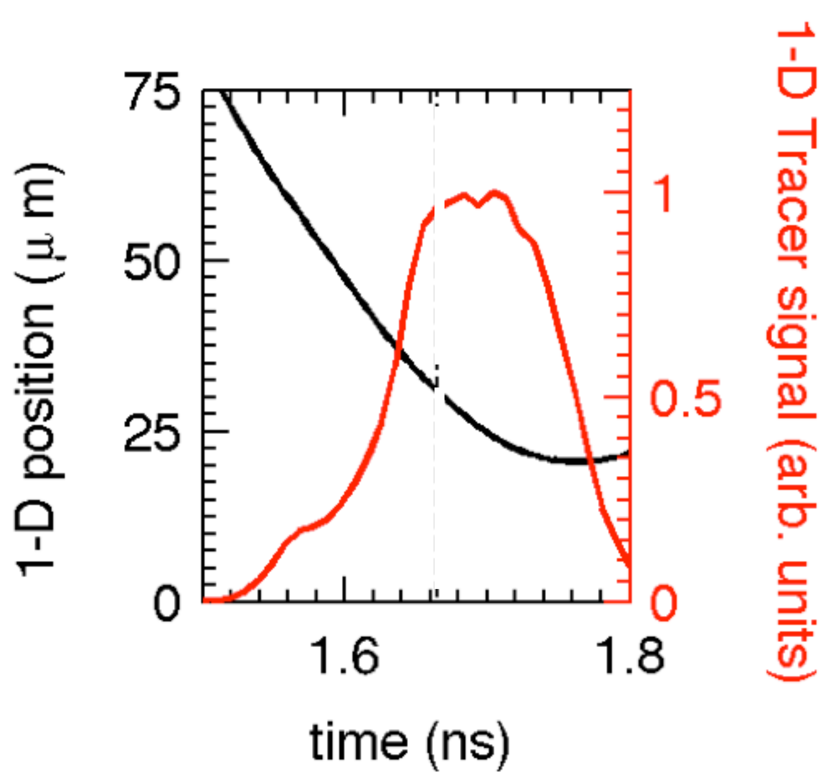
- **Early mixing**
  - J. Baumgaertel *et. al.*, POP (2014).
- **PDD asymmetries**
  - R. C. Mancini *et. al.* POP (2014).
- **Shell areal density asymmetries**
  - H. Johns *et. al.* POP (2016).

To probe the piston, we put the tracer in the high-density periphery (plastic)



Nominal 60 beam
10 / 15 atm DD
20 μ shell
0.1 μ 1% Ti

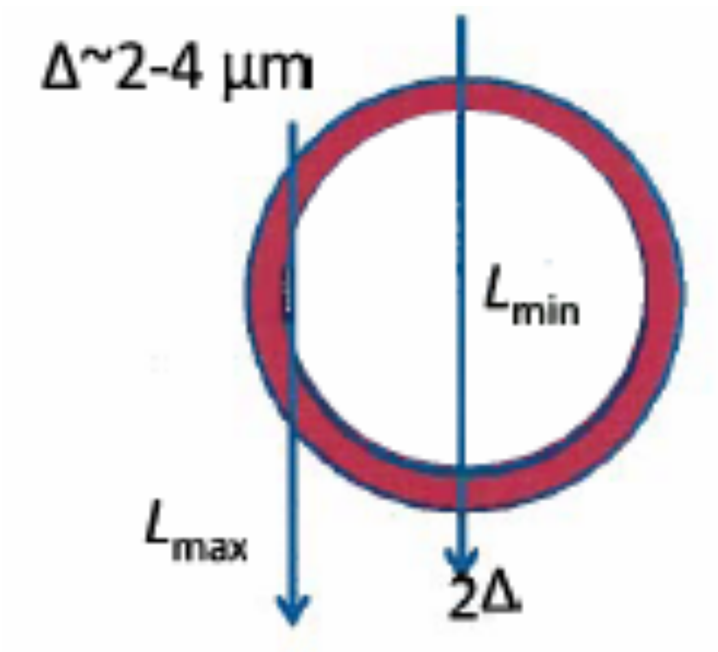
Emission is during deceleration



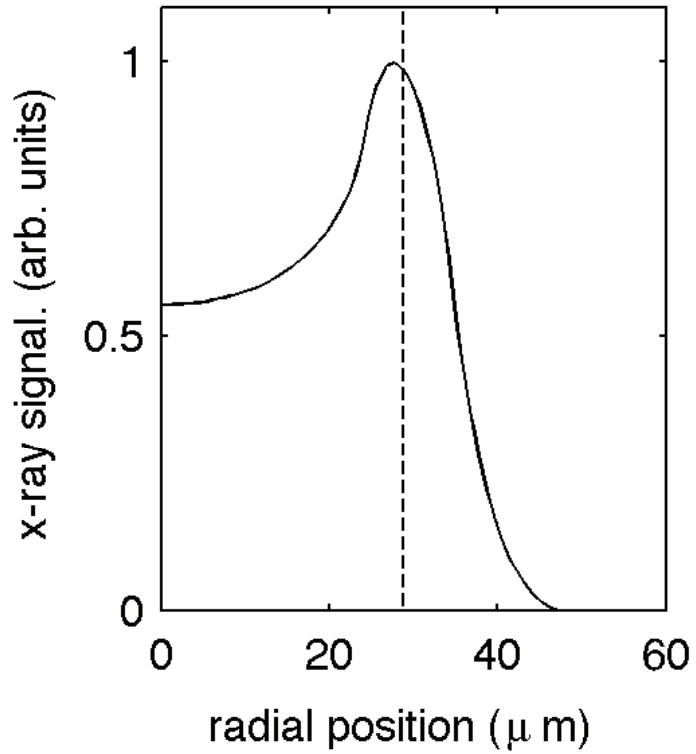
Y_n ~30-40% 1D
$\langle T_i \rangle_n$ ~130-175% 1D

We create a tagged, emitting hollow shell that produces an emission limb

Emission geometry



$I(r)$: Emission limb in 1-D



Pressure is the key to reducing input energy[1]

$$(\rho R_{hs}) \times T \gtrsim 0.3\ \text{g/cm}^2 \times 5\ \text{keV} \quad (1)$$

$$E_{k,min} \sim p_{max}^{-2}. \quad (2)$$

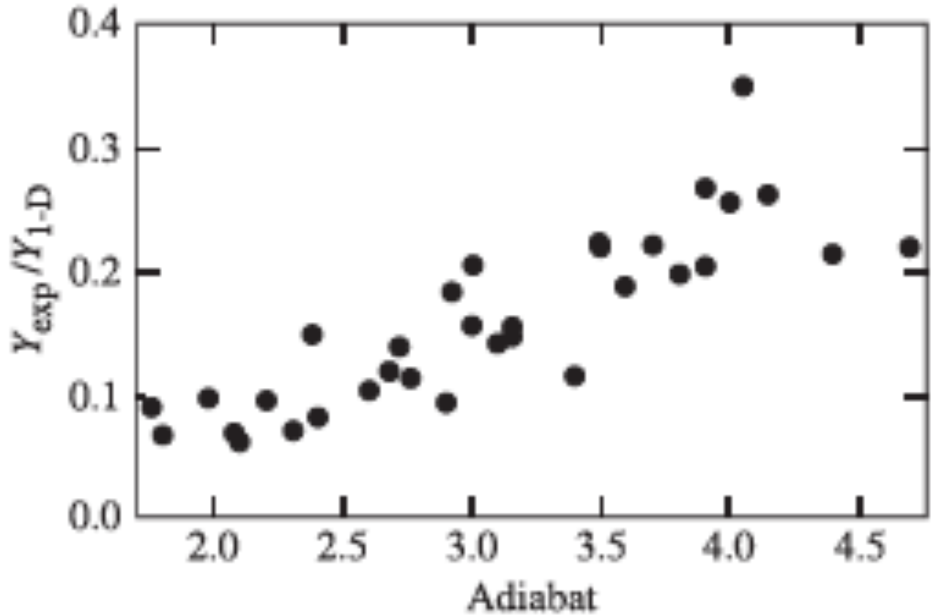
- However ablation pressure is **~100 Mbar** and we need **~100 Gbar**
- **Deceleration in spherical geometry is the pressure amplifier**

[1] Here following V. N. Goncharov *et. al.* Phys. Plasmas (2014)

Is shape a limiter of realized performance at OMEGA?

- Historical emphasis on high mode mix
- Low P_{HS} of higher stability implosions hypothesized to result from mode 1 (S. P. Regan *et al.*, 2016 PRL)

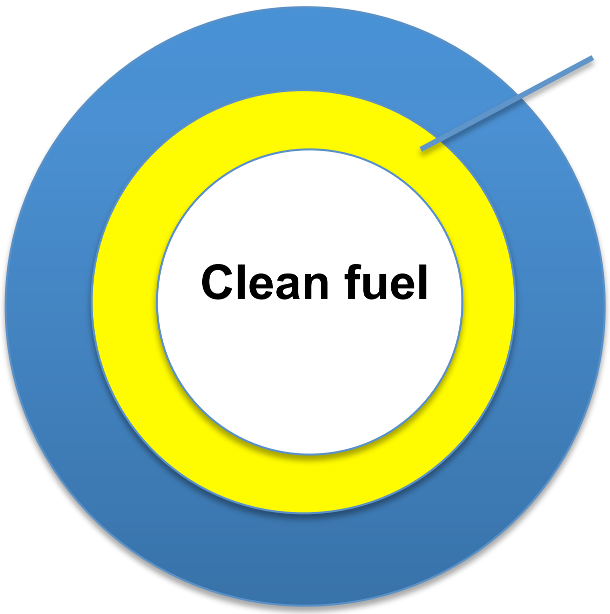
Performance vs. Stability



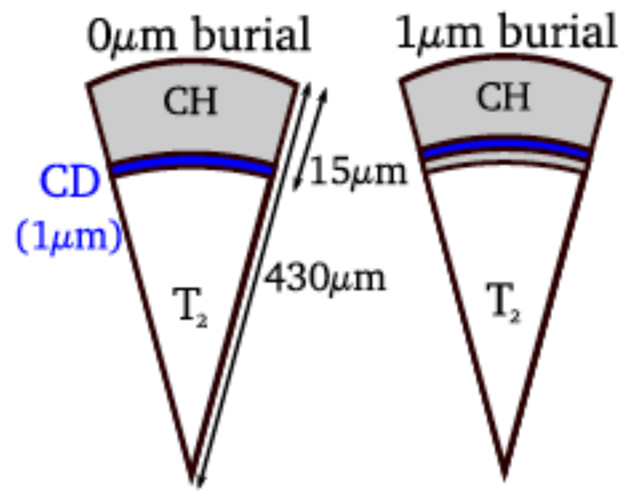
V. N. Goncharov *et. al.* Phys. Plasmas (2014).

High-mode mix is only part of the story

A model of high-mode mix



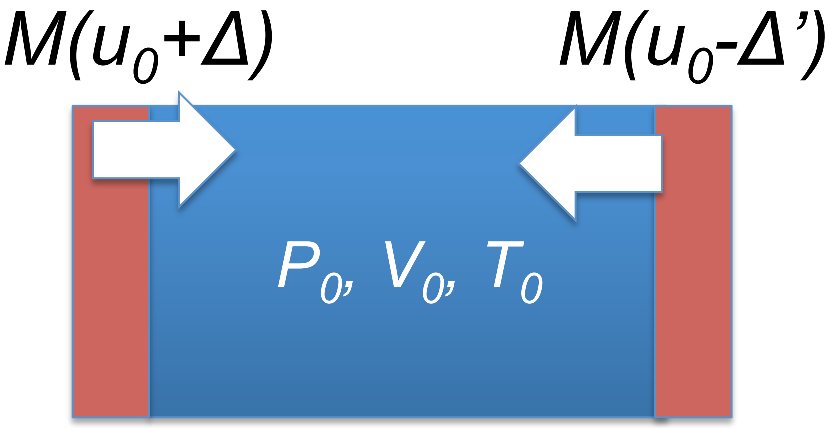
Mix-caps provide a test[1]



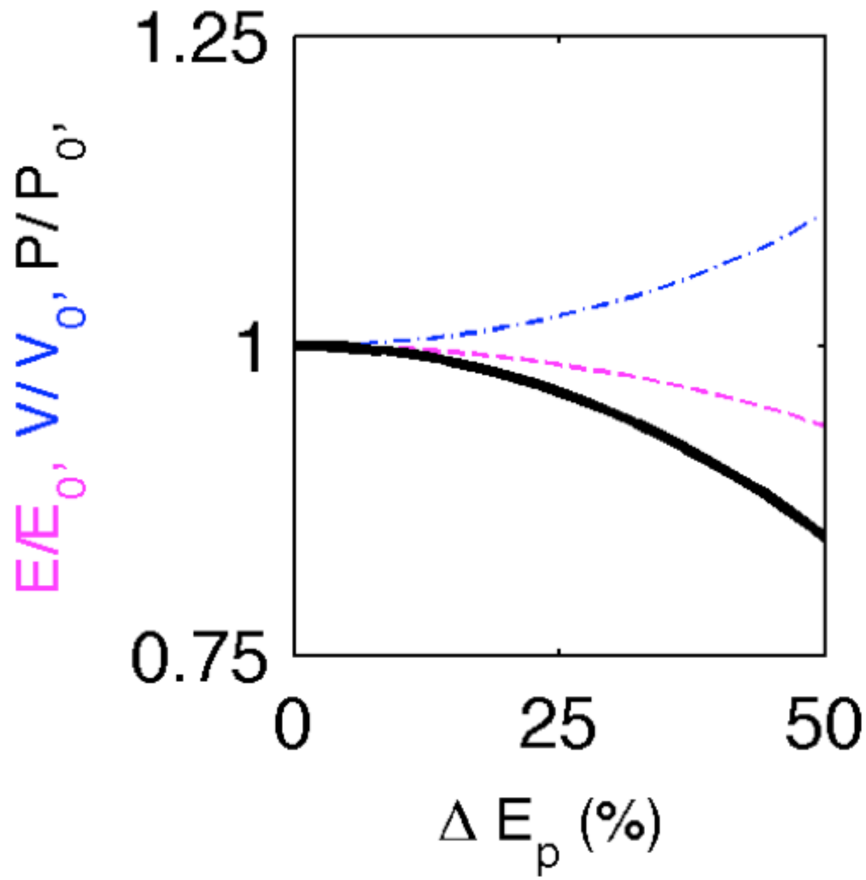
- Mix cap signal explained without perturbing overall performance

[1]B. M. Haines *et. al.* Phys. Plasmas (2016).

For piston model, center-of-mass motion only weakly degrades pressure



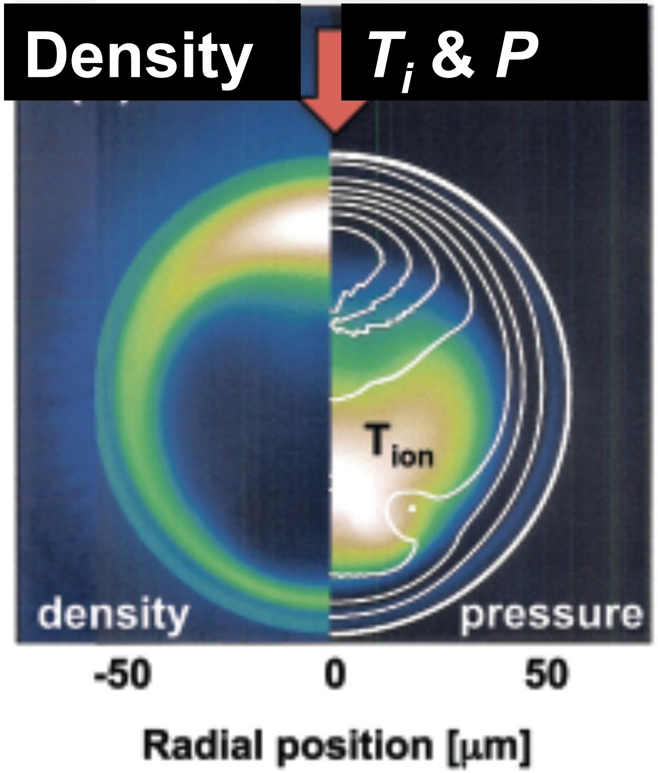
Pressure tolerates large ΔE_p



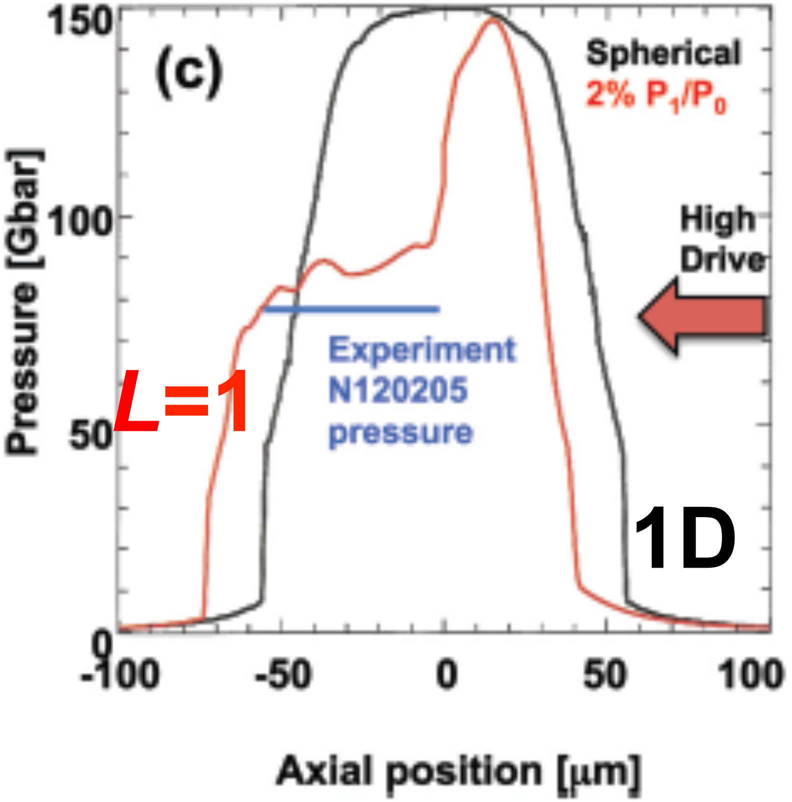
L~1 drive asymmetry *decenters* pressure

B. K. Spears *et. al.*, Phys. Plasmas (2014)

2D Hydra with L=1



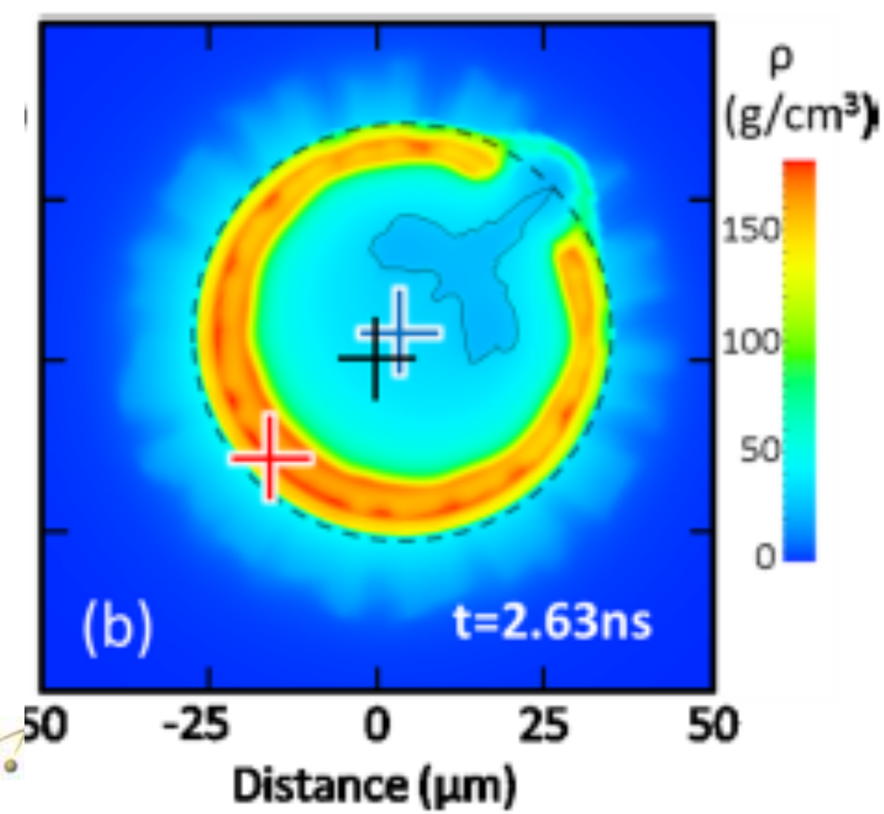
Pressure profile



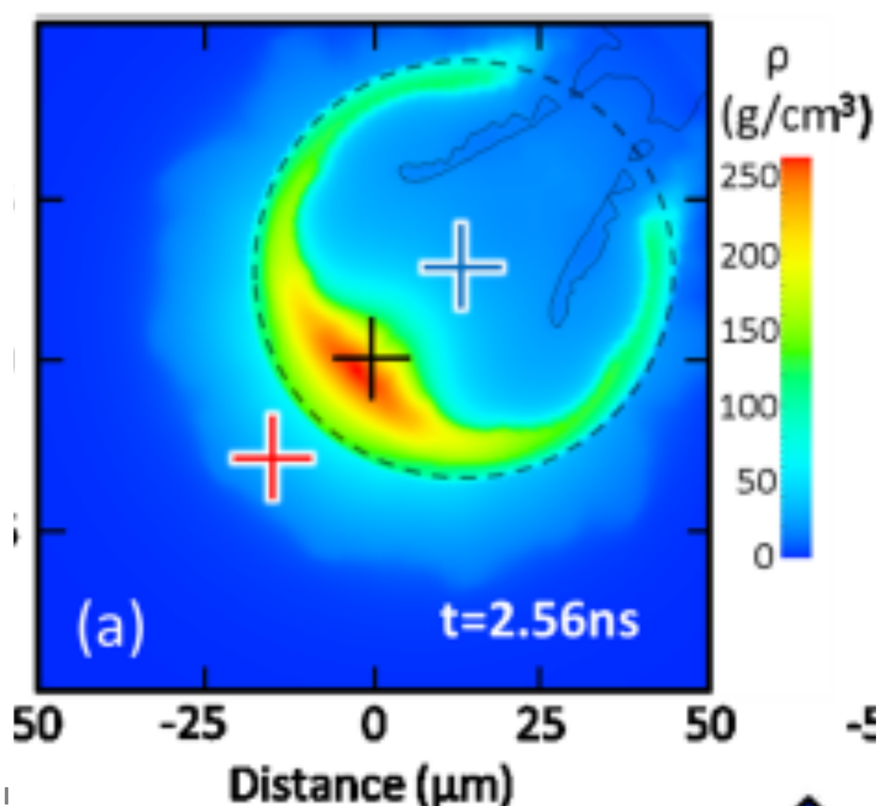
Historically used conduction model has been reducing the calculated impact of asymmetry

I. V. Igumenshchev *et. al.*, Phys. Plasmas (2016)

Flux limited: $Y_{3D/1D}$ = 0.85



Spitzer + CBET: $Y_{3D/1D}$ = 0.25



Motion also inflates inferred ion temperature[1]

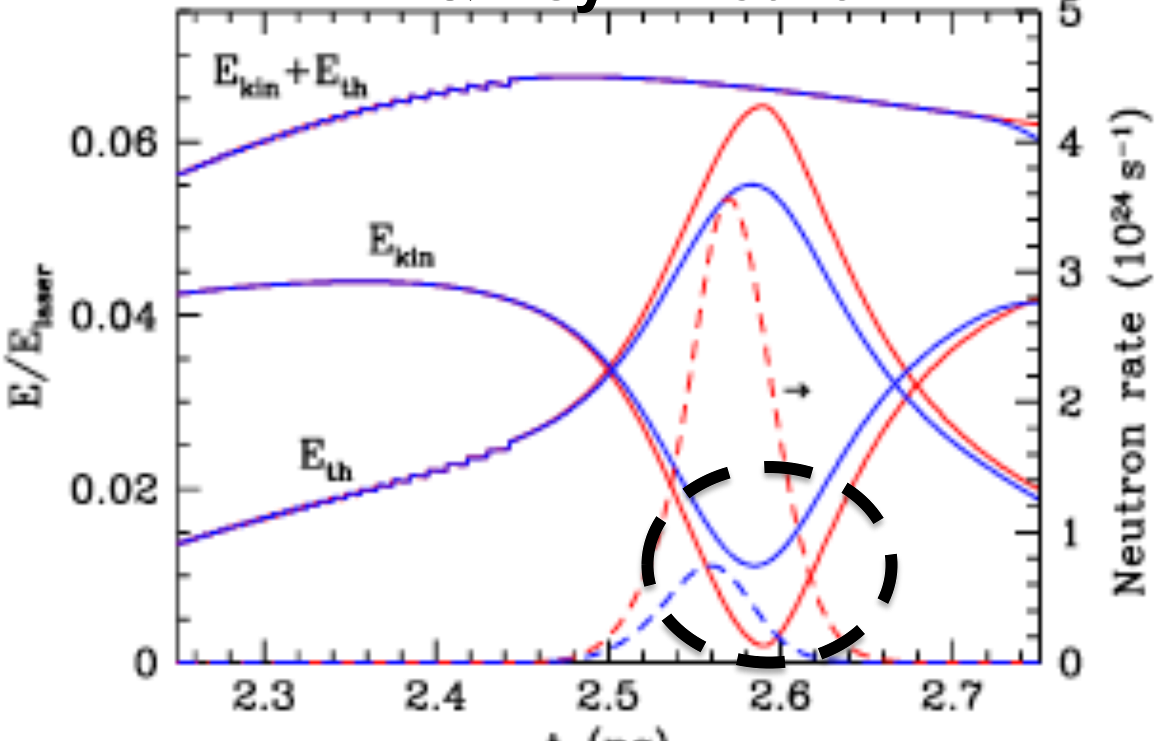
<u>***Apparent***</u> T_i

$\propto \quad E_{th} + 4E_k$

10% inefficiency in KE to U -> 30% inflation

[1]T.J. Murphy, Phys. Plasmas (2014)

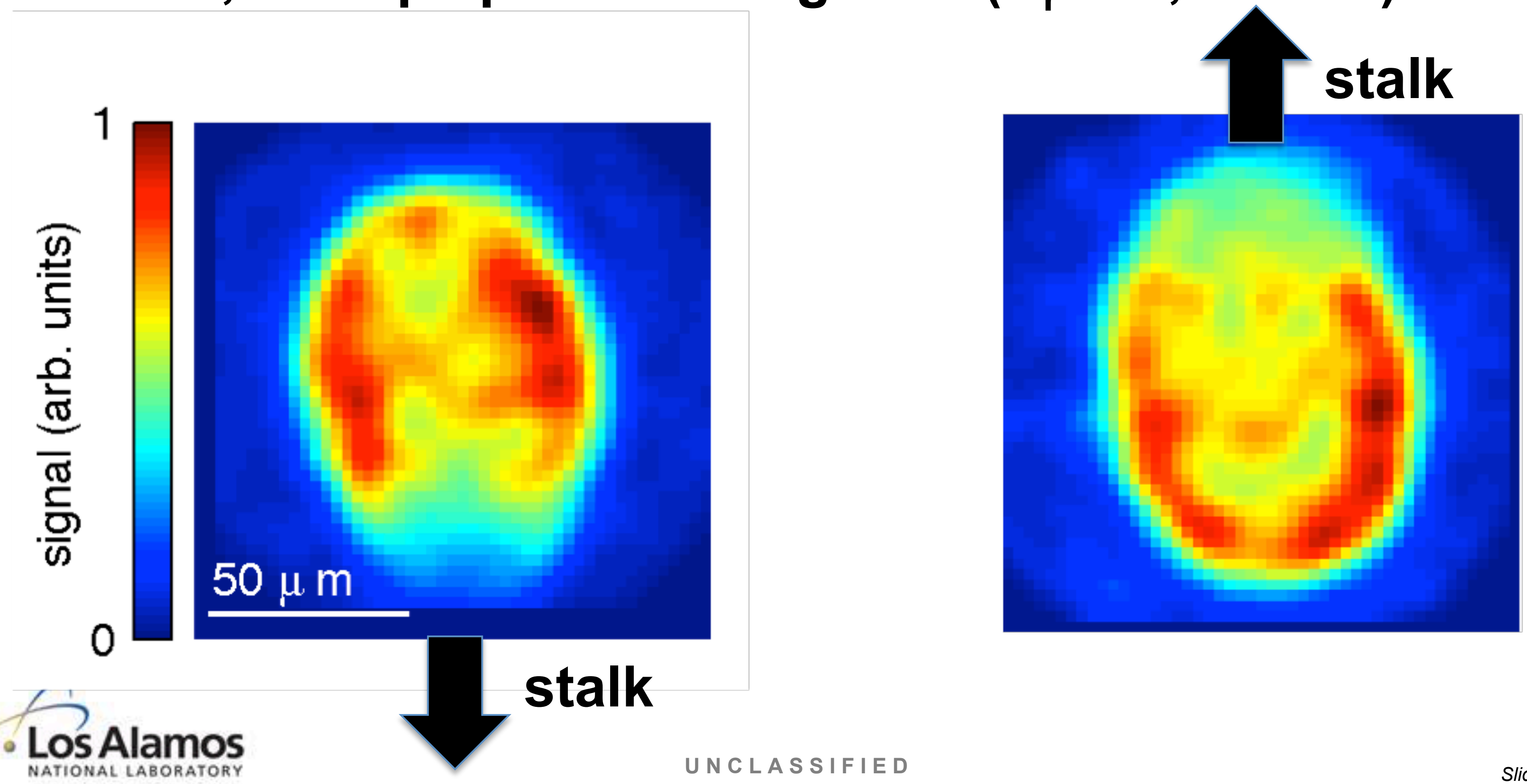
Energy partitioning – 1-D & Asymmetric



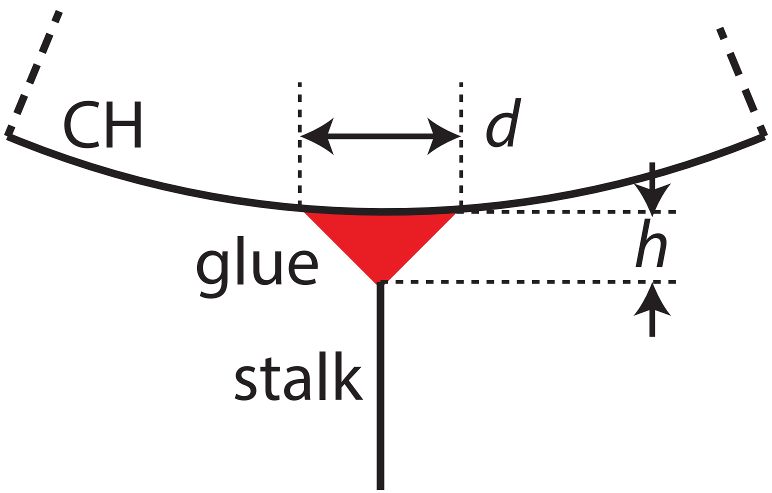
I. V. Igumenshchev *et. al.*, Phys. Plasmas (2016)

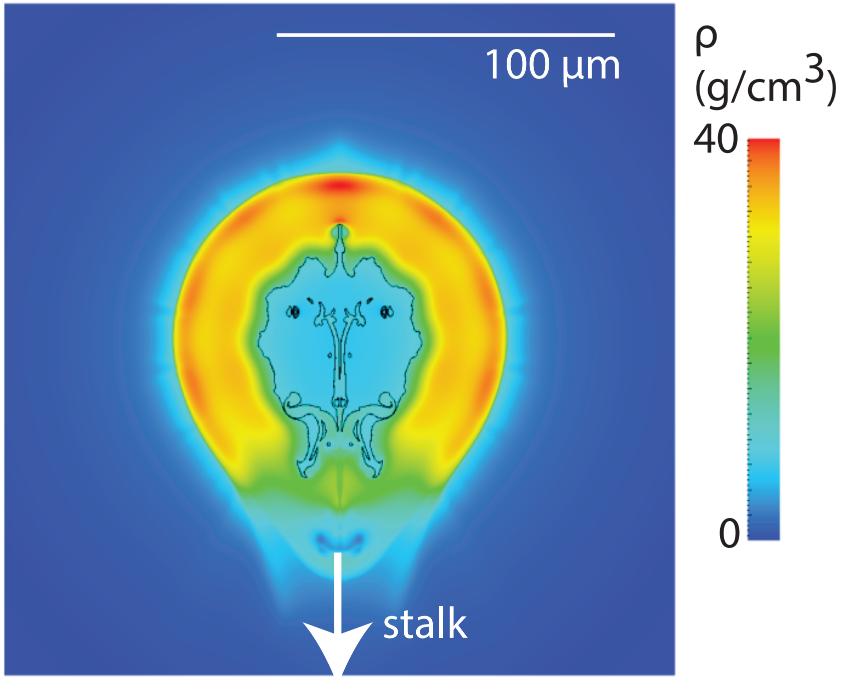
Correlation identifies mounting in images

MMI Images, Fixed viewers - 180° flip of mounting
5-6 keV, ~100 ps prior to bang-time (C_r ~11, 10 atm)



Stalk mounting disturbs symmetry *but* has negligible impact on yield[1]



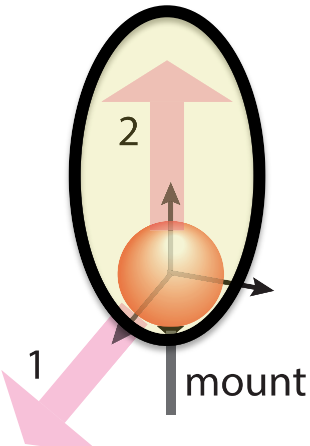


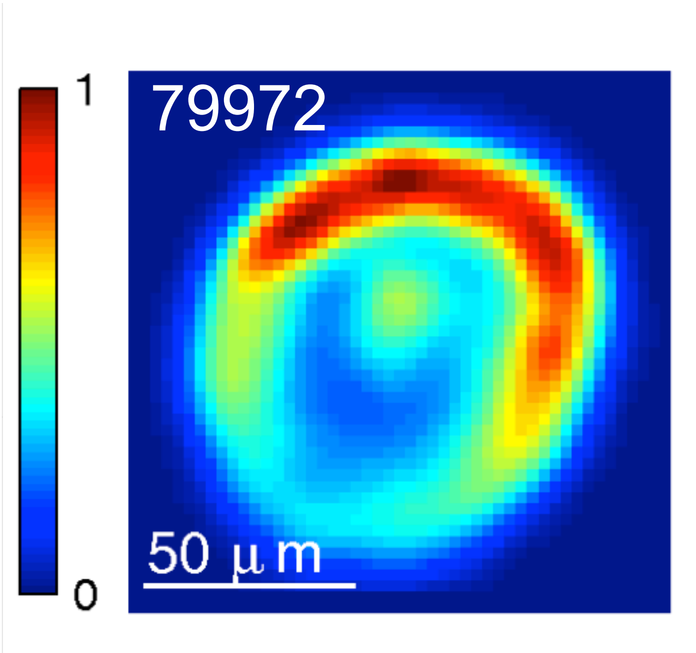
- 10-20% degradation with factor of two changes in calculation
- Experiments insensitive (but always ~70% below 1D)

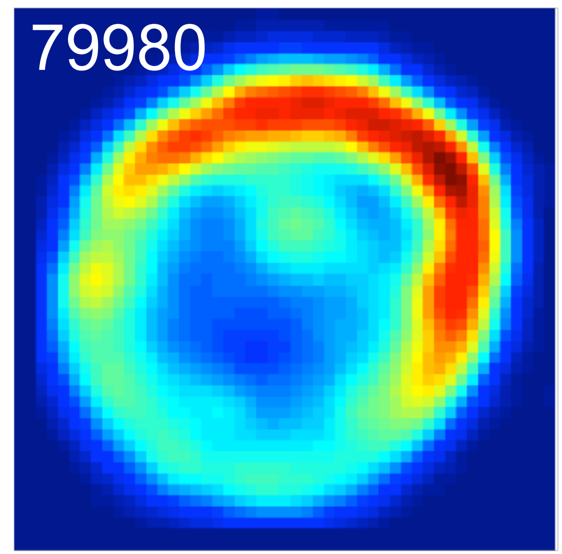
[1] I.V. Igumenshchev *et. al.* Phys. Plasmas (2009).

Looking opposite the mount, mode 1 emission character suggests drive asymmetry

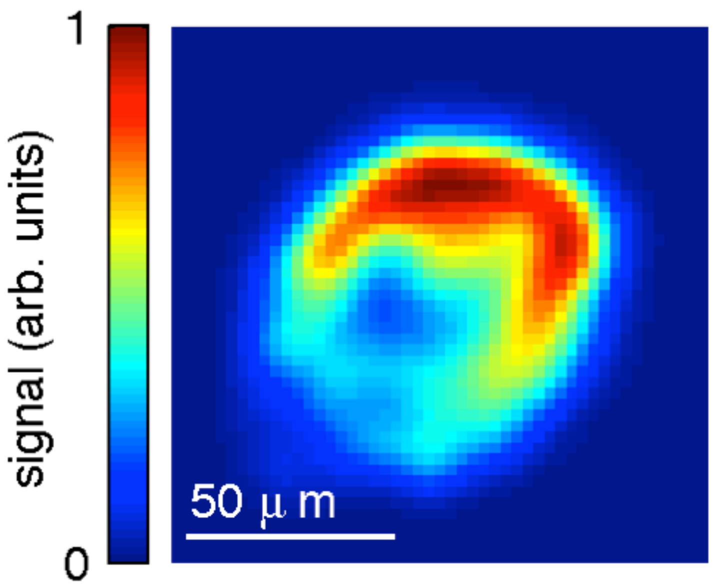
5-6 keV, ~100 ps prior to bang-time (C_r ~9, 15 atm)

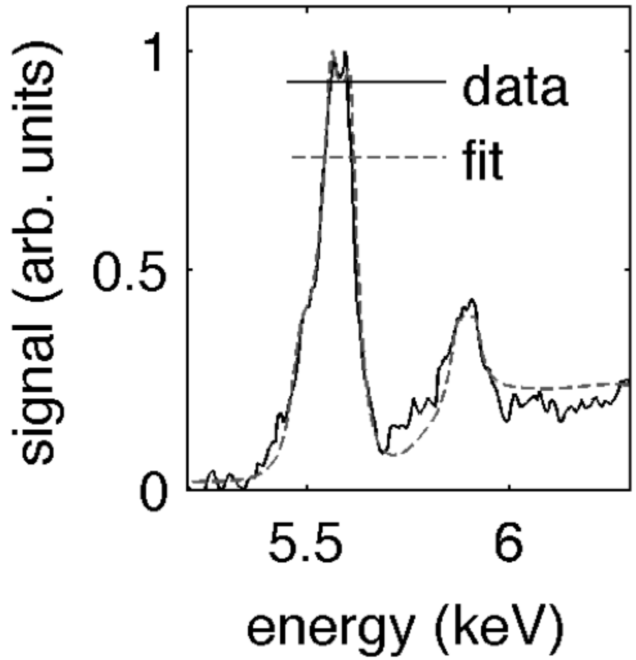






Modulation persists into bang-time, & a spectral fit indicates cause is non-trivial

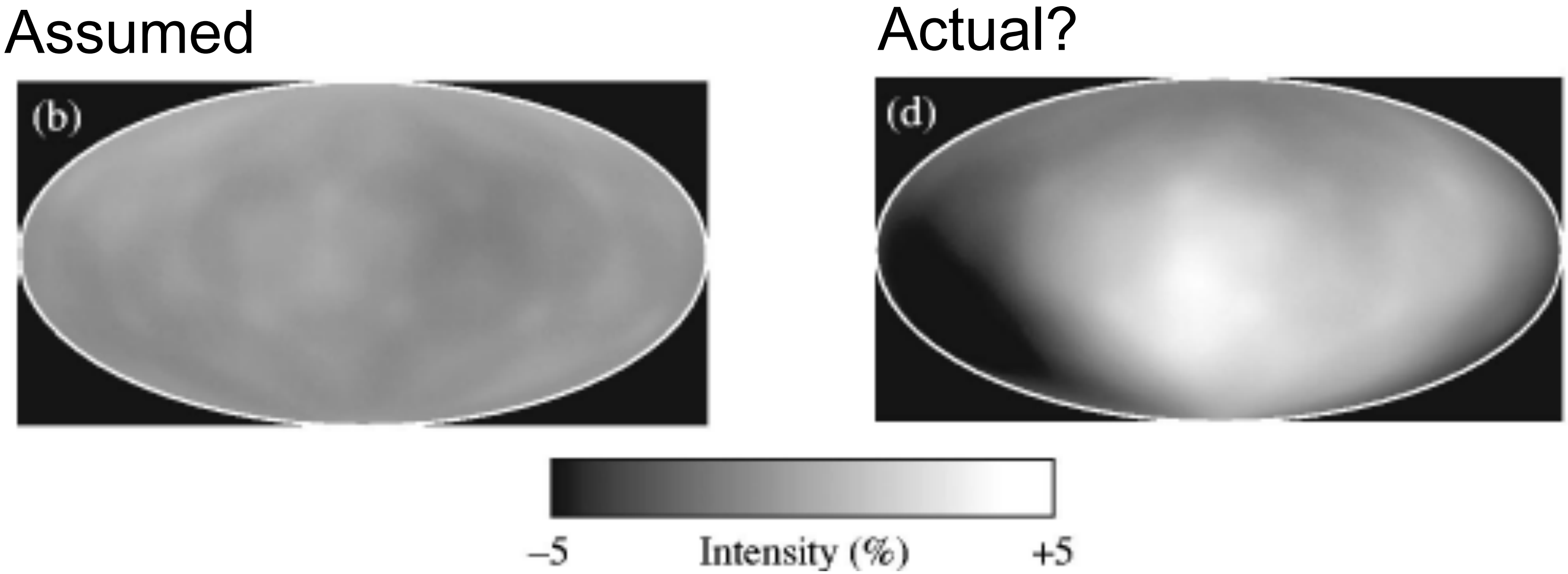




- n_e = 5.5 [-1.5,+2.5] E24 cm^{-3}, T_e = 1350 [-350,+150] eV
- **Assuming isobaric conditions Implies ±20% density/ temperature variation!**

Inferred beam *intensities* suggest low modes are greater than implied by reported beam *energies*[1]

Aitoff projections of laser distribution on target

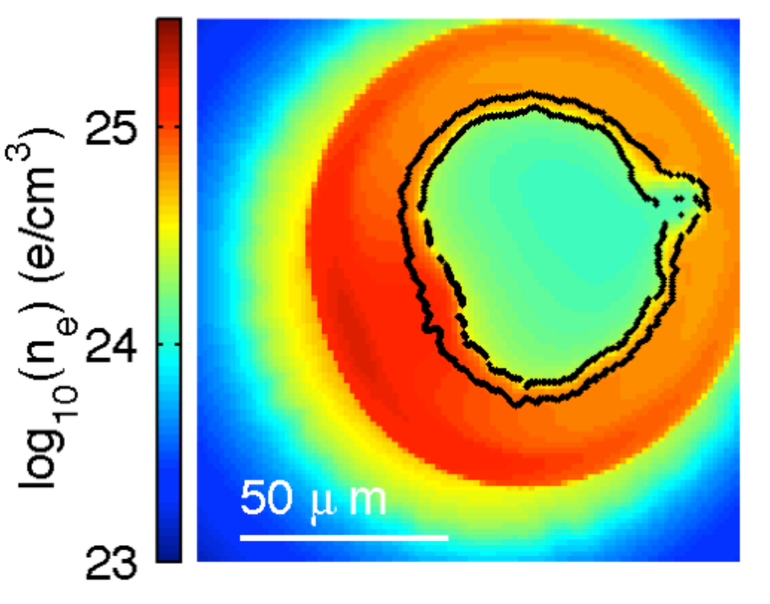


- Recent measurements show the problem persists
- Assumed indicative of magnitude – not orientation

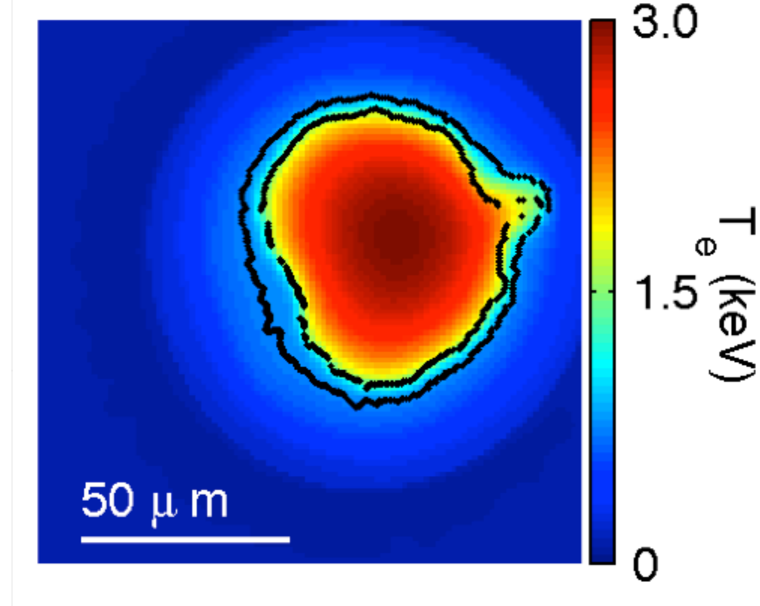
[1] F. J. Marshall *et. al.* Phys. Plasmas (2004).

In 3-D ASTER[1] we find shape (dominantly L~1) limits P_{HS} and decenters Ti conditions

n_e cross-section (bang-time)



T_e cross-section (bang-time)



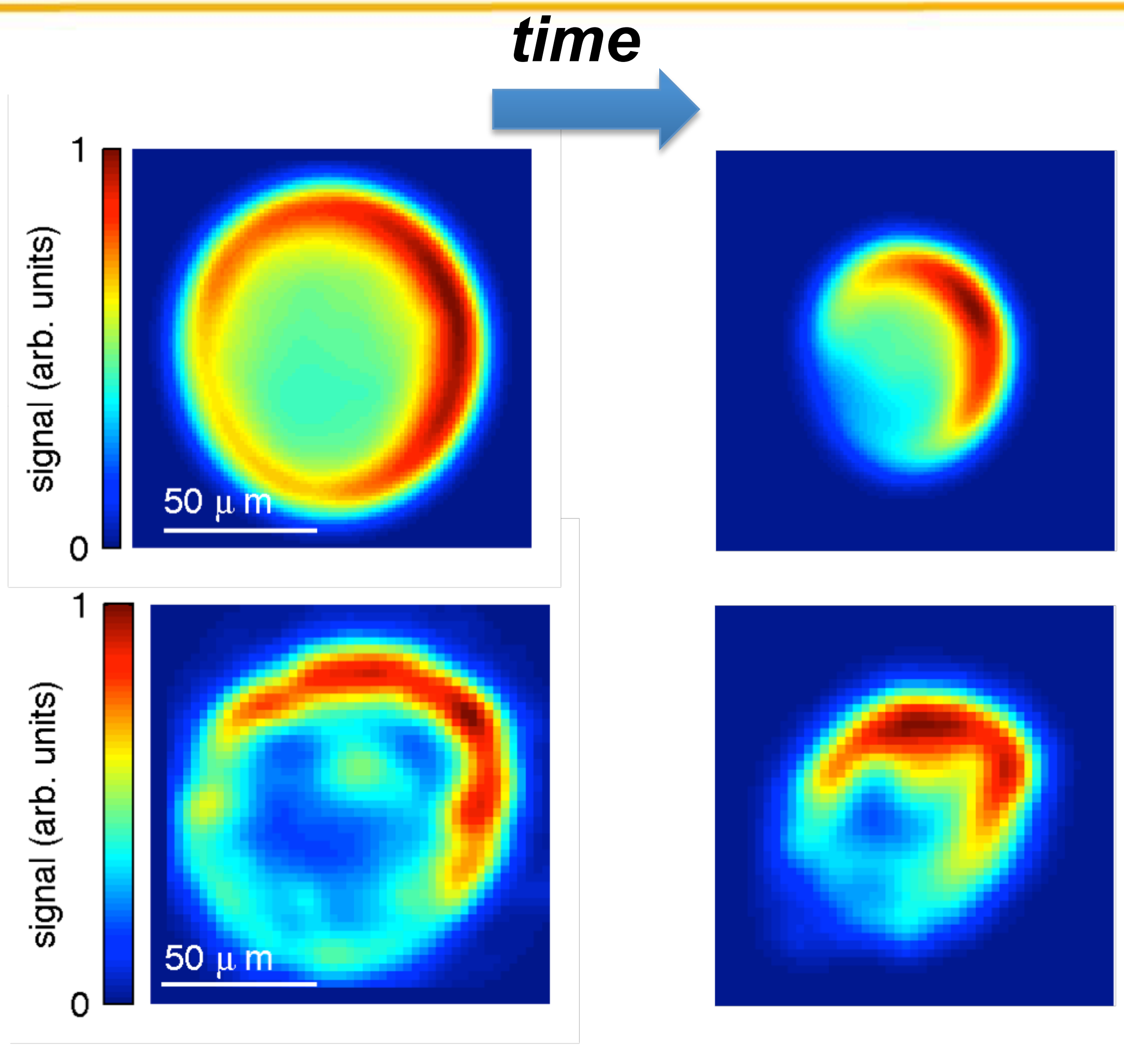
- **±30% variations of density & temperature**
- **Y_{3D} 40% 1-D , P_{hs} 55% 1-D (big-impact relative to observed degradation levels)**

[1] I.V Igumenshchev *et. al.*, Phys. Plasmas (2016).

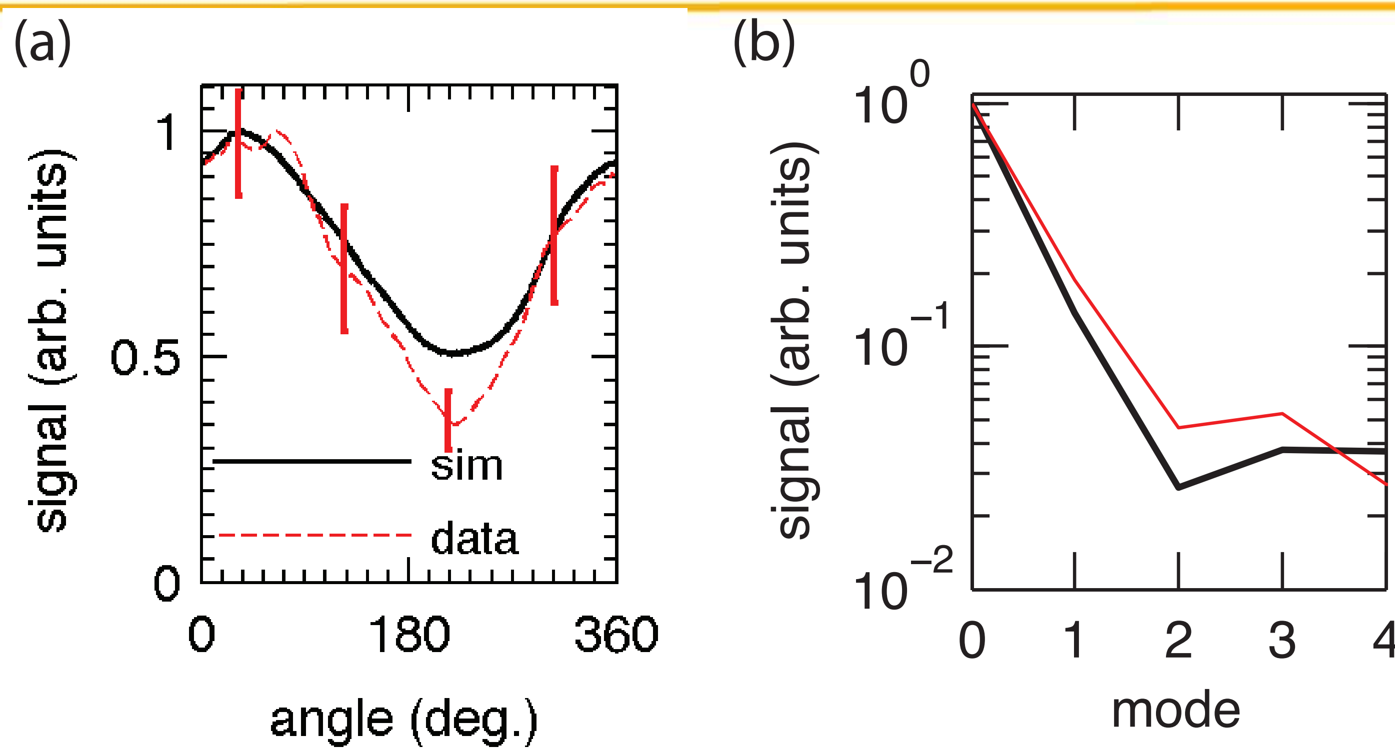
Synthetic images *can* capture the observed trend (but orientation is unconstrained)

ASTER

Data



Comparable modulations suggest comparable underlying physics, dominated by mode 1



- Emission is consistent with low mode in the drive
  - Significant source of performance degradation
  - Suggests a mechanism for elevated T_i

Asymmetry observed using tracer consistent with shape limited performance in Omega implosions[1]

- Ti tracer layer provides specificity to the imaging
- Observed asymmetries are attributed to capsule mounting and L~1 in drive.
- **2-D and 3-D simulations indicate it's the L~1 (not the mounting) that degrades yield by limiting achieved hot-spot pressure.**
- **Look forward to a revolution in symmetry diagnosis – will that enable us to break thru the current plateau?**

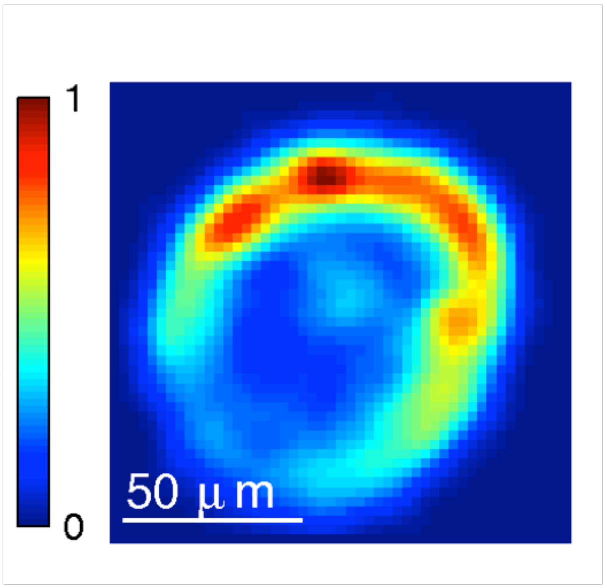
[1] R.C. Shah *et al. Phys. Rev. Lett.* **118**, 135001 (2017)

Additional slides

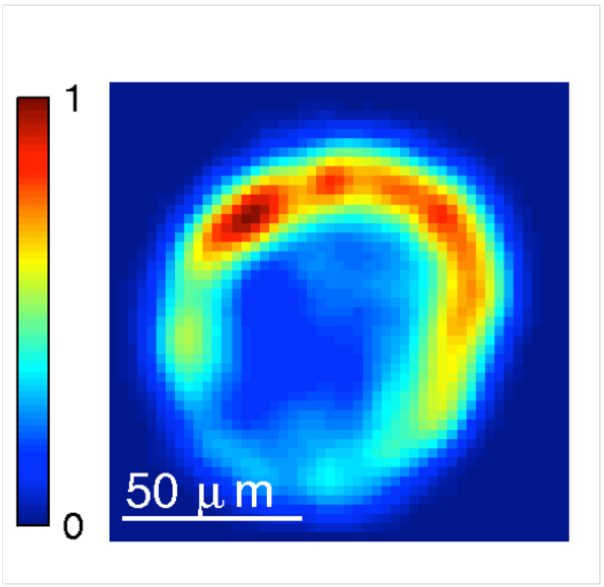
Images at neighboring β lines don't directly elucidate a change in T_e

79972

He



Ly



Spectral dependency runs counter to opacity - Modulations are in self-emission

79976