

# REPORT DOCUMENTATION PAGE

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<b>14. ABSTRACT</b> Three auto-collimating flats (ACFs) of 1.5 meter clear aperture are being manufactured for use in the JSC Cryo-Optical Metrology test of the James Webb Space Telescope. In-process interferometric testing of the ACFs is used to guide their surface-figure processing. The surface measurement is performed in a vacuum chamber at both room (+20 °C) and cryogenic (-240 °C) temperatures. With a 12-inch beam diameter FizCam interferometer, sub-aperture measurements are taken across the ACF diameter at multiple rotations. These measurements are stitched together to compute the surface figure. The figure change between room-temperature and cryogenic temperature is measured and used to enable cryo-figuring based on room-temperature measurements. The data analysis is calibrated to account for gravity sag on test-set optics and surface aberrations caused by vacuum pressure and temperature gradients on vacuum-chamber windows. The completed ACFs will have a surface error of less than 75 nm RMS.					
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# **In-Process Testing For Cryo-Figuring 1.5 meter Diameter Auto-Collimating Flats**

**June 7, 2010**

**presented by**

**David J. Fischer, Ph.D.  
ITT Geospatial Systems**



# 3 Autocollimating Flats used in Cryo-Optical Test of JWST



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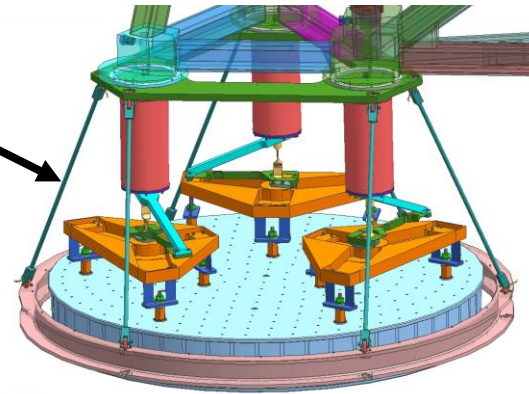
Space Technology



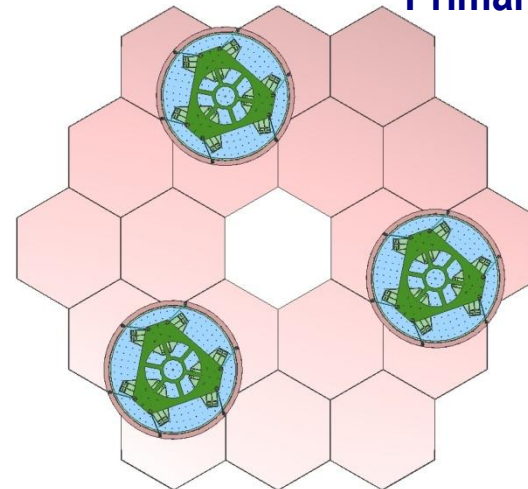
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ACF



ACF Footprint on Primary Mirror





# Skip Test Used for Cryo-Figuring ACFs

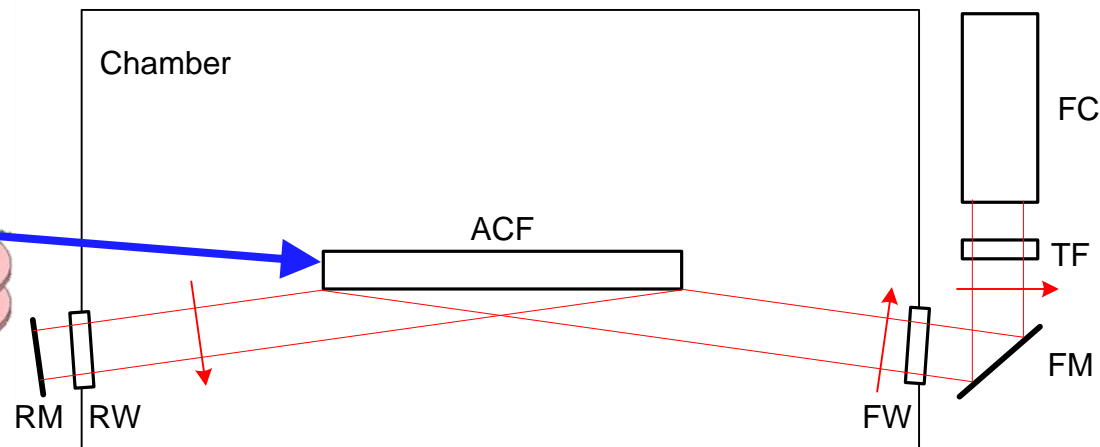
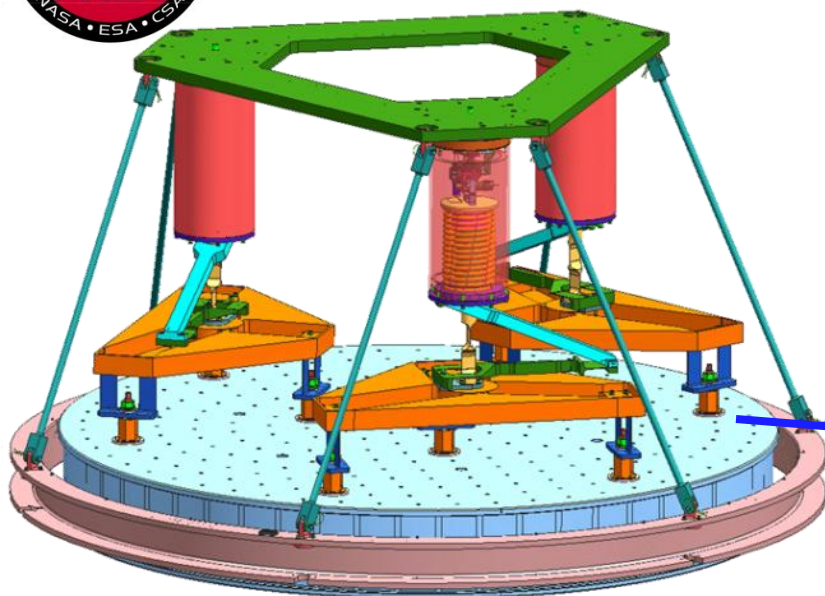


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## ■ Cryo-Vac Skip Test for 32.8 K ACF

- 300 mm beam ( $\lambda=660$  nm) “skips” across ACF diameter at  $8.213^\circ$
- 60 sub-aperture Slices at  $6^\circ$  rotations measure entire surface
- Cryo Backout computed, applied to slice
- Slices stitched together compute surface map

## ■ Requirements

- Clear Aperture of 1.520 m
- 75 nm surface rms (including test uncertainty)
- Uncertainty requirements on power and astigmatism



# CAD Model of Skip Test

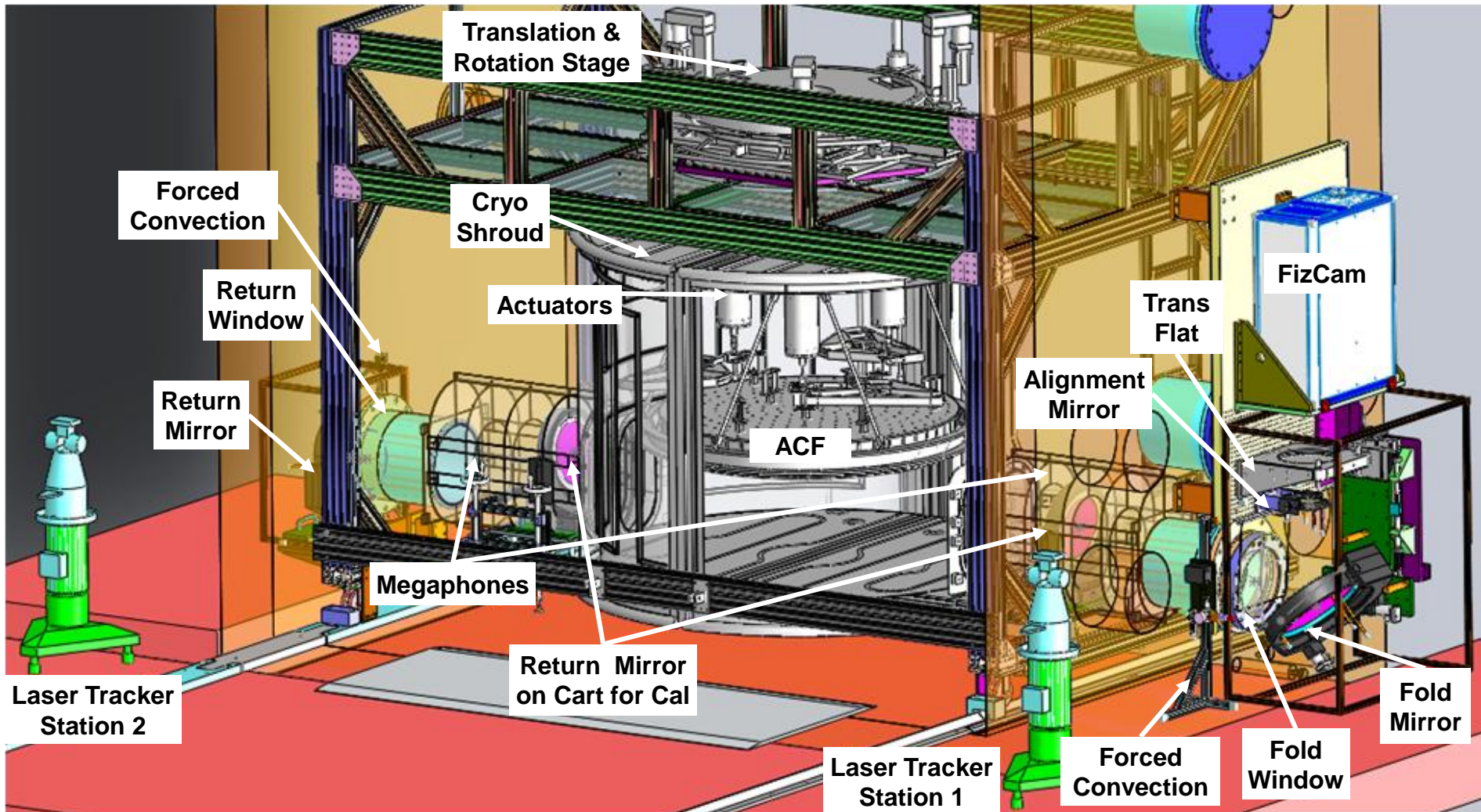


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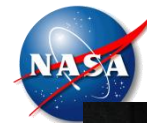


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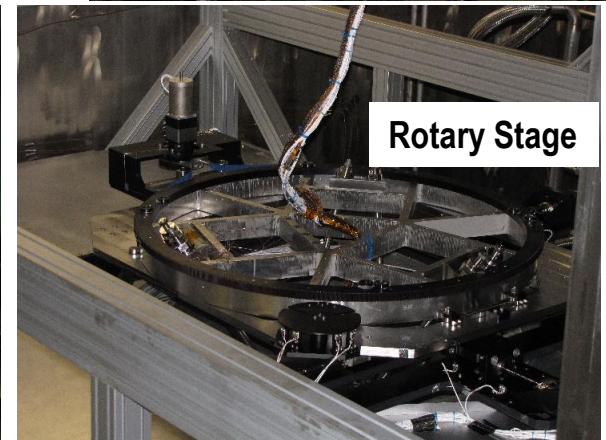
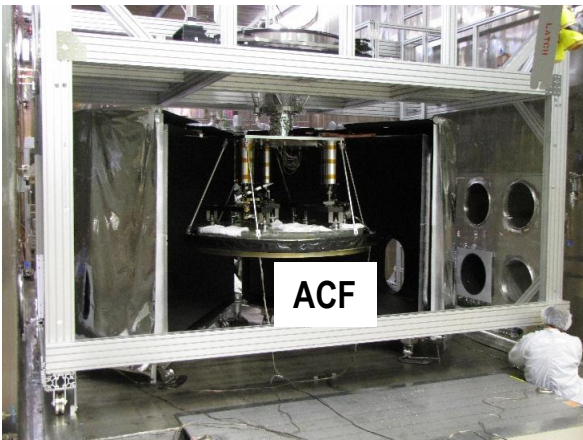
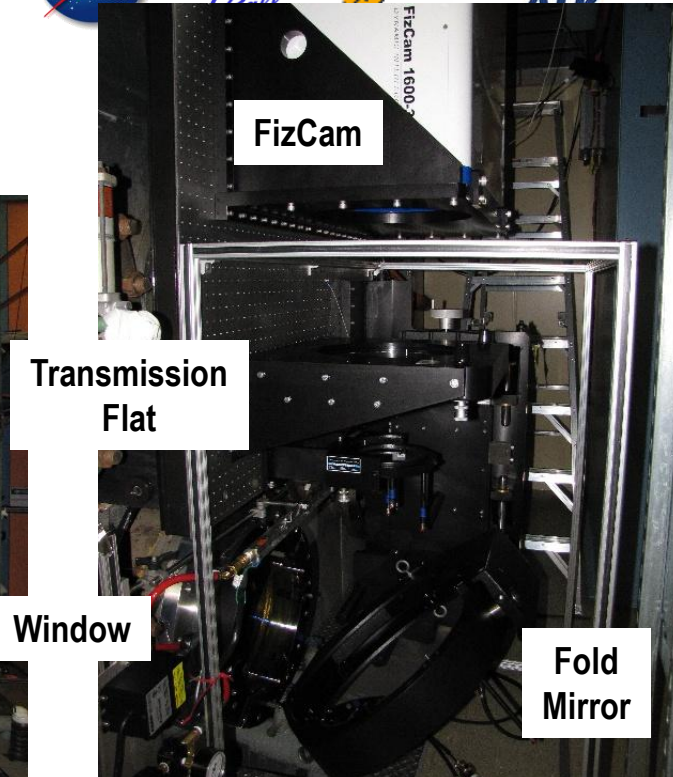
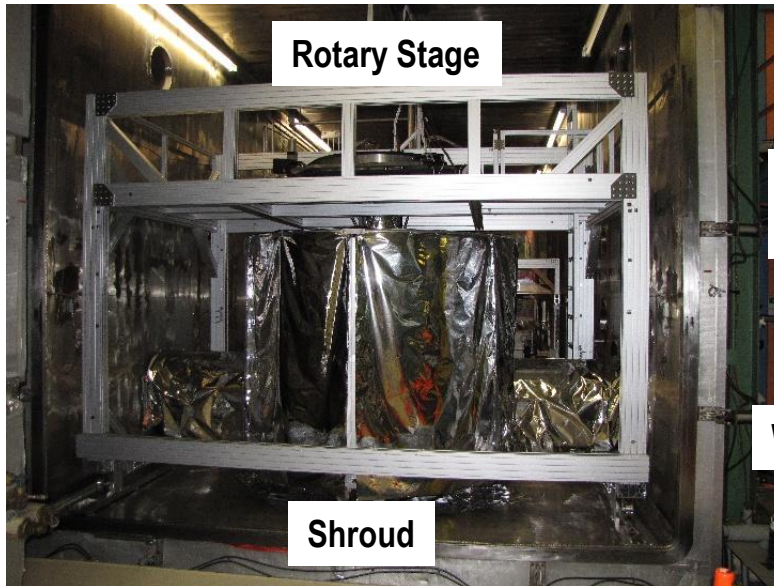
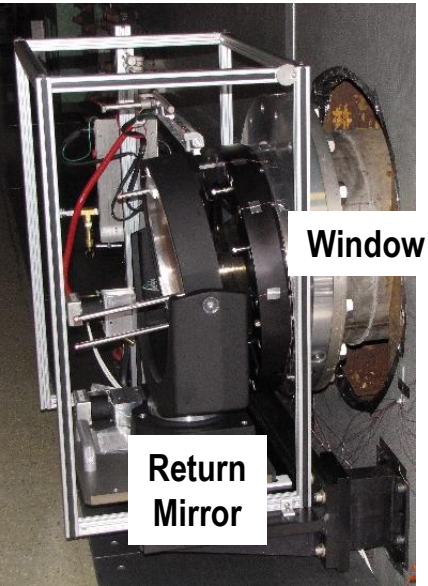


# Photographs of Skip Test Hardware



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# Initial Alignment of Test Set by Laser Tracker

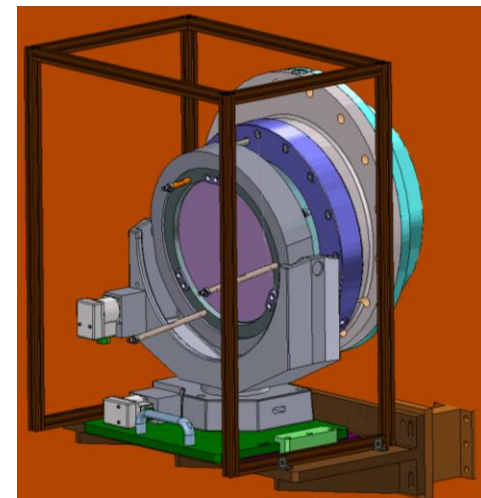
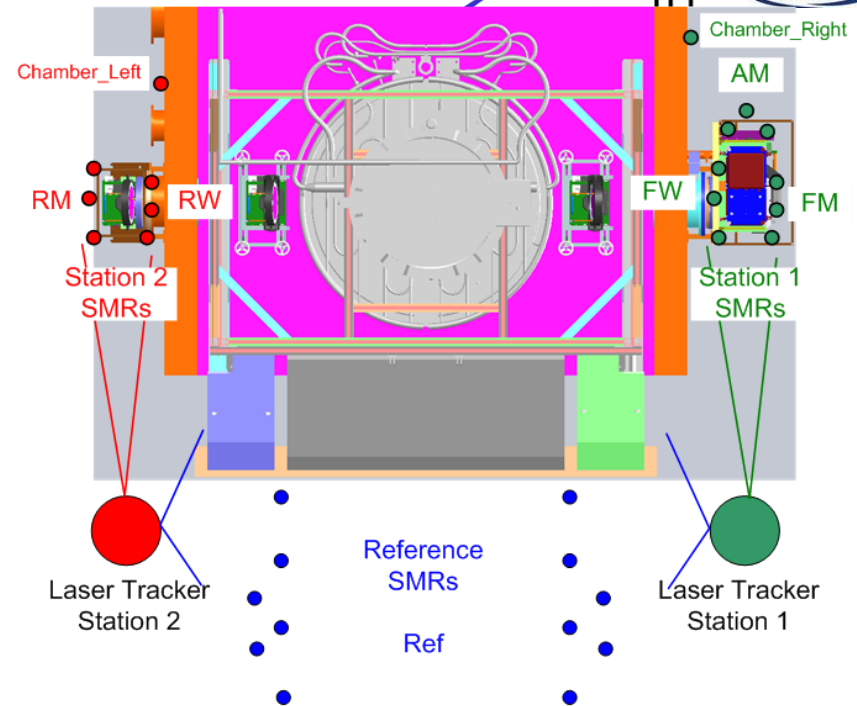


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- Align FizCam Transmission Flat and Alignment Mirror (AM)
- Initial alignment by Laser Tracker
  - Align Return Mirror (RM)
  - Coarse align Fold Mirror (FM)
- RM aligned 1 arcmin ( $0.017^\circ$ ) accuracy per Theodolite
- Laser Tracker shows ACF bias of 12 arcmin ( $0.2^\circ$ )





# Optical Alignment by FizCam

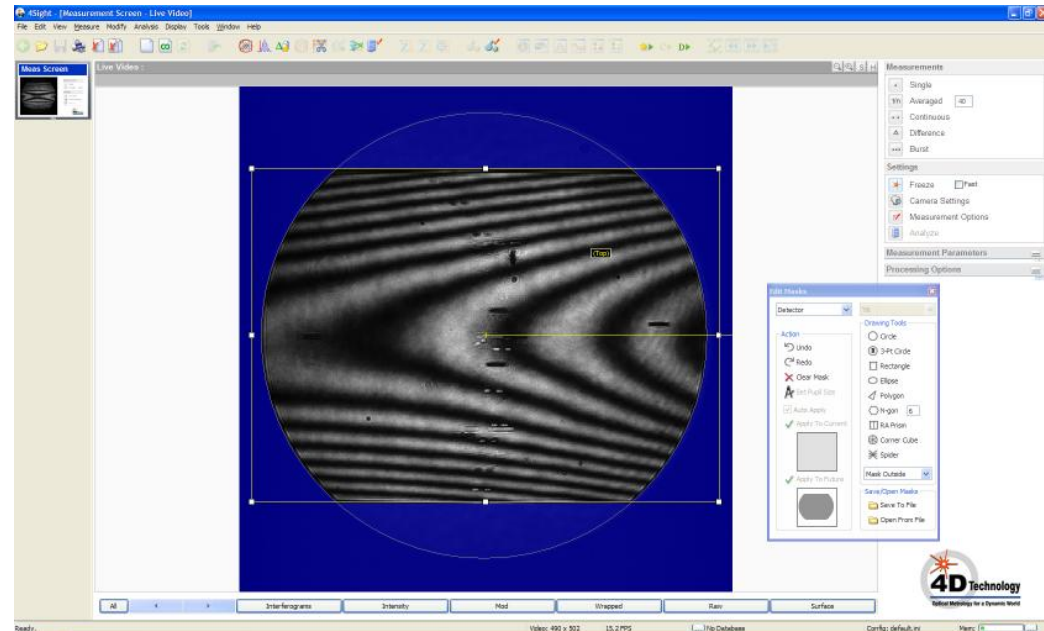
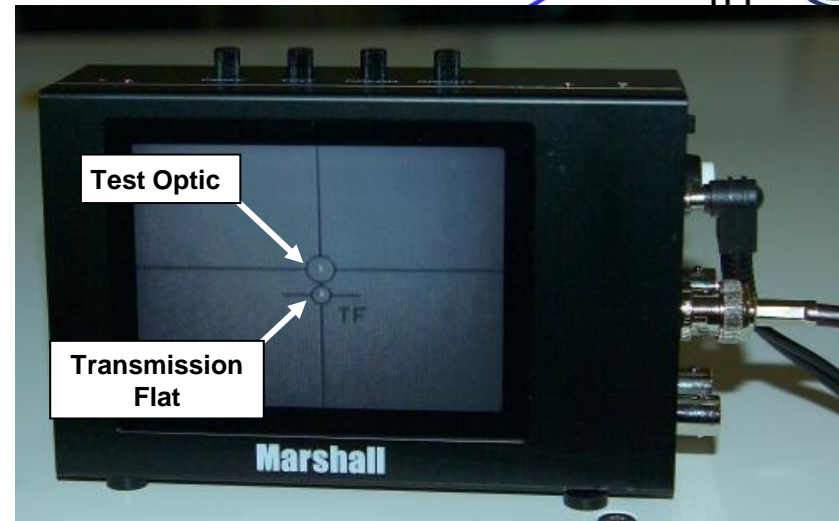


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- Align FizCam's Transmission Flat
- Align Return Mirror by Laser Tracker
- Align FM by Alignment Monitor
- Null fringes with FM
- Adjust ACF centration by live video





# Automated Measurement & Analysis Make Complex Test Simpler



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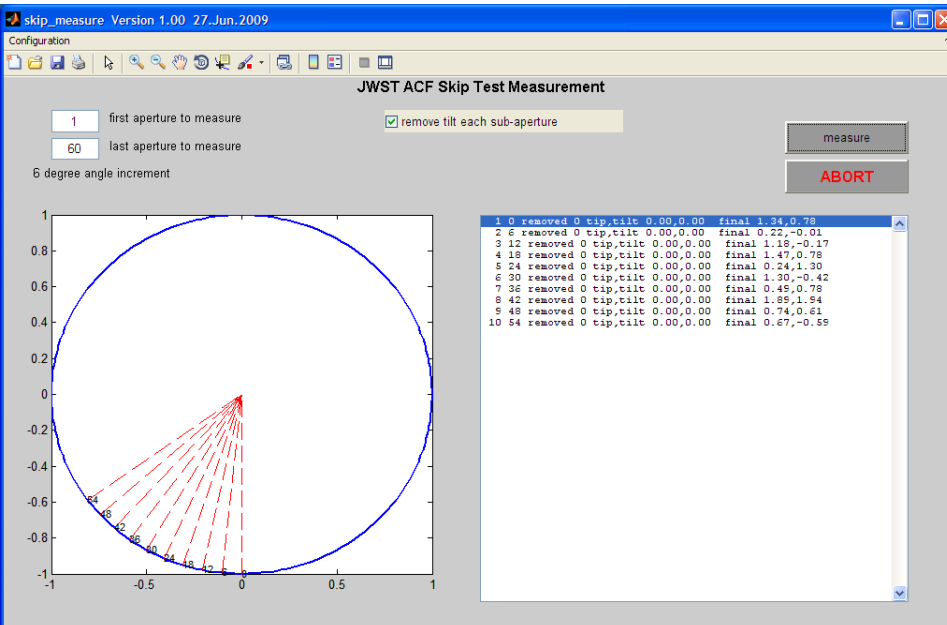
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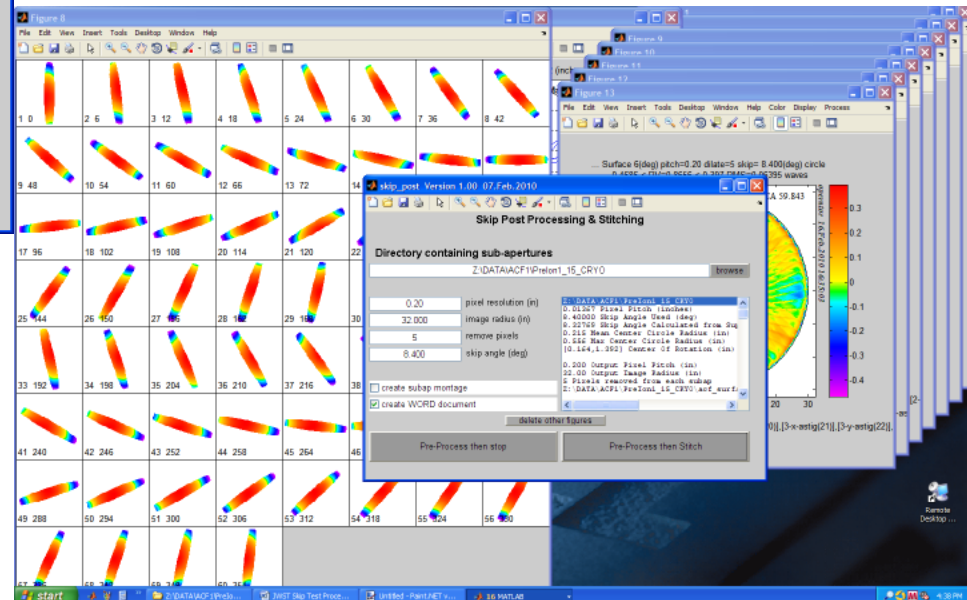
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Stitching software rotates, de-tilts,  
and measures for 360° rotation



Stitching processes 360°  
measurement with summary report

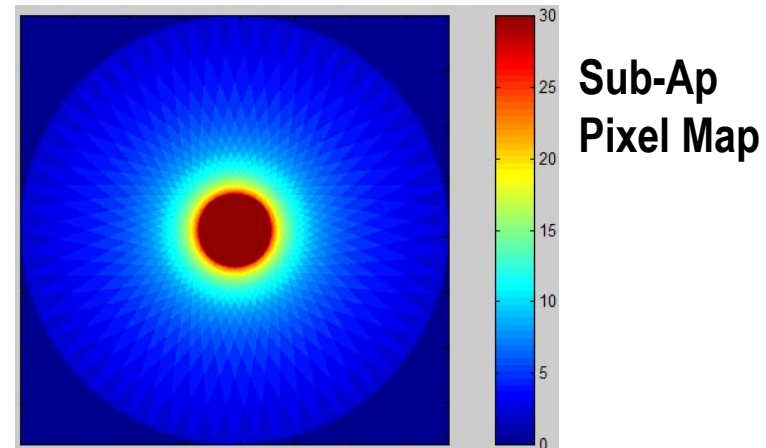
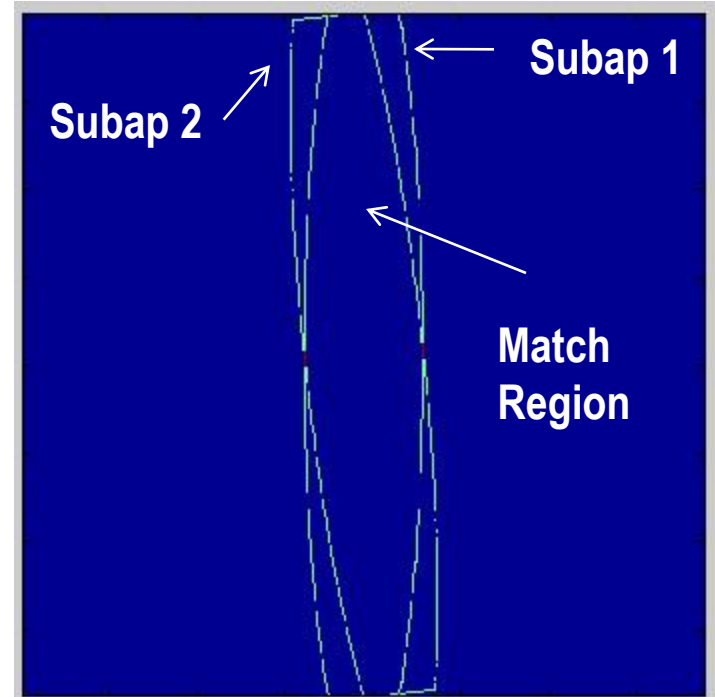




# Description of Stitching Approach



1. Interferograms Scaled, Stretched and Rotated by Nominal Geometry
2. 1st Subap is Reference for Scale
3. Nth Subap Matched to N-1th Subap in data overlap region & replaced with Match. Matching done by fitting tilt & scale
4. Final Map is Sum of Adjusted Subaps, normalized Pixel-by-Pixel using Sub-Ap Pixel Map



Variations on : Otsubo M. et al, "Measurement of large plane surface ...", Opt. Engineering 33, 608-613 (1994).



# ACF Surface Computed by Stitching 60 Slices (6° Rotations)

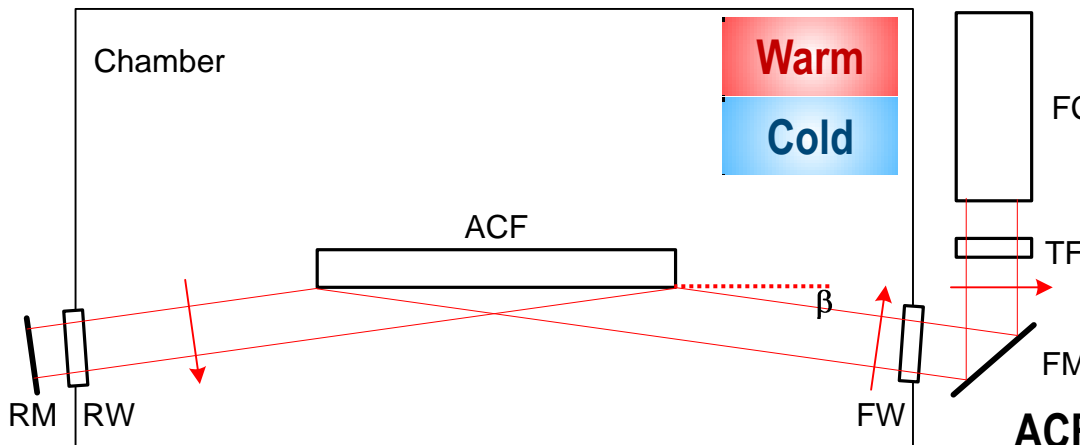


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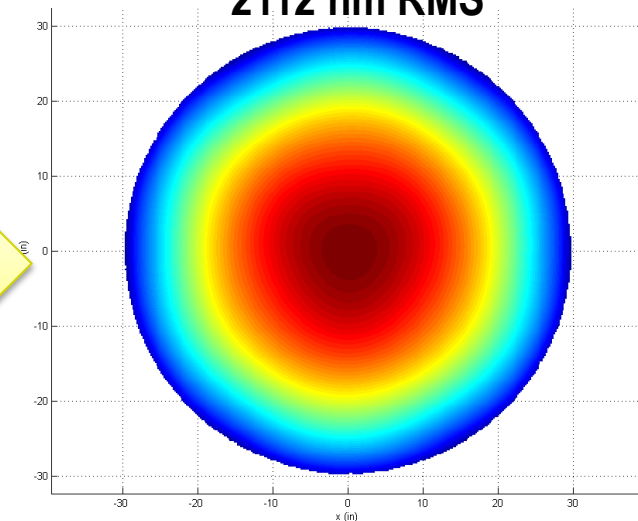
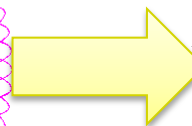
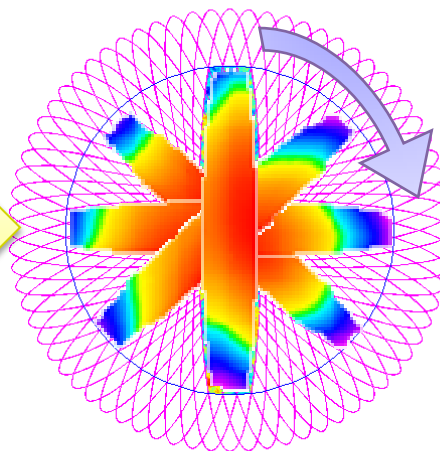
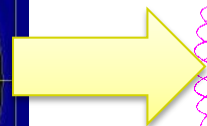
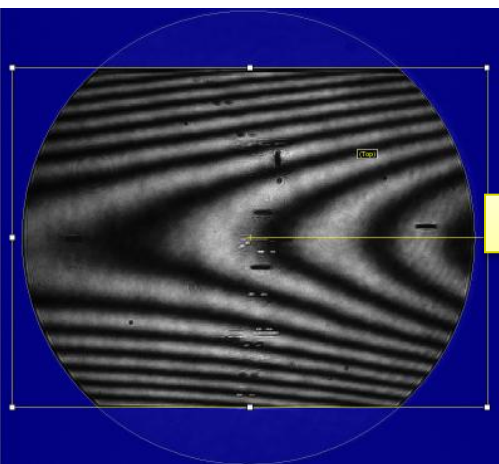
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ACF Surface at 32.8 K  
2112 nm RMS



$$W_{M,n} = 2FC + 2TF + 4FM + 2FW + 2RW + 2RM + 4 \sin \beta \text{ ACF}_n$$



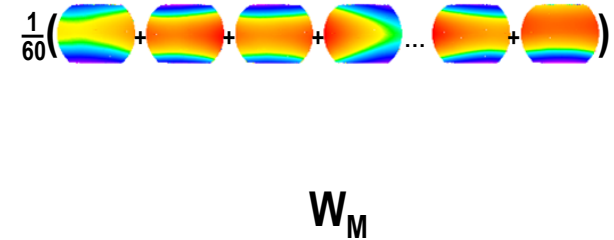
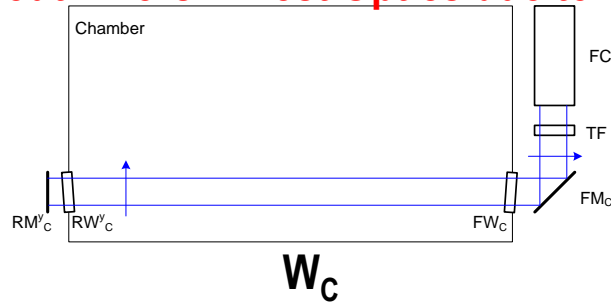
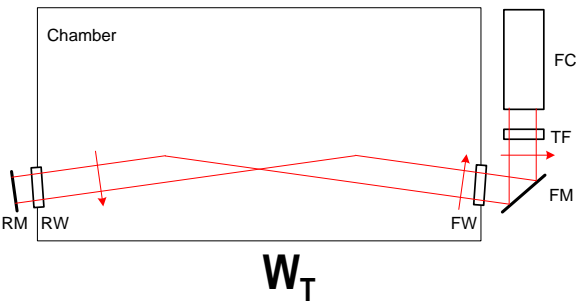
# Cryo Backout: Test Set + Cryo-Delta



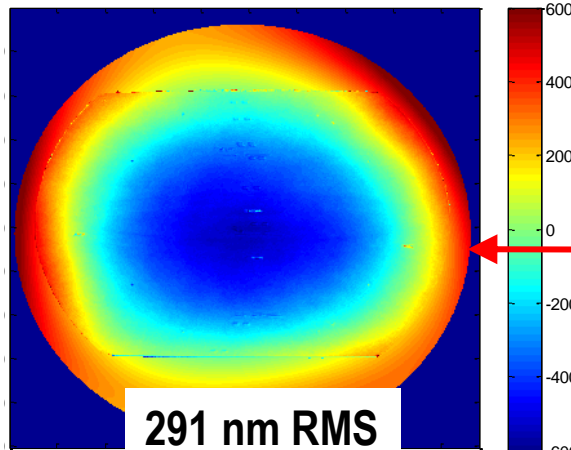
$$W_B = W_T|_{WARM} \leftarrow \text{Backout Errors in Test Optics at Warm-Vac}$$

$$+ \frac{1}{2} \left[ W_C + W_C^y \right]_{CRYO} - \frac{1}{2} \left[ W_C + W_C^y \right]_{WARM} + \left[ W_M - W_M^y \right]_{CRYO} - \left[ W_M - W_M^y \right]_{WARM}$$

## Backout Errors in Test Optics due to Cryo Shift



$$W_B =$$



Subtract Extrapolated Backout from each Slice before Stitching

Gradient Reconstruction Backout not used



# Backout Improves Stitching Results



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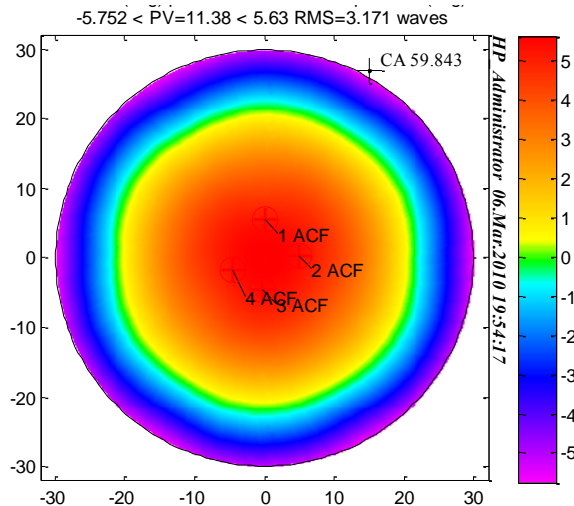
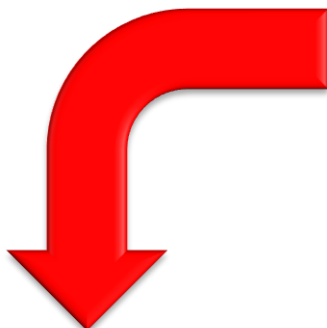
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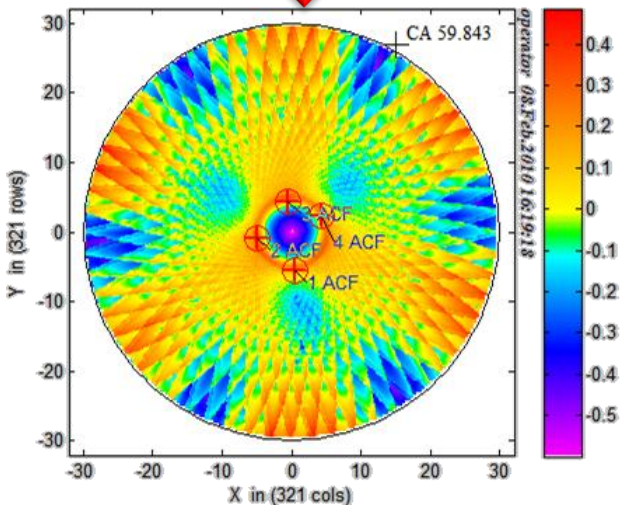
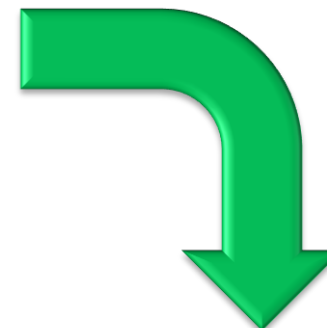


No Backout  
Clear Stitching Artifacts  
Higher Surface Residual

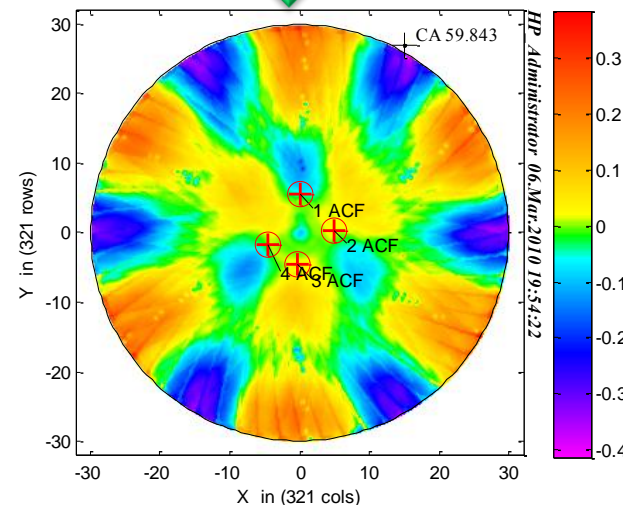


ACF Surface at 32.8 K  
2112 nm RMS

Use Cryo Backout  
Smoother Surface  
Smaller Surface Residual



37-Zernike Fit Residual  
95 nm RMS



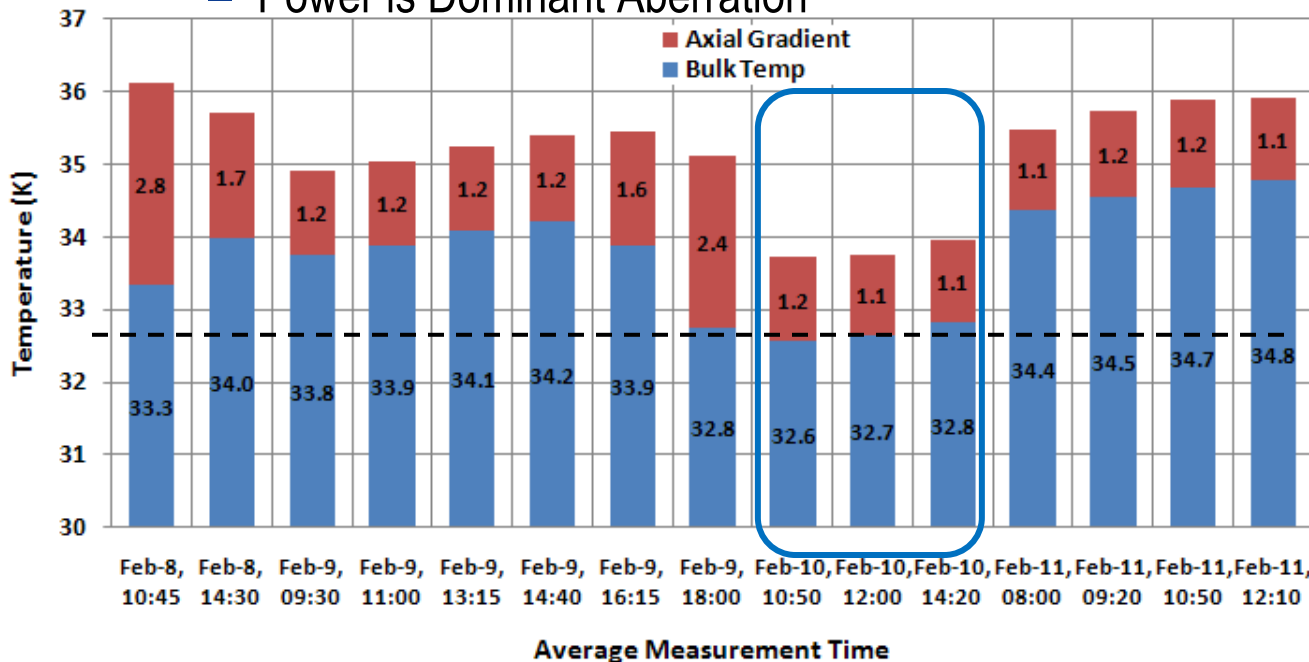
37-Zernike Fit Residual  
77 nm RMS



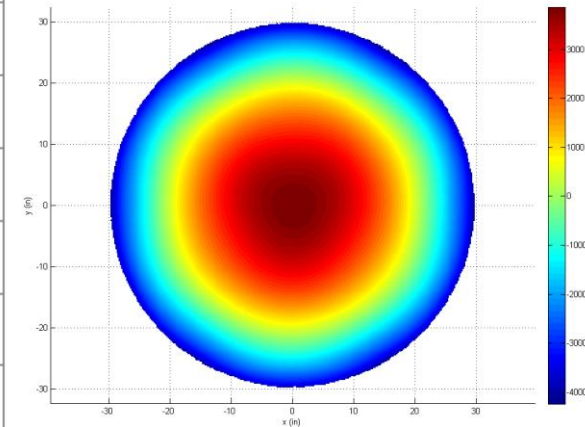
# Cryo Testing Successful



- Pre-Ion 1 Skip Test Complete
- Warm Vac
  - Figure agrees with OAGM Probe
- Cryo-Vac (32.8 K)
  - Hitmap: 3 Surface Maps from Feb 10
  - Close to Warm Vac
  - Power is Dominant Aberration



ACF Surface at 32.8 K  
2112 nm RMS



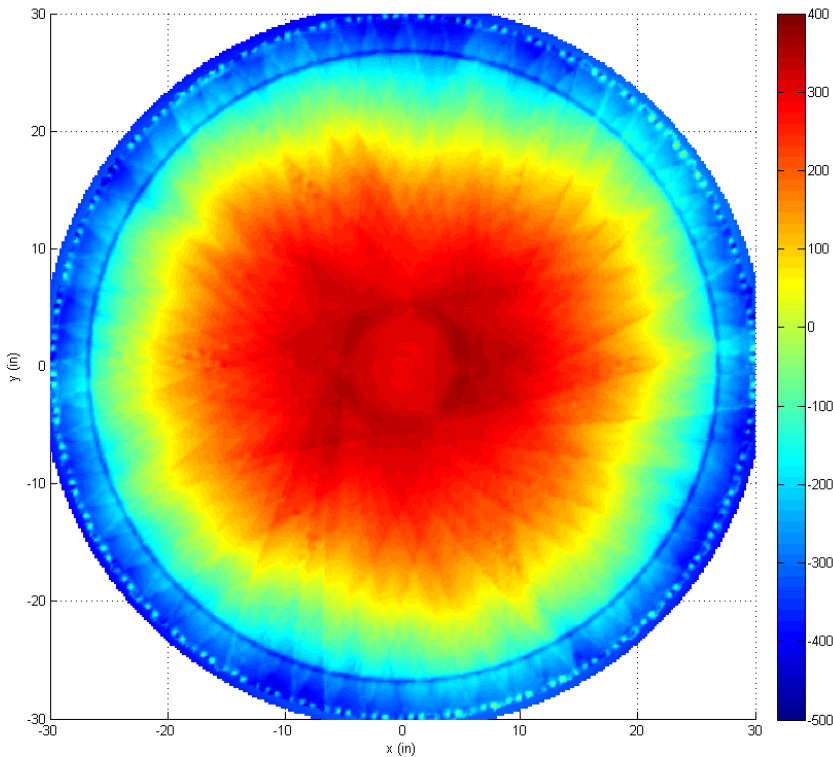


# Cryo Shift Successfully Measured

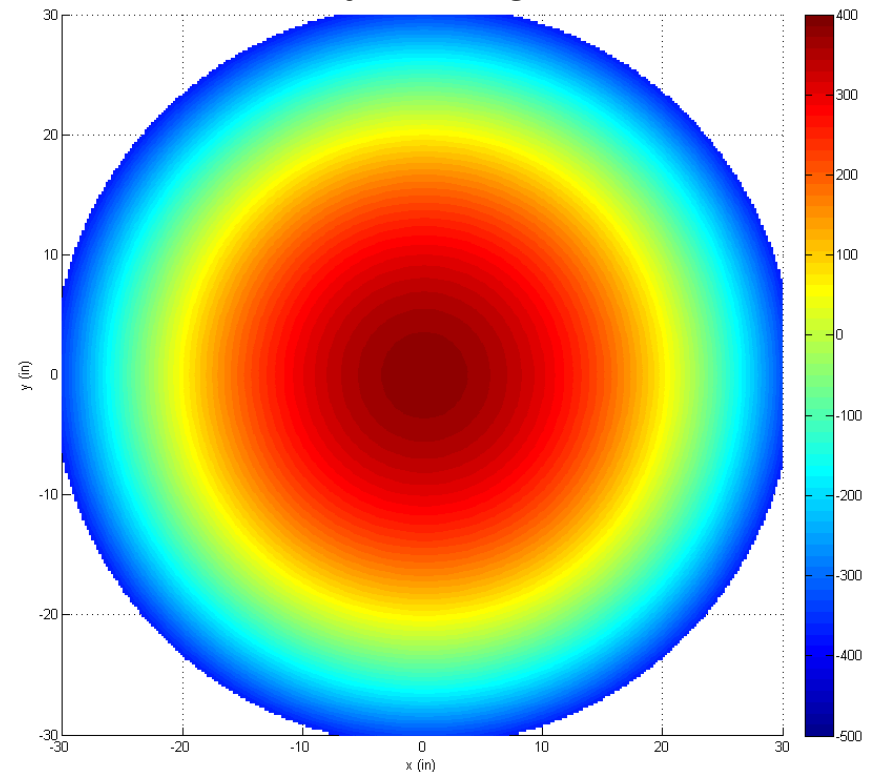


- Cryo Shift is 224 nm RMS
  - Power and Stitching Errors
  - Relatively low compared to worst-case predictions of 3000 nm RMS
- ACF2 & ACF3 to benefit from thermal facility improvements

ACF1 Cryo Shift  
224 nm RMS



Power in Cryo Shift  
220 nm RMS

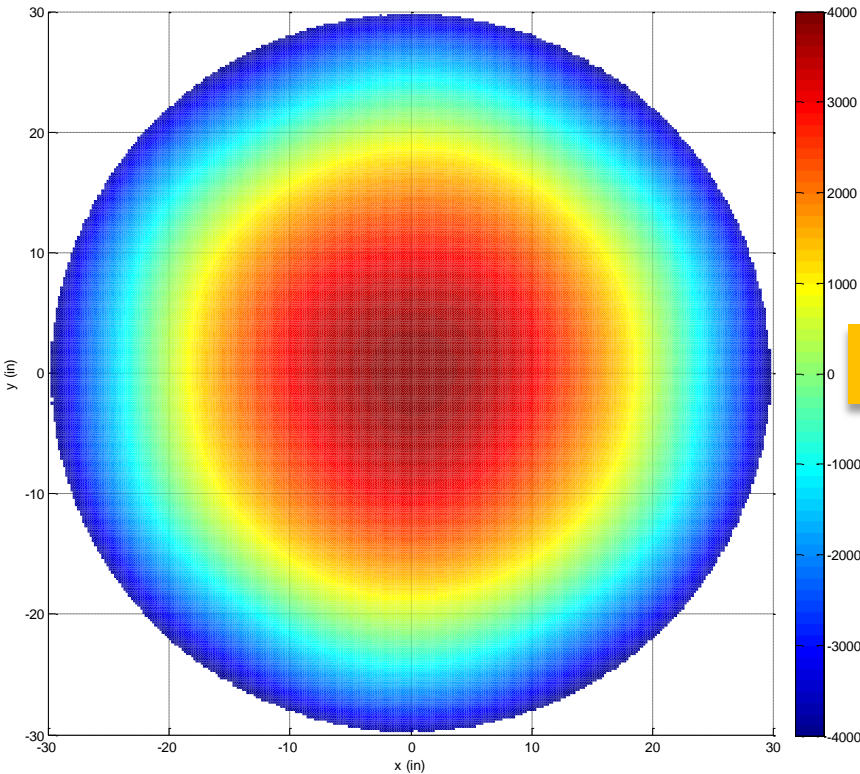




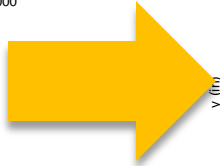
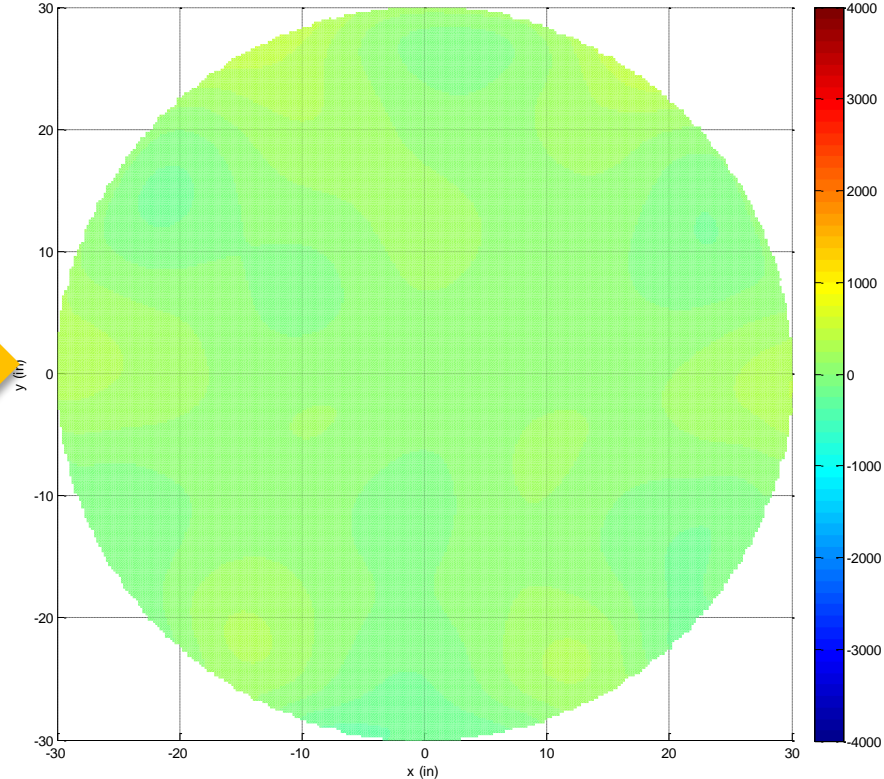
# Cryo Surface Progress



**Initial Surface**  
**2184 nm RMS**



**Current Hitmap**  
**108 nm RMS**



**Stitching Artifacts Removed for Hitmap**



# Summary: ACF1 Nearing Completion



- **ACF Skip Test Fully Functional**
  - Multiple Cryo-Vac Measurements at 32.8 K
  - Multiple Warm-Vac Measurements
  - Complete Backout Measured and Computed for Warm and Cryo
  - Cryo-Shift Computed & Found to be Small
- **ACF #1 Nearing Completion**
  - Final Ion Hit Beginning
  - Final Warm-Vac & Cryo-Vac Testing Planned

**Current Hitmap  
108 nm RMS**

