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Large Volume, Optical and Opto-Mechanical Metrology Techniques for ISIM on JWST

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Outline

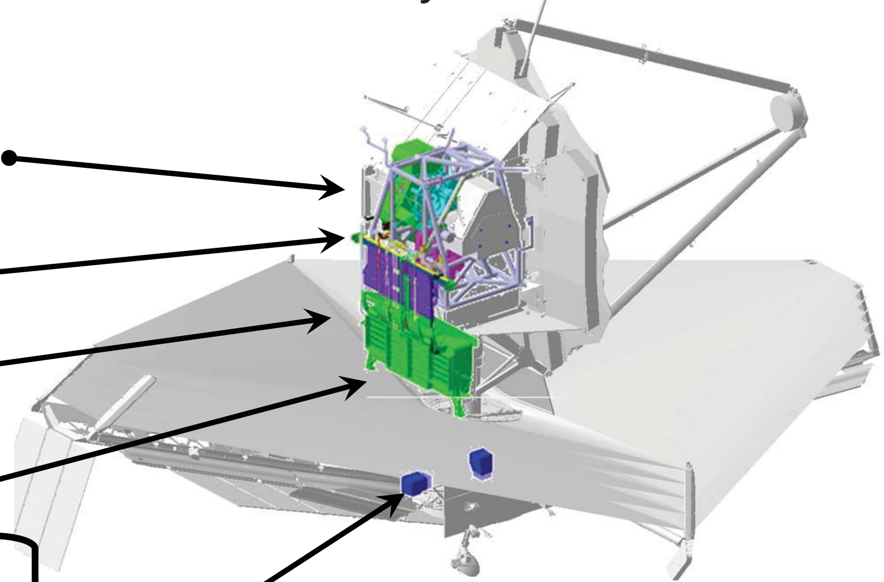
Integrated Science Instrument Module (ISIM) Element

ISIM is one of three elements that together make up JWST

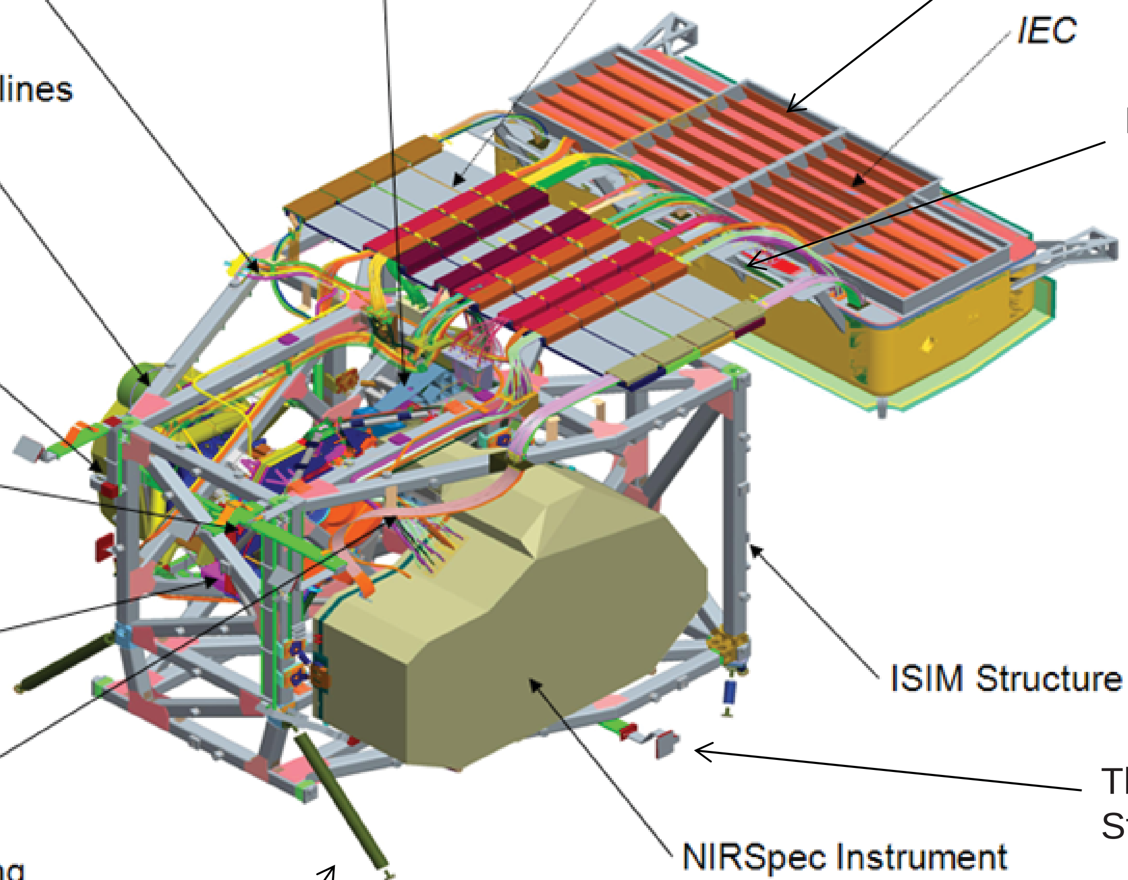
- Approximately 1.4 metric tons, ~20% of JWST by mass

ISIM consists of:

- Five sensor systems
  - MIRI, NIRCam, NIRSpec, NIRISS, FGS
- Nine instrument support systems:
  - Optical metering structure system
  - Electrical Harness System
  - Harness Radiator System
  - ISIM Electronics Compartment (IEC)
  - Cryogenic Thermal Control System
  - Command and Data Handling System (ICDH)
  - ISIM Remote Services Unit (IRSU)
  - Flight Software System
  - Operations Scripts System



ISIM Element



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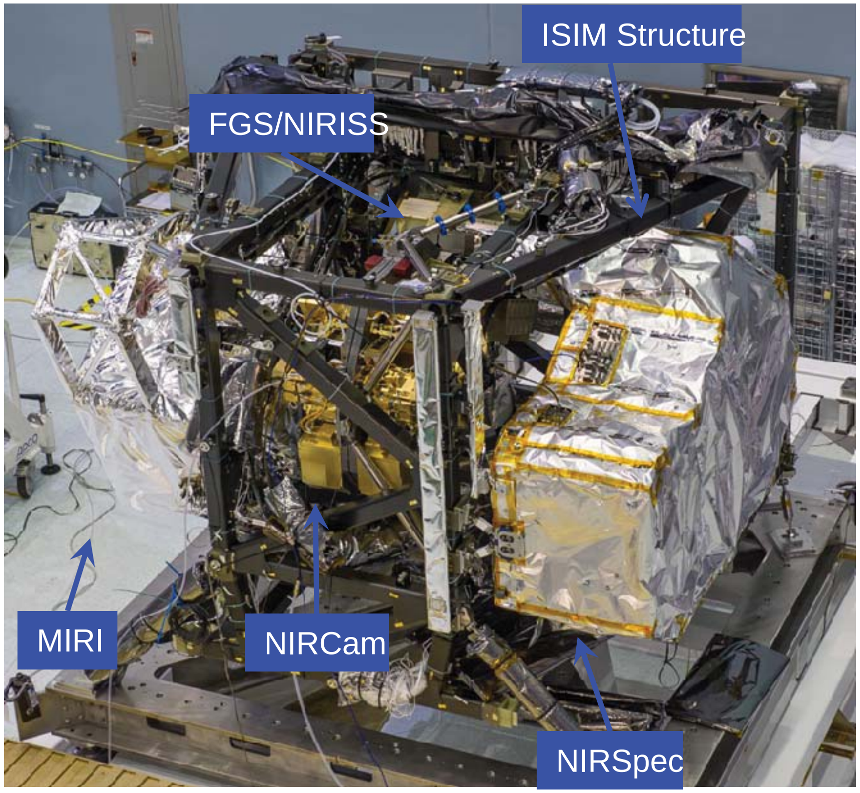
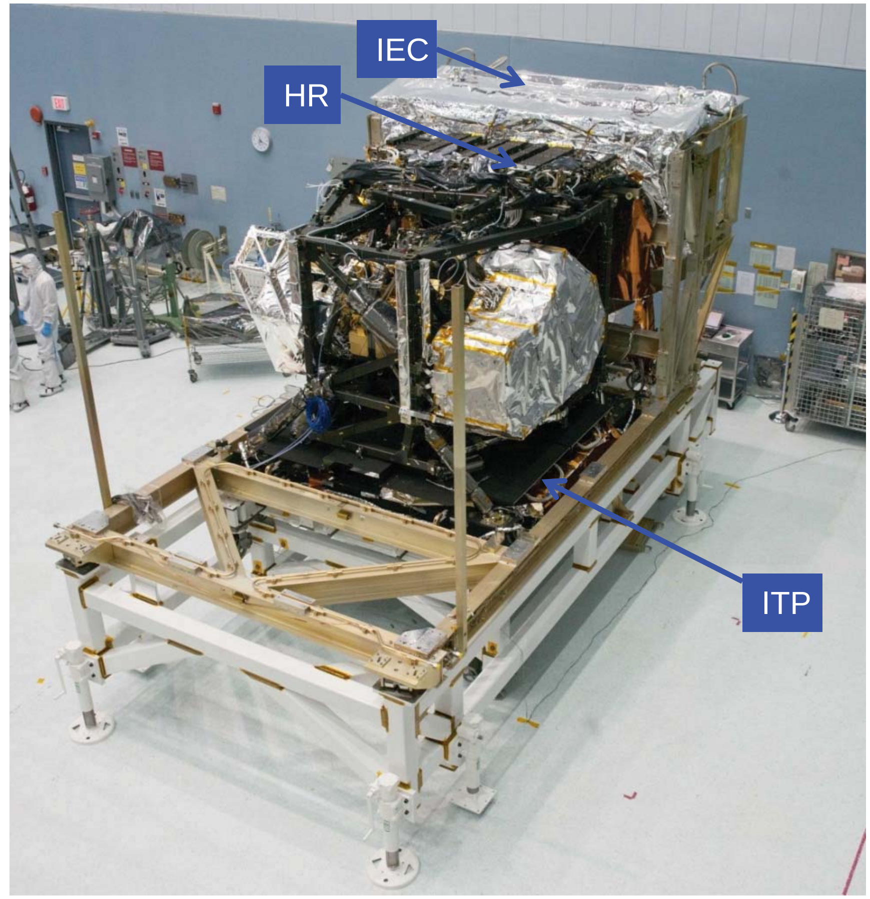
ISIM images from SSDIF, prior to CV2



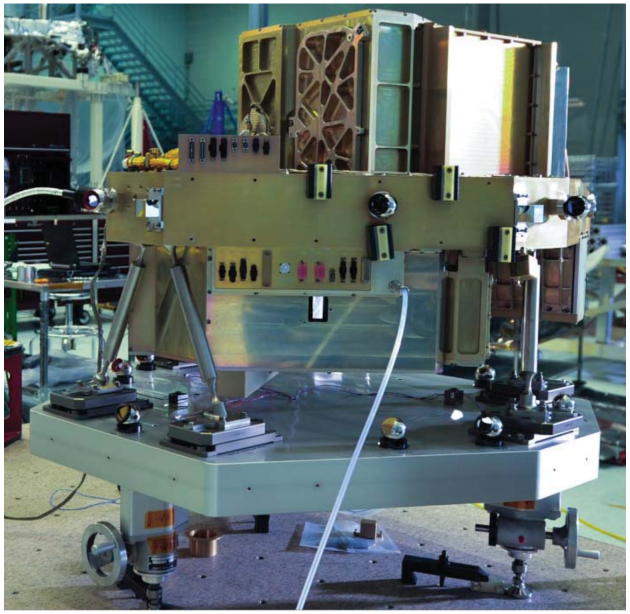


Fine Guidance Sensor (FGS)
Near Infrared Imager and Slitless Spectrograph (NIRISS)
Near Infrared Camera (NIRCam)
Near-Infrared Spectrograph (NIRSpec)
Mid-Infrared Instrument (MIRI)

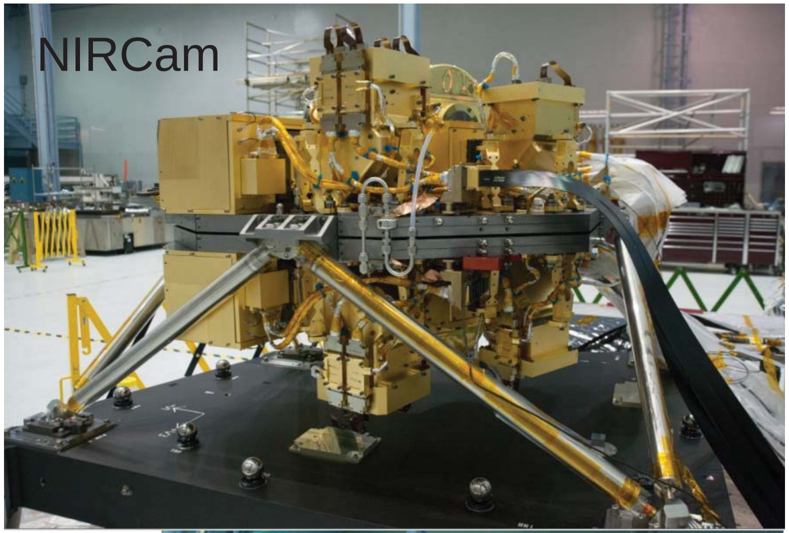
Harness Radiator (HR)
ISIM Electronics Compartment (IEC)
ISIM Test Platform (ITP); ground support equipme

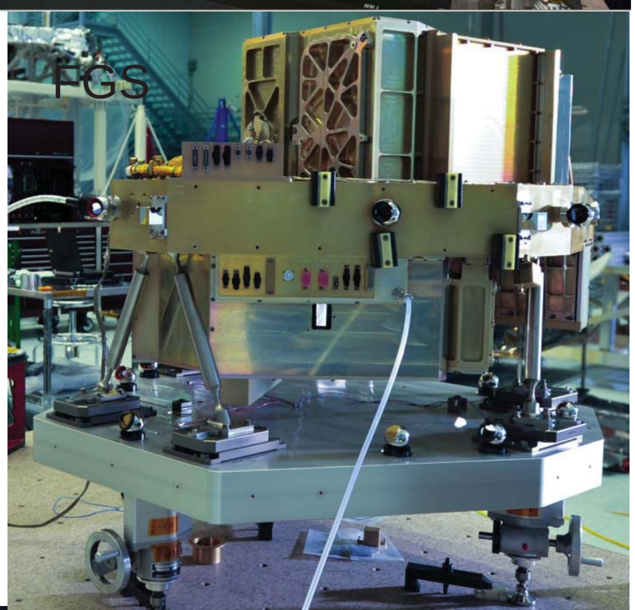
ASMIF and ISIM

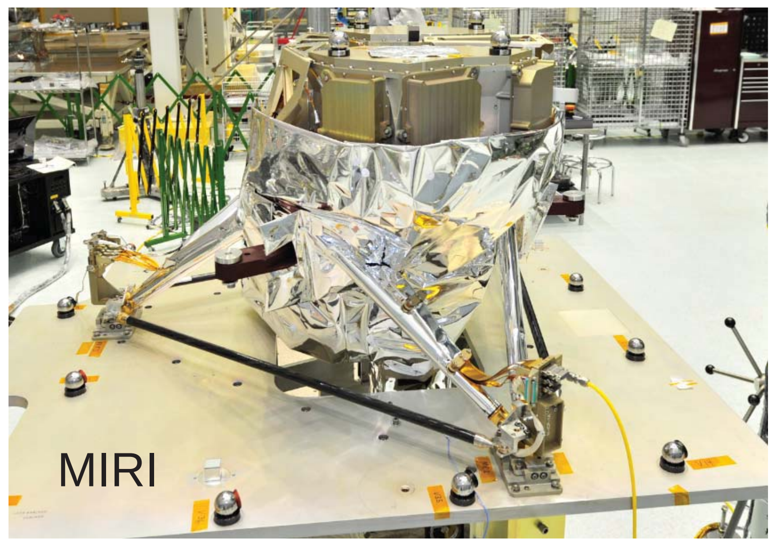
- Instrument were built on a GSE (Ambient Science Insturment Mechanical Interface Fixture, ASMIF) that mimics the ISIM-SI interface
- Identical Science Instrument Interface Plates (SIIP) were fabricated for the ASMIFs and ISIM structure



Science Instruments







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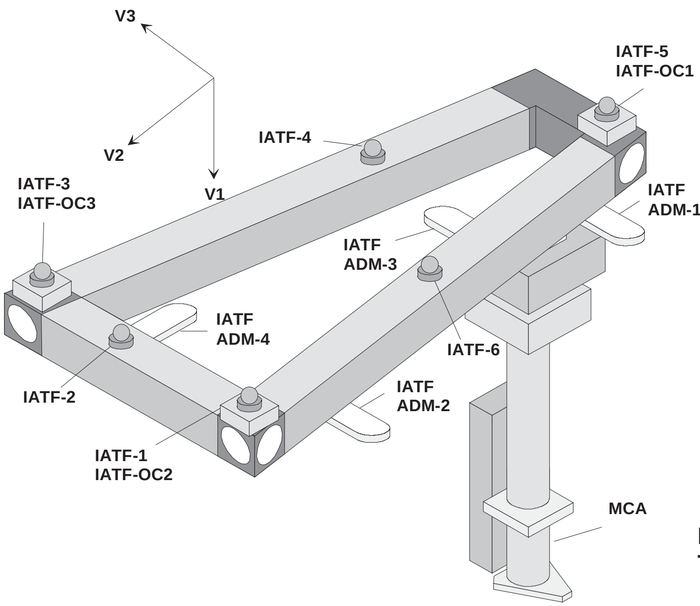
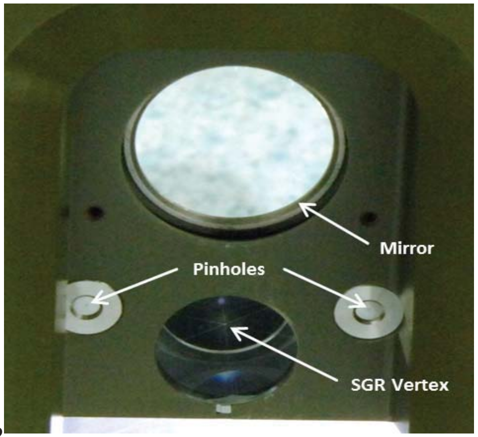
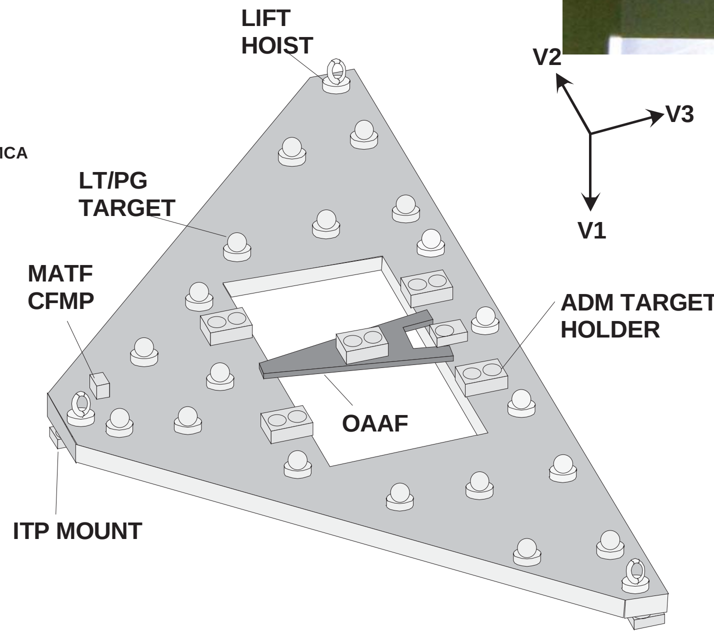
Ground Support Equipment (GSE)

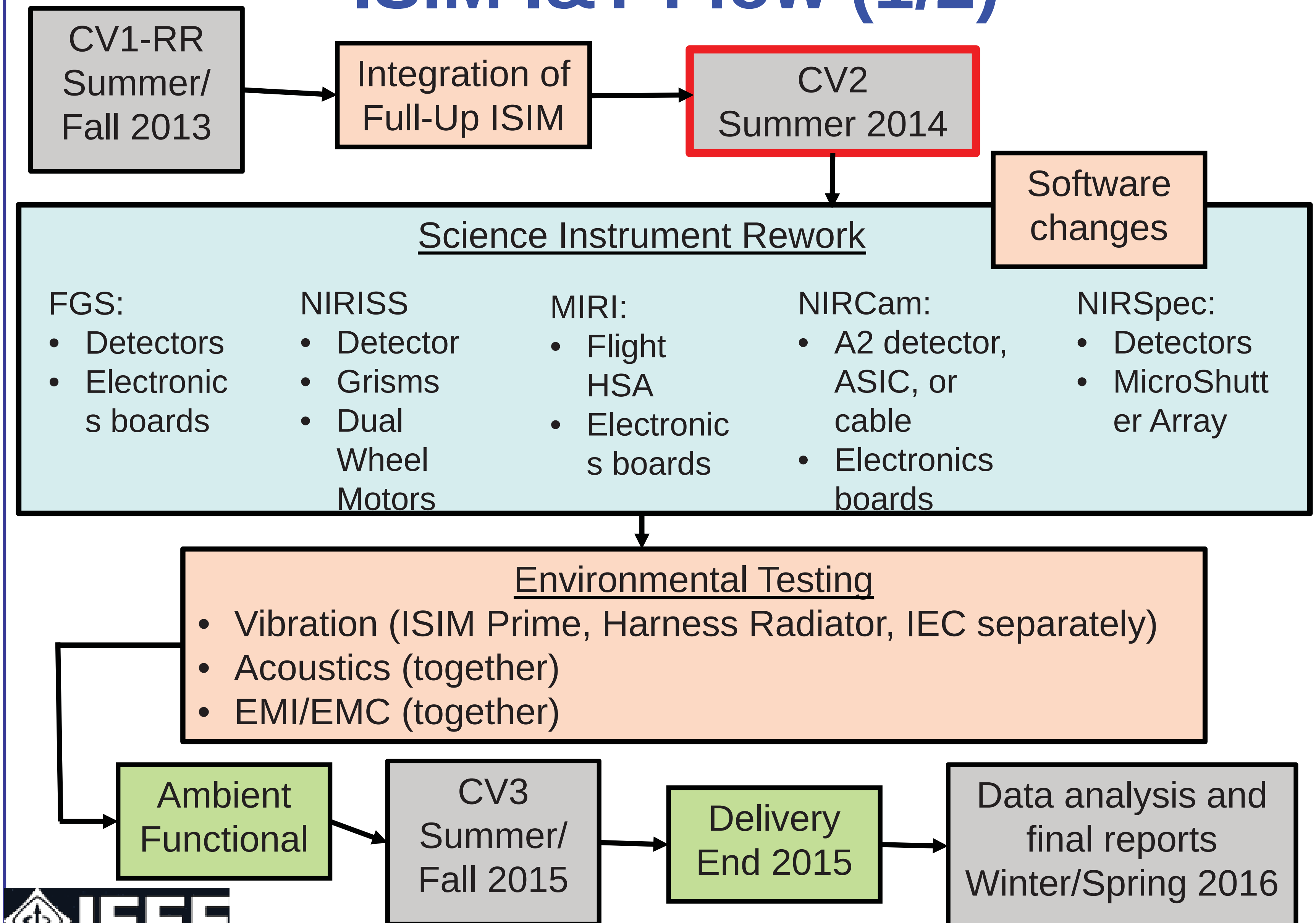
Master and ISIM alignment target fixture (MATF/IATF) Targets tracked and used to align optical simulator to ISIM







ISIM I&T Flow (1/2)



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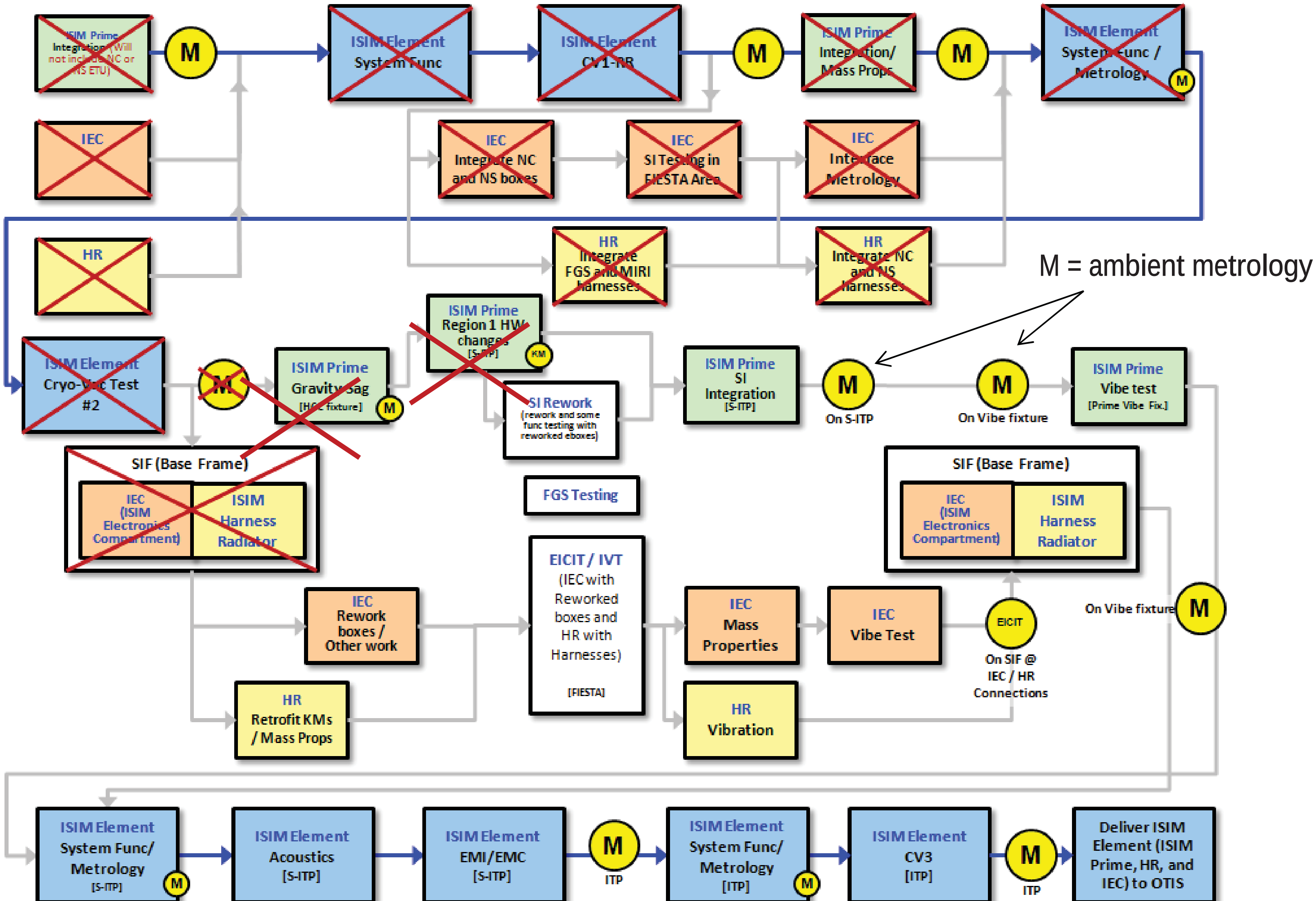
ISIM I&T Flow (2/2)



Purpose of Work

- Verify the ambient 6 degree of freedom (DOF) alignment of the SIs to the ISIM structure
- This is done using various metrology targets located on the ISIM structure and each SI
  - Interchangable spherically Mounted Retroreflector (SMR) and Tooling Ball (TB) nests
  - Optical alignment cubes
  - Locations calibrated relative to precision mechanical interfaces
- In addition, each instrument contains a pupil alignment reference (PAR) that is measured near the nominal predicted ambient OTE exit pupil location
- Build a comprehensive database of tracking targets through all environmental testing

Requirements

- Uncertainties are determined via a bottoms up estimation and are compared to expectations allocated from the top-level ISIM requirements
- Overall test requirement is that the measured SI nests and cube locations are at their predicted locations within the 2-sigma uncertainties of:
  - The SI optical bench (OB) and Ground support equipment (GSE) measured locations when integrated to ISIM
  - The SI OB measured locations while integrated to the ASMIF structure
  - Finite element modeling (FEM) of the above two orientations with respect to gravity
  - Misalignment associated with small differences in ASMIF and Structure precision mount interfaces

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Methods and Tools

- A variety of measurement tools are used depending on the application and requirements
- Tools used include: Leica laser trackers (LT), Nikon laser radar (LR), Leica Wild T3000 theodolites and a Koll Morgen alignment telescope (AT)
- LR is typically used for measurements of the SI optical benches (OB) and ISIM structure TB targets
- LT was used for PAR measurements primarily for its ability to track an SMR for alignment purposes
- Theodolites were used for all optical cube face measurements
- Photogrammetry Cameras used during both ambient and cryogenic testing

IEEE

pc1

Ambient metrology tools: Laser trackers and theodolites

SMR

Laser tracker

Laser tracker[1] is used to measure targets and surfaces

• Operated with Spatial Analyzer[2] software, which includes Unified Spatial Metrology Network (USMN; bundling) routine --- greatly improved uncertainty

• Its target is a spherically mounted retro-reflector (SMR) that attaches to magnetic nest that are interchangeable with the TB targets that are used by the LR

• Uncertainty ~0.005--0.025 mm (1-sigma)

•LT may be used with T-Cam / T-Scan / T-Probe accessories to measure envelopes, surfaces, tooling holes

•May also be used to track hardware during “blind” precision integration activities (Transtrac)

Theodolite

Theodolites are used to measure angles via auto-collimation and targets via triangulation

• Operated manually, data is analyzed with GSFC-developed software

• Autocollimation: Target is a specular flat mirror (cube)

• triangulation: Target is scribe cross hair or specular tooling ball

• Uncertainty ~2 arc-sec (1-sigma) for a single measurements, >5 arc-sec (1-sigma) for a collection of measurements

1. Leica Geosystems AG, Heerbrugg, Switzerland, metrology.leica-geosystems.com
2. New River Kinematics, Inc., Williamsburg, Virginia, www.kinematics.com

IEEE

Slide 14

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pc1 add LR photo description
pcoulter, 7/8/2014

Ambient metrology tool: “Laser radar”

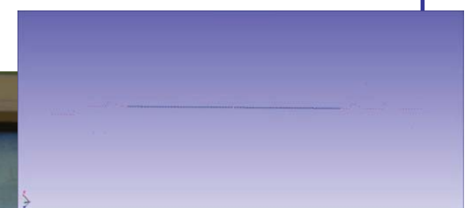
Laser radar[1] (LIDAR) is used to measure targets and surfaces

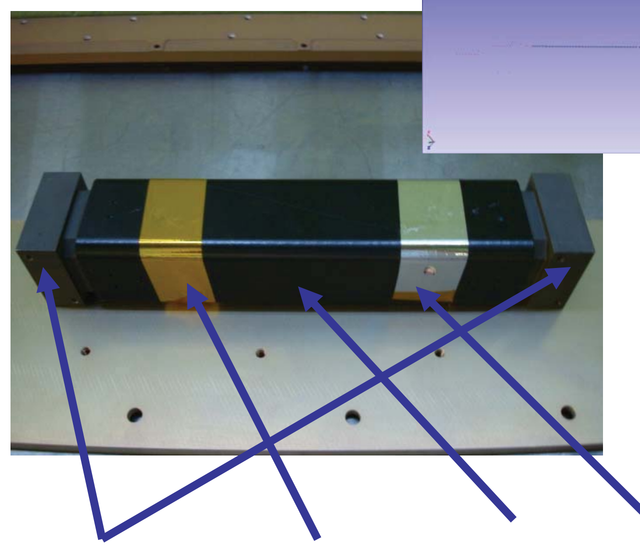
- Operated with Spatial Analyzer software
- Its target is diffuse surface (mechanical surface; matt finish), reflective tooling ball, specular mirror, or high-quality tooling hole
- Uncertainty ~0.010 mm in range (1-sigma), ~0.015 mm per meter in azimuth and elevation (1-sigma)
- Laser Radar scans much faster than Laser Tracker with T-Probe
- USMN-compatible
- At ambient, used for:
    - Used for prescription and alignment measurement for large optics (radius, aperture, etc.)
    - Envelope scans
    - Tooling ball targets on large assemblies

1. Nikon Metrology Inc, http://www.nikonmetrology.com/en_US

Laser radar (LIDAR)

TB/nest

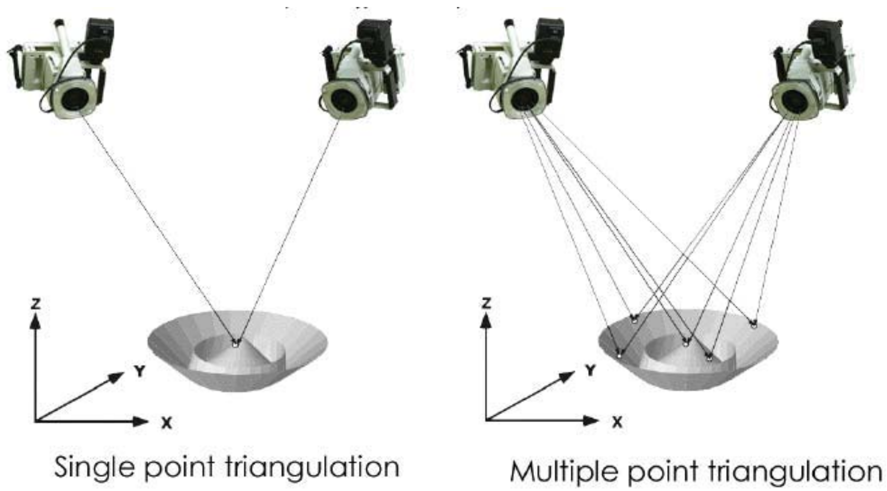




JWST materials test article

Photogrammetry Overview

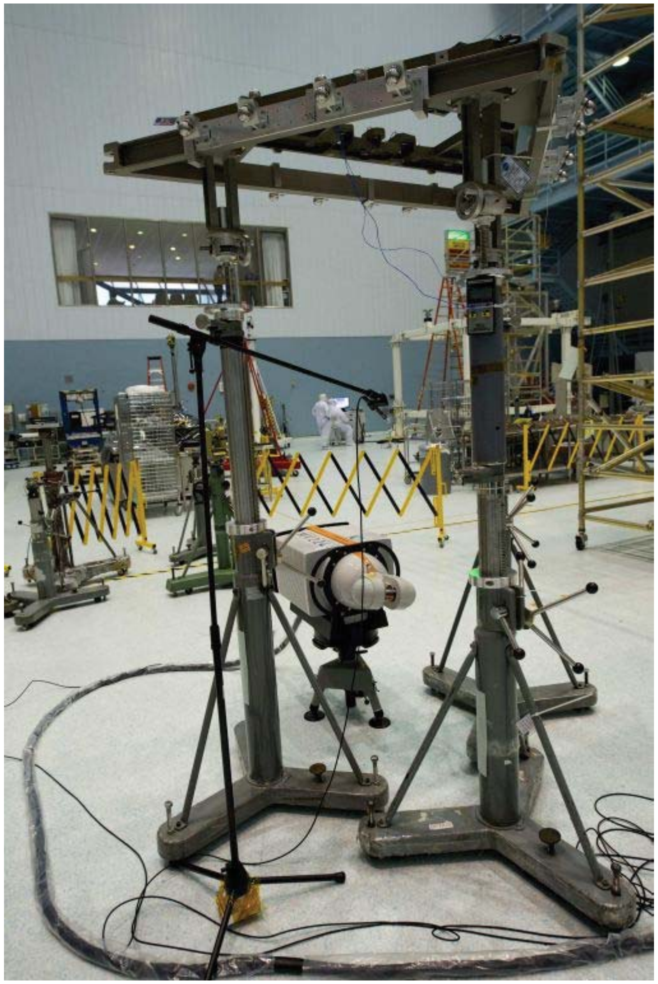
- 3 dimensional metrology system
- Uses triangulation to locate custom targets in 3 coordinates
- Requires multiple camera locations
- Solves for the camera locations and coordinates of the targets simultaneously through the bundling procedure contained in the V-STARS software, proprietary software owned by Geodetic Systems Inc.
- Software contains calibration algorithms to calibrate internal camera errors
- Geometrically diverse scalebars provide scale



Measurement Setups

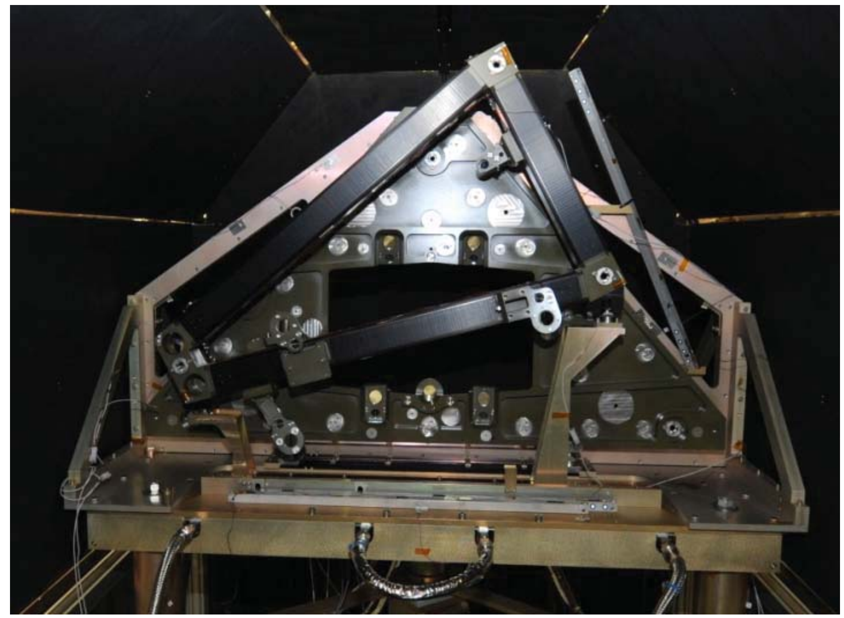
- Measurements conducted in the NASA GSFC Space Systems Development and Integration Facility (SSDIF) and Space Environment Simulator (SES) chamber
- Tests
  - GSE only ambient/cryogenic characterization
  - Full multi-station LR measurements of SI OB and ISIM structure targets
  - Full suite of theodolite measurements of all SI OB cubes and ISIM structure cubes
  - Five sets of measurements taken at each station
  - Resulting final values used for PAR measurements

MATF and IATF (xATF) ambient testing



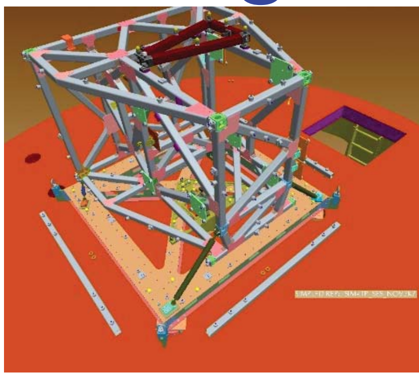
Vertical and Horizontal calibration of all Targets

MATF and IATF (xATF) Cryogenic Testing

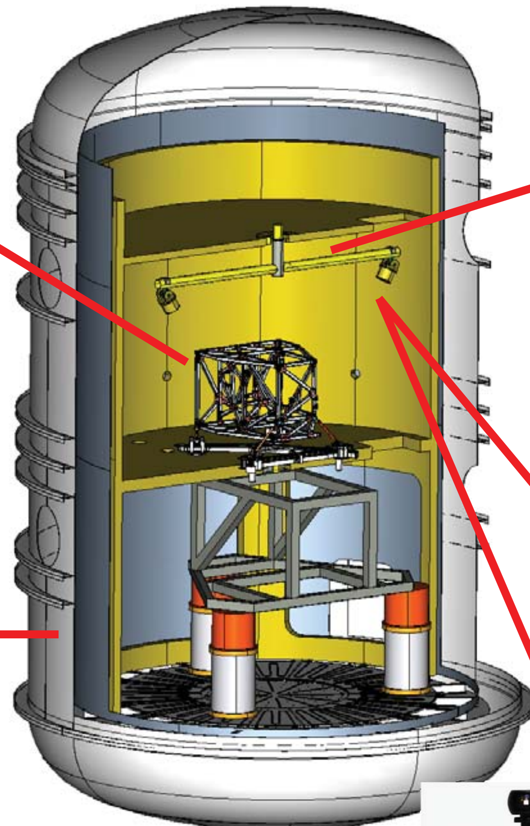


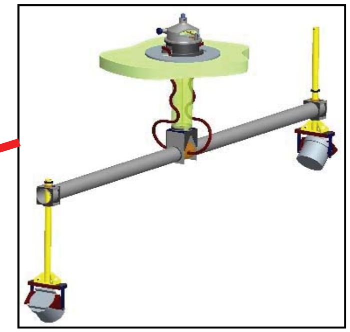
Warm to cold changes of xATF SGR, Mirror, Pinohole and Invar Scalebars tracked in LN chamber fitted with a LHe shroud.

Photogrammetry in SES chamber



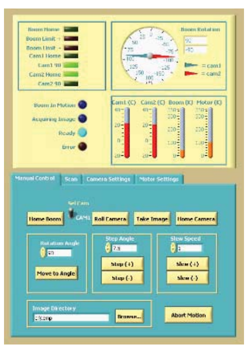
ISIM structure with PG targets and scalebars





Boom assembly and camera supports

Canister



Computer with labview interface

INCA3 Camera

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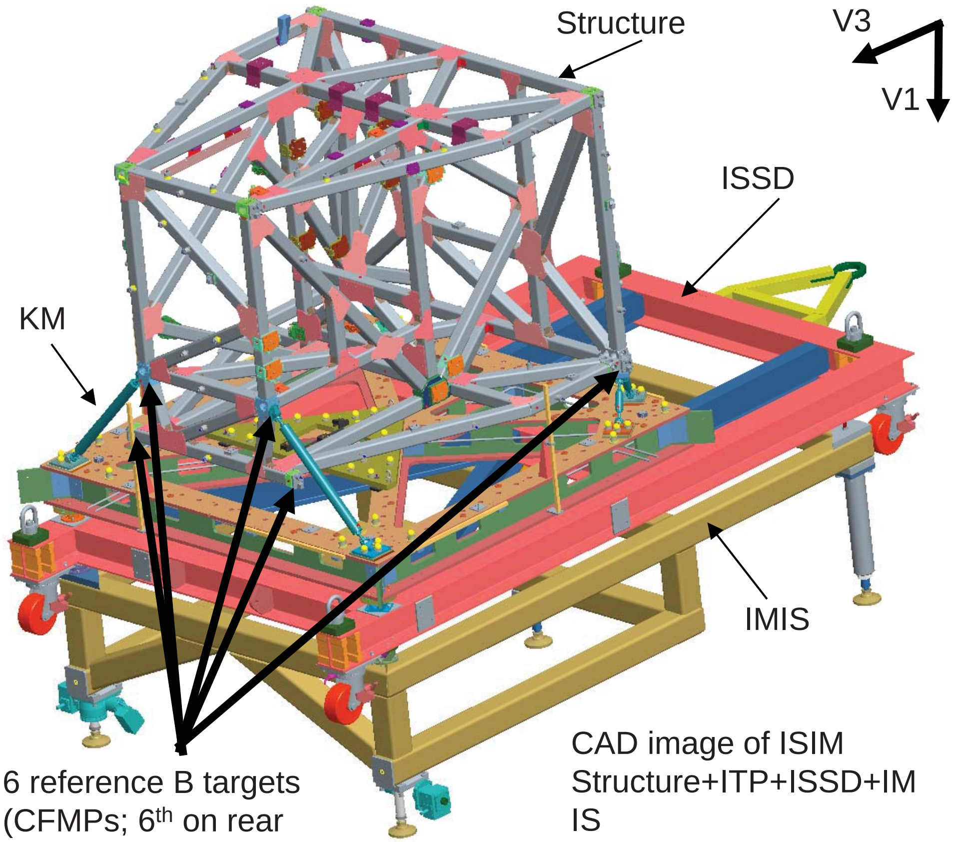
Structure characterization, ambient

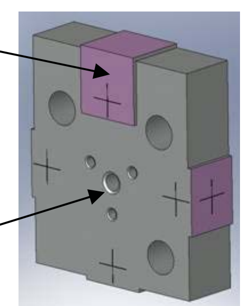
- Ambient measurement of the SI populated structure on ITP in SSDIF
  - Structure contains metrology targets and some limited harnessing (e.g., temperature sensors)
  - Invar, GSE corner fitting metrology plates (CFMP) with integral alignment cubes
  - LT targets (GSE nests) on CFMPs and tubes
  - Most CFMPs remain on Structure throughout I&T
  - Each SI contains metrology nest targets
  - Each SI contains two optical cubes

ISIM: first four sub-items above

SIs: last two sub-items above



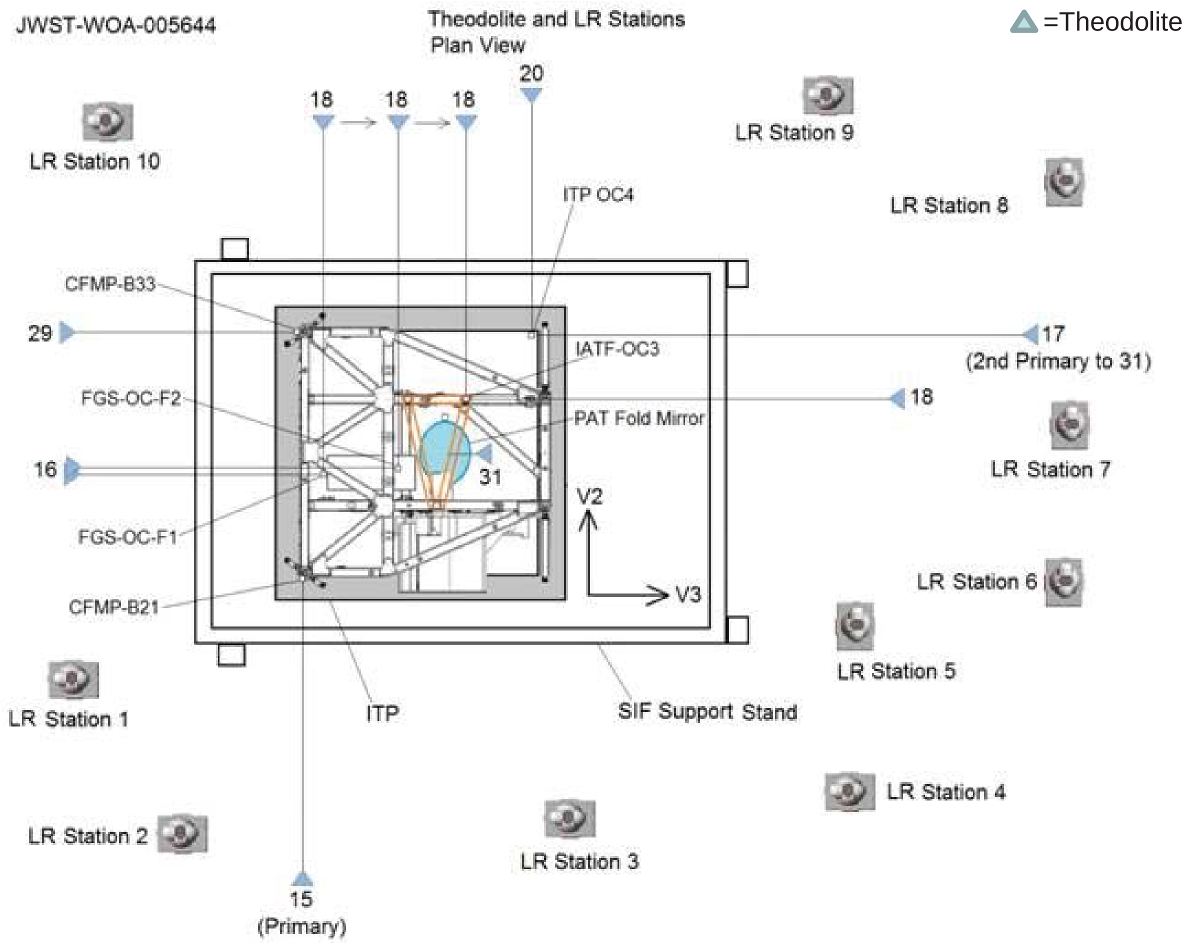
CAD image of ISIM Structure+ITP+ISSD+IMIS



CAD image of invar GSE CFMP

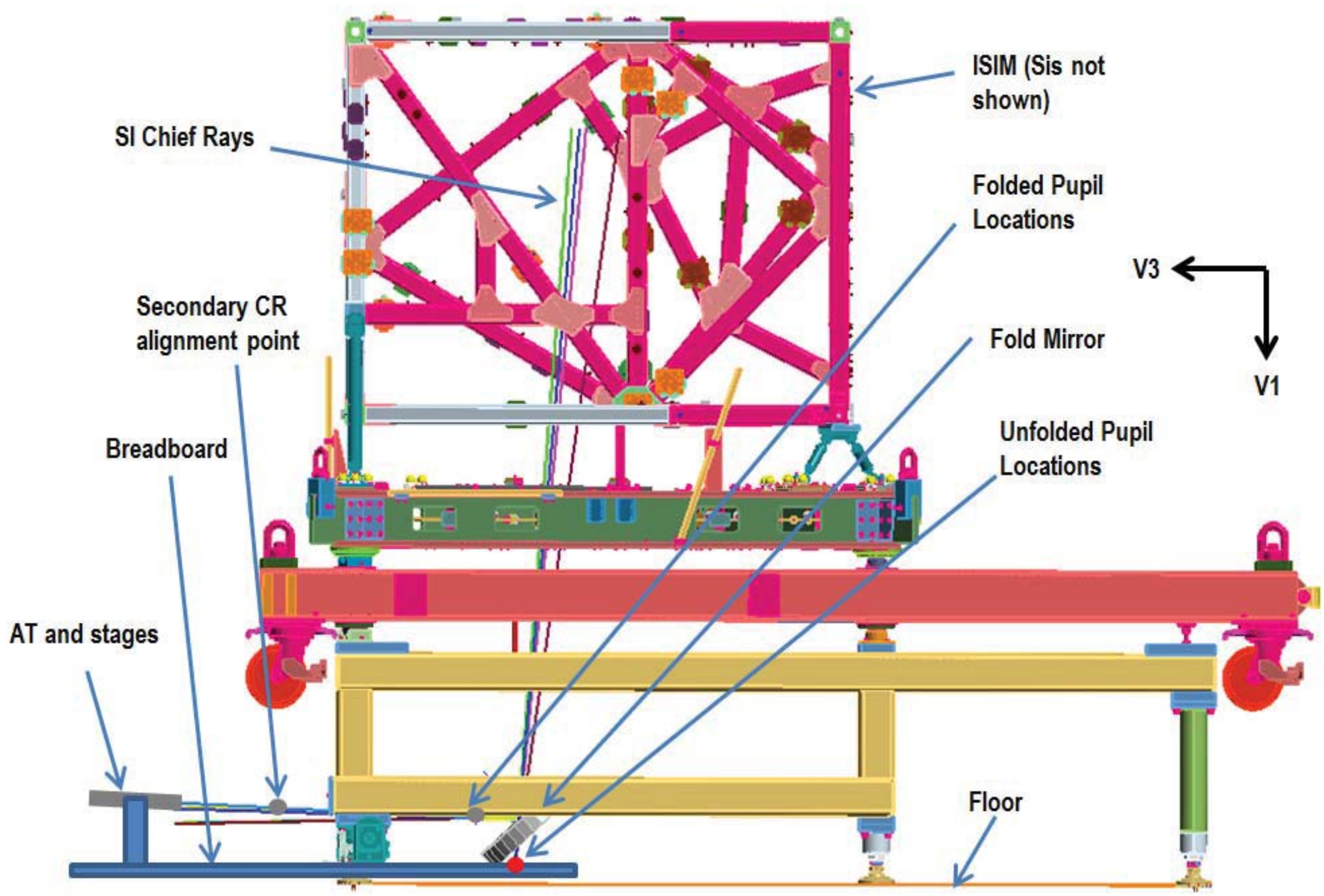
IEEE

Top View of Test Setup

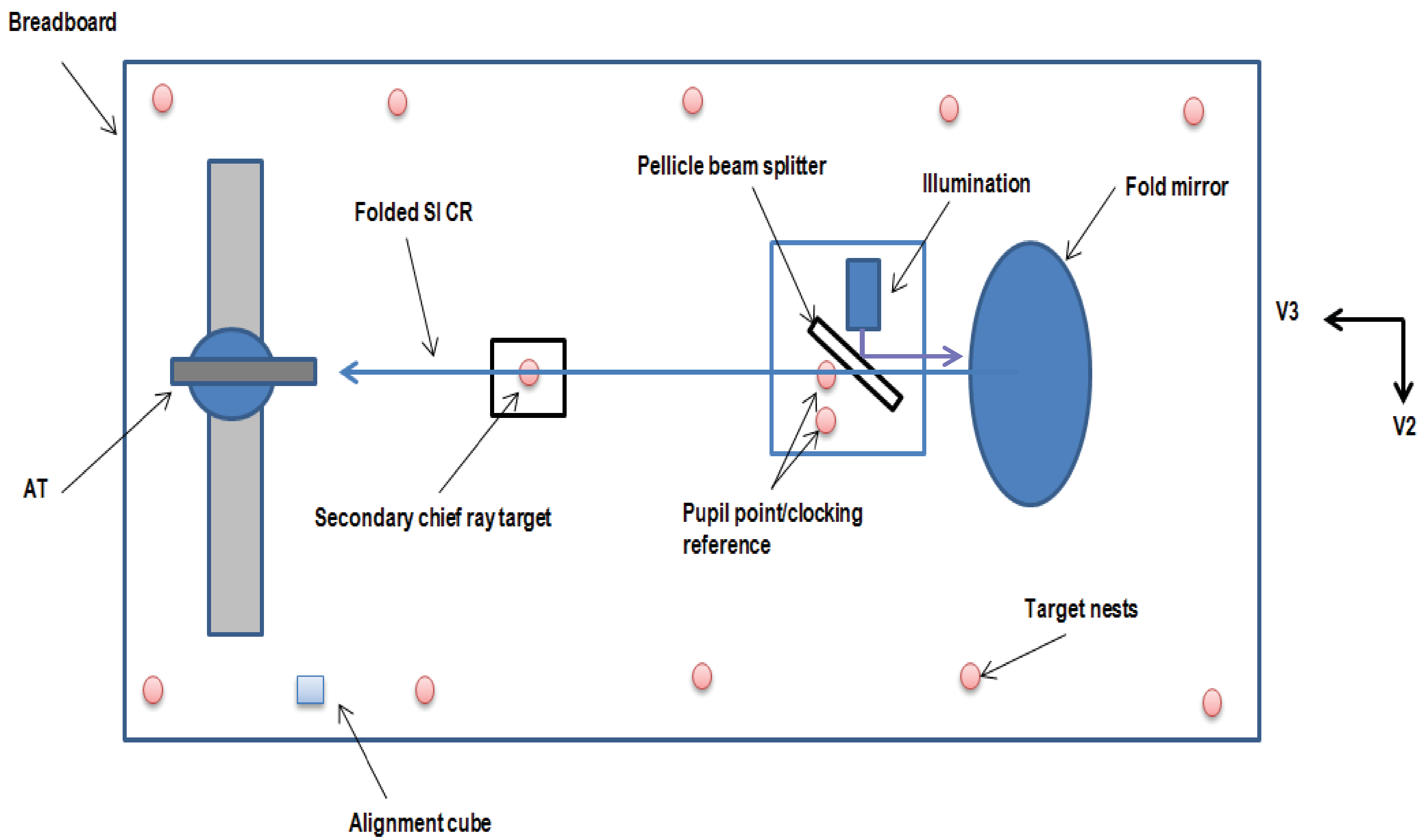


SIs not shown

PAR Measurement Setup



PAR Breadboard Top View



Test Setup

Gravity Release

ISIM in turnover fixture

Slowly rotated using Ransome Table

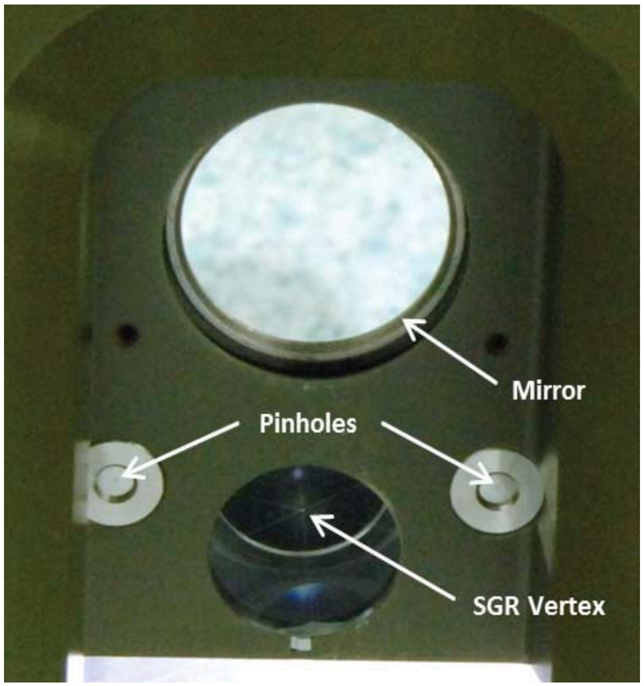
ISIM and SI tooling balls and cubes Measured V1 up then V1 down and compared FEM modeling.

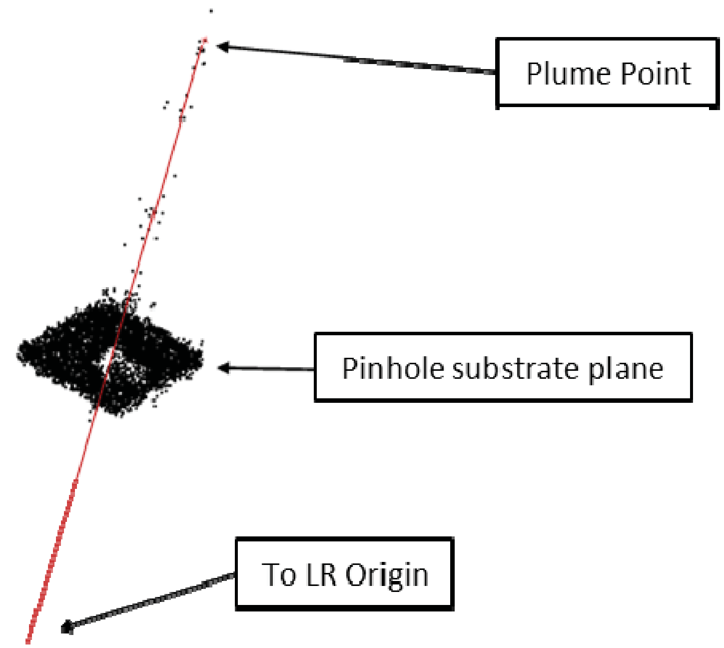
Analysis

- TB/SMR Data analyzed using Spatial Analyzer[1]
- PG Data analyzed with VStars
- Multiple stations were combined using USMN[2, 3]
  - Bundling technique similar to photogrammetry applications
  - Can be used for multiple types of instruments
- ISIM nest target values best-fit transformed to an as-built unpopulated ISIM structure database
- Theodolite data analyzed using Microsoft Excel
- Theodolite data brought into VCS via direct and through measurements using the transfer cube assembly (TCA)
- Students-t (2-sigma)[4] uncertainty calculated from five sets
- FEM differences from gravity are accounted for in the results
- Differences in the coordinate system due to the SIIP from ASMIF to ISIM are accounted for in the results

1. New River Kinematics, Inc., Williamsburg, Va.
2. S. Sandwith & R. Predmore, “Real-time 5-micron Uncertainty with Laser Tracking Interferometer Systems using Weighted Trilateration,” New River Kinematics, Inc. Williamsburg, Va.
3. Spatial Analyzer User Manual, page 322, v. 2013.12.09.
4. J. Hayden et al., “Measurements and Analysis used for the Determination of the James Webb Space Telescope Integrated Science Instrument Module Vehicle Coordinate System,” Coordinate Metrology Society Conference, July 2010.

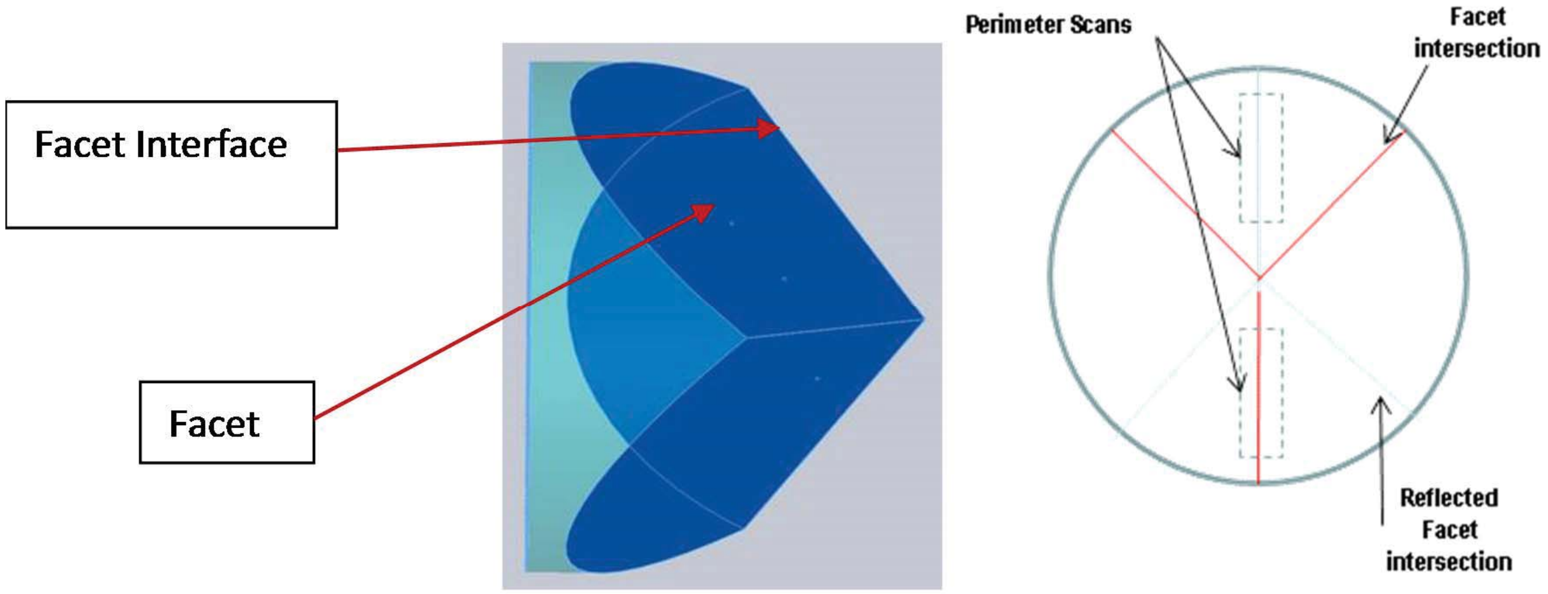
GSE Targets: Pinholes





Ambient Pinhole measurements with Cathetometer
Cryogenic with LR vision scan(output pictured above)

GSE Targets: SGR



GSE Targets: SGR

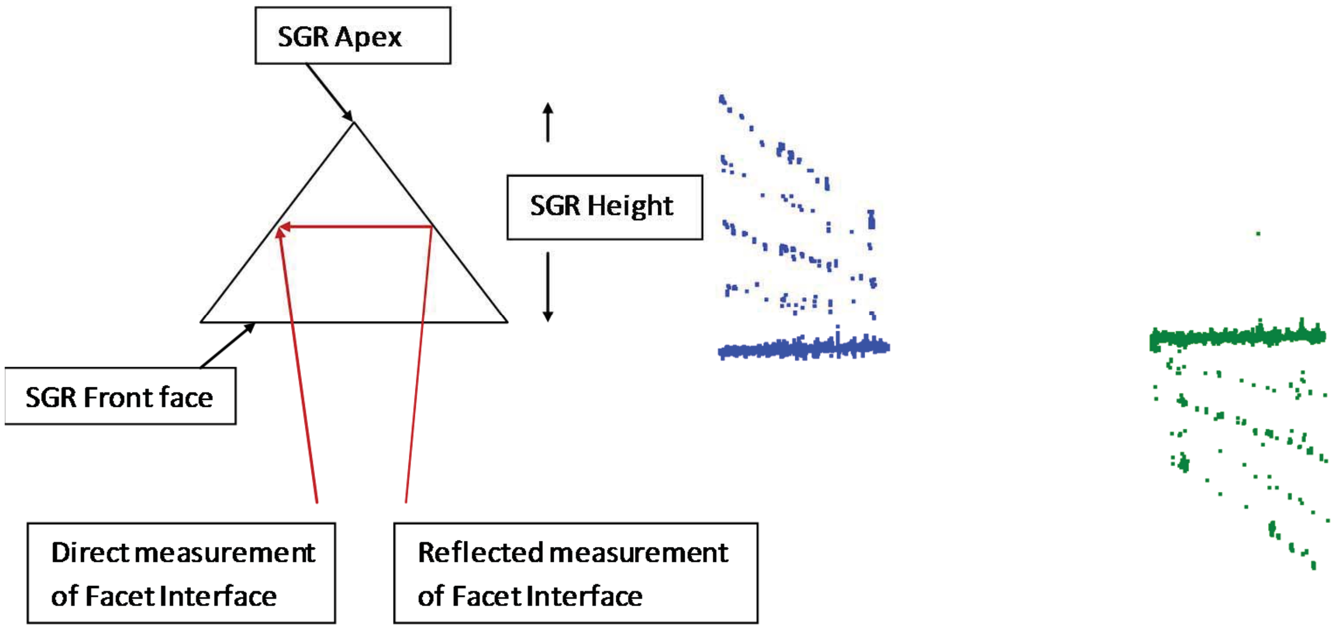
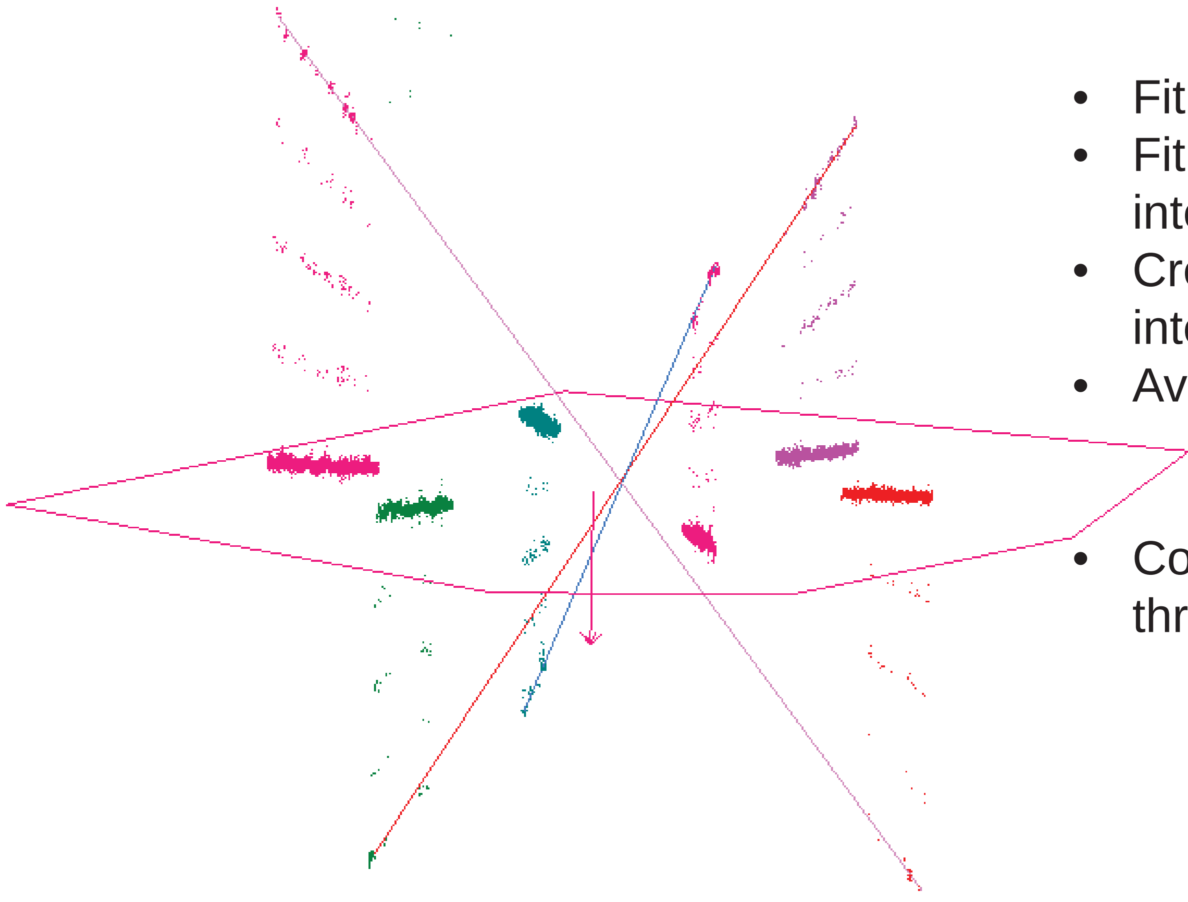


Diagram and data from LR scan of an SGR

GSE Targets: SGR

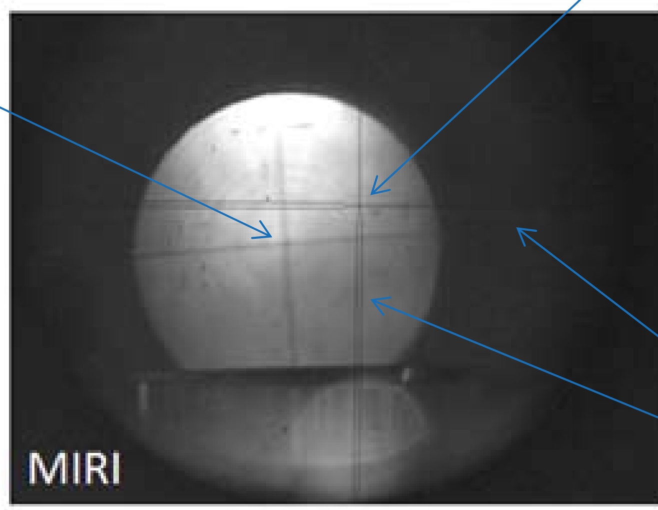


- Fit plane to range points
- Fit lines to facet interfaces
- Create point at line/plane interface
- Average 3 points

- Correct for transmission through glass

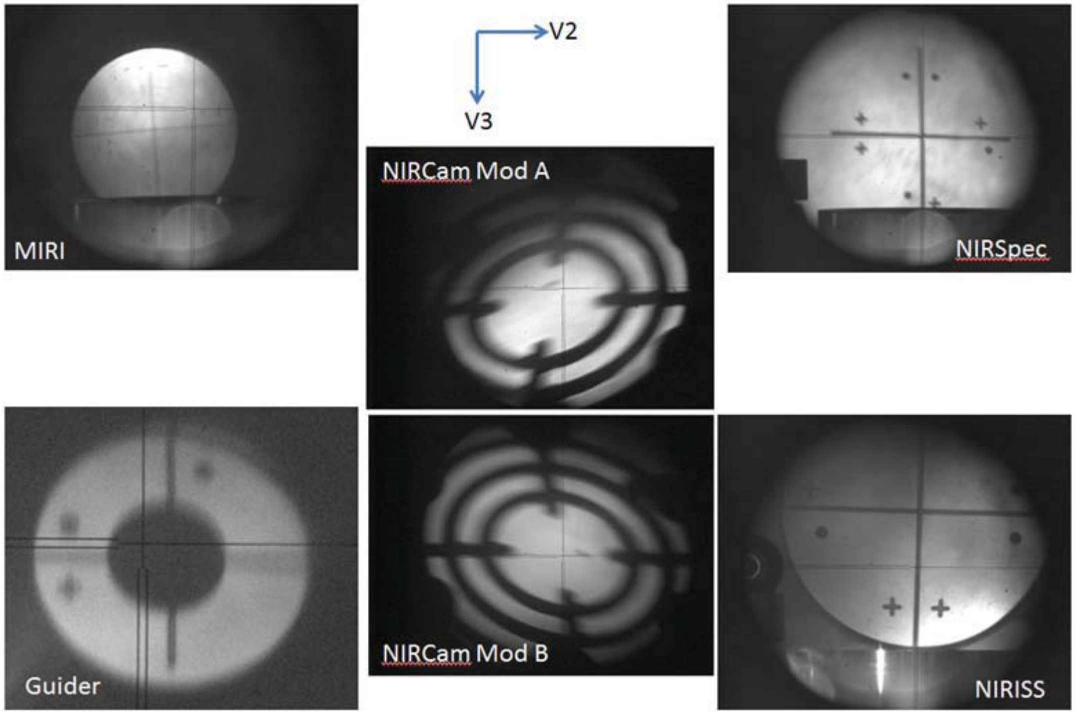
PAR Analysis

- Analysis starts with the final USMN average results from the TB/SMR survey of the structure
- Measurements are made of all visible ISIM structure targets during the PAR measurements and are best-fit transformed to the final USMN results of the ISIM survey
- The measured pupil target location is used as the basis for image analysis
- ImageJ software is used for the image analysis.
- Five images taken with illumination altered between images for each PAR



PAR Analysis

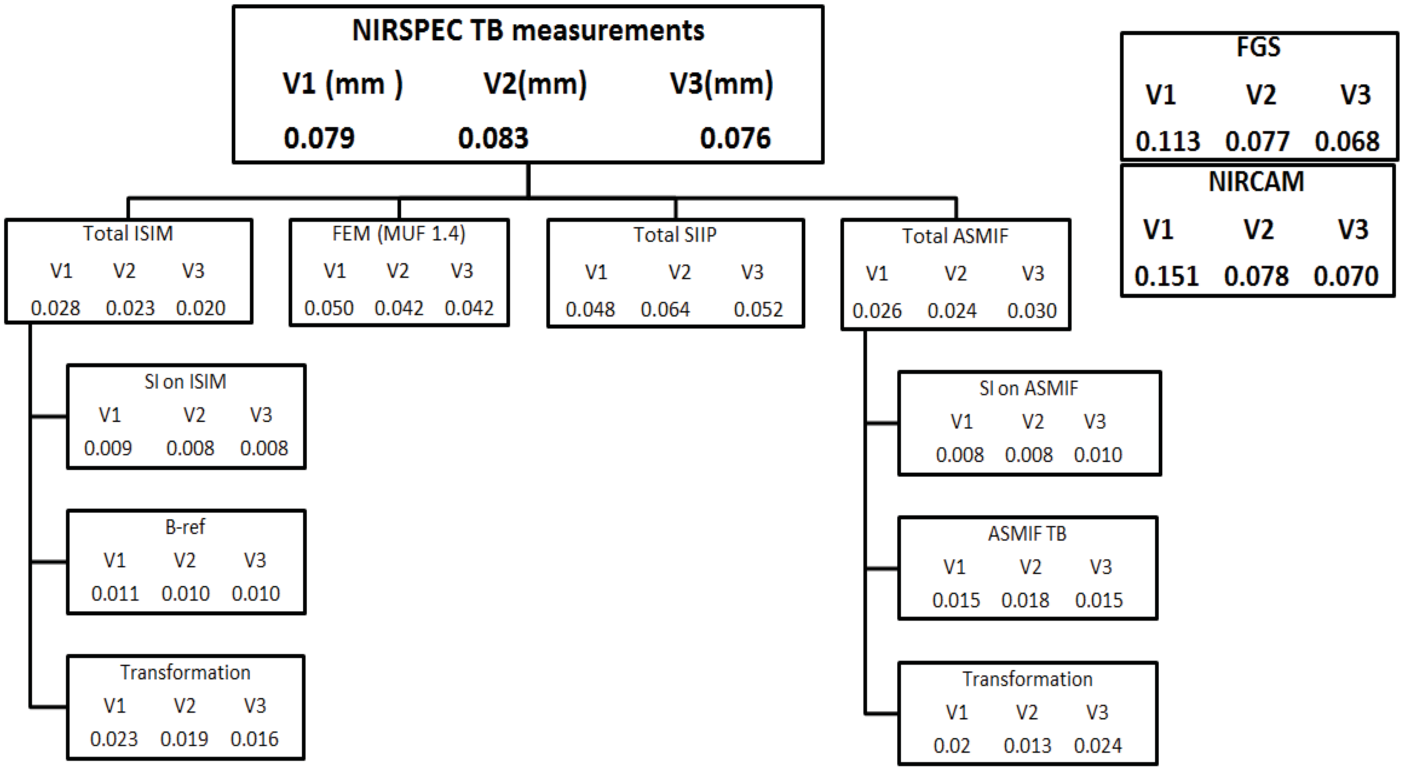
- PAR images from all instruments
- PAR targets are not perfectly aligned to the SI pupil. The offsets are known
- All SIs are not designed to image well at ambient



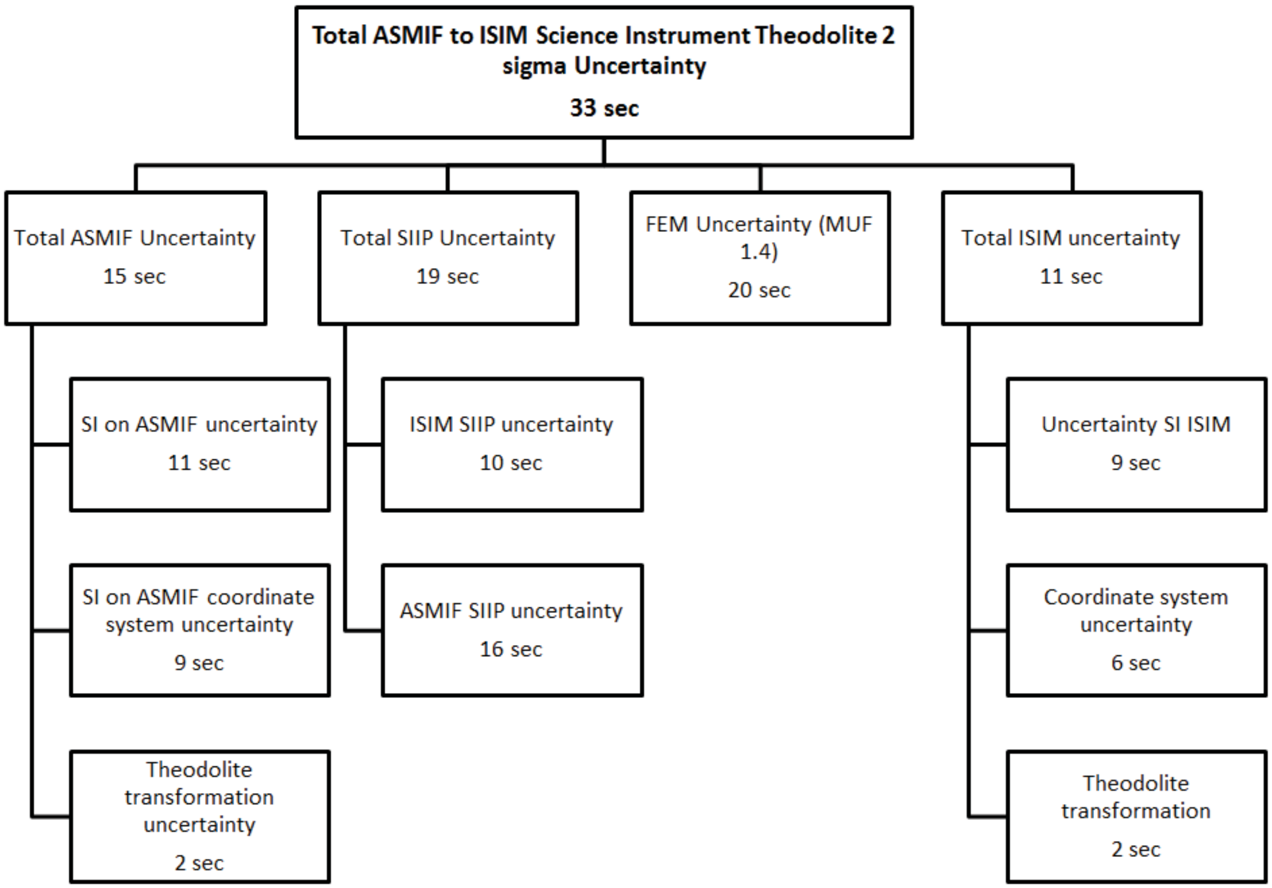
Results

- ISIM structure data presented is from the pre-cryovac 2 testing (May 2014)
  - Pre-CV1 prime—FGS, MIRI
  - Pre-CV1—FGS, MIRI
  - Post-CV1—FGS, MIRI (PAR only)
  - Pre-CV2 prime—All SIs
  - Pre-CV2—All SIs
  - Post-CV2 (Fall 2014)—All SIs
- FEM difference due to the different SI orientation and loading conditions are accounted for in the results.

Example of development of pass/fail values for nest location measurements



Example of development of pass/fail values for cube face orientation measurements



PAR Image Location Pass/Fail Criteria

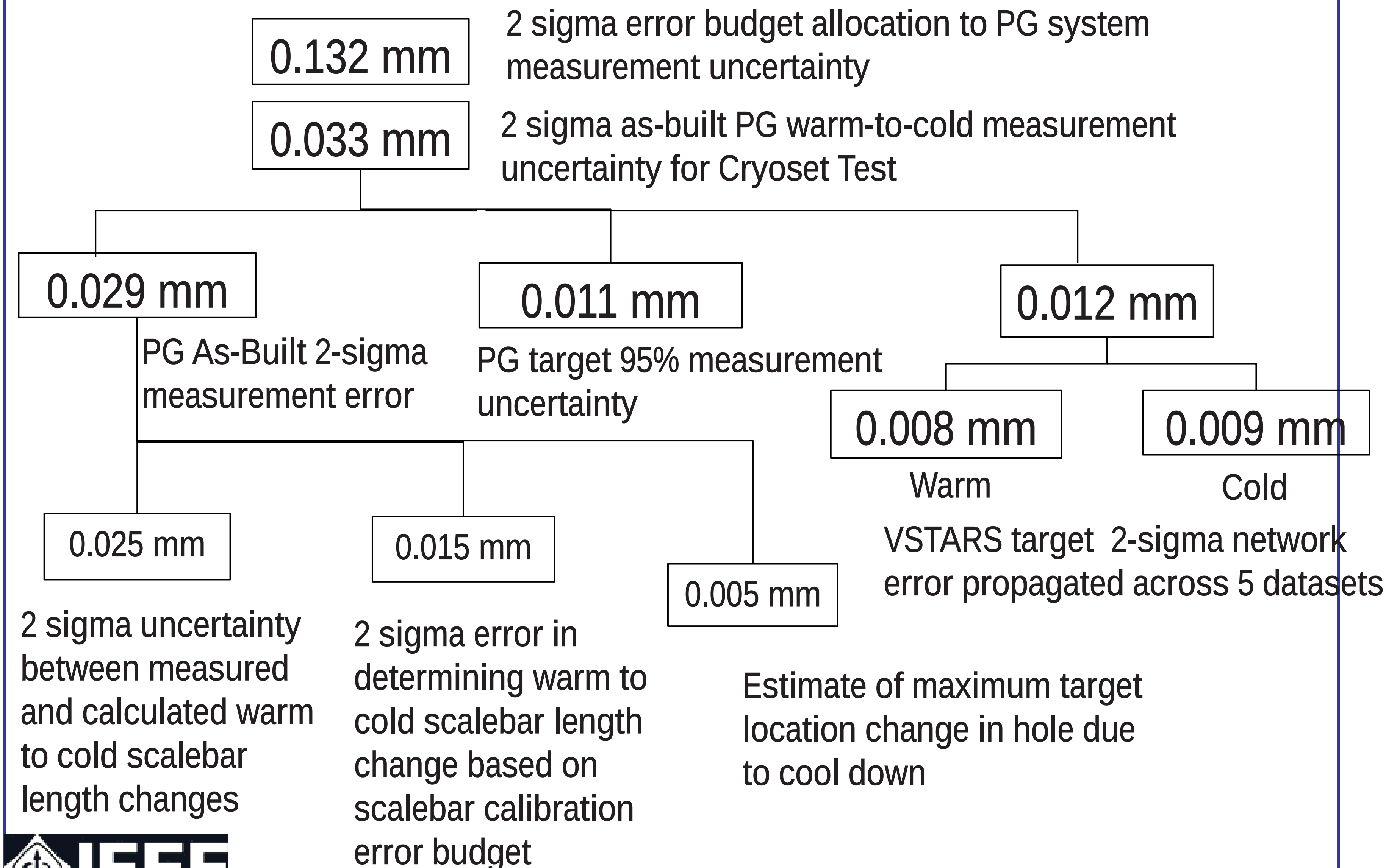
	V1 (mm)	V2 (mm)	V3 (mm)
Test to test uncertainty (2σ)	0.071	0.239	0.239

- Based on relative test to test changes
- Defined in the entrance pupil space
- ISIM level requirement for pupil shear is 3.1%
- To put this into perspective the pass fail values for V2/V3 converted to pupil shear percent is 0.16%. This is a factor of 20 better than the absolute alignment requirement for pupil shear

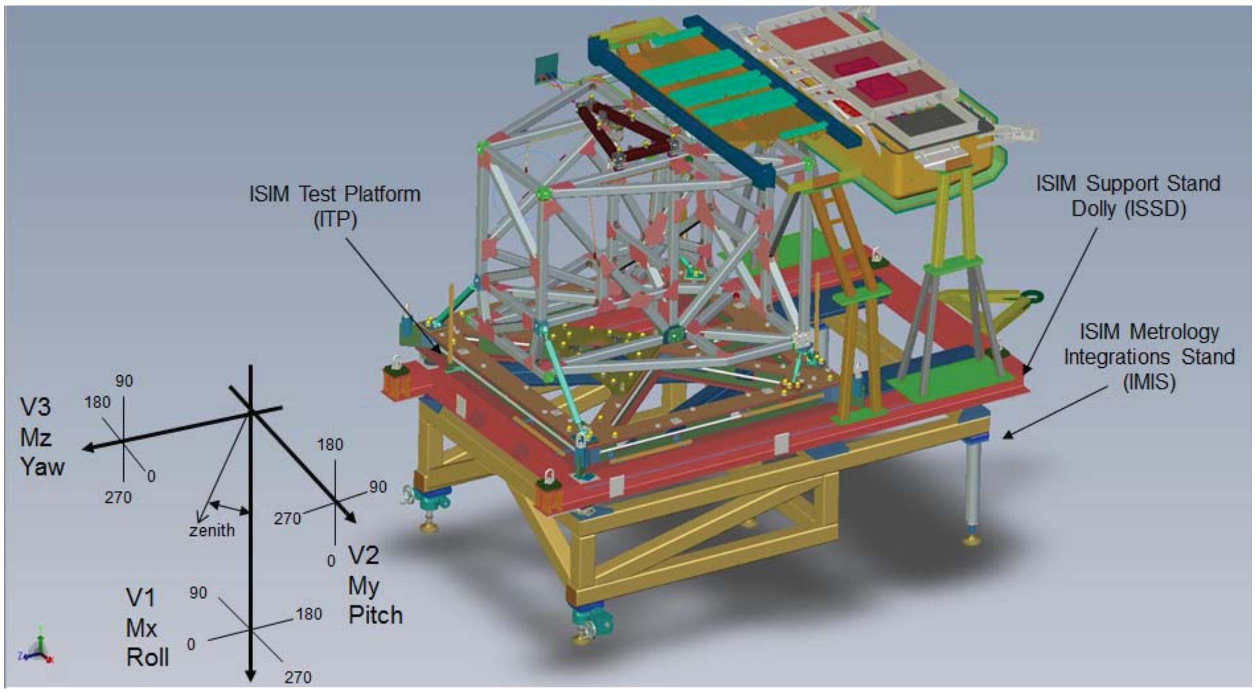
$$\%Pupil\,Shear = 100\frac{\Delta V}{152}mm$$

OTE exit pupil diameter

PG System Measurement Uncertainty



ISIM Coordinate System



ISIM and SI TB/SMR Results

FGS		
V1	V2	V3
0.113	0.077	0.068

NIRCAM		
V1	V2	V3
0.151	0.078	0.070

NIRSPEC TB measurements		
V1 (mm)	V2(mm)	V3(mm)
0.079	0.083	0.076

Frame:VOTE-ISIM-PreCV2-A		Delta Post CV1 FEM corrected			Delta ASMIF FEM corrected		
LR/LT measurments		V1 (mm)	V2 (mm)	V3 (mm)	V1 (mm)	V2 (mm)	V3 (mm)
ISIM Targets	IST-B20	0.000	-0.013	0.005			
	IST-B21	0.003	0.006	-0.013			
	IST-B22	-0.010	-0.014	-0.002			
	IST-B23	-0.009	-0.018	0.001			
	IST-B31	-0.025	0.007	0.006			
	IST-B33	0.032	0.004	-0.010			
	IST-B35	-0.009	-0.012	-0.003			
FGS targets	FGS-OB-F1	0.044	-0.052	-0.029	0.011	0.101	0.022
	FGS-OB-F2	-0.007	-0.029	-0.028	0.026	0.064	0.032
	FGS-OB-F3	-0.033	-0.018	-0.029	0.009	0.051	0.038
	FGS-OB-F5	-0.031	-0.023	-0.020	0.014	0.005	-0.007
NIRCam targets	MODA +V1_1				-0.064	-0.027	0.030
	MODA +V1_3				-0.053	-0.054	0.030
	MODA +V3_4				-0.072	-0.017	0.065
	MODA -V1_3				-0.119	0.034	0.057
	Module A +V3 hole				-0.043	0.023	0.048
	Module A -V1 hole				-0.103	0.000	0.054
	Module B +V3 hole				-0.040	0.002	0.043
	Module B -V1 hole				-0.071	0.008	0.058
NIRSpec targets	OBBP-LTT-01				-0.058	-0.021	-0.030
	OBBP-LTT-02				-0.027	-0.002	-0.047
	OBBP-LTT-03				-0.010	-0.015	-0.054
	OBBP-LTT-04				-0.044	-0.020	-0.056
	OBBP-LTT-05				-0.023	0.005	-0.059
	OBBP-LTT-06				-0.032	-0.110	-0.035
MIRI targets	MIRI-OB-FA				0.016	0.045	-0.077
	MIRI-OB-FB				0.035	-0.002	-0.040
	MIRI-OB-FC				0.033	0.000	-0.033
	MIRI-OB-FD				0.062	0.026	-0.042

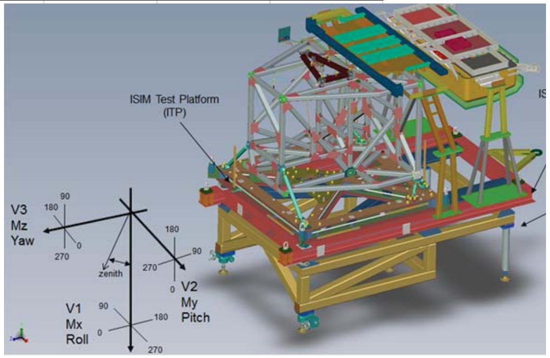
From Pre-CV1 (MIRI targets)

ISIM/SI Cube Results

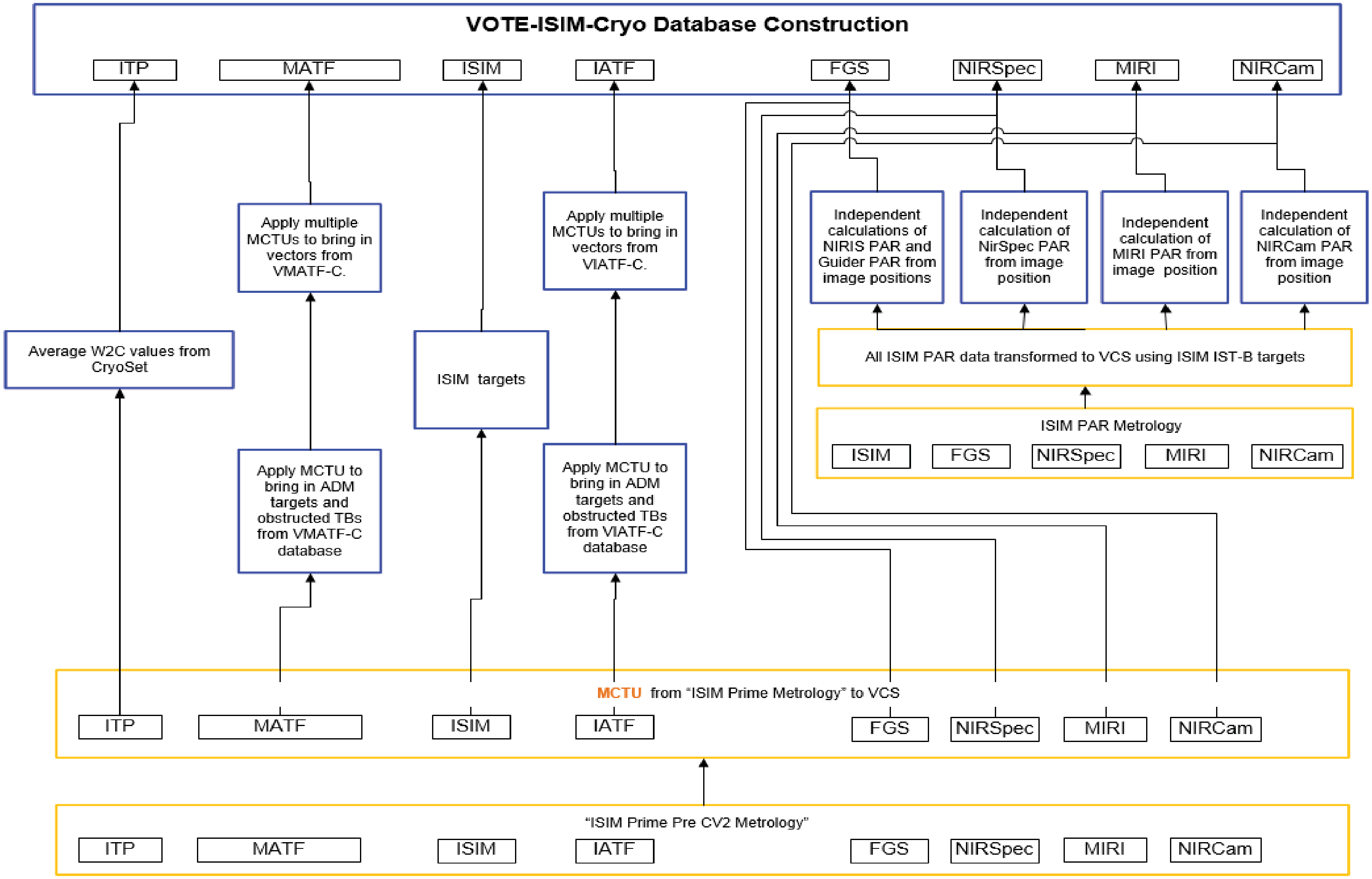
Theodolite FEM Deltas	Roll about V1			Pitch about V2			Yaw about V3		
Cube Vector	deg	min	sec	deg	min	sec	deg	min	sec
ISIM B21 -V2	0	0	-2				0	0	2
ISIM B33 -V3	0	0	1	0	0	-5			
ITP OC4 +V2	0	0	1				0	0	-5
ITP OC4 +V3	0	0	2	0	0	-10			
FGS-OC-F1 +V2	0	0	10				0	0	-27
FGS-OC-F1 -V3	0	0	-4	0	0	18			
FGS-OC-F2 +V2	0	0	-2				0	0	-32
FGS-OC-F2 -V3	0	0	-2	0	0	13			
NIRCam-OC-B +V3	0	0	0	0	0	-5			
NIRCam-OC-B -V1				0	0	-3	0	0	40
NS-OC-01 +V3	0	0	33	0	0	-9			
NS-OC-01 +V1				0	0	-9	0	0	-1
NS-OC-02 -V3	0	0	-39	0	0	4			
NS-OC-02 -V1				0	0	3	0	0	19
MIRI-OC-F1 -V2	0	0	-9				0	0	22
MIRI-OC-F1 -V3	0	0	-21	0	0	13			
MIRI-OC-F2 -V2	0	0	24				0	0	44
MIRI-OC-F2 -V3	0	0	0	0	0	13			

Total ASMIF to ISIM Science Instrument Theodolite 2 sigma Uncertainty

33 sec



Database Build



Summary

- We have successfully verified the SI-level target calibration is in good agreement with measured SI OB locations on ISIM element to better than the required pass/fail values
- This process will be repeated during ISIM level I&T to trend any potential alignment changes due to thermal cycling (CV2, CV3), vibration and acoustic exposure
- This process will also be repeated after SI work during I&T.

Acknowledgements

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Questions?
Thank you for your attention.

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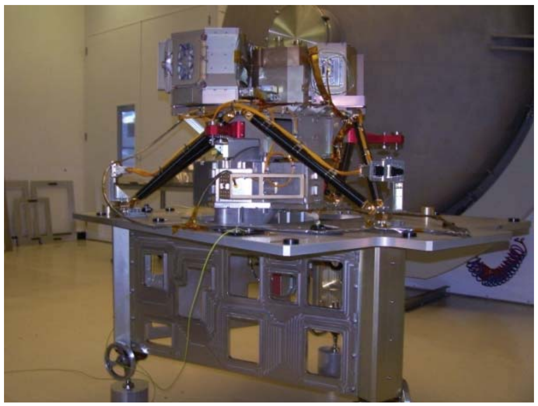
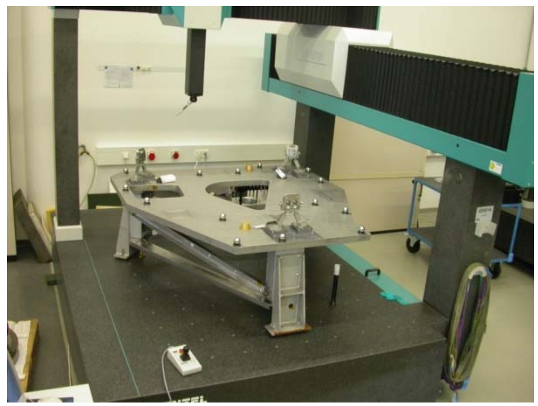
Back up Slides

ASMIF status

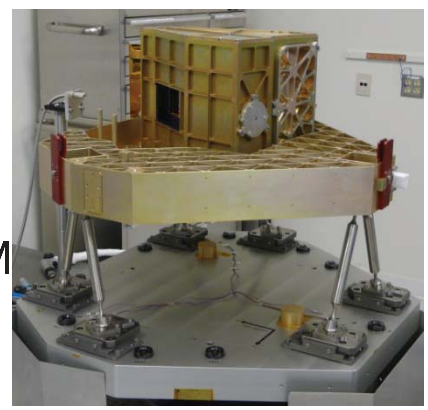
- MIRI ASMIF: Delivered to RAL, May 2007
- NIRSpec ASMIF: Delivered to Astrium, Sep 2007
- FGS ASMIF: Delivered to COM DEV, Dec 2007
- NIRCam ASMIF: Delivered to Lockheed Martin, Jan 2009



MIRI VM with ASMIF at RAL



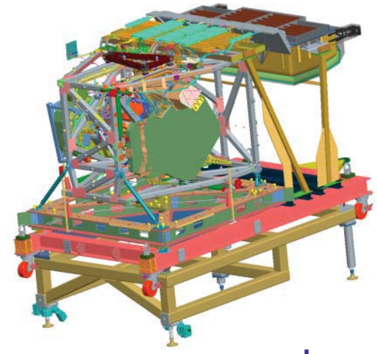
NIRSpec ASMIF post-shipment calibration check and OBK installation at Astrium



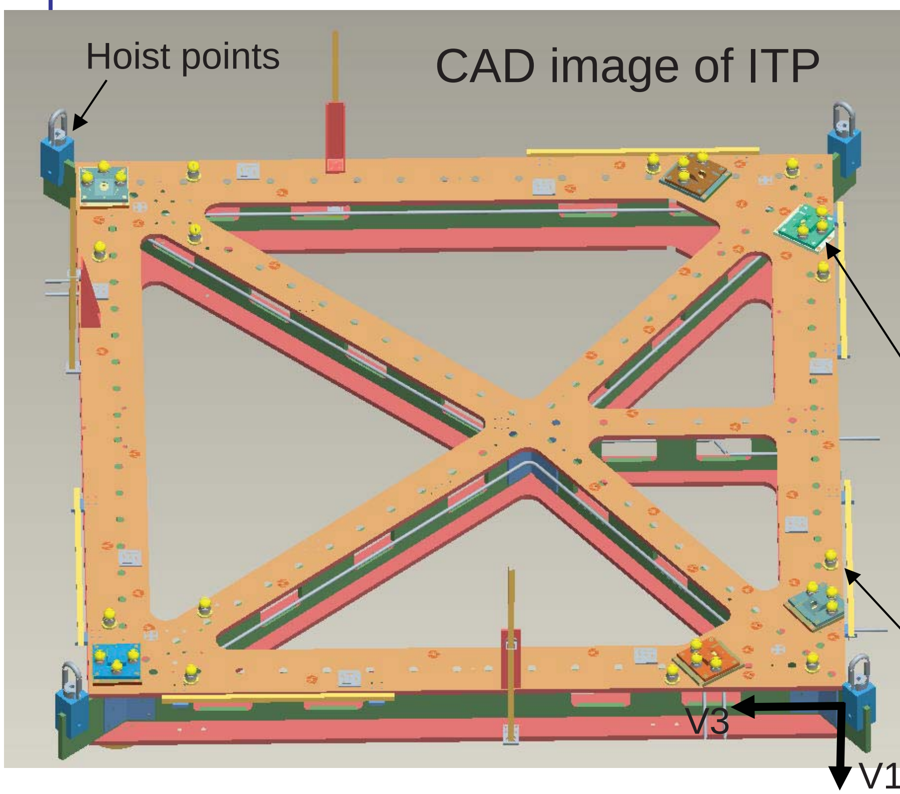
FGS ETU with ASMIF at COM DEV, Ottawa

NC bench installed on ASMIF at LMCO

ISIM Test Platform (ITP)

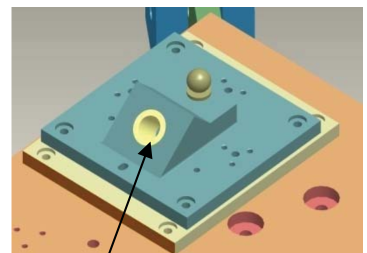


- Master gauge for nominal OTE-ISIM interface (“reference A”)
- Fiduciary points on KM sockets map to MICD
- Used for ambient integration, metrology and alignment (SSDIF)
- Used for cryogenic testing in both Structure cryo-set and Integrated ISIM testing
- Supported by IMIS and ISSD in SSDIF for ambient work
- Supported by Upper GESHA in SES chamber for cryogenic testing
- ~30K ITP is attached to the ~100K Upper GESHA via thermal isolator stand-offs
- Supports MATF for OSIM-to-reference A alignment
- Extensive optomechanical requirements related to alignment and stability

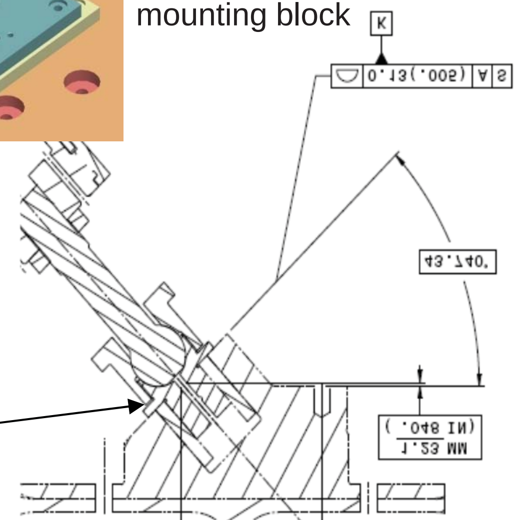


OTE-ISIM kinematic mount socket

Metrology targets



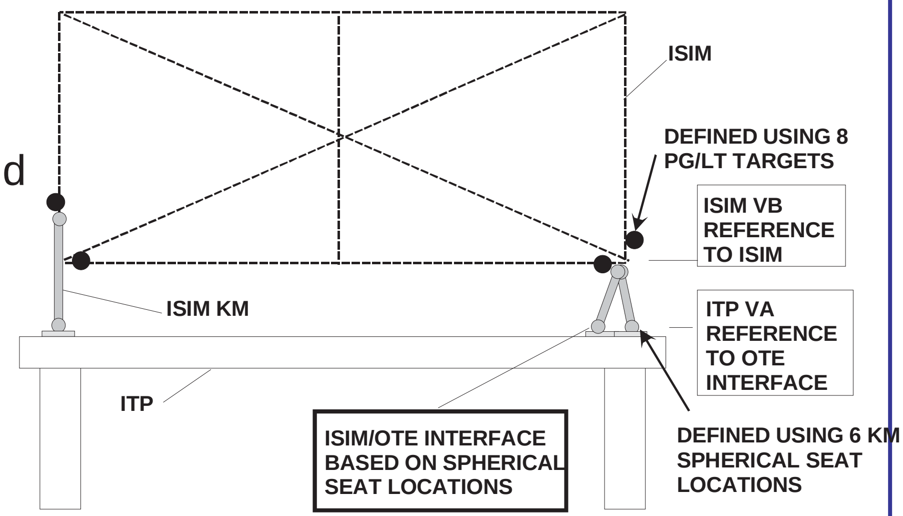
CAD image of OTE-ISIM kinematic mount socket and invar mounting block

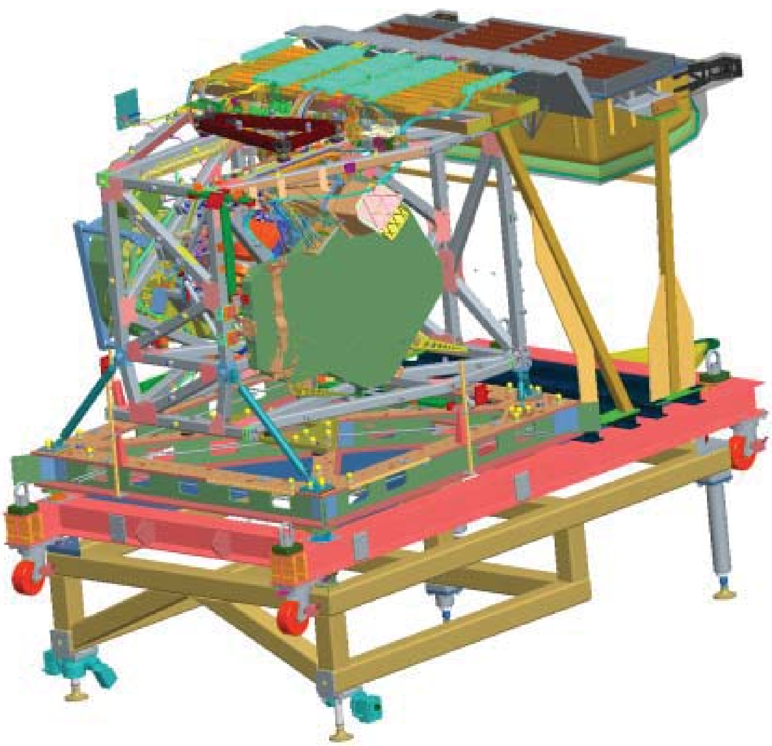


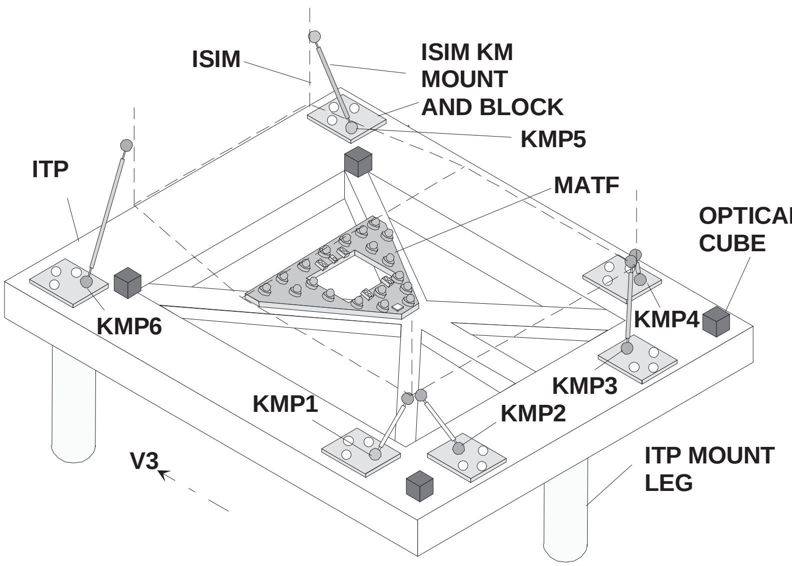
ISIM KM strut and OTE interface

Coordinate system and ISIM hardware

- V-coordinate system is mapped to surrogate backplane (ISIM Test Platform fixture; ITP) via least-squares fit
- Mapping is redefined for different load and temperature configurations (significant warm-to-cold change and gravity sag)

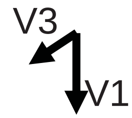


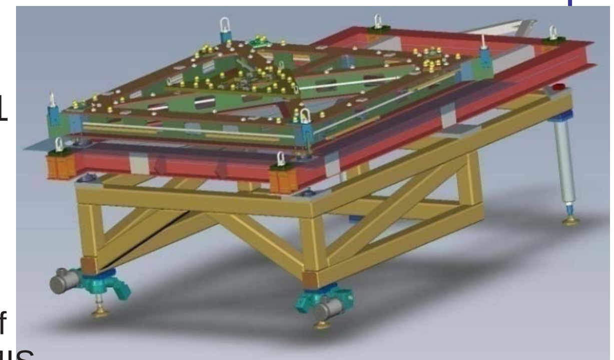




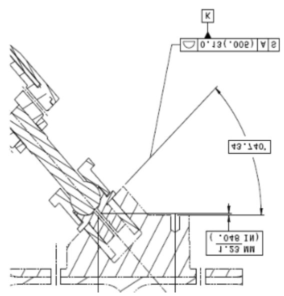
ITP calibration, ambient

- Ambient calibration of ITP
  - Definition of V-coordinate system using interface references and MICD
  - Calibration of ITP metrology references using LT, theodolites, PG
  - Cube normals are aligned to approximately represent axes of V-coordinate system
- Changes to ambient calibration
  - Various load cases (empty, bare Structure, Integrated ISIM, OSIM's BIA)
  - Repeatability with handling and mounting
- MATF installation
  - Calibrate 6 DoF alignment with respect to V-coordinates
  - Repeatability of attachment
- ISIM Error Budget Report (JWST-RPT-008175) documents allocations for ITP metrology uncertainty (knowledge) and impact to flight hardware alignment

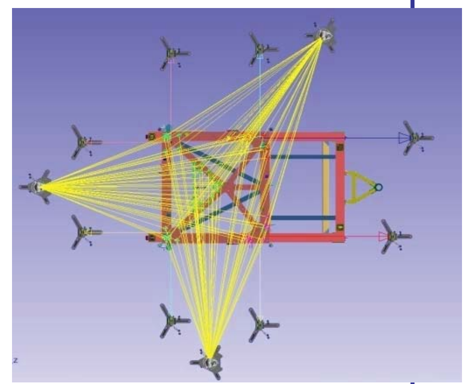




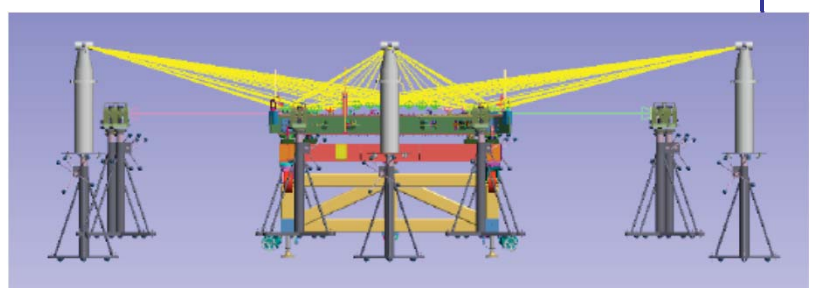
CAD image of ITP+ISSD+IMIS showing metrology references



Extraction from MICD showing 1 KM interface



Simulation of ITP metrology (top view, looking in +V1 direction; SSDIF)



Simulation of ITP metrology (side view; SSDIF)

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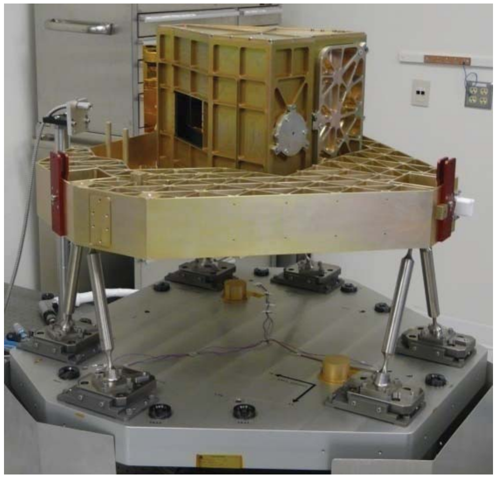
Alignment approach for SI-to-Structure (Ambient Science Instrument Mechanical Interface Fixture; ASMIF)

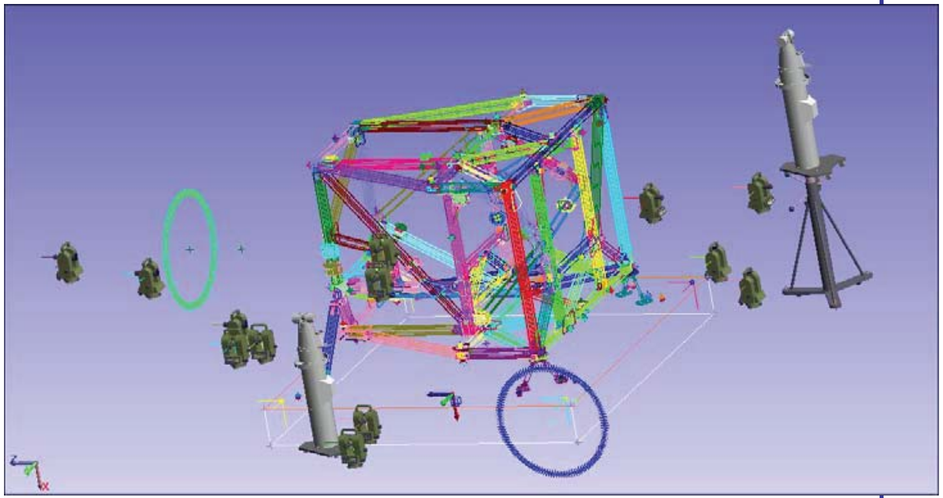
- Alignment of SI optical train relative to SI-ISIM interface is verified by SI developer using optomechanical tooling (i.e., ASMIF)
- Levy requirements on Structure to avoid iterative compensated cryogenic alignment (i.e., no “windage” within Structure --- no pre-alignment at ambient to achieve correct placement at cryogenic operating temperature)
- Place SI-Structure interface plats on the ground at ambient at their nominal on-orbit alignment positions and orientations --- differences between warm vs. cold structure and loaded vs. 0g structure are small and captured in error budget
- Measure bare Structure cryogenic performance to verify that it meets alignment requirements and increase confidence in Integrated ISIM performance (Structure’s “cryo-set” test)

FGS ETU with ASMIF at COM DEV, Ottawa

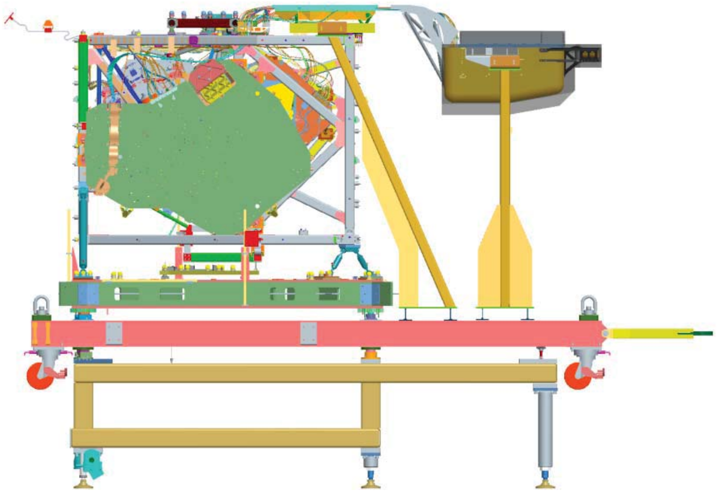


Ambient integration of SIs with Structure

- SIs are integrated to Structure
- Integrated ambient baseline metrology performed after Structure is populated with SIs: SI optical bench and ISIM Structure targets are measured using laser trackers and theodolites at ambient temperature under 1-g
- Measurements are compared with expectations based on
  - SI+ASMIF metrology results
  - As-built ITP, Structure, and SI validated mechanical models (e.g., gravity sag, ITP distortion)
- Measurements, including uncertainty, must agree with as-built mechanical models and “blueprints”
- This step ensures that SIs are where they should be in Structure at ambient under 1-g



Simulation of metrology for NIRSpec instrument integration



CAD view of Integrated ISIM showing NIRSpec side of assembly