SAND2019-6967C

Ultrafast Diagnostics in Challenging Environments

PRESENTED BY

Megan Paciaroni

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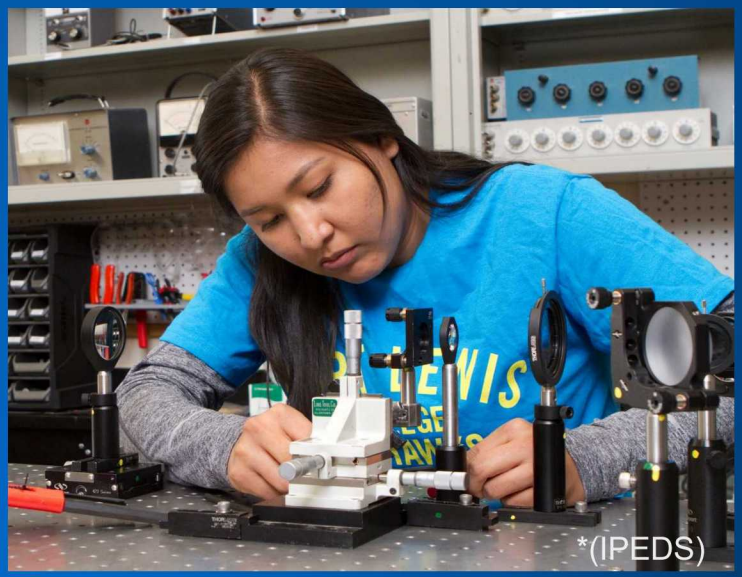
Ultrafast Diagnostics in Challenging Environments

Megan Paciaroni
Associate Professor of Physics & Engineering
Fort Lewis College
Durango, Colorado USA

Sandia National Laboratories

FORT LEWIS COLLEGE

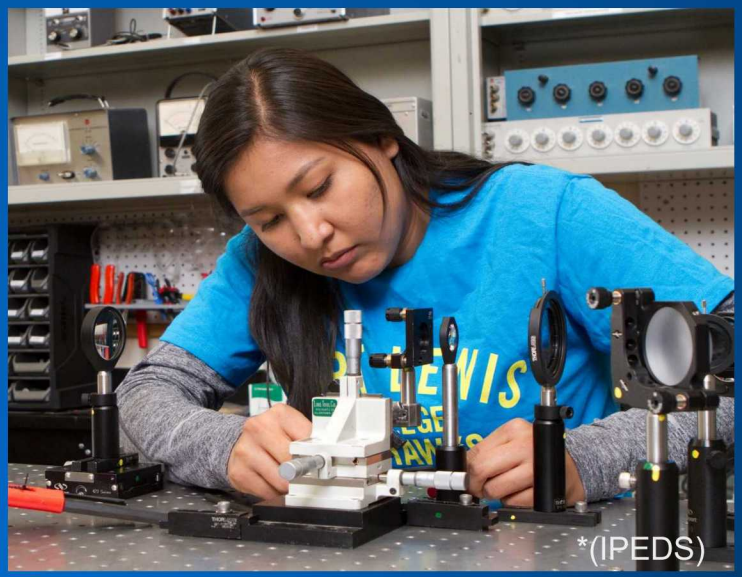
FLC awards more STEM baccalaureate degrees to Native American students than any other baccalaureate institution in the United States*



*(IPEDS)

FORT LEWIS COLLEGE

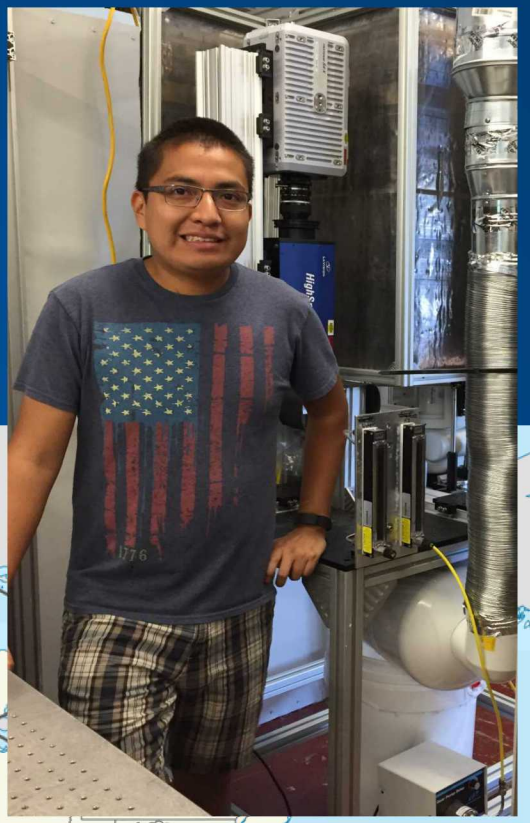
The College ranks 3rd in the nation in percent of Native American students enrolled at a non-tribal college or university and 4th in the nation for the percentage of American Indian students earning bachelors' degrees*

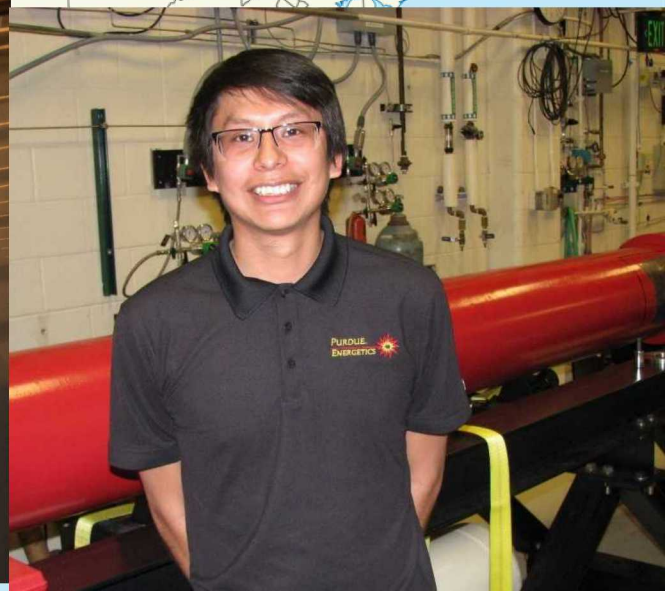


*(IPEDS)

FORT LEWIS COLLEGE

We enjoy close proximity to many national labs, and several recent students have gone onto work at Sandia National Laboratories, New Mexico



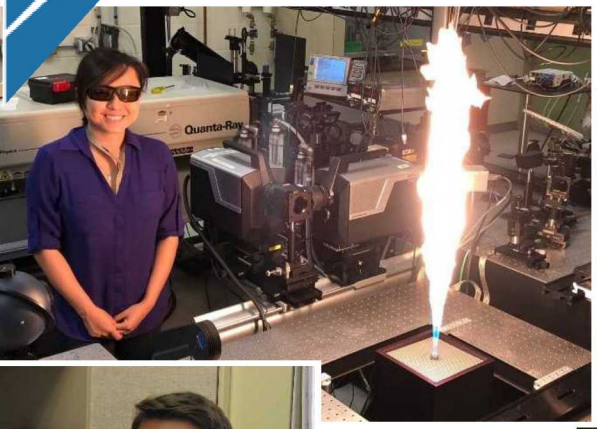


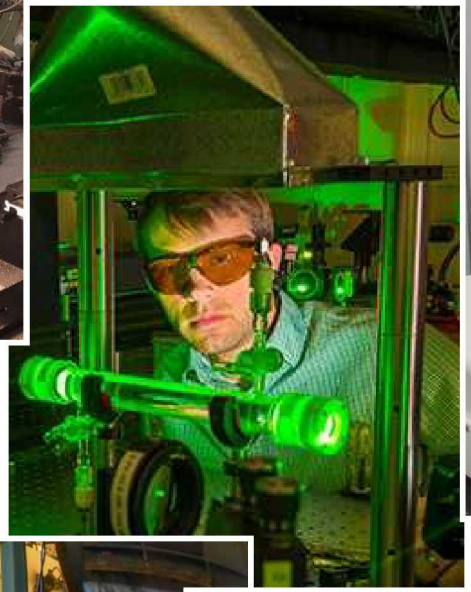
FORT LEWIS COLLEGE

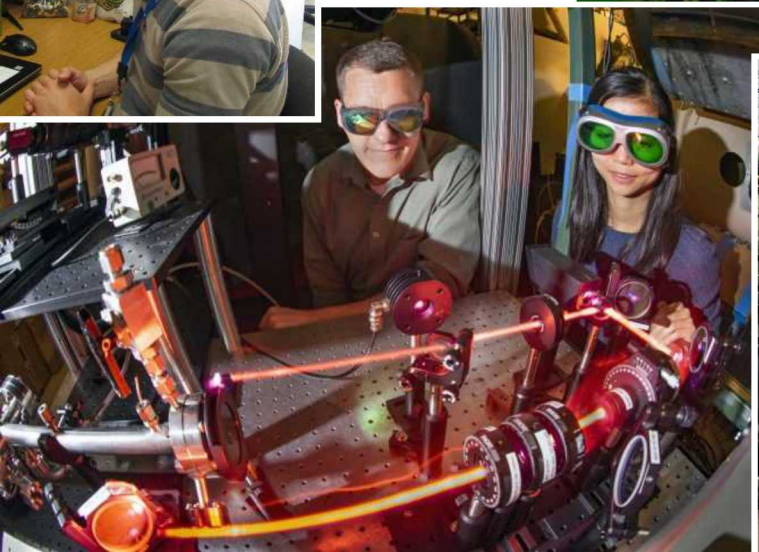
Sandia National Laboratories

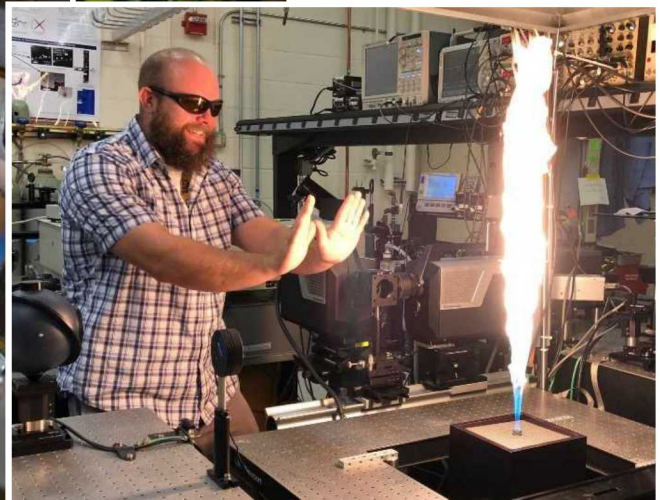
FORT LEWIS COLLEGE

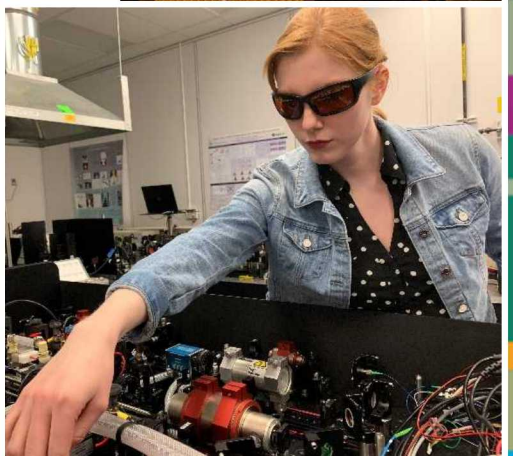
Since 2015, I have spent summers and breaks collaborating with the Diagnostic Science Research and Engineering Group at Sandia, New Mexico



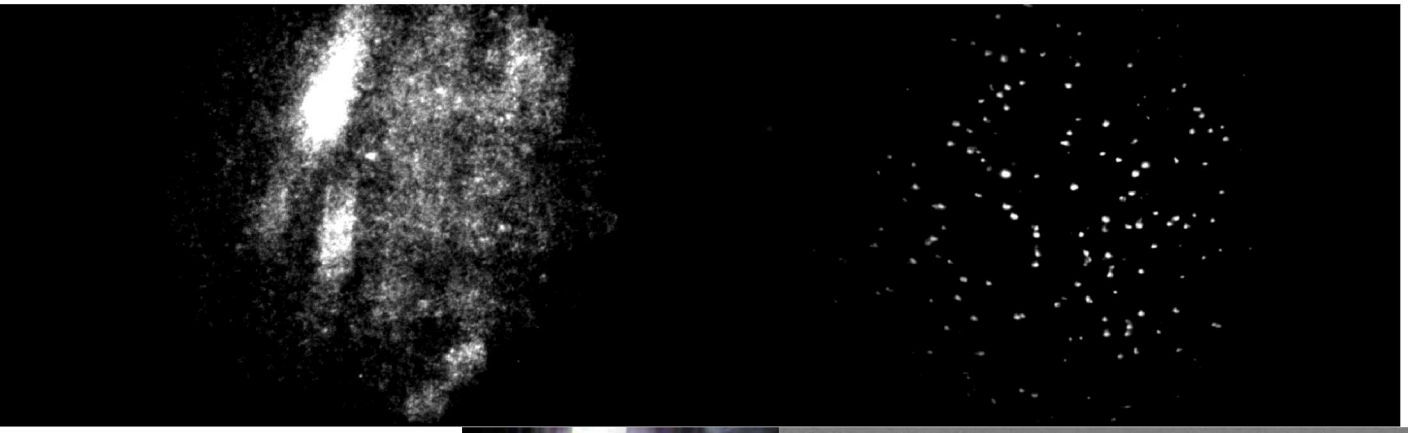






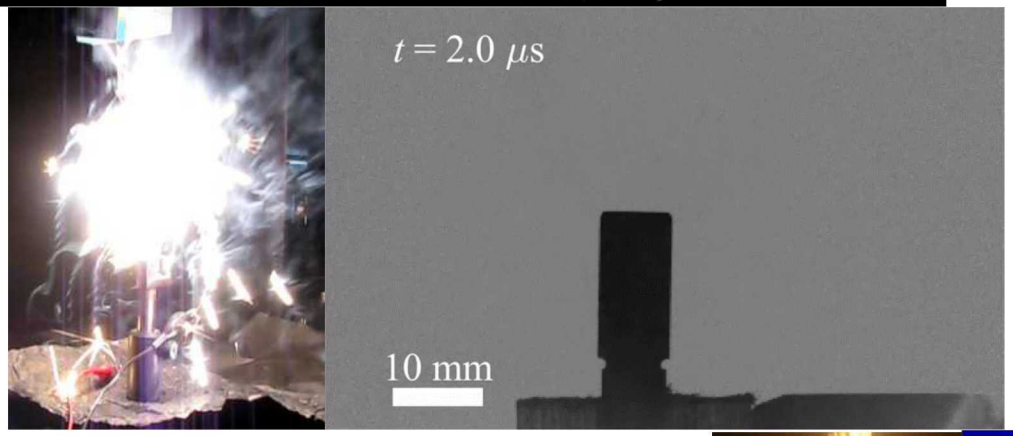


Today's Talk Highlights Developments at Fort Lewis and Sandia, NM in High-Speed and Ultra-Fast Diagnostics

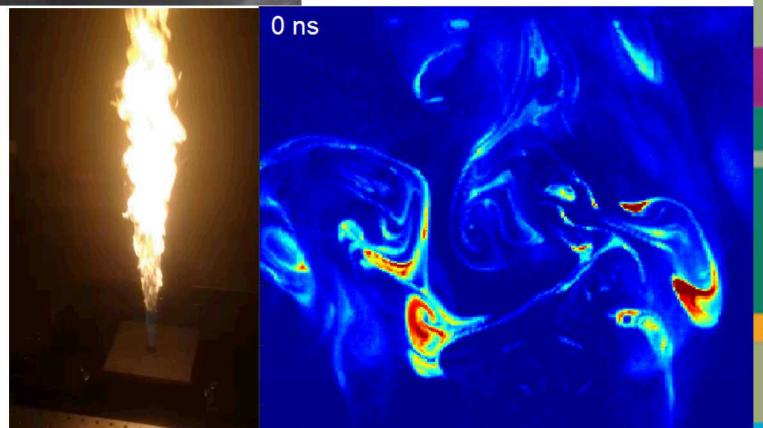


Update on Backscatter Particle Image Velocimetry via Optical Time-of-Flight Sectioning (PIVOTS)

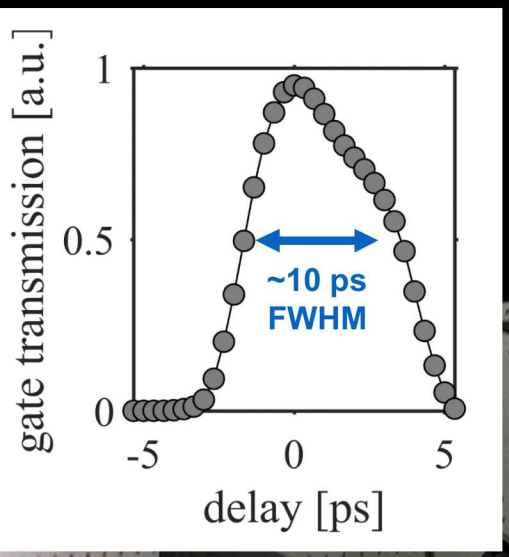
Fire, Supersonic and Explosive Diagnostics At Sandia, New Mexico



Time-Resolved and Tomographic Laser Induced Incandescence



Backscatter Particle Image Velocimetry via Optical Time-of-Flight Sectioning (PIVOTS)



Spectra-Physics Solstice
2.5 mJ, 1 kHz, 800 nm, 80 fs

Delay Stage

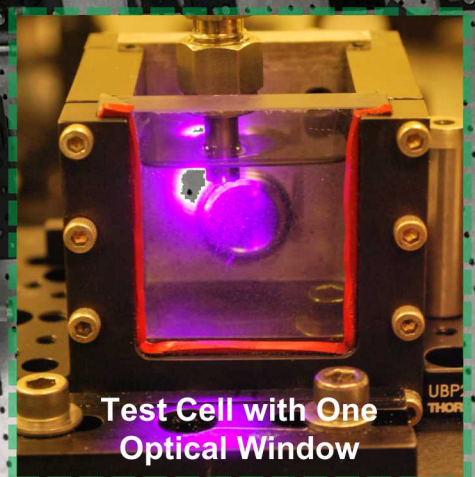
α-BBO

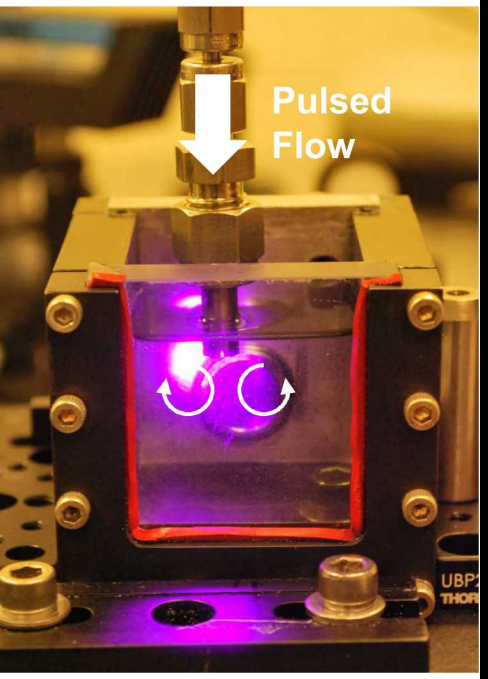
Crossed Polarizers

f = 200 mm

CS_2 Cell
(1 cm OPL)

Intensifier and Imager at 1 kHz





Water Seeded with 40 μm neutrally buoyant particles

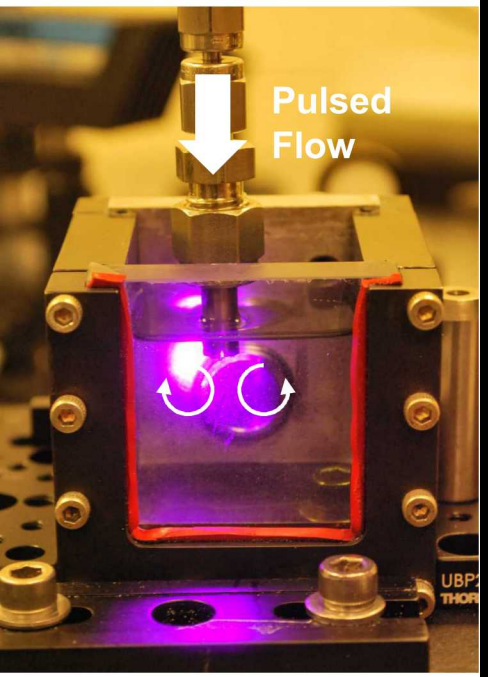
*With Daniel Guildenbecher

$t = 1.0$ ms

Scattering from tube and cell walls

1 mm

Without OKE gate



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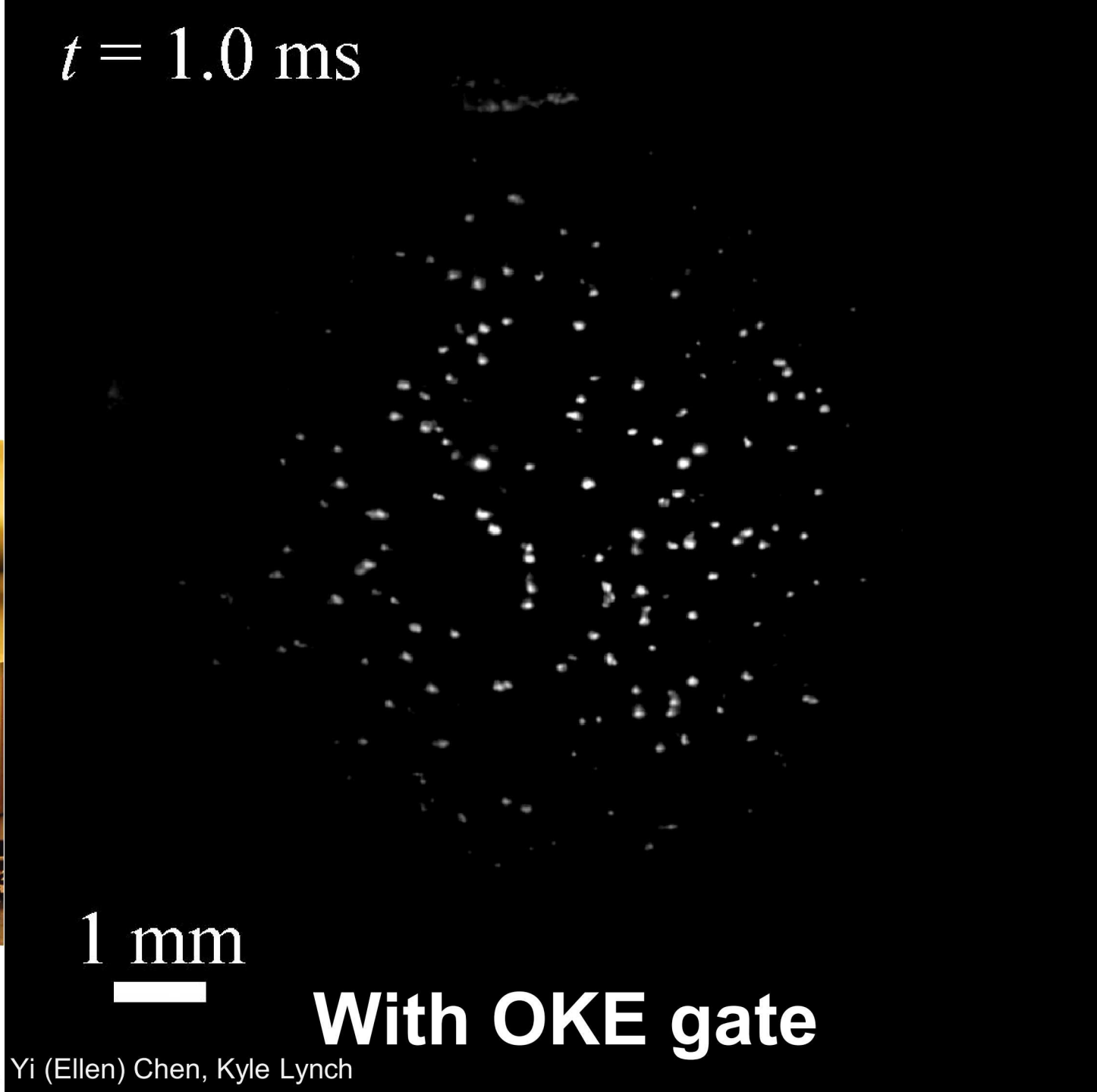
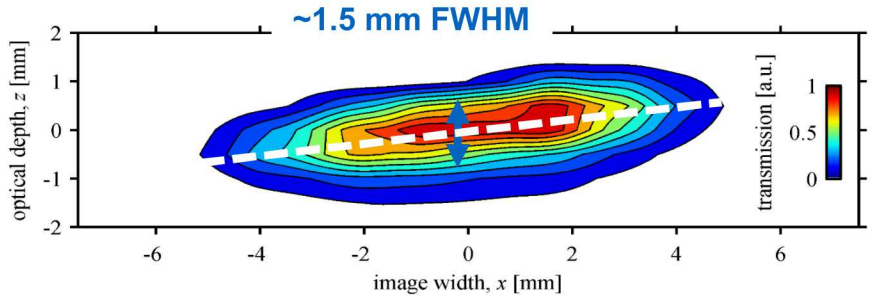


*With Daniel Guildenbecher, Yi (Ellen) Chen, Kyle Lynch

Characterizing the Measurement Volume

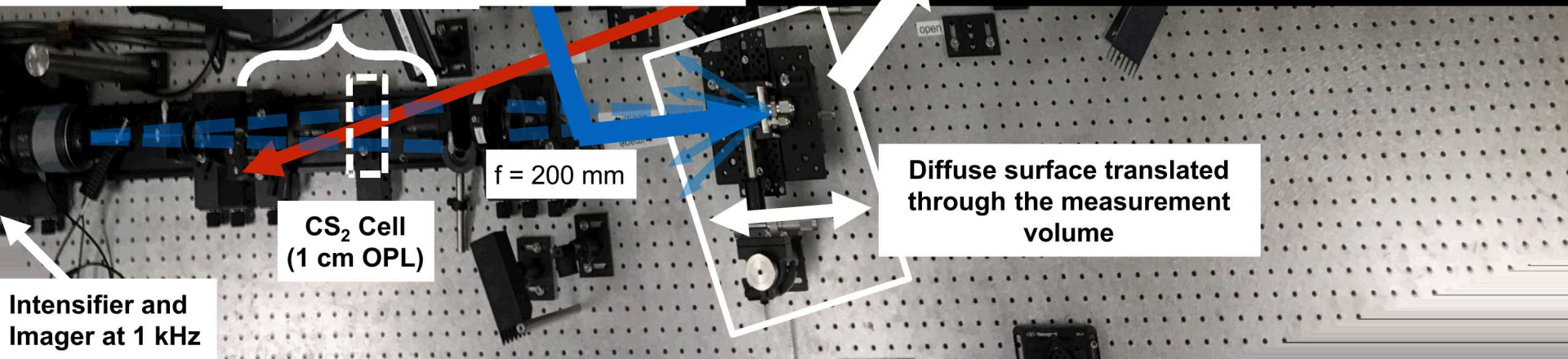


Top Down View of the Effective Measurement Volume

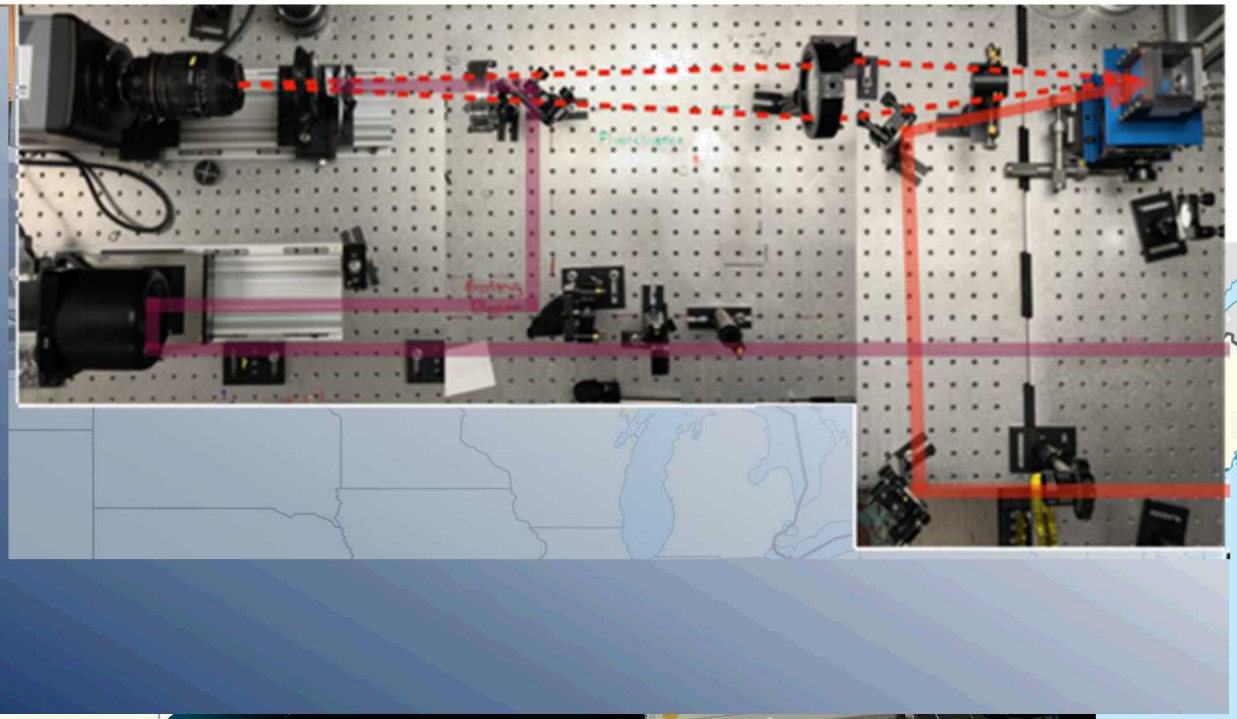
- FWHM in *z* (~1.5 mm) is determined by the OKE gate duration (~10 ps)
- Tilt due to off-axis switch beam

z = -2.0 mm

1 mm



FLC Undergraduates are Now Leading PIVOTS Research



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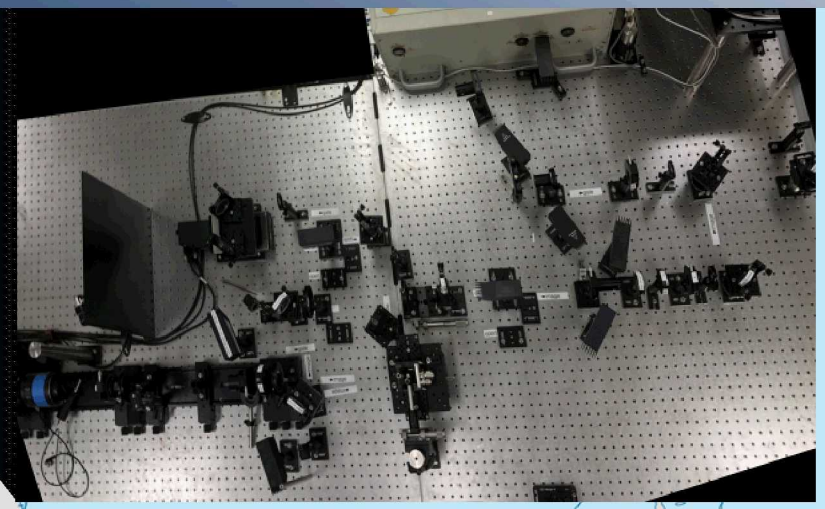
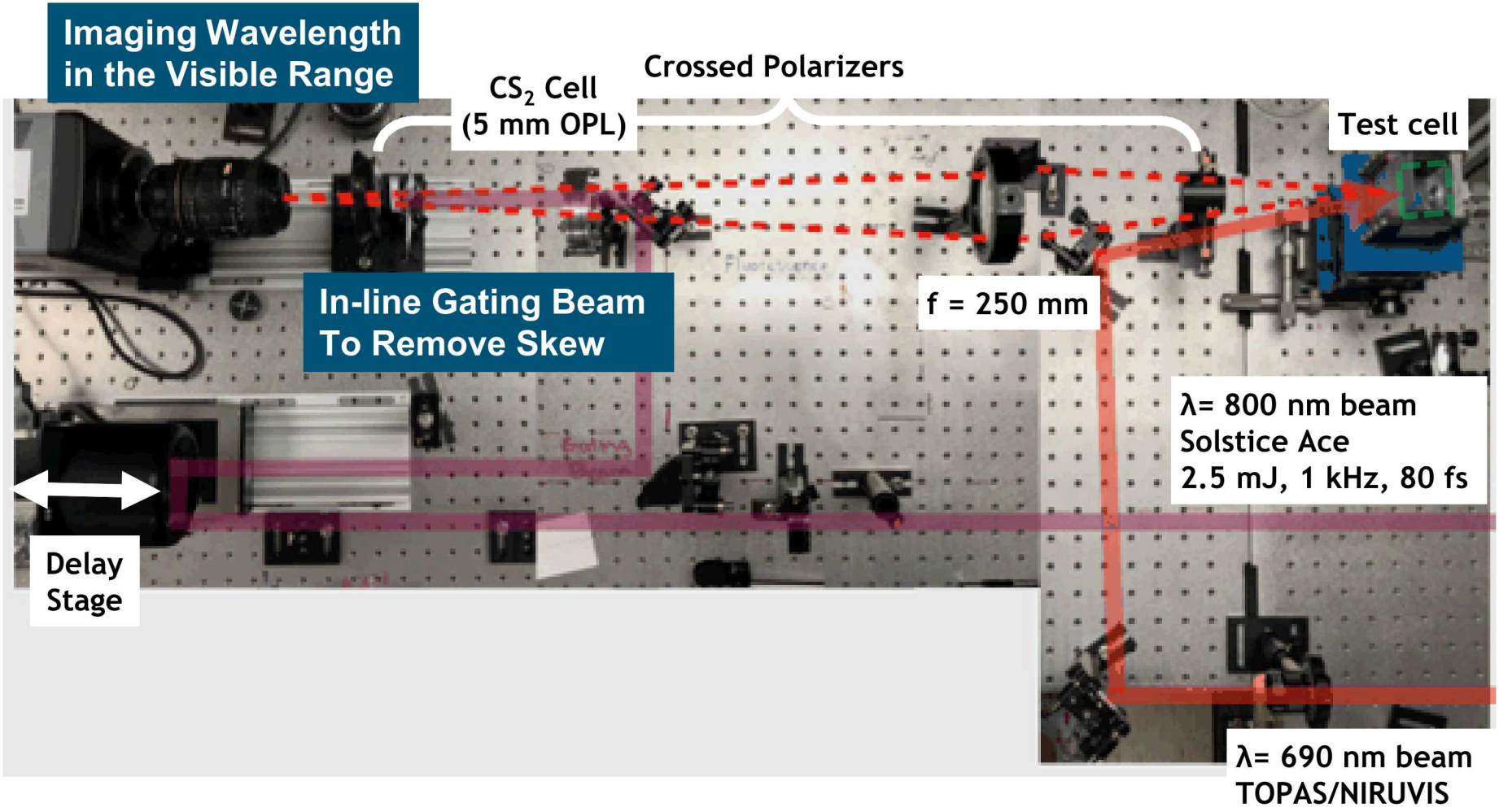


Improved Setup Addressing Sensitivity and Skew



*With Tommy Swimmer and James Sumpter

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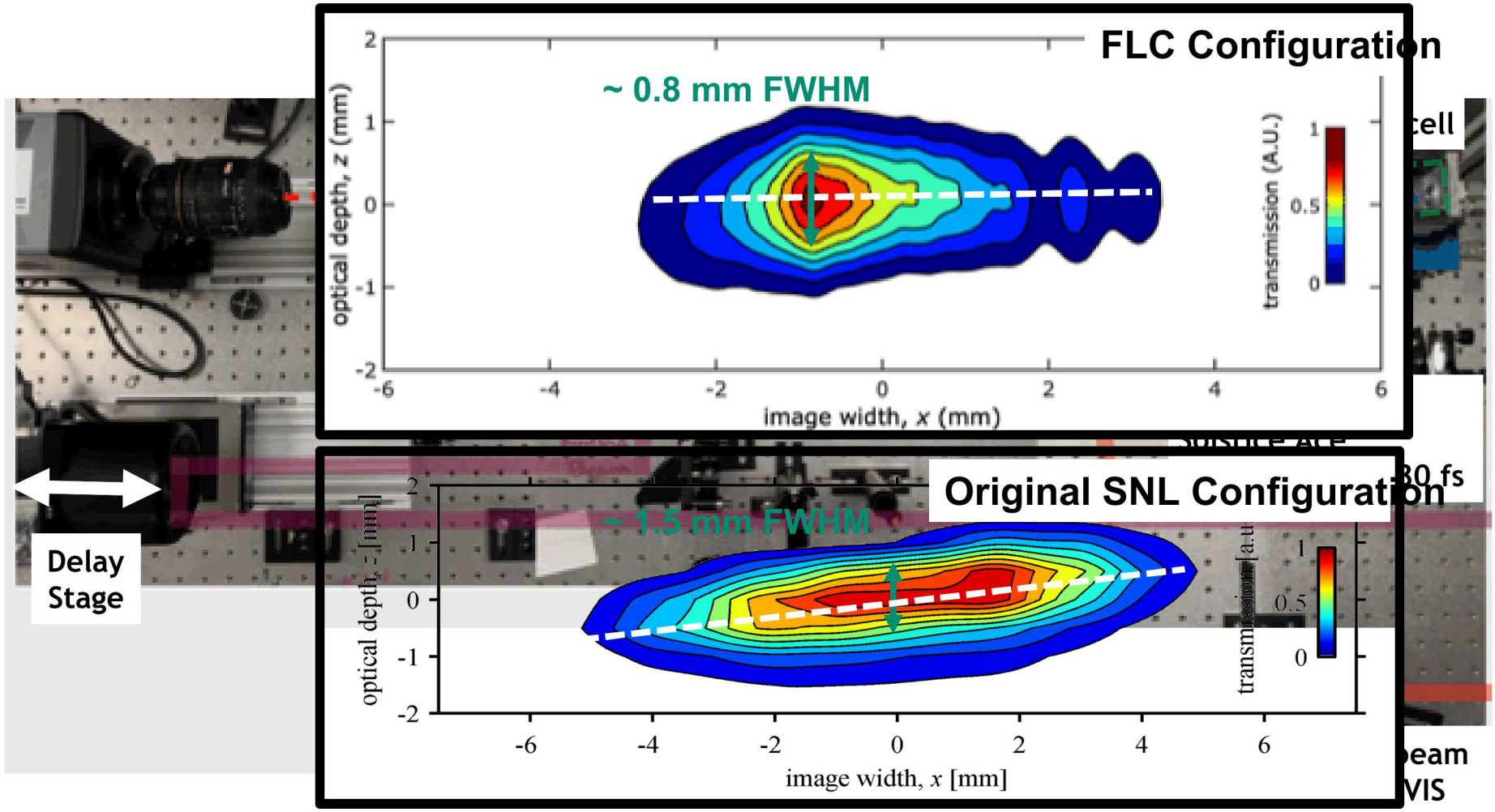

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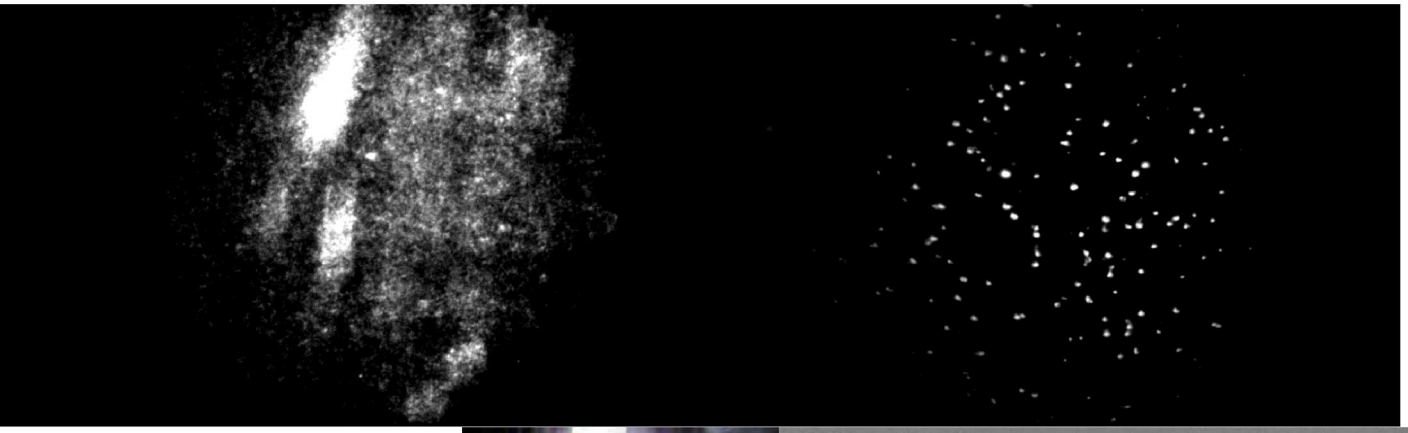

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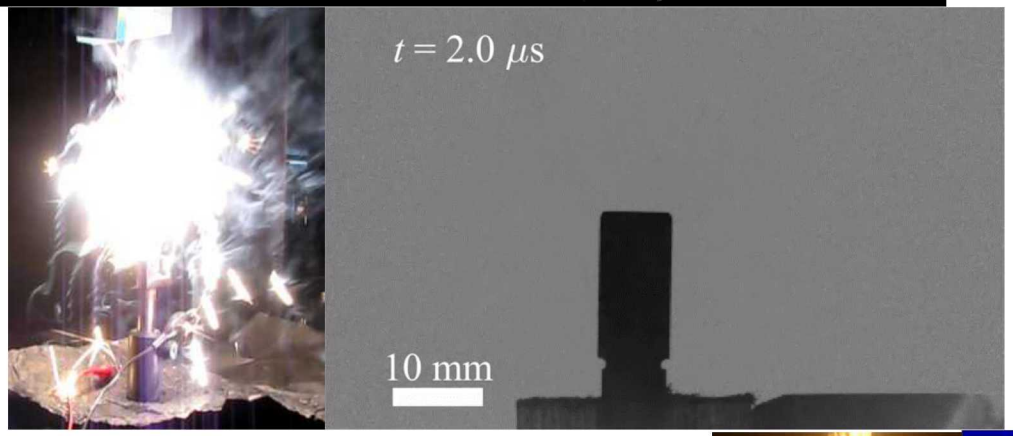

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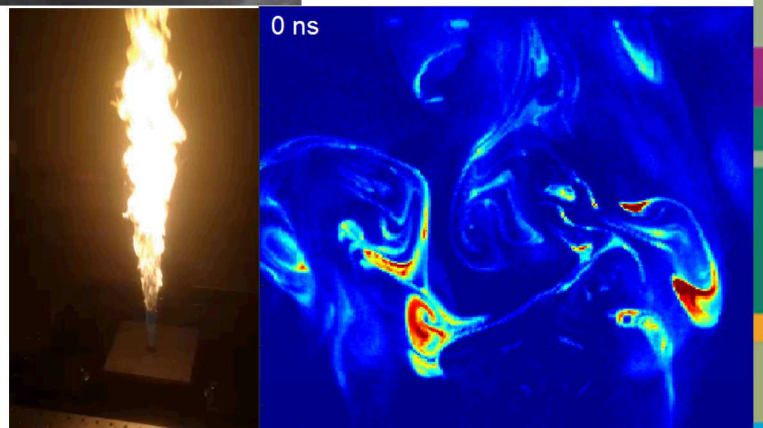
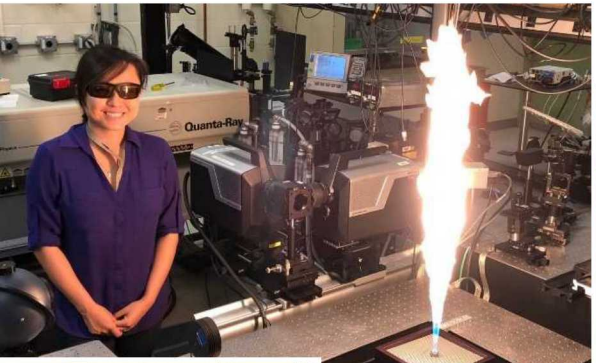
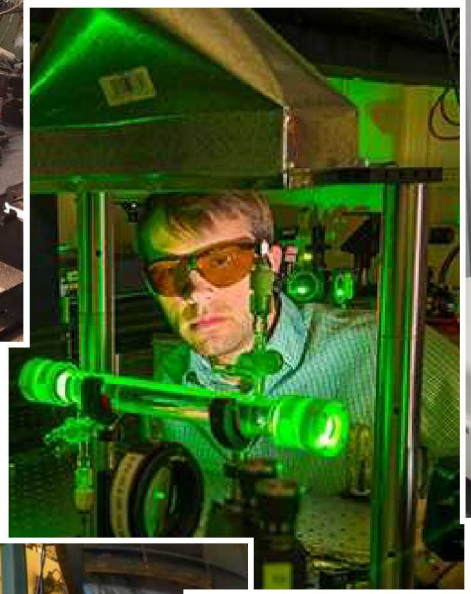
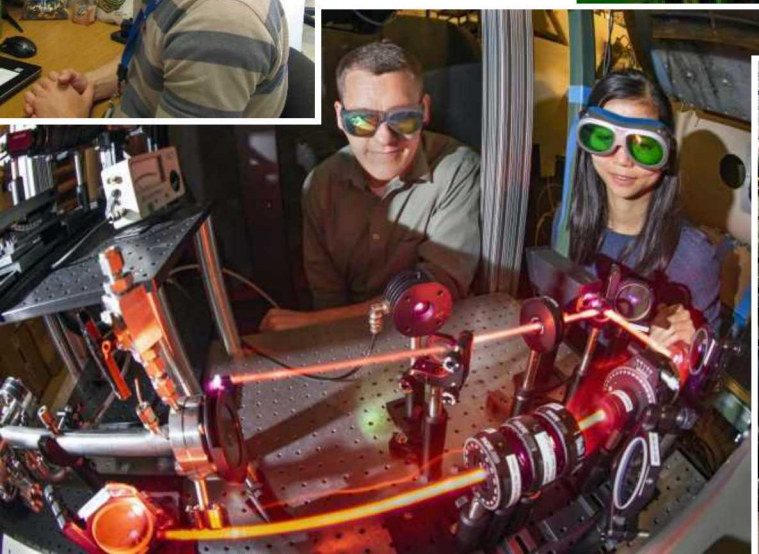
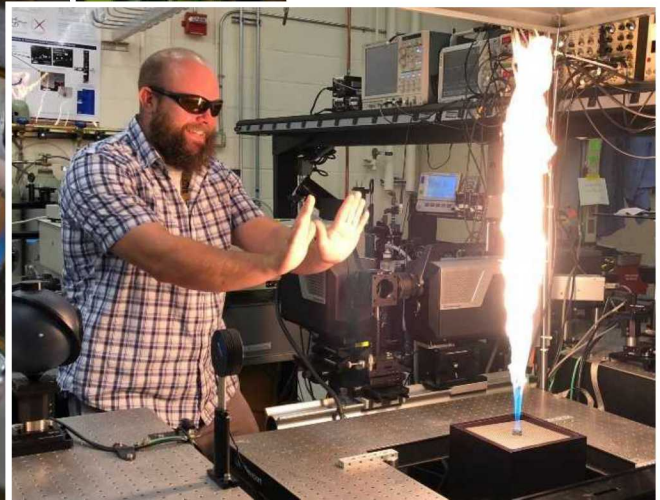


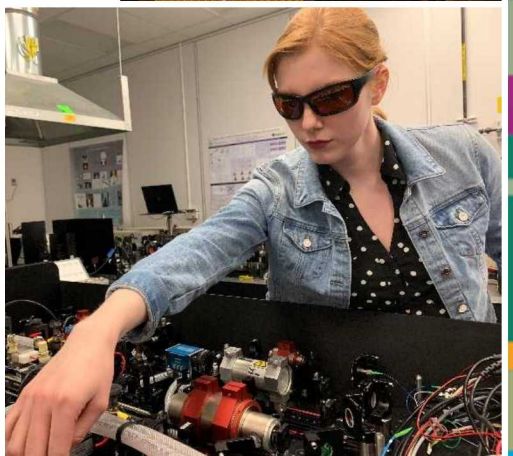
The SNL Group Addresses a Broad Range of Applications









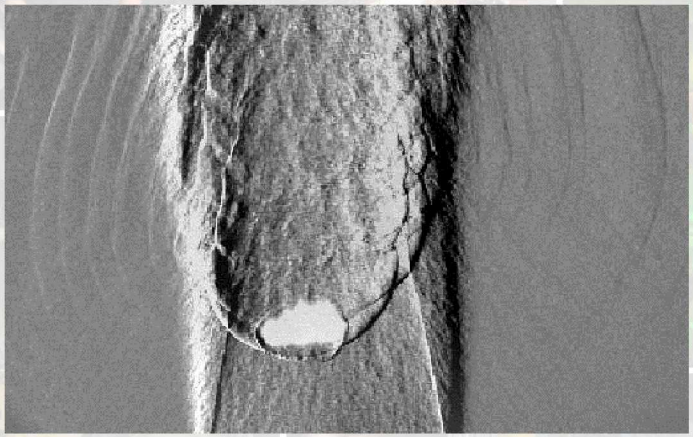


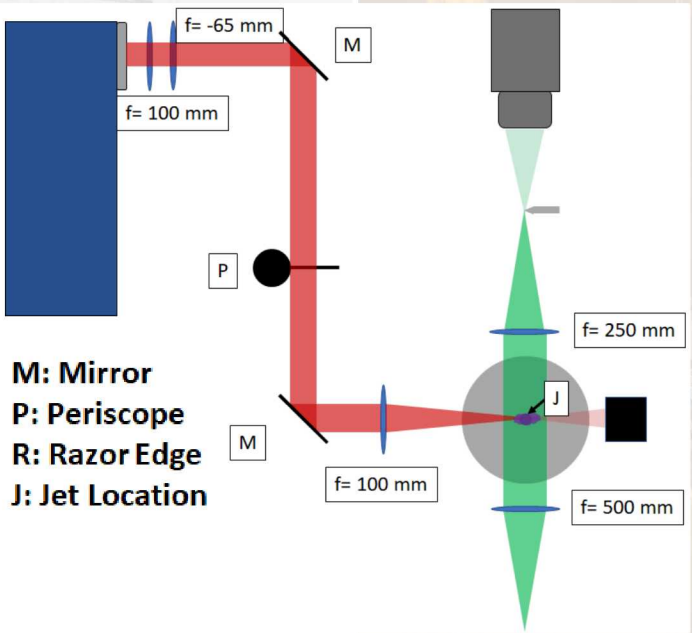
Burst-Mode Laser-Induced Plasma Diagnostics

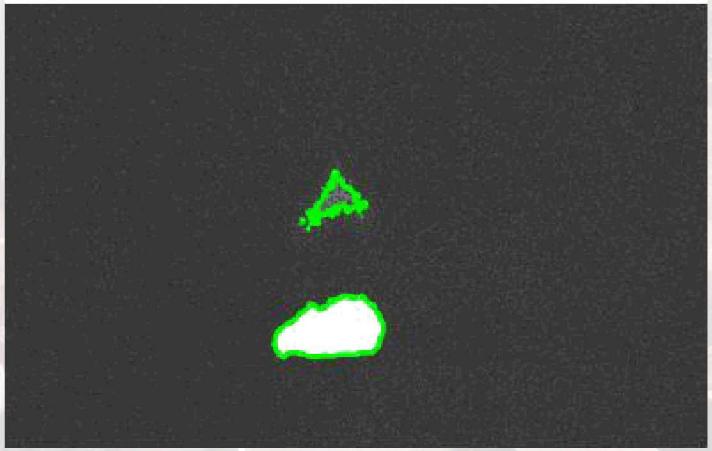
Sandia National Laboratories

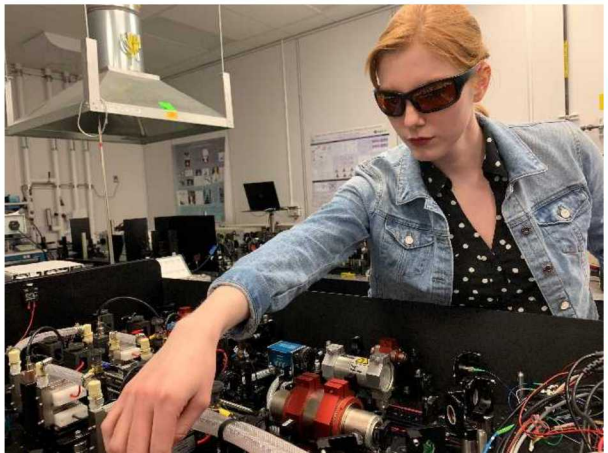
Interrogation of Burst-Mode Laser-Induced Plasma at 300-500 kHz Repetition Rate in an Overexpanded Jet via Advanced Spectroscopic and Imaging Diagnostics

Caroline Winters and Justin Wagner





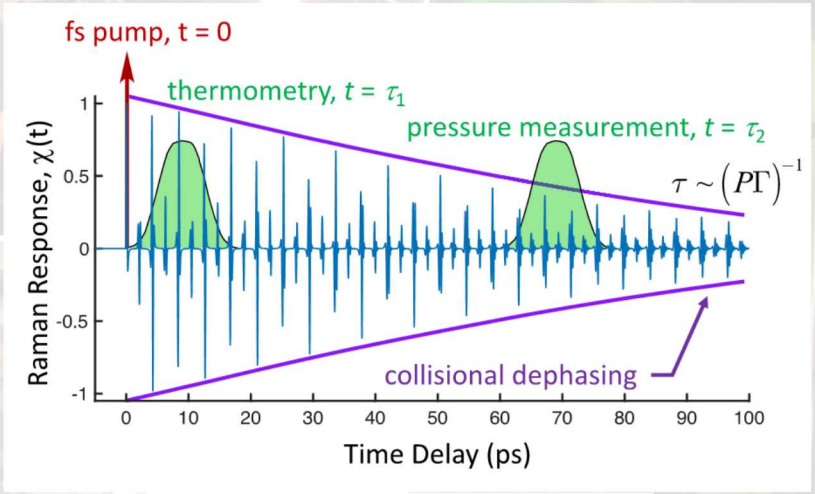


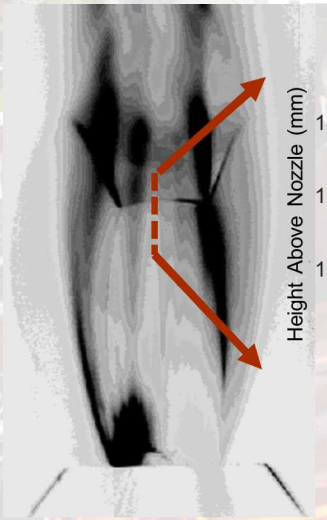


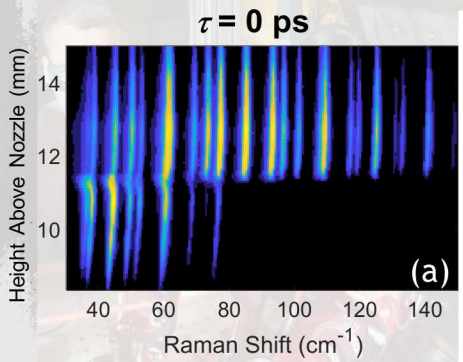
CARS for Simultaneous P and T in a High-Speed Gas

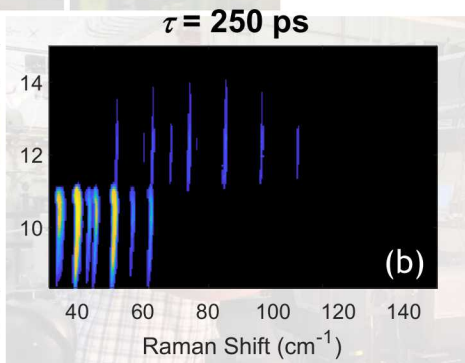
Simultaneous Pressure/Temperature Measurements Using Hybrid fs/ps Rotational CARS

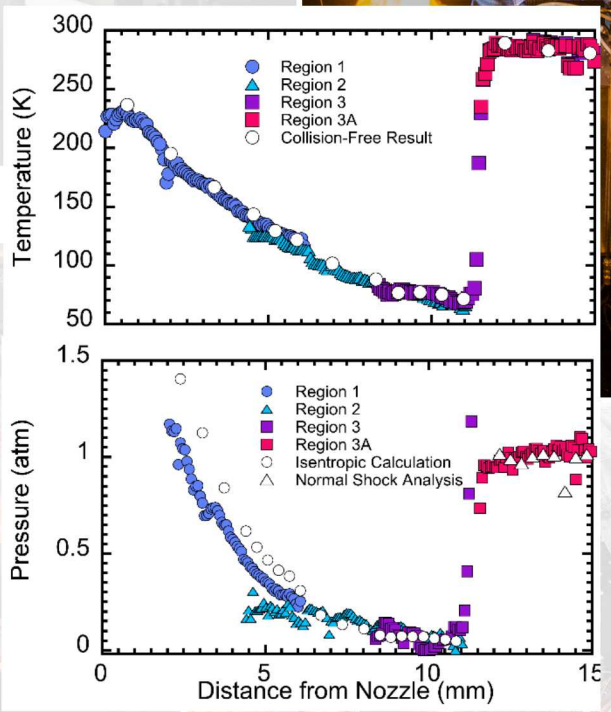
Sean P. Kearney,[1] Daniel R. Richardson,[1] Jonathan E. Retter,[1] Paul M. Danehy,[2] and Chloe Dedic[3]
[1]Engineering Sciences Center, Sandia National Laboratories, Albuquerque, NM 87185
[2]NASA Langley Research Center, Hampton, VA 22681
[3]Department of Mechanical and Aerospace Engineering, University of Virginia, Charlottesville, VA 22911







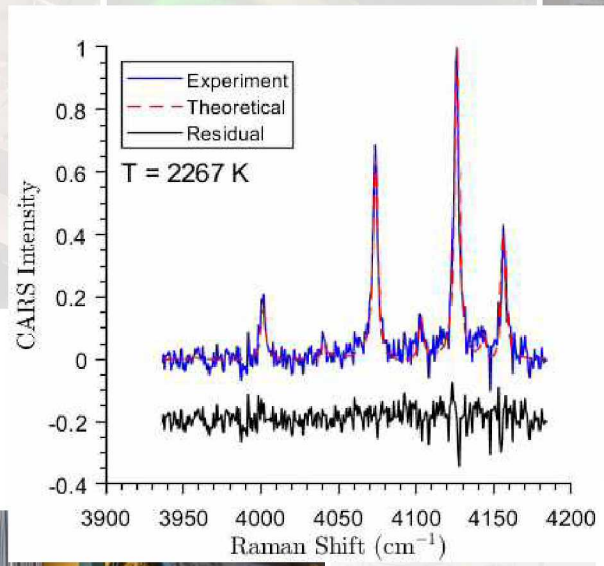


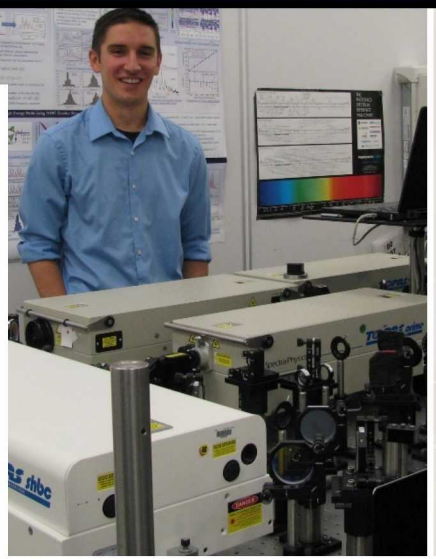


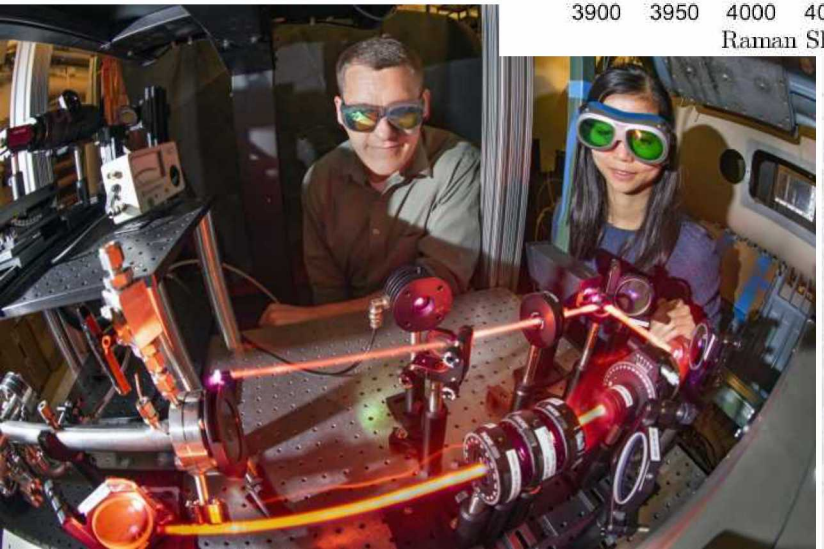
H_2 Vibrational CARS in Multiphase Propellant Fires

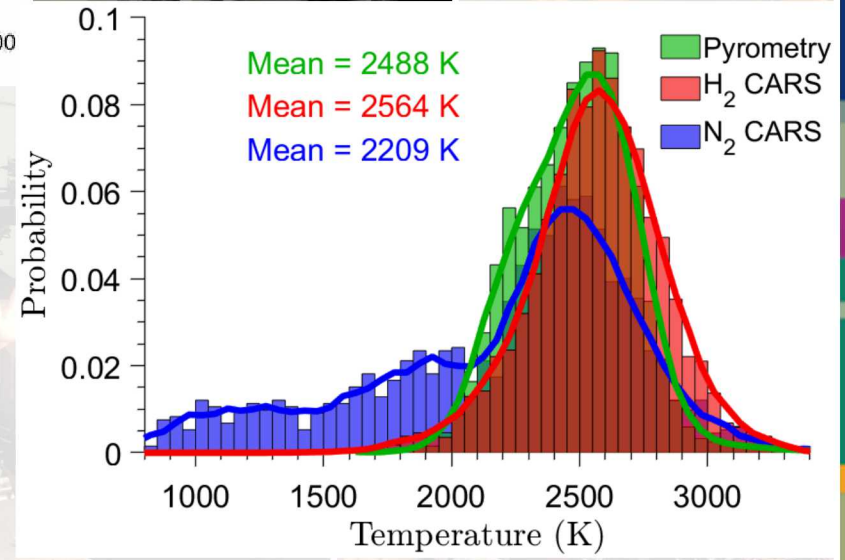
CARS in Explosives and Pyrotechnics

Daniel R. Richardson, Jonathan Retter, Daniel R. Guildenbecher, Sean P. Kearney
Engineering Sciences Center, Sandia National laboratories, Albuquerque, NM 87185









1D N_2 Rotational CARS in Explosive Fireballs

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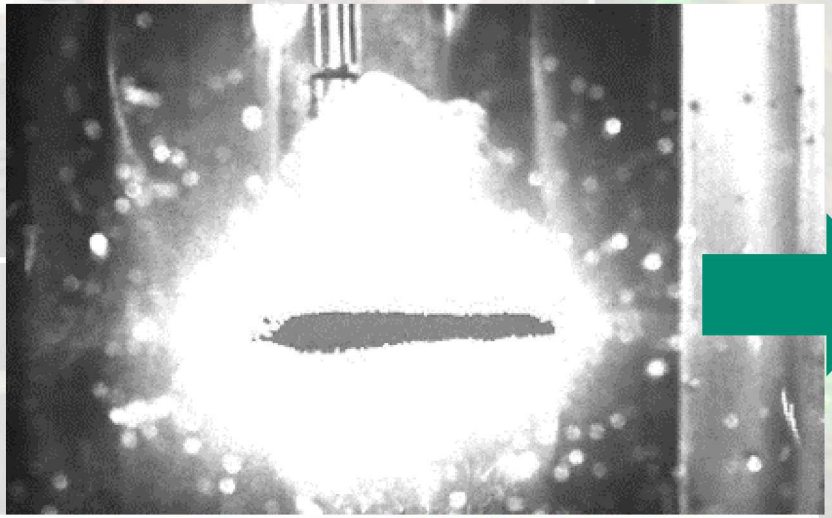
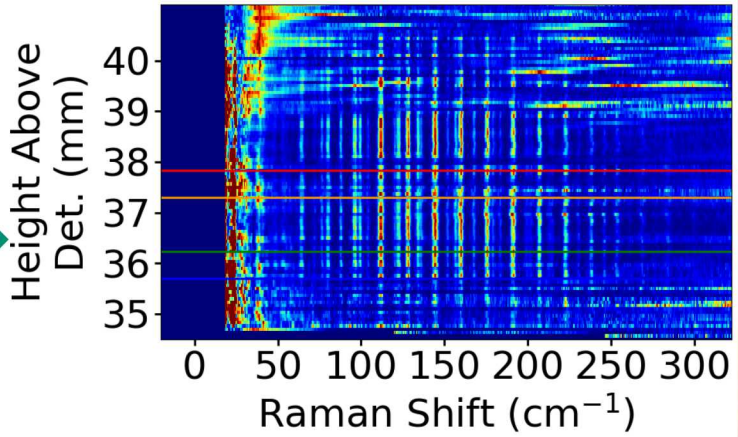
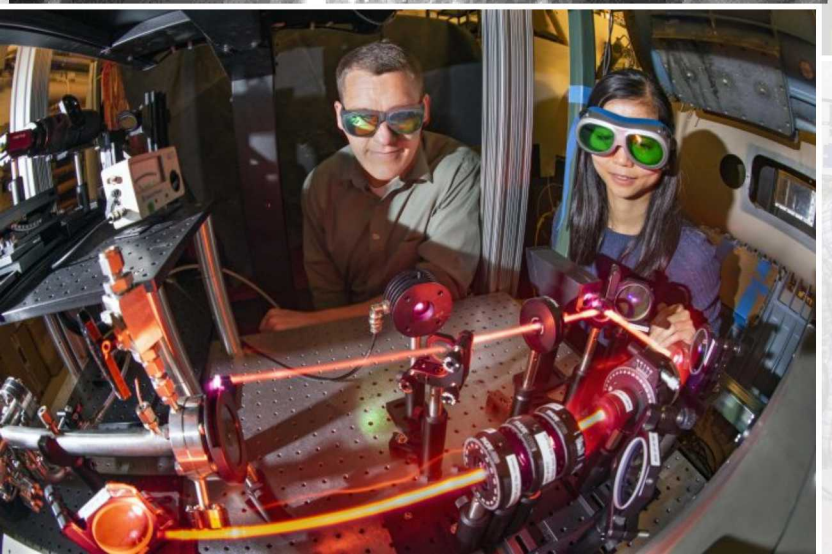
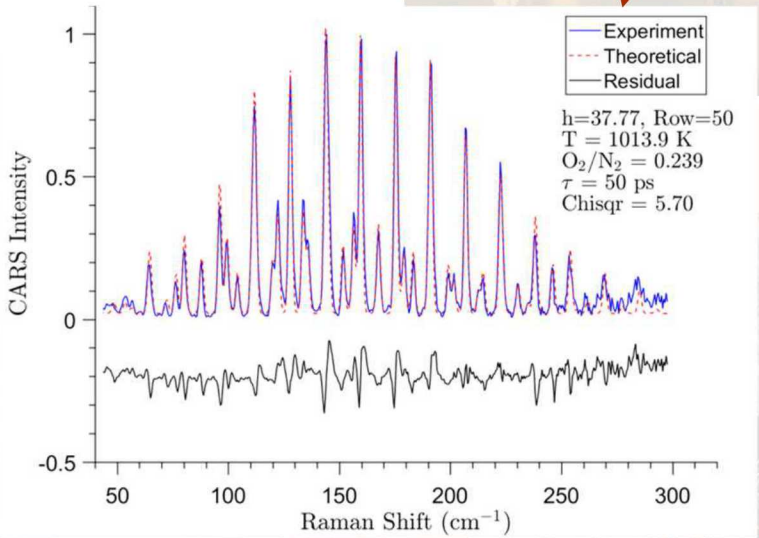








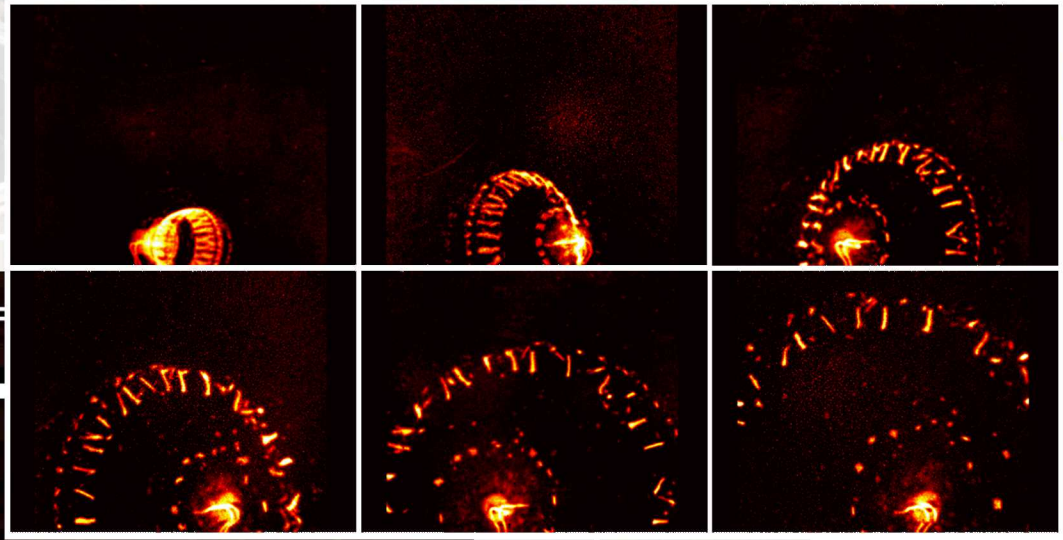
X-ray Diagnostics for Explosive Fragmentation

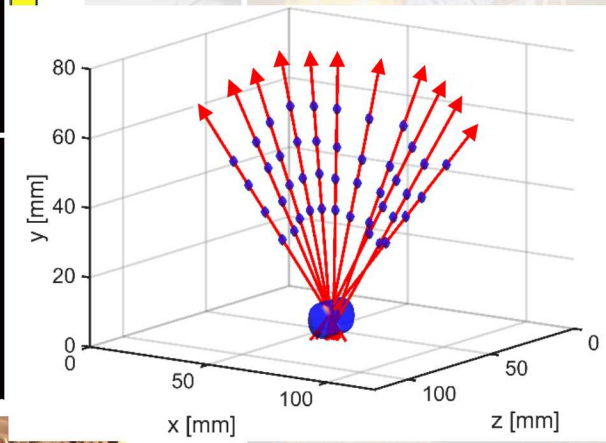
4D particle tracking using space-time interlaced tomography and apparent mass loss due to image blur

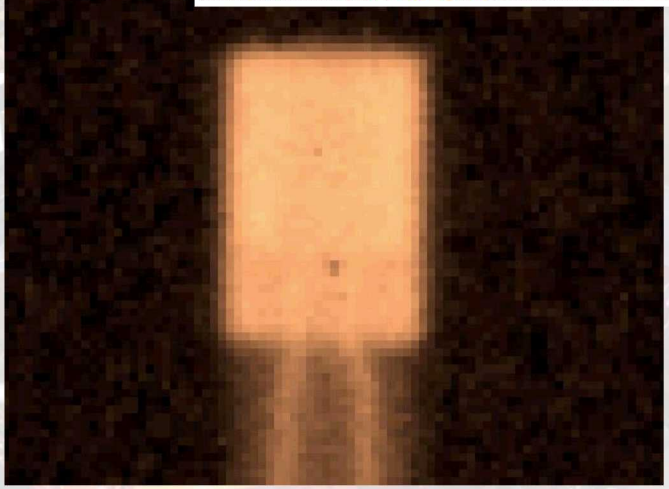
Benjamin R. Halls, Lucas K. Lebow, Enrico C. Quintana and Daniel R. Guildenbecher
Engineering Sciences Center, Sandia National Laboratories
Albuquerque, New Mexico 87185 USA

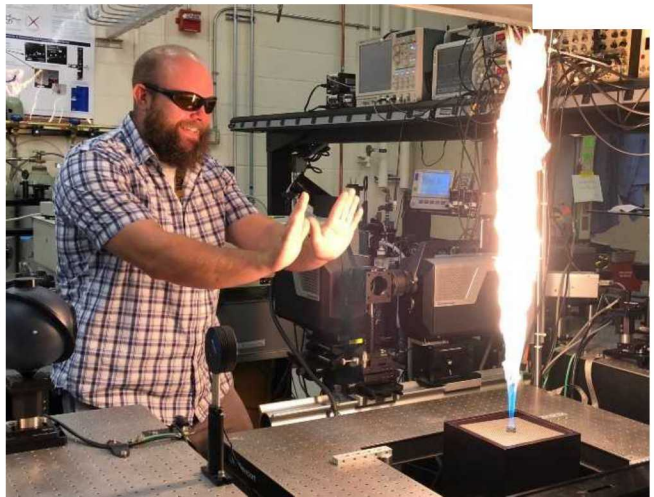
Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

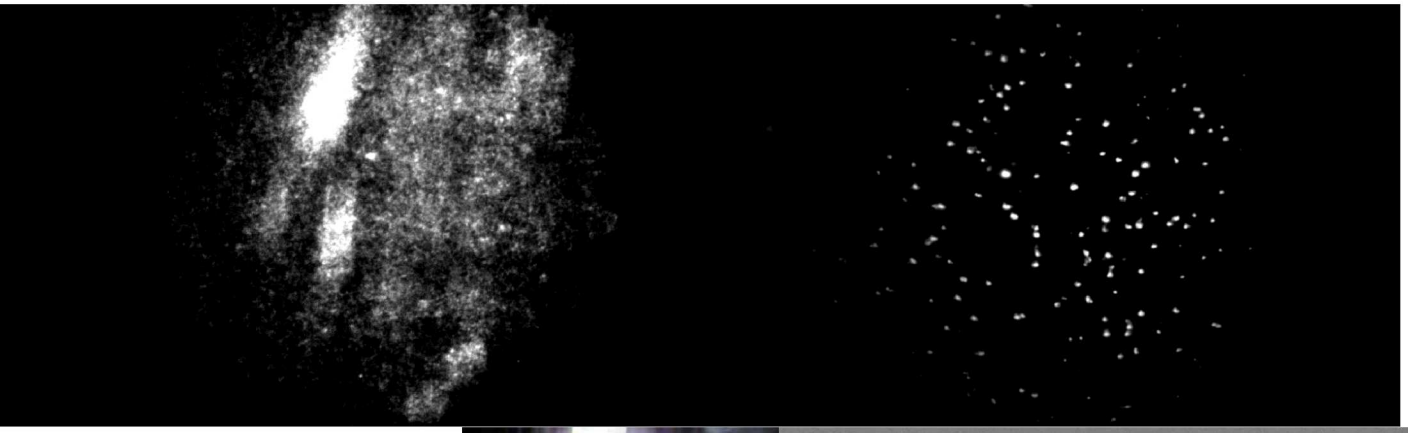






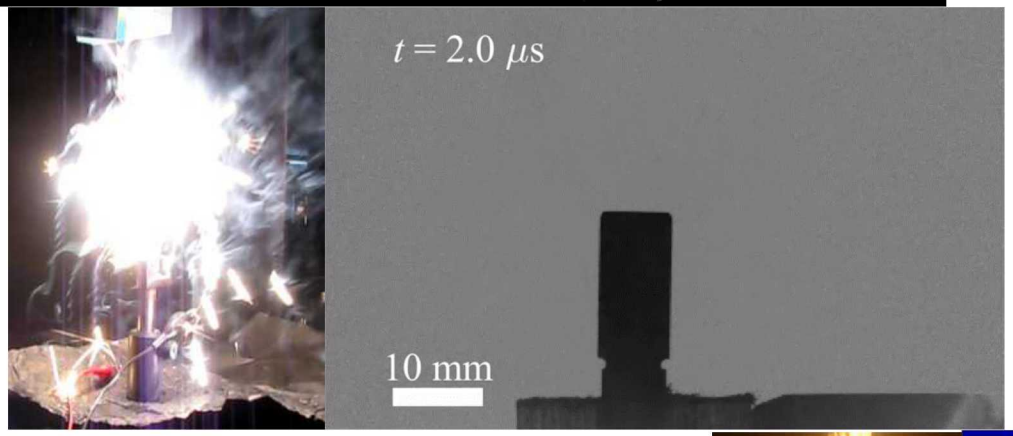


Today's Talk Highlights Developments at Fort Lewis and Sandia, NM in High-Speed and Ultra-Fast Diagnostics

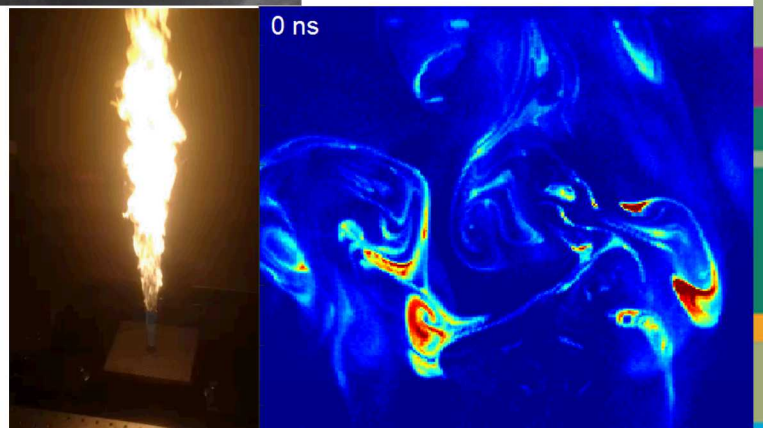


Update on Backscatter Particle Image Velocimetry via Optical Time-of-Flight Sectioning (PIVOTS)

Fire, Supersonic and Explosive Diagnostics At Sandia, New Mexico



Time-Resolved and Tomographic Laser Induced Incandescence



Laser Induced Incandescence (LII) in Harsh Environments

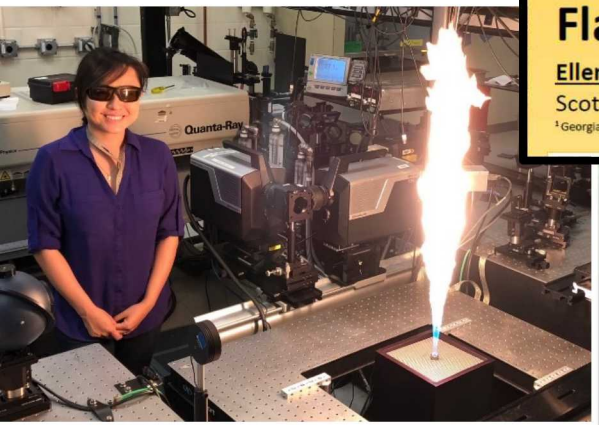
Single-shot Soot Particle Sizing in Turbulent Flames using Ultra-High-Speed Imaging

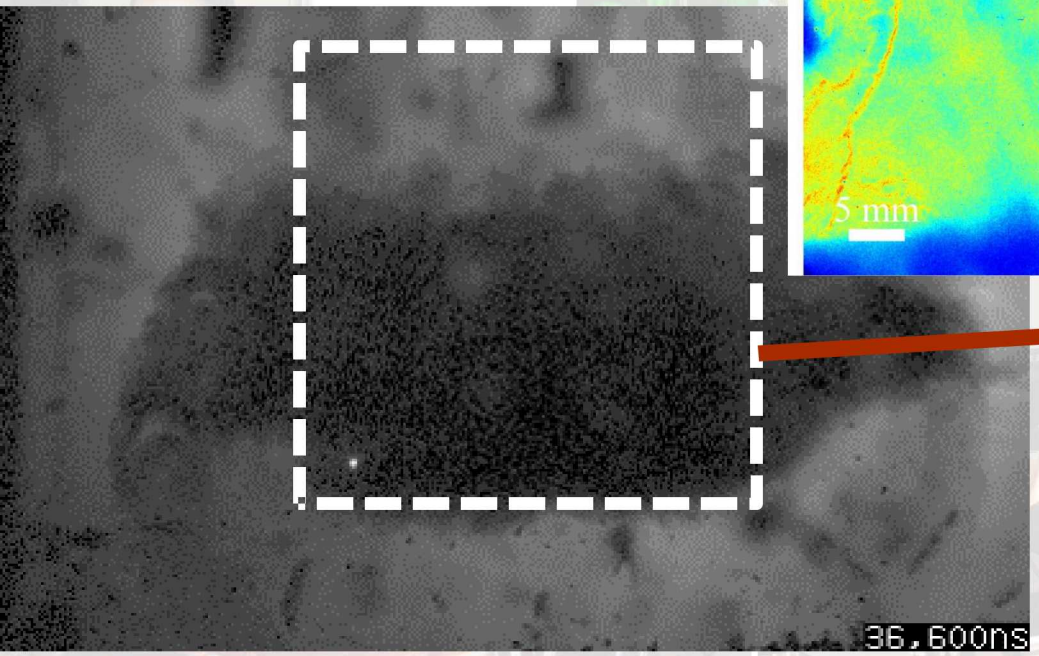
Ellen Yi Chen Mazumdar[1], Emre Cenker[2], Daniel R. Richardson[3], Sean P. Kearney[3], Benjamin R. Halls[3], Scott A. Skeen[4], Christopher R. Shaddix[4], and Daniel R. Guildenbecher[3]

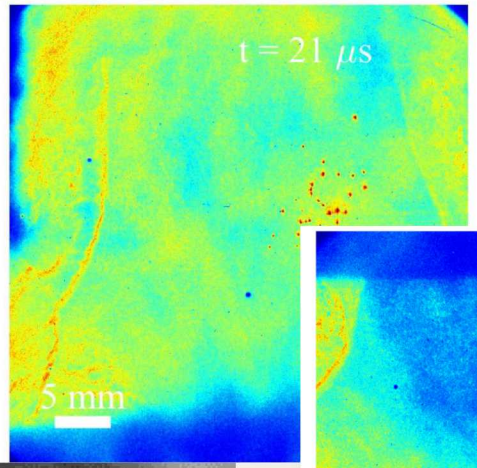
[1] Georgia Institute of Technology, [2] University of Birmingham, [3] Sandia National Laboratories New Mexico, [4] Sandia National Laboratories California

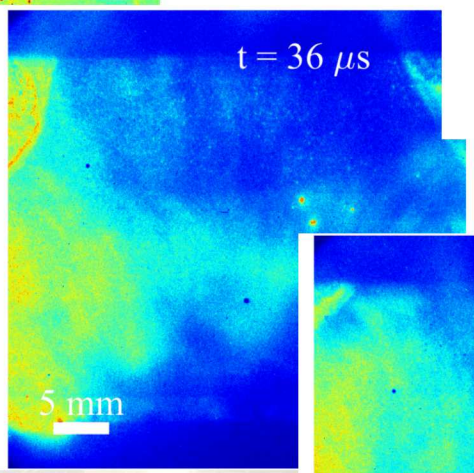
Georgia Institute of Technology

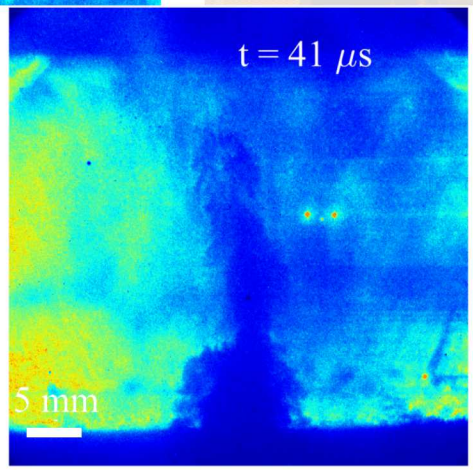
Sandia National Laboratories

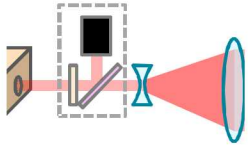






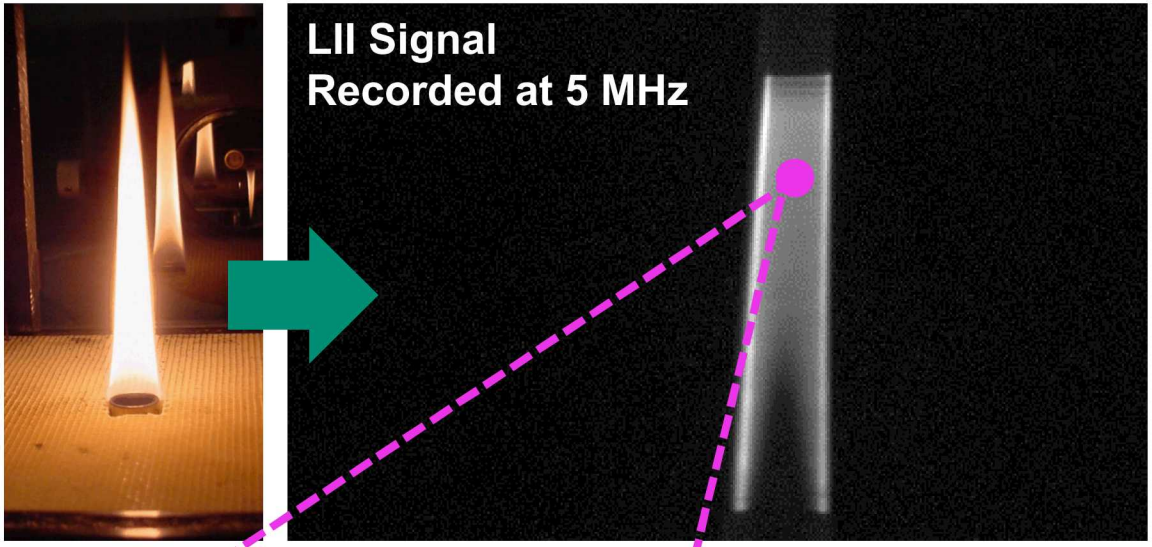


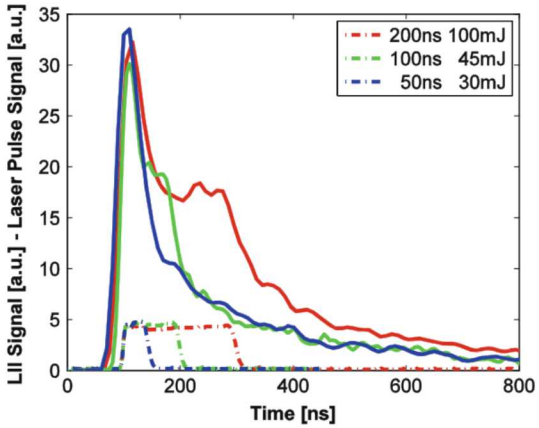




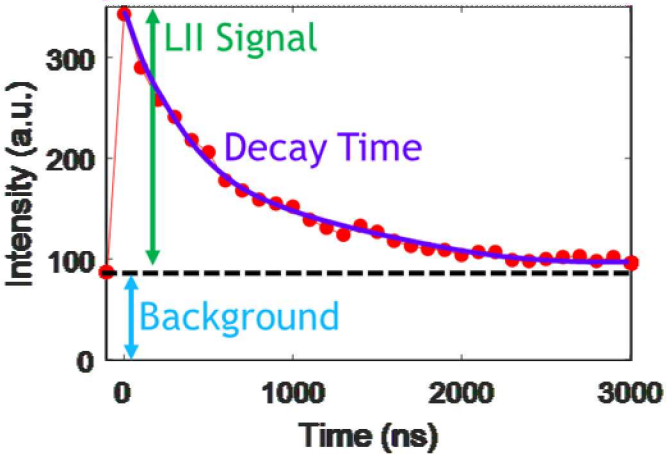
*Courtesy Daniel Guildenbecher, Yi (Ellen) Chen, Daniel Richardson, Lee Stauffacher

To check timing, a MHz Camera Imaged the LII Signal…

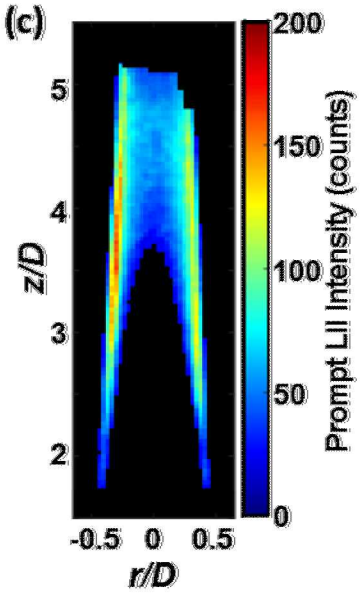


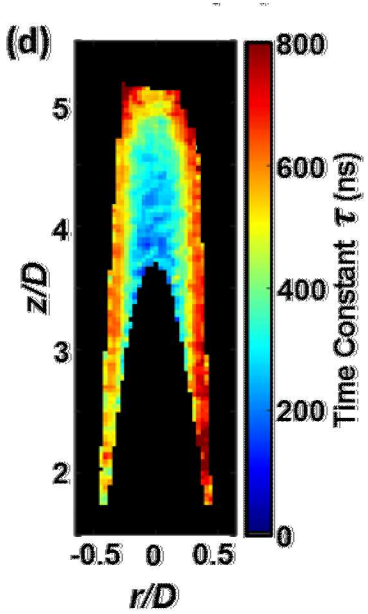


Typical time-resolved LII (Ditaranto *et al* 2013)



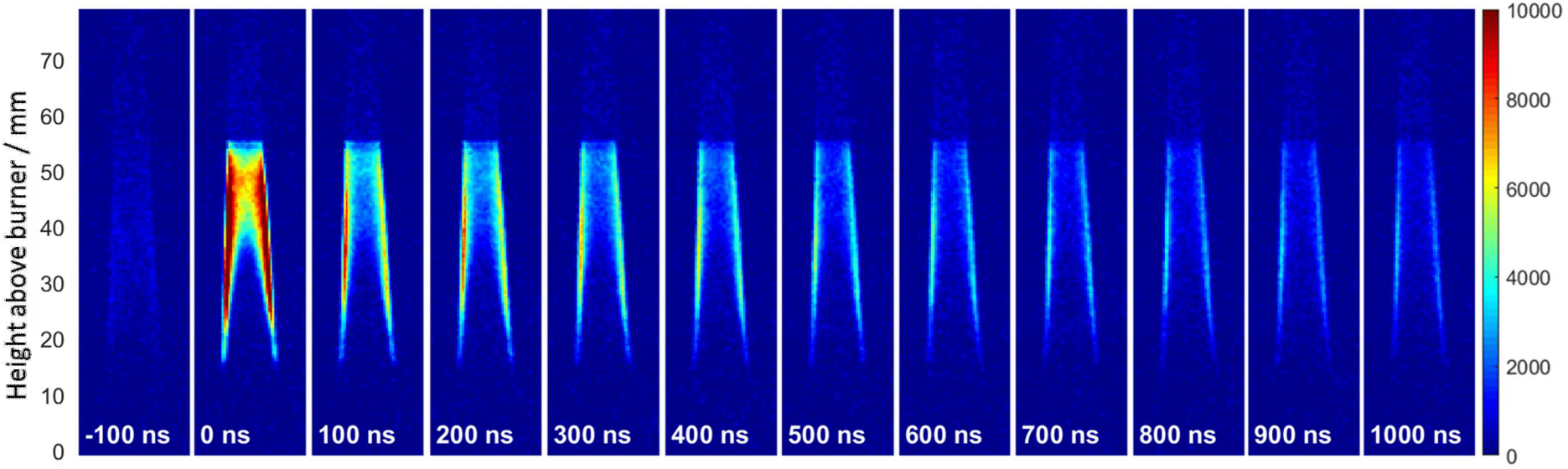
Time- and spatially-resolved LII (Chen *et al* 2018)





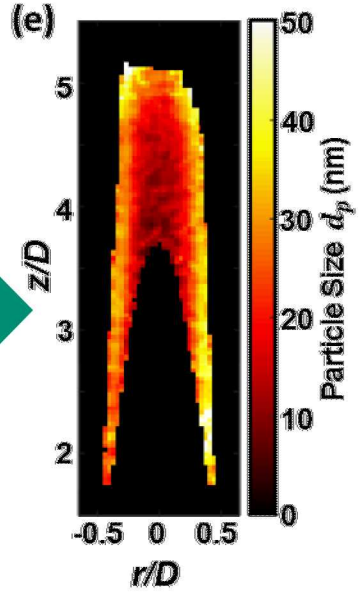
*Courtesy Yi (Ellen) Chen, Emre Cenker, Daniel Richardson, Sean Kearney, Ben Halls, Scott Skeen, Chris Shaddix, Daniel Guildenbecher

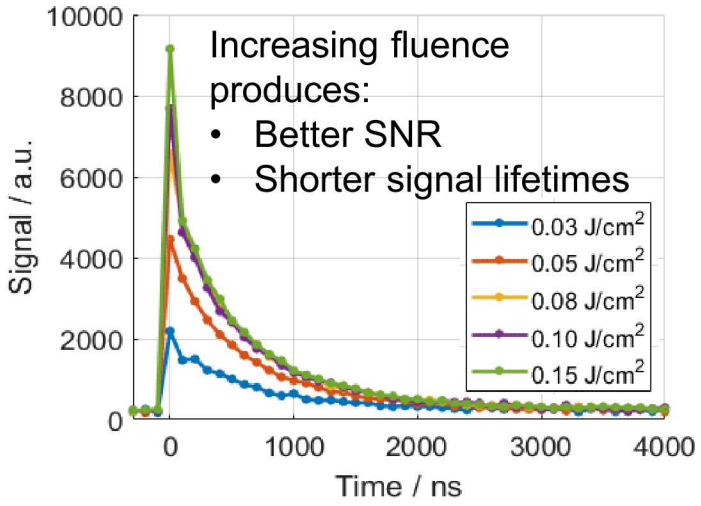
Particle Size Measurements Validated with Santoro Flame



LII model from Emre

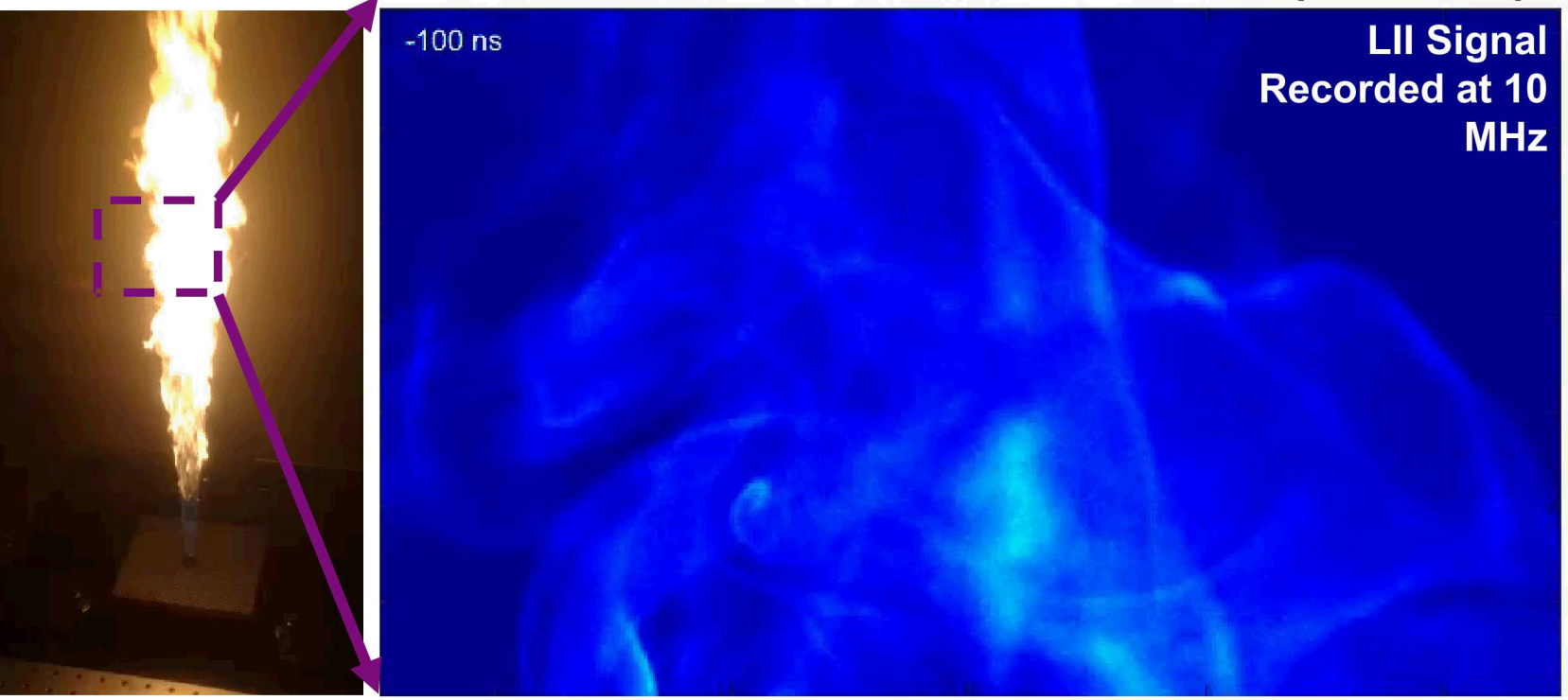
HAB	40 mm
Gas temperature	1850 K (pyrometry)
Pressure	0.84 bar (5000 ft)
Laser fluence	0.08 J/cm^2
$E(m)$	0.4 (literature)
TAC	0.37 (literature)
Aggregate size	60 (TEM)
Time domain	4500 ns (aLaser)
Detection band	603 – 678 nm
Bath-gas heating	On (f_v = 6 ppm)

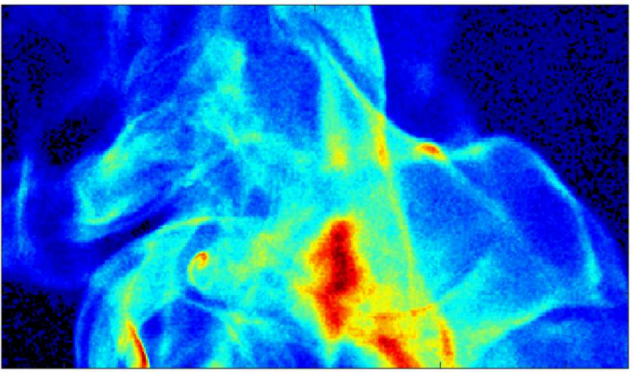




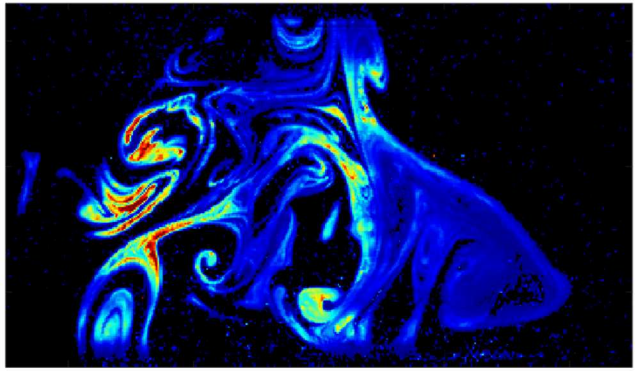
*Courtesy Yi (Ellen) Chen, Emre Cenker, Daniel Richardson, Sean Kearney, Ben Halls, Scott Skeen, Chris Shaddix, Daniel Guildenbecher

Time-Resolved Laser Induced Incandescence (TiRe-LII)

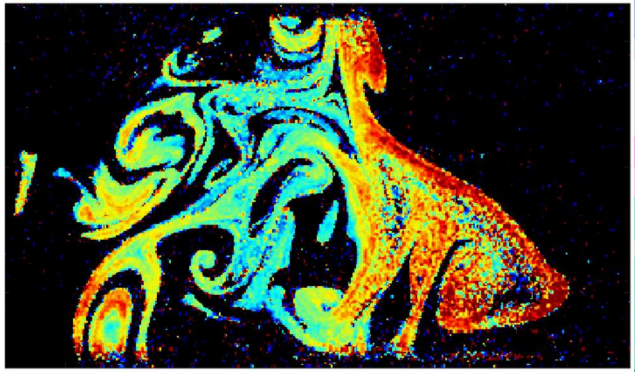




Background Intensity



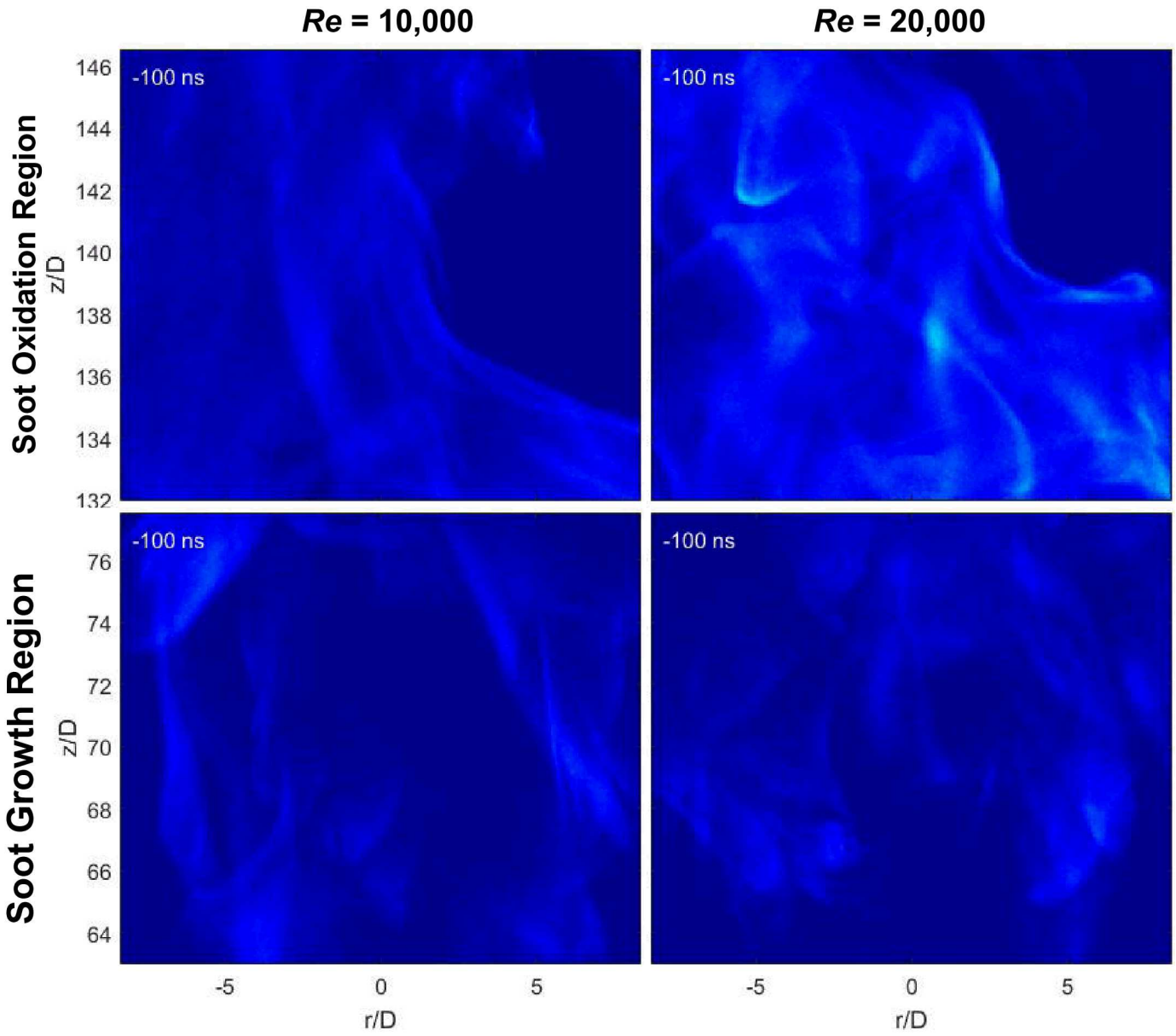
LII Signal Intensity

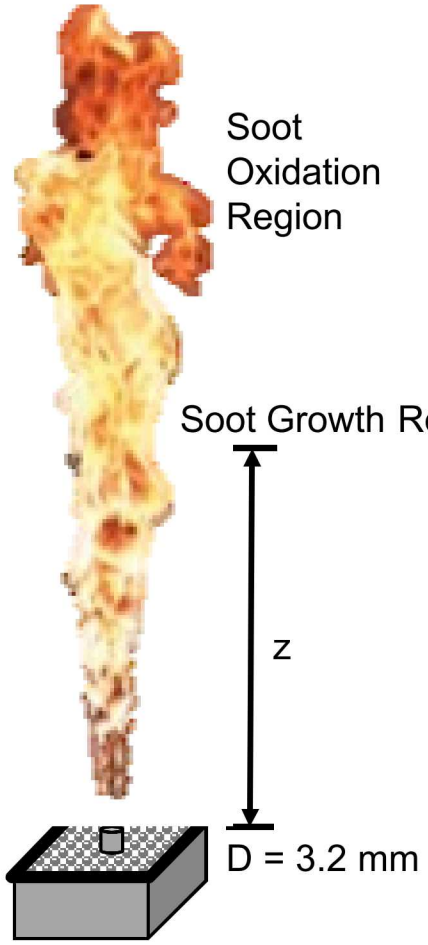


Decay Time Constant

*Courtesy Yi (Ellen) Chen, Emre Cenker, Daniel Richardson, Sean Kearney, Ben Halls, Scott Skeen, Chris Shaddix, Daniel Guildenbecher

Single-Shot TiRe-LII Results

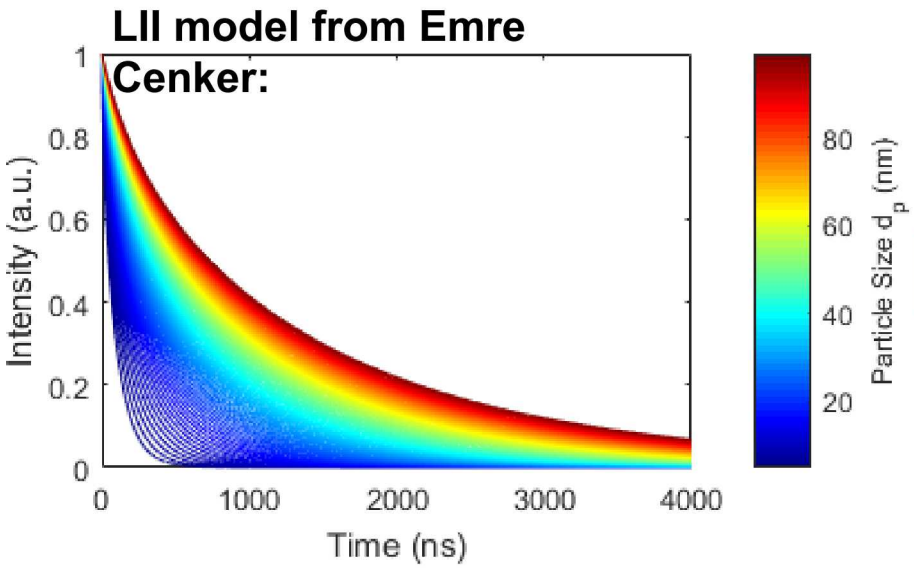


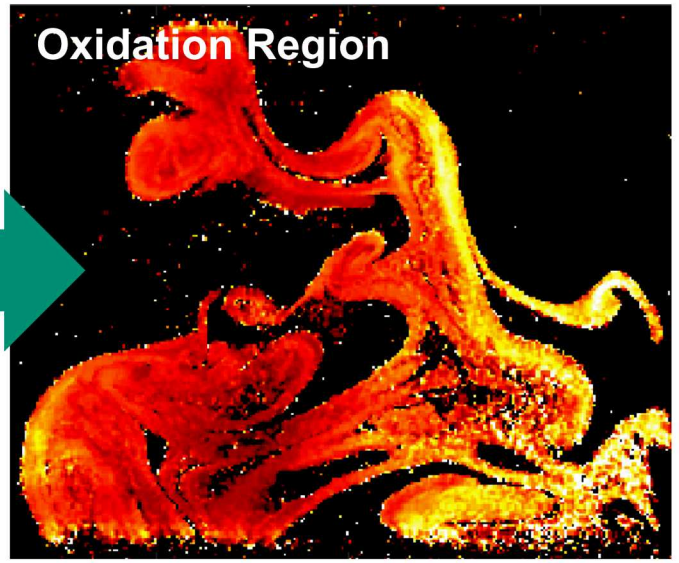


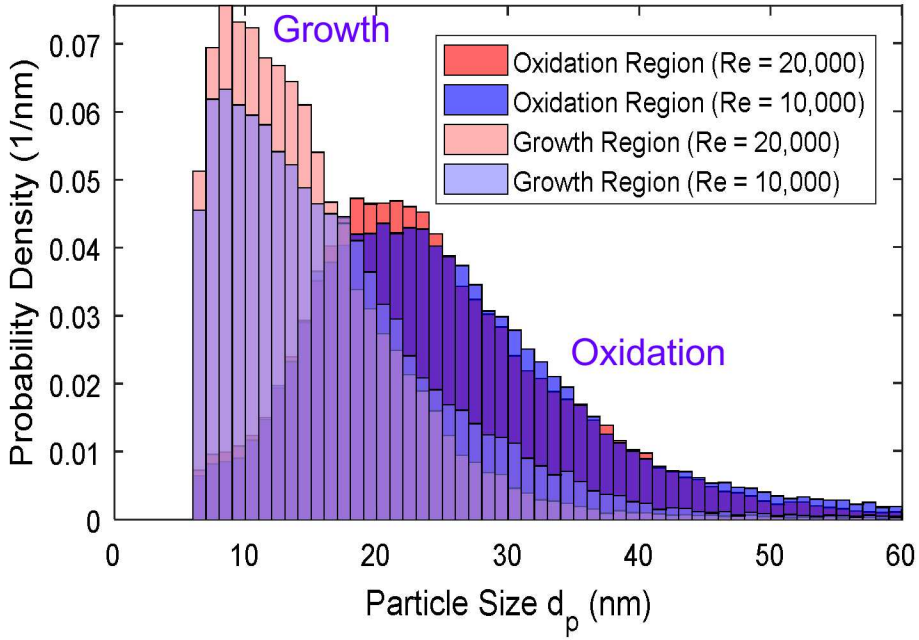
Sampled at 10 MHz
Fluence of ~0.15 J/cm^2

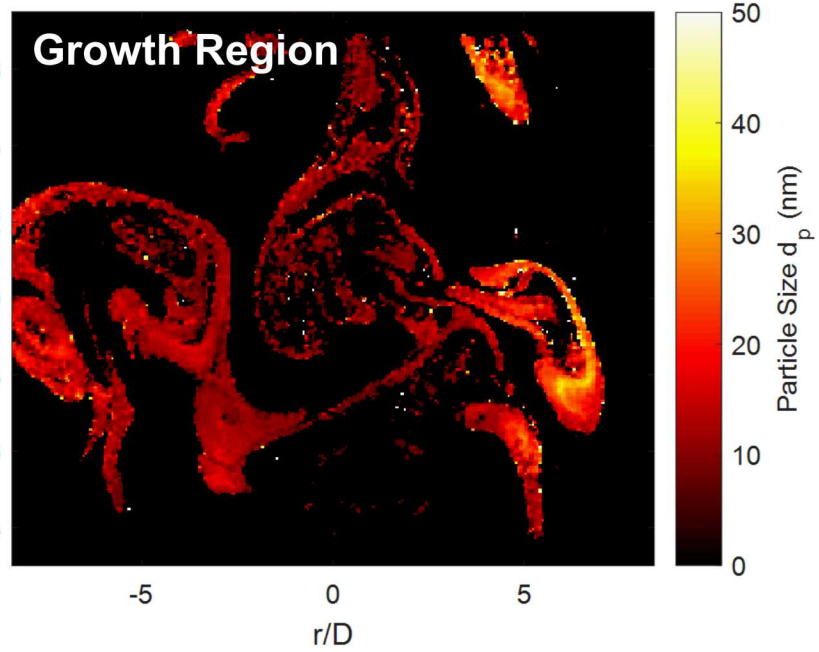
*Courtesy Yi (Ellen) Chen, Emre Cenker, Daniel Richardson, Sean Kearney, Ben Halls, Scott Skeen, Chris Shaddix, Daniel

Single-Shot TiRe-LII Results





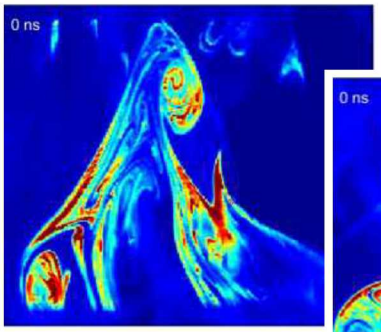


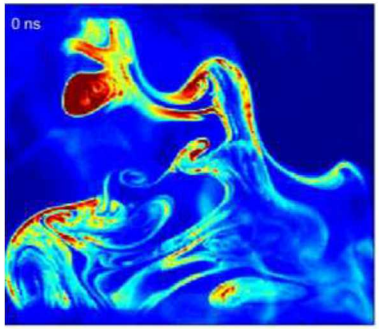


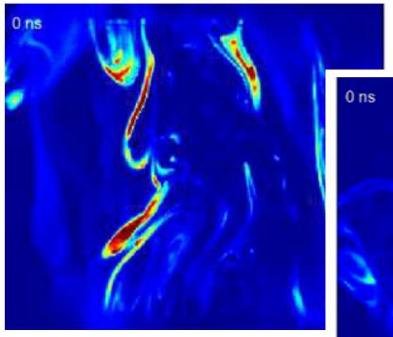
*Courtesy Yi (Ellen) Chen, Emre Cenker, Daniel Richardson, Sean Kearney, Ben Halls, Scott Skeen, Chris Shaddix, Daniel Guildenbecher

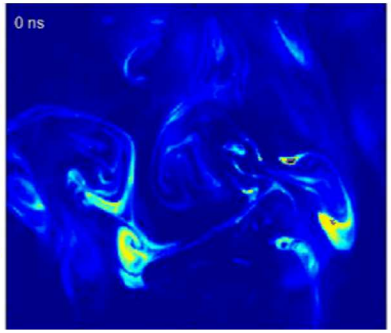
2D TiRe-LII

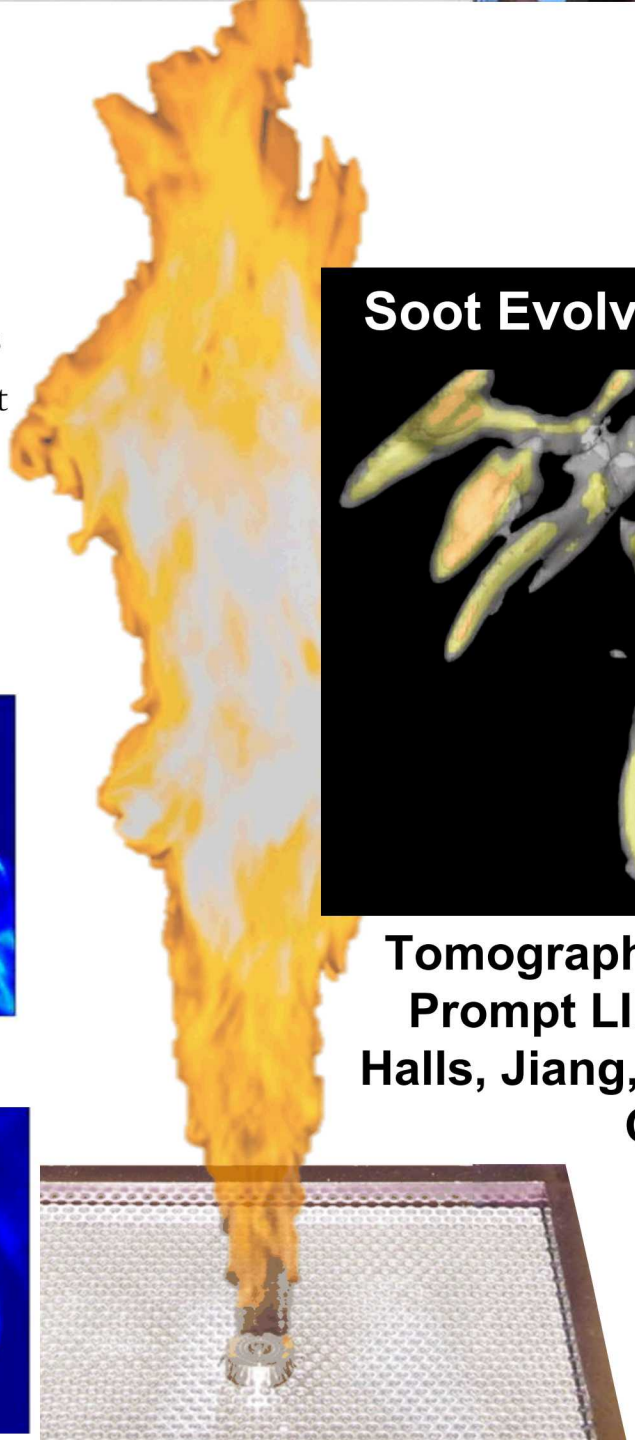
- Enables soot size imaging in turbulent/unsteady flames
- Eliminates multi-camera pixel registration and image intensifiers
- Future work: calibrate the prompt LII signal, improve SNR, obtain simultaneous temperatures, and further develop LII models of these flows



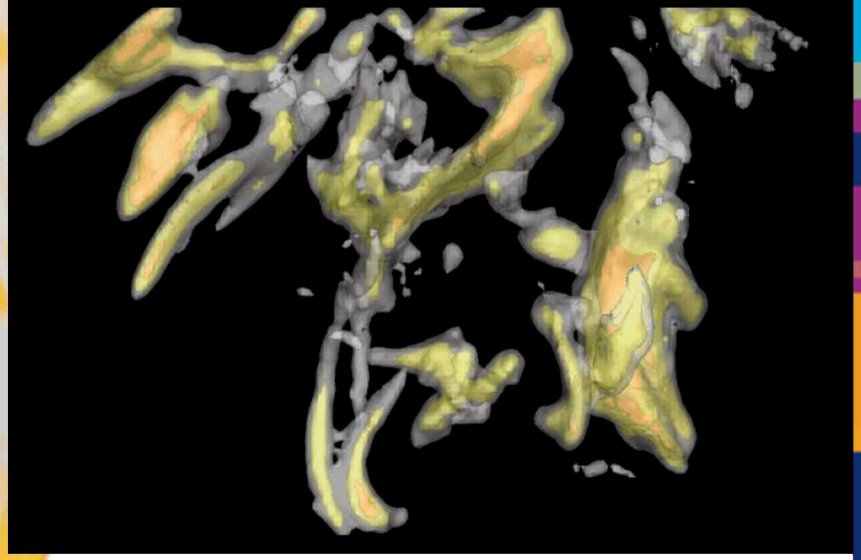






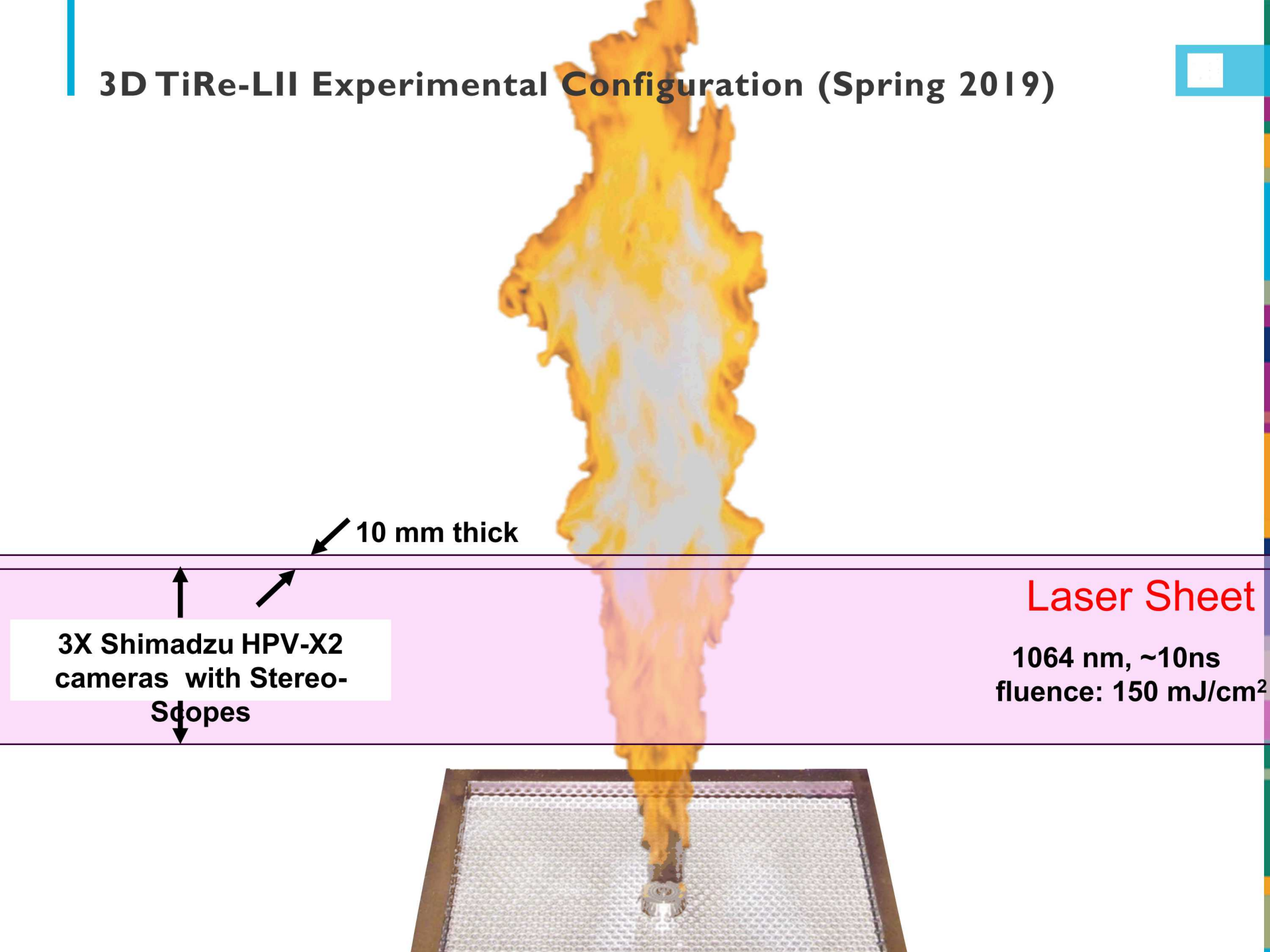


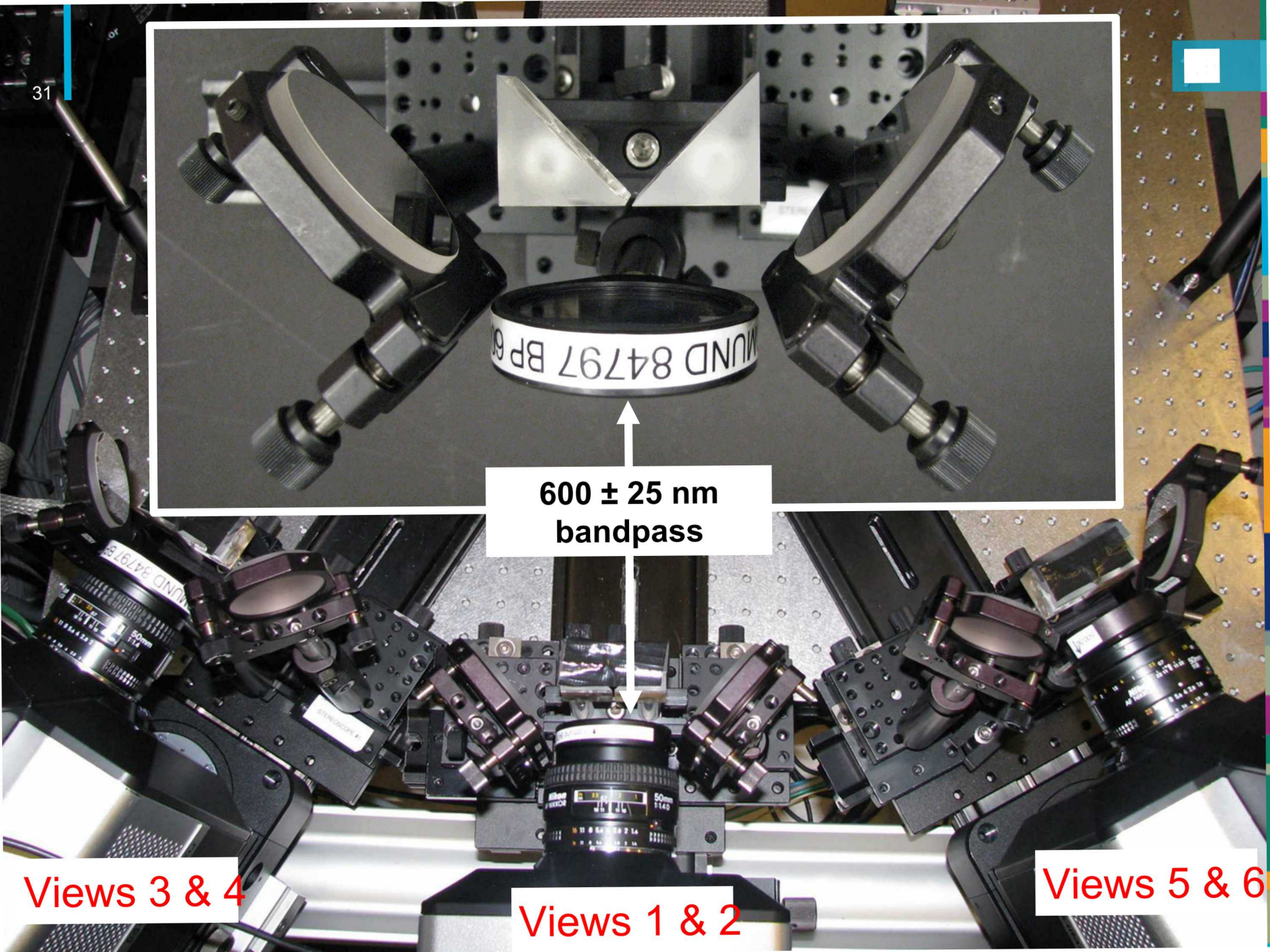
Soot Evolves in 3D Structures



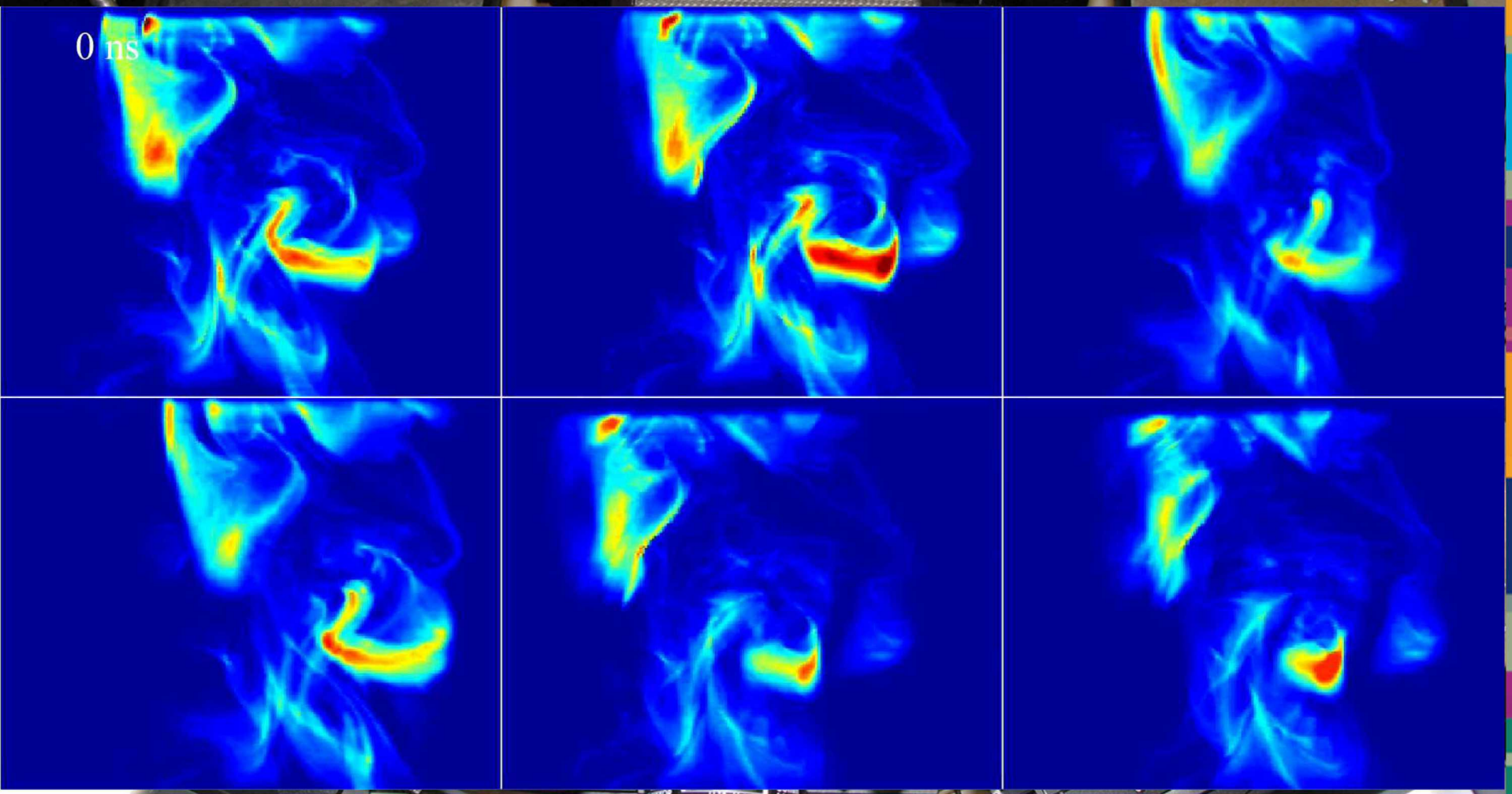
Tomographic Reconstruction of Prompt LII Intensity by Meyer, Halls, Jiang, Slipchenko, Roy, and Gord, 2016

3D TiRe-LII Experimental Configuration (Spring 2019)




600 ± 25 nm
bandpass
Views 3 & 4
Views 1 & 2
Views 5 & 6

Raw Data (pseudocolor)

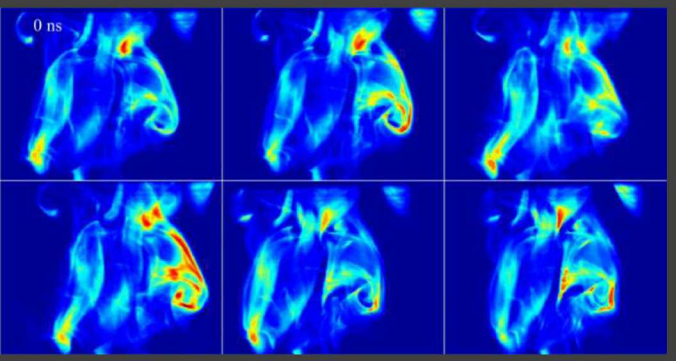


Views 3 & 4

Views 1 & 2

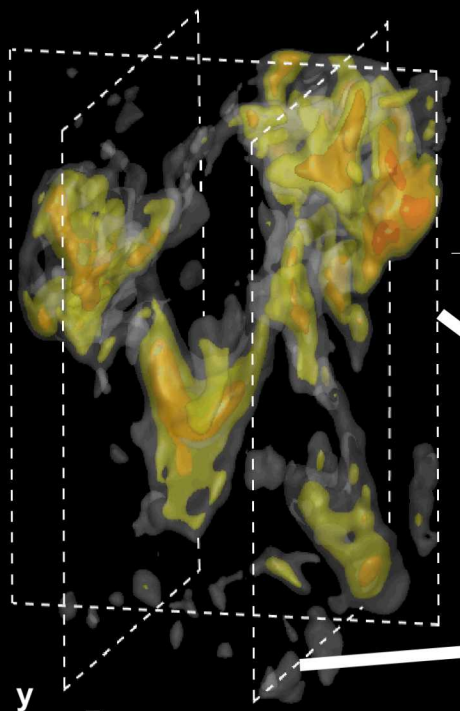
Views 5 & 6

Tomographic Reconstruction Performed with LaVision FastMART

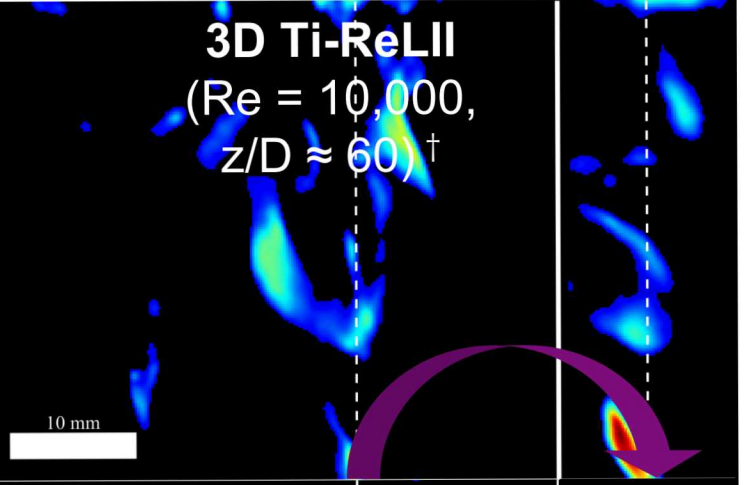


*With Daniel Guildenbecher, Ben Halls, Daniel Richardson, Emre Cenker, Ellen (Yi) Chen

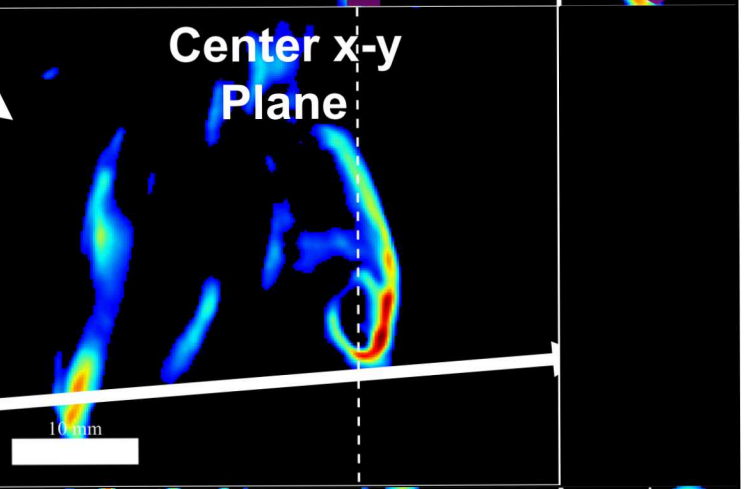
2D vs 3D Tr-ReLII

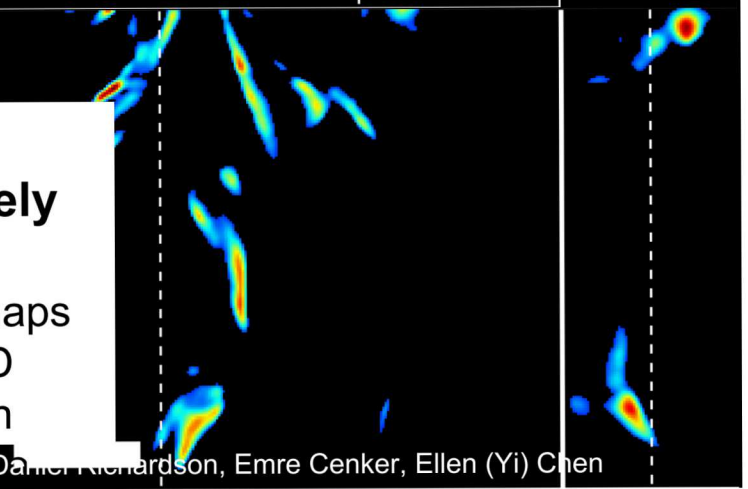


3D Ti-ReLII
(Re = 10,000,
z/D ≈ 60) †

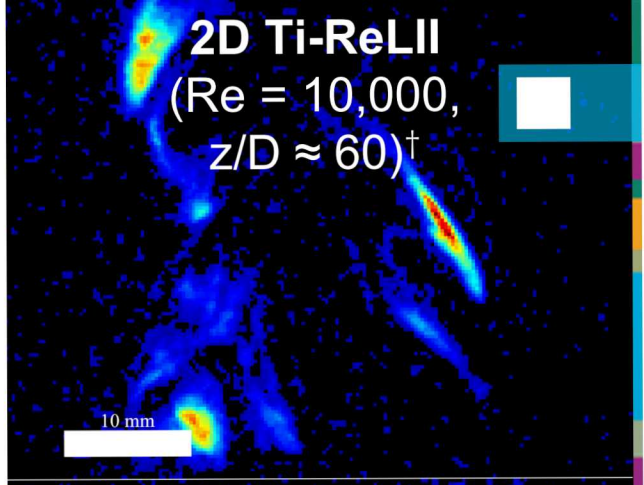


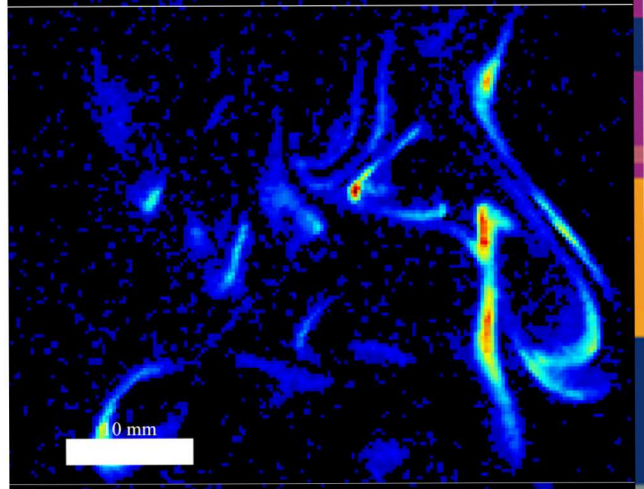
Center x-y Plane

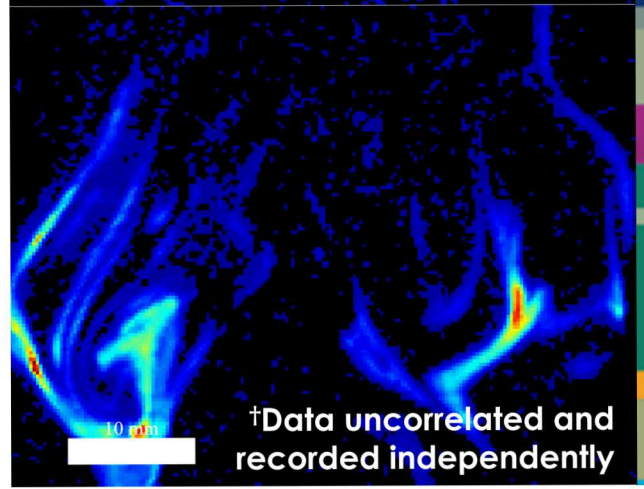




2D Ti-ReLII
(Re = 10,000,
z/D ≈ 60)†







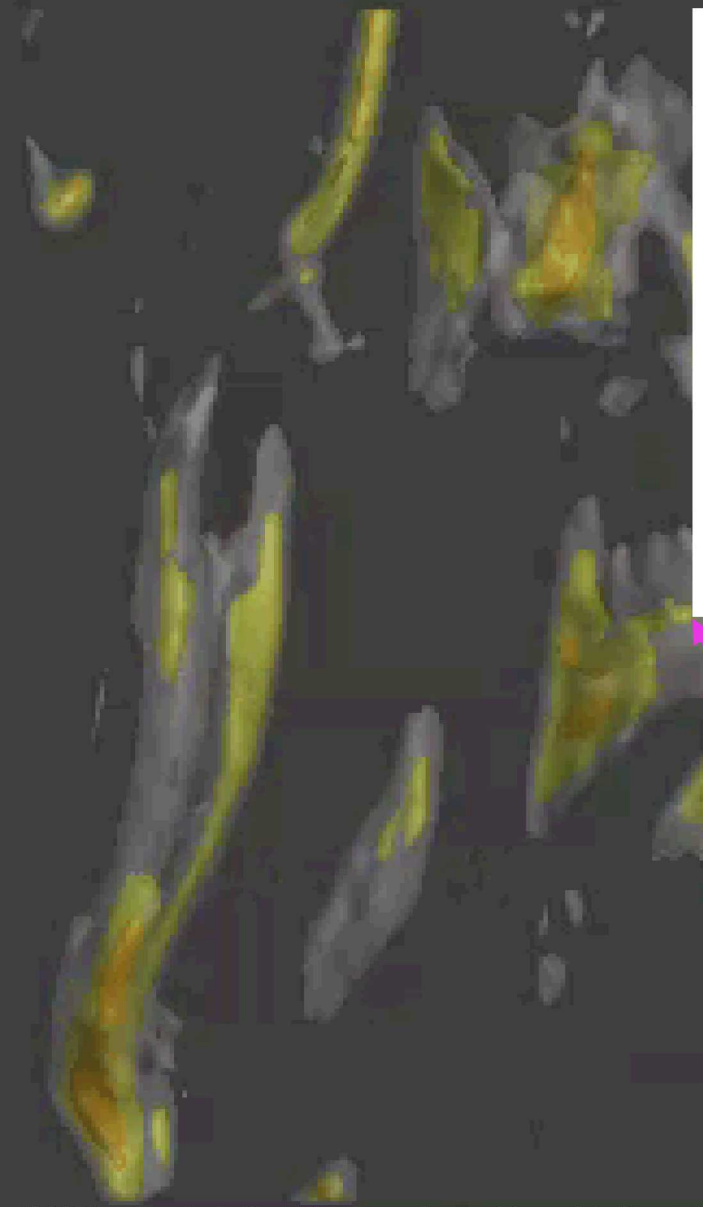
Reconstructed Structures Qualitatively Match 2D Data

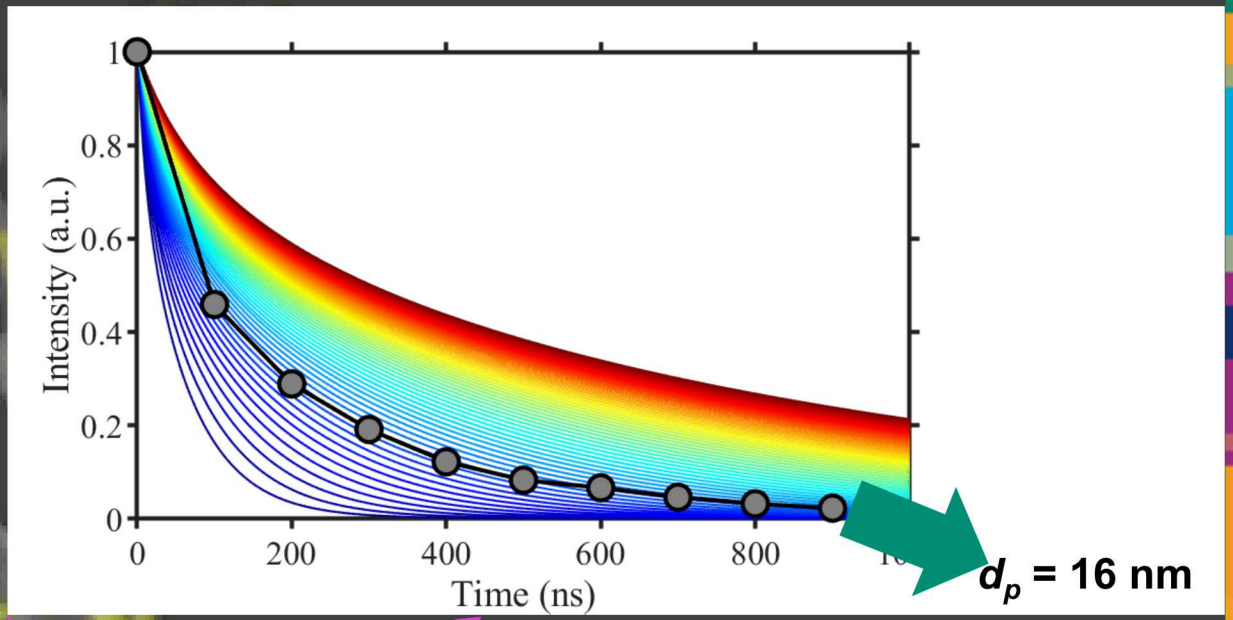
- Spatial Resolution Perhaps Slightly Degraded vs 2D
- Out-of-Plane Resolution

†Data uncorrelated and recorded independently

*With Daniel Guildenbecher, Ben Halls, Daniel Richardson, Emre Cenker, Ellen (Yi) Chen

Every Voxel Measures a Temporal Decay



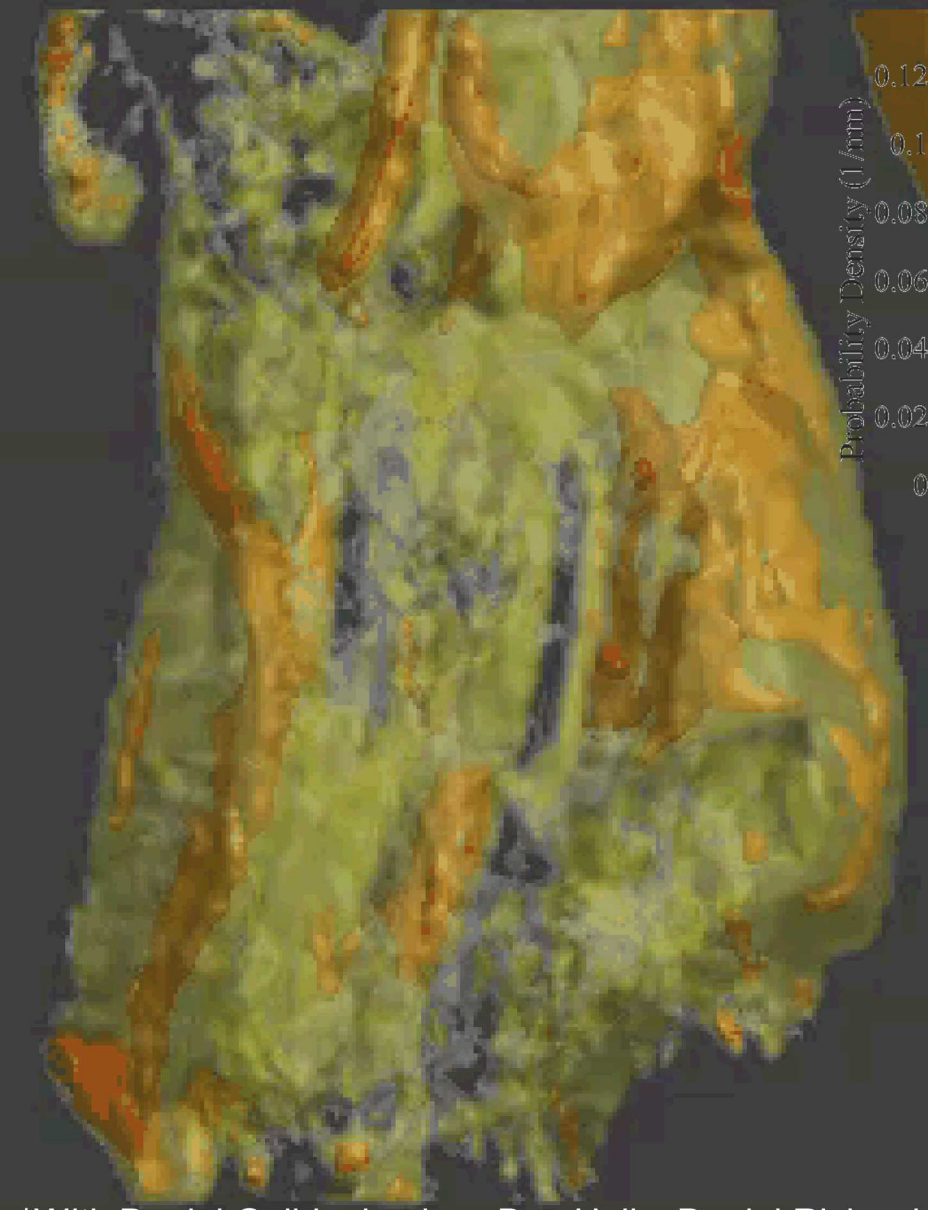


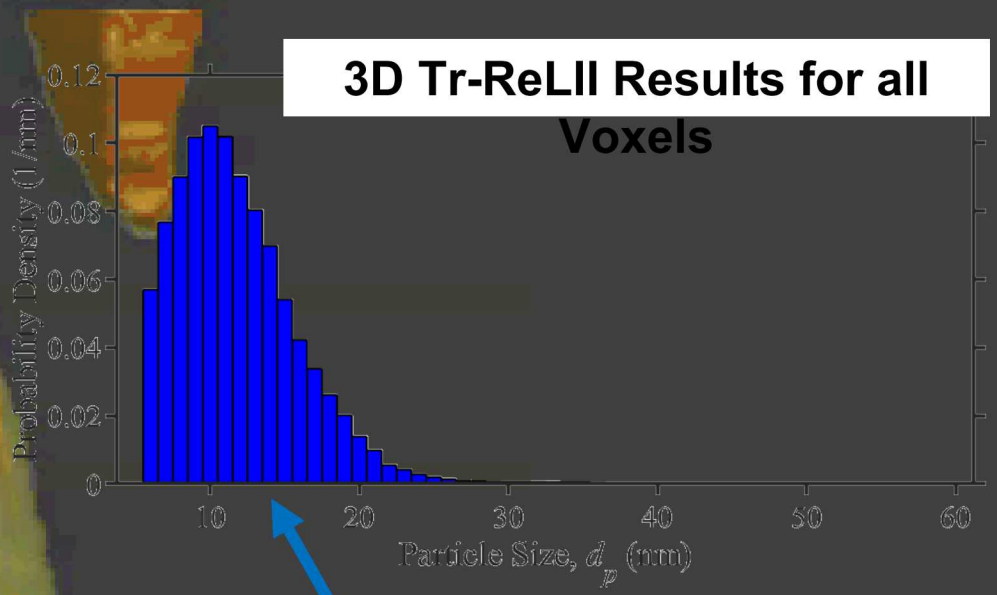
LII Model from Emre

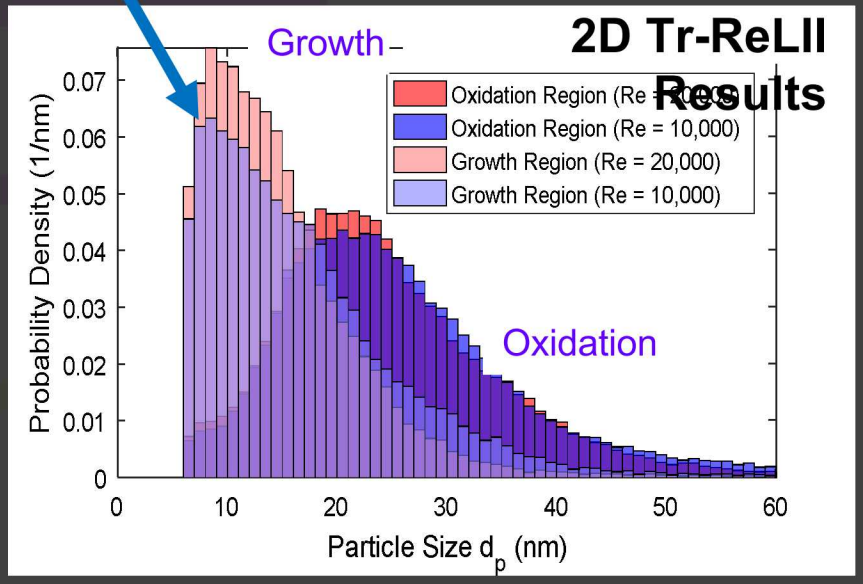
Gas temperature	1550 K
Pressure	0.84 bar (5000 ft)
Laser fluence	0.150 J/cm^2
$E(m)$	0.3
TAC	0.37
Aggregate size	30
Time domain	4800 ns
Detection band	575 – 625 nm
Bath-gas heating	On (f_v = 6 ppm)

*With Daniel Guildenbecher, Ben Halls, Daniel Richardson, Emre Cenker, Ellen (Yi) Chen

Primary Particle Size Measurements (*Re* = 10,000; z/D ≈ 60)

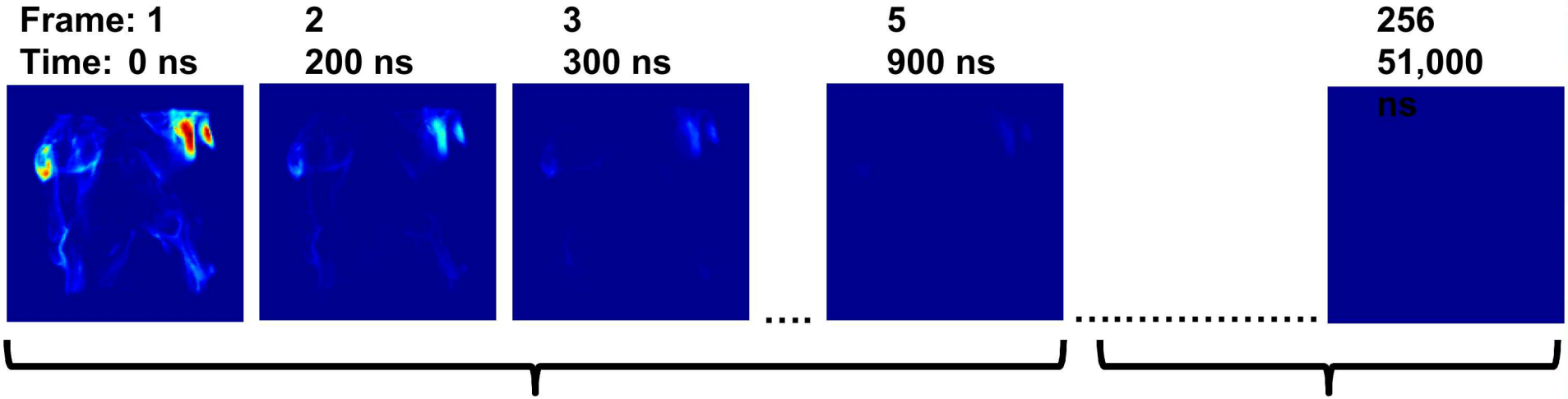






*With Daniel Guildenbecher, Ben Halls, Daniel Richardson, Emre Cenker, Ellen (Yi) Chen

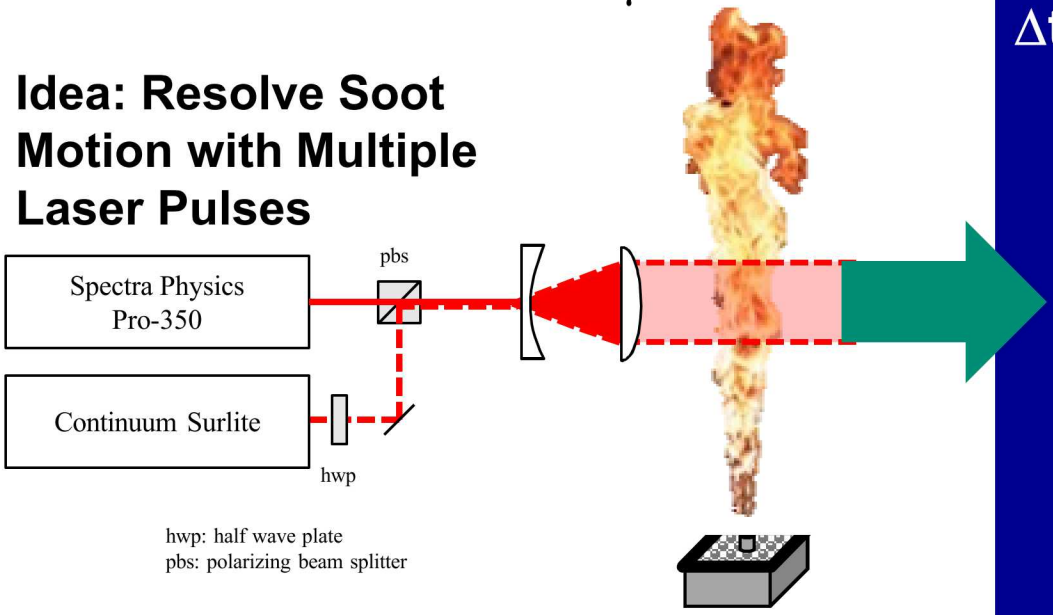
The MHz Camera has a Fixed Number of Frames Regardless of Framerate or Resolution

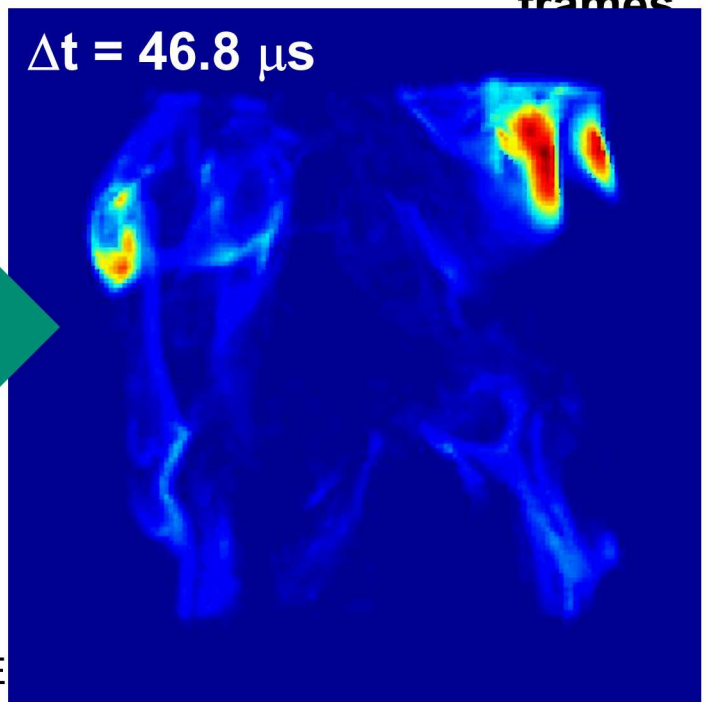


2MHz Ti-ReLII Signal Contained in ~1 μs

50 μs of blank frames

Idea: Resolve Soot Motion with Multiple Laser Pulses





*With Daniel Guildenbecher, Ben Halls, Daniel Richardson, E

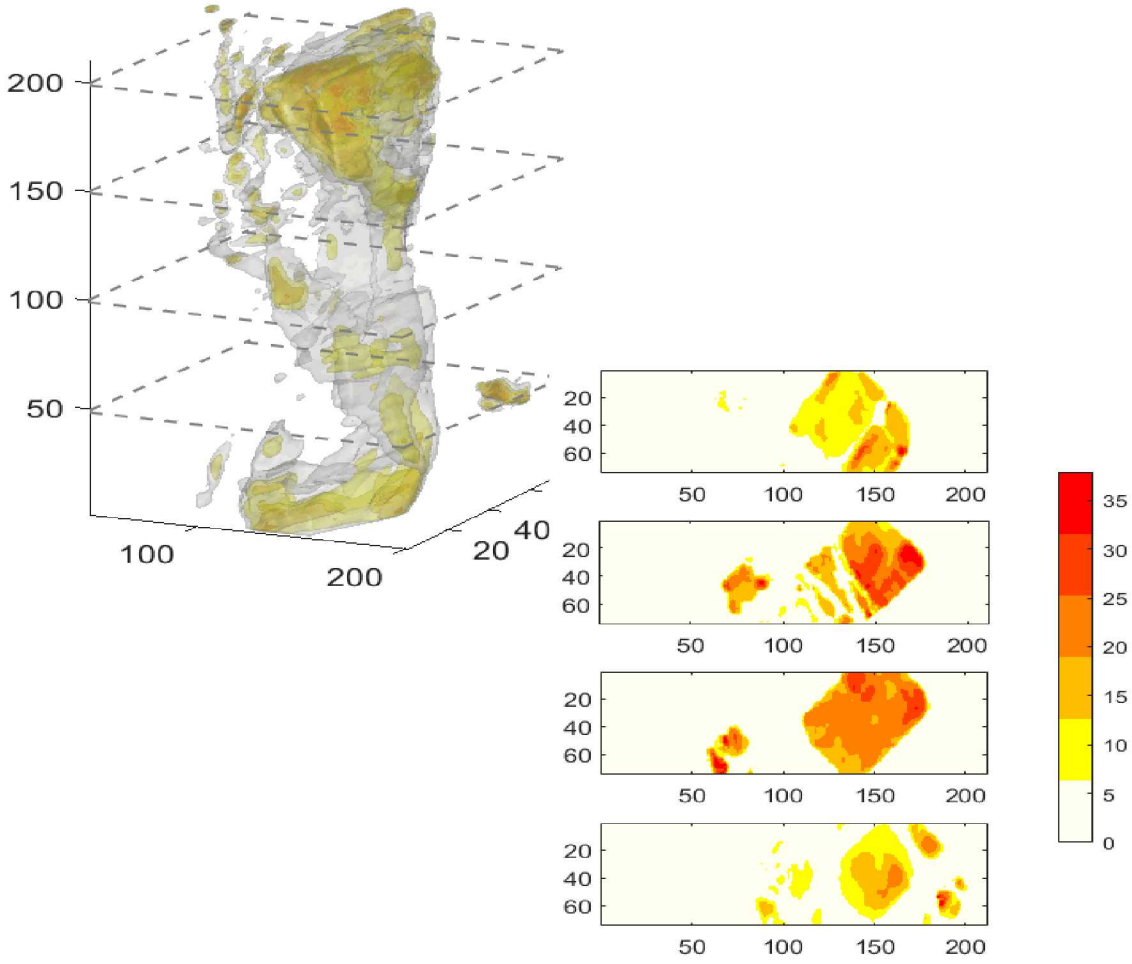
Conclusions

Volumetric soot particles sizing has been demonstrated.

Results agree with several models and the planar data of Chen et al.

Future work includes:

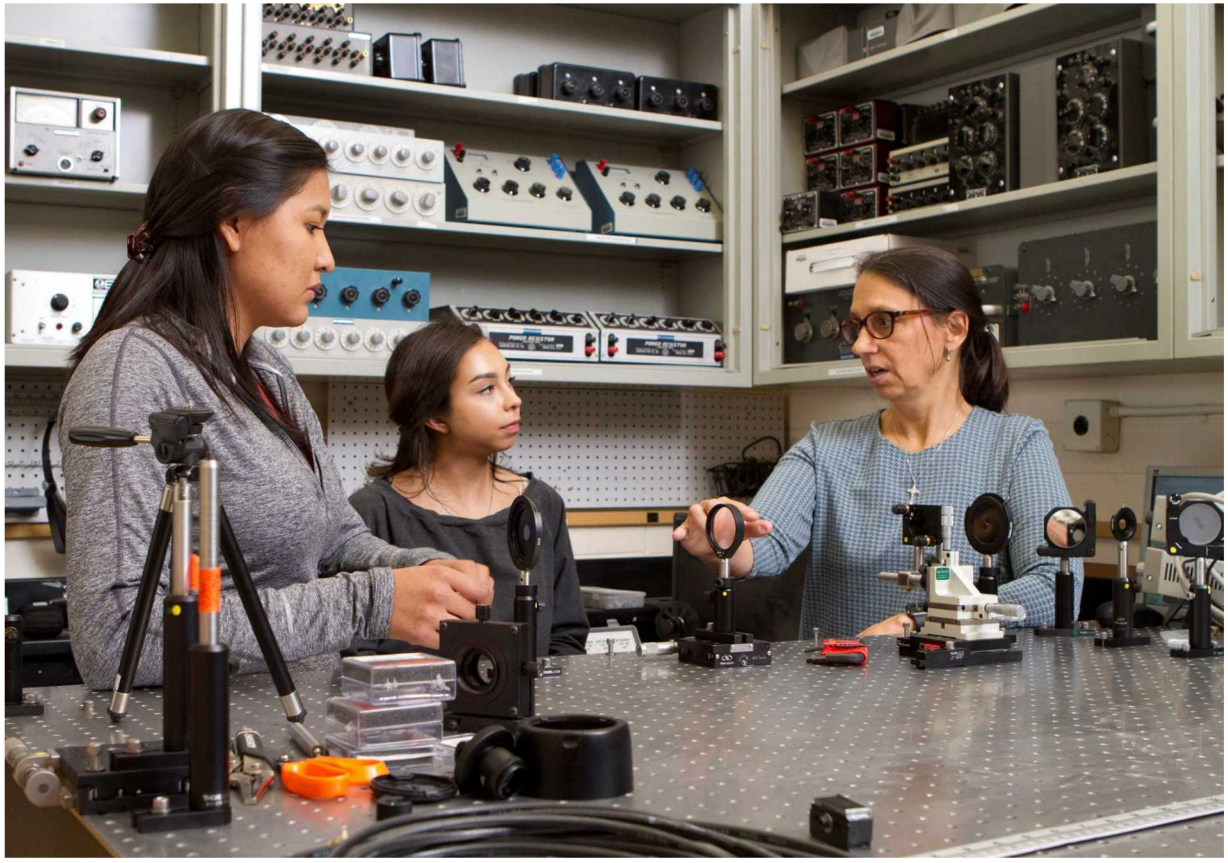
- Improving camera-laser synchronization
- Repeating measurements at several heights above the burner and Reynolds numbers
- Potentially adding temperature & volume fraction measurements
- Improving the velocity



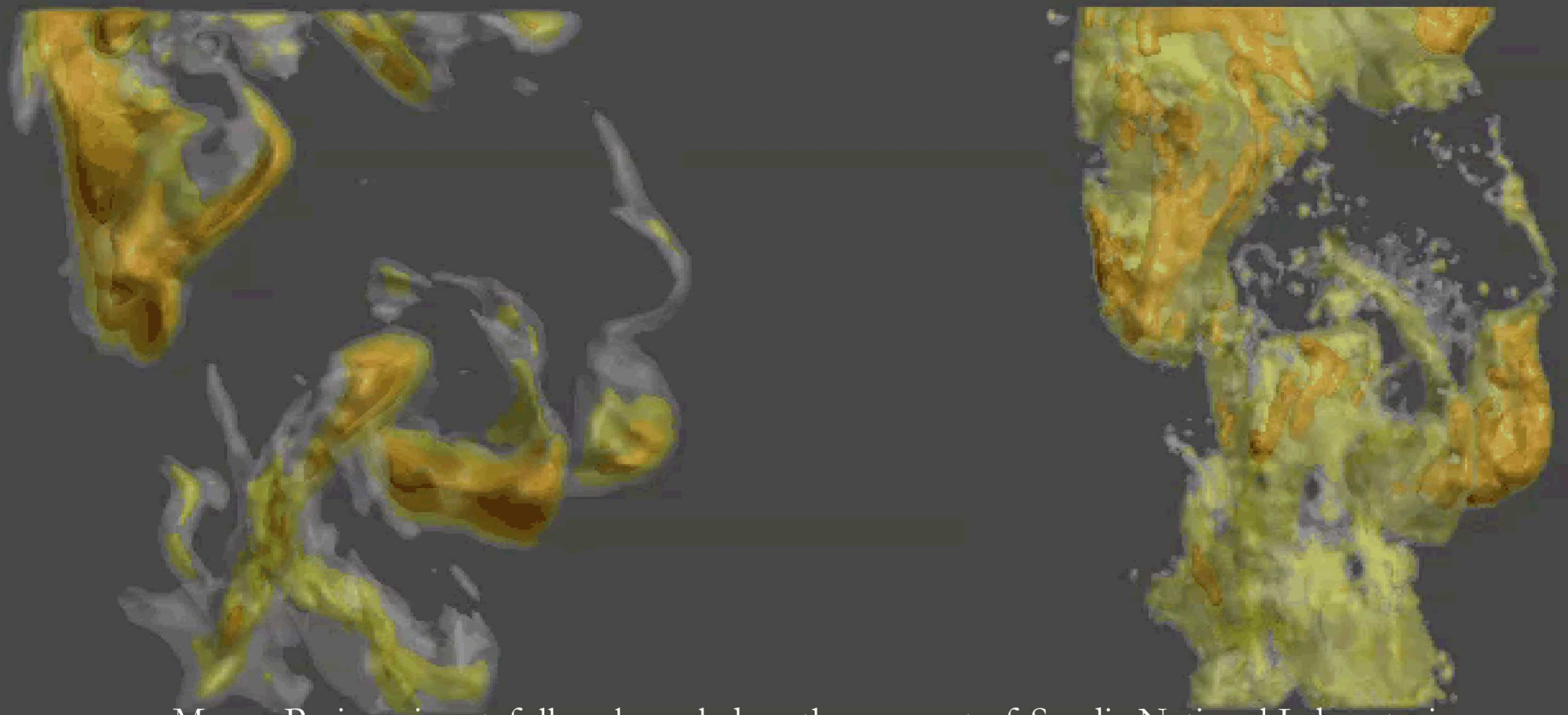
Broader Impacts

The ongoing research at Sandia, New Mexico help us understand combustion processes in extreme environments

In my case, the added bonus is I can use these research experiences to transform the lives of my students at Fort Lewis College



Questions?



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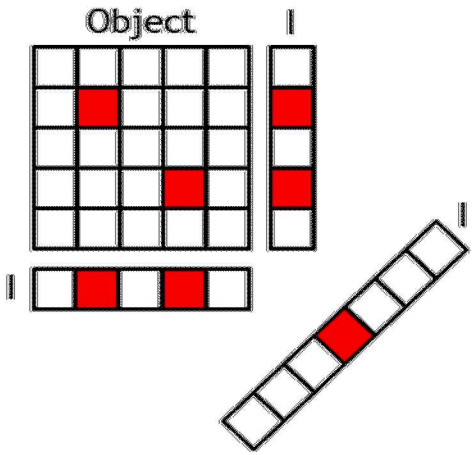
Tomographic Reconstruction

Object & Images



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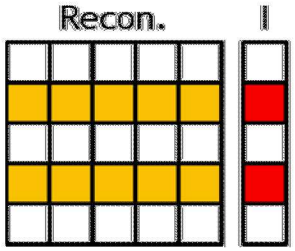

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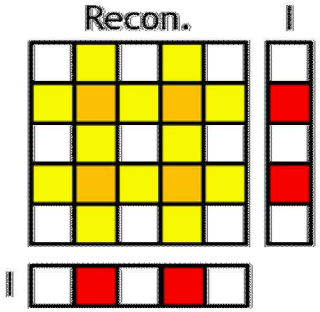

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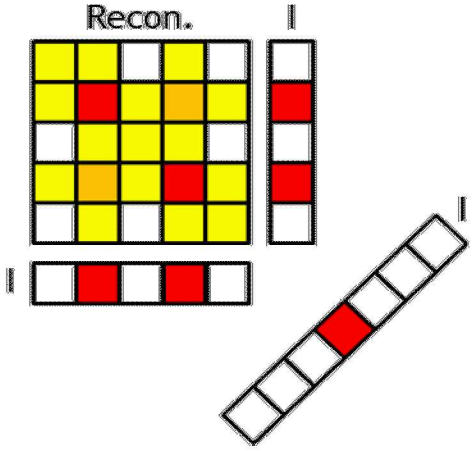
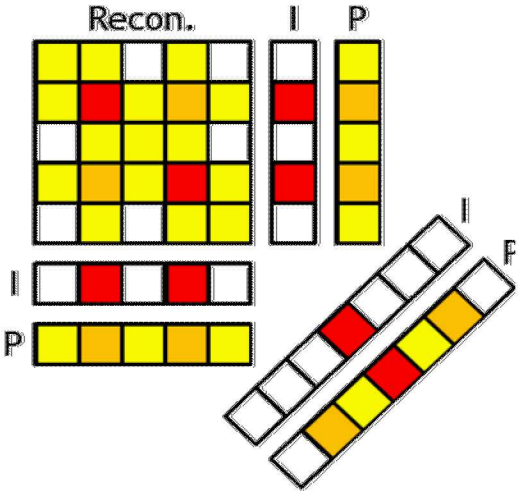
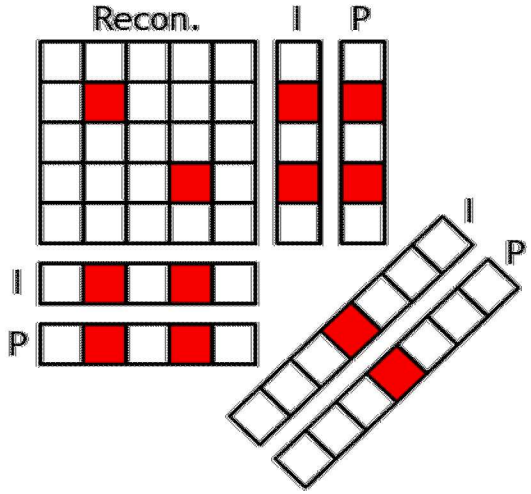


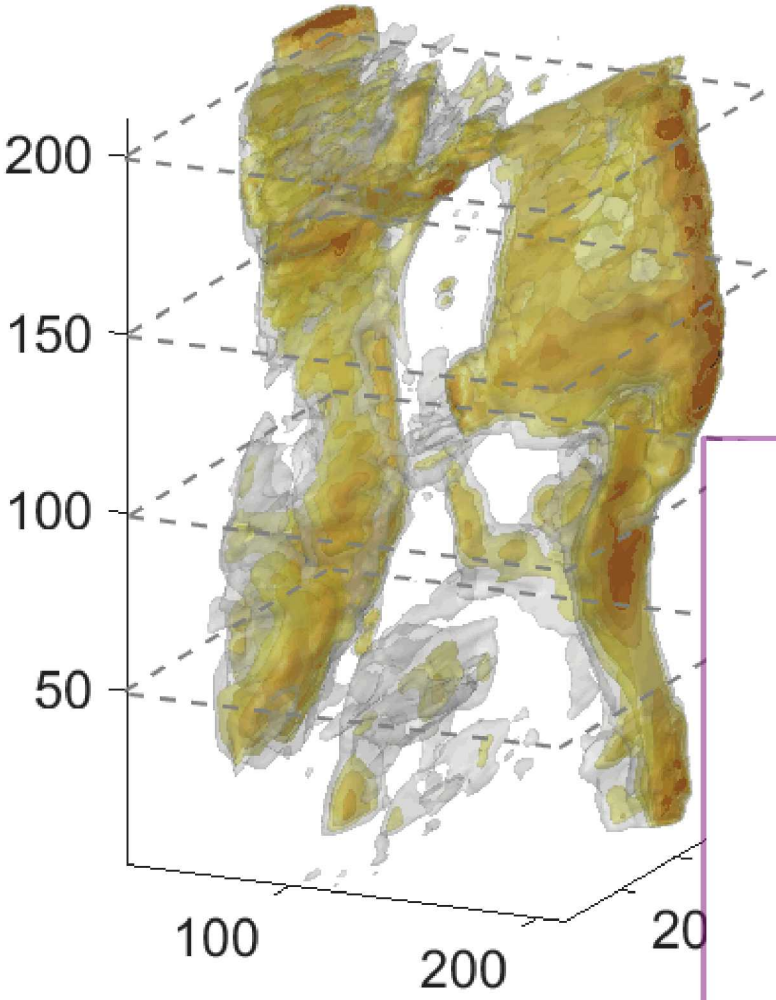
Guessed Images

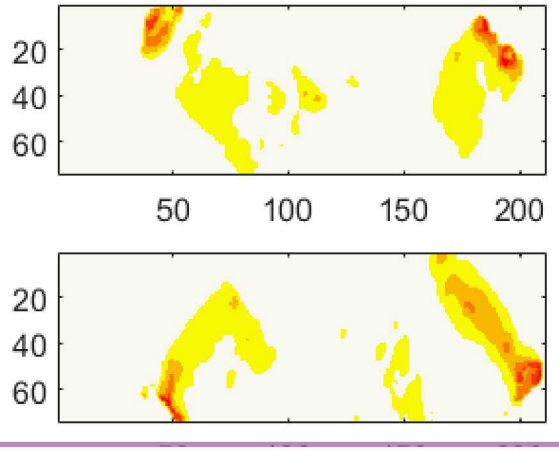


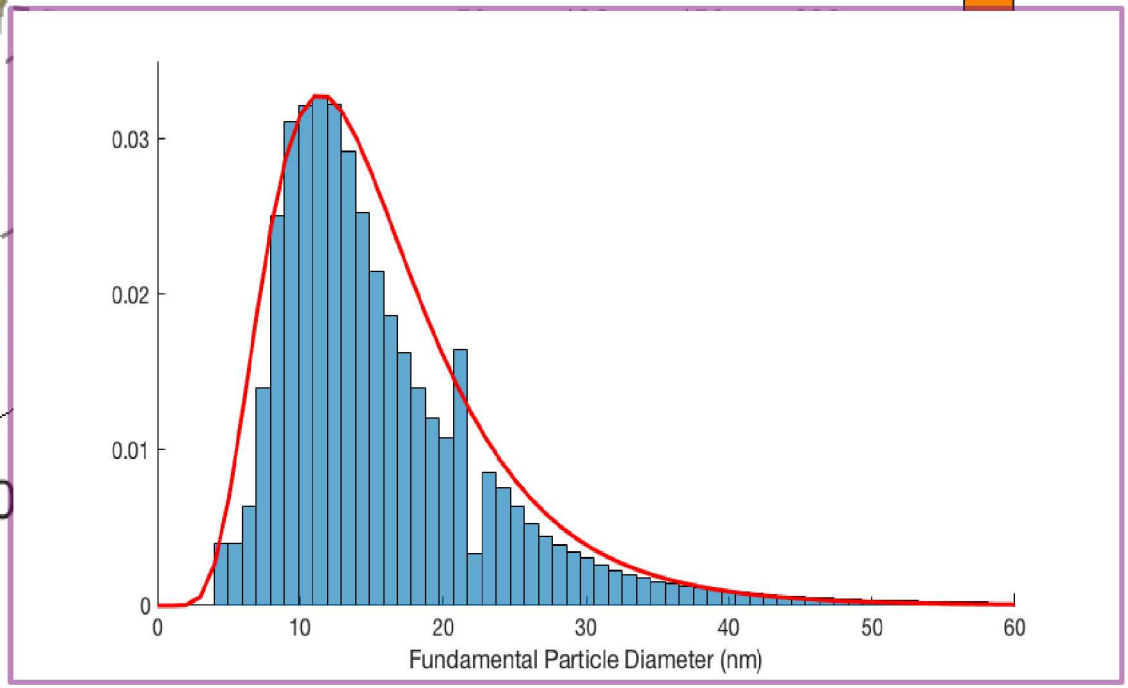
Iterative Recon.



Results







*With Daniel Guildenbecher, Ben Halls, Daniel Richardson, Ellen (Yi) Chen, ???

Modeling

Particle sizing with LII modeling:

Soot particles are heated via absorption of light from a laser pulse to temperatures well above the flame temperature and the subsequent blackbody radiation is recorded during the heat-up and cooling phase. Small particles cool down faster than large ones due to their larger surface-to-volume ratio and therefore provide signal with different decay times. Quantitative particle-size information can be obtained from a best-fit comparison of the temporal signal decay and simulations based on the particles' energy and mass balance equations.

Numerically solve heat and mass balance equation for a single particle:

$$\frac{dM}{dt} = \left(\frac{dM}{dt}\right)_{sub} + \left(\frac{dM}{dt}\right)_{ox}$$

$$\frac{dU_{int}}{dt} = \dot{Q}_{abs} + \dot{Q}_{rad} + \dot{Q}_{cond} + \dot{Q}_{sub} + \dot{Q}_{ox} + \dot{Q}_{ann} + \dot{Q}_{therm}$$

Details of our LII simulation tool:

4^{th} order Runge-Kutta numerical solution.

Levenberg-Marquardt non-linear least-squares fitting algorithm.

Accounts for local-gas heating.

Includes aggregate conduction shielding with bridging effects.

Temperature dependent density and specific heat.

Annealing mechanism was turned off.

Model input parameters were chosen to be values close to median of reported values in the literature for non-premixed flames.

Gas temperature	1750
Pressure	0.84 bar (5000 ft)
Laser fluence	0.15 J/cm^2
$E(m)$	0.3
TAC	0.37
Aggregate size	60
Time domain	3900 ns (after laser)
Detection band	575 – 625 nm
Bath-gas heating	On (f_v = 6 ppm)

Tab.1 Model input parameters

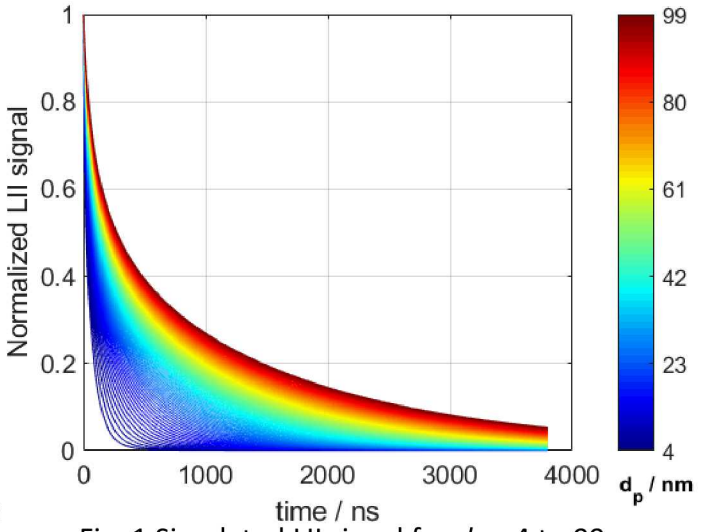
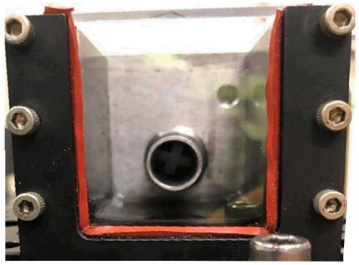


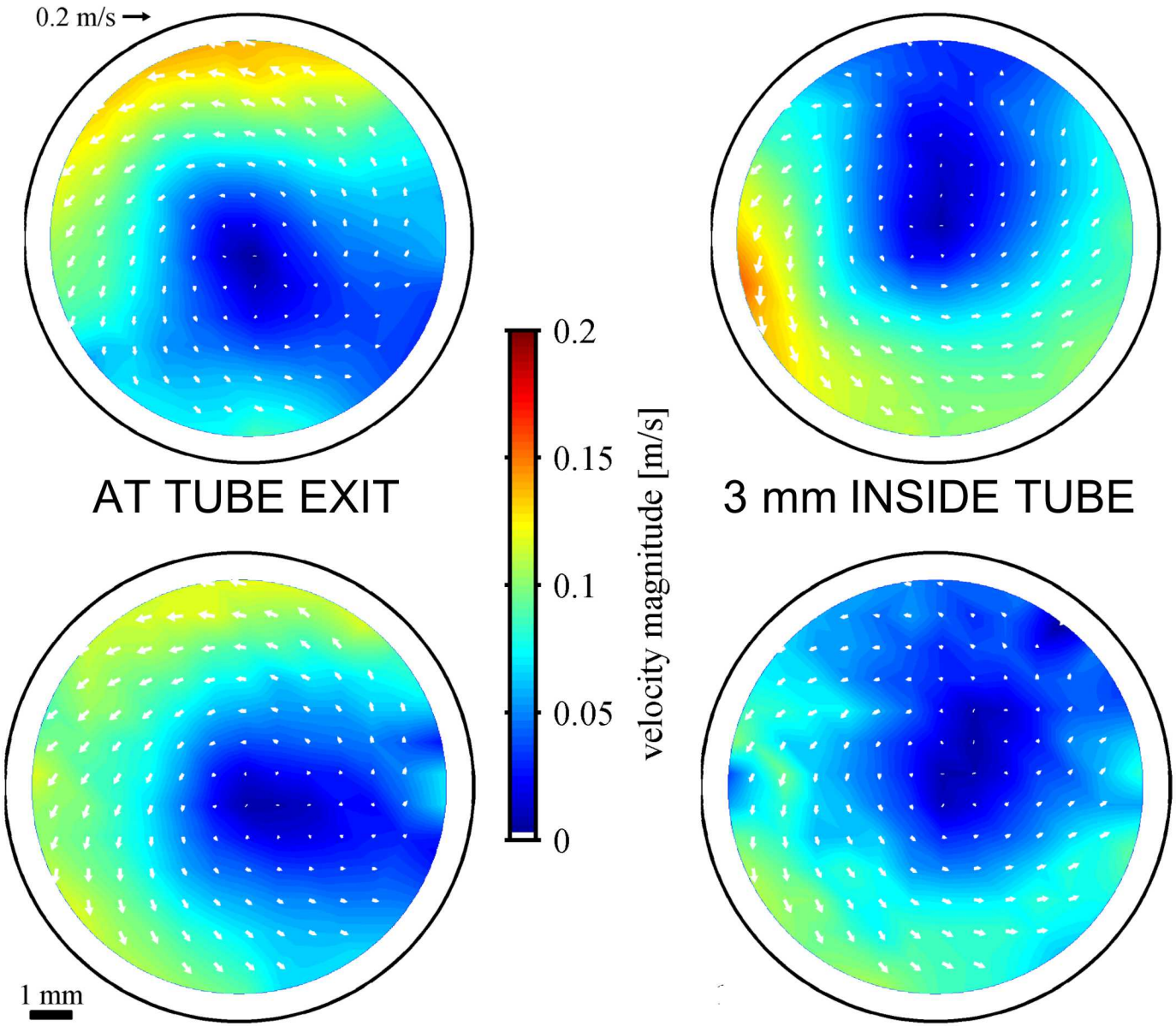
Fig. 1 Simulated LII signal for d_p = 4 to 99 nm

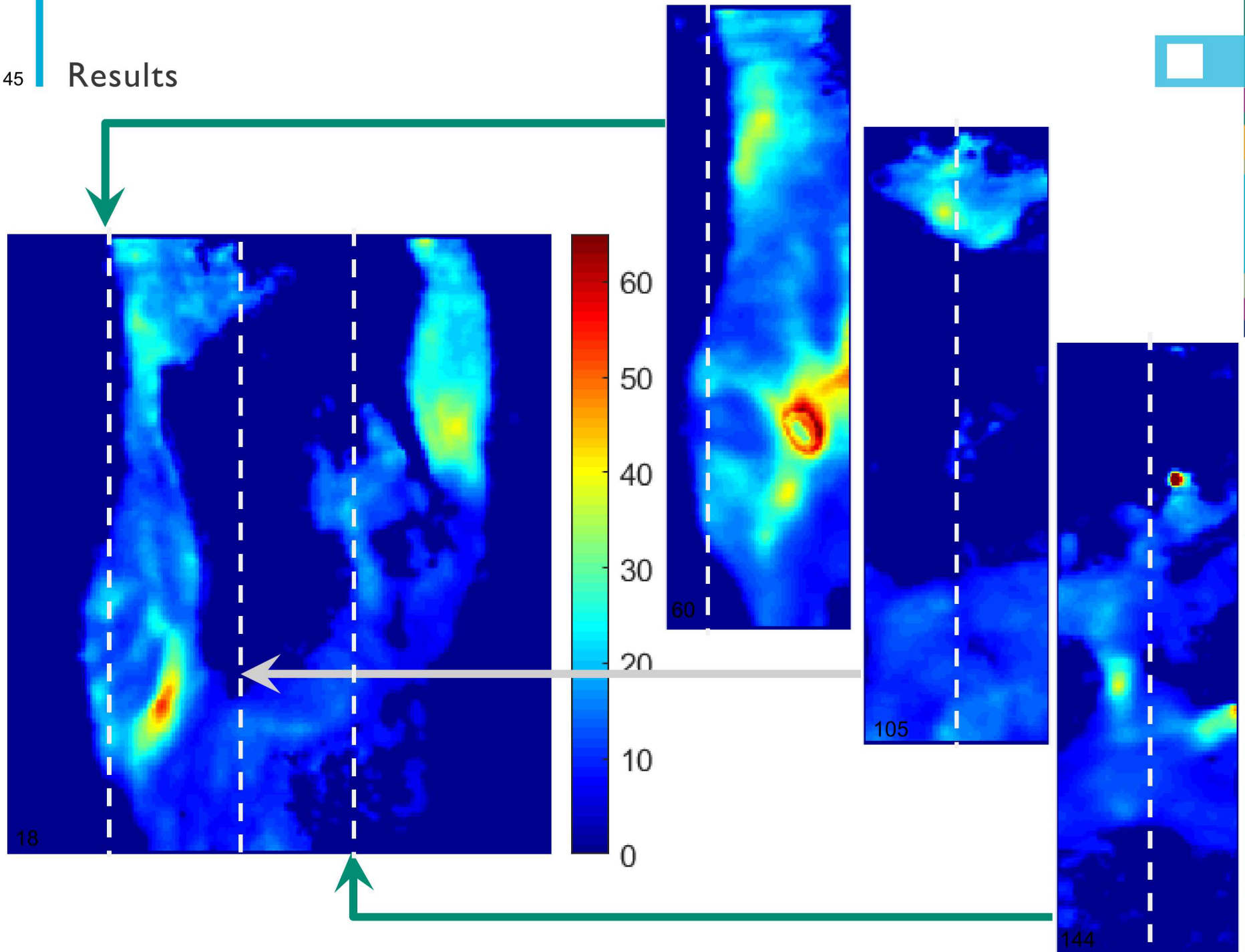
Measuring Internal Flow



Test Cell with Tube and Flow Swirler

Top Down View of Test Cell

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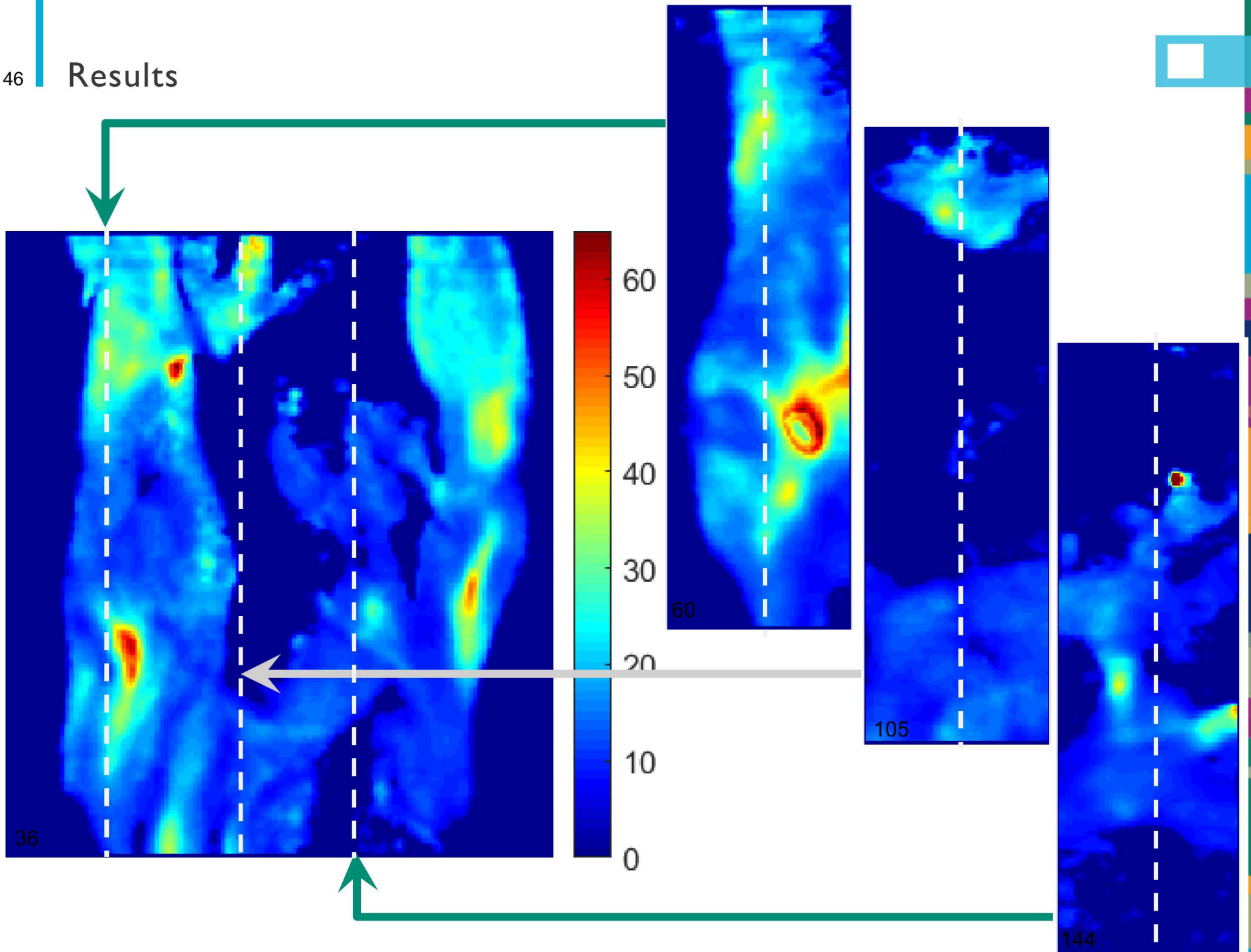
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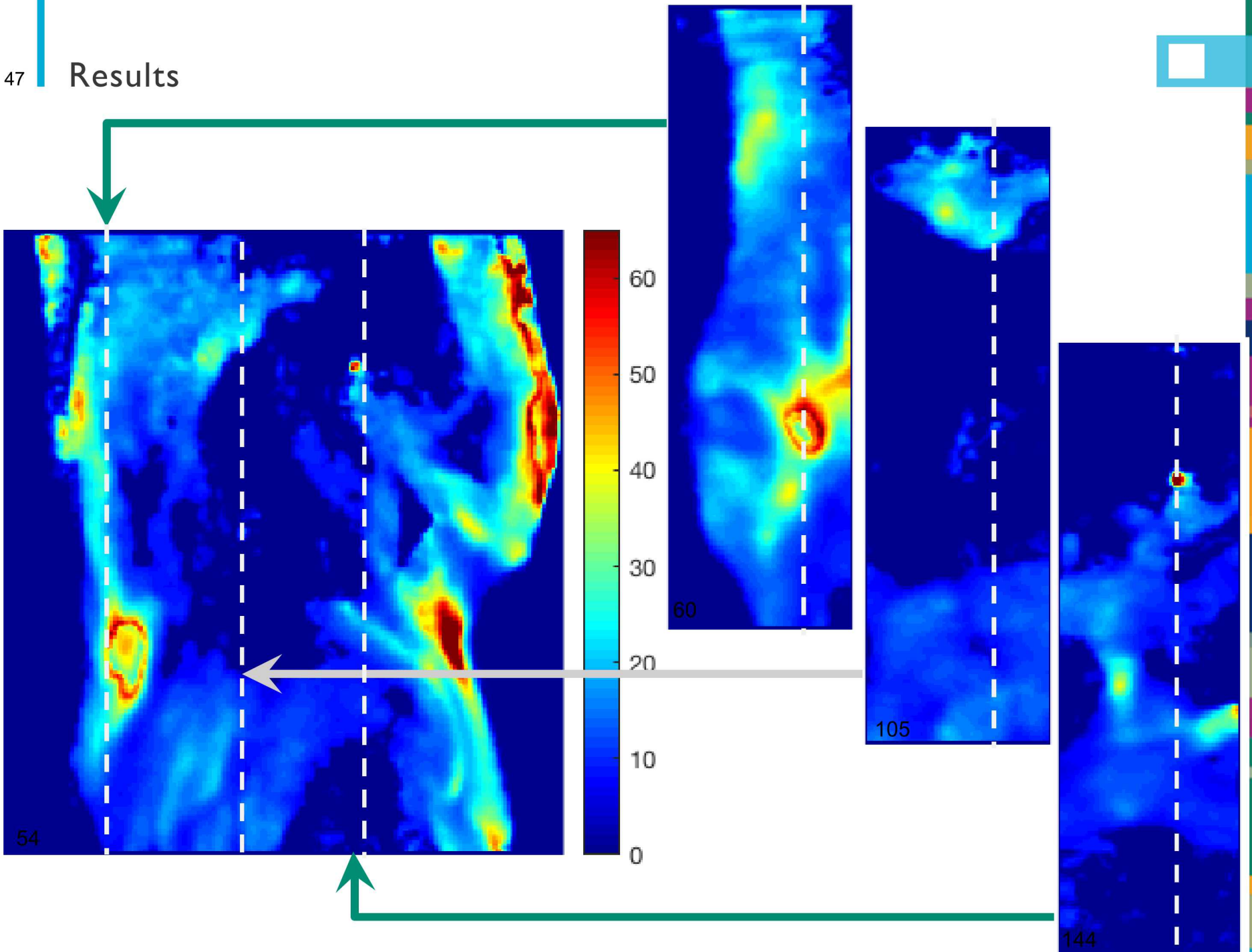
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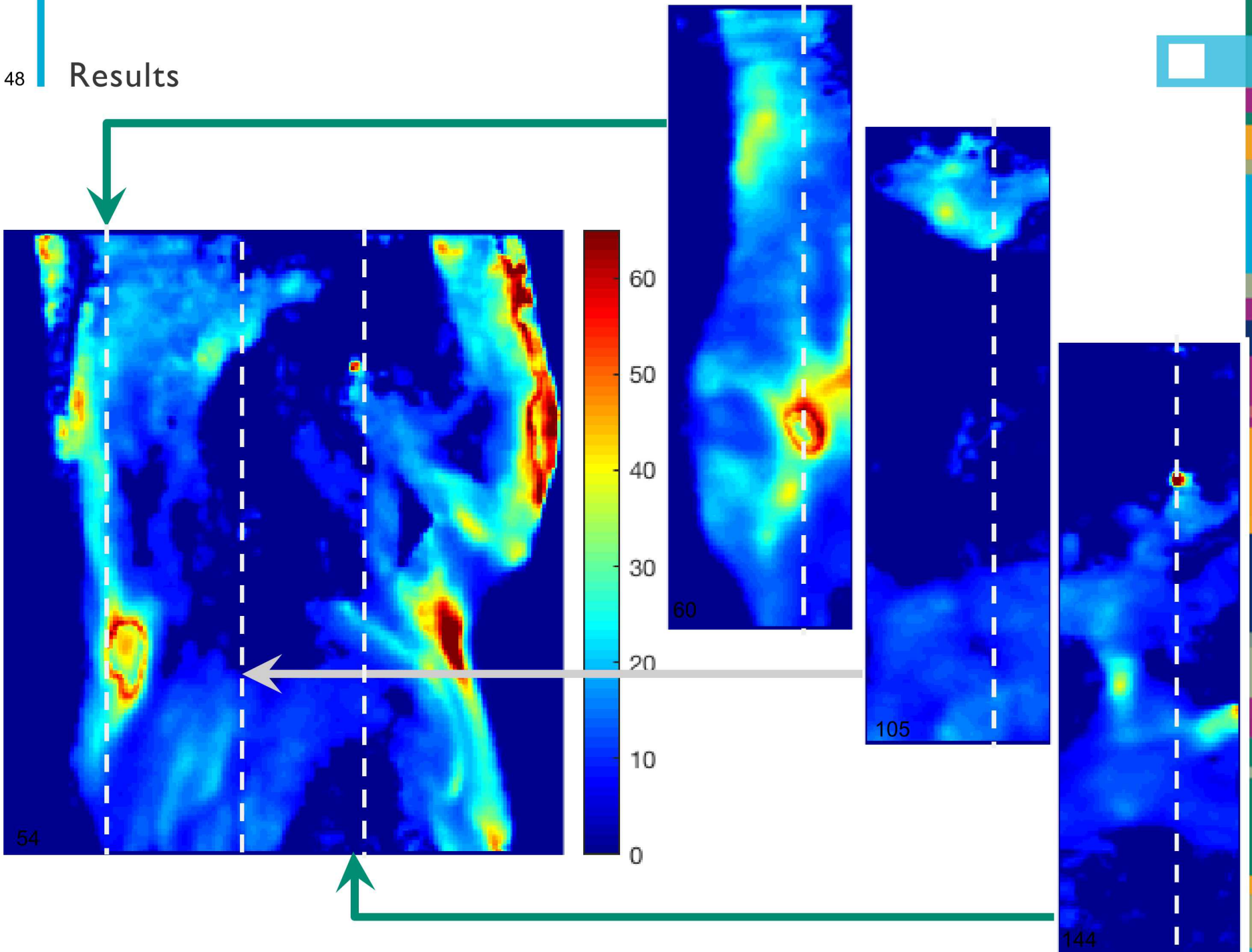
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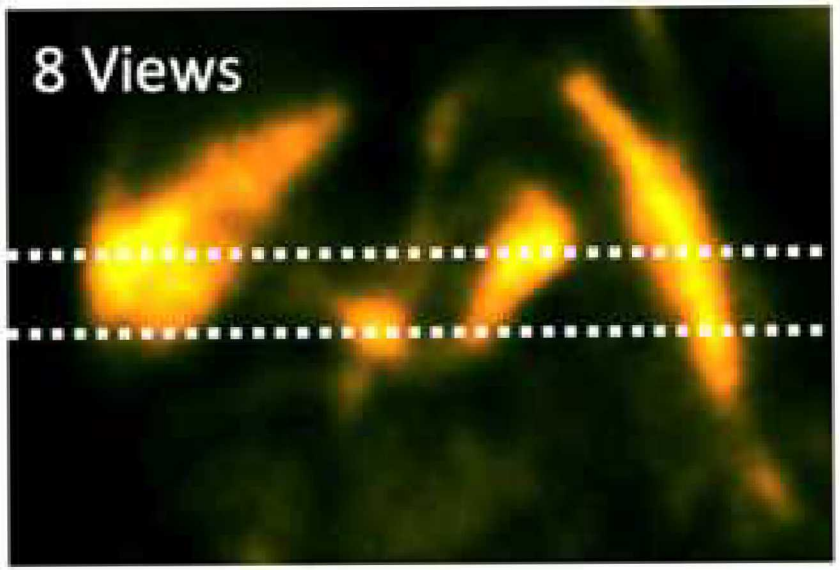

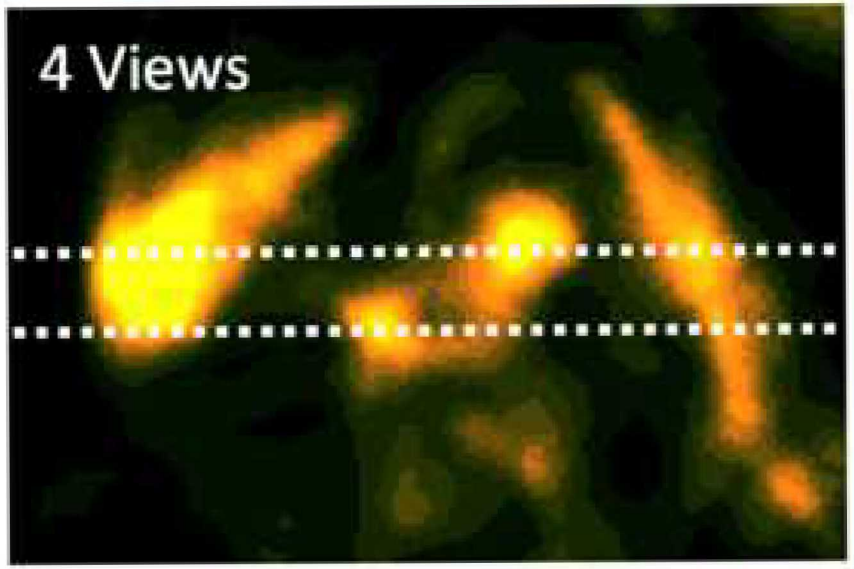

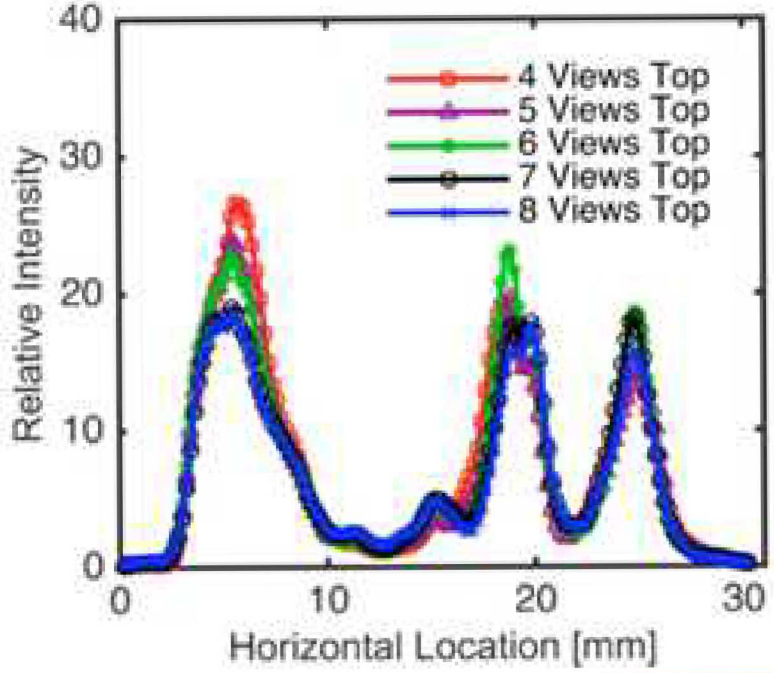

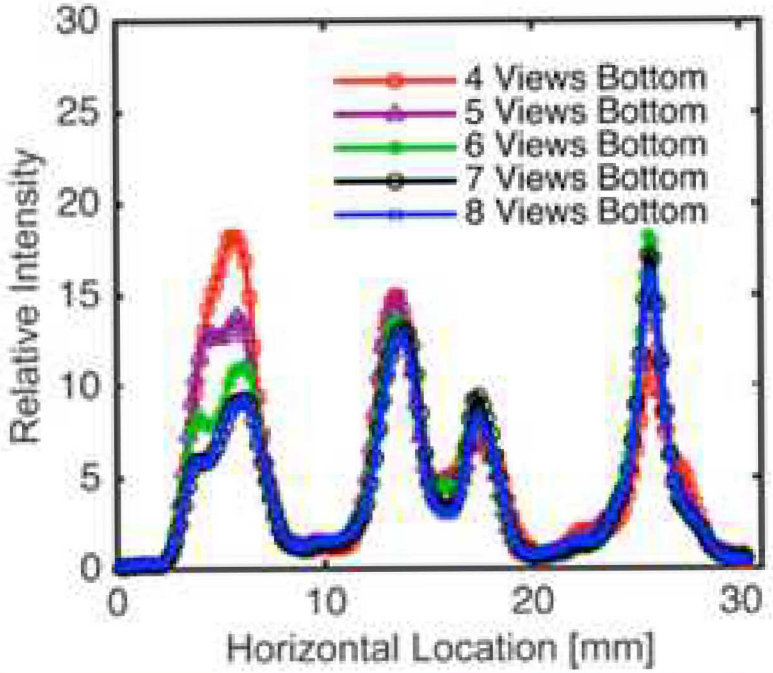

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