Attachment of Interferogram INT files in WISE and MIC2 As-Built CODE V Models

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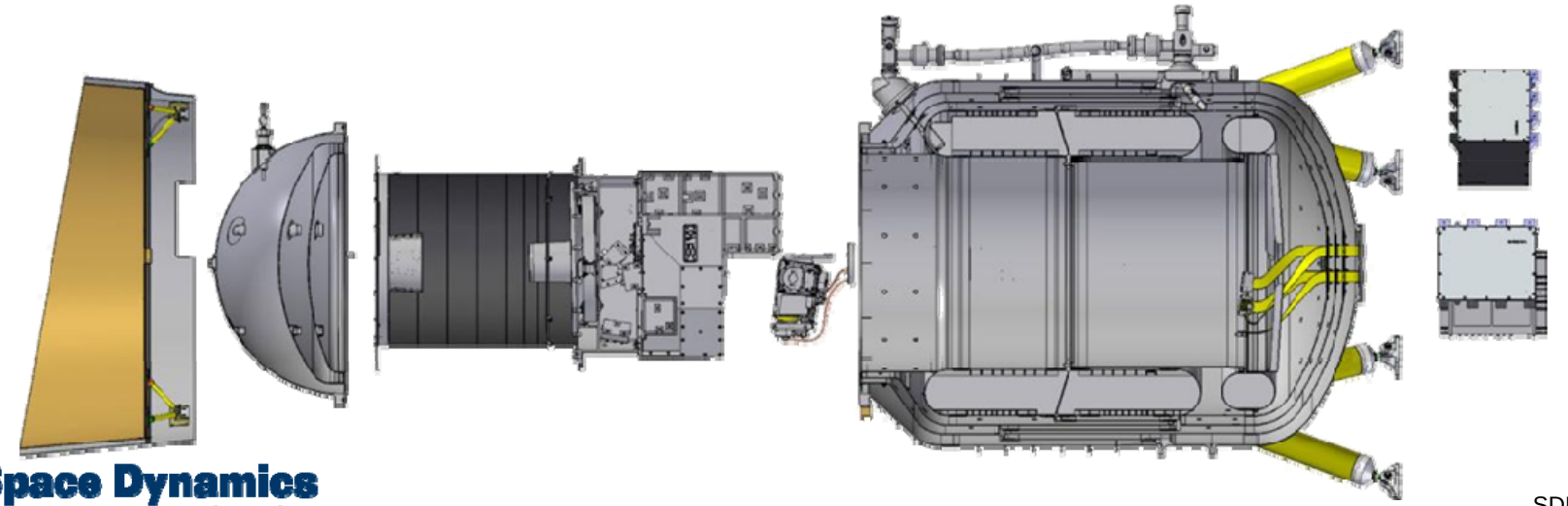


Outline

- Afocal-Imager Design Residual Correction Interferograms
- Interferogram CODE V attachment rules
- Afocal module interferograms
- Imager module interferograms
- Beamsplitter interferograms
- Filter interferograms
- MIC2 (SDL testing collimator) interferogram

Afocal-Imager Design Residual Correction Interferograms

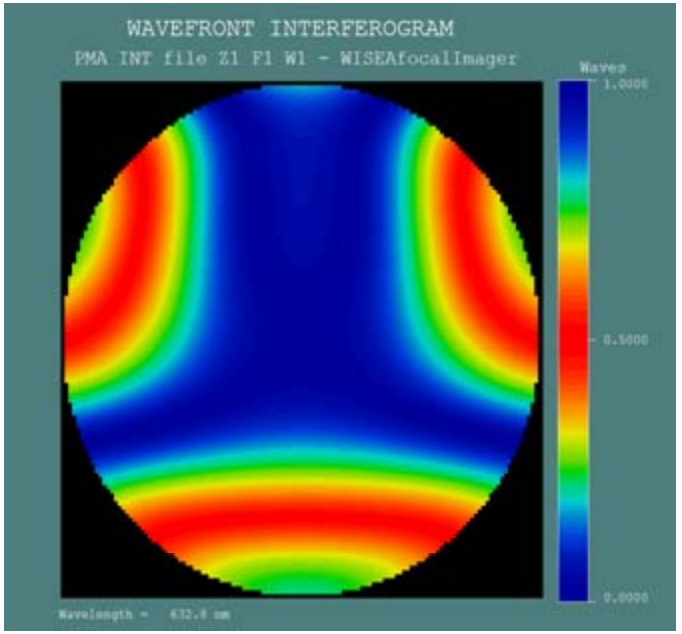
Interferograms were used to correct the design residuals of the Afocal and Imager modules so that these design residuals would not be double counted when measured interferograms for the Afocal and Imager modules were attached to the CODE V prescriptions.

A CODE V model named WISEAfocalImager.len, which includes the Afocal and Imager prescription but not the beamsplitters or filters, was used to generate Afocal-Imager design residual correction interferograms at the WISE entrance pupil at a wavelength of 632.8nm.

These interferograms with ISF -1 to reverse the sign of this wavefront error were attached to dummy non-sequential surfaces at the WISE aperture stop. The WISE entrance pupil is at the WISE aperture stop.

Interferograms were computed at each field angle and scan mirror position used in the as-built CODE V models.

These design residual interferograms are effectively flipped in and out of the optical beam by using non-sequential surfaces and a different zoom for each field angle.



Afocal-Imager design residual correction interferogram for the on-axis field position with the scan mirror in its central position. Note that these interferograms were

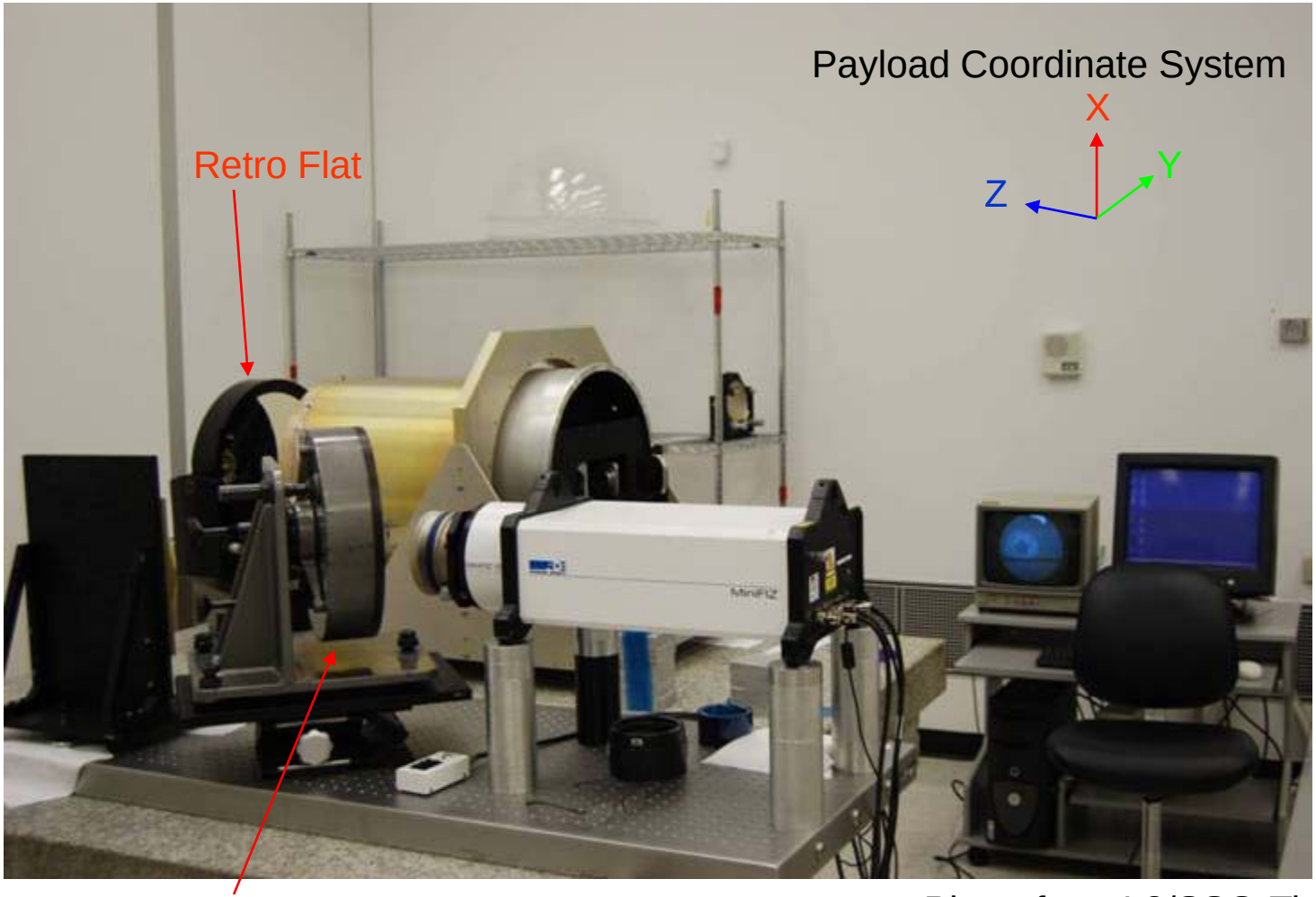
CODE V INT Attachment Rules

1. “Code V always places the +X and the +Y axes of the interferogram file data to coincide with the +X and +y axes of the lens (before any orientation commands are applied),…”, CODE V 9.82 Reference Manual page 10-19.
2. “Notice it is the deformation data that moves; the axes do not move.”, CODE V 9.82 Reference Manual page 10-14.
3. “IMI XC moves the deformation data to the opposite X-coordinate.”, CODE V 9.82 Reference Manual page 10-14.
4. “IMI YC moves the deformation data to the opposite Y-coordinate.”, CODE V 9.82 Reference Manual page 10-14.
5. “A positive angle of rotation …; the positive X axis rotates toward the positive Y axis.”, CODE V 9.82 Reference Manual page 10-19. (This is the standard definition for right-handed coordinate systems.)
6. “..a positive surface deformation represents a ‘bump’ regardless of the direction of the Z axis”, CODE V 9.82 Reference Manual page 10-20.
7. “..a leading wavefront as producing a positive OPD.” CODE V 9.82 Reference Manual page 10-19.

Afocal Module Interferograms

- Afocal module interferograms were measured with a MiniFiz interferometer at L3/SSG-Tinsley.
- Afocal module interferograms are wavefront error interferograms measured in double-pass from the exit pupil side. See next slide for more on the measurement configuration including the auxiliary optics used.
- Afocal interferograms are attached to dummy non-sequential surfaces that are effectively at the Afocal exit pupil. The centers of these non-sequential surfaces are at the center of the Imager scan mirror, but unlike the scan mirror, these surfaces are perpendicular to the gut ray.
- These measured Afocal interferograms are effectively flipped in and out of the optical beam by using non-sequential surfaces and a different zoom for each field angle.

Afocal Room-Temperature Wavefront Error Test Configuration



Optical Coordinate System
CODE V
Afocal surfaces 1 and 2

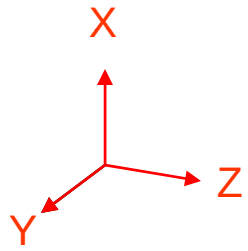
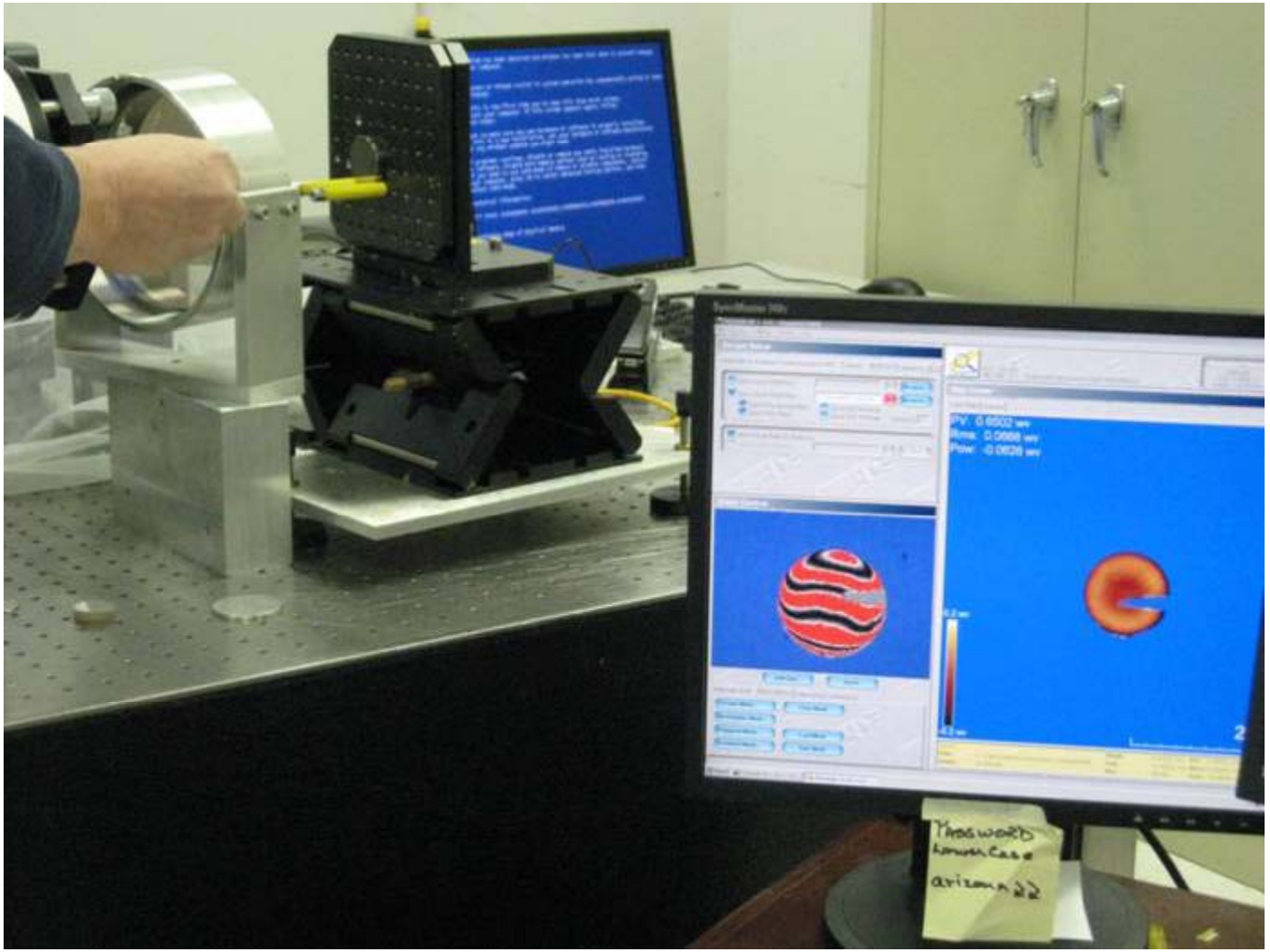
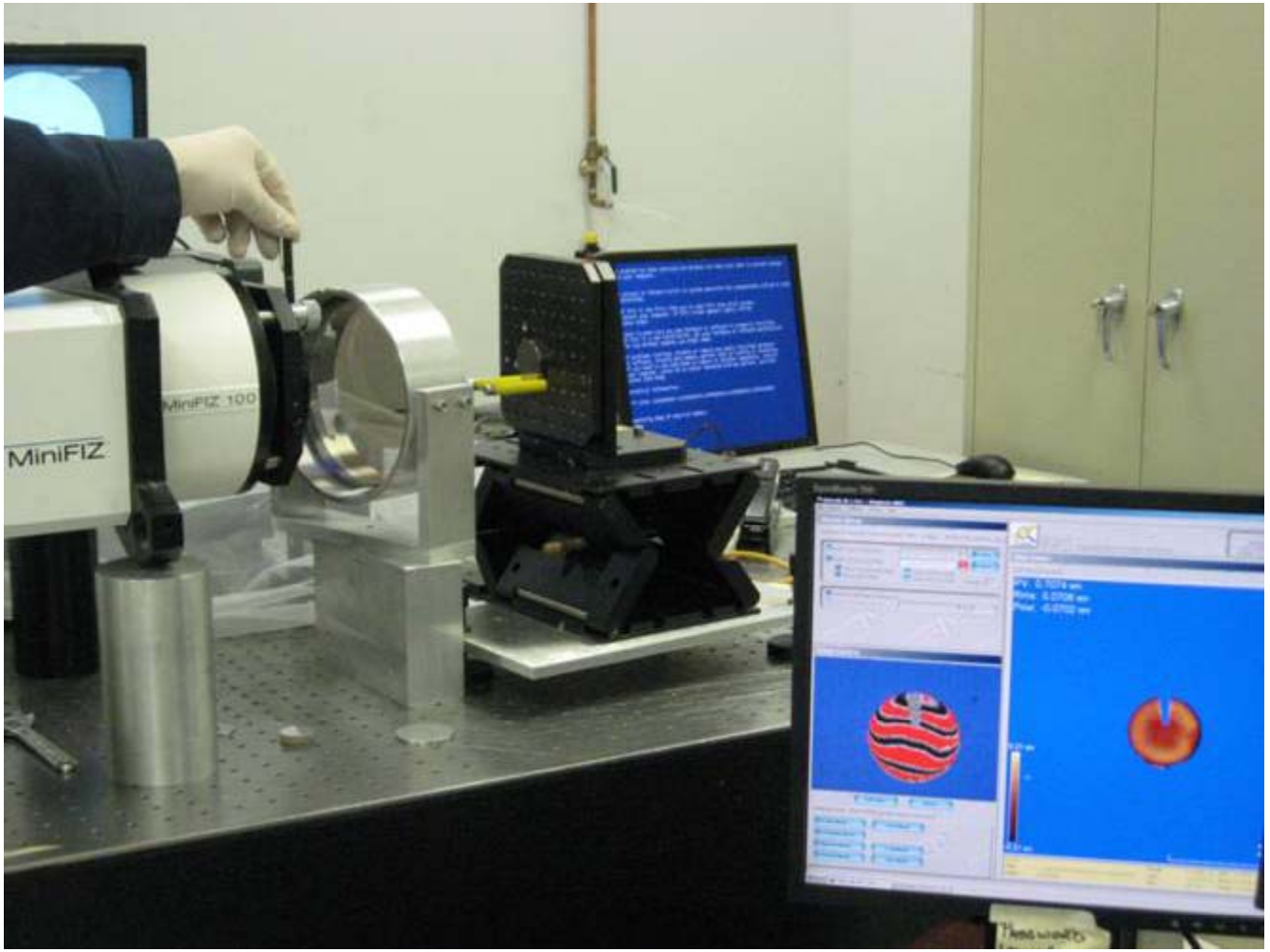


Photo from L3/SSG-Tinsley

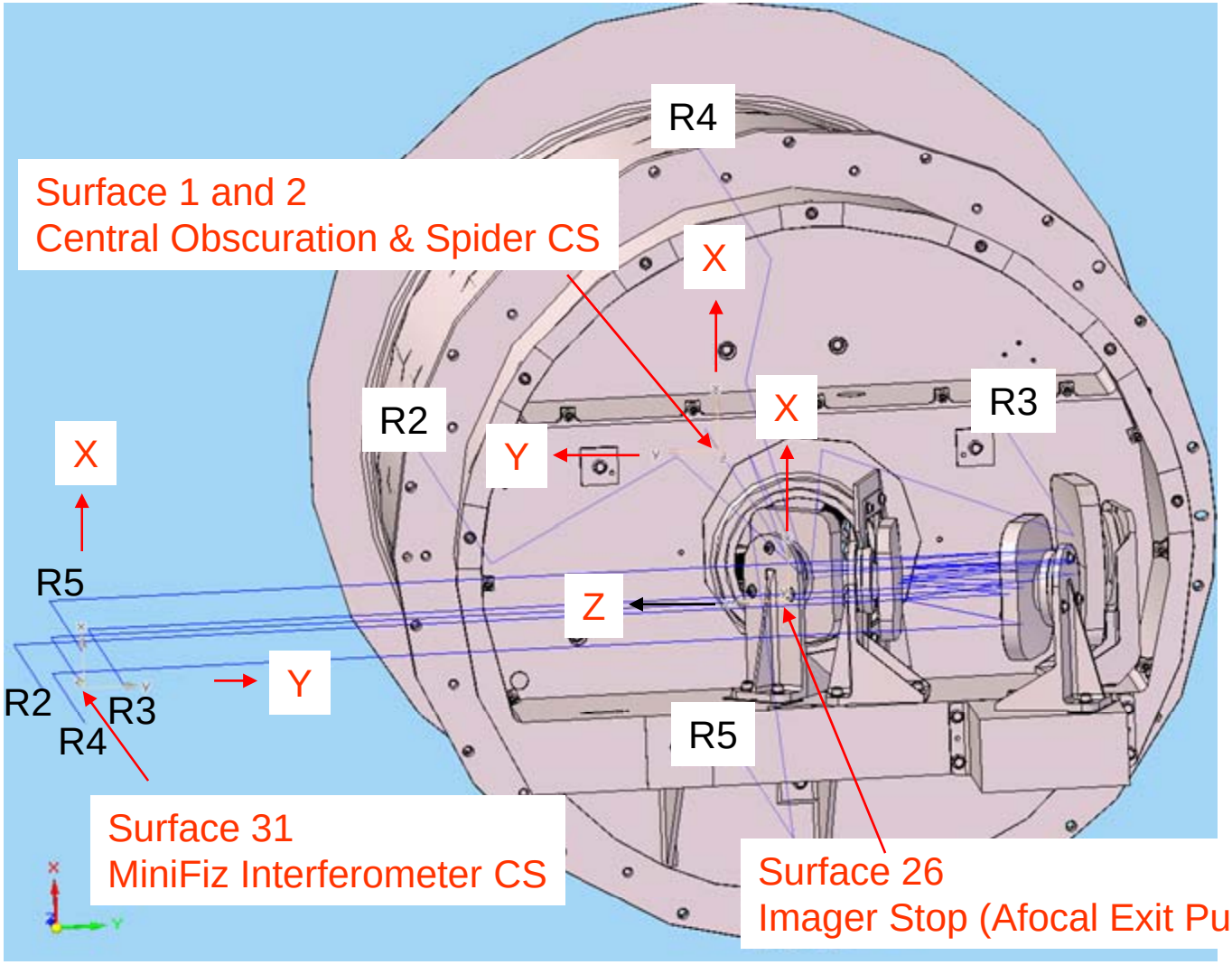
MiniFiz Interferometer Interferogram Left-Right Orientation



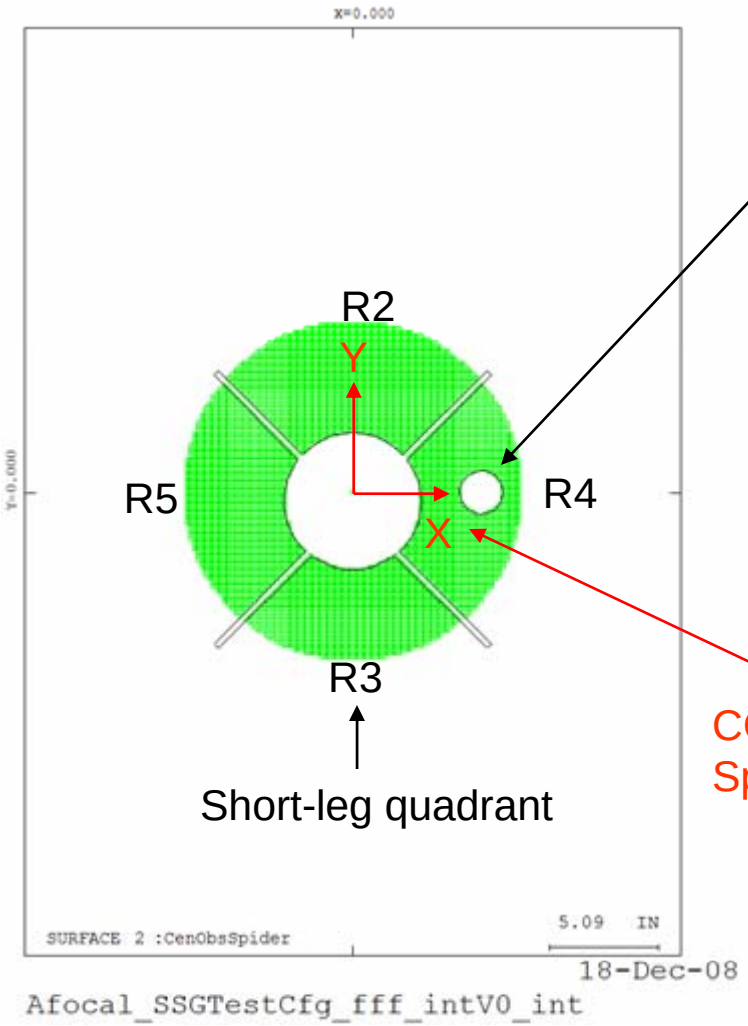
MiniFiz Interferometer Interferogram Up-Down Orientation



Afocal Solid Model with CODE V Coordinate Systems (CS) and Reference Rays



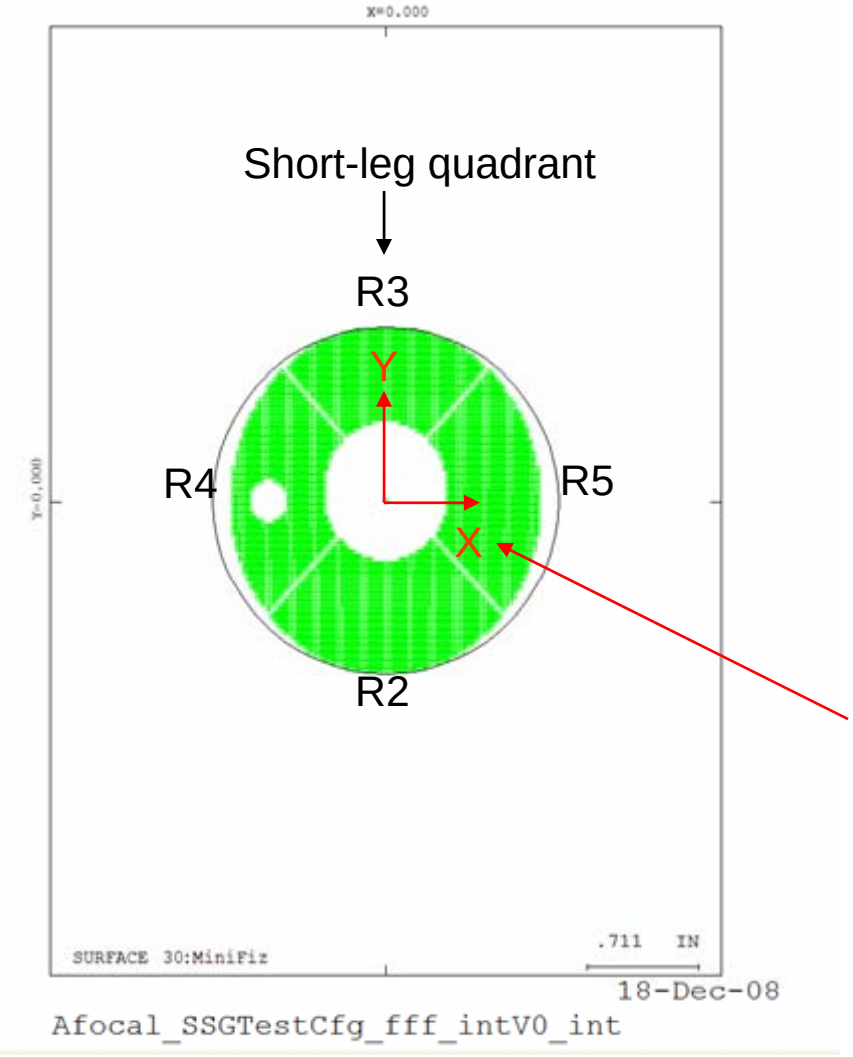
Footprint at Central Obscuration and Spider for On-Axis Light



Non-physical off-axis obstruction temporarily added to differentiate left and right.

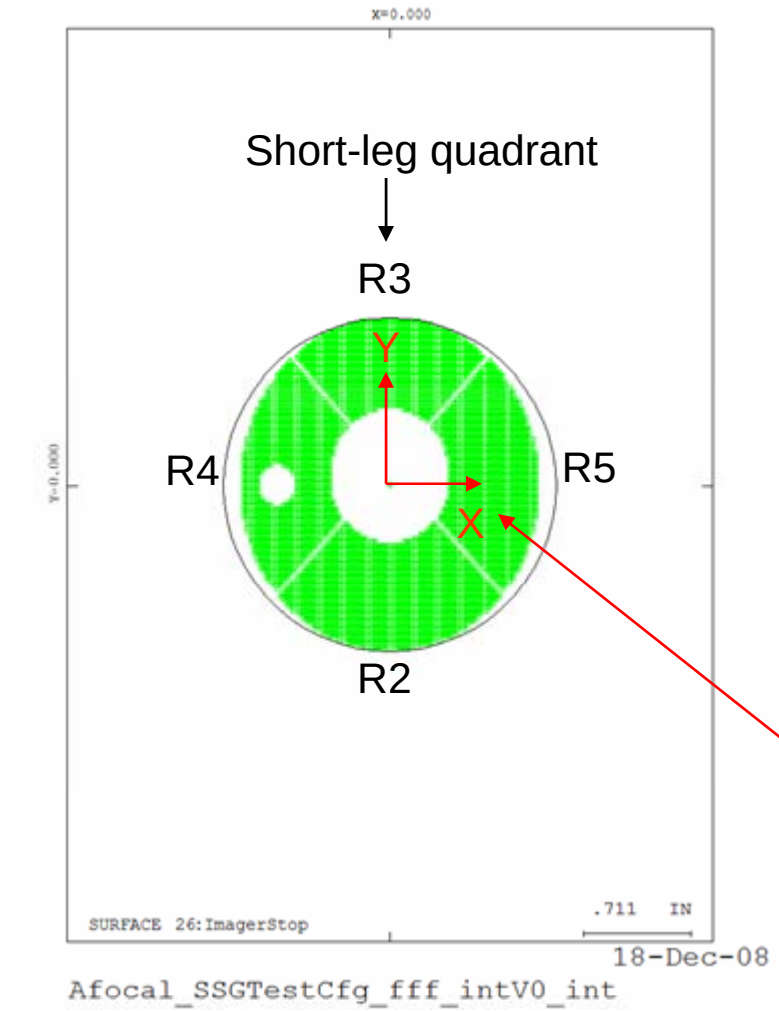
CODE V Central Obscuration & Spider Surface Coordinate System

Footprint at MiniFiz Interferometer For On-Axis Light



CODE V Interferometer Surface Coordinate Systems

Footprint at Afocal Exit Pupil (Imager Stop) For On-Axis Light

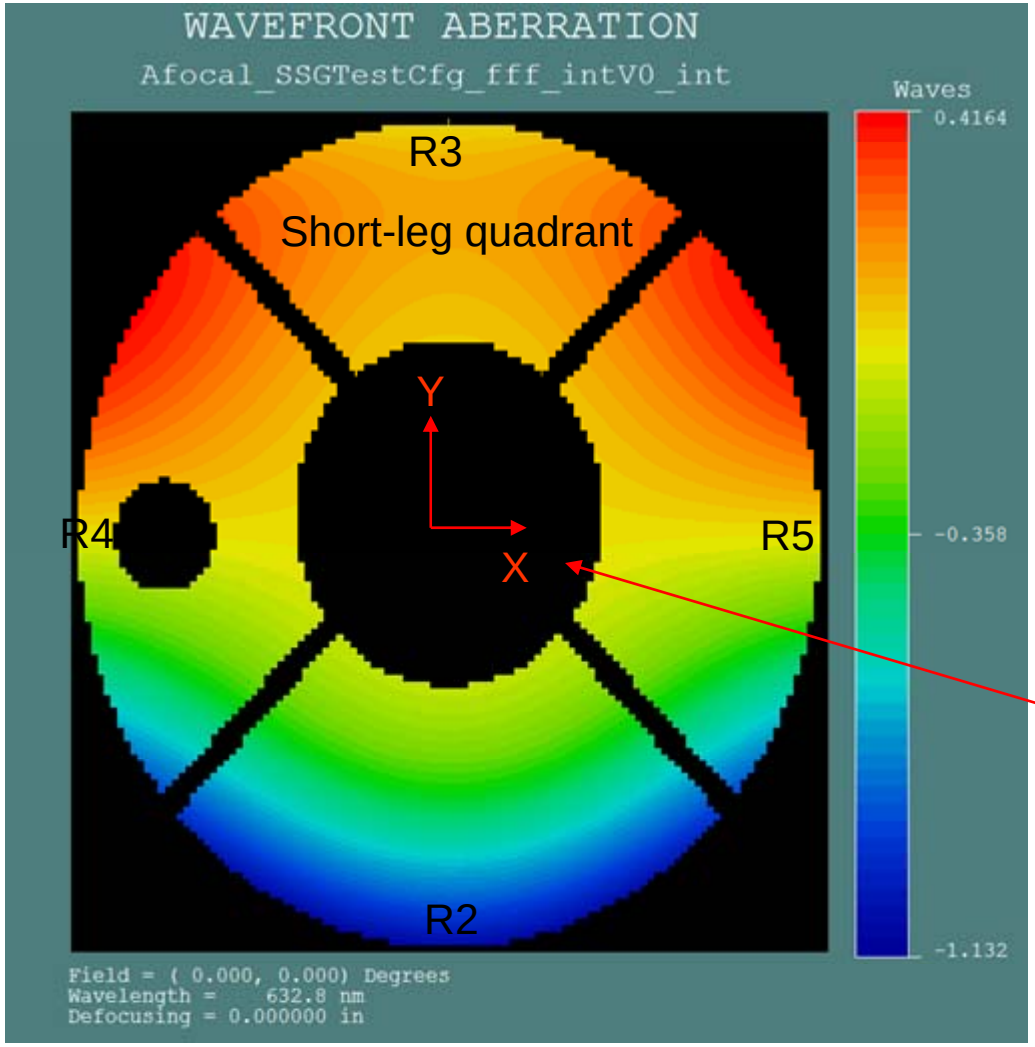


This footprint looks exactly the same as the footprint at the interferometer surface because both the coordinate system and the footprint are flipped left to right by the auxiliary fold flat used in the Afocal test configuration.

There is significant pupil aberration, so I decided to place Afocal interferogram at exit pupil of Afocal, the imager stop, rather than at the entrance pupil.

CODE V Imager Stop (Afocal Exit Pupil) Surface Coordinate Systems

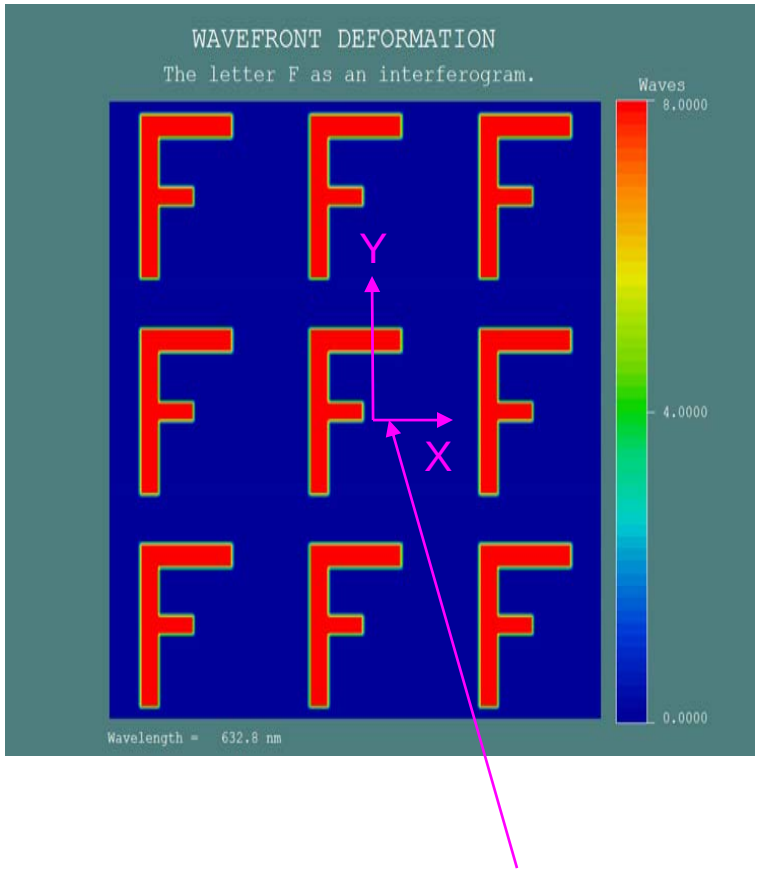
Pupil Map of Afocal with Perfect Lens Added at Output



With a perfect lens at the output of the Afocal module the pupil map matches the footprint plot at the interferometer plane both left-to-right and top-to-bottom. Thus, the pupil map correctly describes the wavefront orientation at the interferometer plane.

CODE V Interferometer and Afocal Exit Pupil (Imager Stop) Surface Coordinate Systems

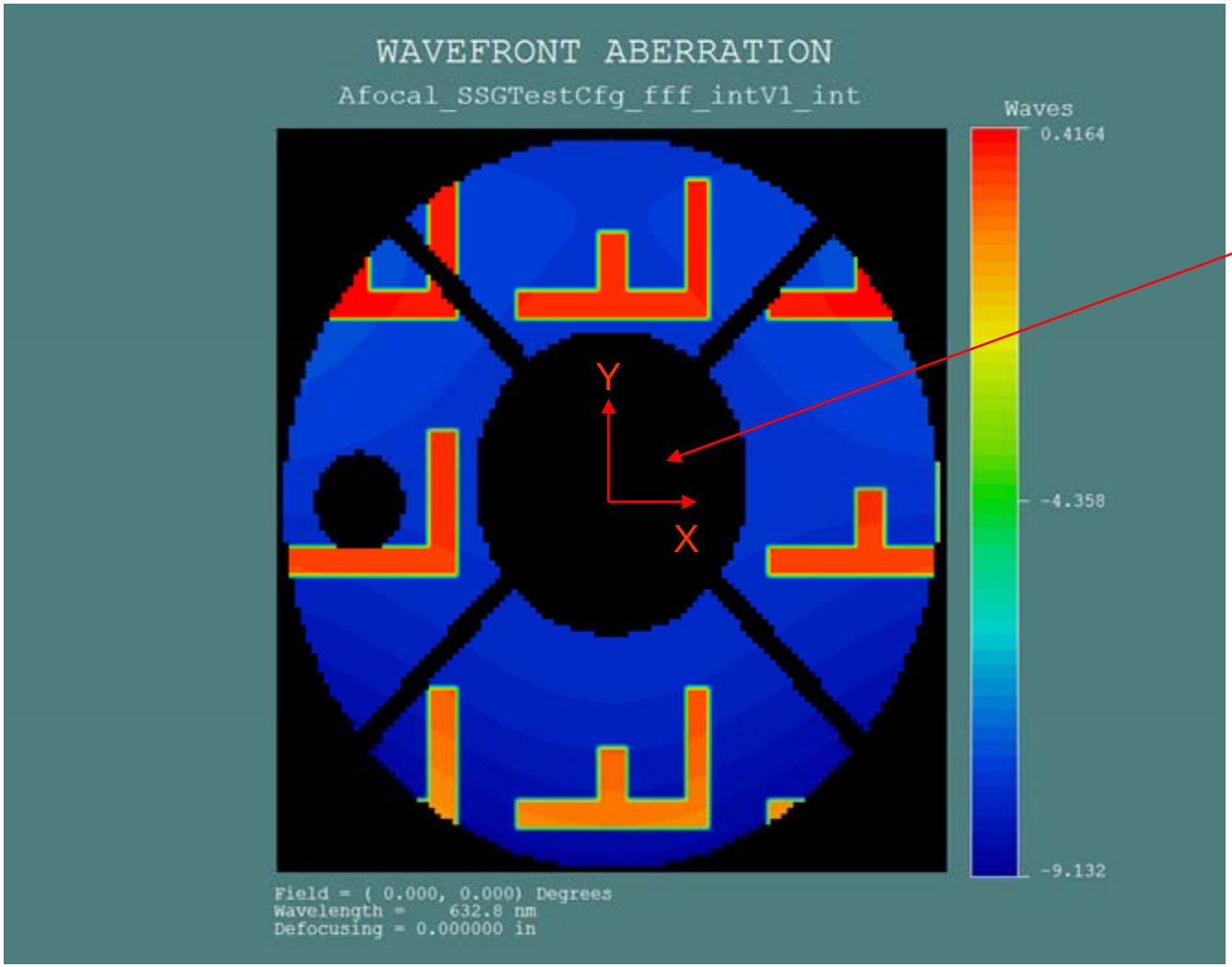
Attaching Afocal Interferograms at the CODE V Interferometer Surface



Interferogram coordinate system

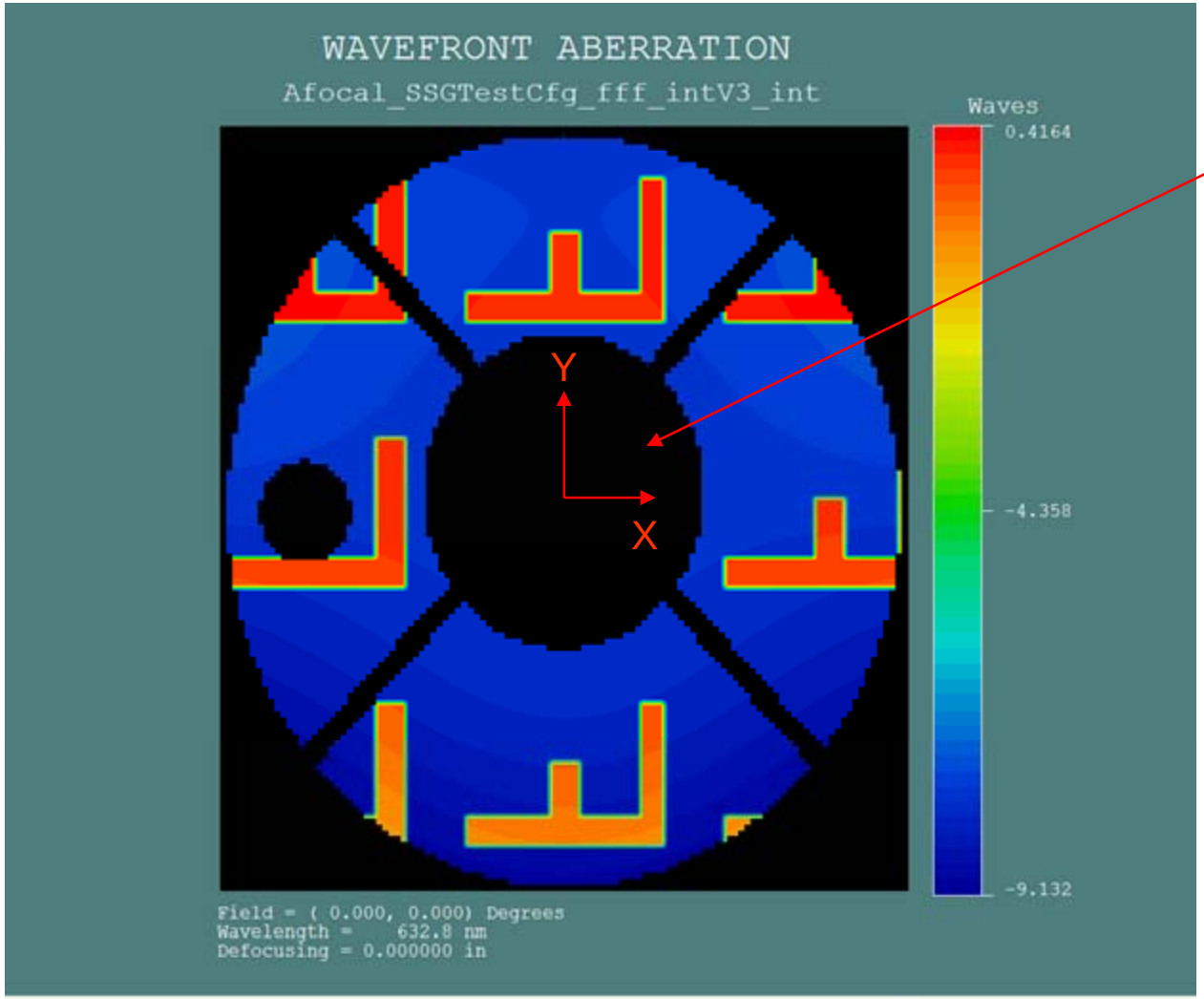
Measured Afocal interferograms must be oriented as shown in this figure when the interferogram is viewed from behind the MiniFiz interferometer. Afocal interferograms are attached to the CODE V interferometer surface in the correct orientation by using the CODE V commands INT, IMI XC and IRO -90 and ISF 1.
The fact that these commands correctly orient the interferogram can be verified by making a copy of this slide and then orienting it relative to the Afocal solid model slide. By Rule 1 the INT command attaches the interferogram coordinate system to the interferometer surface coordinate system. By Rules 2 and 3 IMI XC moves the deformation data to the opposite X-coordinate, which is equivalent to flipping about the Y axis. By Rule 5 IRO -90 rotates the new +X deformations away from the +Y deformations, which puts the tops of the F letters up and the open faces of the F letters to the right when viewed from behind the interferometer as desired.
ISF 1 follows from Rule 7 and MiniFiz wavefront error sign convention.

Afocal Exit Pupil Map with Interferogram Attached to the Interferometer Surface Using INT, IMI XC, IRO -90 and ISF 1



CODE V Interferometer and Afocal Exit Pupil (Imager Stop) Surface Coordinate Systems

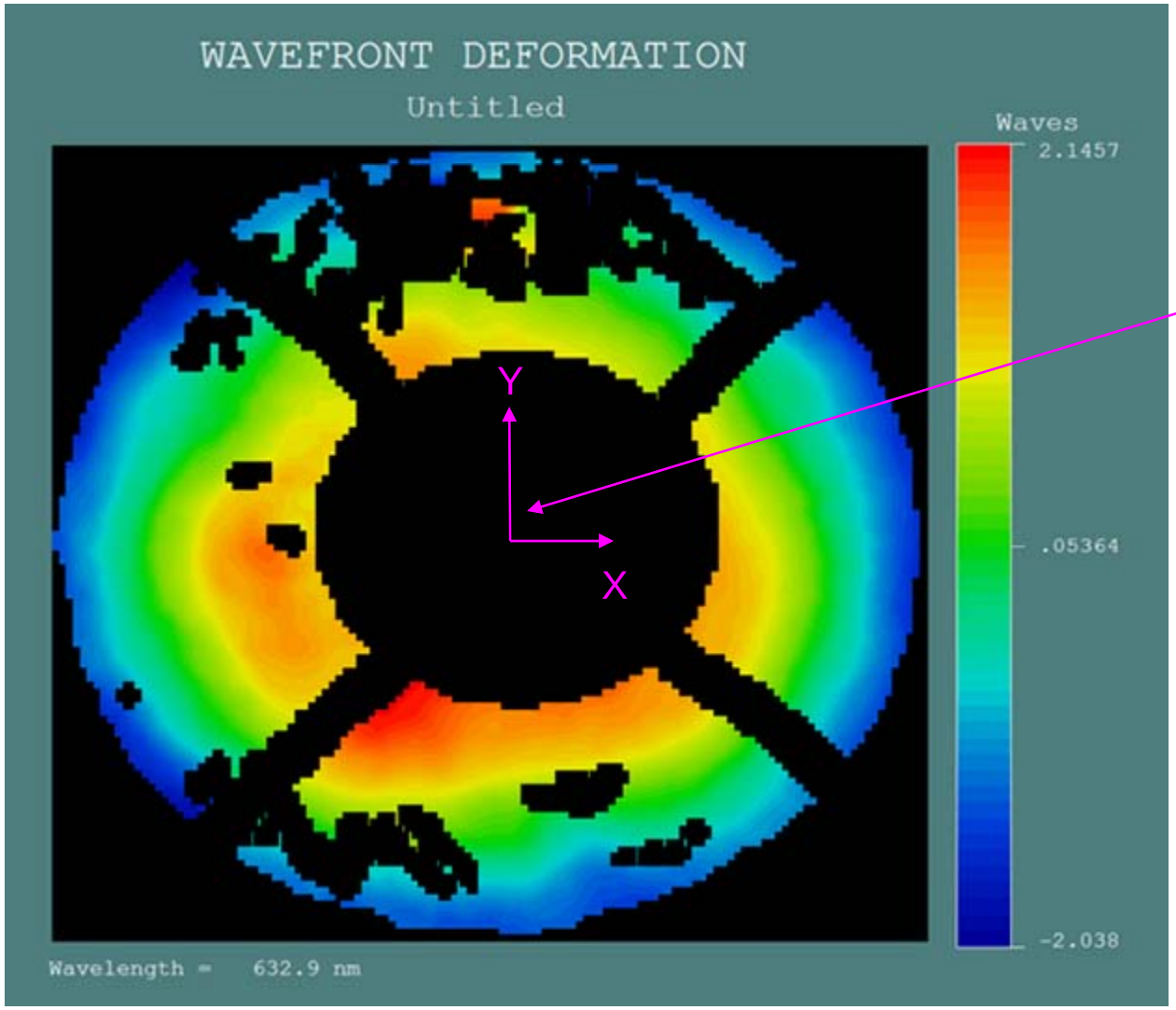
Afocal Exit Pupil Map with Interferogram Placed on the Imager Stop Surface Using INT, IMI XC, IRO -90 and ISF 1



CODE V Interferometer and Afocal Exit Pupil (Imager Stop) Surface Coordinate Systems

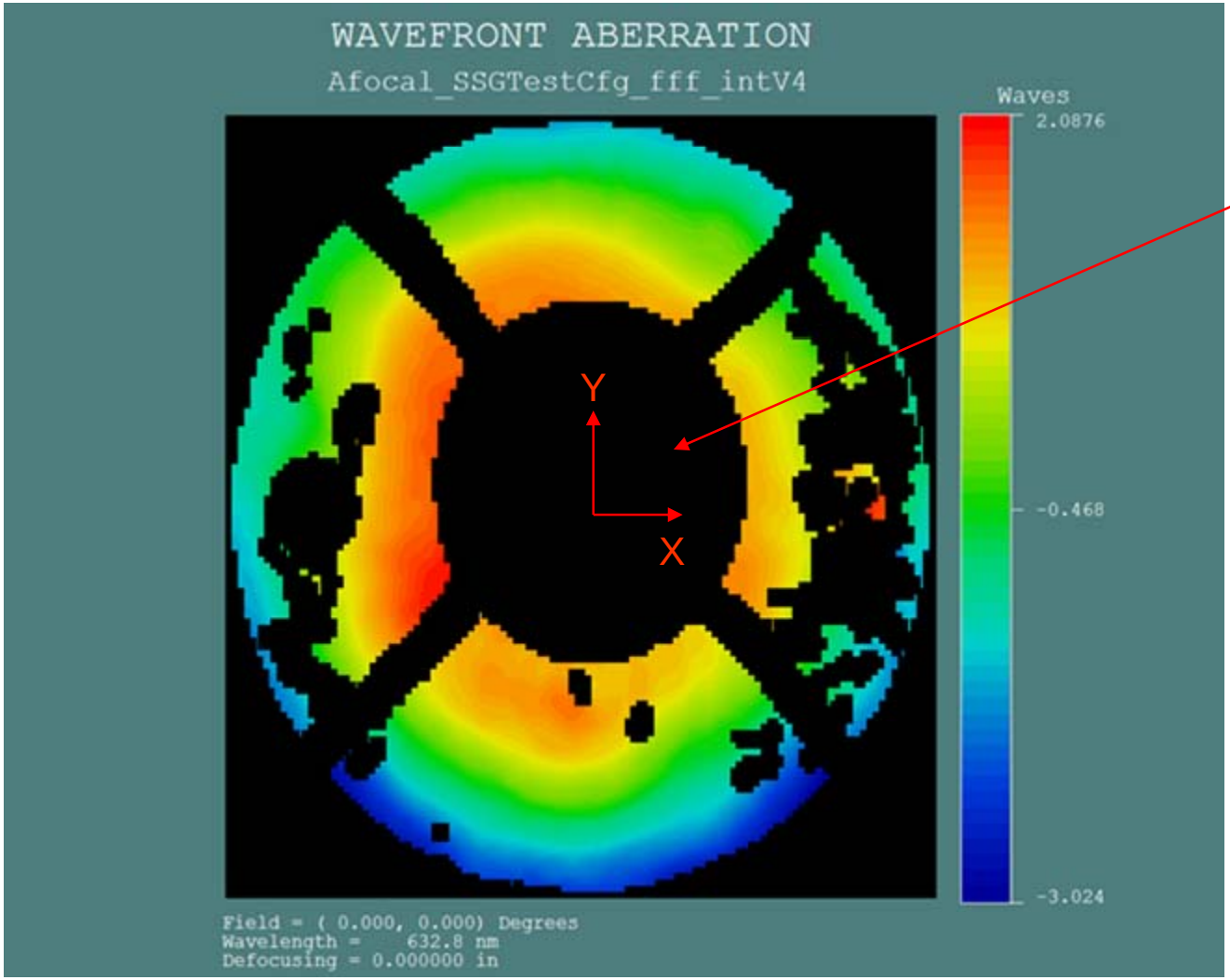
CODE V Interferogram placement commands same as at the interferometer because coordinates are reflected in the auxiliary fold flat.

Afocal On-Axis Interferogram at 100K



Interferogram coordinate system

Pupil Map with Interferogram at Imager Stop Location
IMI XC, IRO -90, and ISF 1



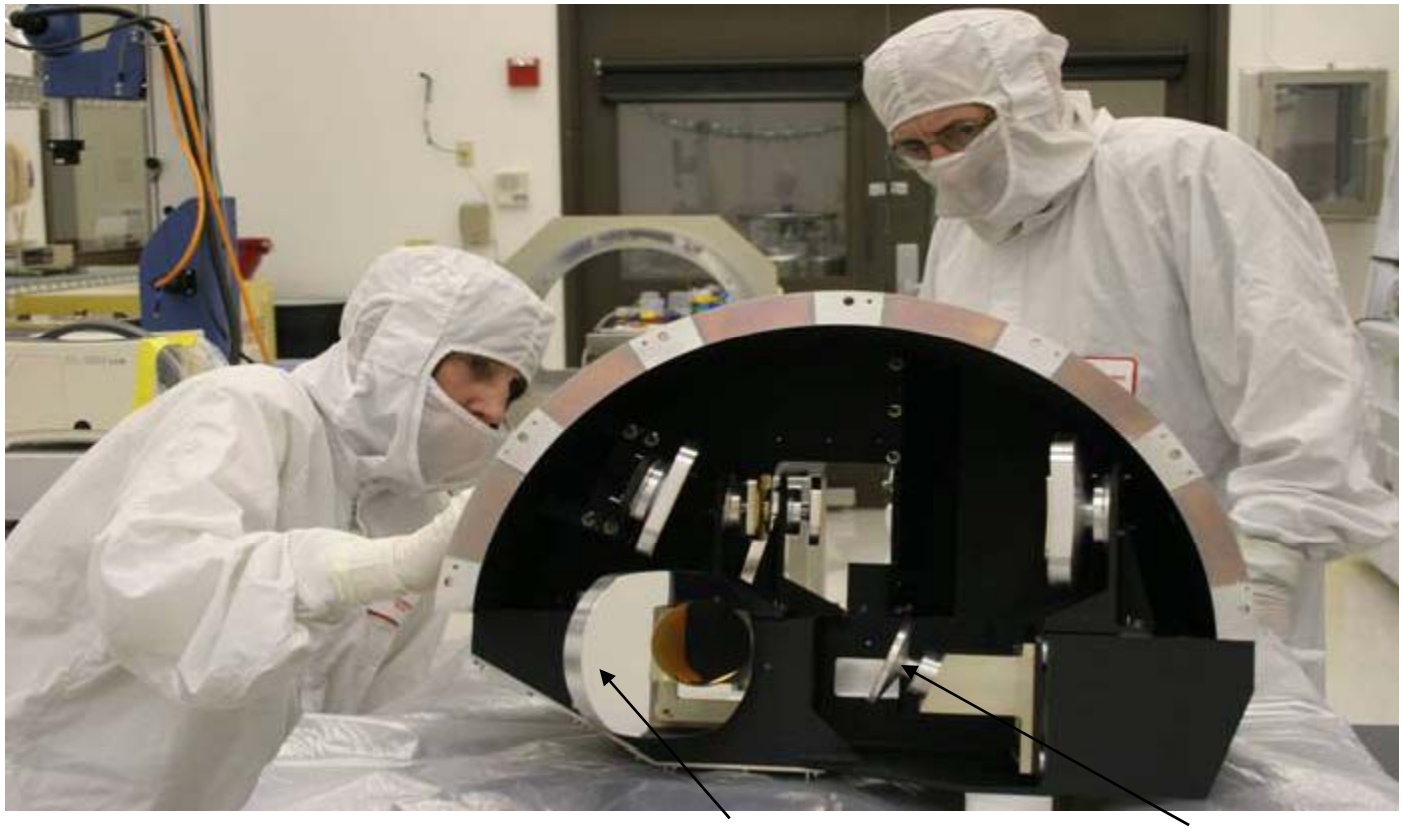
CODE V Interferometer and Afocal Exit Pupil (Imager Stop) Surface Coordinate Systems

Alignment of the spider legs in the interferogram with the shadows of the CODE V spider obstructions confirm that the interferogram is correctly oriented in the y direction.

Imager Module Intereferograms

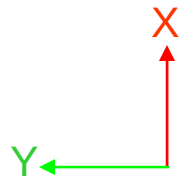
- Imager module interferograms were measured with a MiniFiz interferometer at L3/SSG-Tinsley.
- Interferograms for the Imager module are wavefront error interferograms measured in double-pass from the scan-mirror side with a temporary aperture stop attached to the surrogate scan flat. See next two slides for more on the measurement configuration including the auxiliary optics used.
- Imager interferograms are attached to dummy non-sequential surfaces that are effectively at the Afocal exit pupil. The centers of these non-sequential surfaces are at the center of the scan mirror, but unlike the scan mirror, these surfaces are perpendicular to the gut ray.
- These measured Imager interferograms are effectively flipped in and out of the optical beam by using non-sequential surfaces and a different zoom for each field angle.

Imager with Auxiliary Optics Installed for Cryogenic WFE Test

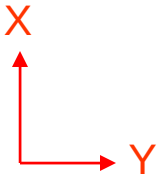


During the Imager Module Cryo Testing, the VU Alignment Flat and the Surrogate Scan Flat were installed in the Imager Module. BSA Simulator Fixture Plate 2 (diamond-turned concave spheres) was installed at the Image Plane.

Payload Coordinate System

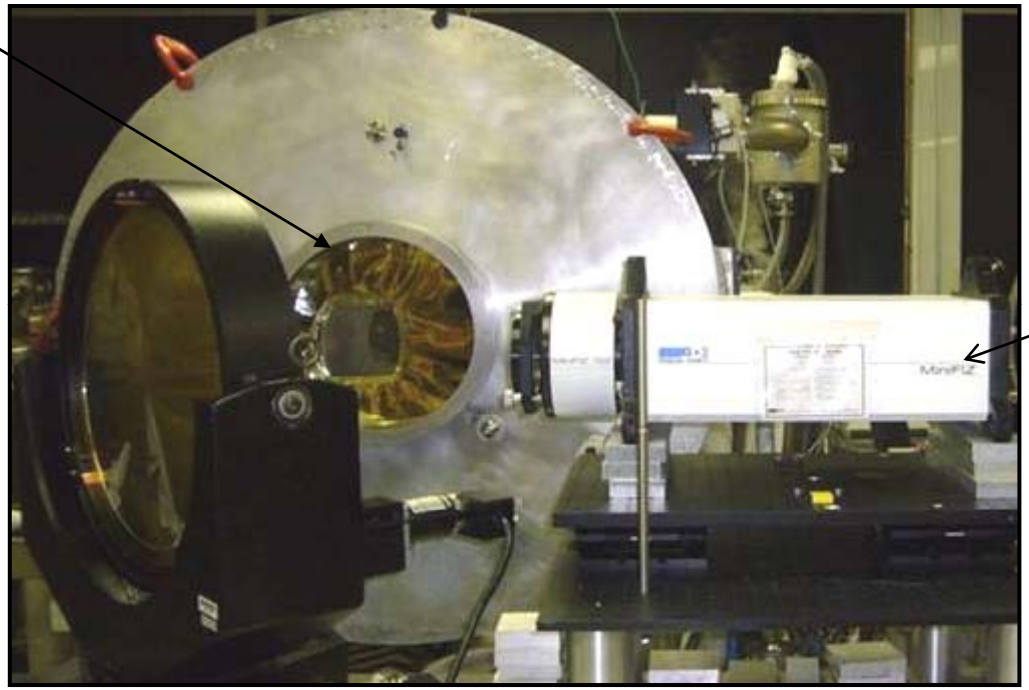


Afocal Surface 1 Coordinate System



This slide is an augmented version of a L3/SSG-Tinsley slide from WISE Imager Module Pre-Ship Review.

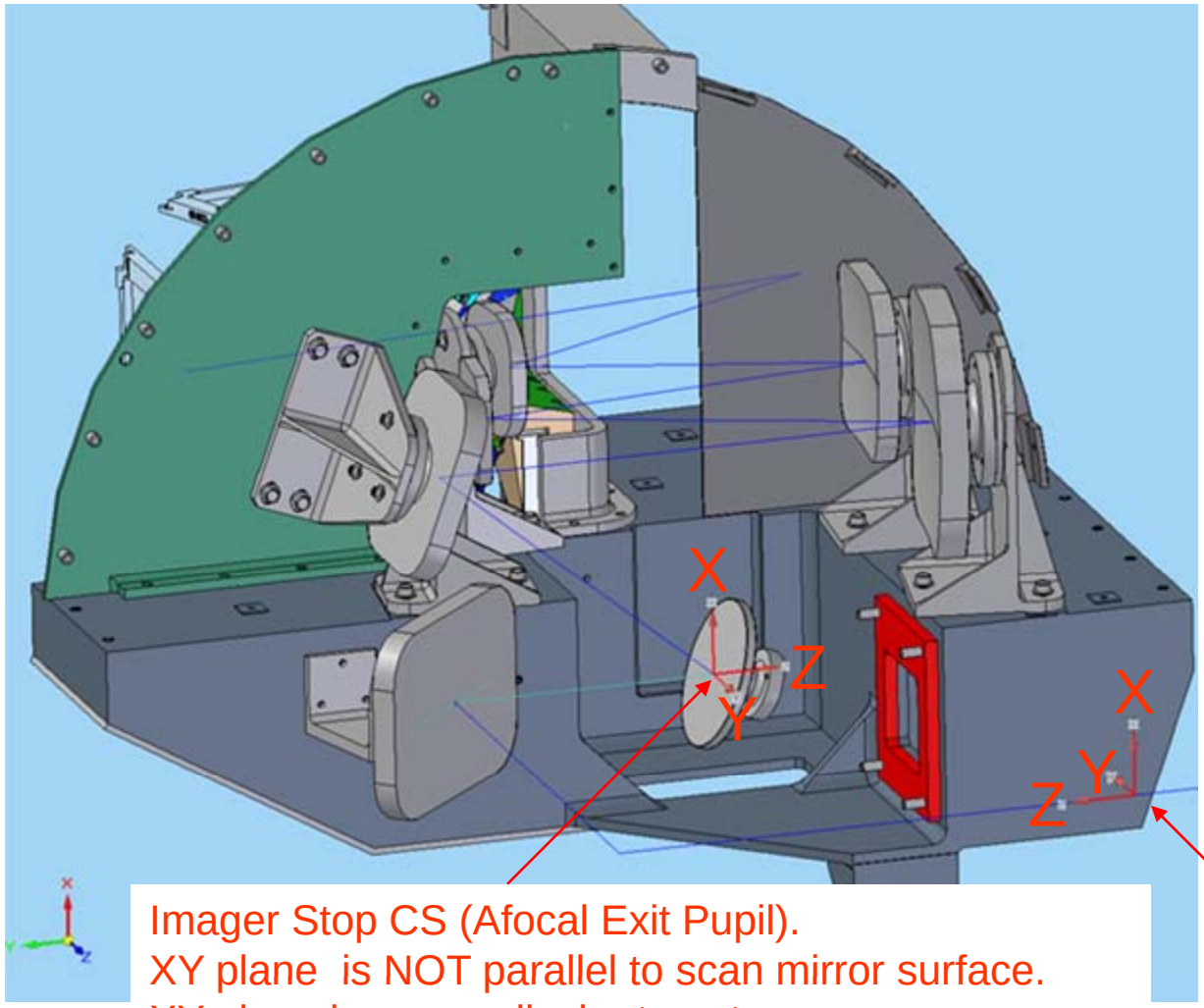
Imager Cryogenic WFE Test Configuration



This is a re-titled L3-SSG slide from WISE Imager Module Pre-Ship Review.

•A MiniFiz Interferometer (with Durango software) was used to measure the double-pass Wavefront Error of the Imager Module during the Cryo Test.
•A large, motorized test flat was used to steer the collimated MiniFiz beam through the vacuum chamber window, and into the Imager Module (incident on the VU Alignment Flat)

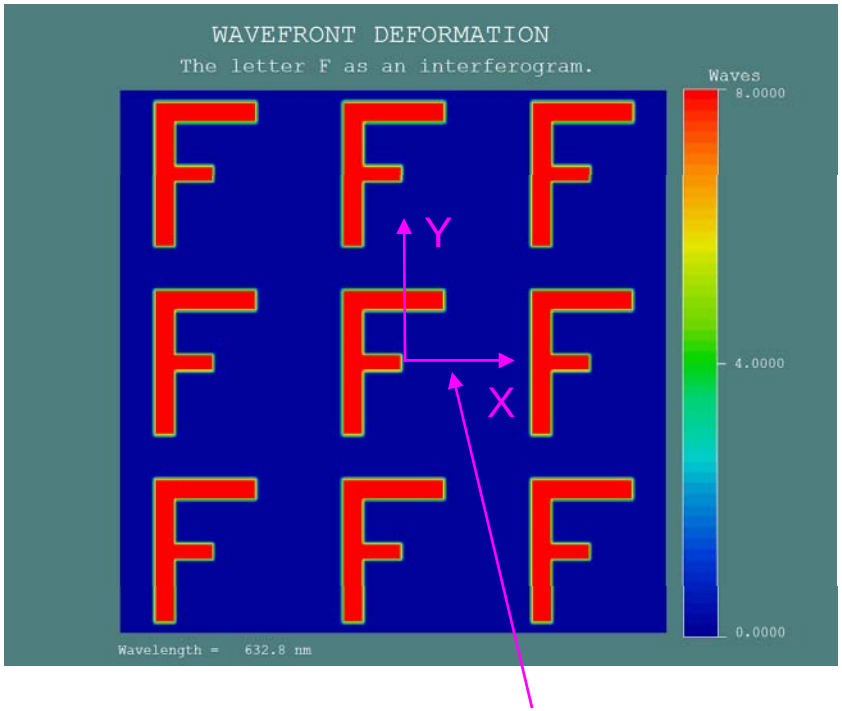
Imager Solid Model With CODE V Coordinate Systems (CS)



Imager Stop CS (Afocal Exit Pupil).
XY plane is NOT parallel to scan mirror surface.
XY plane is perpendicular to gut ray.

MiniFiZ
Interferometer CS

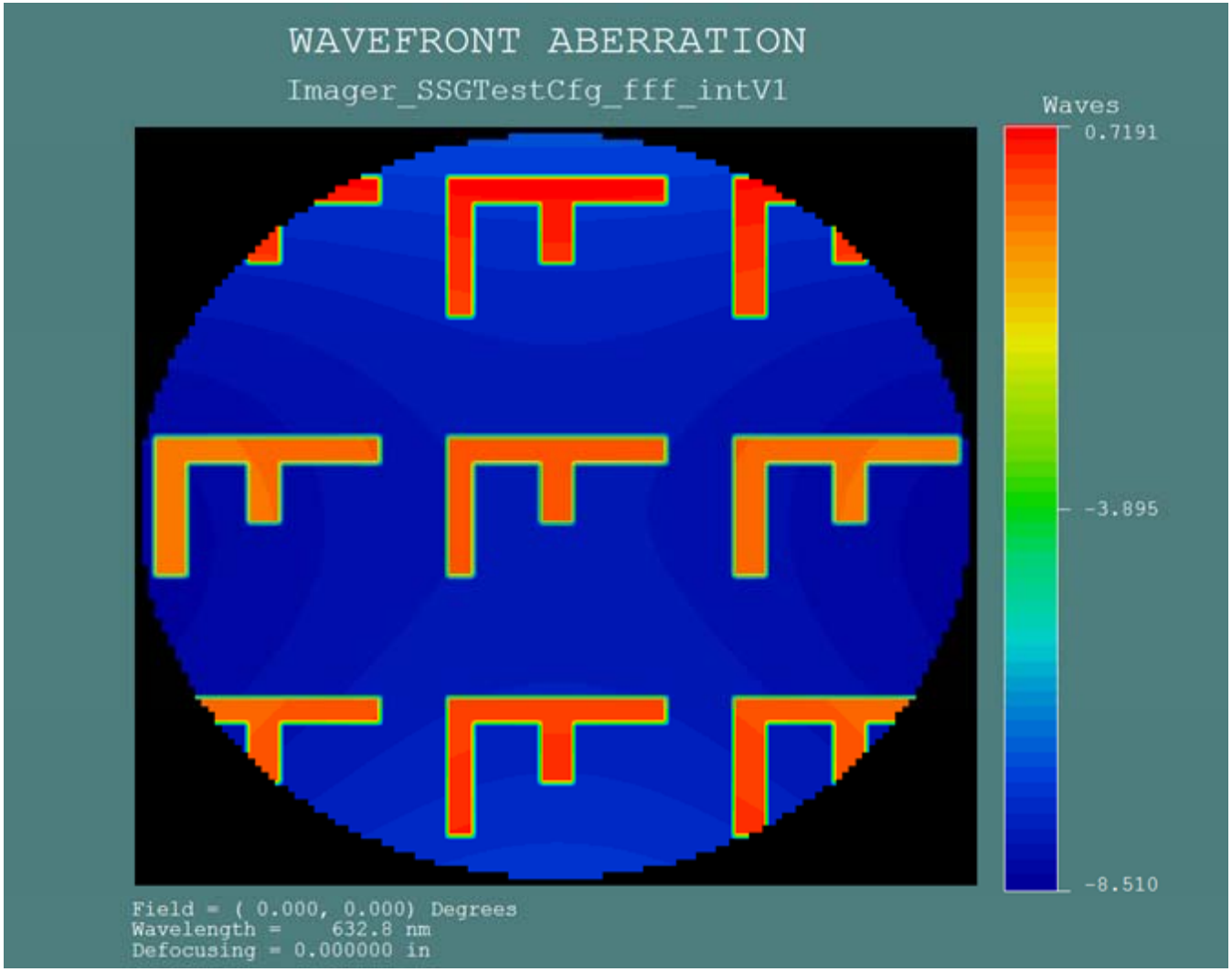
Orienting Imager Interferograms at the CODE V Interferometer Surface



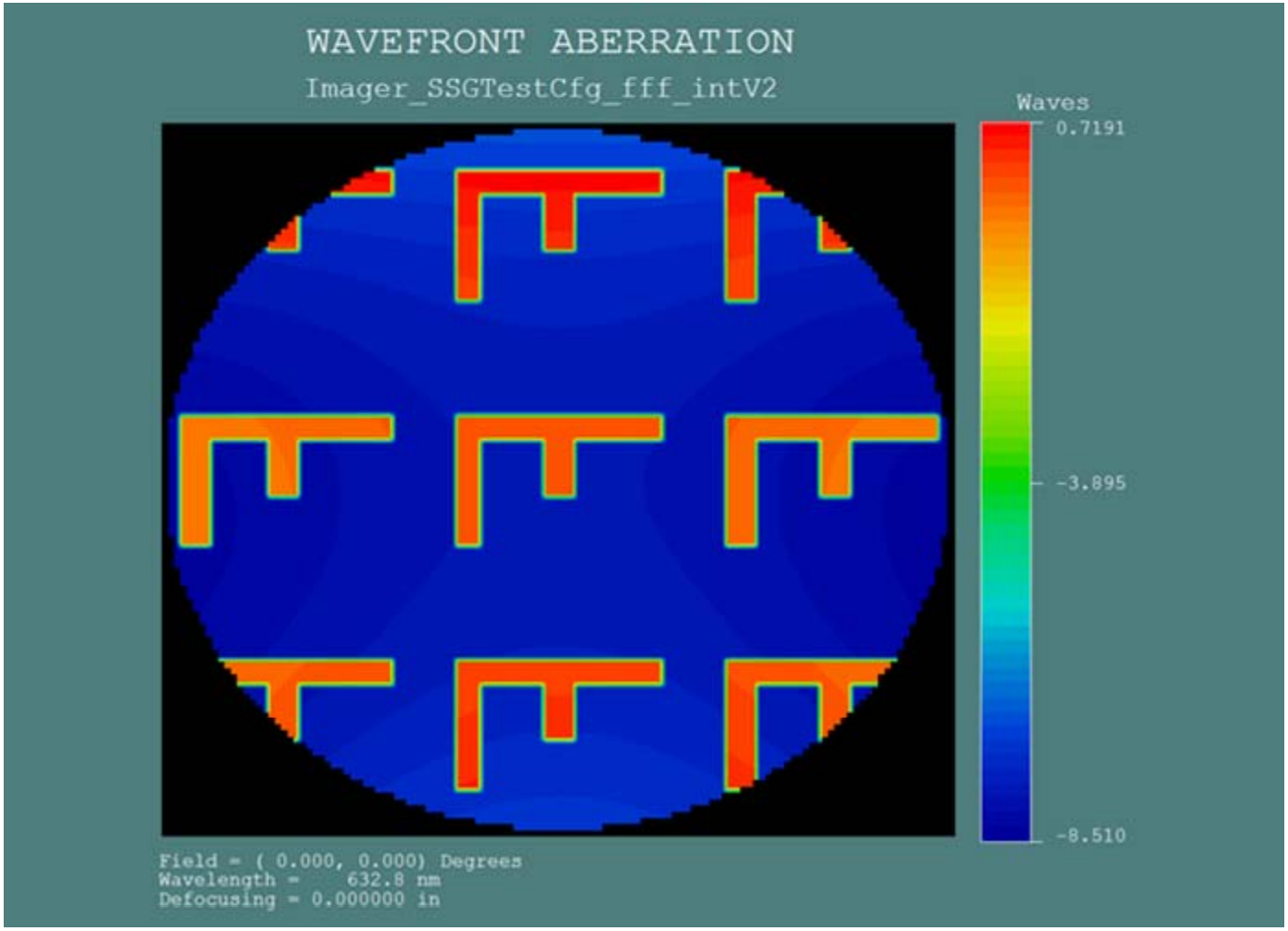
Interferogram coordinate system

Measured Imager interferograms must be oriented as shown in this figure when the interferogram is viewed from behind the MiniFiz interferometer.
Imager interferograms are attached to the CODE V interferometer surface in the by using the CODE V commands INT, IMI XC, IRO -90 and ISF 1.
The fact that these commands correctly orient the interferogram can be verified by making a copy of this slide and then orienting it relative to the Imager solid model slide. By Rule 1 the INT command attaches the interferogram coordinate system to the interferometer surface coordinate system. By Rules 2 and 3 IMI XC moves the deformation data to the opposite X-coordinate, which is equivalent to flipping about the Y axis. By Rule 5 IRO -90 rotates the new +X deformations away from the +Y deformations, which puts the tops of the F letters up and the open faces of the F letters to the right when viewed from behind the interferometer as desired.
ISF 1 follows from Rule 7 and MiniFiz wavefront error sign convention.

Imager Exit Pupil Map with Interferogram Attached to the Interferometer Surface Using INT, IMI XC and IRO -90



Imager Exit Pupil Map with Interferogram Attached to the Imager Stop (Afocal Exit Pupil) Surface Using INT, IMI XC and IRO -90

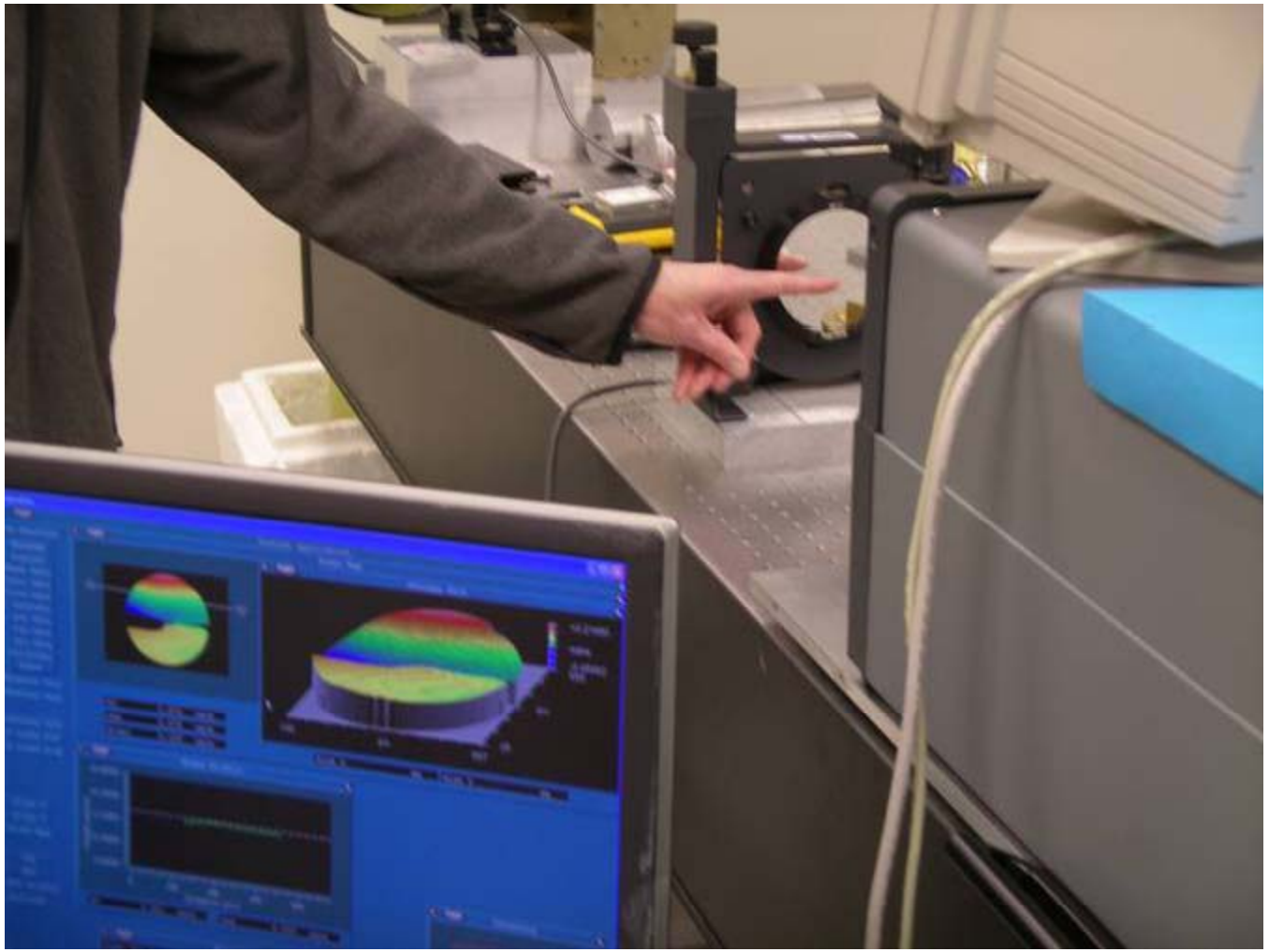


This exit pupil map is identical to the exit pupil map with the interferogram attached to the interferometer surface.
Thus, Imager interferograms can be attached at the Imager Stop (Afocal Exit Pupil) using the CODE V commands INT, IMI XC and IRO -90.

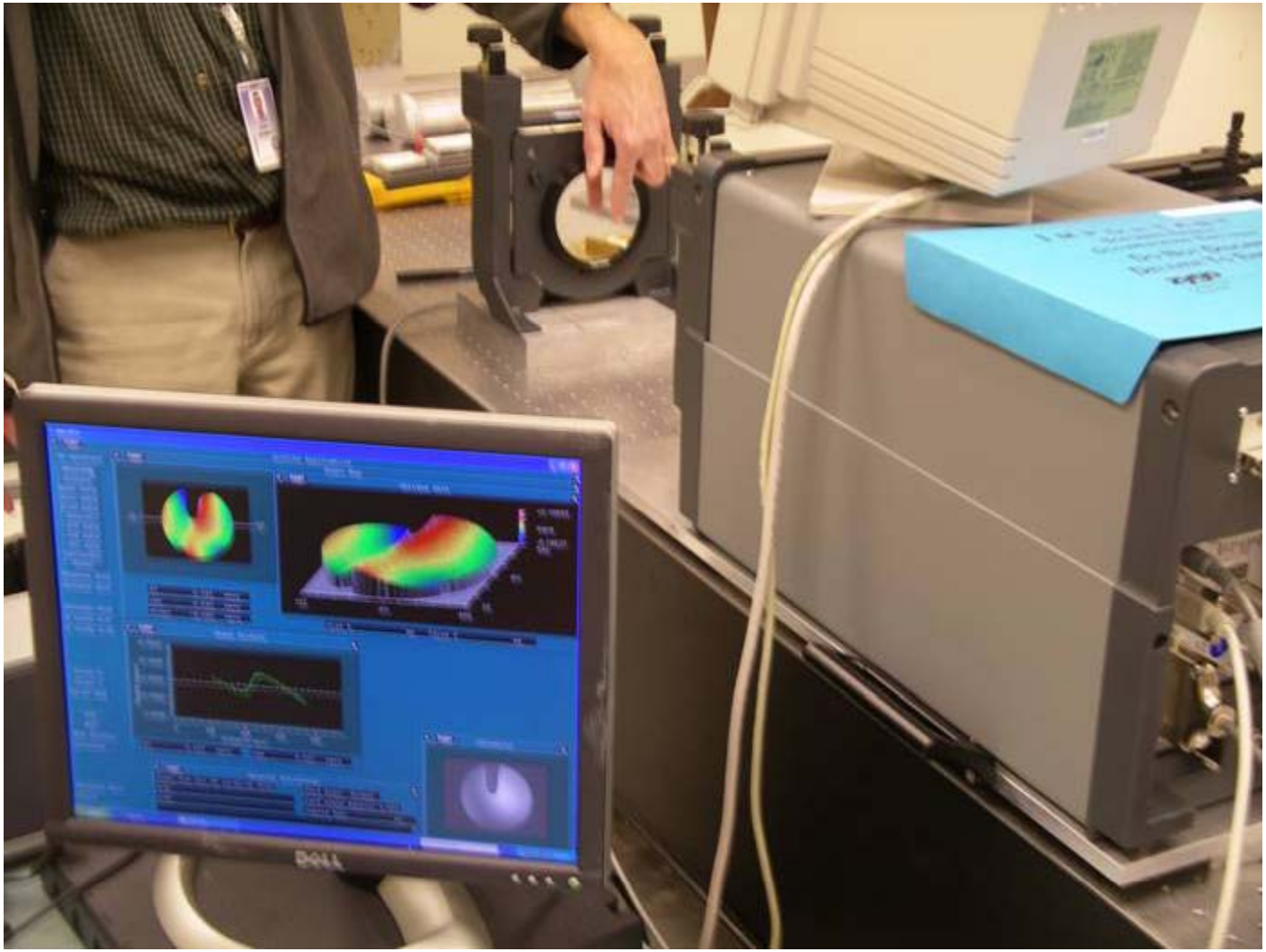
Beamsplitter and Filter Interferograms

- Beamsplitter and filter interferograms measured with a Zygo interferometer at SDL.
- Imager interferograms are surface deformation interferograms and they are attached to their corresponding CODE V optical surface.

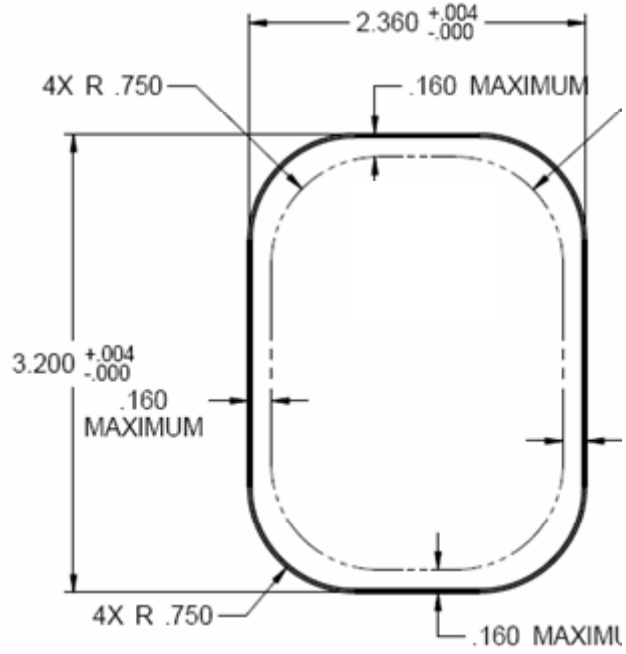
Zygo Interferometer Interferogram Left-Right Orientation



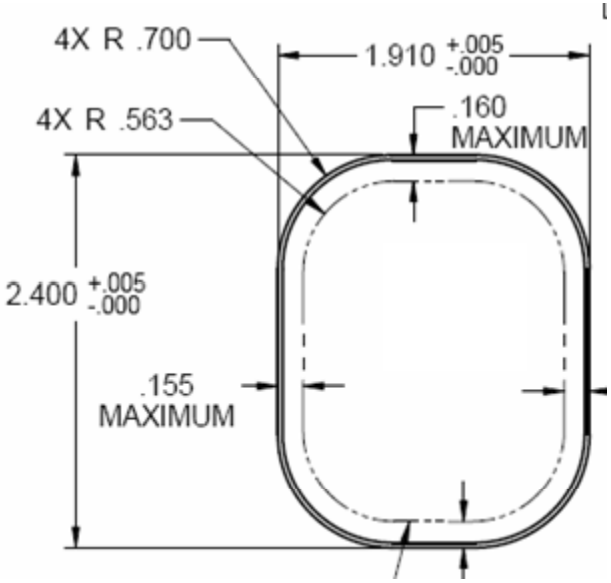
Zygo Interferometer Interferogram Up-Down Orientation



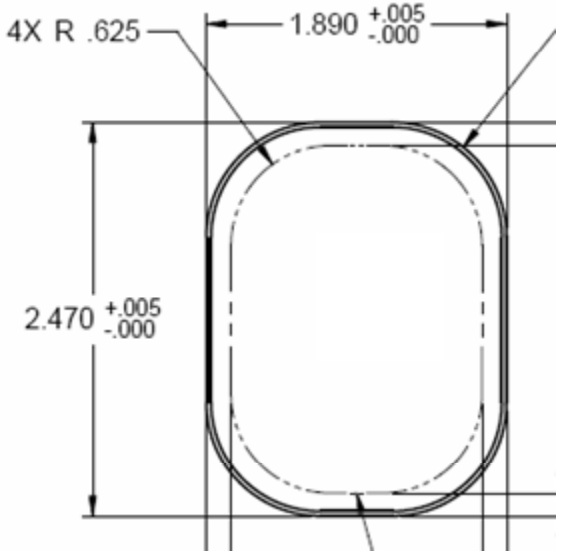
Beamsplitter Width and Length Dimensions



Beamsplitter 1 (BS1)
from Drawing 62-0054C



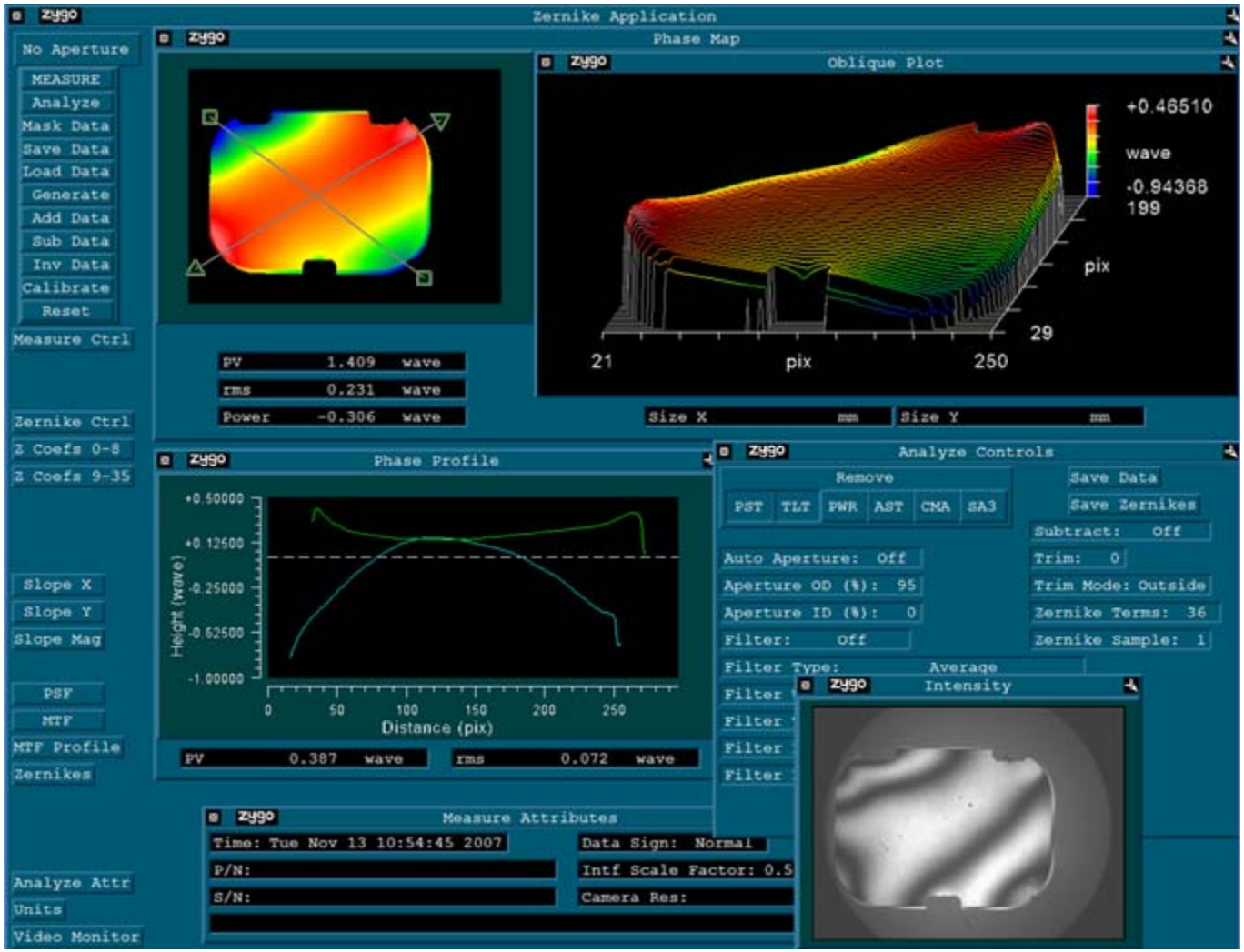
Beamsplitter 2 (BS2)
from Drawing 62-0055C



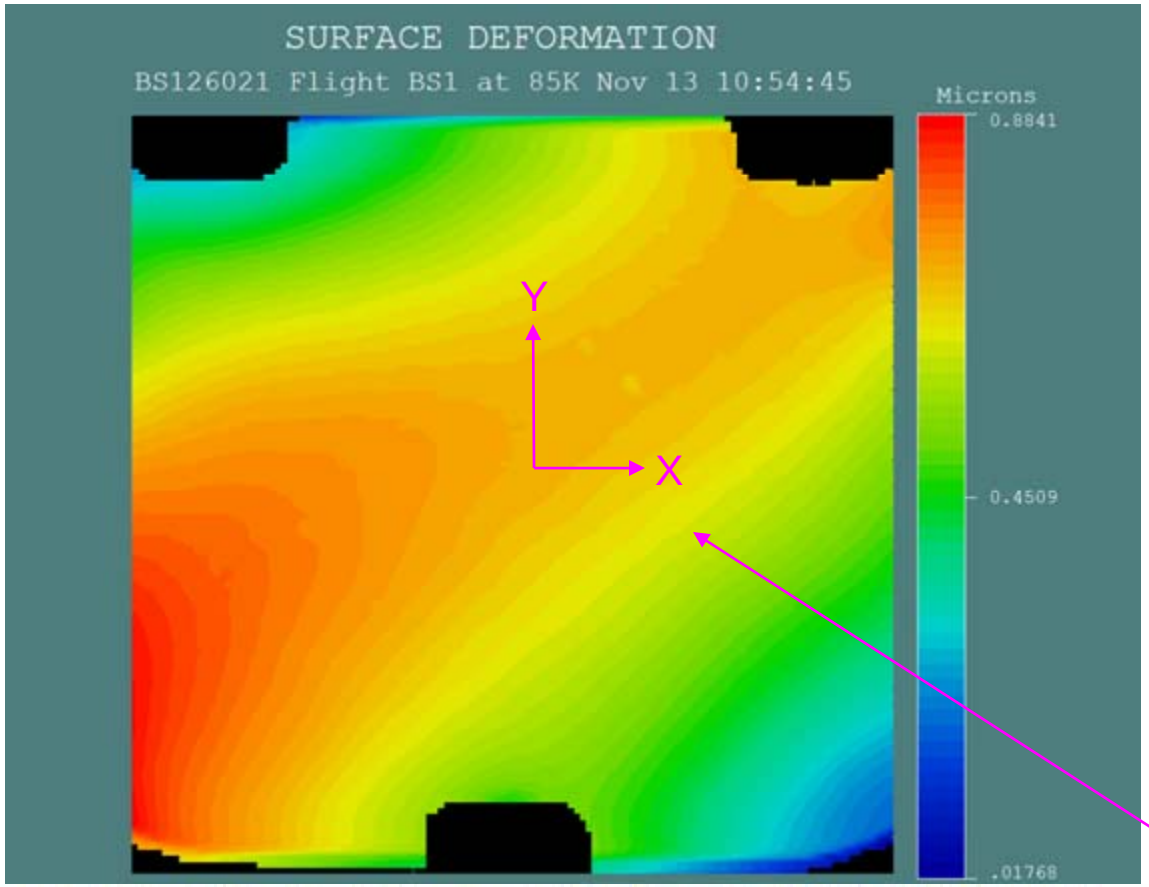
Beamsplitter 3 (BS3)
from Drawing 62-0056C

Linear dimensions in inches

Flight BS1 AR Surface Flatness Measured at 85K



Flight BS1 Interferogram at 85 K



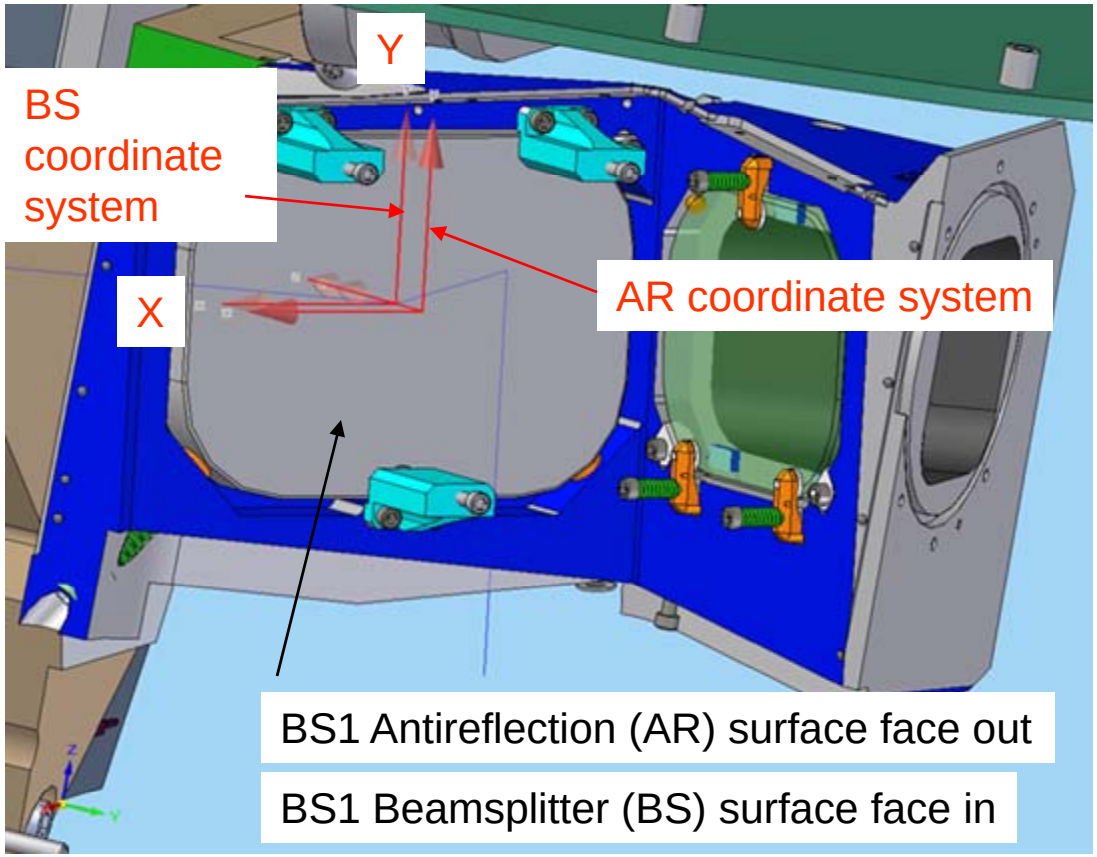
Zygo file modified as follows:

1) WFR replaced with SUR
2) XSC 1.347 added (229/170=1.347)

Interferogram coordinate system

```
BS126021 Flight BS1 at 85K Nov 13 10:54:45 2007
GRD 229 170 SUR WVL 0.6328 SSZ 16384.000000 NDA -32768 XSC 1.347
 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768
 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768
```

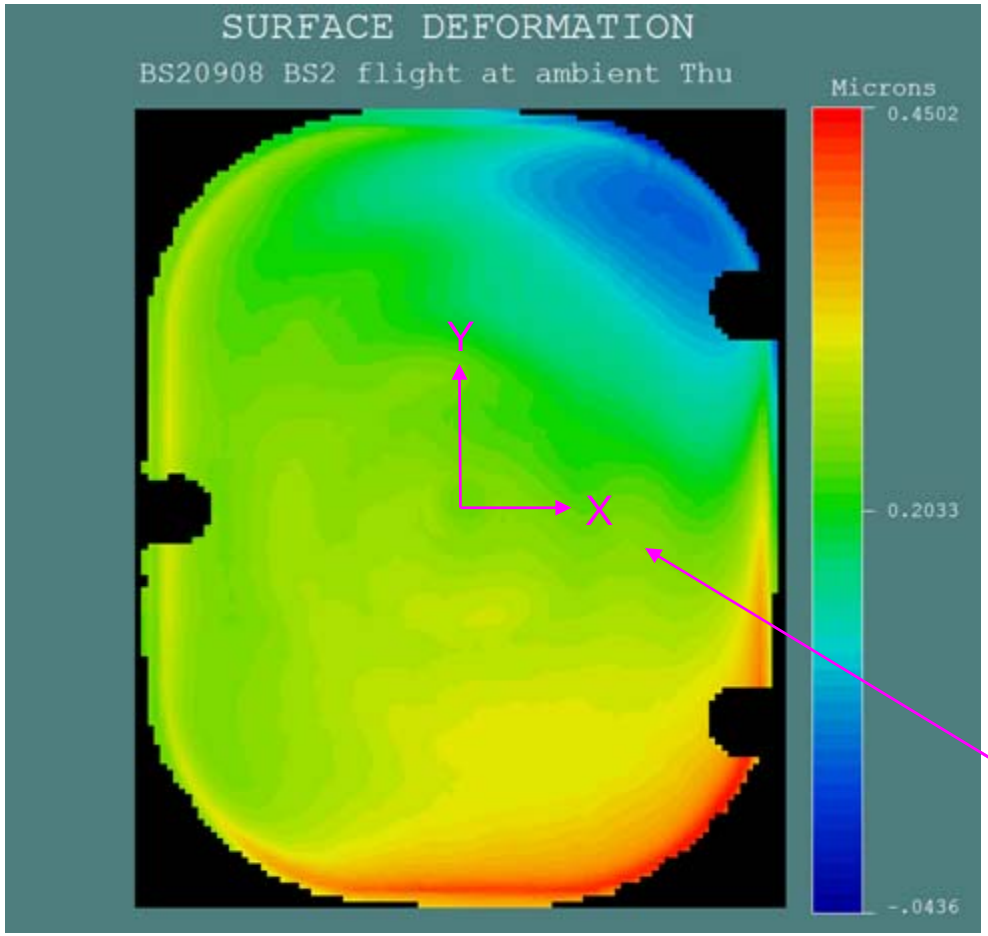
Beamsplitter 1 (BS1) CODE V Coordinate Systems



BS1 Interferogram was measured from the AR side. This interferogram is attached to both the BS and the AR surfaces using the CODE V commands INT, IMI XC. ISF -1 is used for the BS surface and ISF 1 for the AR surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the BS1 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1 and then deformation data is moved to the opposite X-coordinate by Rule 3.

Flight BS2 AR Surface Flatness Measured at Ambient Temperature

Flight BS2 Interferogram at Ambient Temperature

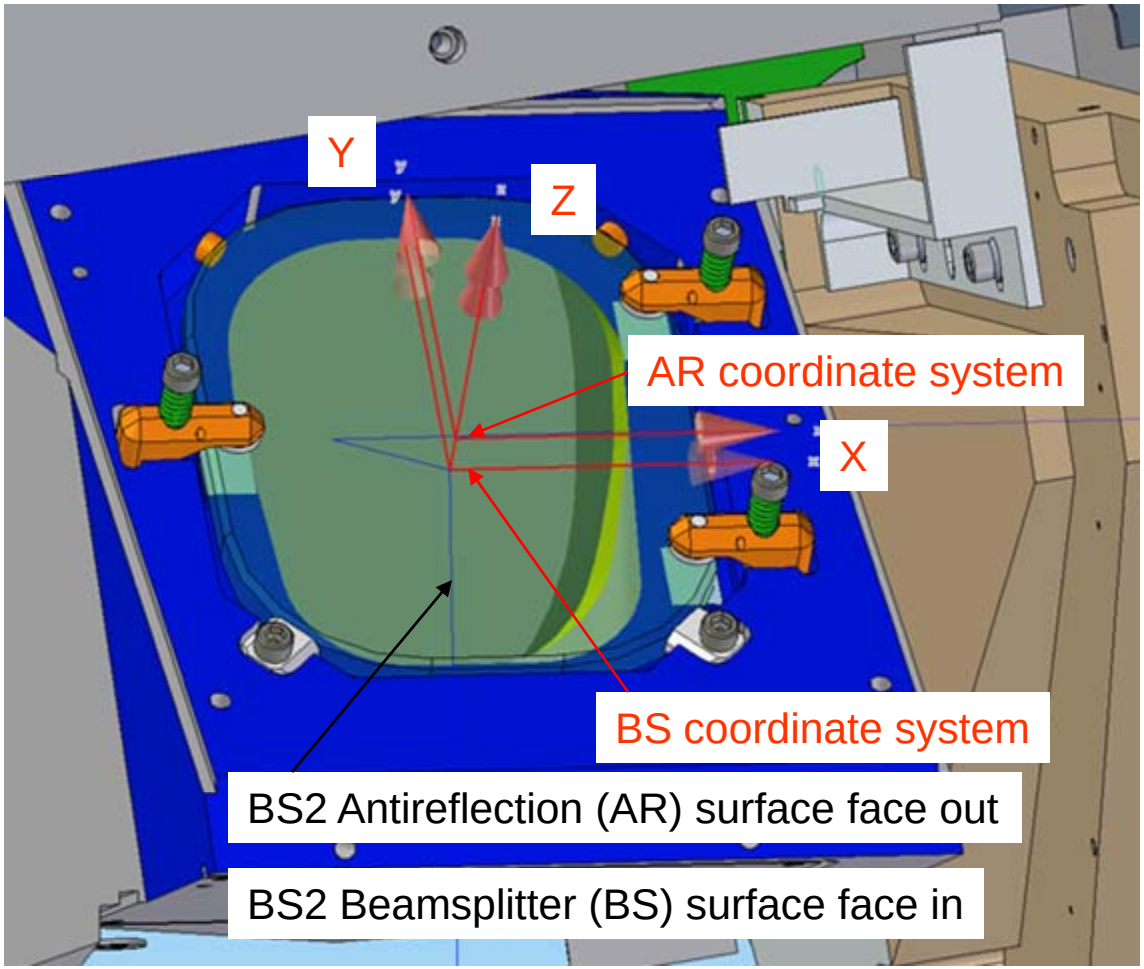


Zygo file modified as follows:
WFR replaced with SUR
XSC 0.800 added (164/205=0.800)

Interferogram coordinate system

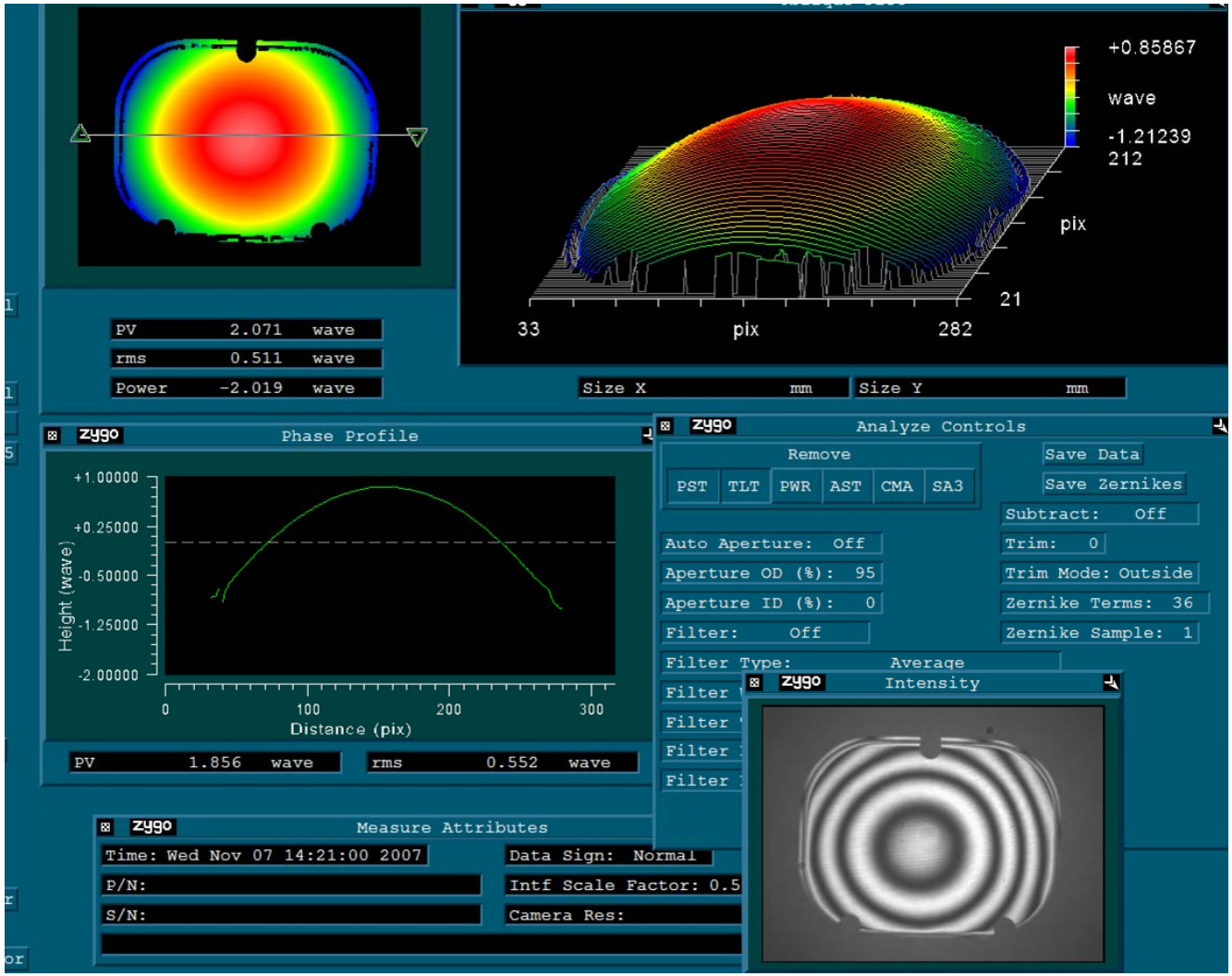
```
BS20908 BS2 flight at ambient Thu Nov 15 14:15:11 2007
GRD 164 205 SUR WVL 0.6328 SSZ 32768.000000 NDA -32768 XSC 0.800
 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768
```

Beamsplitter 2 (BS2) CODE V Coordinate Systems

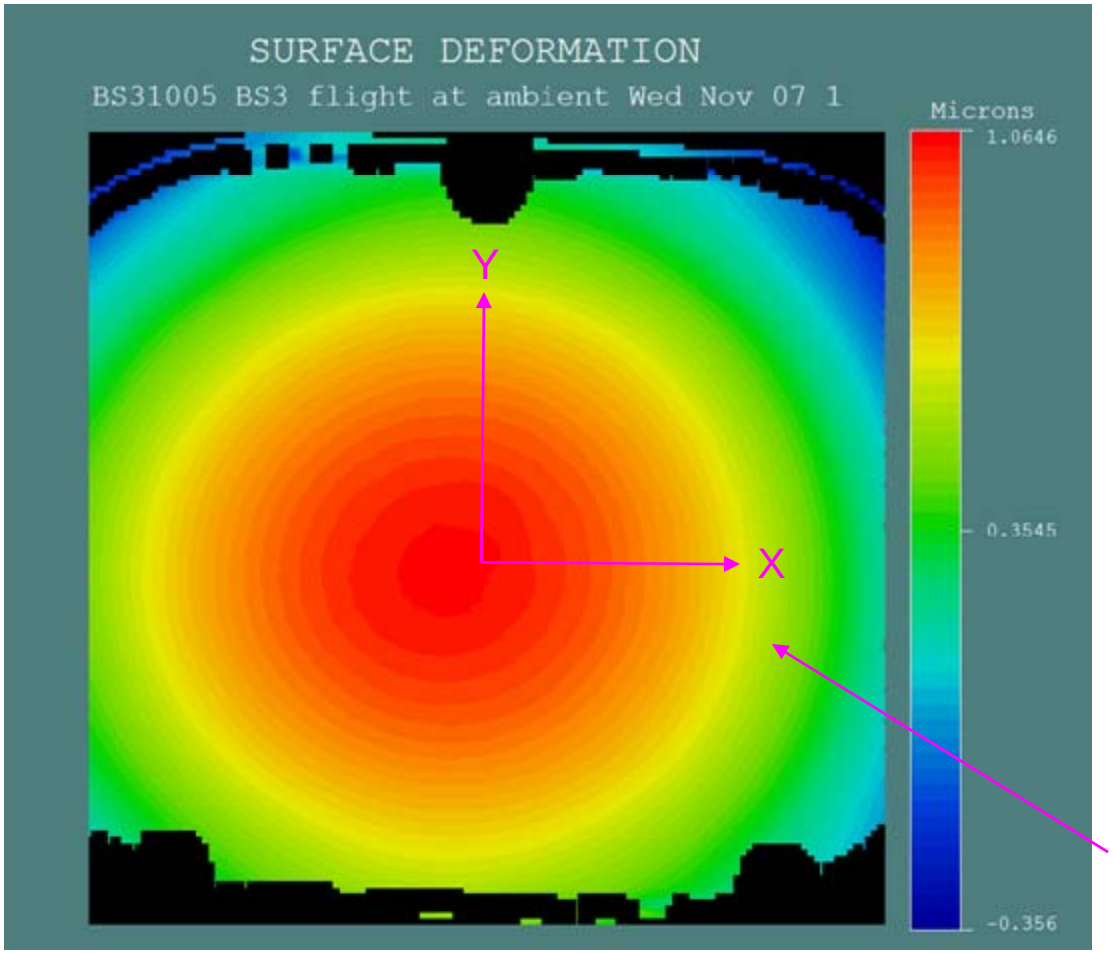


BS2 Interferogram was measured from the AR side. This interferogram is attached to both the BS and the AR surfaces using the CODE V commands INT. ISF -1 is used for the BS surface and ISF 1 for the AR surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the BS2 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1.

Flight BS3 BS Surface Flatness Measured at Ambient Temperature



Flight BS3 Interferogram

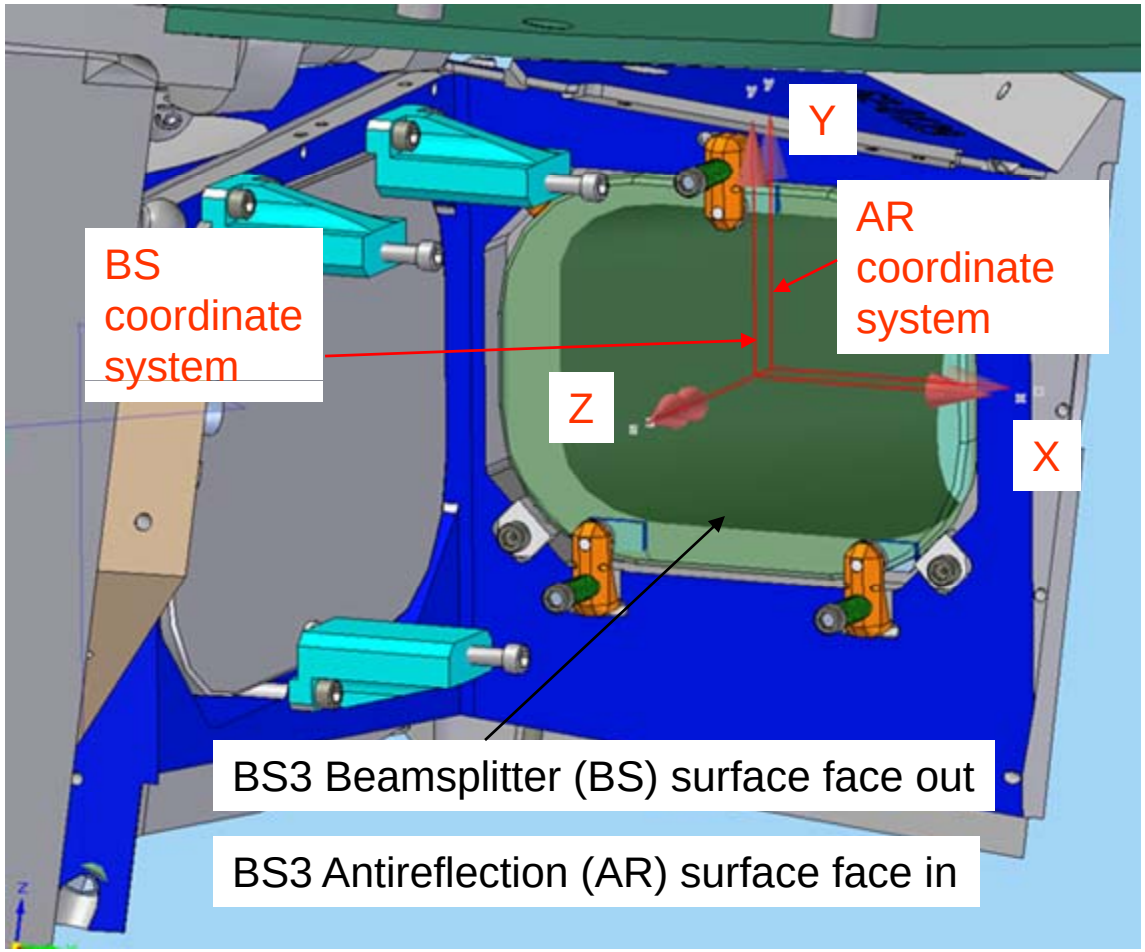


Zygo file modified as follows:
WFR replaced with SUR
XSC 1.304 added (249/191=1.304)

Interferogram coordinate system

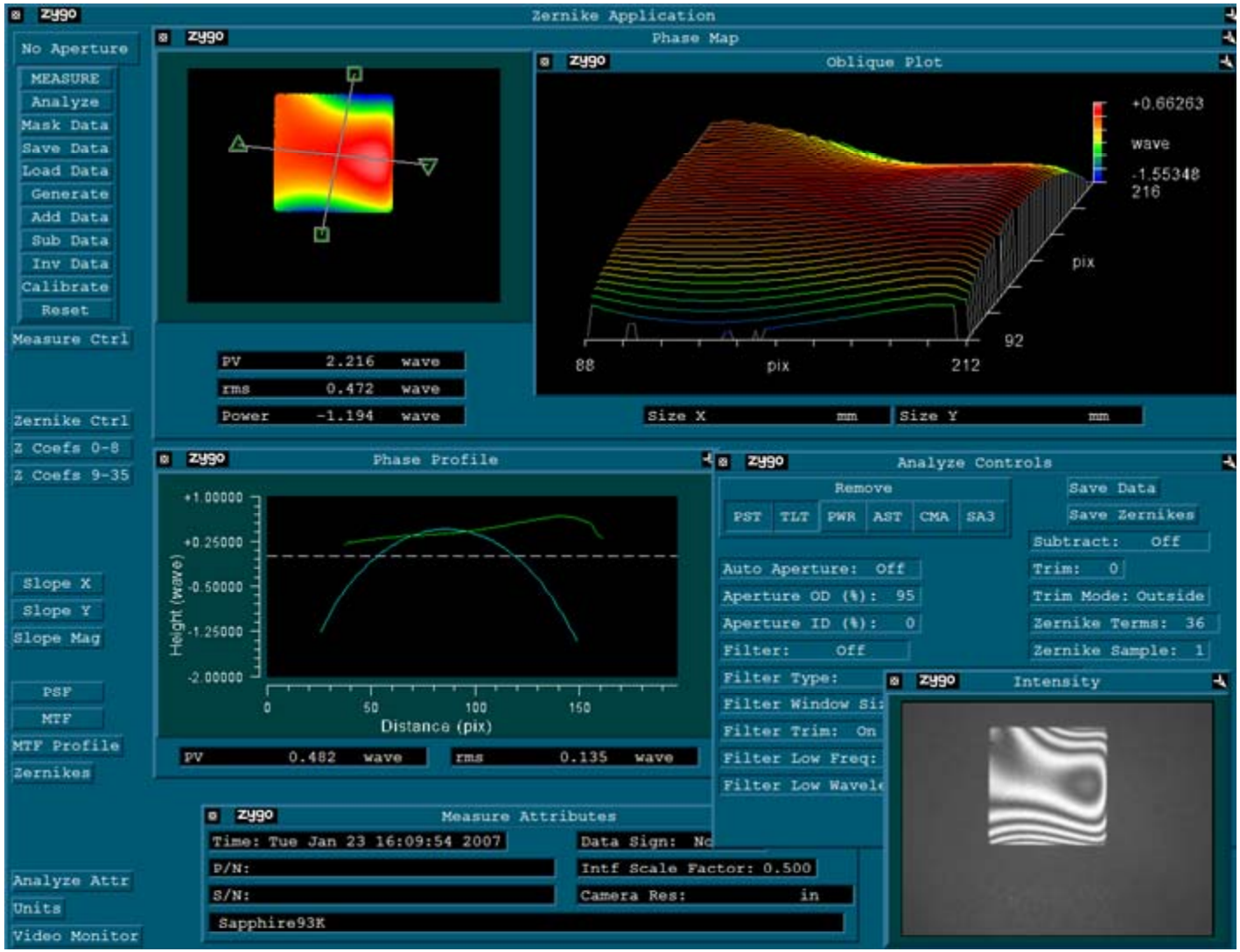
```
BS31005 BS3 flight at ambient Wed Nov 07 14:21:00 2007
GRD 249 191 SUR WVL 0.6328 SSZ 16384.000000 NDA -32768 XSC 1.304
 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768 -32768
```

Beamsplitter 3 (BS3) CODE V Coordinate Systems



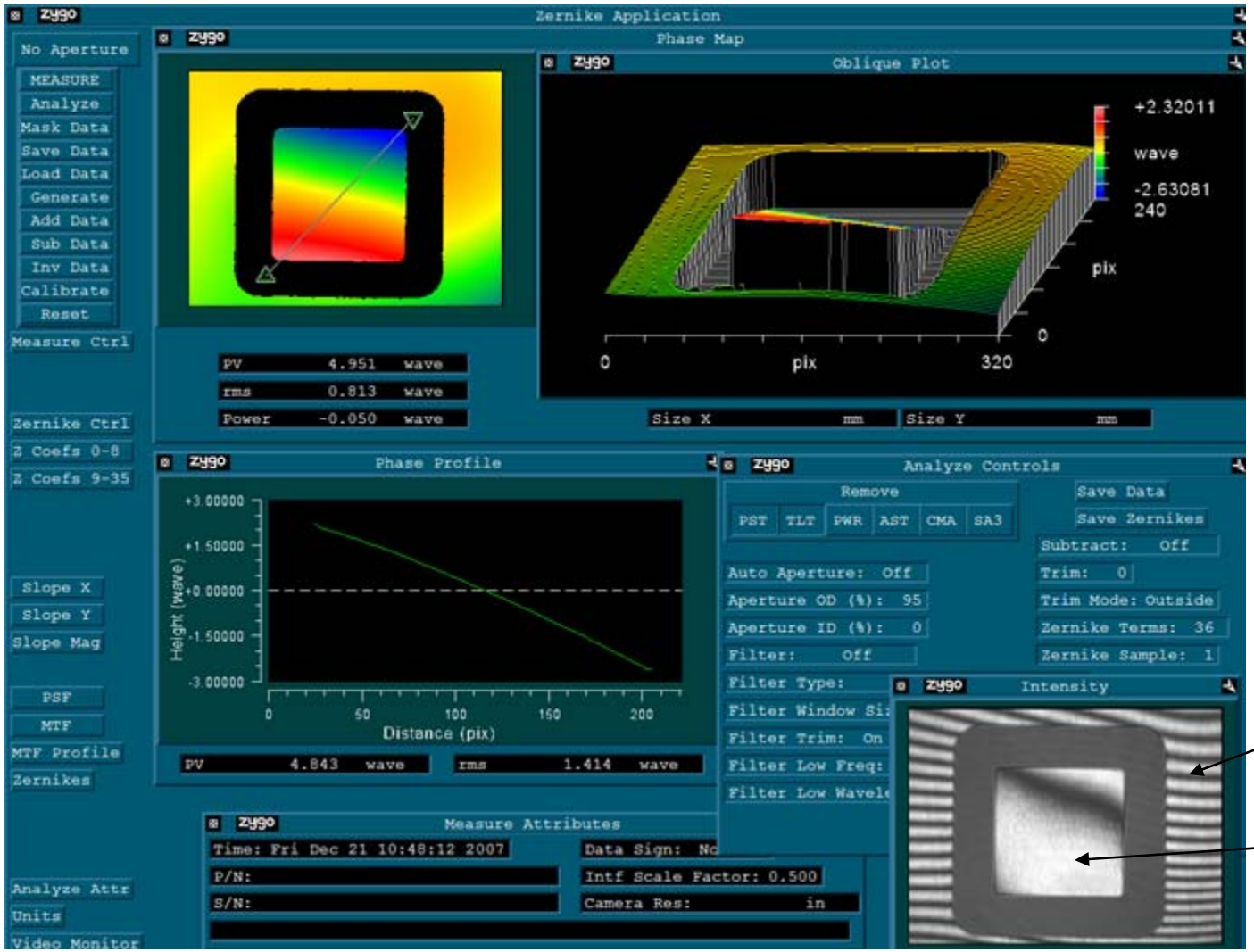
BS3 Interferogram was measured from the BS side. This interferogram is attached to both the BS and the AR surfaces using the CODE V commands INT. ISF 1 is used for the BS surface and ISF -1 for the AR surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the BS3 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1.

Mounted Sapphire Substrate for Filters 1 and 2 at 93 K after 1 ½ Thermal Cycles

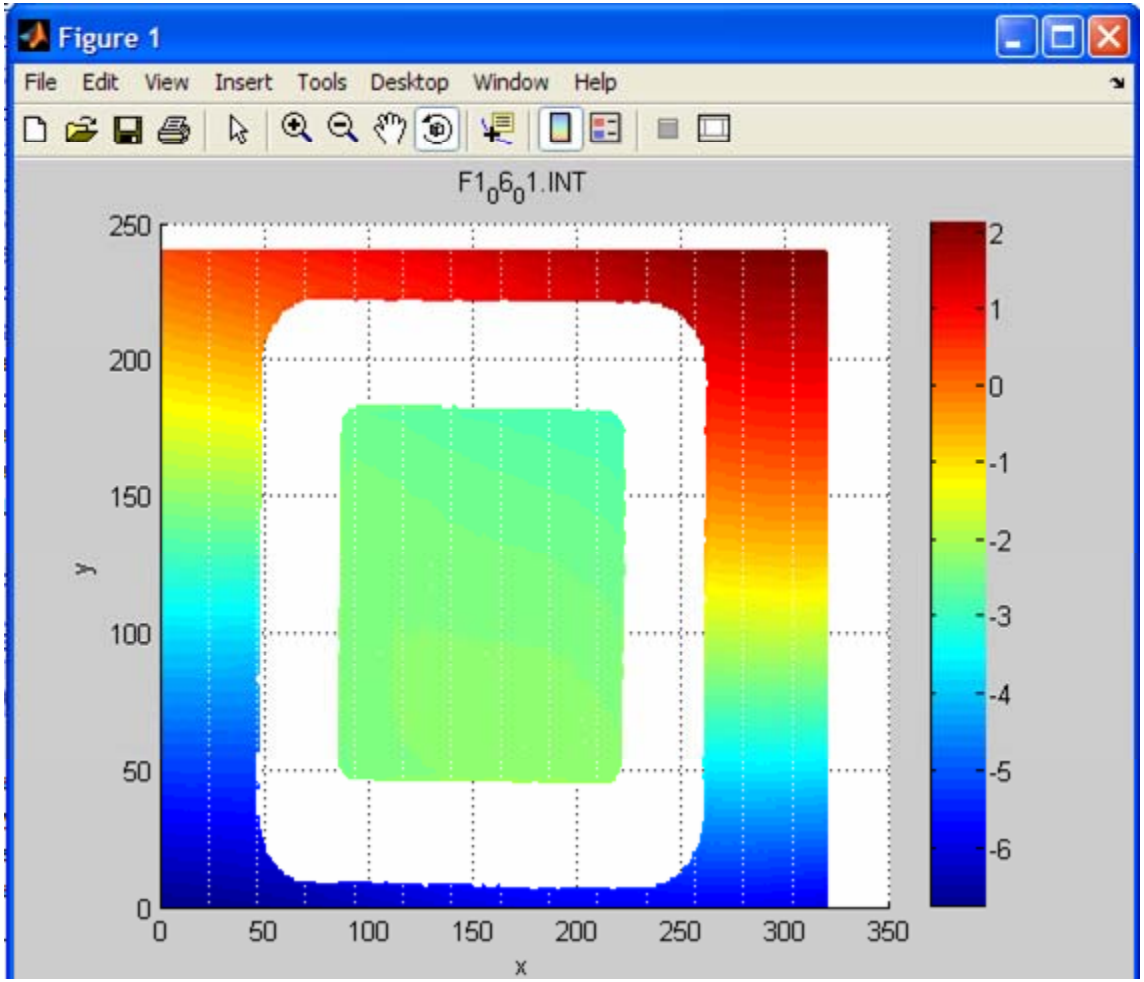


After two thermal cycles the effect of the filter mounts on WISE wavefront error is negligible. The filter clear aperture is 0.85 inches on a side, while the optical beam footprint from a point source on the filter is less than 0.015 inches in diameter.

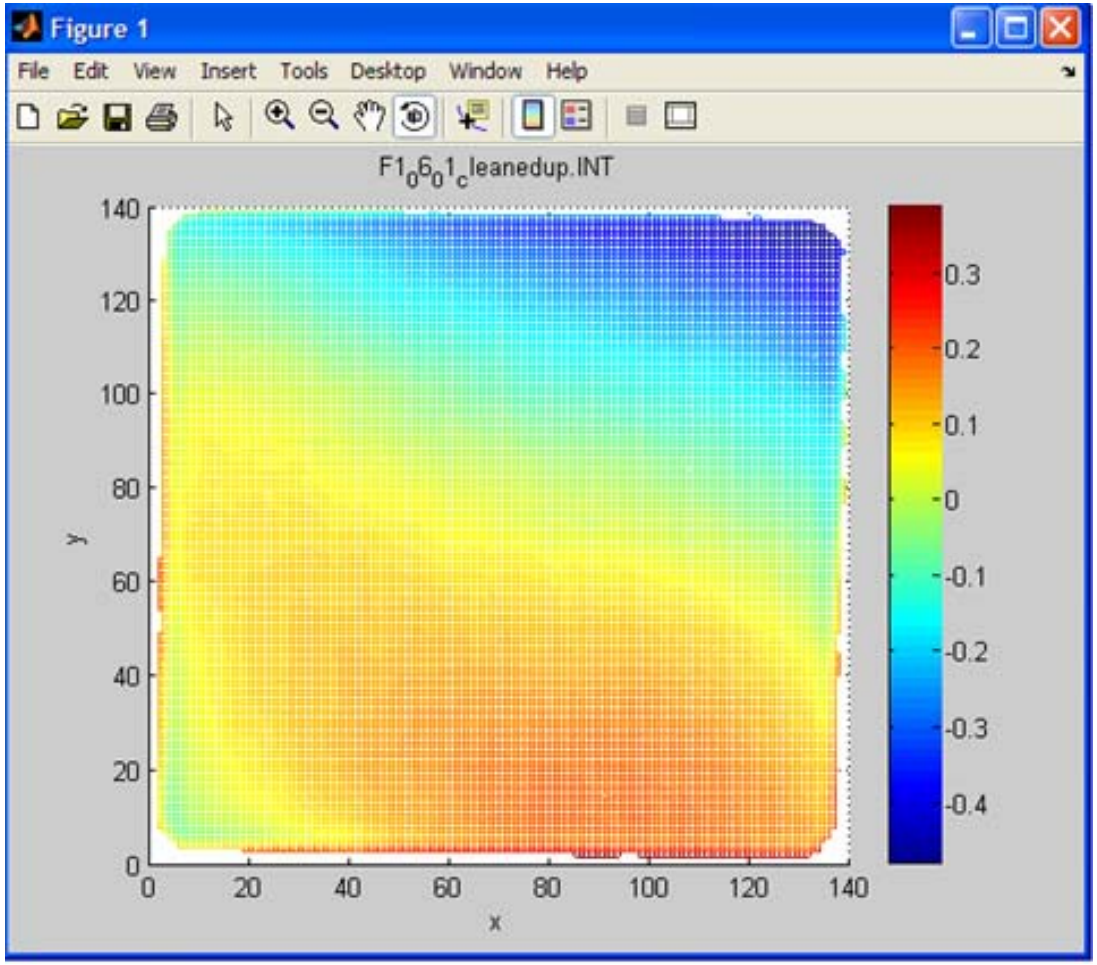
Mounted Flight Filter 1 at Ambient Temperature



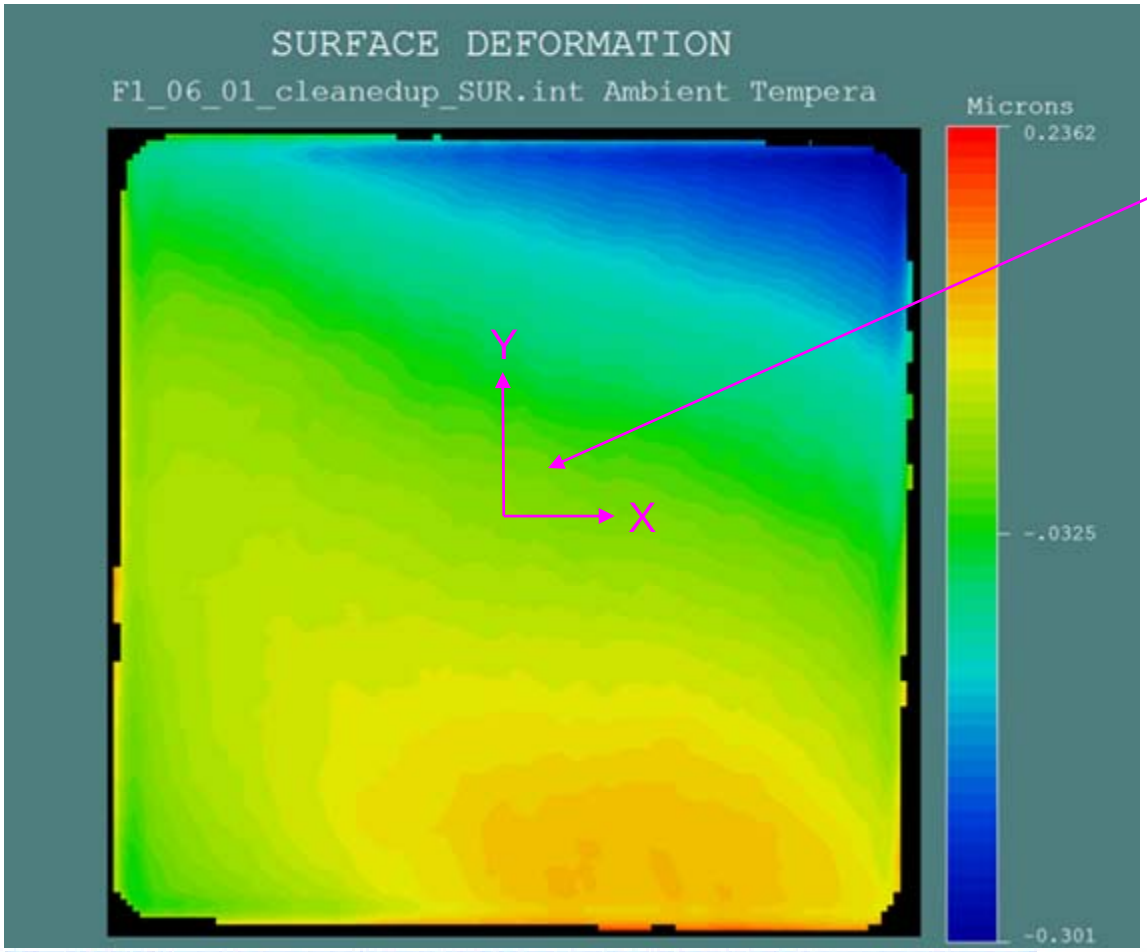
Filter 1 Surface Deformation in 633nm Waves Before Trimming Off Region Due to Lapped Mount



Filter 1 Surface Deformation in 633nm Waves After Trimming Off Region Due to Lapped Mount



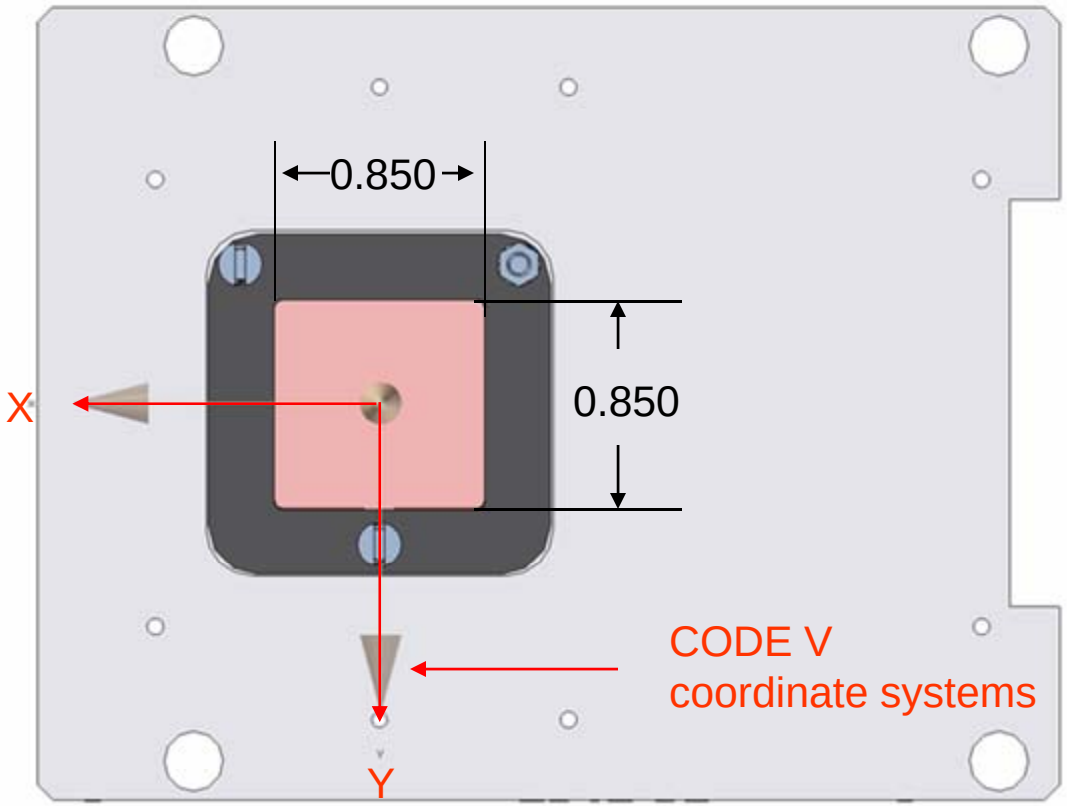
Flight Filter 1 Interferogram



Interferogram coordinate system

F1_06_01_cleanedup_SUR.int Ambient Temperature
GRD 140 140 SUR WVL 0.6328 SSZ 68701 NDA 32767 XSC 1.0000
32767 32767 32767 32767 32767 32767 32767 32767 32767 32767

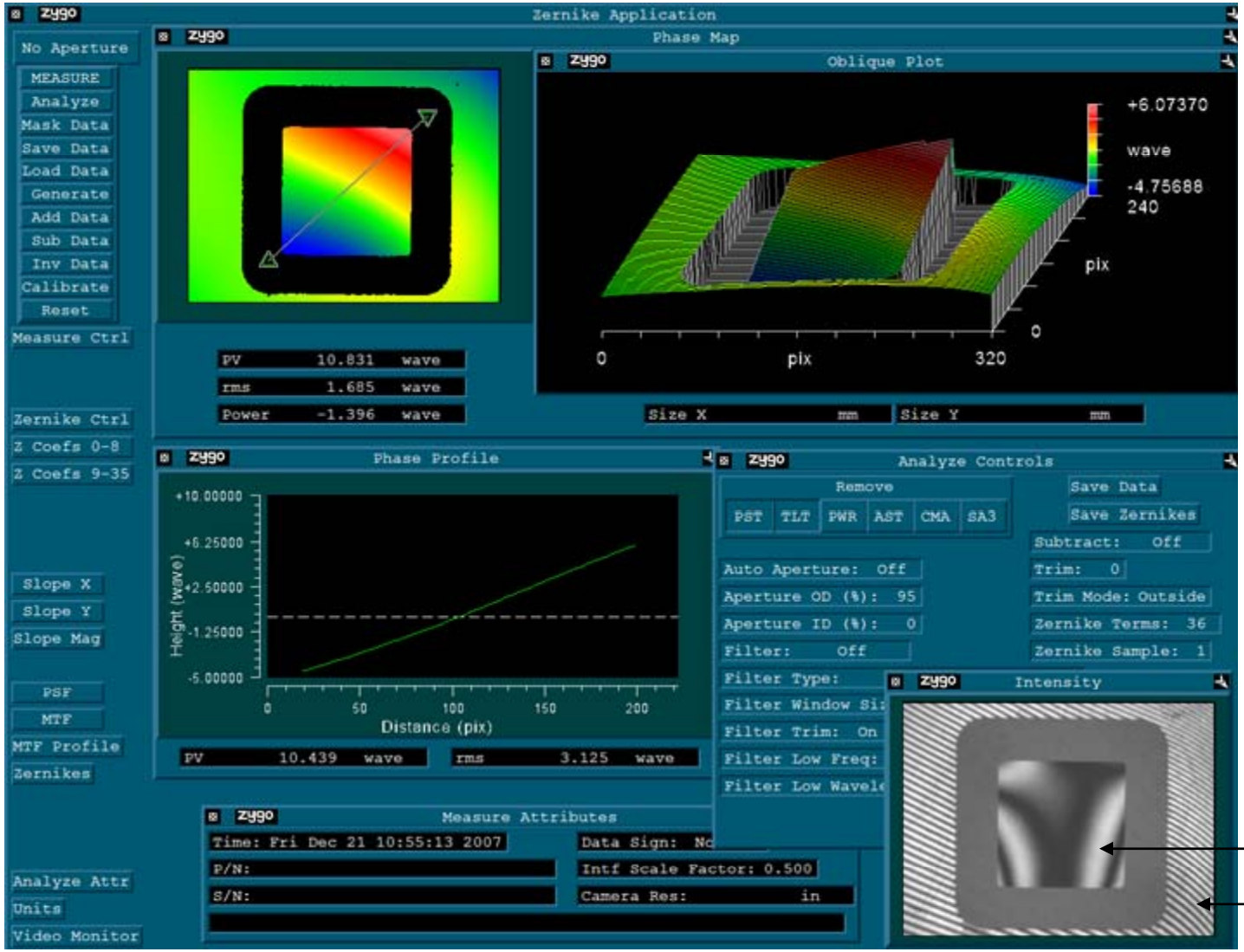
Filter 1 Coordinate Systems



Linear dimensions in inches

Filter 1 interferogram was measured from the front surface oriented as shown in this figure. This interferogram is attached to both the front and back surfaces using the CODE V commands INT, IRO 180. ISF 1 is used for the front surface and ISF -1 for the back surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the Filter 1 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1 and then the deformation data is rotated 180 degrees by Rule.

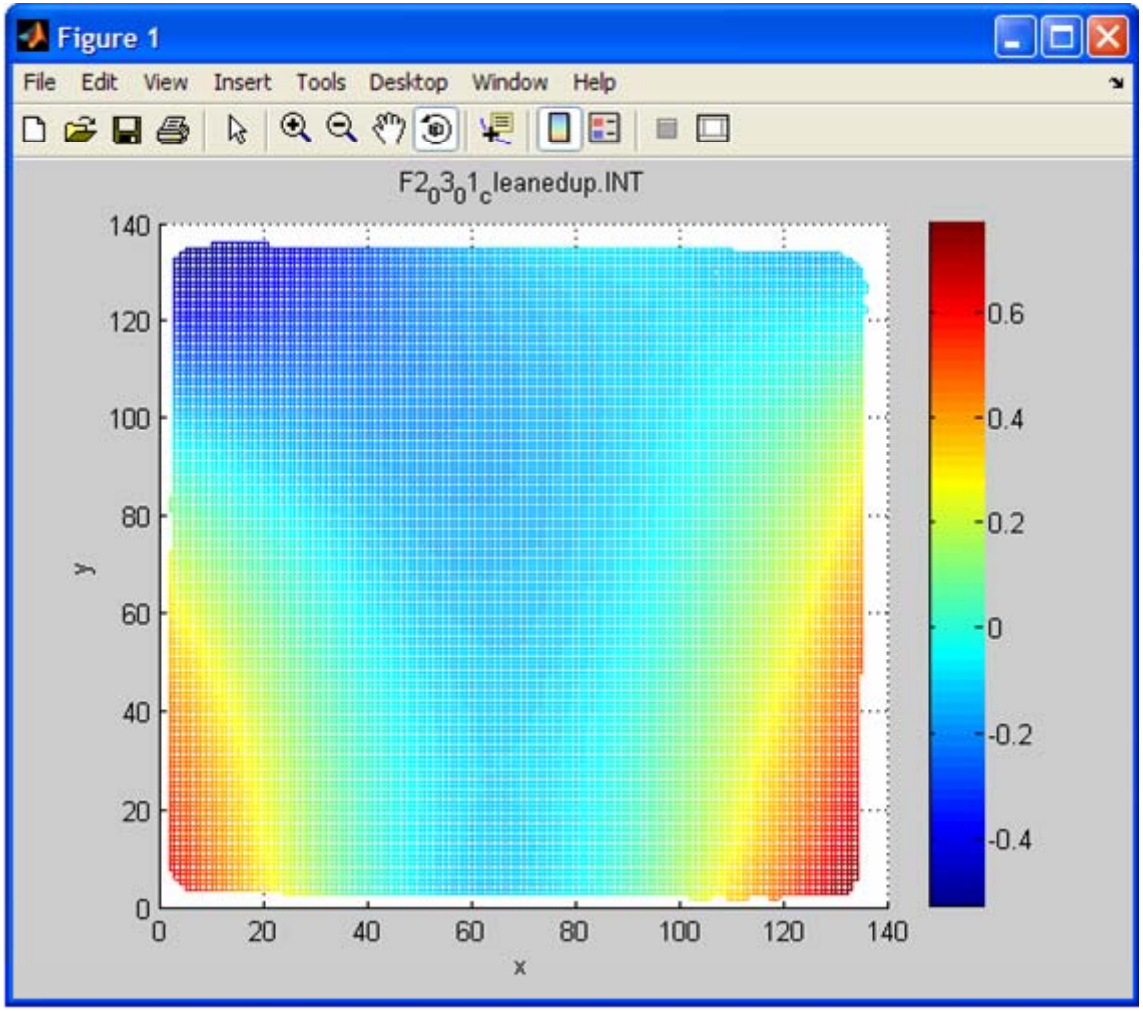
Mounted Flight Filter 2 at Ambient Temperature



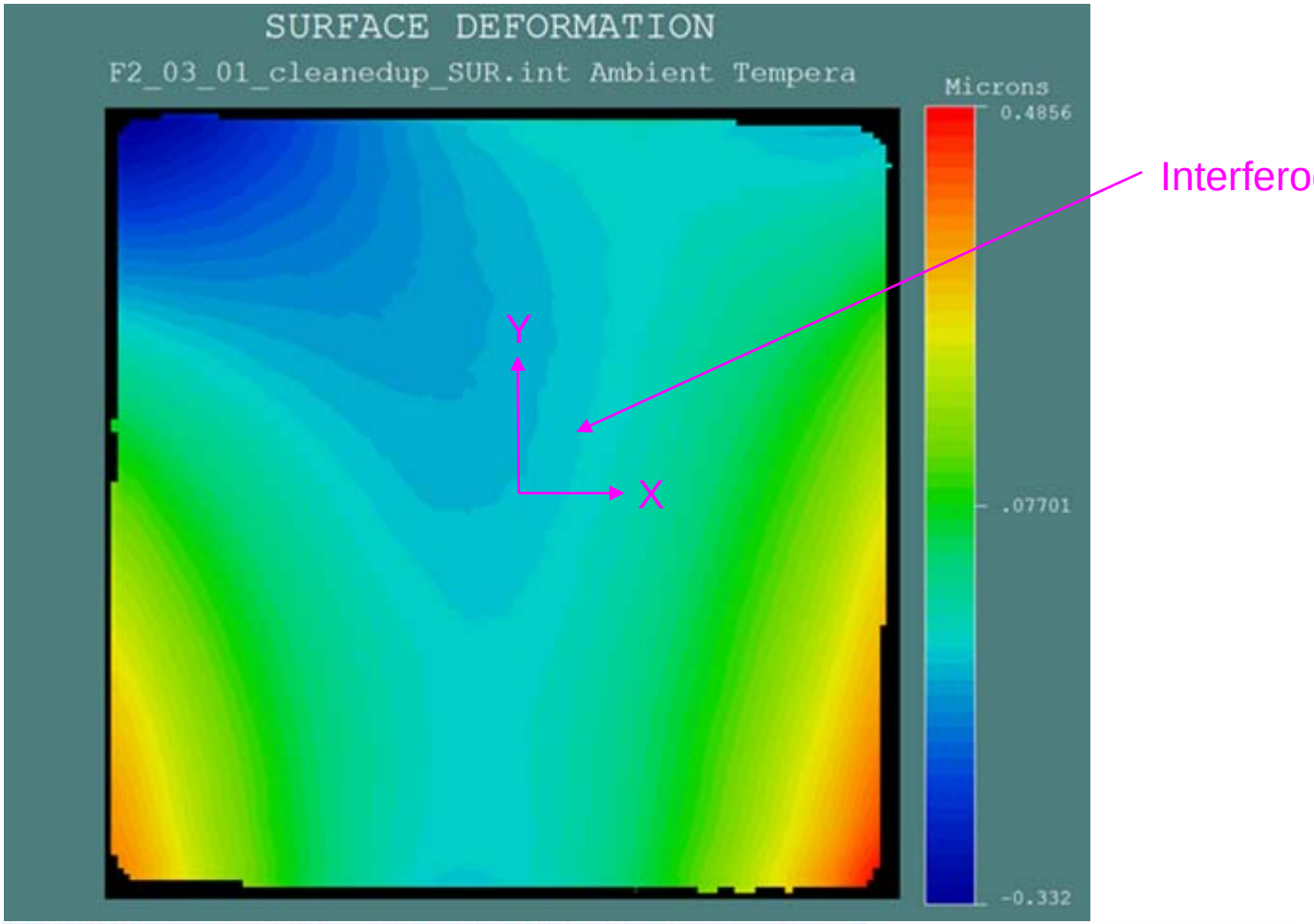
Filter

Lapped Mount

Flight Filter 2 Surface Deformation in 633nm Waves After Trimming Off Region Due to Lapped Mount

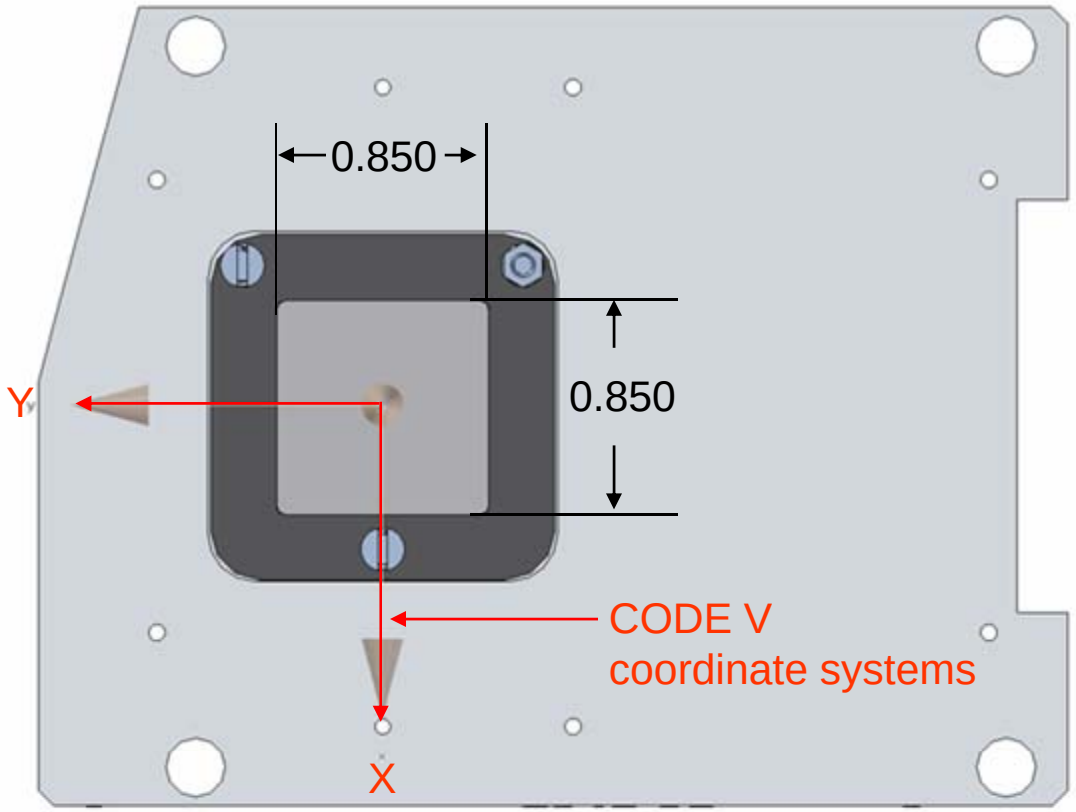


Flight Filter 2 Interferogram



F2_03_01_cleanedup_SUR.int Ambient Temperature
GRD 137 137 SUR WVL 0.6328 SSZ 42291 NDA 32767 XSC 1.0000
32767 32767 32767 32767 32767 32767 32767 32767 32767 32767

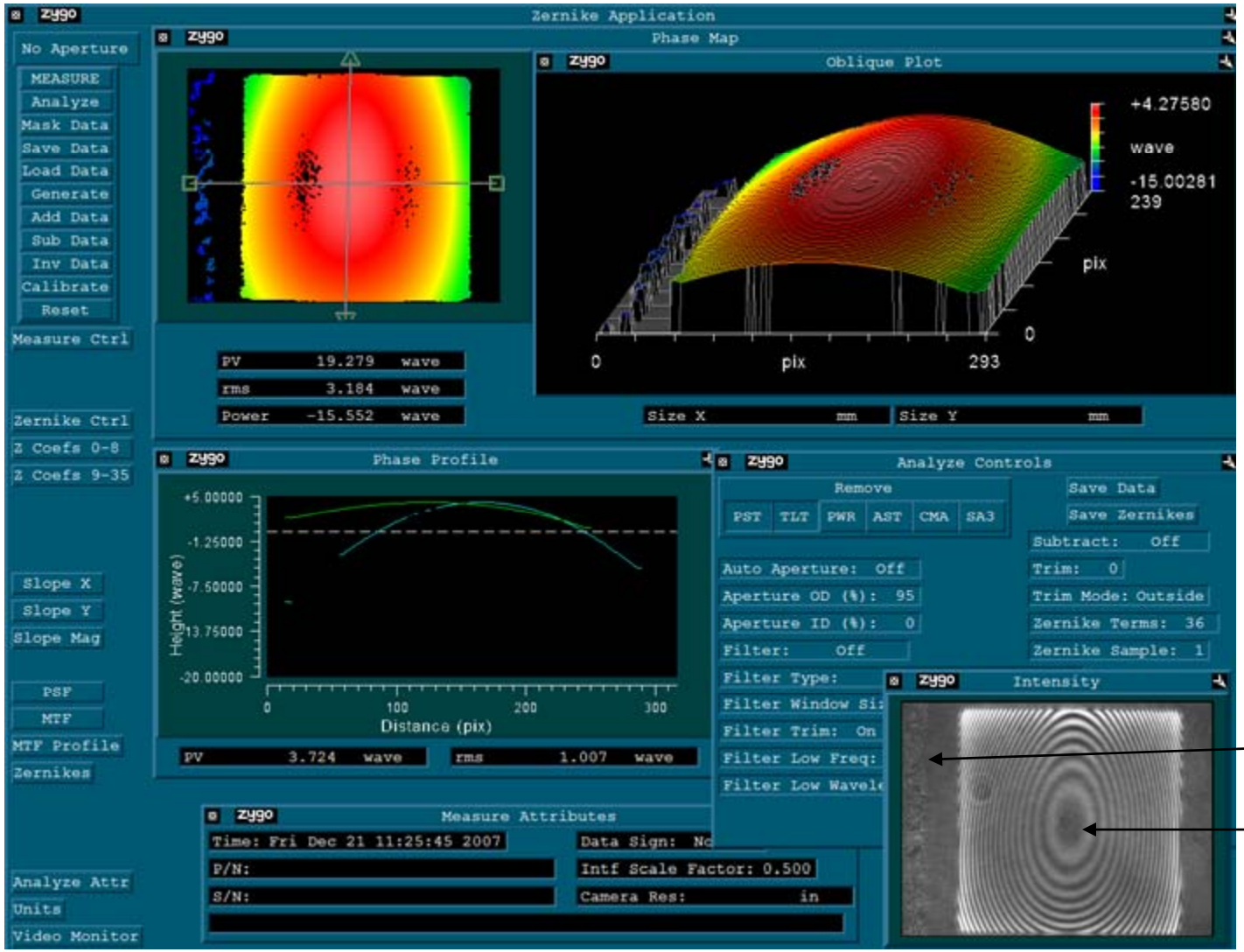
Filter 2 Coordinate System



Linear dimensions in inches

Filter 2 interferogram was measured from the front surface oriented as shown in this figure. This interferogram is attached to both the front and back surfaces using the CODE V commands INT, IMI XC, IRO 90. ISF 1 is used for the front surface and ISF -1 for the back surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the Filter 2 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1 and then the deformation data is moved to the opposite X-coordinate by Rule 3 and then it is rotated +90 degrees by Rule 5.

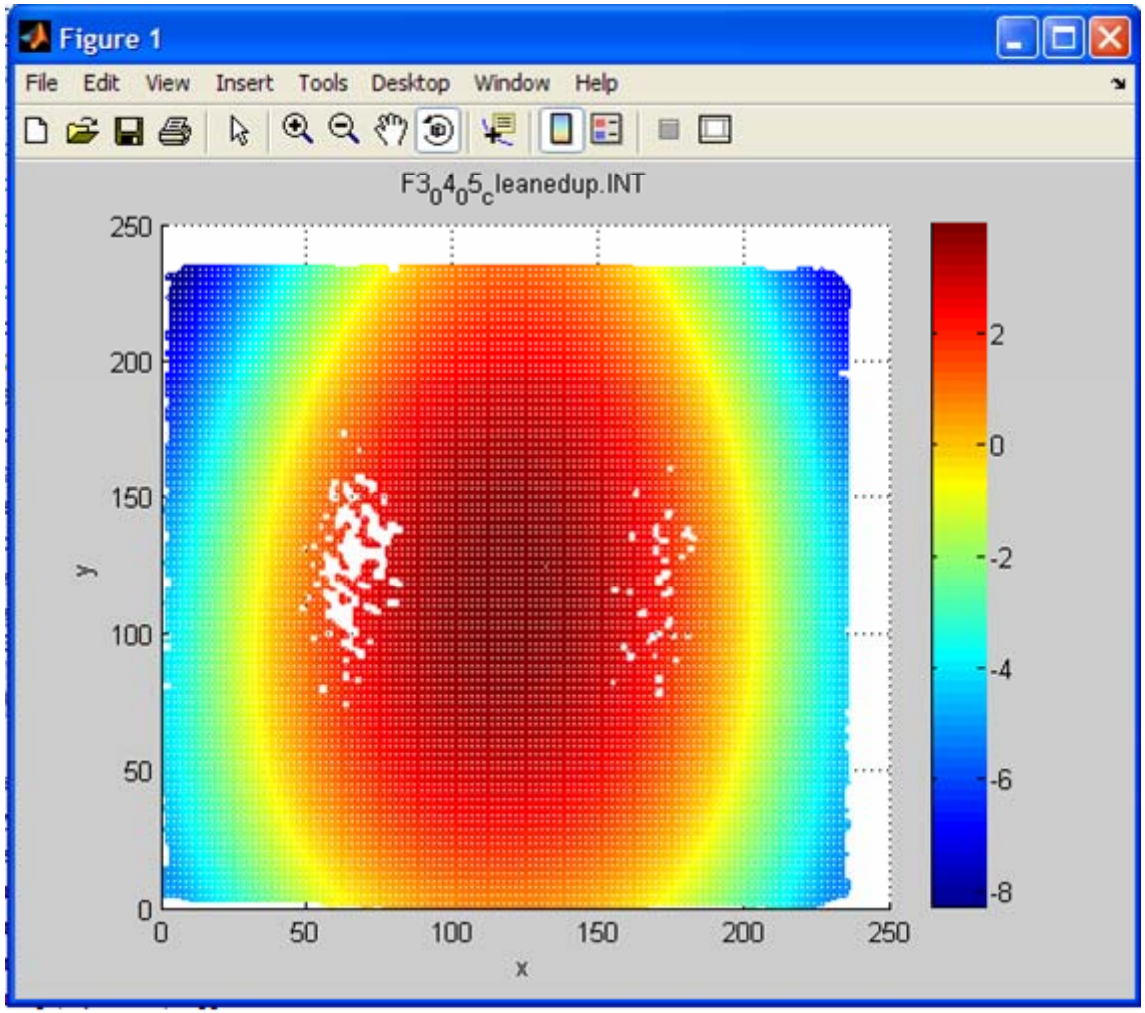
Mounted Flight Filter 3 at Ambient Temperature



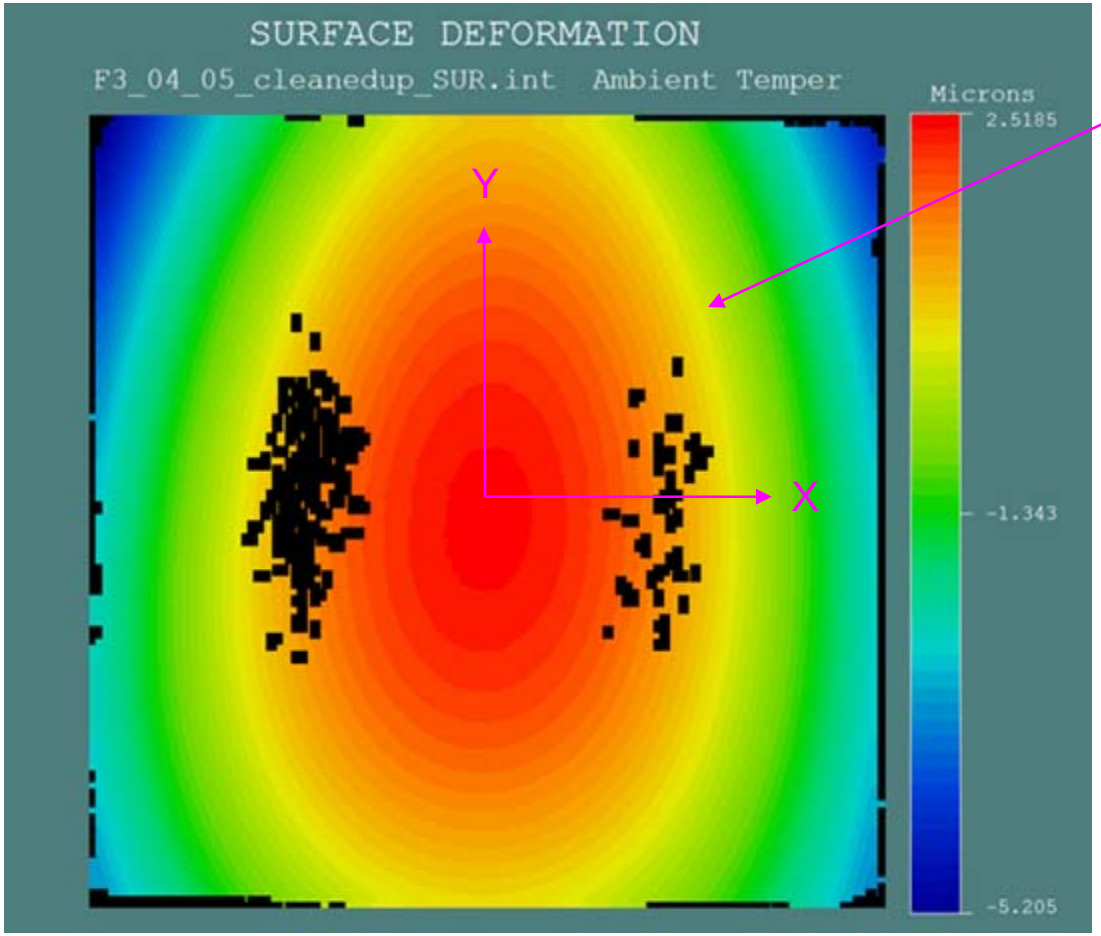
Lapped Mount

Filter

Flight Filter 3 Surface Deformation after Trimming Off Region Due to Lapped Mount



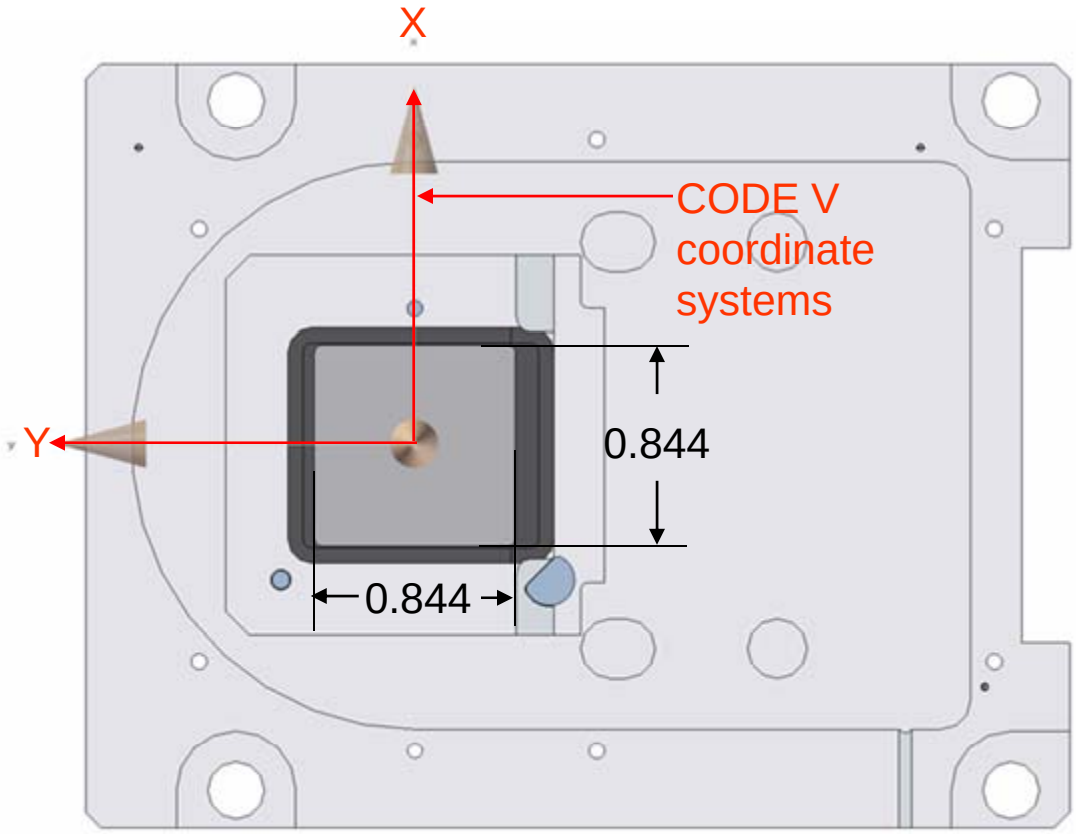
Flight Filter 3 Interferogram



Interferogram coordinate system

```
F3_04_05_cleanedup_SUR.int  Ambient Temperature
GRD 236 235 SUR WVL 0.6328 SSZ   3967 NDA  32767 XSC 1.0043
 32767  32767  32767  32767  32767  32767  32767 -31711 -31413 -30979
```

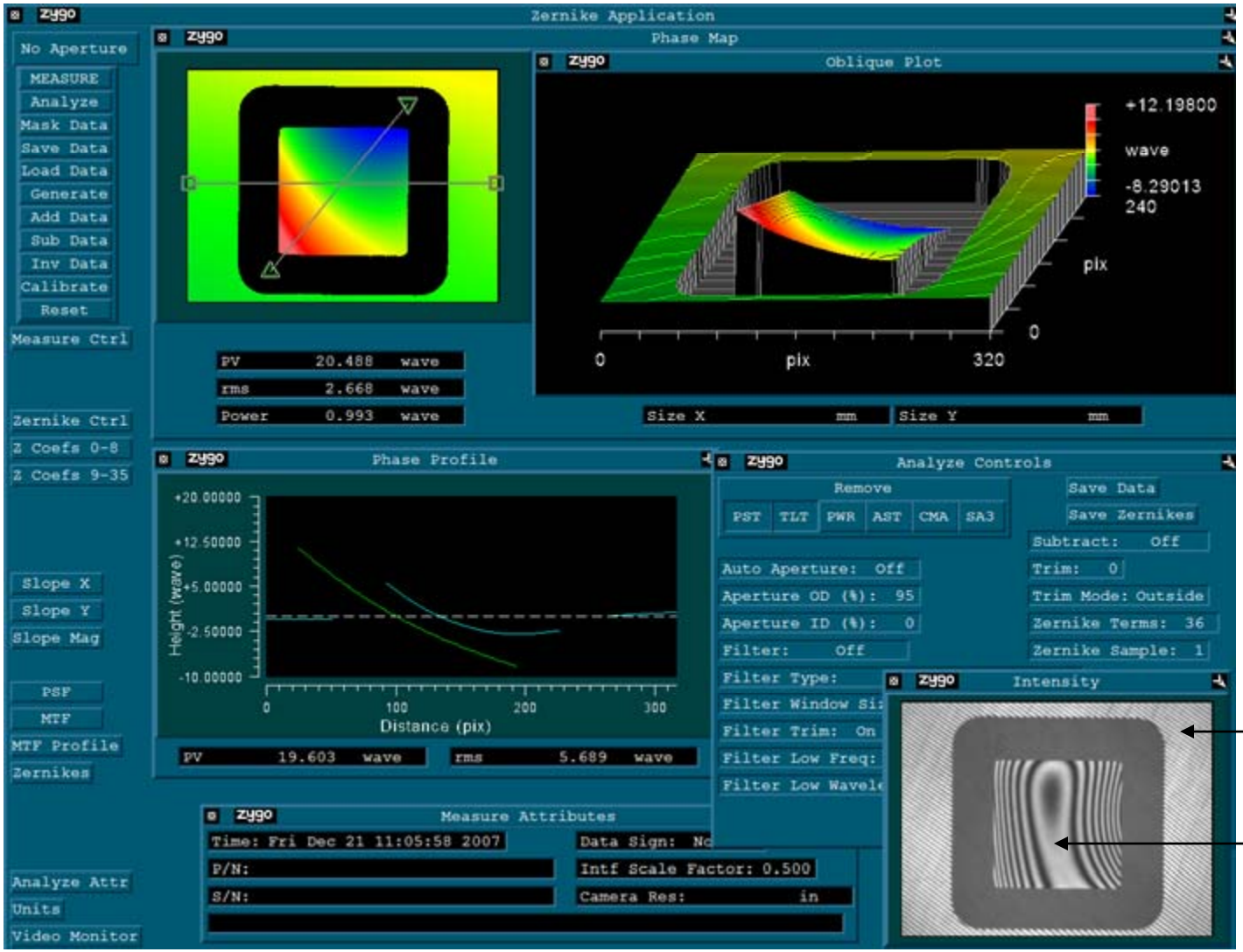
Filter 3 Coordinate Systems



Linear dimensions in inches

Filter 3 interferogram was measured from the back surface oriented as shown in this figure. This interferogram is attached to both the front and back surfaces using the CODE V commands INT, IRO -90. ISF 1 is used for the back surface and ISF -1 for the front surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the Filter 3 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1 and then the deformation data is moved to the opposite X-coordinate by Rule 3 and then it is rotated -90 degrees by Rule 5.

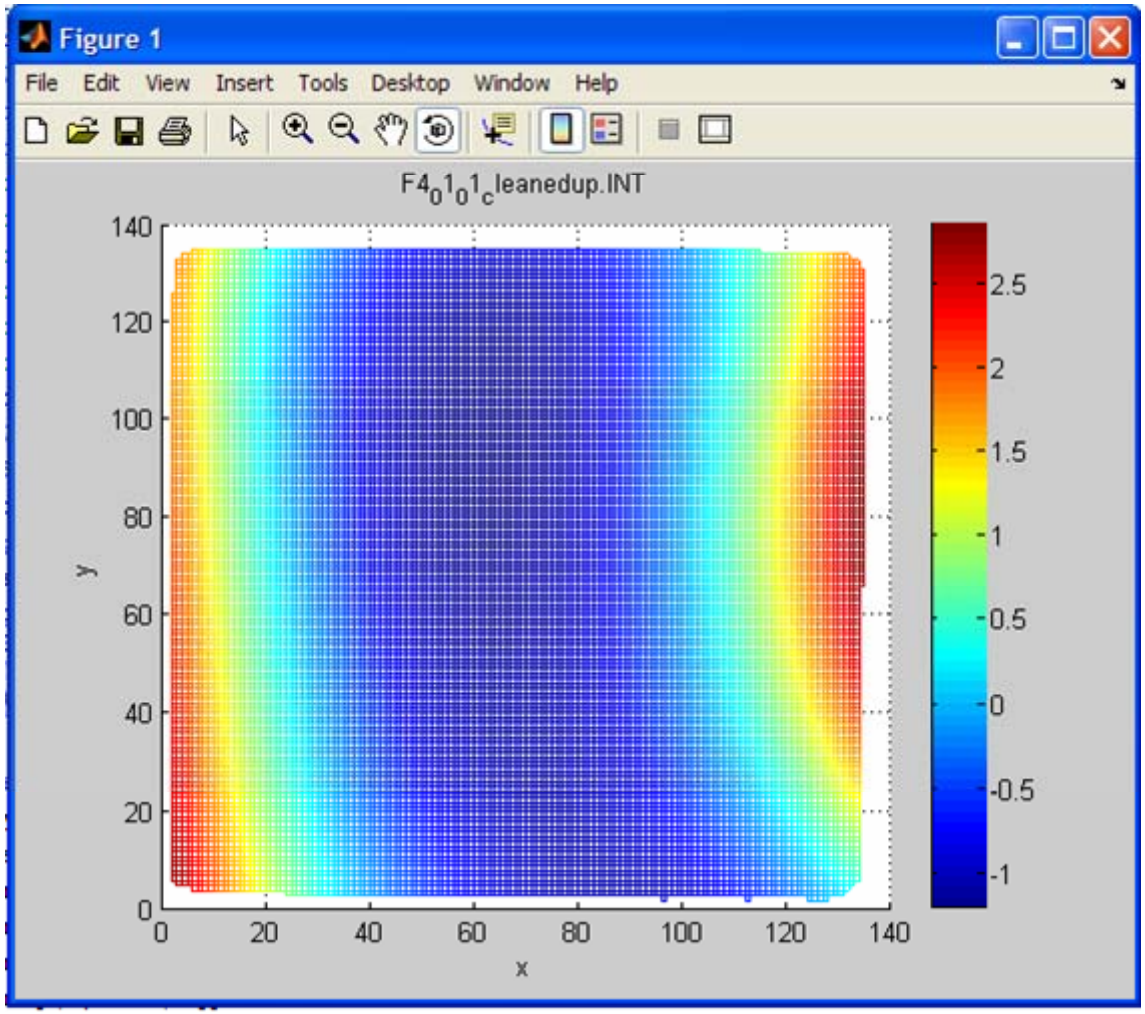
Mounted Flight Filter 4 at Ambient Temperature



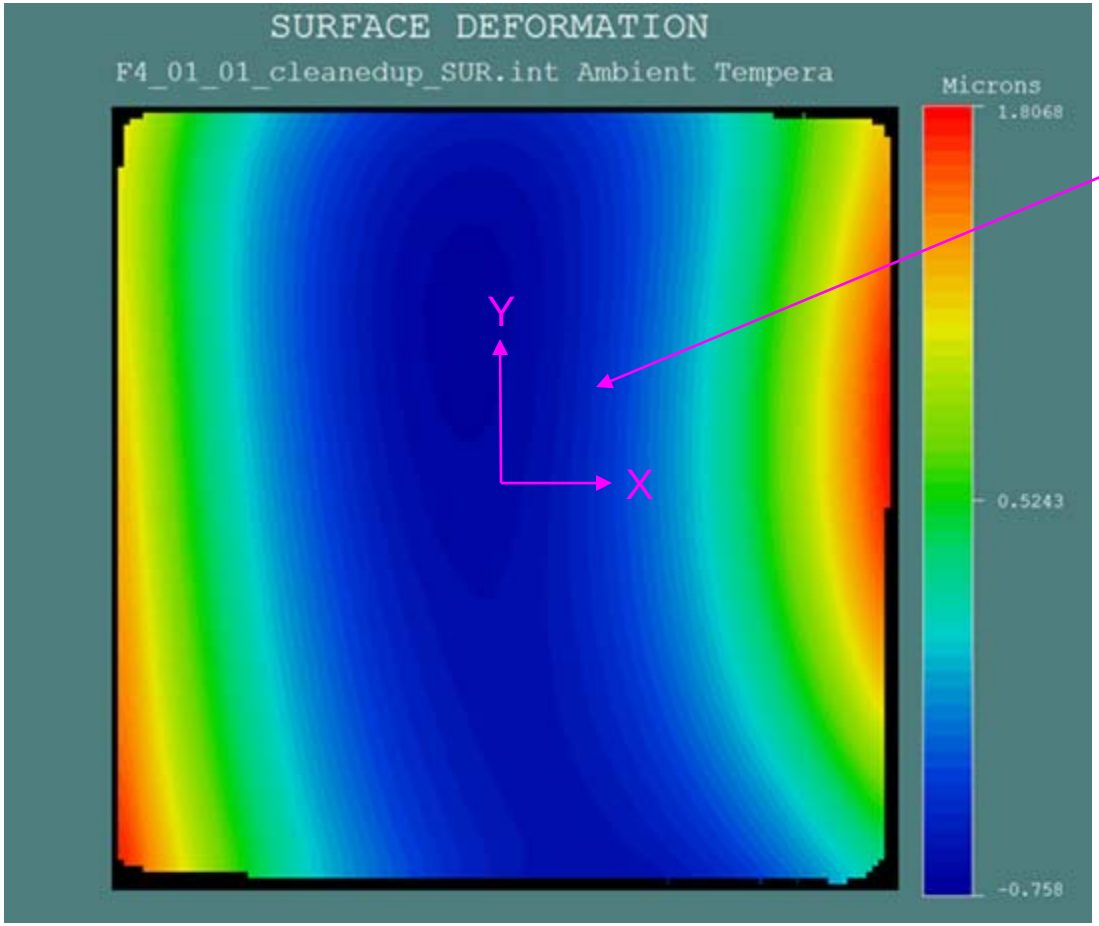
Lapped Mount

Filter

Flight Filter 4 Surface Deformation in 633nm Waves After Trimming Off Region Due to Lapped Mount



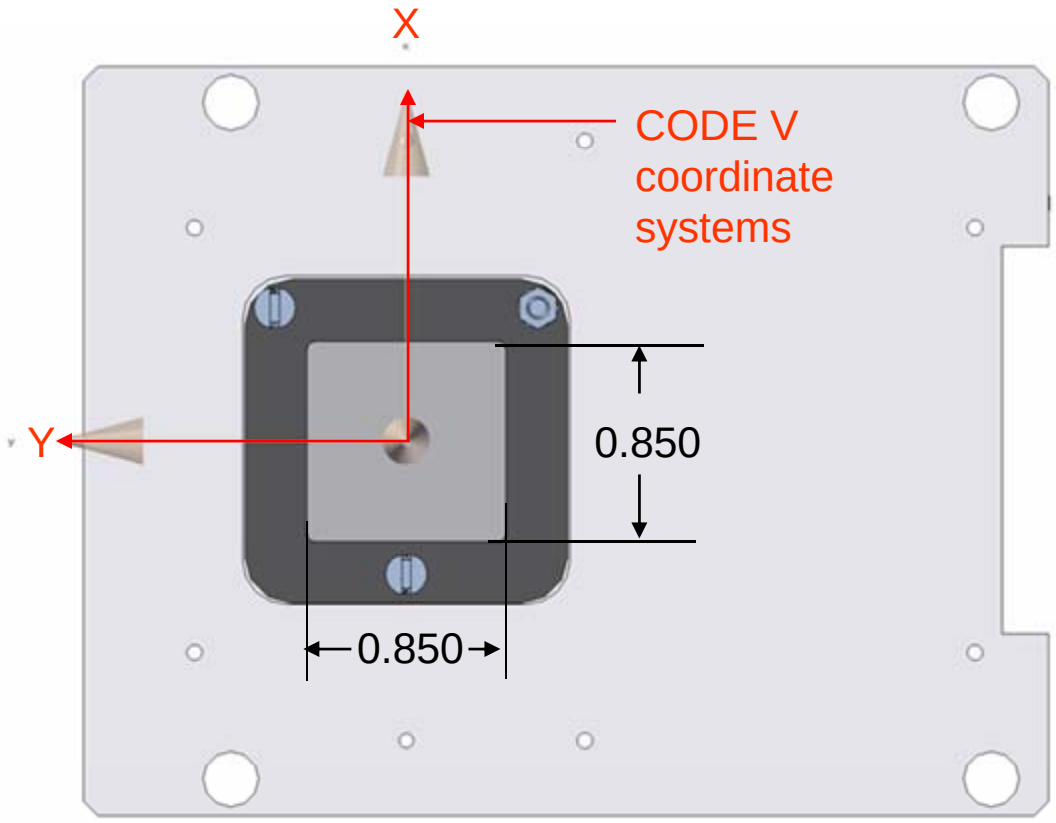
Flight Filter 4



Interferogram coordinate system

```
F4_01_01_cleanedup_SUR.int Ambient Temperature
GRD 136 136 SUR WVL 0.6328 SSZ  11453 NDA  32767 XSC 1.0000
 32767  32767  32767  32767  32767  32767  32767  32767  32767  32767
```

Filter Band4



Linear dimensions in inches

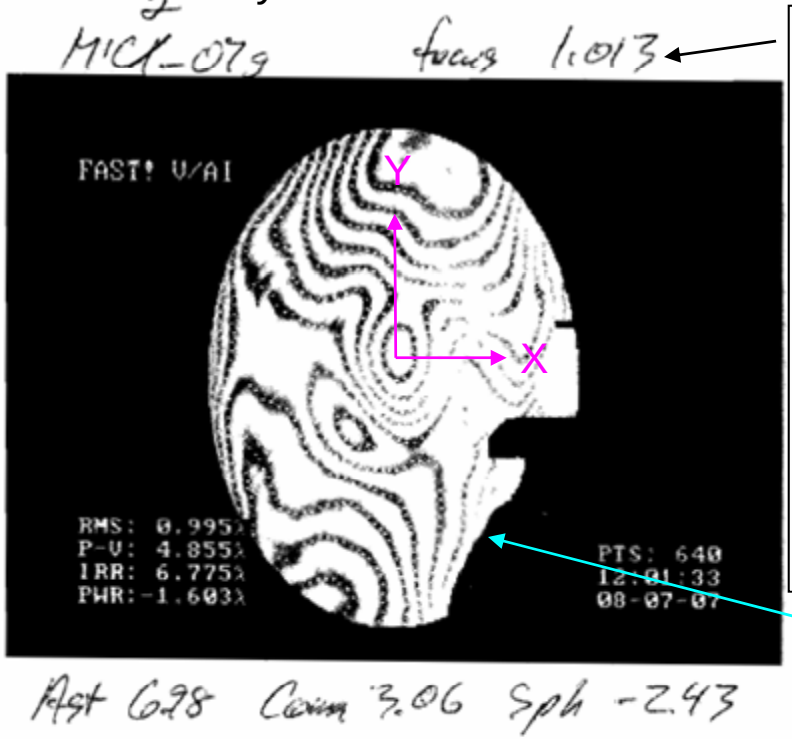
Filter 4 interferogram was measured from the front surface oriented as shown in this figure. This interferogram is attached to both the front and back surfaces using the CODE V commands INT, IRO -90. ISF 1 is used for the front surface and ISF -1 for the back surface. These two surfaces were essentially parallel before coating and mounting. The correctness of these commands can be verified by making a copy of the Filter 4 interferogram slide and orienting it with respect to this slide using these commands and the interferogram placement rules given above. The interferogram coordinate system aligns to the coordinate systems in this figure by Rule 1 and then the deformation data is rotated -90 degrees by Rule 5.

MIC2 (SDL Test Collimator) Interferogram

- The wavefront error interferogram of the MIC2 collimator cooled to near liquid helium temperature was measured in double pass at SDL using a Buccini MIC-1 LUPI interferometer, SDL's 19.5-inch diameter fused silica window, SDL's 22-inch diameter test flat, and a 1 to 2 inch diameter fused silica or glass window.
- The MIC2 interferogram with the LUPI focus 0.15 inches outside the MIC2 pinhole is shown on the next slide. The pinhole is located at a focus micrometer scale reading of 0.8635 inches. (1.013 – 0.8635) = 0.15 inches.
- The surface flatness error of the 22-inch test flat is less than lambda/10 at 633 nm.
- The transmitted irregularity of the 19.5 inch window is less than lambda/2 at 633 nm.
- The transmitted irregularity of the 1 to 2 inch diameter window is believed to be less than lambda/4. The uncertainty in the irregularity of this window is much-much less than the measured MIC 2 wavefront irregularity.
- The thermal conditions for the 19.5-inch fused silica window were very similar to those of the 1st blue-tube WISE test except that the blue-tube inner cold shield extension was not used. According to modeling this should made the wavefront power introduced in the MIC2 test by the thermal gradient in this window approximately half that of the 1st blue-tube test.

MIC2 Interferogram Orientation

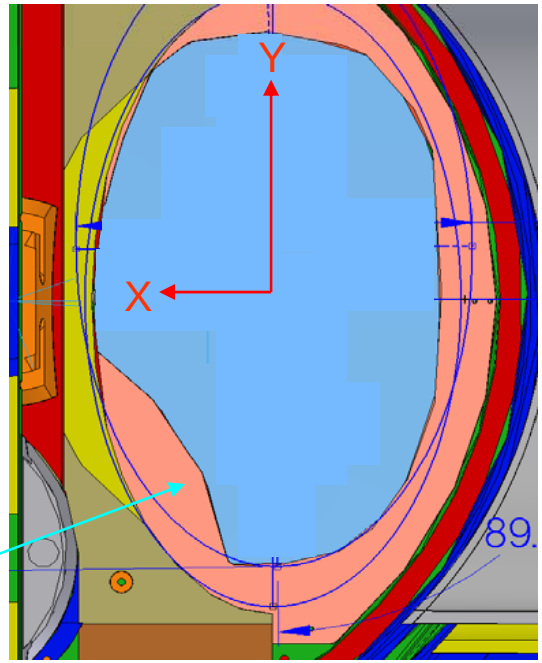
MIC2 double-pass interferogram and its coordinate system



Focus micrometer reading in inches. The LUPI moves away from MIC2 as this number increases.

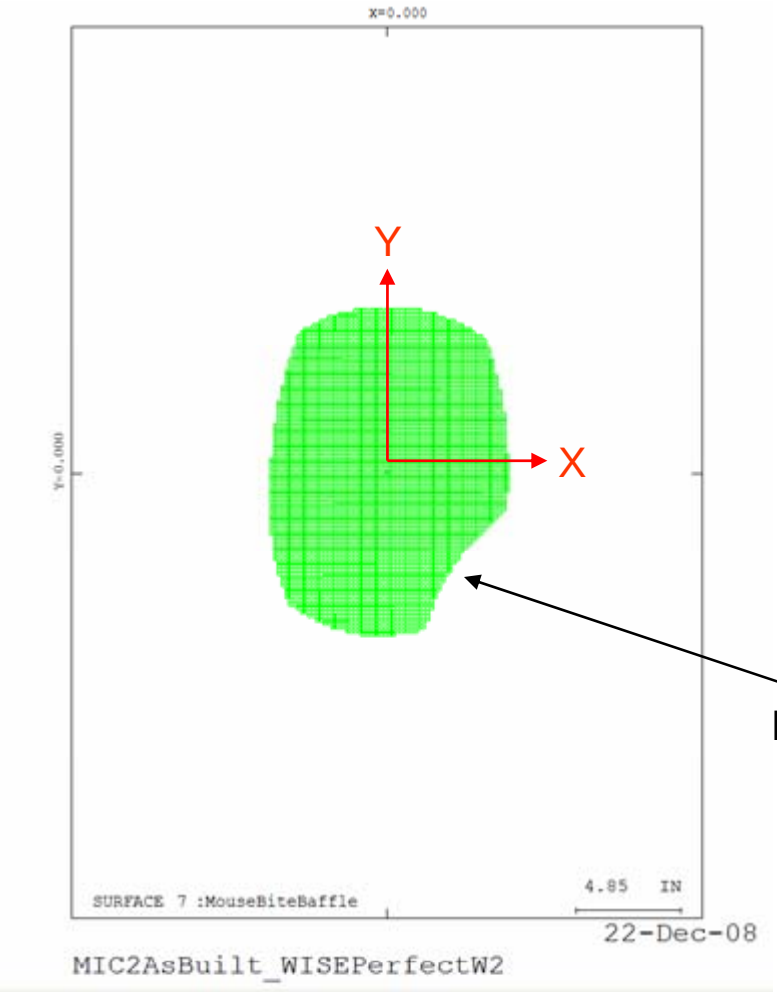
Mouse bite

Solid model of MIC2 mouse-bite baffle and its CODE V coordinate system

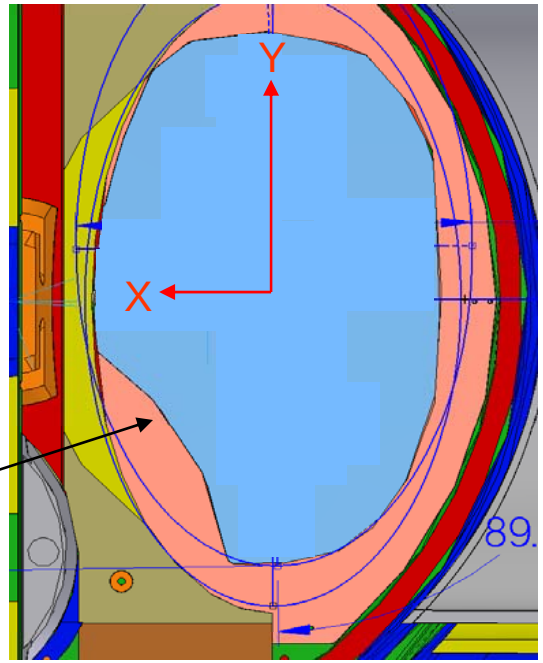


There is only one possible way that the location of the mouse bite in the interferogram matches the location of the mouse bite in solid model and that is when the interferogram coordinate system is aligned with the CODE V mouse-bit baffle coordinate system. Therefore by Rule 1 of interferogram placement the INT command with no IMI or IRO correctly places the interferogram.

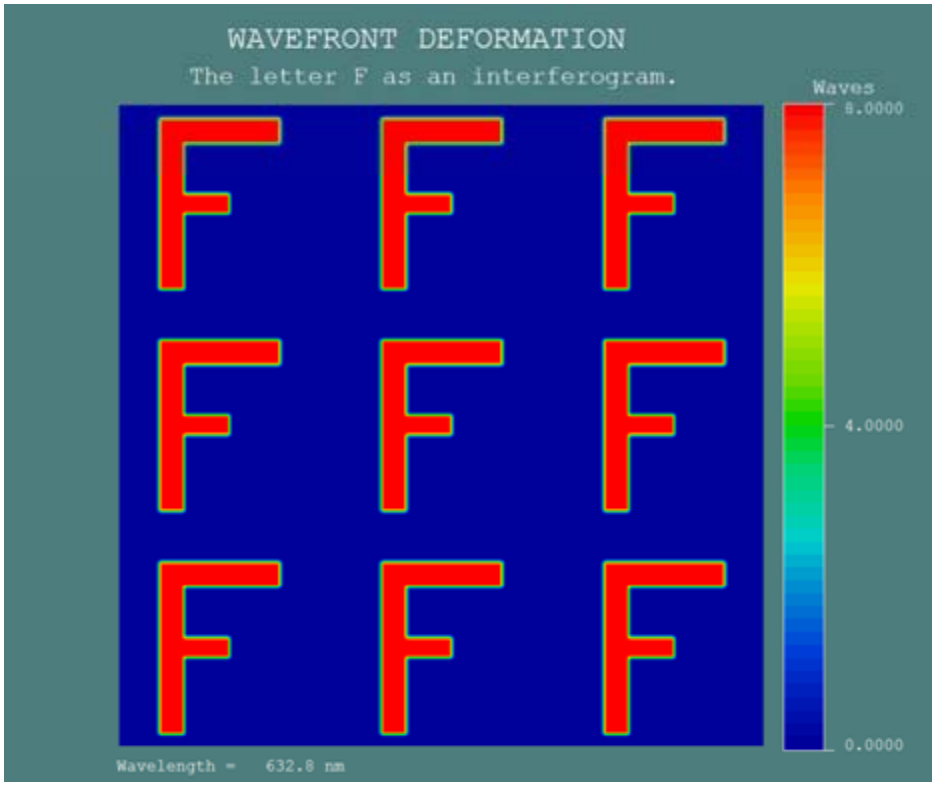
Verification of CODE V Mouse Bite Coordinate System Orientation



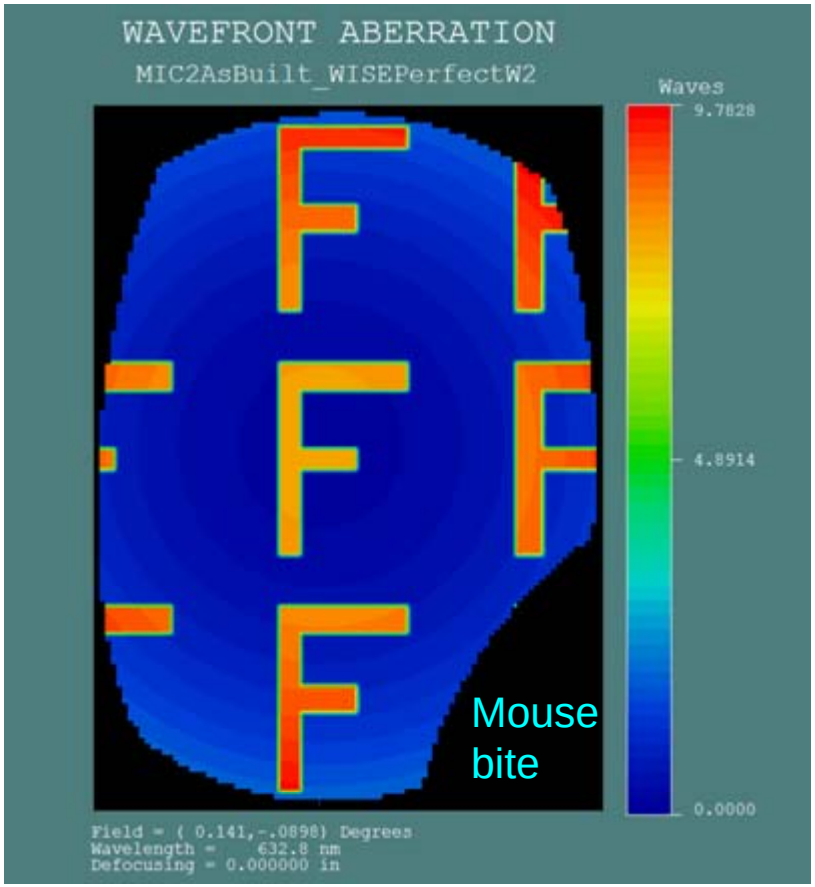
Mouse bite



Alternative Verification of MIC2 Interferogram Orientation

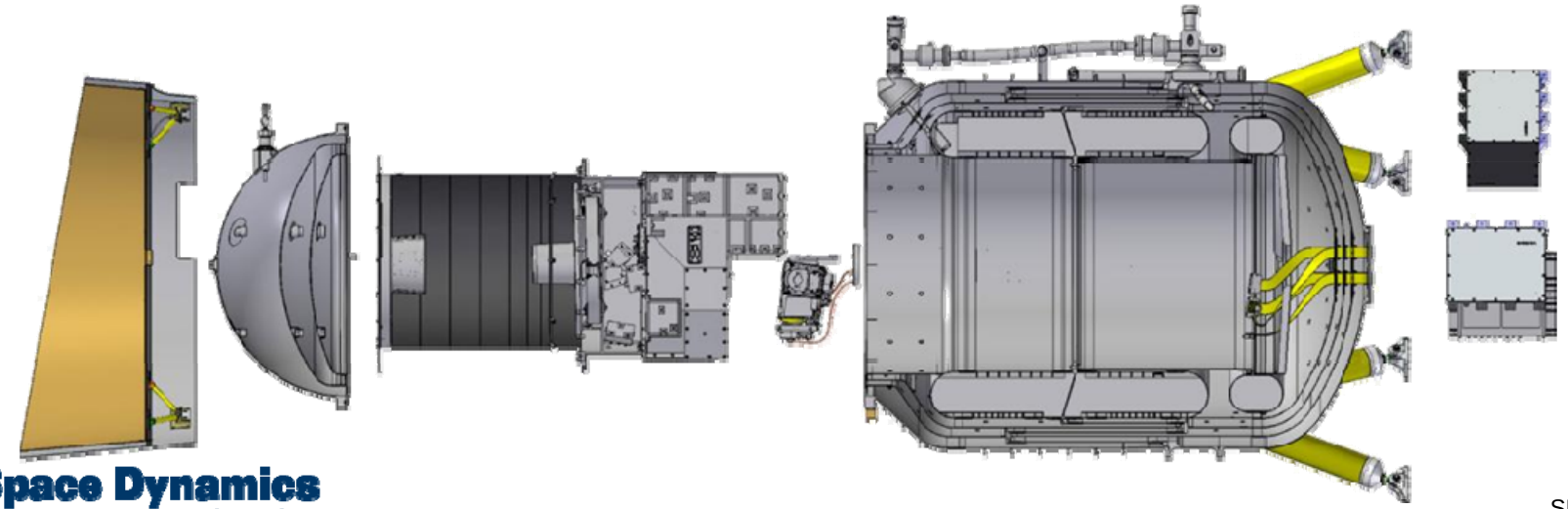


FFF interferogram attached to mouse bite baffle with INT and no IMI or IRO.



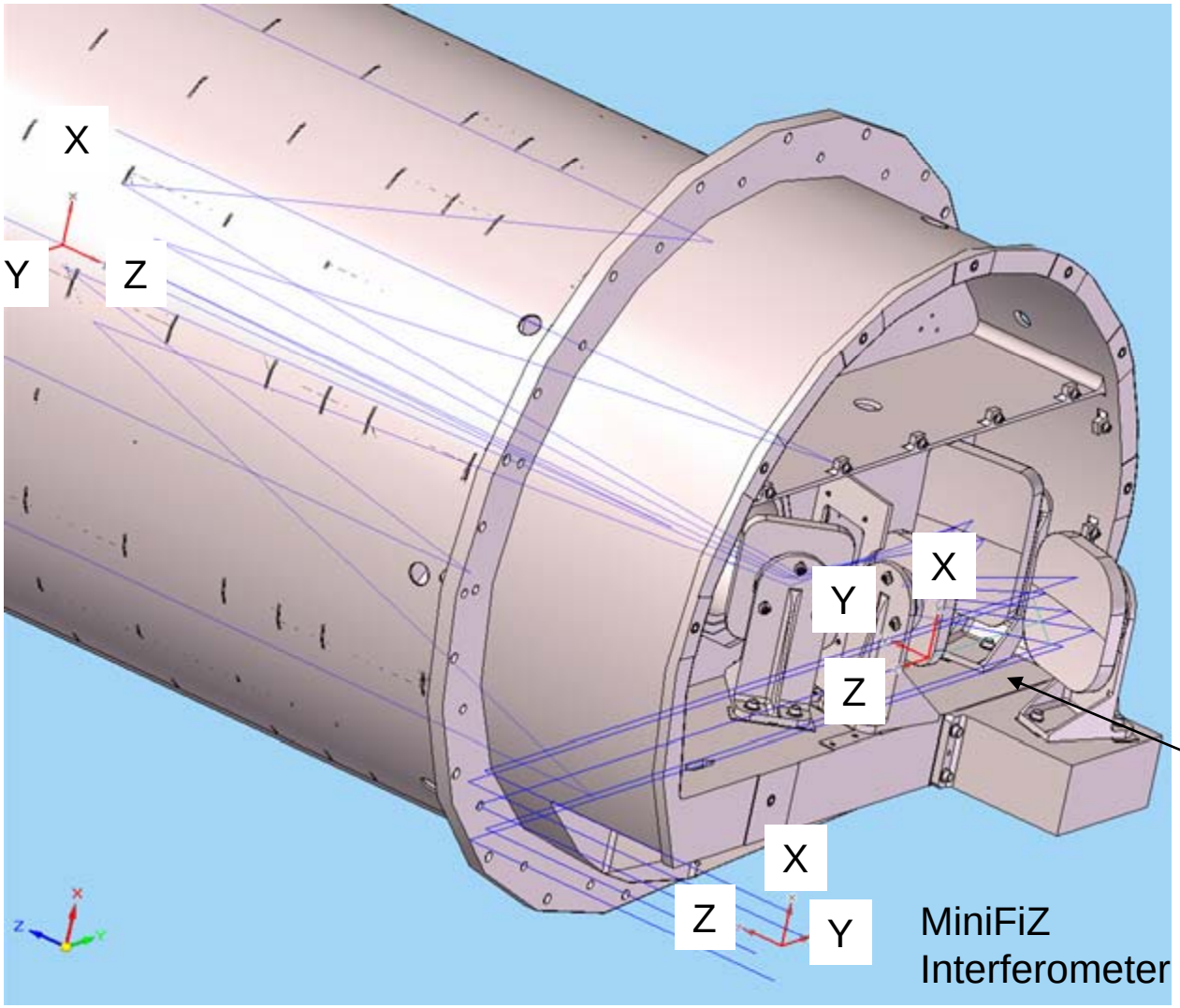
Pupil map with FFF interferogram correctly placed relative to mouse bite.

Supplementary Slides



Afocal CODE V Coordinate Systems (CS)

Optical CS (CODE V Afocal Surface 1)



Filter Code V Coordinate Systems (CS)