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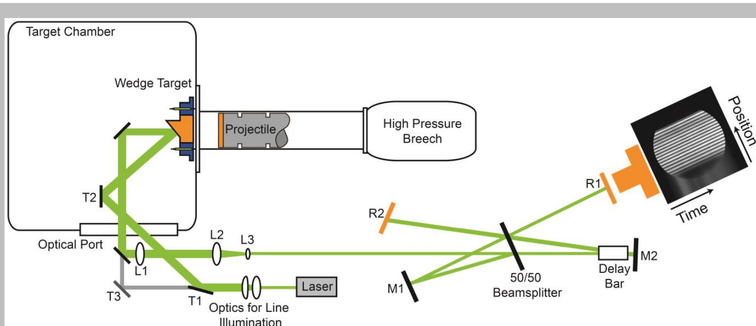

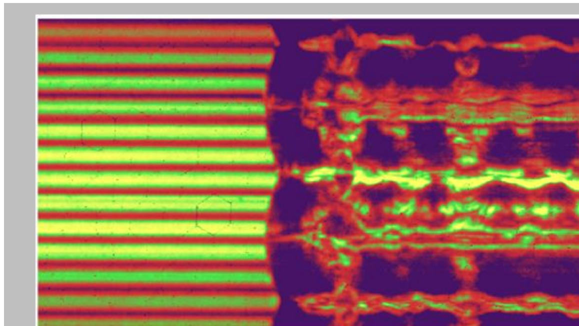

Optically Recording Velocity Interferometer System (ORVIS): Applications and Challenges

Marcia Cooper

APS-SCCM

June 14-19, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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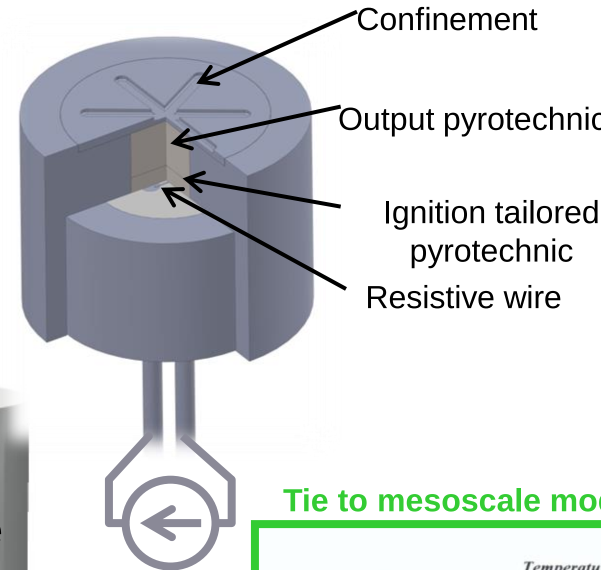
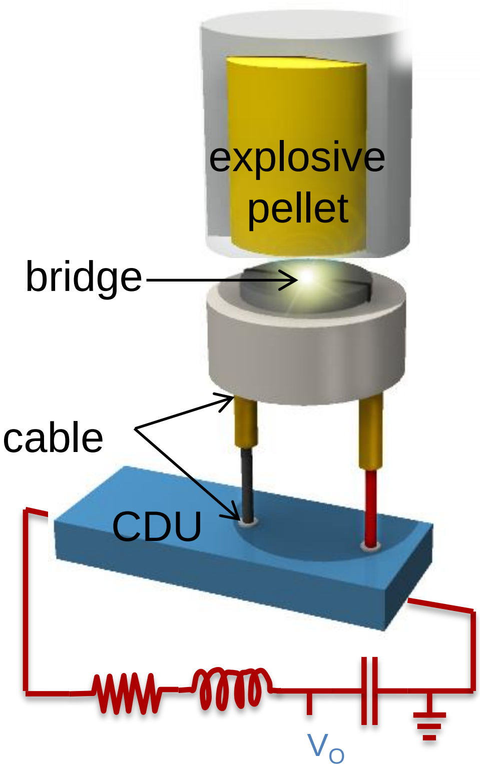
SNL/ECF requires optical velocimeters for the study of high speed material motion

- Our mission contributes to the R&D and design of small-scale components that contain energetic materials (pyrotechnics and explosives)

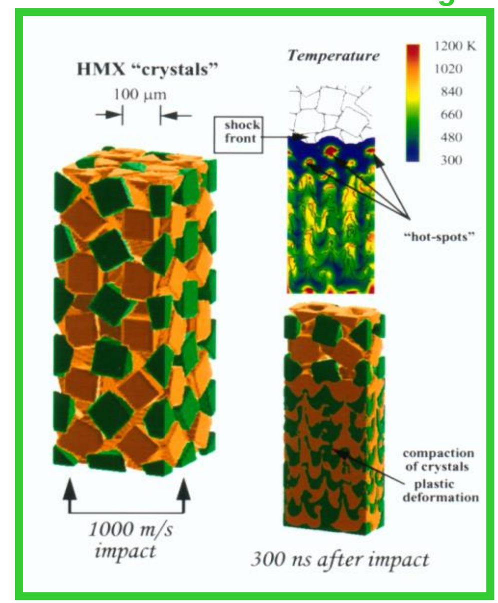
- Measurement of fast-moving surfaces necessary for design of EBWs, hotwire devices, understanding EM sensitivity and performance.

- Many of our diagnostic tools rely on optical velocity interferometry at an exterior surface or interface.

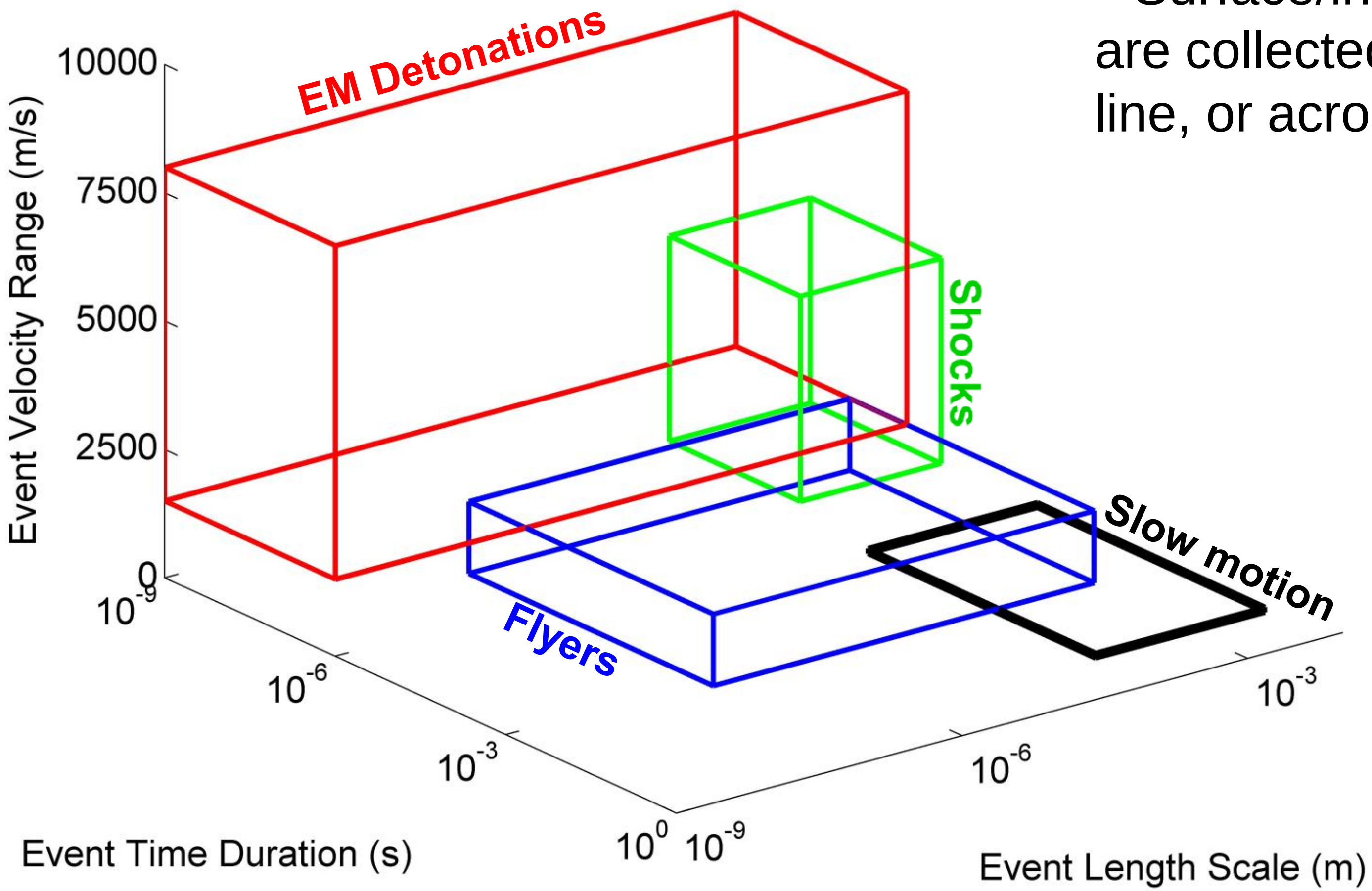




Tie to mesoscale modeling:

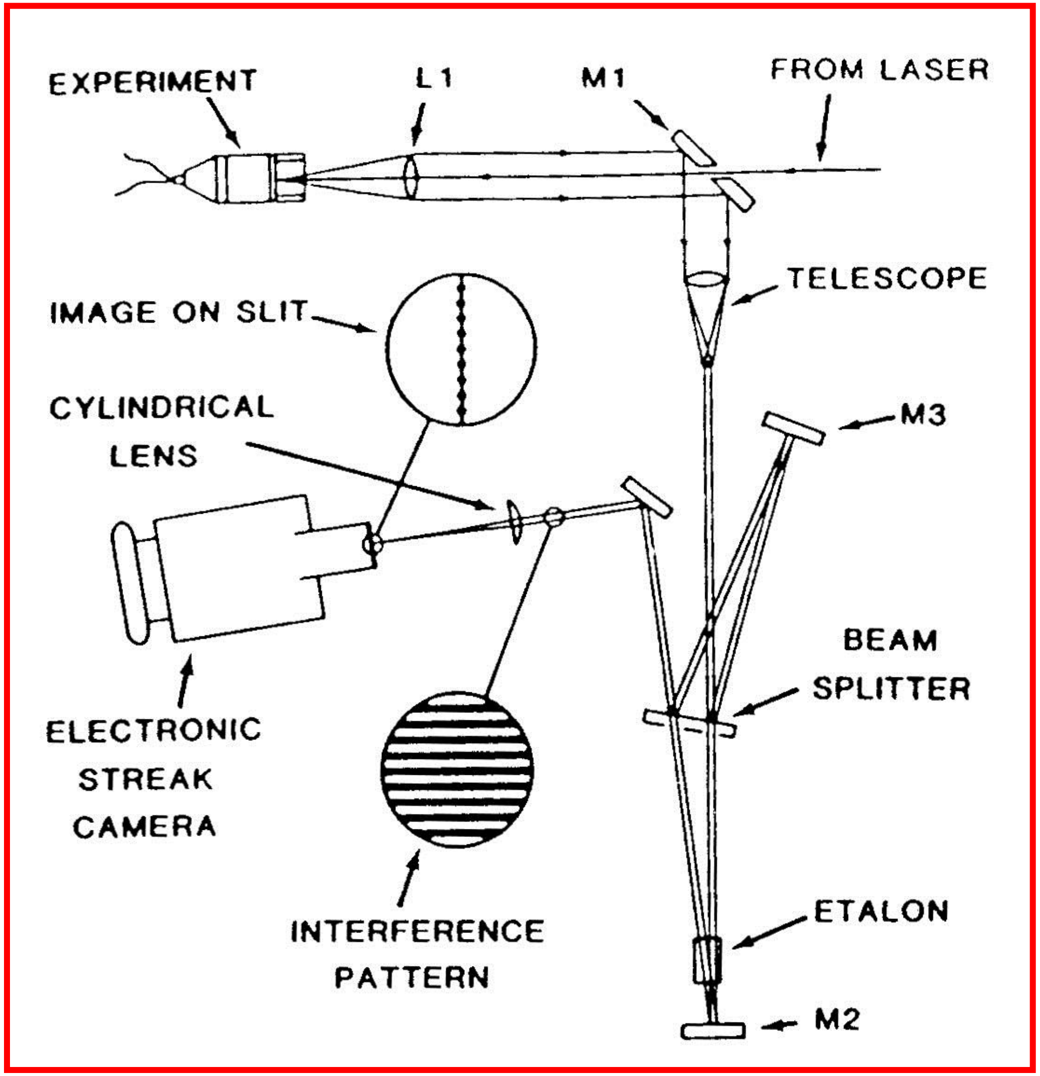


Motions spanning several orders of magnitude in velocity, event duration and length scales must be measured to impact component development needs



- Surface/interface velocities are collected at a point, over a line, or across an area.

ORVIS sought to overcome temporal limitations of VISAR

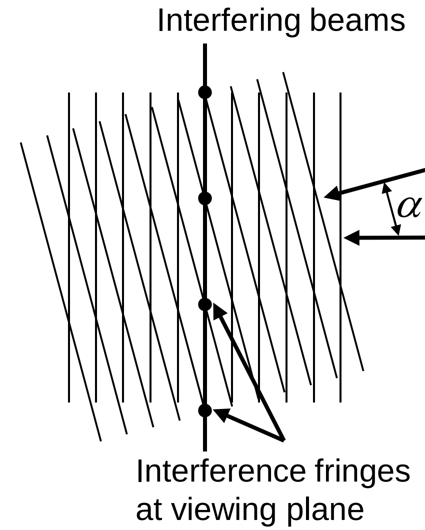


Design Motivations:

- To improve the temporal resolution of the velocity interferometer via electronic streak recording
- To simplify data analysis (recorded image of the fringe motion believed to be a direct indication of velocity history)

Operating Principle:

- M2 rotated off of 'bullseye' where they have a known density and are parallel.
- Velocity determined from observed fringe motion



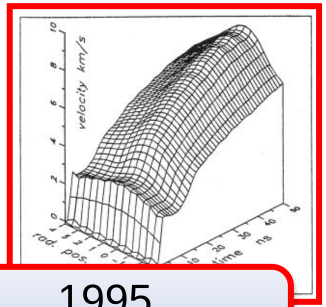
$$v(t - \tau/2) = \frac{\lambda_0 F(t)}{2\tau(1+\delta)} \qquad F(t) = y(t)/d$$

D.D. Bloomquist and S.A. Sheffield, J. Appl. Phys. 54, 1717 (1983) also SAND82-2918

ORVIS development since its start at SNL

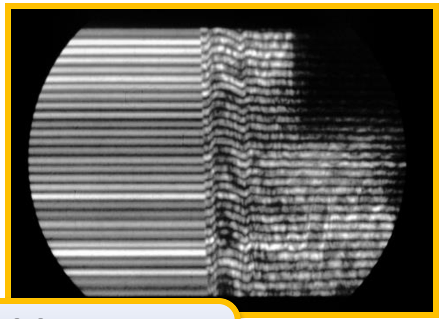
1977
Fringes on Camera

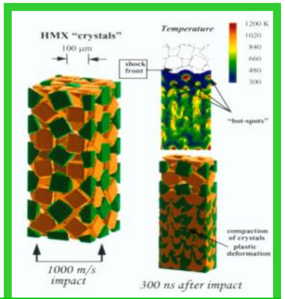
1982
ORVIS is born!

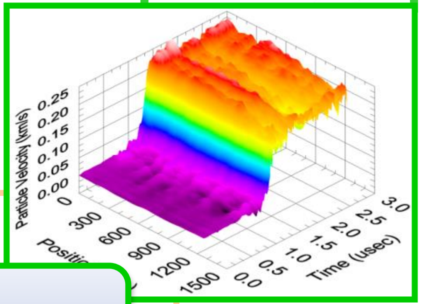


1995
Oh! Line Imaging!

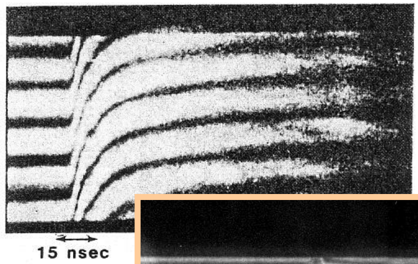
1984-2002
Flyers, Flyers and more Flyers…

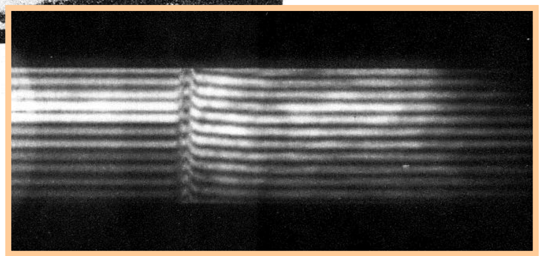






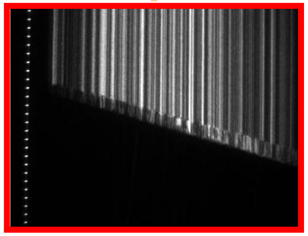
1999-2005
Inert Material Studies

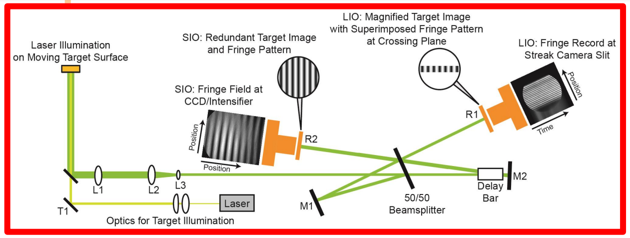




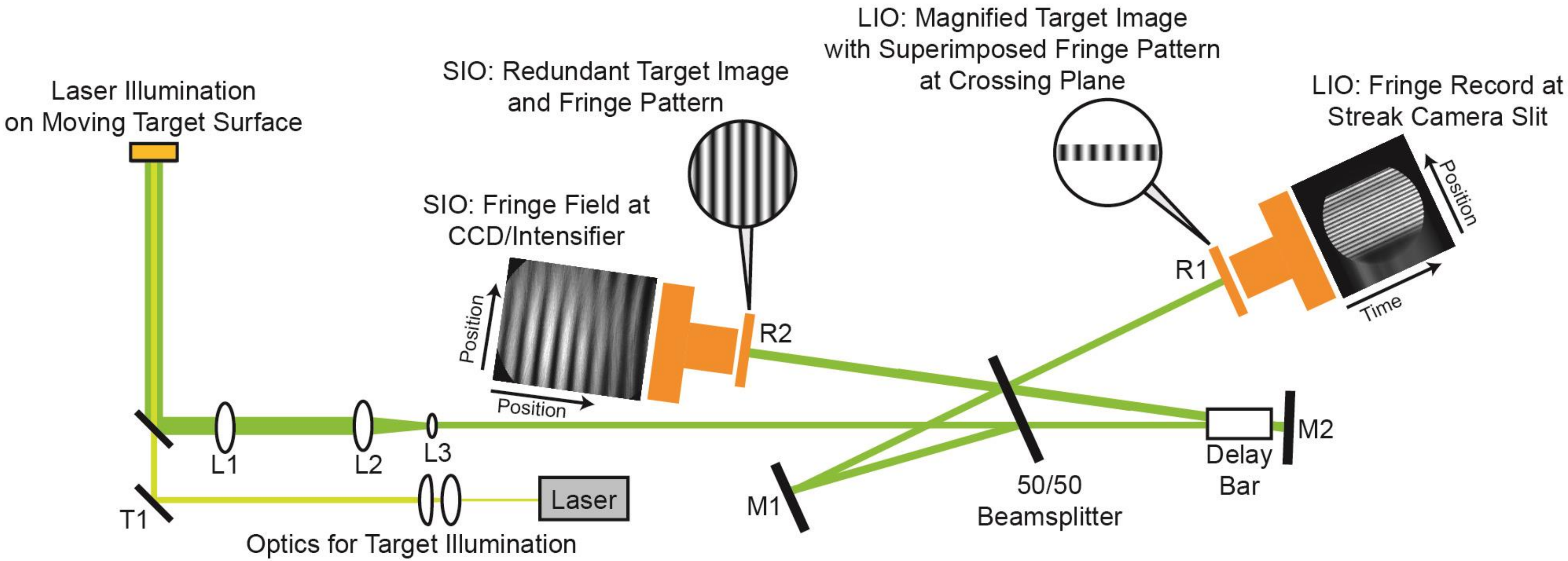
2000-Present
EM Studies at the Mesoscale

Moving forward with expanded applications….
Non-planar geometries, multi-ORVIS, SIM-ORVIS





Optically Recording Velocity Interferometer System (ORVIS) for point, line, and surface imaging



Varied settings: Camera recording time, Velocity-per-fringe, Image magnification and fringe density

Understanding fringe records with an idealized problem

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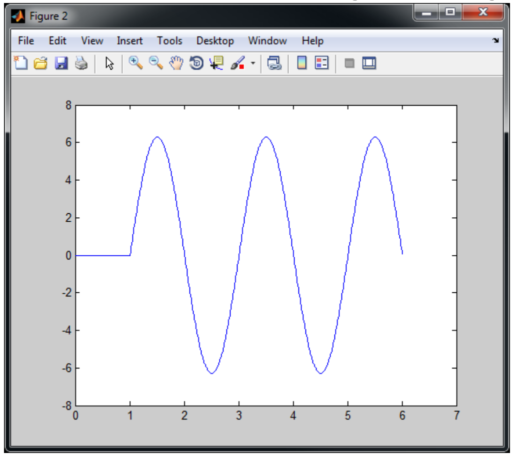
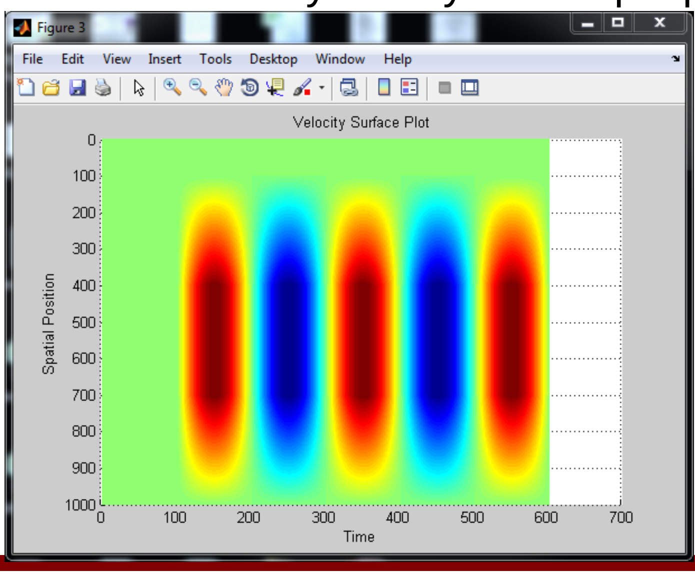
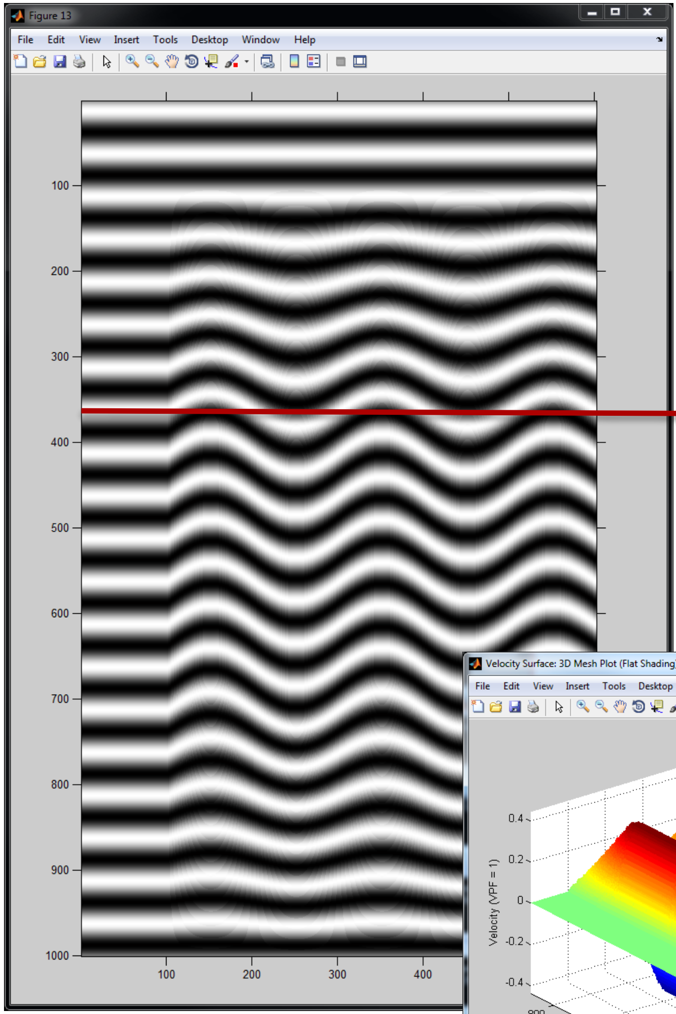
1. Prescribe a velocity history



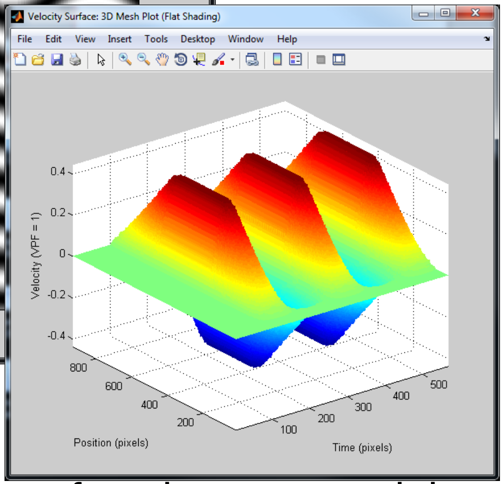
2. Prescribe velocity history at multiple points



3. Generate fringe record by specifying VPF and fringe spacing



Change of phase from baseline relationship implies non-zero velocity



4. Calculate velocity surface in space and time

Careful use of ORVIS requires appreciation of experimental realities….

Target Construction

- Reflective surface preparation
- Window conditions

Temporal Resolution

- Interferometer VPF
- Illumination Source Intensity
- Detector Sensitivity/Resolution
- Required Recording Time
- Trigger Reliability

⋮

Velocity Resolution

- Interferometer VPF
- Interferometer Fringe Spacing
- Detector Sensitivity/Resolution
- Material Properties (Dispersion)

⋮

Spatial Resolution

- Image Magnification
- Interferometer Fringe Spacing
- Detector Sensitivity/Resolution

⋮

Image Analysis

- Methodology (QM or FTM)
- Pre-analysis FT filtering
- Practicalities of adding fringe jumps

⋮

Laser-Driven Flyer Studies Motivated by Direct Optical Initiation Concepts

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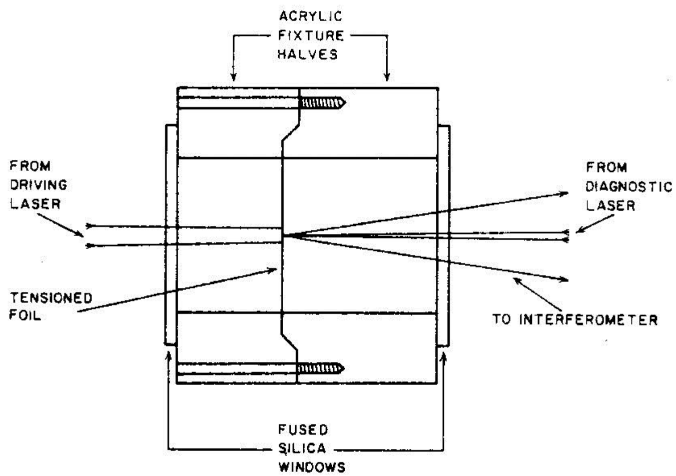
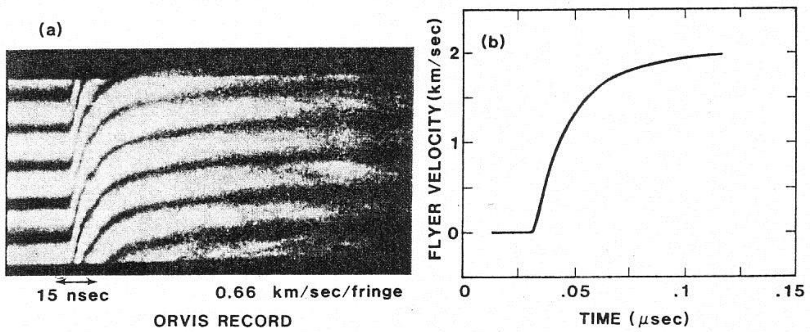
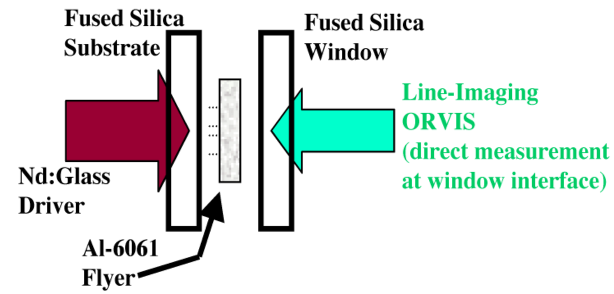


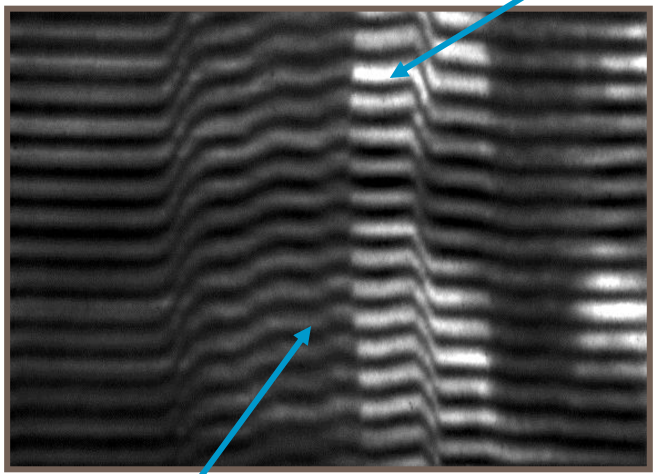


S.A. Sheffield, J. W. Rogers, Jr., and J.N. Castañeda, in Shock Waves in Condensed Matter, ed. Y. M. Gupta (Plenum, New York, 1986),pp. 541-545.

Photonic Driver EOS Studies



EOS data from post-impact state

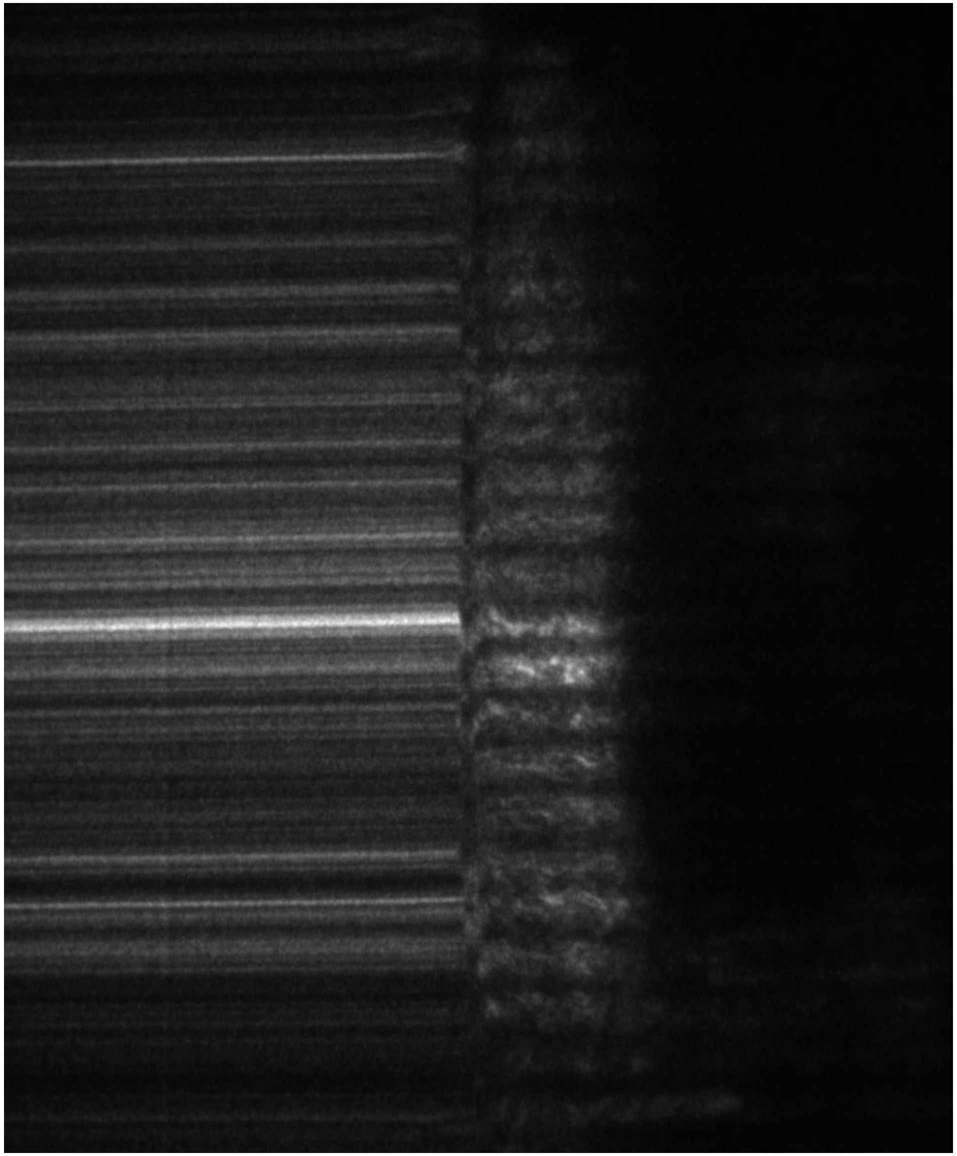


Flyer launch record provides impact velocity and planarity

R. E. Setchell et al., SAND2002-0005 (January 2002)

CDU-Driven Flyer Studies

- Polymer flyers launched with a high-capacitance CDU are used in chip slapper devices.
- Seek understanding of flyer shape for boundary conditions of mechanical stimulus to EM.
- ORVIS useful due to spatial resolution across flyer shape.
- Affords new motivations to automatically track front shape via contrast loss.



Tests with engineered spatial features result in complex shocks measureable with ORVIS

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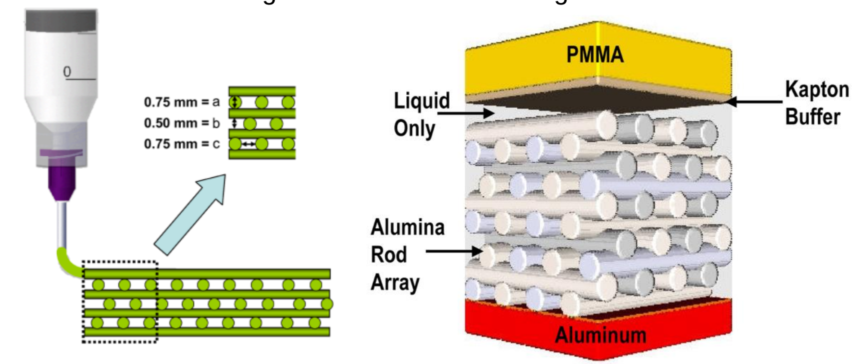
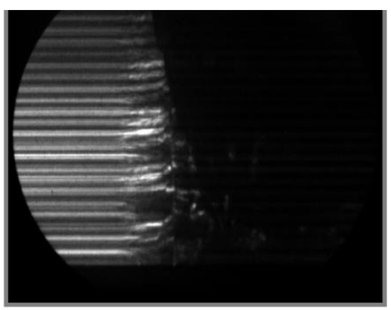
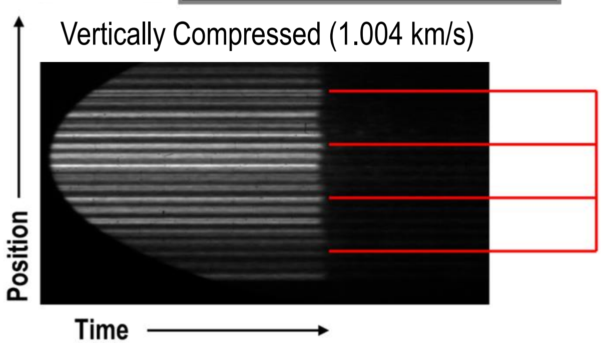
Configuration of Robocast Target:



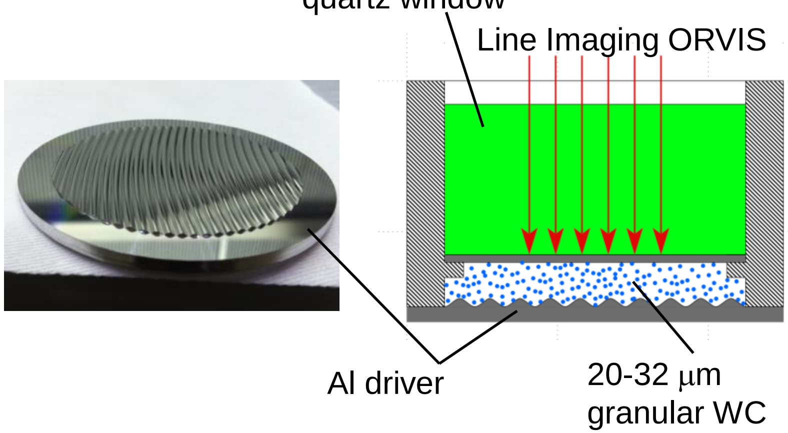
Nitromethane/DETA (0.793 km/s)

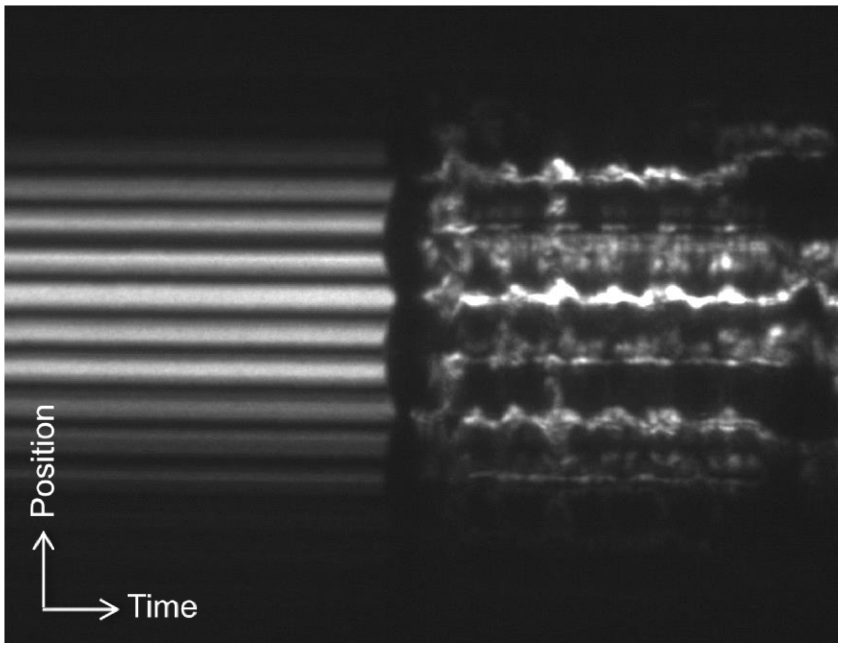


Vertically Compressed (1.004 km/s)



Periodic spatial structure (1.5 mm transverse rod spacing of the alumina insert)





ORVIS can record statistics of temporal and spatial transmitted shock behavior

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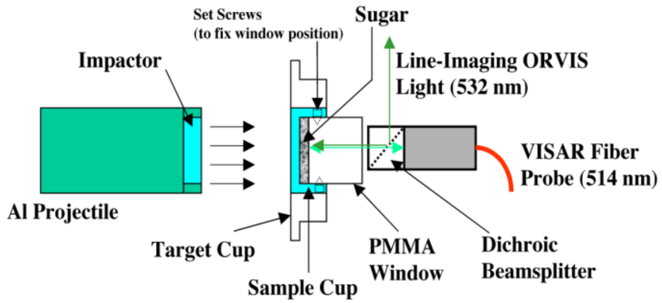
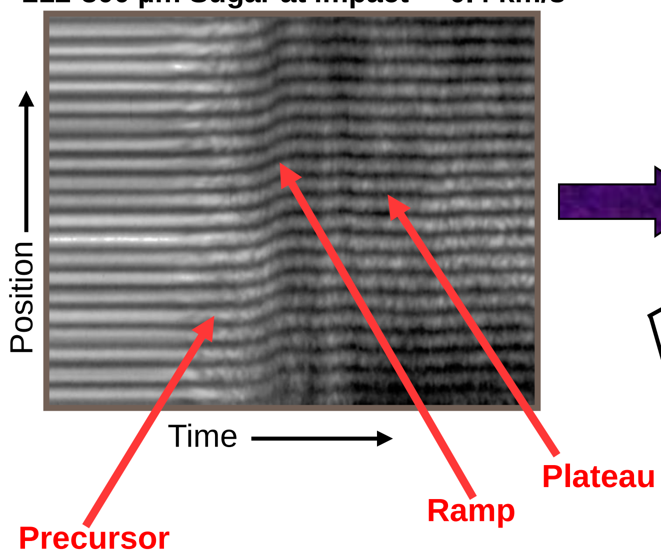
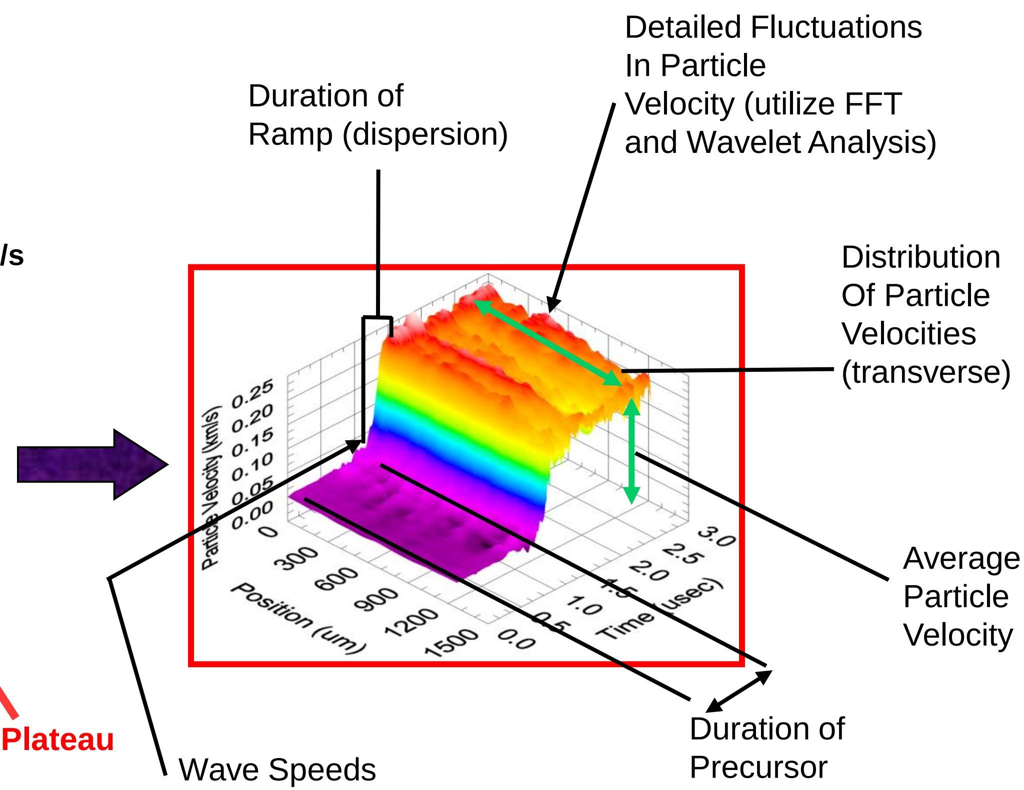
Standard target for powder bed experiments



212-300 µm Sugar at impact = 0.4 km/s



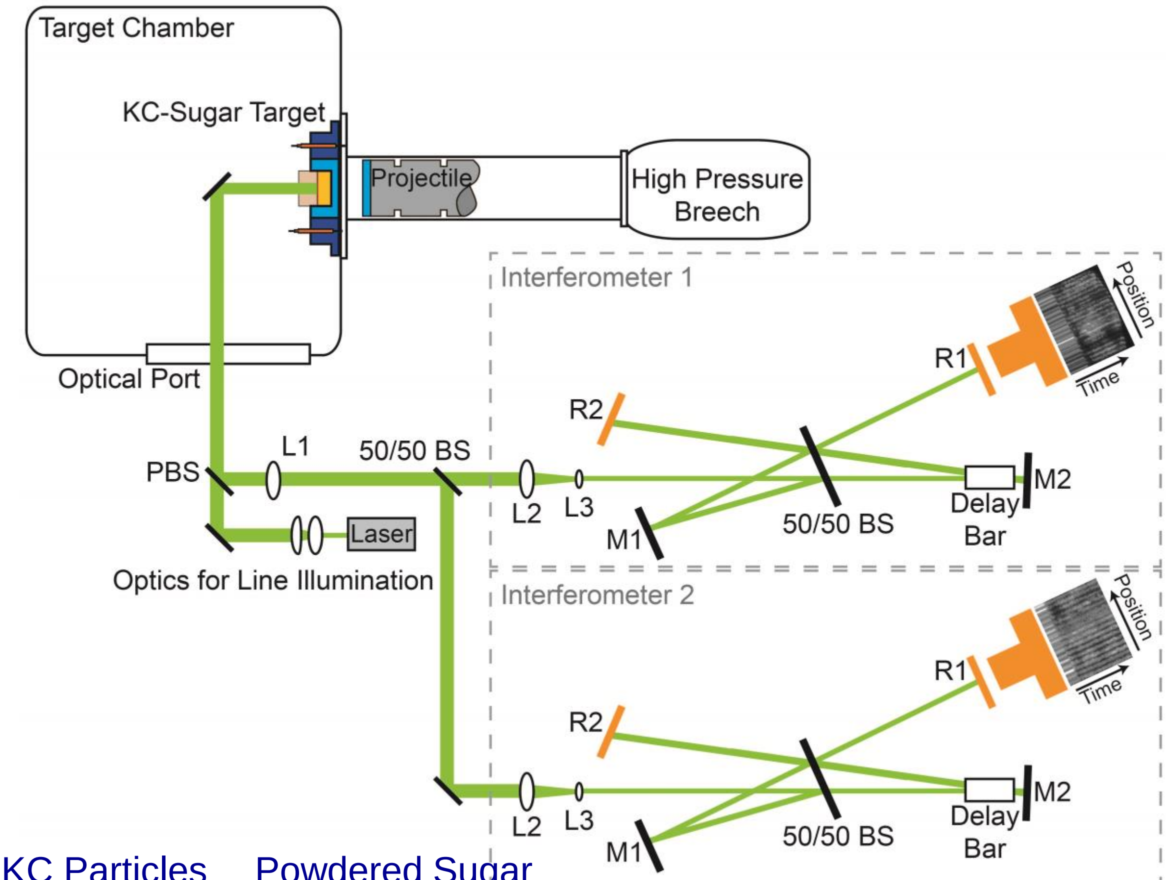


- Impact Velocity
- Sample Thickness
- Particle Size Distribution

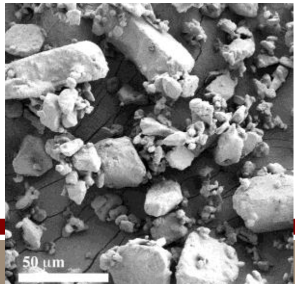
Influence statistics

Characteristic "signatures" for computational validation

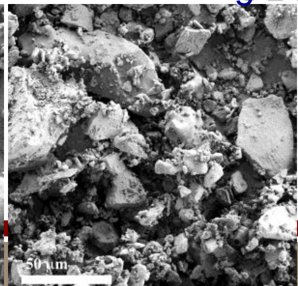
Add second ORVIS interferometer for dual-delay-leg operation

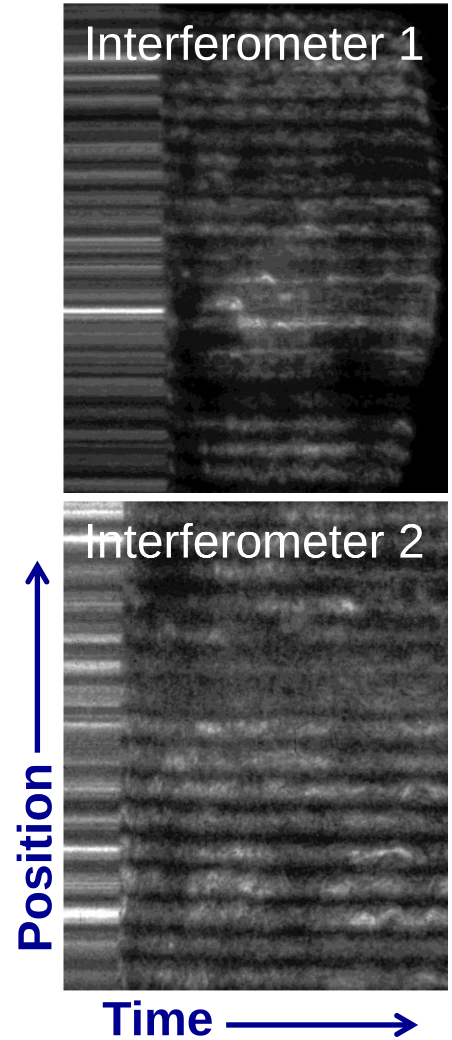


KC Particles



Powdered Sugar

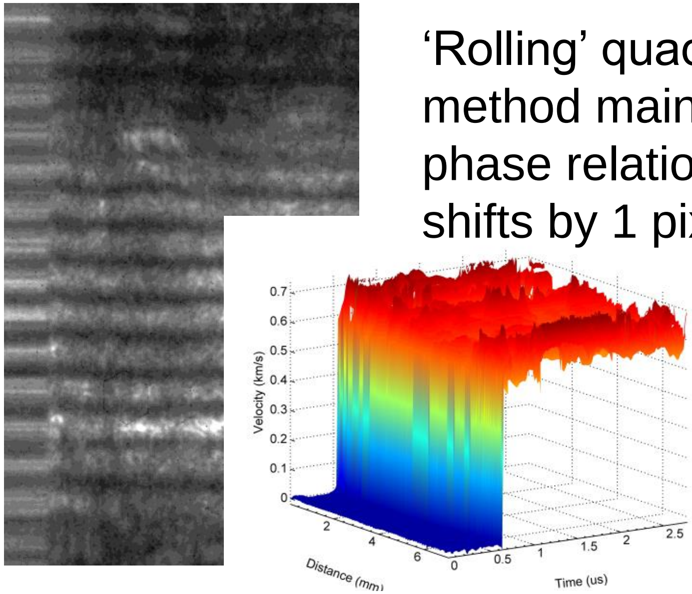




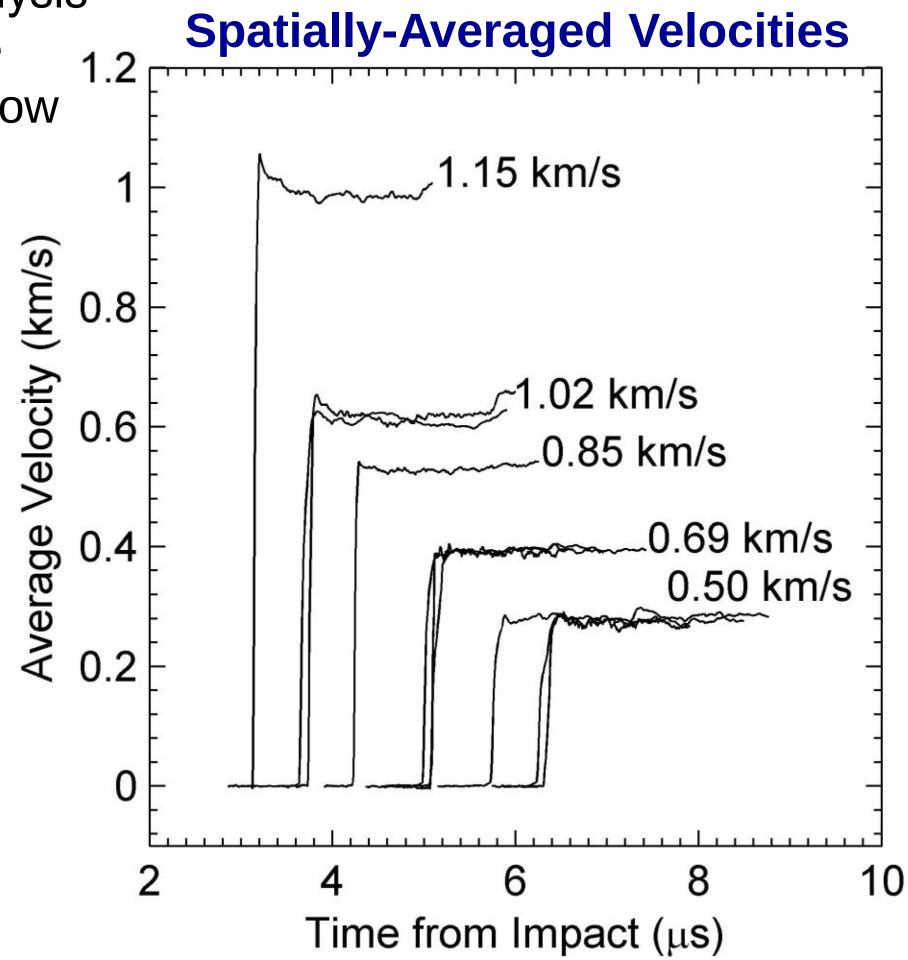
Interferometer 1: 50 px/cyc, 135 px/mm, 370 µm/cyc

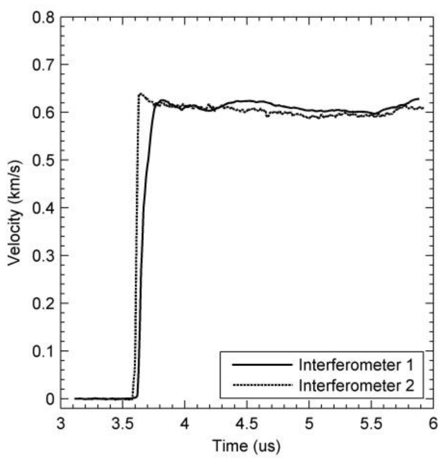
Interferometer 2: 60 px/cyc, 250 px/mm, 240µm/cyc

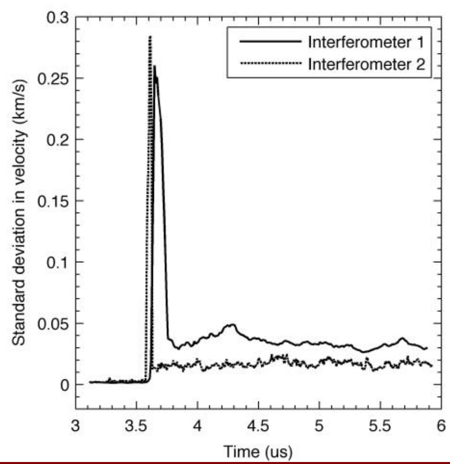
ORVIS records analyzed for particle velocity in position and time



'Rolling' quadrature analysis method maintains fringe phase relationship yet now shifts by 1 pixel.





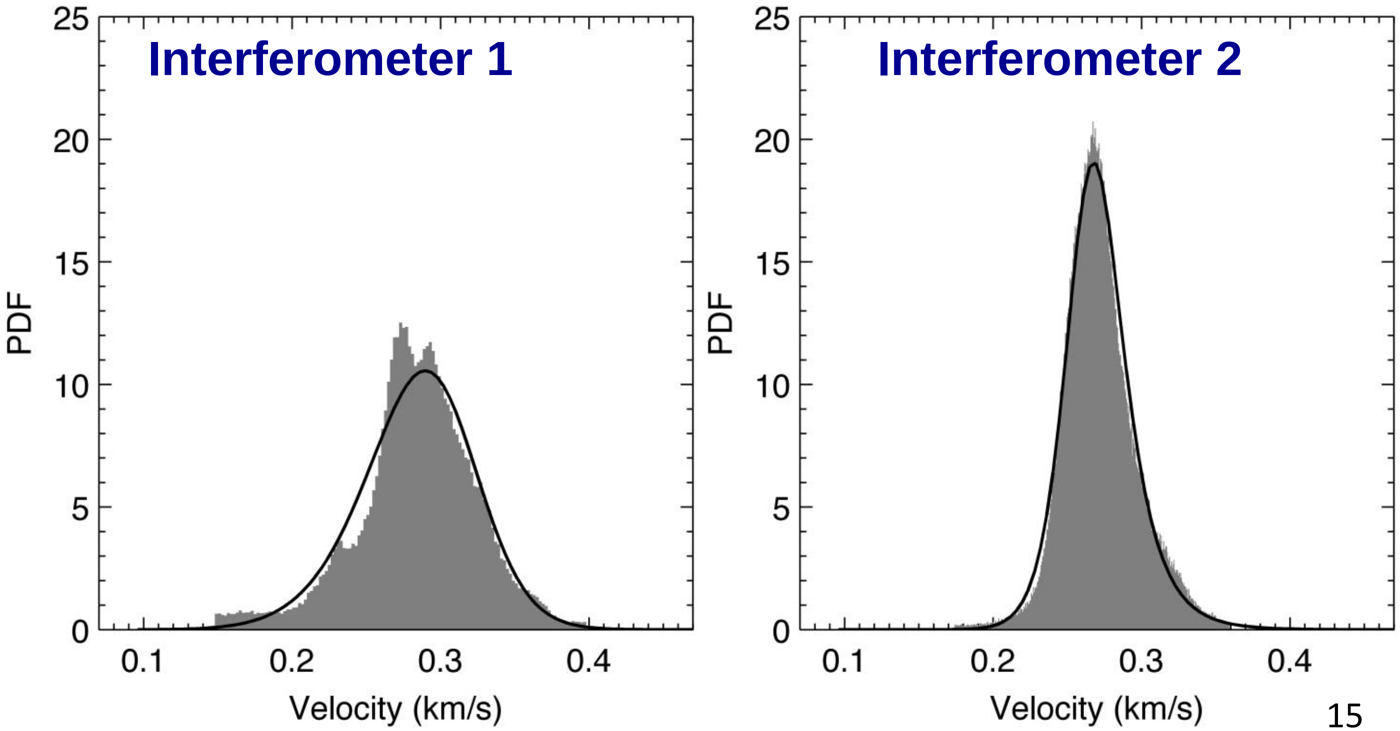


But more can be extracted from ORVIS records! Characterize fluctuations about mean…

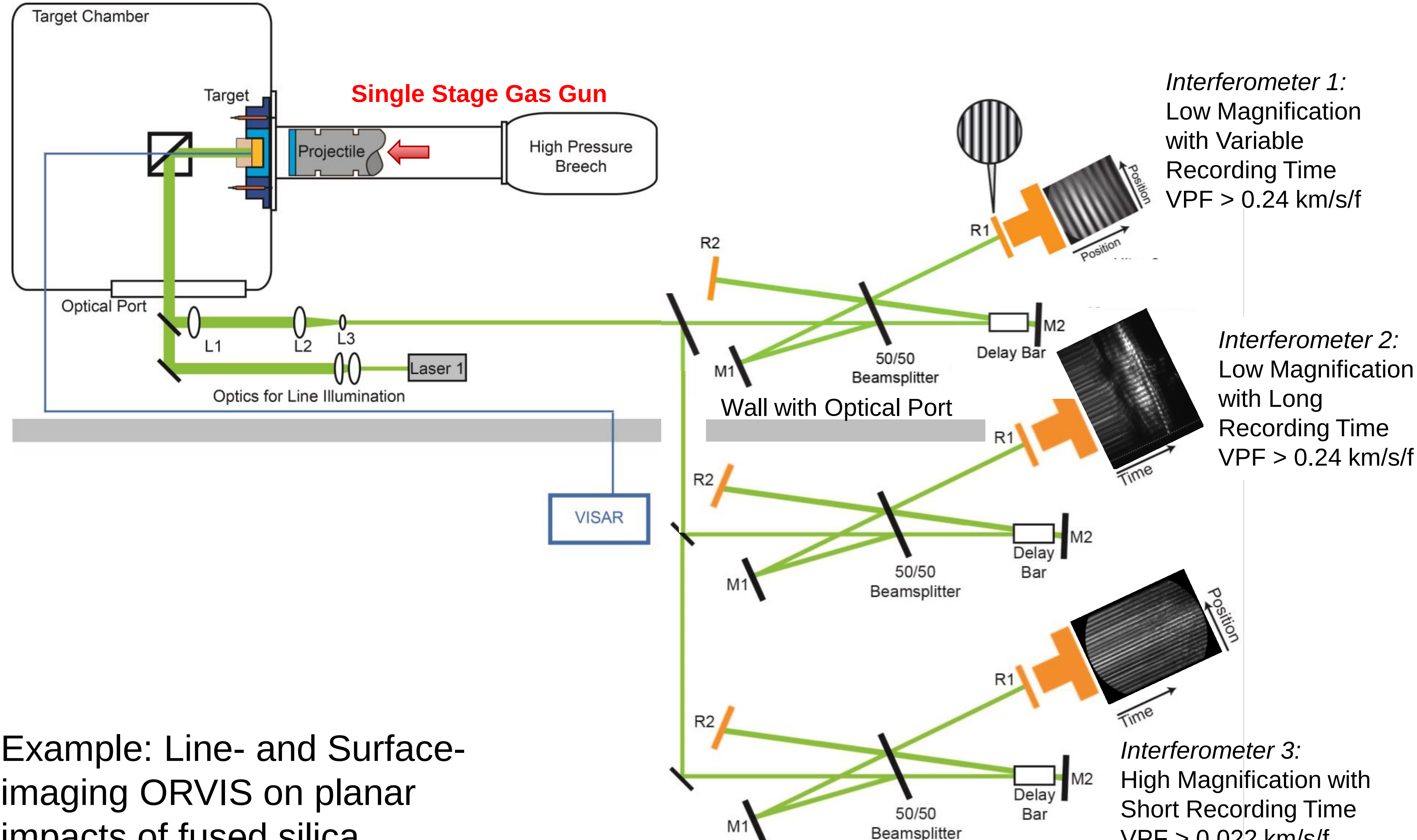
- Probability Density Functions (PDF) useful for describing distribution of states. Currently, prevailing “language” for coordination with mesoscale simulations.
- Distributions shown here consider all positions and time within ROI.

Burr Distribution

$$f(x \mid \alpha, c, k) = \frac{\frac{kc}{\alpha}\left(\frac{x}{\alpha}\right)^{c-1}}{\left(1+\left(\frac{x}{\alpha}\right)^{c}\right)^{k+1}}$$

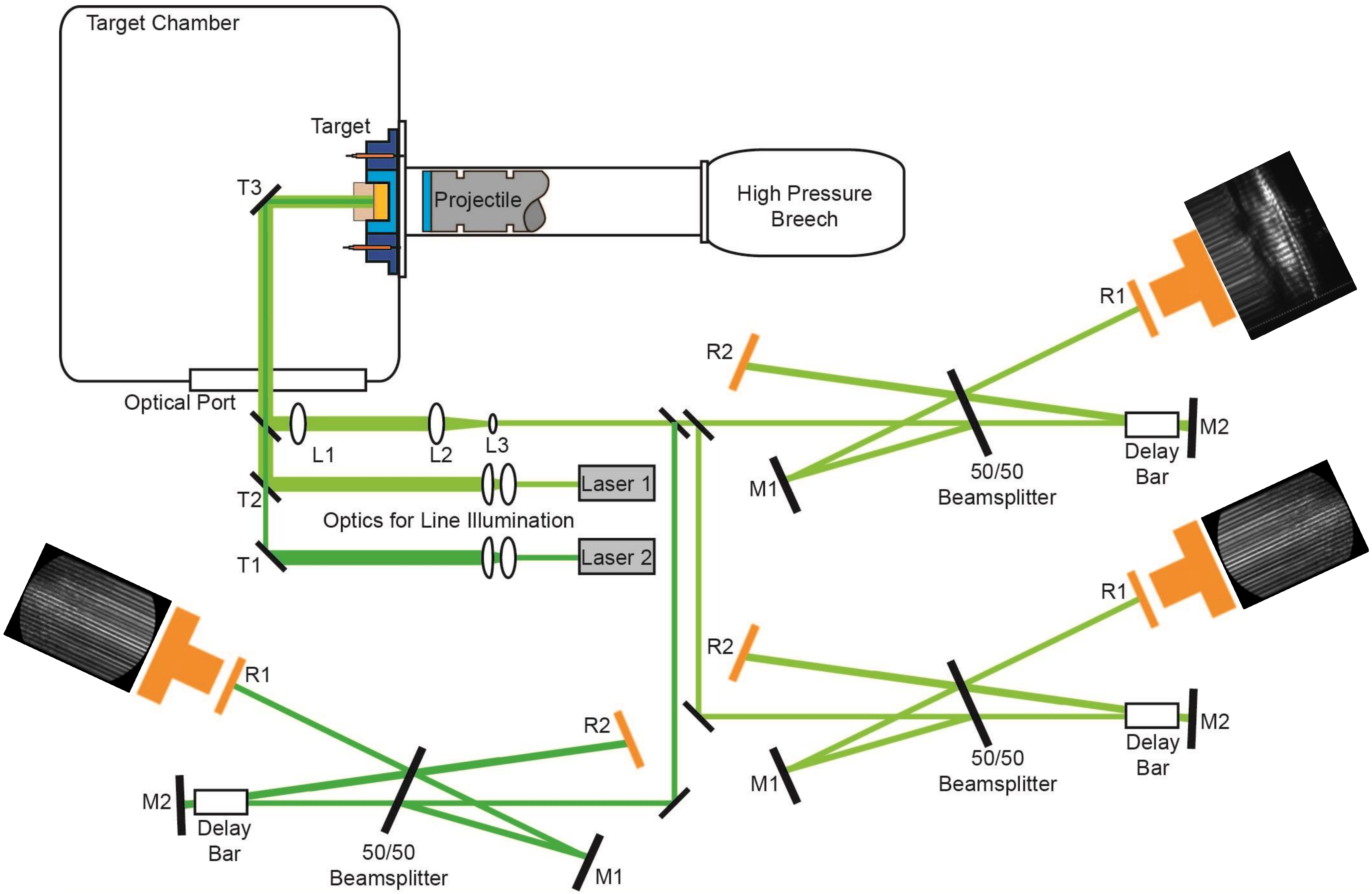


Multiple ORVIS coupled to gas gun at the Explosive Components Facility



Example: Line- and Surface-imaging ORVIS on planar impacts of fused silica

Multiple lasers afford additional ORVIS lines for interrogation at high temporal resolution



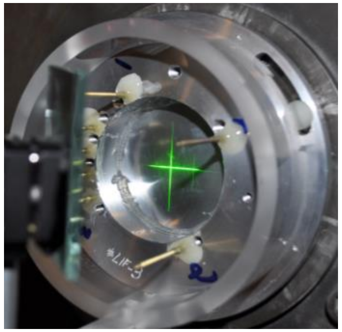
Demonstrated ability to independently position two laser lines on target

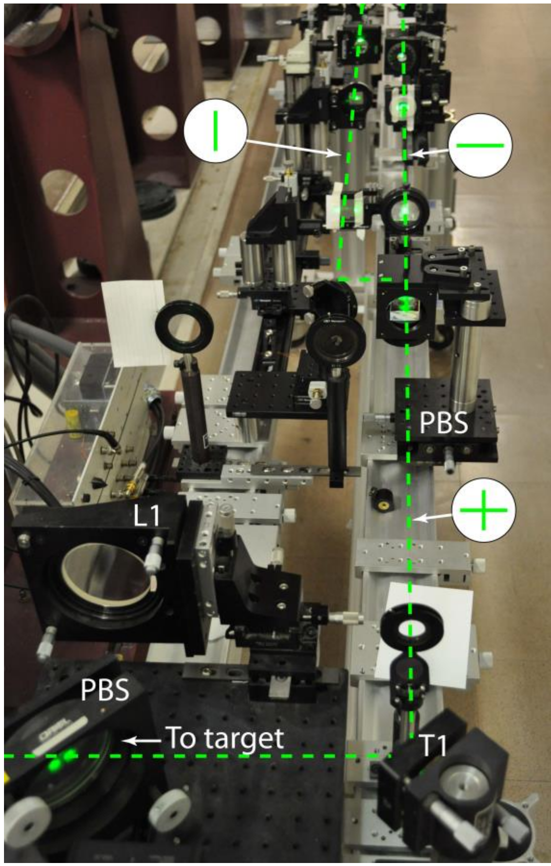
- Configuration exploits modifications to laser polarization, polarizing beam splitters and dove prisms for light sheet manipulation onto target and through interferometers.

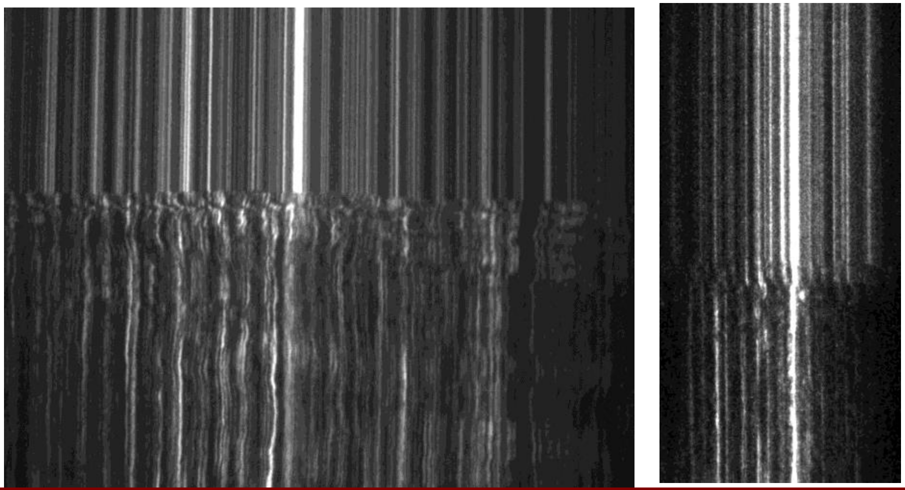
- While successfully demonstrated in ‘cross-hair’ arrangement, not suitable for use on large wedge samples in ‘T’ arrangement. Limited by finite size collection optics and corresponding off-axis image distortion.

- Cross-talk observed at the crossing point.

Optical arrangement for cross-line ORVIS



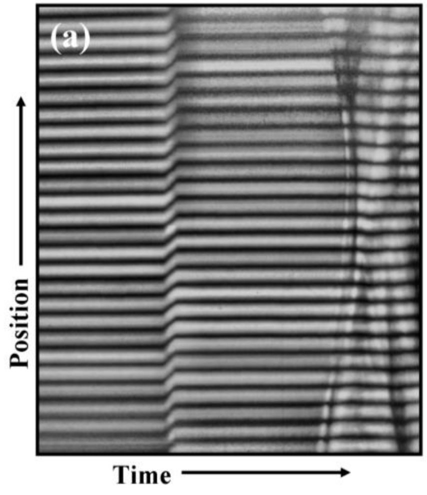




Raw fringe images from each line of cross-hair. Symmetric aluminum impact at 0.35 km/s.

ORVIS has inherent benefits, but also significant challenges for EM

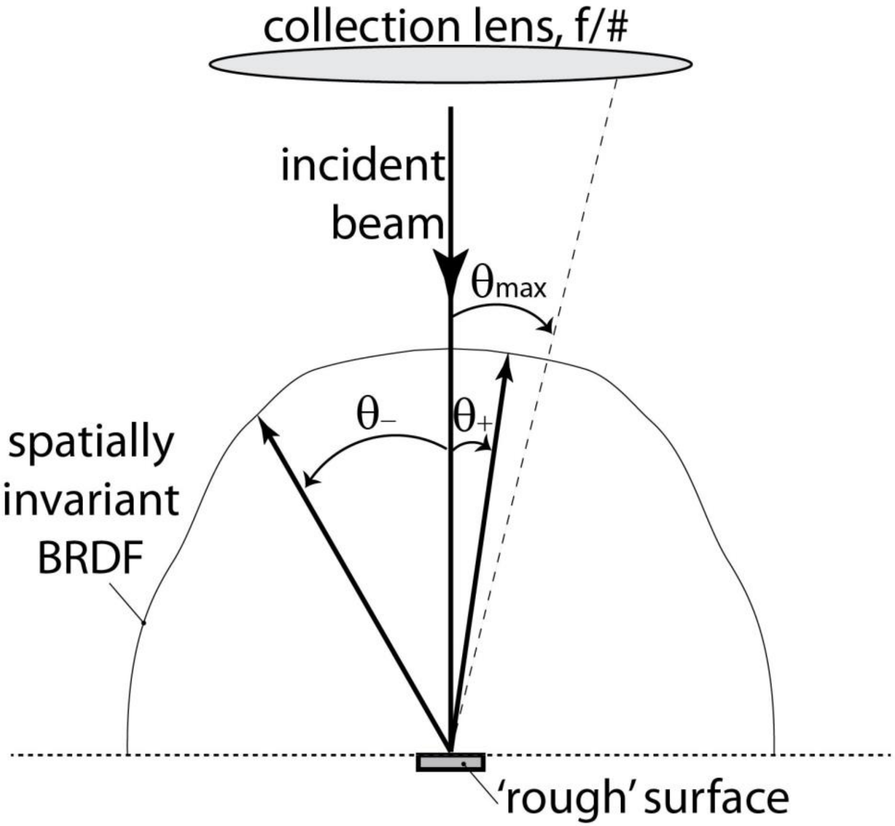
Light collection is paramount



Challenges increase with increased deviation from planar geometry:

- Heterogeneous test materials with thin buffers
- Non-planar geometries
- Edge-on interfaces

- Focus attention on the target reflectance and seek a quantitative method to optimize surface properties for a given test geometry.

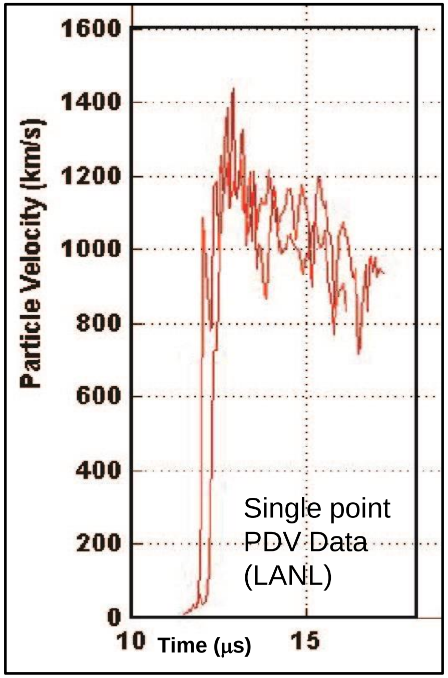


First, some examples to motivate….

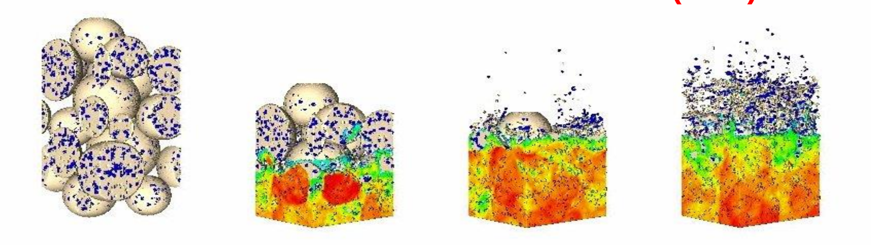
Large scale heterogeneities are common in NX materials of current interest

- Bed of Ammonium Nitrate prills with Fuel Oil (ANFO) has very large heterogeneities compared to most other explosives.

- Very long duration precursor with dispersive shock observed.

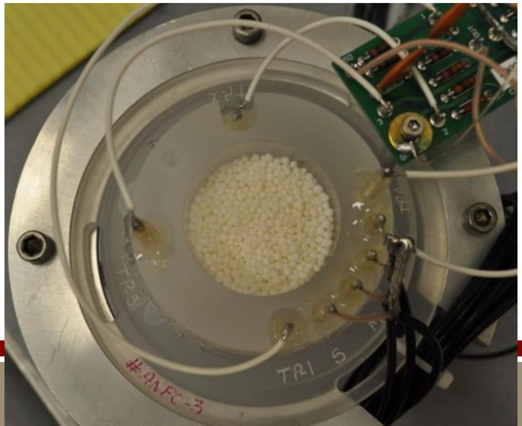


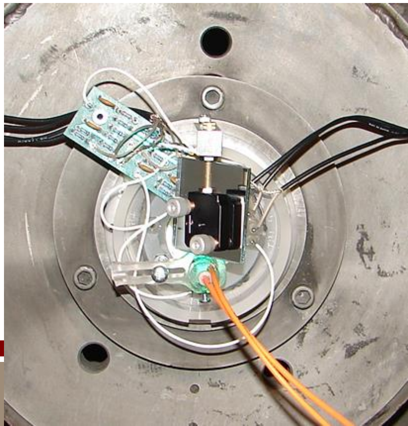
3D Reactive Mesoscale Simulations (CTH)



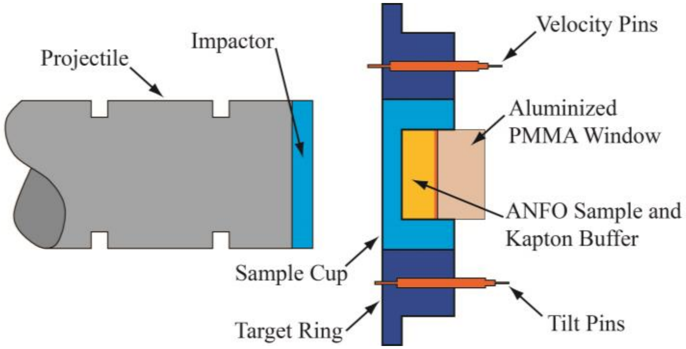
Meso-volume

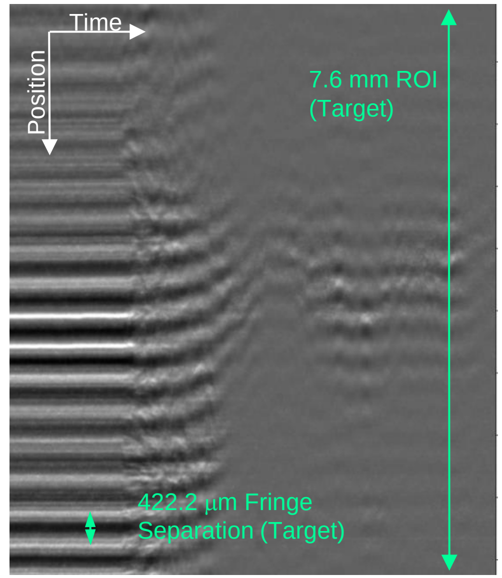
Stress fields during detonation loading



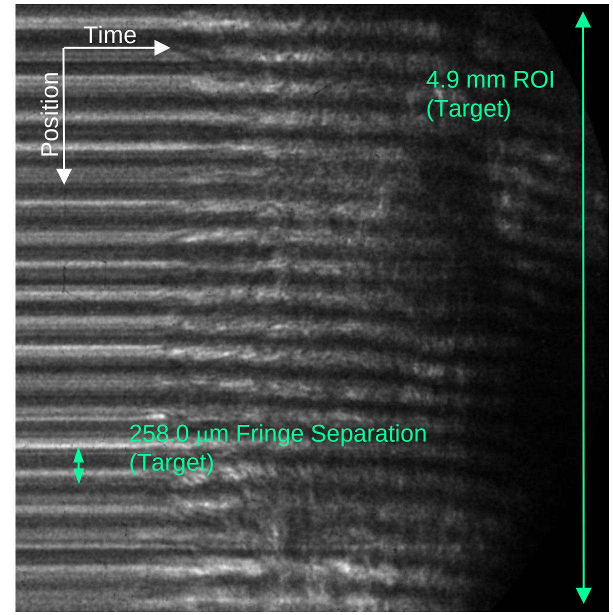


Fringe records show light loss after precursor motion – tradeoff with buffer thickness

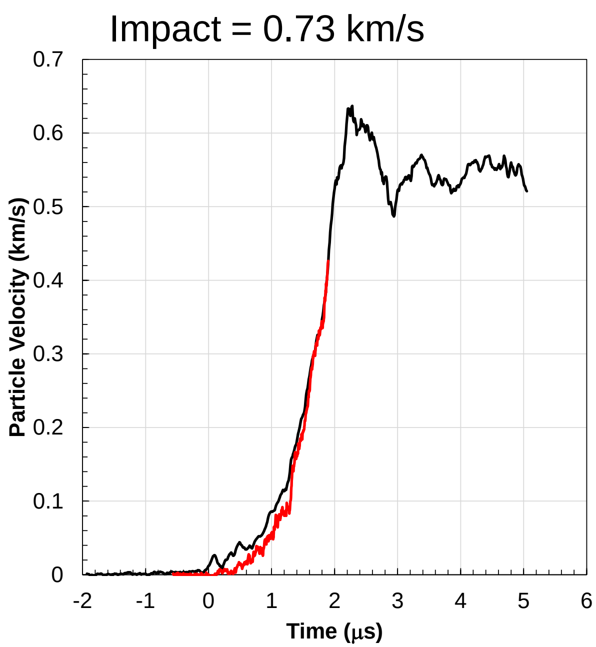


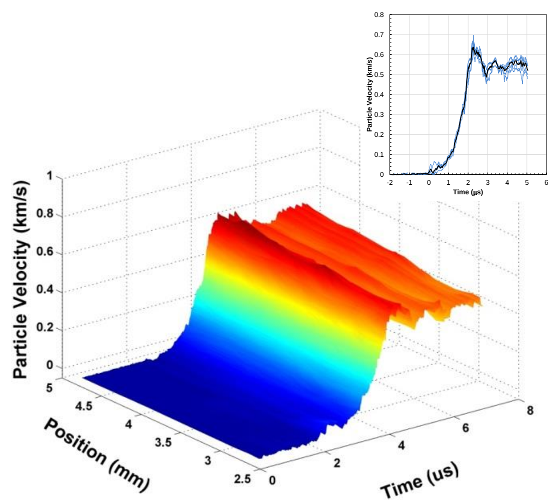


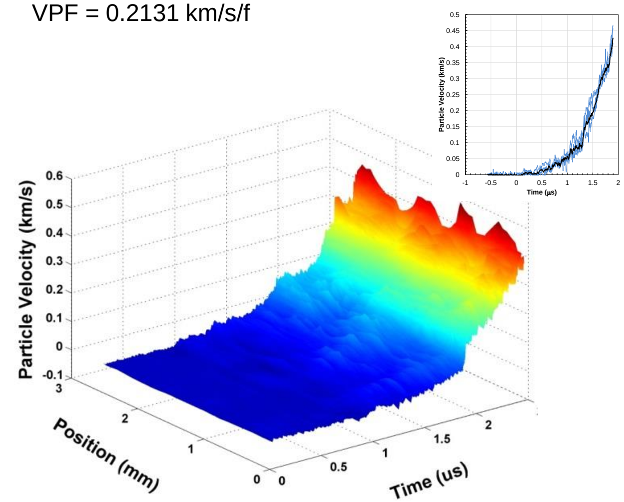
VPF = 0.2804 km/s/f



VPF = 0.2131 km/s/f



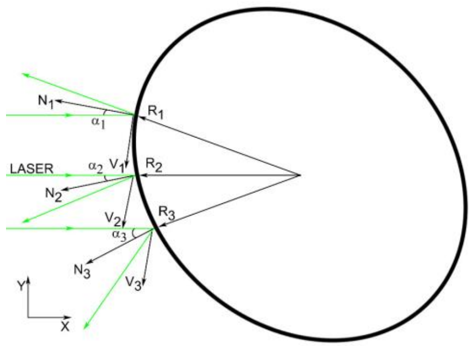


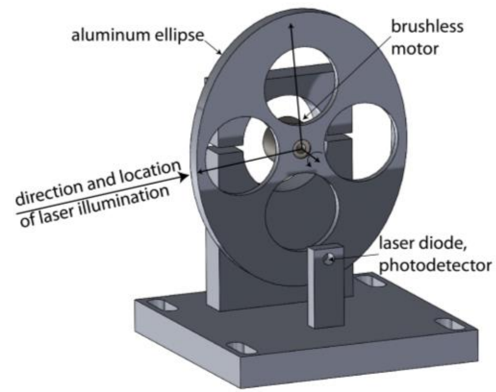


SIM-ORVIS captures transverse motion of curved surface when diffuse reflector employed

- ORVIS can collect transverse surface velocities due to large collection optics. However, the apparent velocity measured depends on V_x and V_y of all reflected light.

$$V_a = 1/2 V_x(\cos(2\alpha)+1) + 1/2 V_y \sin(2\alpha)$$



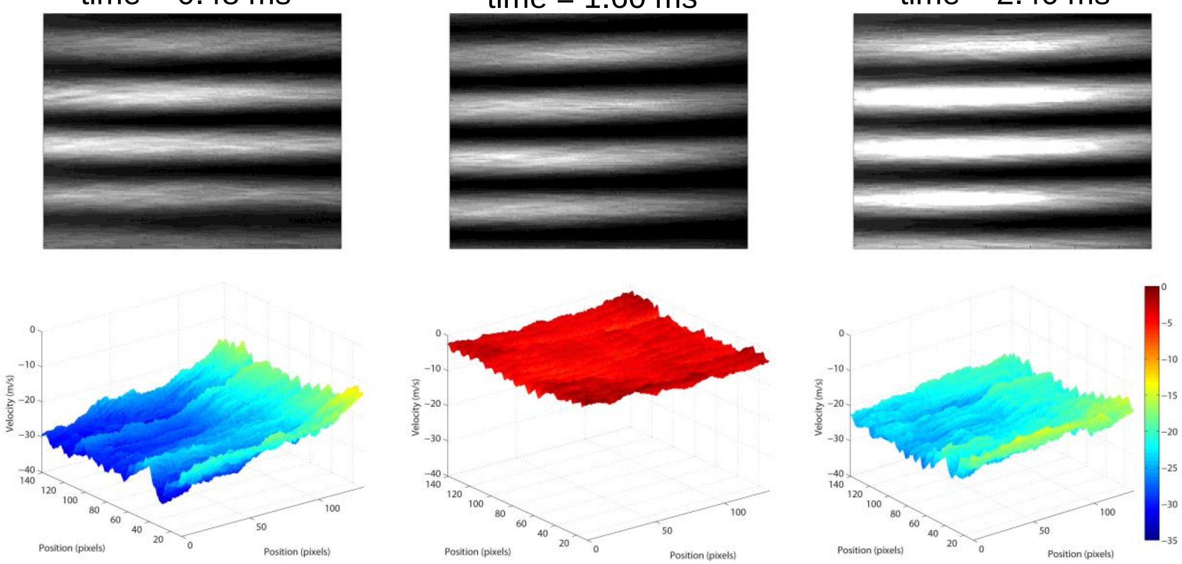


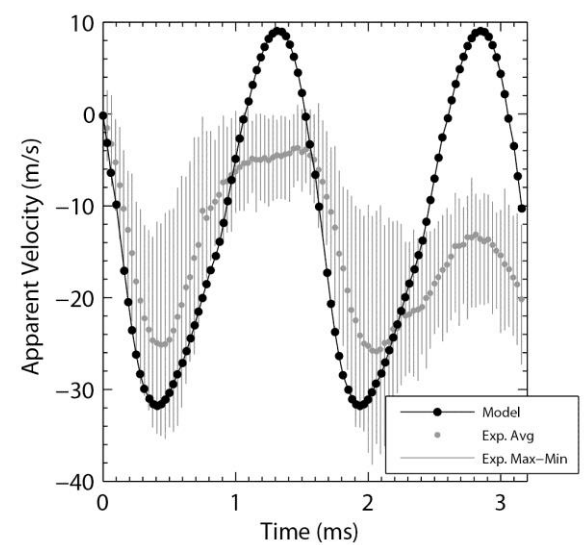
- 25,000 rpm ellipse rotation for peak speeds ~30 m/s compared with VPF ~100 m/s/f. 102 images captured at 32,000 fps with Shimadzu HPV-2.

time = 0.48 ms

time = 1.60 ms

time = 2.40 ms

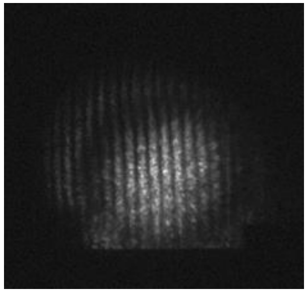
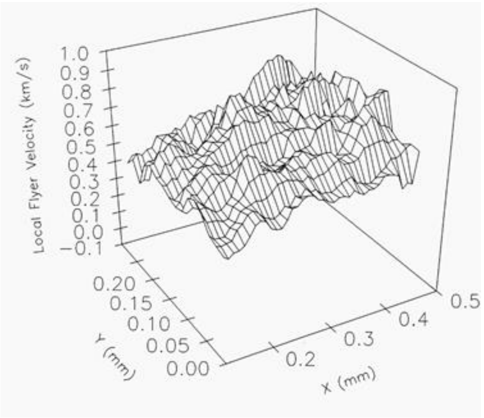




Cooper et. al., In print, AIP Conf. Proc. (2014).

Polymer flyer shape and impact studied with SIO

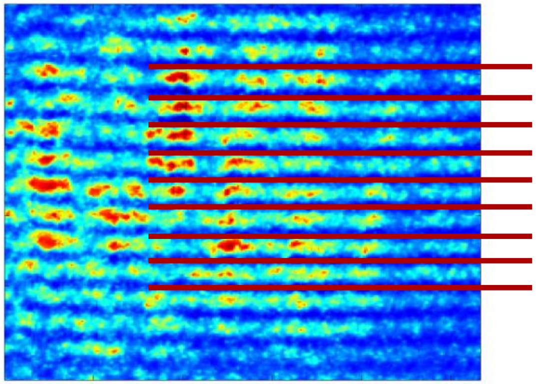
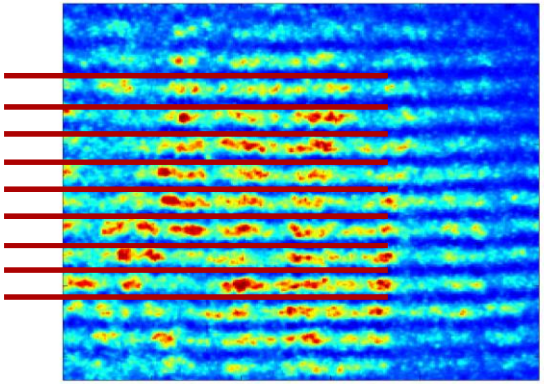
- Earliest demonstration of SIO collected one frame per test.
- Renewed interest due to modern camera technology, high energy CDU capabilities, and EM modeling needs.
- Experimental challenges associated with the transparent properties of the polymer, fast exposures required for stop motion (<10 ns) and plasma light emission affect data quality and resolution.

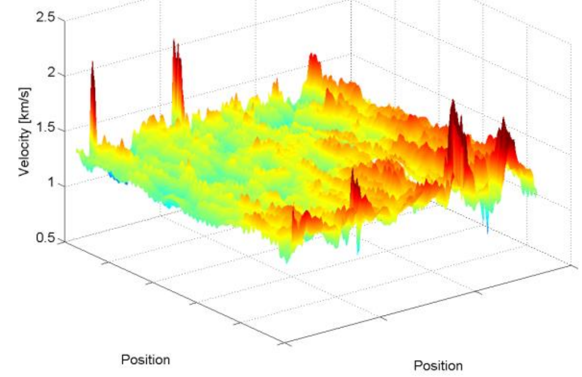
Stop motion of fringe field from laser-driven flyer launch (Trott, et al. 2001)

Time = 0 ns

Time = 90 ns

Velocity (x, y, t=90 ns)



Maximum flyer velocities between 1-2 km/s were measured (VPF = 0.94 km/s).

SNL's Impact-Loaded Wedge Test for modernized shock-to-detonation transition data

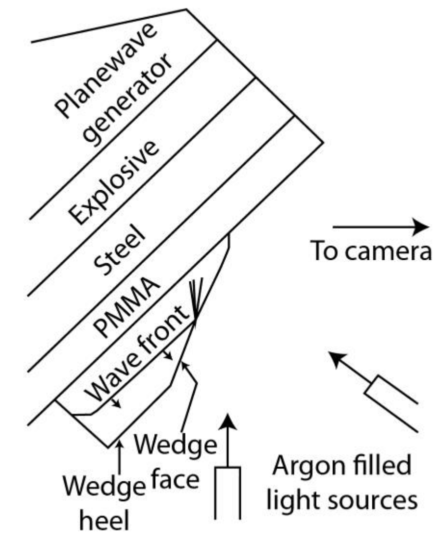
Sandia National Laboratories

The Impact-Loaded Wedge Test combines:

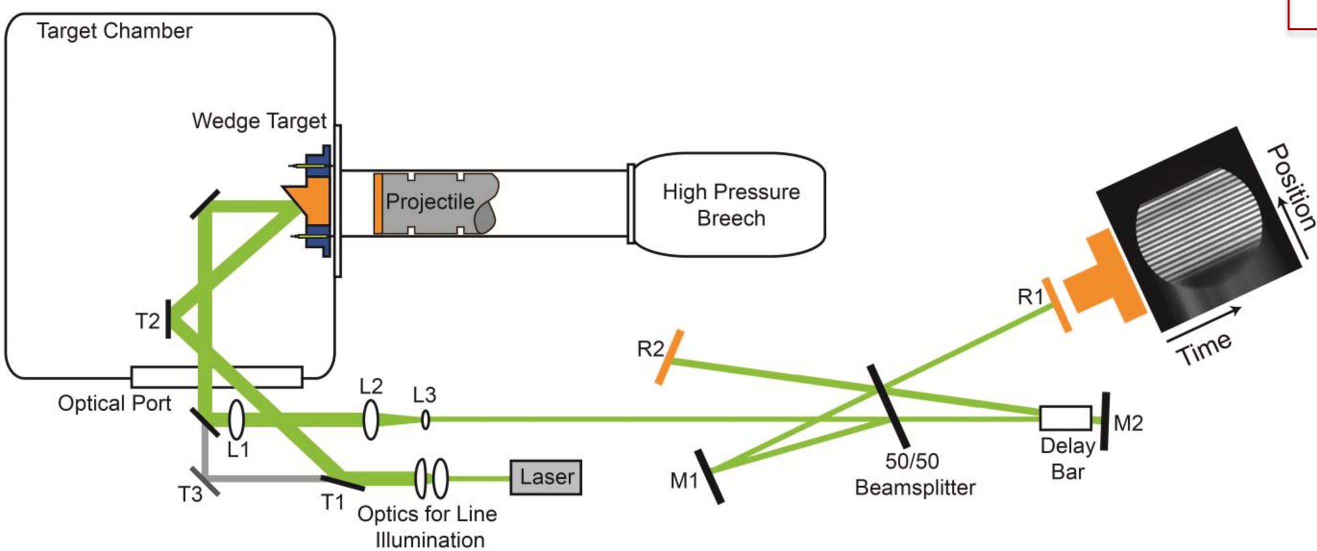
- controllability of gun testing
- ease of wedge tests
- coupled to ORVIS

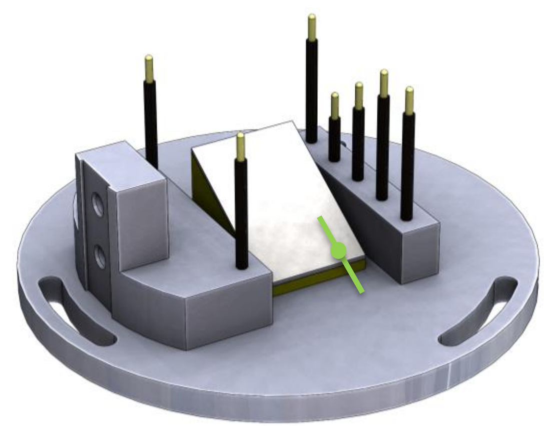
Collected data includes wave arrival times and post-shock/detonation particle velocities with high spatial and temporal resolution.

Note that laser light directed to collect specific component of velocity (not aligned with surface normal).



Traditional Wedge Test

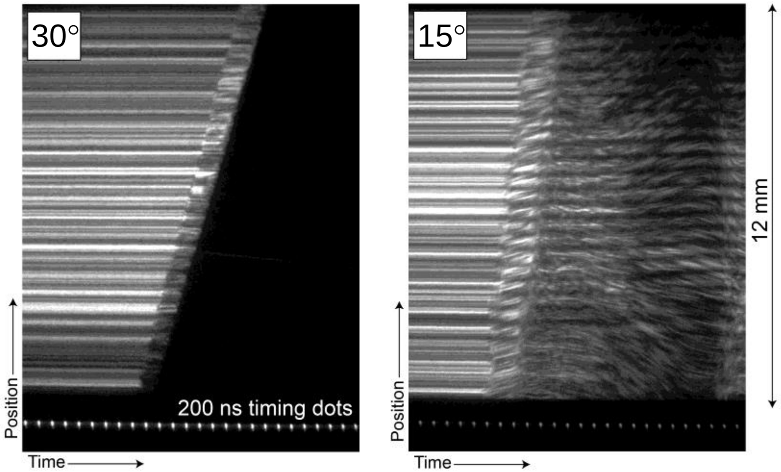


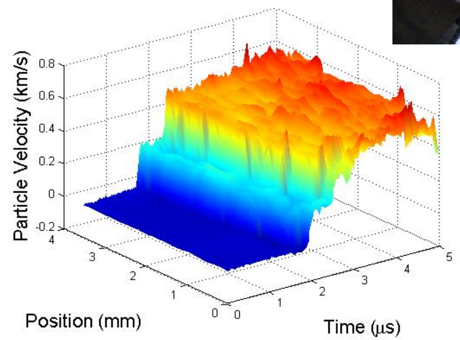


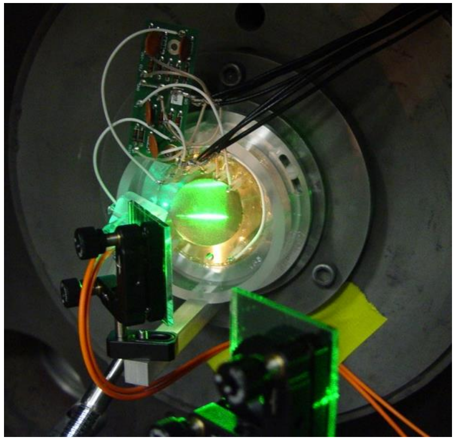
EM Wedge Target Arrangement

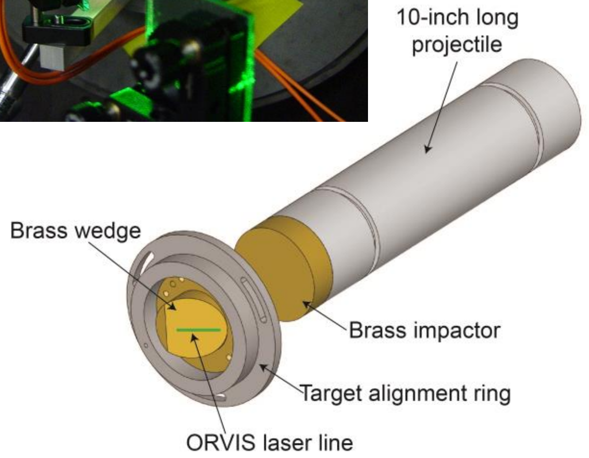
ILWT requires ORVIS coupled to non-planar geometries

- Concept demonstrated using brass (inert) wedges
- Distance-time and particle velocity data possible
- Recent testing with plastic wedges and diffuse reflectors



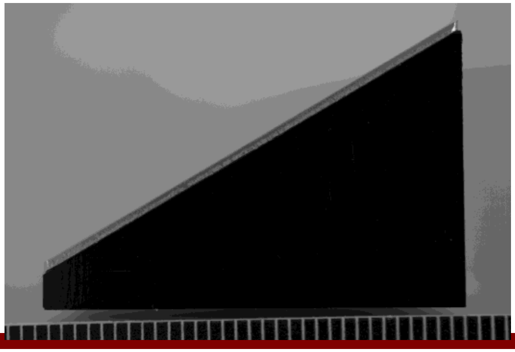


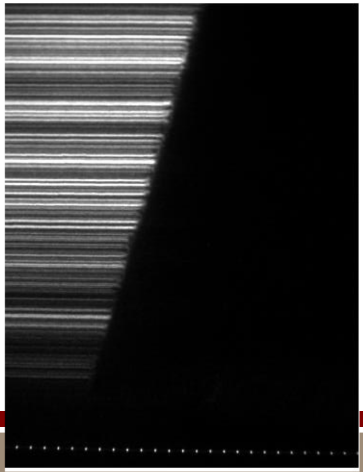


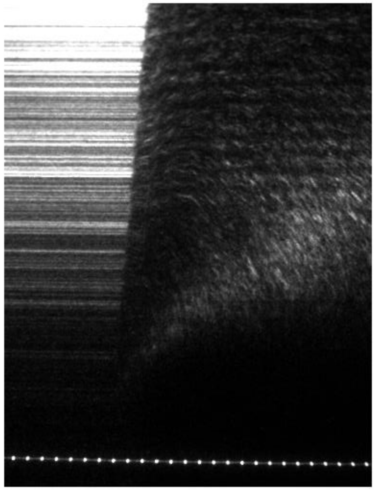


Cooper and Trott. AIP Conf. Proc. (2012)

- Consistent loss of light results correlated with wedge angle.



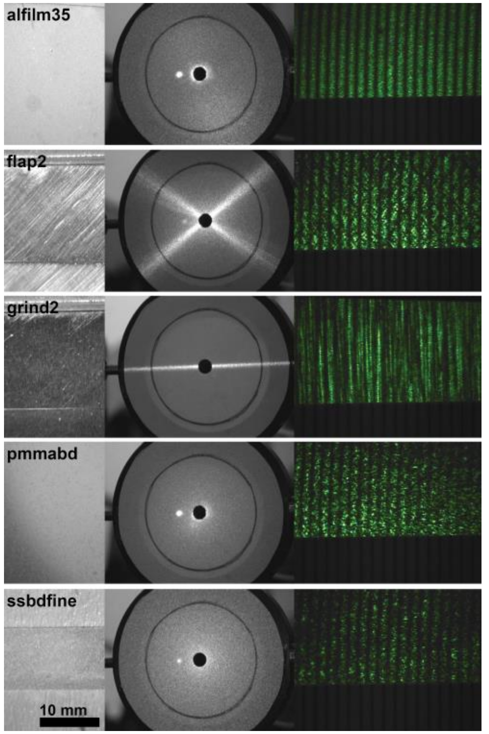




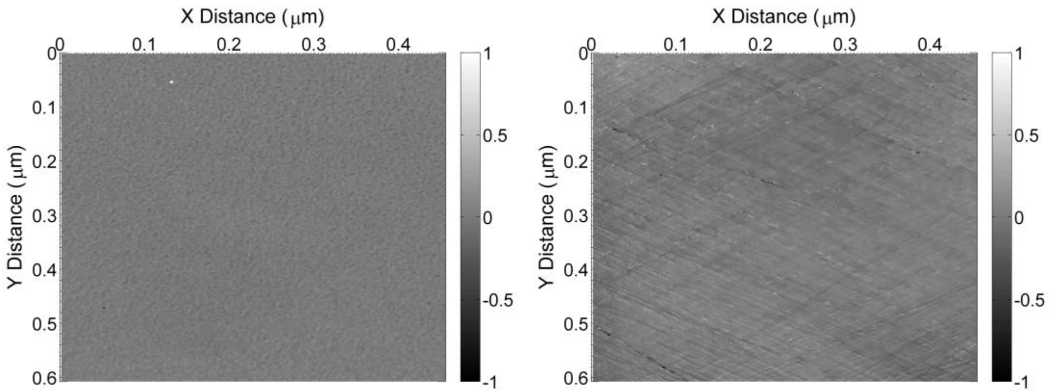
Start exploring role of target reflectance and dependence on surface roughness - BRDF

- Disruptions to the surface reflectance properties and geometrical relationship to collection optics directly influences data quality. One of the outstanding experimental challenges due to non-planar targets and highly heterogeneous EM.

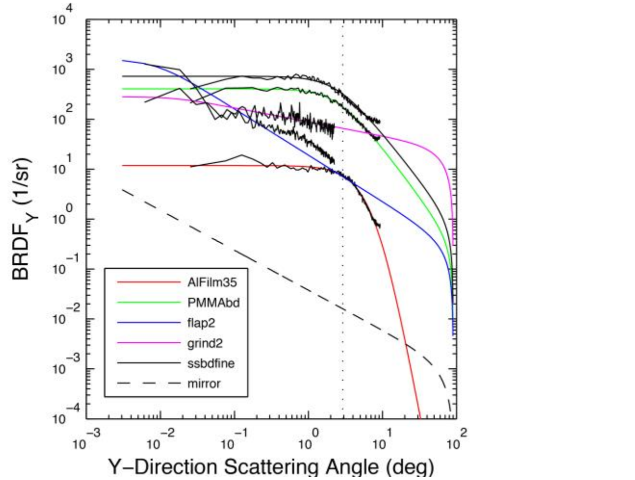
- Bidirectional Reflectance Distribution Function explored as a quantitative means to predict light collection from surface. Cooper, M. (2014) Applied Optics **53**(24), F21-F30.



Evidence that surface preparation impacts fringe quality



Surface roughness measured with WYKO optical profilometer.
(Left) 35 μm-thick aluminum plating on fused silica window.
(Right) Flat lapped aluminum plate to 2 μm



Diffuse and Patterned Surfaces with Associated Bidirectional Reflectance Distribution Function (BRDF)

ORVIS suited for mission-related R&D covering range of event velocities, time durations, and length scales

Established capabilities in:

- low and high velocity events
- systematic studies of powder bed response to impact
- quantification of statistical distributions of response
- collecting data in non-traditional materials and geometries

Plenty of opportunities for more diagnostic advancements and enhanced application:

- Optimizing trade-offs of velocity, temporal, and spatial resolution to tailor diagnostic to a particular application.
- Efficient image analysis methods with modernized uncertainty analysis.
- Reduce overhead required to field ORVIS diagnostic – opportunities exist for near standardized operation in specific applications while maintaining novel state-of-the-art advancements to complex materials and new applications.

After 25 years, why are the number of ORVIS researchers still small?

ORVIS-Related Publications

- Specht, P.E. and M.A. Cooper (2014). Development of a Spatially-Resolved Microwave Interferometer. Submitted to: *Gordon Research Conference on Energetic Materials*. June 15-20. Newry, ME.
- Trott, W.M., J.N. Castaneda, and M.A. Cooper (2014). ADL ORVIS: An Air-Delay-Leg, Line-Imaging Optically Recording Velocity Interferometer System. *Review of Scientific Instruments*, In review.
- Cooper, M.A., P.E. Specht, and W.M. Trott (2014). Measuring Three-Dimensional Deformation with Surface-Imaging ORVIS. *AIP Conference Proceedings*, In print.
- Cooper, M.A. (2013). The Design, Development and Applications of ORVIS at SNL Explosive Components Facility. Invited presentation at the *AFRL High Explosives Research Directorate Seminar Series*. May 22, Eglin AFB, FL.
- Cooper, M.A., W.M. Trott, R.G. Schmitt, M. Short, and S.I. Jackson (2012). ANFO Response To Low-Stress Planar Impacts. Ed. by M.L. Elert, W.T. Buttler, J.P. Borg, J.L. Jordan, and T.J. Vogler. AIP Conference Proceedings 1426(1), 595-598.
- Cooper, M.A. and W.M. Trott (2012). On the Development of an Impact-Loaded Wedge Test Using ORVIS. Ed. by M.L. Elert, W.T. Buttler, J.P. Borg, J.L. Jordan, and T.J. Vogler. AIP Conference Proceedings 1426(1), 430-433.
- Cooper, M.A. (2012). Optically Recording Velocity Interferometer System (ORVIS): Application to Shocked Energetic Materials. In: *Gordon Research Conference on Energetic Materials*. June 17-22. West Dover, VT.
- Bouyer, V., Ph. Hebert, A. Sollier, B. Crouzet, D. Dattelbaum, S. Sheffield, R. Gustavsen, M. Cooper and W. Trott (2012). Shock Initiation and Detonation of High Explosives. *CEA-DAM-DOE-NNSA FOCUS Magazine*, No. 3, June.
- Trott, W.M., M.R. Baer, J.N. Castaneda, L.C. Chhabildas, and J.R. Asay (2007). Investigation of the Mesoscopic Scale Response of Low-Density Pressings of Granular Sugar under Impact. *Journal of Applied Physics*, 101, 024917-1-21.
- Trott, W.M., J.N. Castaneda, J.J. O'Hare, M.R. Baer, L.C. Chhabildas, M.D. Knudson, J.-P. Davis, and J.R. Asay (2000). Dispersive Velocity Measurements in Heterogeneous Materials, Sandia National Laboratories, SAND2000-3082.
- Bloomquist, D.D. and S.A. Sheffield (1983). Optically Recording Interferometer for Velocity Measurements with Subnanosecond Resolution. *Journal of Applied Physics*, 54, 1717-1722.
- Bloomquist, D.D. and S.A. Sheffield (1982). ORVIS, Optically Recording Velocity Interferometer System, Theory of Operation and Data Reduction Techniques. Sandia National Laboratories, SAND1982-2918