SAND2019-2995C

Experimental Imaging Diagnostics for Extreme Fire and Explosive Events at Sandia National Laboratories

PRESENTED BY

Daniel Guildenbecher

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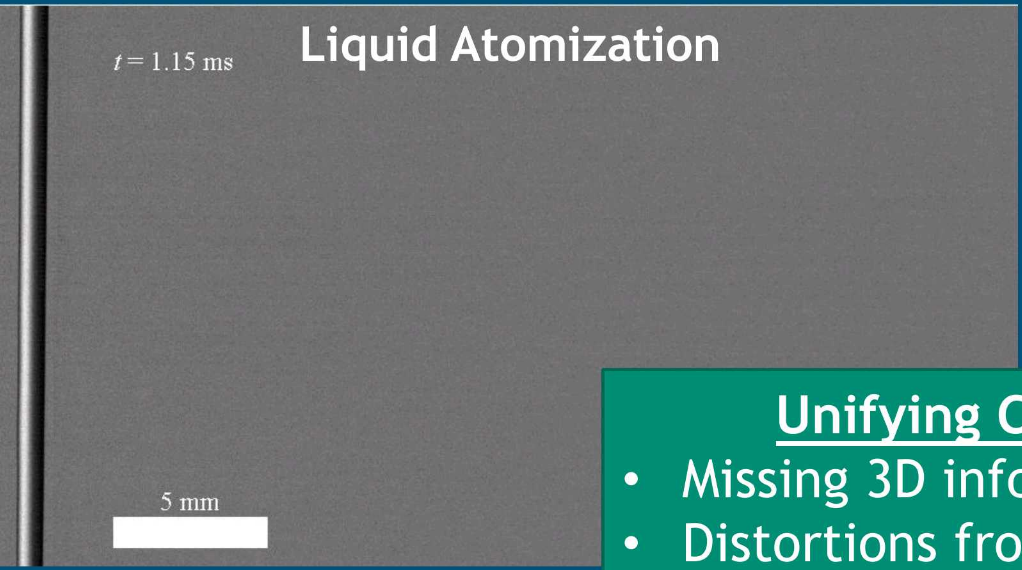
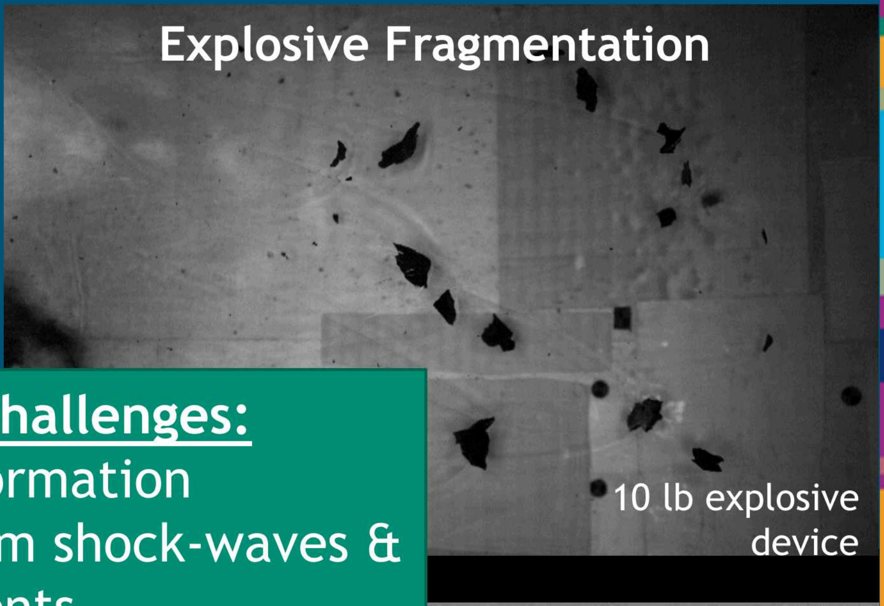
SAND2019-###

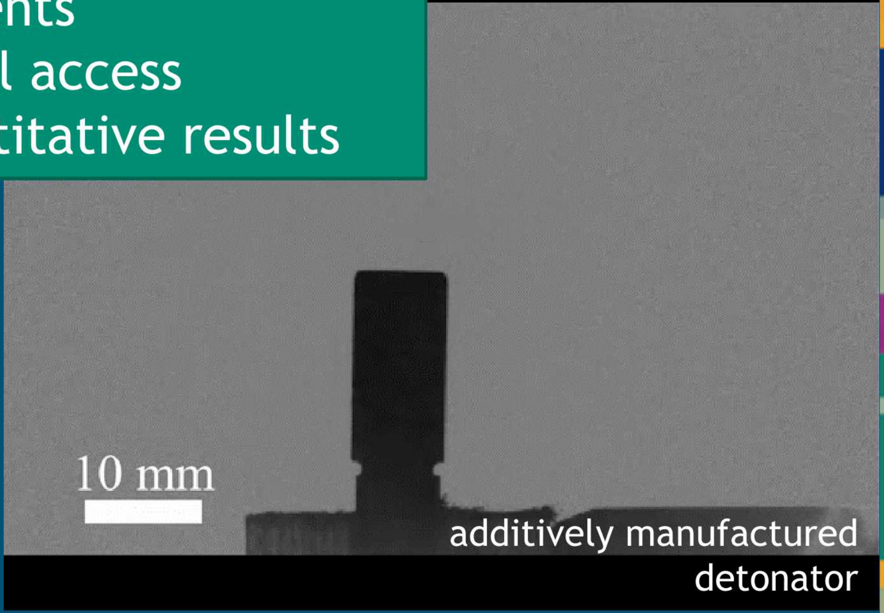
Diverse Applications, Common Challenges



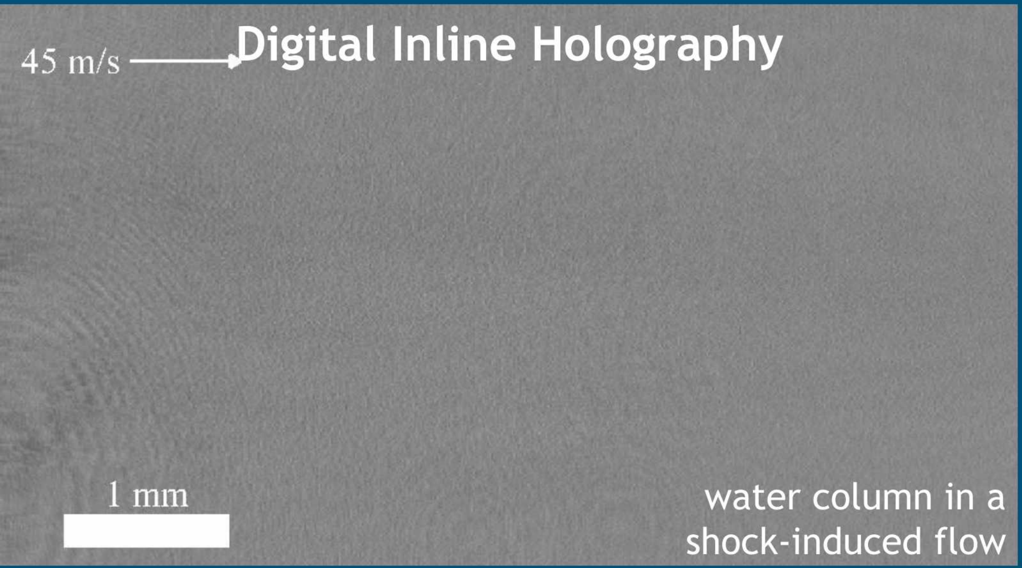


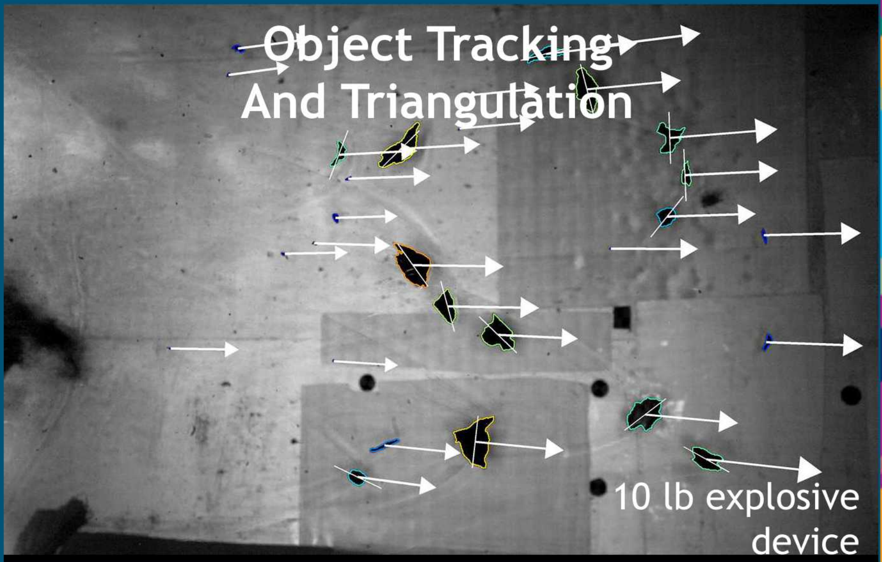
<u>Unifying Challenges:</u>

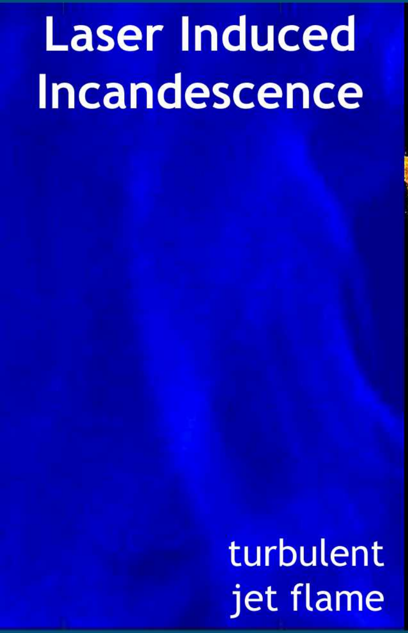
- Missing 3D information
- Distortions from shock-waves & thermal gradients
- Limited optical access
- Need for quantitative results

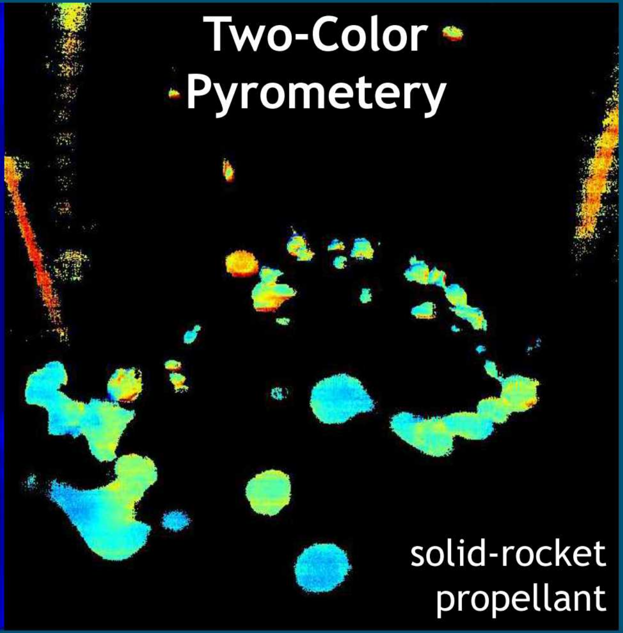


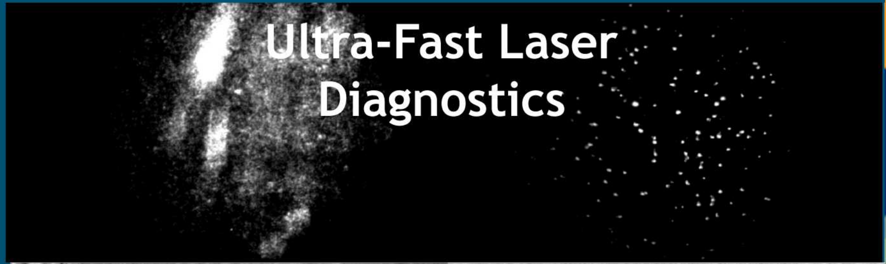
Measurements Require Advanced Diagnostics

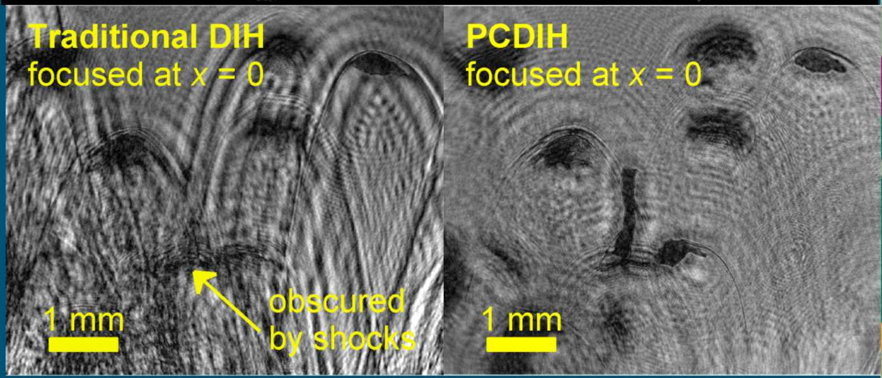












Acknowledgements

The work presented here is the results of a large, creative, and productive team whose contributions are gratefully acknowledged

Post-Docs: Ellen Chen, Kate Hoffmeister, Ed DeMauro, Caroline Winters

Students: Luke Engvall, Elise Hall, Spencer Ketchum, Michael Smyser, Anthony McMaster, Patrick Sanderson, Aaron Turbin, William Sealy, Samuel Albert, and many others….

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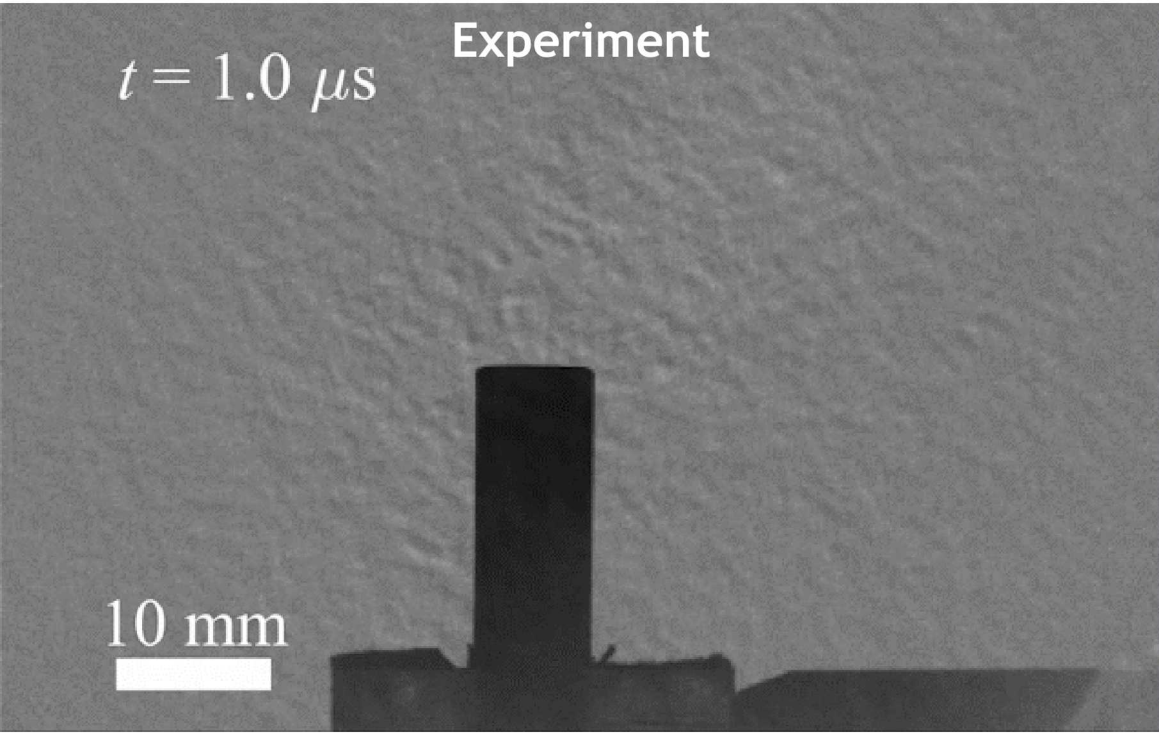
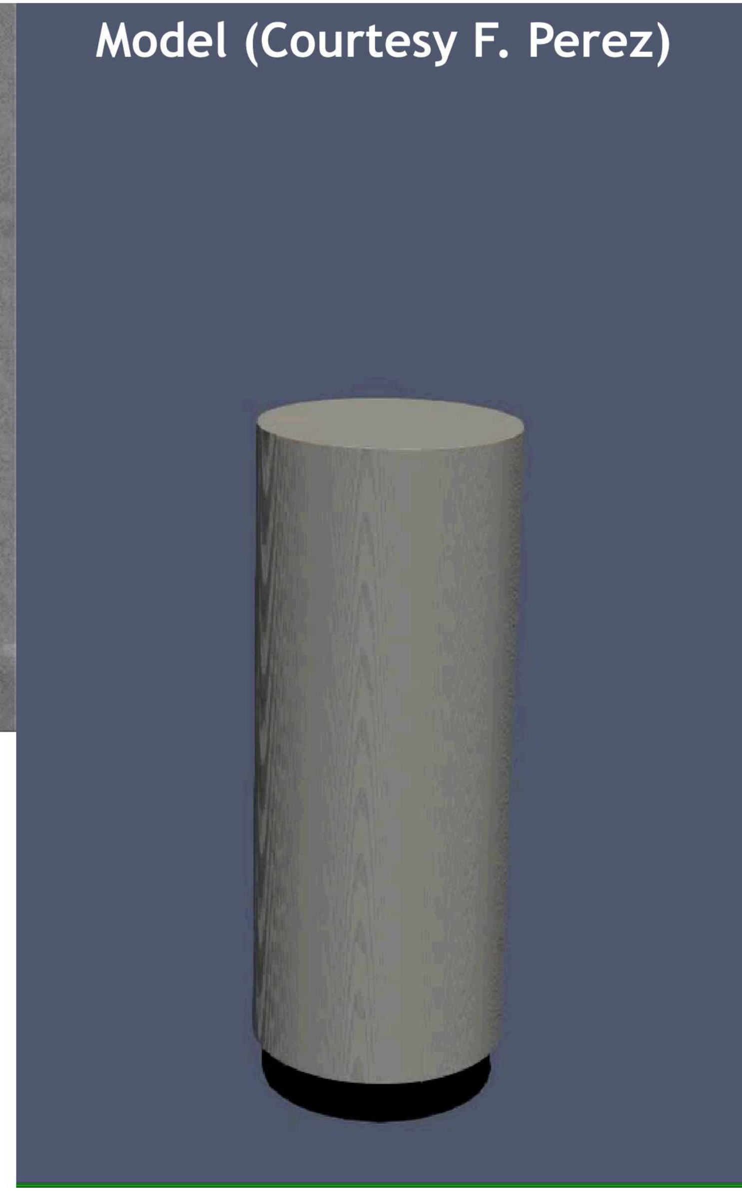
Collaborators: Sean Kearney, Justin Wagner, Daniel Richardson, Ben Halls, Kyle Lynch, Steve Beresh, Katya Casper, Joe Olles, Phil Reu, Tim Miller, Steve Attaway, Mark Anderson, Enrico Quintana, John Korbin, Martin Nemer, Marcia Cooper, John Hewson, Marco Arienti, Emre Cenker, Scott Skeen, Chris Shaddix, David Kittell, Walt Gill, Bill Sweat, Megan Paciaroni, Patrick Bowden, John Yeager, Ephraim Washburn, Jian Gao, Brian Thurow, Jenna Klemkowsky, Tim Fahringer, Jun Chen, Paul Sojka, Steve Son, Michael Powell, Emre Gunduz, Varun Kulkarni, Weixiao Shang, Travis Sippel, James Michael, Mikhail Slipchenko, Naibo Jiang, Jason Mance, Sukesh Roy, Nicholas Niemiec, Waruna Kulatilaka, Zach Falgout, Cpt. Alex LeSieur, Maj. Andrew Lingenfelter, and many others….

Fragmentation Models Need Experimental V&V





Measurement needs include:

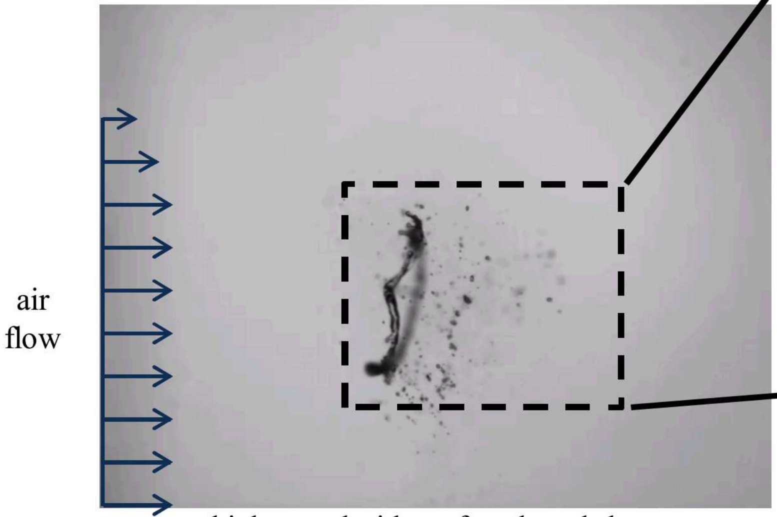
- Initial case deformation → DIC
- Breakup dynamics → X-ray
- Sizes and Velocities → Fragment Tracking

*With Frank Perez, Andrew Thompson, Steve Attaway

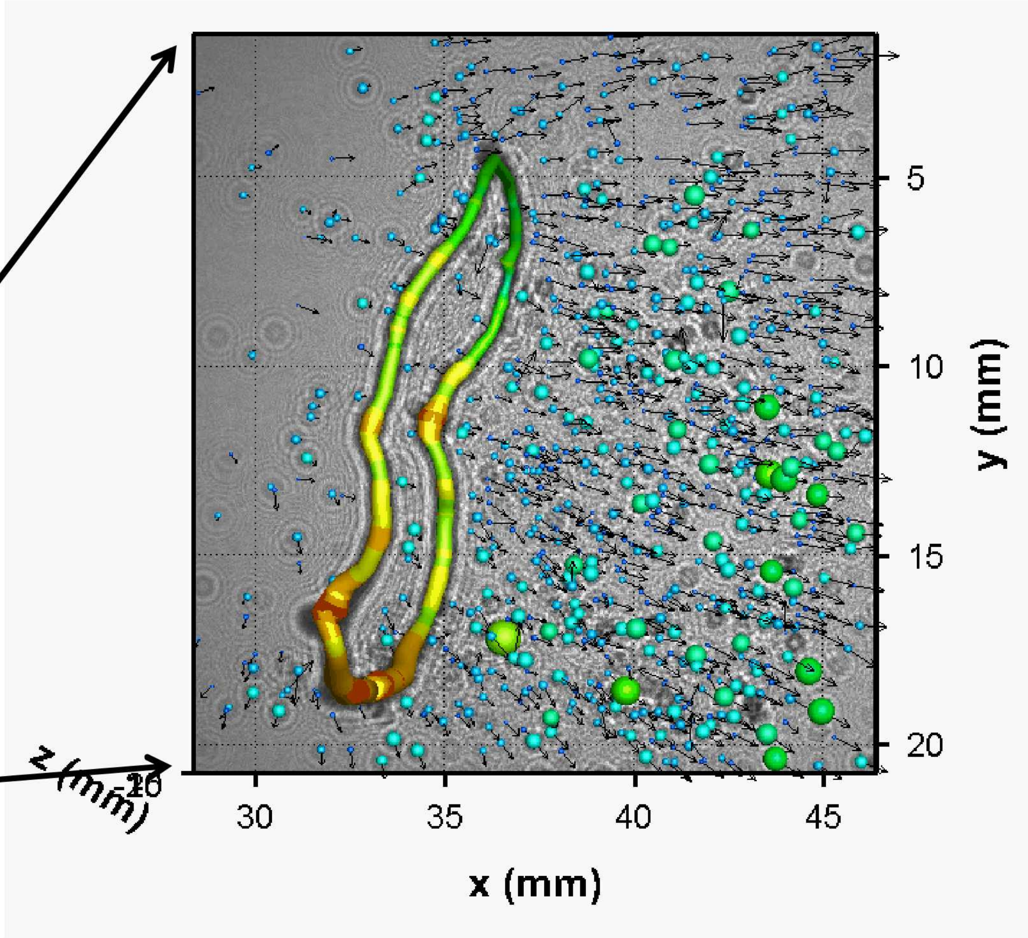
3D Imaging for a 3D World

2D imaging or point-wise measurement techniques are often insufficient to resolve 3D flow phenomena

- Repetition needed to capture spatial statistics



high-speed video of a ethanol drop in an air-stream

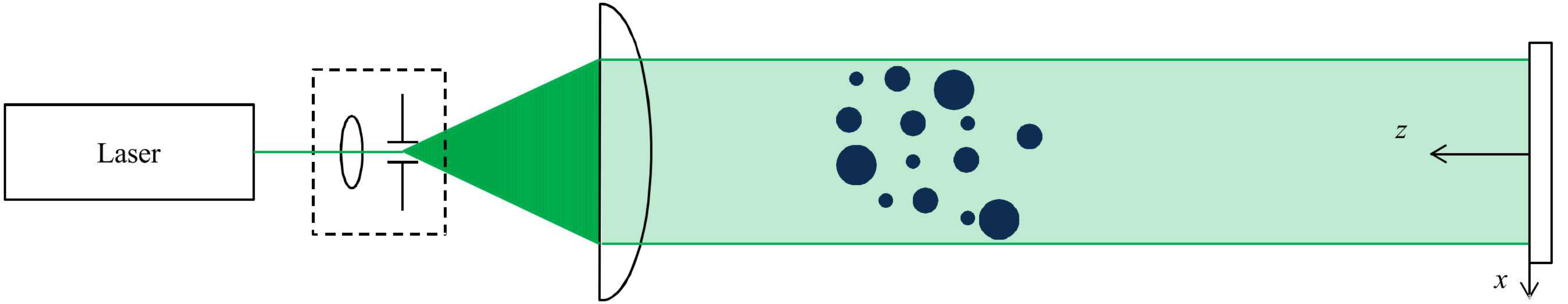


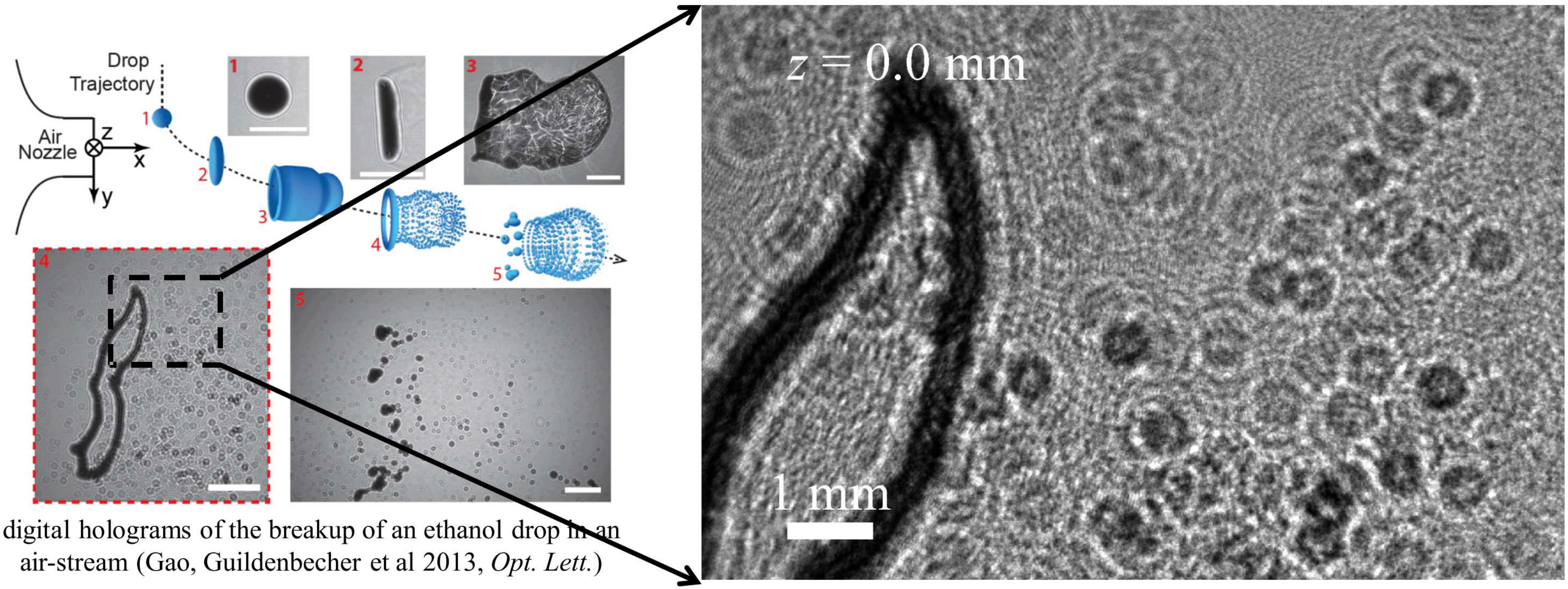
digital holographic measurement (Gao, Guildenbecher et al, 2013, *Opt. Lett.*)

Holography is an optical technique to record and reconstruct a 3D light field

*With Phil Reu, Jun Chen (Purdue), Jian Gao (Purdue)

Digital Inline Holography (DIH)

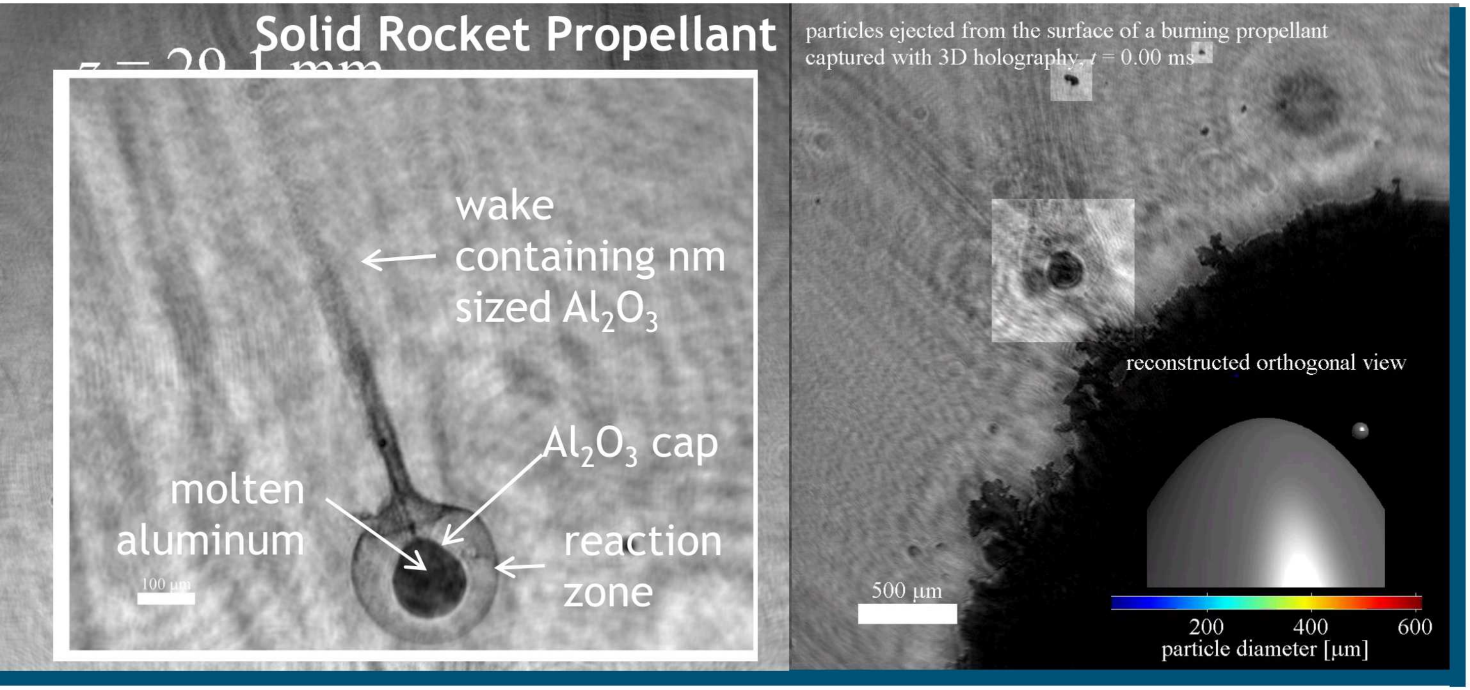


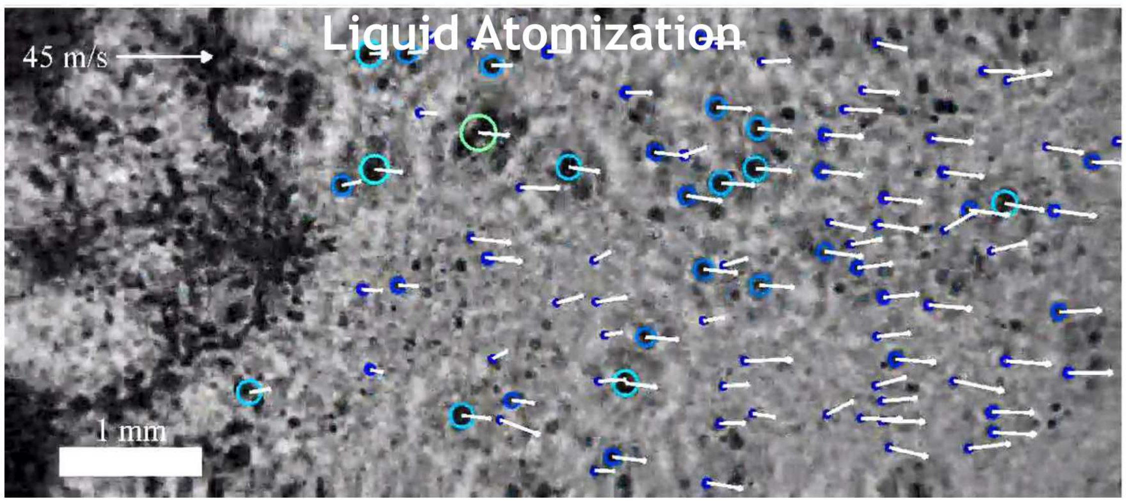


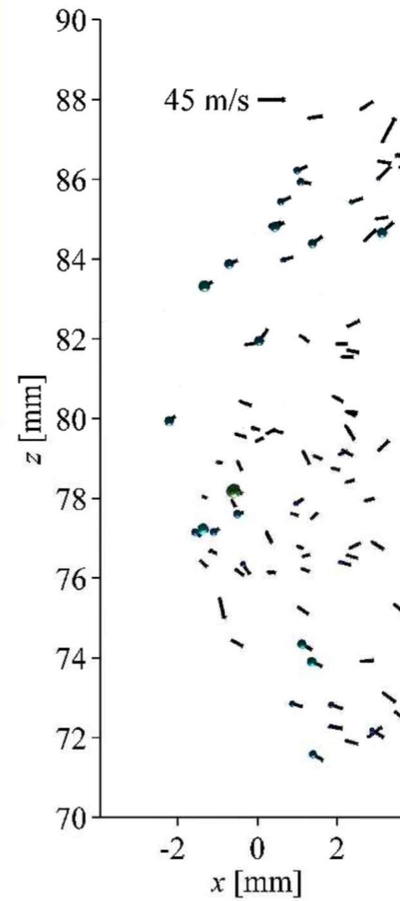
digital holograms of the breakup of an ethanol drop in an air-stream (Gao, Guildenbecher et al 2013, *Opt. Lett.*)

*With Phil Reu, Jun Chen (Purdue), Jian Gao (Purdue)

Digital Inline Holography (DIH)

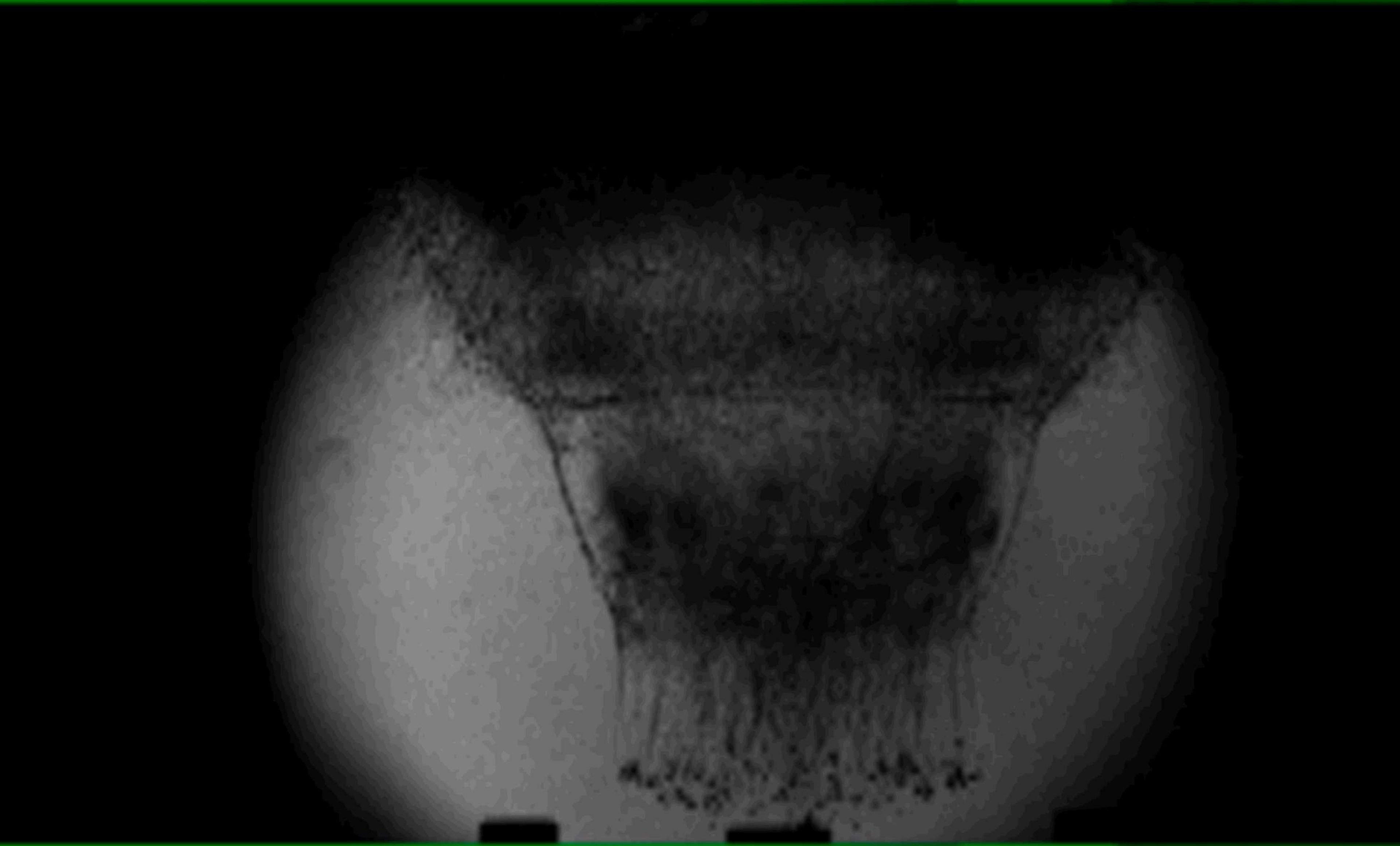






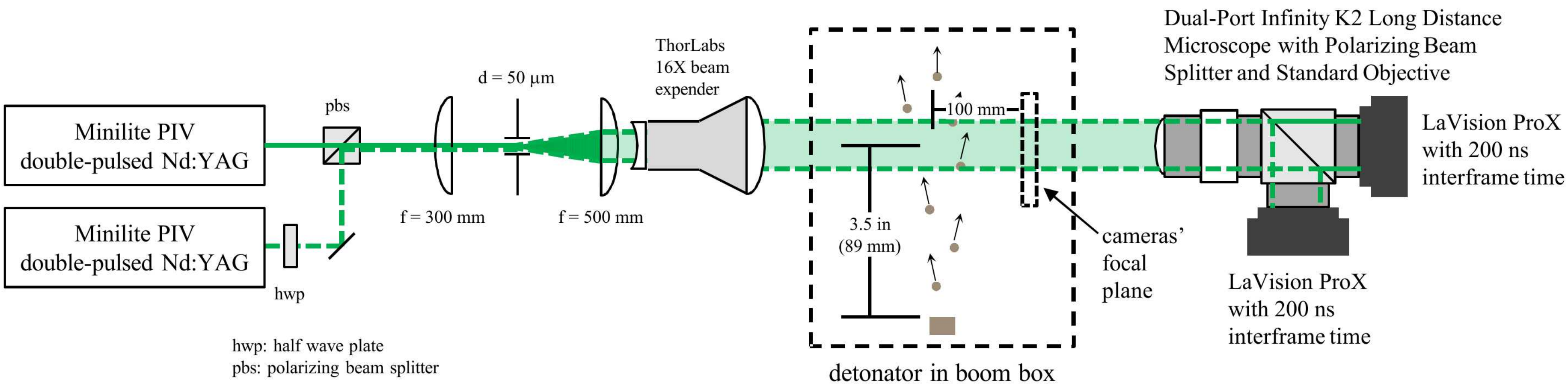
*With Ellen (Yi) Chen, Justin Wagner, Marcia Cooper, Lee Stauffacher, Paul Sojka (Purdue), and many others

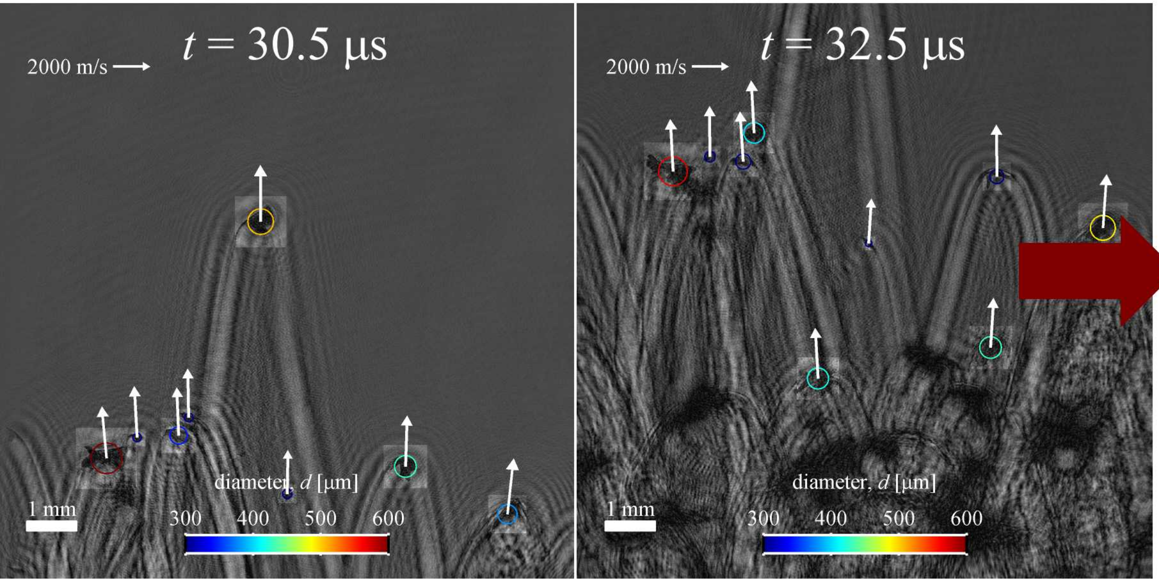
HE Initiation by Fragment Impact

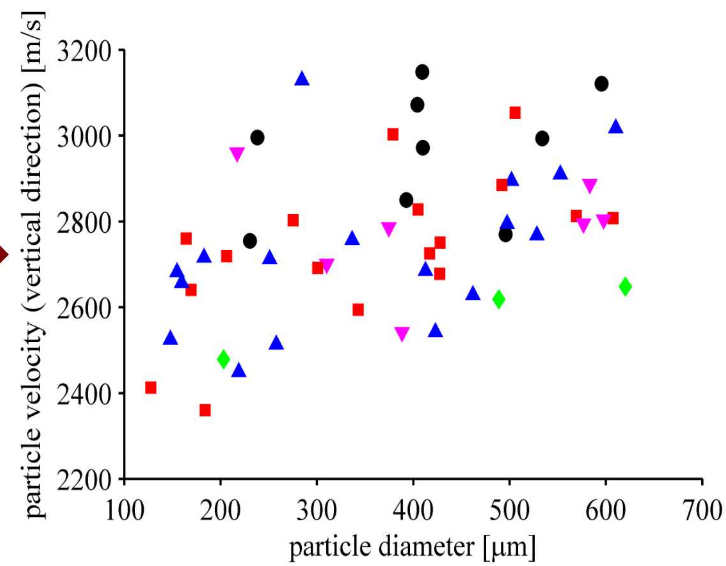


*With John Yeager, Pat Bowden, Joe Olles, Pat Ball

HE Initiation by Fragment Impact







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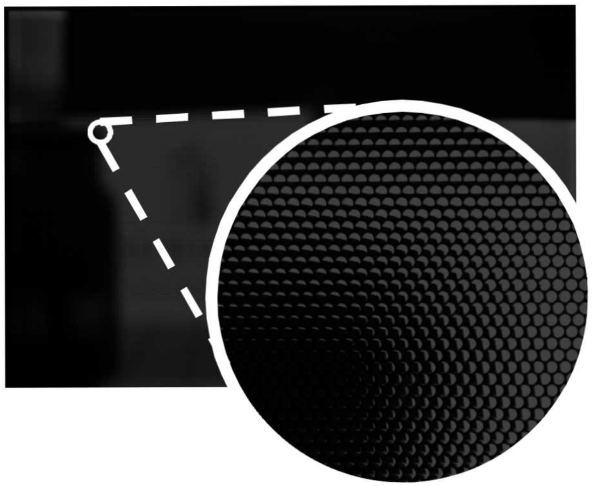
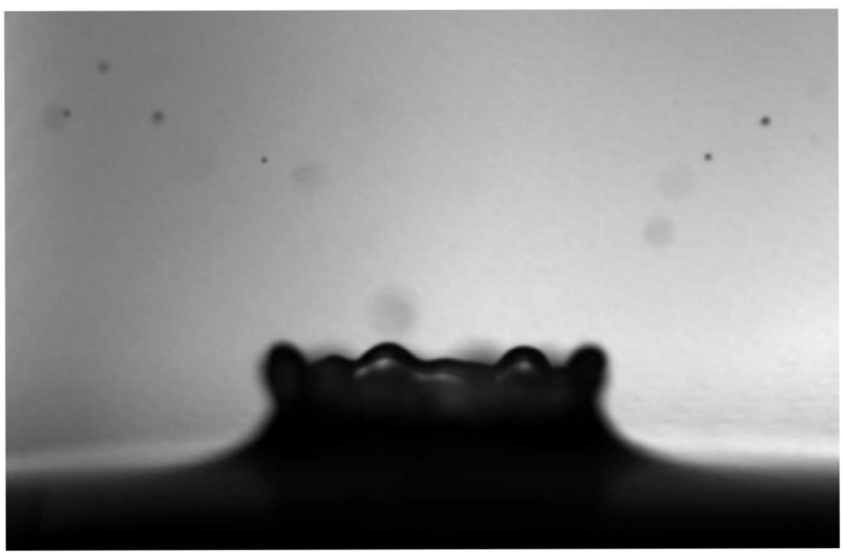
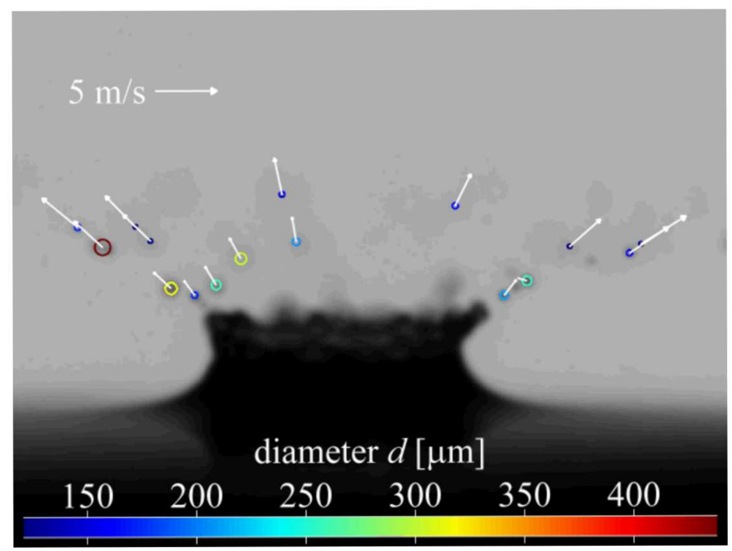
Alternative 3D Imaging Architectures?

Plenoptic cameras use micro-lens arrays and white light to create a 3D image



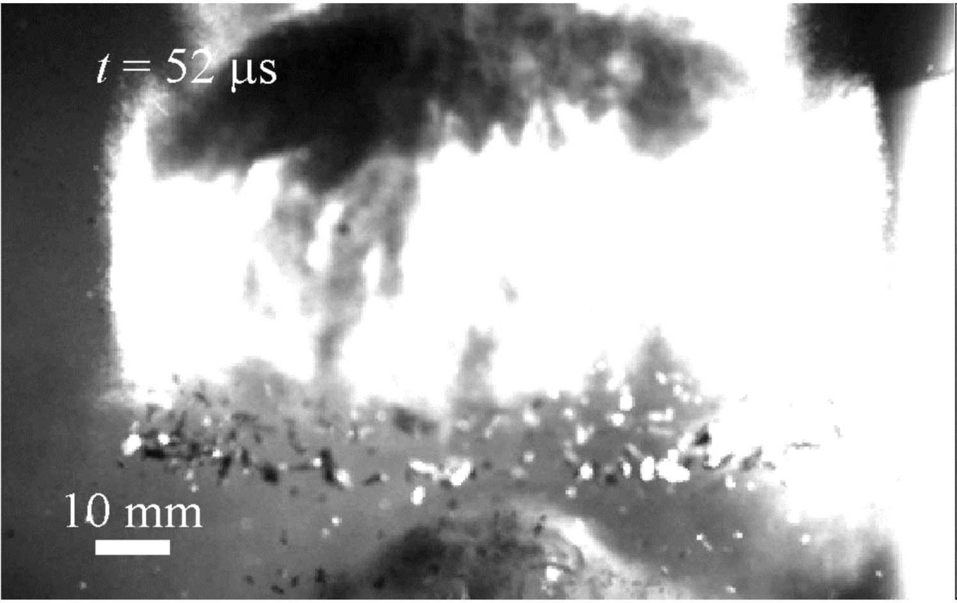


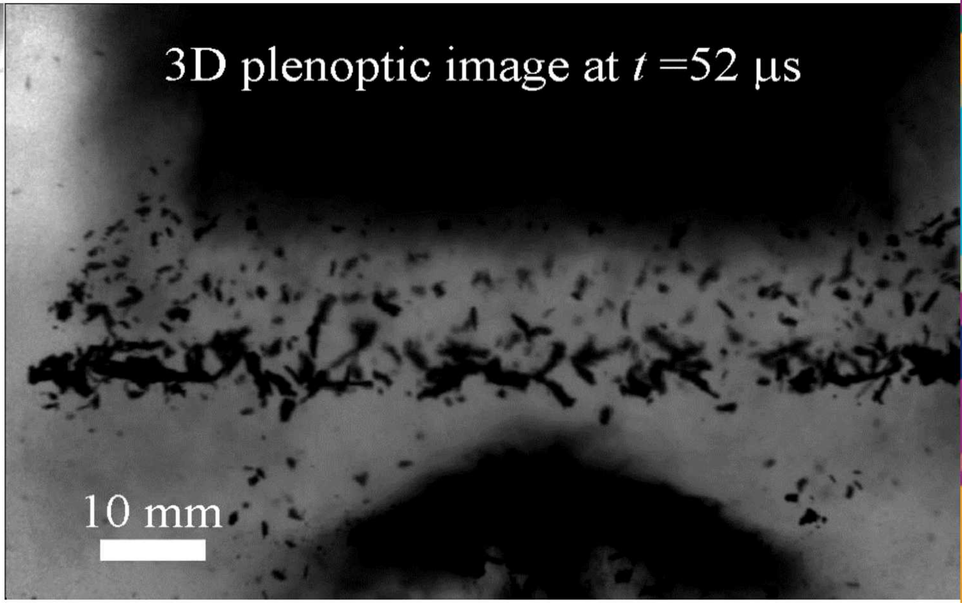


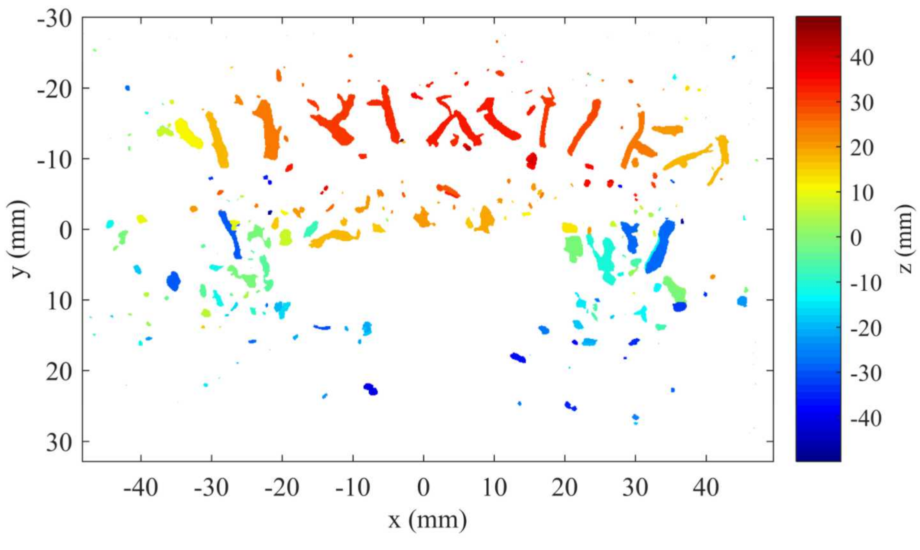
(Hall et al 2016, *Appl. Opt.)*

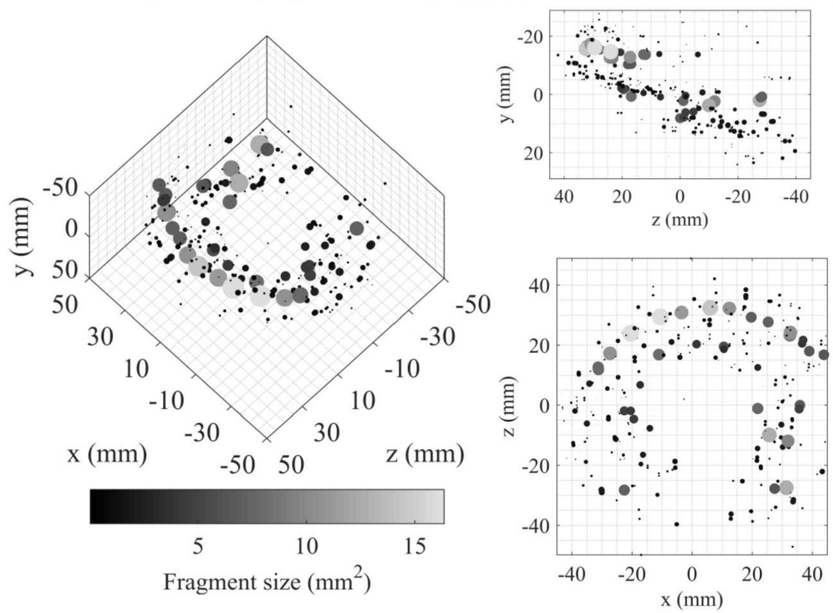
*With Elise Hall (Auburn University), Brian Thurow (Auburn University)

Plenoptic Imaging of Fragments



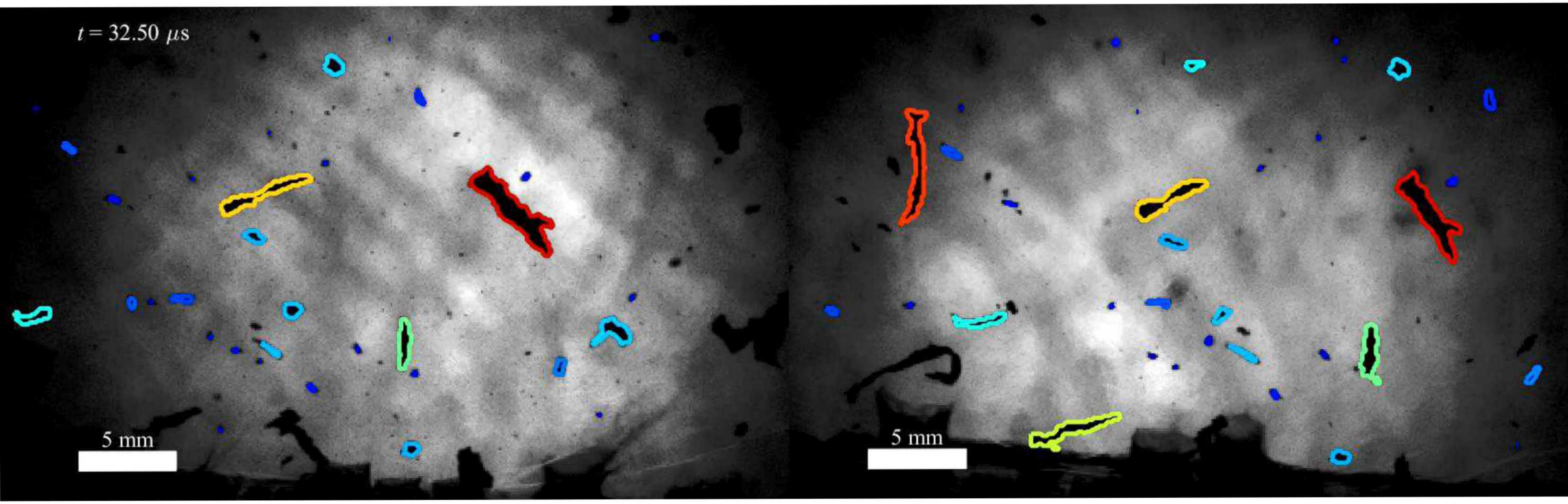


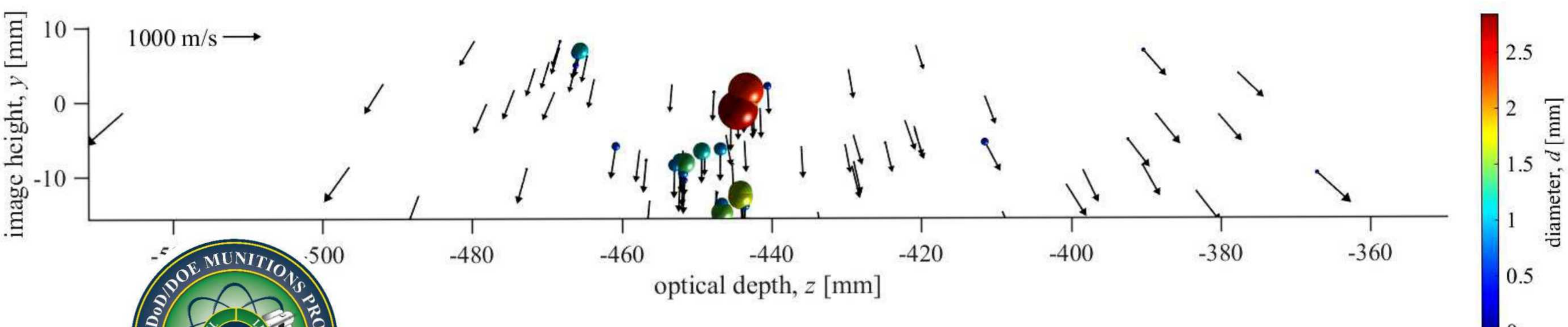




*With Elise Hall (Auburn University), Brian Thurow (Auburn University), Lee Stauffacher

Fragment Tracking at 2 MHz



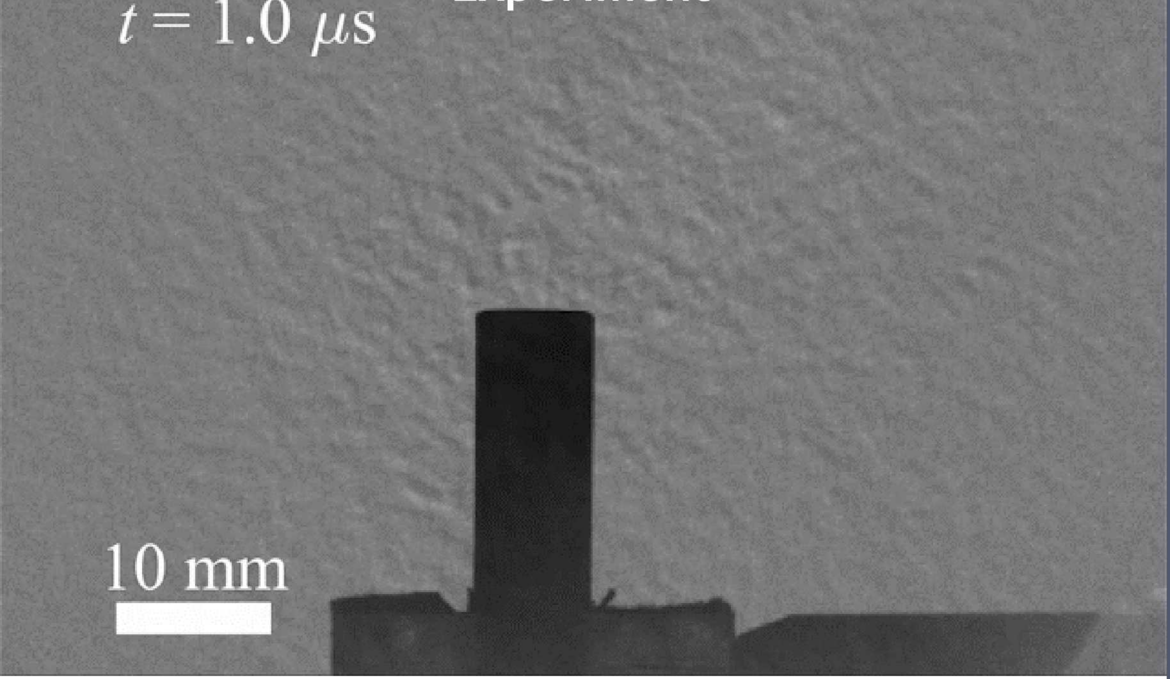


***DIC, x-ray, and fragment tracking experiments are supported by the Joint DoD/DOE Munitions Program**

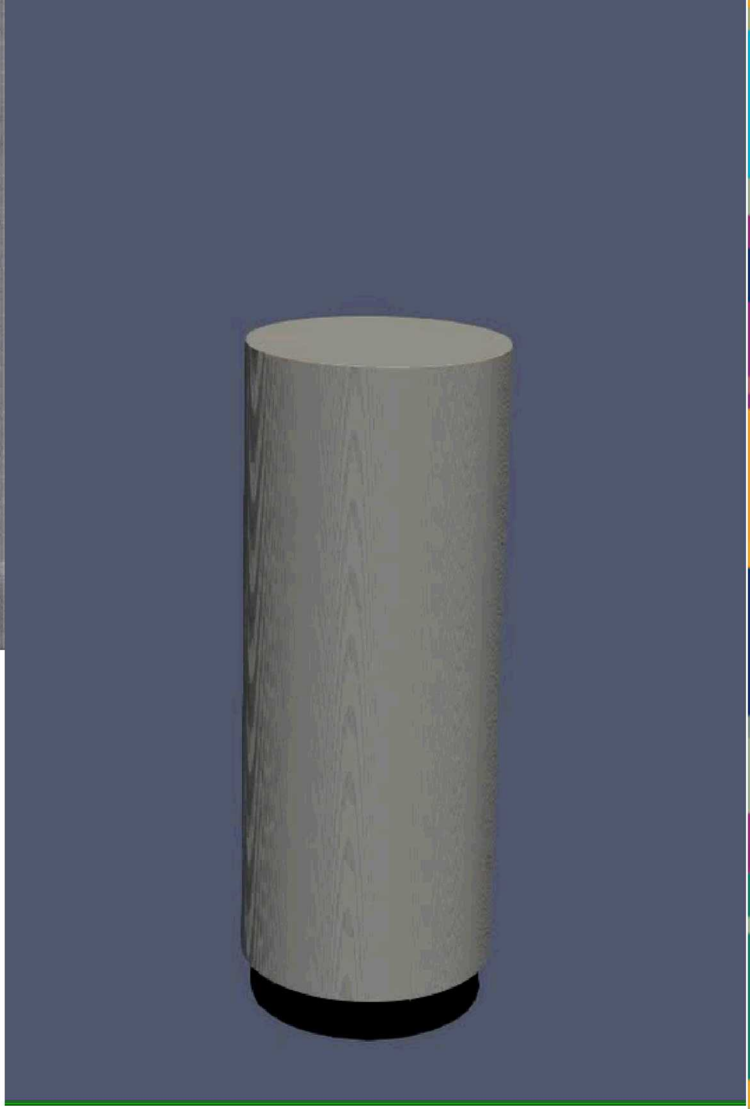
*With Phil Reu, Tim Miller, Pat Ball

Fragmentation Models Need Experimental V&V

Experiment



Model (Courtesy F. Perez)



Measurement needs include:

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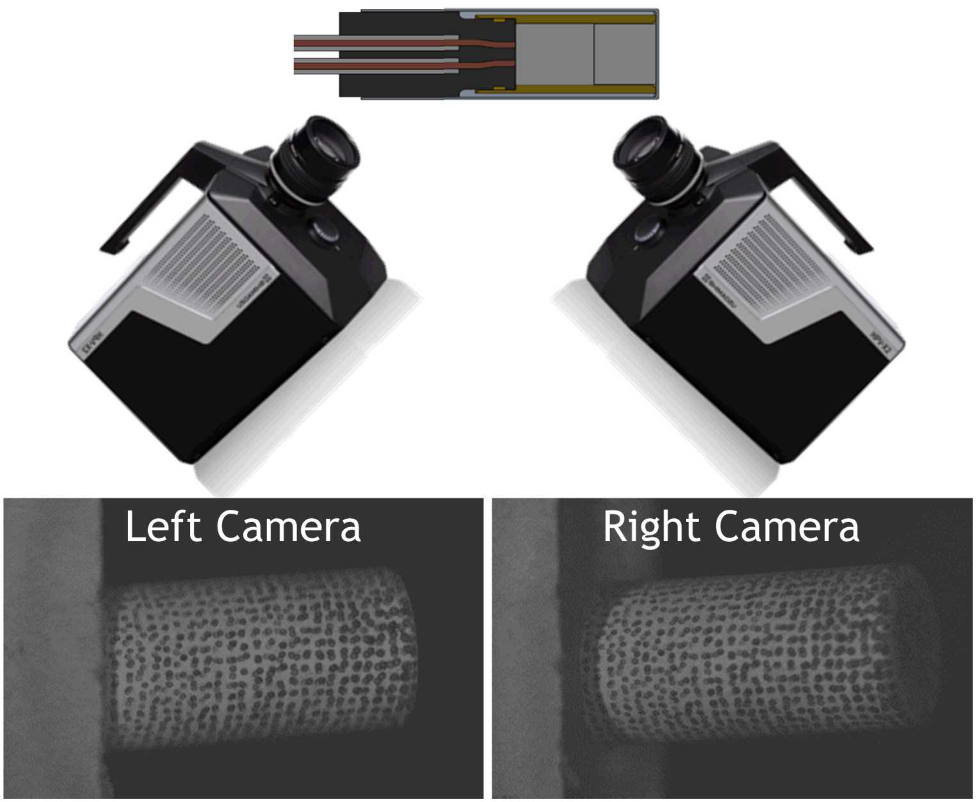
*With Frank Perez, Andrew Thompson, Steve Attaway

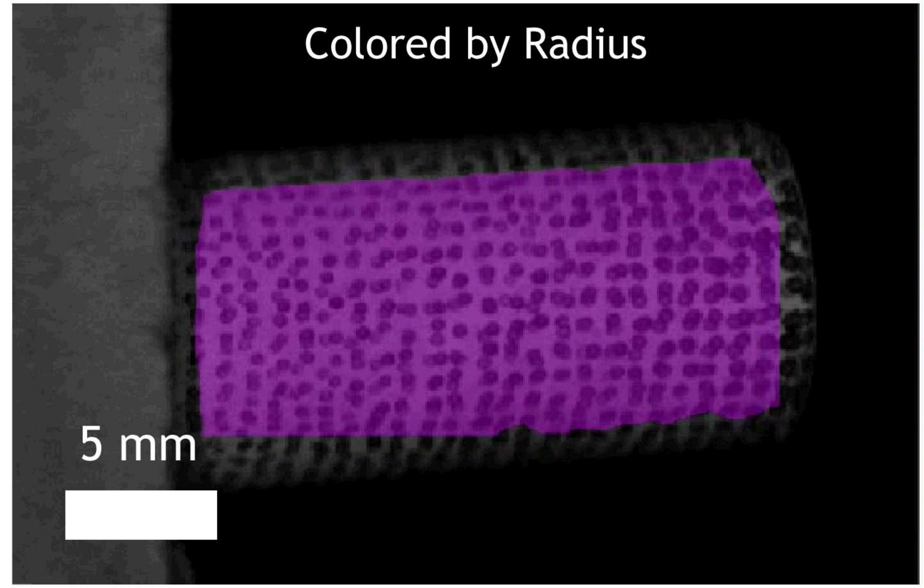
Case strain at 5 MHz (P. Reu, T. Miller)

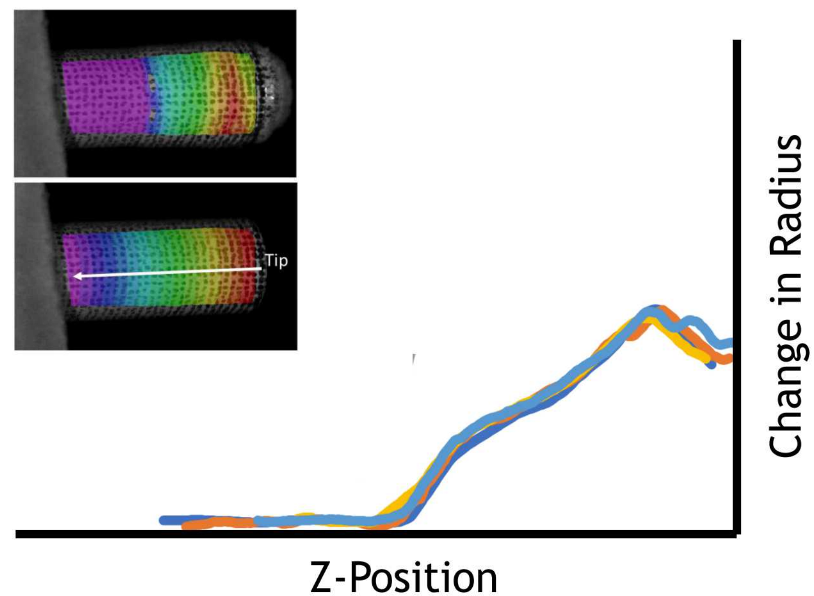
Digital Image Correlation (DIC)

Full-field surface tracking for solid mechanics investigations

RP-80 Detonator



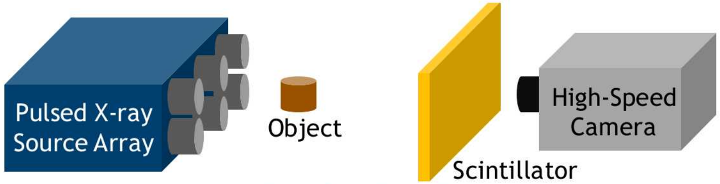




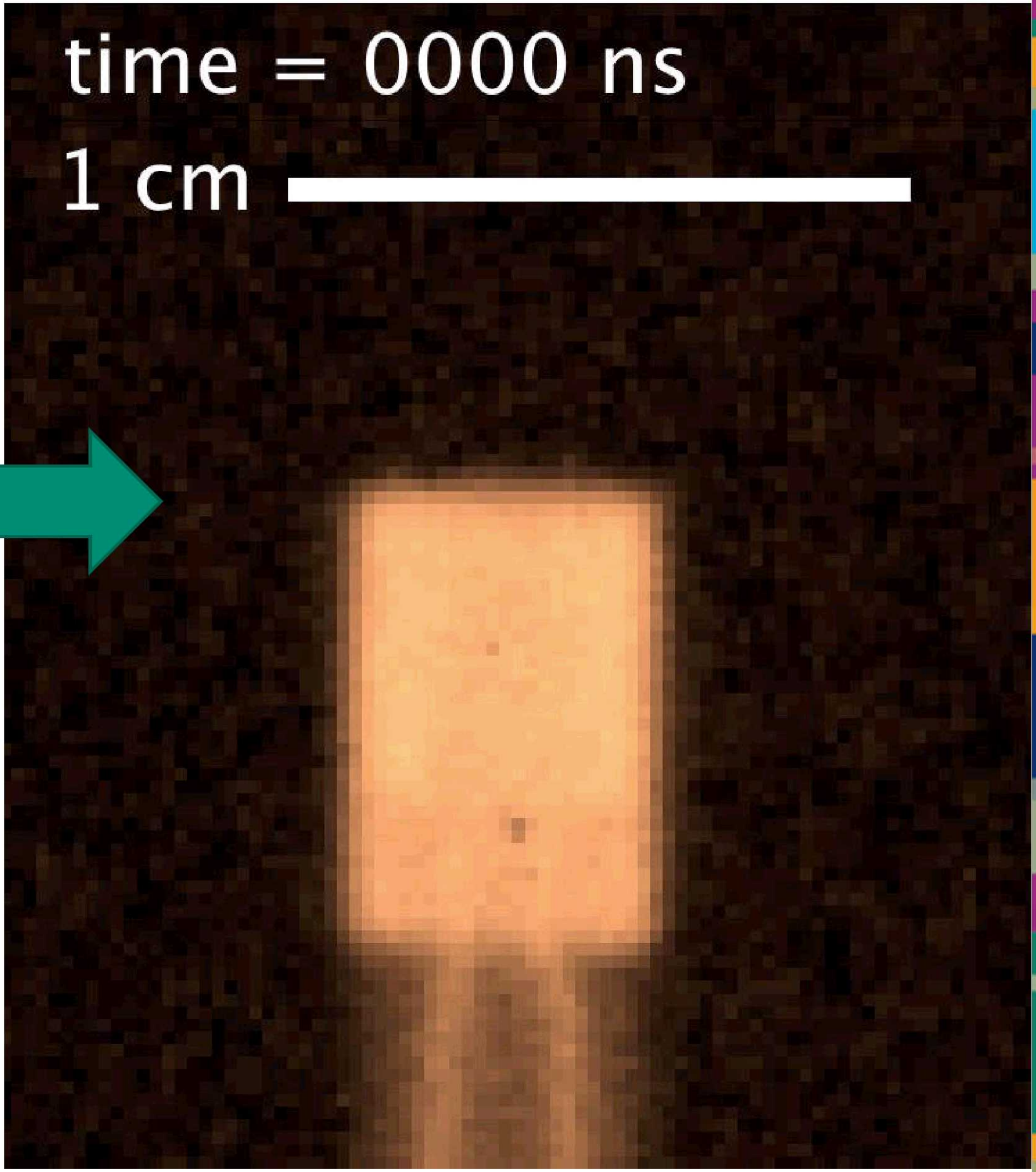
*With Phil Reu, Tim Miller, Pat Ball

X-Ray Diagnostics at 2 MHz (B. Halls, L. Lebow)

X-rays penetrate the flash and smoke during fragmentation

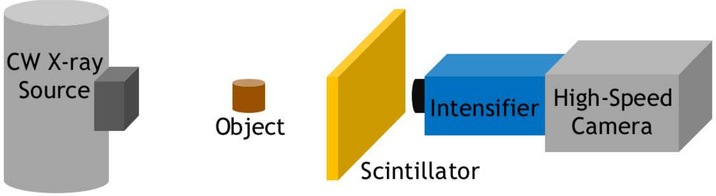


Six-Headed Flash System



Working toward:

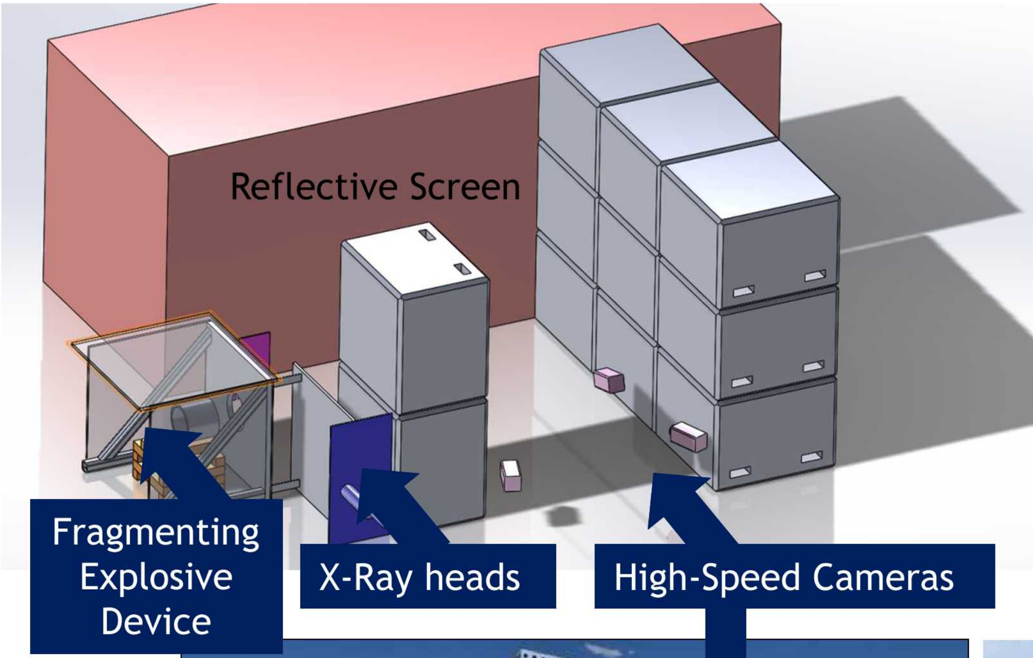
- Continuous movies
- Tomographic reconstruction

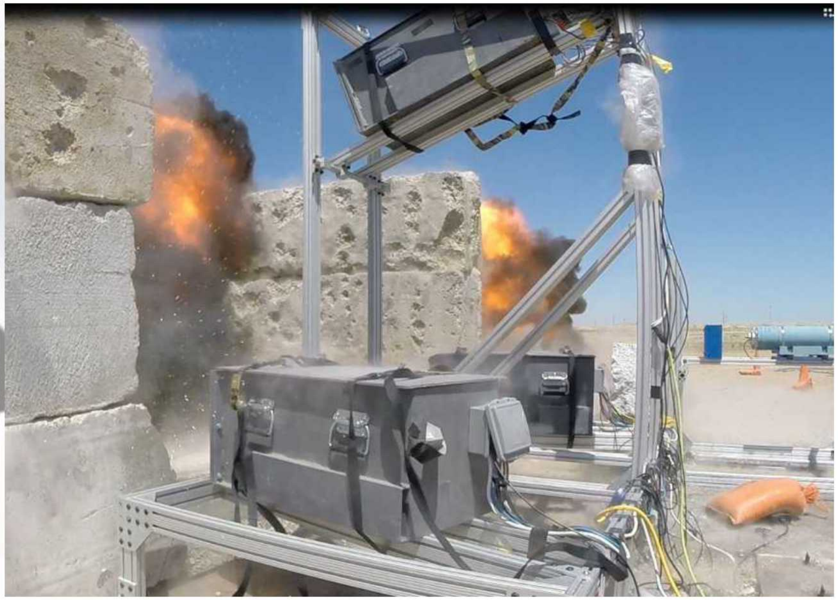


Continuous Wave System

*With Ben Halls, Luke Lebow

~10 pound fragmenting explosive device at SNL





*With Phil Reu, Tim Miller, Mark Anderson, Steve Attaway, and many others

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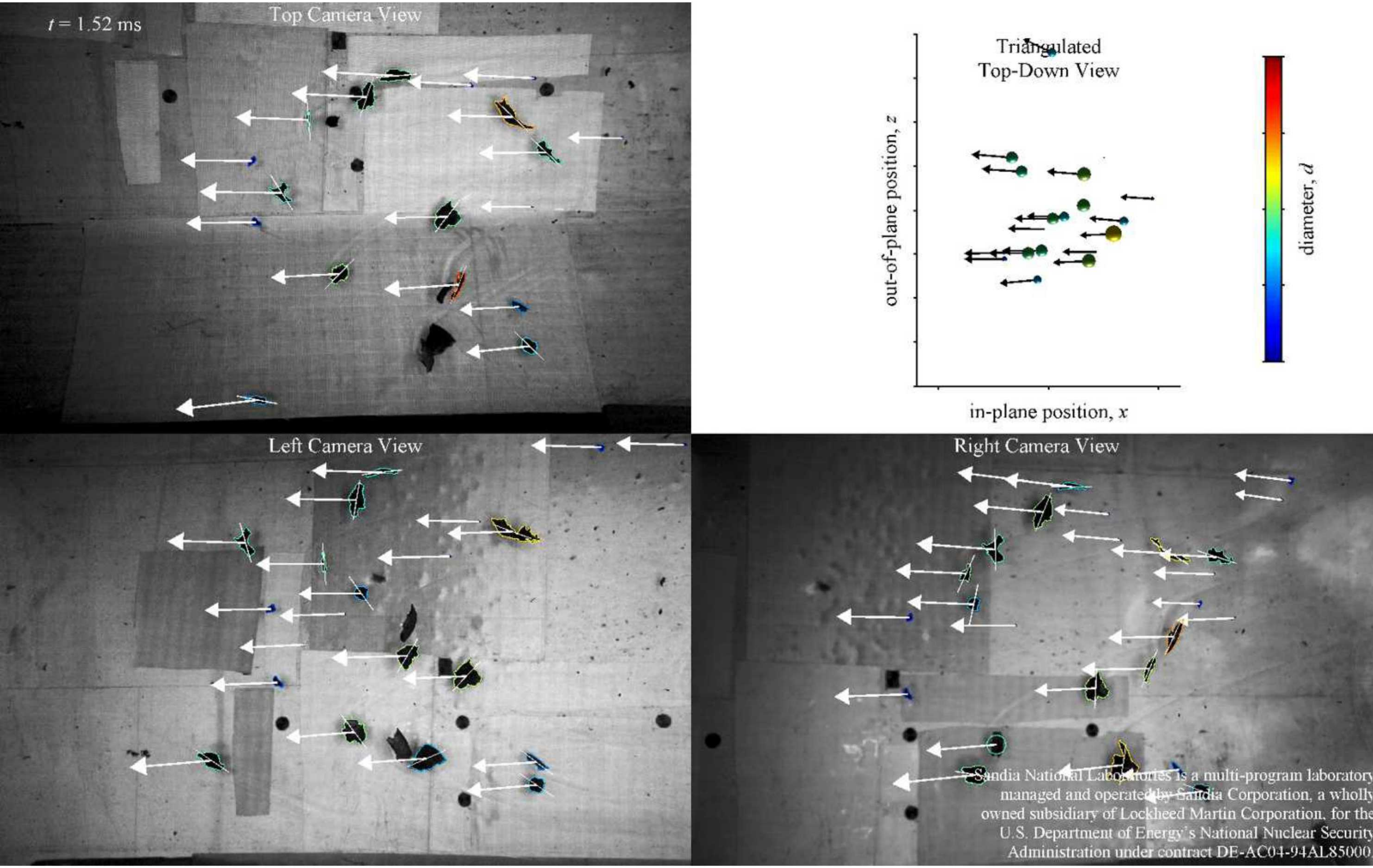

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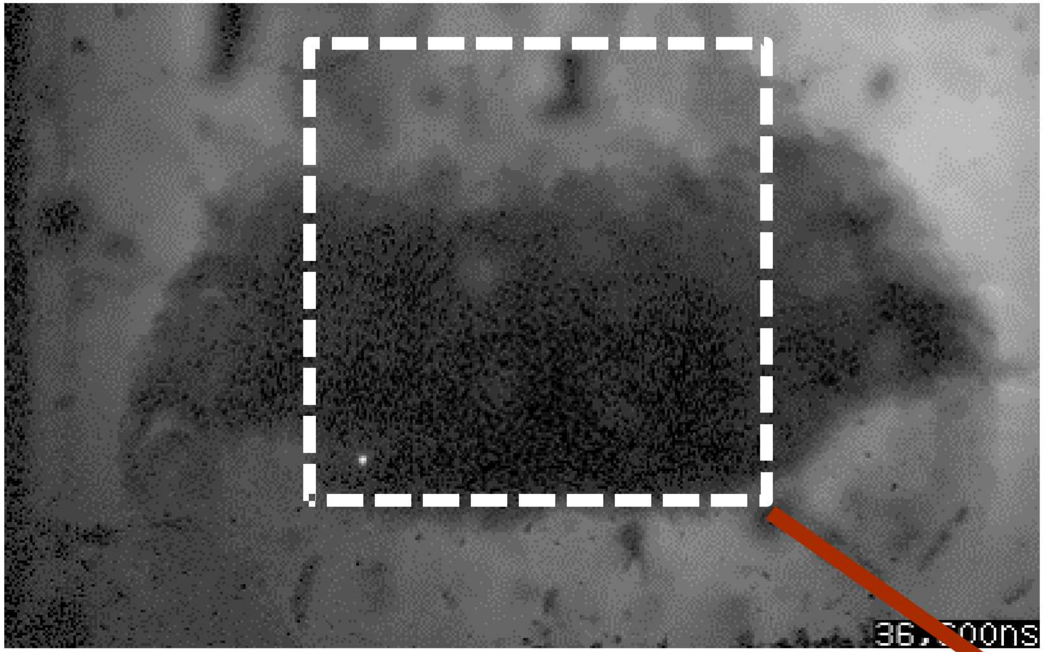
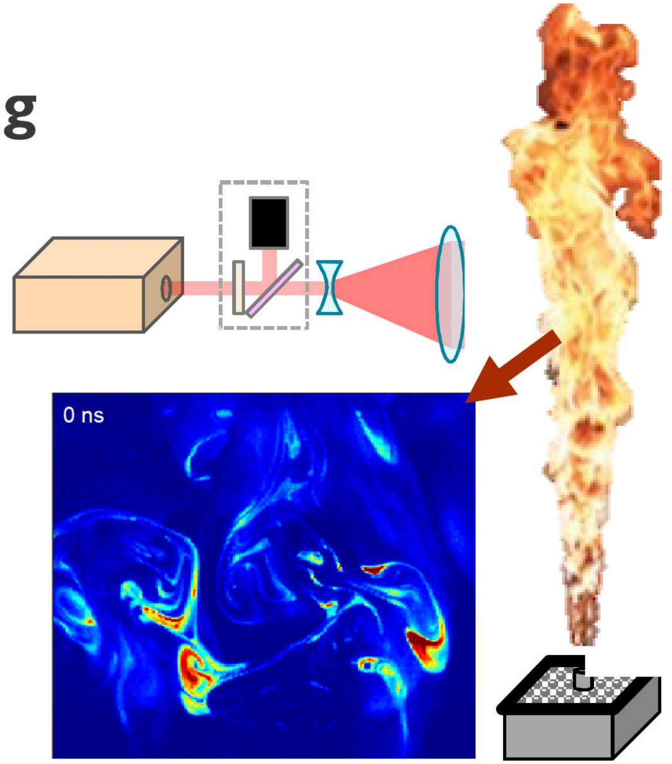
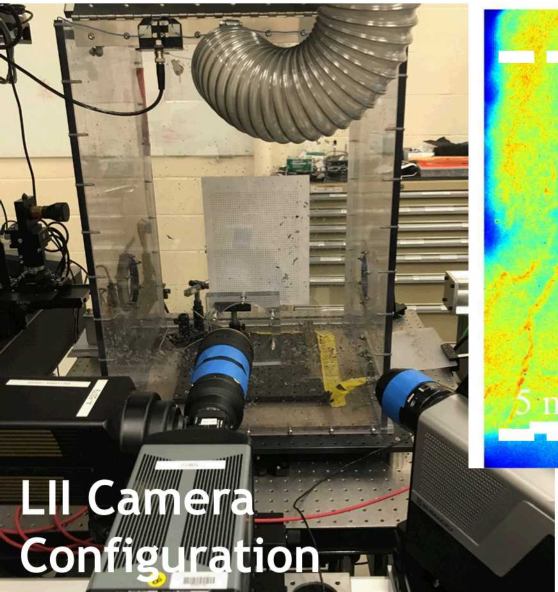
Soot Concentration and Sizing

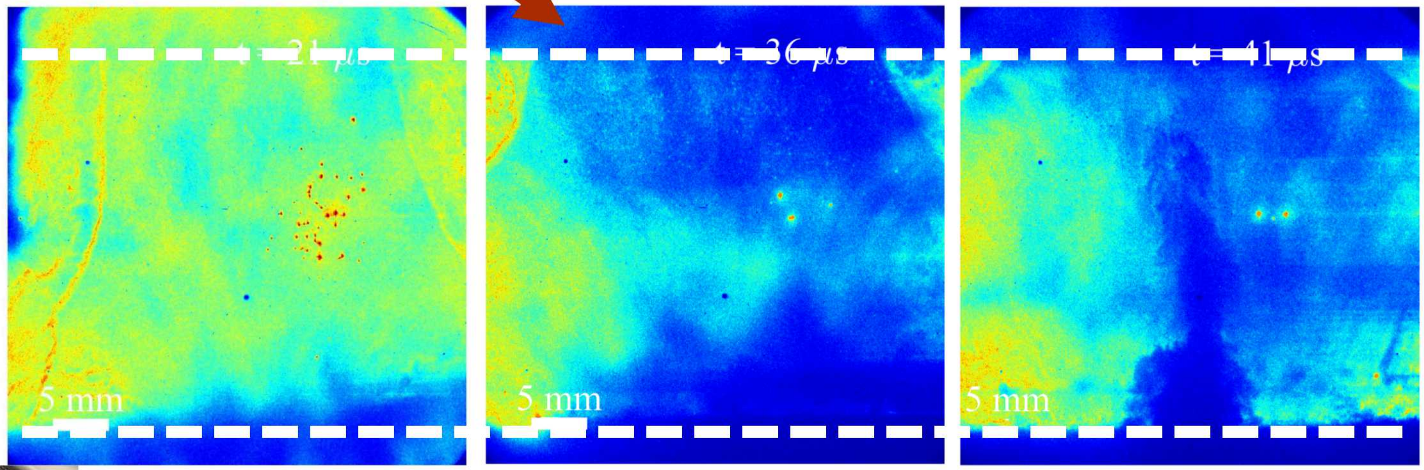




Laser Induced Incandescence (LII)



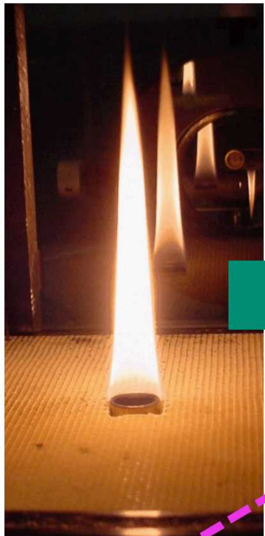
LII Camera Configuration

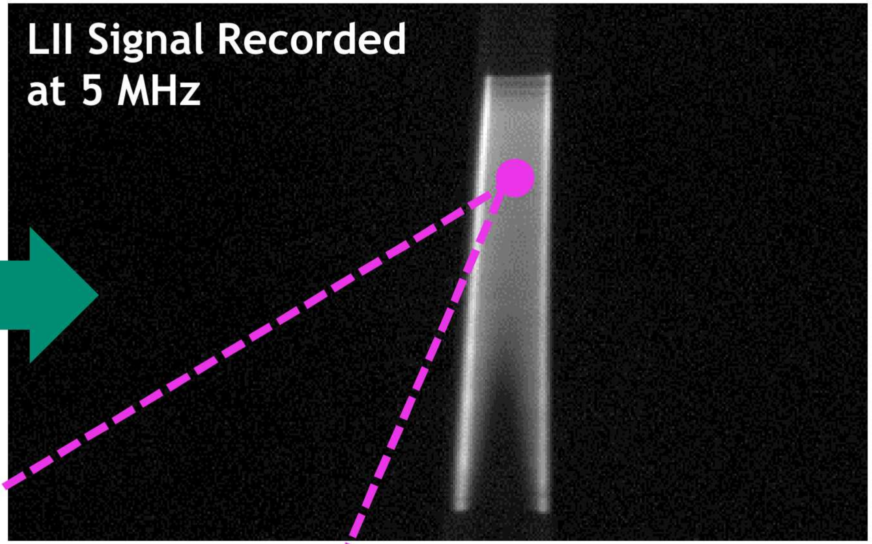


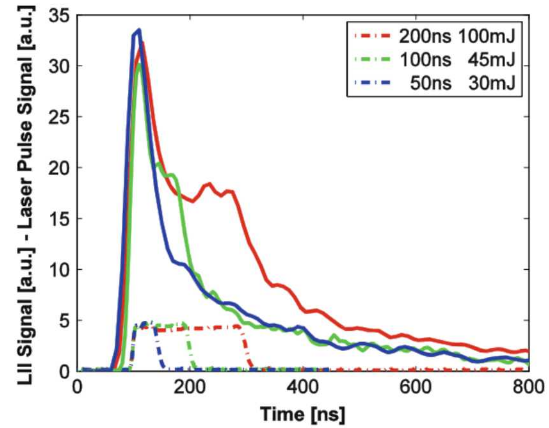
First Detonator LII Measurements

*With Daniel Richardson, Yi (Ellen) Chen, Lee Stauffacher, Tom Grasser, Marley Kunzler

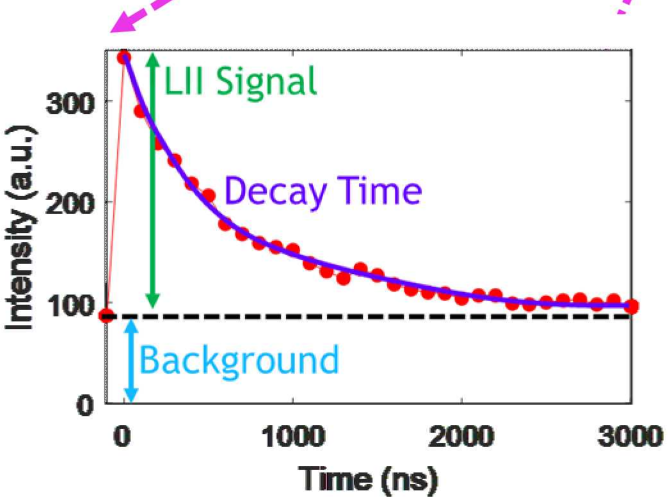
Time-resolved Laser Induced Incandescence



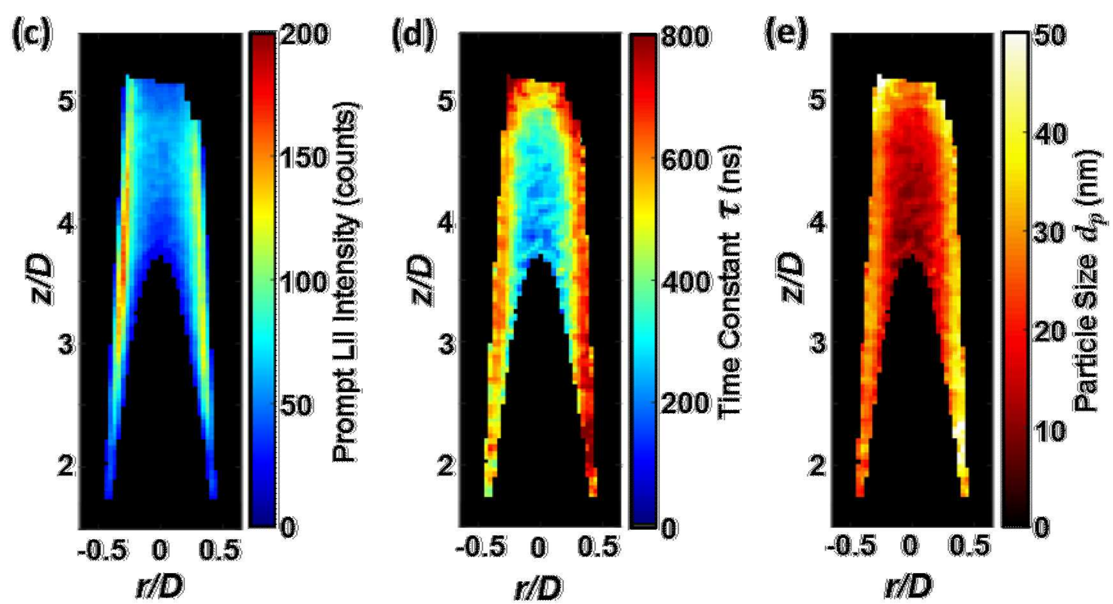




Typical time-resolved LII
(Ditaranto *et al* 2013)



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



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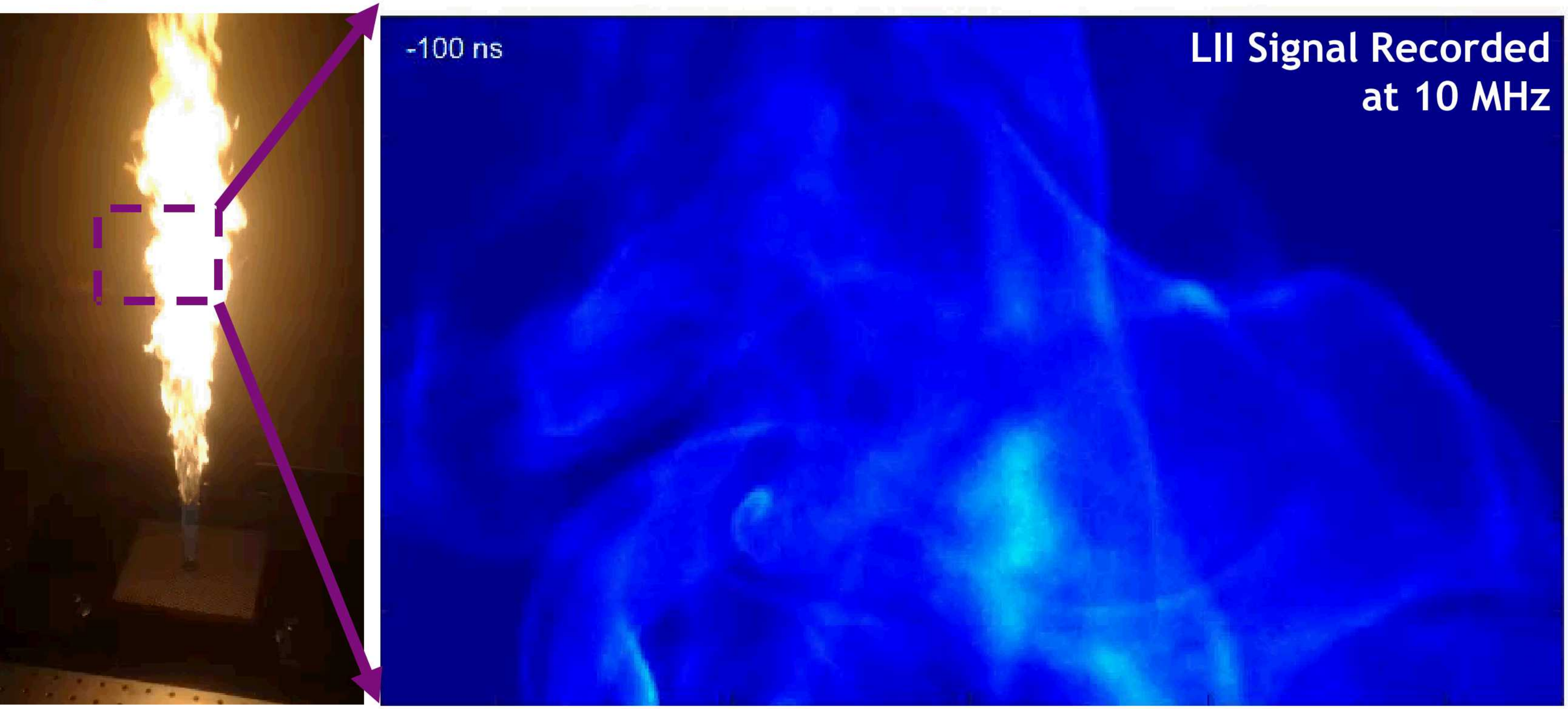
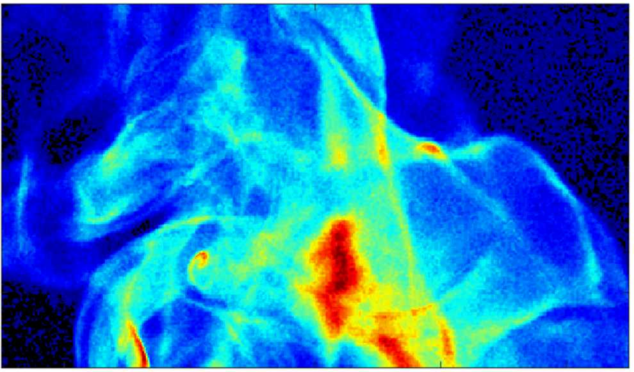
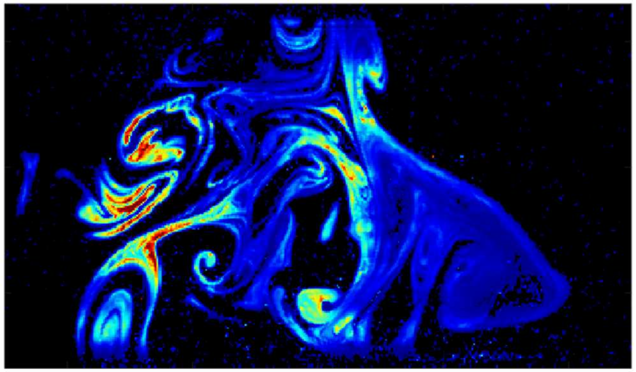
Time-resolved Laser Induced Incandescence

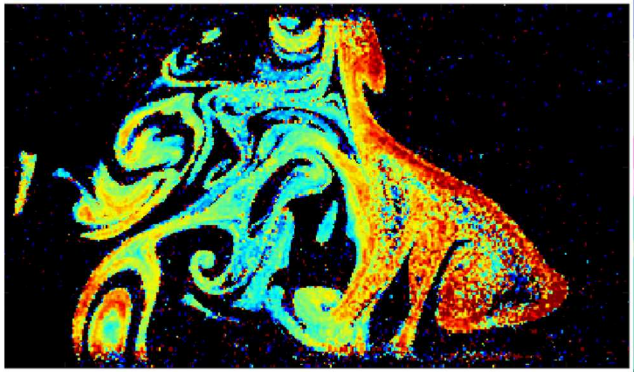




Background Intensity



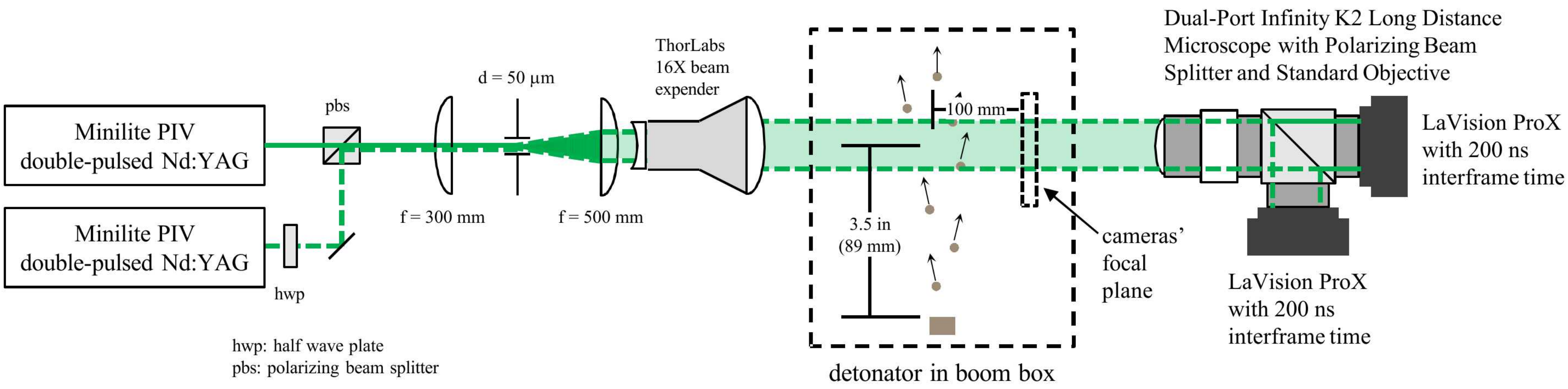
LII Signal Intensity

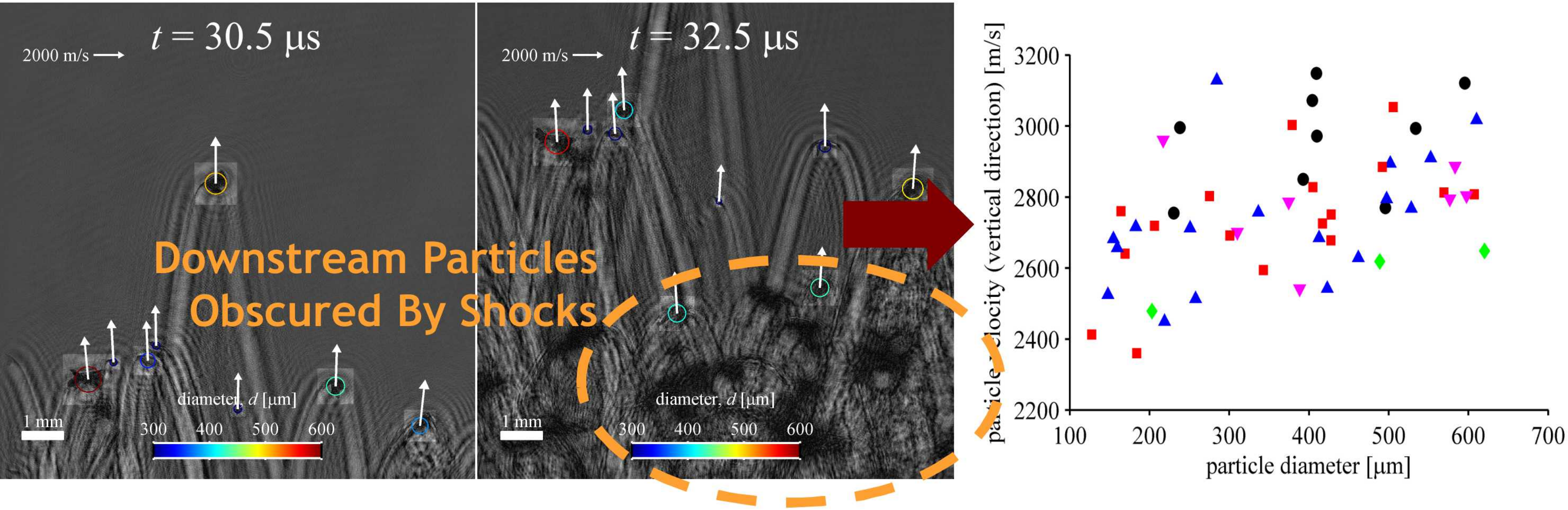


Decay Time Constant

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

Imaging Through Shock Waves





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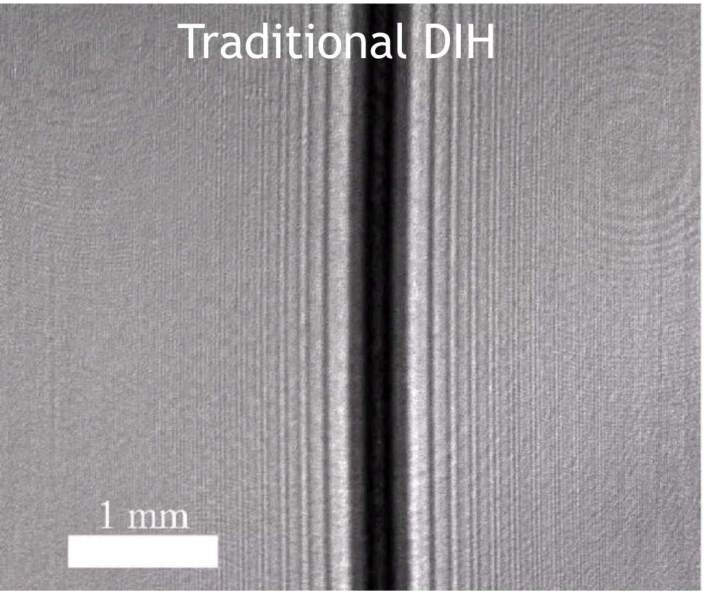

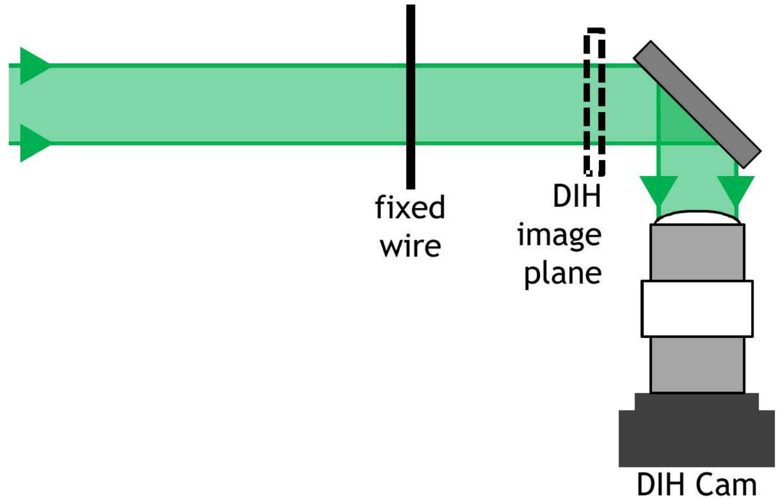

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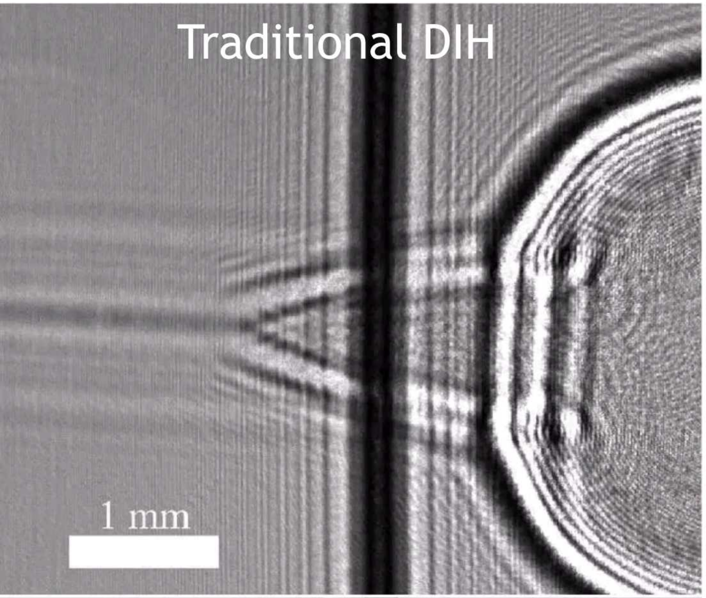
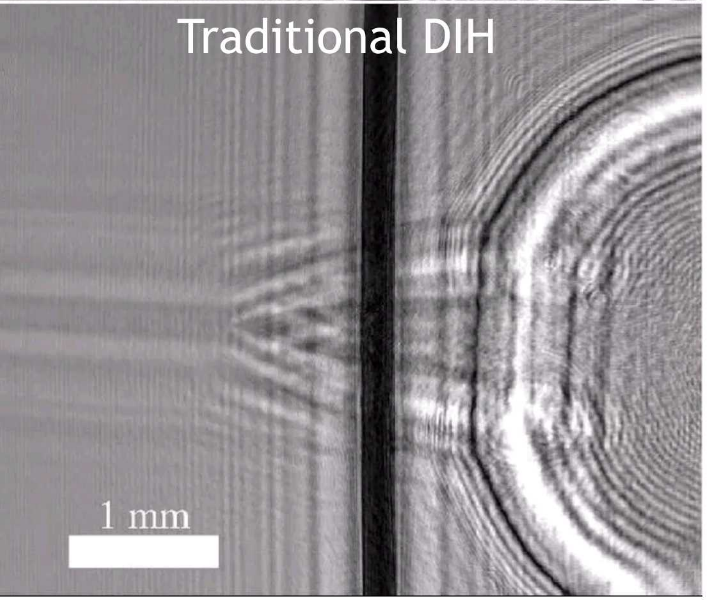
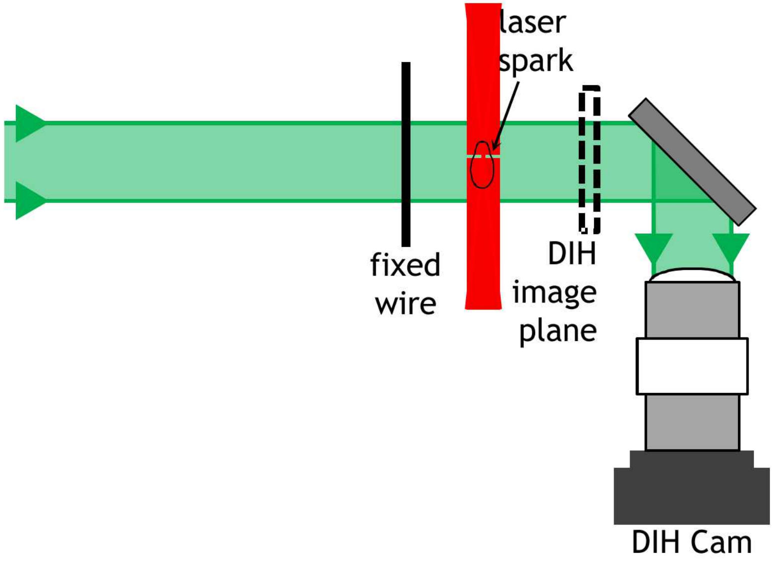
Imaging Through Shock Waves

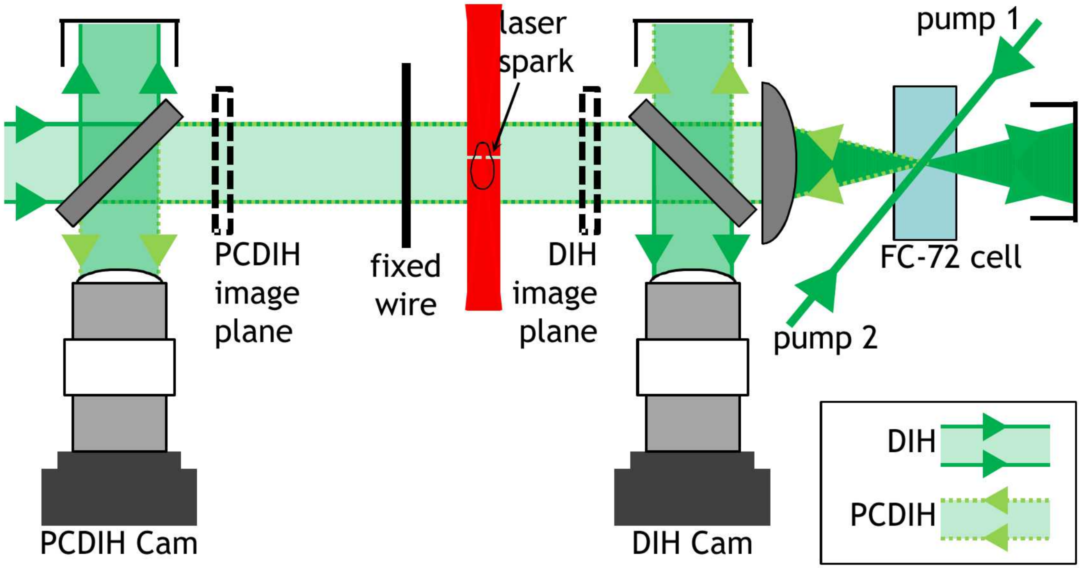


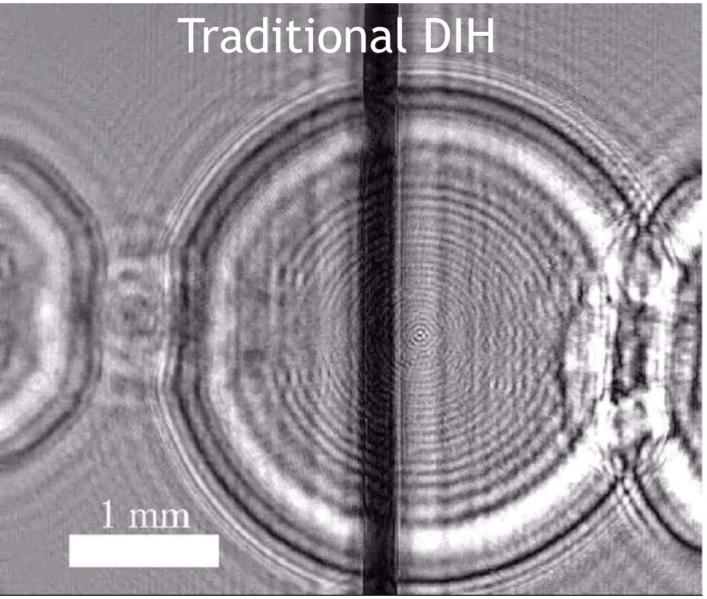




*With Kate Hoffmeister, Marley Kunzler, Daniel Richardson, Sean Kearney

Imaging Through Shock Waves





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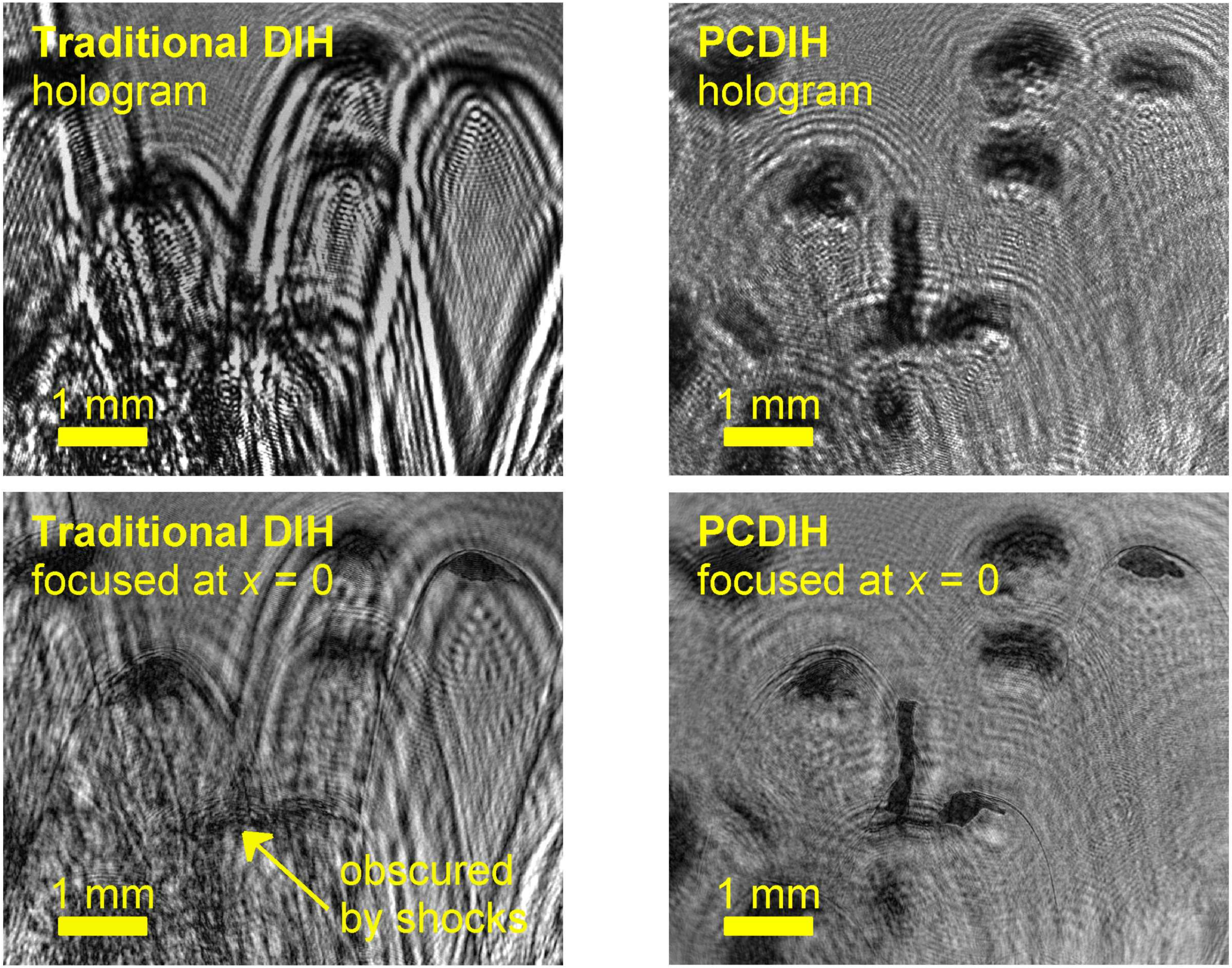
Imaging Through Shock Waves



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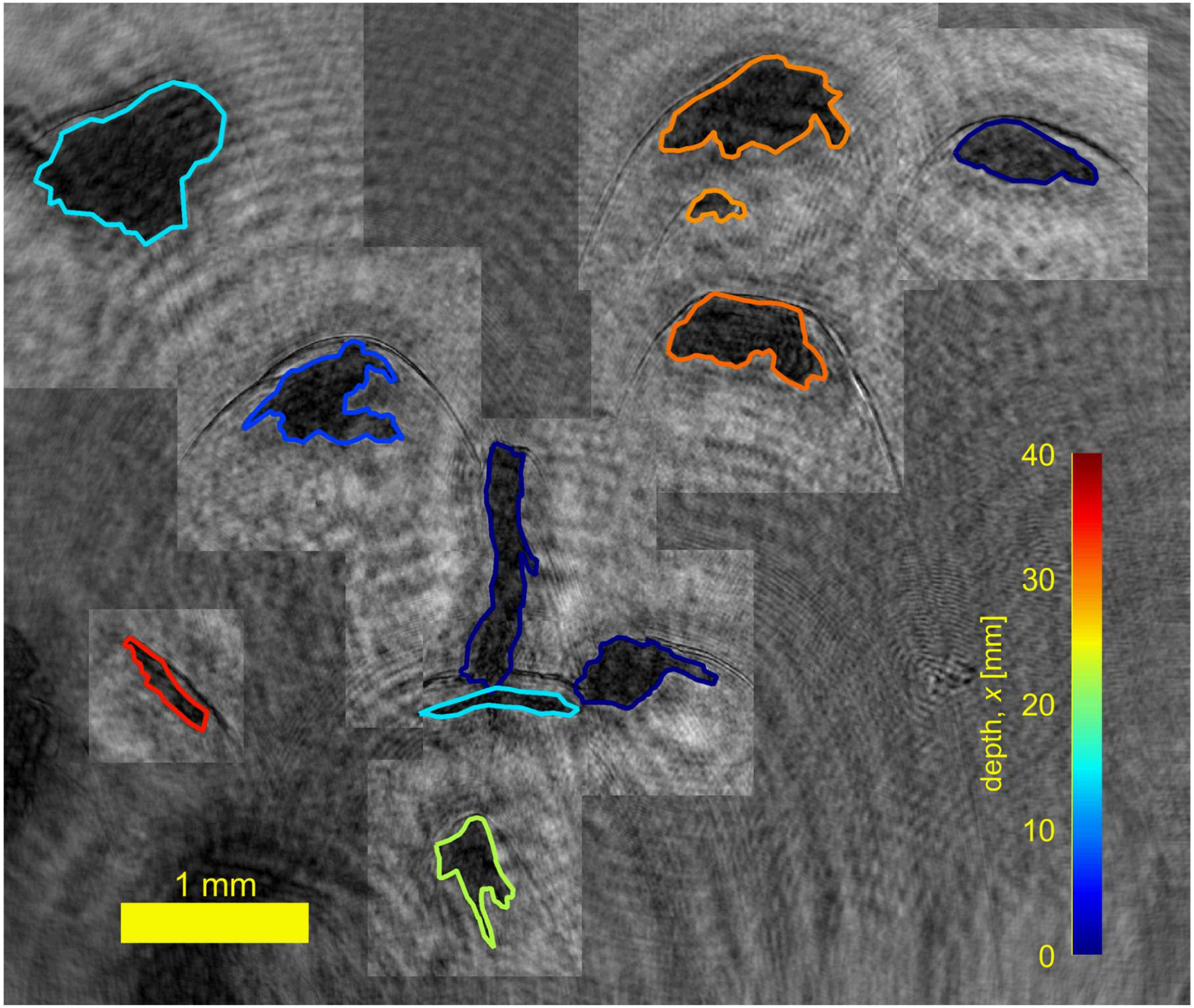
Imaging Through Shock Waves



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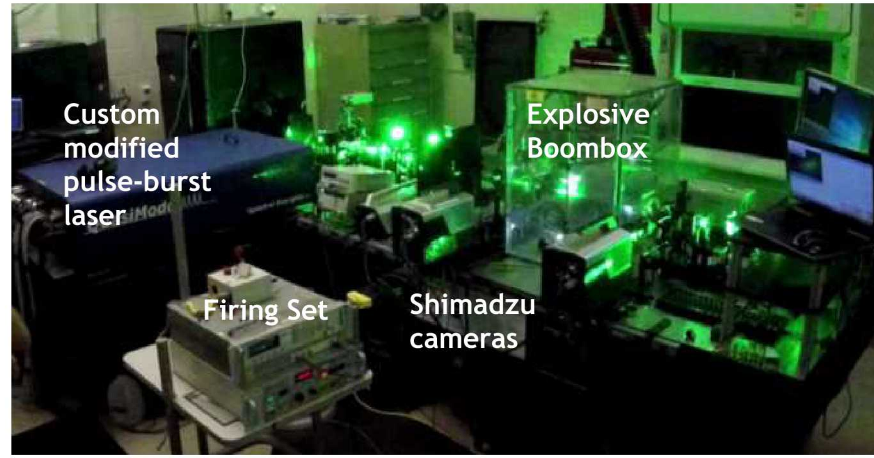
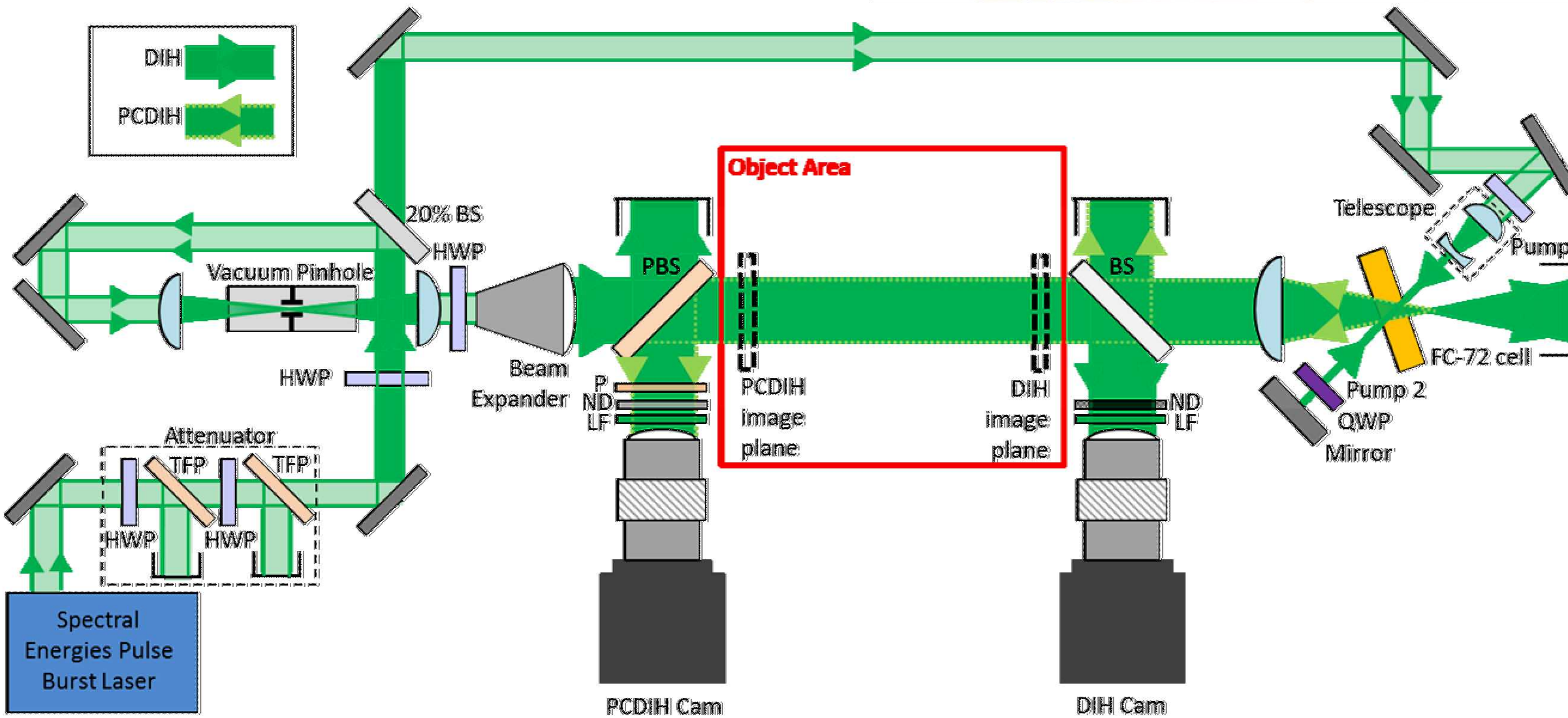
Imaging Through Shock Waves

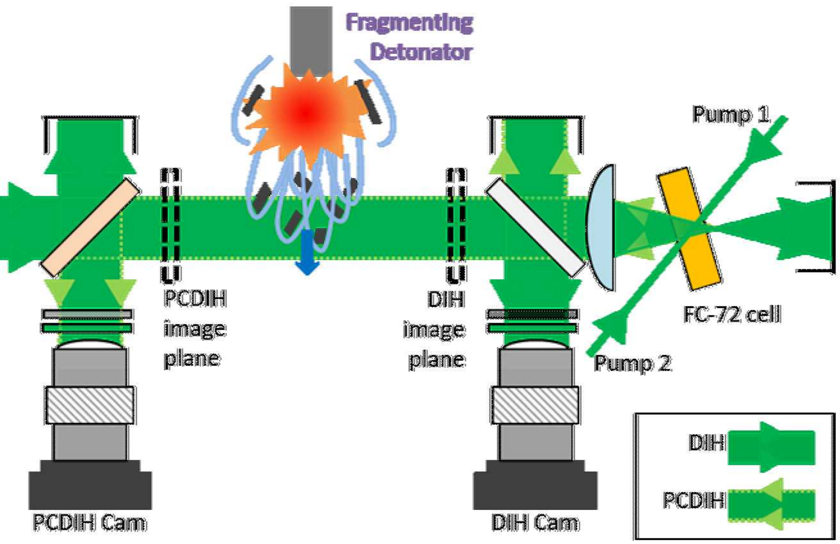


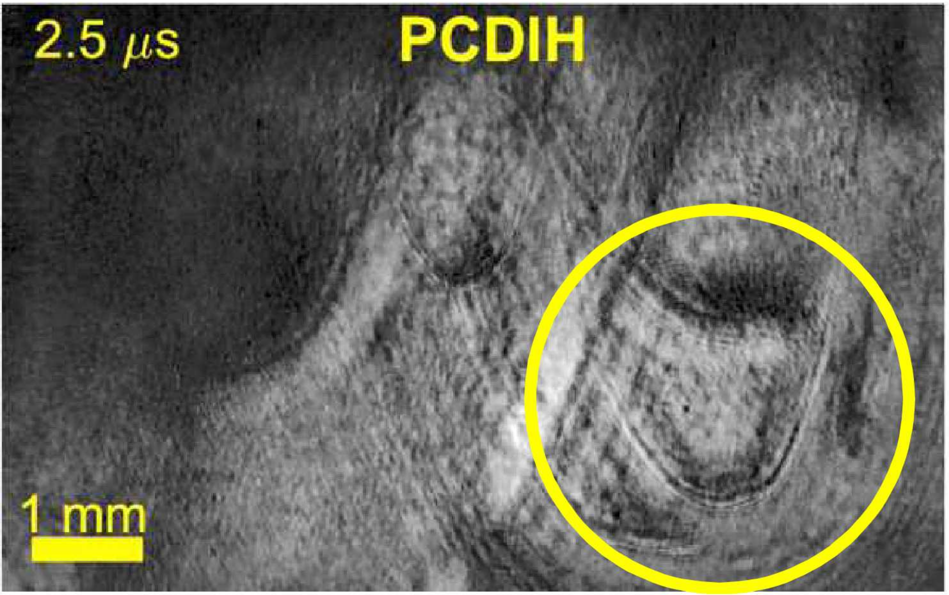
Very recently, we have extended this to MHz rate video recording using a pulse burst laser

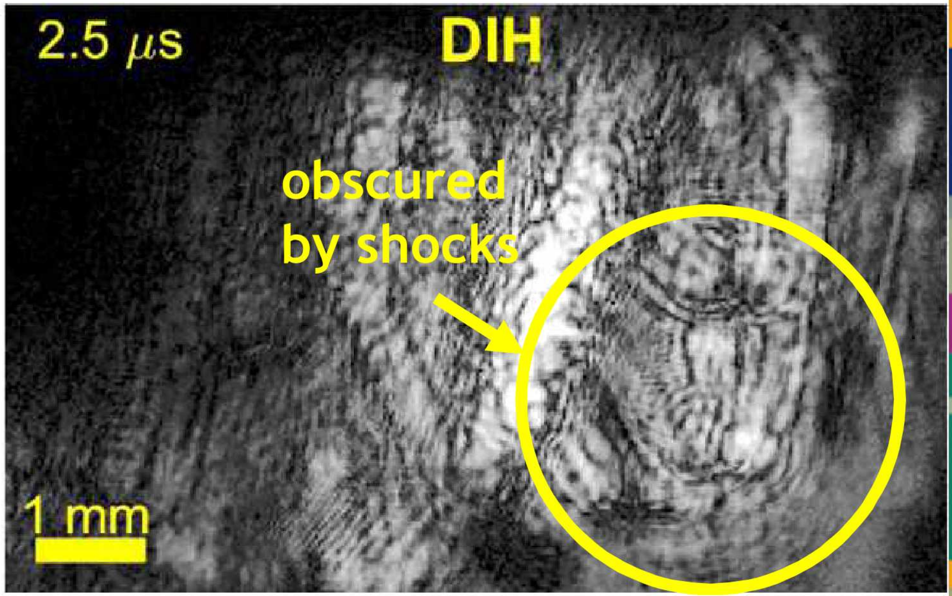


*With Yi (Ellen) Chen, Jeff Heyborne, Mike Smyzer (Purdue), Mikhail Slipchenko (Purdue)

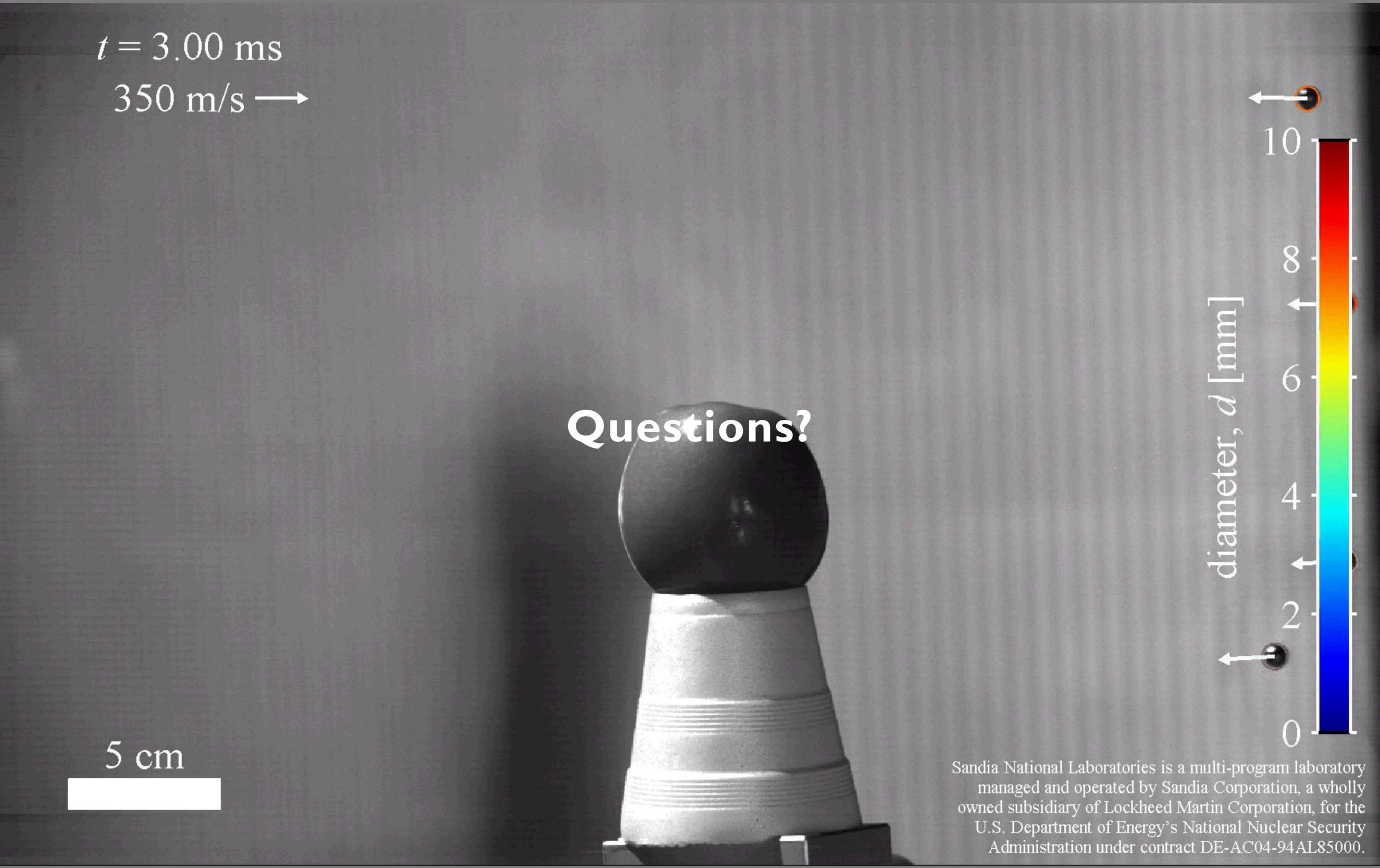
Imaging Through Shockwaves







*With Yi (Ellen) Chen, Jeff Heyborne, Mike Smyzer (Purdue), Mikhail Slipchenko (Purdue)



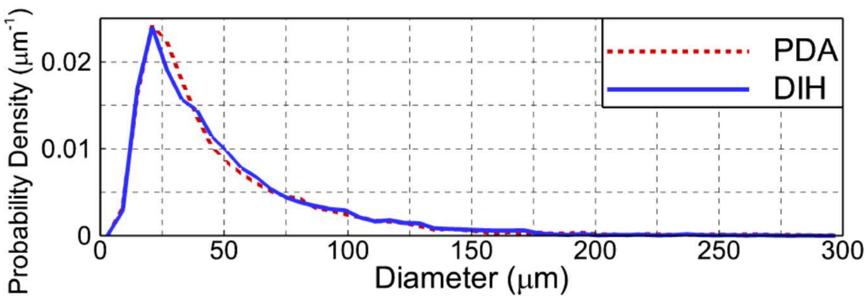
Questions?

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Aerodynamic breakup experiments

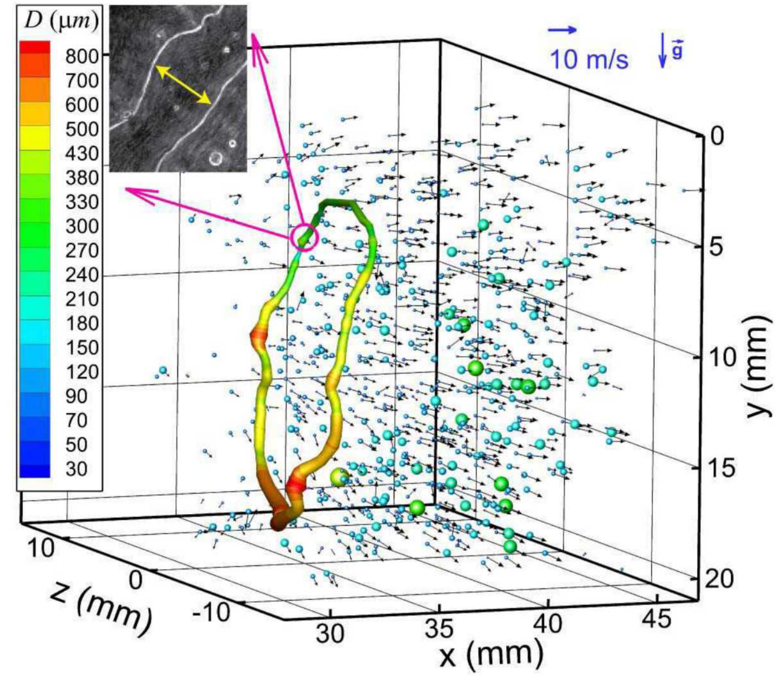
Secondary drop sizes/positions extracted with custom algorithms

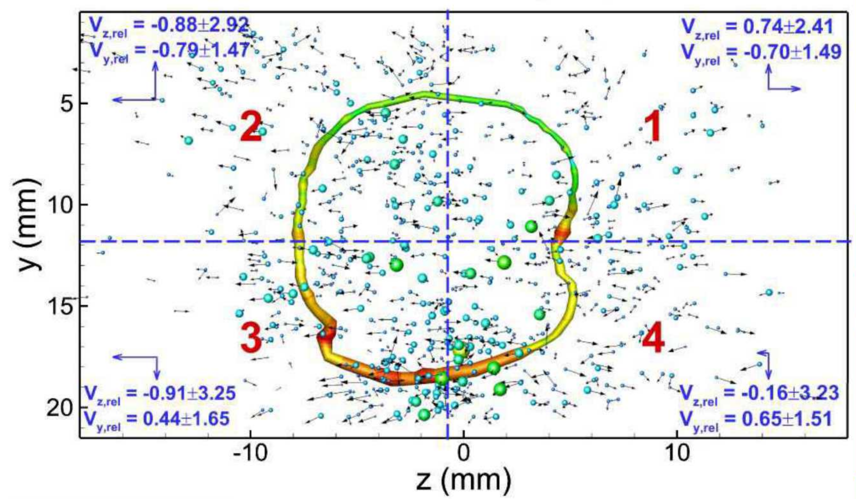
- Comparison with phase Doppler anemometer (PDA) data confirms accuracy of measured sizes



Ring measured from z-location of maximum image gradient

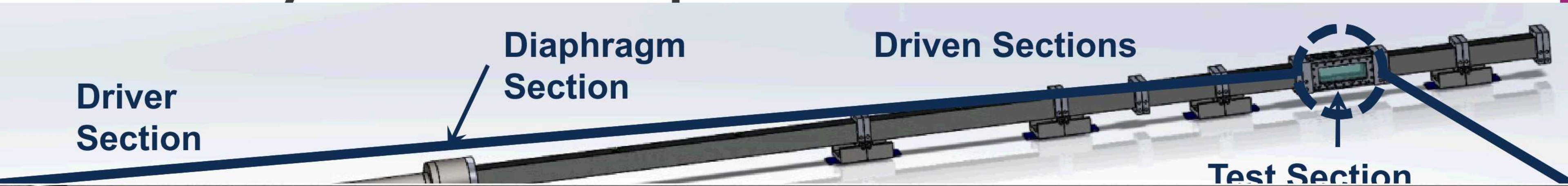
- Total volume of ring + secondary drops is within 2.2% of the initial volume

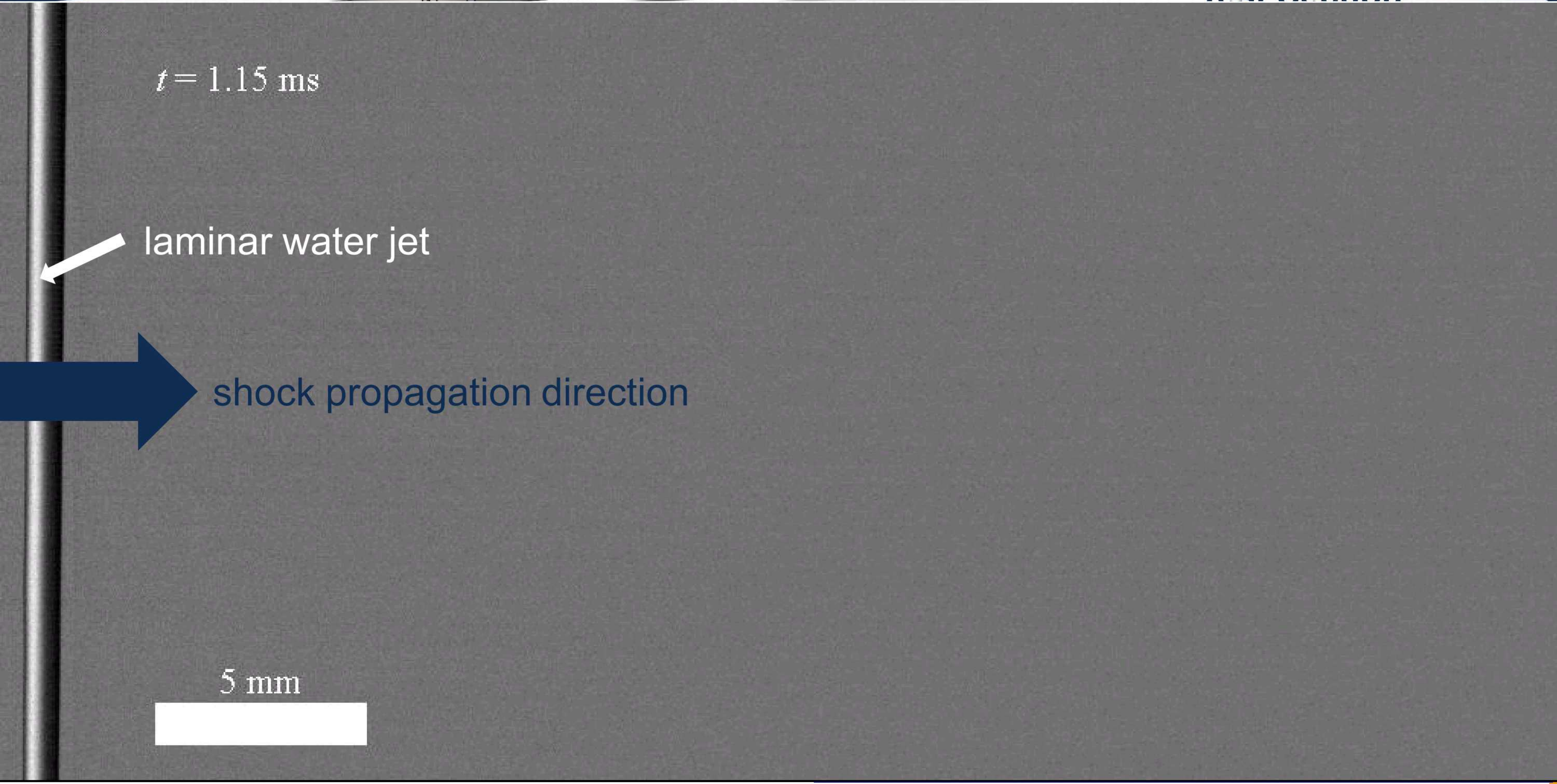




*With Phil Reu, Jun Chen (Purdue), Jian Gao (Purdue)

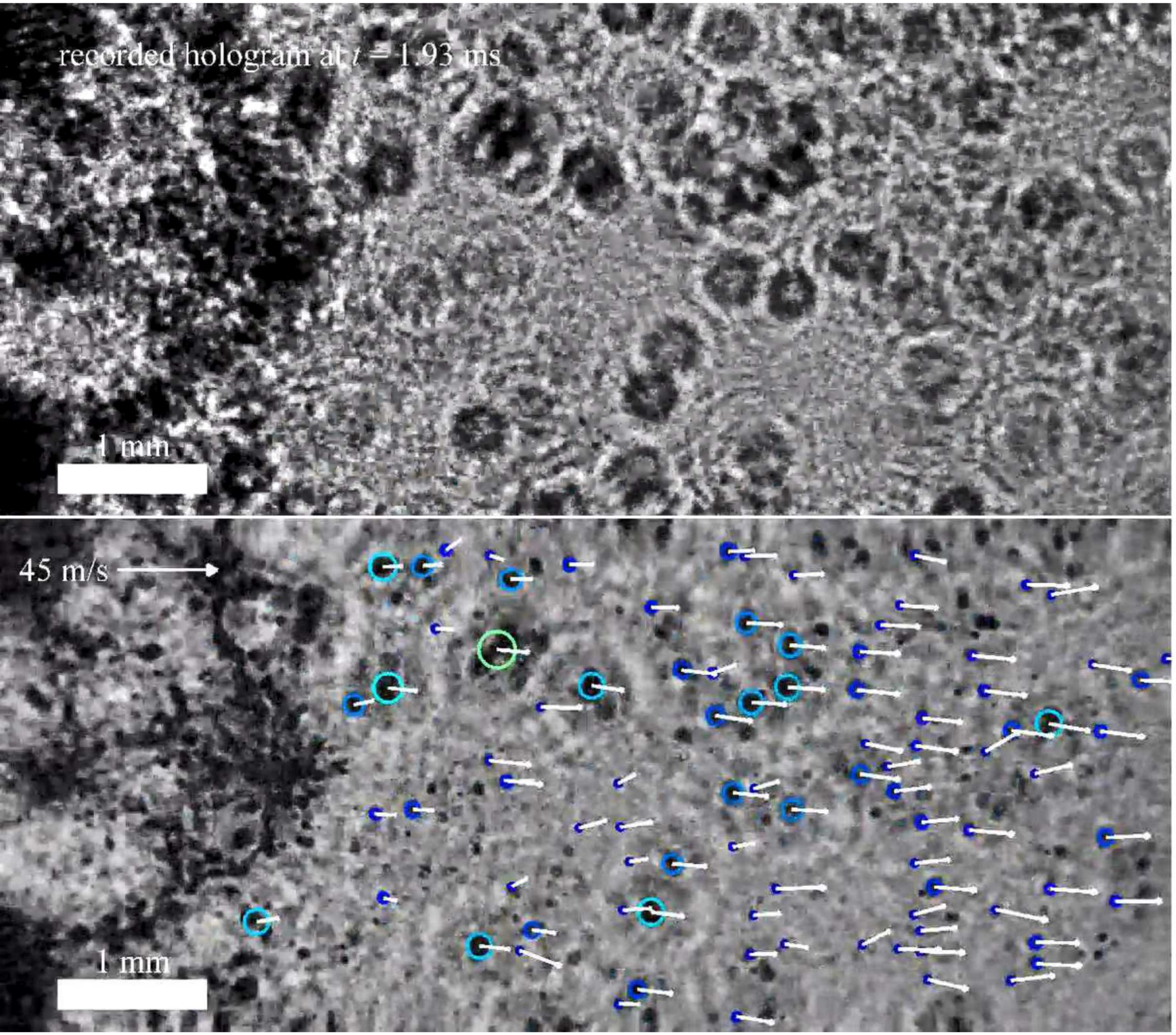
Aerodynamic Breakup of a Water Column

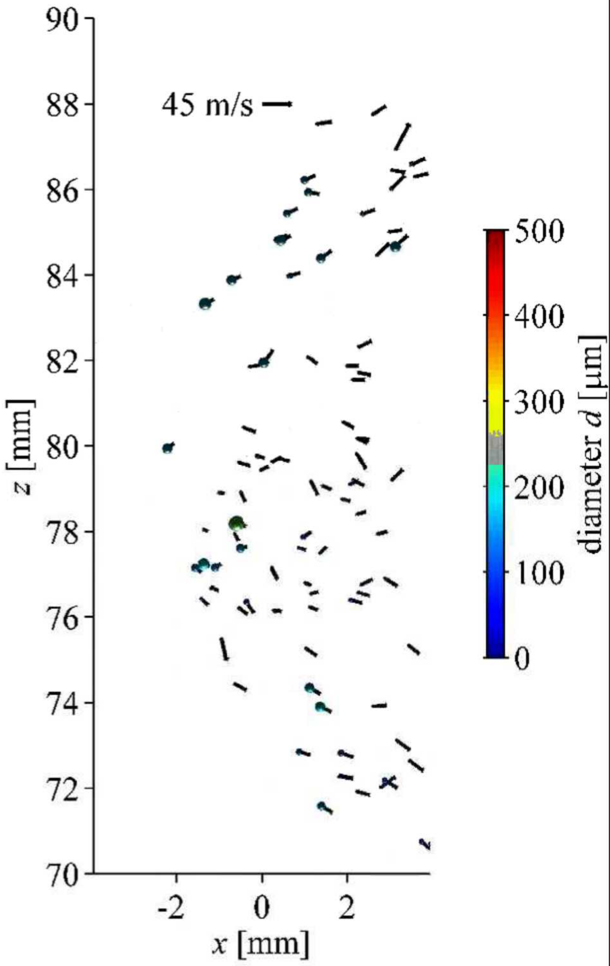




*With Justin Wagner, Yi (Ellen) Chen, Ed DeMauro, Paul Farias

Aerodynamic Breakup of a Water Column





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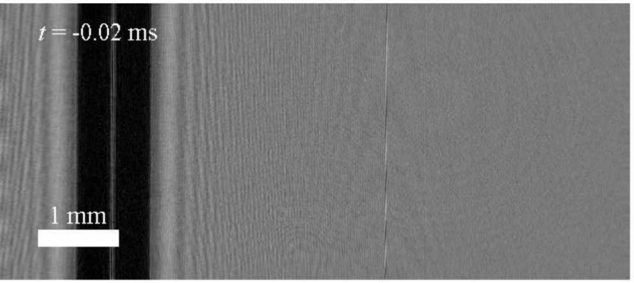
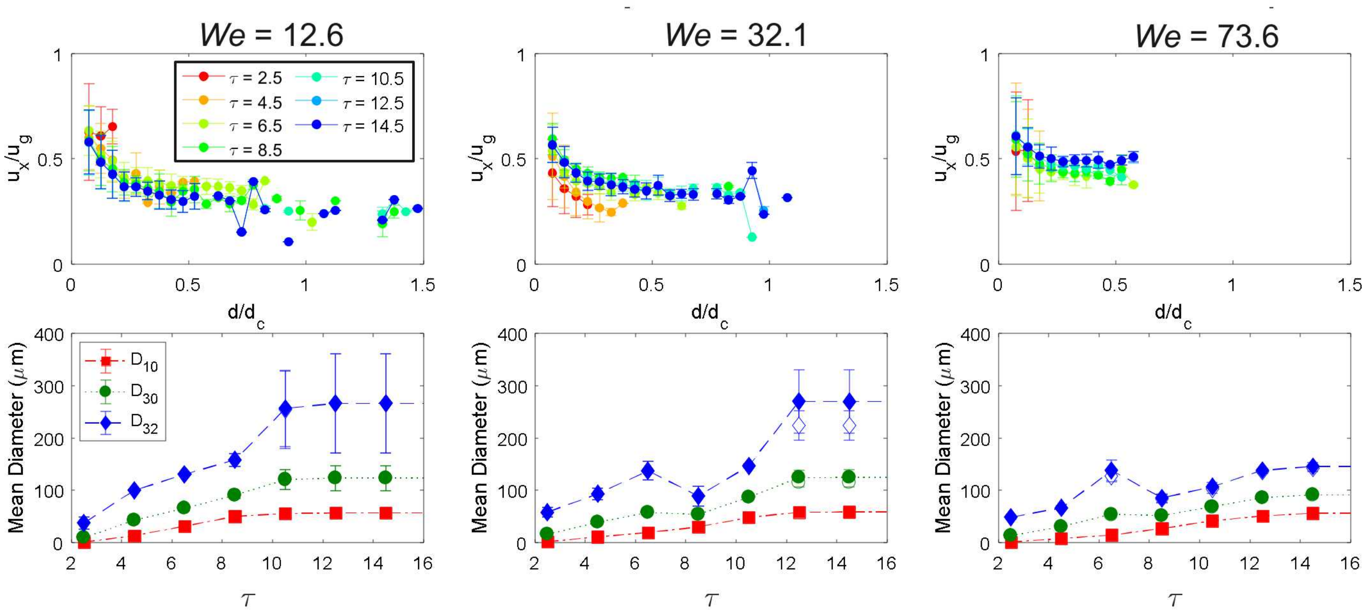
Aerodynamic Breakup of a Water Column





100 khz DIH Enables:

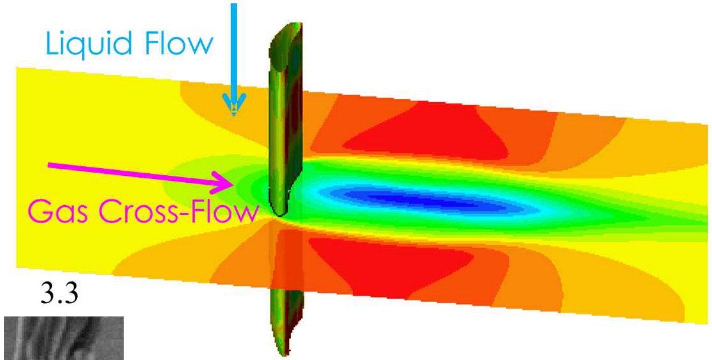
- Model validation quality data
- Measurements near the site of breakup
- Correlated size/velocity statistics

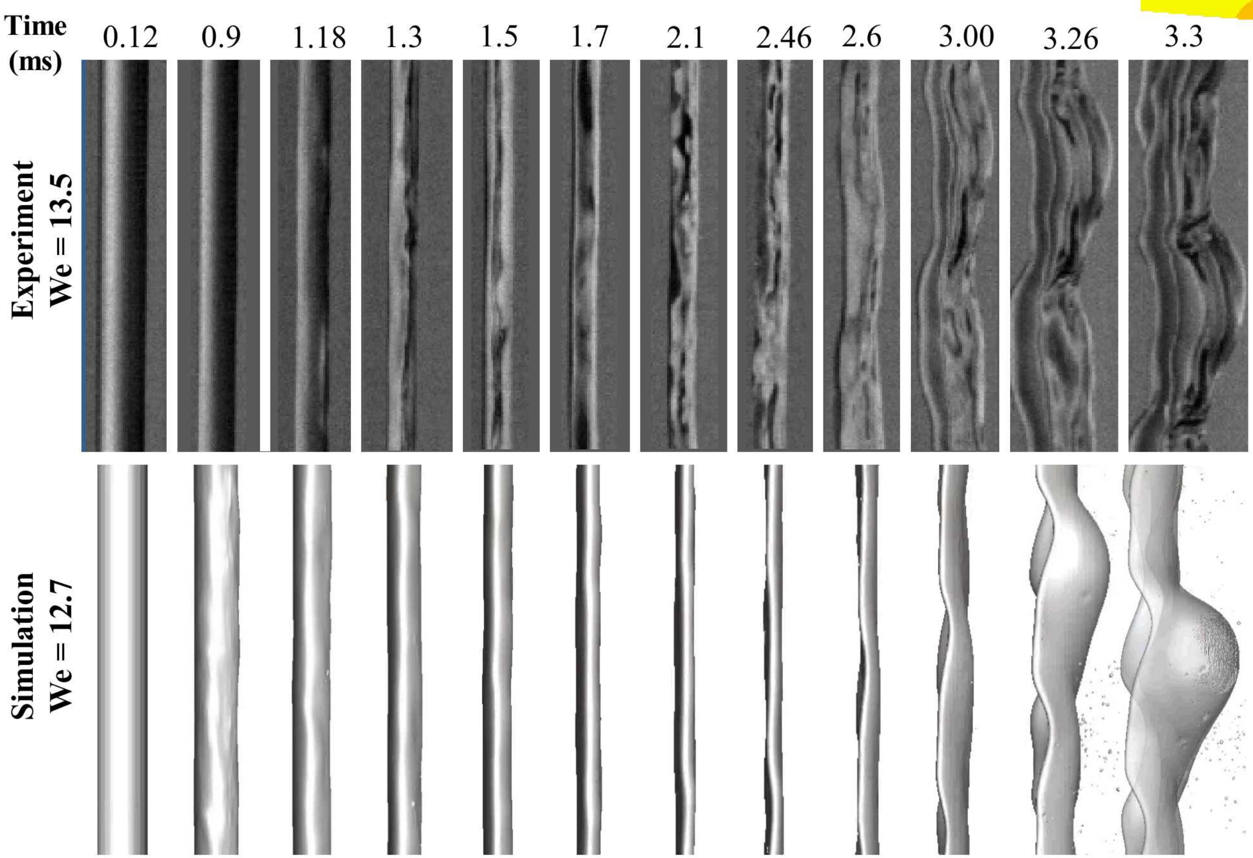
*With Justin Wagner, Yi (Ellen) Chen, Ed DeMauro, Paul Farias

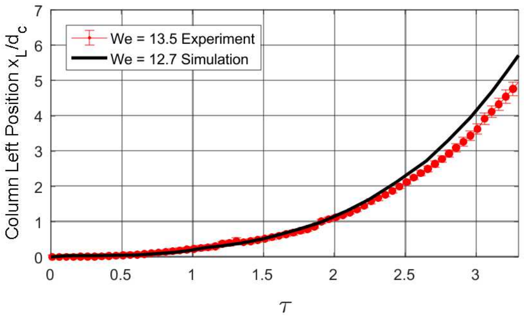
Aerodynamic Breakup of a Water Column

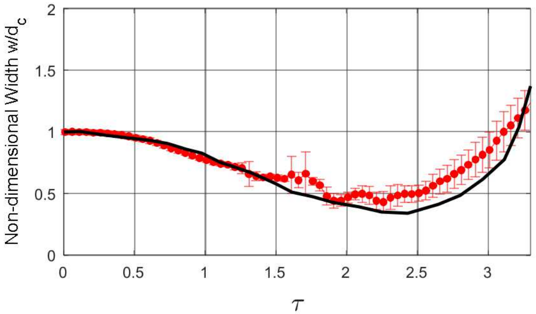
Combined Level Set Volume of Fluid (CLSVOF) method (M. Arienti)

- Captures interfacial dynamics
- Good initial agreement with measured quantities



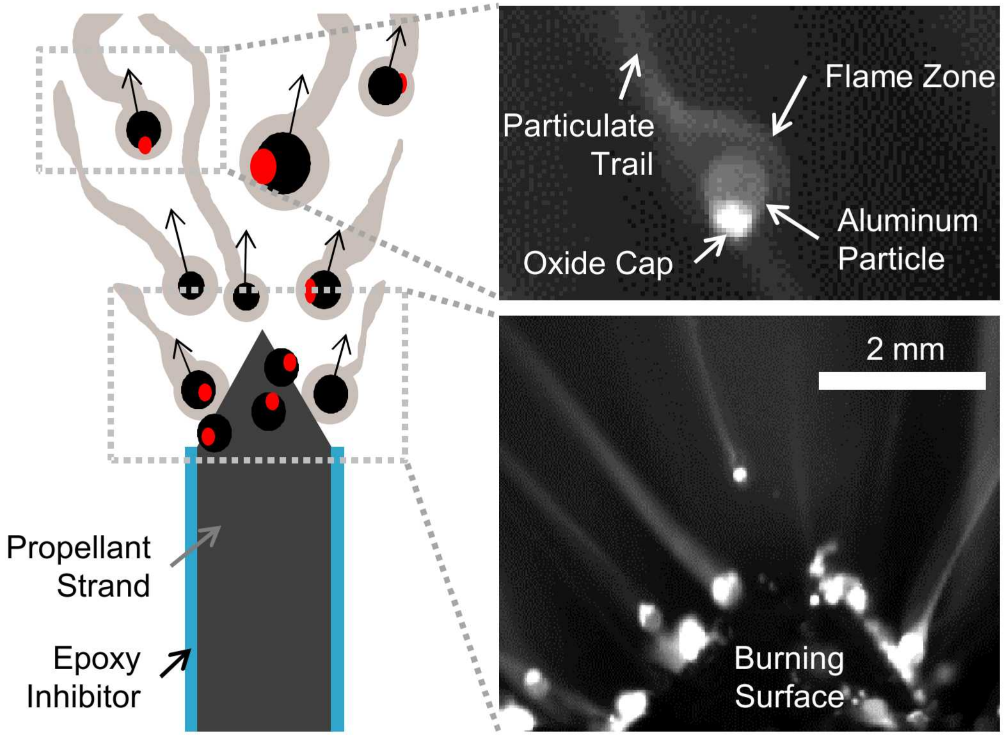


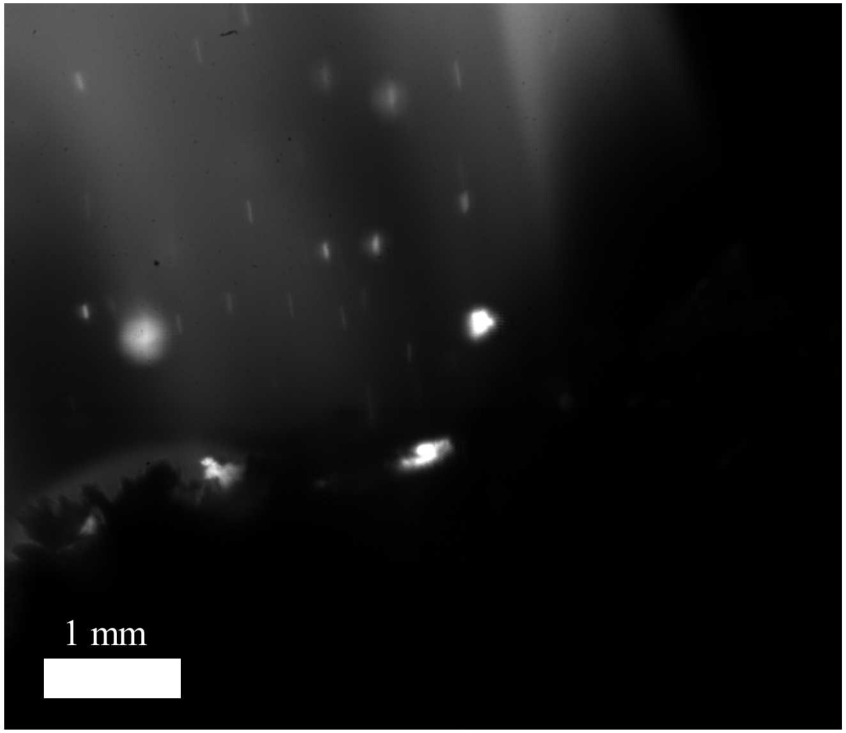


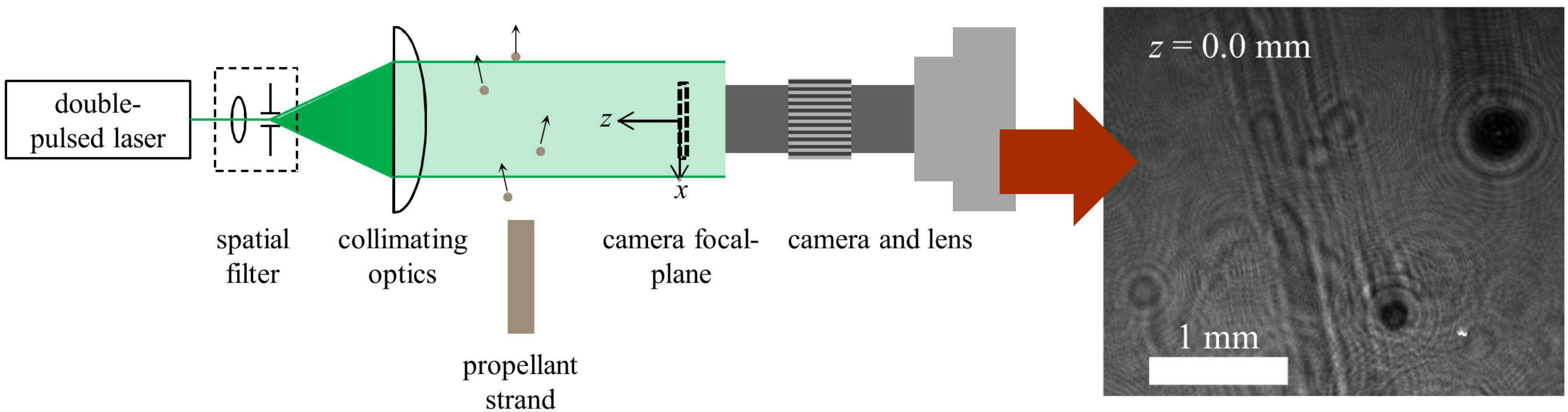


*With Justin Wagner, Yi (Ellen) Chen, Ed DeMauro, Paul Farias, Marco Arienti

Solid Propellant Diagnostics

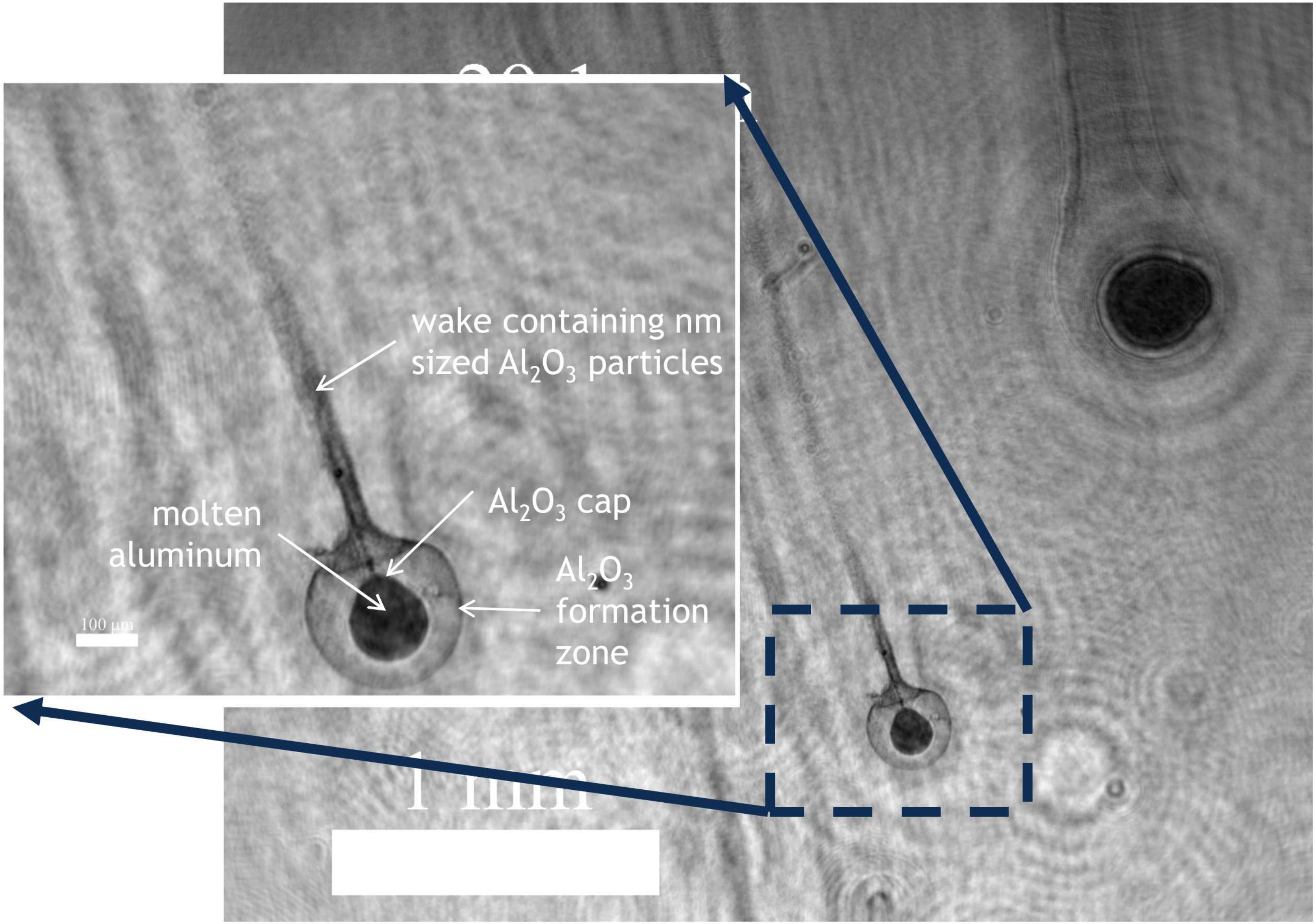






*With Marcia Cooper, Walt Gill, Lee Stauffacher, Mike Oliver, Tom Grasser

Solid Propellant Diagnostics



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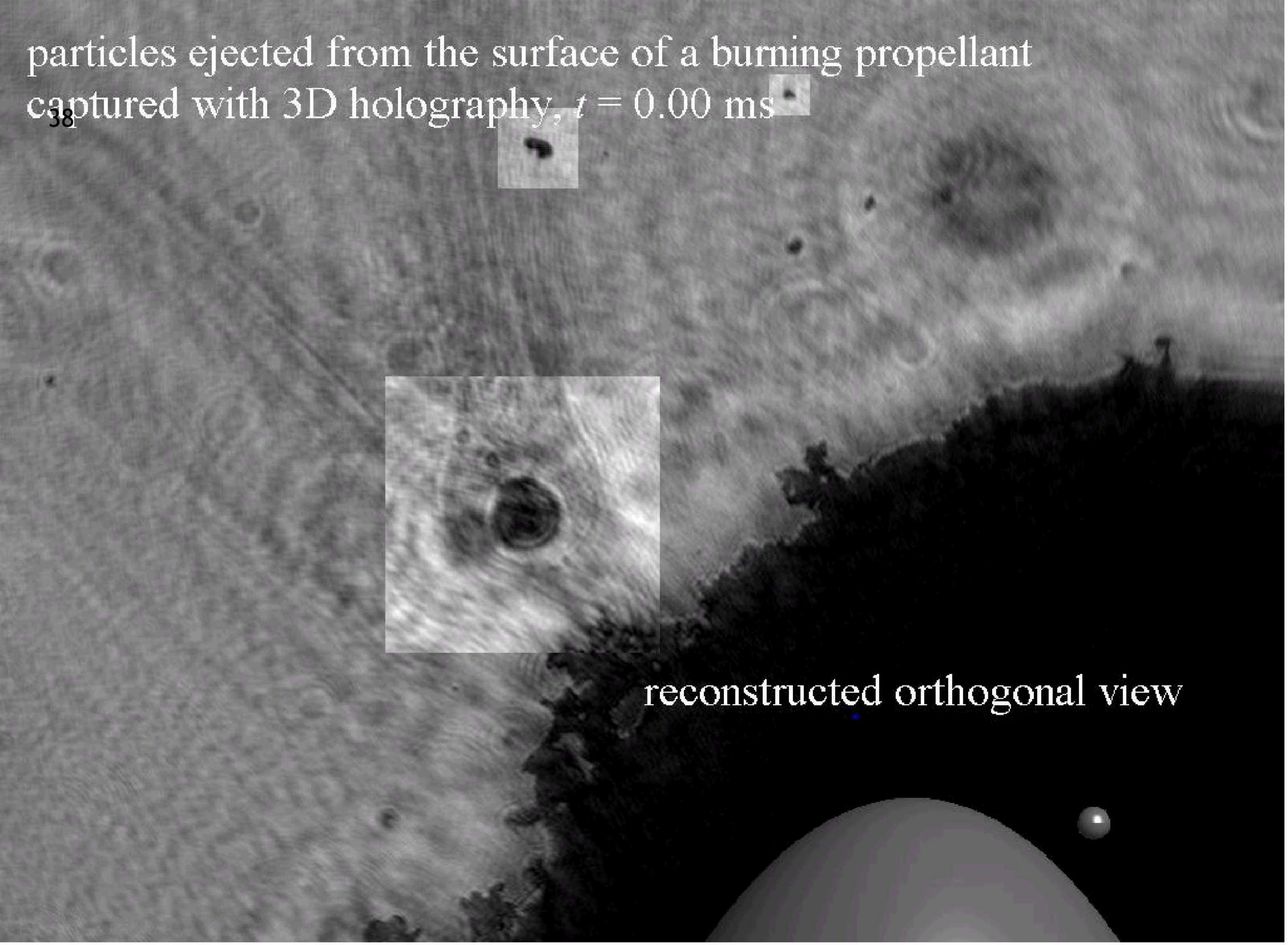


Recorded at 20,000 fps

Camera: Photron SA-Z

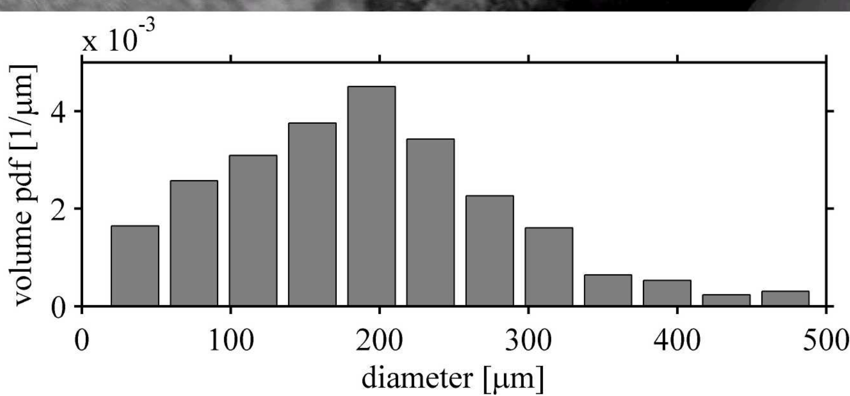
Laser: Coherent Verdi V6

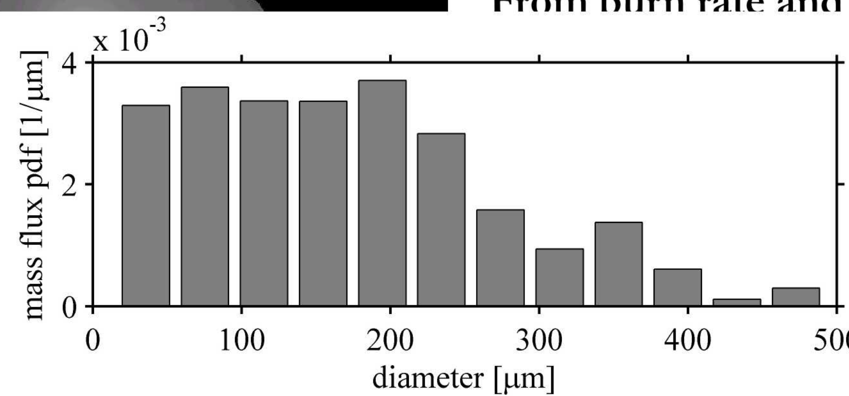
43,684 frames →

15,991 drops

Measured mass flux is 0.24 mg/s·mm²

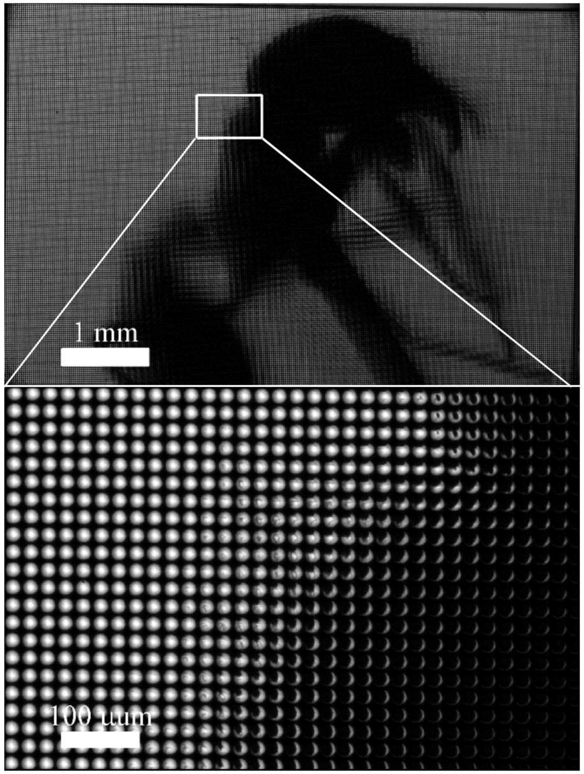
From burn rate and





New 5X Magnification, Long-Standoff Plenoptic

First demonstration

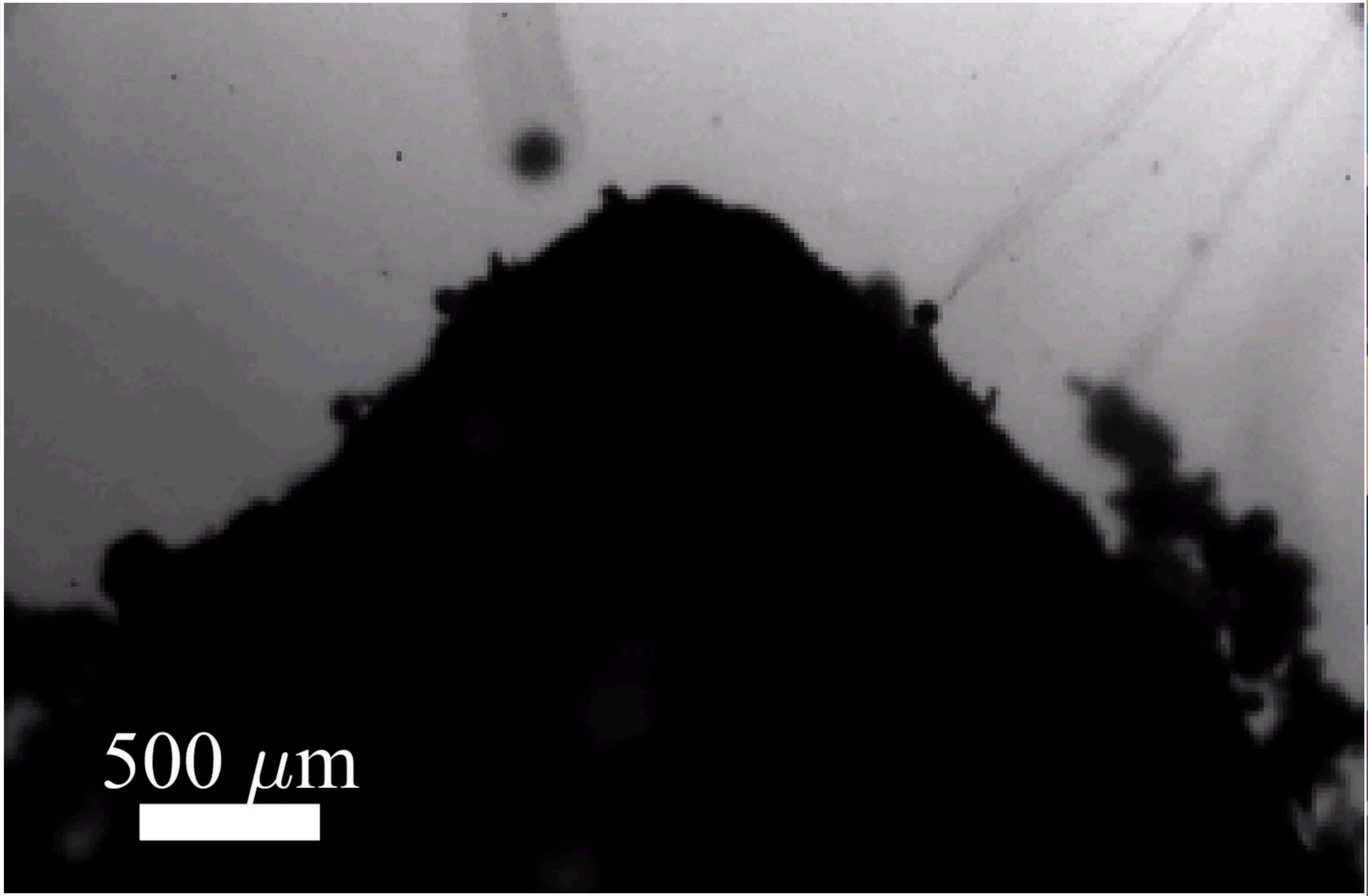


Recorded at an 11" standoff

*With Marley Kunzler, Bill Sweat, Brian Thurow (Auburn University), Jenna Klemkowsky (Auburn University)

New 5X Magnification, Long-Standoff Plenoptic

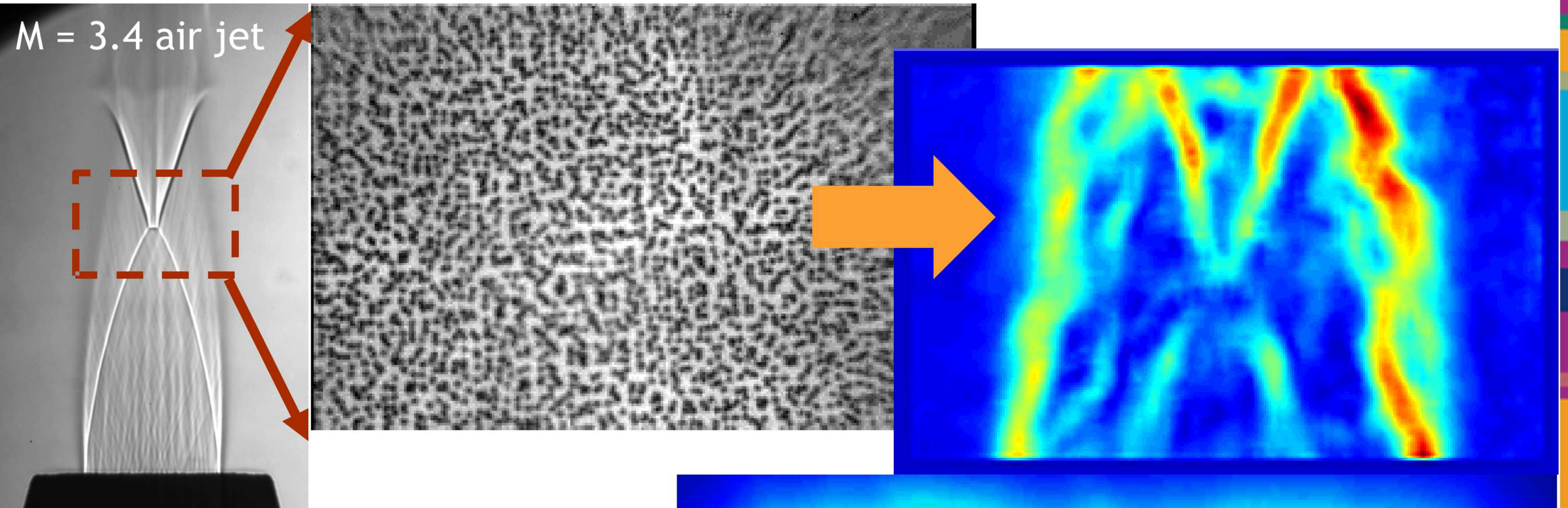
Developments enable measurement in harsh environments



Plenoptic imaging of a propellant fire

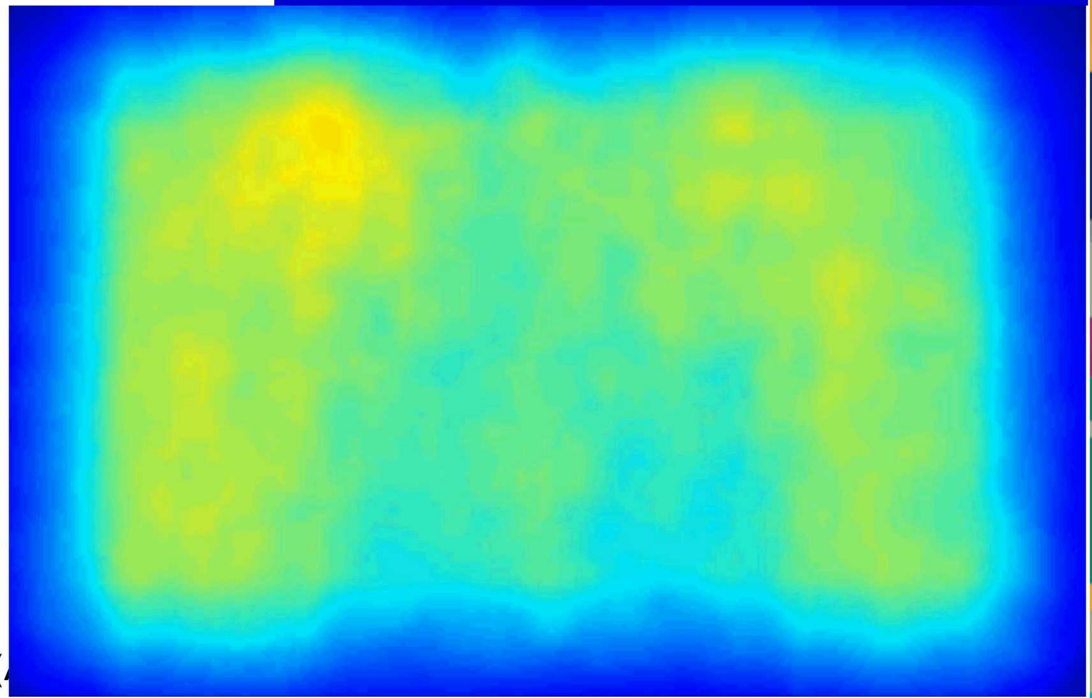
*With Marley Kunzler, Bill Sweat, Brian Thurow (Auburn University), Jenna Klemkowsky (Auburn University)

Exploring Application to 3D Density Gradients



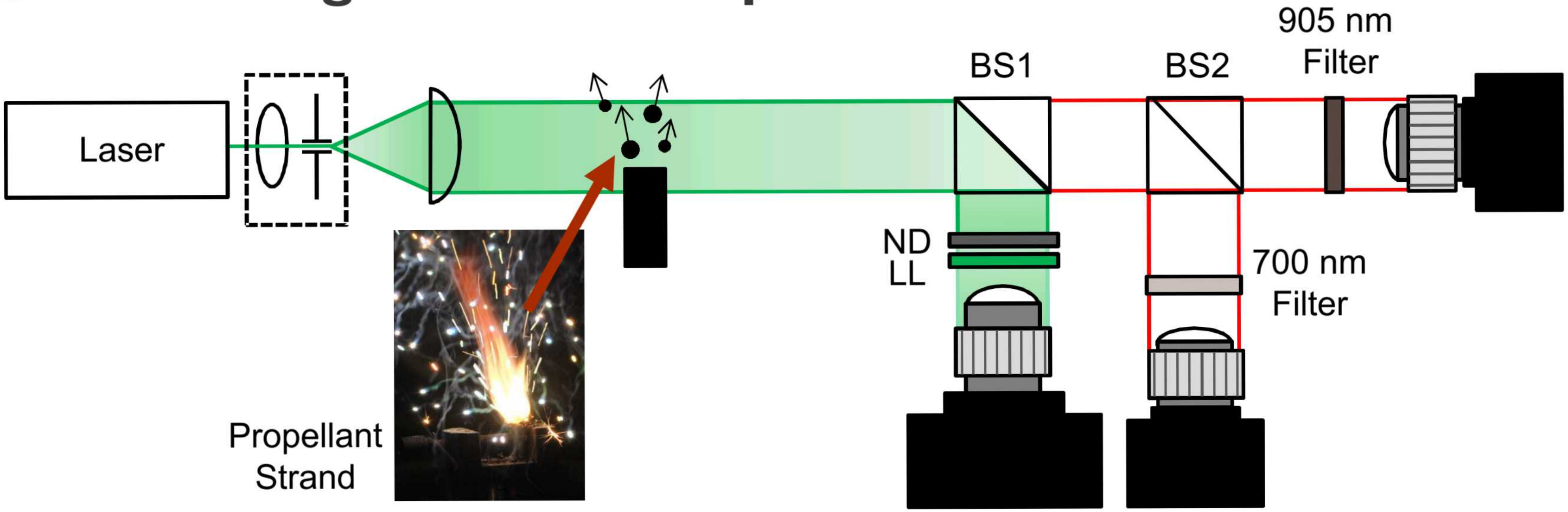
Plenoptic Background Oriented Schlieren (BOS)

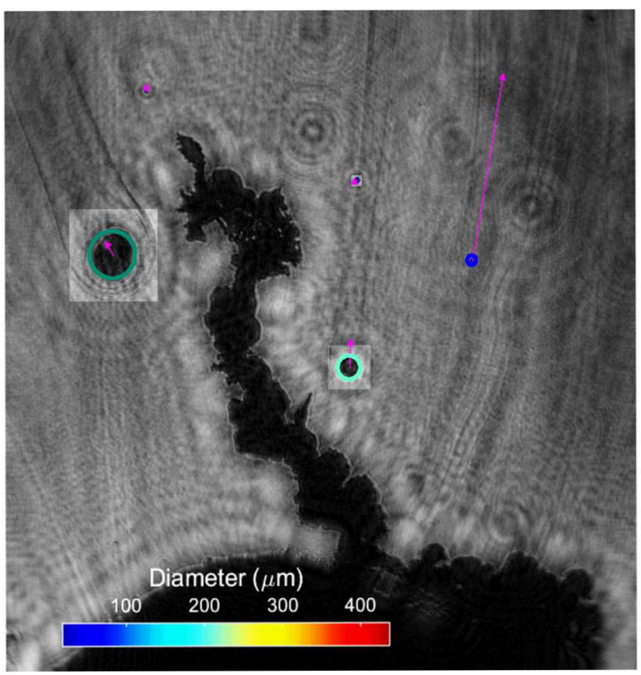
- Optical flow tracks apparent motion
- Plenoptic perspectives allows 3D rendering

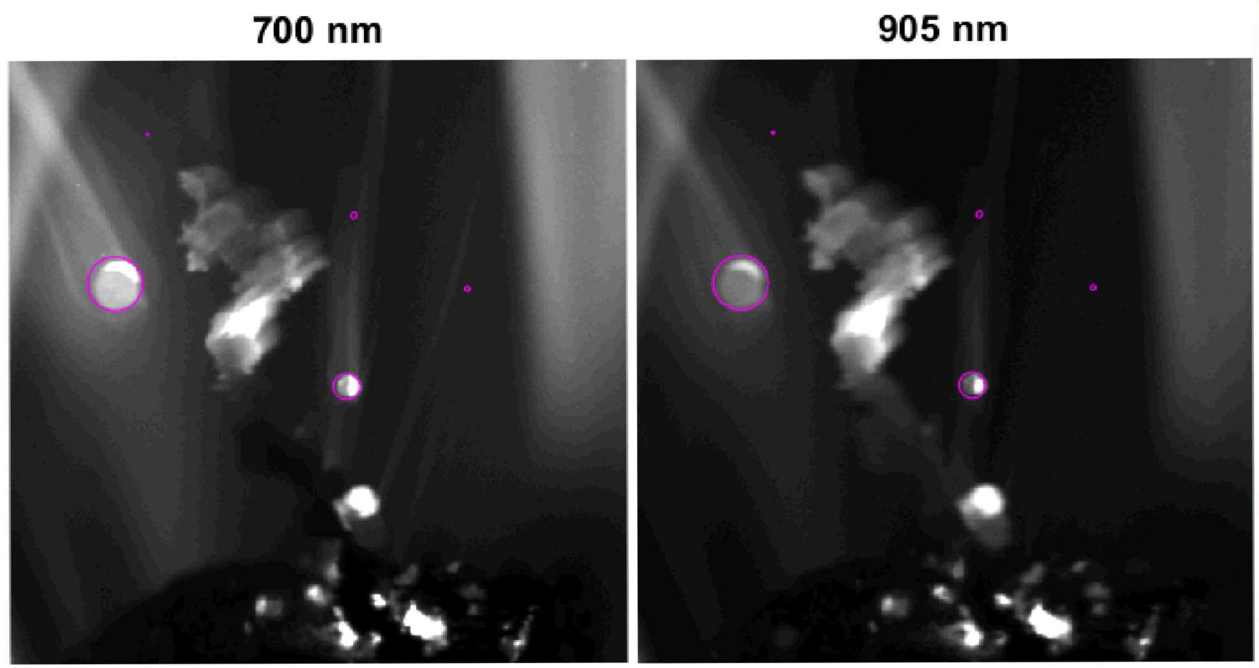


*With Marley Kunzler, Bill Sweat, Brian Thurow (

Measuring Particle Temperatures

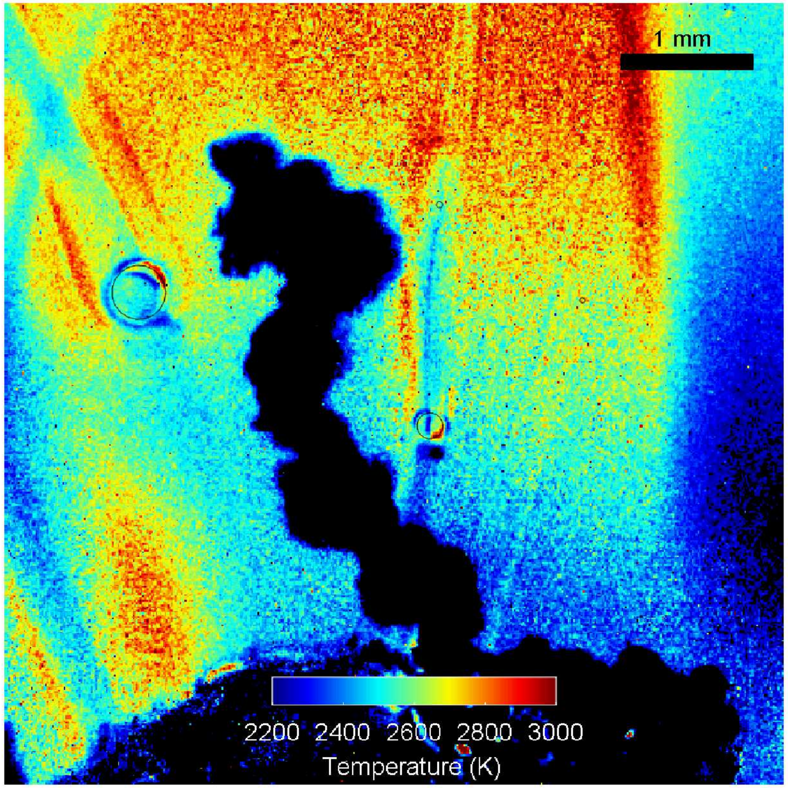






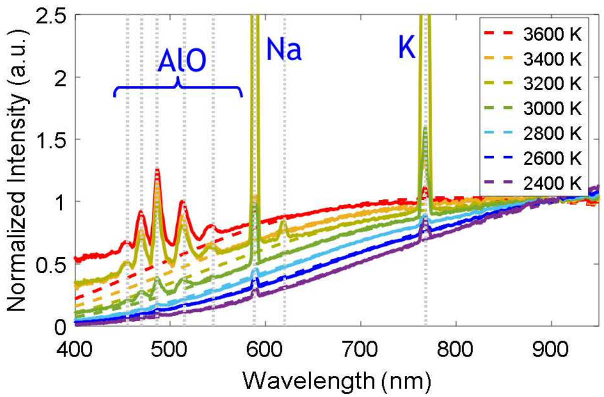
*With Yi (Ellen) Chen, Kate Hoffmeister, Marcia Cooper, Lee Stauffacher, Mike Oliver, Sean Kearney, Ephraim Washburn (China Lake)

Measuring Particle Temperatures



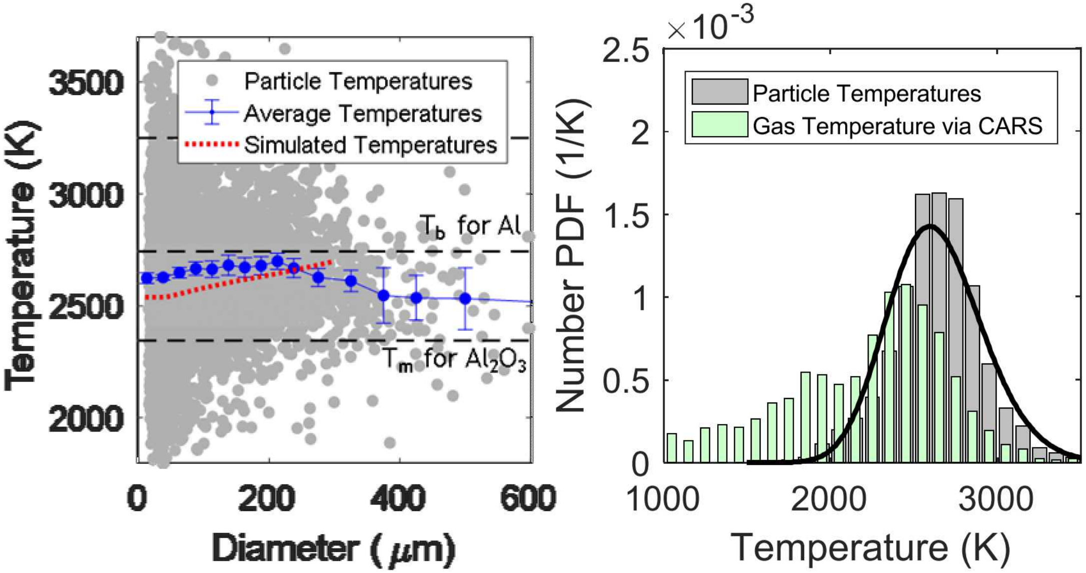
Particle Emission is Approximated as a Gray Body

- Critical to avoid gas phase emission peaks



Many thousands of particles measured to gather statistics

- Particle temperatures approximately bounded by melting and boiling points of Al and Al_2O_3
- On average, particles are hotter than gas-phase temperatures measured with CARS

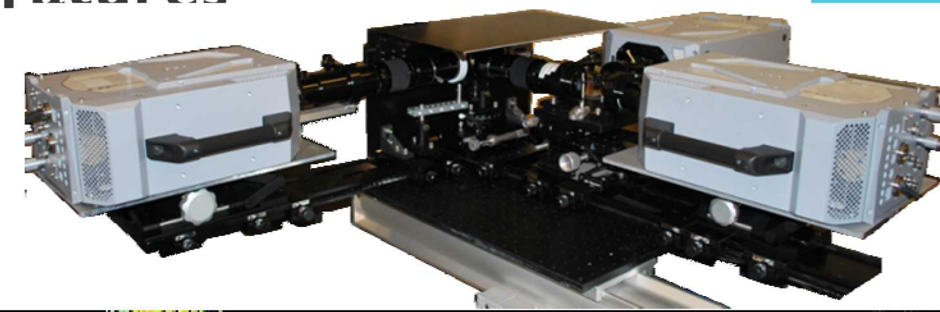


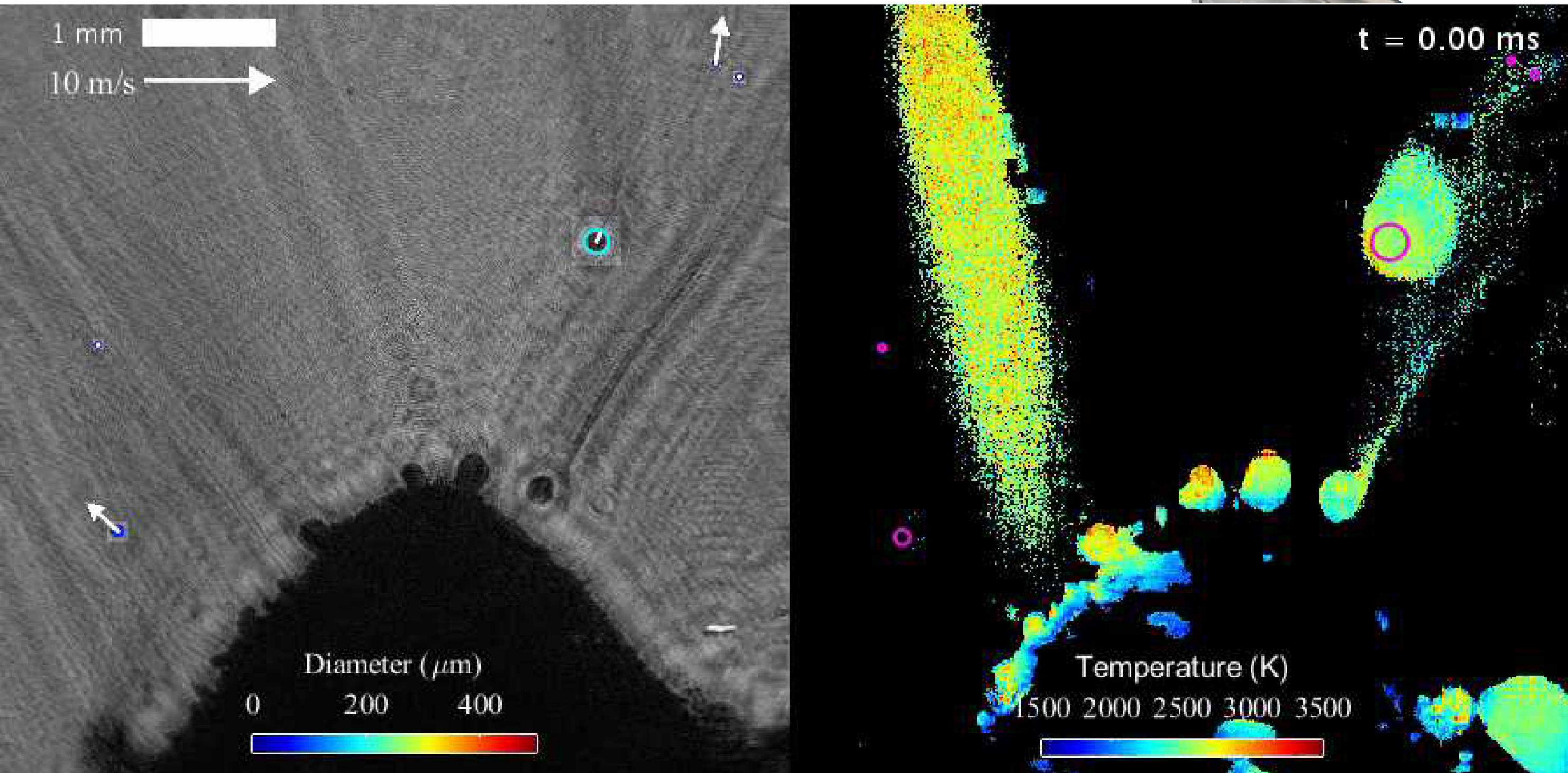
*With Yi (Ellen) Chen, Kate Hoffmeister, Marcia Cooper, Lee Stauffacher, Mike Oliver, Sean Kearney, Ephraim Washburn (China Lake)

Measuring Particle Temperatures

Measurements are also possible at high-speed

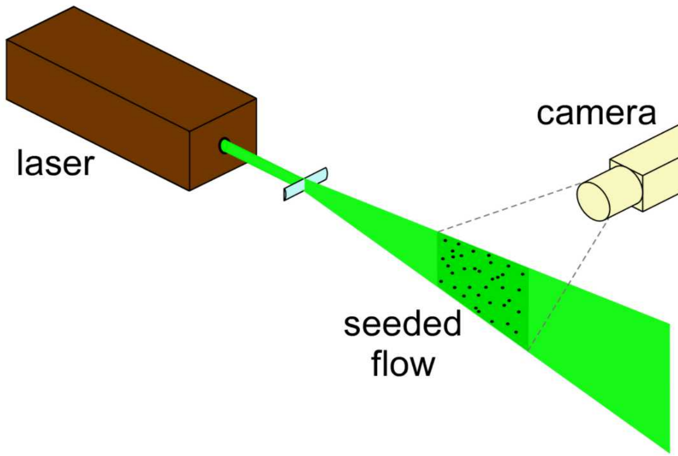
- 20 kHz in this example

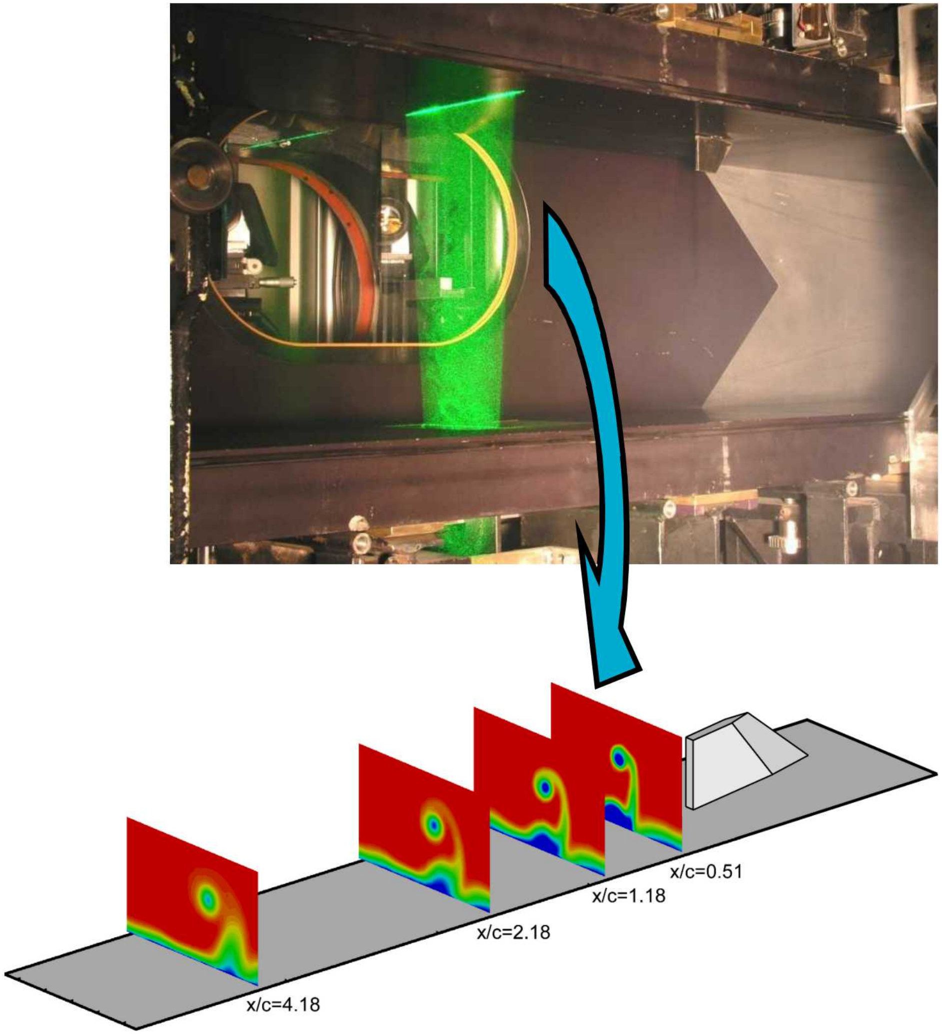




*With Yi (Ellen) Chen, Kate Hoffmeister, Marcia Cooper, Lee Stauffacher, Mike Oliver, Sean Kearney, Ephraim Washburn (China Lake)

Velocimetry from a single viewport?





Particle image velocimetry (PIV)

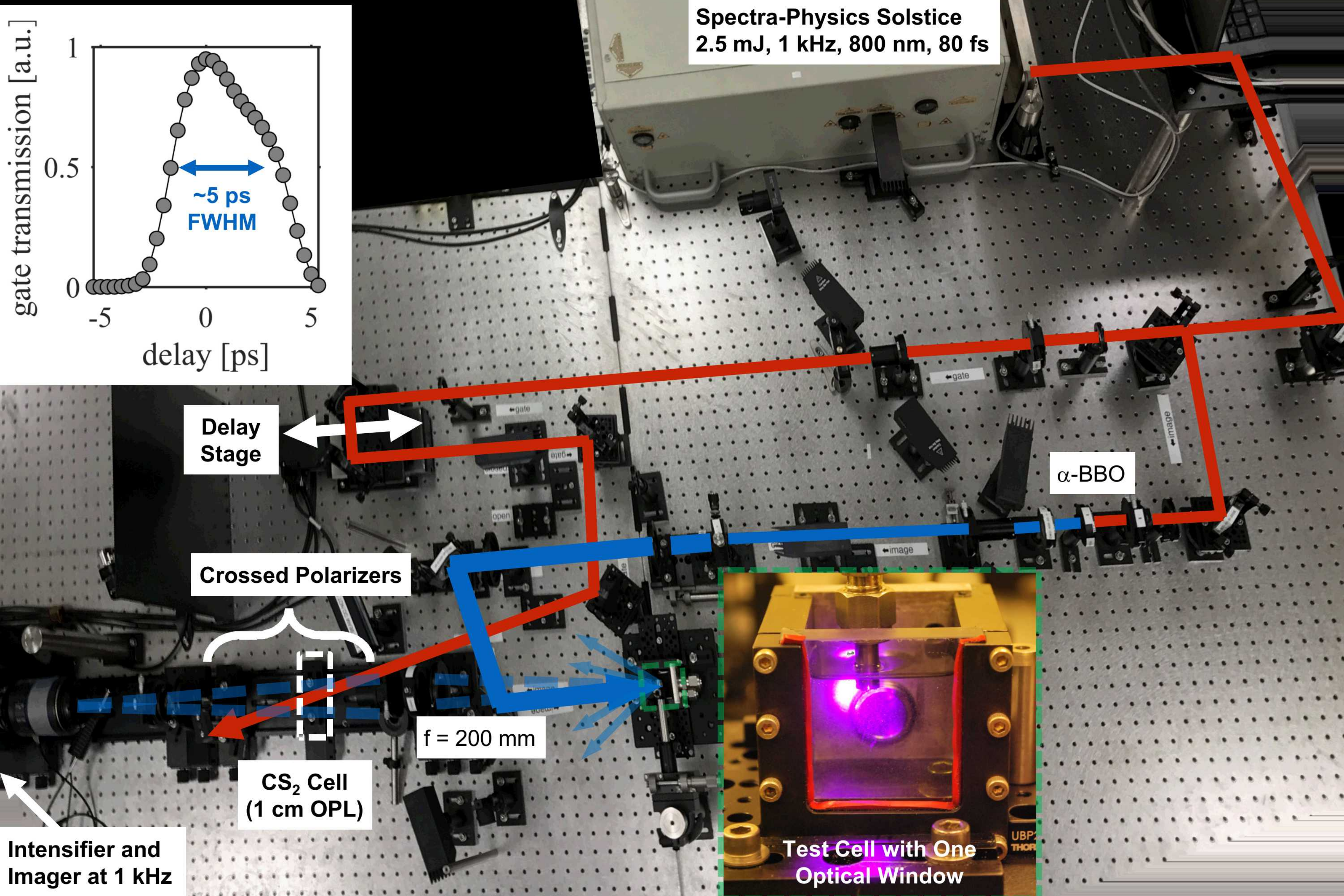
- Quantifies 2D flow velocities by tracking the motion of seed particles
- Widely used in fluid dynamics from micro-fluidics up to windtunnel scales and beyond

Requirements for two orthogonal optical access ports can limit some applications

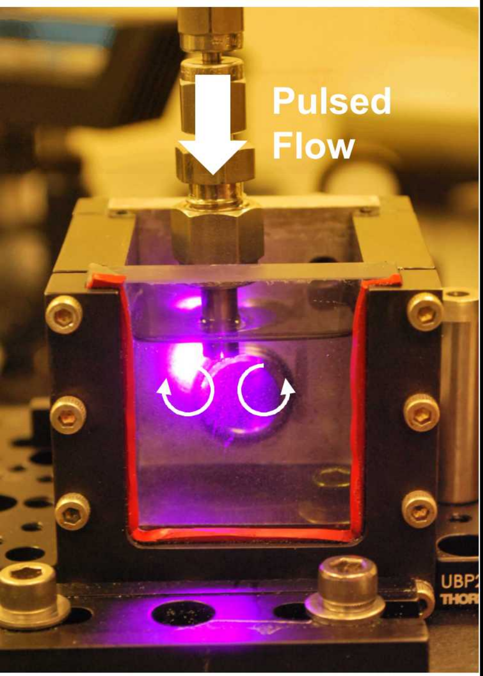
PIV in the Sandia wind-tunnel (courtesy Beresh *et al*)

*With Megan Paciaroni (Ft. Lewis College), Yi (Ellen) Chen, Kyle Lynch

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

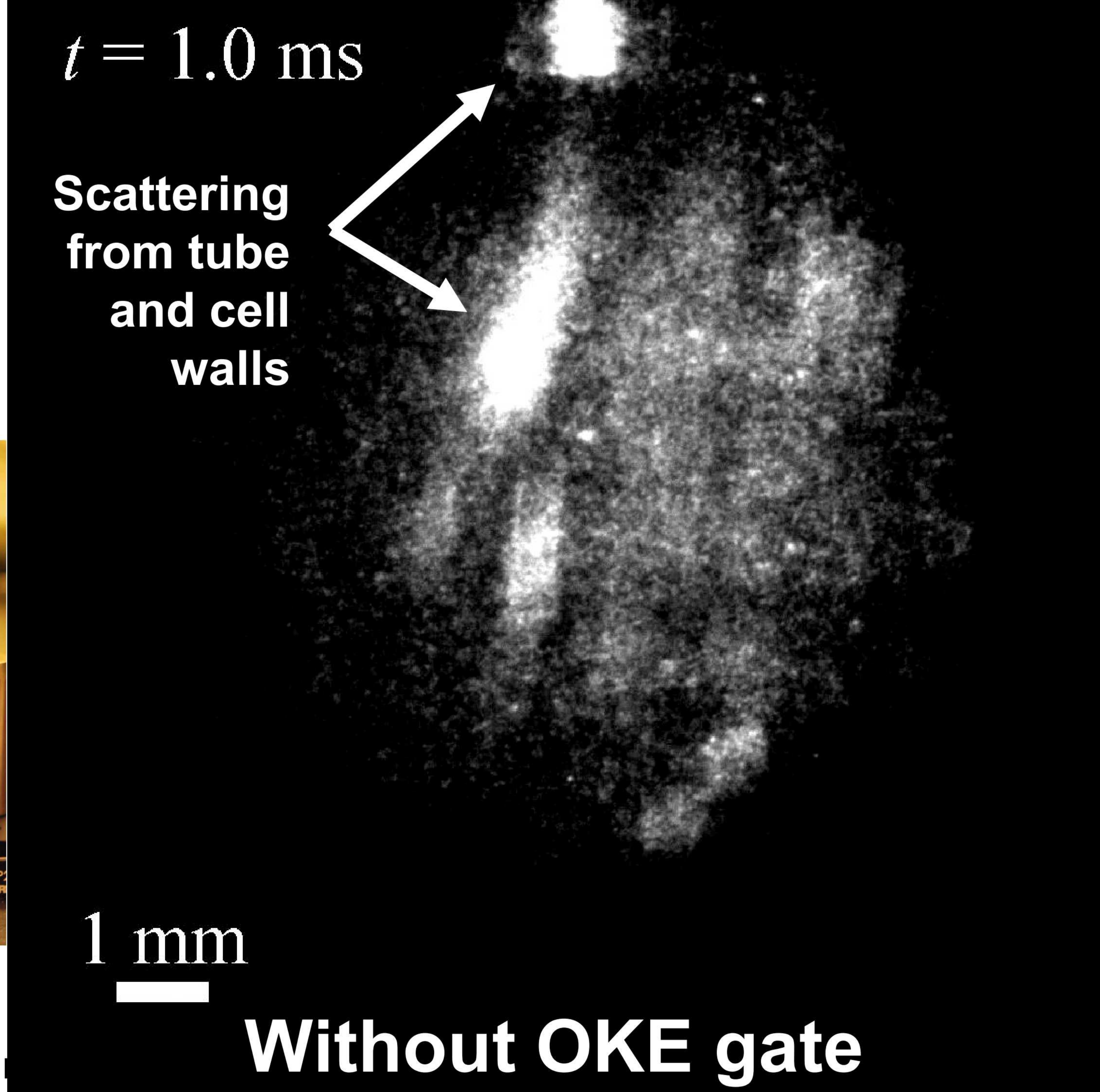


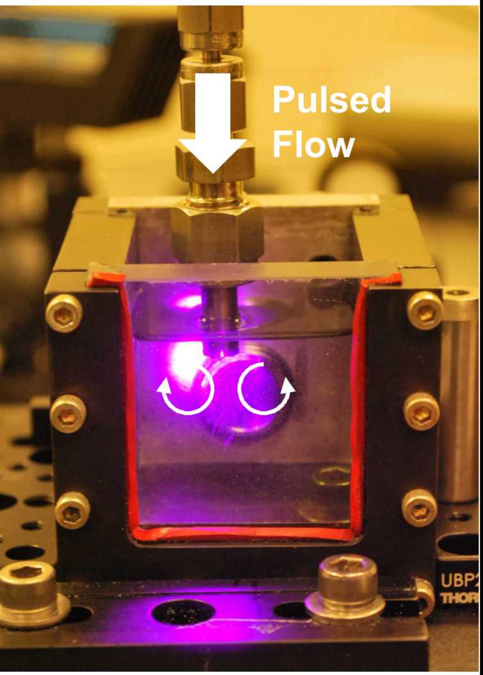
PIVOTS



Water Seeded with 40 μm neutrally buoyant particles

*With Megan Paciaroni (Ft.





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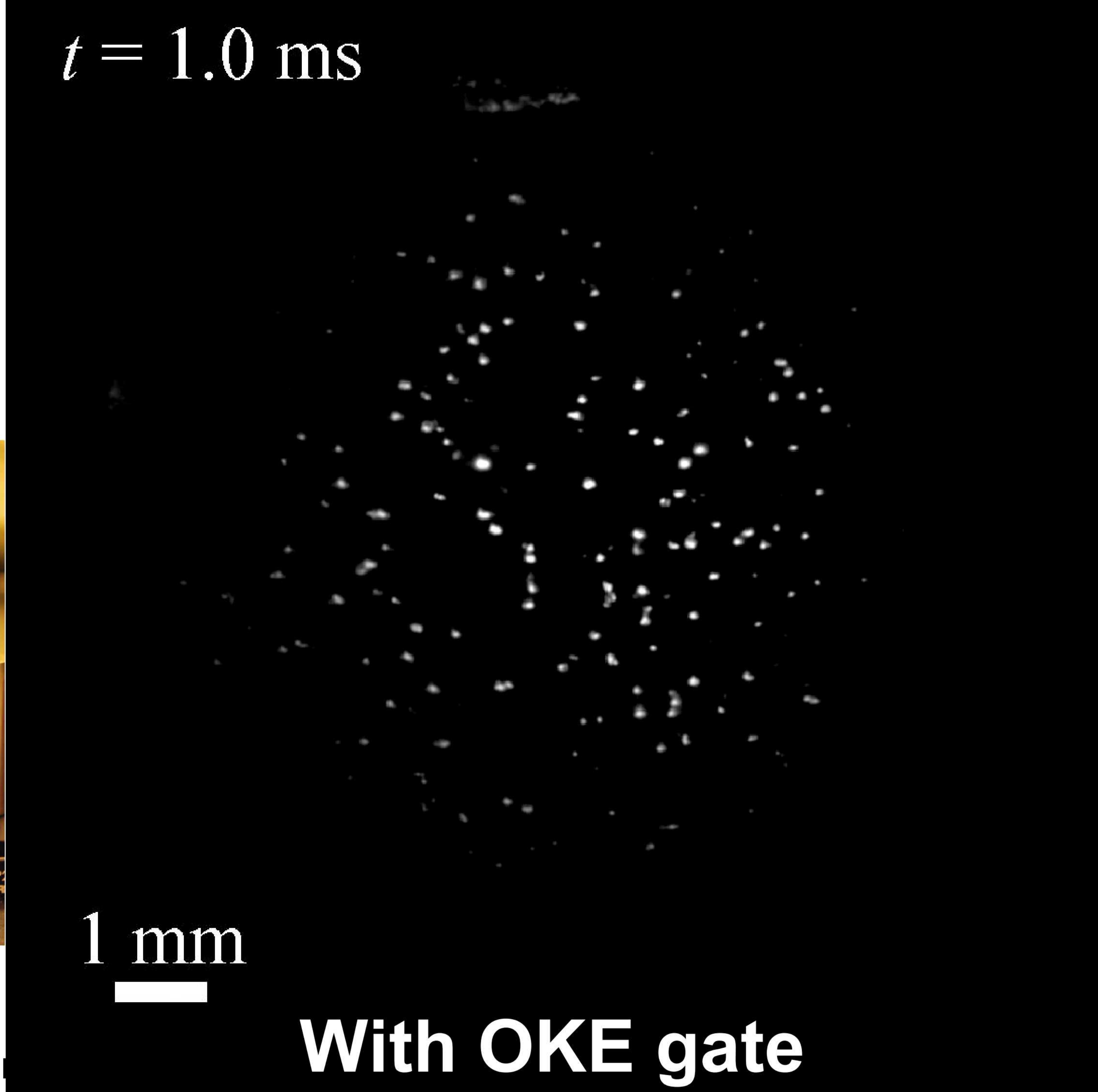
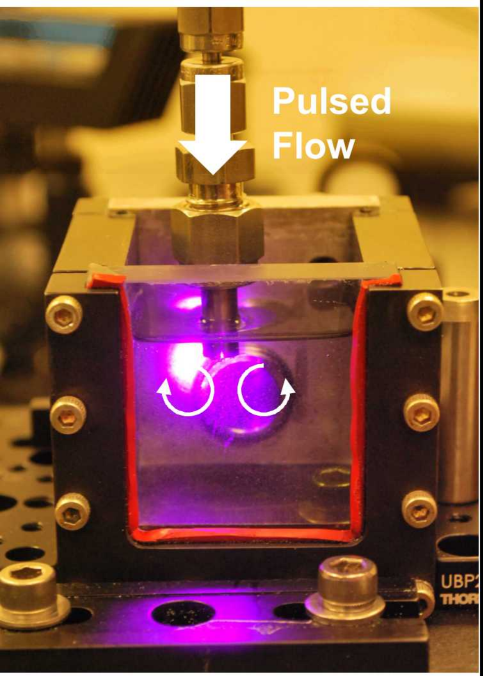


PIVOTS



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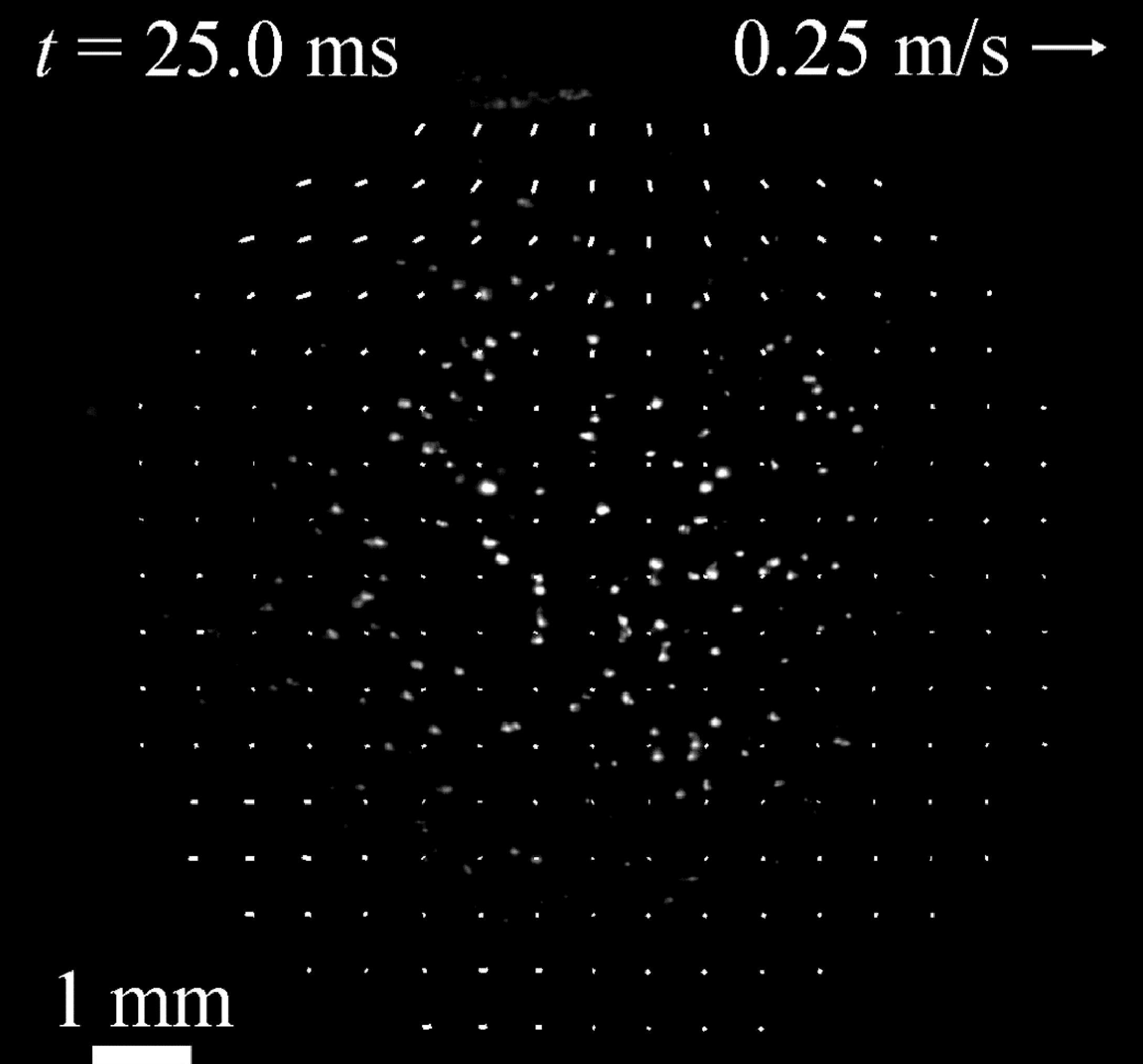

Processed Results