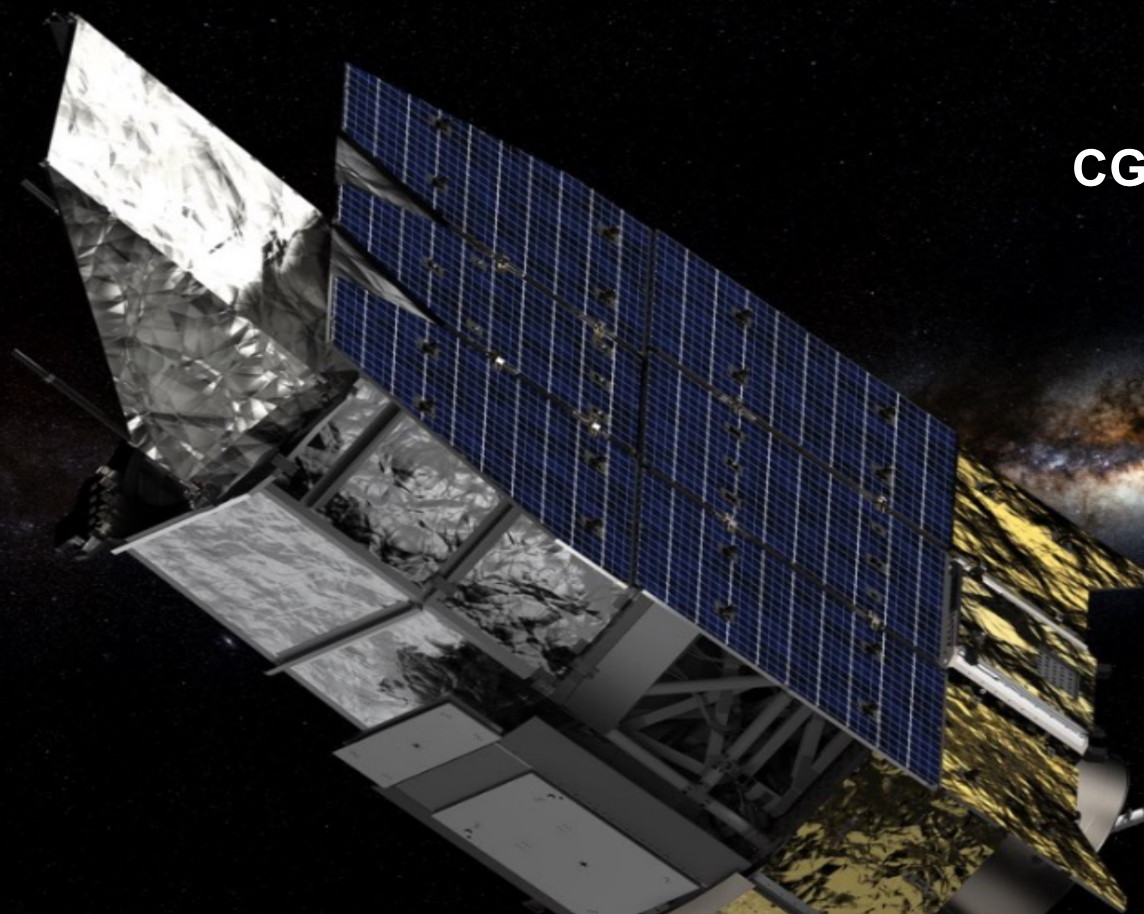

CGI Mask Characterization and Active Optics Mechanisms

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International Contributions

Max Planck Institute for Astronomy (MPIA):
PAM Mechanisms

Japan Aerospace Exploration Agency (JAXA):
Si and FS Mask Substrates

• NASA GODDARD SPACE FLIGHT CENTER • JET PROPULSION LABORATORY •
• L3HARRIS TECHNOLOGIES • BALL AEROSPACE • TELEDYNE • NASA KENNEDY SPACE CENTER •
• SPACE TELESCOPE SCIENCE INSTITUTE • INFRARED PROCESSING AND ANALYSIS CENTER •
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• CENTRE NATIONAL d'ÉTUDES SPATIALES • MAX PLANCK INSTITUTE FOR ASTRONOMY •

URS CL#24-4475

Outline

- CGI Masks Post-fab characterization and selection
  - Focal Plane Masks (FPM)
  - Shaped Pupil Masks
  - Lyot Stop Masks
  - Field Stop Masks
- CGI Active Optics mechanisms test:
  - Precision Alignment Mechanism (PAM) (6X)
    - Shaped Pupil Alignment Mechanism (SPAM), Focal Plane Alignment Mechanism (FPAM), Lyot Stop Alignment Mechanism (LSAM), Field Stop Alignment Mechanism (FSAM), Color Filter Alignment Mechanism (CFAM), Dispersion/Polarization Alignment Mechanism (DPAM),
  - Fast Steering Mirror (FSM)
  - Focus Control Mirror (FCM)

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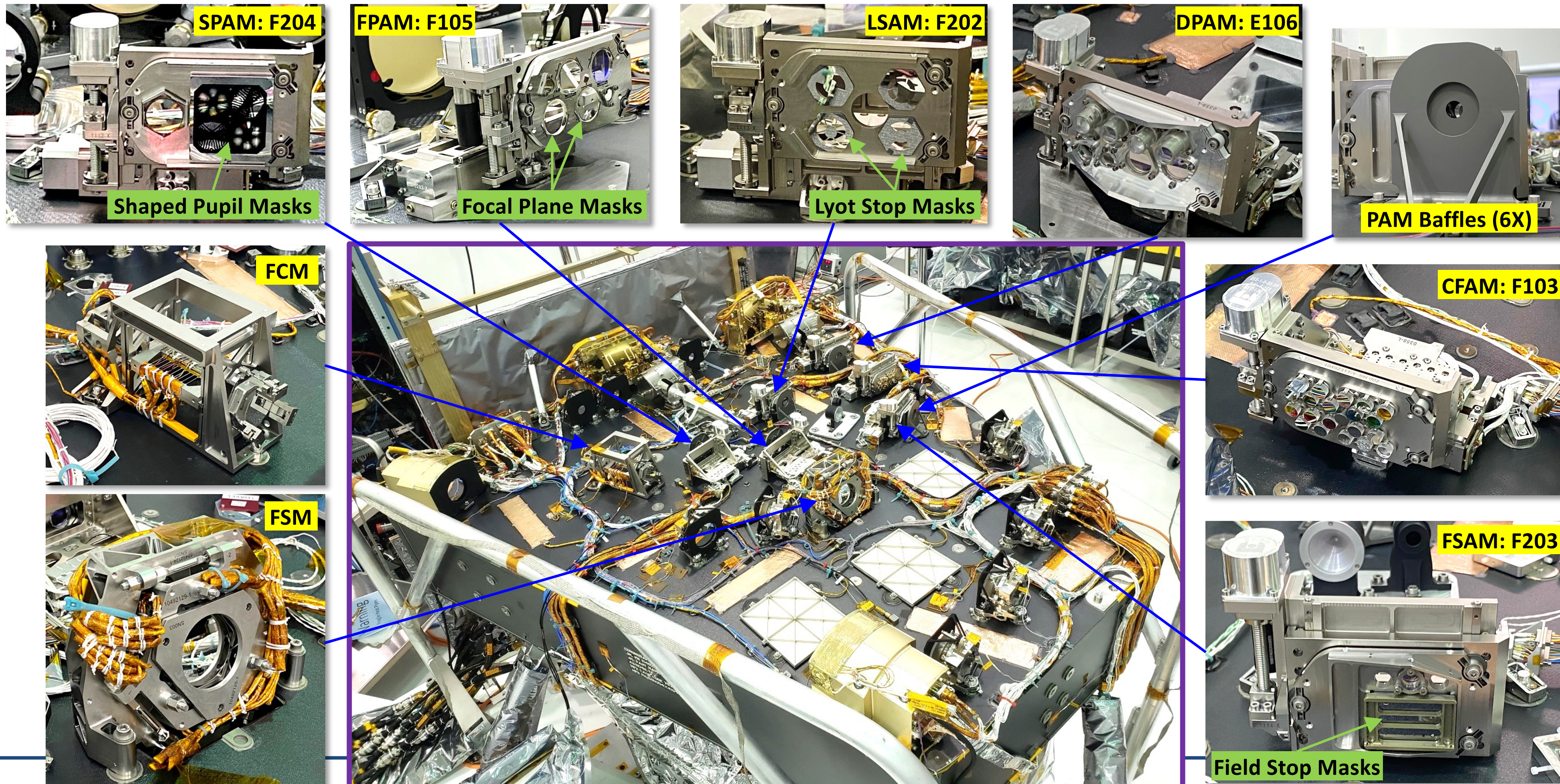
CGI Mechanisms and Masks on Optical Bench

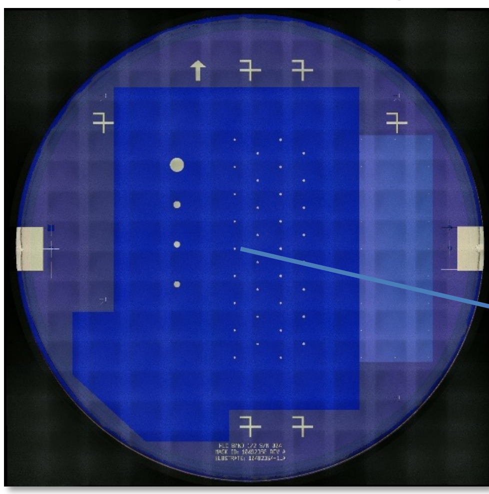
ROMAN CORONAGRAPH



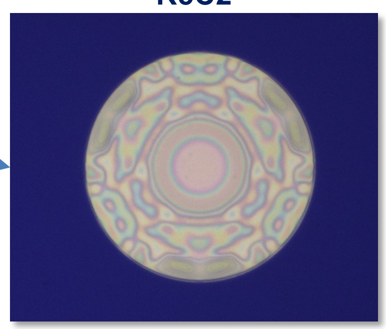
CGI Masks: Band 1 & 2 HLC FPM SN004

- Mask substrates of Silicon for SPM and fused silica for FPM are contributed by Japan Aerospace Exploration Agency (JAXA)
- All CGI masks are fabricated by JPL's Microdevices Lab (MDL)
- Masks were imaged and measured with Nikon microscope. Images were inspected for potential defects for ranking.
- One Band 1 and one Band 2 HLC occulter's PMGI profiles were measured by Atomic Force Microscope (AFM)
- HLC FPM measurements are used for CGI HOWFS model

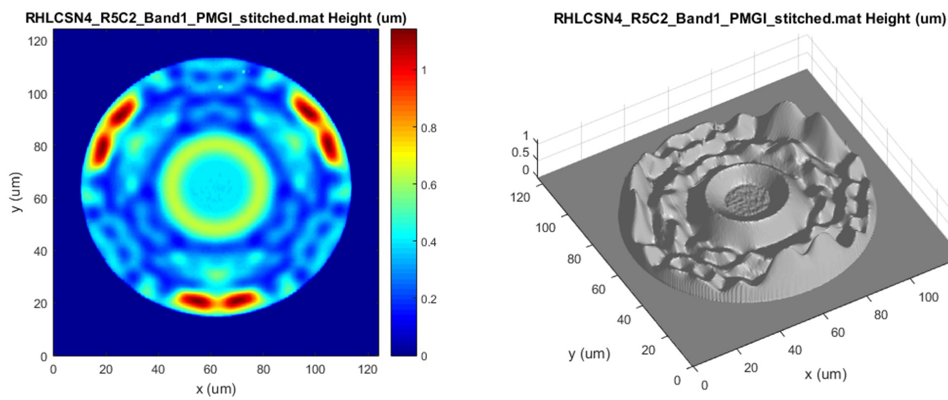
HLC Band 1 & 2 SN 004: Keyence Microscope Stitched Image



R5C2



HLC Band 1 SN 004 R5C2: AFM Scan (Stitched)



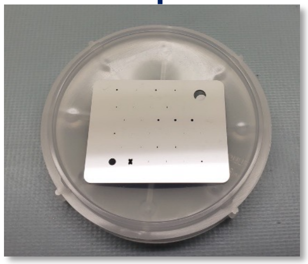
From section analysis:

- PMGI Bias = 136 nm (goal 111 nm) → Error = 25 nm
- PMGI Peak-to-Valley = 1004 nm (goal 1004 nm) → Error = 0 nm
- Stitched data from 2x2 AFM scans was provided to modeling team

CGI Masks: HLC NFOV Lyot (SN 002) and Field Stop Array (SN 003)

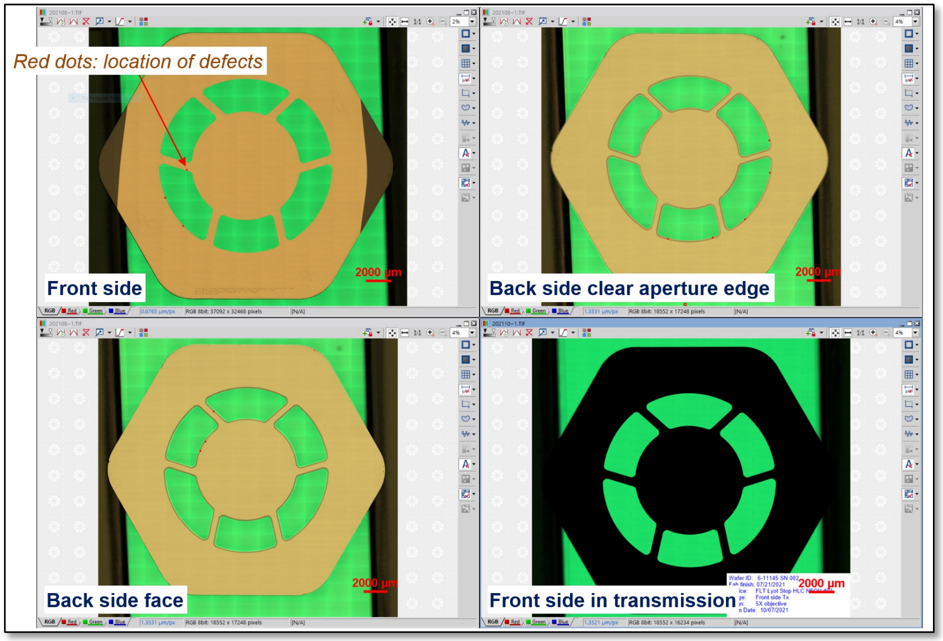
- Lyot Stops and Field Stops were examined, measured, and ranked based on the high power microscope measurement
- Measurements are used for CGI modeling

Field Stop Masks



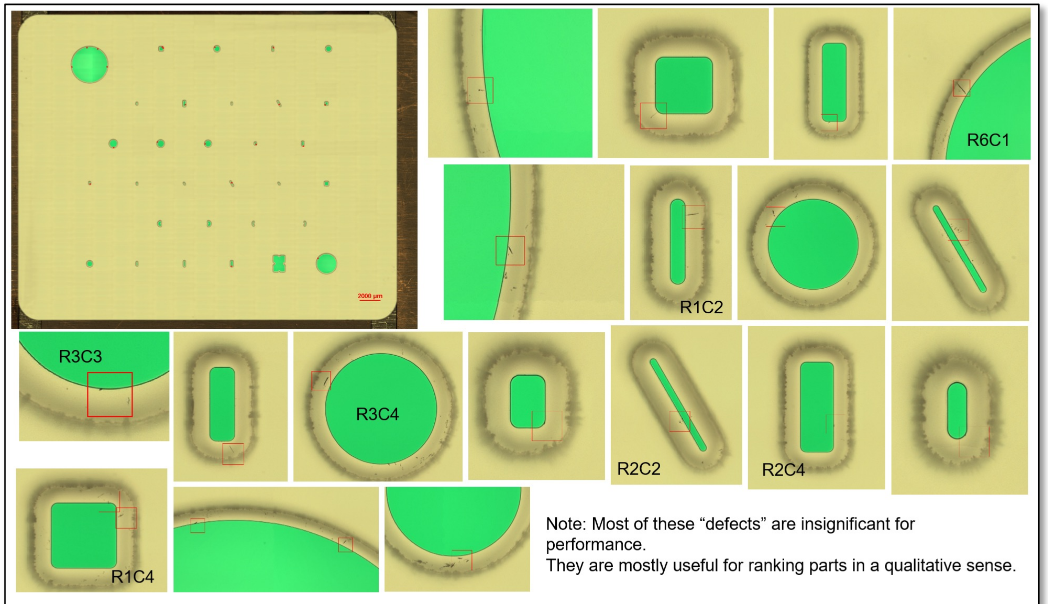
CGI Flight HLC NFOV Lyot Stop

Wafer 6-11145 SN 002, HLC NFOV #03



CGI Flight Field Stop Array

Wafer 6-11145 SN 003, Field Stop #04



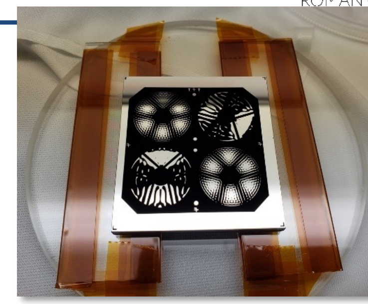
Note: Most of these "defects" are insignificant for performance.
They are mostly useful for ranking parts in a qualitative sense.

Each red square is 100 x 100 um

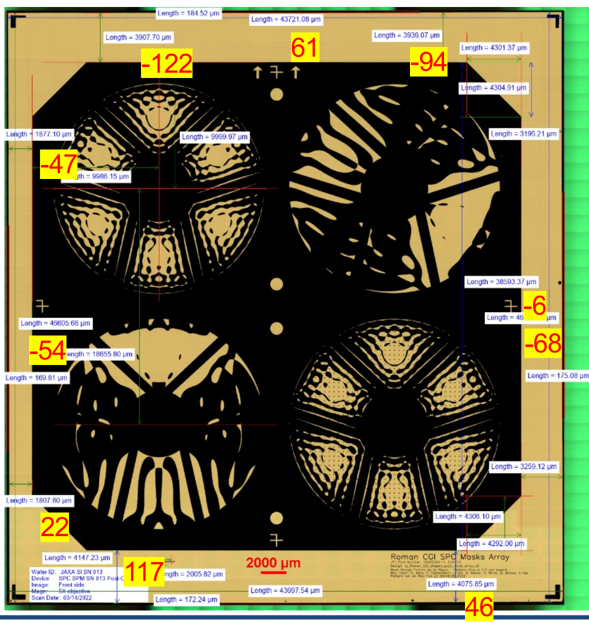
CGI Masks: SPM SN 013

- SPM masks were imaged with Nikon microscope. Images were inspected for potential defects
- Masks' reflected wavefront was measured with Zygo
- Al and Black Si reflectivity was measured with Perkin Elmer and Mask Reflectivity Testbed on witness samples from the same MDL fabrication run

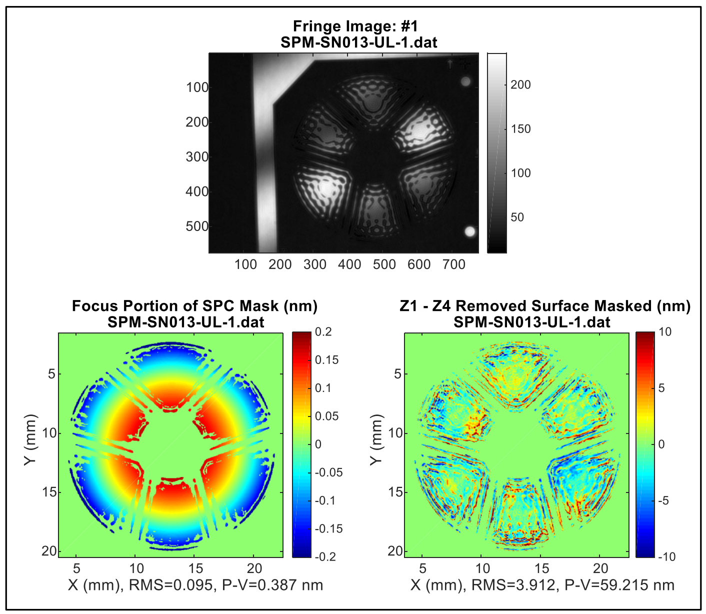
SPM Mask Array



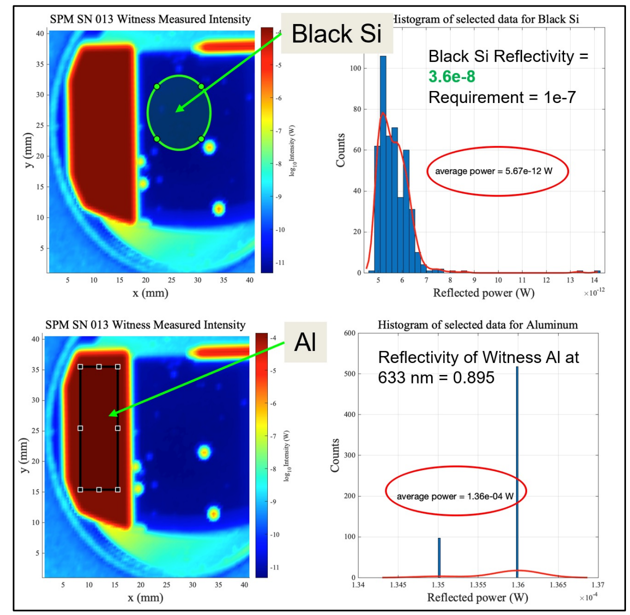
SPM Microscope Measurement



WFOV SPM Zygo Interferometer Test



SPM Al and Black Si Reflectivity



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PAM: L5 Requirements Verification Tests

ROMAN CORONAGRAPH

- PAM mechanisms are contributed by Max Planck Institute for Astronomy (MPIA) in Heidelberg, Germany
- All six PAMs have the same performance requirements even though not all PAMs need all the tight requirements. Flight PAM assignment was based on the as-measured PAM performance to ensure the CGI performance.
- Mechanism requirements do not need CGI PAM Electronics (PAME) were tested at MPIA using their GSE and summarized in Table below.
- PAM L5 requirement associated with PAME are tested at JPL in PAM TVAC test chamber.
- PAMs are also tested and calibrated with CGI flight software during CGI system in-air and TVAC tests

Summary of Flight PAM Mechanism Performance

				-------------------- Large PAMs --------------------						-------------------- Small PAMs --------------------					
				E106		F103		F105		F202		F203		F204	
	L5 reqt	Name	Reqt	*Vertical/Z*	*Horizontal*	*Vertical/Z*	*Horizontal*	*Vertical/Z*	*Horizontal*	*Vertical/Z*	*Horizontal*	*Vertical/Z*	*Horizontal*	*Vertical/Z*	*Horizontal*
X/Y axes		Repeatability	± 1.2 um/axis	± 0.24 um	± 0.101 um	± 0.27 um	± 0.20 um	± 0.31 um	± 0.17 um	± 0.28 um	± 0.23 um	± 0.277 um	± 0.155 um	± 0.36 um	± 0.16 um
		Position knowledge	± 0.3 um/axis	± 0.050 um	± 0.075 um	± 0.04 um	± 0.065 um	± 0.167 um	± 0.067 um	± 0.049 um	± 0.15 um	± 0.066 um	± 0.066 um	± 0.090 um	± 0.087 um
	636843 (416)	Drift	0.2 um/axis RMS@10h							0.018 um	0.017 um	0.038 um	0.043 um		
Tip/Tilt	636880 (423)	Repeatability	± 2.1"/axis	0.96" [h]	0.30" [h]	± 0.6"	± 0.9"	± 0.67"	± 0.54"	± 0.62"	± 0.93"	± 0.47"	± 0.36"	± 1.04"	± 0.59"
		Runout	41.2"/axis	43.9" [g]	86.2" [c,g]	94" [c]	63" [c]	38"	41.5"	14.4"	40.3"	35.2"	21.8"	28"	24"
	636845 (424)	Drift	0.031"/axis RMS@10h							0.016"	0.008"	0.016"	0.019"		
Z axis	636879 (452)	Repeatability	± 5 um	± 1.38 um [h]		± 0.61 um		± 1.43 um		± 1.11 um		± 0.26 um		± 0.51 um	
		Runout	20 um	4.78 um [h]		8.2 um		2.72 um		1.32 um		1.44 um		0.77 um	
	636844 (454)	Drift	0.5 um RMS@10h							0.004 um		0.006 um			
Clocking		Runout	270"	78" [h]		124"		68"		136"		197"		117"	
	766507 (464)	Drift	6.18" RMS@10h							5.0"		5.6"			
First Mode	758719 (470)	Mode 1 Freq: X	> 90 Hz	466.0 Hz		150.0 Hz		198.0 Hz		190.0 Hz		236.2 Hz		218.0 Hz	
		Mode 1 Freq: Y		232.0 Hz		161.2 Hz		186.0 Hz		162.3 Hz		187.5 Hz		208.0 Hz	
		Mode 1 Freq: Z		148.0 Hz		156.2 Hz		190.0 Hz		187.8 Hz		196.2 Hz		212.0 Hz	
Heat to bench		Power dissipation	250 J	89.8 J		75.1 J		77.1 J		72.4J		68.0 J		76.7 J	
Encoder read		Power dissipation	10 J	3.2 J		3.3 J		3.2 J		3.24 J		3.2 J		3.3 J	

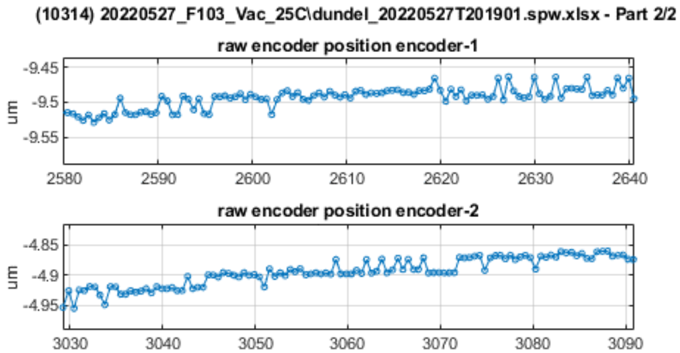
PAMs: PAM Repeatability & Encoder Noise Test with PAME

- All mechanism, both axes, tested at 15 °C and 25 °C
- Tested with PCE electronics and FDD defined move profiles
- The worst case repeatability error over all mechanisms, is ±0.53 um, compliant with the ±1.2 um requirement (right side table and bottom plots)
- Also shown the encoder measurement noise (below)

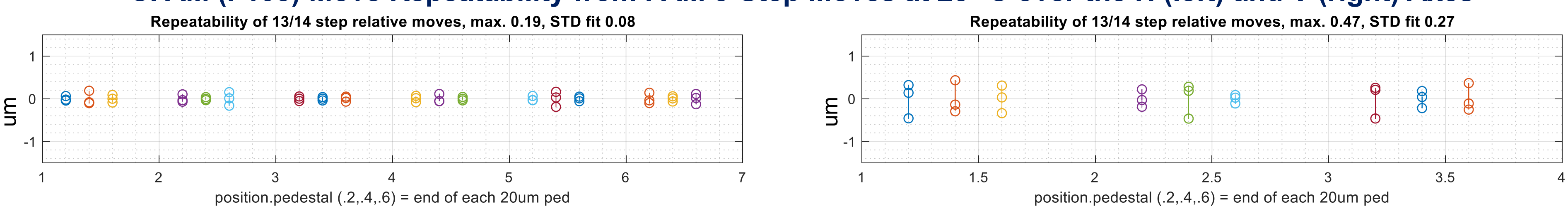
PAM Move Repeatability Tested with PAME

	H repeatability, um max	H repeatability, um rms	V repeatability, um max	V repeatability, um rms
F103	0.19	0.08	0.47	0.25
	0.22	0.10	0.53	0.26
F105	0.22	0.09	0.23	0.11
	0.17	0.07	0.22	0.10
F202	0.32	0.10	0.25	0.14
	0.23	0.10	0.26	0.12
F203	0.20	0.07	0.31	0.16
	0.13	0.04	0.33	0.13
F204	0.12	0.06	0.43	0.15
	0.18	0.07	0.34	0.18
E106	0.28	0.09	0.22	0.09
	0.32	0.13	0.30	0.13
	max of H and V max:	**0.53** um		
	Requirement:	**1.20** um		

CFAM (F103) Encoder Noise at 25 °C



CFAM (F103) Move Repeatability from PAM 3-Step Moves at 25 °C over the H (left) and V (right) Axes



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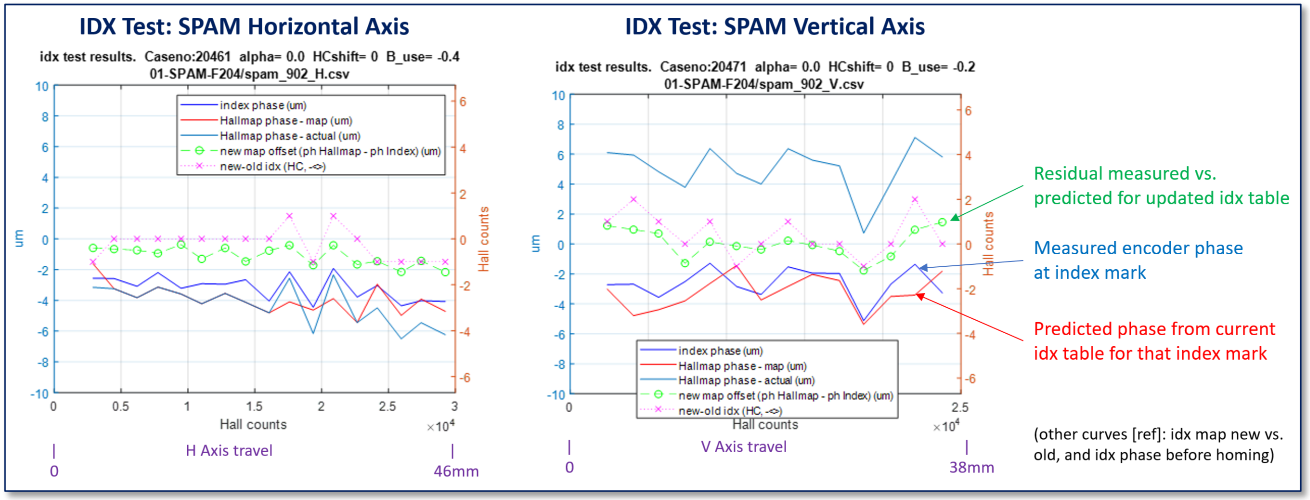
PAMs: VAP Test during FFT and TVAC

ROMAN CORONAGRAPH

- PAMs have been tested and calibration updated during CGI system full function test (FFT) and thermal vac (TVAC) test.
- The calibration test summary is shown in the Table at right.
- The SPAM encoder index calibration during TVAC are shown in plots below.

PBAT Section	Test Case	Status						Activity Report
		SPAM	FSAM	DPAM	CFAM	FPAM	LSAM	
6	PAM Standard Update State	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902
	PAM Standard Home	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902
7 - Cycle 1	PAM IDX Calibration With Hall Sensors	PASS	PASS	PASS	PASS	RETEST: PASS	PASS	CGIAR-902
7 - Cycle 2	PAM IDX Calibration With Hall Sensors	PASS	PASS	PASS	PASS	RETEST: PASS	PASS	CGIAR-902
7 - Cycle 3	PAM IDX Calibration With Hall Sensors	PASS	PASS	PASS	PASS	RETEST: PASS	PASS	CGIAR-902
7 - Cycle 4	PAM IDX Calibration With Hall Sensors	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902
7 - Cycle 5	PAM IDX Calibration With Hall Sensors	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902
7 - Cycle 6	PAM IDX Calibration With Hall Sensors	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902
8	PAM Encoder Calibration	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902
9	Post IDX Calibration Update Verification	PASS	PASS	PASS	PASS	PASS	PASS	CGIAR-902

SPAM Encoder Index Calibration During TVAC

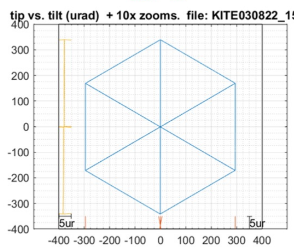


FSM: L5 Test Examples

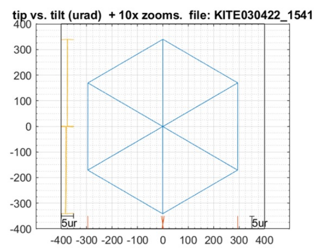
- FSM mechanism actuation design has Space Interferometer Mission (SIM) FSM heritage
- FSM performance requirement verification tests consist of:
  – TVAC test with specially designed metrology GSE with accuracy of < 1nm over operation temperature range (18 – 22 °C)
  – In-air test with a high speed COTS metrology (SmarAct) GSE with 20 kHz sampling rate
  – Zygo test of FSM mirror surface error

TVAC Test of FSM Tip-Tilt Stroke Range (Acquisition)

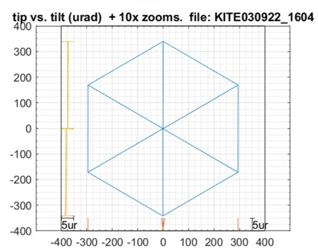
18 °C



20 °C



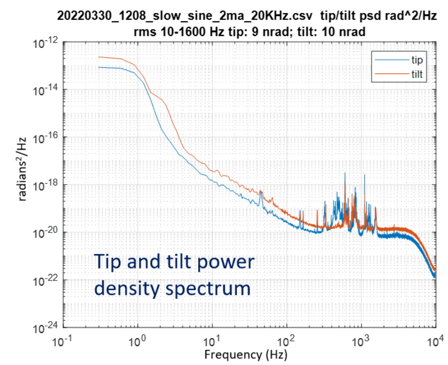
22 °C

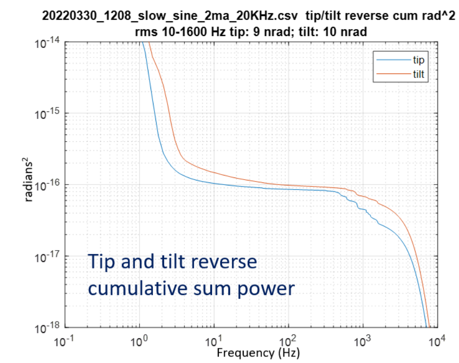


Results: inscribed radius of tip/tilt hexagon: ≥ 290 urad radius for all 3 temperatures.

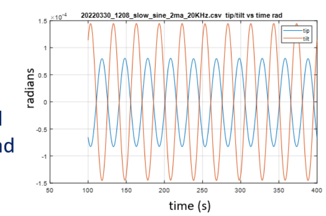
Requirement: ≥ 200 urad

SmarAct Test of FSM Tip-Tilt Jitter (Tracking)





Slow sinusoidal tracking inputs
- Tip: ±70 urad
- Tilt: ±140 urad



Results (also shown in plot title captions)
- Tip: 0.009 urad rms 10-1600 Hz
- Tilt: 0.010 urad rms 10-1600 Hz

Req: <0.037 urad between 10-1600 Hz

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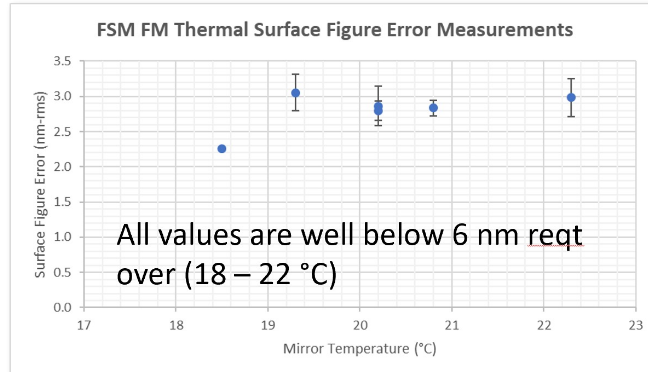
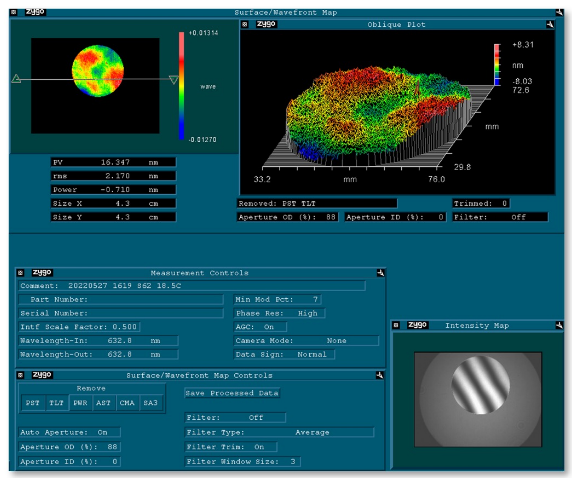
FSM: L5 Test Examples

ROMAN CORONAGRAPH

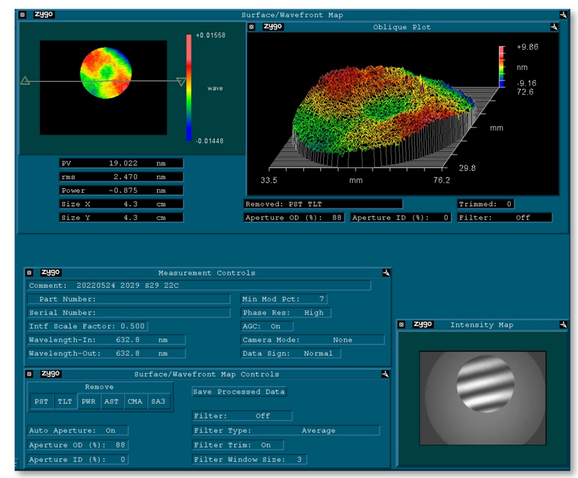
- Assembled FSM mirror surface figure WFE was tested in front of a Zygo interferometer
- FSM was inside a thermally controlled box that provided required temperature range of 18 – 22 °C
- WFE measured were well below the 6 nm requirement



Zygo Measurement at 18.5 °C



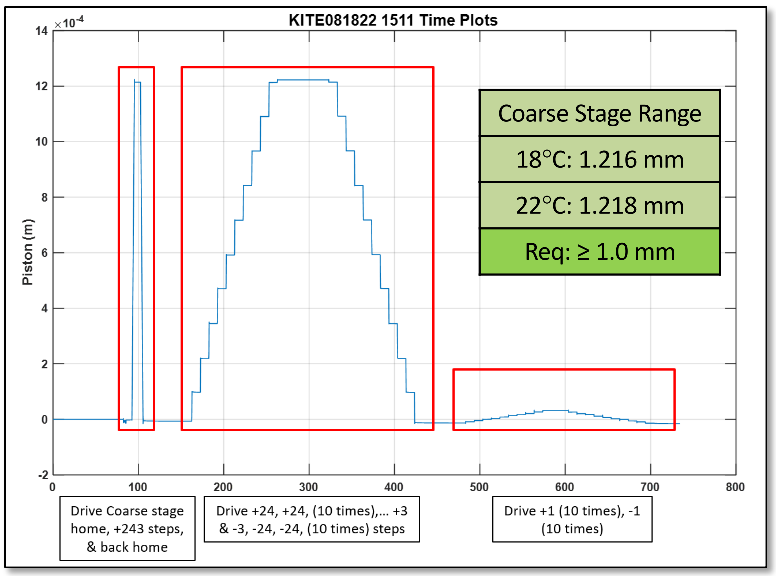
Zygo Measurement at 22.3 °C



FCM: L5 Coarse Stage Test Examples

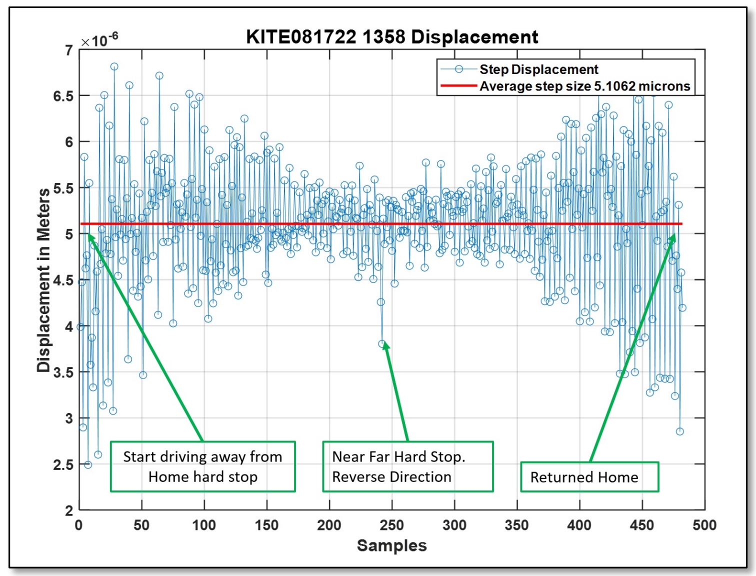
- FCM performance requirement verification tests
  - TVAC test with specially designed metrology GSE with accuracy of < 1nm over operation temperature range (18 – 22 °C)
  - In-air test with a high speed COTS metrology (SmarAct) GSE with 20 kHz sampling rate
  - Zygo test of FCM mirror surface error

FCM Coarse Stage Range



Coarse Stage Range
18°C: 1.216 mm
22°C: 1.218 mm
Req: ≥ 1.0 mm

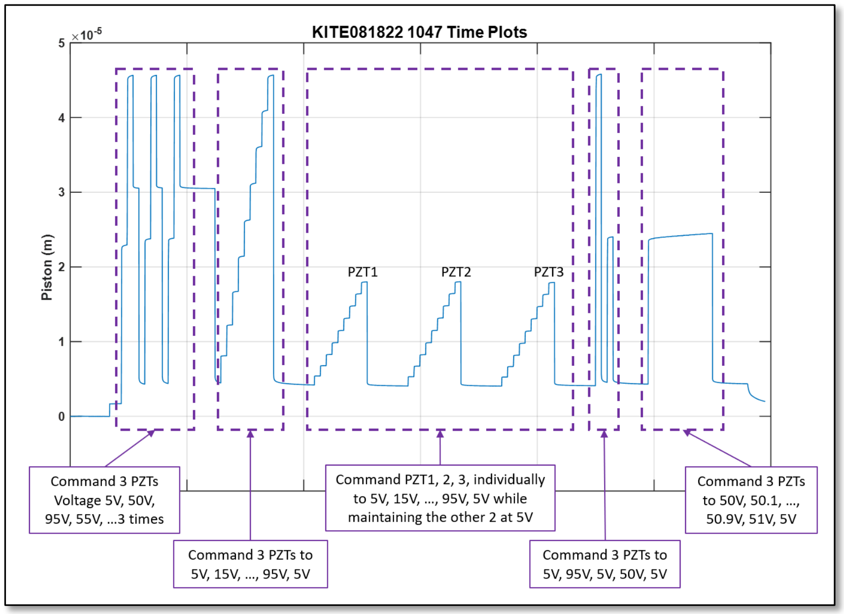
FCM Coarse Stage Step Size



Coarse Stage Step Size
18°C: 5.110 um
22°C: 5.106 um
Req: ≤ 7 um

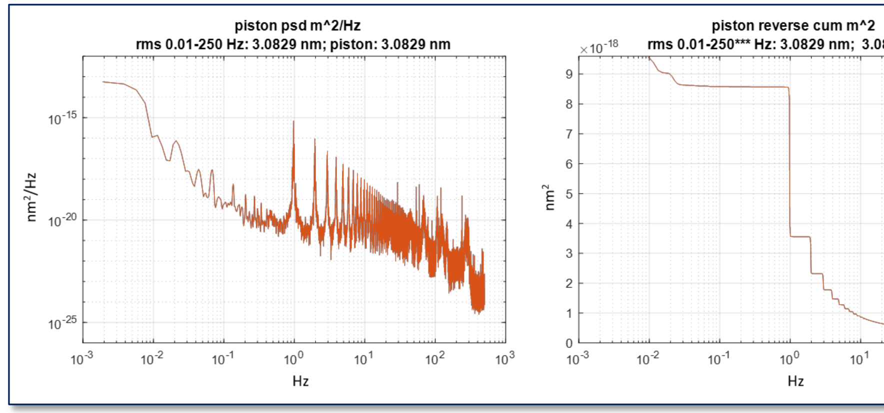
FCM: L5 Fine Stage Test Examples

FCM Fine Stage Travel Range



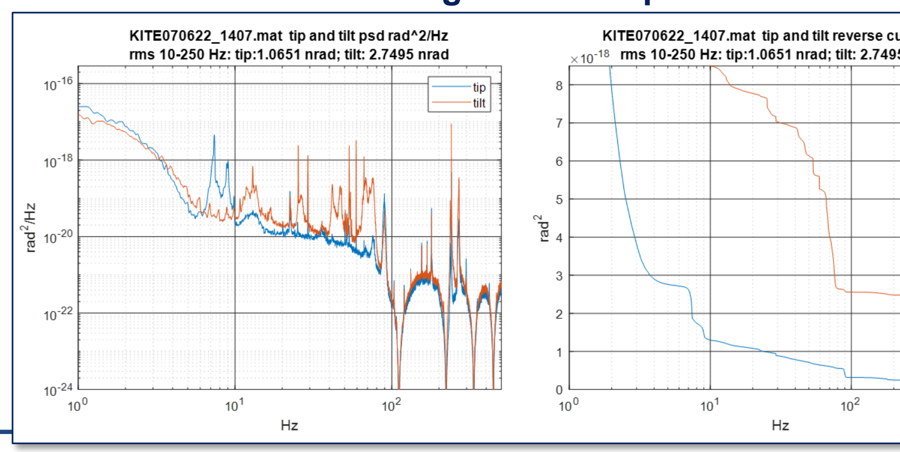
Fine Stage Range
18°C: 41.05 um
22°C: 41.18 um
Req: ≥ 27 um

FCM Fine Stage Motion Piston Jitter



Piston Jitter
18°C: 3.06 nm
22°C: 3.08 nm
Req: ≤ 16 nm

FCM Fine Stage Motion Tip-Tilt Jitter



Tip-Tilt Jitter
18°C: 2.7 nrad
22°C: 2.6 nrad
Req: ≤ 32 nrad

Summary

- All Active Optics mechanisms (PAMs, FSM, FCM) and masks (SPMs, FPMs, Lyot Stops, Field Stops) have been delivered and integrated to CGI.
- Mechanisms and masks all have performed well during CGI in-air full function test (FFT) and thermal vac (TVAC) test