



Join the OptiPro Revolution.

New Developments in the Non-Contact Metrology of Freeform Surfaces

By: Scott DeFisher

NASA Mirror Tech Days

Open Session

November 2, 2016

Measurement Methods

- Equipment
- Software
- Capabilities

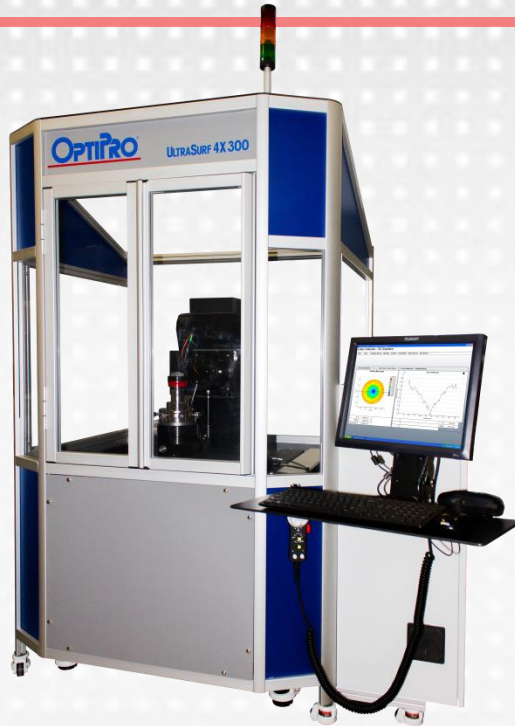
Measurement Examples

- Freeform
- Toroidal Window

UltraSurf 4X/5X



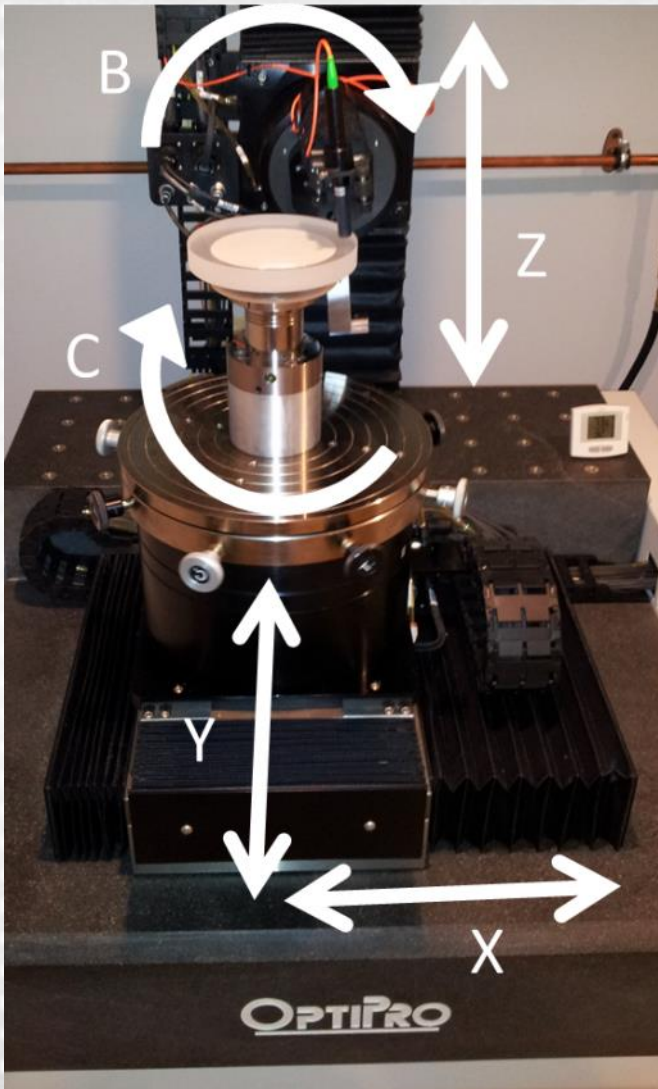
Join the OptiPro Revolution.



Non-contact 3D measurement system

- **High precision measurements:** Granite base and air bearing axes allow for measurement of workpieces down to 1/8 wave (.075 μm RMS)
- **Easy setups:** Intuitive Graphical User Interface for simple instrument operation
- **Fast measurements:** Aspheric measurement in under a minute
- **Highly productive:** Proprietary software and the use of a variety of sensors allow for multiple feature measurements in one setup
- **Infinite asphere capability:** Accurately measure ANY asphere up to 300mm in diameter
- **Freeform capable:** Ability to perform full 5-axis measurements of freeform optics
- **Material flexibility:** Capable of measuring glass, ceramics, crystals and metals
- **Ground or polished workpieces:** Variety of sensors available at different wavelengths allow for measurement of optics in the ground or polished state
- **Engineered with the customer in mind:** Combination of small footprint and exceptional ergonomics optimize floor space and operating efficiency





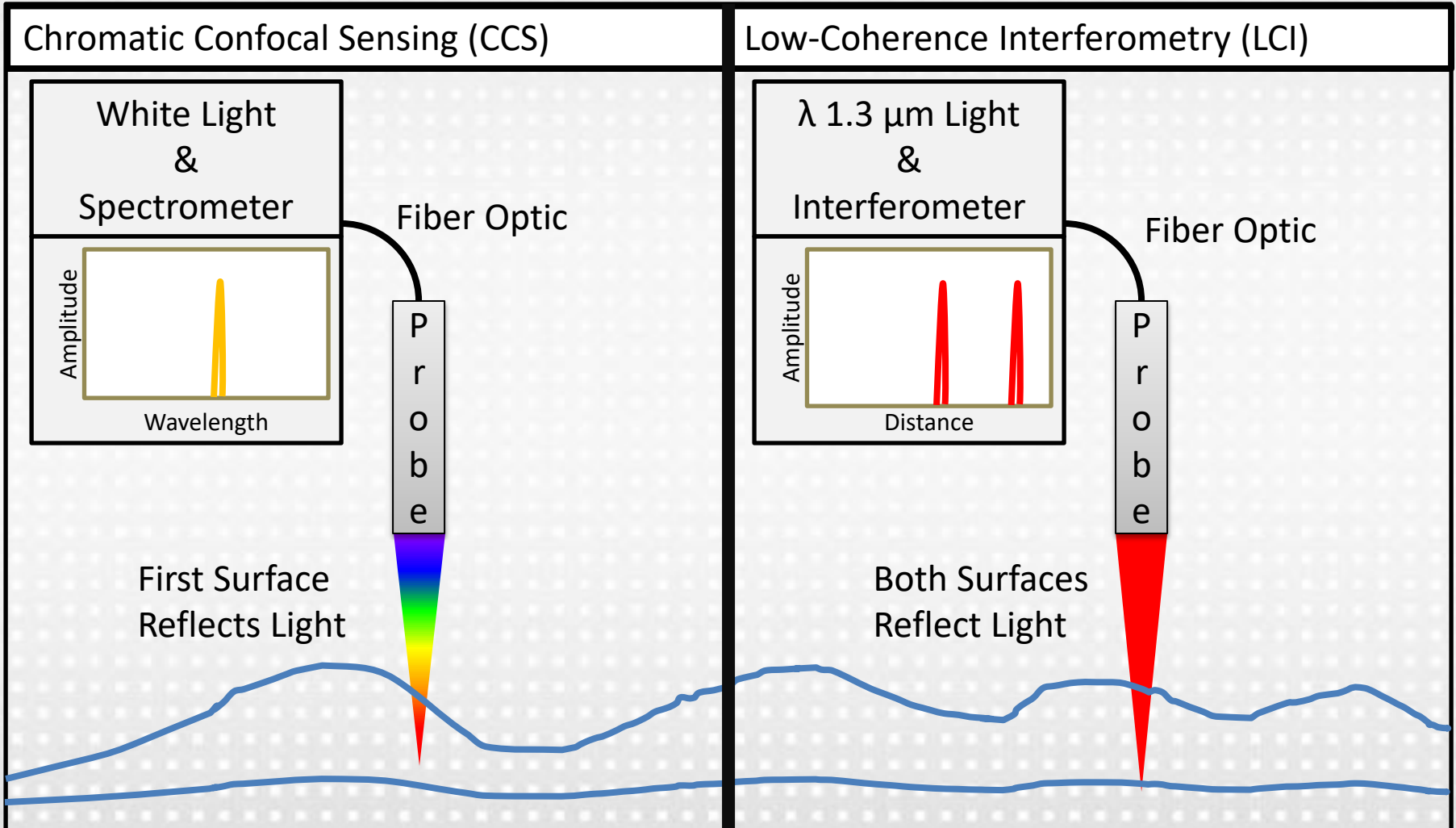
- 5-Axis Non-Contact Measuring System
- Scans With Various Non-Contact Probes
- All Air Bearing Axes
- Linear Motors
- Brushless DC Rotary Motors
- X,Y,C move the part
- Z,B move the probe

Axis:	X,Y,Z	B	C
Travel:	200 mm	360°	360°
Resolution:	5 nm	0.02 second	0.01 second
Max. Velocity:	20 mm/s	6 RPM	6 RPM

Non-Contact Probes



Join the OptiPro Revolution.



1-10 μm Lateral and 10 nm Vertical resolution

30-50 μm Lateral and 30 nm Vertical resolution

Current Measurement Abilities



Join the OptiPro Revolution.

Rotationally Symmetric

Spheres

Aspheres

Ogives

Parabolas

Non-Rotationally Symmetric

2-D Flats

Cylinders

Profiles

Freeform/Conformal

Mathematical Equation

Cloud of Points

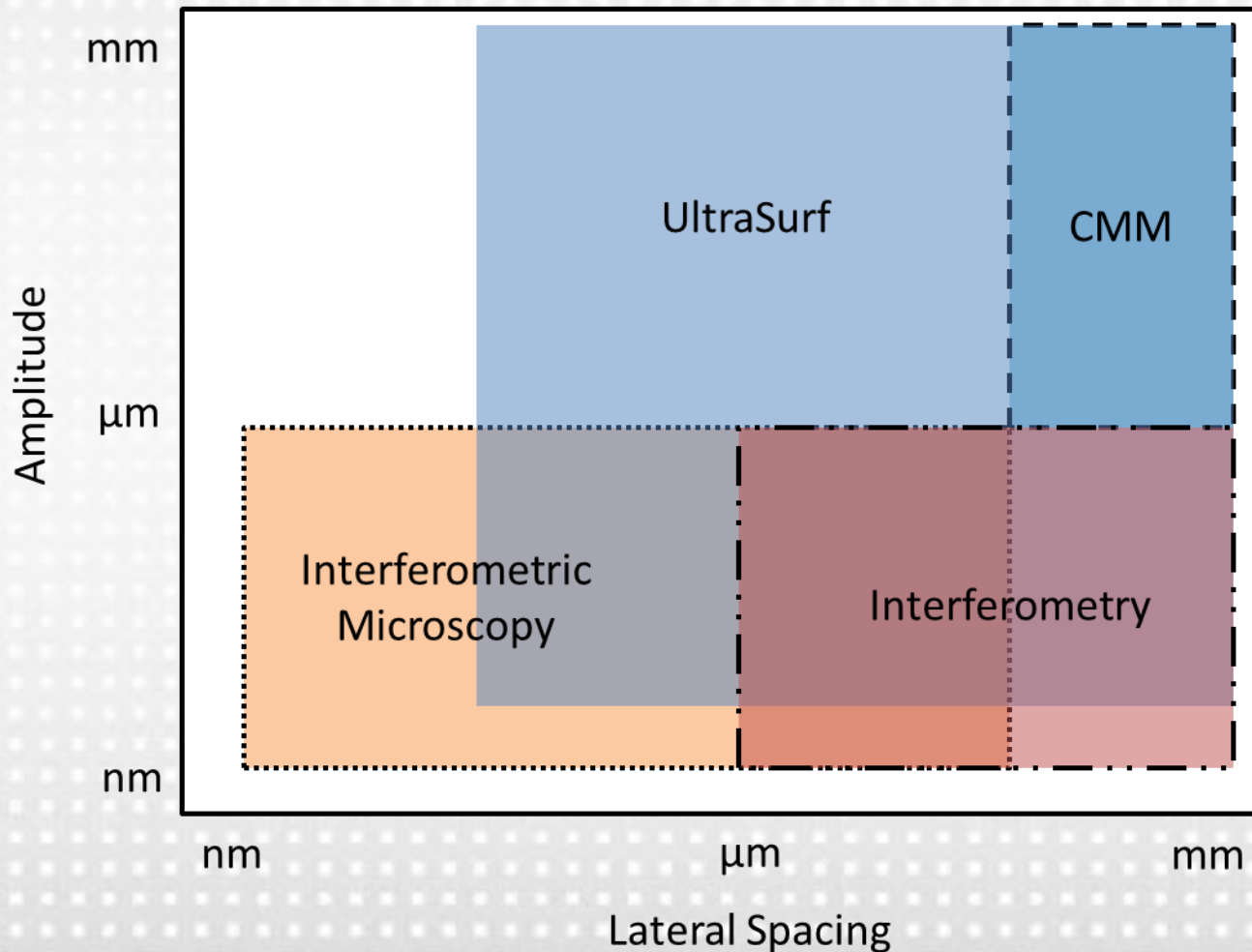
CAD

Instrument Capabilities



Join the OptiPro Revolution.

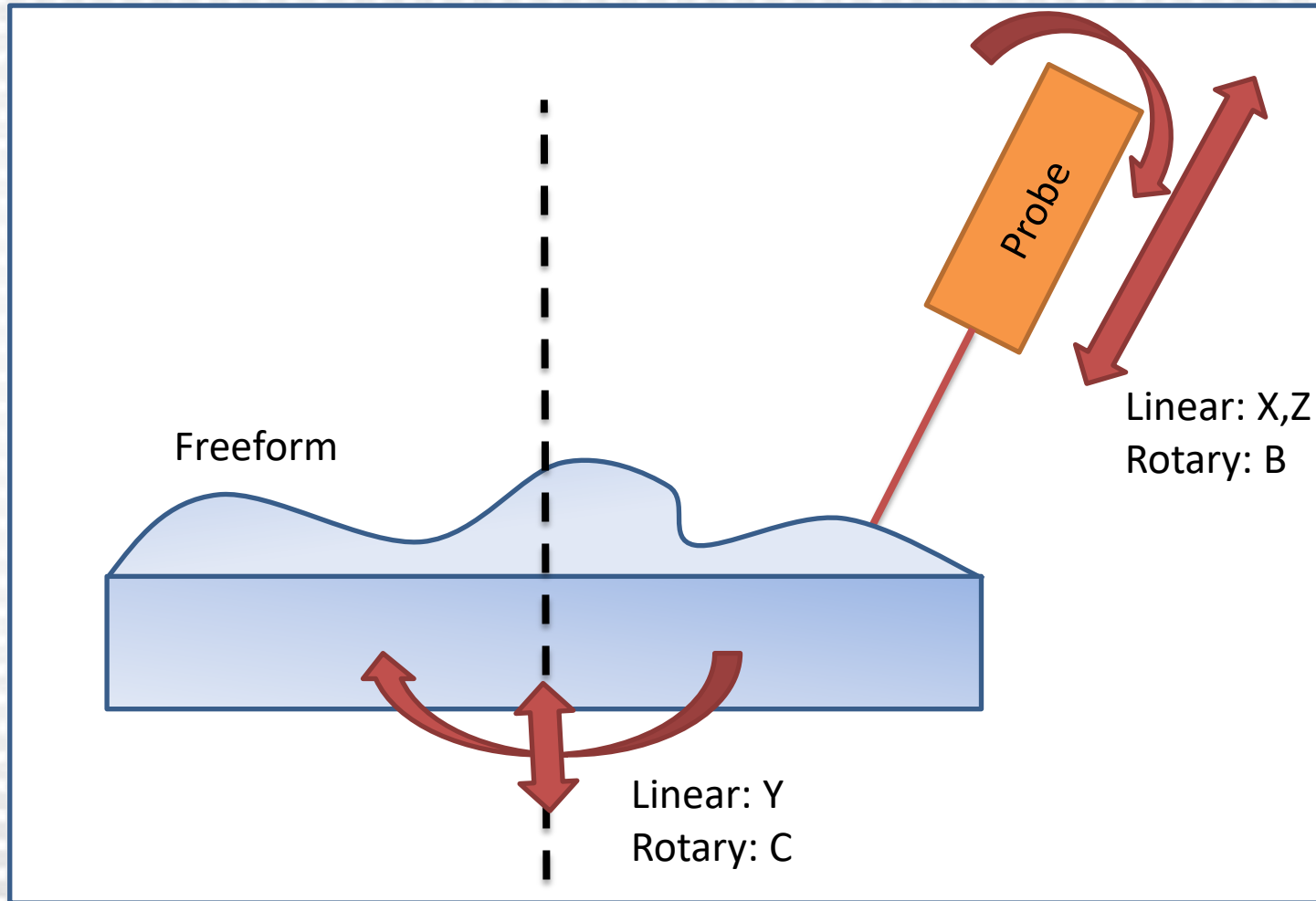
UltraSurf compared to common fabrication instruments



5-Axis Freeform Example



Join the OptiPro Revolution.

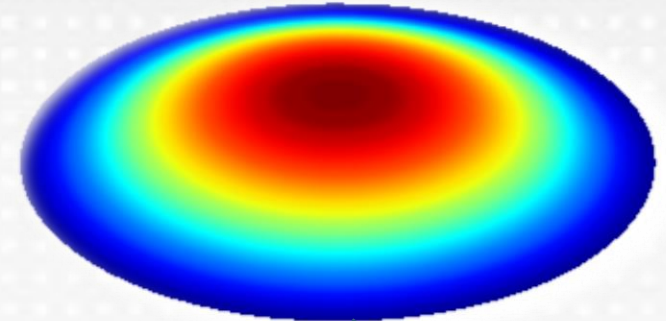


Point Cloud Registration

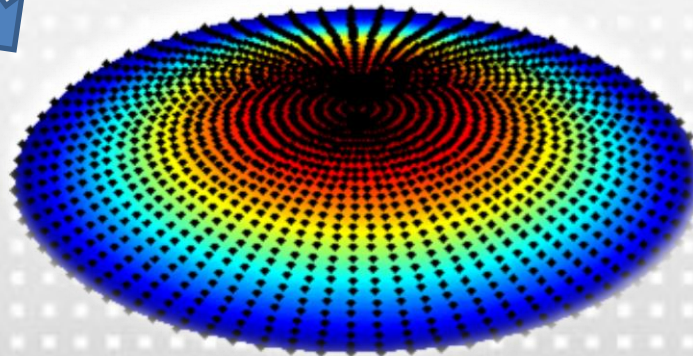
Measured Point Cloud



Ideal Shape



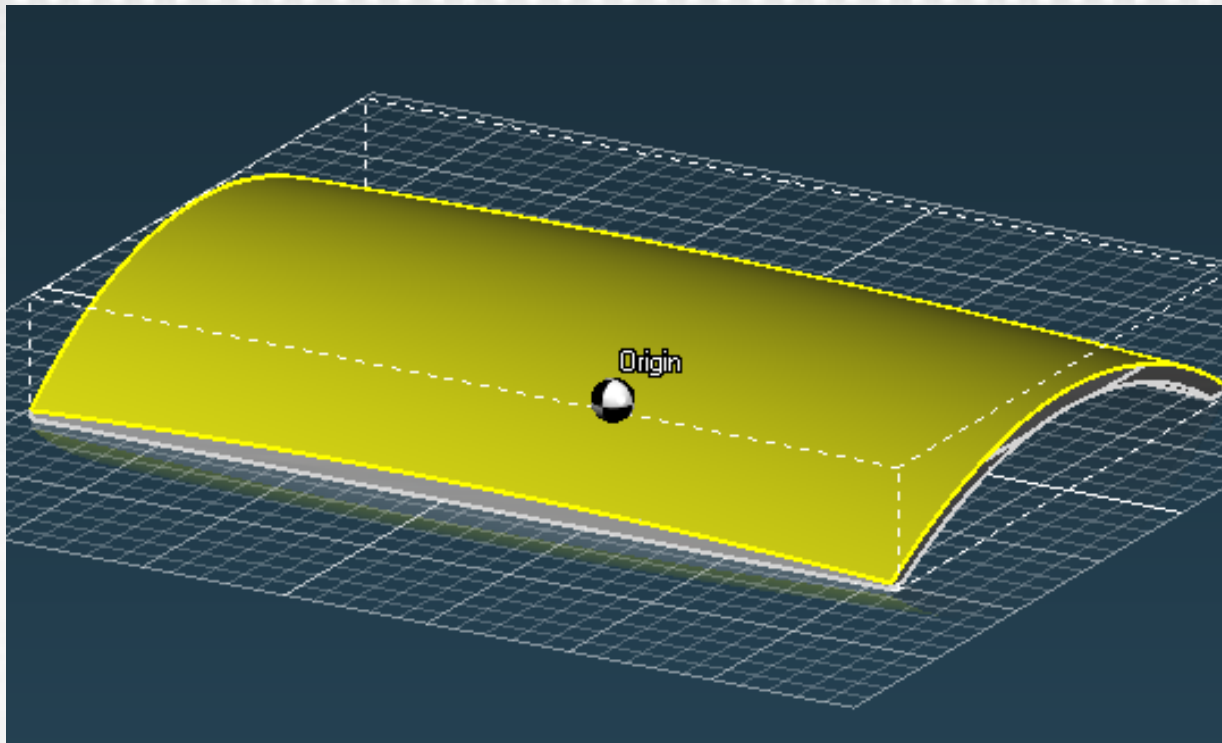
Final Point Cloud Fit



UltraSurf 3D Interface



Join the OptiPro Revolution.



- Quickly generate measurement paths from CAD files
- Control measurement strategies for each surface
 - Data resolution
 - Path geometry
- Allows user to easily locate part on the UltraSurf machine

UltraSurf 3D Interface



Join the OptiPro Revolution.

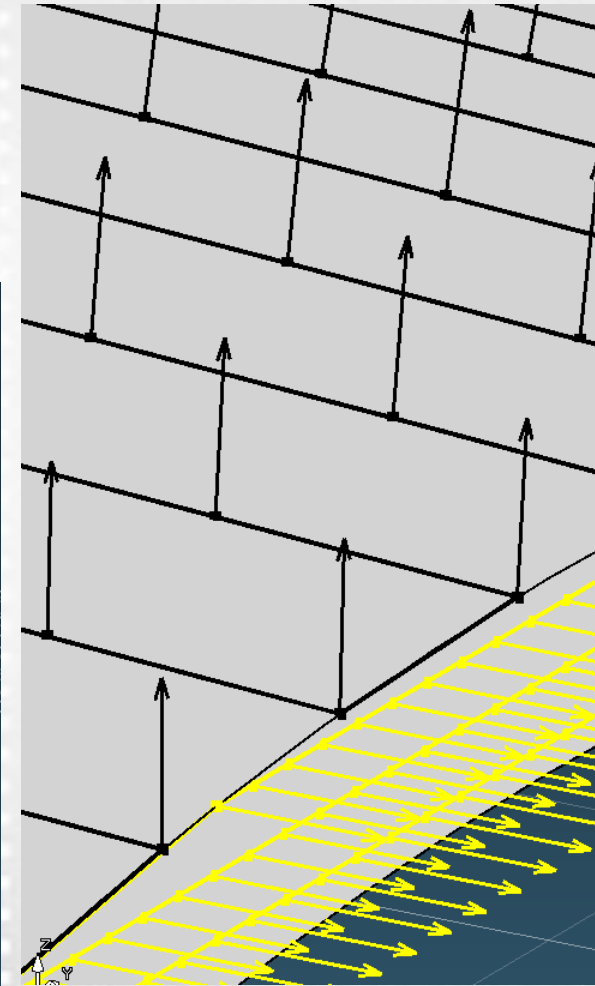
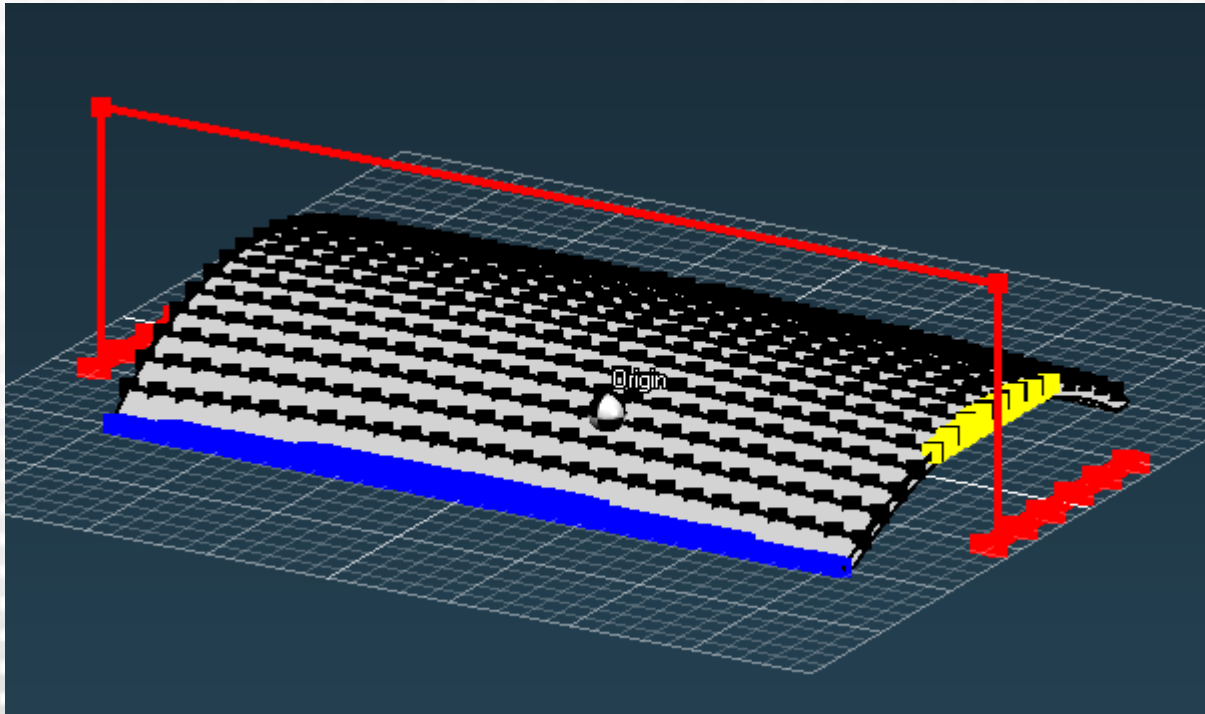
Example measurement paths with normal vectors

Datum A (Red)

Datum B (Blue)

Datum C (Yellow)

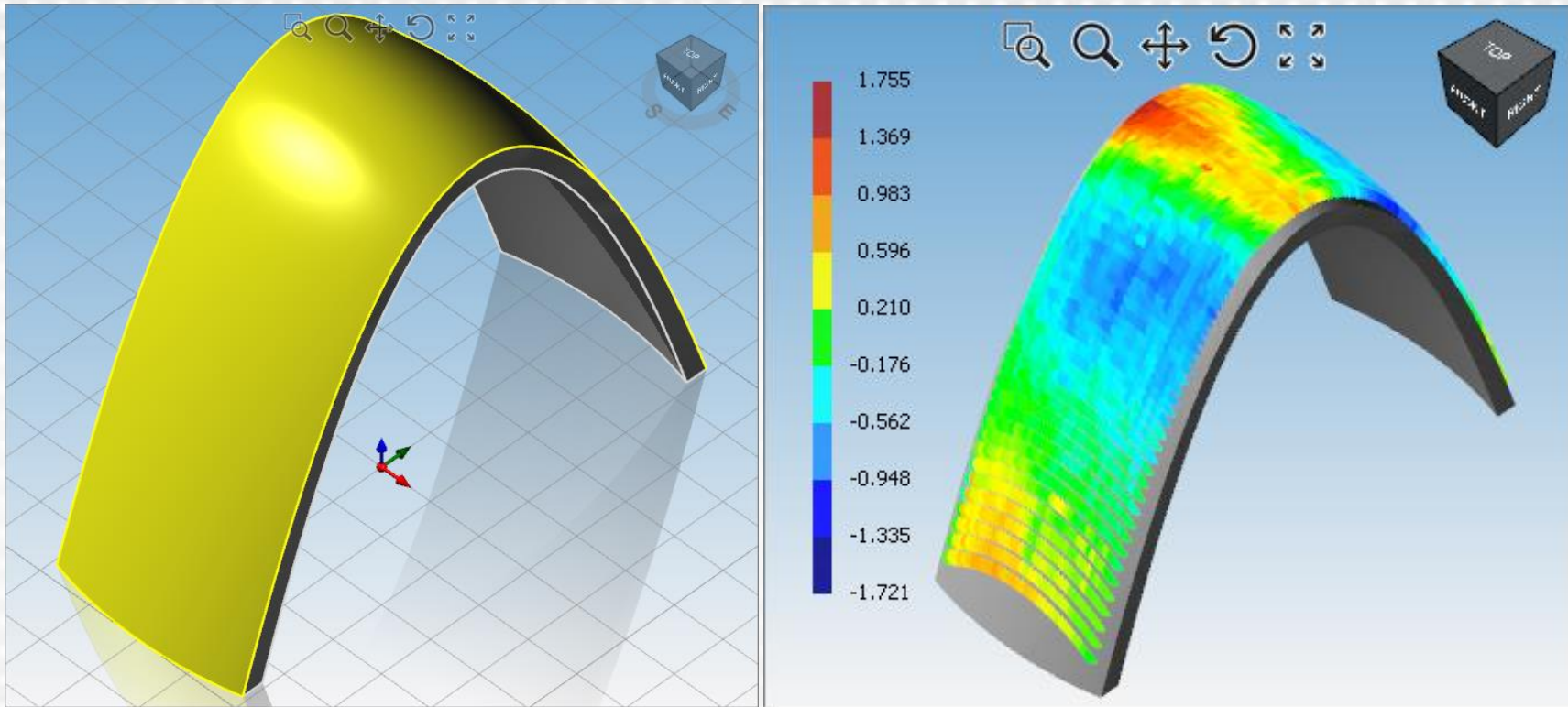
Conformal/Freeform Surface (Black)



UltraSurf 3D Interface



Join the OptiPro Revolution.

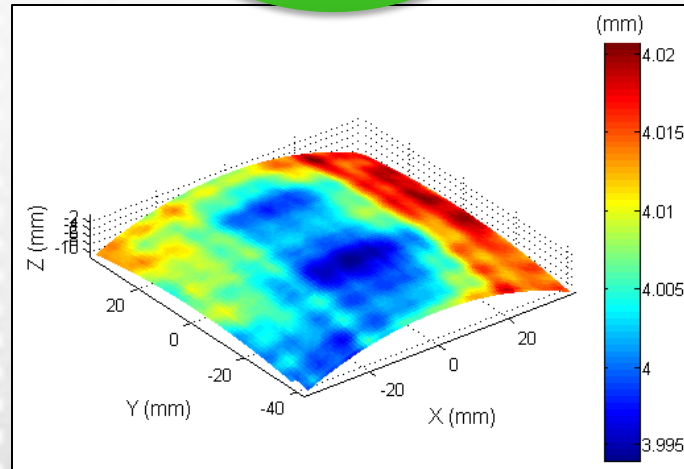
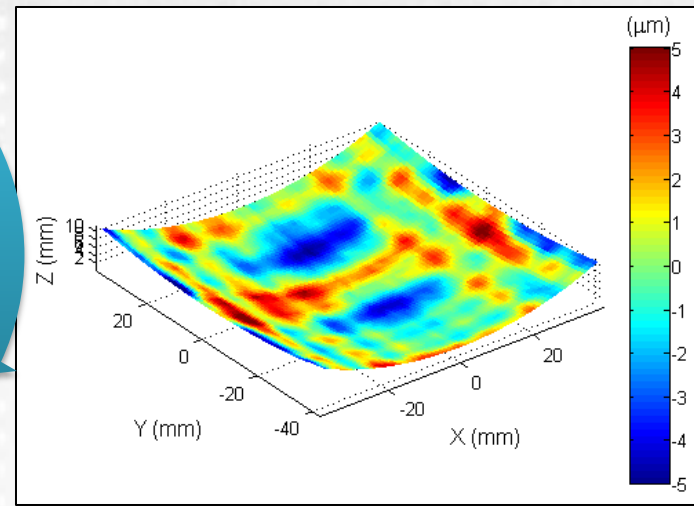
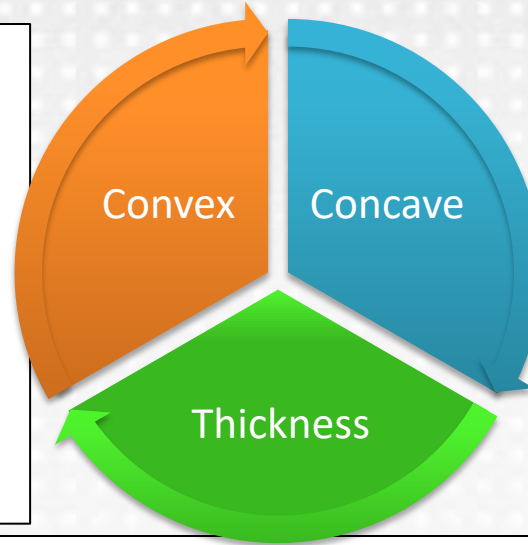
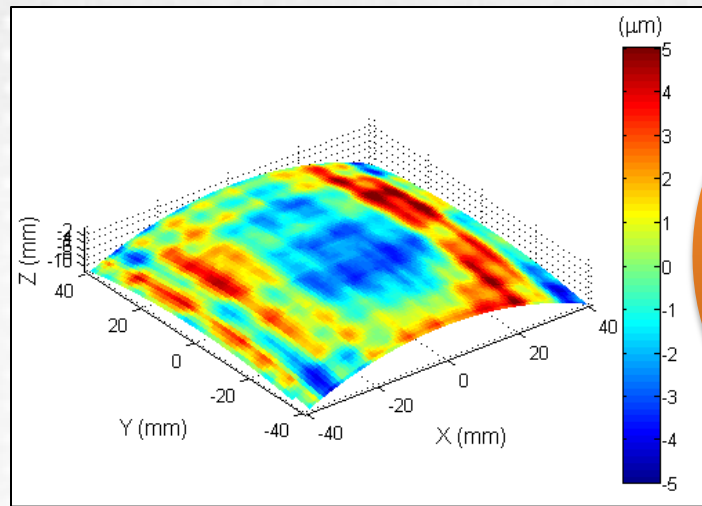


- Example of an freeform window measured with UltraSurf and OptiPro's freeform GUI

Square Toroid Surface Error



Join the OptiPro Revolution.

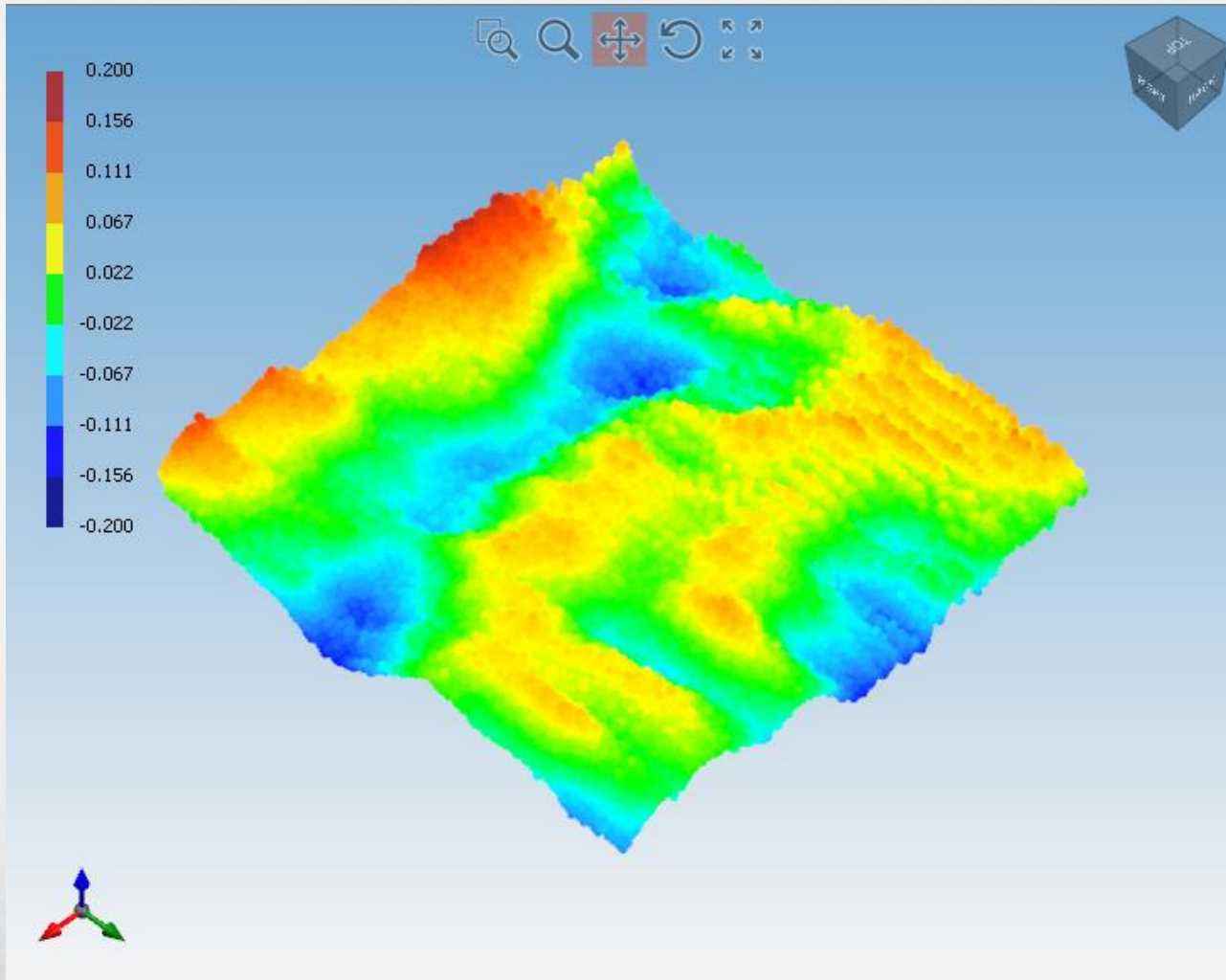


UltraSurf 3mm x 3mm



Join the OptiPro Revolution.

High resolution ($<10 \mu\text{m}$ / point), small sub-aperture to inspect texture

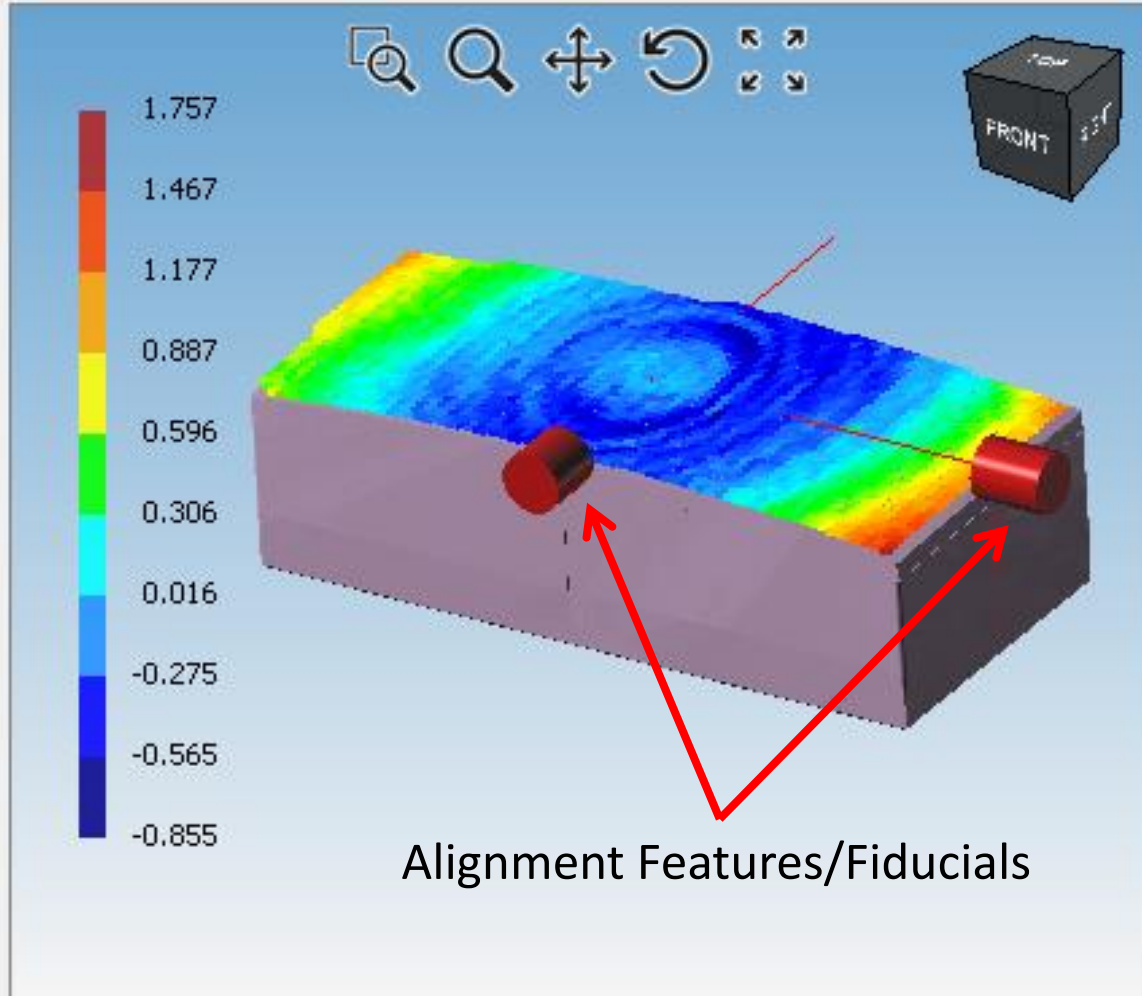


UltraSurf 3D Interface



Join the OptiPro Revolution.

Freeform Measurement (With CAD)



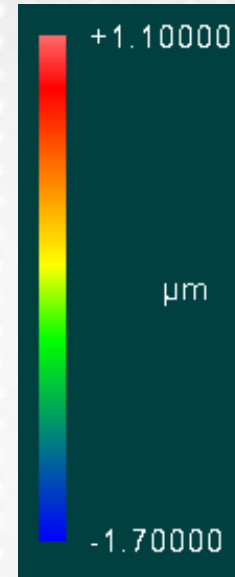
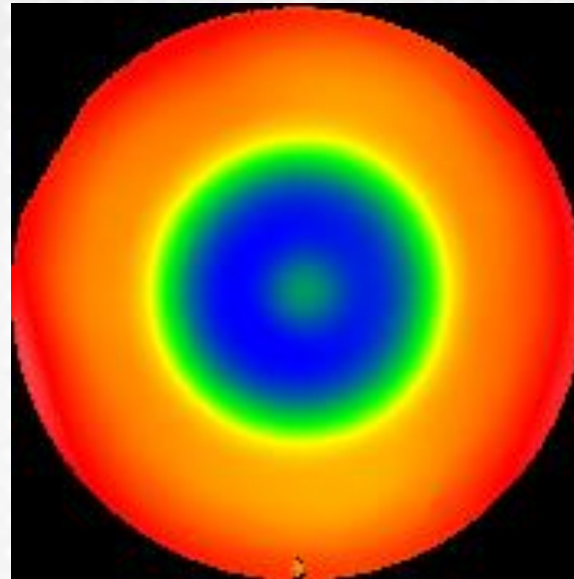
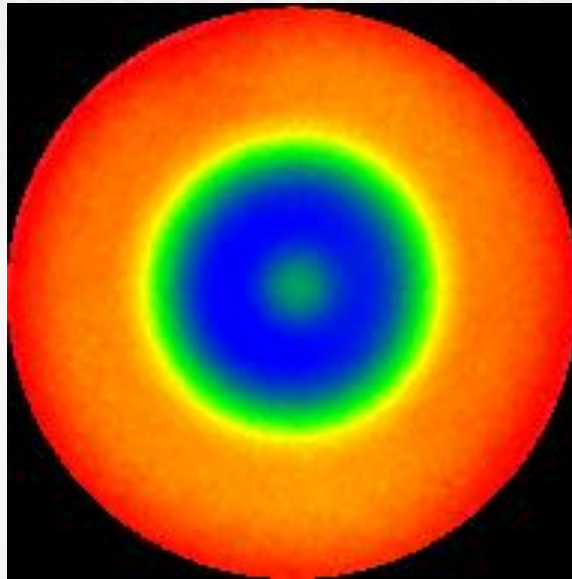
Transmitted Wavefront



Join the OptiPro Revolution.

UltraSurf

Zygo GPI



PV	2.749	μm
rms	0.758	μm
Power	2.364	μm
Size X	47.8	mm
Size Y	48.0	mm

PV	2.695	μm
rms	0.743	μm
Power	2.328	μm
Size X	48.1	mm
Size Y	48.1	mm

- 3 x 3 median filter applied to remove spikes
- Piston and Tilt Removed
- Lumetrics OptiGauge Probe

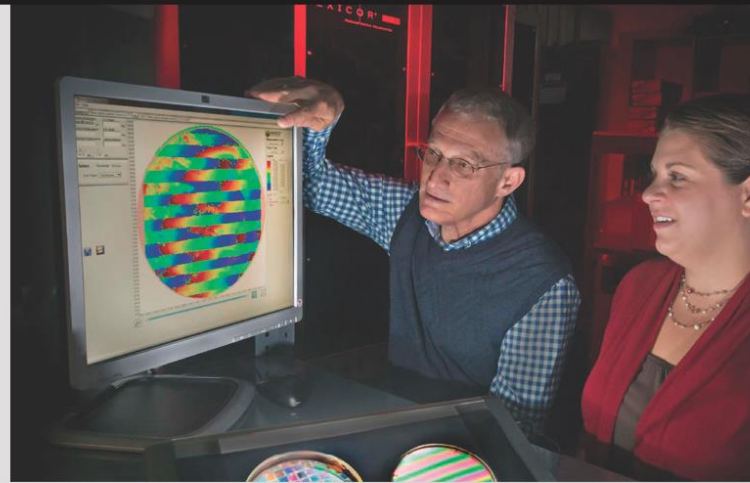
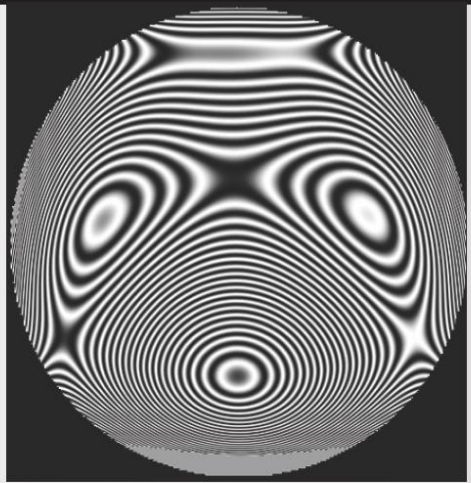
- UltraSurf can measure windows that have wedge, flex or spring.
- 280 nm of wedge as measured by UltraSurf

Summary & Future Work

- UltraSurf is a flexible platform for freeform optical surface metrology
- Current 3D interface is making progress, and will provide an easy to use interface for freeform shapes
- We are also working on a process to communicate the shape, orientation, and location of freeform surfaces with regards to manufacturing and metrology

JOIN THE FREEFORM REVOLUTION

THE CENTER FOR FREEFORM OPTICS
AN INDUSTRY/UNIVERSITY COOPERATIVE RESEARCH CENTER



The Center for For Freeform Optics

Vision: Compact, affordable, and performant optical systems will permeate precision technologies of the future.

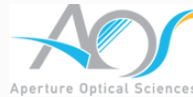
Mission

The mission of the **Center for Freeform Optics** is to advance research and education in the science, engineering, and applications of systems based on freeform optics through a dedicated, continuing industrial partnership based on shared value and promotion of technical advantage leading to a competitive economic advantage for **CeFO members**.





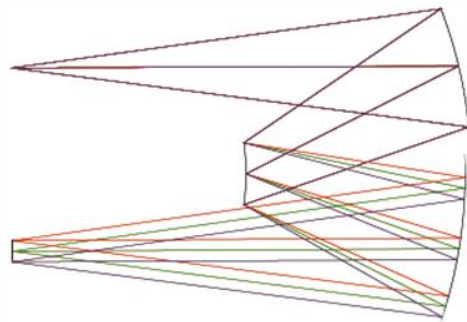
*Quickly growing support and global market reach, CeFO has 15 members and has received more than **\$1.7 million** in funding.*



A miniature imaging spectrometer was designed and manufactured within CeFO

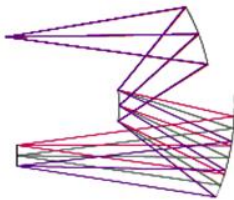
F/3.8; wavelengths span 200-1500 nm; 10 mm slit; 100nm/mm

University of Rochester (Optics)



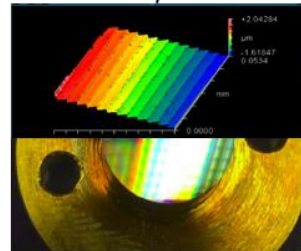
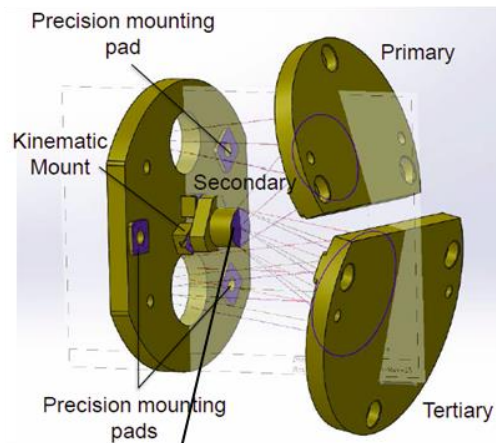
Spherical design

5x smaller

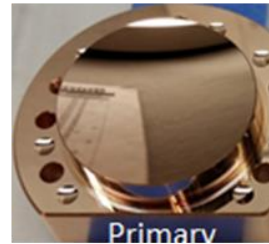


Freeform design

UNC Charlotte (Mechanical)



Grating (300 lines/mm)

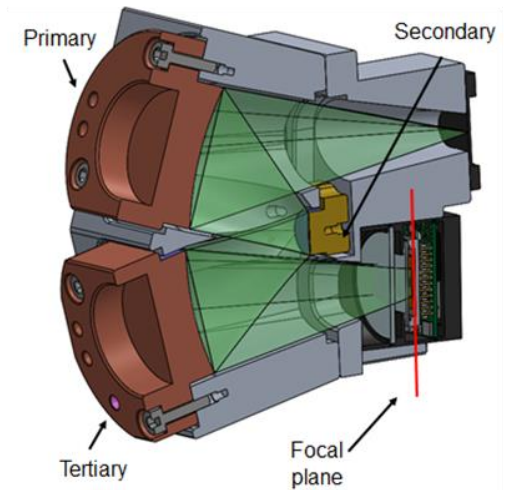


Primary

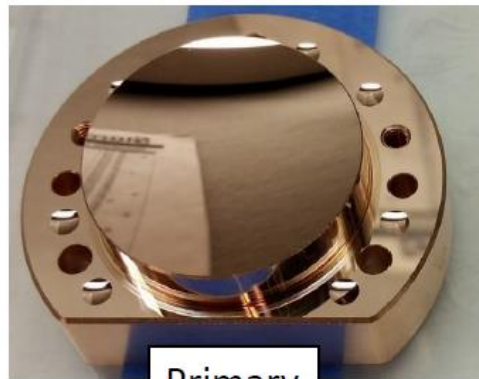


Tertiary

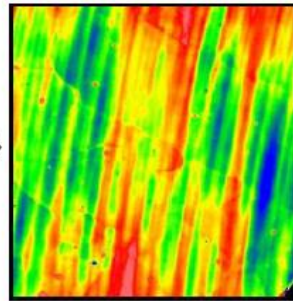
Both Universities – Assemble & Test



The primary and tertiary were then machined and measured by Ultrasurf (Optipro), a non-contact CMM



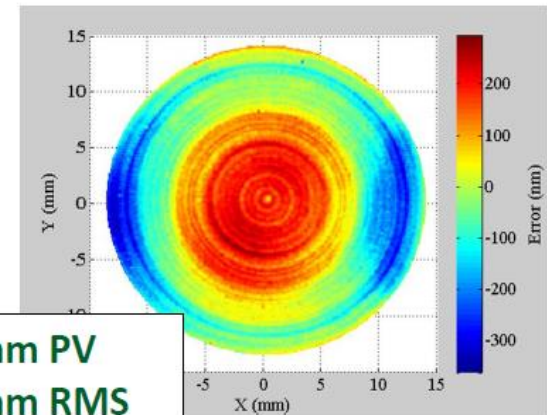
Primary



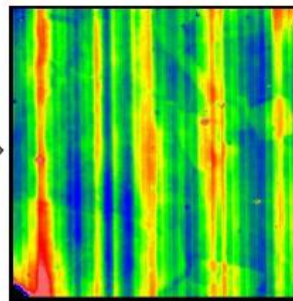
Finish: SWLI, 50x
Target: 2 nm Sa
Actual: **1 - 2 nm**

655 nm PV
133 nm RMS

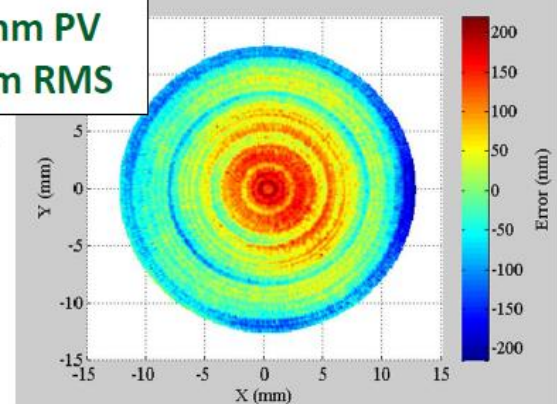
Form error: OptiPro UltraSURF
Target (best effort): 400 nm PV



Tertiary



434 nm PV
72 nm RMS





THE CENTER FOR FREEFORM OPTICS
AN INDUSTRY/UNIVERSITY COOPERATIVE RESEARCH CENTER

ACADEMIC PARTNERS



LEARN MORE AT
www.CenterFreeformOptics.org

Or contact **JANNICK P. ROLLAND** at ROLLAND@OPTICS.ROCHESTER.EDU