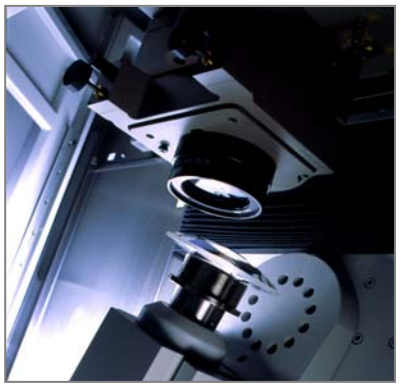
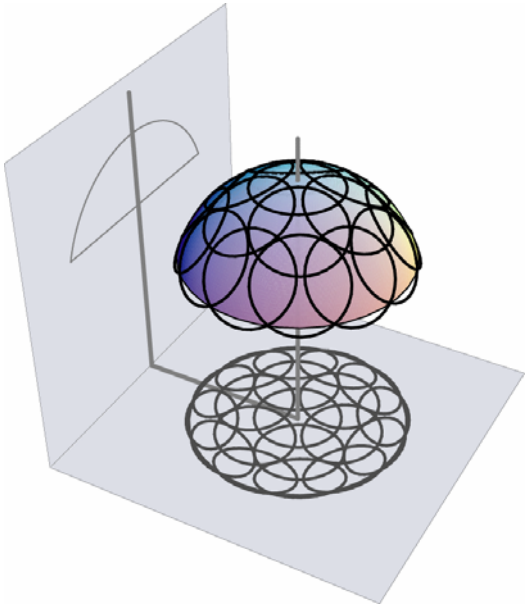
# Subaperture stitching interferometer (SSI)



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**Acknowledgements:**

Dr. Jim Kirsch

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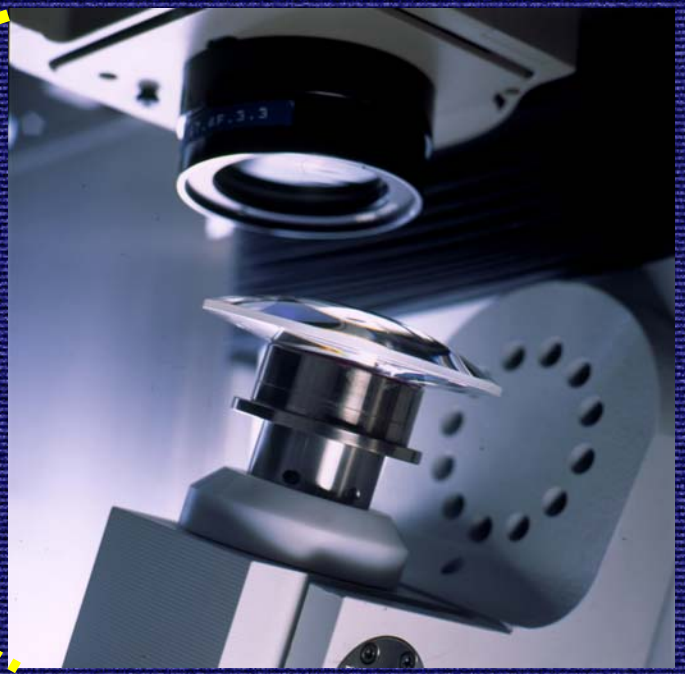
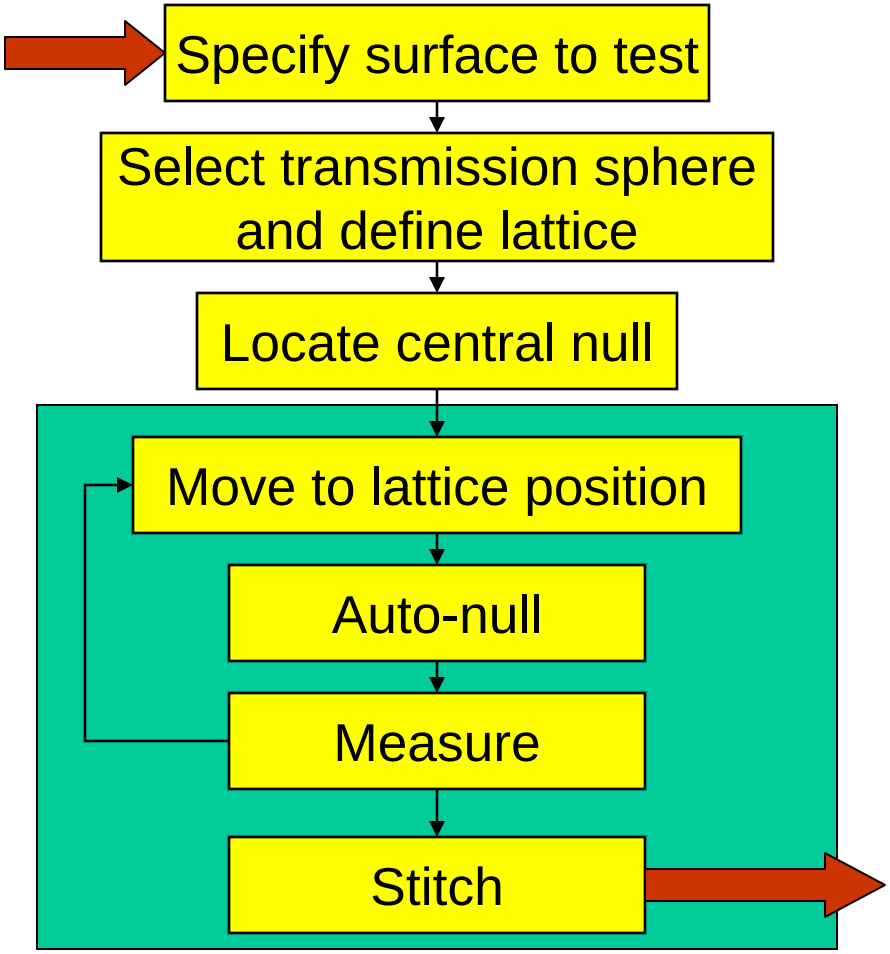
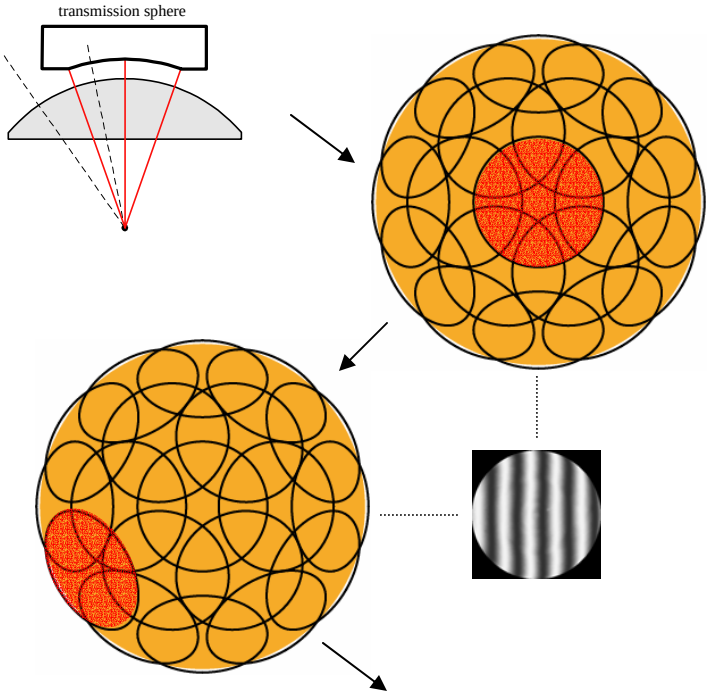
# What is QED's Subaperture Stitching Interferometer?

- Precision six axis machine
  - Engineered in cooperation with Schneider Opticmachines
- Standard Zygo 4" or 6" interferometer
- QED control software
  - Measurement process automation + advanced algorithms

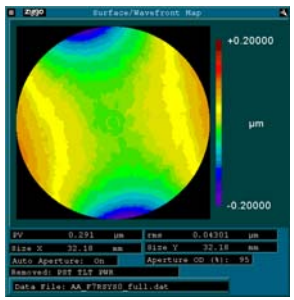


# SSI measurement process



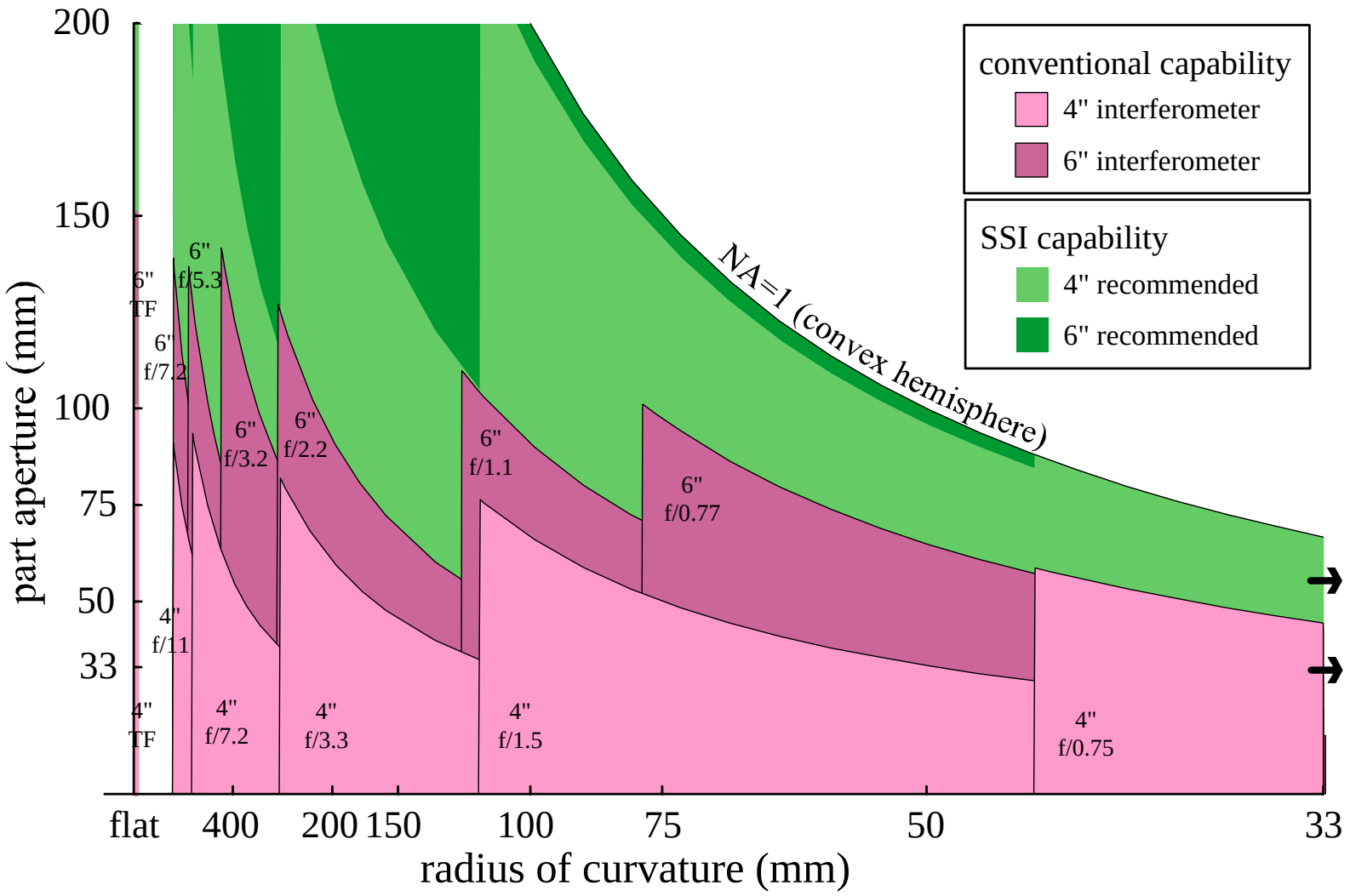

Full-aperture map



# Overview of stitching benefits

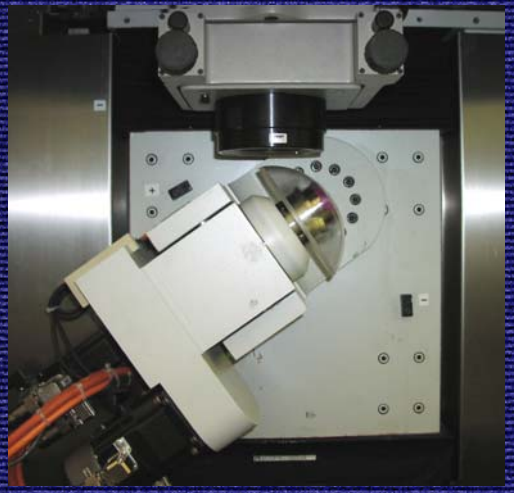
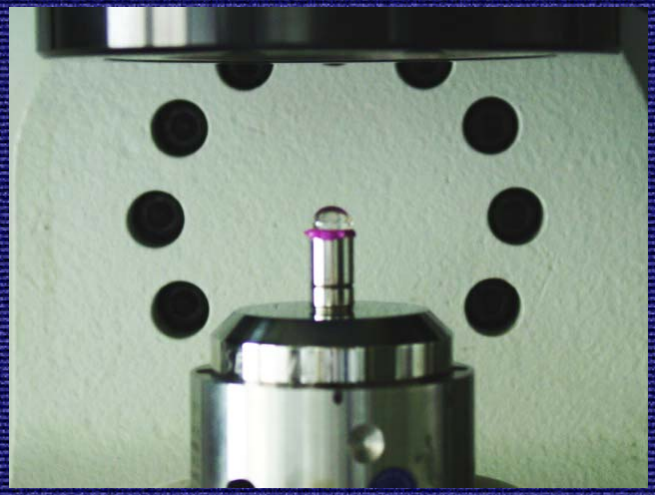
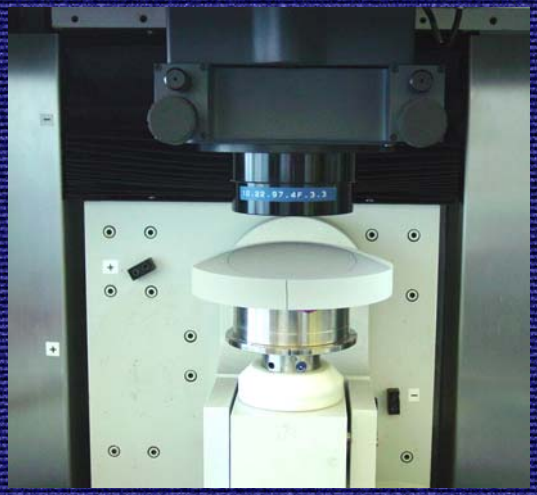
- Increase lateral dynamic range
  - Increased lateral range by a factor of XF ("Extension Factor")
    - Includes large numerical apertures (domes, hemispheres, etc.)
  - Can improve lateral resolution (data density)
- Superior accuracy
  - Automatic computation or measurement of reference wave
  - Calculation of mapping errors (pixel scale, distortion)
- Increased longitudinal range
  - Asphericity is "spread" among the subapertures, gain ~ $XF^2$
    - One factor of XF from magnification
    - Another factor ~XF from fitting a local best-fit sphere
    - *Demonstrate this effect on later slides*

# Extended lateral range



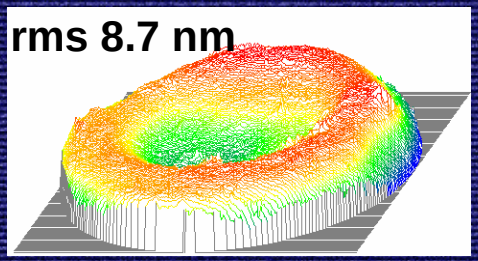
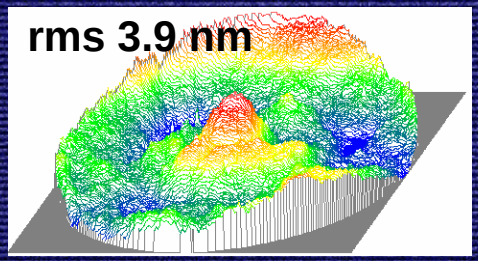
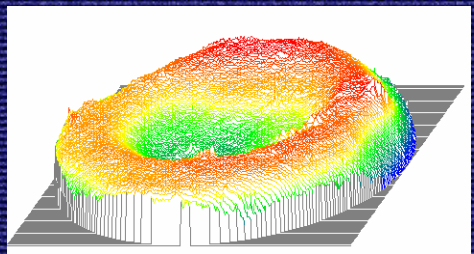
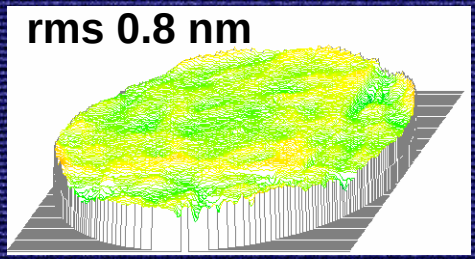
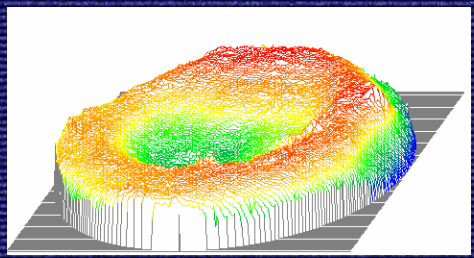
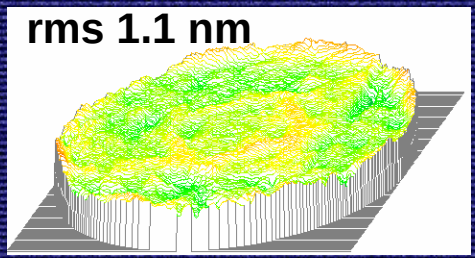
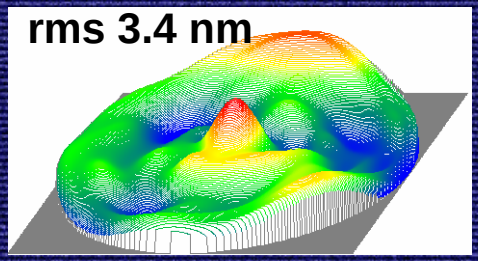
# Sample of parts that can be measured on the current SSI

- Measures surfaces that have traditionally challenged commercial interferometers
  - Aperture up to 200 mm, angle up to 90º (hemisphere)

| Large dome | Small hemisphere | Large convex |
|---|---|---|
|  |  |  |
| Ø: 148 mm<br>R: 82 mm<br>NA: 0.90 (64º) | Ø: 9 mm<br>R: 4.5 mm<br>NA: 1.0 (90º) | Ø: 200 mm<br>R: 500 mm<br>NA: 0.2 (12º) |

# Stitch / full aperture cross-test

- Concave: aperture 80, radius 126 mm

| | Test surface (scale 50 nm) | Difference from two-sphere test surface (scale 20 nm) | Reference surface (scale 20 nm) |
|---|---|---|---|
| Two-sphere | rms 8.7 nm  | | rms 3.9 nm  |
| Stitched (reference: two-sphere) |  | rms 0.8 nm  | |
| Stitched (reference: calculated, 230 Zernike terms) |  | rms 1.1 nm  | rms 3.4 nm  |

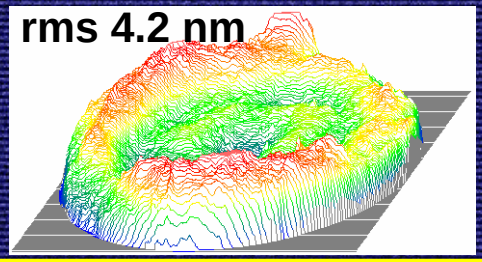
# Transmission sphere cross-test

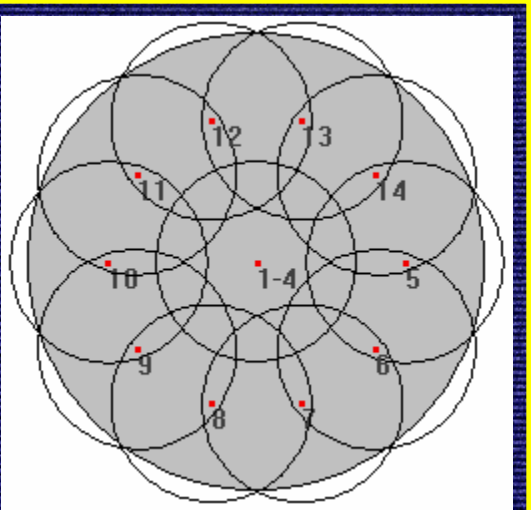
- Convex: aperture 80, radius 126 mm

  - Not testable with 4” f/1.5 or 6” f/1.1
  - Stitch with 4” f/3.3 and 4” f/7.2

**f/3.3**
**(36 mm field of view)**
**14 subapertures**
**XF =2.2**

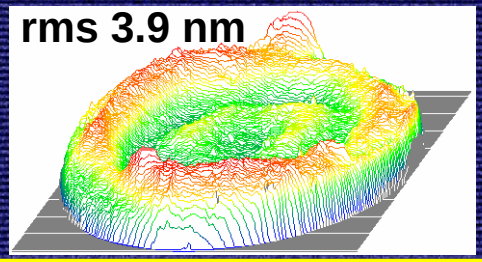
rms 4.2 nm

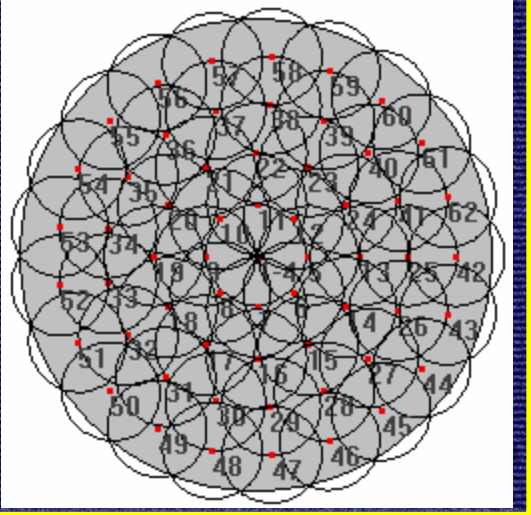





**f/7.2**
**(17 mm field of view)**
**62 subapertures**
**XF = 4.7**

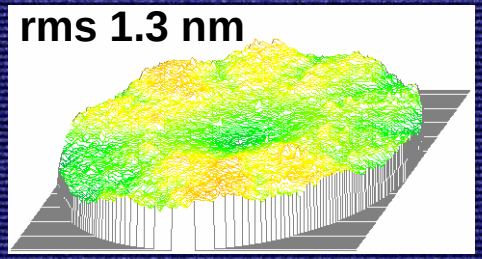
rms 3.9 nm





**Difference between f/3.3 and f/7.2 stitches**

rms 1.3 nm



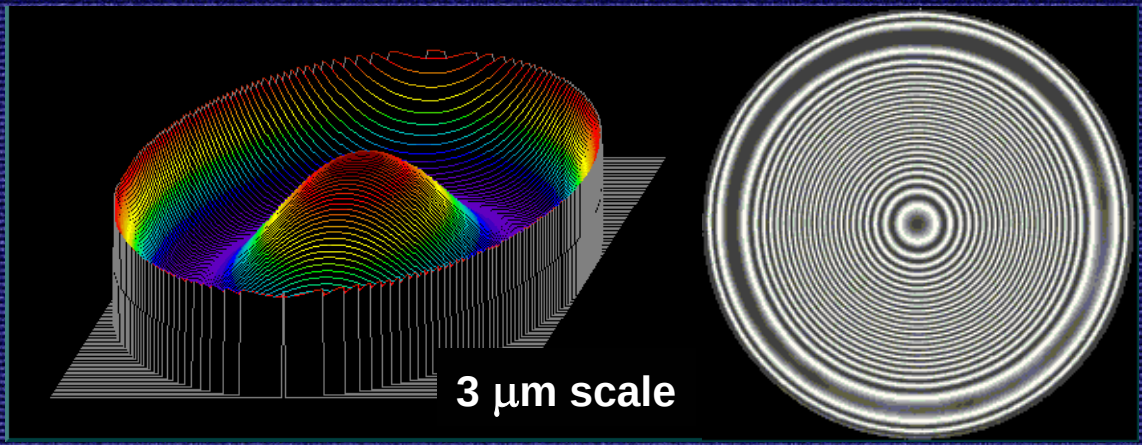
***Still quite accurate, even with many subapertures***

# Non-null test example

❖ Very mild hyperbola: 3.1 μm departure

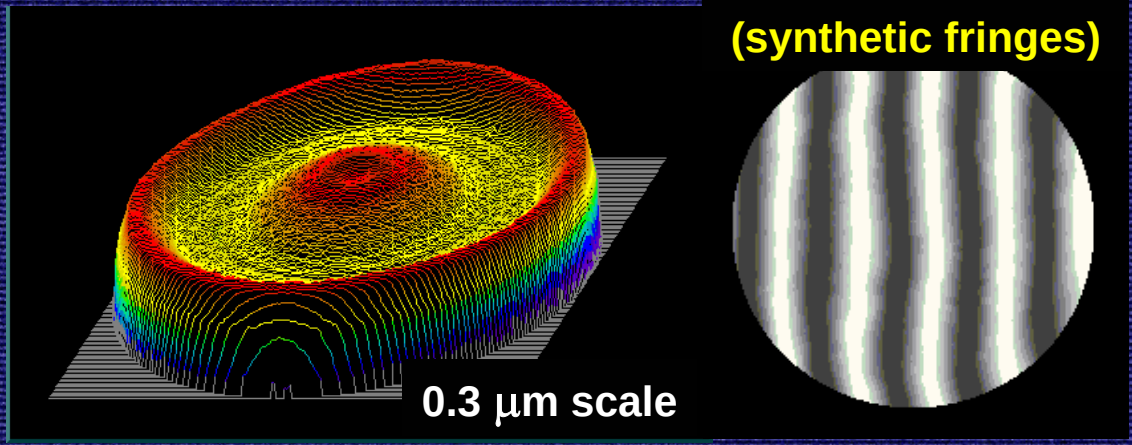
Non-null measurement
(spherical reference)

(this asphere is close to the slope limit of a standard interferometer)




(synthetic fringes)

Deviation from asphere
(nominal prescription subtracted from the measurement)

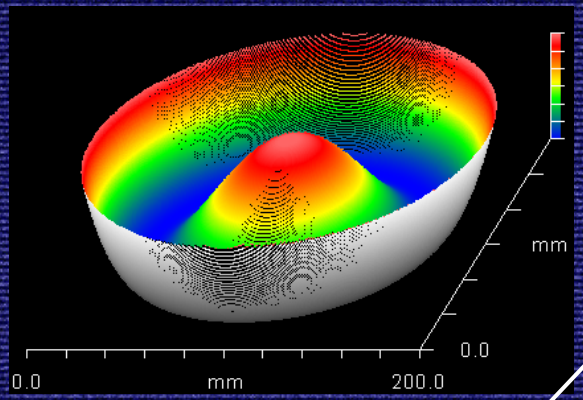


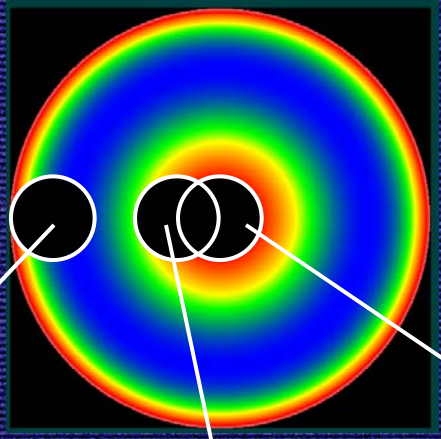
# Non-null test issues

- Fringe resolution
  - Dense fringes cannot be resolved, limiting the amount of aspheric departure measurable in a non-null test
- Retrace error
  - Many fringes in view cause a loss of accuracy that depends on the local fringe density
- Alignment
  - More sensitive to lateral calibration and distortion
  - Tilt and translation are not equivalent (e.g. induced coma)
  - Confocal position is ill-defined (continuum of pseudo-nulls)
- *QED is developing software to alleviate these issues*

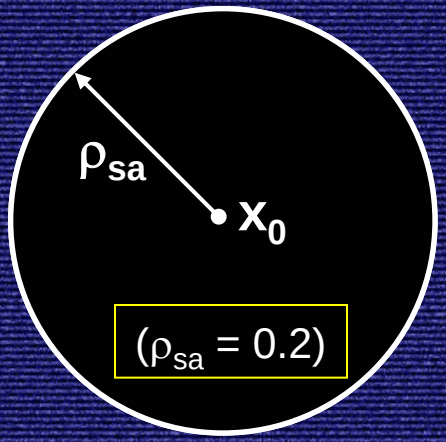
# Extended longitudinal range example

4th order sag, scale: PV 25 μm

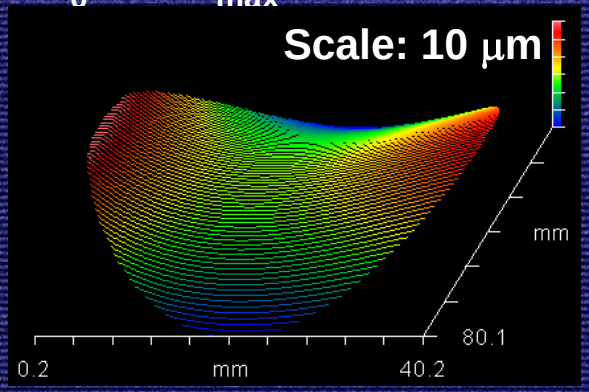


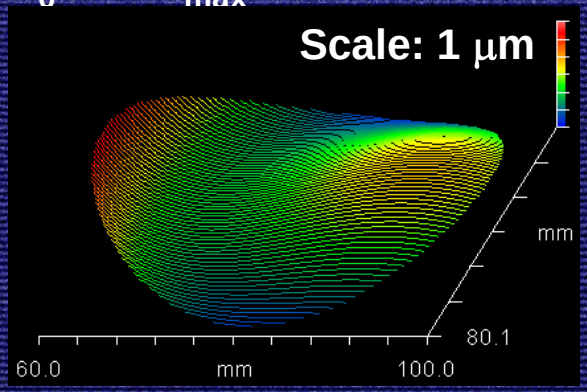
Subaperture close up



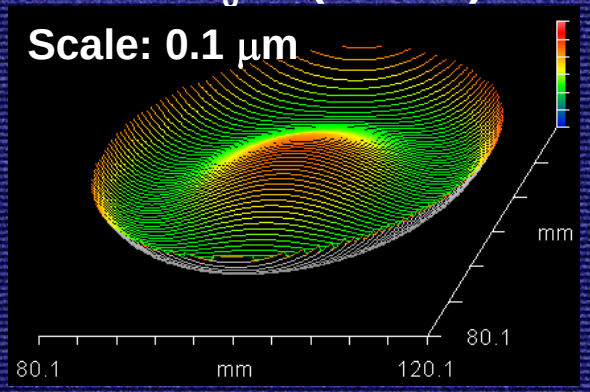

x0: 0.8 rmax




x0: 0.2 rmax

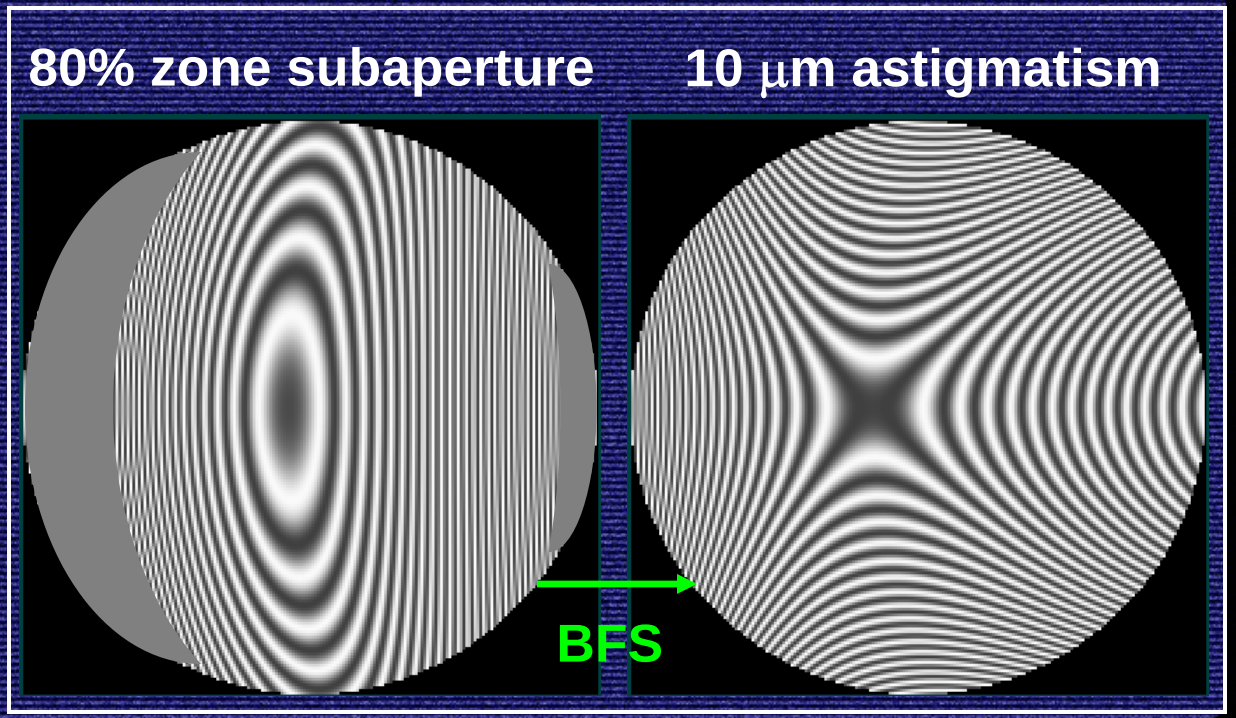



x0: 0 (center)



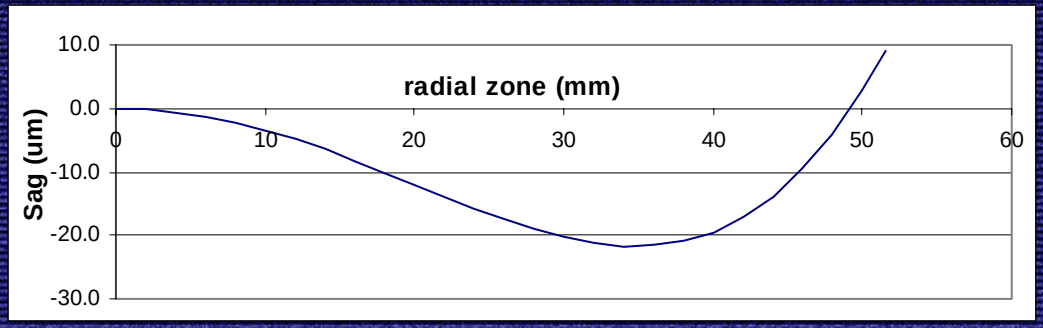
# Vertical range extension

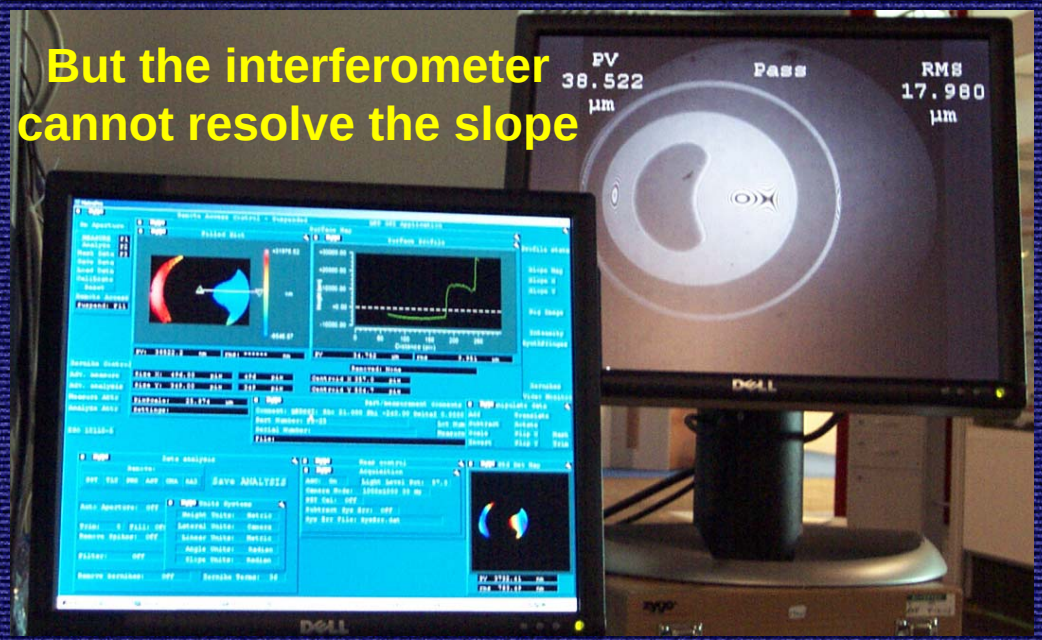
- From 25 to 10 μm may not seem like much, but…
  - measurement limits are usually driven by *slope*
  - spherical slope is ~10x astigmatism for a given PV
  - XF of 5 can get a vertical dynamic range extension of up to 25x



# Example asphere measurement

- Live at Optatec show, June 2004



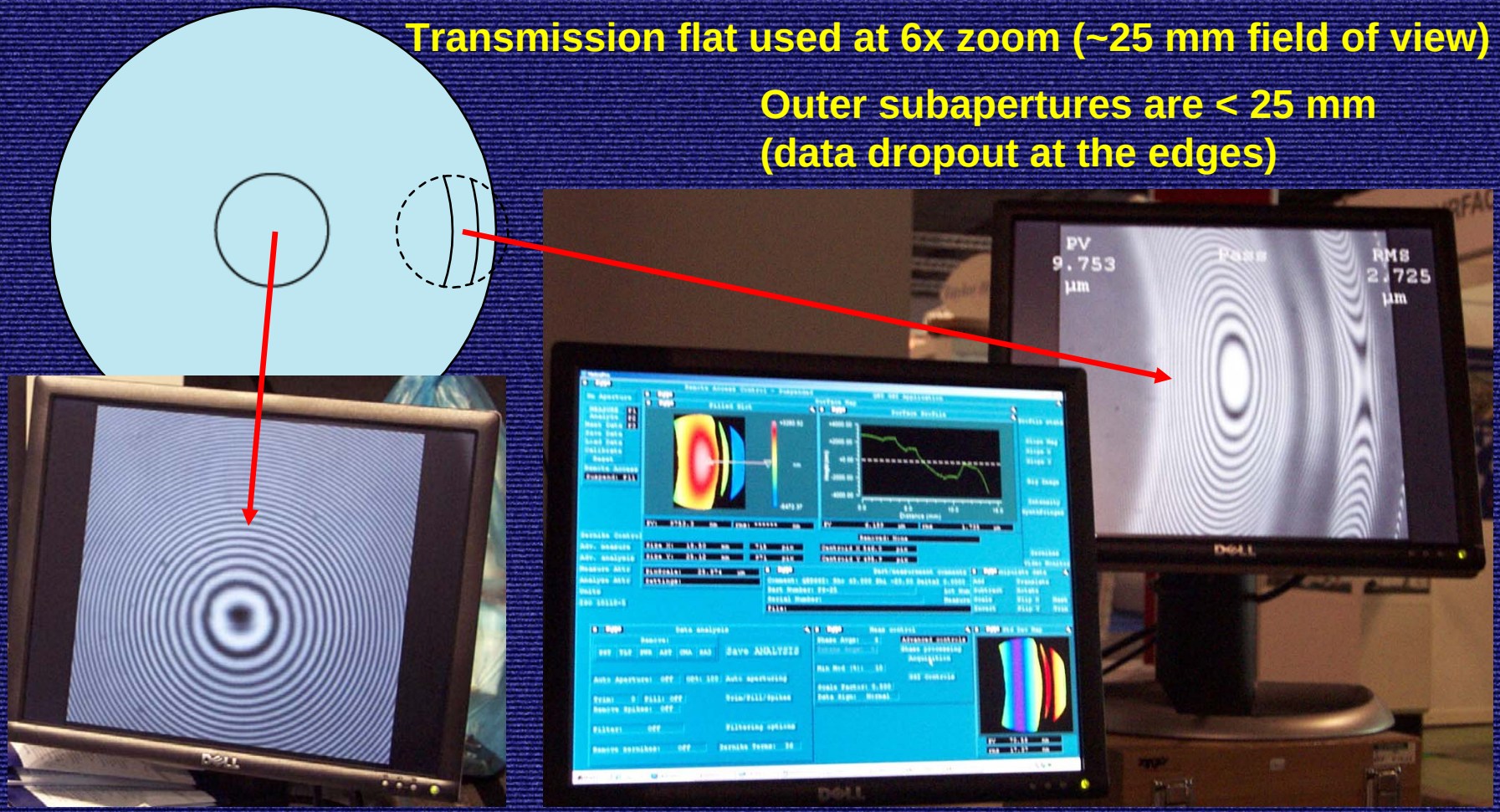




# Acquisition in progress

- Measurement time ~30 min (~70 subapertures)

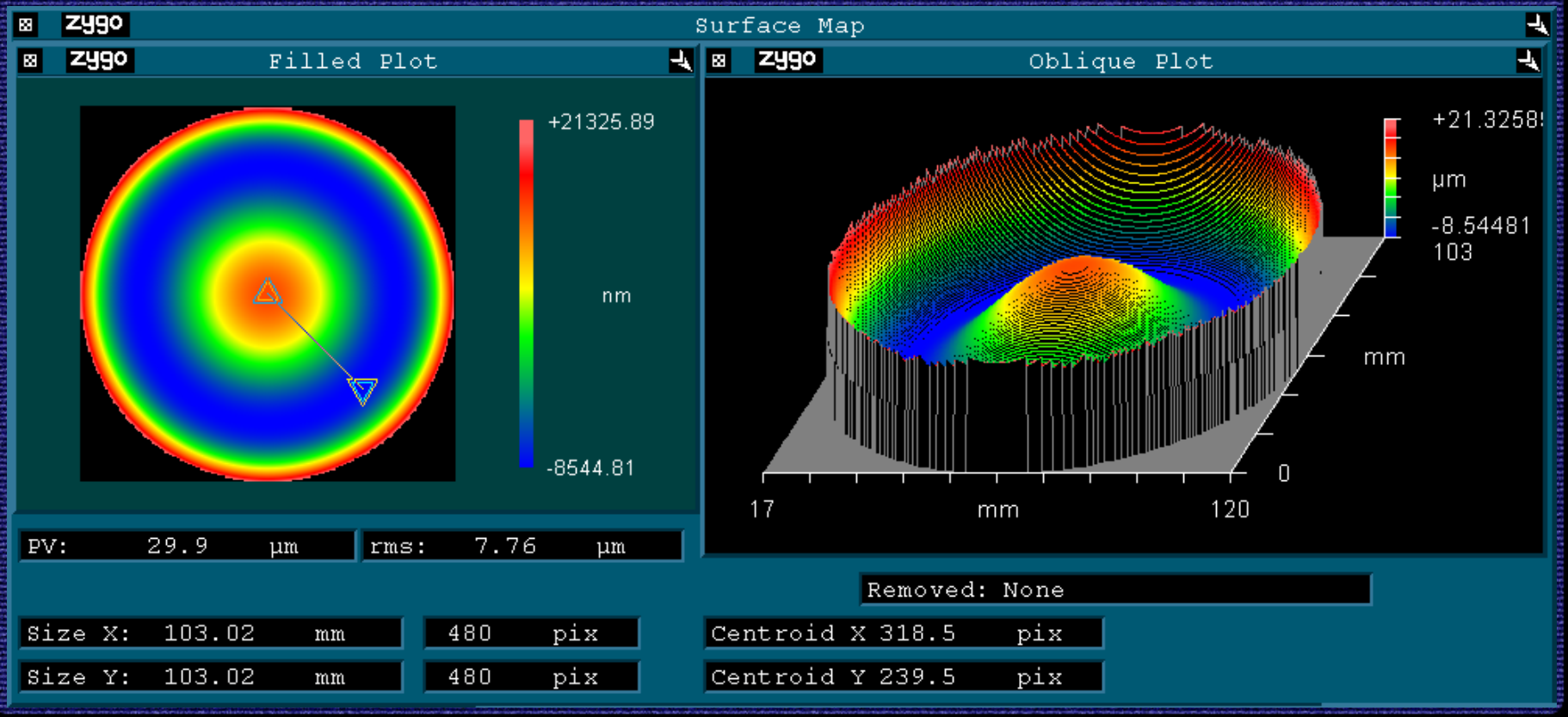
**Transmission flat used at 6x zoom (~25 mm field of view)**

**Outer subapertures are < 25 mm (data dropout at the edges)**



# Stitching results

- Deviation of the part from a plane
  - accuracy analysis pending



# Asphere roadmap

- Presently: up to ~3 μm (w/o SSI), ~10 μm (w/ SSI)
  - User skill is required to address shape subtraction, alignment compensation, and retrace error assessment
- Mild asphere software for SSI
  - Current capability (ready to test)
    - Acquire data on aspheres with ~30-50+? μm of departure
    - Subtraction of aspheric shape from non-null test
  - Under development
    - Automatic lattice design
    - Improved error compensation
- Moderate departure asphere system
  - In R & D

# Comments on first asphere test

- This first attempt demonstrates promising results
- But many unanswered *scientific* questions remain!
  - Complete characterization of performance
    - Uncertainty in the null measurement
    - Repeatability / reproducibility of stitched measurement
    - How fast does the accuracy degrade with slope?
    - What is the sensitivity to poor part figure?
  - What performance improvements are reasonable?
    - Lattice optimization
    - Retrace calibration
    - Other data pre-processing / inteferometer setting management
    - Etc.

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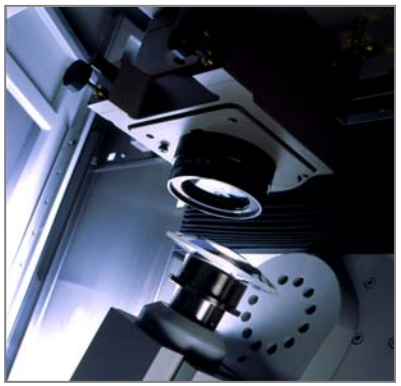

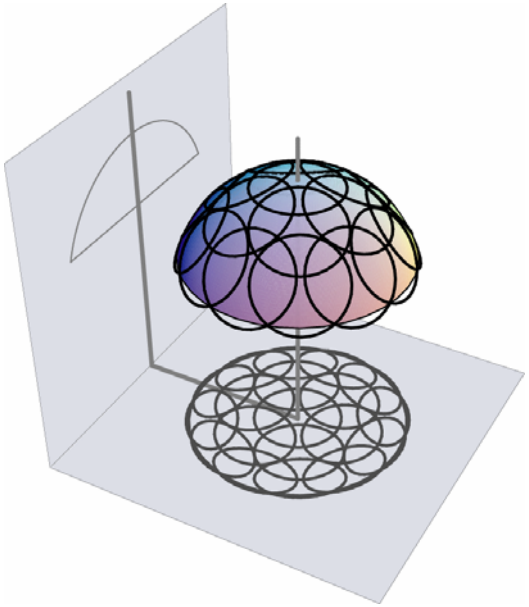


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