UCRL-PRES-236550

Measurements of the non-uniformities seeded by NIF ignition capsule ablator materials

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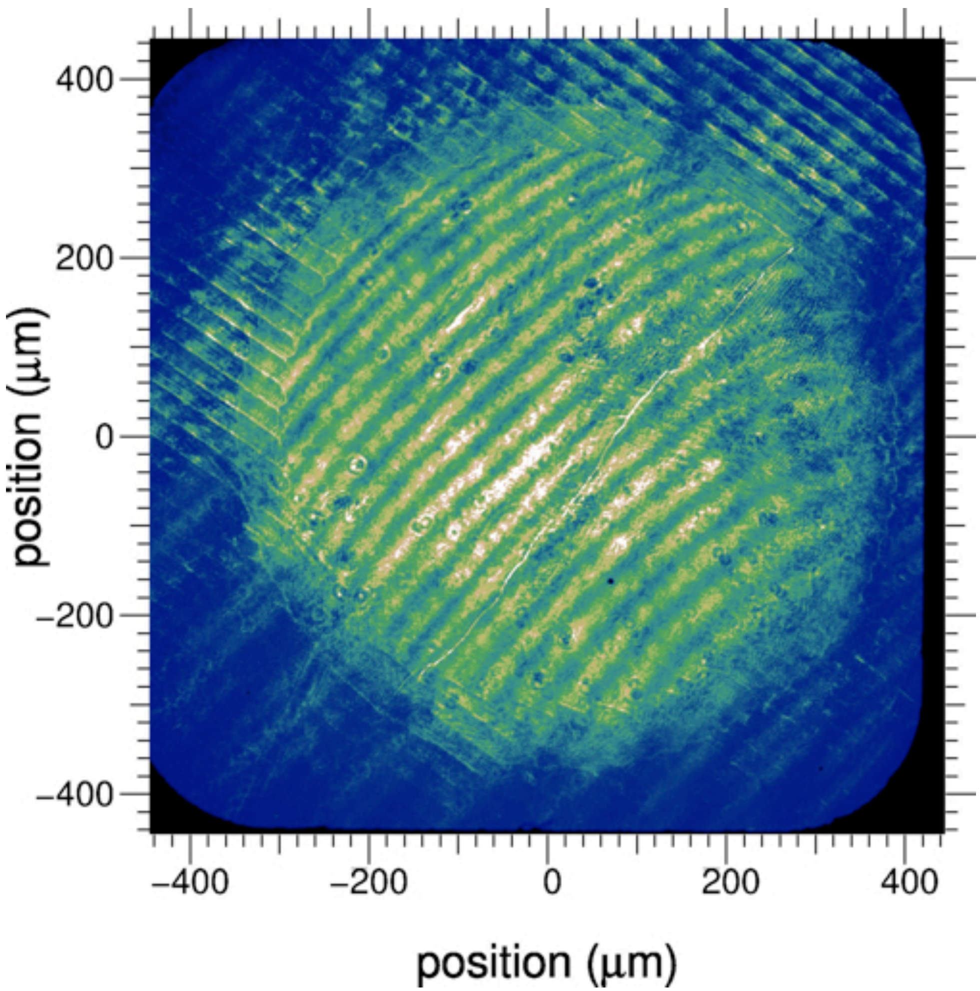

Presented at the 49th Annual Meeting of the Division of Plasma Physics
November 12-16, 2007
Rosen Centre Hotel
Orlando, Florida

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory in part under Contract W-7405-Eng-48 and in part under Contract DE-AC52-07NA27344.

NIC
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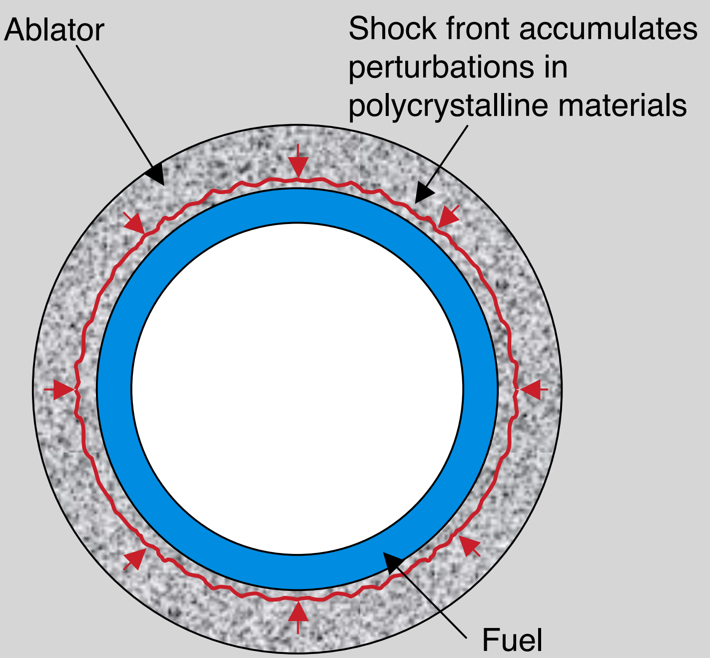
Summary

- **Characterization of ablator non-uniformities at the seed level during the first shock stage requires ultra-high sensitivity velocimetry**
- **A high resolution two-dimensional imaging VISAR has been built and fielded at OMEGA**
- **Tests on NIF ablator materials have begun**
- **Preliminary results (qualitative):**
  - **Non-uniformities seeded by Be(1%Cu) samples appear to be at levels near the detection limit of the interferometer**
  - **The level of non-uniformities seeded by diamond ablators is higher**
  - **Data analysis is ongoing**

Direct characterization of seed-level non-uniformities during the first shock stage requires a high sensitivity measurement

Goal: characterize non-uniformities at the seed level



Capsules are predicted to remain stable if the level of velocity non-uniformites is < few parts in 10^4

Requirements to detect seed-level non-uniformities

- **Flow non-uniformities ~ 1 m/s within a flow field moving at ~ 10 km/s (velocity resolution at 1 part in 10^4)**
- **High spatial resolution (≤ 5 μm)**
  - **Be grain size ~ 10 μm**
  - **HDC grain size ~ 200 nm**
- **Two-dimensional time-resolved snapshot to identify dominant modes & scale lengths**

Current line-VISAR capabilities (e.g. at NIF and OMEGA) are not adequate for this measurement

Concept: detect non-uniformities in the shock just after it transits the ablator

Estimated ripple amplitude corresponding to NIF uniformity specification

Ripple oscillation time:

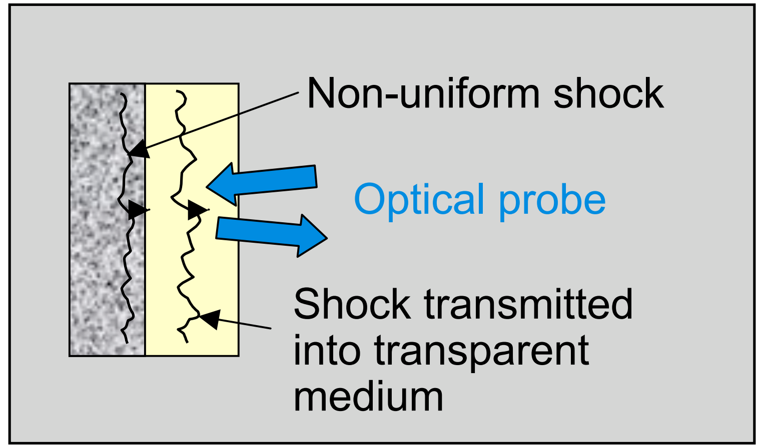
$$\Delta t \sim L/U$$

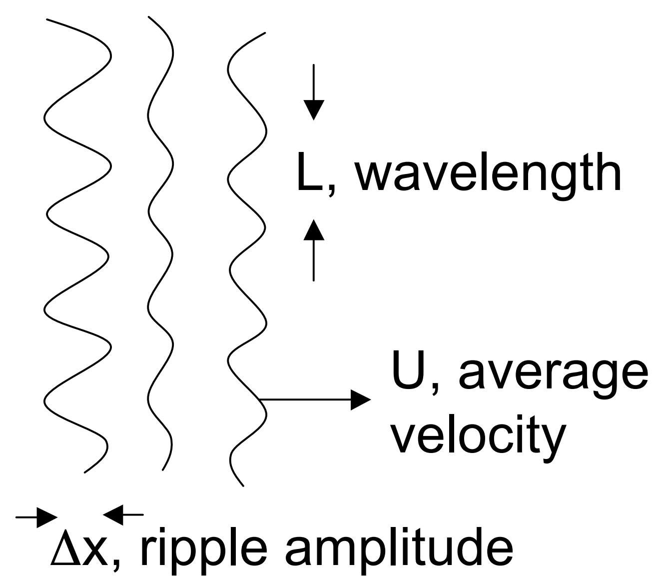
Ripple amplitude for current NIF designs:

$$\Delta x = \Delta U\ \Delta t = \Delta U/U\ L = 10^{-4}\ L$$

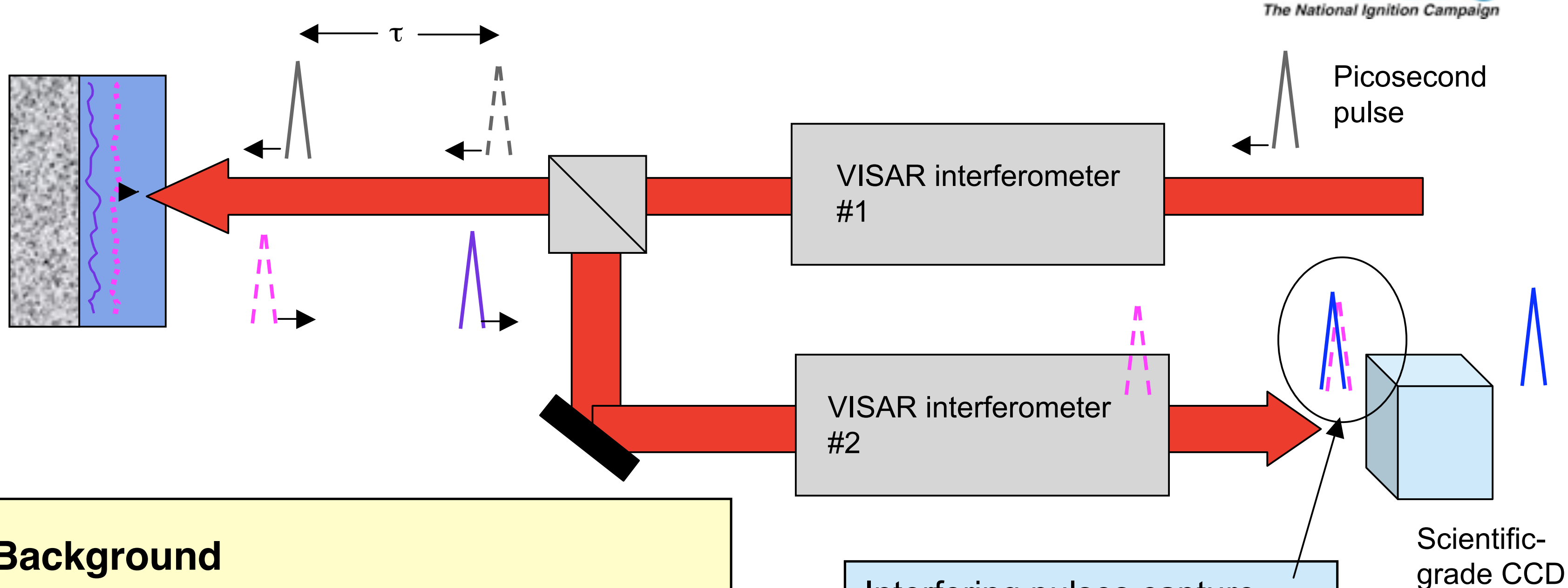
For ripple wavelengths near L ~ 2 μm, our resolution limit, the NIF ripple amplitude is $\Delta x \sim 0.2$ nm.

For a λ = 400 nm probe wavelength this is equivalent to ~λ/2000 or ~3 mrad





Two-dimensional VISAR with picosecond pulse illumination



Interfering pulses capture *changes* in the shock front surface topology that have taken place during the delay interval τ.

Background

- **Scheme is a variation on a *white light VISAR****
- **Uses quadrature readout for high accuracy phase extraction**
- **New content**
  - **Picosecond pulse illumination**
  - **High dynamic range scientific-grade-CCD detection**
  - **Two-dimensional velocity field**

Previous literature

[1] L. Barker & R. Hollenbach, J. Appl. Phys. **41**, 4208, (1970); J. Appl. Phys. **43**, 4669 (1972)
[2] W. Hemsing, Rev. Sci. Instrum. **50**, 73 (1979)
[3]* D. J. Erskine & N.C. Holmes, Nature **377**, 317 (1995)

The interferometer system records 4 frames simultaneously with 90 degree phase differences

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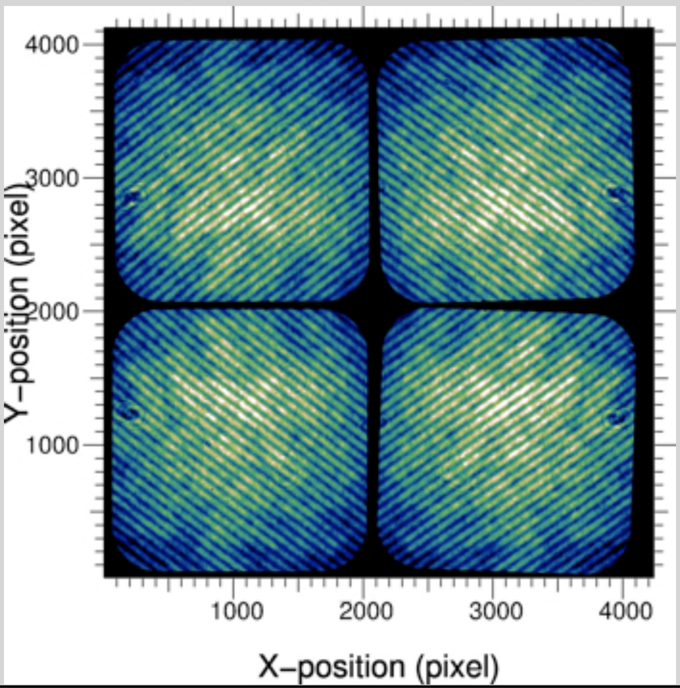
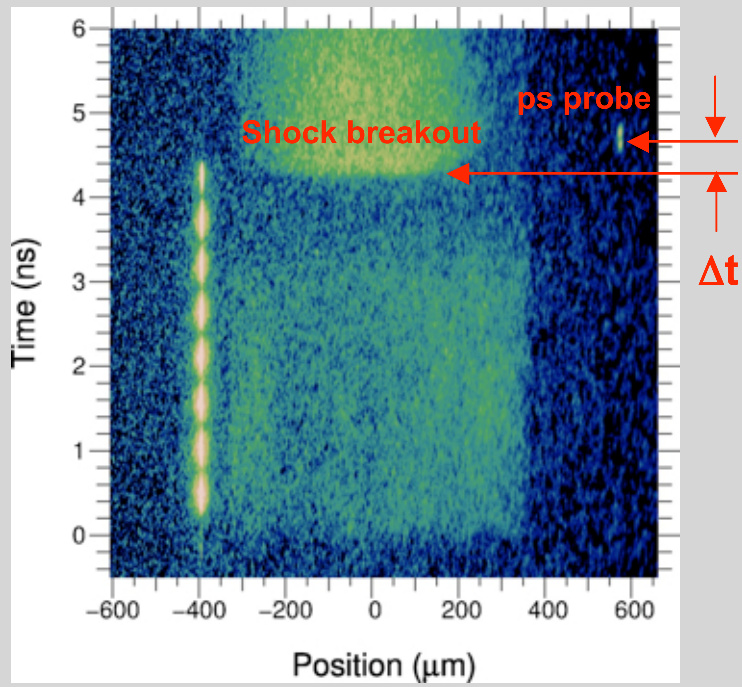
- Diffraction-limited f/3 image relay system, 800 μm field of view
- System is implemented at OMEGA and known as the OHRV: "OMEGA High Resolution Velocimeter System"
- Incorporates a 1 mJ, 395 nm, ~ 2 ps laser source
- Streak camera for obtaining shock breakout & probe timing data

Raw four-frame interferogram



Each frame is π/2 phase-shifted relative to its neighbor

Probe timing measurement



Detection limit (noise floor) of the system meets the NIF requirements

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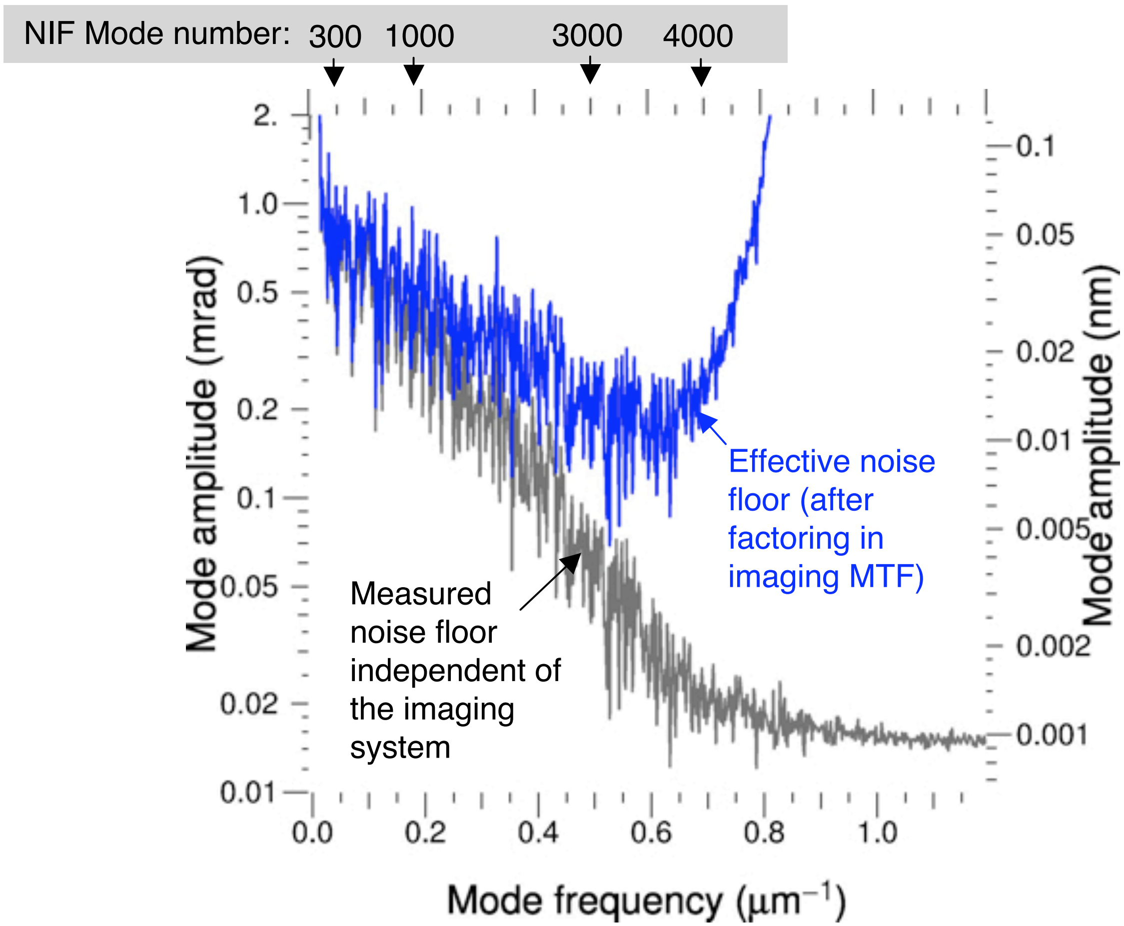
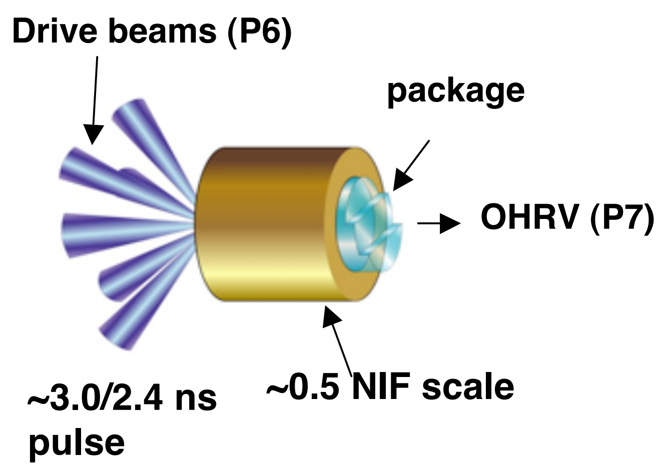
Detection limit (noise floor)

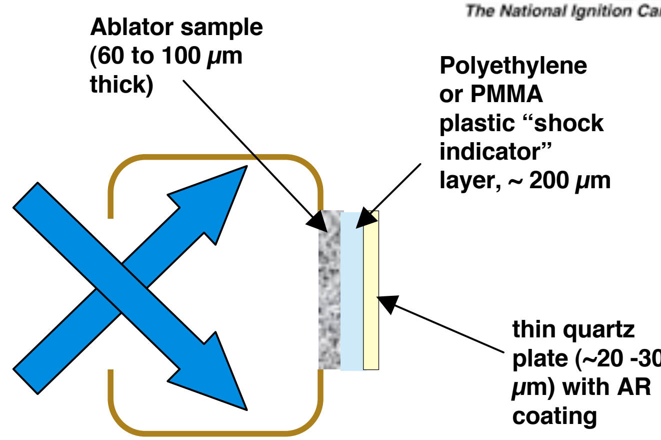


A platform for testing NIF ablator materials has been developed and fielded on OMEGA

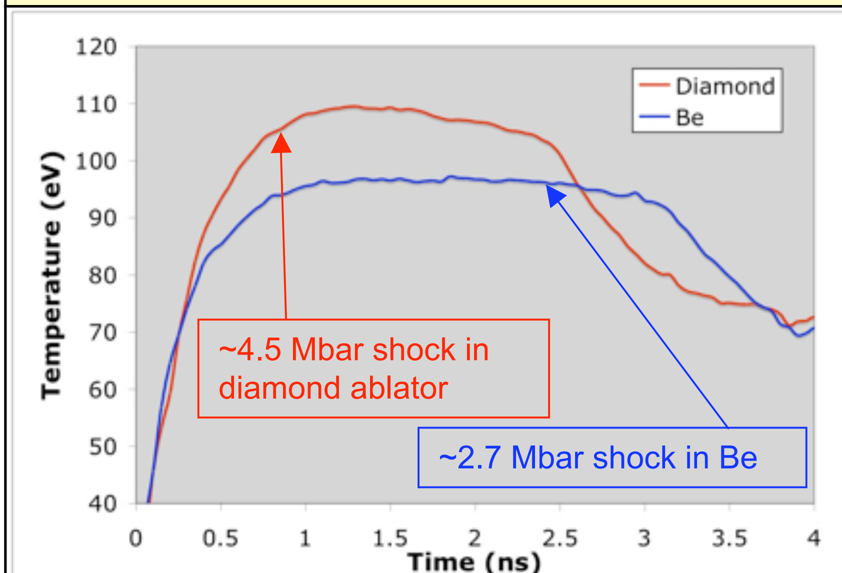
Omega Experiment for OHRV platform characterization



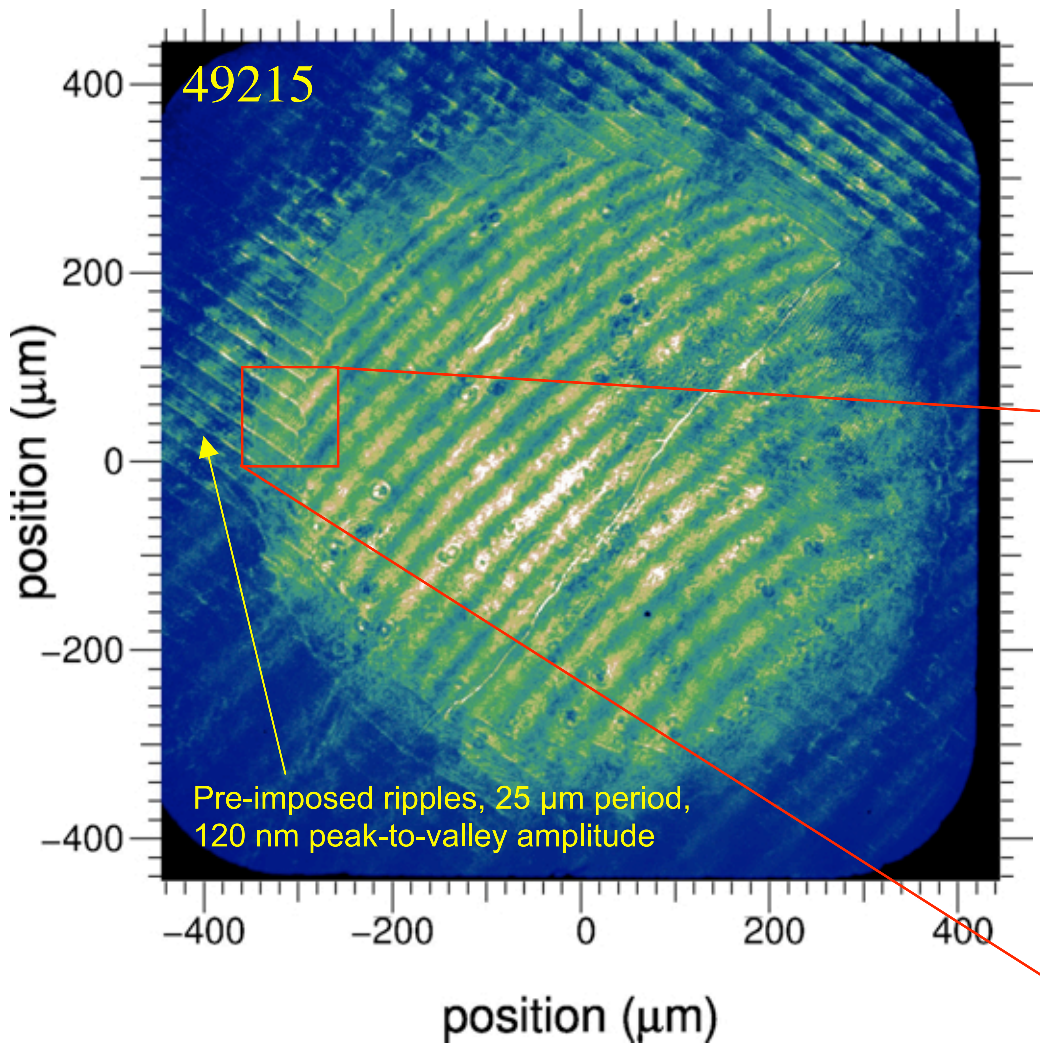
- Hohlraum size scaled from NIF to match Omega power
- Laser intensity & fraction of wall illuminated same as NIF



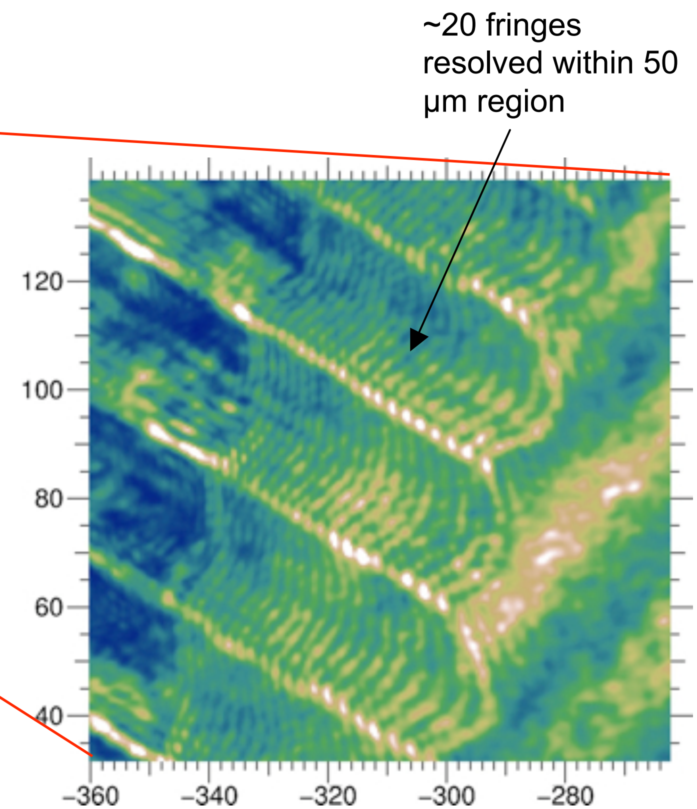
DANTE drive measurement



Example: Be(1%Cu) sample with pre-imposed ripples probed ~ 200 ps after shock breakout



- **Details down to ~ 2 µm spatial scales can be resolved winthin the 800 µm x 800 µm field of view**



Example: nano-crystalline diamond with pre-imposed ripples probed ~ 50 ps after shock breakout

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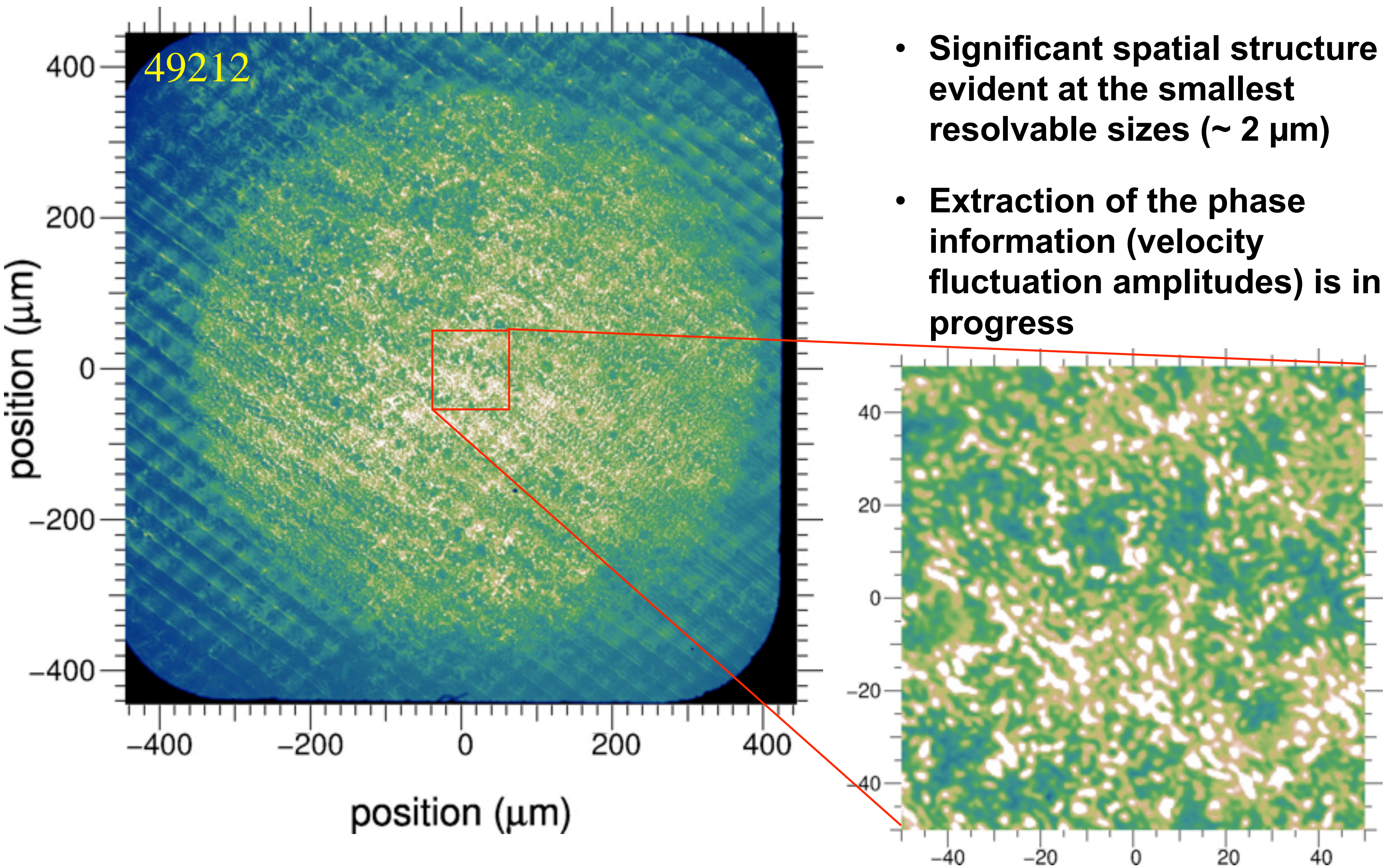
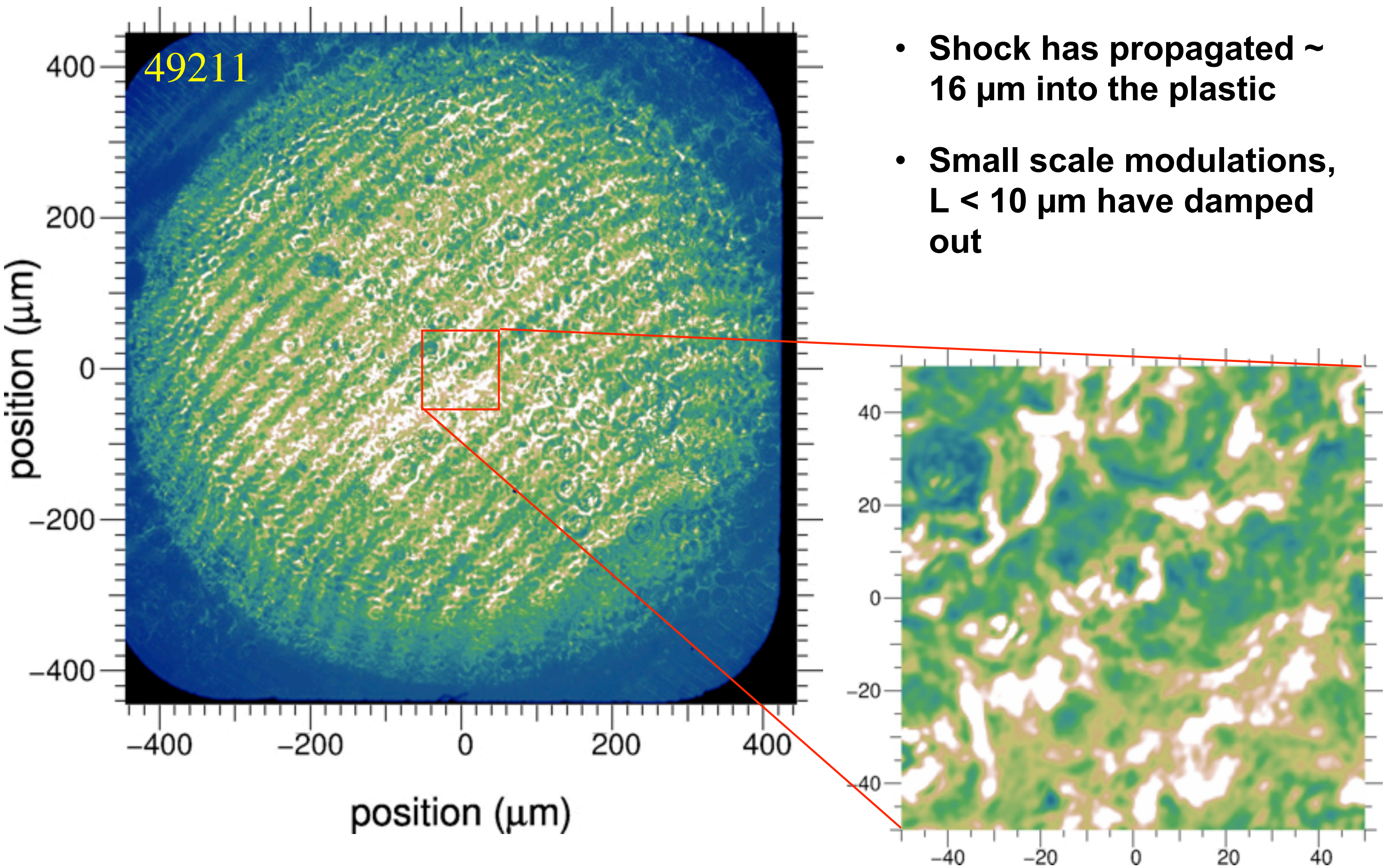


- Significant spatial structure is evident at the smallest resolvable sizes (~ 2 µm)
- Extraction of the phase information (velocity fluctuation amplitudes) is in progress

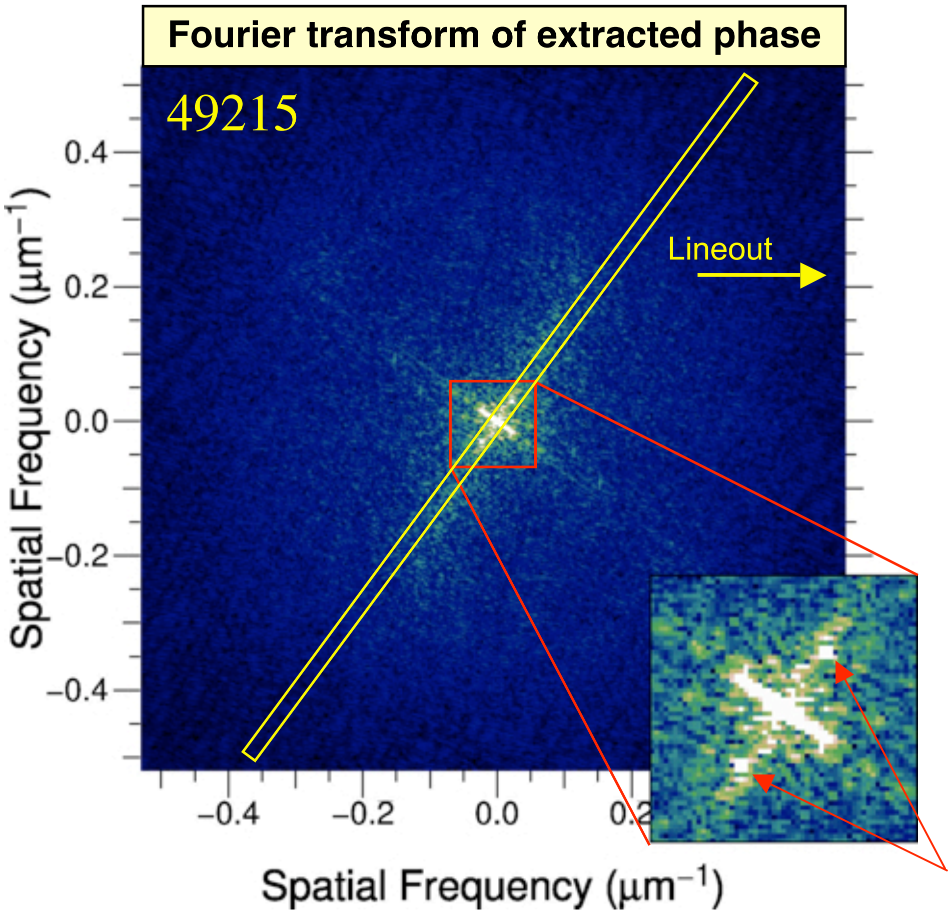
Example: nano-crystalline diamond with pre-imposed ripples probed ~ 950 ps after shock breakout

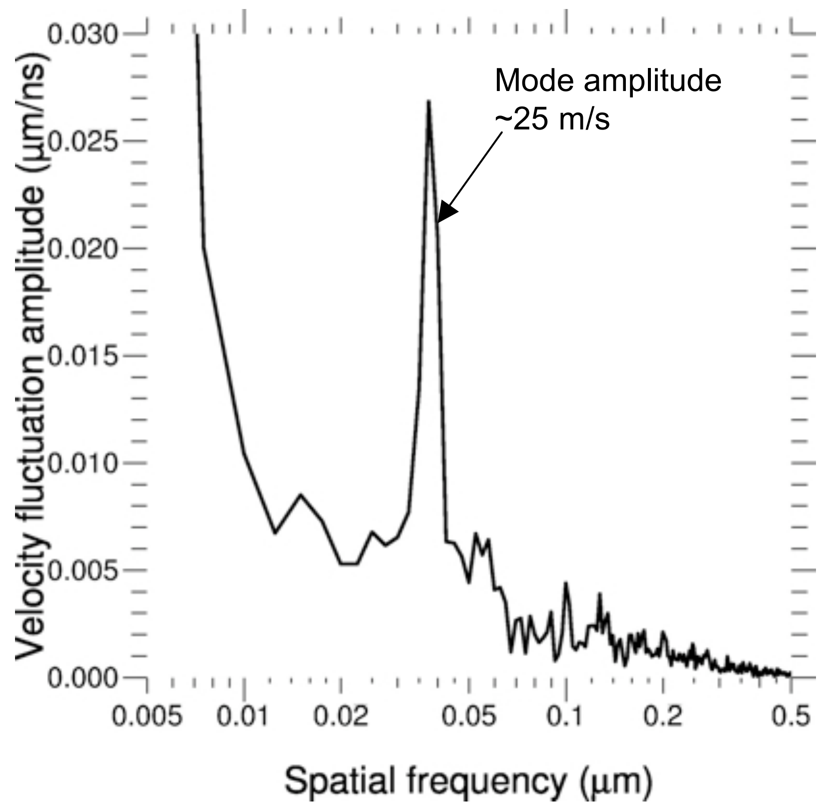


- **Shock has propagated ~ 16 µm into the plastic**
- **Small scale modulations, L < 10 µm have damped out**

The pre-imposed ripple in 49215 is detected in the spatial frequency spectrum

- **Observed ripple mode amplitude ~25 m/s compared to a noise floor of ~1 m/s per mode**





These peaks in the 2D spectrum originate from the 25 µm wavelength pre-imposed ripple

Acknowledgments

- University of Rochester OMEGA facility
  - Jack Armstrong
  - Tom Hinterman
  - Bob Keck
  - Steve Loucks
  - Andrey Okishev
  - Greg Pien
  - Rick Roides
  - Keith Thorp
  - Jon Zuegel
  - OMEGA operations staff

- LLNL
  - Jim Cox
  - Ken Haney
  - Dana Hargrove
  - Glenn Jones
  - Zack Sober

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Extras

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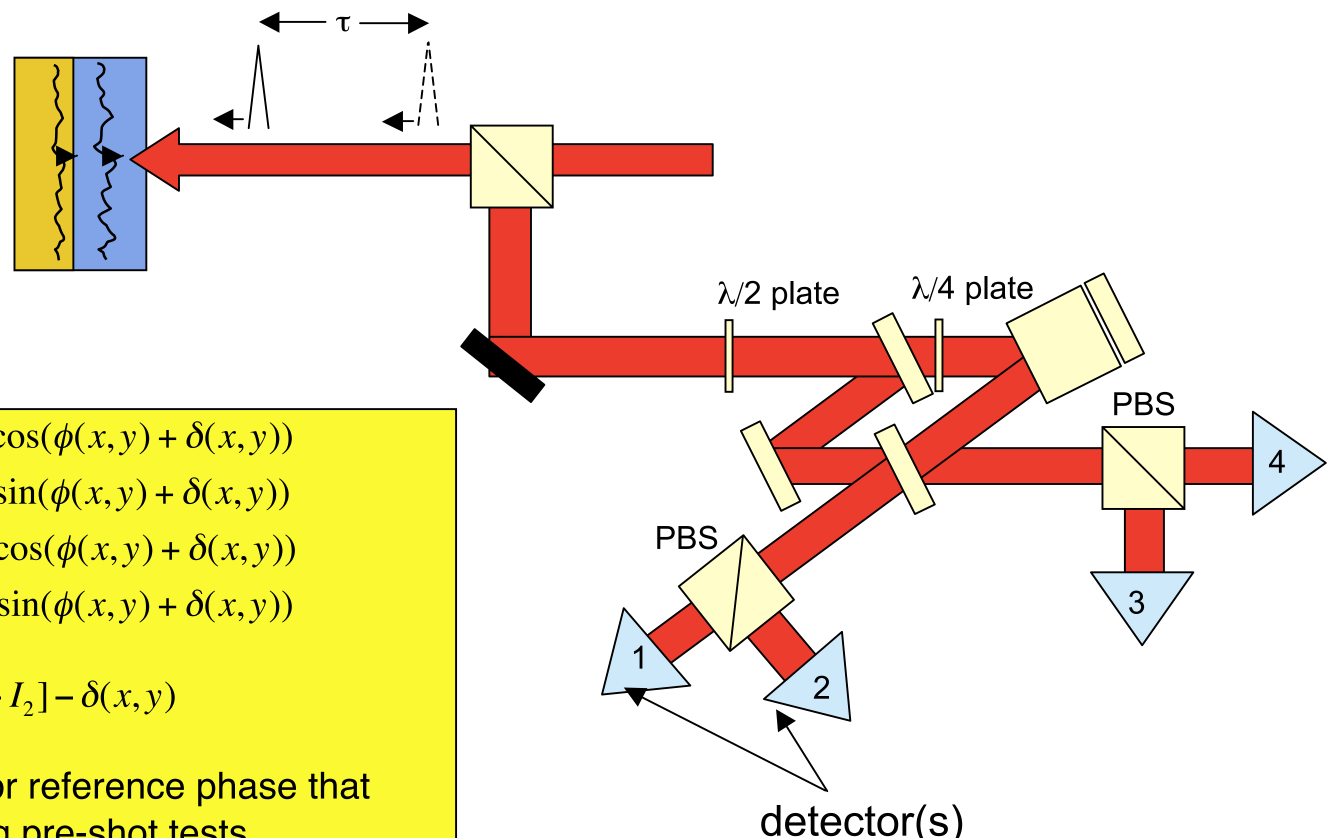
A quadrature readout system is used to extract the phase

- **Standard method for point VISARs used at other high pressure facilities**
- **Accurate phase extract down to single resolution element level**



$$I_1(x,y) = B(x,y) + A(x,y)\cos(\phi(x,y) + \delta(x,y))$$
$$I_2(x,y) = B(x,y) - A(x,y)\sin(\phi(x,y) + \delta(x,y))$$
$$I_3(x,y) = B(x,y) - A(x,y)\cos(\phi(x,y) + \delta(x,y))$$
$$I_4(x,y) = B(x,y) + A(x,y)\sin(\phi(x,y) + \delta(x,y))$$

$$\phi(x,y) = \arctan[I_1 - I_3, I_4 - I_2] - \delta(x,y)$$

δ(x,y) is a background or reference phase that can be measured during pre-shot tests

The interference pattern produces a two-dimensional measurement of the velocity field just like a conventional VISAR

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- **Position of target (shock front) surface given by**

$$Z(x,y,t) = -\int_{t_0}^{t} u(x,y,t)\ dt$$

  — **here t_0 is the time of shock breakout into the D_2 fluid, u(x,y,t) describes the velocity of the shock front**

- **By construction all fixed path delays cancel out: we set pulse 1 to interrogate the target at time *t*, pulse 2 at time $t+\tau$**
- **Net optical path delay:**

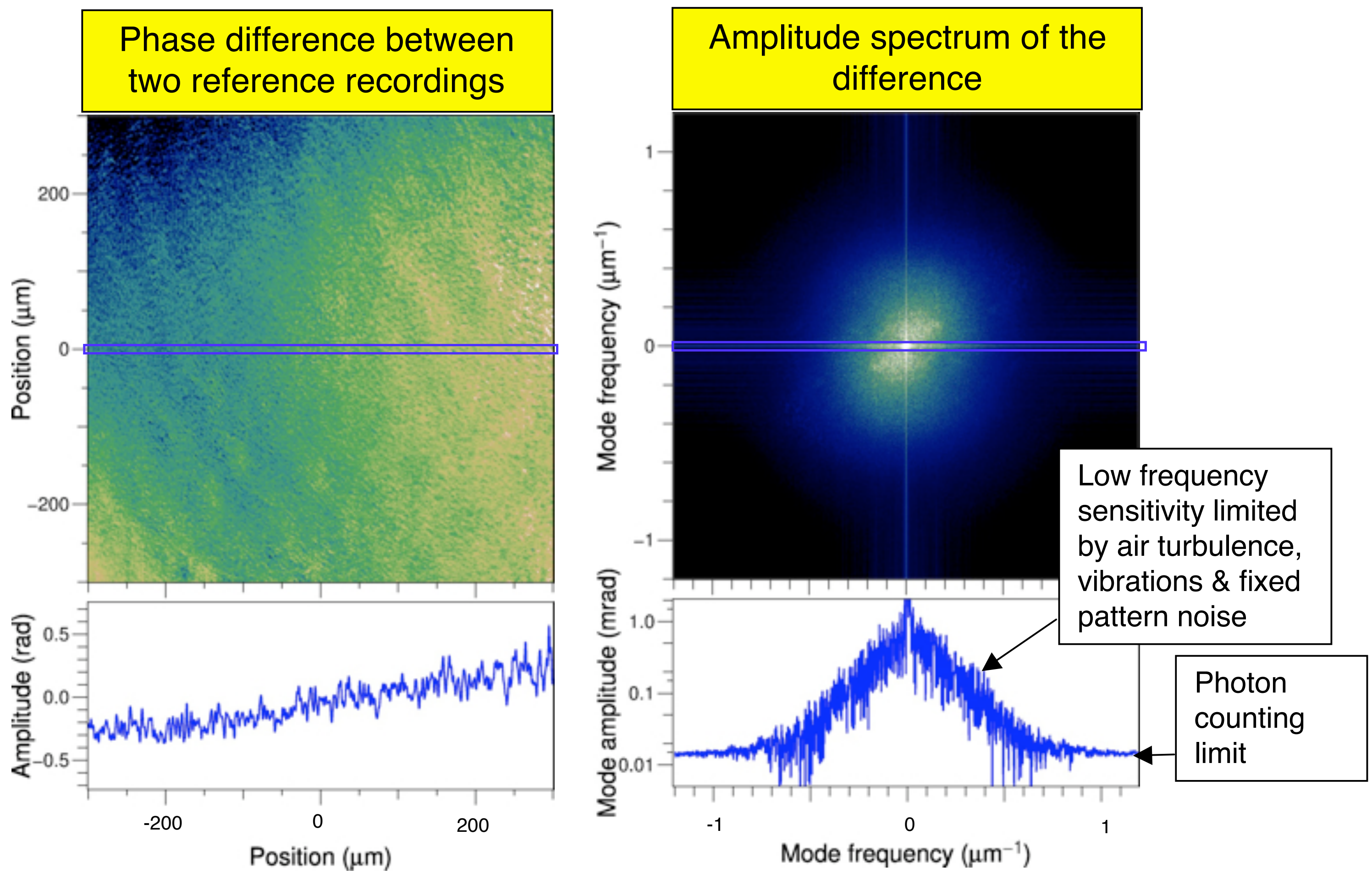
$$\Delta Z(x,y,t) = -\int_{t_0}^{t+\tau} u(x,y,t)\ dt + \int_{t_0}^{t} u(x,y,t)\ dt = -\int_{t}^{t+\tau} u(x,y,t)\ dt = -\tau \langle u(x,y,t+\tau/2)\rangle\Big|_\tau$$

$$\Rightarrow \quad \phi(x,y,t) = 2nk(1+\delta)\Delta Z(x,y,t) = -\frac{4\pi n}{\lambda}(1+\delta)\Delta Z(x,y,t) = -\frac{4\pi n\tau}{\lambda}(1+\delta)\langle u(x,y,t+\tau/2)\rangle\Big|_\tau$$

- **Observed phase is proportional to a moving average over time τ of the velocity field, centred at time $t+\tau/2$**
- **This is identical with the standard VISAR formula relating phase to velocity**

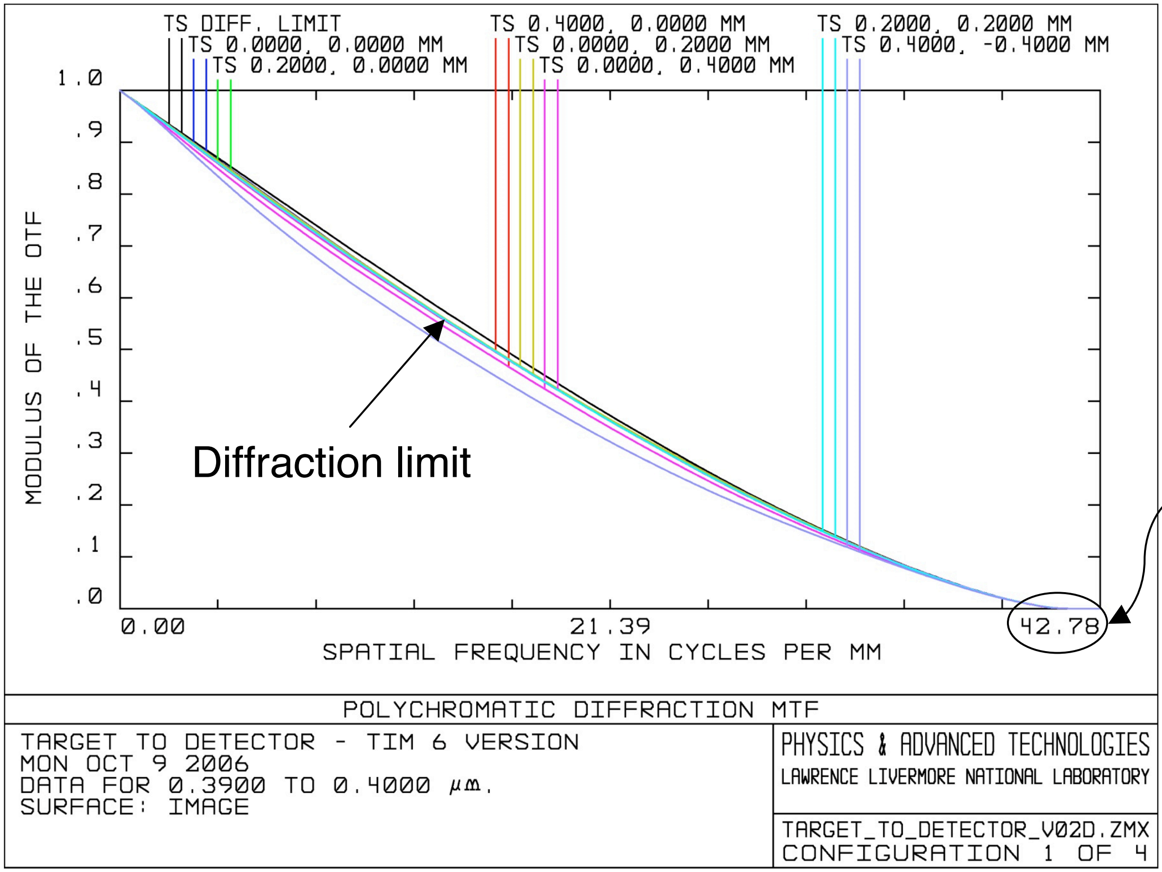
Determination the detection limit

- Record several blank interferograms and extract phase (reference phase maps)
- Subtract any two of the reference maps, difference reveals baseline noise level
- Apply FFT to evaluate noise spectrum



Spatial resolution of the OHRV system

- **Design is modeled in ZEMAX and has been ray-traced from the target to the detector through the interferometer**
- **The design has been optimized to produce a diffraction-limited image at F/3 over the 800 µm x 800 µm field of view**



Note: Calculation refers to image plane, multiply scale by 20 (system magnification) to get object plane response