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Line Imaging VISAR / ORVIS from the Sandia DMP perspective

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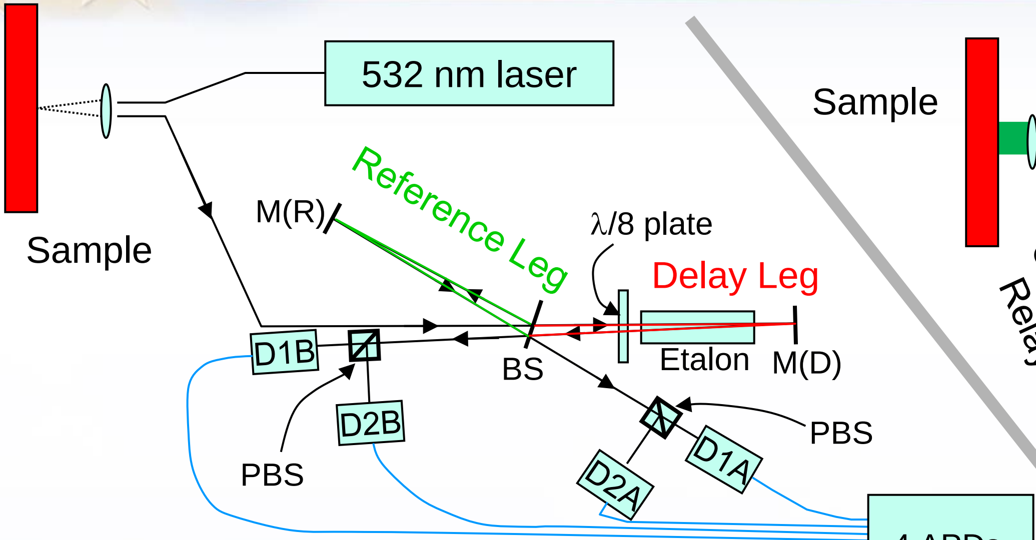
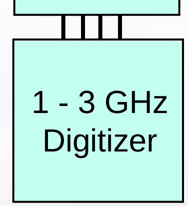
NSTec Special Technologies Laboratory

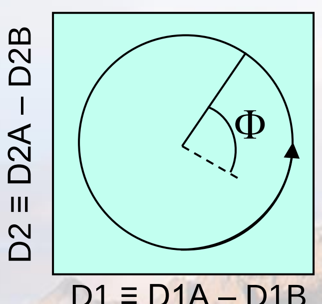
Line imaging ORVIS is an illuminated line imaged through a VISAR and recorded optically





VISAR beats Doppler-shifted light against same light slightly delayed

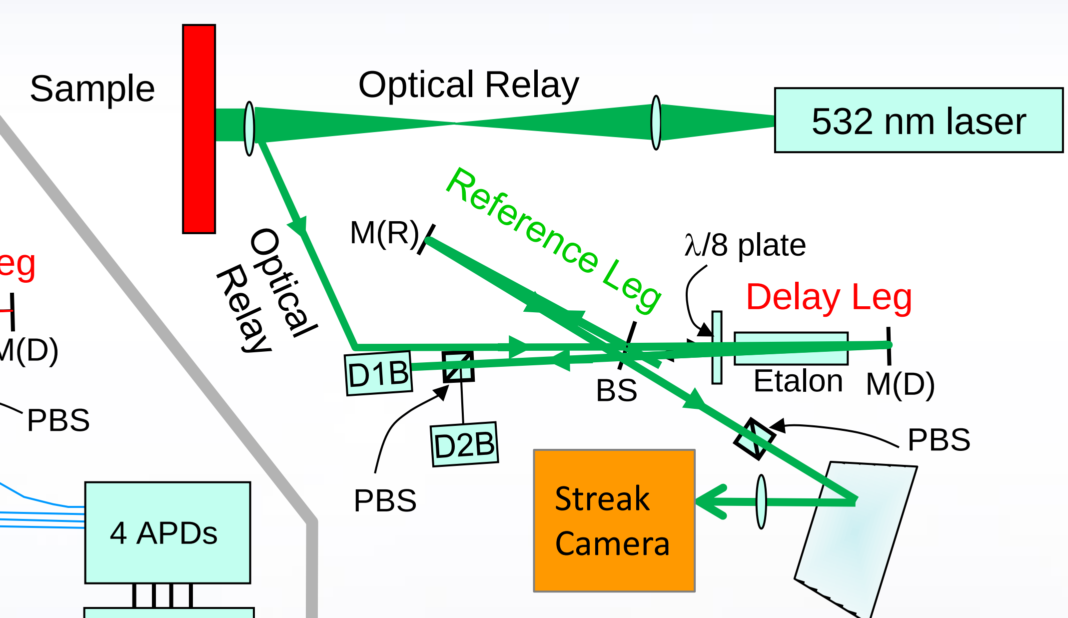
➔ Beat frequency ∝ sample acceleration

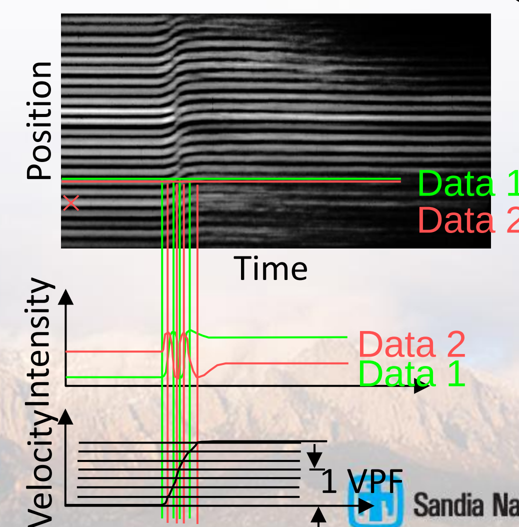


Radius ~ contrast

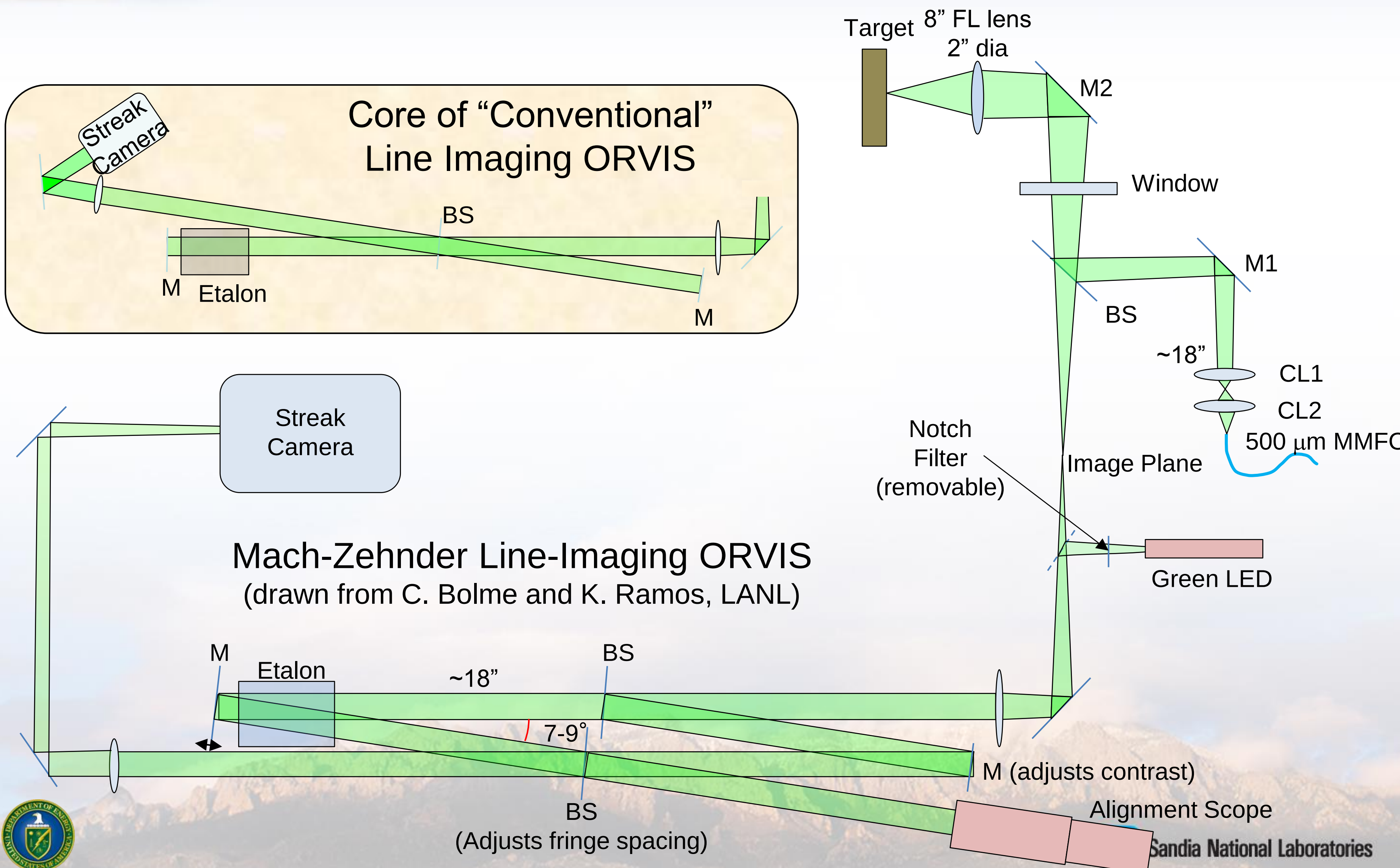
$\Phi(t) = (4\pi\tau_0/\lambda_0) * \text{velocity}$

(or 1 VPF = $\lambda_0 / 2\tau_0$)





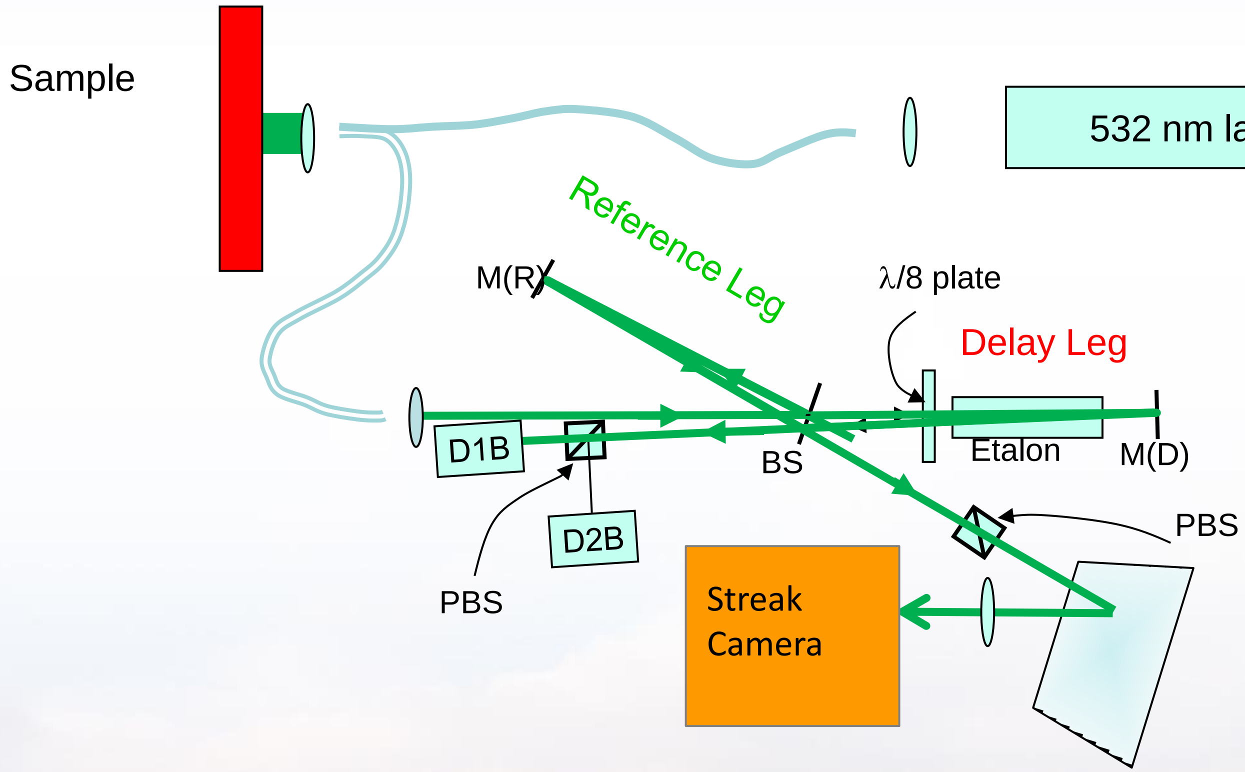
A Mach-Zehnder Line Imaging ORVIS is an alternative configuration



Consider two types of “line imaging VISAR / ORVIS”

- **True imaging VISAR uses an optical relay to return the image of the line on the target, then records via a streak camera (useful for materials data as well as high-precision time measurement)**
  - Requires optical relay access to sample (➔ window)
  - Common timebase for recording motion of all spots on line is “automatic”; time resolution depends on streak camera limits.
  - Spatial resolution depends on data reduction method used and whether it’s recorded in quadrature.
- **Multipoint VISAR uses an array of fiber optics to return the signal to a single VISAR; the image of this array is focused on the output fiber rosettes, and recording is done using either a streak camera or optical/electrical converters and digitizers.**
  - Can work with fiber optic coupling
  - Timebase must be carefully calibrated (e.g. common optical timemark) for optimal time interval measurements
  - Spatial resolution defined by spot array ↔ probe geometry, and limited by number of spots (19? 40?).

It may be useful to substitute an image-preserving fiber bundle for the relay



- This allows access to targets inside chambers without optical ports.
- Resolution is now defined by imaging of fiber bundle (60 fibers?)
- Recording proceeds as with conventional line-imaging ORVIS (single-ϕ or quadrature)

The light delivery for either system may use fiber or open beam.

Outbound signal

- Open beam is "traditional" for line-imaging VISAR because it avoids fiber speckle problems.
- Safety engineering required for open beam is more difficult than for fiber coupling. It may not be possible for containment systems (Z SNM, NTS LBPG, etc.)
- NIF Mach-Zender line imaging VISAR doesn't use free beam; the laser is injected into 3 1 mm 0.12 NA fibers in a close-packed arrangement, looped to mix modes and reduce speckle size.
- Power losses with fiber coupling may be significant; NIF system uses 60 kW 0.5 – 1.2 μs pulse.

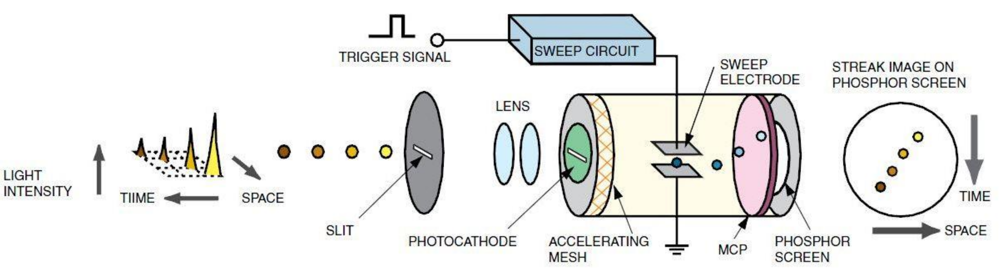
Returned signal

- For imaging system, typically a free-beam optical relay is required
- Fiber coupling for the multibeam VISAR is required
- Fibers may introduce modal dispersion (largely eliminated at Z with dispersion-corrected graded-index fibers) and very slight length discrepancies (100 ps ~ 1 inch).

Recording may be done by digitizers or streak cameras

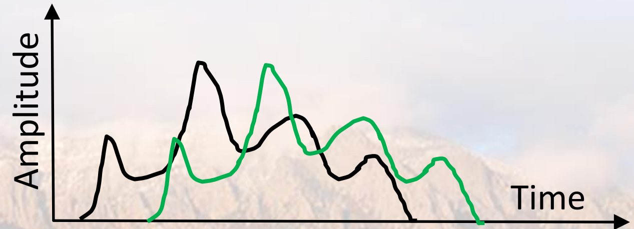
Streak cameras (the only option for imaging line ORVIS):

- **BN camera (LOE-200) at Z has board with 30 – 480 ns sweep; with 4K x 4K CCD, 1 pixel in time coordinate = 7.5 – 120 ps; longer sweep also available.**
- **Similar Hamamatsu camera (C7700) at 500 ns sweep time claims time resolution of "better than 5 ps" (unsure of CCD assumed). This may correspond to the input slit limit.**
- **We have several streaks available with the [long overdue] repair of 2 Hadland streak cameras with similar specifications.**
- **Can also be used for multipoint VISAR recording (NSTec has designed couplings into camera and software for data reduction).**

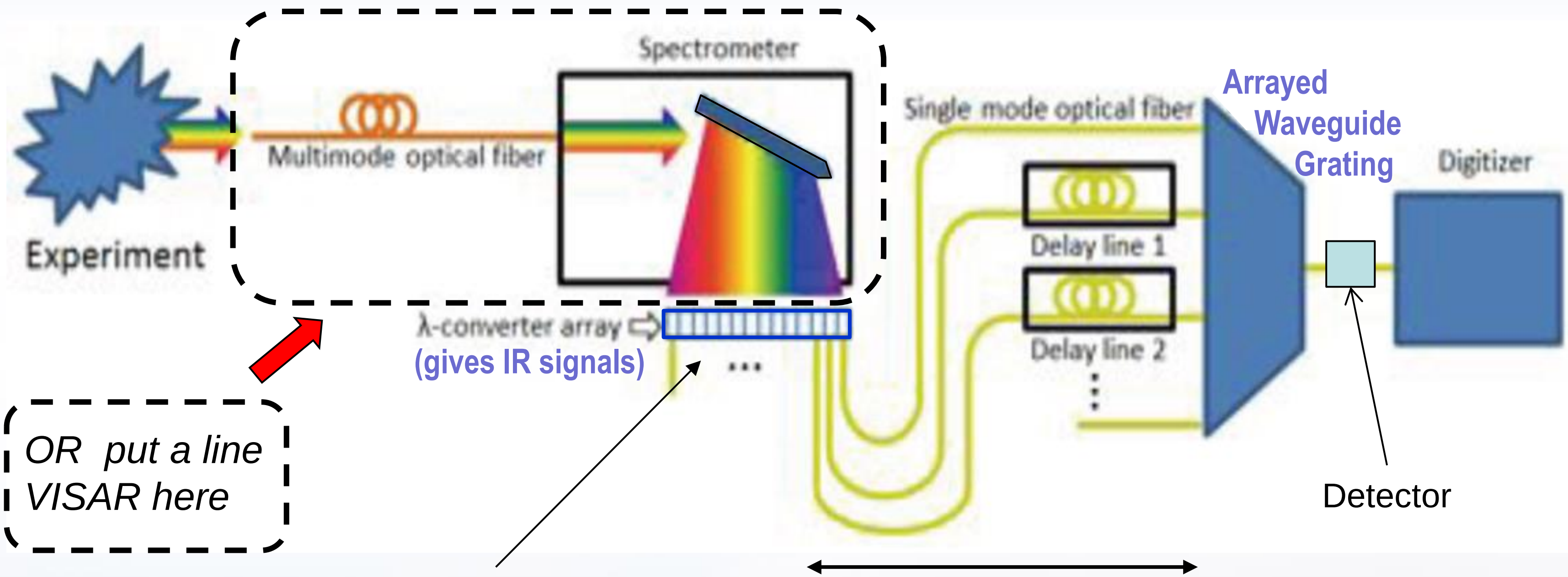


Avalanche photodiodes and digitizers:

- **APDs available to 500 MHz; these are the limiting factor in a world with 13 GHz Toasters (8 channel digitizers) and faster Tek and Agilent instruments**
- With nonsimple timing pulses, synchronization of signal timing to perhaps 200 ps is possible. Using carefully matched optics and a single VISAR cavity, a slight improvement may be realized.
- **Total resolution fo**r measuring wave transit times of samples is ~300 - 400 ns.
- Ultimately multipoint PDV may also be suitable for these studies; higher bandwidth detectors will improve time resolution beyond 500 MHz VISAR APDs.



It may be possible to use IR multiplexing in place of streak cameras in the near future



Need 400 -700 nm spectrum conversion
GHx bandwidth
30 dB (10 bits) of dynamic range needed

Fiber losses minimal (0.2 db/km)
⇒ time mutiplexing is feasible
(200 m of fiber = 1 μs delay)

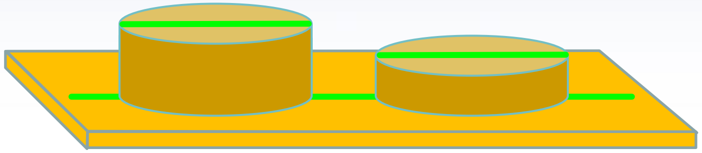
Large-volume commercial hardware

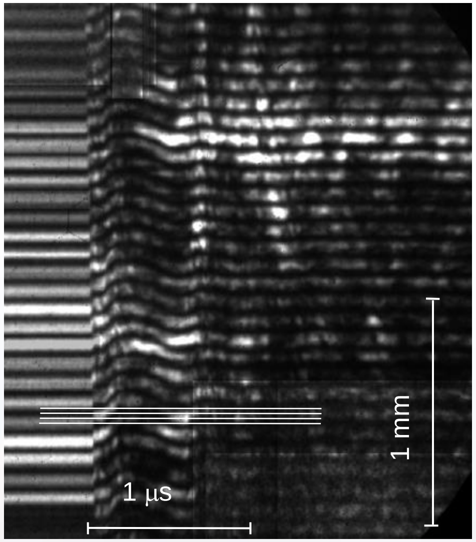
- **Operates for fast pyrometry (IR, visible or UV)**
- **Wavelength conversion inside a containment port**
- **XRD for phase identification?**

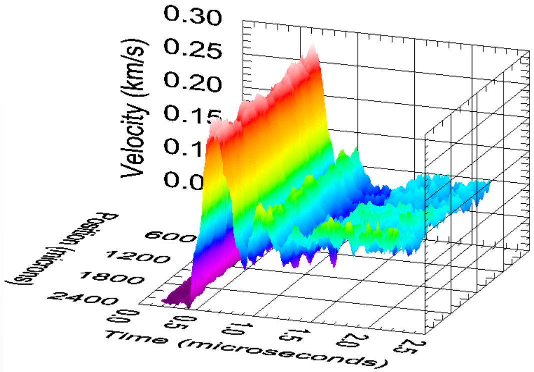
8:1 multiplexing appears feasible

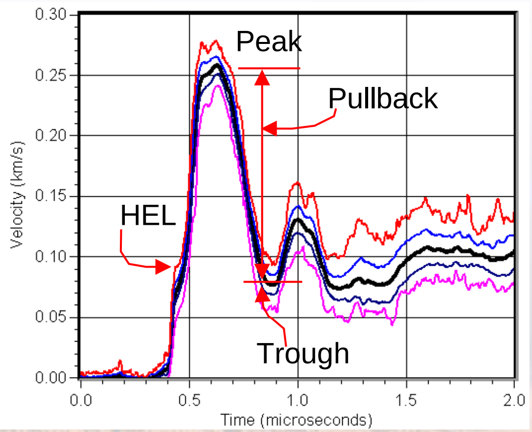
There are two main purposes for line ORVIS

- **Line ORVIS can improve the measurement of shock transit times over conventional VISAR (10 – 30 ps vs. a few 100’s of ps or more with standard VISAR)**
- **Line ORVIS can image the position dependence of velocity histories.**
  - **On fine scale (1 – 2 mm line for 20 µm resolution) to look at material texture effects, grain boundary effects, spall nucleation, etc.**
  - **On larger scale (10 – 15 mm line) to look at instability effects in homogeneous targets, target distortion effects, edge effects, and the behavior of joints and large crystal boundaries.**









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Line ORVIS benefits research on Z and other SNL platforms

What it is:

Illuminated line on target is imaged through ORVIS onto streak camera aperture.

Motivation:

Primary – Improved accuracy for measuring shock transit times (a few 10's of ps) and time-correlation of wave structures

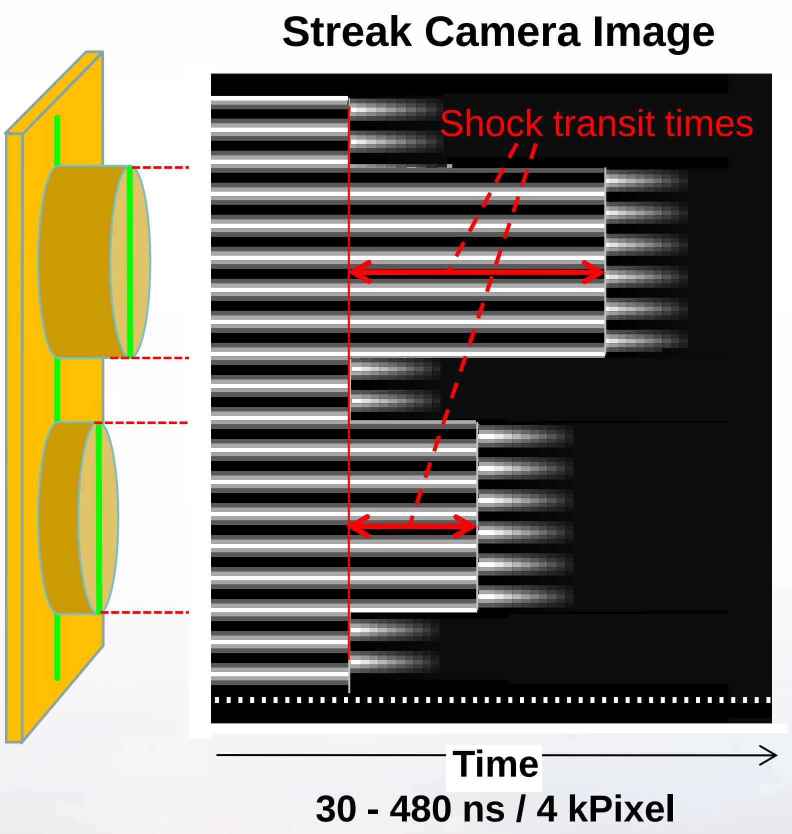
Secondary – Ability to measure nonplanarity of flyers, ICE components, effects of material grain structure / heterogeneities / instability growth

Status for Z:

- Basic diagnostic is mature
- Screenbox is in place (with tables and much old hardware)
- LV was successfully used on Z prior to 2006-2007 ZR upgrade

Status for Other SNL Platforms:

- Working ar STAR (1 system), DICE (1 system) and ECF (3 systems)
- Single BS models used (vs. Mach-Zehnder)
- LV was successfully used on Z prior to 2006-2007 ZR upgrade



Key limits and parameters

Minimum line length: 1 – 2 mm (resolution 20 -30 μm)

Maximum line length: ~15 mm?? (maybe more)

Scan speeds: 30 – 480 ns for Z; 2 – 10 μs for STAR and DICE; slower also available, but resolution limited by 4K x 4K (or lower) CCD spec

Light delivery: Can be free beam or via twisted-triplet 1 mm fibers to reduce speckle

Use in containment vessel: Either with port for at least returning beam or with image-preserving fiber optics

Minimum velocity: A few m/s

Maximum velocity: Unknown; possibly > 100 km/s if reflecting interface available.

Timing jitter: A few ps? This will be mainly in the fid delivered by the facility.

To understand resolution, let's first consider the methods of data analysis for LV data

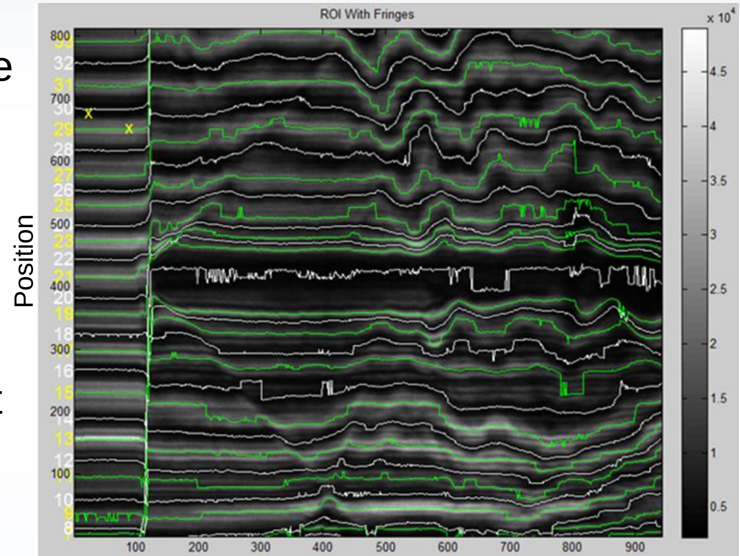
<u>1. Fringe trace:</u>
(Based on single phase recording)

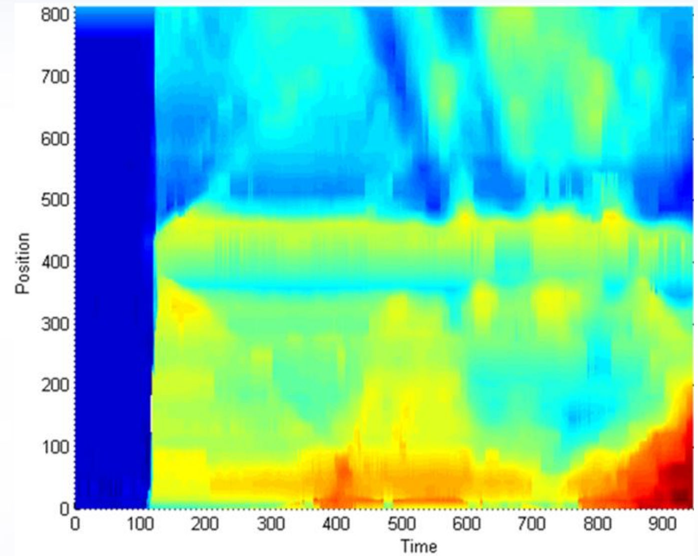
Establish fringe positions, then calculate the phase at each (x,t) point relative to the starting phase at (x,t=0).

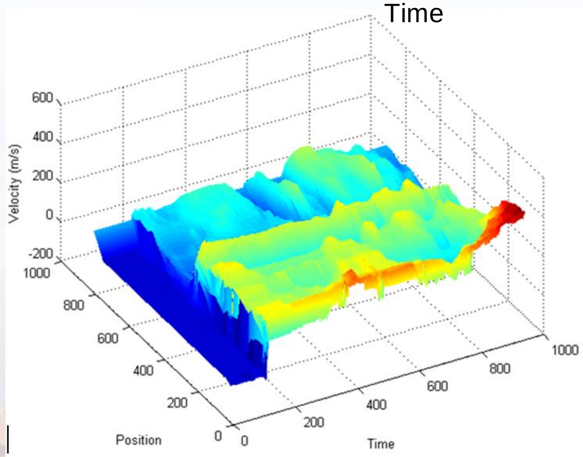
This can use maxima/minima[1] or also include inflection points[2].

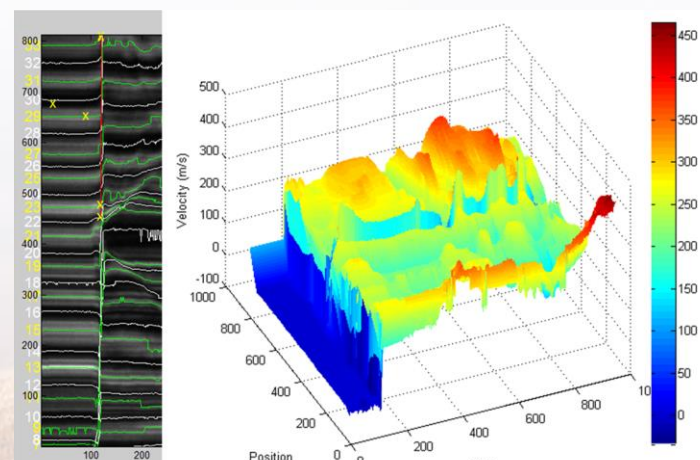
Robust for complicated fringe patterns (large spatial dependence of velocity)

Can require substantial operator interaction.









[1]M. Furnish,SAND2014-1632; [2]M. Philpott, personal communication

The mock quadrature method is the second method when only one phase is recorded.

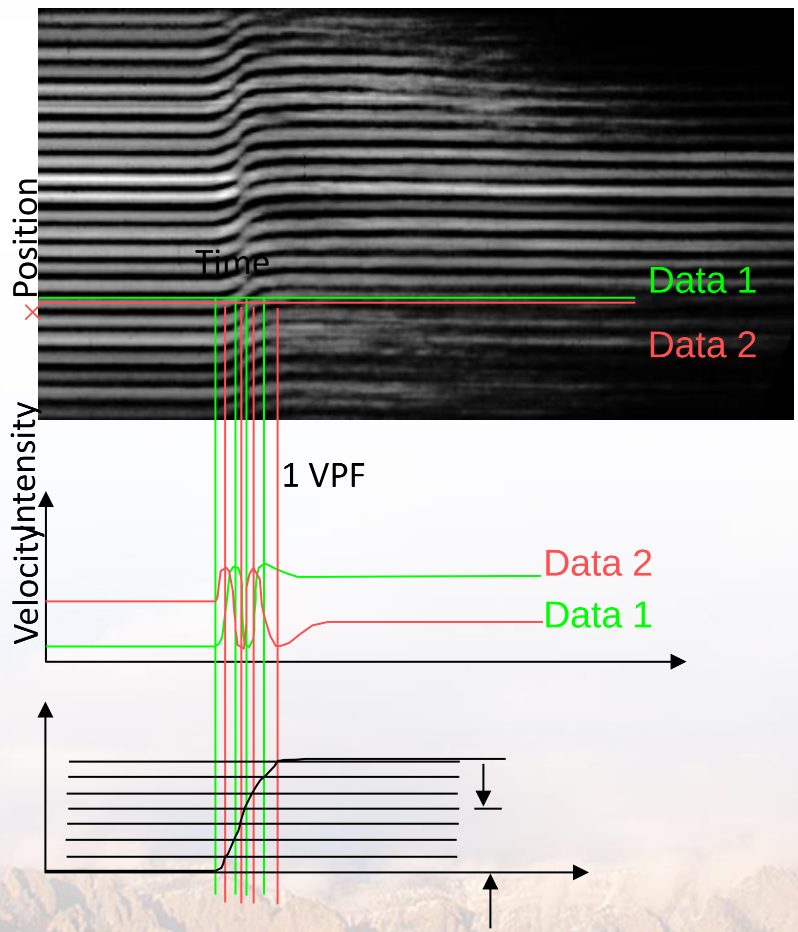
2. Mock Quadrature[1]:

For each lineout, consider that to be D1, then add lineouts at $\lambda/4$, $2\lambda/4$, and $3\lambda/4$ as D2, D1' and D2', respectively.

Need to fit overall intensity envelope to pattern (normalize fringe amplitude). If successful, the velocity unwrap is fairly well automated.

Fringe pattern must be resized to allow discrete analysis.

Can require substantial operator interaction for adding/deleting fringe jumps.



Data1', Data2' not shown

[1]W.Trott, M.Knudson, L.Chhabildas, J.Asay. AIP Conf. Proc. **505**, 993 (2000)

The FFT method is the third method when only one phase is recorded.

3. FFT Method[1,2]:

Initial image (real, then as complex + c.c)

$$S(x,t) = B(x,t) + A(x,t)\cos[\phi(x,t) + 2\pi f_0 x + \delta_0]$$
$$= B(x,t) + C(x,t)\exp[i(2\pi f_0 x + \delta_0)] + c.c., \quad C(x,t) = A(x,t)\exp[i\phi(x,t)]/2$$

Extract phase(x,t), then window

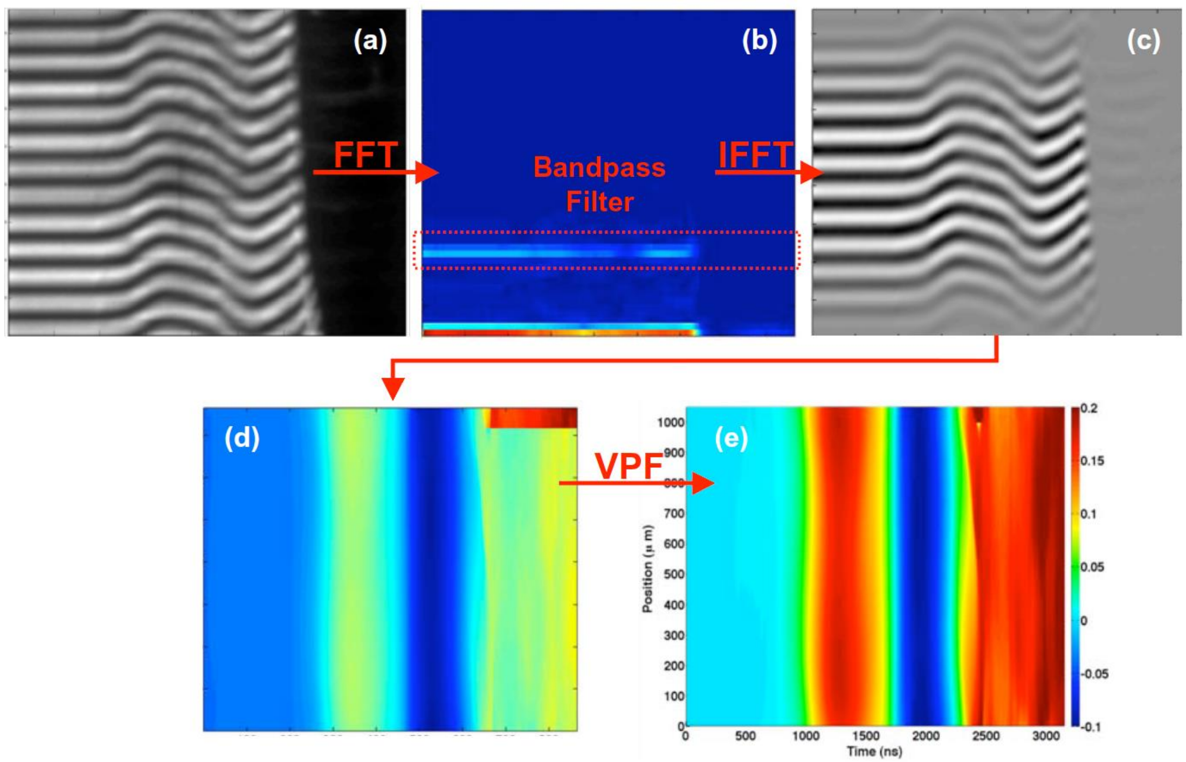
$$s(f,t) = \mathbf{FFT}\{S(x,t)\} = b(f,t) + c(f - f_0, t) + c^*(f + f_0, t)$$
$$s_{BP}(f,t) = \mathbf{BP}\{s(f,t)\} = c(f - f_0, t)$$

Take inverse FFT,

$$D(x,t) = \mathbf{IFFT}\{s_{BP}\} = C(x,t)\exp[i(2\pi f_0 x + \delta_0)]$$

Extract real part,
And correct for fringe constant
to calculate velocity

$$W[\phi(x,t) + 2\pi f_0 x + \delta_0] = \arctan\left[\frac{\mathbf{Im}\{D\}}{\mathbf{Re}\{D\}}\right]$$



[1]T. Ao, SAND2009-3236

[2] M Takeda J. Opt. Soc. Am/Vol. 72 (1), January 1982

Continuous Wavelet Transform, a variation on the FFT method, involves adding a localizing function[1].

4. CWT method

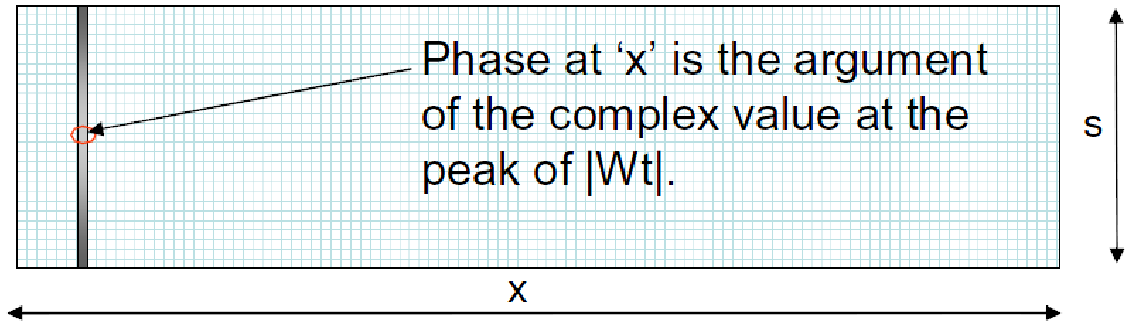
Wavelet analysis is similar to Fourier analysis however it has the advantage of spatial localisation.

$$Wt(x,s) = f(x,t) \otimes \psi^{*}(x,s)$$

This is a process of dilations and translations of a mother wavelet function ψ.

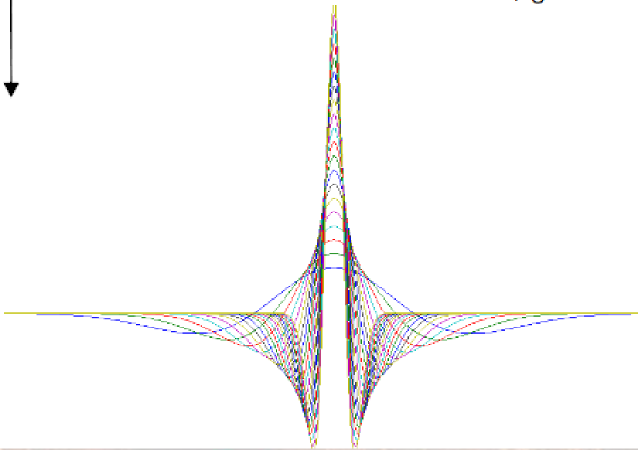
The dilation parameter 's' controls the wavelet scaling.

Matrix of coefficients Wt



$$\psi_s(x) = \frac{1}{\sqrt{s}}\psi\left(\frac{x}{s}\right)$$

Scaled wavelets ψ_s



So far we have only looked at the 'Mexican hat' wavelet. This wavelet is the 2nd differential of a Gaussian function.

There are many more complex wavelets to consider.

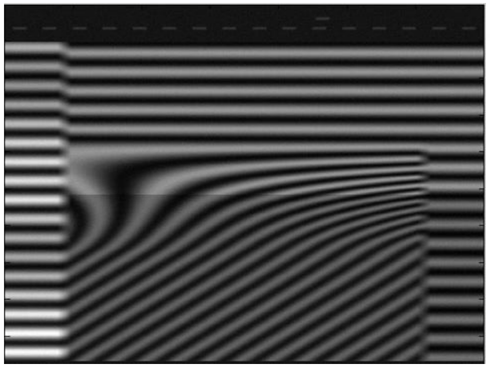
[1] This slide from "Demonstrating High Resolution Line VISAR at AWE", a presentation by M. Philpott et al, 1/2014, used with permission (and encouragement).

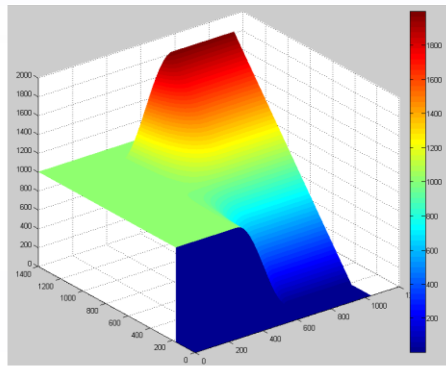
The Fringe Trace method is the most viable method when fringe position is not a function of time

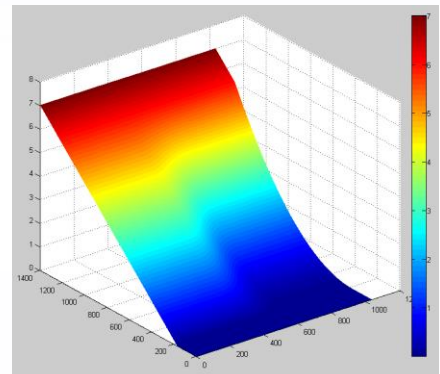
Fringe Pattern

Velocity

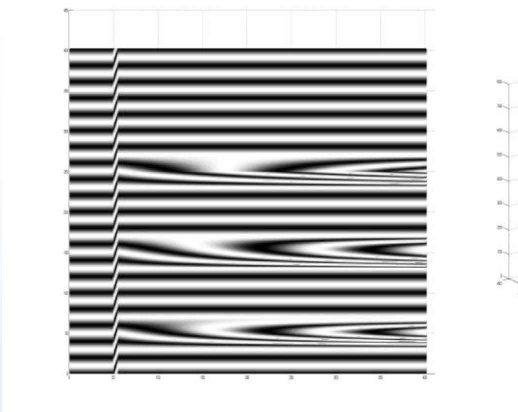
Displacement

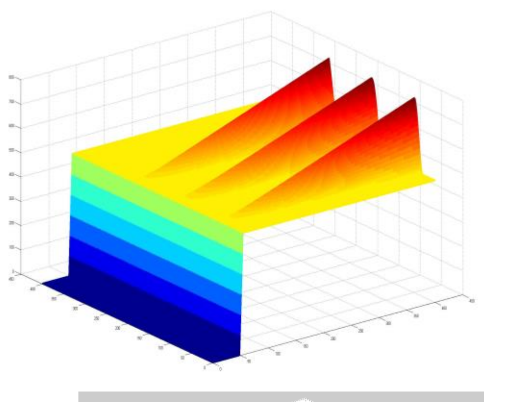




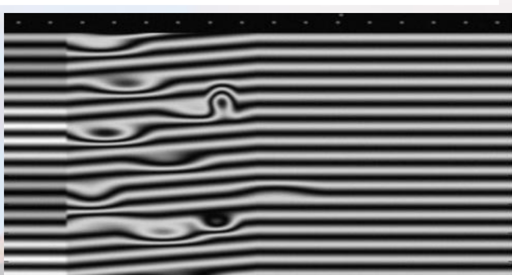


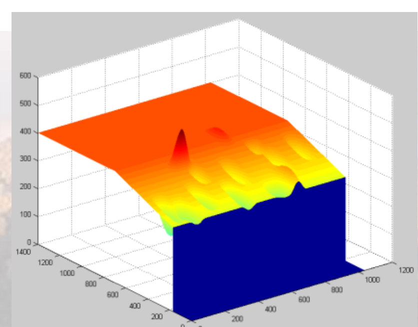
Welded grains

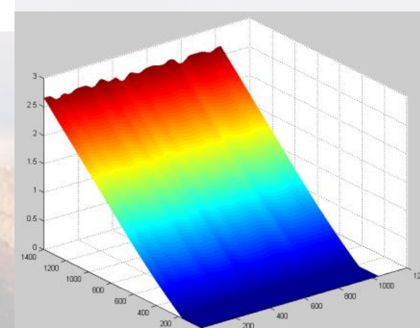




R-T Instability

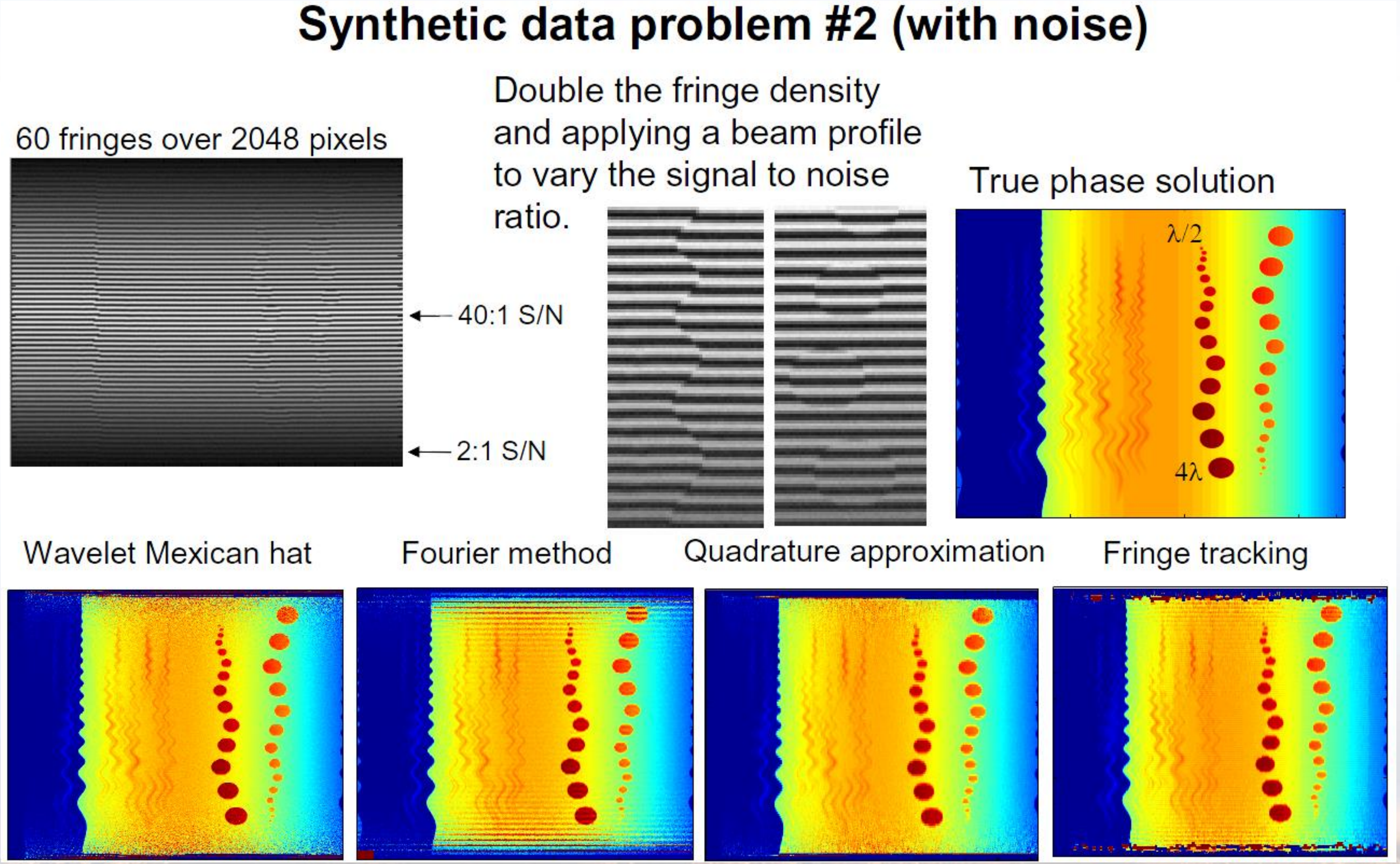






Lumpy solid

These analyses may be applied to a synthetic problem to assess fidelity and resolution[1].



[1] This slide from "Demonstrating High Resolution Line VISAR at AWE", a presentation by M. Philpott et al, 1/2014, used with permission (and encouragement).

Brainstorming for applications

Improve transit time measurements

Validate flyer plate shapes for stripline, etc. (Early work done prior to ZR upgrade on coax)

Diagnose any spall or separation in the flyer plate (Z)

Rayleigh-Taylor growth (currently done with VISAR, radiography)

R-T (MRT) Instabilities on outside of cylindrical implosion experiments

Instabilities in inside of cylindrical implosion experiments (very difficult)

Grain boundary instabilities

Heterogeneities in foams

Phase coexistance regions

Richmeyer-Meshkov experiments (evolution of sinusoidal perturbations
(currently done with radiography; $\lambda \sim 1$ mm)

Various experiments with porous wedges (energetics and inert)

Continued work on incipient spall mechanisms, strength statistics, etc.