In-Process Testing For Cryo-Figuring 1.5 meter Diameter Auto-Collimating Flats

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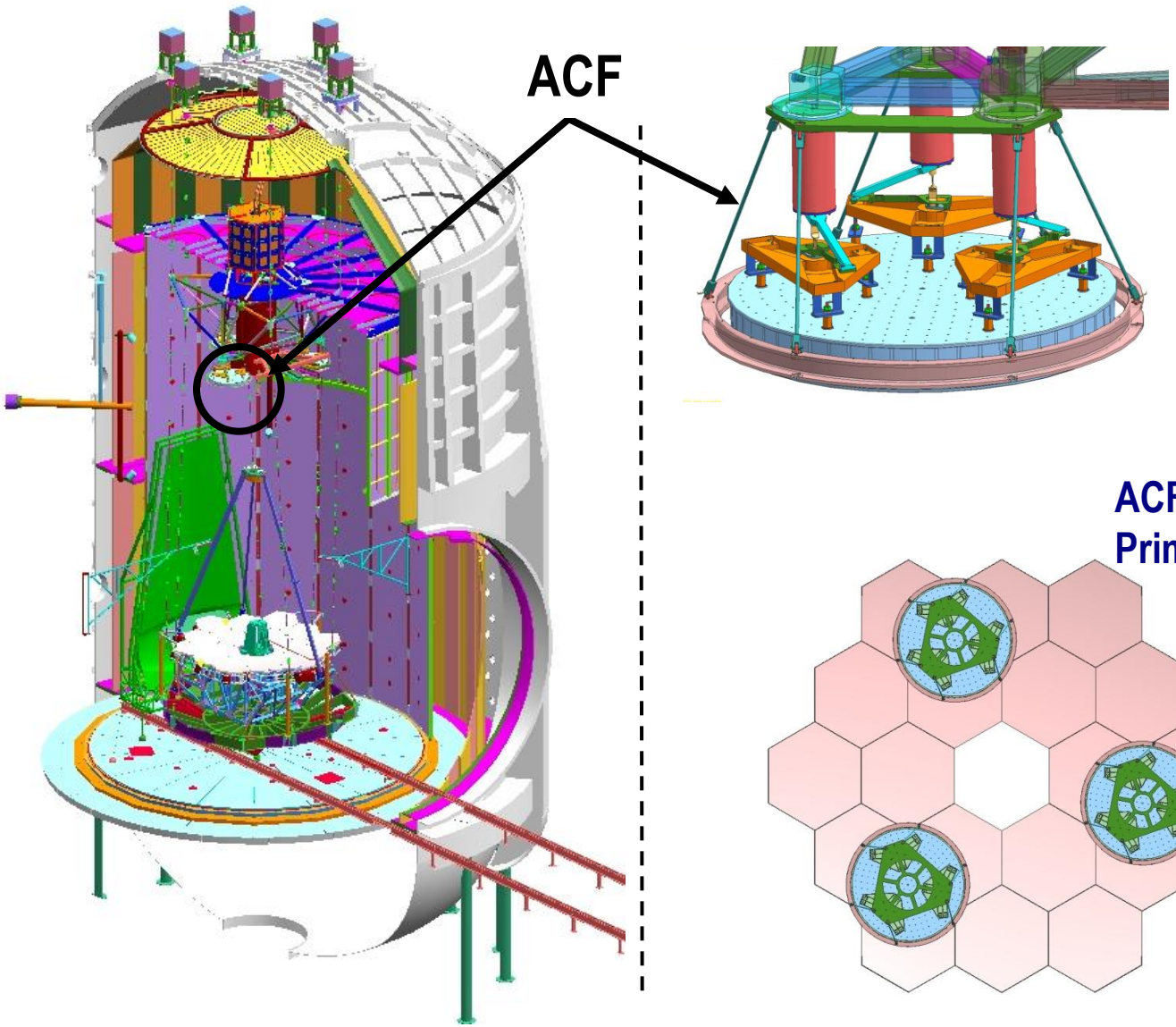
presented by

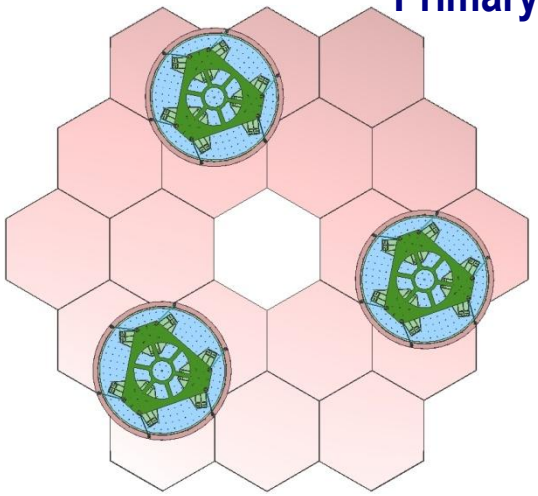
David J. Fischer, Ph.D.
ITT Geospatial Systems

22 CFR 125.4(b)(13) Applicable

3 Autocollimating Flats used in Cryo-Optical Test of JWST



ACF Footprint on Primary Mirror



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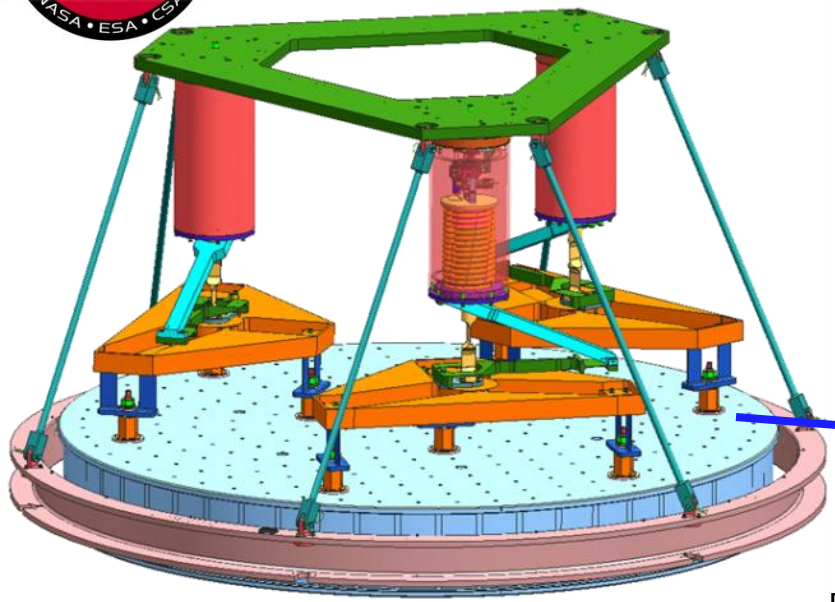
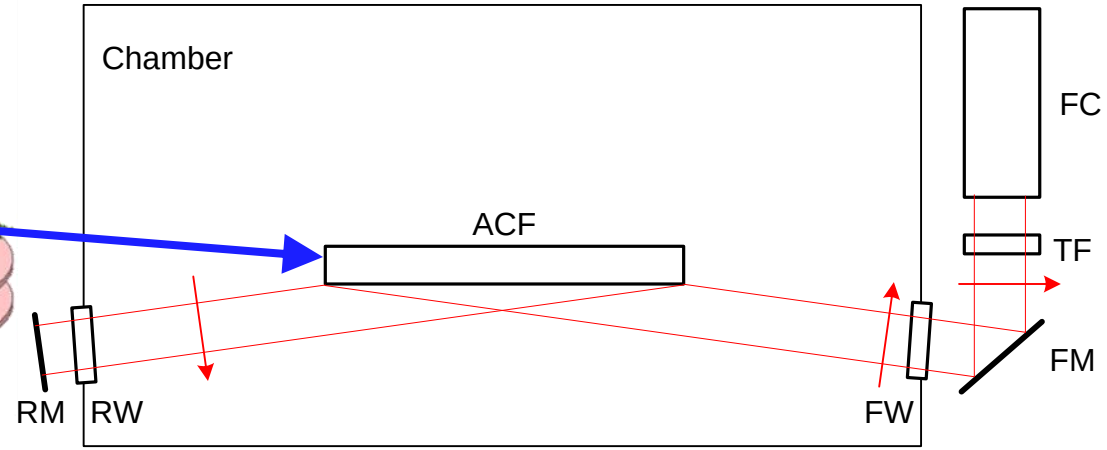
Skip Test Used for Cryo-Figuring ACFs





- **Cryo-Vac Skip Test for 32.8 K ACF**
  - 300 mm beam (λ=660 nm) "skips" across ACF diameter at 8.213°
  - 60 sub-aperture Slices at 6° 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

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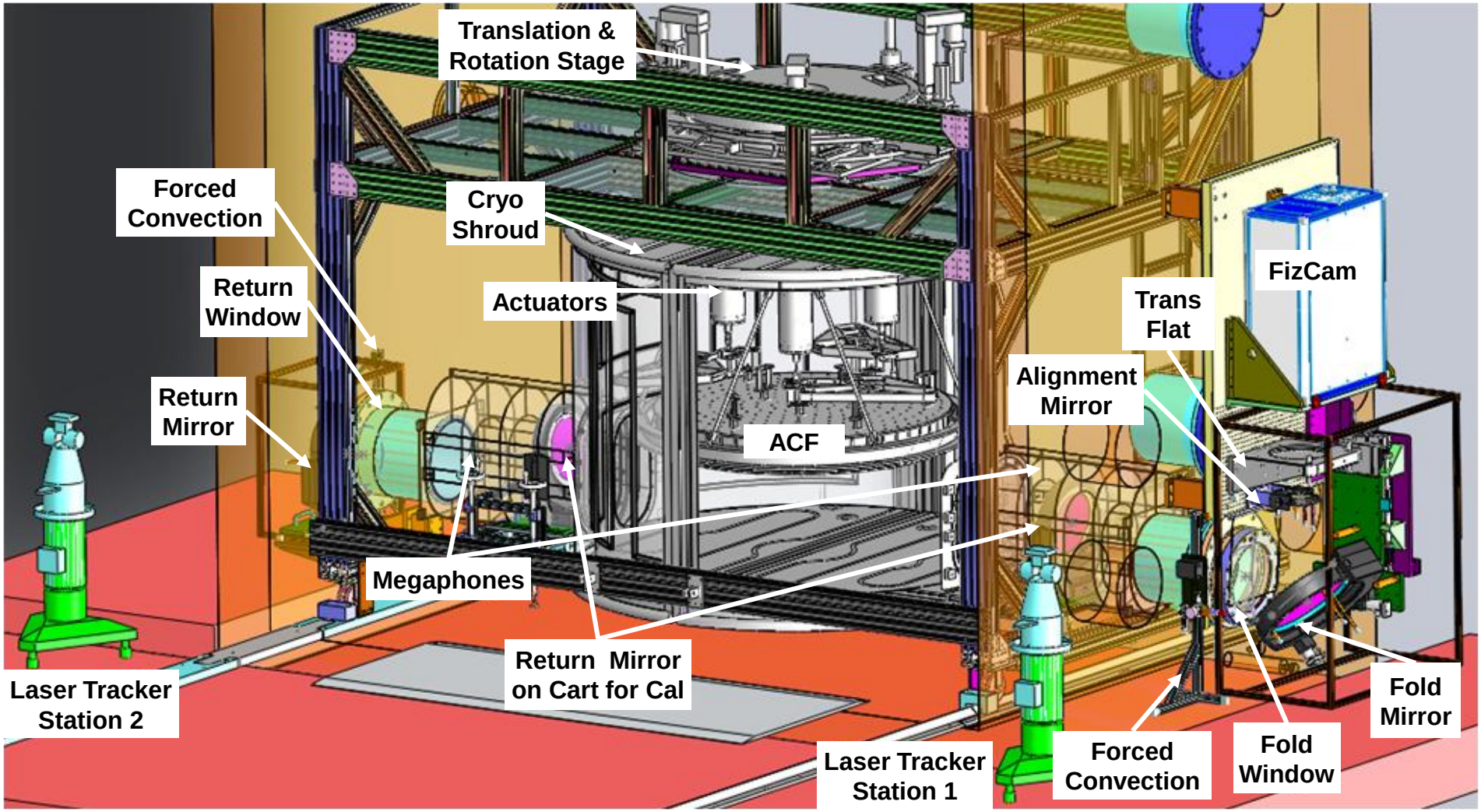
CAD Model of Skip Test



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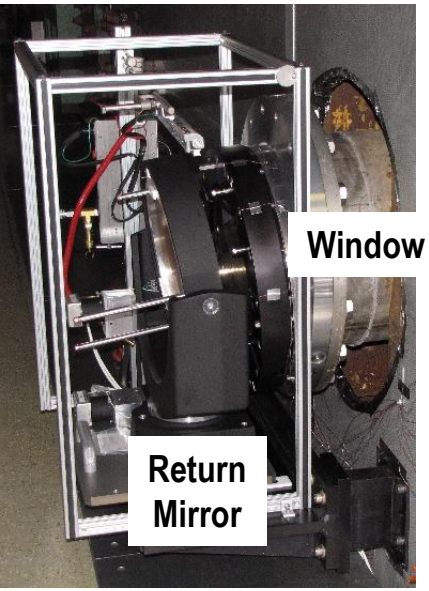
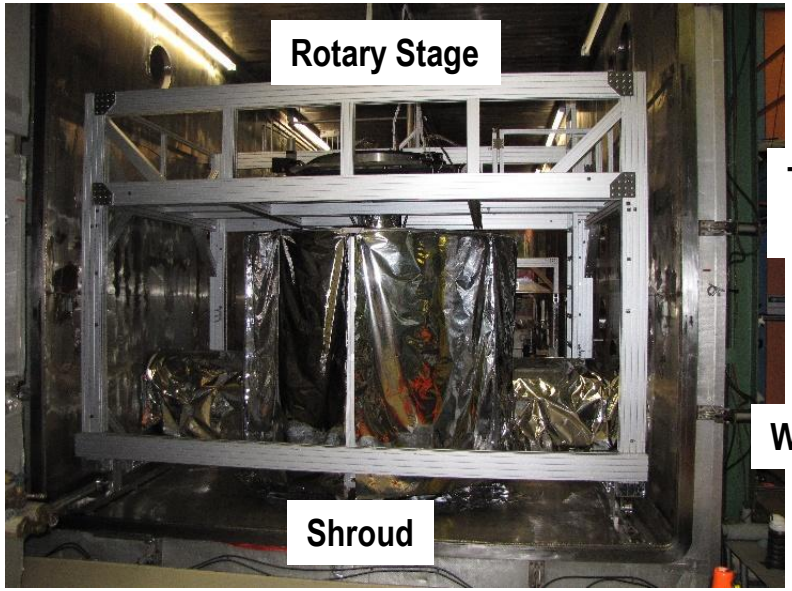
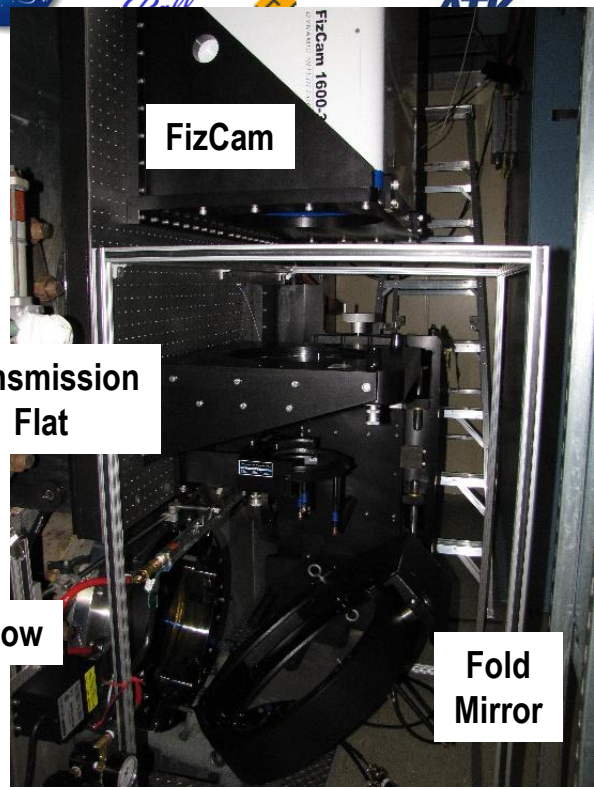
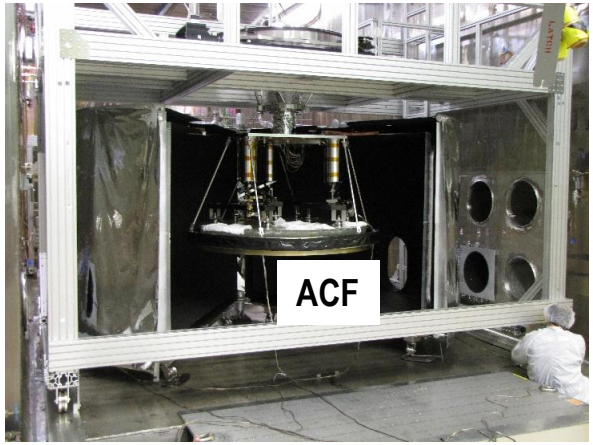
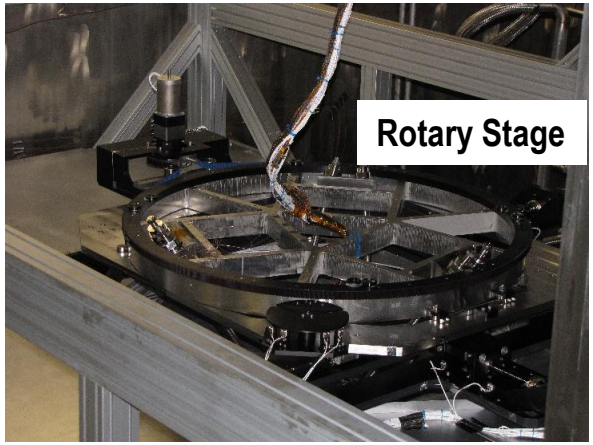
Photographs of Skip Test Hardware











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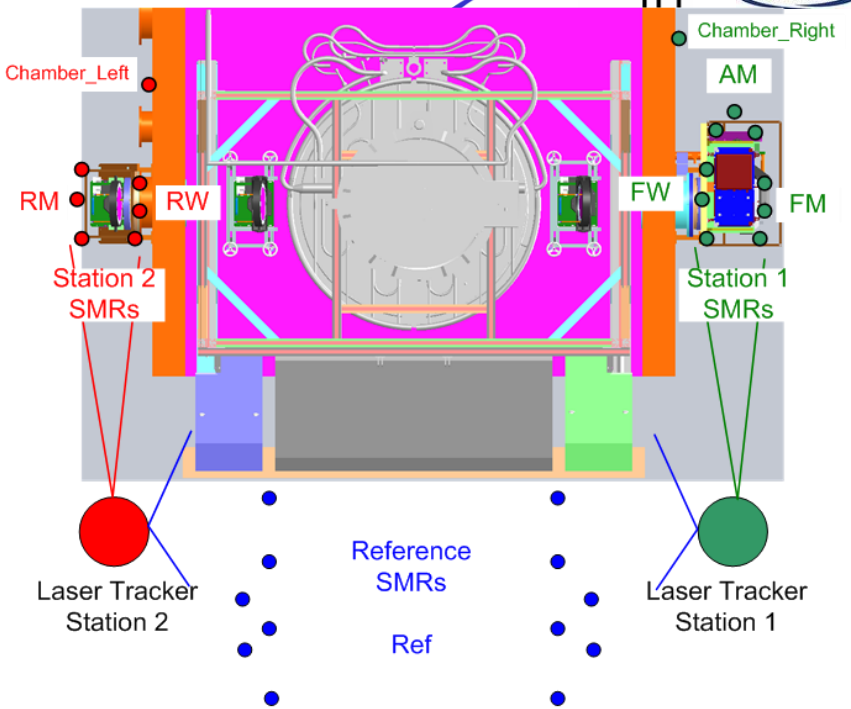
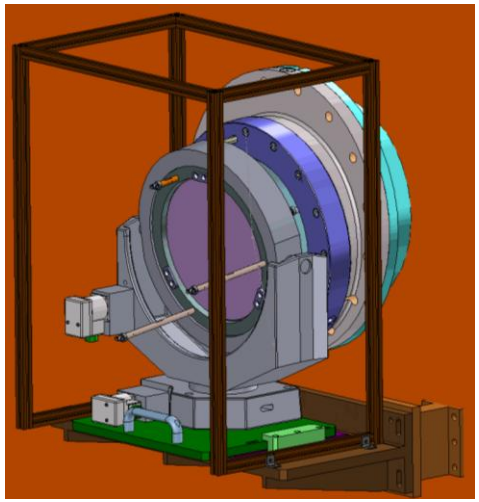
Initial Alignment of Test Set by Laser Tracker

- **Align FizCam Transmission Flat and Alignment Mirror (AM)**
- **Initial alignment by Laser Tracker**
  - Align Return Mirror (RM)
  - Coarse align Fold Mirror (FM)

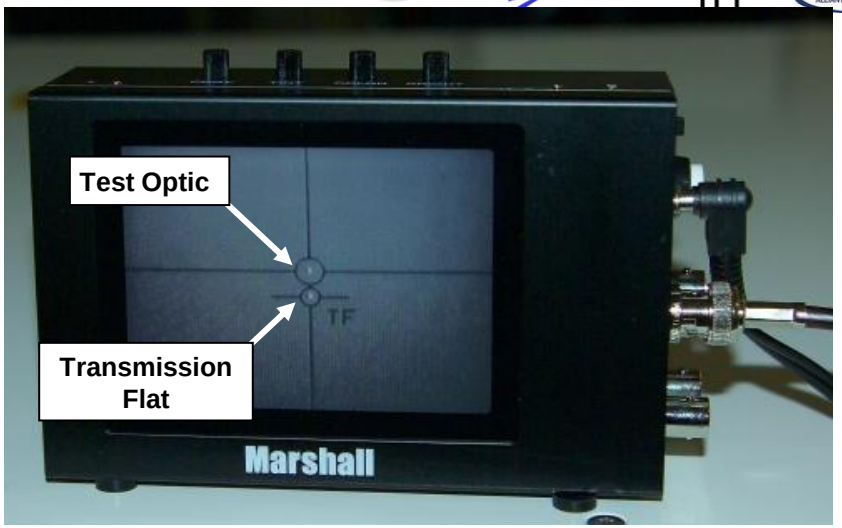
- **RM aligned 1 arcmin (0.017°) accuracy per Theodolite**
- **Laser Tracker shows ACF bias of 12 arcmin (0.2°)**

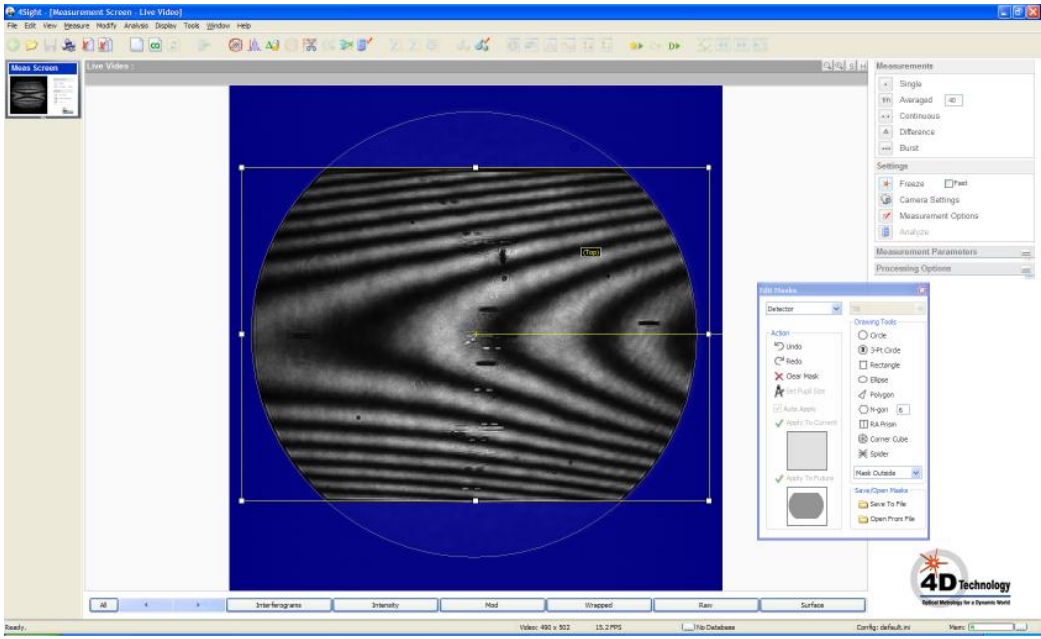




Optical Alignment by FizCam

- 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





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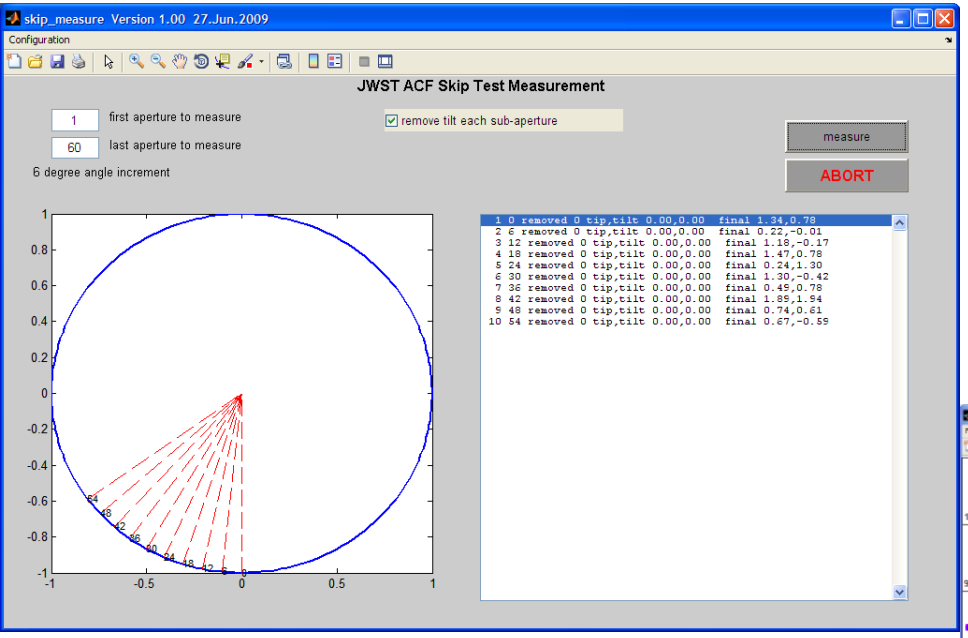
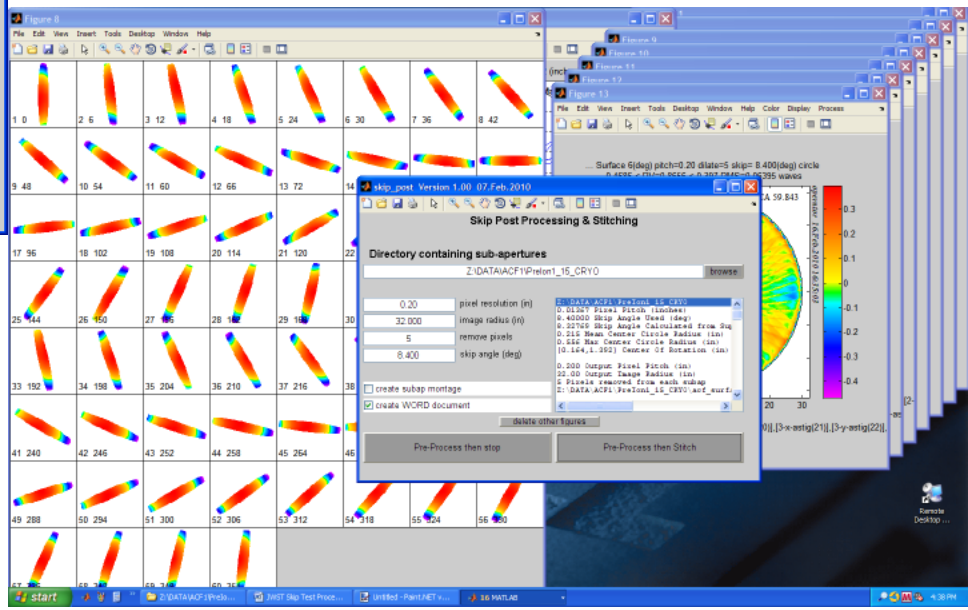
Automated Measurement & Analysis Make Complex Test Simpler

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



Stitching processes 360° measurement with summary report



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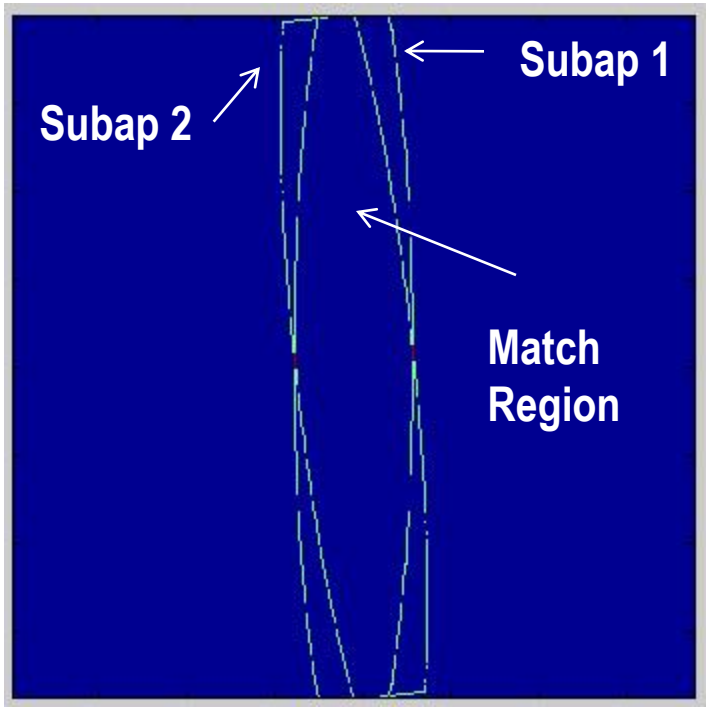
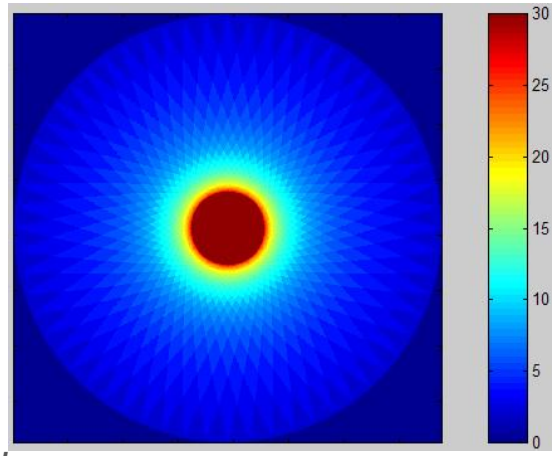
Description of Stitching Approach

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





Sub-Ap Pixel Map

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

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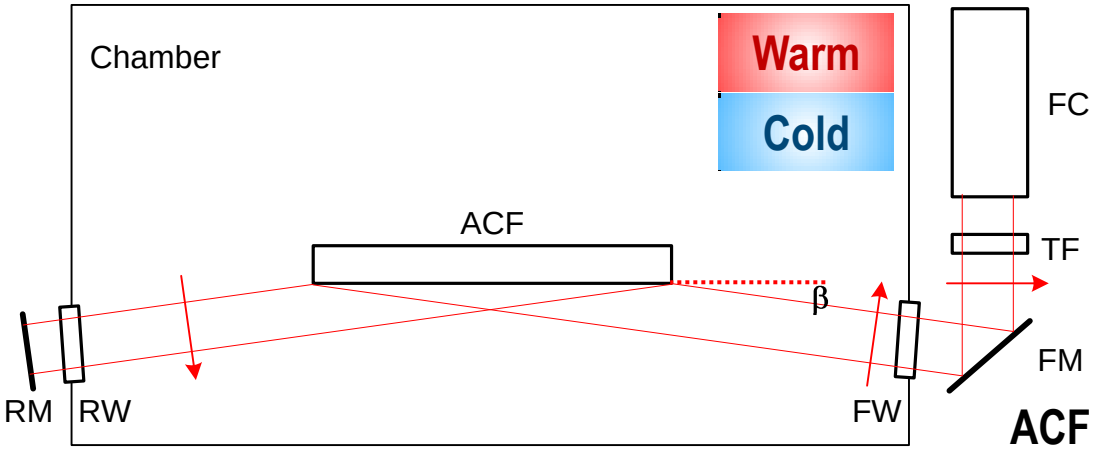
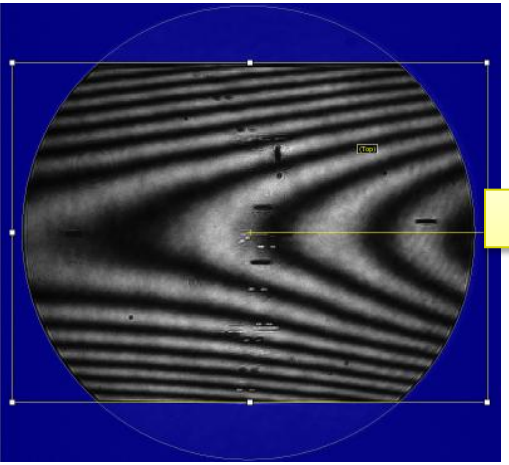
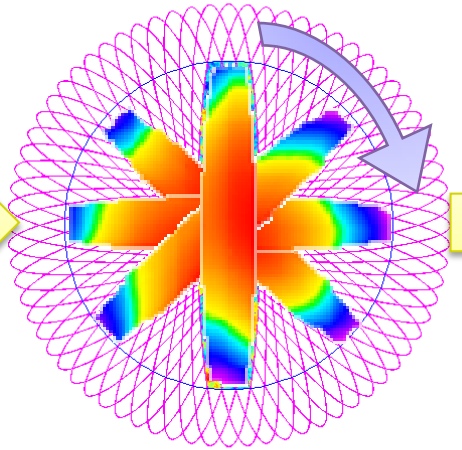
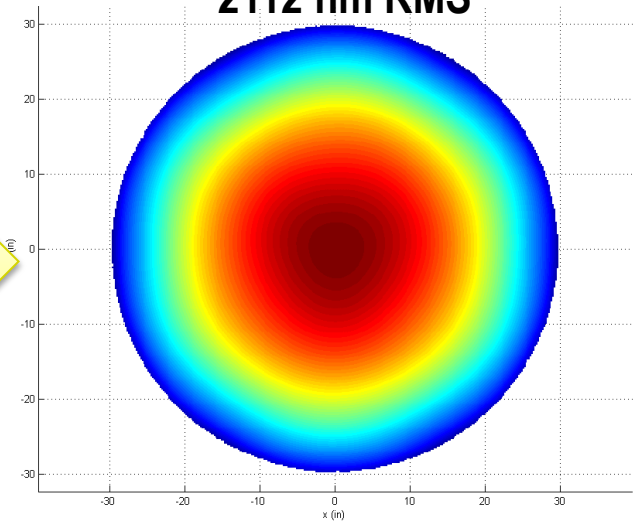
ACF Surface Computed by Stitching 60 Slices (6° Rotations)



ACF Surface at 32.8 K
2112 nm RMS







$$W_{M,n} = 2FC + 2TF + 4FM + 2FW + 2RW + 2RM + 4\sin(\beta)ACF_n$$

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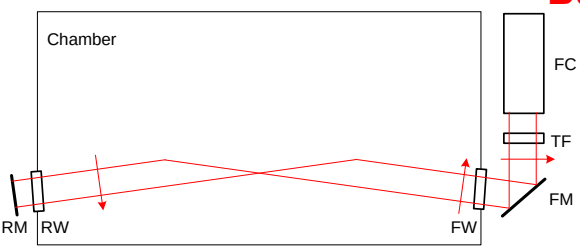
Cryo Backout: Test Set + Cryo-Delta

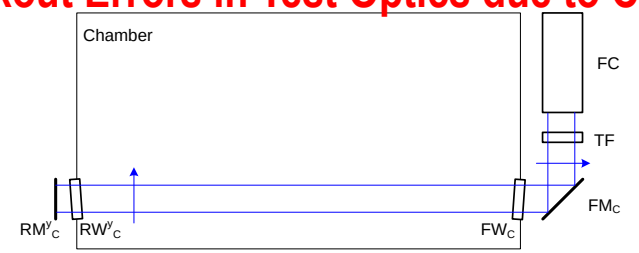
$$W_B = W_T\big|_{WARM} + \frac{1}{2}\left[\left(W_C + W_C^y\right) + \left(W_M - W_M^y\right)\right]_{CRYO} - \frac{1}{2}\left[\left(W_C + W_C^y\right) + \left(W_M - W_M^y\right)\right]_{WARM}$$

Backout Errors in Test Optics at Warm-Vac

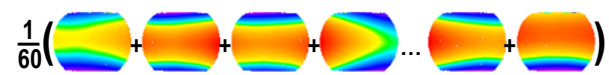
Backout Errors in Test Optics due to Cryo Shift



W_T

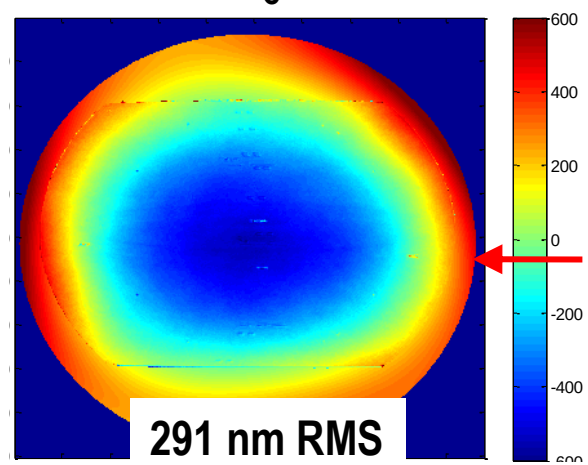


W_C



W_M

$W_B =$

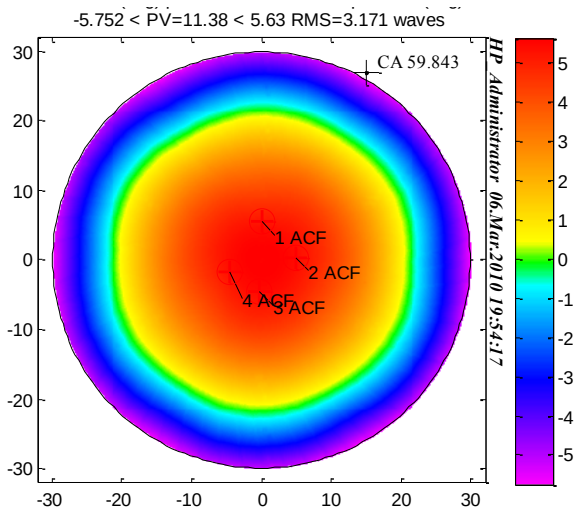


Subtract Extrapolated Backout from each Slice before Stitching

Gradient Reconstruction
Backout not used

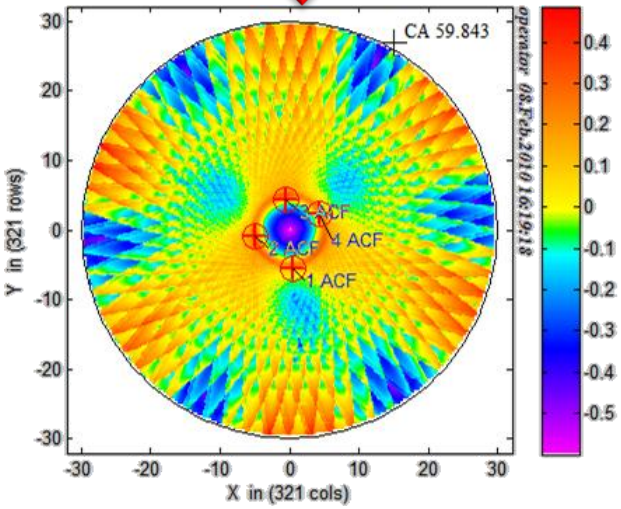
Backout Improves Stitching Results

No Backout
Clear Stitching Artifacts
Higher Surface Residual

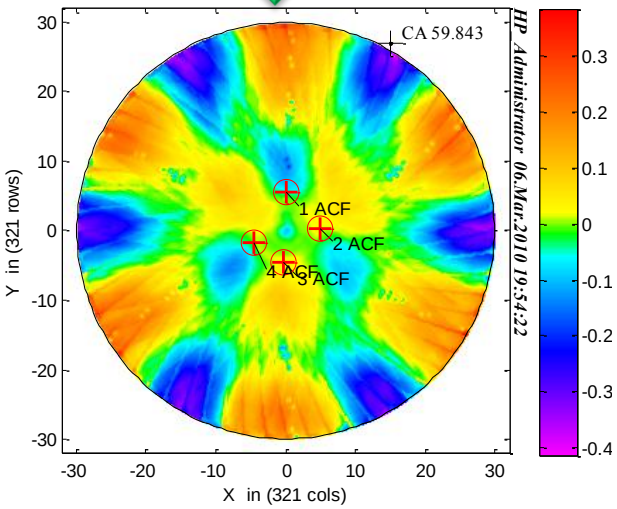


ACF Surface at 32.8 K
2112 nm RMS

Use Cryo Backout
Smoother Surface
Smaller Surface Residual



37-Zernike Fit Residual
95 nm RMS



37-Zernike Fit Residual
77 nm RMS

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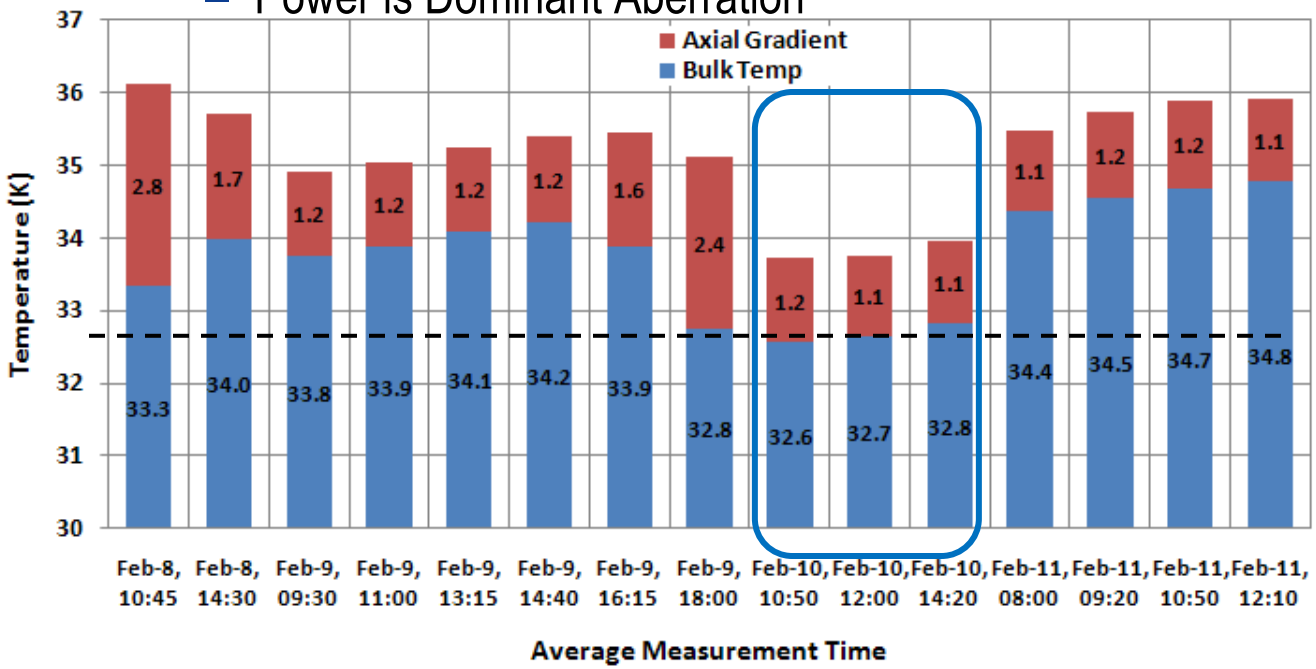
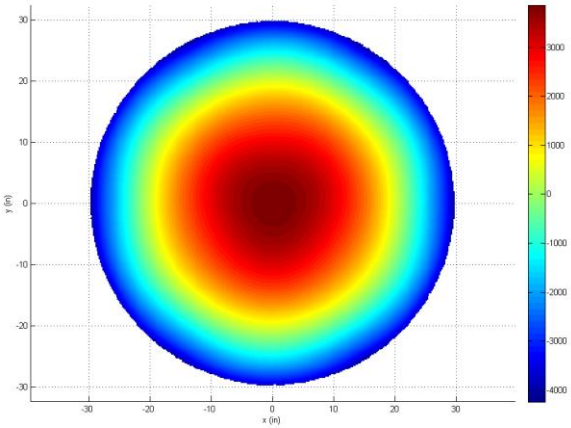
Cryo Testing Successful

- **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



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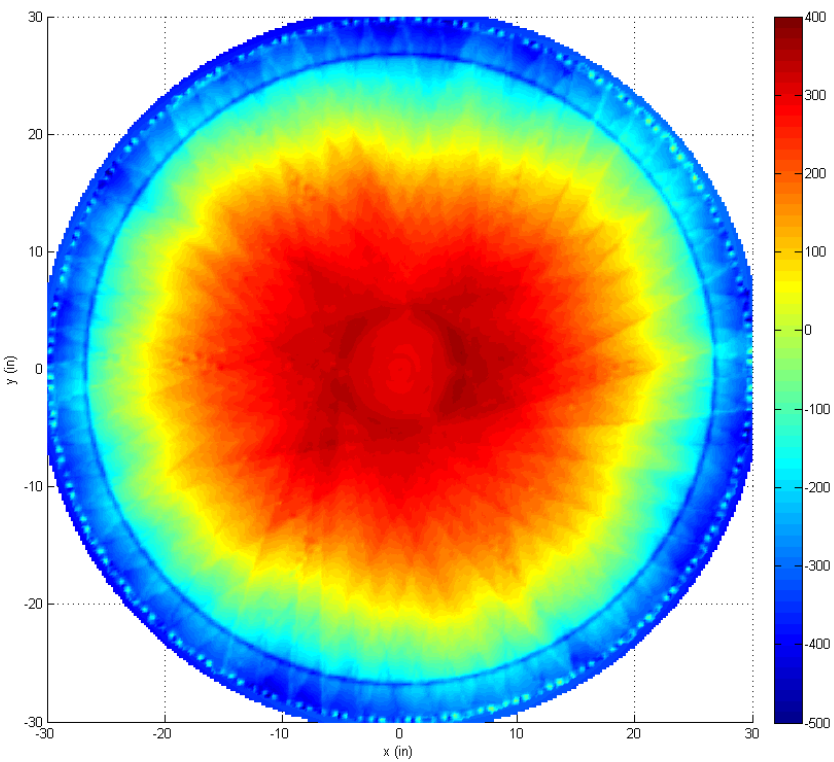
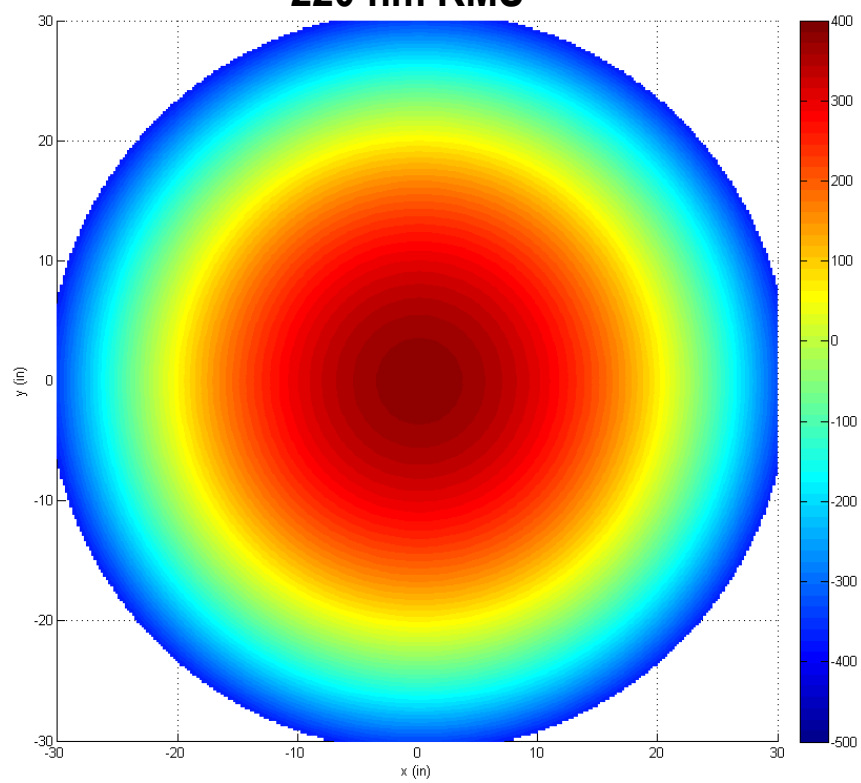
Cryo Shift Successfully Measured

- **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



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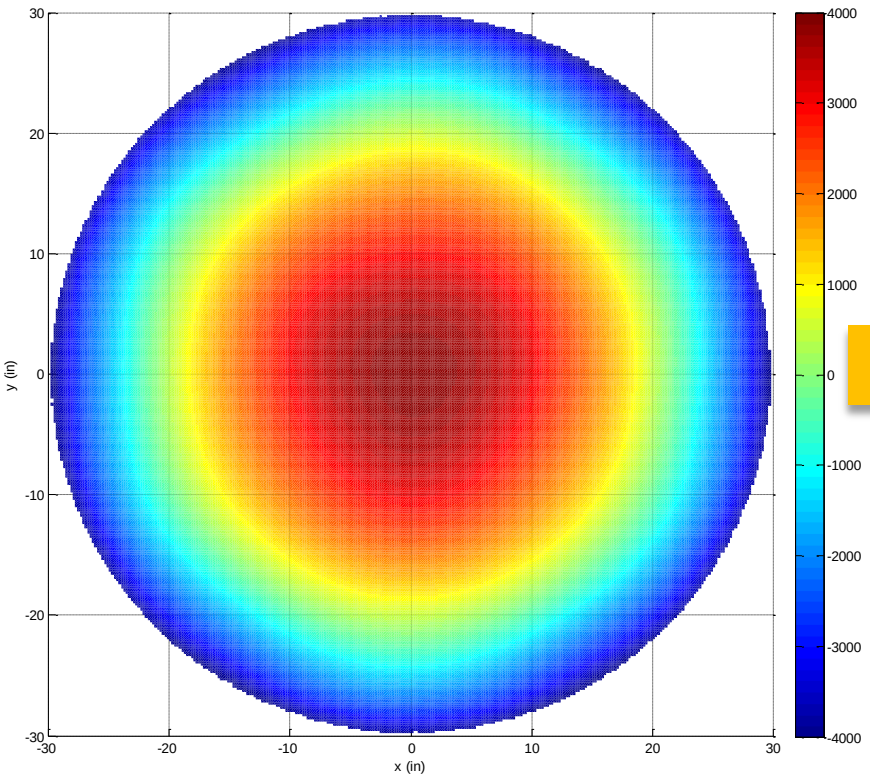
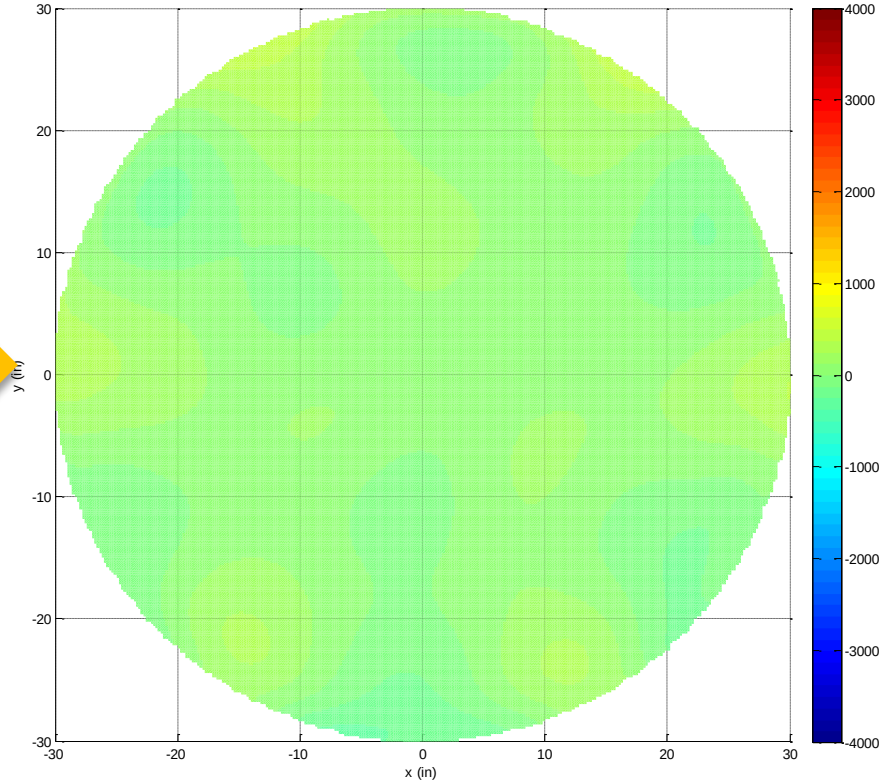
Cryo Surface Progress

Initial Surface
2184 nm RMS



Current Hitmap
108 nm RMS



Stitching Artifacts Removed for Hitmap

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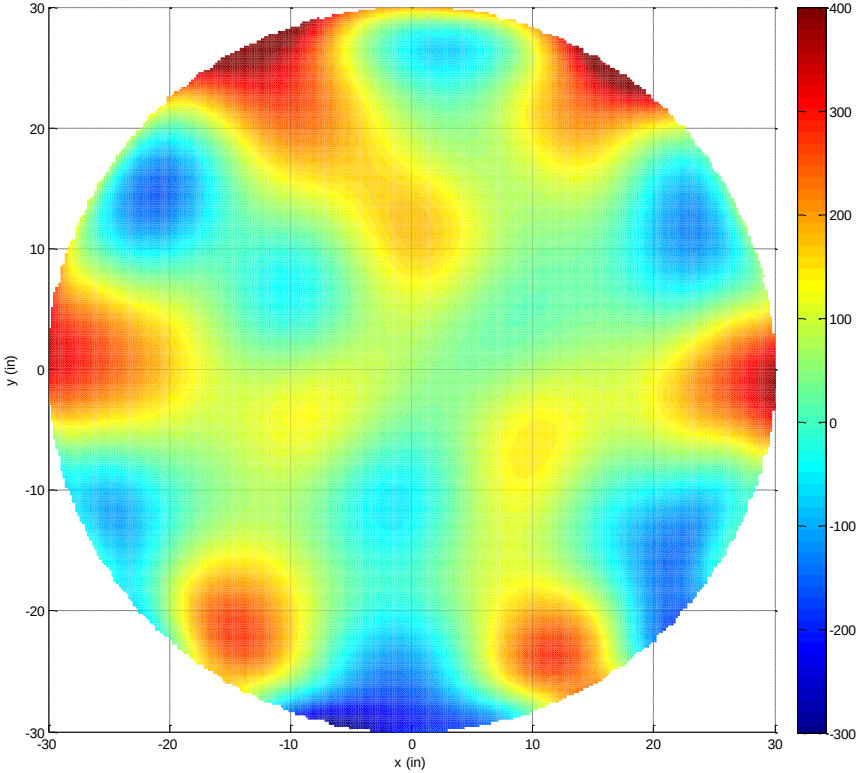
Summary: ACF1 Nearing Completion

- **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