



Walter Lempert's contributions to NASA: the early years through 1 MHz PLIF Imaging

Naibo Jiang, Spectral Energies
and
Paul Danehy, NASA Langley Research Center

Walter's pre-NASA career



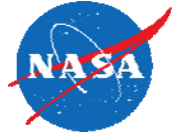
- BS in Chemistry from Lehigh in 1975
- PhD in Physical Chemistry from U of Utah, 1981
- Post-doc for 2 years at NBS in Gaithersburg, Md
 - Temperature and Pressure measurements using high-resolution nonlinear Raman
 - Special skill: computer instrument interfacing and control.

Walter's career at NASA Langley



- Started at NASA Langley Res. Center August 1983
- Left NASA in late 1987 or early 1988.
- Publications:
 - Microwave resonance lamp absorption technique for measuring temperature and OH number density in combustion environments, Lempert, Walter R. Combustion and Flame 73; 89-98, Jul. 1988.
 - Supersonic combustion performance of hydrogen/hydrocarbon mixtures as determined by a nonintrusive temperature monitor, Northam, G. Burton; Lempert, Walter R.; Diskin, Glenn S.; Gregory, Ray W.; Bell, Randy A. AIAA PAPER 88-3293
 - Half-collision analysis of far-wing diffuse structure in Cs-Xe, Exton, R. J.; Hillard, M. E.; Lempert, W. R., Journal of Physics B - Atomic and Molecular Physics, 1987.
 - Molecular flow velocity using Doppler shifted Raman spectroscopy, Exton, Reginald J.; Hillard, Mervin E., Jr.; Lempert, Walter R.; Covell, Peter F.; Miller, David S., AIAA PAPER 87-1531
 - RELIEF work with Princeton and Diskin...

Lempert absorption instrument



- OH discharge as a light source to measure OH concentration and temperature.
- Developed for studying supersonic combustion at NASA

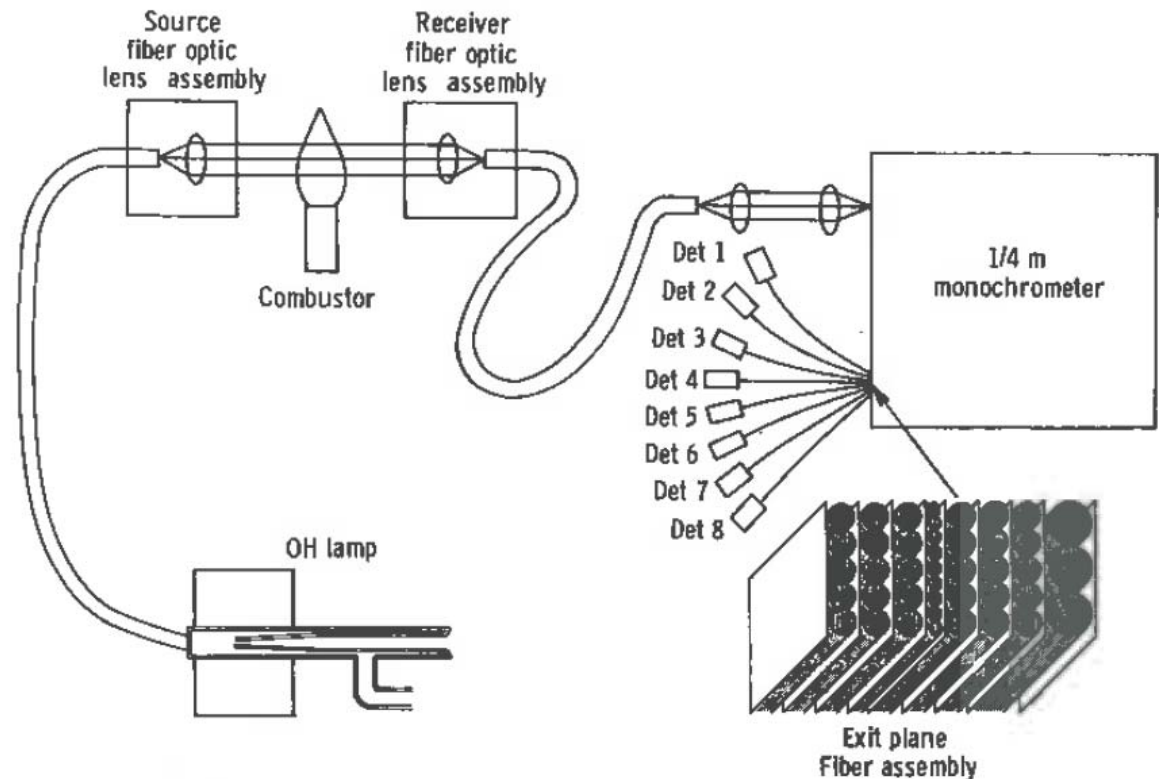


Fig. 1. Schematic diagram of OH temperature instrument.

Microwave resonance lamp absorption technique for measuring temperature and OH number density in combustion environments, Lempert, Walter R. Combustion and Flame 73; 89-98, Jul. 1988.

Results from Lempert (1988)

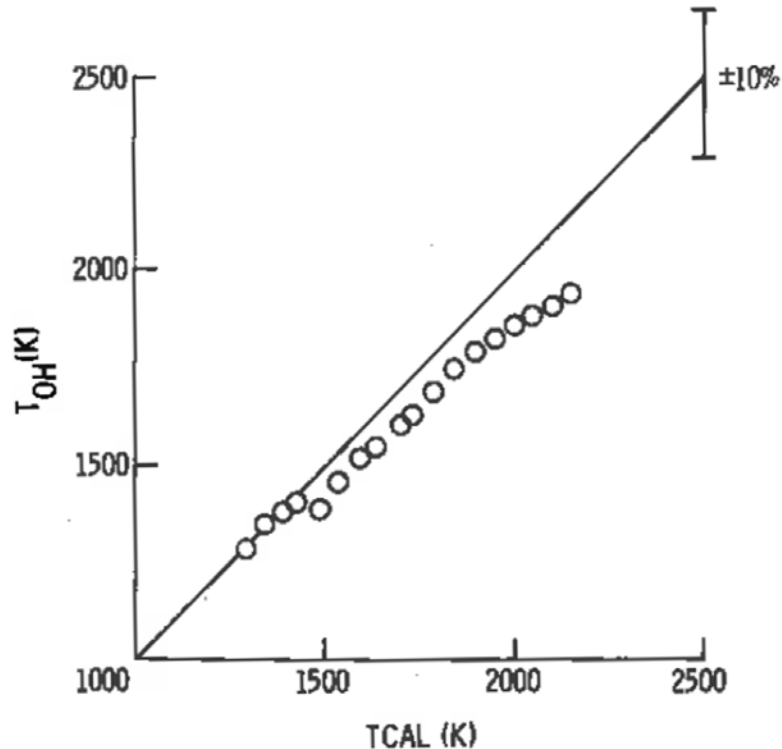


Fig. 6. Experimental OH absorption temperature plotted against thermodynamic heat balance calculation as discussed in Ref. [17].

Flat flame burner comparisons

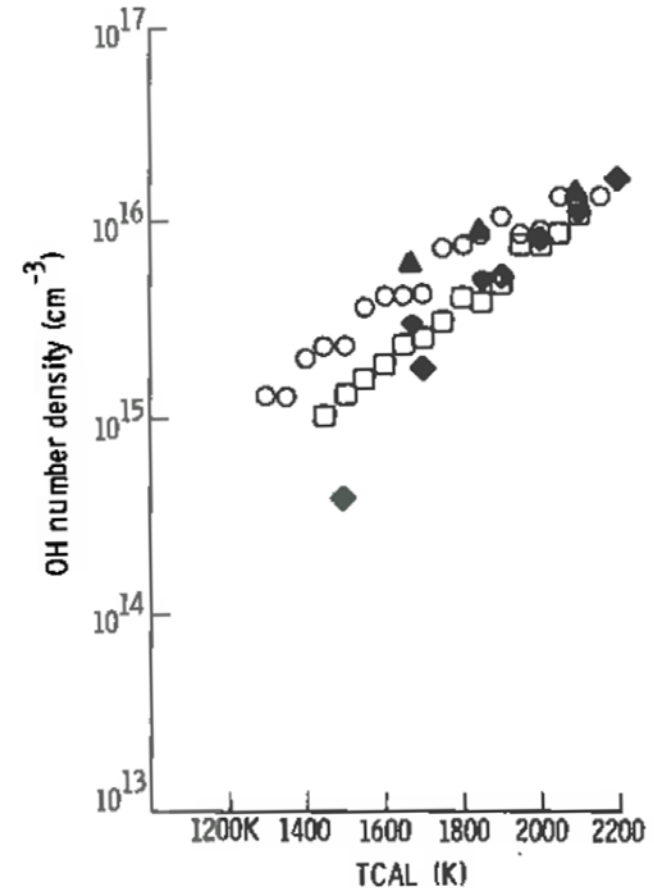


Fig. 8. Experimental OH number density as a function of temperature for two different times downstream from flame front: $\circ$ = this work at 2 ms; $\square$ = this work at 4 ms; $\diamond$ = adiabatic calculation; $\blacktriangle$ = Ref. [18], 2 ms; $\blacktriangledown$ = Ref. [18], 4 ms.

Time in The Ohio State University



- Taught Thermodynamics, Quantum Mechanics in Chemistry.
- Advanced Laser Diagnostics including Maxwell equation, etalon, PLIF, Raman scattering, OPO.

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$



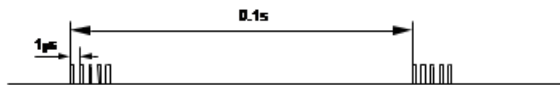
Pulse Burst Laser



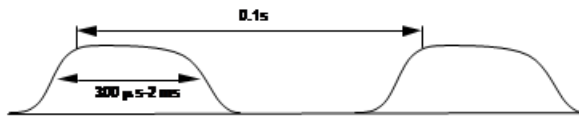
Pulse Burst Laser Concept

(Based on Lempert and Miles, et. al, AIAA-96-0500, 1996)

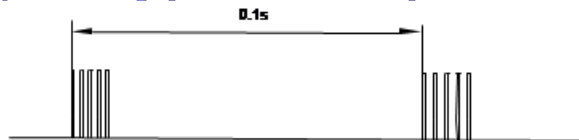
(a) CW laser is sliced into pulse-burst, repeated every 0.1s



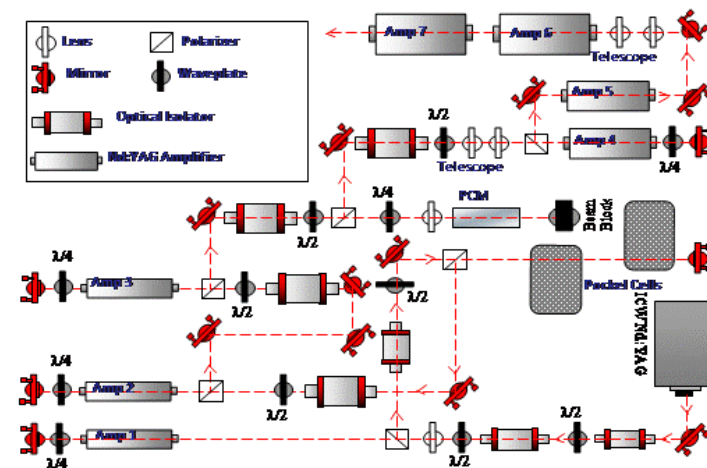
(b) Nd:YAG gain curve



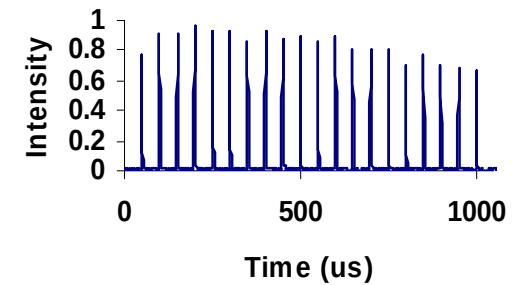
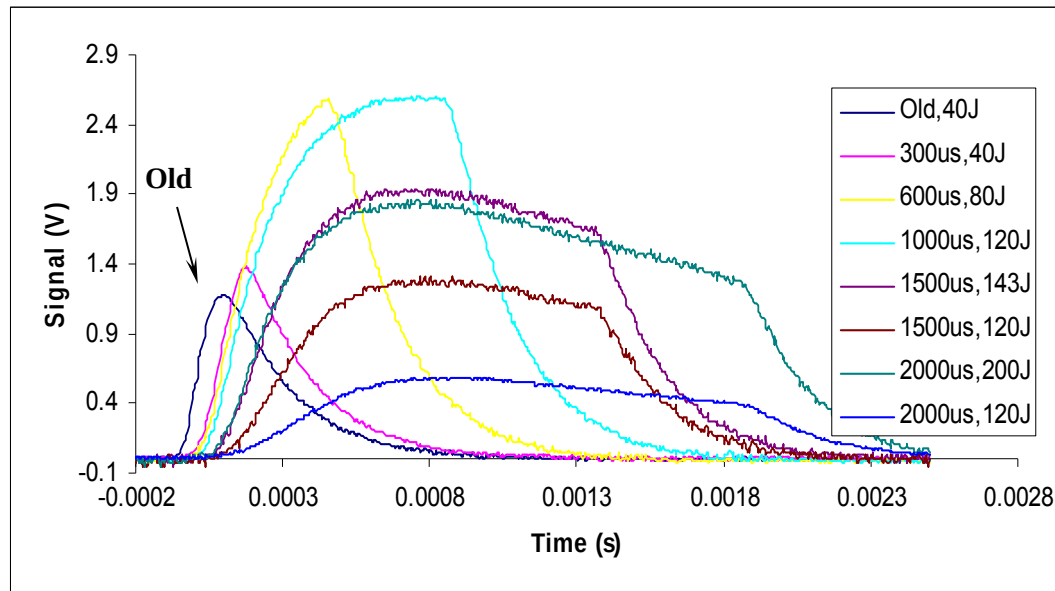
(c) Result is high power "burst" of 1-99 pulses



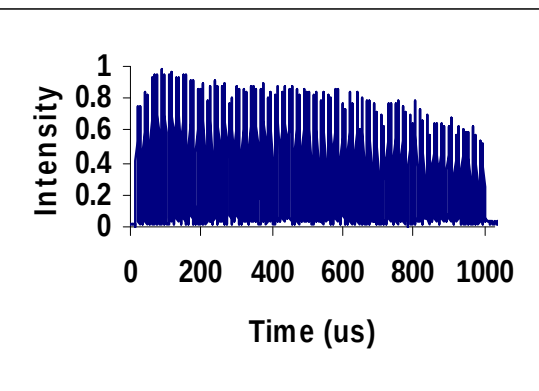
Pulse Burst Laser System



Extending the Burst Width



20 Pulses, 50 usec spacing, 400 mJ/Pulse



99 Pulses, 10 usec spacing, 27 mJ/Pulse

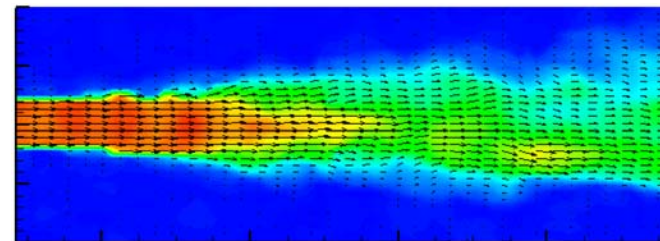
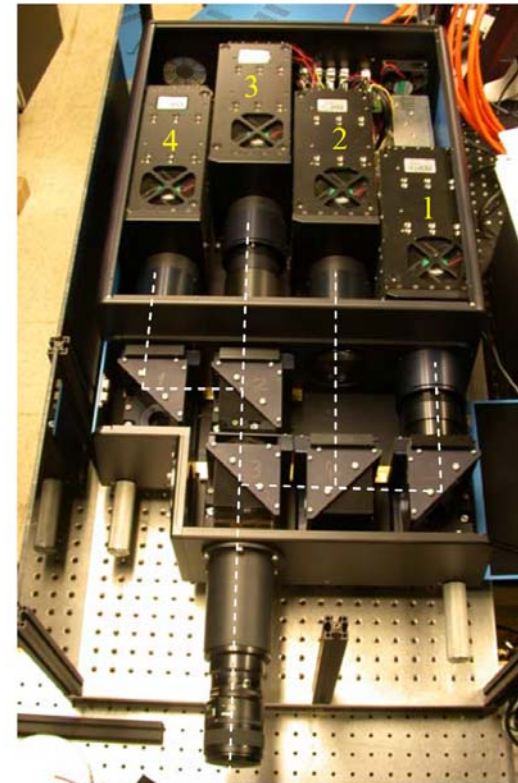
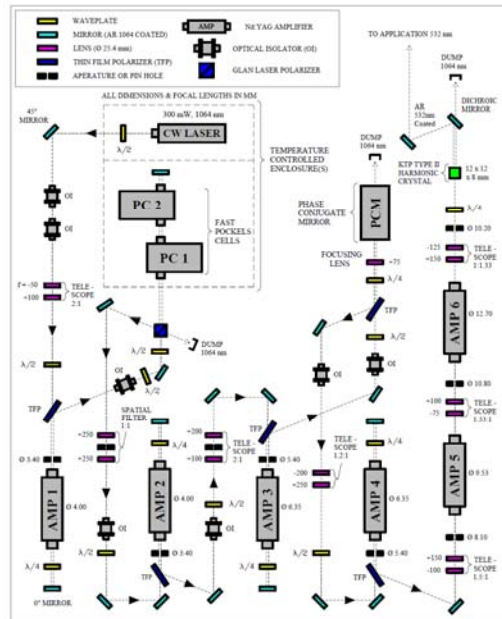
Comparison of small signal gain between “traditional” 300 us fixed and variable “flat pulse” power supplies (2V ~1000 X double pass gain).

AIAA 2004-2184

Development and Application of a MHz Frame Rate Digital Particle Image Velocimetry System

Mark P. Wernet*
NASA Glenn Research Center
Cleveland, OH 44135

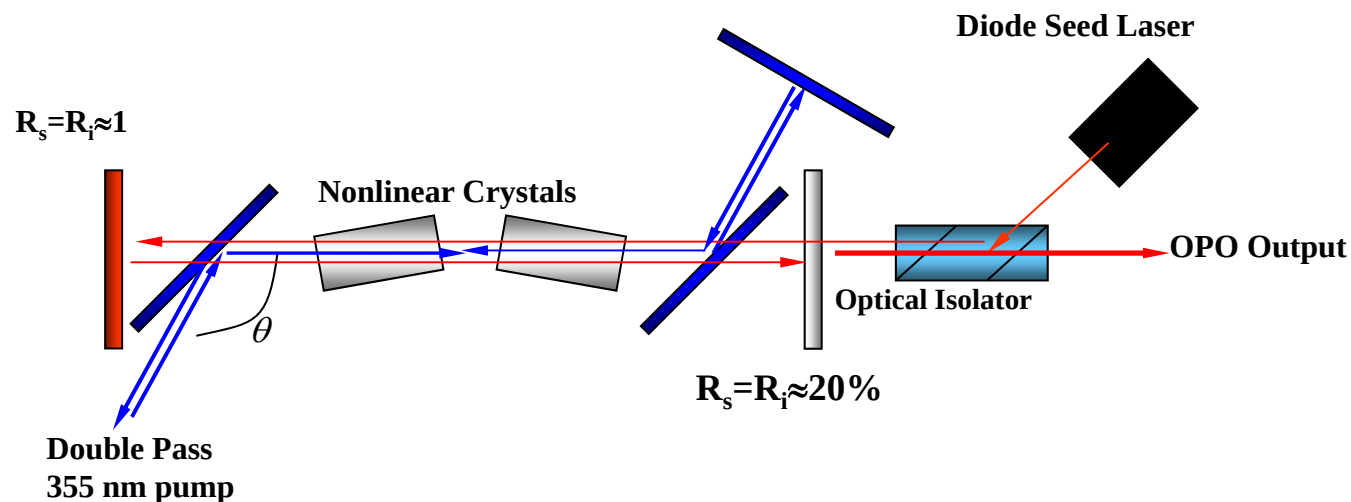
Anthony B. Opalski[†]
QSS Group, Inc.
Cleveland, OH 44135



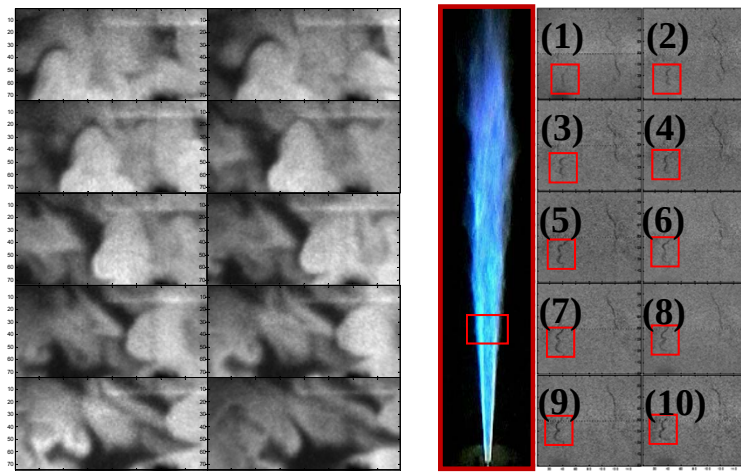
High-Speed Wavelength Tunable Source



- C.F. Kaminski, J. Hult and M. Alden, “High repetition rate PLIF of OH in a turbulent non-premixed flame”, Applied Physics B, 68, 757, 1999.
- In cooperation with Wright-Patterson Air Force Base, Dr. James R. Gord, and Dr. Terrence R. Meyer.
- Decide to use solid state source, OPO, for high-speed wavelength tunable.

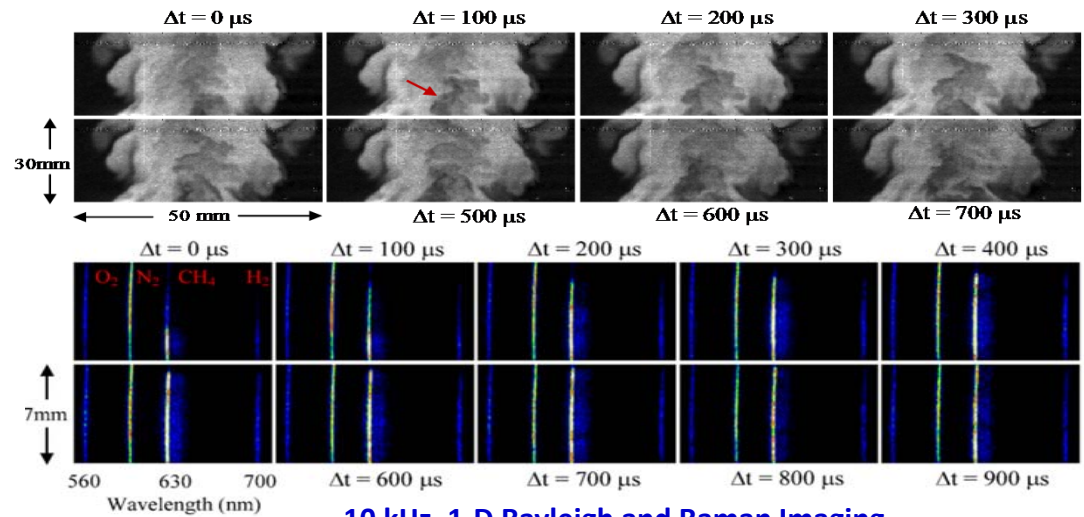


High-Speed PLIF with OPO

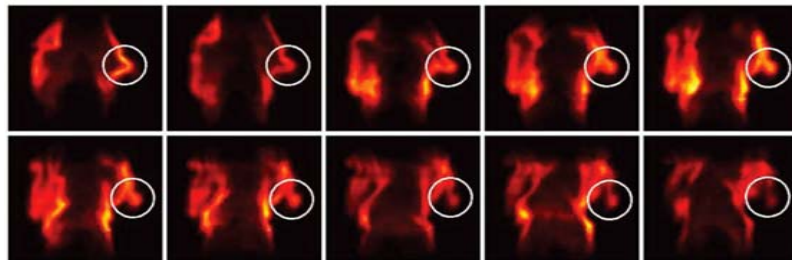


500 kHz, NO PLIF Imaging

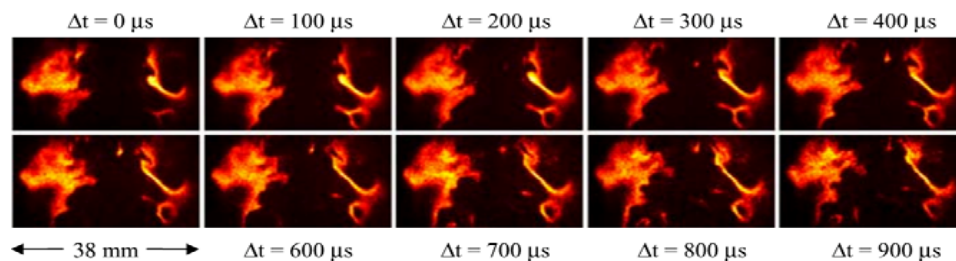
10 kHz, CH PLIF Imaging



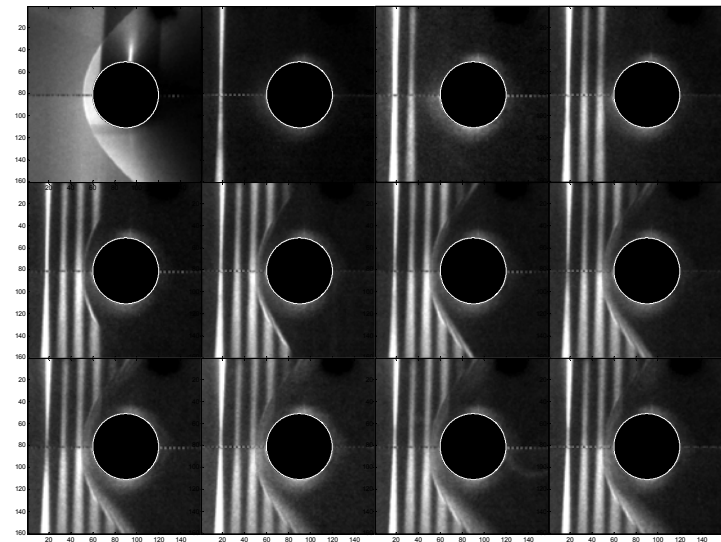
10 kHz, 1-D Rayleigh and Raman Imaging



50 kHz, OH PLIF Imaging



10 kHz, CH₂O PLIF Imaging



500 KHz NO₂ MTV in Mach 5 Flow

Lempert led NRA + SBIR, 2007-2009



- NASA NRA: **“Development of MHz Frame Rate Optical Diagnostics for Hypersonic Ground Test Facilities”** (Lempert, PI; Meyer, CI; Danehy, TM)
 - Cooperative Agreement (OSU/ISI/NASA)
 - Built PB Laser + OPO + Mixing = 226 nm for NO.
 - Brought to NASA Langley for test entry.
- NASA SBIR: **“Quantitative kHz to MHz Frame Rate Flow Diagnostics for Aerodynamic Ground Test Facilities”** Followed on with SBIR in collaboration with Spectral Energies (Roy, Meyer, Gogineni, Lempert, Jiang)
 - Develop PB Laser system for NO₂ → NO velocimetry



Orbiter BLT flight experiment wind tunnel simulations: nearfield flow imaging and surface thermography

*Paul M. Danehy, Jennifer A. Inman, Stephen B. Jones, Brett
Bathel*, Chris Ivey**, Andrew McCrea⁺*

NASA Langley Research Center

*National Institute of Aerospace, Hampton, Virginia
and The University of Virginia, Charlottesville, Virginia
**NASA LaRSS Program and Johns Hopkins University
⁺ATK Space Division, Hampton, Virginia

*N. Jiang, M. Webster, W. Lempert
Ohio State and
J. Miller, T. Meyer
Iowa State*

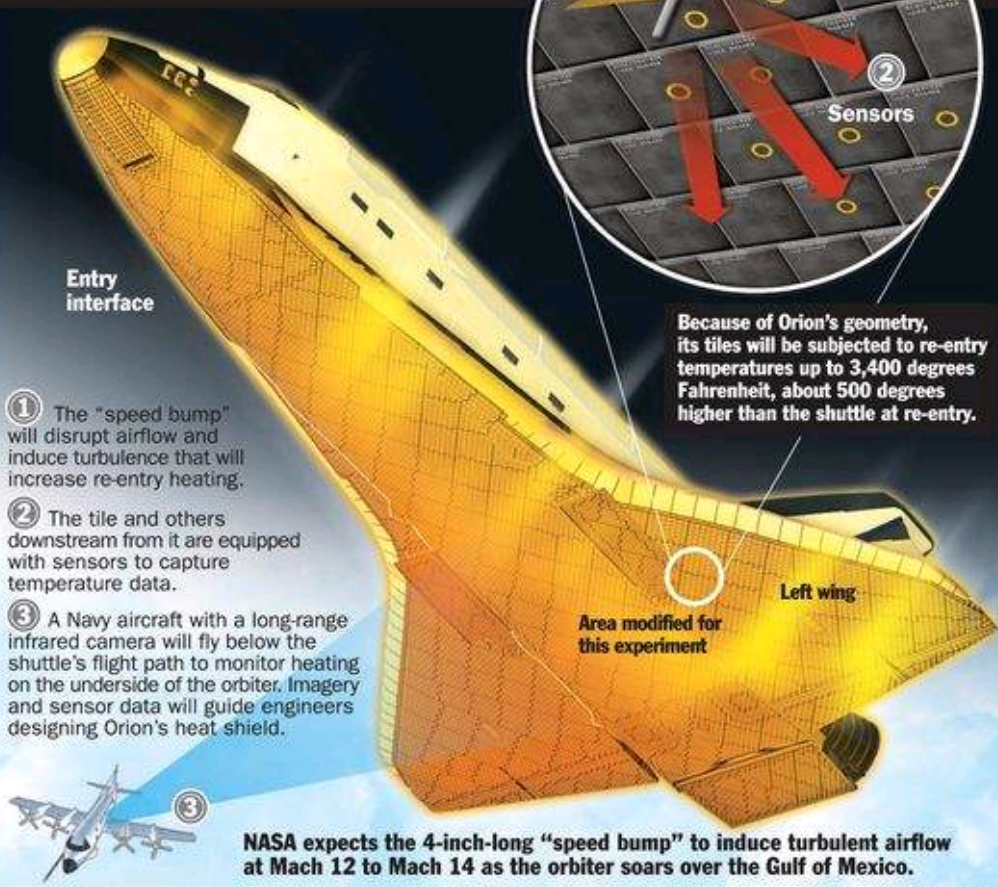
NASA Fundamental Aeronautics Program: Hypersonics Project, ExCap and AAP Disciplines
(Later: SBIR Phase 1 with Spectral Energies/OSU/ISU)

Shuttle Orbiter Boundary Layer Transition Flight Experiment



Heating up Discovery's heat shield

Discovery will plunge back through Earth's atmosphere with a built-in "speed bump" on one of its thermal tiles. The quarter-inch protuberance will increase temperatures to simulate conditions NASA's next-generation Orion space capsules will encounter during atmospheric re-entries.



Sources: NASA, The Boeing Co., researched by James Dean, FLORIDA TODAY

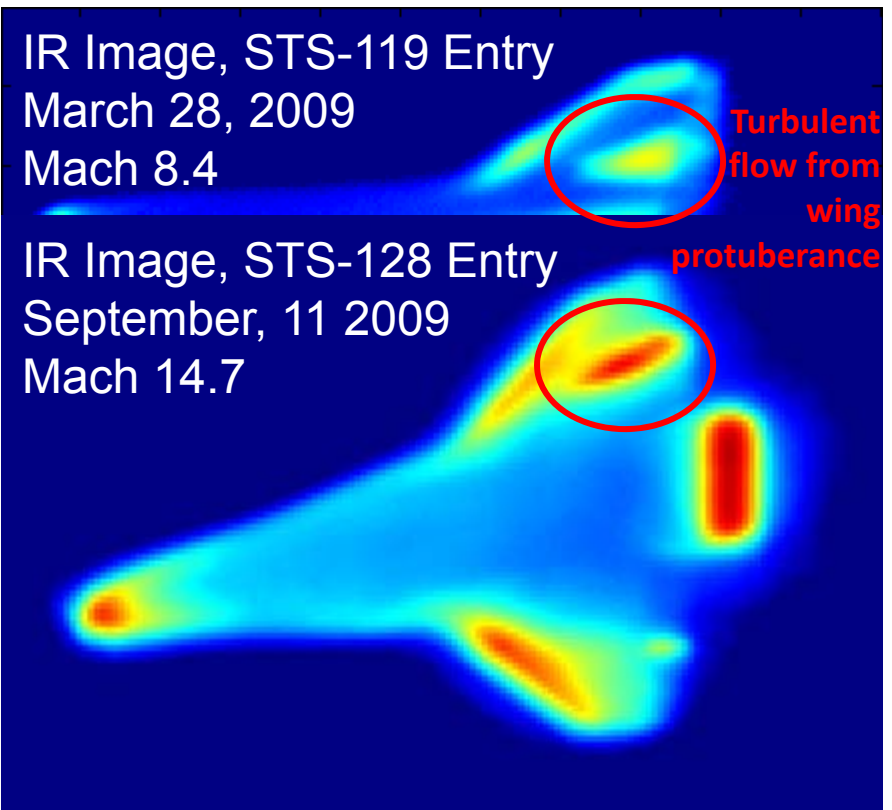
Dennis Lowe, FLORIDA TODAY



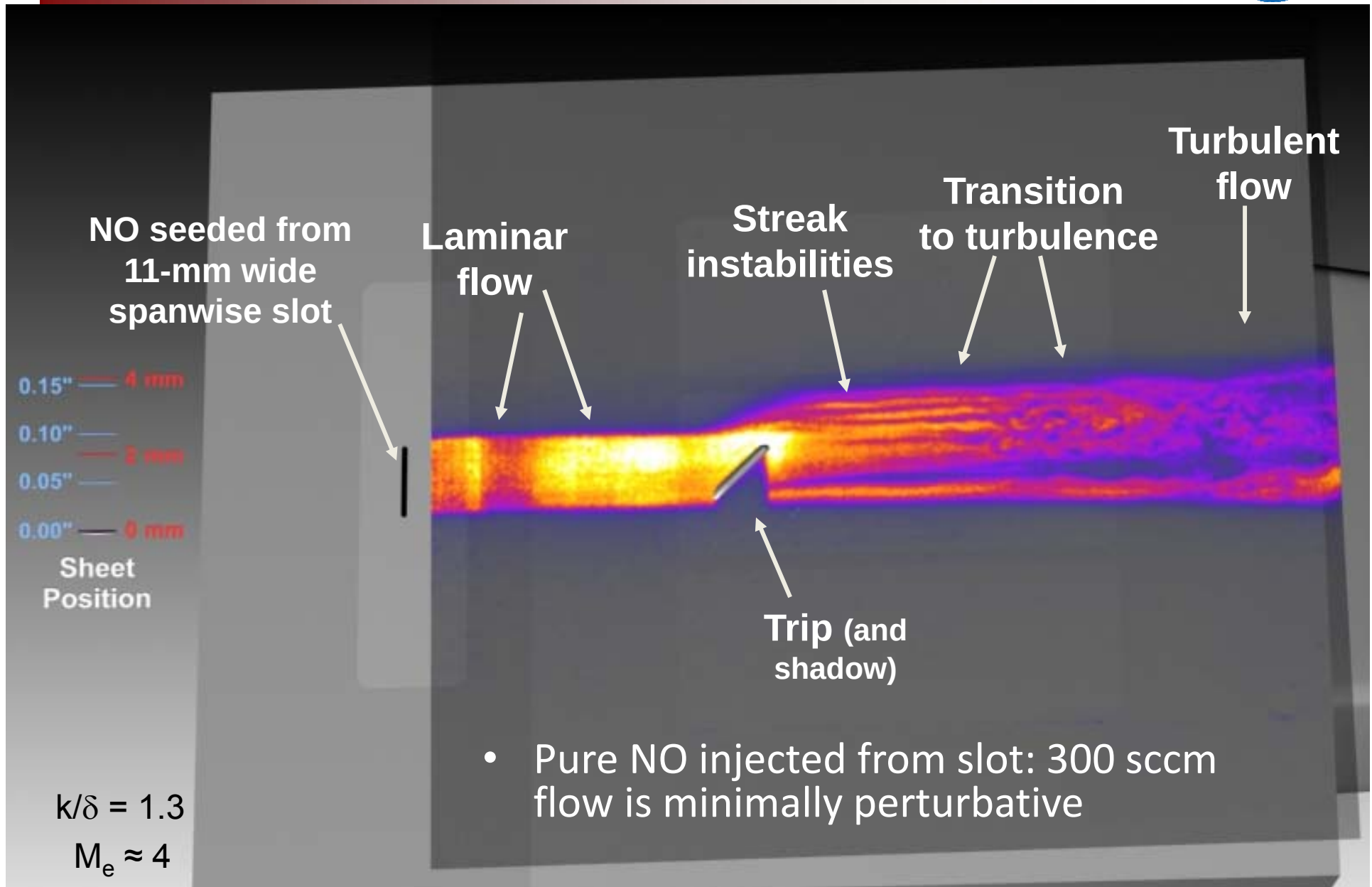
*HYTHIRM:
Remote,
quantitative,
global heating*

IR Image, STS-119 Entry
March 28, 2009
Mach 8.4

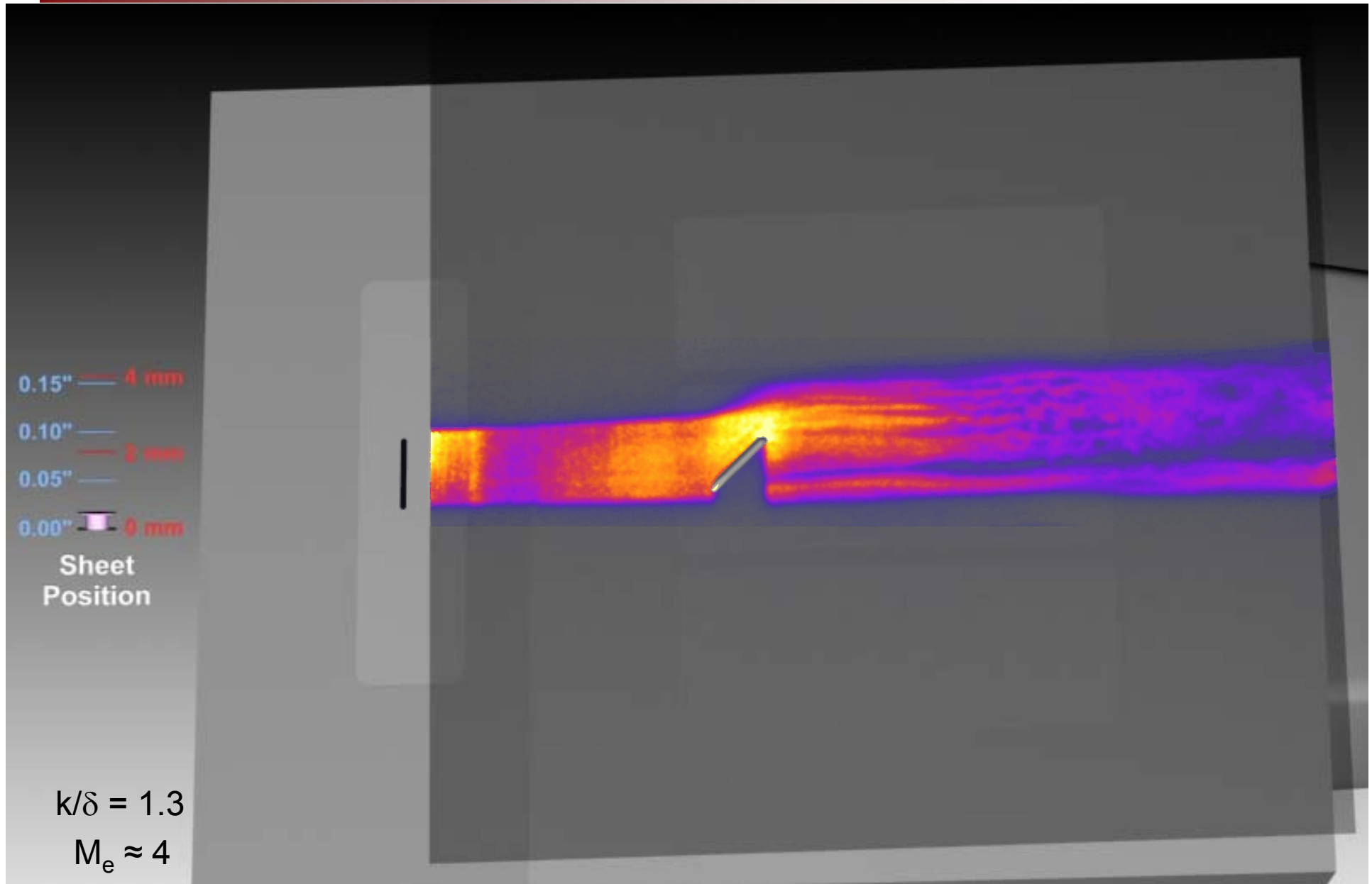
IR Image, STS-128 Entry
September, 11 2009
Mach 14.7



Flow over DTO Trip at High-Re

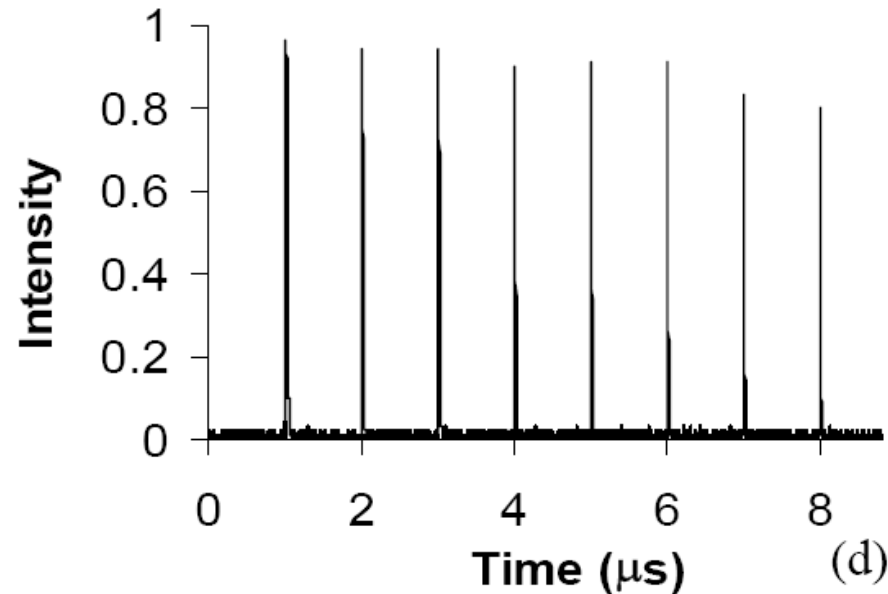


DTO Trip at High Re: Animation



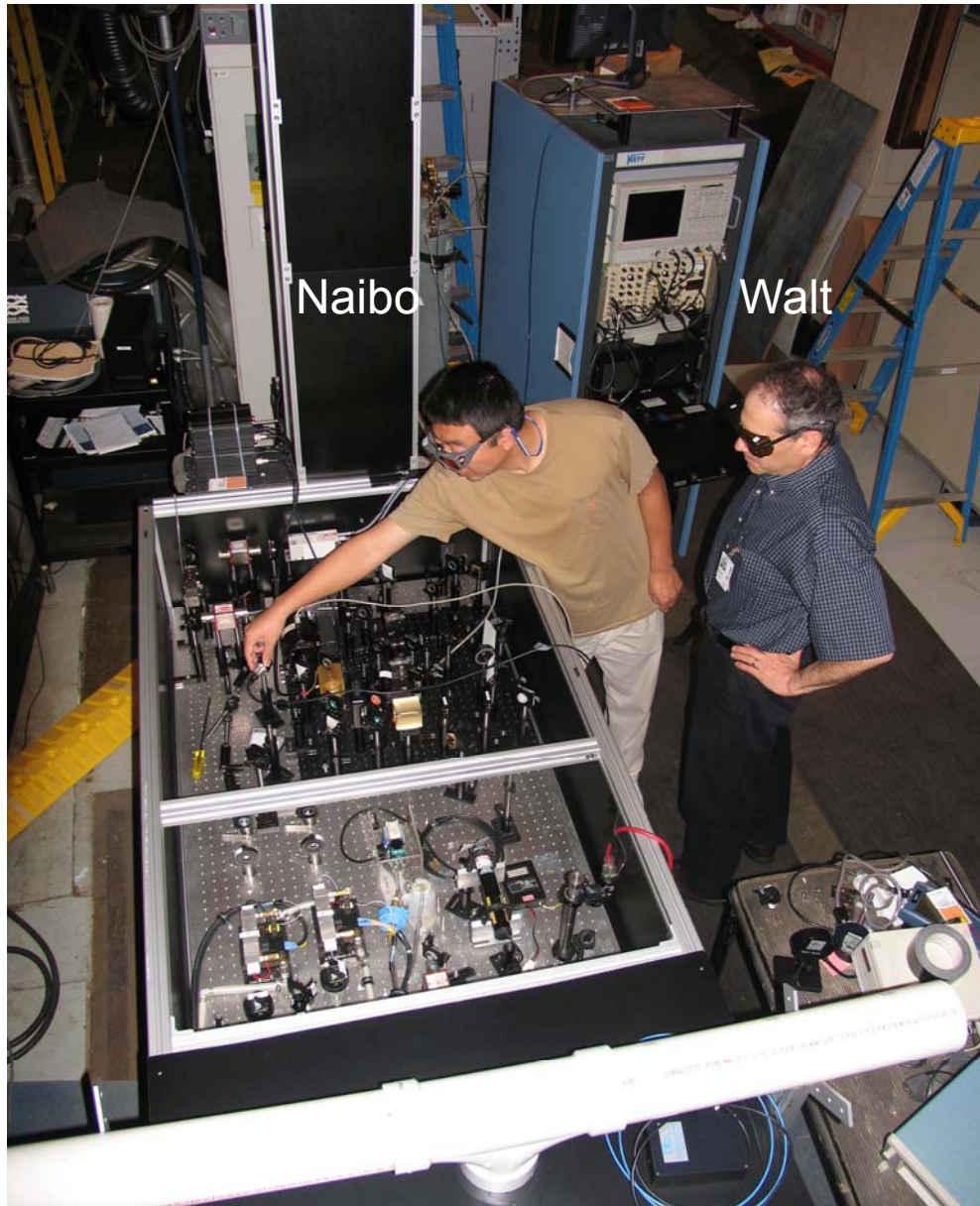
MHz Rate NO PLIF Imaging System

- System acquired about a dozen images at a time spacing of 1 to 10 microseconds, resulting in time-accurate movies of the flow at 1 MHz – 100 kHz
 - Ohio State (Lempert) and Iowa State (Meyer) Universities
 - Flow visualization and velocity measurement capabilities

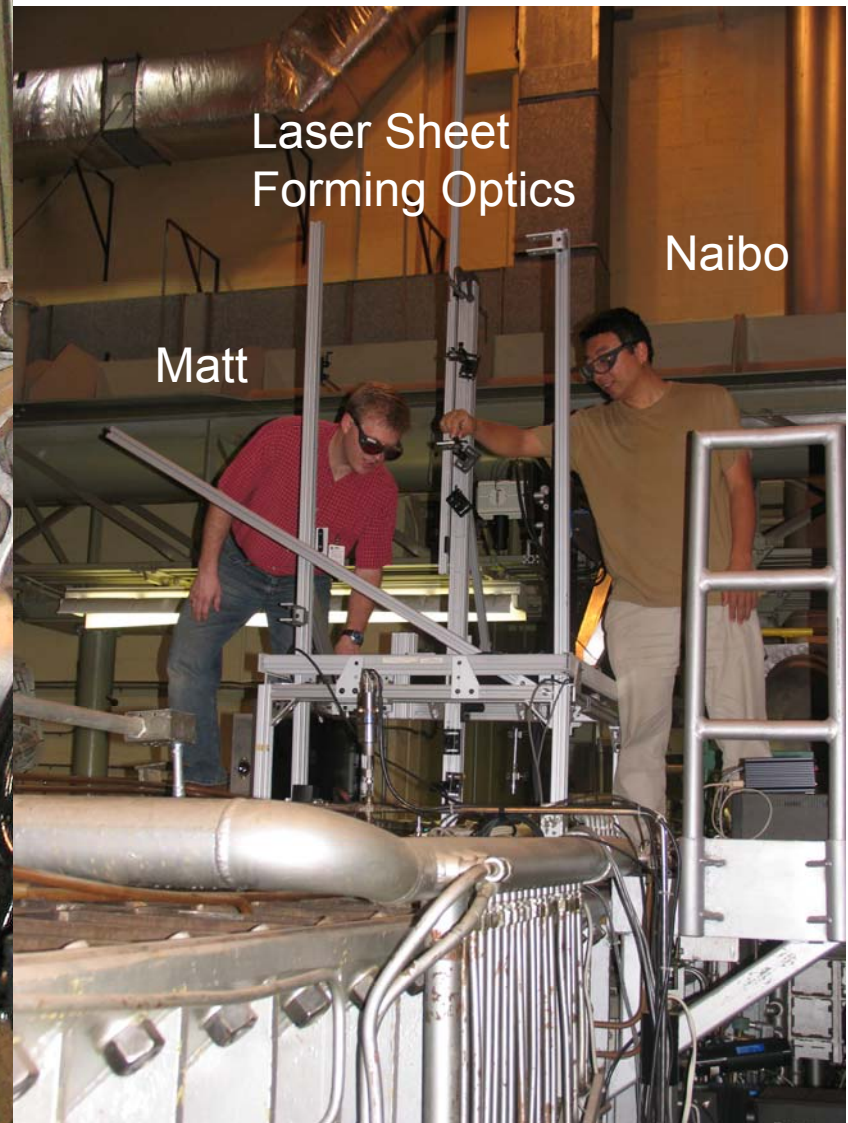


226nm (~0.2 mJ/pulse)

Laser/Camera Setup



Facility: Inside



Naibo

Matt

OSU/ISU/SE/NASA MHz PLIF Setup

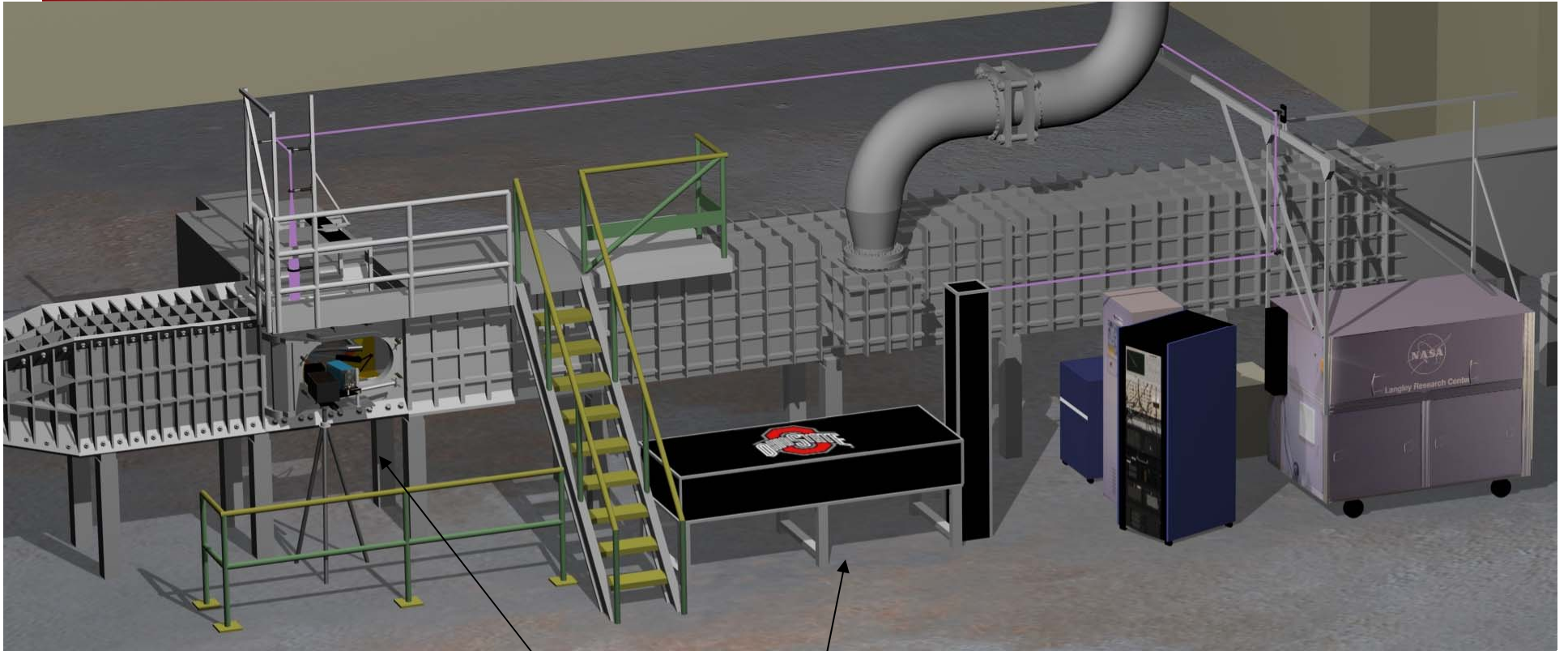


Brett, trying to find a screw that Paul dropped on the floor

Terry (not talking into his phone)



NASA Langley's 31-Inch Mach 10



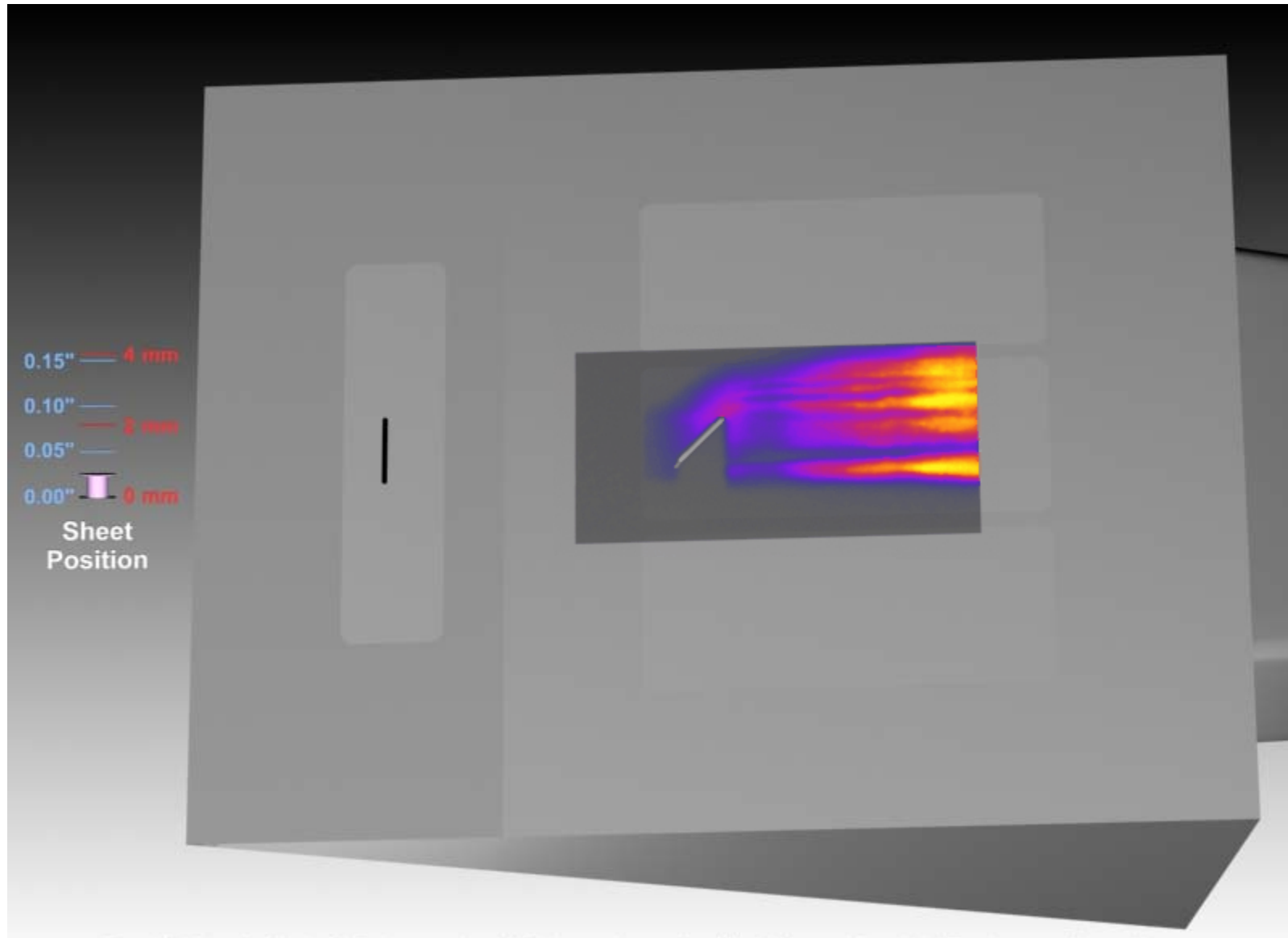
OSU/ISU MHz NO PLIF System

March 2009

500 kHz Imaging, High Re



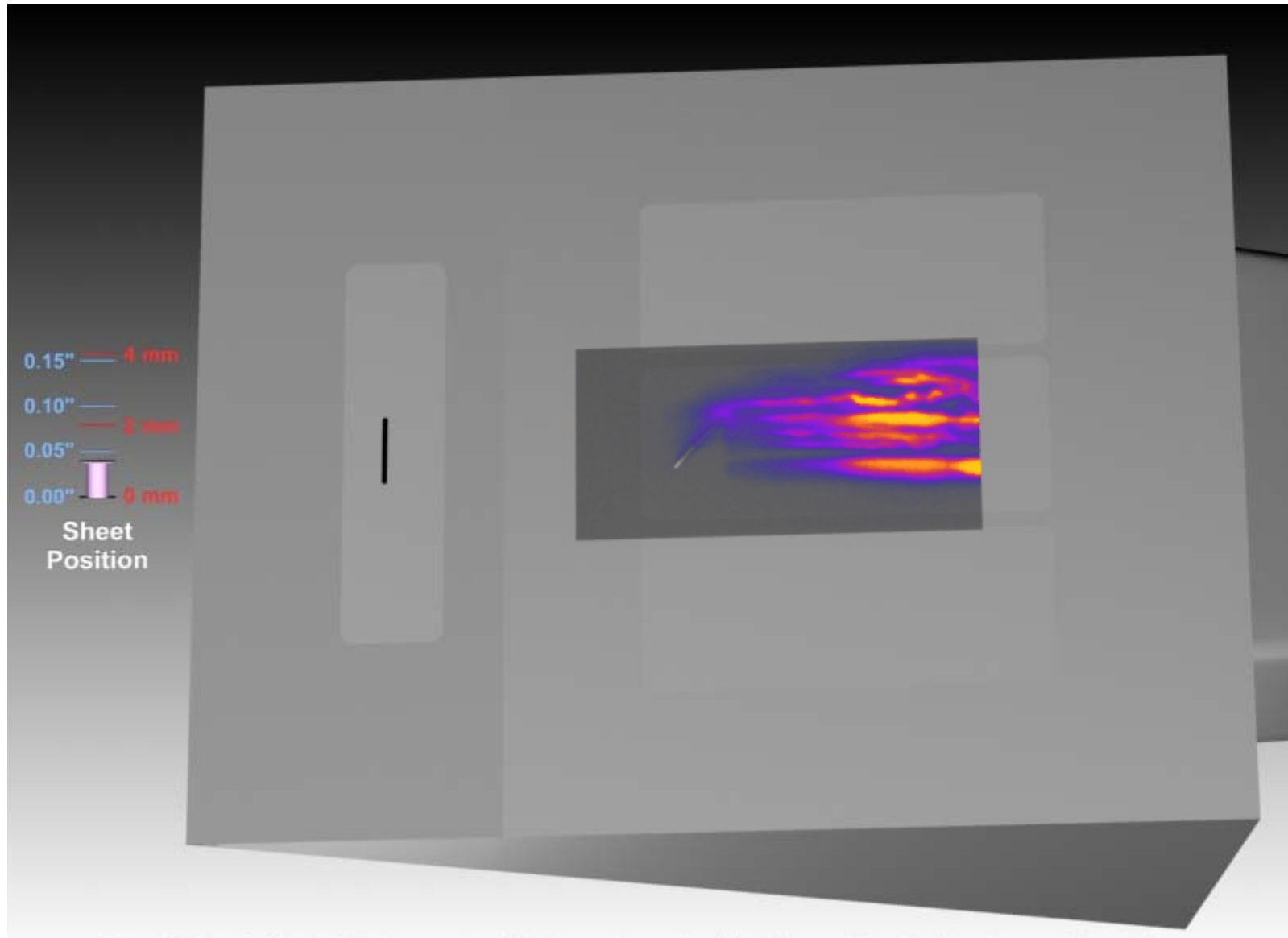
Laser sheet position = 0.7 mm above flat plate



500 kHz Imaging , High Re



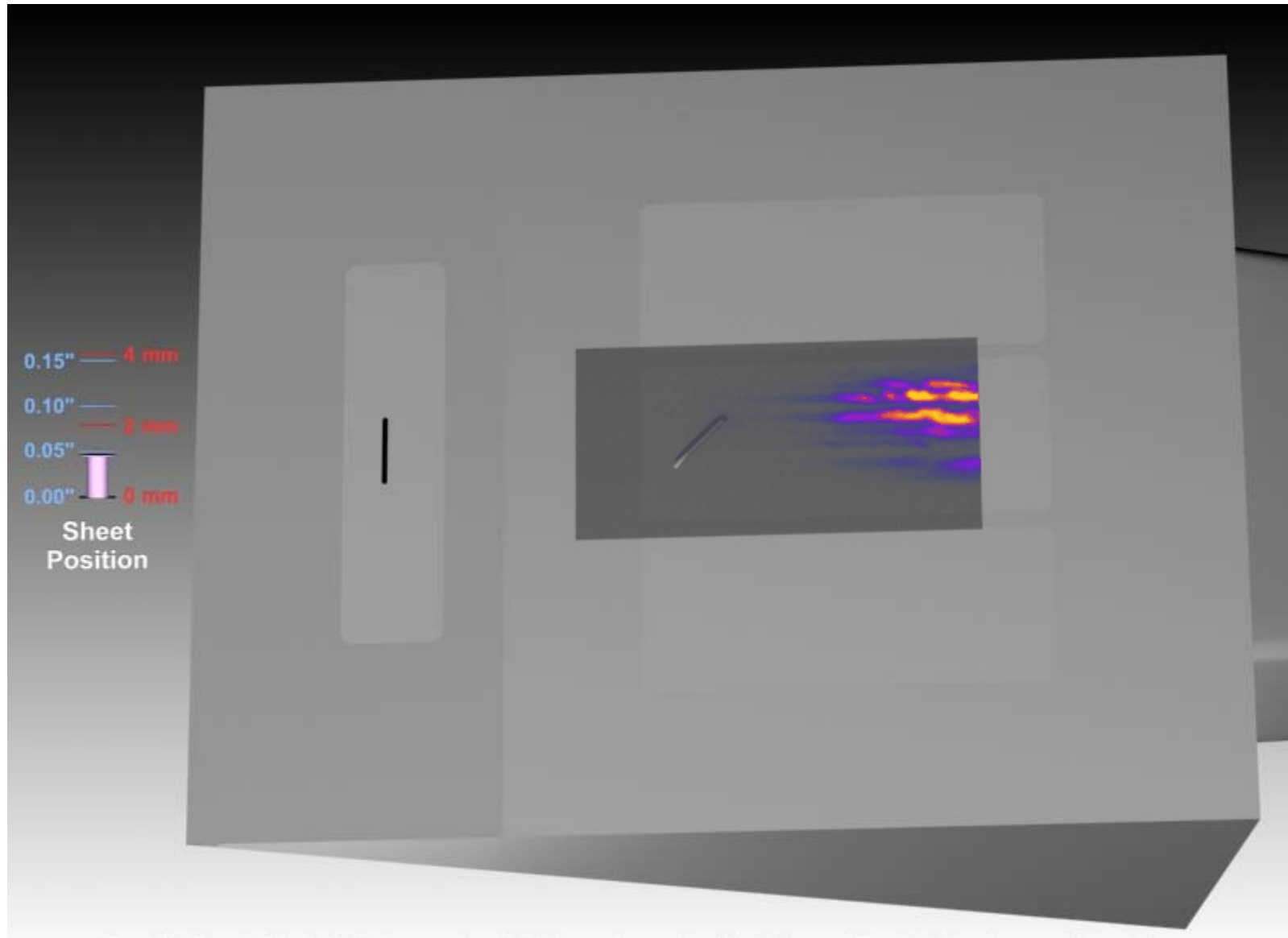
Laser sheet position = 1.0 mm above flat plate



500 kHz Imaging, High Re



Laser sheet position = 1.2 mm above flat plate



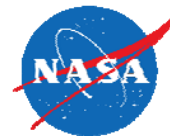
Stereoscopic NO PLIF



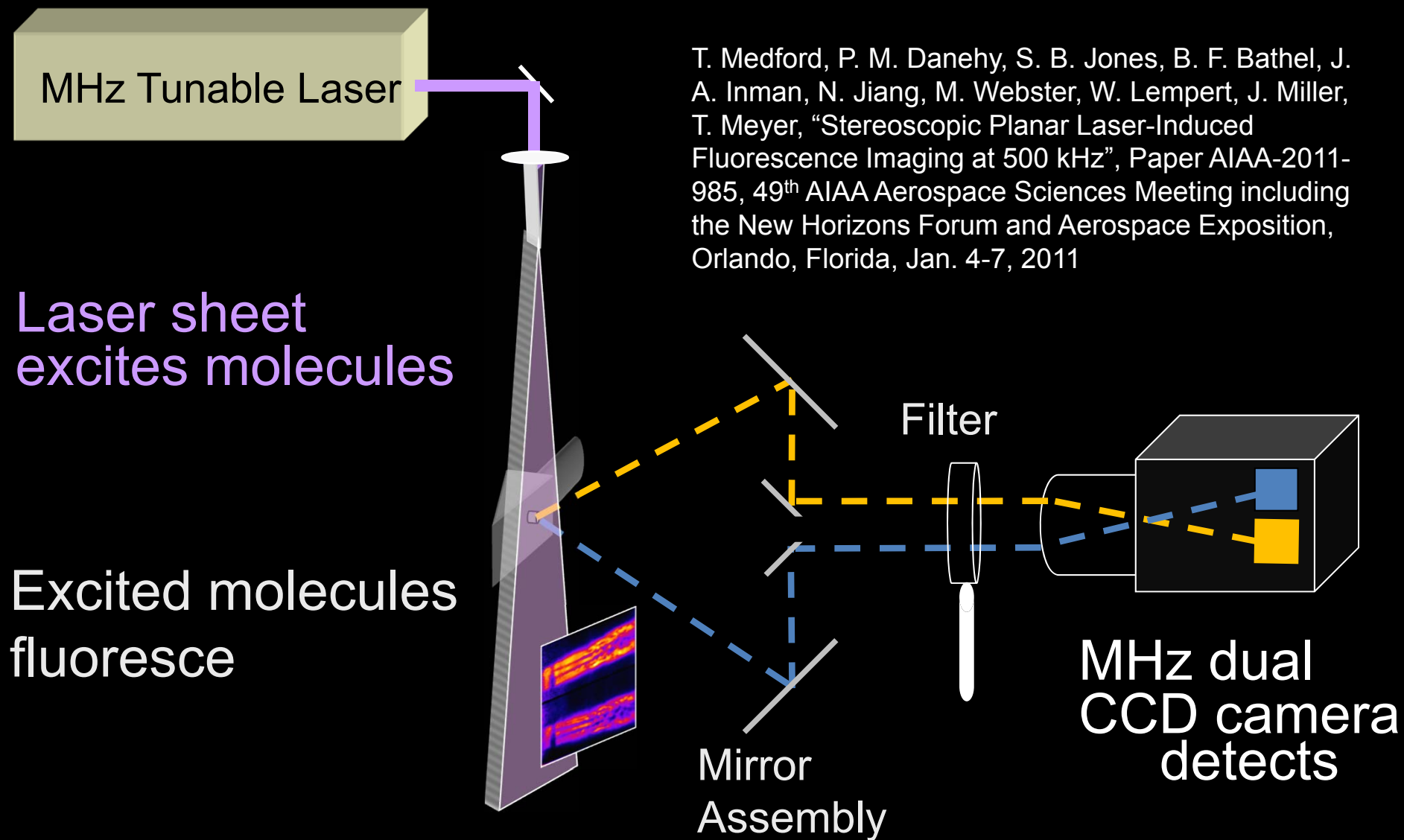
- Meanwhile, NASA had done an experiment using 10 Hz lasers and a thick laser sheet to do stereoscopic imaging.
 - P. M. Danehy, J. A. Inman, B. Bathel, D. W. Alderfer, S. B. Jones, “Stereoscopic Imaging in Hypersonics Flows using Planar Laser Induced Fluorescence”, Paper Number 2008-4267, 26th AIAA Aerodynamic Measurement Technology and Ground Testing Conference, Seattle, WA June 23-26, 2008

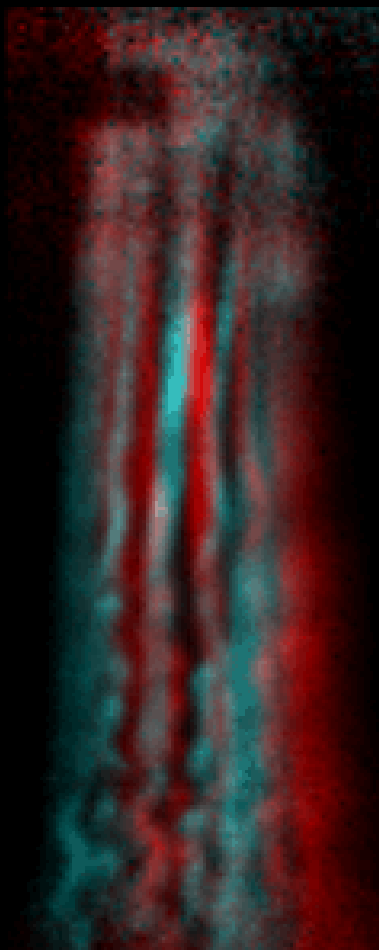
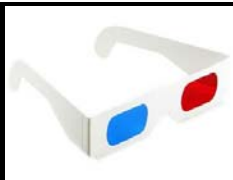


MHz Stereoscopic NO PLIF



T. Medford, P. M. Danehy, S. B. Jones, B. F. Bathel, J. A. Inman, N. Jiang, M. Webster, W. Lempert, J. Miller, T. Meyer, "Stereoscopic Planar Laser-Induced Fluorescence Imaging at 500 kHz", Paper AIAA-2011-985, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 4-7, 2011





1-mm tall by 4-mm wide cylinder

NO PLIF at CUBRC (10 kHz)



- 10 Hz lasers systems can only obtain 1 image / tunnel run in impulse facilities
- Pulse Burst system brought to CUBRC to image supersonic combustor flow NO doped fuel
 - 10 kHz system used
 - Joint NASA / AF support

Air Force Office of Scientific Research (John Schmisser – program monitor), and a NASA Phase I Small Business Innovative Research grant to Spectral Energies, Inc

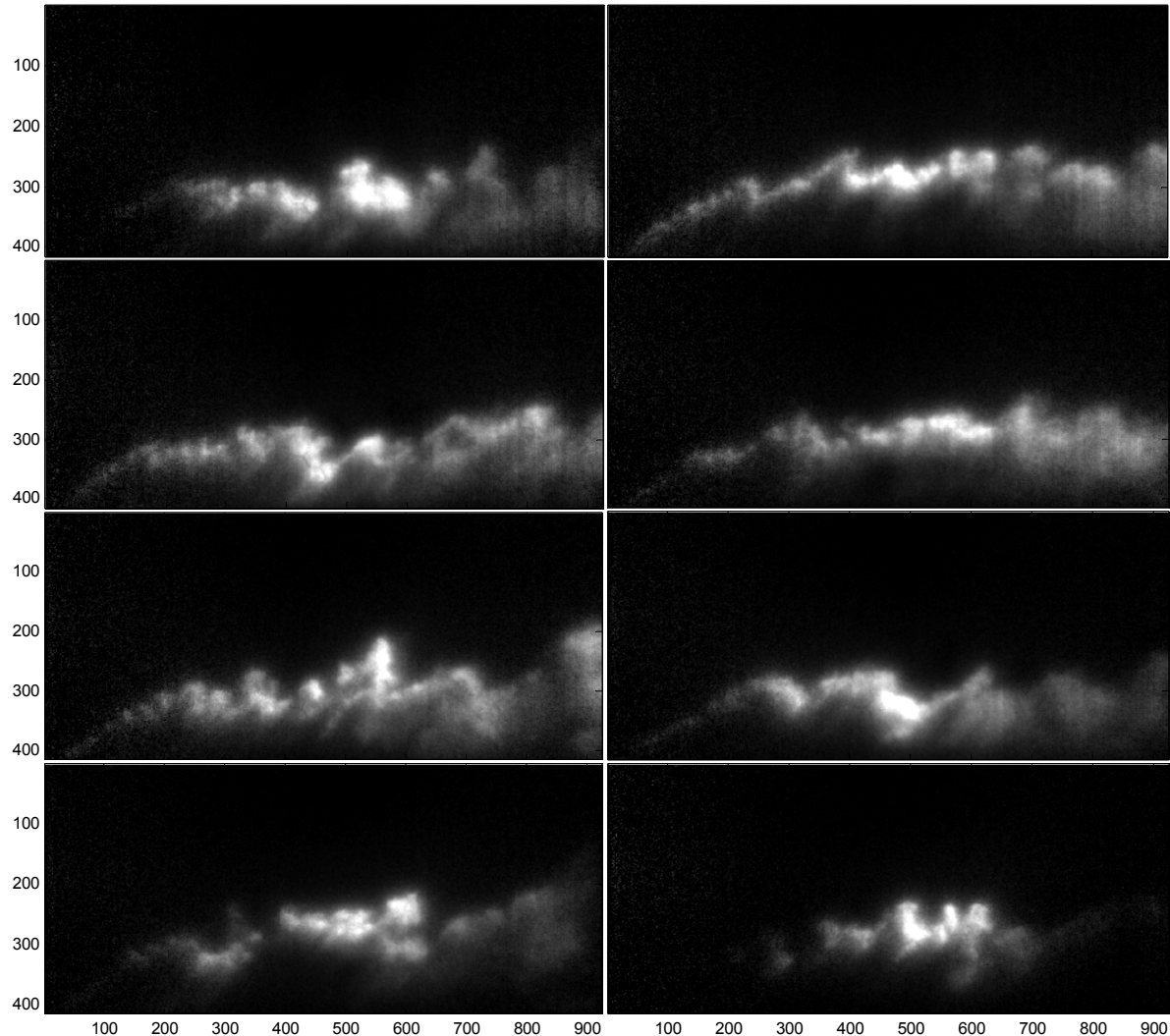


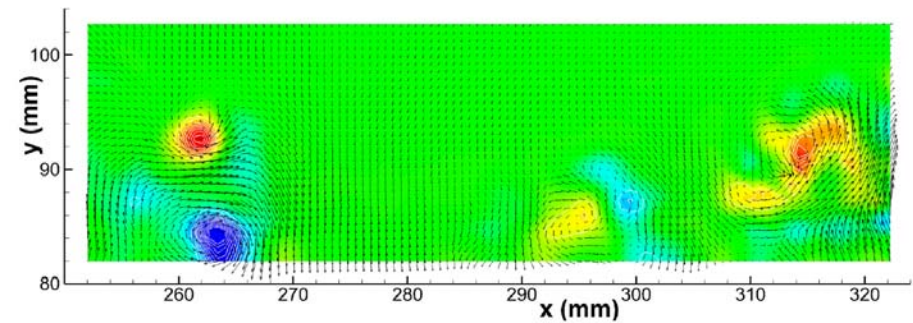
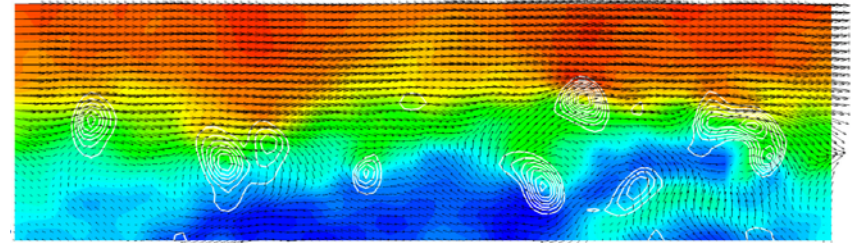
Figure 9: 10 KHz NO PLIF images of flow in a supersonic combustor cavity. Injected gas is 5% NO in Helium at 500 psi pressure. Test gas is pure N_2 . Injector angle is 30 degrees. The numbers on the axes indicate pixels. Field of view is ~ 3.0 cm x 6.5 cm.

MHz NO PLIF Publications with NASA



- N. Jiang, J. Bruzzese, R. Patton, J. Sutton, R. Yentsch, D.V. Gaitonde, W.R. Lempert, J. D. Miller, T.R. Meyer, R. Parker, T. Wadham. NO PLIF imaging in the CUBRC 48-inch shock tunnel. Experiments in fluids. Dec 1;53(6):1637-46 (2012).
- N. Jiang, M. Webster, W. R. Lempert, J. D. Miller, T. R. Meyer, C. B. Ivey, and P. M. Danehy, "MHz-rate nitric oxide planar laser-induced fluorescence imaging in a Mach 10 hypersonic wind tunnel," Applied Optics, Vol. 50, No. 4, Feb. (2011).
- T. Medford, P. M. Danehy, S. B. Jones, B. F. Bathel, J. A. Inman, N. Jiang, M. Webster, W. Lempert, J. Miller, T. Meyer, "Stereoscopic Planar Laser-Induced Fluorescence Imaging at 500 kHz", Paper AIAA-2011-985, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 4-7, 2011.
- N. Jiang, J. Bruzzese, R. Patton, J. Sutton, W. Lempert, J. D. Miller, T. R. Meyer, R. Parker, T. Wadham, M. Holden and P. M. Danehy, "NO PLIF Imaging in the CUBRC 48" Shock Tunnel," Paper AIAA-2011-928, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, Jan. 4-7, 2011.
- P.M. Danehy, C. B. Ivey, J.A. Inman, B. Bathel, S.B. Jones, A. C. McCrea, N. Jiang, M. Webster, W. Lempert, J. Miller, T. Meyer "High-speed PLIF imaging of hypersonic transition over discrete cylindrical roughness," Paper AIAA-2010-0703, the 48th AIAA Aerospace Sciences Meeting, Fluid Dynamics TC, Orlando Florida, January 2010.
- P.M. Danehy, C. B. Ivey, B. F. Bathel, J.A. Inman, S.B. Jones, A. N. Watkins, K. Goodman, A. C. McCrea, B. D. Leighty and W. K. Lipford, N. Jiang, M. Webster, W. Lempert, J. Miller, T. Meyer, "Orbiter BLT flight experiment wind tunnel simulations: nearfield flowfield imaging and surface thermography," Paper AIAA-2010-1571, the 48th AIAA Aerospace Sciences Meeting, Orlando Florida, January 2010.
- N. Jiang, M. Webster, W. R. Lempert, J. D. Miller and T. R. Meyer, P. M. Danehy, "MHz-Rate NO PLIF Imaging in a Mach 10 Hypersonic Wind Tunnel," Paper AIAA-2010-1407, the 48th AIAA Aerospace Sciences Meeting, AMT TC, Orlando Florida, January 2010.

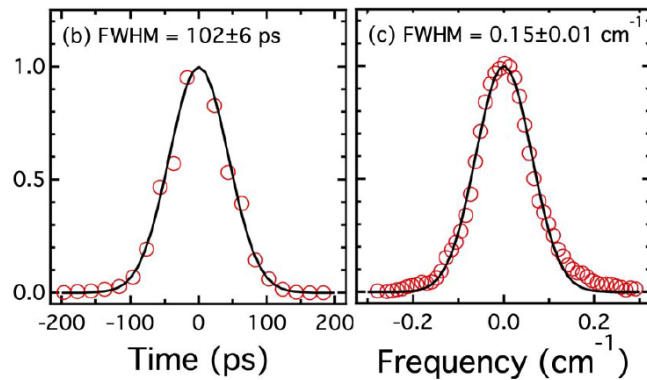
Commercial PBL System



Steven J. Beresh, Sean P. Kearney, Justin L. Wagner, et al., *Measurement Science and Technology*, 26, 095305, 2015.

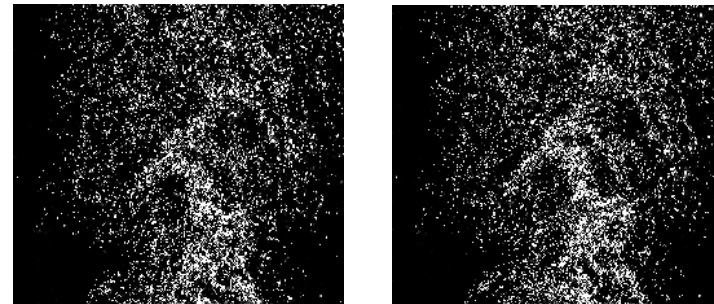
Developed by Spectral Energies under multiple SBIRs
Applied in Sandia National Laboratory, Lund University, Purdue University

PBL Application in Wright-Patterson Air Force Base

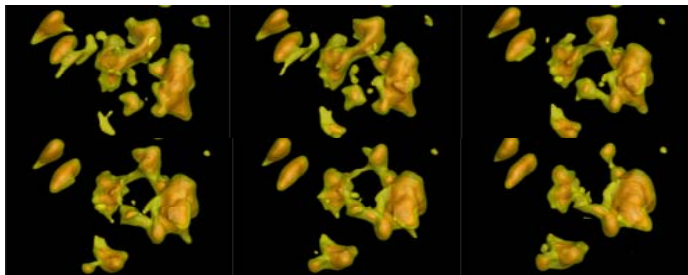


100-ps Pulse Burst Laser

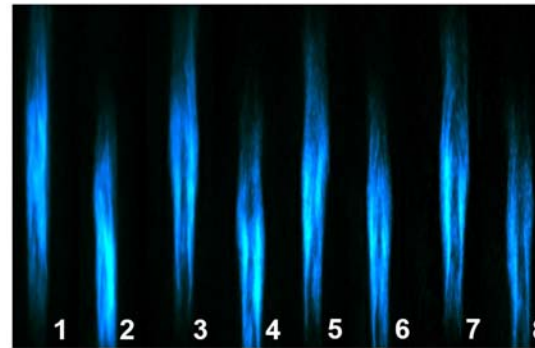
100 kHz, $\Delta t = 10$ μs



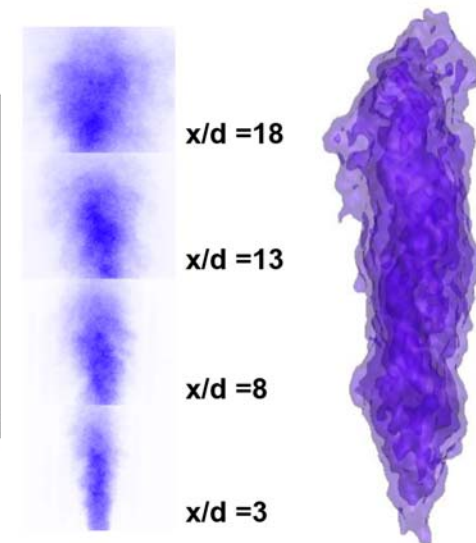
100 kHz PIV



10 kHz Tomo-LII



20 kHz Tomo-CH₂O LIF



20 kHz Tomo-Acetone LIF

Other Applications



REVIEW OF SCIENTIFIC INSTRUMENTS **79**, 10E736 (2008)

A pulse-burst laser system for a high-repetition-rate Thomson scattering diagnostic^{a)}

D. J. Den Hartog,¹ N. Jiang,² and W. R. Lempert²

- Mostly in Optical Diagnostics Community.
- Maybe other potential applications.

Walter R. Lempert $\longleftrightarrow$ High-speed

