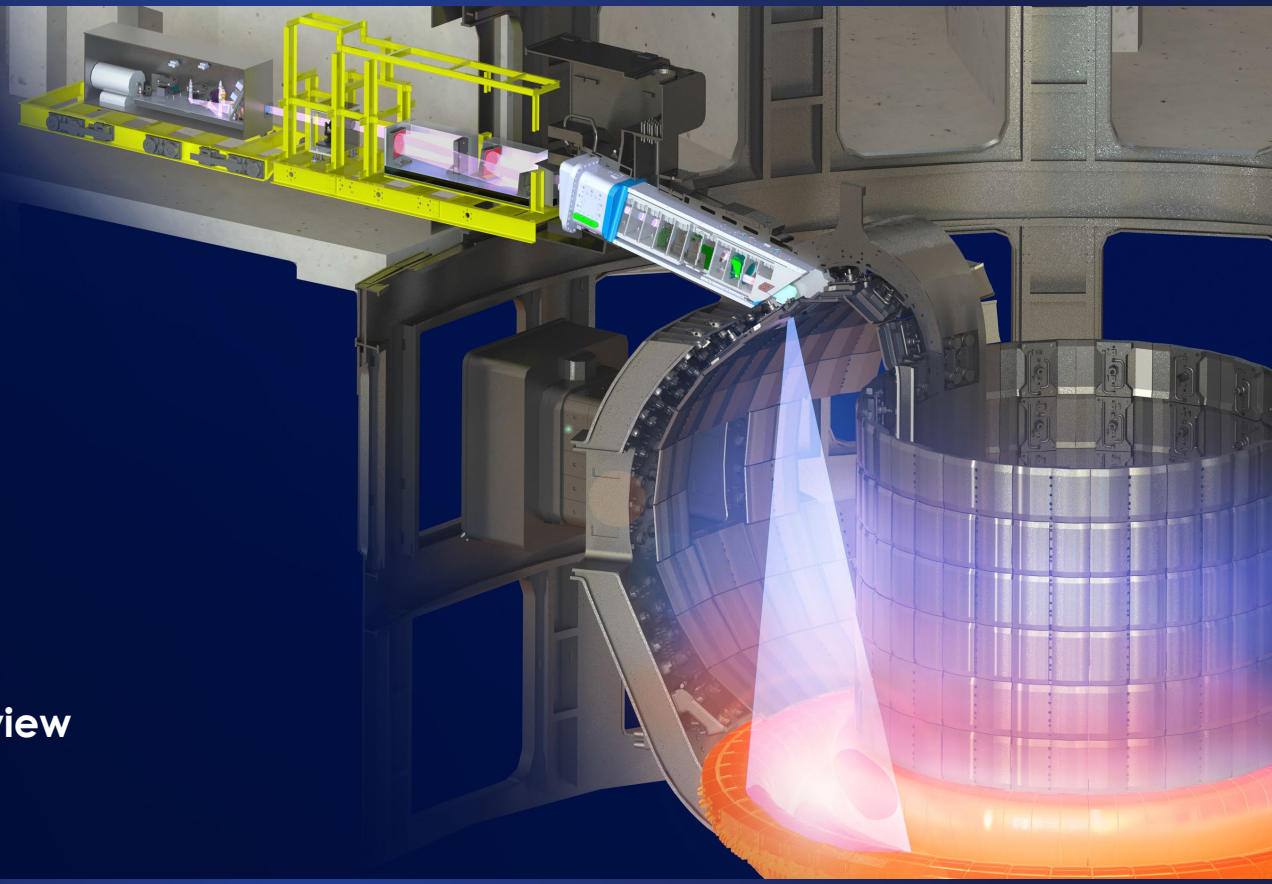
55.GA UWAVS Optical Alignment



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Systems Engineer
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Presented at the
UWAVS Preliminary Design Review
September 17-19, 2024

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PALOMAR SCIENTIFIC INSTRUMENTS

GENERAL ATOMICS

Objectives & requirement

UWAVS alignment

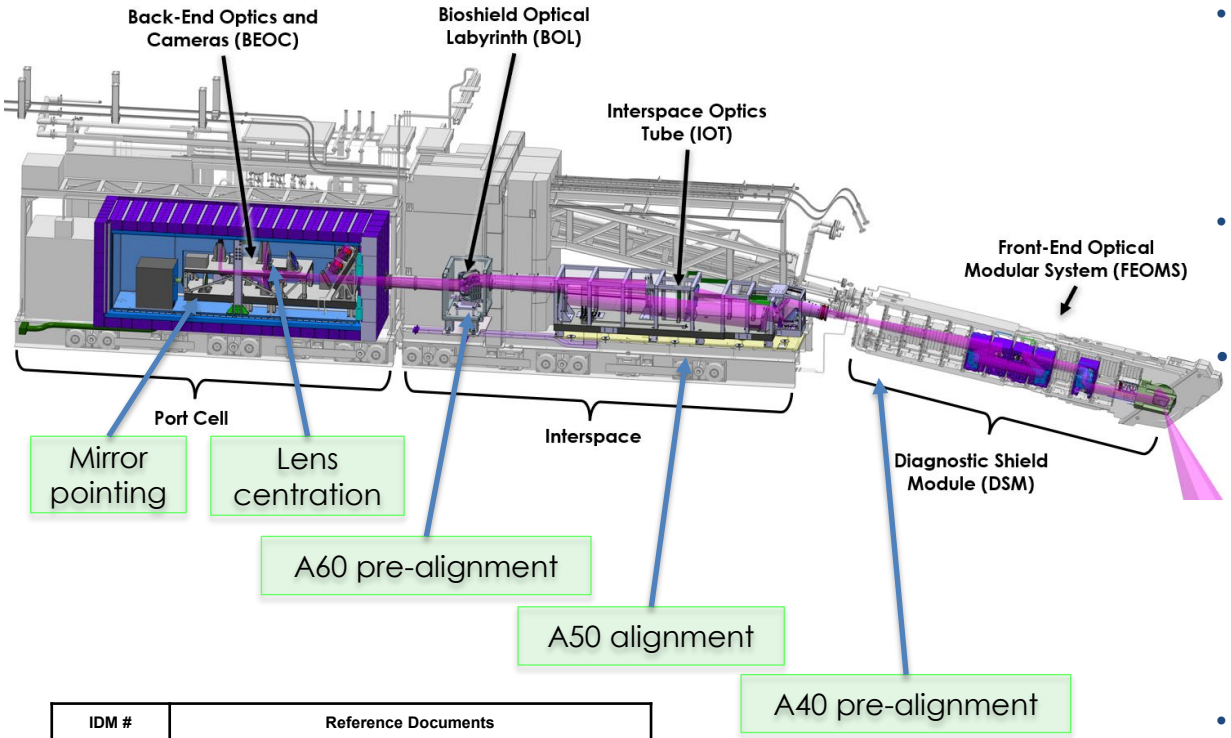
- **Optical alignment is key**
  - To achieve the imaging resolution
  - After initial alignment
  - And to accommodate vessel deformation
- **Optical alignment is performed**
  - Using alignment laser and targets
  - Using active alignment system
- **Optical alignment**
  - Is part of the overall alignment plan, feeds into assembly and qualification
  - Is considered in tolerance analysis
  - Accuracies are proposed

Key Assumptions

- **Alignment**
  - DSM interfaces errors well known & small
  - Laser tracker available in PIF and port cell
- **Active alignment**
  - In-vessel contrast in visible and IR
  - Vessel deformation shows smooth behavior
  - Vibrations are not corrected

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results
AK7KBE	55.GA UWAVS-35 Onsite Assembly Plan
WL7A5Y	55.GA UWAVS-35 Onsite Testing and Commissioning Plan

System initial alignment and role of optical alignment



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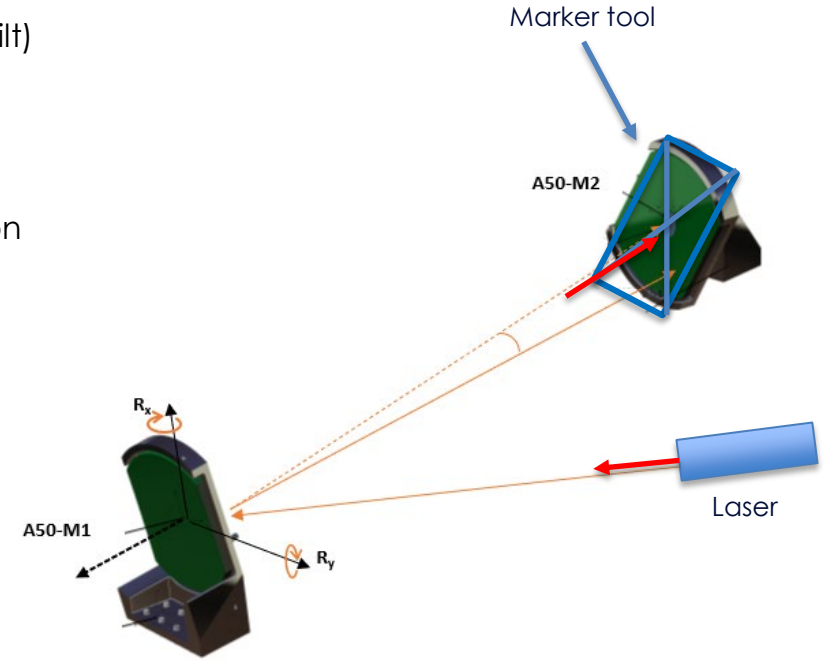
Central role for optical alignment in assembly, integration & test procedure

- **Mechanical alignments**
  - Measure & correct shims or adjust element
  - Mainly elements & modules
  - CMM measurements
- **Laser tracker alignment**
  - Modules in EPP, ISS &PCSS
  - Mainly larger units
- **Optical alignments**
  - A40 pre-alignment
  - A50 mirror alignment
  - A60 pre-alignment
  - A80, A90 & A100 alignment
  - To pre-align compensator and
  - Achieve better element alignment
- **Optical verification**
  - Optical axes
  - Imaging performance

A50 Alignment to improve IOT imaging

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results
AK7KBE	55.GA UWAVS-35 Onsite Assembly Plan
WL7A5Y	55.GA UWAVS-35 Onsite Testing and Commissioning Plan

- **Goals**
  - Adjust A50 mirrors in 2 degrees of freedom (tip and tilt)
  - To place optical axis centred on the mirrors
  - *To improve the imaging IOT imaging resolution*
- **Approach**
  - Set up alignment laser at nominal position & direction using laser tracker and fiducial
  - Measure transmitted beam position & direction
  - Iteratively adjust A40 tip-tilt & piston
- **Tools**
  - Alignment laser with small beam
  - Laser tracker to measure positions in 3D
  - Fiducial to link beam to position
  - Beam position markers for each mirror to mark the spot

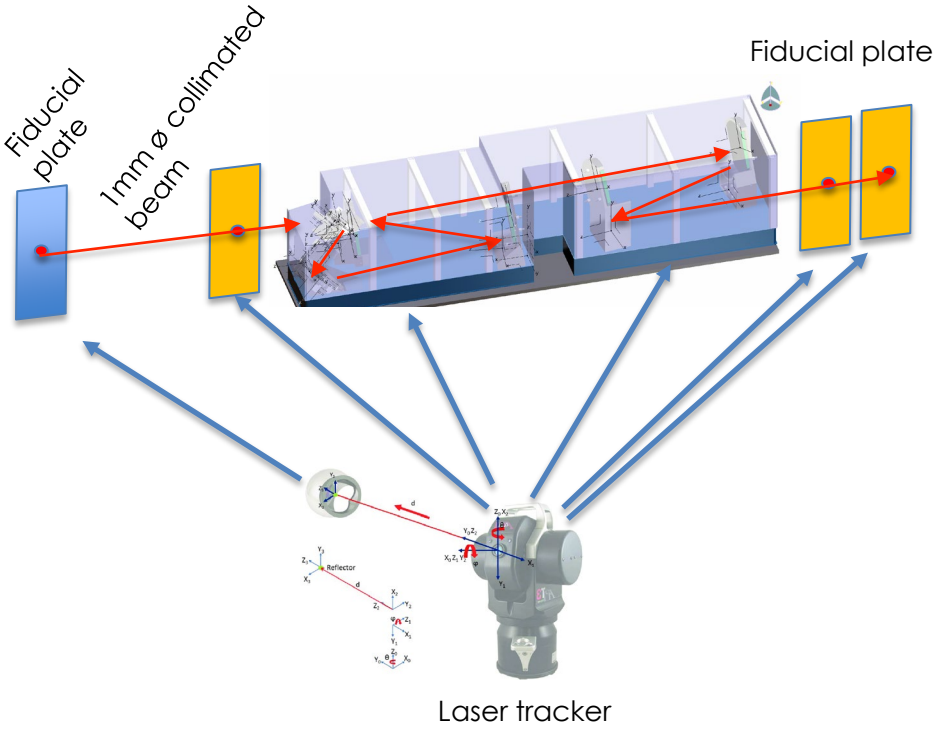


Example optical alignment of A50 mirror group mirrors

A40 pre-alignment for ISS integration

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results
AK7KBE	55.GA UWAVS-35 Onsite Assembly Plan
WL7A5Y	55.GA UWAVS-35 Onsite Testing and Commissioning Plan

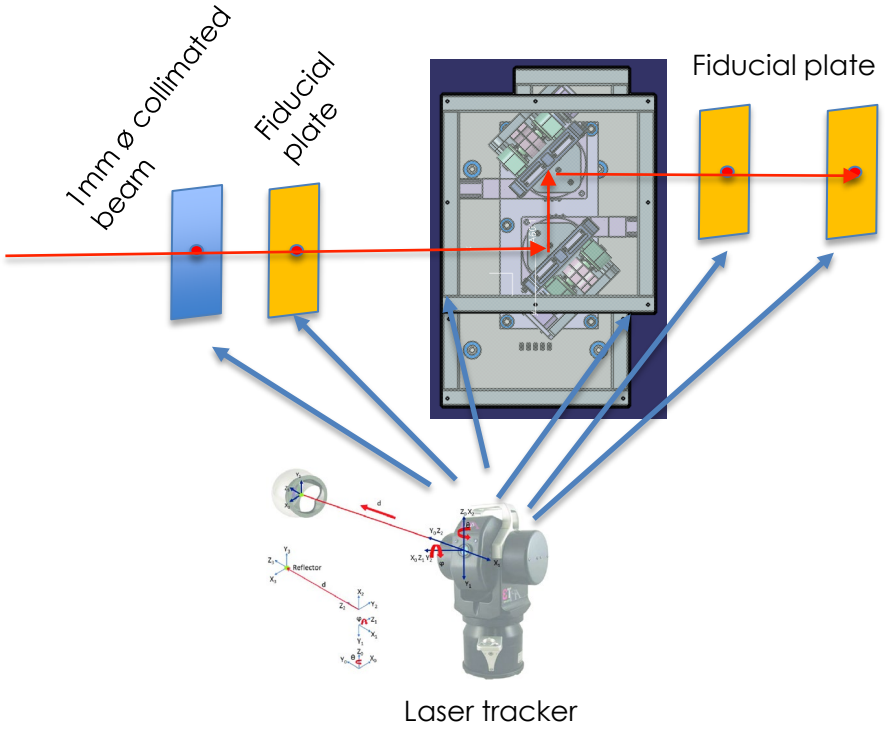
- **Goals**
  - Adjust A40 mirror in 5 degrees of freedom
  - To place optical axis right wrt mechanical axis
  - *In preparation to ISS integration and verification*
- **Approach**
  - Set up alignment laser at nominal position & direction using laser tracker and fiducial
  - Measure transmitted beam position & direction
  - Iteratively adjust A40 tip-tilt & piston
- **Tools**
  - Alignment laser with small beam
  - Laser tracker to measure positions in 3D
  - Fiducial to link beam to position



A60 pre-alignment for ISS integration

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results
AK7KBE	55.GA UWAVS-35 Onsite Assembly Plan
WL7A5Y	55.GA UWAVS-35 Onsite Testing and Commissioning Plan

- **Goals**
  - Adjust A60 mirror in 2 times 2 degrees of freedom (tip-tilt)
  - To place optical axis out wrt the axis in
  - *In preparation to ISS integration and verification*
- **Approach**
  - Set up alignment laser at nominal position & direction using laser tracker and fiducial
  - Measure transmitted beam position & direction
  - Iteratively adjust A40 tip-tilt & piston
- **Tools**
  - Alignment laser with small beam
  - Laser tracker to measure positions in 3D
  - Fiducial to link beam to position



BEOC mirror & IR breadboard alignment for integration

- **Goals**
  - Adjust A80, A100 mirrors and IR baseplate in 2 degrees of freedom
  - To place optical axis right on the imagers
  - *In preparation to integration & verification*
- **Approach**
  - Set up alignment laser at nominal position & direction using laser tracker and fiducial
  - Measure transmitted beam position & direction
  - Iteratively adjust A40 tip-tilt & piston
- **Tools**
  - Alignment laser with small beam
  - Fiducials and reference tool to mark beam position

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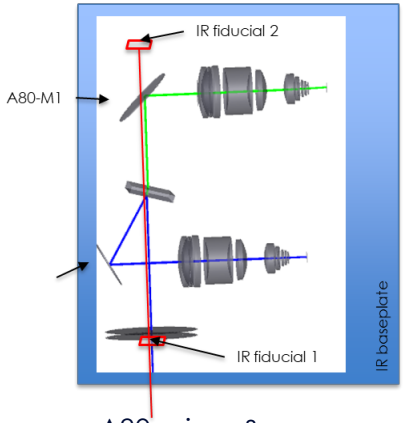
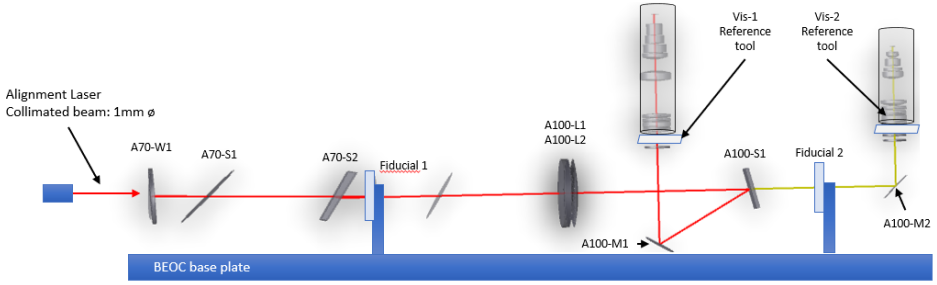
WL7A5Y	55.GA UWAVS-35 Onsite Testing and Commissioning Plan



A80 mirror & baseplate alignment



A100 mirror alignment

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GENERAL ATOMICS

A90 and A110 lens centration to improve imaging

- **Goal**
  - Reduce positioning tolerances of lenses in the lens barrels
  - To achieve imaging resolution
- **Approach**
  - Align barrel
  - Align lens
  - Lock position & move to next lens
- **Tool**
  - Lens centration bench

IDM #	Reference Documents
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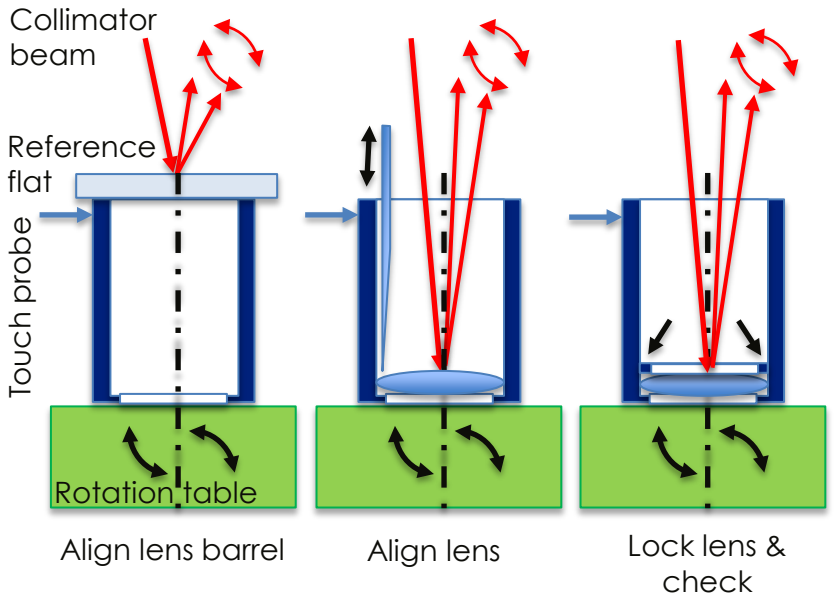
AK7KBE	55.GA UWAVS-35 Onsite Assembly Plan
WL7A5Y	55.GA UWAVS-35 Onsite Testing and Commissioning Plan

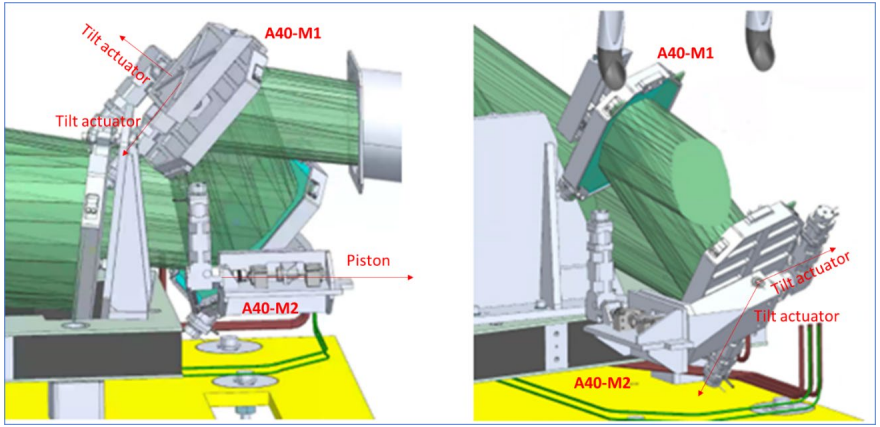


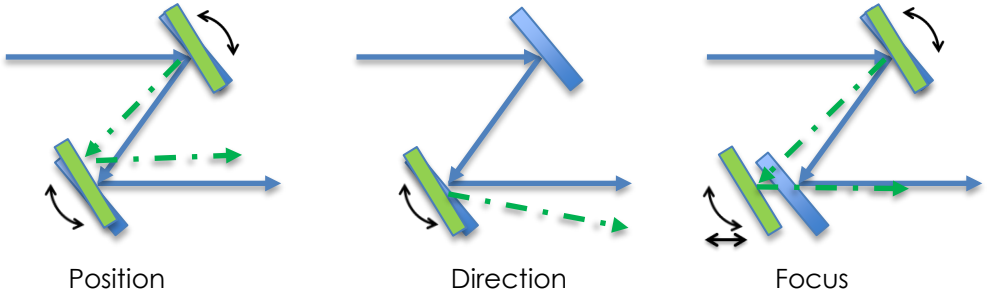
Active alignment system overview

- **System needs**
  - Correct beam position, pointing and focus
  - For initial alignment
  - And to compensate for vessel deformation
- **Implementation**
  - A40-M1: Tip-tilt
  - A40-M2: Tip-tilt & piston
  - Visible camera focus adjustment
- **Operation**
  - Bandwidth ~1Hz, so only thermal deformations
  - Use pre-determined thermal correction
  - And image position on detectors

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results

Alignment system implementation

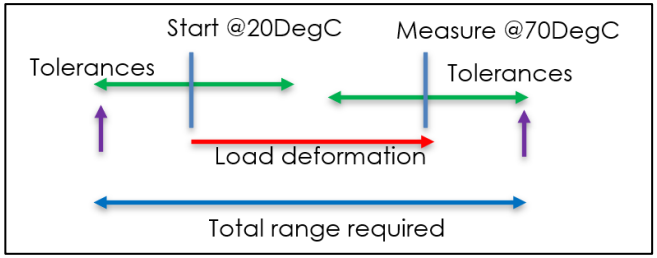




Alignment system Operation

Performance evaluation: A40 actuation range

- **Actuation range is determined by adding:**
  - Tolerance analysis alignment ranges
  - STOP deformation correction, this is in one direction only
- **Outcome**
  - Tip-tilt ranges are fine
  - Focus requires non-central use of range (shift center of range)



Overview	A40-M1		A40-M2		
Coordinates	ZLCS	ZLCS	TGCS Port 0	ZLCS	ZLCS
	Rx [mrad]	Ry [mrad]	dz [mm]	Rx [mrad]	Ry [mrad]
STOP IOT-Zemax temp analysis (52°C) BEOC-Zemax temp analysis (37°C) Vacuum vessel deformation	-0.31	-23.35	-19.20	0.23	-21.80
Tolerances (-) direction	-25.20	-32.37	-4.70	-31.21	-38.57
Tolerances (+) direction	25.20	32.37	4.70	31.21	38.57
Total range required: Thermal + tolerances	50.71	88.10	28.60	62.65	98.94

Active alignment system has sufficient range

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results

Performance evaluation: A40 Actuator resolution

- **Actuation resolution need**
  - Sub-pixel alignment on detector
  - To minimize impact on data interpretation
- **Implemented resolution**
  - +/- 1µm on focus
  - +/- 0.65mrad on tip-tilt
- **Outcome**
  - Better angular resolution required, foreseen for FD-phase

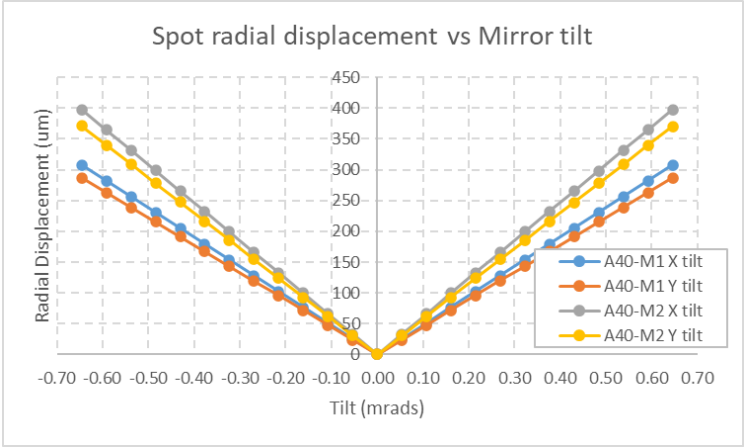


Image displacement by A40 mirror tilt

Targeted resolutions for A40 actuators	
Tilt actuators	<0,008 mrad
Piston	<0,045 mm

Targeted actuator resolution

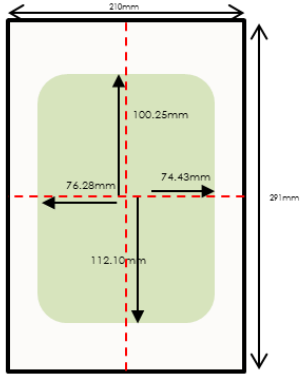
Active alignment resolution needs improvement

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results

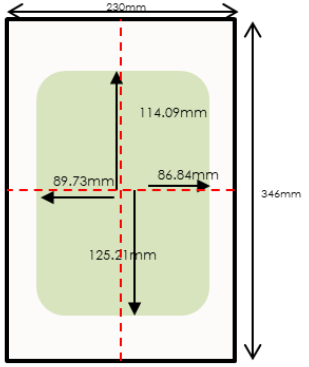
Performance evaluation: A40 Mirror size

- **Beam shift is determined by adding**
  - Thermal deformation beam shift (From STOP analysis)
  - Initial alignment beam shift (tolerance analysis)
  - Pivot point effect (rotation point is 69.5mm behind surface
- **Outcome**
  - Smallest margin is ~5mm
  - No vignetting will occur on A40 mirrors during alignment and operation

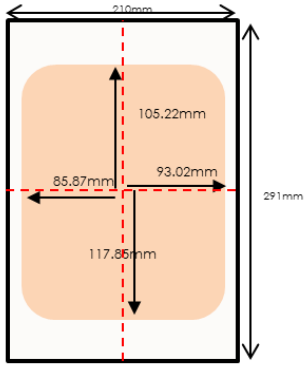
Nominal footprint on A40-M1



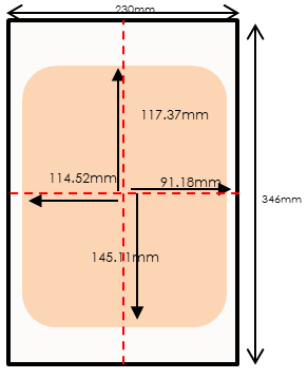
Nominal footprint on A40-M2



Max. footprint on A40-M1 after tolerances



Max. footprint on A40-M2 after tolerances



Active alignment mirrors sufficiently large

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results

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GENERAL ATOMICS

Camera focus adjustment visible cameras

- **Focus correction difference visible and IR**
  - A40 adjusts all channels at same time, yet
  - Thermal behaviour Visible and IR channels BEOC different
- **Implementation**
  - Also visible camera focus added
  - Use A40 for general focus
  - And visible camera for difference only
  - Use model based LUT and BEOC temperature for adjustment

Alignment	Vis-1	IR-1
A40-M2 focus	2.4	-1.06
A40-M1 X tilt	0.285	-0.15
A40-M1 Y tilt	0.003	0.02
A40-M2 X tilt	0.285	-0.14
A40-M2 Y tilt	-0.003	0.03
Camera focus	**-0.352**	0

Final system compensator range for IR-1 and Vis-1 channels

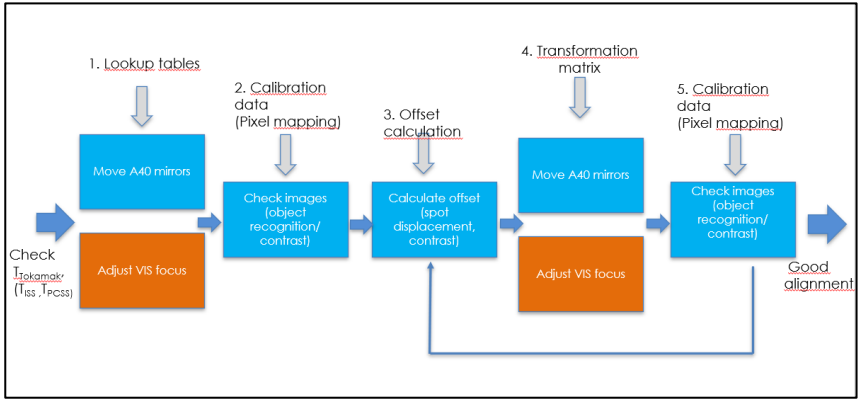
Active alignment camera focusing implemented

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results

Active alignment system operation

- **Active alignment system**
  - Combines thermal and initial alignment
  - During operation only has image position data
  - Focus correction requires some scanning
  - Angular correction
- **Approach**
  - Perform initial alignment scan & optimization of all degrees of freedom after installation (T=20DegC)
  - Repeat alignment scan & optimization of all degrees of freedom on warm vessel (T=70DegC)
  - Create LUT for temperature correction
  - Add image position correction during operation/between pulses
- **Open issues**
  - Available contrast in-vessel around pulses

Active alignment process flow



Active alignment process flow defined

IDM #	Reference Documents
AQLWZW	55.GA UWAVS-35 Optical Model Results

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PALOMAR SCIENTIFIC INSTRUMENTS
GENERAL ATOMICS

Summary slide

UWAVS alignment

- **System optical alignment is presented for**
  - Initial system alignment
  - Active alignment system for vessel deformation
  - Using two flat mirror tip, tilt and piston adjustment
- **Initial system optical alignment**
  - Helps to achieve accurate optics alignment
  - Prepares for system qualification measurements
- **Active alignment system**
  - Has sufficient actuator range
  - Mirrors are sufficiently large
  - Actuator resolution will be improved in FD-phase

Open Issues & way forward

- **Alignment**
  - DSM interfaces errors well known & small
  - Access for Laser tracker measurement in PIF and port cell
  - Plan: discuss with PI in FD-phase
- **Active alignment**
  - Actuator resolution to be improved (in FD-phase)
    - Plan: Update design in FD-phase
  - Illumination & contrast around pulses for alignment
    - Plan: Inventory options in FD-phase