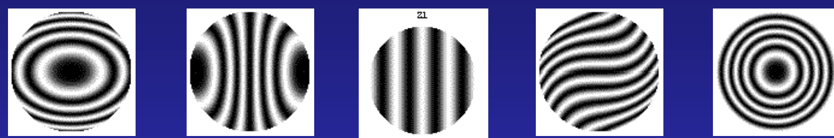
Dynamic Interferometry



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4D Technology

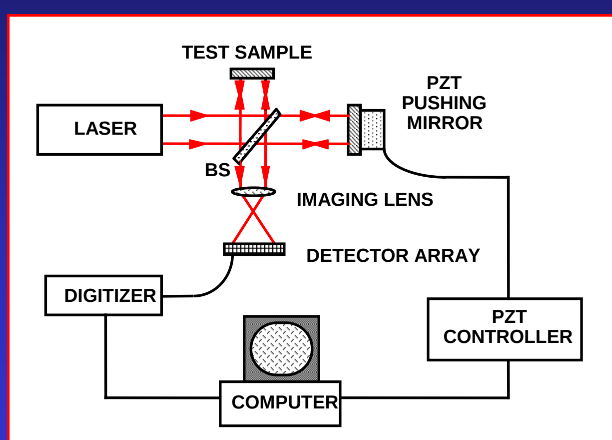
and

James C. Wyant

Optical Sciences Center

University of Arizona

Phase-Shifting Interferometer



Four Step Method

phase shift

$$I(x,y) = I_{dc} + I_{ac} \cos[\phi(x,y) + \phi(t)]$$

measured object phase

$\mathbf{I_1(x,y)} = \mathbf{I_{dc}} + \mathbf{I_{ac}} \cos[\phi(x,y)]$ $\phi(t) = 0$ (0°)

$\mathbf{I_2(x,y)} = \mathbf{I_{dc}} - \mathbf{I_{ac}} \sin[\phi(x,y)]$ $= \pi/2$ (90°)

$\mathbf{I_3(x,y)} = \mathbf{I_{dc}} - \mathbf{I_{ac}} \cos[\phi(x,y)]$ $= \pi$ (180°)

$\mathbf{I_4(x,y)} = \mathbf{I_{dc}} + \mathbf{I_{ac}} \sin[\phi(x,y)]$ $= 3\pi/2$ (270°)

$$\mathrm{Tan}[\phi(x,y)] = \frac{I_4(x,y) - I_2(x,y)}{I_1(x,y) - I_3(x,y)}$$

Serious Problem in Interferometry

Vibration!!

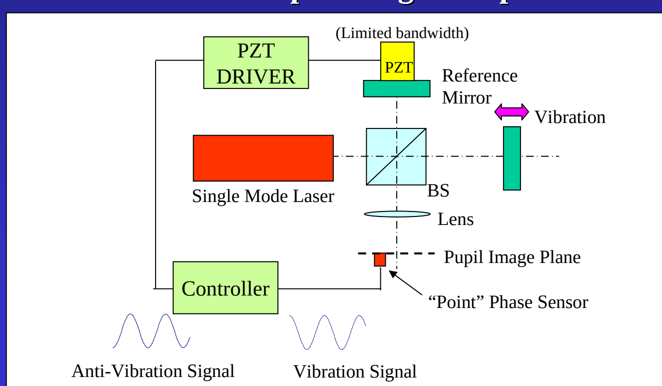
Vibration is often the limiting factor in interferometry applications

Best Way to Fix Vibration Problem

- Retrieve frames faster
- Control environment
- Common-path interferometers
- Measure vibration and introduce vibration 180 degrees out of phase to cancel vibration
- Grab all frames at once (Single Shot)
- Carrier Frequency
- Pixelated Array

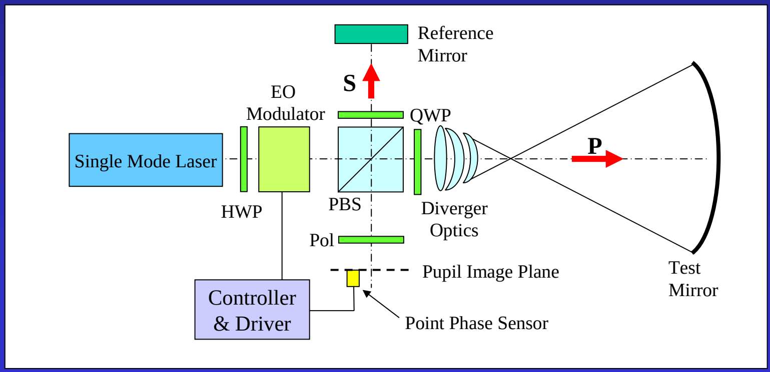
Vibration Compensation Concept

- Example: Twyman-Green configuration
  - Sense optical phase
  - Feed back out-of-phase signal to phase shifter

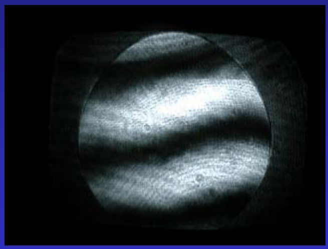


Achieving High Speed Phase Modulation

- Use polarization Twyman-Green configuration
- EOM changes relative phase between ‘S’ & ‘P’ components
  - Can be very fast: 200 kHz - 1 GHz response



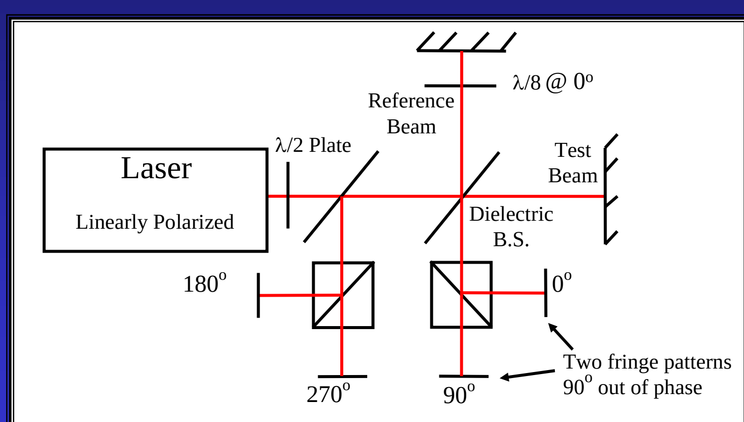
Results



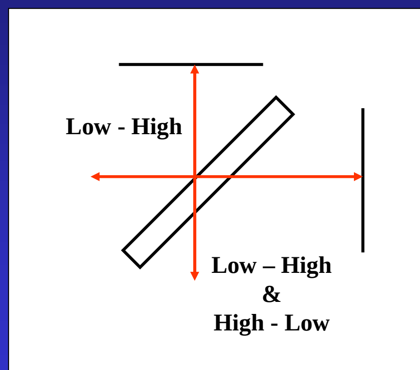
Conclusions - Active Vibration Cancellation Interferometer

System works amazingly well, but it is rather complicated and expensive.

Simultaneous Phase-Measurement Interferometer

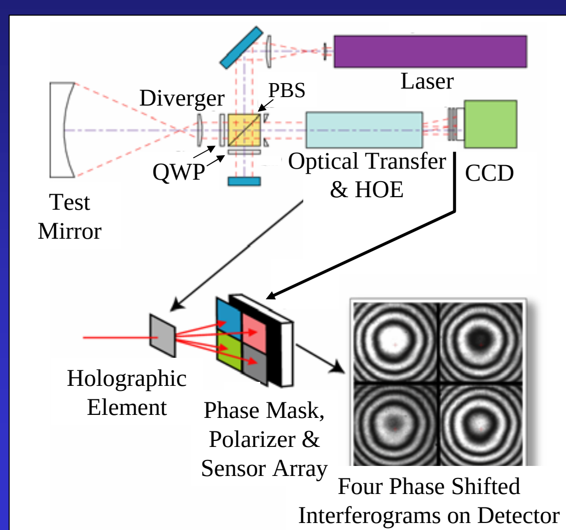


Dielectric beamsplitter and phase shift upon reflection for test and reference beams



4D PhaseCam Operation

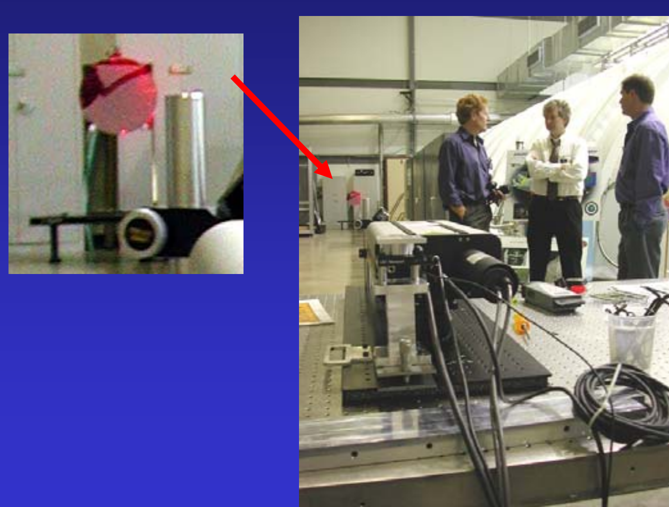
- Twyman-Green
  - Two beams have orthogonal polarization
- 4 Images formed
  - Holographic element
- Single Camera
  - 1024 x 1024
  - 2048 x 2048
- Polarization used to produce 90-deg phase shifts



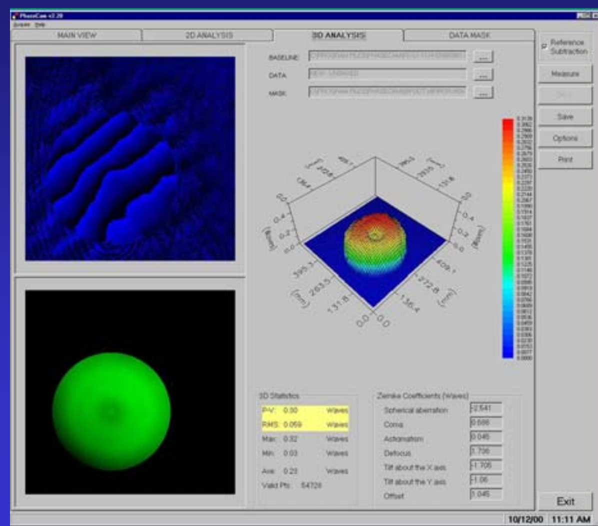
Effects of Vibration

Phase relationship is fixed

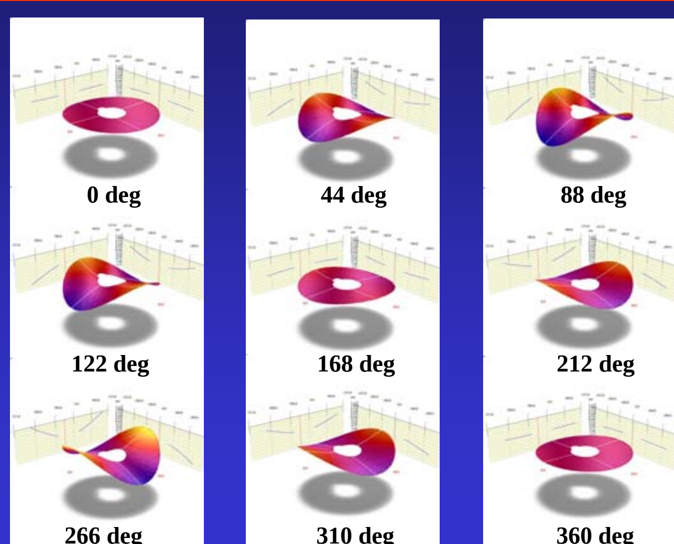
Testing a 0.5 meter diameter, 20 meter ROC mirror



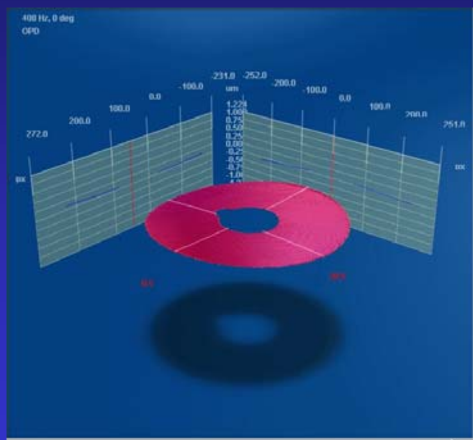
0.5 m diameter mirror, 20 m ROC
5 nm rms repeatability (in air)



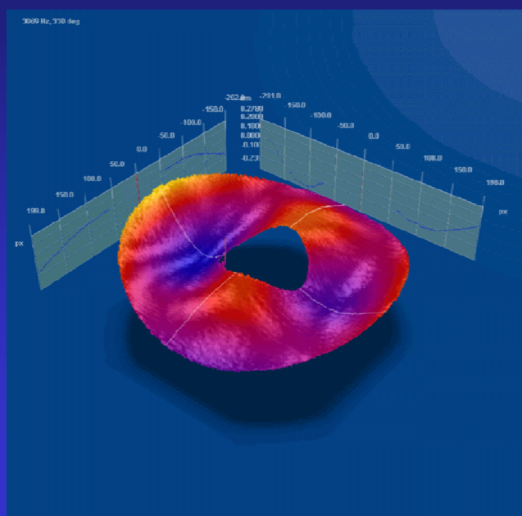
Phase Sweep at 408 Hz



Hard Disk Platter Excited by PZT at 408 Hz



Hard Disk Platter Excited by PZT at 3069 Hz

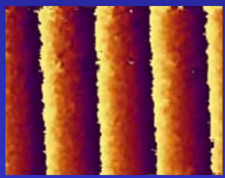


Surface Subtraction

Subtraction in interferogram domain (diffuse and specular surfaces)

Stetson - 8 frame phase-difference

$$\Delta Z = \frac{\lambda}{2}\,\mathrm{atan}\left(\frac{[D_0 - B_0][A(t) - C(t)] - [A_0 - C_0][D(t) - B(t)]}{[A(t) - C(t)][A_0 - C_0] + [D_0 - B_0][D(t) - B(t)]}\right)$$



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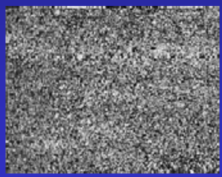

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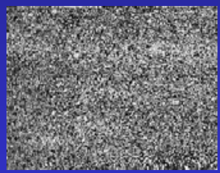


\+
Unwrapping

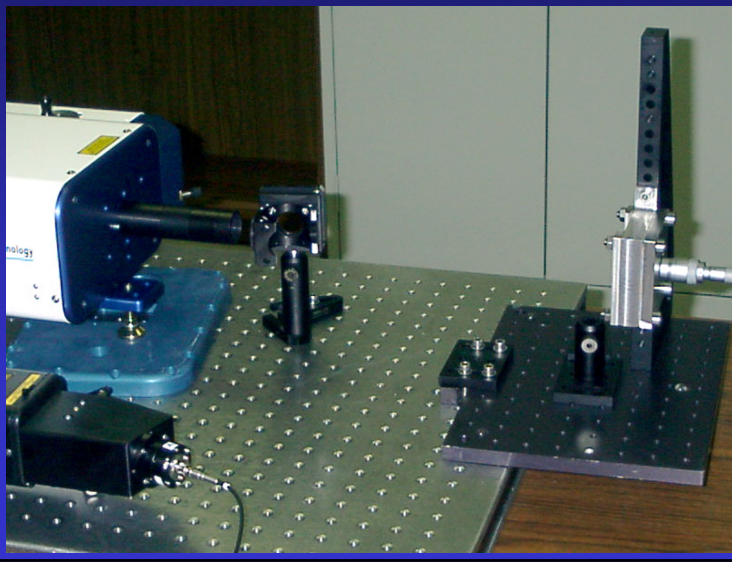
A(t),B(t),C(t),D(t)

A_0,B_0,C_0,D_0

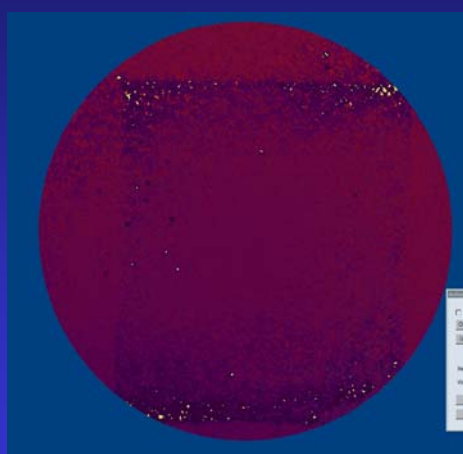
• *Not necessary to solve for random phase*

Backplane Deformation Holder

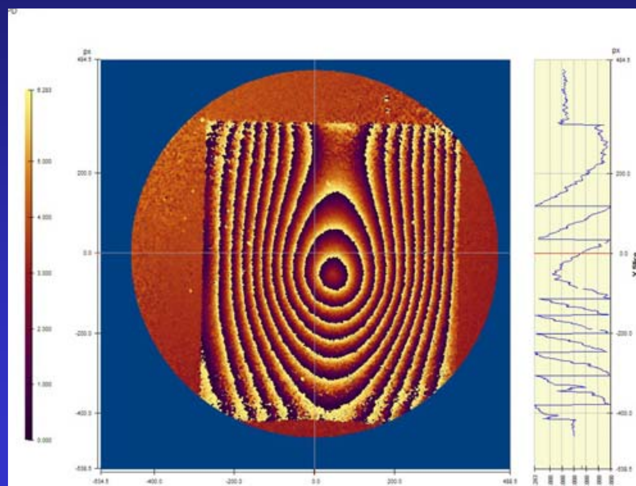
Set Up for Backplane Deformation Measurement



Backplane



Carbon Fiber Deformation



(Metrology for JWST Backplane)

Conclusions – Single Shot Interferometer

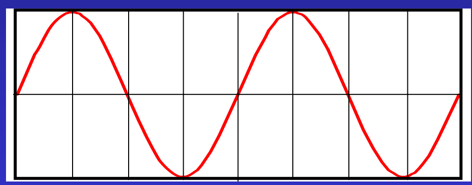
- Vibration insensitive, quantitative interferometer
- Surface figure measurement (nm resolution)
- Snap shot of surface height
- Acquisition of “phase movies”

Still not perfect

Not easy to use multiple wavelength
or white light interferometry

N-Point Technique (Carrier Frequency)

Phase shifting algorithms applied to consecutive pixels thus requires calibrated tilt

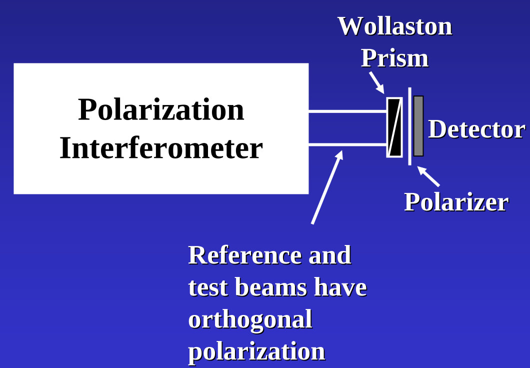


4 pixels per fringe for 90 degree phase shift

Creating the Carrier Frequency

- Introduce tilt in reference beam
  - Aberrations introduced due to beam transmitting through interferometer off-axis
- Wollaston prism in output beam
  - Requires reference and test beams having orthogonal polarization
- Pixelated array in front of detector
  - Special array must be fabricated

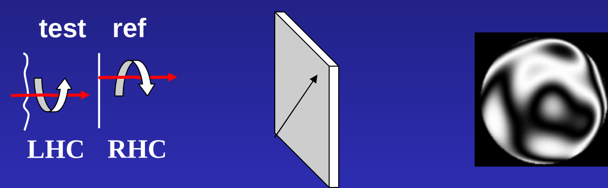
Use of Wollaston Prism to Produce Carrier Fringes



Pixelated Phase Sensor

- Compacted pixelated array placed in front of detector
- Single frame acquisition
  - High speed and high throughput
- Achromatic
  - Works from blue to NIR
- True Common Path
  - Can be used with white light

Use polarizer as phase shifter

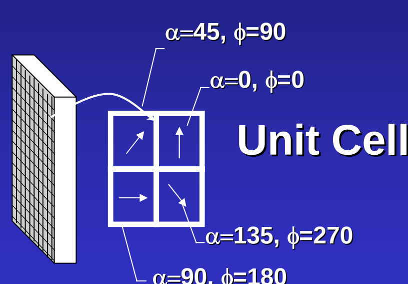


Circ. Pol. Beams ($\Delta\phi$) + linear polarizer (α) ⟶ cos ($\Delta\phi$ + 2α)

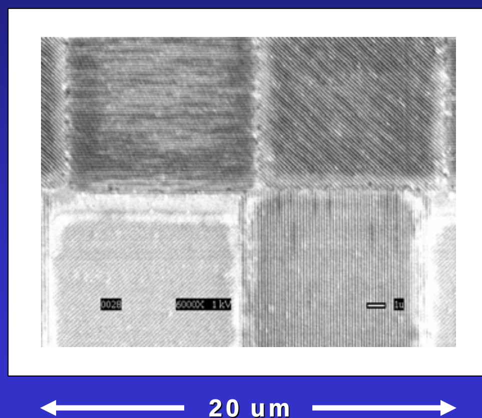
Phase-shift depends on polarizer angle

Array of oriented micropolarizers

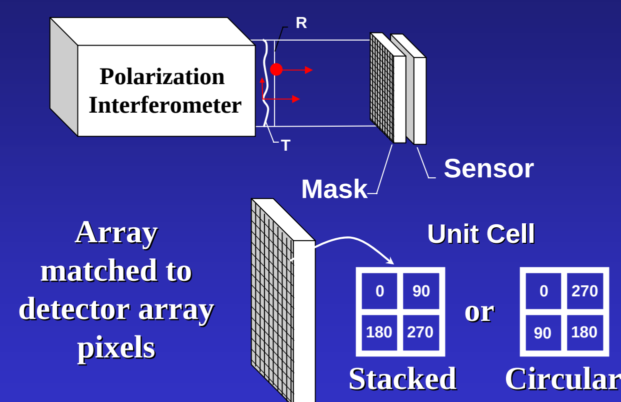
Polarizer array Matched to detector array pixels



Electron micrograph of wire grid polarizers

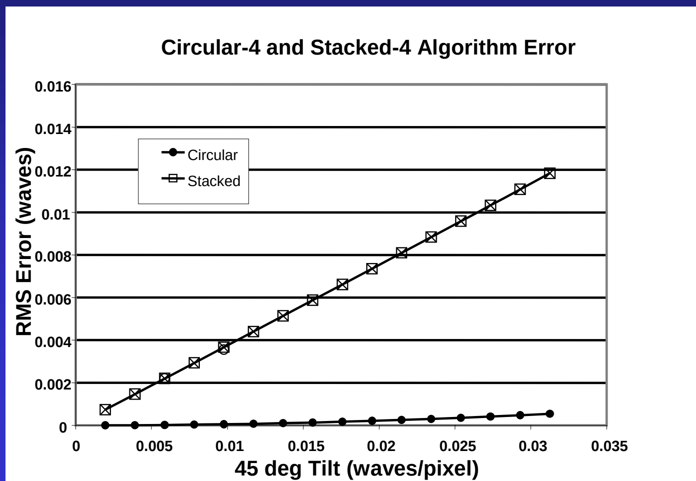


Array of phase-shift elements unique to each pixel

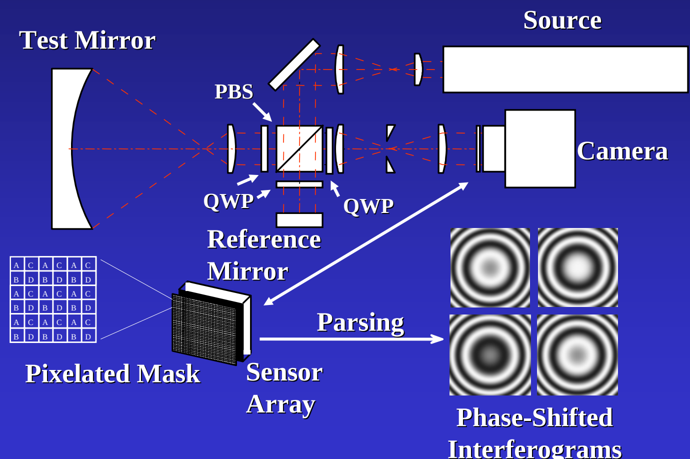


- Similar to spatial carrier but
  - true common path
  - fixed carrier period

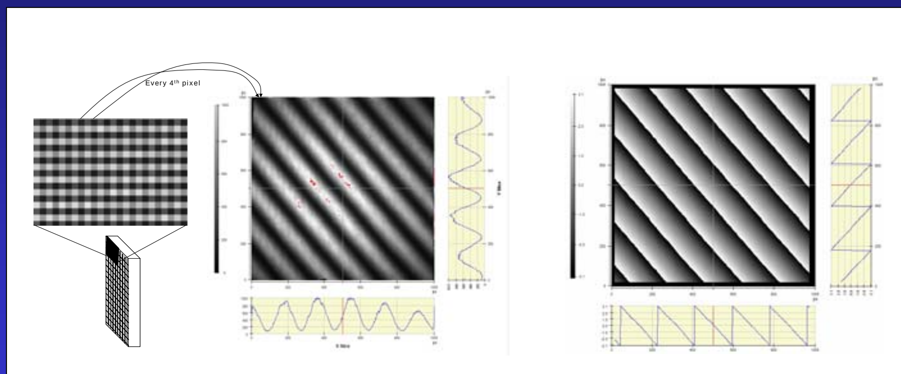
Phase error vs fringe tilt



System Configuration



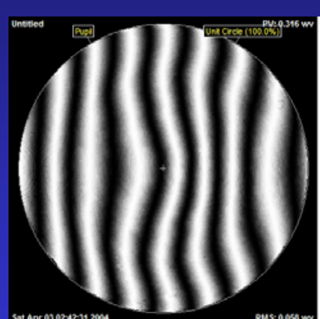
Measurements

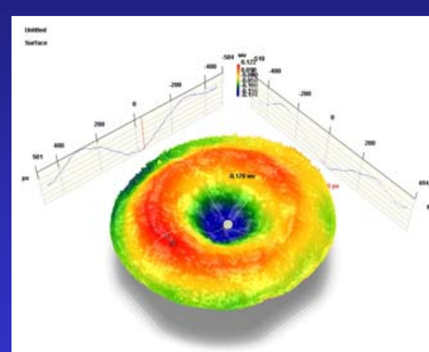


Fringe pattern synthesized by selecting every fourth pixel.

Phase map.

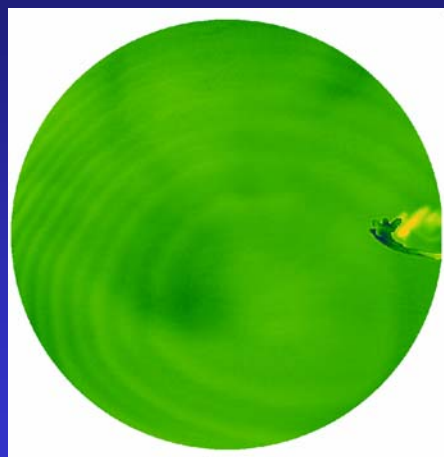
Measurement of 300 mm diameter, 2 meter ROC mirror





Mirror and interferometer on separate tables!

Measurement Results



Air burst
Phase w/reference subtraction

Pixelated Phase Sensor Advantages

- Single frame acquisition
  - High speed and high throughput
- Achromatic
  - works from blue to NIR
- True Common Path
  - Can be used with white light
- Fixed Carrier
  - Faster processing and calib.
- Compact
  - no bigger than camera
- Versatile
  - can be interfaced to many interferometer configurations

Thank you!