
RAPT
INDUSTRIES
when speed and precision matter RAPT Industries
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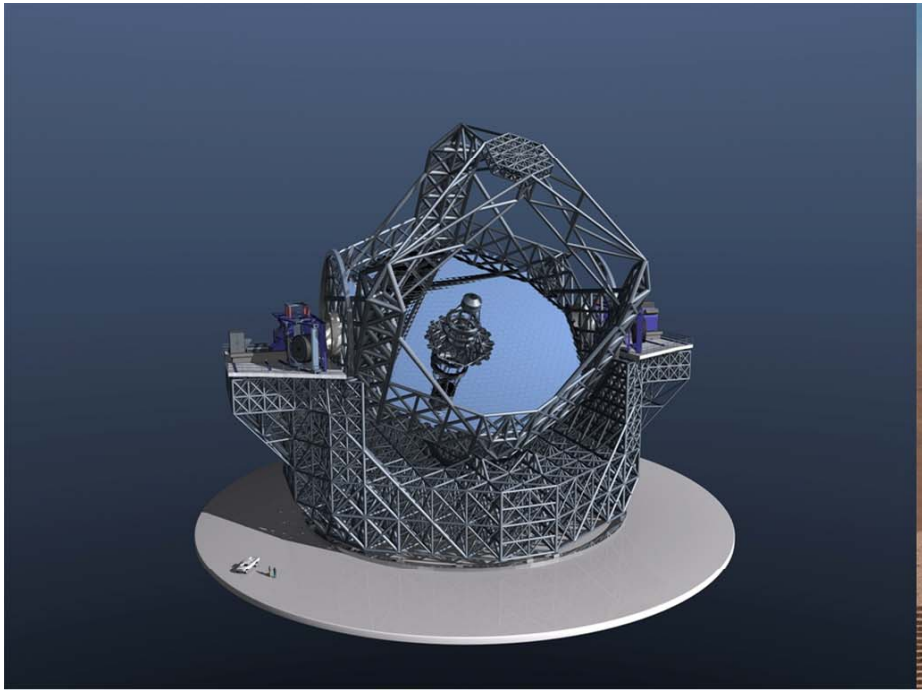
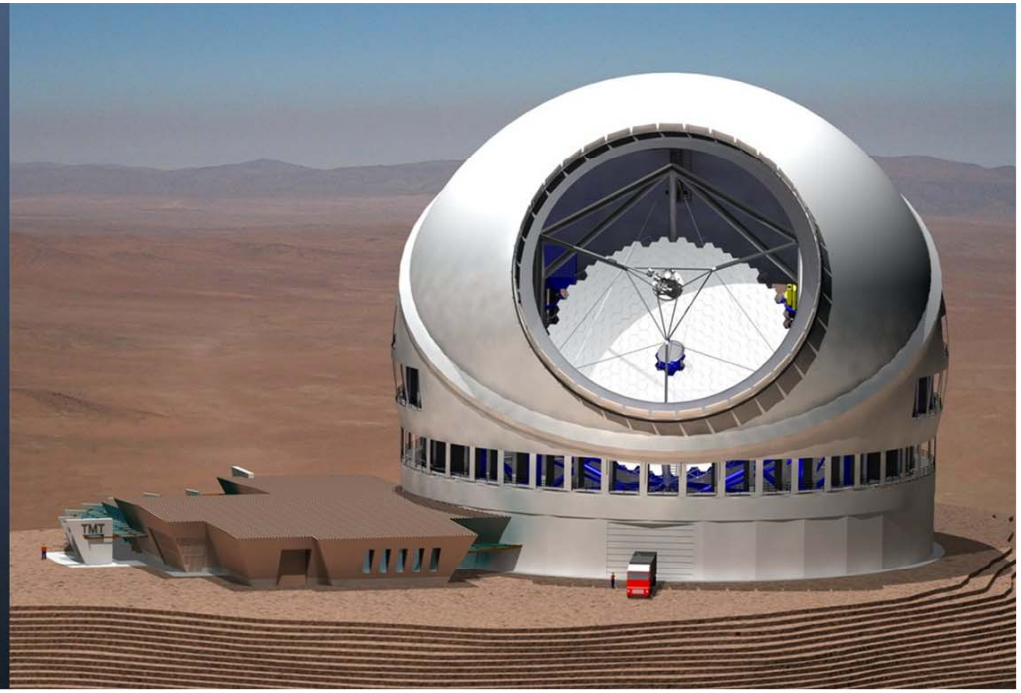
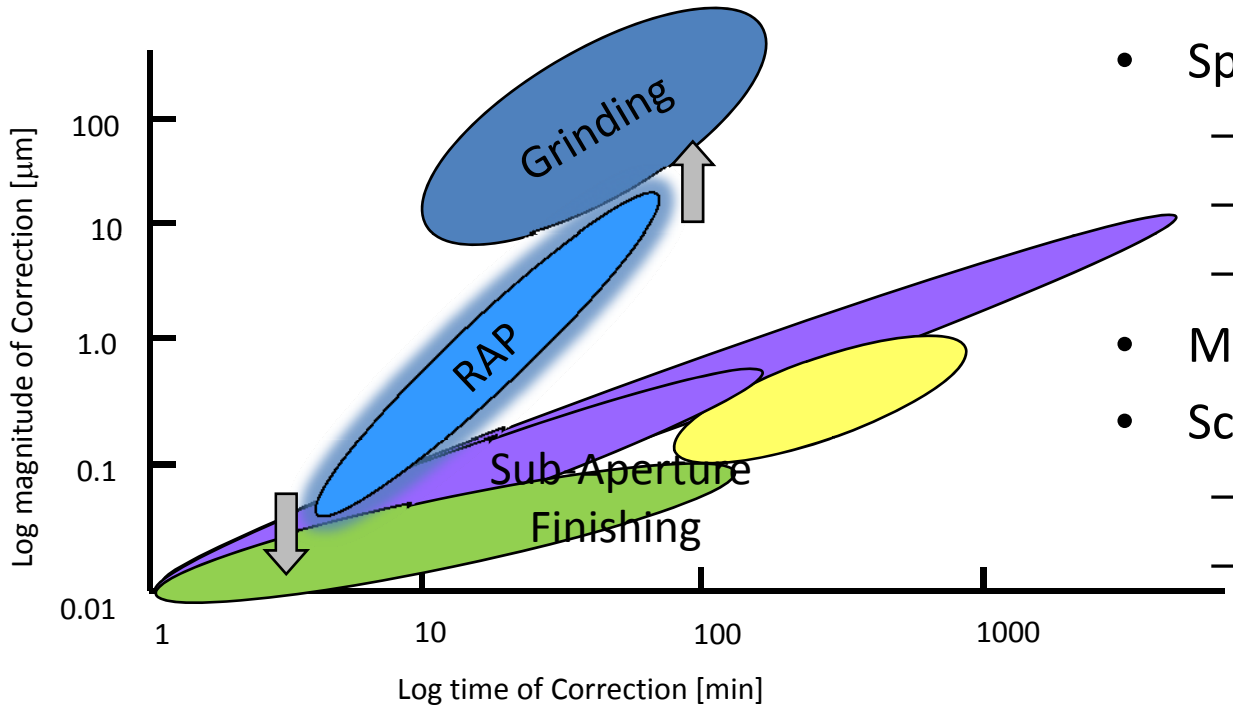
# Case Study – Next generation ground based telescopes





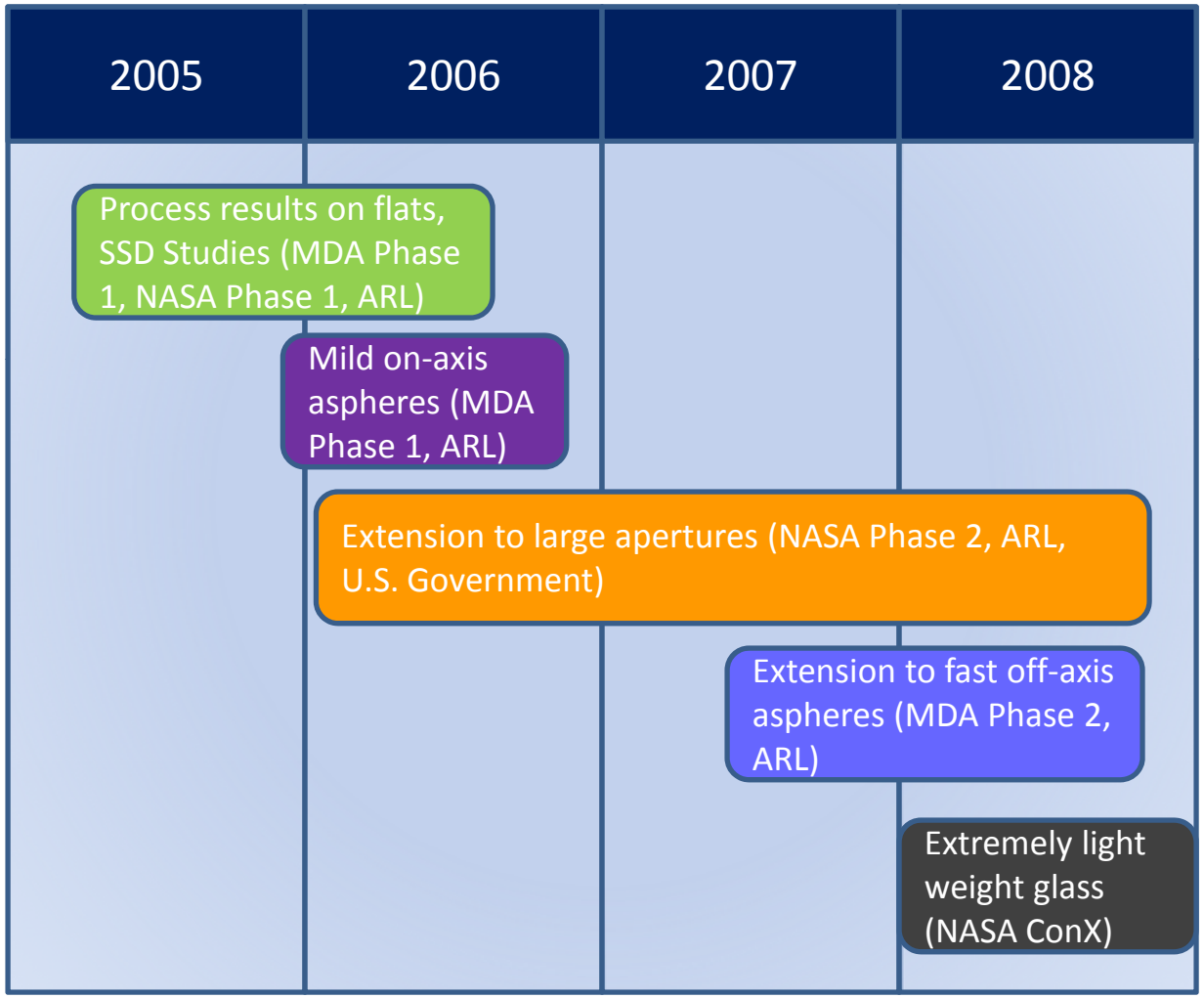

- E-ELT Primary - 906 segments each 1.45m wide
- TMT Primary – 492 segments each 1.44m wide
- Significant manufacturing challenge
- Challenges conventional paradigms

# Optics Manufacturing Requirements




- Speed/Cost
  - Sub-surface damage
  - Material removal rates
  - Determinism/Convergence
- Mid-Spatial frequencies
- Scalability
  - Large clear aperture
  - Smaller feature sizes

# Our Programs




- W911NF-04-2-0001 – Army Research Laboratory

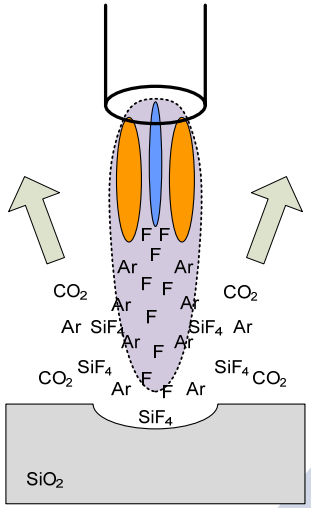
  COTR: Dr. Jane Adams
- NNM06AA11C – NASA Phase 2 SBIR – MSFC

  COTR: Mr. John West
- W9113M-07-C-0149 – MDA Phase 2 SBIR – AFRL

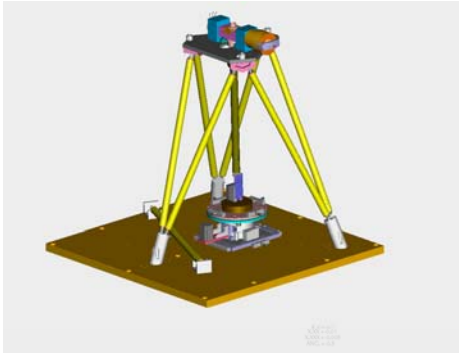
  COTR: Dr. Larry Matson
- NNX08CC82P – NASA Phase 1 SBIR – MSFC

  COTR: Mr. William Jones
- U.S. Government Contract

# To look ahead, Look back




2001 - Lab demonstration

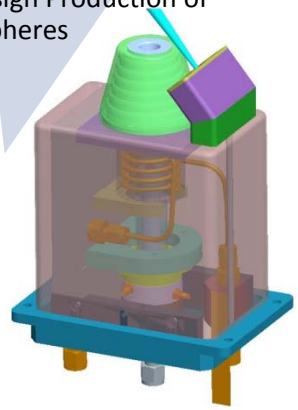


2004 – Prototype machines (350mm)

2005 – Shipment of prototype to Cranfield, Swing Arm Profilometry


2006 – First asphere figuring

2007 – Moving torch design, 1.2m tool design Production of aspheres



# 2007/2008 RAPT Optics Roadmap

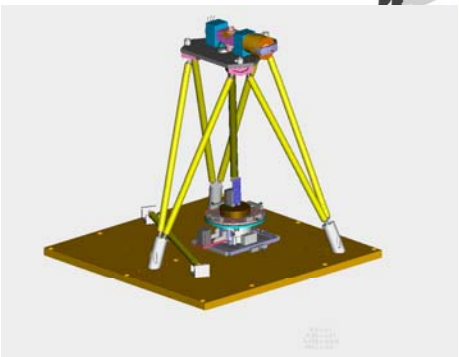

Release of EOS 500

Integration of Helios with other platforms

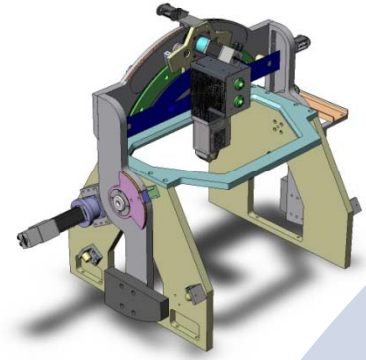
Ability to imprint high-frequency features

Shipment of Helios 1200 tool to Cranfield

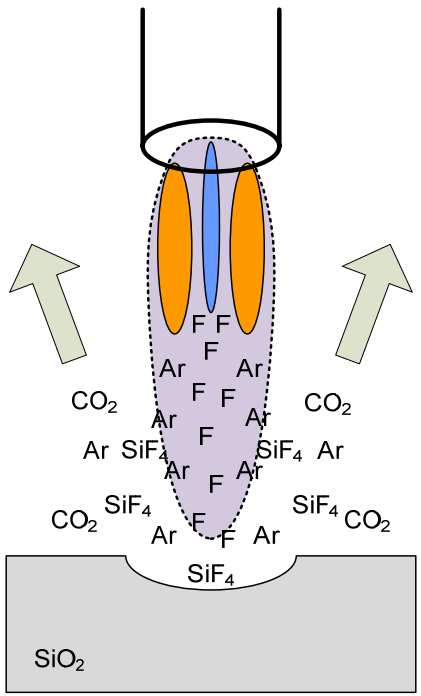
Off-axis metrology, production of off-axis segments



Gimbaled torch



# The Chemistry of the Process




$$Rate = Ae^{-E_a/RT}$$

**For $SiO_2$:**

$$SiO_2 + CF_4 \rightarrow SiF_4 + CO_2$$

**For silicon:**

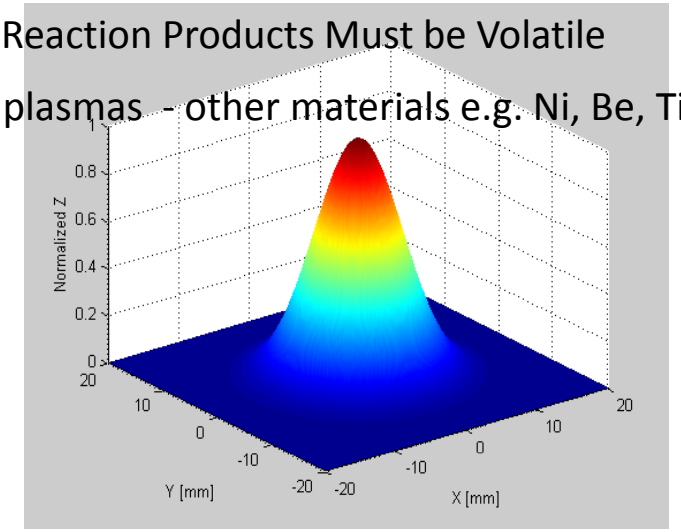
$$Si + CF_4 + O_2 \rightarrow SiF_4 + CO_2$$

**For SiC:**

$$SiC + CF_4 + O_2 \rightarrow SiF4 + 2CO$$

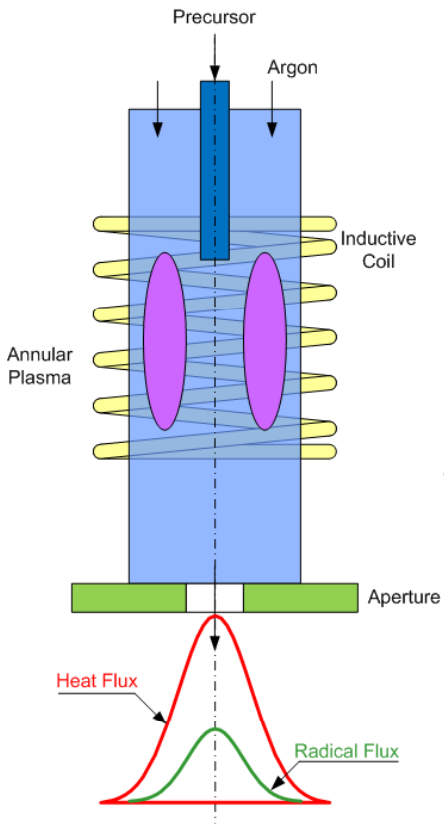
Reaction Products Must be Volatile

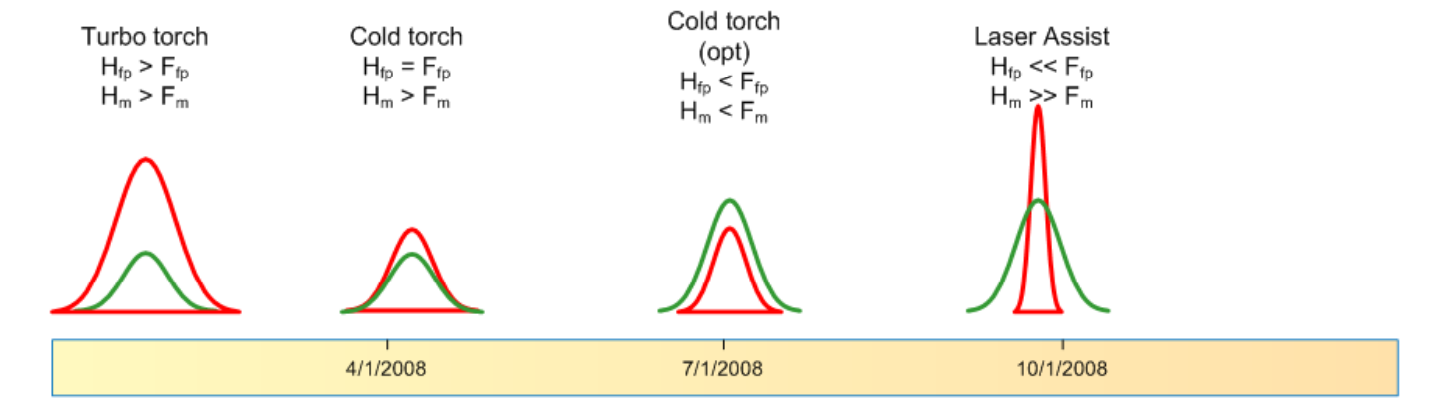
Other plasmas - other materials e.g. Ni, Be, Ti…

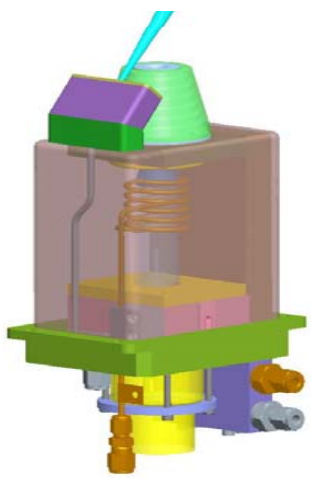


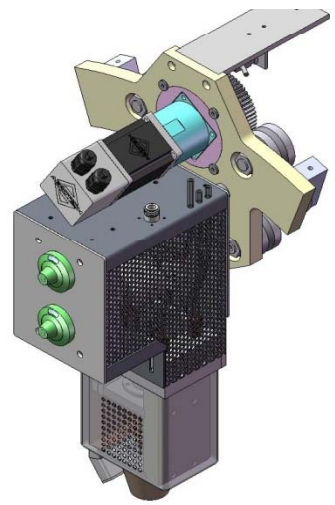

- Damage-free figuring @ atmospheric pressure
- Gaussian footprint for chemical figuring tool
  - Arrhenius rate reaction

# Torch Technology Roadmap



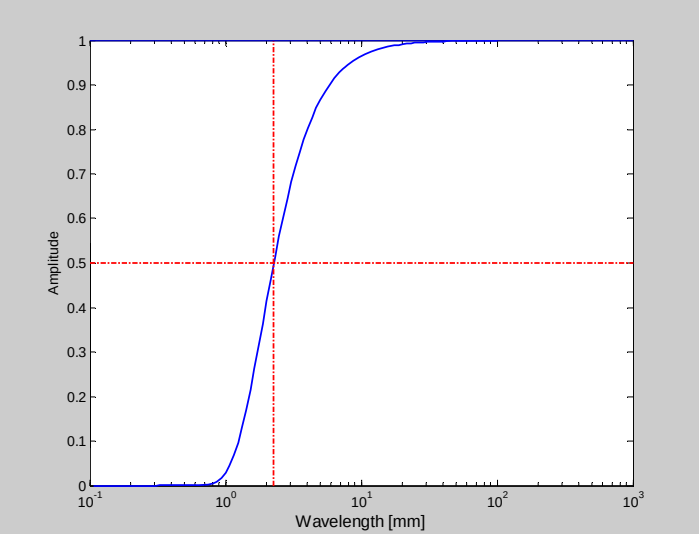



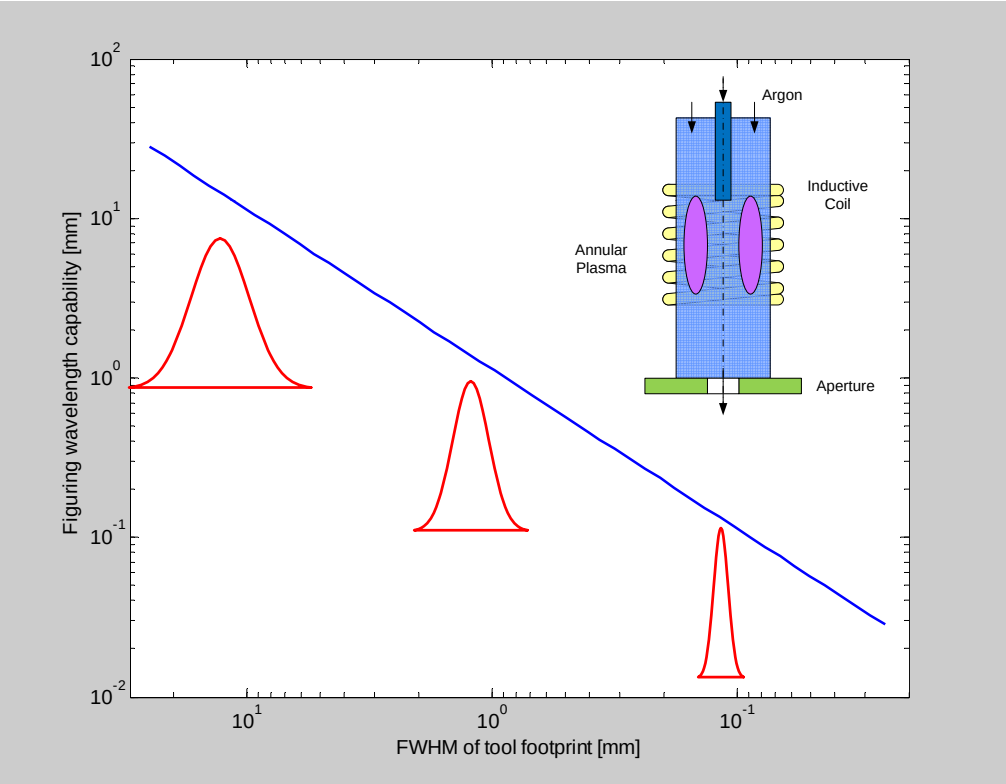





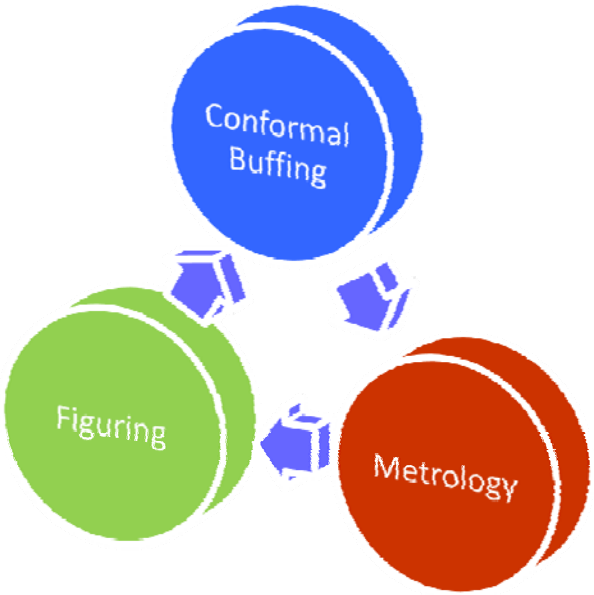
# Figuring capability as a function of spatial frequency

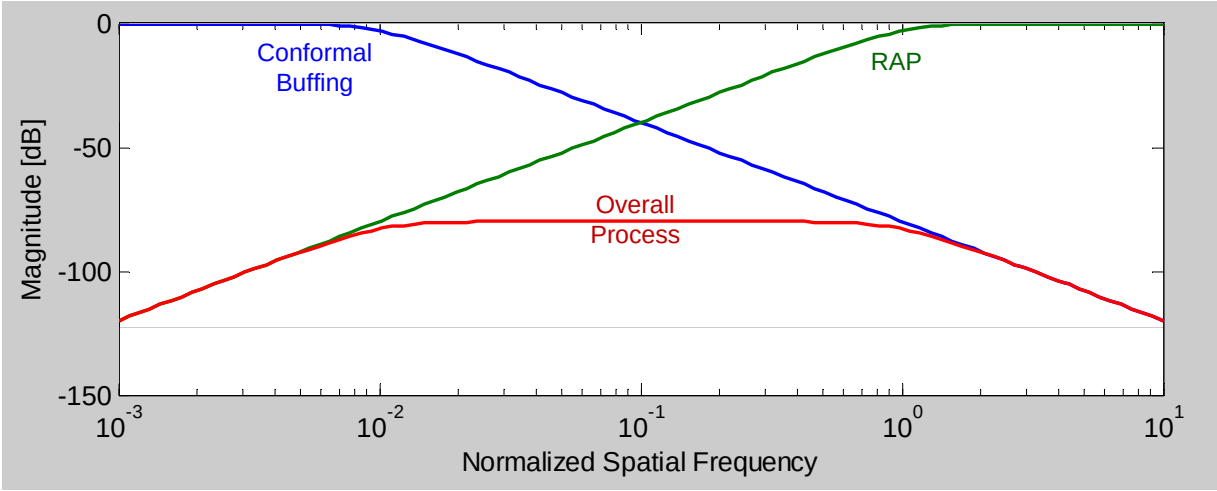
- Gaussian does not introduce ringing but is limited in ability to figure higher spatial frequencies
- Roadmap to changing spot size on the fly to permit MRR vs. figuring capability tradeoff



# RAP IMP – Application to SiC

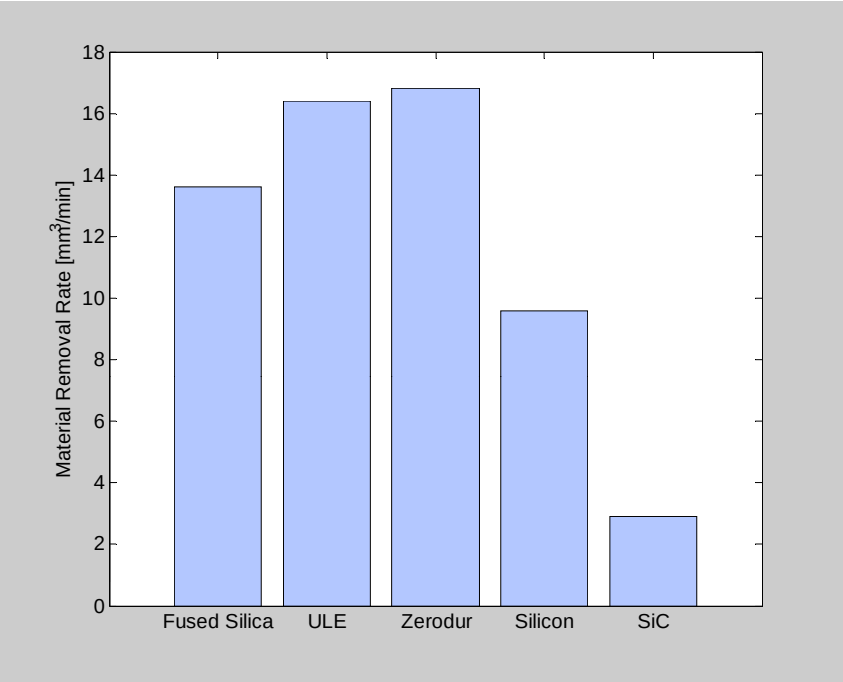


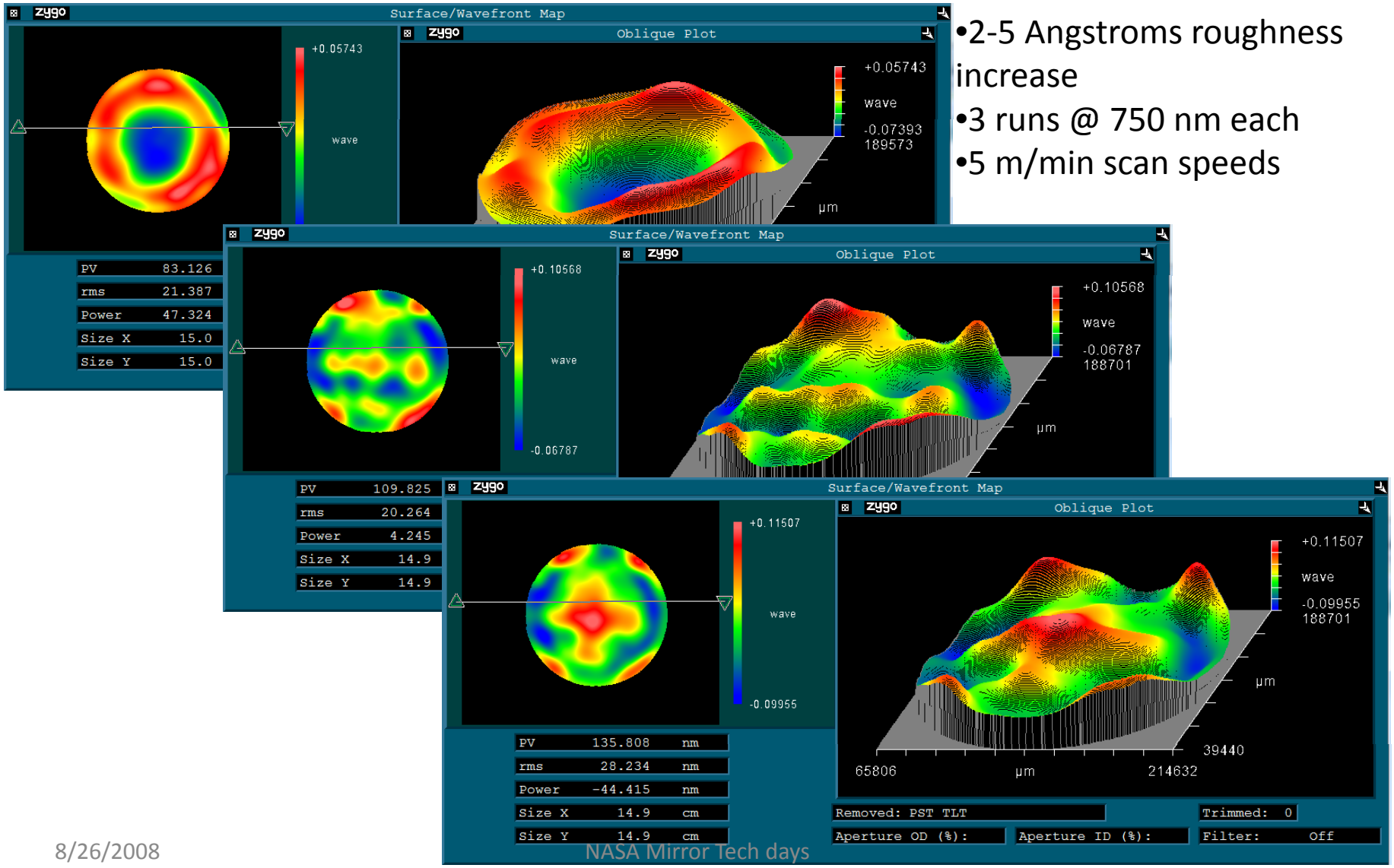

- High activation energy for SiC – thermal management during figuring critical
- Considerable knowhow to minimize edge-effects
- Polycrystalline/multi-phase materials roughen up, iteration between figuring and buffing needed to obtain desired figure/roughness
- 150$^{th}$ wave RMS figure and 3 Angstroms RMS roughness achieved repeatably

# RAP Assisted Manufacturing

- Material Removal Rate
- SSD removal/figuring
- Determinism
  - Repeatability
  - Uniformity of neutral removal
  - Figuring capability ($f(\omega_s)$)
- Roughness Evolution
  - Grain boundaries
  - Sub-surface damage sites
  - Inclusions and inhomogeneity
- Manufacturing economy



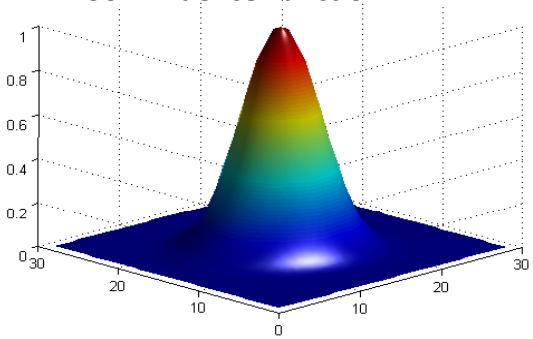
# Fused Silica (3 um removal)



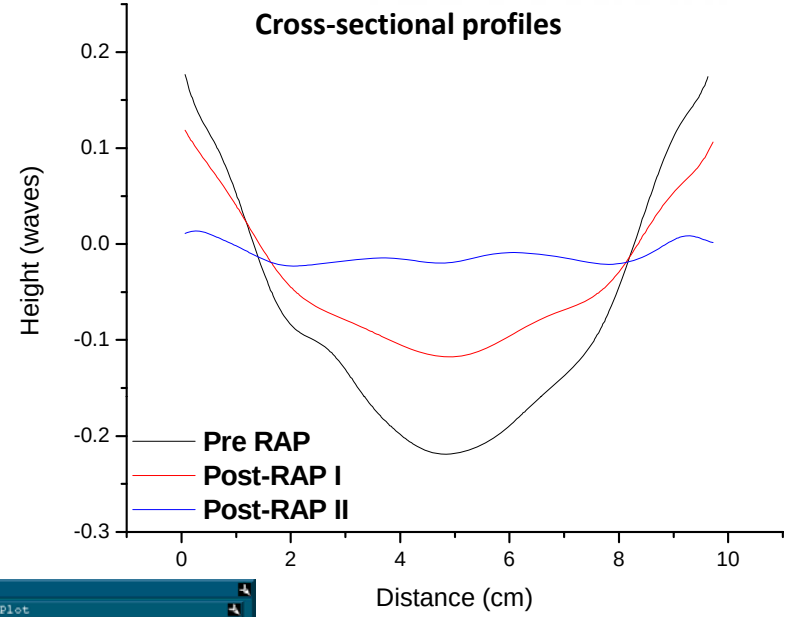

- 2-5 Angstroms roughness increase
- 3 runs @ 750 nm each
- 5 m/min scan speeds

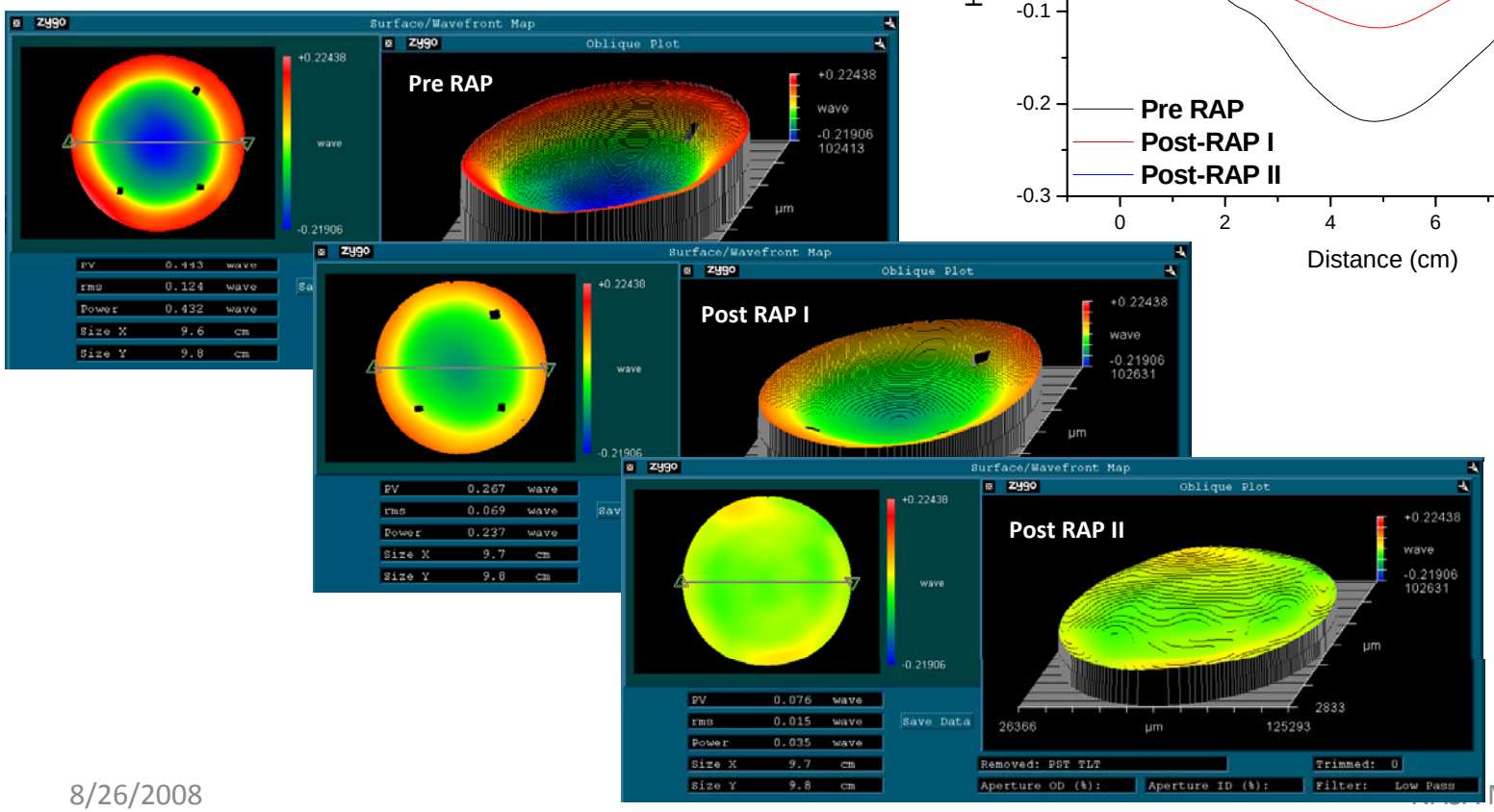
# RAP Figuring

**Tool Influence Function**



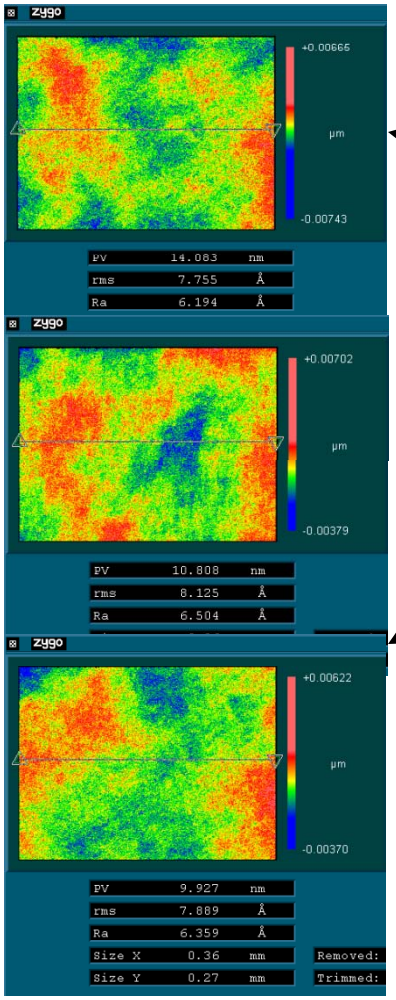

RAP process conditions:
Estimated run time: 12 mins/run
Number of iterations: 2

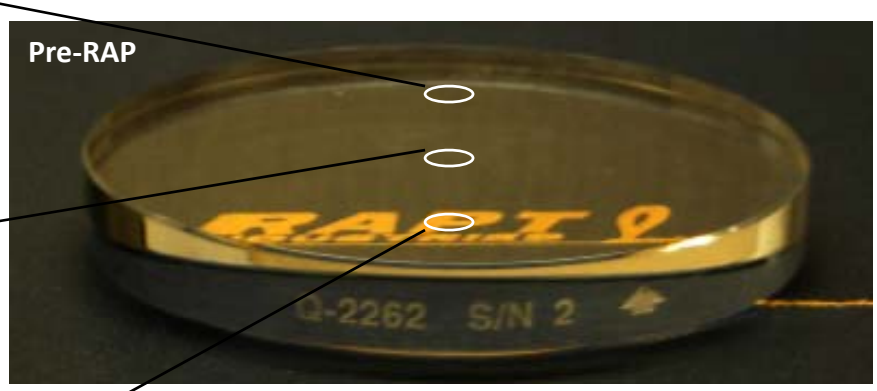


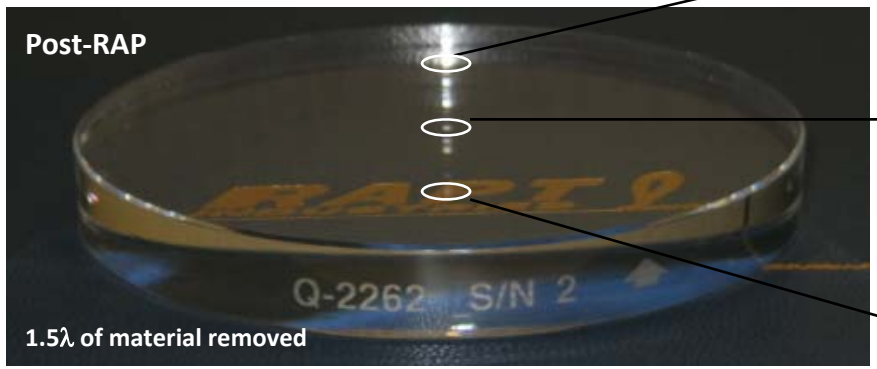



# Roughness Measurements – NewView @ 20X

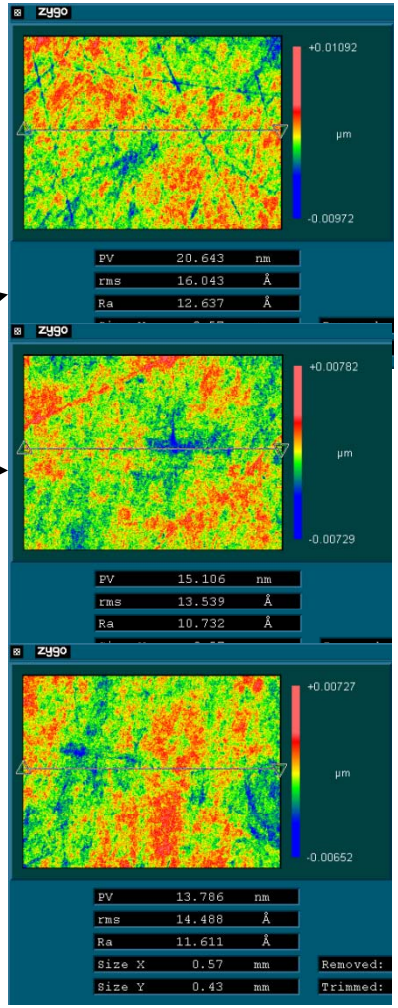
**Pre-RAP**



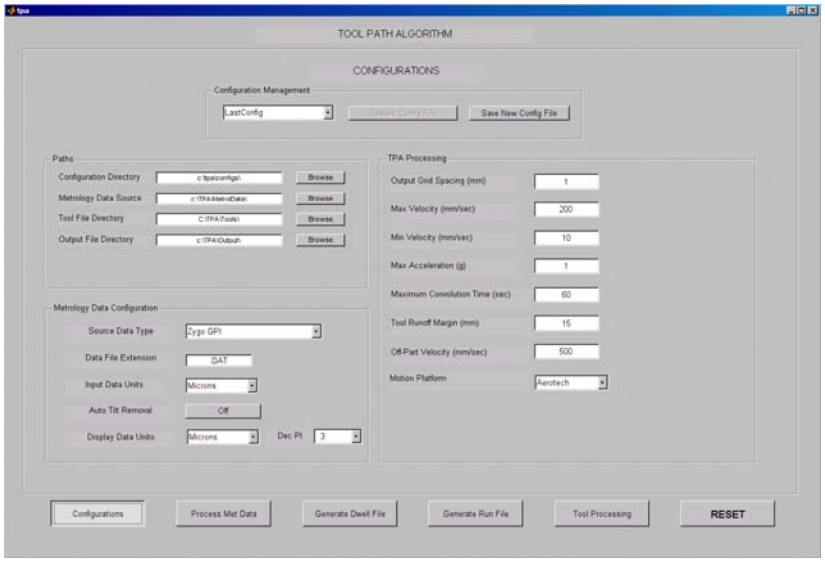



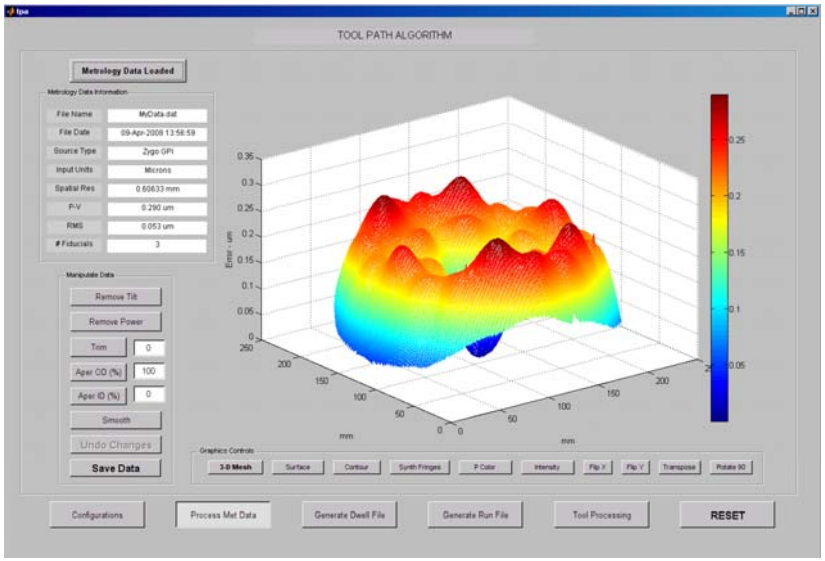




**Post-RAP**



# Tool Path Algorithm

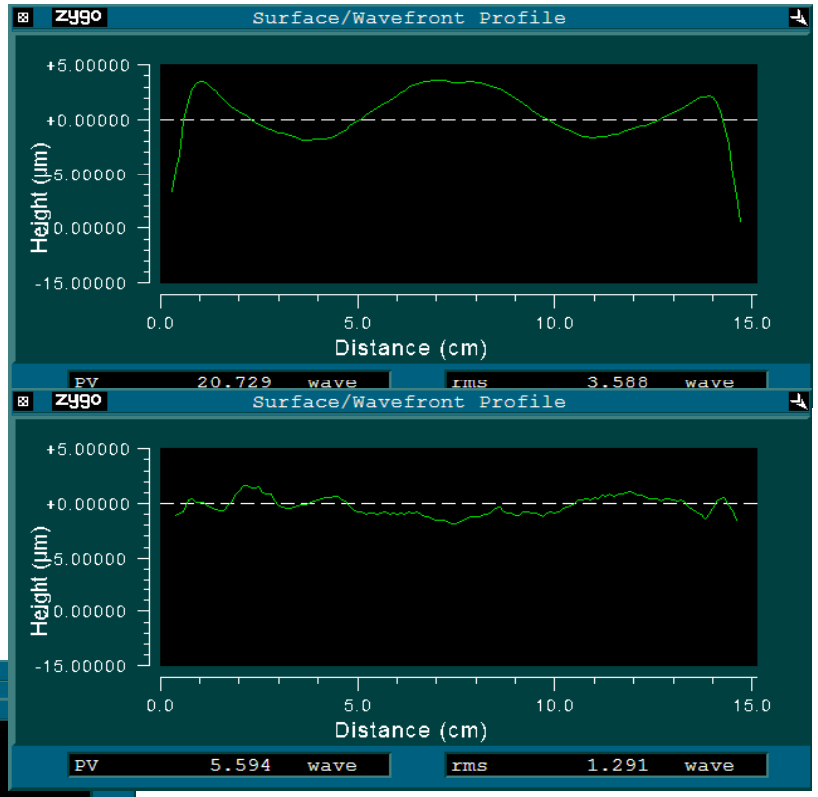


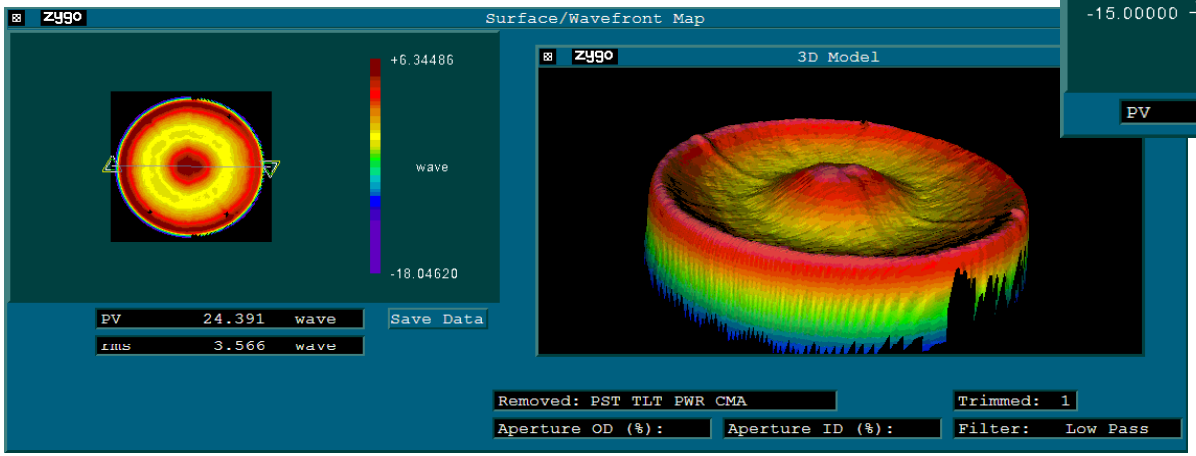




- Decouple path planning from dwell algorithm
- Dwell algorithm accepts
  - Error map
  - Footprint
  - PER
- Outputs
  - ROC
  - Dwell map
- Path planning based on machine configuration/options

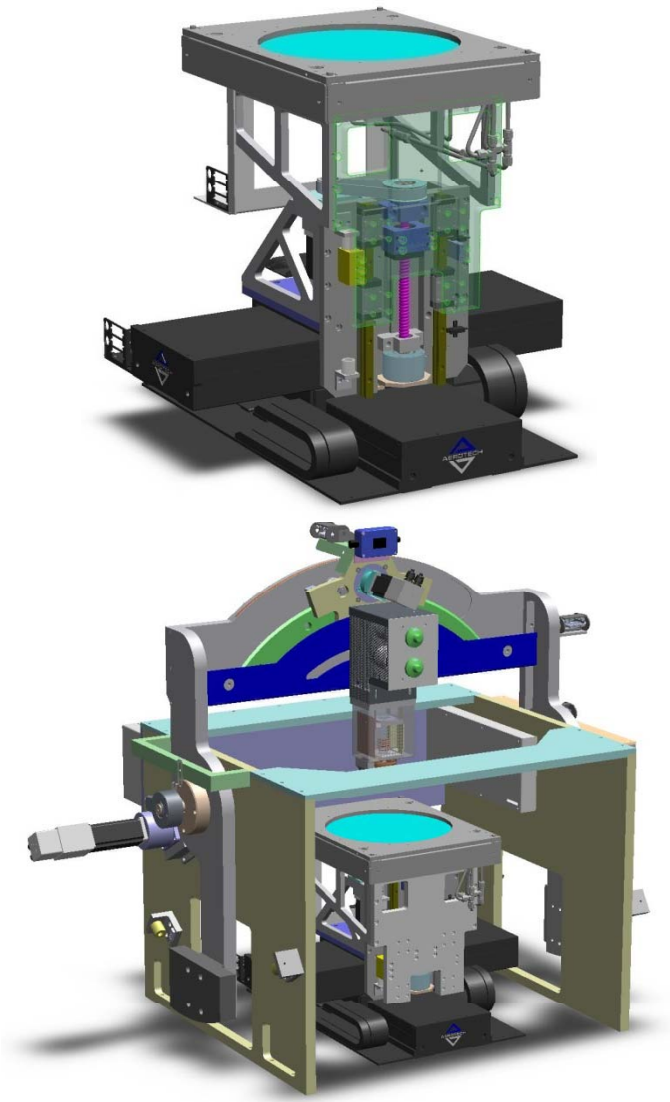
# NASA SBIR Phase II
# ~100% Clear Aperture

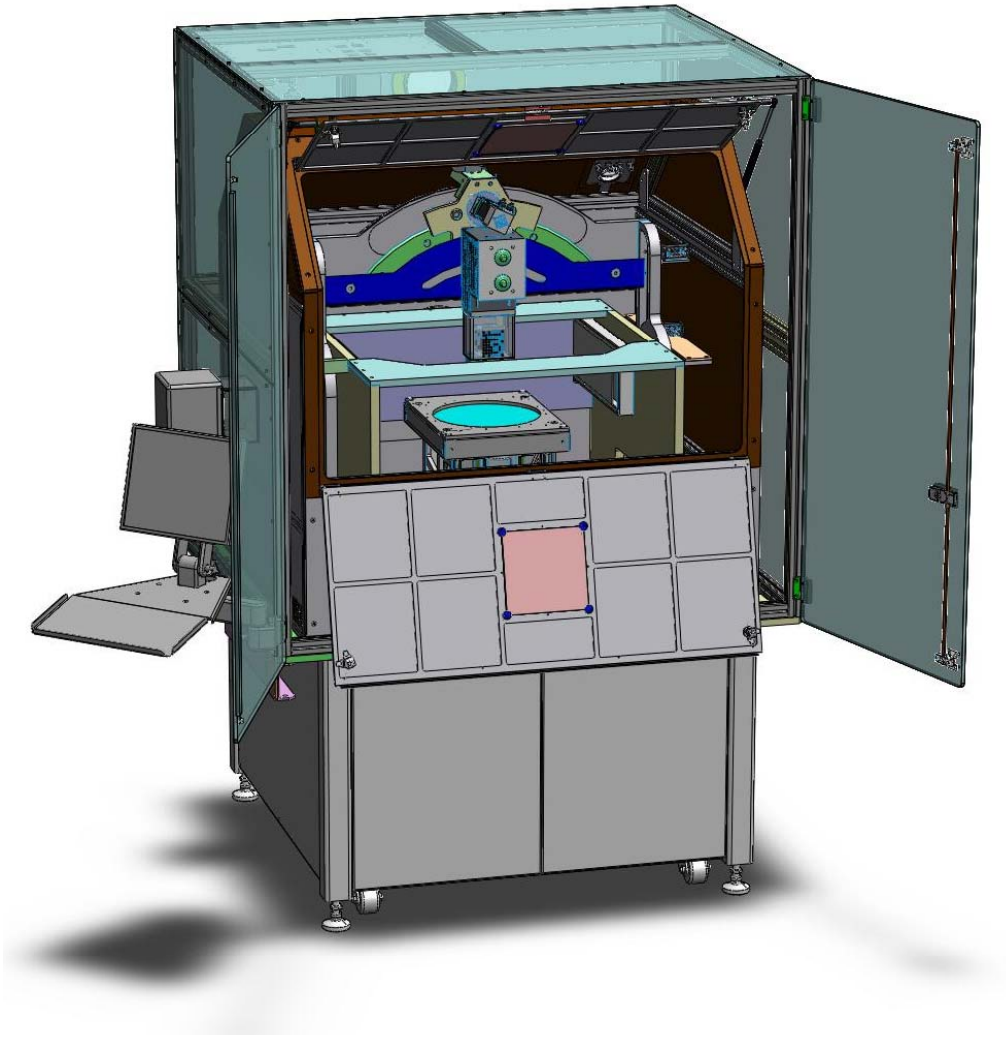
- 6” Clear Aperture
- Light-weighted SiC primary
- f/4 Parabola
  - Pathfinder to a 12” CA, f/2 Parabola
  - Meter class segmented mirror pathfinder



# Motion platform

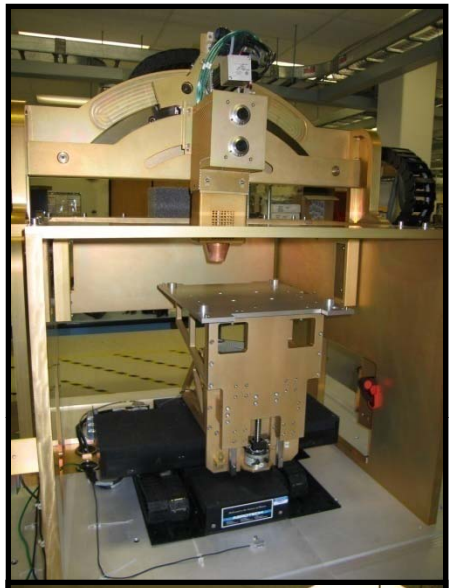


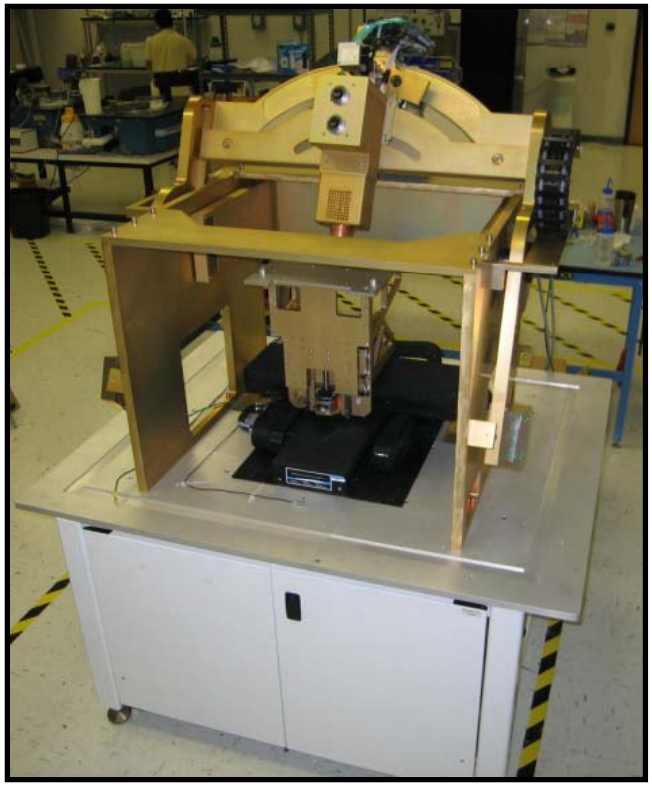


# MDA Phase II: 5-Axis Upgrade, 300mm RAP Tool

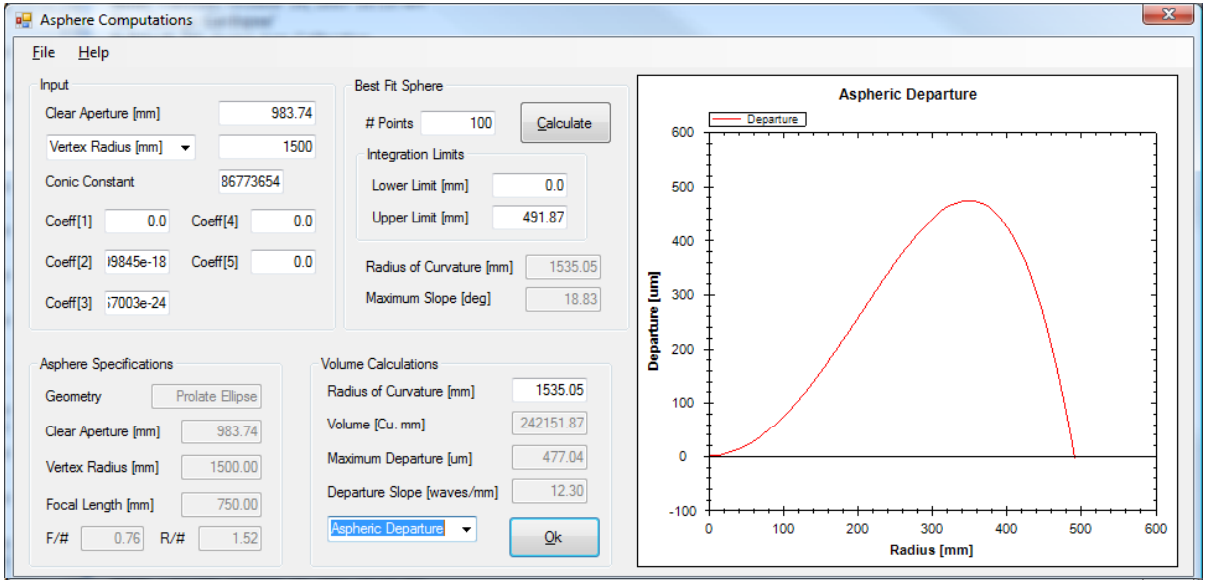
- 2 Axis Tip Tilt Torch Stage
  - Built on 300 mm Proto 1 Platform
  - Increased Z Stroke: 100mm travel
  - Working Travel: +/- 30 degrees
  - Max Angular Velocity: 44 deg/sec
  - Integrated IR Heater Assembly
  - Additional Electrical Enclosure required for 2X servo amplifiers
  - Lightweight Torch and Matching Network

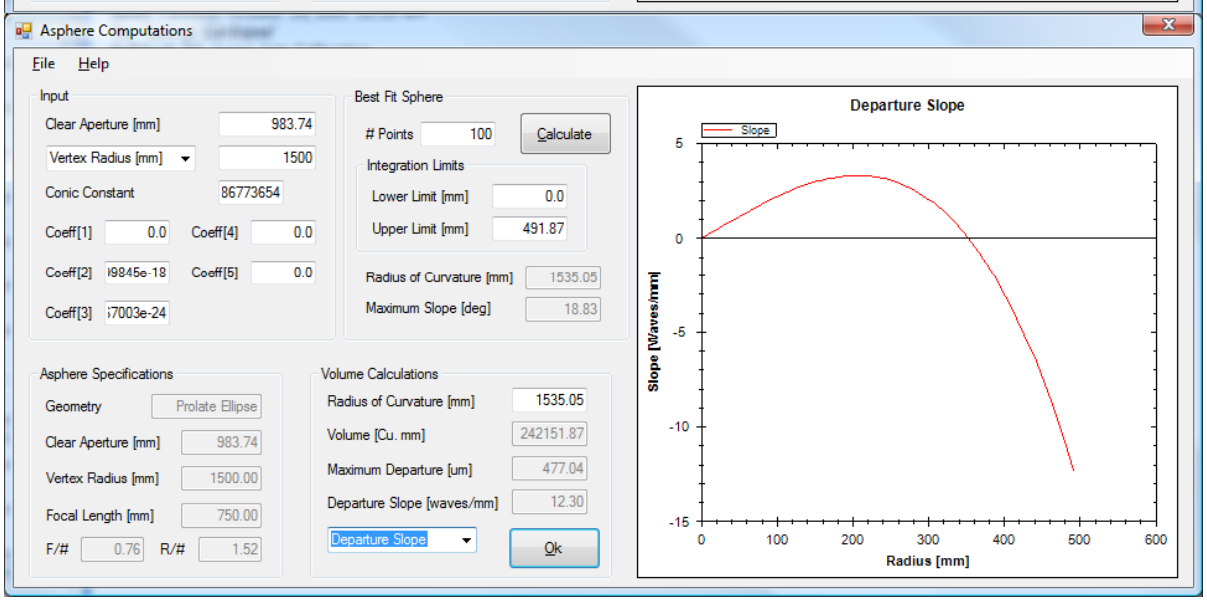
Dbl. Click to Play Movie Clip



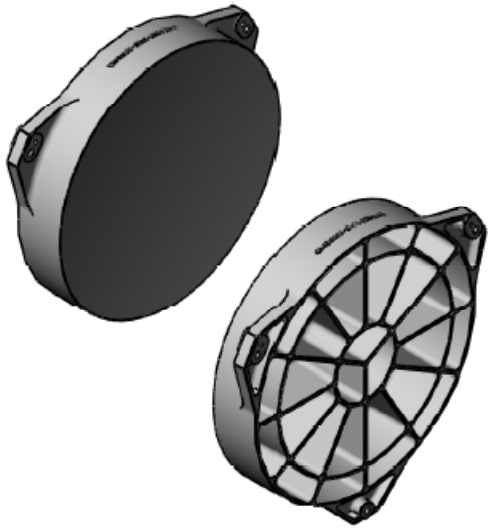


# MDA Phase II: Primary Mirror Substrate



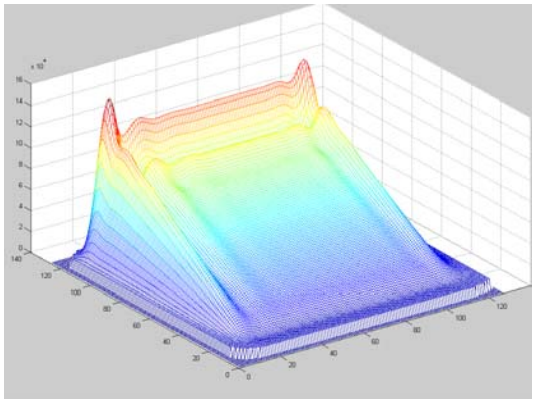

- Off-axis ellipse
- f/0.76
- Poco Graphite Material

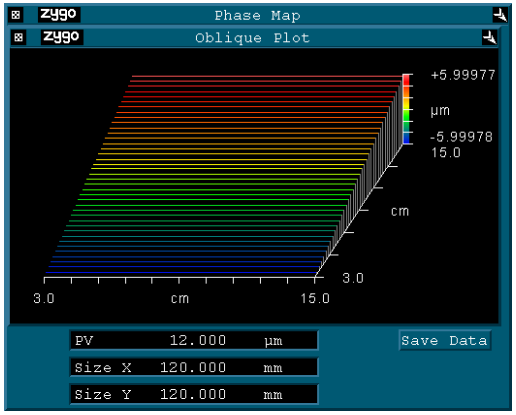


| Parameter | Value |
|---|---|
| Clear Aperture [mm] | 223.74 |
| Off-axis displacement [mm] | 380 |
| Parent Diameter [mm] | 983.74 |
| Vertex Radius [mm] | 1500 |
| Conic Constant | -0.86773654 |

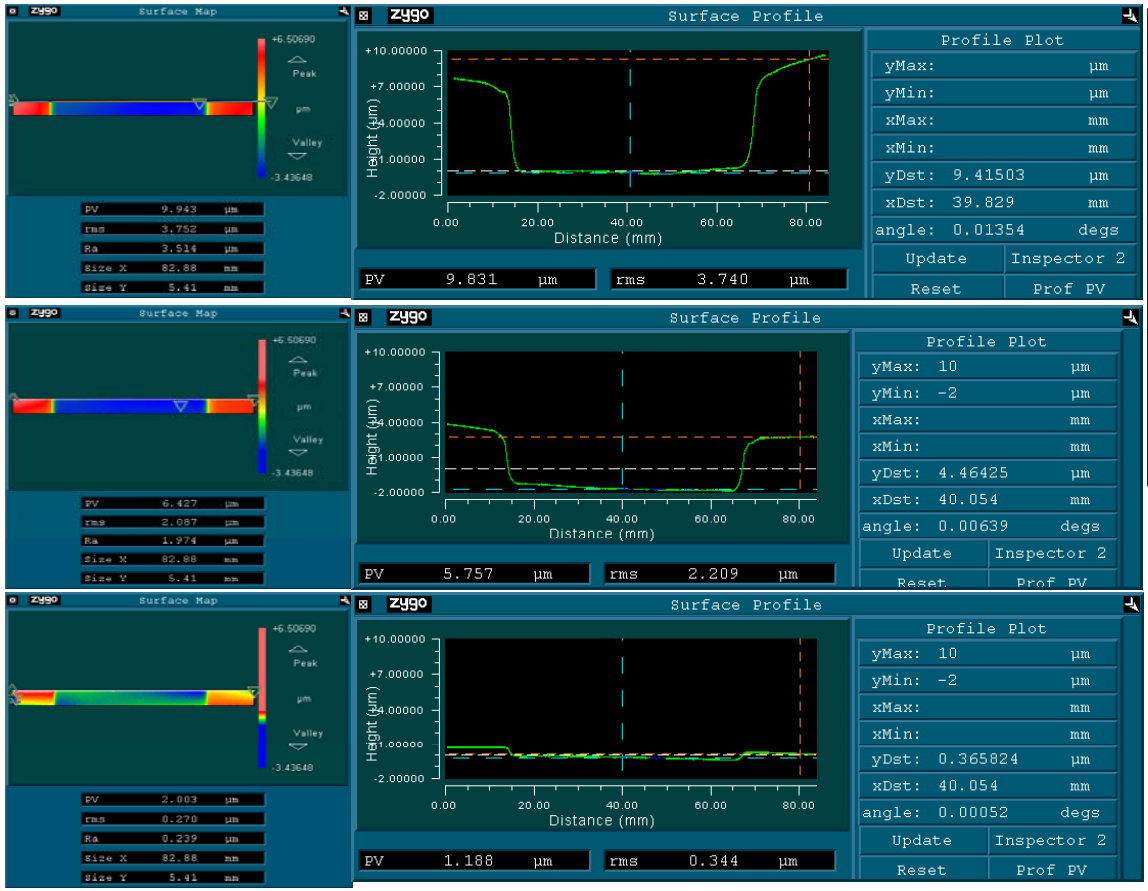
# NASA ConX [IXO] – SBIR Phase I

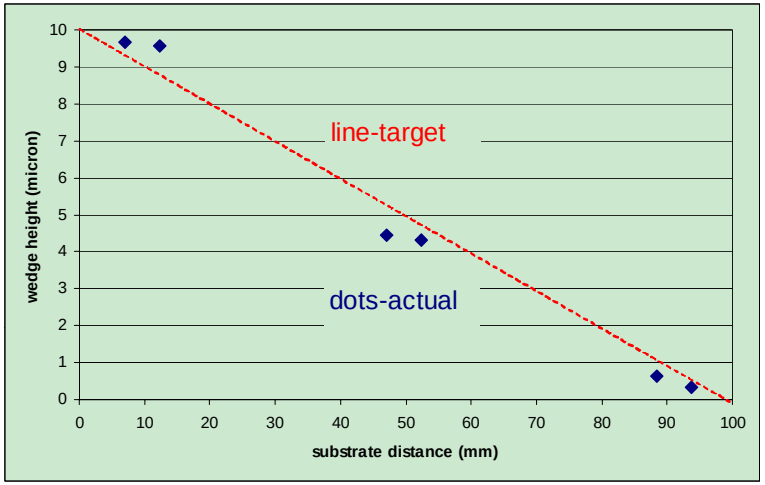
- "Fabricate & Assemble" approach
- Slumped glass mirrors with glass spacers (wedges)
  - Curvature
  - Thickness taper in optical axis
  - Radial thickness
- Phase 1 demonstrator
  - 10 μm wedges on 1mm thick, 100mm square flats
  - Borosilicate glass
  - Metrology challenge (warp)
  - NewView slices (subtractive maps)





# NASA ConX [IXO] – SBIR Phase I



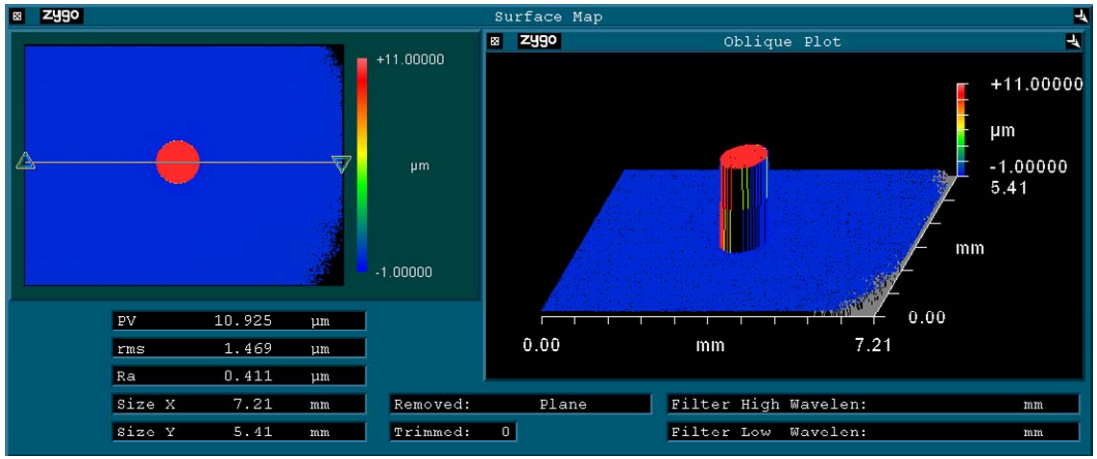

- Met program objectives
- Rapid manufacturing of wedges is possible
- Extend to curved surfaces
- Metrology challenges

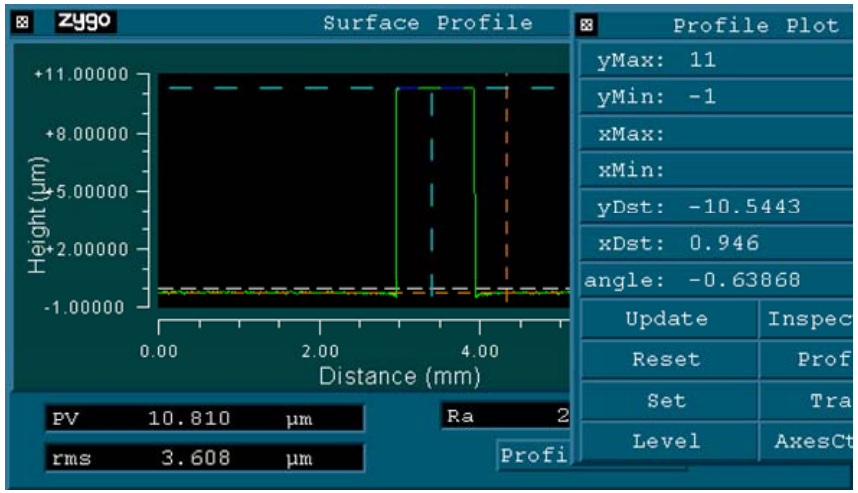
# Helios range of tools

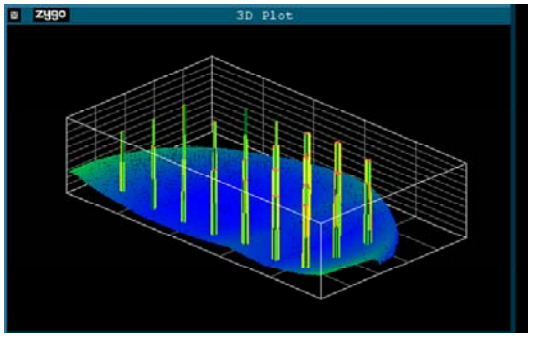
- Astronomy applications
- Helios 1200 is the first offering
  - Cranfield University is our first customer
  - Machine commissioned at Cranfield University
- Configurable in various platforms per user specification
- Simplified CNC motion control
  - G codes
  - PVT specifications

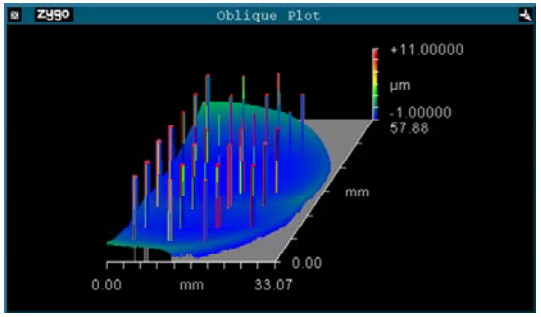
# Machine Pictures


# Patterning Capability



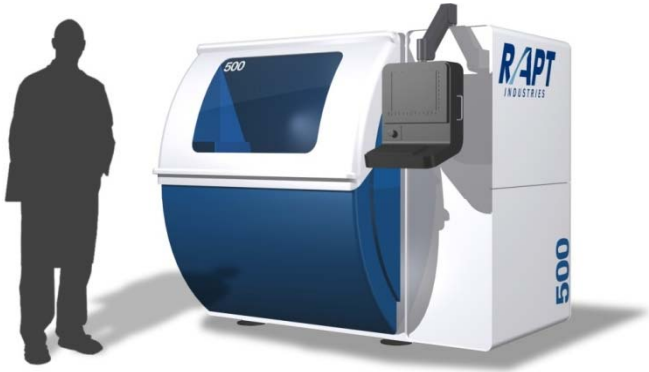

- Patterning ULE posts
- 10 µm tall
- Range of diameters
  - 450 µm to 850 µm

# 500mm Tool – EOS Series


- Standard offering
  - 5 axis tool
- 500mm clear aperture
- Tip tilt to handle upto f/0.3 surfaces
- Available for sale in Dec. 2008
- Torch design allows easy integration onto other motion control platforms
- Roadmap to smaller footprints

# Conclusions

- Rapid manufacturing using a combination of conventional and non-conventional steps
- Utilize RAP for damage-free shaping, damage removal, and/or final figuring *where appropriate*
- Non-contact, Atmospheric pressure operation
- Rapid optics fabrication leads to
  - big reductions in schedule risk
  - quicker prototyping/design cycles
  - lower overall program cost/performance risk
- Scaling
  - Larger clear apertures
  - Smaller features (on the fly)

# Questions?