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Development of a portable line VISAR system
for measurement of non-uniform dynamic material behaviour

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Spatial Velocimetry Workshop
Institute of Physics, 9 Sept 2013

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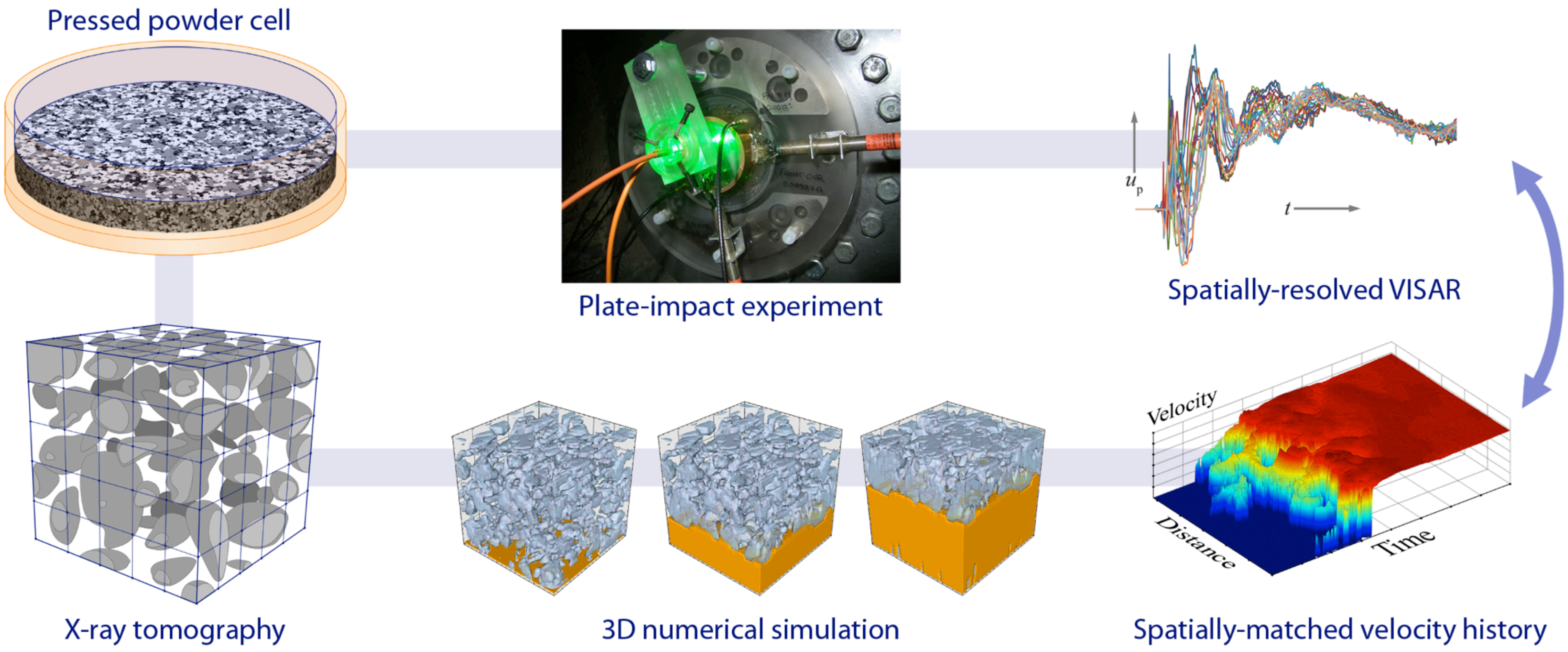
Why are we here?



The next generation of multiscale materials models require information about the distribution of states. In some cases to better define error, in others to directly assign these variances to specific mechanisms.

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How do we usually measure behaviour?

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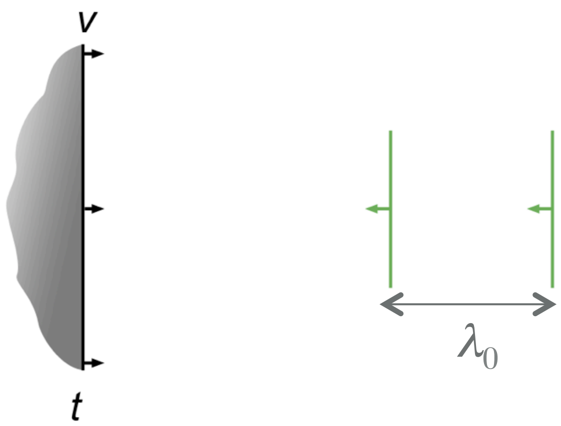
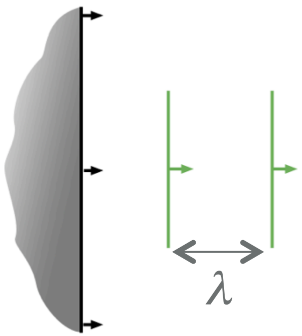
How do we usually measure behaviour?

We use light – convenient, non-invasive, and fast

Consider the motion of a target surface





- Moving surface acts as both the receiver and source

  probe light is double doppler shifted

$$\frac{\Delta\lambda}{\lambda_0} \approx -\frac{2v}{c}$$

- Example: 1000 m/s, 532 nm is shifted by 0.004 nm.
- Frequency is 564 THz, or one cycle per 1.8 fs

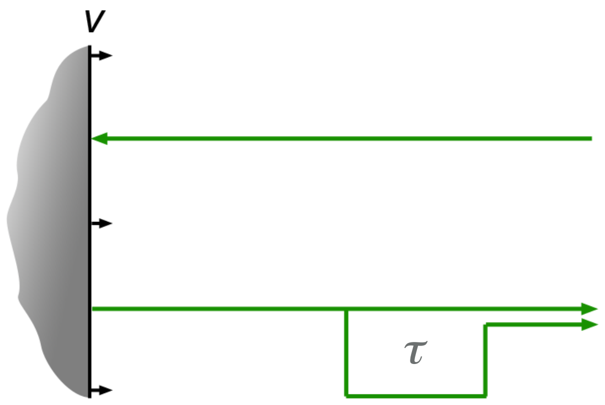
Very complicated to measure directly.

Interference can be helpful

Mix our signal with an appropriate reference to detect intensity changes in the cosine envelope:

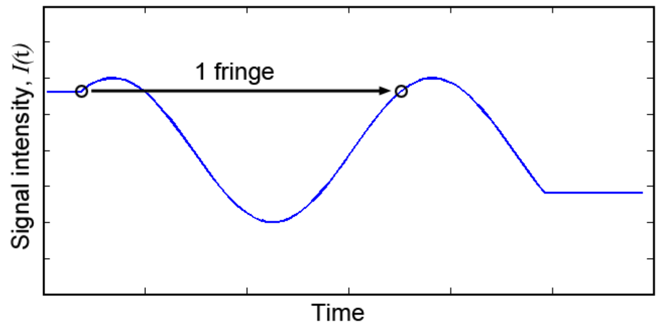
$$I(t) = I_1 + I_2 + 2\sqrt{(I_1 I_2)}\cos\left(\phi_1(t) - \phi_2(t)\right)$$

VISAR uses a time-delayed version of the doppler-shifted signal



Self-referencing, signal intensity

- remains steady at constant velocity
- changes during accelerations

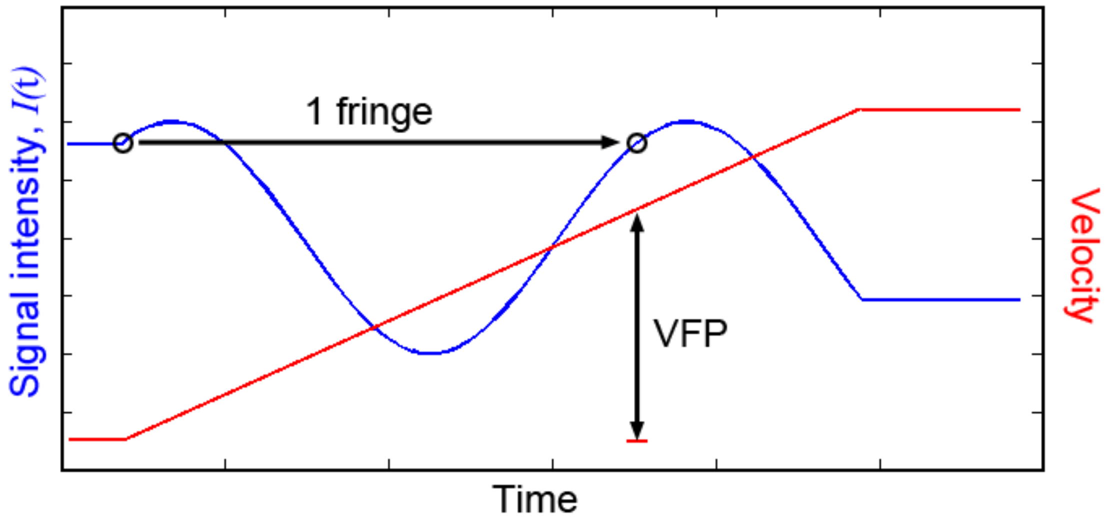


How do we recover velocity?

Approximation:
Total fringe shift related to change in velocity through the *velocity per fringe constant*:

$$\mathrm{VPF} = \frac{\lambda_0}{2\tau}$$

$$v = F\left(\frac{\lambda_0}{2\tau}\right)$$



VPF inversely proportional to τ

- Longer τ → higher velocity sensitivity
- Approximation breaks down near τ

$$v(t-\tau/2) = \frac{\lambda_0}{2\tau\underbrace{(1+\Delta v/v_0)}_{\text{window}}\underbrace{(1+\delta)}_{\text{dispersion}}}F(t)$$

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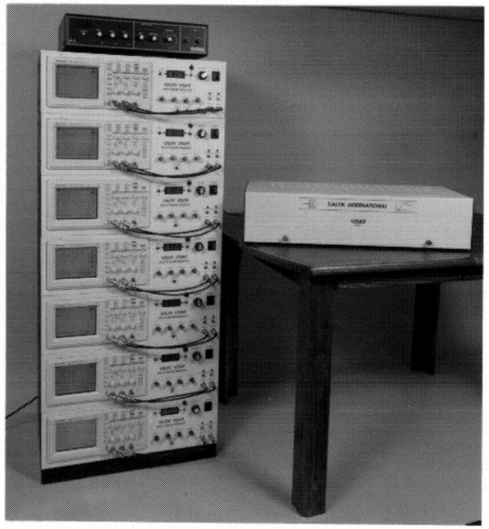
Some limitations of point velocimetry

- Integrates heterogeneous response in area of collection → VISAR has difficulty dealing with multiple velocities, interference gets complicated.
- Spatial response usually from multiple probes, practical limit to number of distinct measurement points. Cost scales. How closely should probes be spaced?



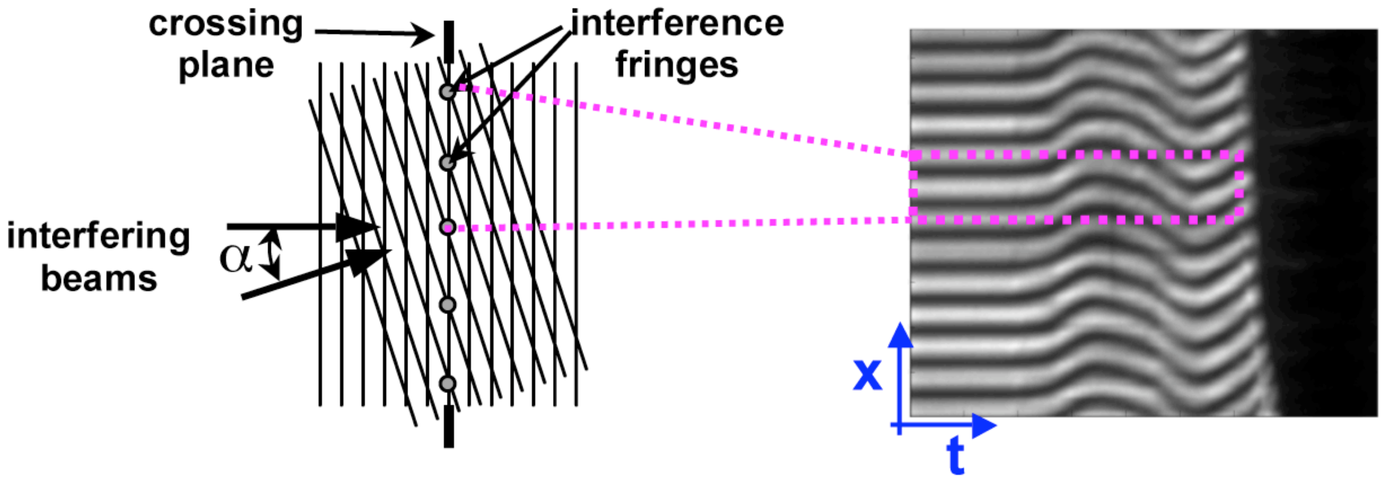
T. Somerlinck (CEA), PDV workshop 2012

How then to study heterogeneous behaviour?

Imaging is the key

- Relay the target image through the interferometer to maintain spatial registry between target, diag. arms, and recording instrument.
- Produce a carrier phase modulation in space (fringe comb):

  Eliminates direction ambiguity, coarse spatial resolution



Acceleration of the target results in an apparent vertical shift in the fringe comb, directly proportional to the velocity (VPF).

[1], [29]

Method of analysis, Line VISAR

Extract $\Delta\phi(t)$ from the fringe comb, apply VPF

Coarsening methods

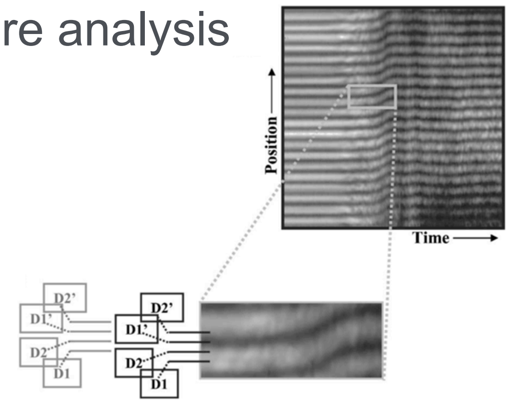
- Global analysis
- Thinning

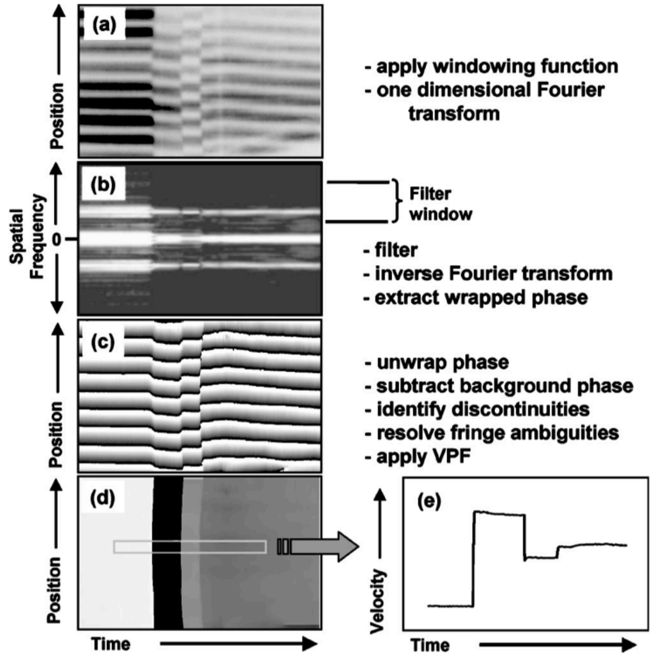
FFT + Phase unwrapping

$$S(x,t) = B(x,t) + A(x,t)\cos\left[\phi(x,t) + 2\pi f_0 x + \delta_0\right]$$

Pseudo-quadrature analysis

Wavelet analysis





[2], [17], [24]

A brief history in (1-D space x) time

1983 **Bloomquist and Sheffield**

ORVIS developed

1990 **Hemsing et al.**

Fibre-relay, push-pull line VISAR

1996 **Baumung et al.**

Fast collection optics, low power req.

1998 **Trott et al.**

Line-imaging mode, improved spatial res.

2005 **Robinson**

Optically-relayed push pull line VISAR

2007 **Ao et al.**

ORVIS comes to Veloce

1990- 1991 **Warnes, Mathews et al.**

Fabry-Pérot (area, line)

1998 **Celliers et al.**

Mach-Zehnder (MZ) design

2004 **Malone et al., Celliers et al.**

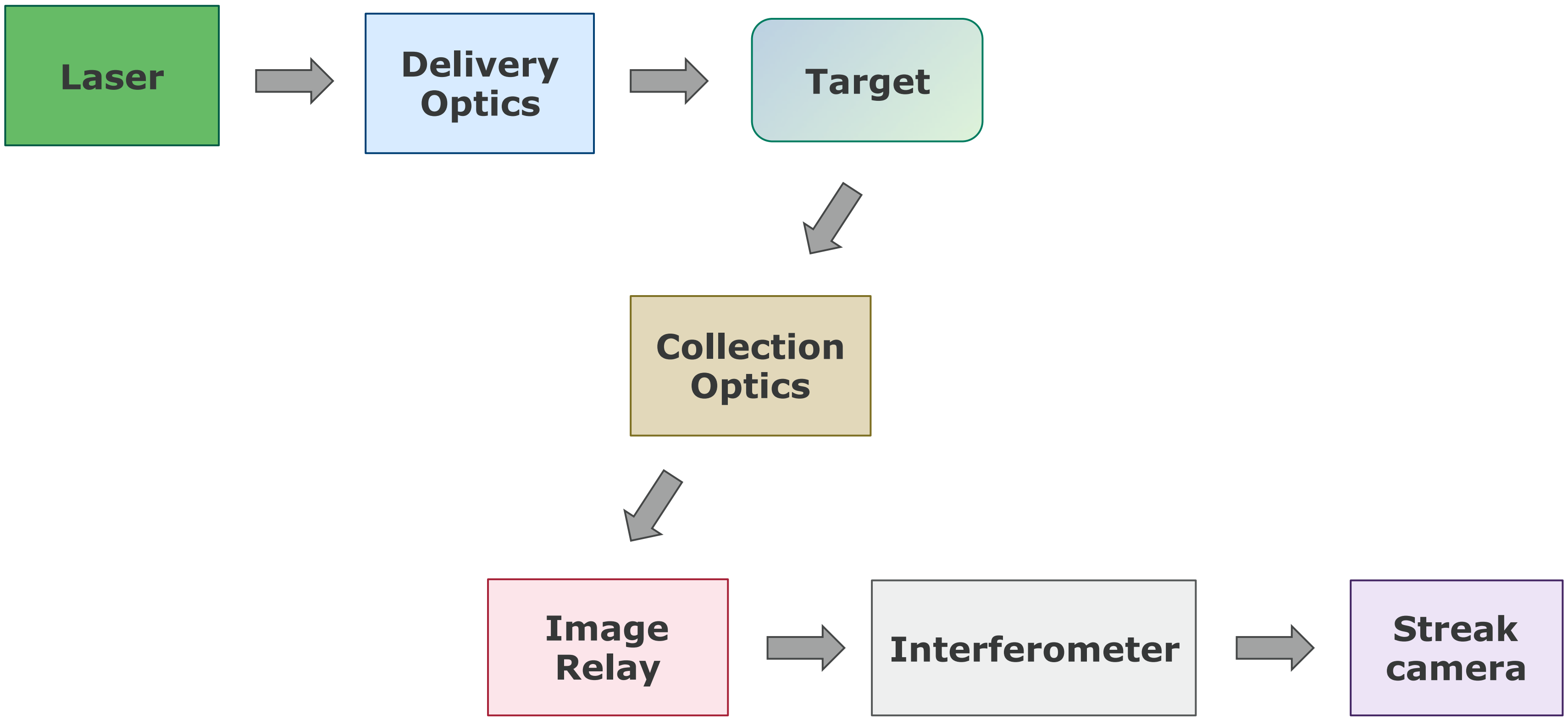
MZ comes to NIF and Omega

2013 **Bolme and Ramos**

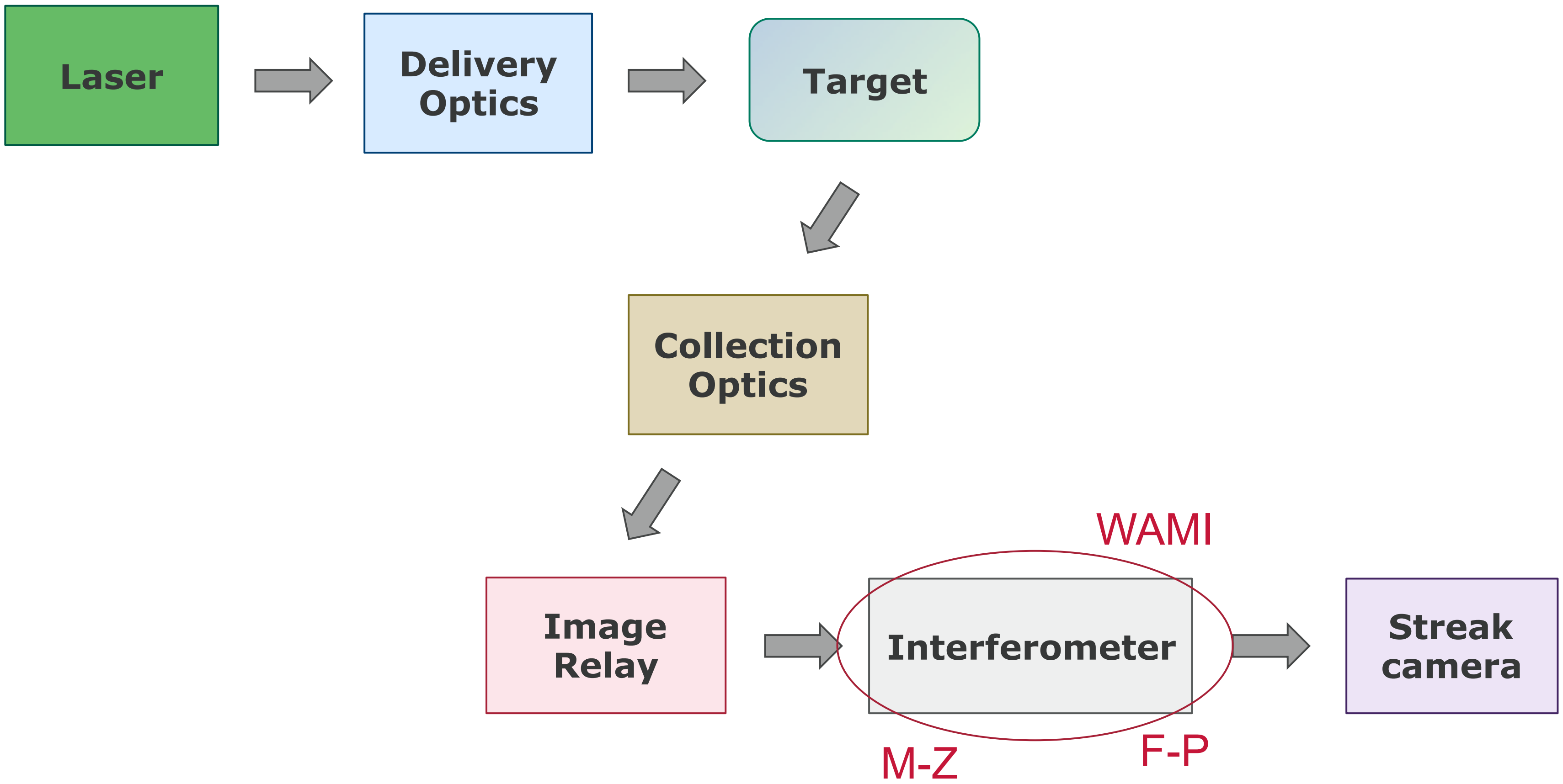
MZ used on gas gun

[1], [4-9], [15-17], [20], [25], [33]

Components of a line-imaging VISAR



Components of a line-imaging VISAR



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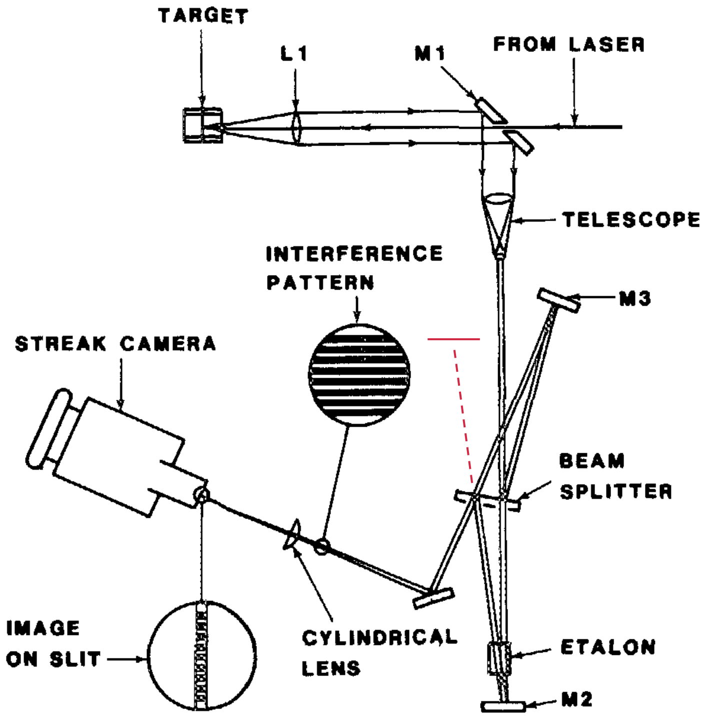
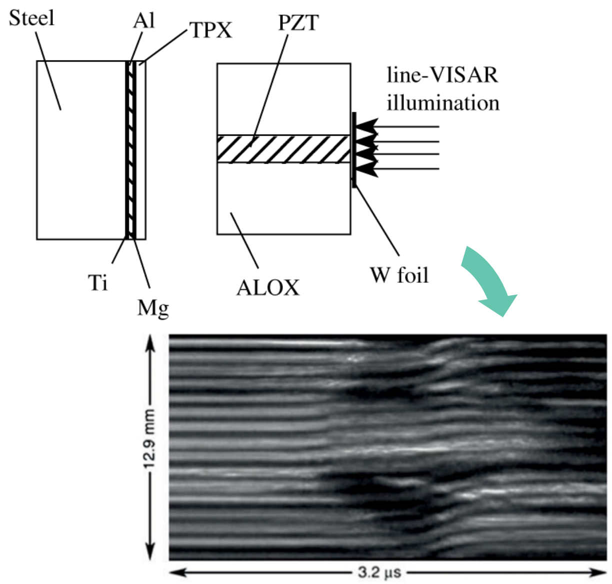
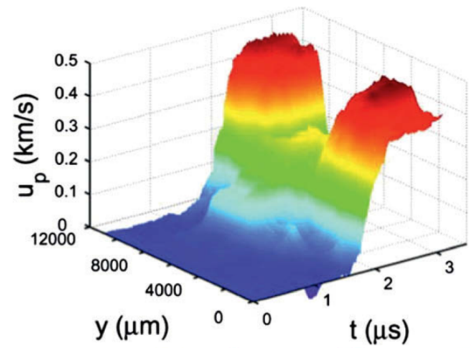
The Wide-Angle Michelson Interferometer (WAMI)

- Original line velocimeter, ORVIS
- Single beamsplitter







Predominant approach for gun-based studies

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[1], [9], [20], [26]

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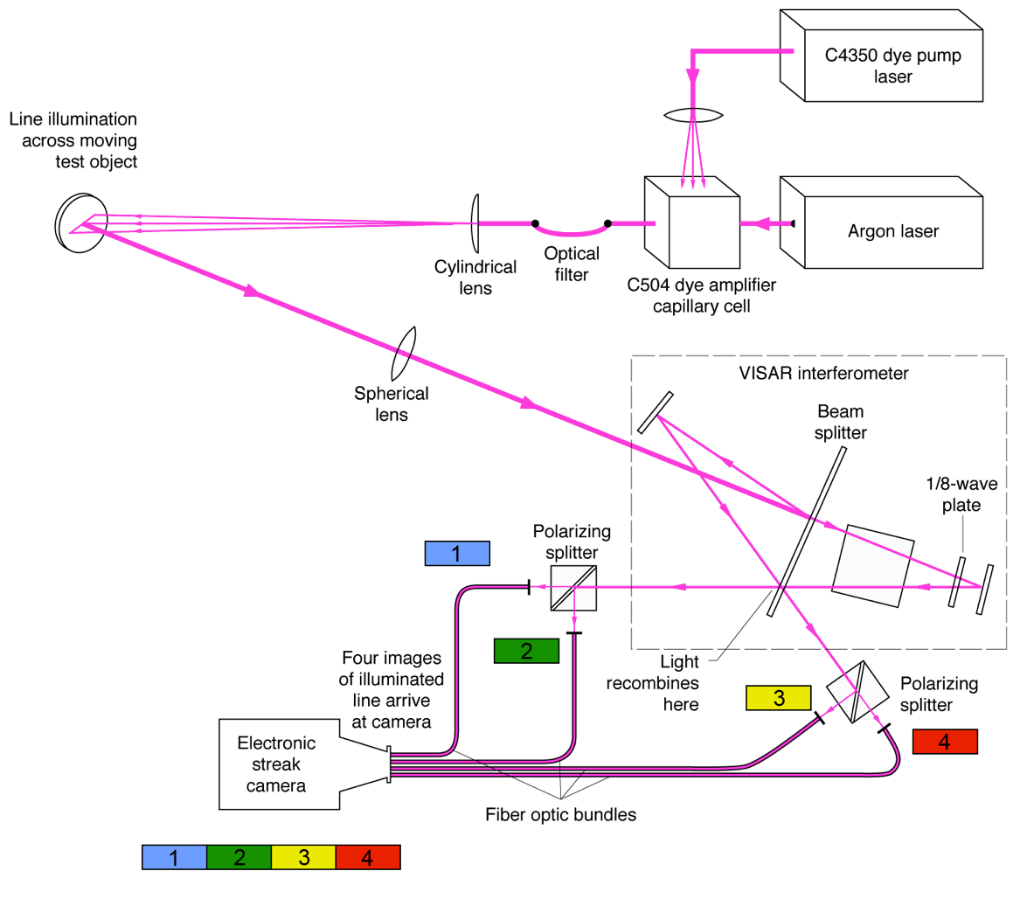
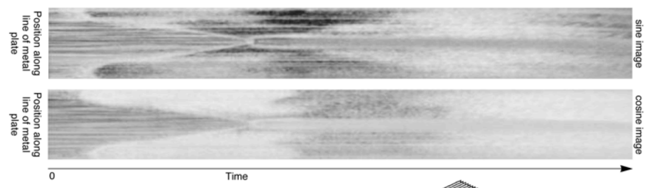
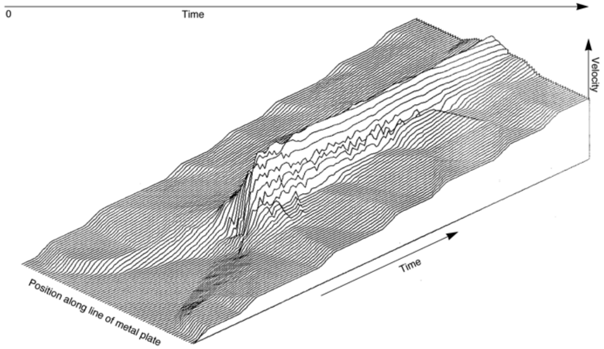
Fibre-relay systems (Hemsing et al.)



- Target illuminated by line focus
- Spherical lens images target through WAMI
- PBS at both outputs quadrature images of target
- Relayed by 4 fibre bundles, combined at camera slit.





[4], [6]

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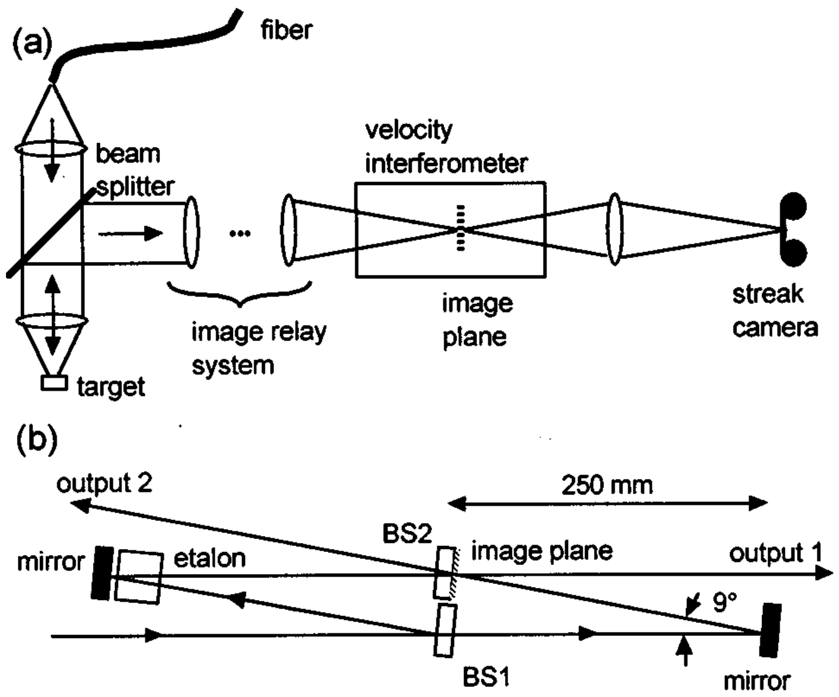
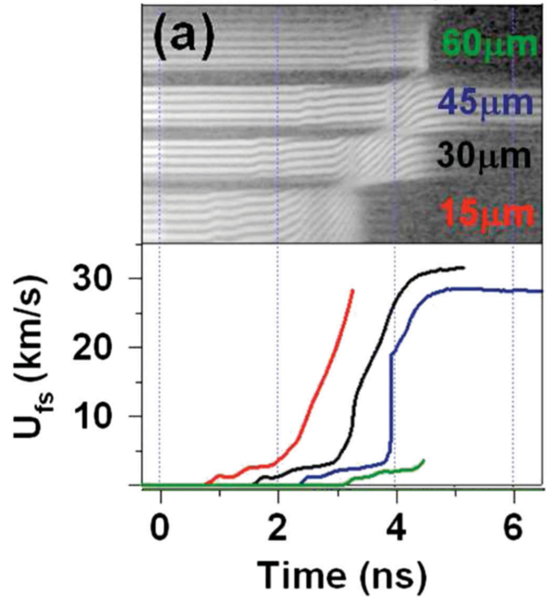
The Mach-Zehnder Design

- Introduced by P. Celliers in 1998
- Split beamsplitters separate fringe contrast and alignment



Stepped C target



Implemented at JLF, NIF, Omega

[8], [17], [34]

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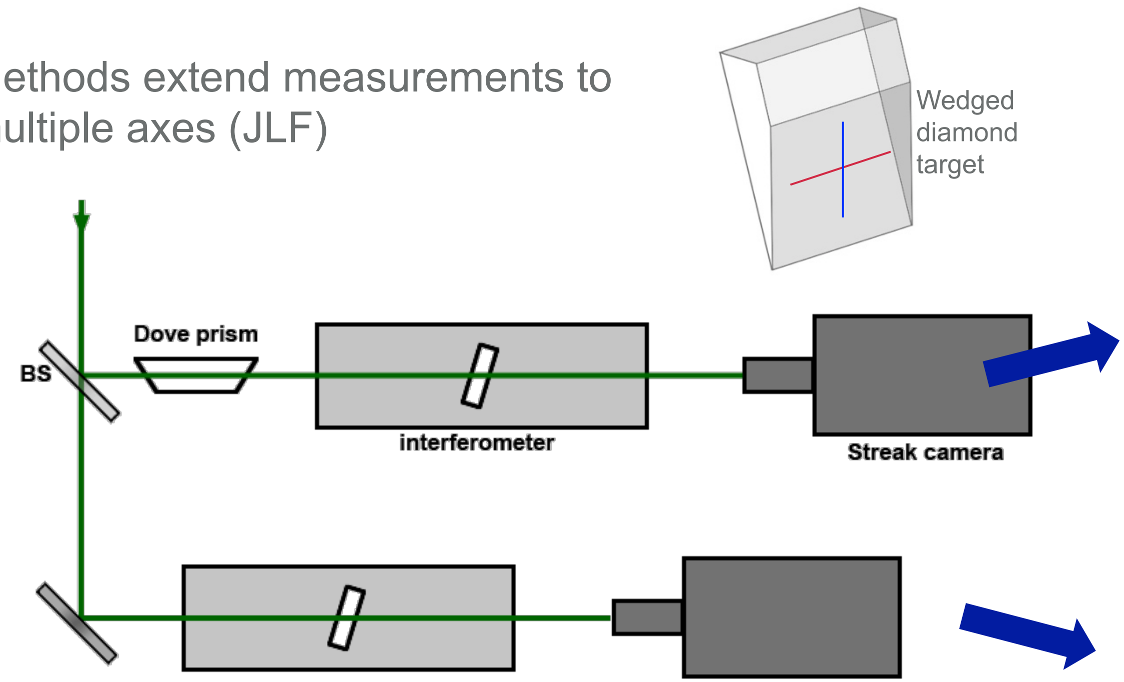
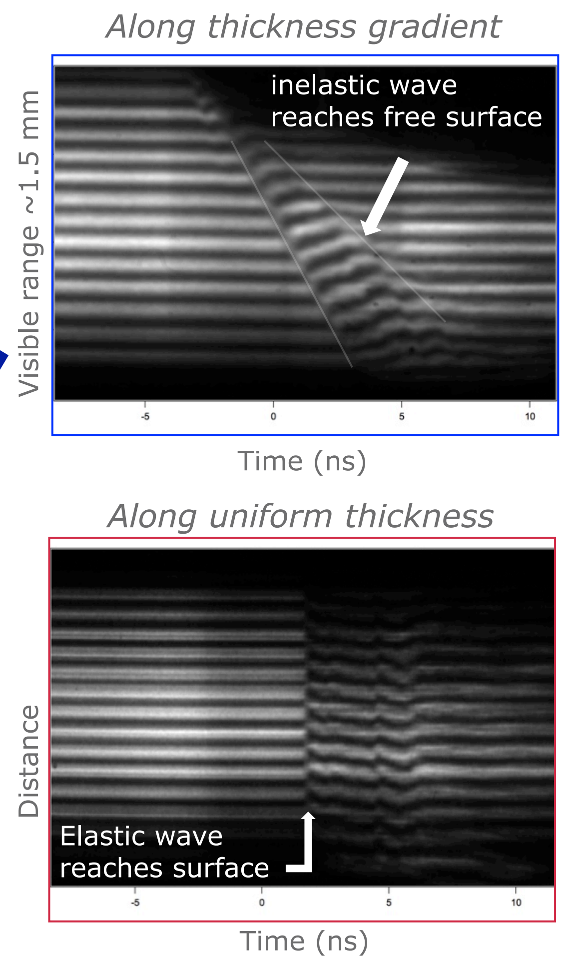
Multiaxis (1.5 D) systems

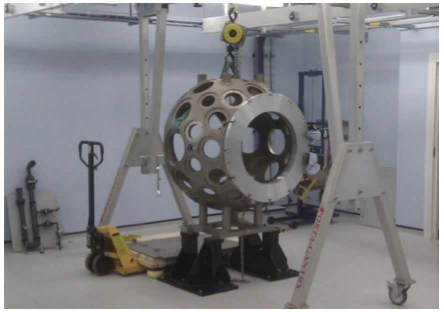
Methods extend measurements to multiple axes (JLF)





- Uniform areal illumination of target
- Dove prism inserted before one of two interferometers:
  - Rotates image 90 degrees
  - SC slits sample orthogonal directions

Need for a portable system



Ongoing experiments at multiple locations/environments

- L54 to gun lab
- L54 to H147
- Diamond
- ESRF

These target areas have many users, permanent installations are impractical

Local lasers available

Multiple streak cameras, 8 mm – 35 mm photocathode

Robust, portable, flexible line-imaging VISAR system

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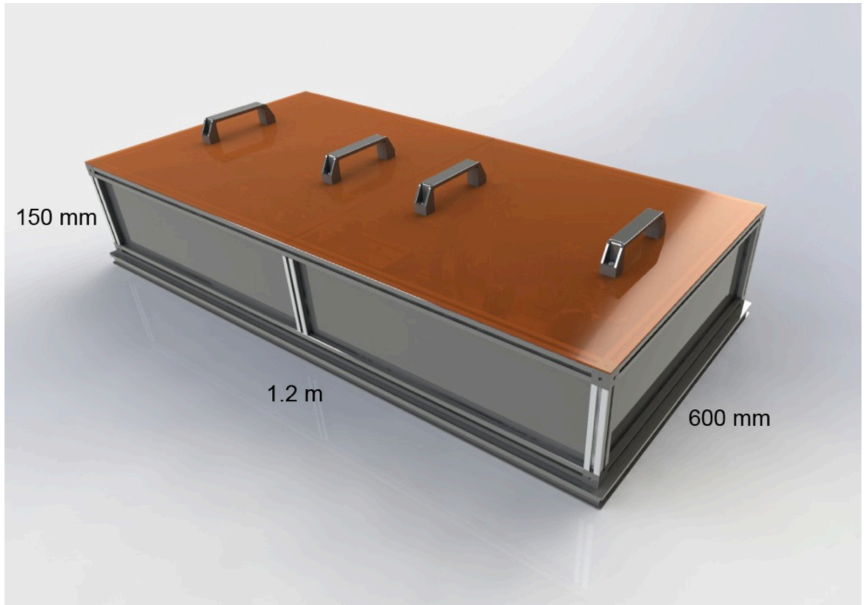
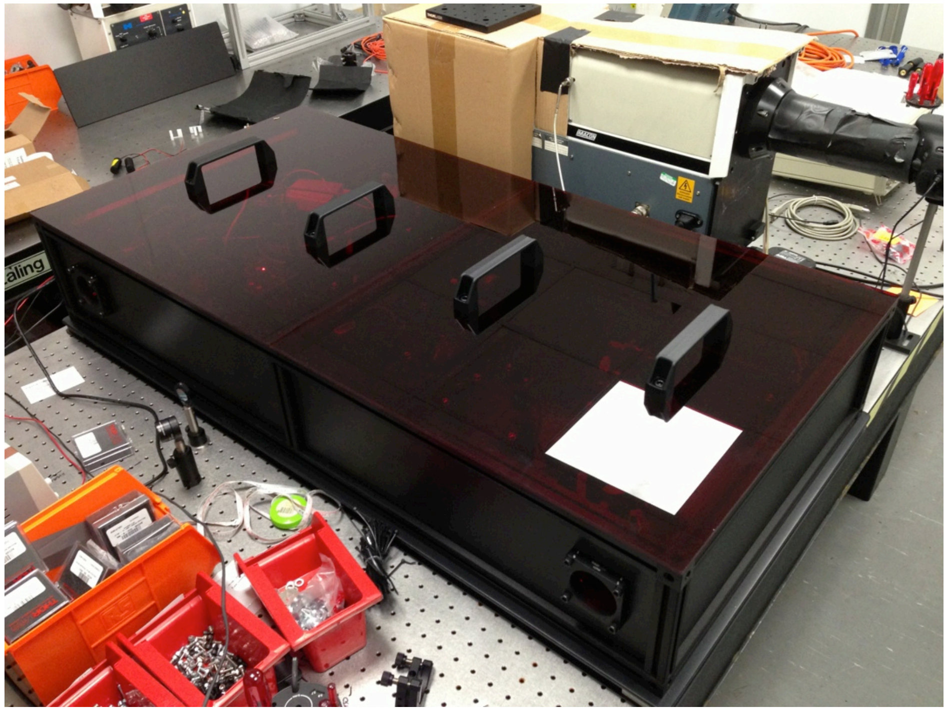
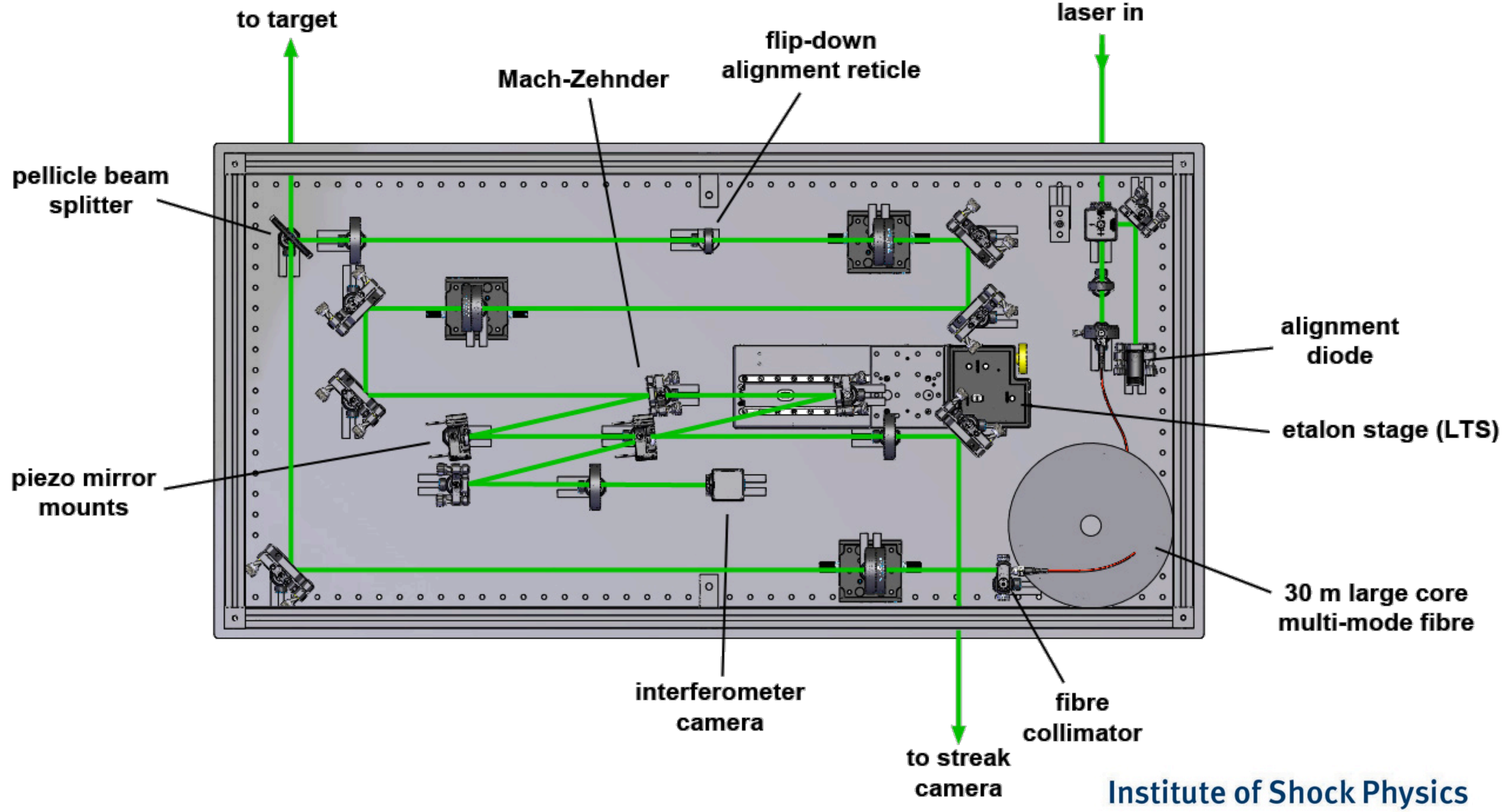
Design Overview





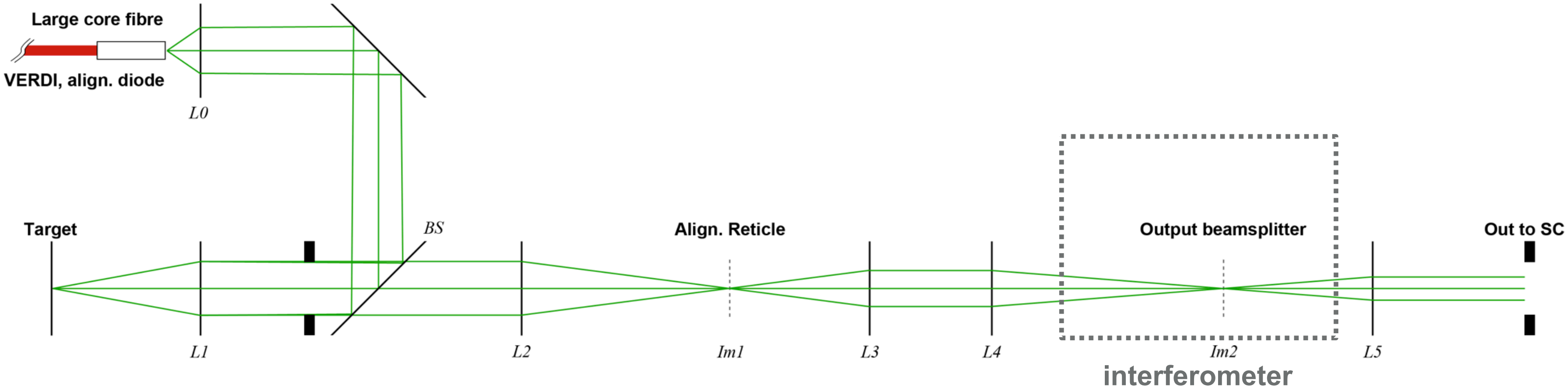
- 1.2 m wide, standard optical table width
- 28 kg total mass
- Laser absorptive covers

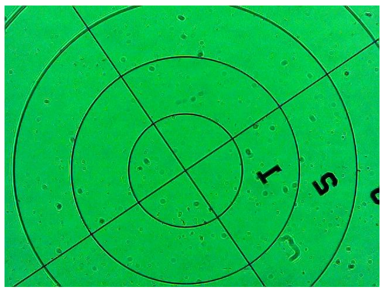
Under the hood



Ray diagram

- Near collimation to and from target
  Flexible placement in exp. hutch
- Internal magnification x4-10, *L3*





- External collection optics
  Easily change magnification, *L1*
- Near collimation to streak camera

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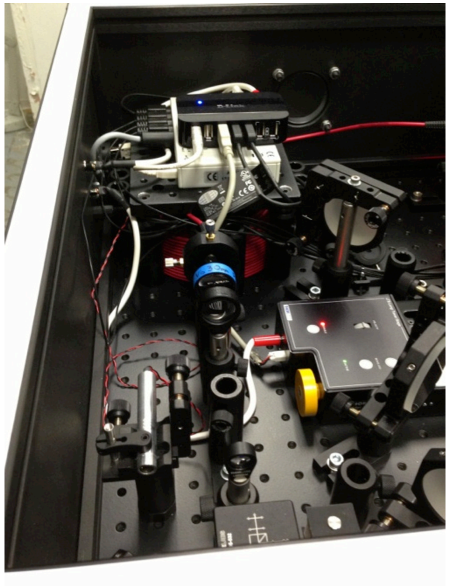
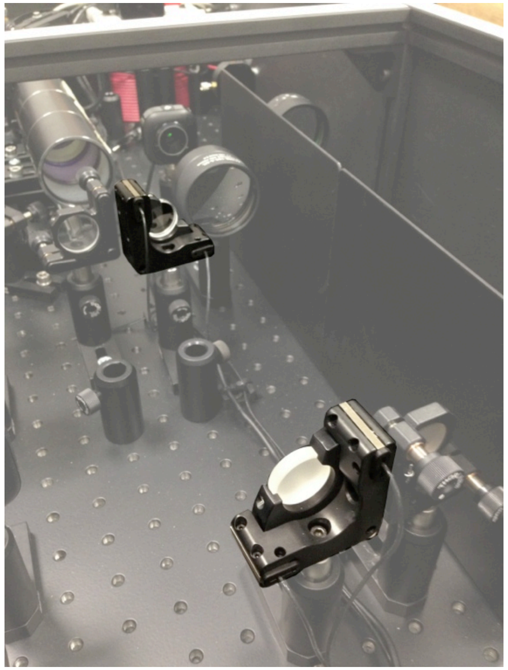
Remote control

External ports

- USB-hub (LTS, Cameras, Agilis hub)
- Agilis final optic translation mount
- Power input, LTS and USB-hub





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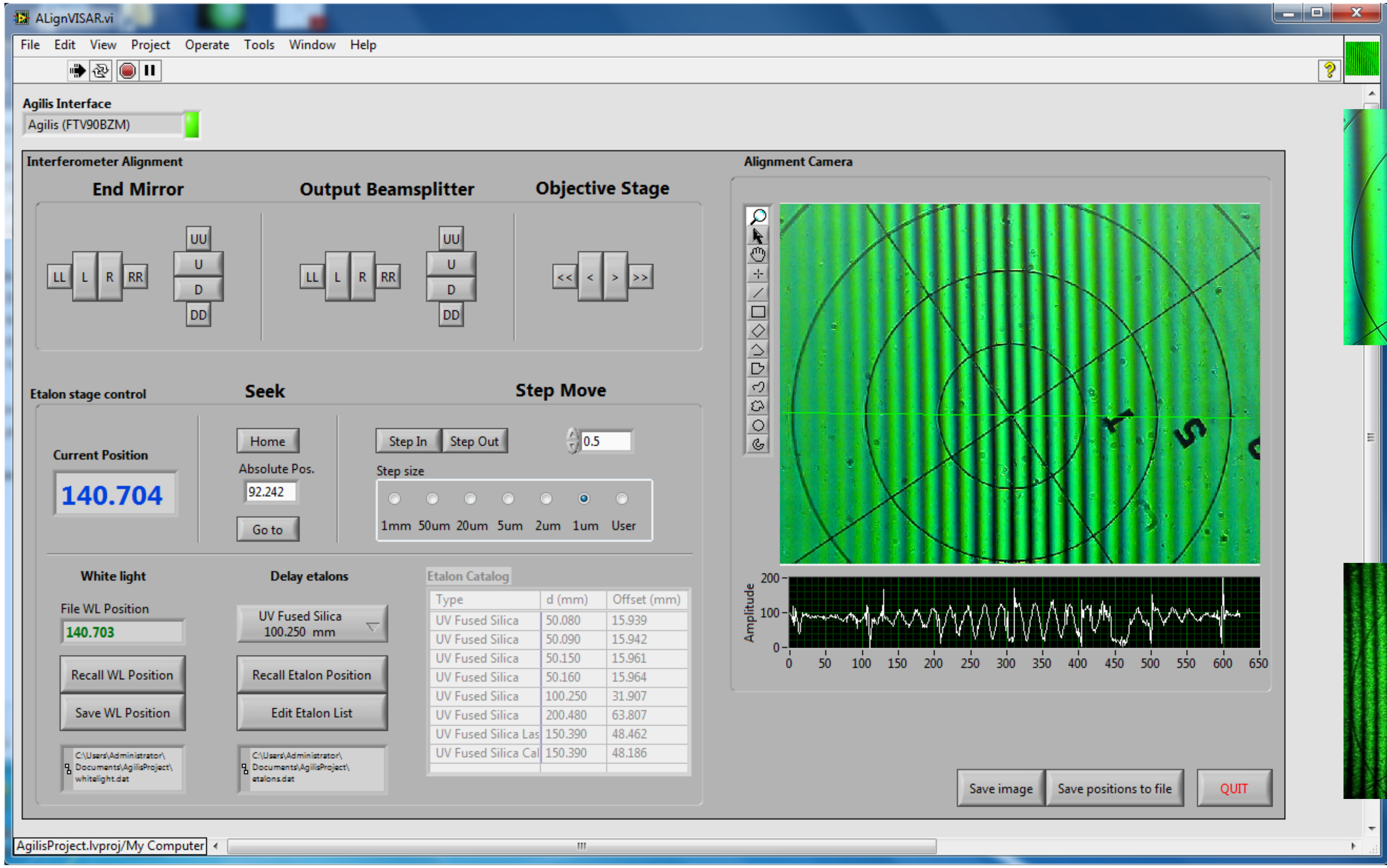
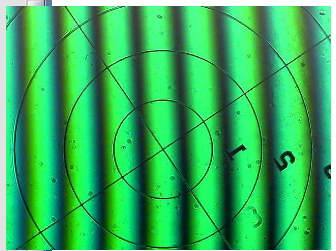
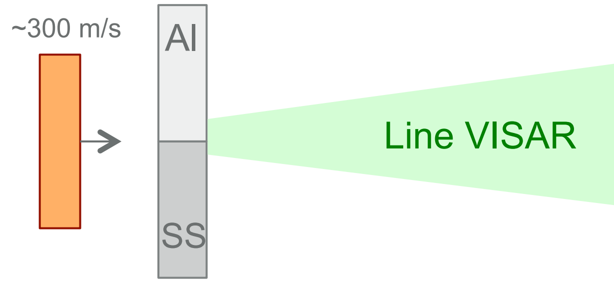
LabVIEW control system - ALignVISAR

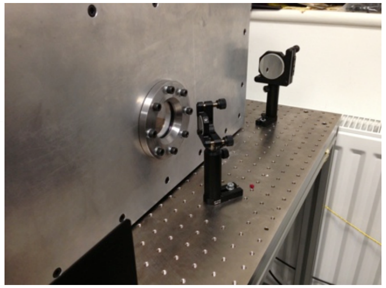


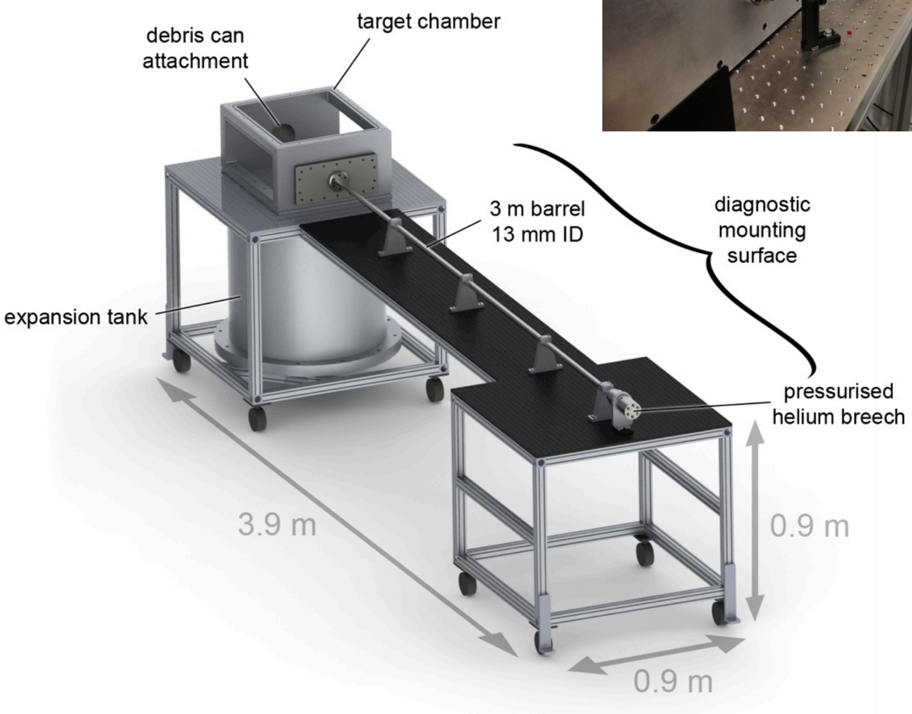


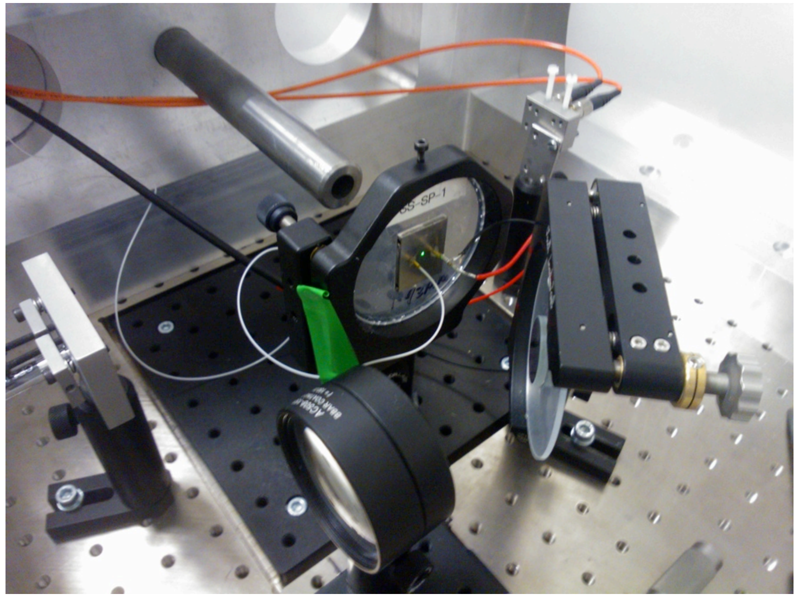
First experiments – Al/SS Interface

Probing breakout at multi-component interfaces









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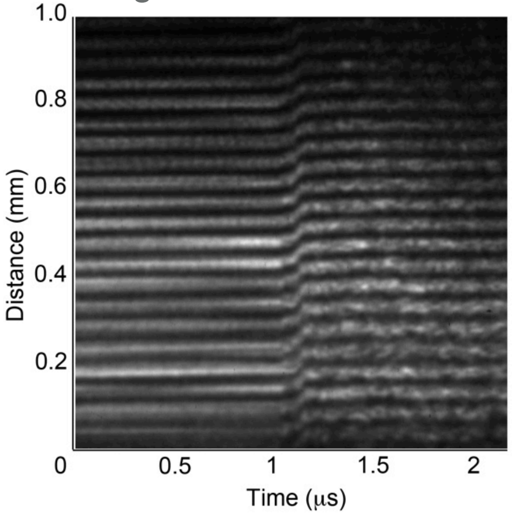
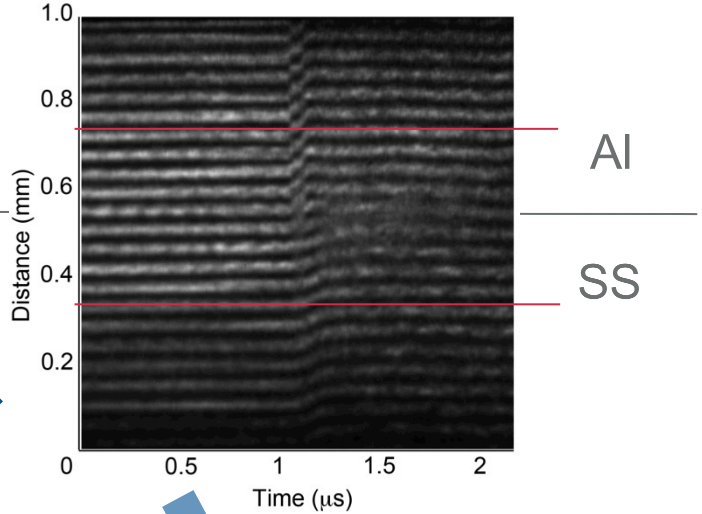
First experiments – Al 7068 / 316 SS Interface

Single material – 316 SS



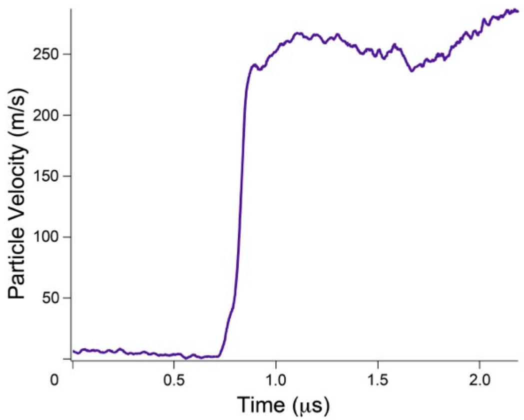
Multi-material – Al 7068 / 316 SS

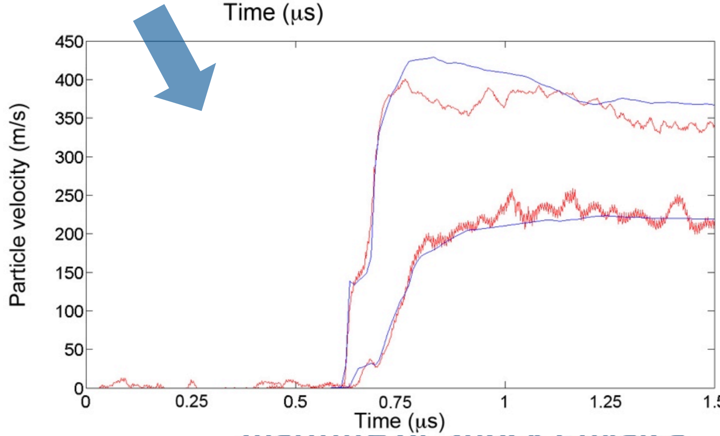


← v = 325 m/s

VPF = 330 m/s/F

v = 293.7 m/s →





Future Directions

Cheap objective lenses result in poor imaging

- Aplanatic doublet + meniscus lens pair at f/3.3

Self compensating lenses to minimize wavefront error

Implement routine alignment aids

- Inspection telescope
- Beamsplitter reticles

Complete remote capability

- Flip-down reticle and interferometer beam block

Engineering controls

- Ext. interlock, beam shutters

Continue study of material interfaces, examining role of angle, component strength.

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Summary

- Line-imaging VISAR, demonstrated technique for measuring spatial variations in dynamic material response.
- Design evolved over past few decades, but seen limited take-up outside US National Laboratories.
- We have constructed a portable line imaging VISAR for integration into multiple on- and off-site experiments.
- Initial studies conducted on metal friction pairs – revealed spatial variation in velocity in accordance to acoustic properties, release wavelets originating at boundary.

- Will feature in future experiments at the Diamond and ESRF.

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