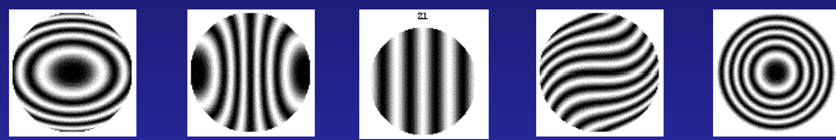
Vibration Insensitive Interferometry



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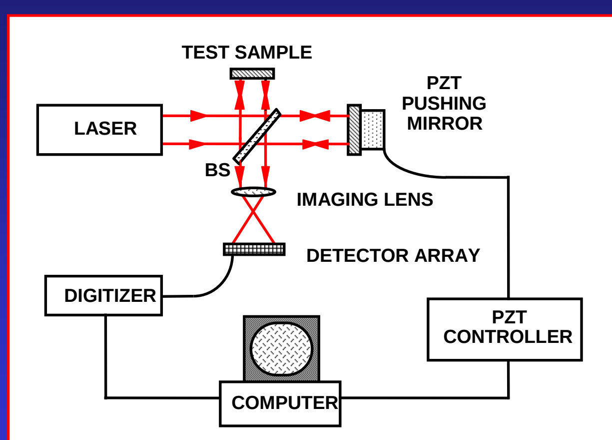
Phase-Shifting Interferometer



Four Step Method

phase shift

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

measured object phase

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

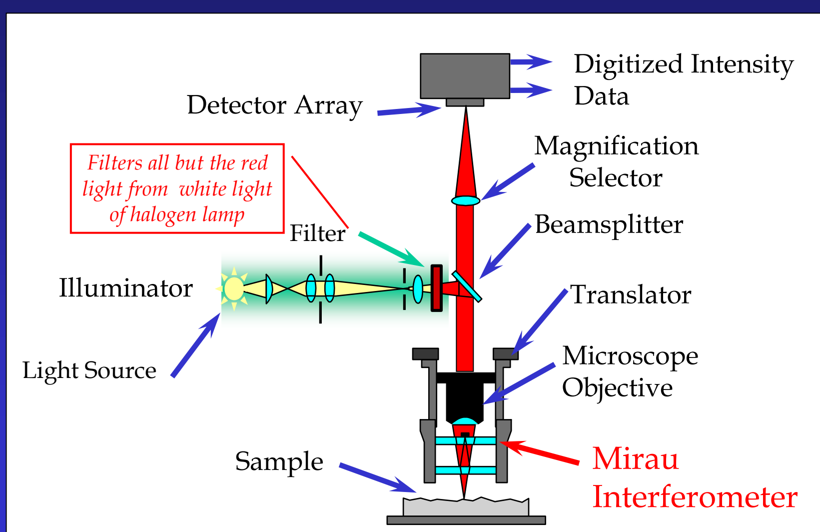
$$\mathbf{I_2(x,y)} = \mathbf{I_{dc}} - \mathbf{I_{ac}} \sin[\phi(x,y)] \qquad = \pi/2 \quad (90°)$$

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

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

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

Interference Microscope Diagram



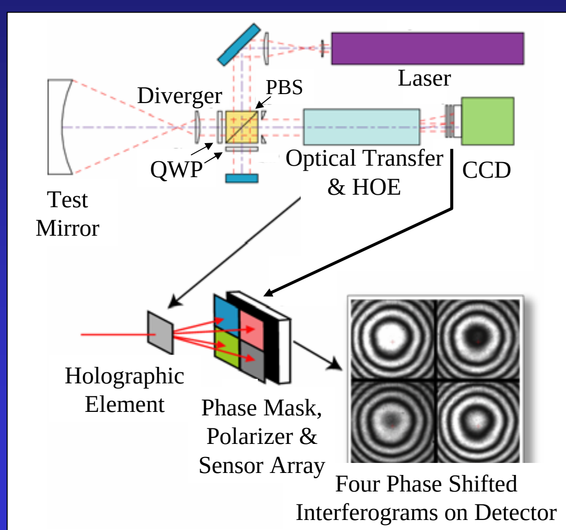
Serious Problem in Interferometry

Vibration!!

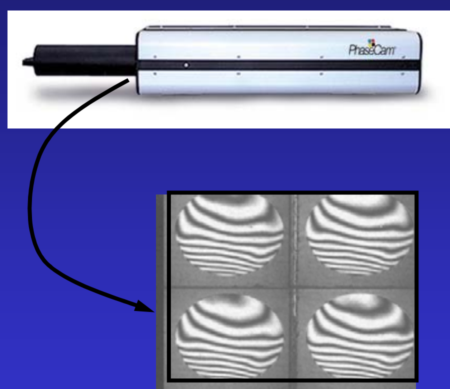
Vibration is often the limiting factor in interferometry applications

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**



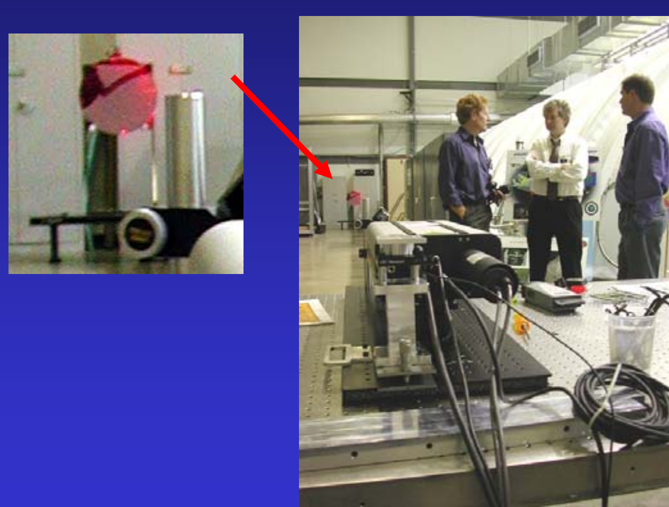
Effects of Vibration



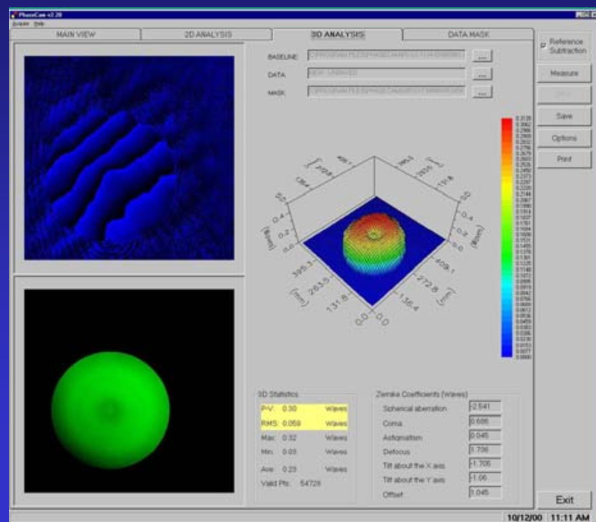
Relative motion between PhaseCam and test object

Phase relationship is fixed

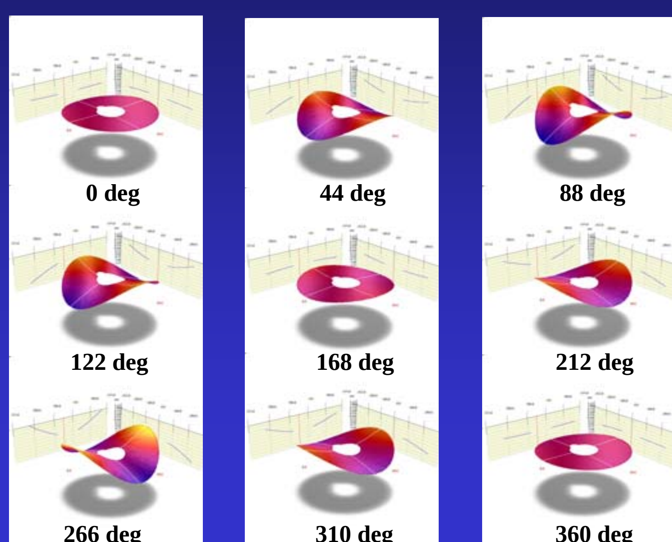
Testing a 0.5 meter diameter, 20 meter ROC mirror



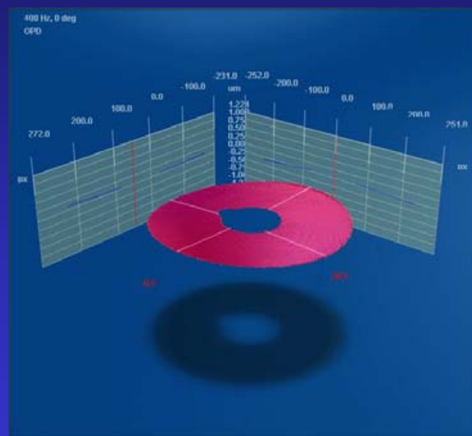
0.5 m diameter mirror, 20 m ROC
5 nm rms repeatability (in air)



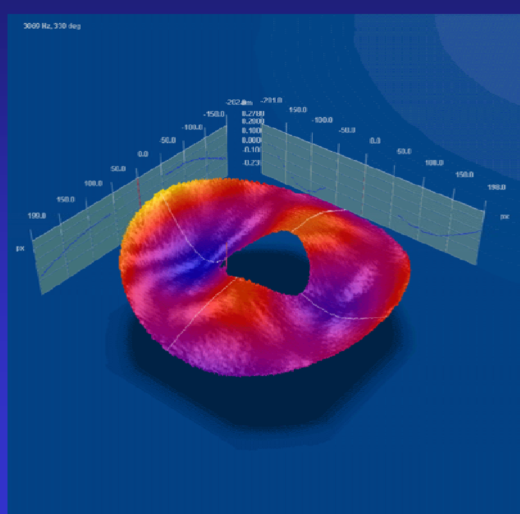
Phase Sweep at 408 Hz



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

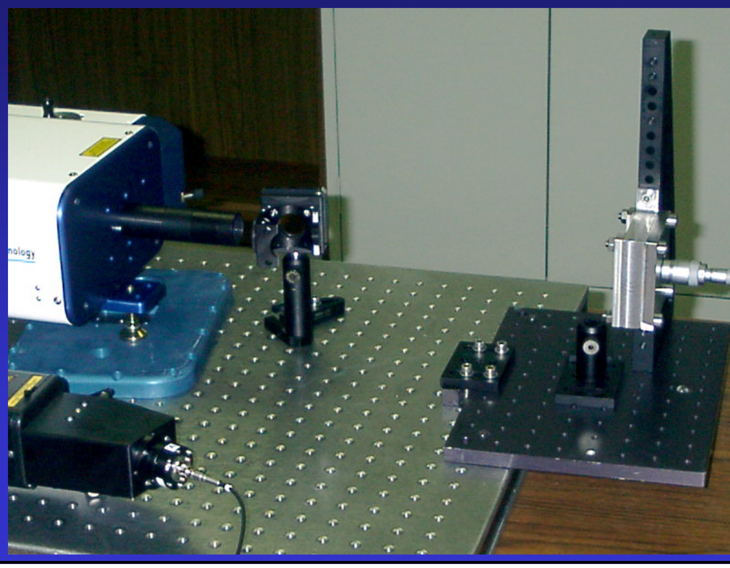
$$\Delta Z = \frac{\lambda}{2}\,\mathrm{atan}\left(\frac{[D_0 - B_0][A(t) - C(t)] - [A_0 - C_0][D(t) - B(t)]}{[A(t) - C(t)][A_0 - C_0] + [D_0 - B_0][D(t) - B(t)]}\right)$$

+ Unwrapping   A(t),B(t),C(t),D(t) A_0,B_0,C_0,D_0

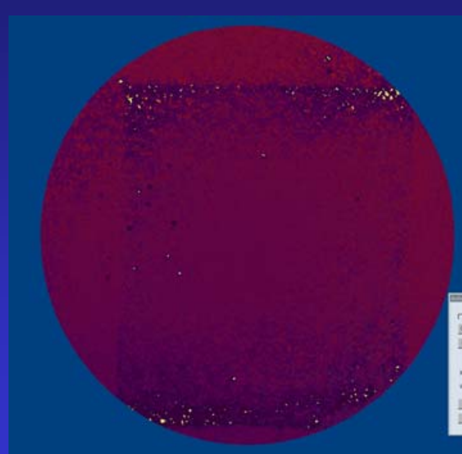
• *Not necessary to solve for random phase*

Backplane Deformation Holder

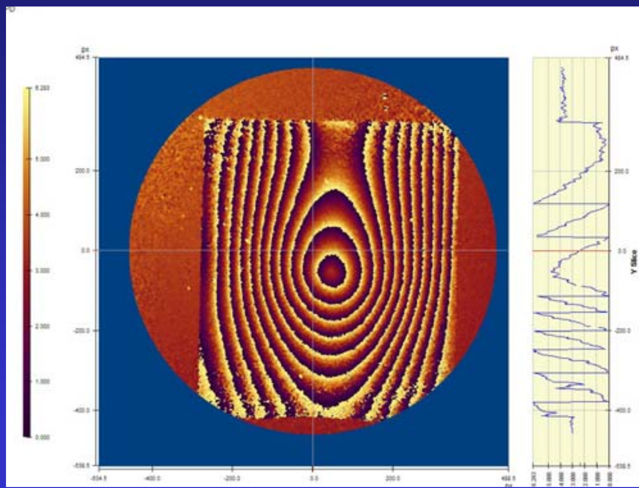
Set Up for Backplane Deformation Measurement



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"

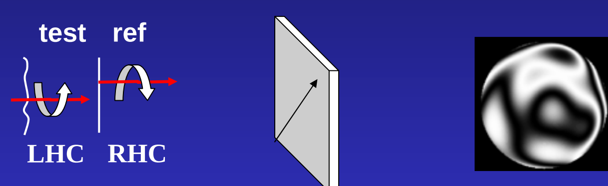
Still not perfect

Not easy to use multiple wavelength or white light interferometry

Pixelated Phase Sensor

- 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

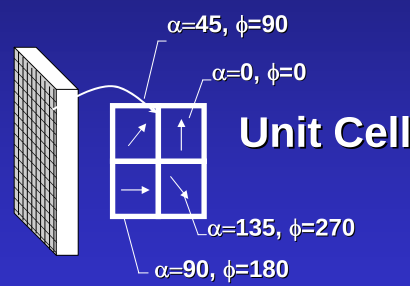


Circ. Pol. Beams ($\Delta\phi$) + linear polarizer (α) ⟶ cos ($\Delta\phi + 2\alpha$)

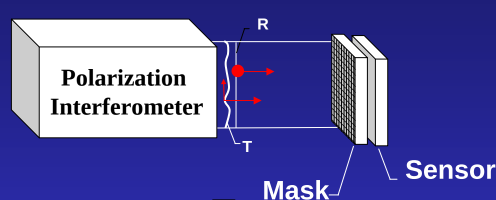
Phase-shift depends on polarizer angle

Array of oriented micropolarizers

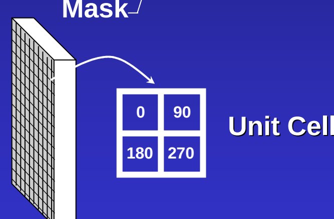
Polarizer array
Matched to
detector array
pixels



Array of phase-shift elements unique to each pixel

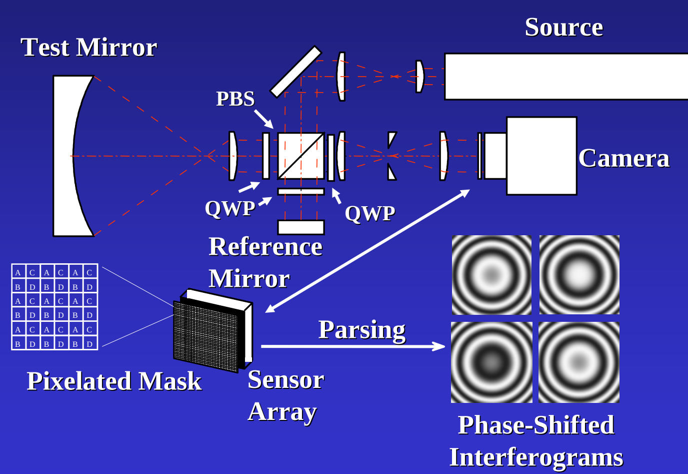


Array
matched to
detector array
pixels

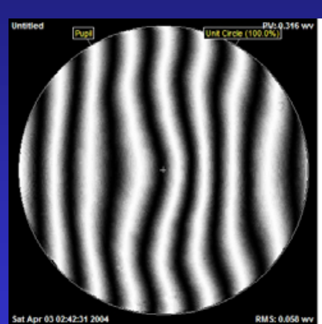


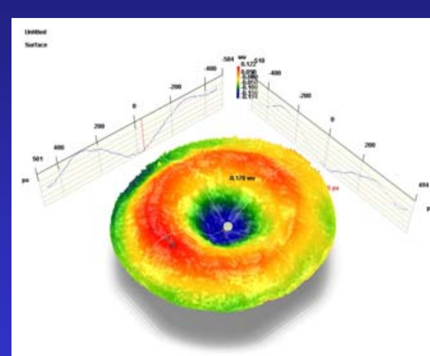
- Similar to spatial carrier but
  - true common path
  - fixed carrier period

System Configuration



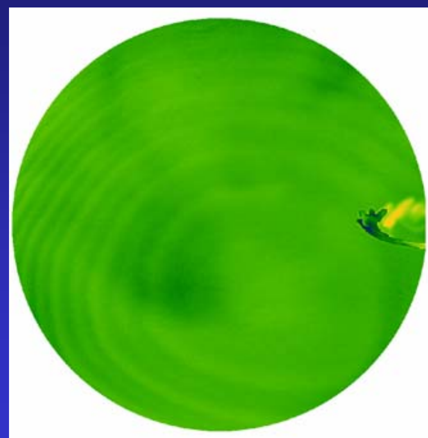
Measurement of 300 mm diameter, 2 meter ROC mirror





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!