Thermal Infrared Sensor
TIRS
Design and Status

Landsat Science Team Meeting

June 22 – 24, 2009

Rochester NY

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NASA/GSFC Code 693

301-286-2042

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Introduction

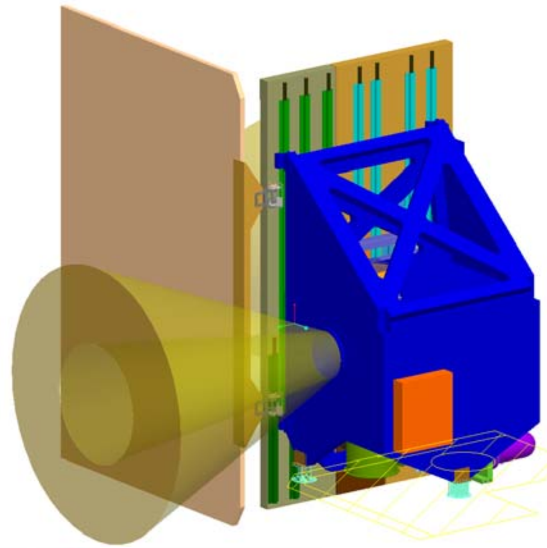
- TIRS is a two channel thermal imager that provides data continuity for the Landsat thermal band.
  - The LDCM TIRS Level 3 requirements have been approved and are under configuration control.
  - TIRS operates in concert with, but independently of, the Operational Land Imager (OLI). The OLI is a procured instrument from Ball. It successfully completed its CDR October, 2008.
- TIRS will produce radiometrically calibrated, geo-located thermal image data
  - TIRS will deliver algorithms and parameters necessary to evaluate data and produce required outputs
  - Final scene data generated as part of the Data Processing and Archive Segment at the United States Geological Survey/ Earth Resources Observation and Science (EROS) facility in Sioux Falls, South Dakota.
  - USGS responsible for operational algorithms
  - OLI and TIRS data will be merged into a single data stream.
- LDCM launch date of December 2012 allows for incorporation of TIRS into the mission.
- TIRS Delivery date is December 2011.
- TIRS High-Level Requirements
  - TIRS Shall Not delay launch of LDCM
  - TIRS Operation Shall Not affect OLI
- The TIRS delivery schedule is a significant driver of the overall TIRS development.

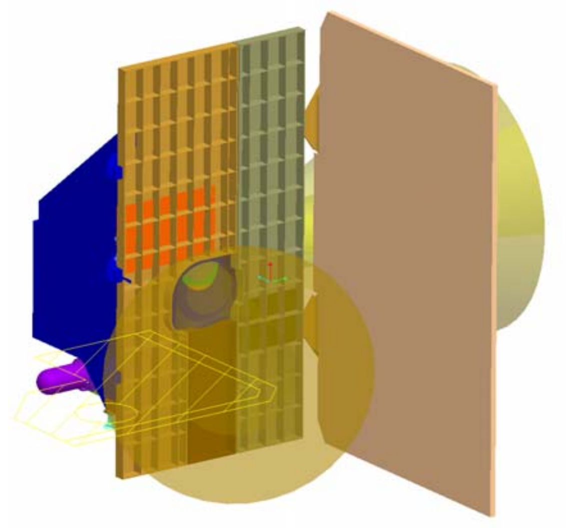
History of Current TIRS Implementation

- A Phase A study was initiated by HQ on July 1, 2008.
  - The purpose of the study was to develop a concept design, assess the programmatic implementation, including a schedule and cost assessment, and begin the instrument development activity.
  - The instrument concept and implementation approach satisfies the LDCM level 3 requirements without delaying the planned December 2012 launch of LDCM.
- Systems Concept Review was successfully completed on October 17th, 2008
- System Requirements Review was successfully completed on February 2-3, 2009.
- A separate Cost and Schedule review was successfully conducted on February 12, 2009.
- All subsystems carried out Engineering Peer Reviews from April – May 2009
- Preliminary Design Review was successfully completed on May 27-28, 2009.
  - Reduced schedule risk by 6 months
  - 14 RFAs, Several of which will be closed by Mission PDR
- Second Cost and Schedule review was successfully conducted on May 29, 2009.

TIRS Overview

- 2 channel (10.8 and 12 um) thermal imaging instrument
- Quantum Well Infrared Photometer (QWIP) detector/FPA built in-house at Goddard
- <120 m Ground Sample Distance (100 m nominal)
- 185 km ground swath (15° field of view)
- Operating cadence: 70 frames per second
- Pushbroom design with a precision scene select mirror to select between calibration sources
  - "Cold OLI" (B. Markham)
- Two full aperture calibration sources: onboard variable temp black body and space view
- Passively cooled telescope assembly operating at 180K
- Actively cooled (crycooler) FPA operating at 43K
- 3 Year Design Life, Class C Instrument





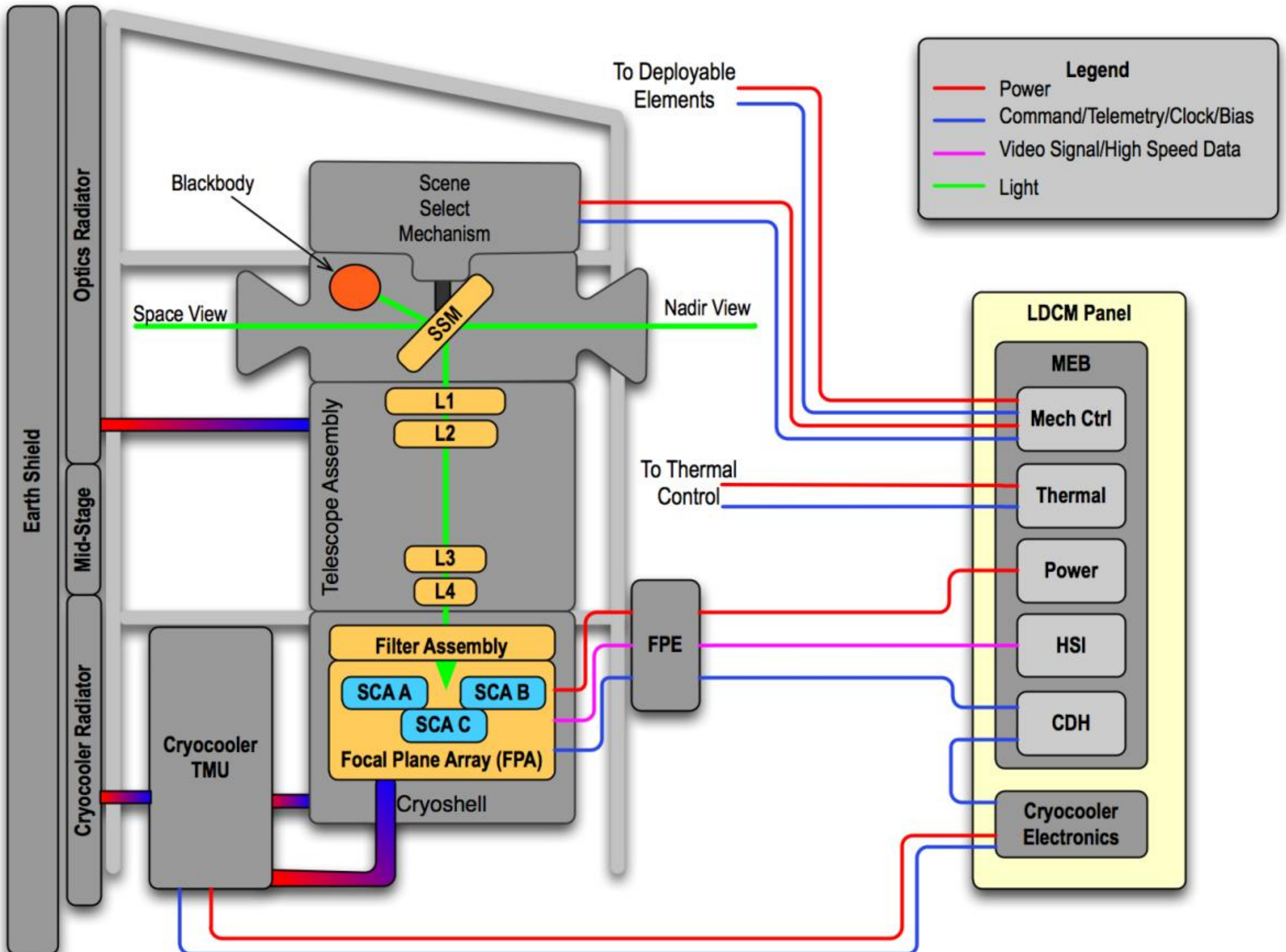
Top Level Operations Concept

- Imaging Requirements
  - 400 WRS-2 scenes/24 hour period
  - Image up to 15 degrees off-nadir
  - Acquire up to 77 contiguous sun-lit scenes per orbit
  - Acquire up to 38 contiguous night scenes per orbit
- Calibration Operations Requirements
  - Onboard calibration capability
    - Spaceview and onboard NIST Traceable Black Body
  - No calibration maneuvers required
  - No planned vicarious calibration sources
- Orbit Requirements
  - 705 km altitude
  - 98.2 ± 0.015 degrees inclination
  - 10:00 AM equatorial crossing descending node

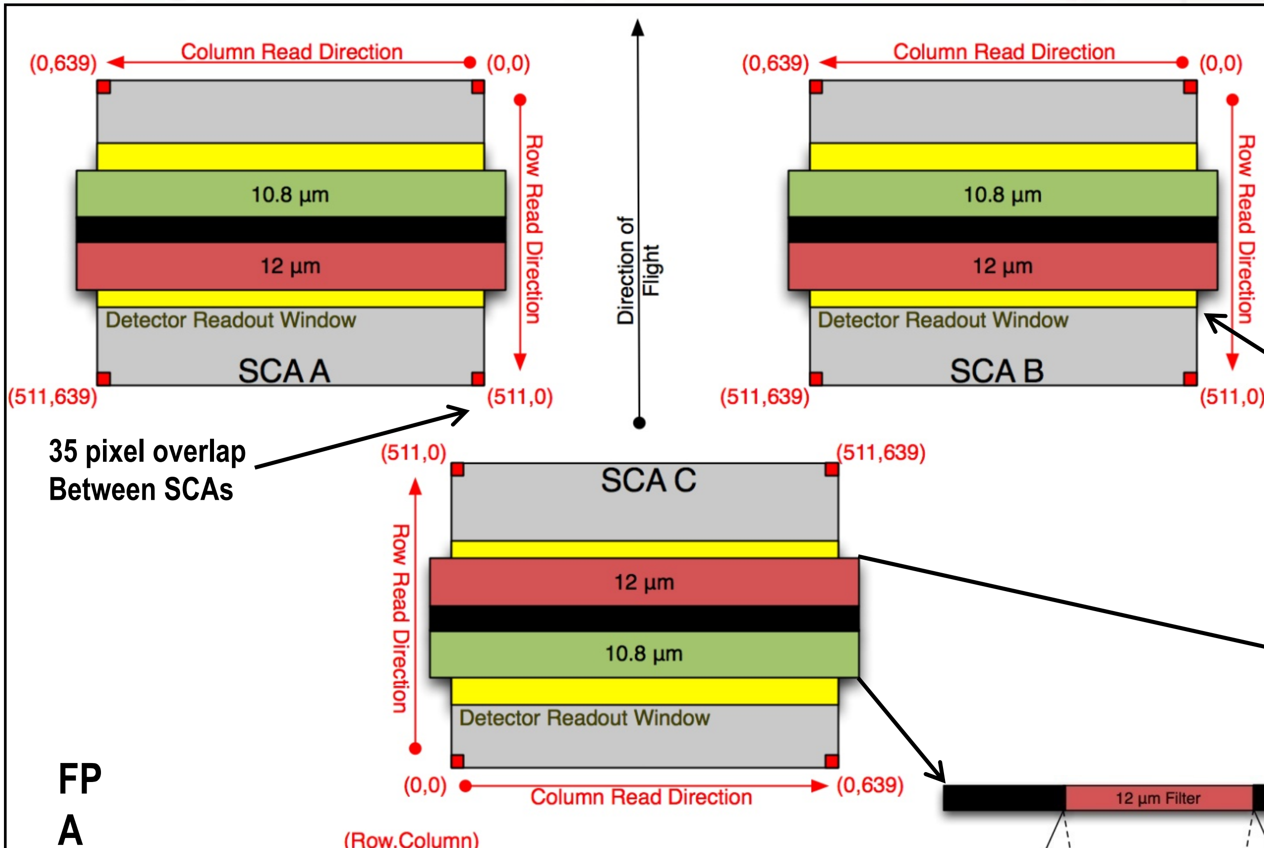
Effect of Cryocooler Jitter on OLI

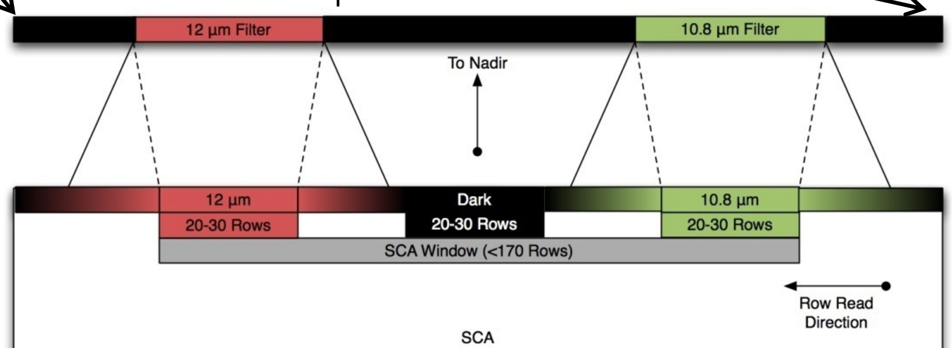
- LDCM Observatory Interface Requirements Document (IRD) specifies the allowable translational and rotational disturbance levels at the OLI/Spacecraft interface.
  - Disturbance requirements were derived to meet the OLI jitter requirement.
- Disturbances generated by TIRS must meet the IRD disturbance requirements.
- Disturbance allocation to TIRS is tentatively set at 30% (TBR) of the total energy requirement.
  - Project is working on finalizing the disturbance requirements and updating the requirements document.
- BATC Cooler Selected has very good jitter characteristics
  - Static Analysis indicates no significant issues
- Mitigation strategies implemented as a precaution
  - Require an on-orbit variable drive frequency
  - Implement passive isolation system to protect against modal frequency uncertainty

Functional Block Diagram



FPA Architecture





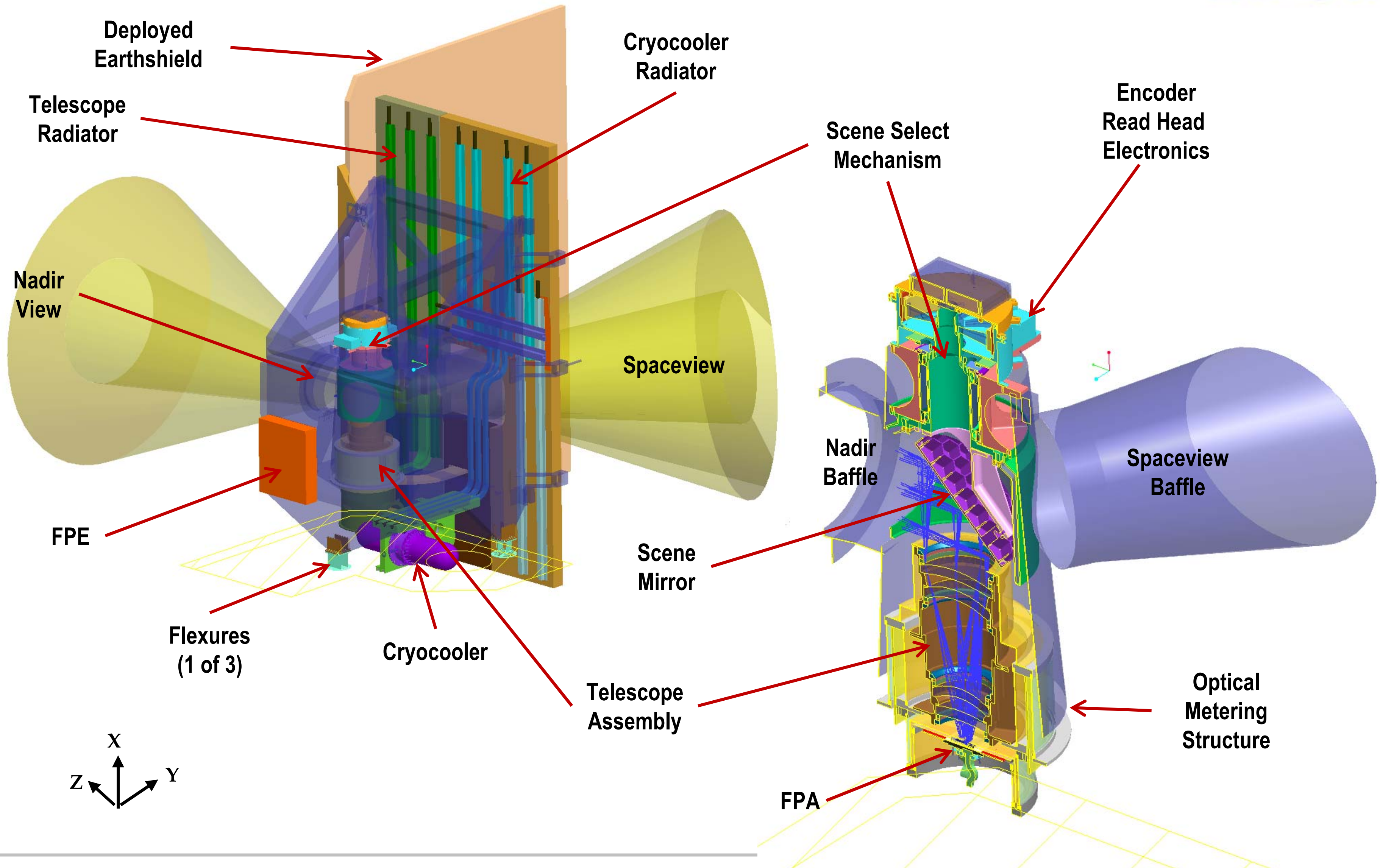
FPA has 1850 unique pixel columns
Corresponds to 185 km swath width
In-track FOV < 5.4 degrees

Filter band locations based on FPA selection . Optimized to best region on FPA.

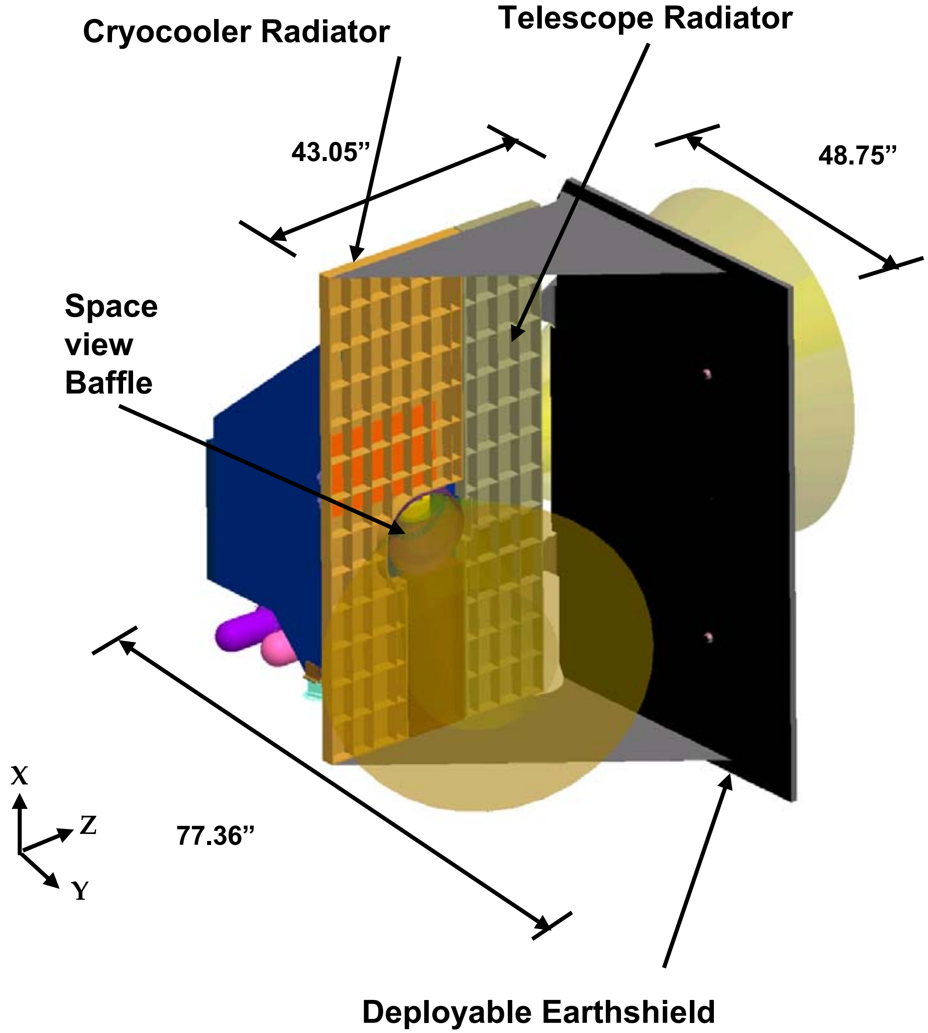
Data Delivered

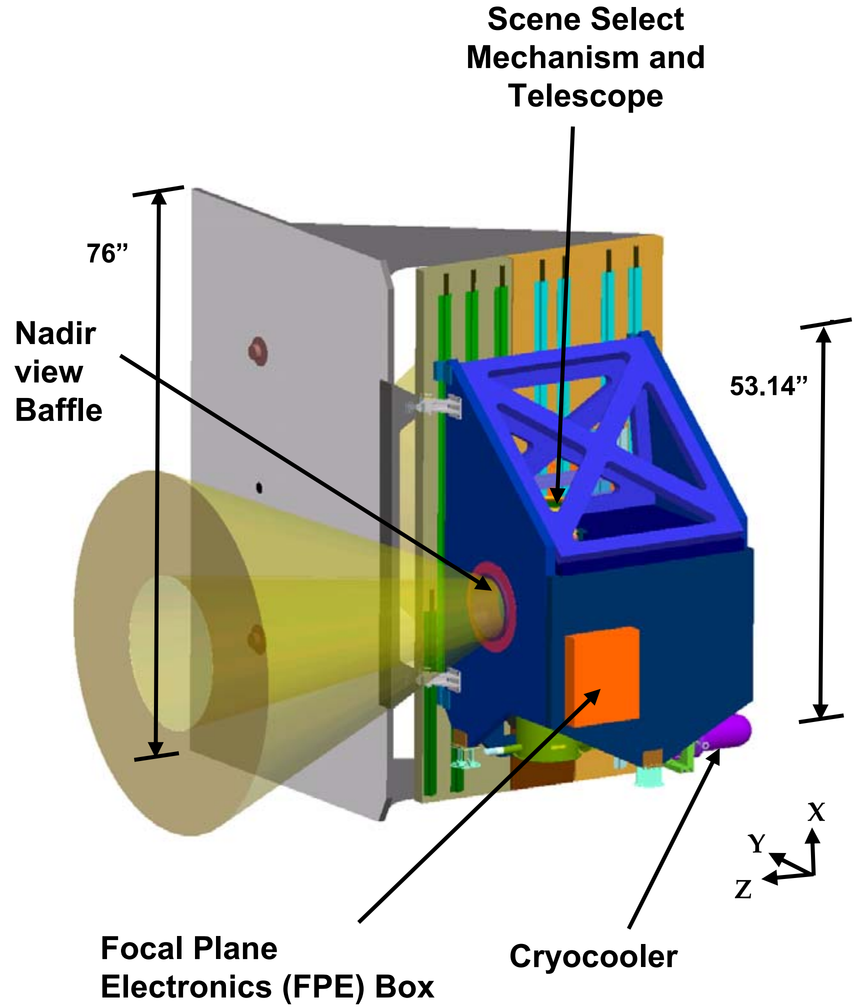
- For normal imaging, every line will include:
  - Two rows each of 10.8 μ, 2 rows of dark, and 2 rows of 12 μ
  - Data truncated to 12 bits by MEB before transfer to Solid State Recorder
  - Includes TIRS Generated Image Header
- During detector diagnostics, a line may include:
  - Up to 512 rows of detector data
  - Data truncated to 12 bits by MEB before transfer to Solid State Recorder
  - Includes TIRS Diagnostics Image Header
- Maximum TIRS Science data rate will be less than 26.2 mbps
  - Normal operating rate <14 mbps

TIRS Sensor Unit Internal View

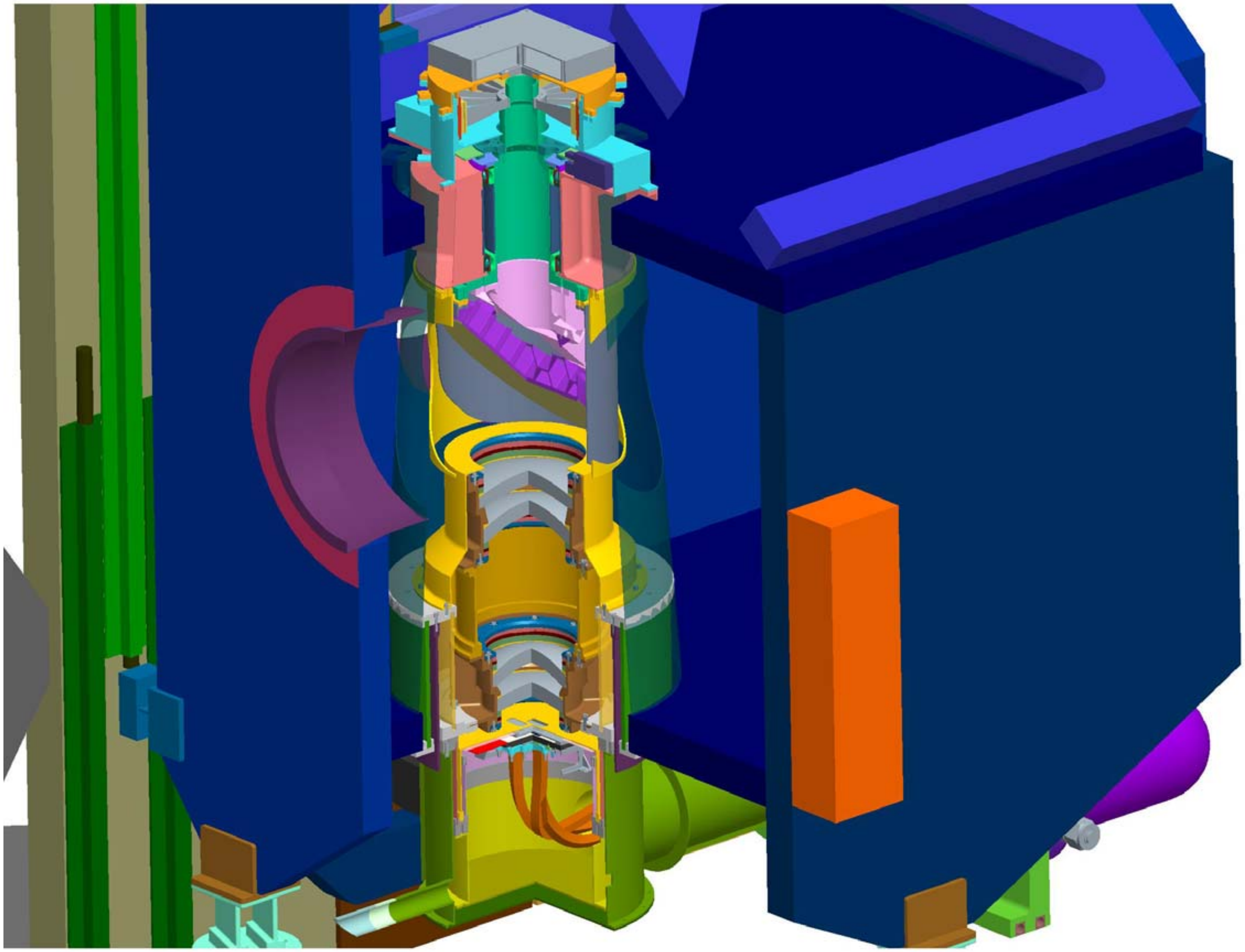


TIRS Deployed



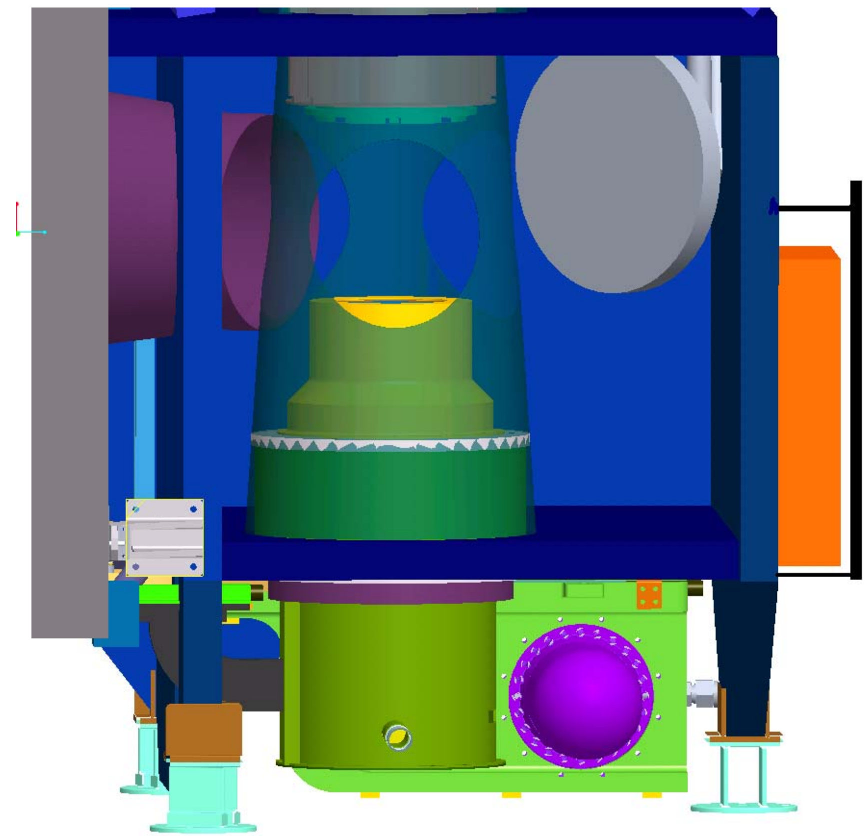


TIRS Internal View

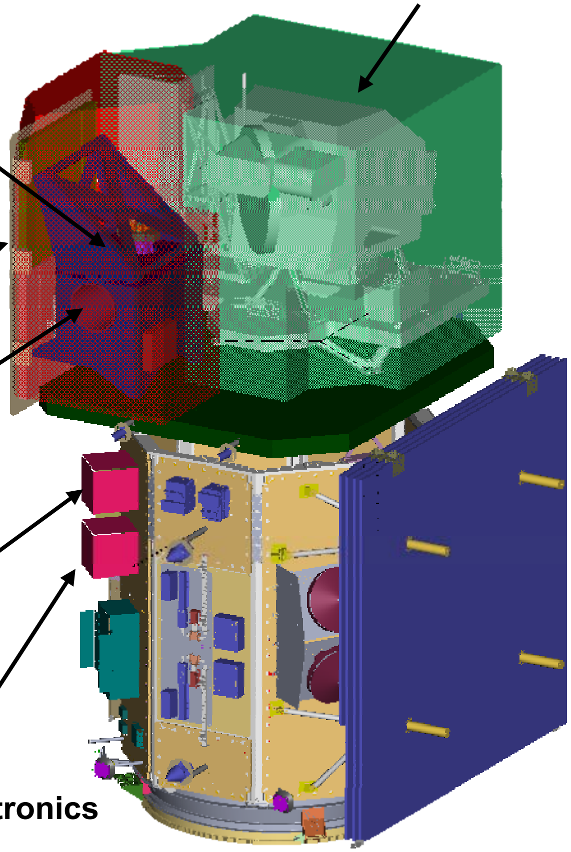


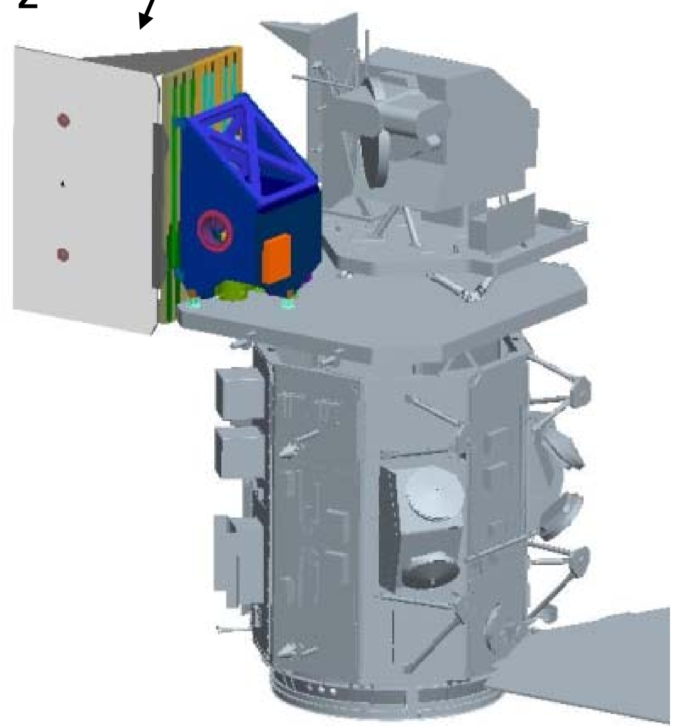
Black Body Calibrator

- Ridged, heated plate with structural support
- Baffle or MLI tunnel to SCONE
- Mounted to primary structure with thermal isolation
- FCL runs from black body calibrator to radiator held off –Y primary structure panel
- FCL will run through fitting opening between panels

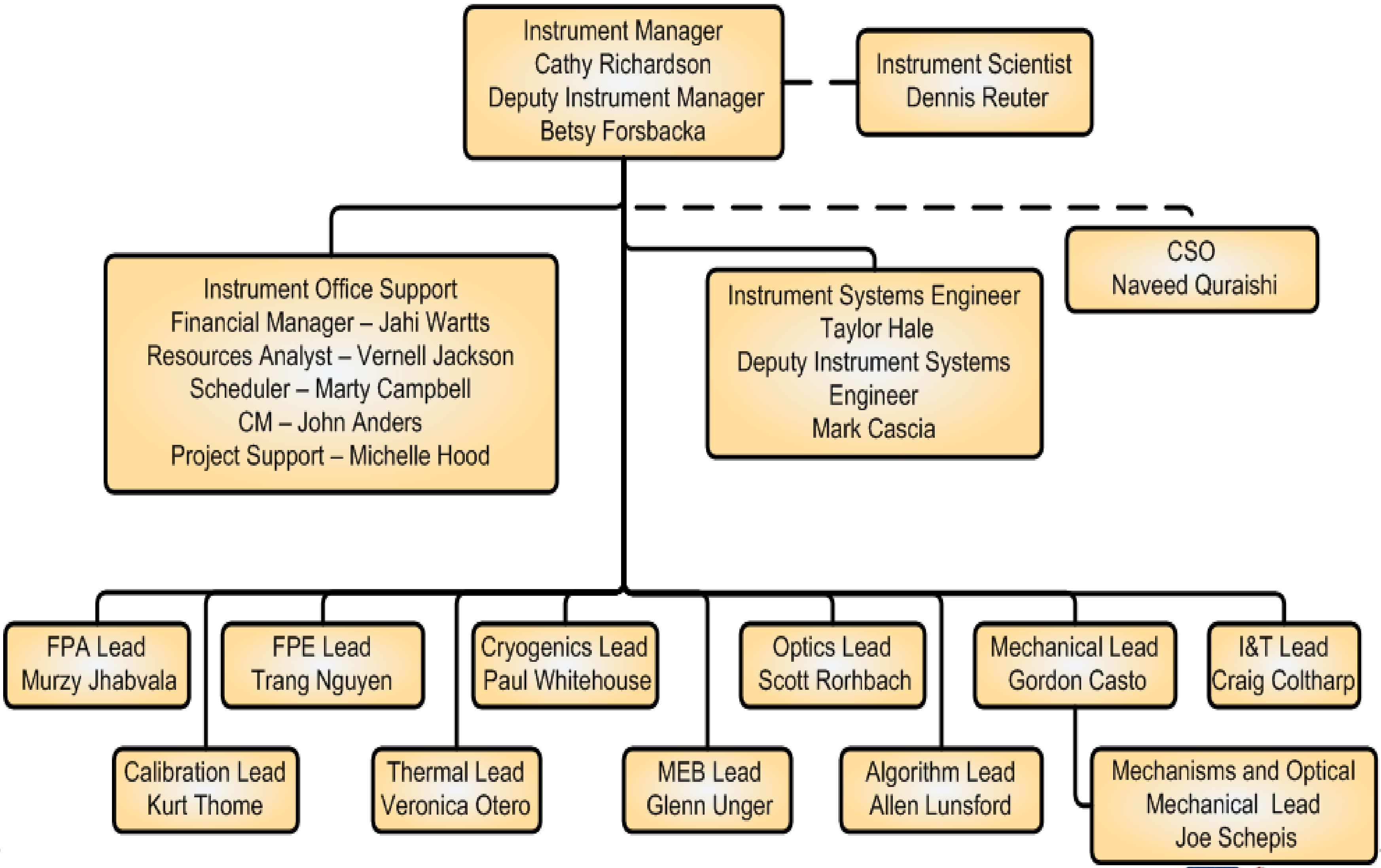


Instrument Configuration on Spacecraft

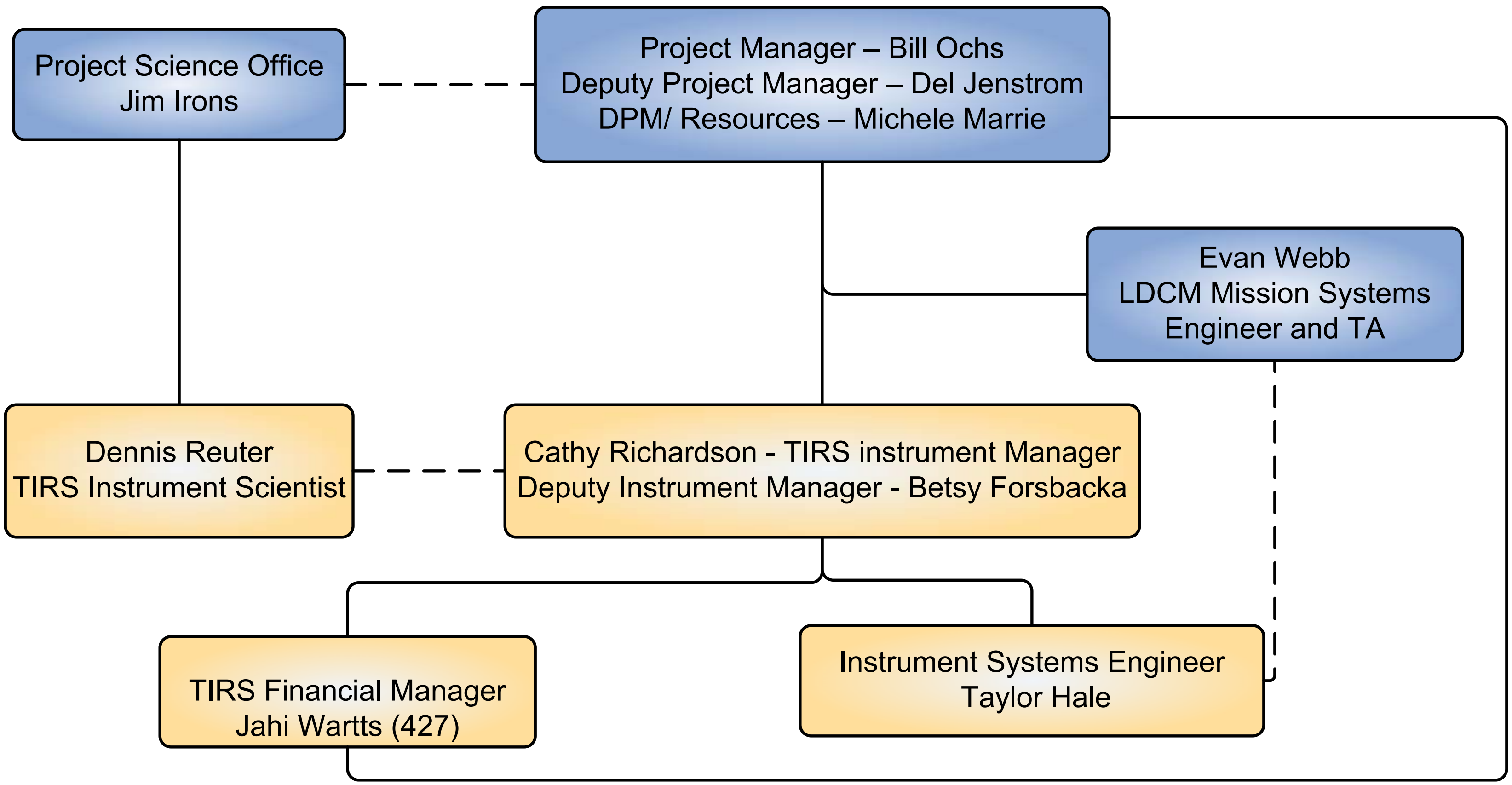




TIRS Organization



LDCM and TIRS Organization



ITA for TIRS is John Leon, Branch Head of 556
Evan Webb, MSE for LDCM will be ITA once TIRS is approved.

Requirements Flowdown

LDCM Level 3 Specifications

- RD
- SCTR
- OBS-IRD
- LEVR
- IMAR

- Level 3 requirements specify
  - Mission performance
  - Mission environment
  - Testing (instrument and subsystem)
  - Design process

TIRS Level 4 Specifications

- Flight Specification
- Simulator/EGSE Specification
- Calibration Test Plan
- Environmental Test Plan

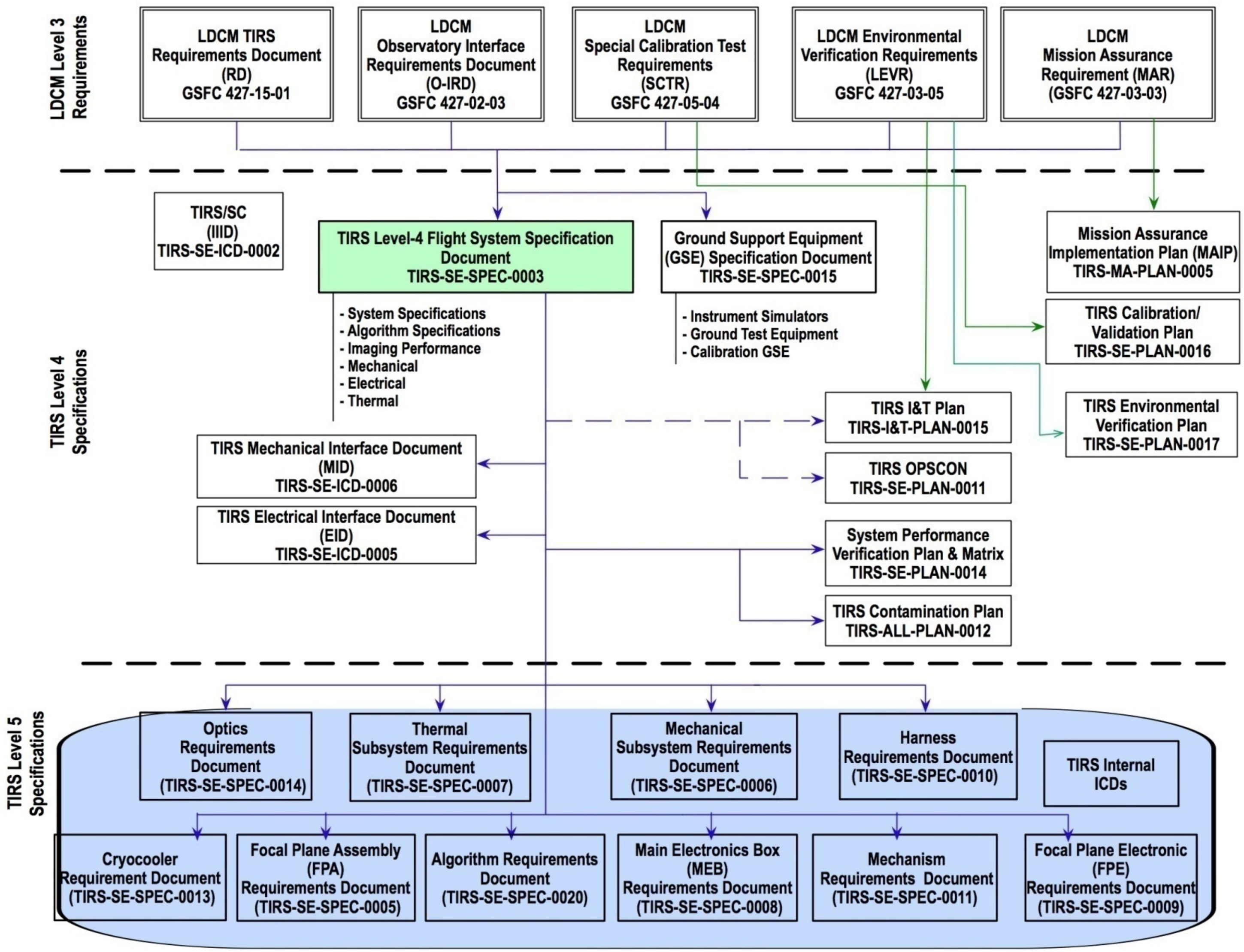
- Level 4 specifications capture TIRS instrument, algorithm, simulator and testing requirements
- Predicted performance and margin shown against Level 4
- Instrument verification will be performed against Level 4
  - Verification by analysis, test, inspection, design or some combination

Subsystem Level 5 Specifications

- Telescope
- Focal Plane Assembly
- Focal Plane Electronics
- Main Electronics Box
- Thermal
- Mechanism
- Cryocooler
- Algorithms
- Mechanical
- Harness

- Level 5 specifications are populated with allocated or derived requirements
- Captures specific subsystem requirements necessary for subsystem buy-off
- PDLs are responsible for verification before delivery to to I&T
  - Verification by analysis, test, inspection or some combination

TIRS Specification Tree



Driving Requirements

TIRS LDCM

	RD #	TIRS #	Parameter	L3 Requirement	Systems Affected	Notes
Radiometry	5.6.2.1	FS-461	NEΔL	$\leq$ 0.059 W/m^2 sr µm (10.8 µ channel) $\leq$ 0.049 W/m^2 sr µm (12 µ channel)	Optics, Thermal, FPE, FPA	Stability based over 24 second WRS-2 scene
	5.6.4	FS-562	Stability	0.7%	Optics, Thermal, FPE, FPA	Over 40 minutes
	5.5.6	FS-442	Bright Target	<1% radiance outside an 11x11 pixel area affected	FPA, FPE	
Spatial Performance	5.5.2.1	FS-400	RER	> 0.007 /m in-track and cross-track	Optics	
	5.5.2.2	FS-404	Edge Extent	<150 m in-track and cross-track	Optics	
	5.5.1	FS-386	GSD	<120 m	Optics, FPA	
Spectral Shape	5.4.1.2	FS-374	Center Band	Band 10 (Thermal 1) 10.8 µ ($\pm$ 200nm) Band 11 (Thermal 2) 12 µ ($\pm$ 200nm)	Optics, FPA	
	5.4.1.2	FS-799	Bandwidth	Band 10 - 10.3 µ to 11.3 µ Band 11 – 11.5 µ to 12.5 µ	Optics. FPA	
	5.4.3	FS-376	Uniformity	Within $\pm$ 5% FWHM of measured mean	Optics, FPA	

Driving Requirements - Continued

	RD #	TIRS #	Parameter	L3 Requirement	Systems Affected	Notes
Out of Spec Detectors	5.6.5.1	FS-566	Dead Pixels	< 0.1% dead pixels within any row	FPA	2 for 1 ground pixel selection allowed
	5.6.5.2	FS-570	Inoperable Pixels	<0.25% fail to meet specifications during any WRS-2 scene	FPA, Algorithms	2 for 1 ground pixel selection allowed
Image Registration	5.7.1	FS-625	LOS	27 microradians per axis	Thermal, Mechanism, Mechanical	Knowledge per 16 day orbit repeat cycle
	5.7.2	FS-179	Timing Accuracy	Timestamp science data within ±0.001 seconds of LDCM time stamp	MEB	
	5.7.3.1	FS-606	Registration	2 thermal bands co-registered within <18 m after geometric correction	Mechanism, Algorithm	Stability from band to band (2.5 seconds)
	5.7.3.2	FS-608	Geoditic	Pixels at earths surface located relative to reference system to within 76 m	Mechanism, Algorithm	

TIRS Continuous Risk Management Plan

Continuous Risk Management Process

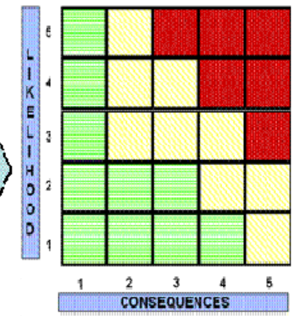
- Documented in TIRS-SE-PLAN-0002, TIRS Risk Management Plan
  - Augments LDCM Continuous Risk Management Plan (427-01-02)
- Monthly Risk Meetings open to LDCM members
- Top TIRS risks reported during TIRS Monthly Status meetings to LDCM, Code 500, and CMC

TIRS Risk Management Score Card

Likelihood Definitions

Likelihood	Safety (Estimated likelihood of safety event occurrence)	Technical (Estimated likelihood of not meeting performance requirements)	Cost/Schedule (Estimated likelihood of not meeting cost or schedule commitment)
5 Very High	(P_{SE} > 10[illegible])	(P_T > 50%)	(P_{CS} > 75%)
4 High	(10[illegible] < P_{SE} ≤ 10[illegible])	(25% < P_T ≤ 50%)	(50% < P_{CS} ≤ 75%)
3 Moderate	(10[illegible] < P_{SE} ≤ 10[illegible])	(15% < P_T ≤ 25%)	(25% < P_{CS} ≤ 50%)
2 Low	(10[illegible] < P_{SE} ≤ 10[illegible])	(2% < P_T ≤ 15%)	(10% < P_{CS} ≤ 25%)
1 Very Low	(P_{SE} ≤ 10[illegible])	(0.1% < P_T ≤ 2%)	(P_{CS} ≤ 10%)

5X5 Matrix



Consequence Definitions

Risk Type	1 Very Low	2 Low	3 Moderate	4 High	5 Very High
Safety	Negligible or No Impact.	Could cause the need for only minor first aid treatment	May cause minor injury or occupational illness or minor property damage	May cause severe injury or occupational illness or major property damage	May cause death or permanently disabling injury or destruction of property
Technical	No impact to full mission success criteria	Minor impact to full mission success criteria	Moderate impact to full mission success criteria. Minimum mission success criteria is achievable with margin	Major impact to full mission success criteria. Minimum mission success criteria is achievable	Minimum mission success criteria is not achievable
Schedule	Negligible or no schedule impact	Minor impact to schedule milestones; accommodates within reserves; no impact to critical path	Impact to schedule milestones; accommodates within reserves; moderate impact to critical path	Major impact to schedule milestones; major impact to critical path	Cannot meet schedule and program milestones
Cost	<2% increase over allocated and negligible impact on reserve	Between 2% and 5% increase over allocated and can handle with reserve	Between 5% and 7% increase over allocated and can not handle with reserve	Between 7% and 10% increase over allocated, and/or exceeds proper reserves	>10% increase over allocated, and/or can't handle with reserves

GaAs QWIP Focal Plane Fabrication

Two parallel paths for QWIP array fabrication and hybridization

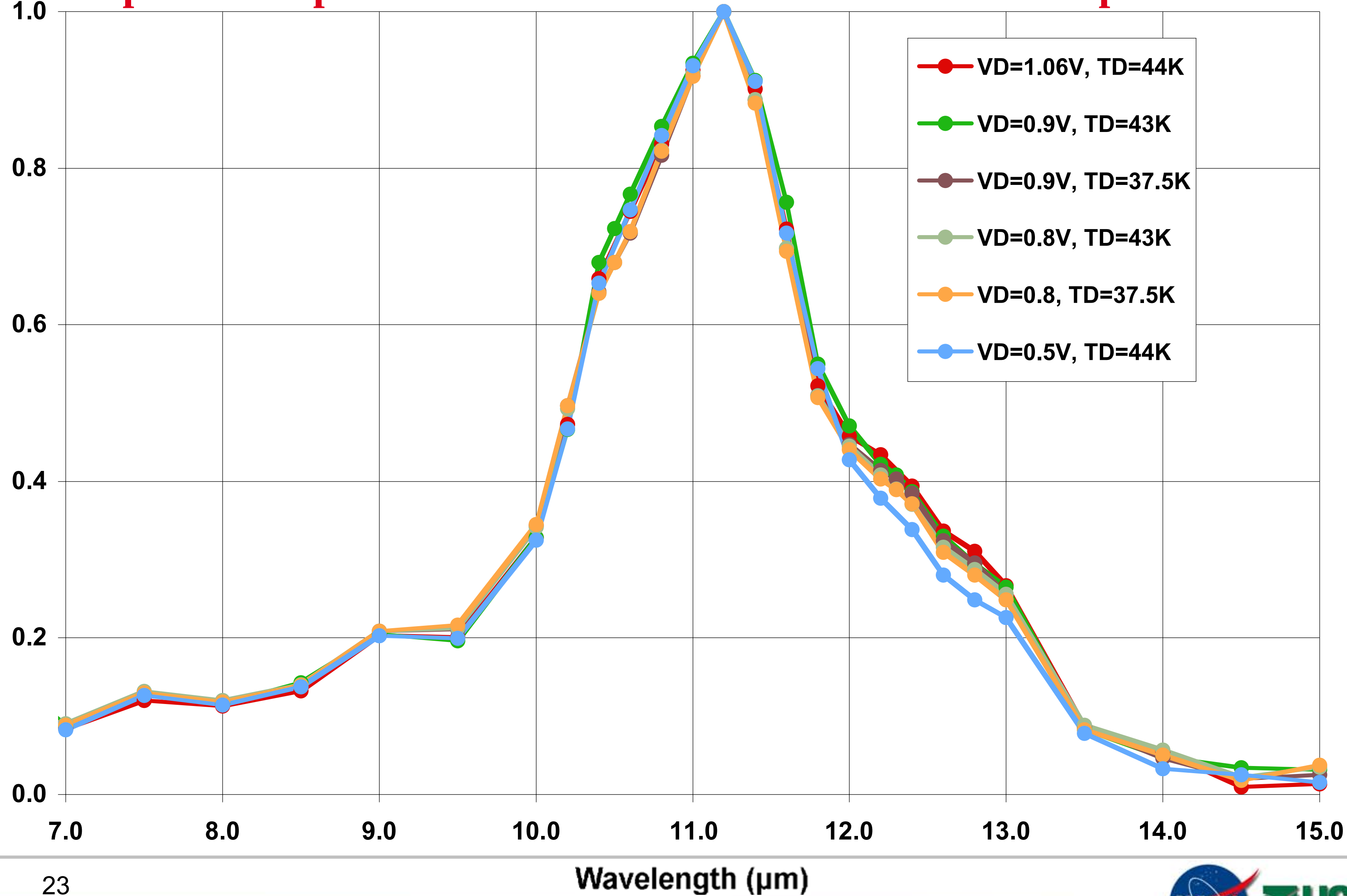
1. **QWIP arrays fabricated jointly by GSFC/ARL in the Goddard DDL based on corrugated light coupling mechanism.**

2. **QWIP arrays fabricated by QmagiQ, LLC based on a grating light coupling mechanism structure.**

Both processes will produce similar performing devices

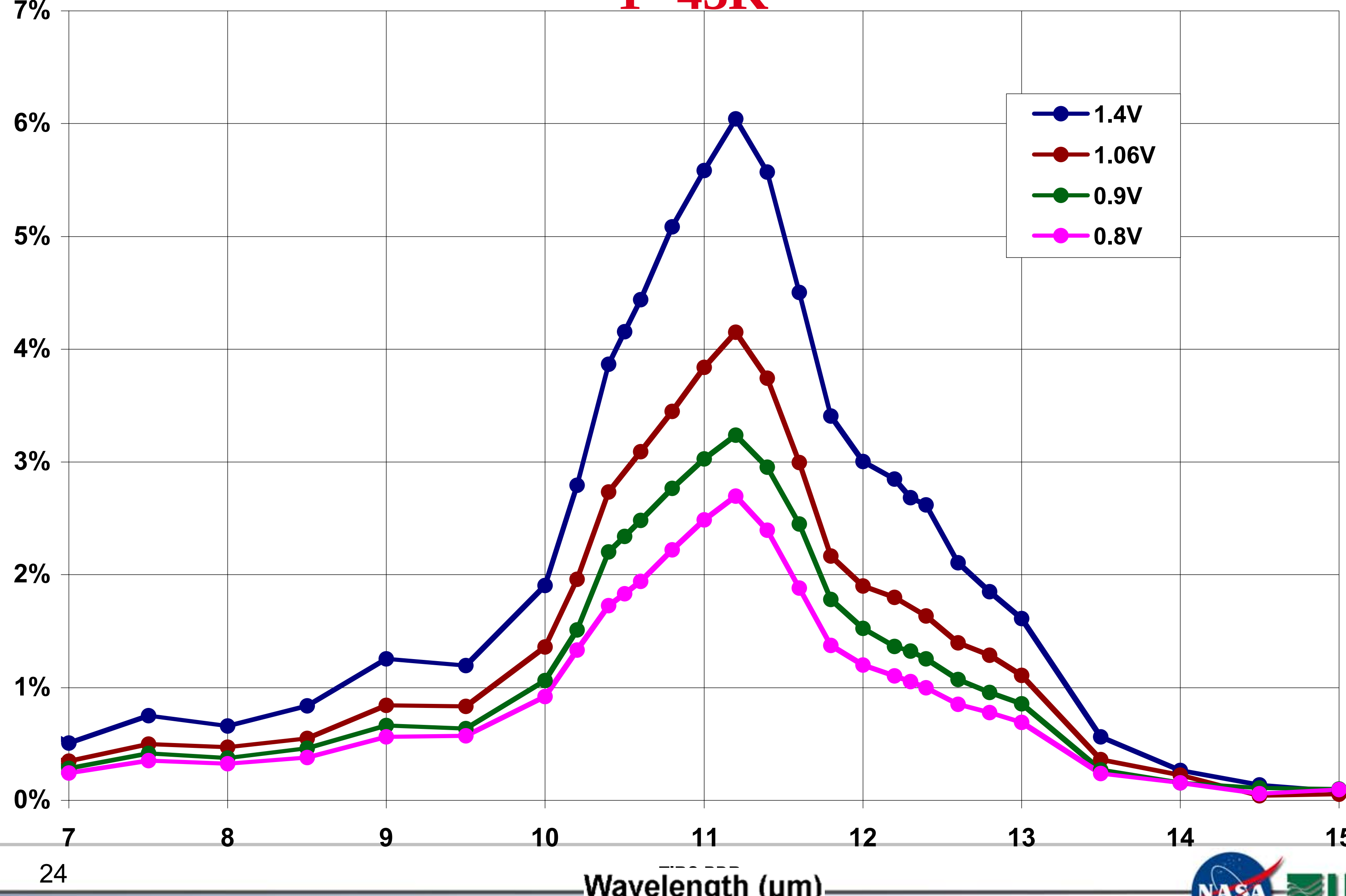
Relative Spectral Response
QWIP Hybrid Q239 (QmagiQ)

Spectral response as a function of detector bias and temperature



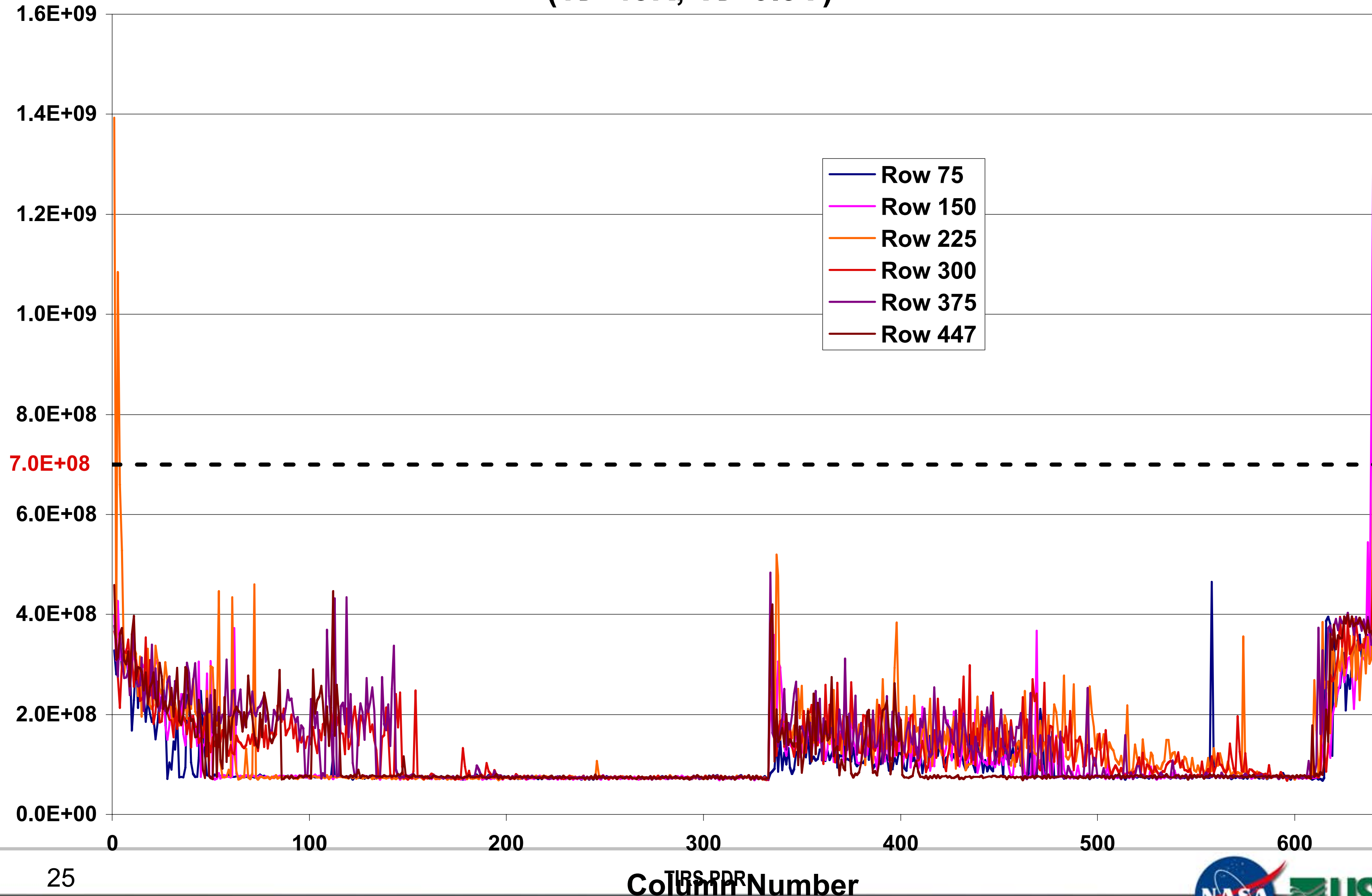
QWIP Hybrid Q239

Conversion Efficiency vs Detector Bias
T=43K



QWIP Hybrid Q239

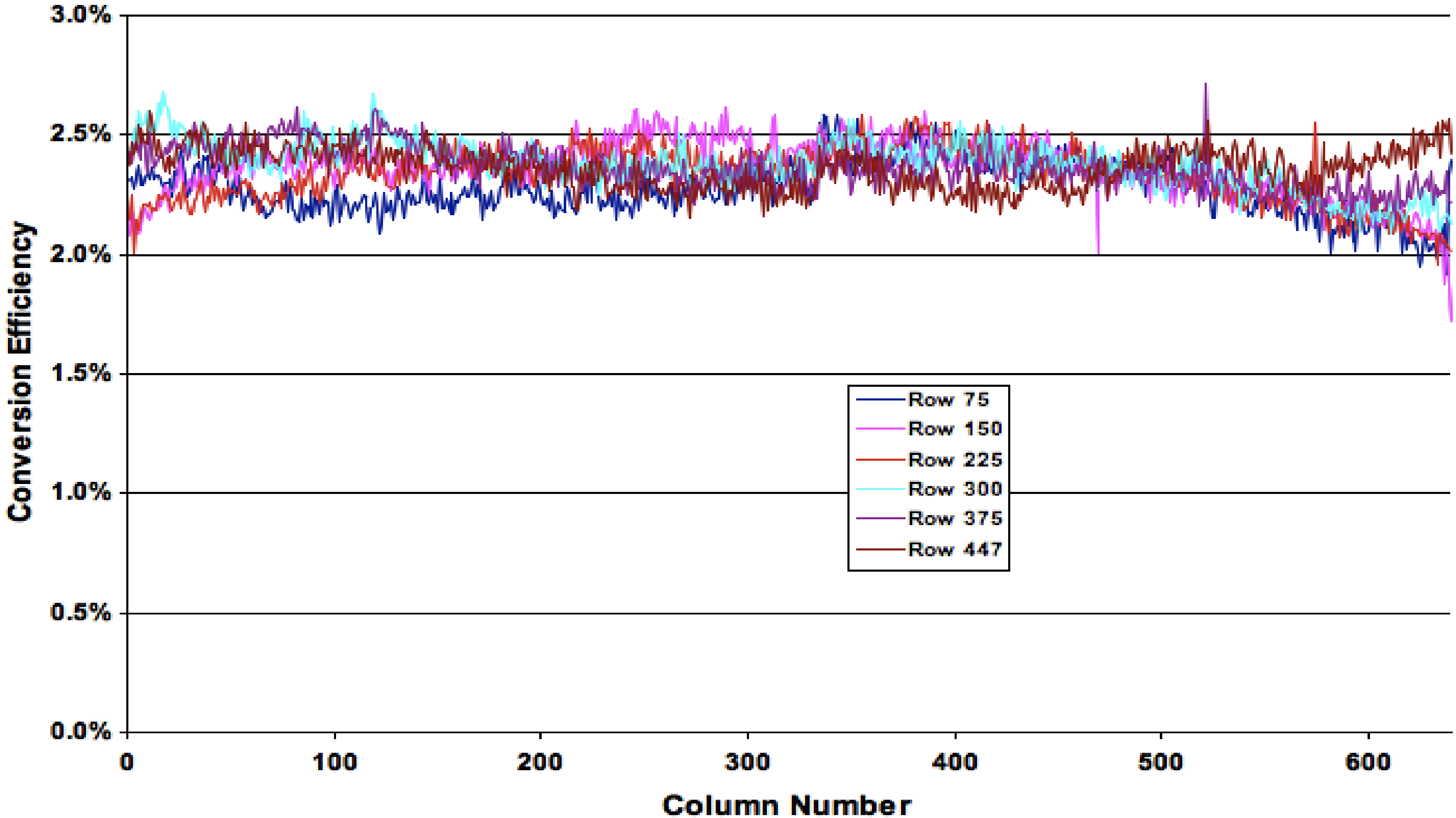
Dark Current Row Plots
(T_D=43K, V_D=0.9V)



TIRS LDCM

QWIP Hybrid Q239

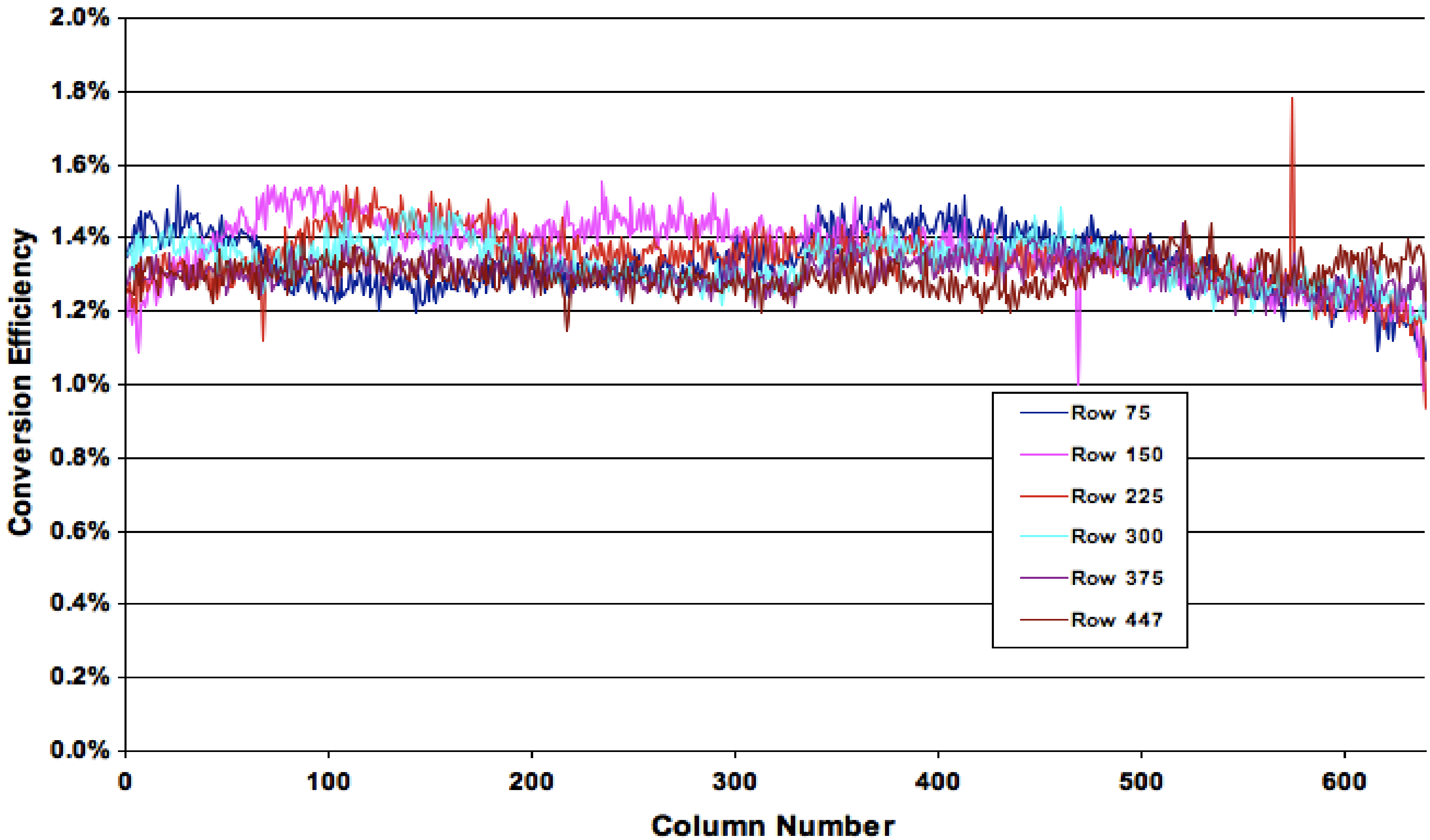
Conversion Efficiency Row Plots
(λ=10.5µm, T_D=43K, V_D=0.9V)



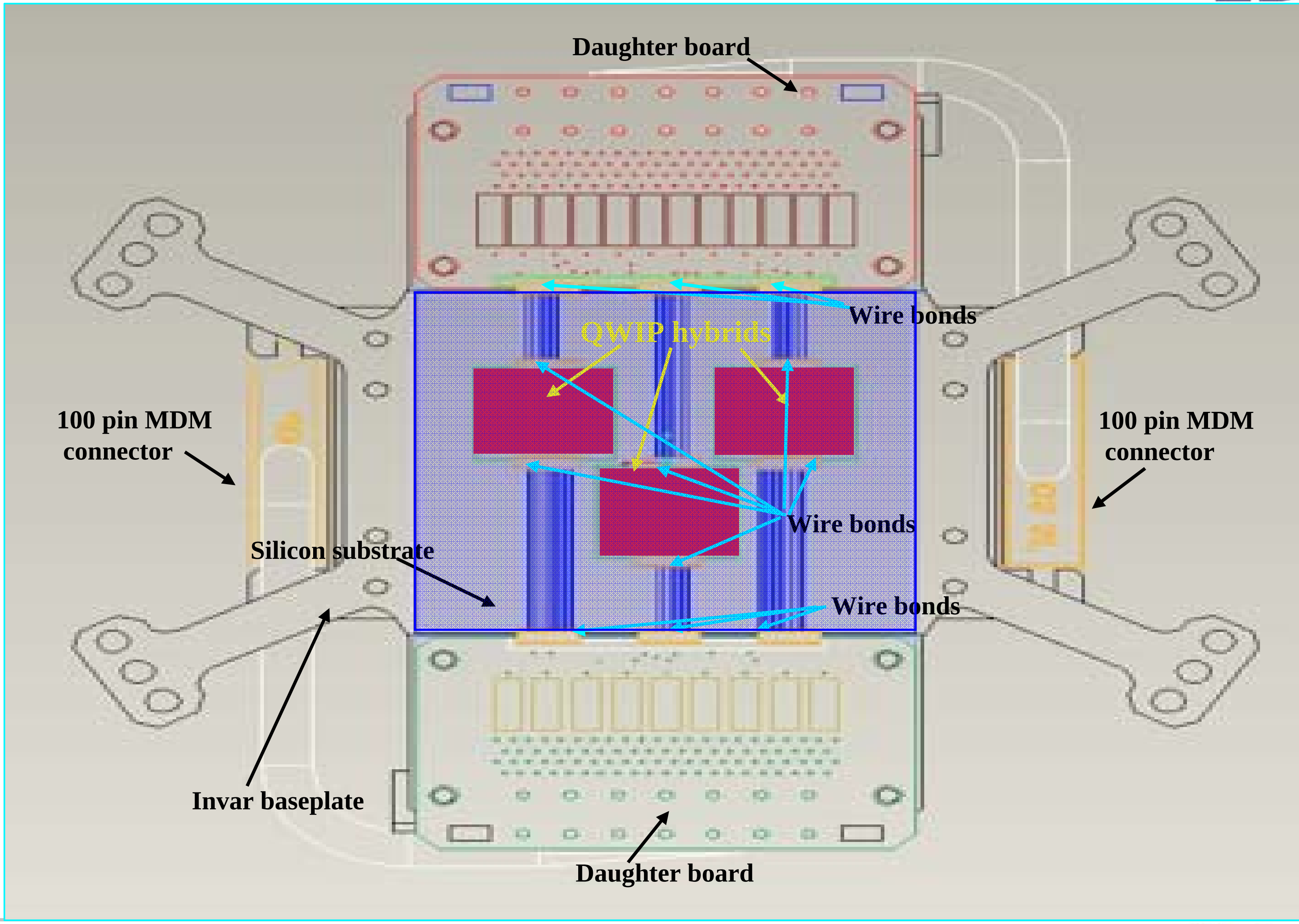
QWIP Hybrid Q239

Conversion Efficiency Row Plots

(λ=12.3µm, T_D=43K, V_D=0.9V)

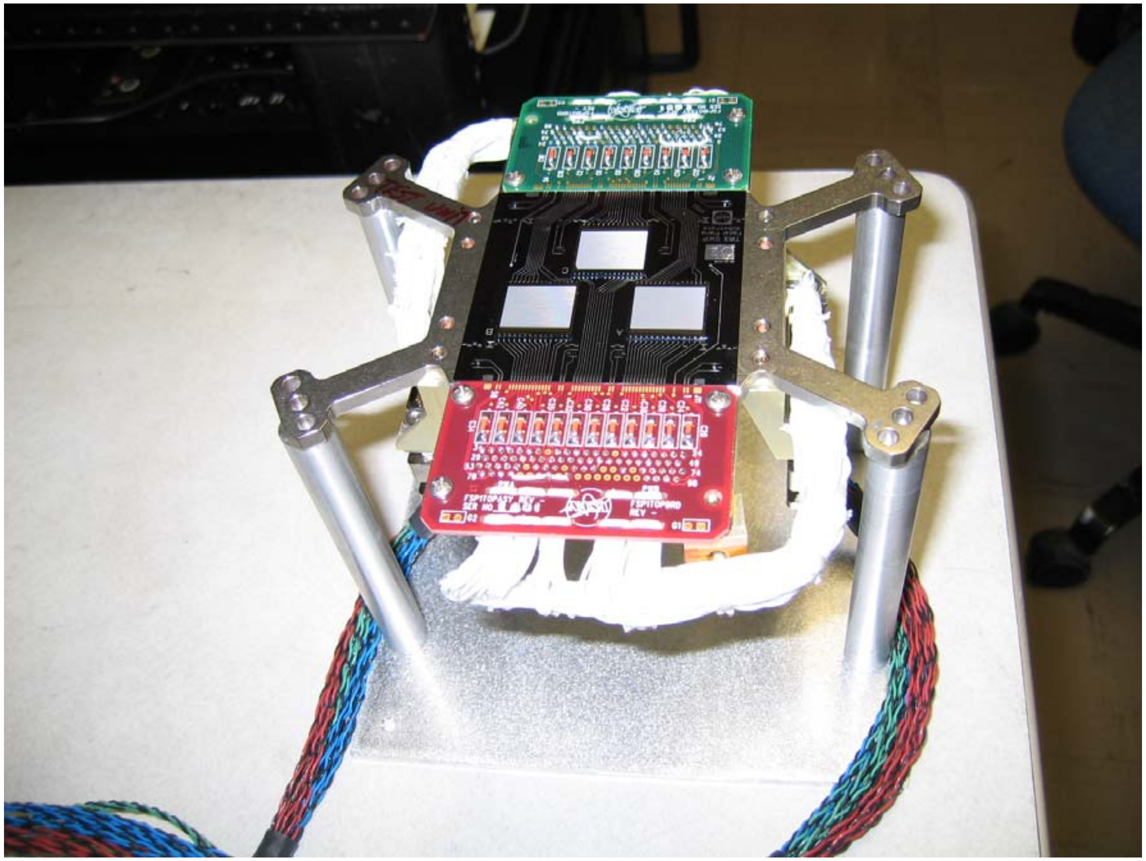


Focal Plane Mechanical Layout

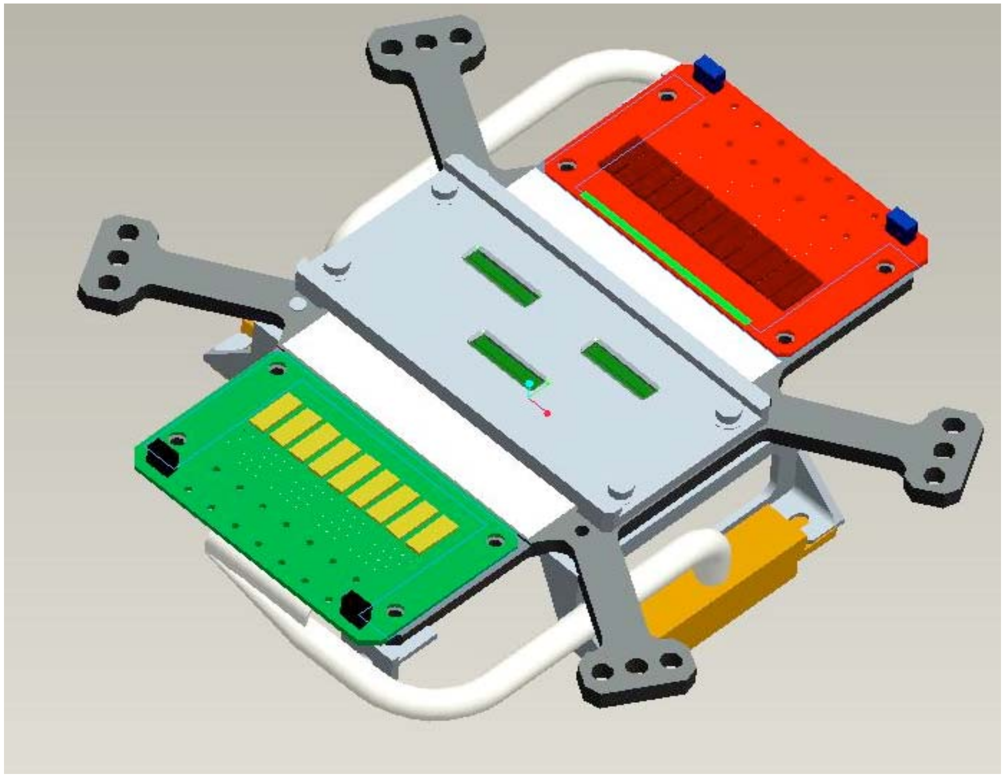


Pathfinder Layout

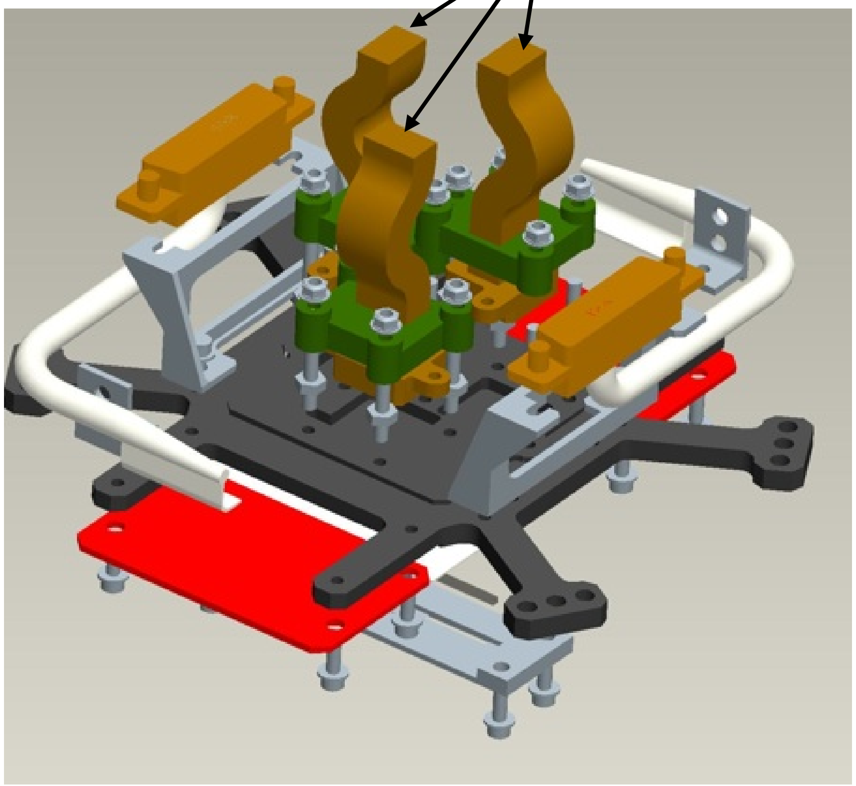
Proper Electrical Operation Already Demonstrated



Focal Plane Assembly Sequence



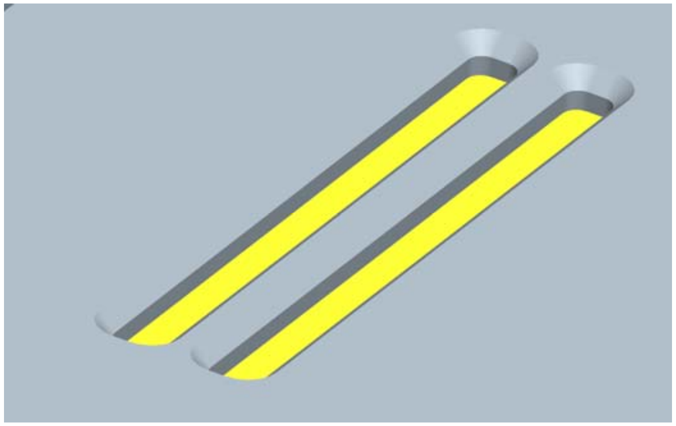
Fully assembled FPA
Front side

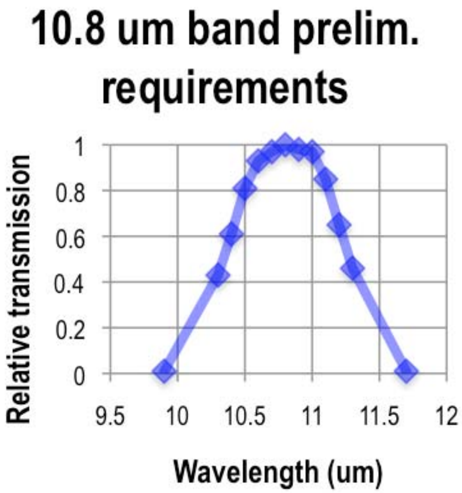


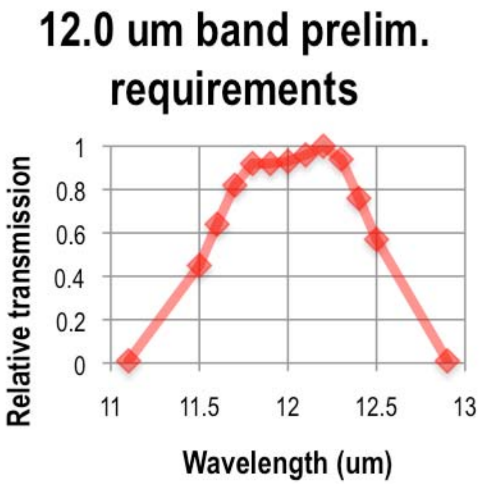
Fully assembled FPA
Back side

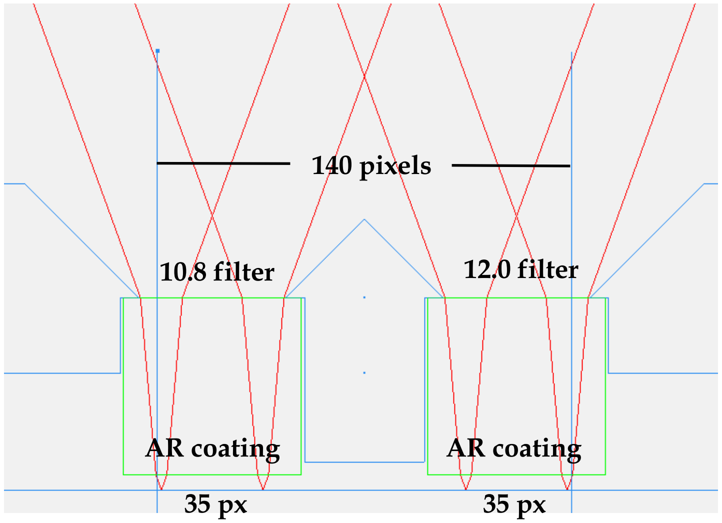
Filters

- 1 pair of filters over each SCA
  - 1.5 mm x 1.5 mm x 17 mm
  - Length spans long direction of QWIPs
- Bandpass filter on top side, AR coating on bottom side
- Filter shape defined by detector spectral response
- Within the 140 pixel readout region:
  - 30 pixel region under each filter where the incidence light path is unobstructed
  - 40 pixel central dark region, obscured by Invar filter holder structure



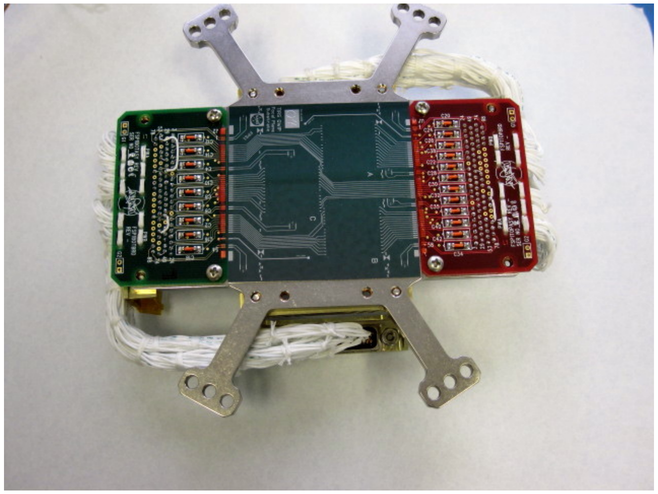


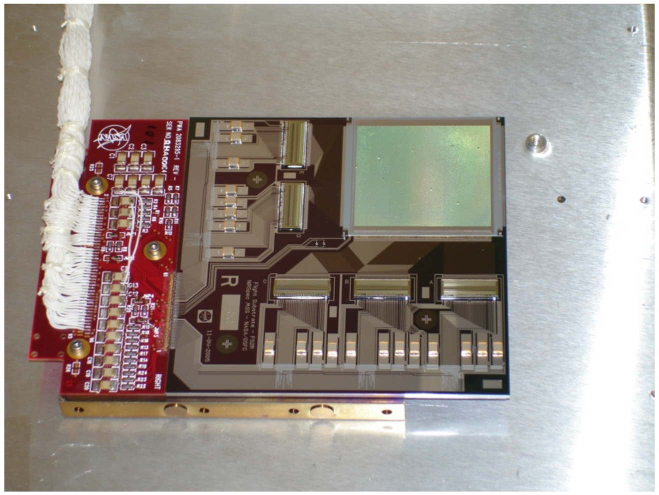




Plans to Achieve FPA TRL 6

Component	Current TRL	Heritage
Assembled unit	5	Similar to JWST/MSA





The TIRS FPA and JWST Microshutter Assembly (MSA) are very similar in construction.

- **Key thermal interfaces on the TIRS FPA have been tested**
- **All components and adhesives are thermally compatible with each other proven by test or high confidence by analysis**
- **We will perform complete FPA vibration by 8/15/09 (before and after tests).**
- **We will thermally cycle the FPA by 9/15/09 (monitor fuctionality during tests).**

➢ **TRL Review : "… low risk in advancing the technology to TRL-6 and beyond."**

TIRS Noise Model

- **TIRS noise is a function of inherent signal variance (electron "shot noise"), system instability noise, electronics and array noise ("read noise") and quantization noise**
- **For an integration time t, Source flux F(S), Background flux F(B), Scene Select Mirror flux F(M), Optics flux F(O) and detector dark current I(D)**

$$N = \sqrt{\begin{array}{l} 2gt\left(F(S)+F(B)+F(M)+F(O)+I(D)\right) \\ +t^2\left[\left(\frac{\delta F(B)}{\delta T}\Delta T(B)\right)^2+\left(\frac{\delta F(M)}{\delta T}\Delta T(M)\right)^2+\left(\frac{\delta F(O)}{\delta T}\Delta T(O)\right)^2+\left(\frac{\delta F(D)}{\delta T}\Delta T(D)\right)^2\right] \\ +\left(R(D)^2+R(E)^2+Q^2\right)\end{array}}$$

Where

$$F(S) = B(S)\frac{CE\,\tau_l\tau_f r_m\pi}{1+(2f)^2} \qquad F(M) = B(M)\frac{CE\,\tau_l\tau_f\varepsilon_m\pi}{1+(2f)^2} \qquad F(O) = B(O)\frac{CE\,\tau_f\varepsilon_o\pi}{1+(2f)^2}$$

$$F(B) = B(B)\left(CE\,\tau'_f\,\pi\right)\left(\Omega_b - \frac{1}{1+(2f)^2}\right)$$

Ω_b = Solid Angle Above Cold Shield

g = Photoconductive Gain

$B(x)$ = Appropriate Planck Integral for Temperature x

r_m = Mirror Reflectance

ε_m = Mirror Emittance

ε_o = Optics Emittance

CE = Conversion Efficiency

τ_l = Lens Transmittance

τ_f = Filter Transmittance

$R(D)$ = Detector Read Noise

$R(E)$ = Electronics Read Noise

$$\tau'_f = \frac{1+\tau_f}{2}$$

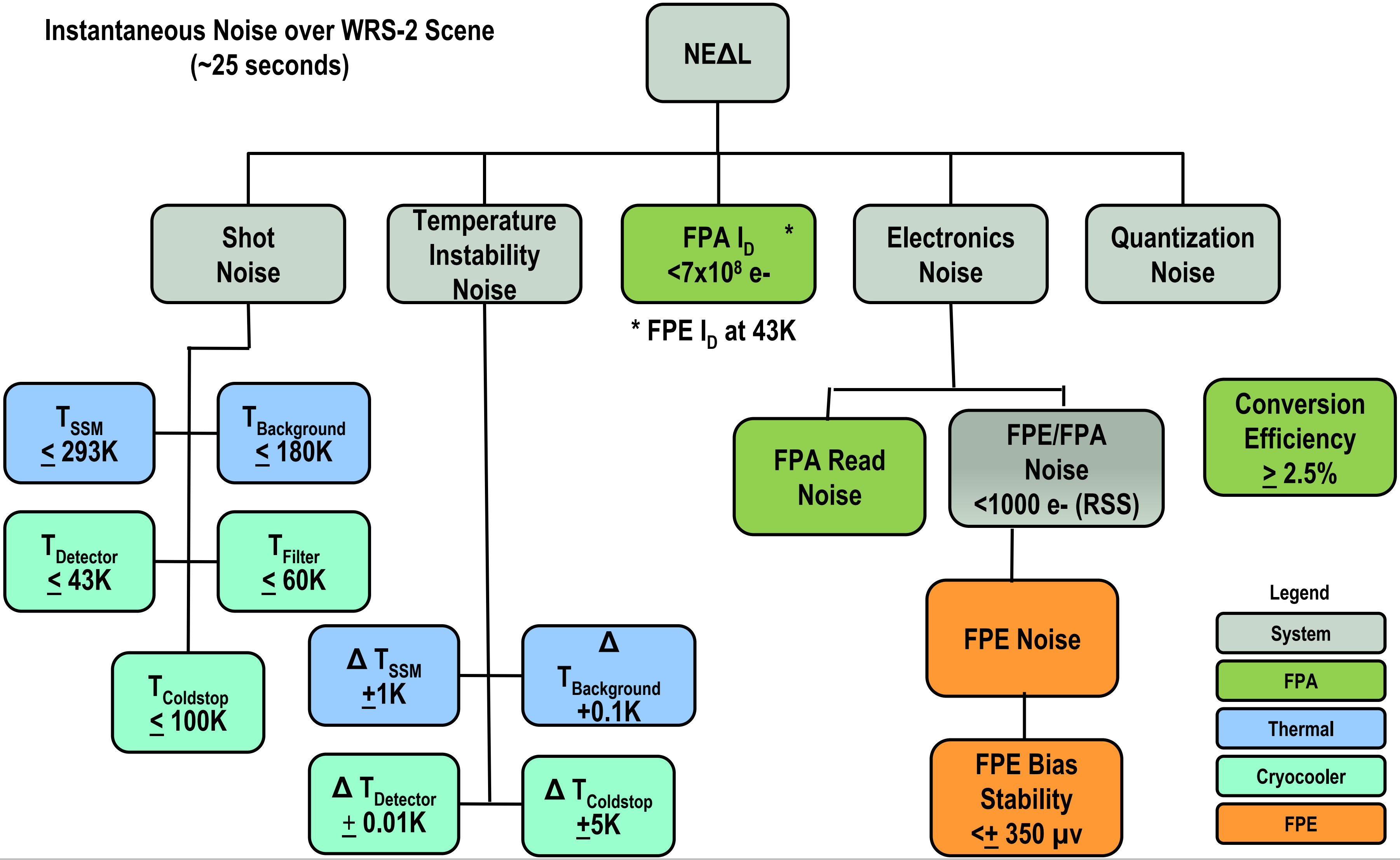
f = f#

$$Q = \left(\begin{array}{l}\text{12 Bit}\\ \text{Quantization}\\ \text{Noise}\end{array}\right) = \frac{\text{Well Depth}/4094}{\sqrt{12}}$$

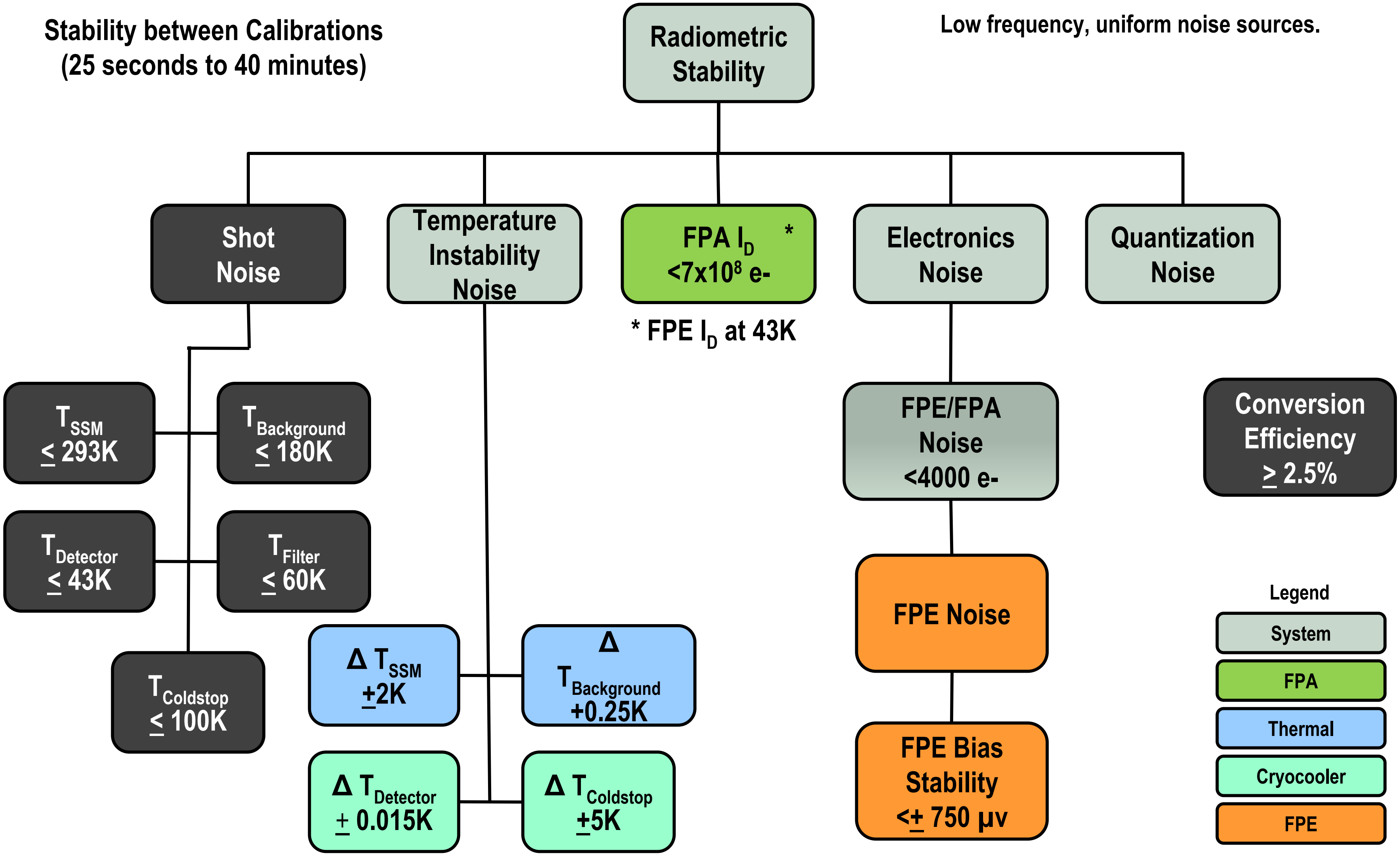
$$I(D) = 5.6\text{x}10^{17}\,e^{-1.4388\frac{cutoff}{T_d}}$$

NEdL Allocation Tree

Instantaneous Noise over WRS-2 Scene
(~25 seconds)



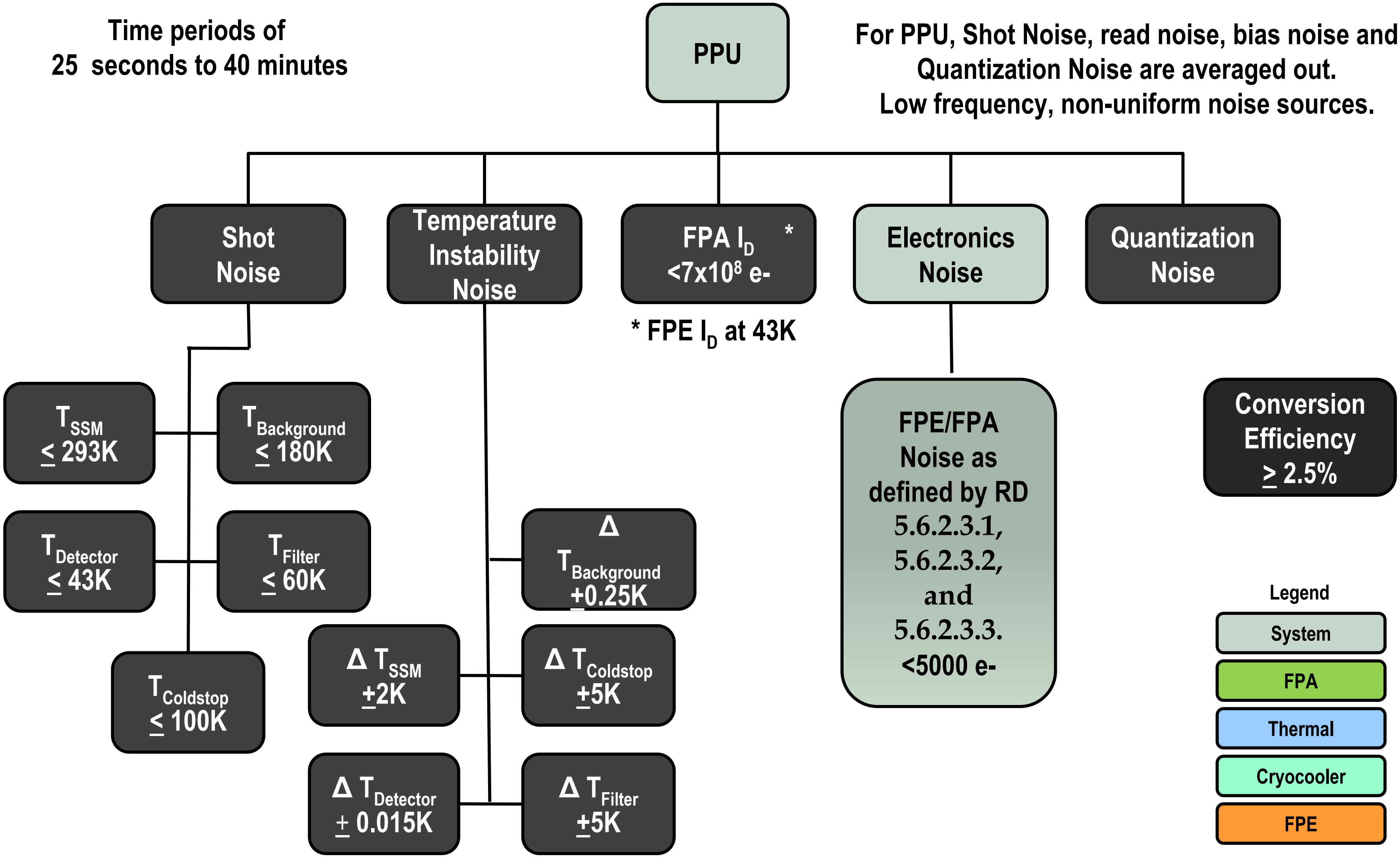
Radiometric Stability Allocation



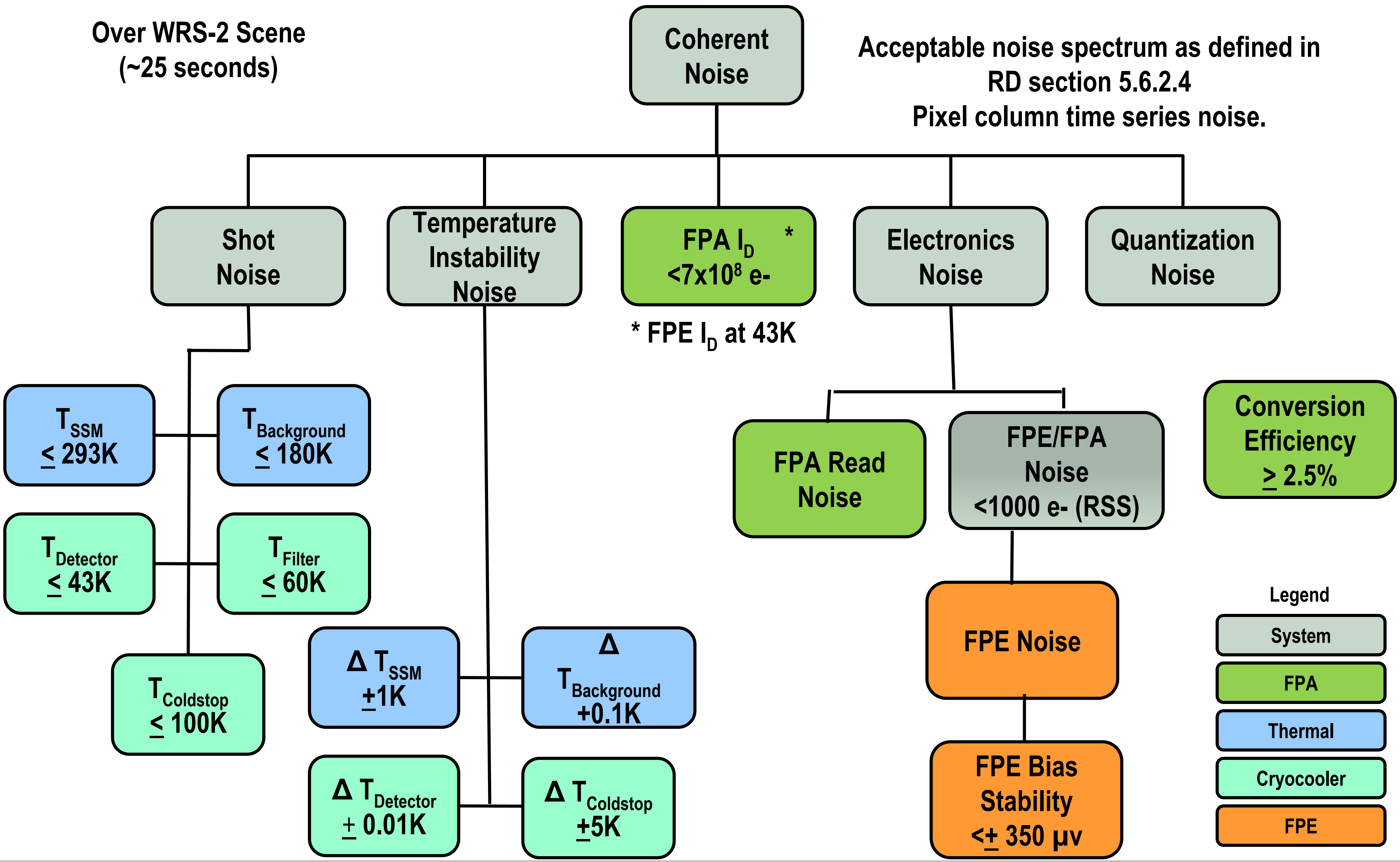
Pixel to Pixel Uniformity

Time periods of
25 seconds to 40 minutes

For PPU, Shot Noise, read noise, bias noise and Quantization Noise are averaged out.
Low frequency, non-uniform noise sources.



Coherent Noise



Performance Margins

	Requirement	Based on Allocation	Based on PDR CBEs	Margin
NEdL – 10.8 μ (Calculated as NEdT at 360K)	0.27	0.14	0.0845	220%
NEdL – 12 μ (Calculated as NEdT at 360K)	0.29	0.17	0.098	196%
Radiometric Stability – 10.8 μ	0.7%	0.56%	0.44%	59%
Radiometric Stability – 12 μ	0.7%	0.58%	0.44%	59%

LOS Knowledge Performance

	Allocation	Estimated Performance
SSM Position Control	20 µrad/2.5 sec	4 µrad
Thermal Stability	10 µrad	10 µrad
Jitter	10 µrad	10 µrad
Unallocated (System Reserve)	11 µrad	11 µrad
Totals (RSS)	27 µrad	18.3 µrad

- **Assuming identical performance for all three axis, have 47% margin on knowledge**
- **Post PDR will start reallocating terms as necessary and based on STOP analysis**

Relative Edge Response

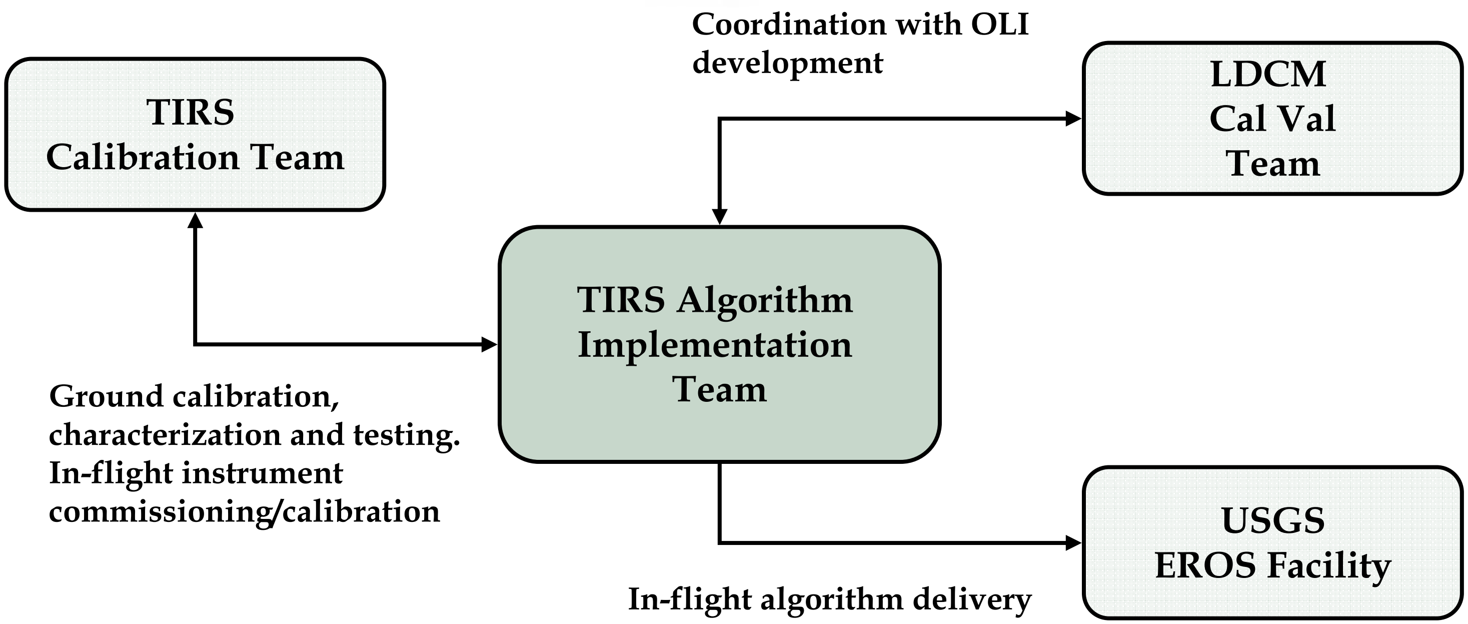
- Based on 100 m Ground Sample Distance, RER allocation to Optics is >0.008 /m
- Given a maximum integration time of 6 ms, the only contributor to RER is optical focus/defocus errors (Wavefront Error)
  - A wavefront error of 857 nm is equivalent to a defocus of 65 µ
  - An initial allocation tree for Wavefront Error identifies contributions for manufacturing residuals, on orbit cryodistortion, therma distortions, etc.
- With the current defocus error budget, the 100 m GSD required RER is being met with margin

	Requirement	CBE	Margin
In-Track	>0.008 /m	0.01024	22%
Cross-Track	>0.008 /m	0.0985	19%

TIRS Algorithm Outline

- Provide the set of data processing algorithms (descriptions and software) required to process and evaluate TIRS science data and ancillary data in all instrument development phases as required
  - Ground Testing: FPM and Flight Instrument
  - LDCM Integrated Ground Testing
  - On-Orbit: Commissioning, Calibration
- Provide a processing system to support ground testing and calibration of the FPM and the Flight Instrument
  - Record TIRS detector data and ancillary data during ground testing
  - Display, process, and archive all instrument data
  - Process data with TIRS algorithm software to verify performance and characterization
- Provide detailed algorithm descriptions (including prototype code) to support automated data processing of on-orbit TIRS data
  - Integrate with the LDCM Data Processing and Archive Segment (DPAS) at USGS/EROS
  - Process data with TIRS algorithm software to meet performance and imagery requirements
  - Coordinate with OLI processing software to produce integrated data products

Algorithm Team Coordination



TIRS Algorithms Design Summary

- **Reuse legacy knowledge, documentation, and software where possible from legacy missions**
  - Landsat 7, and ALI algorithms and components are foundations of much of the OLI processing algorithms
- **Mimic LDCM/OLI algorithm flows where possible**
  - Instrument processing is similar
  - Easier for LDCM to follow TIRS data processing flows if they are similar to OLI
- **Create Algorithm Testbed system prior to FPM readiness**
  - Begin TIRS data processing and software version control
- **Create Algorithm Toolkit to process TIRS data**
  - Algorithm descriptions and code available to project
- **Implement Algorithm Toolkit on Calibration Test System**
  - Support ground calibration and characterization
  - Support in-flight commisioning activities
- **Deliver Algorithms to USGS**

Calibration team

- Dennis Reuter – Instrument Scientist
- GSFC
  - Allen Lunsford (Algorithm Lead)
  - Ramsey Smith
  - Kurt Thome (Calibration Lead)
- Millennium Engineering and Integration (MEI)
  - Sue Hall
  - Lee Murrer
  - Zelalem Tesfaye
  - Steve Miranda
- Major activities
  - Cal/Val Peer Review
  - Weekly Telecons
  - Algorithm TIMs

Team Member	Role
GSFC	Oversight, Landsat heritage
	Instrument design, integration & test, algorithm develepment
MEI	GSE Development

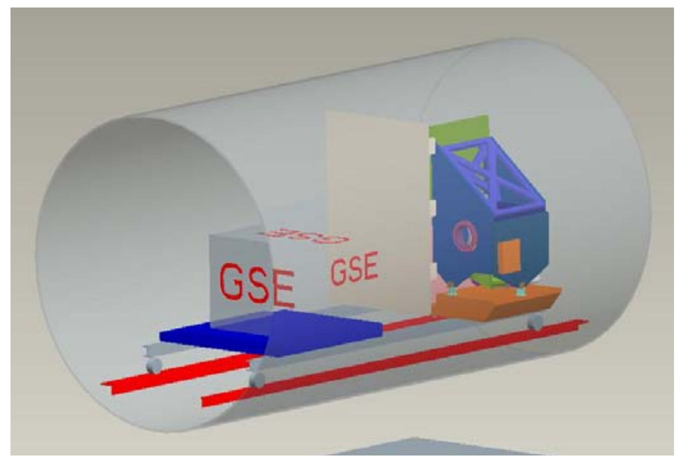
TIRS test and calibration overview

- TIRS performance measured at component, subsystem and system level
- System-level radiometric and image quality assessed using a functional performance model (FPM)
  - Early identification of performance issues
  - Verification of models
  - Development of test procedures and calibration algorithms
  - No acceptance level testing
- All acceptance testing and calibration done at GSFC
  - Meet Special Characterization Test Requirements (SCTRs) and requirements related to calibration/characterization
  - Vendor tests verified at GSFC
  - Support contract augments equipment and test chamber preparation
- All radiometric acceptance testing and calibration will employ NIST-traceable standards

Thermal/vacuum chamber

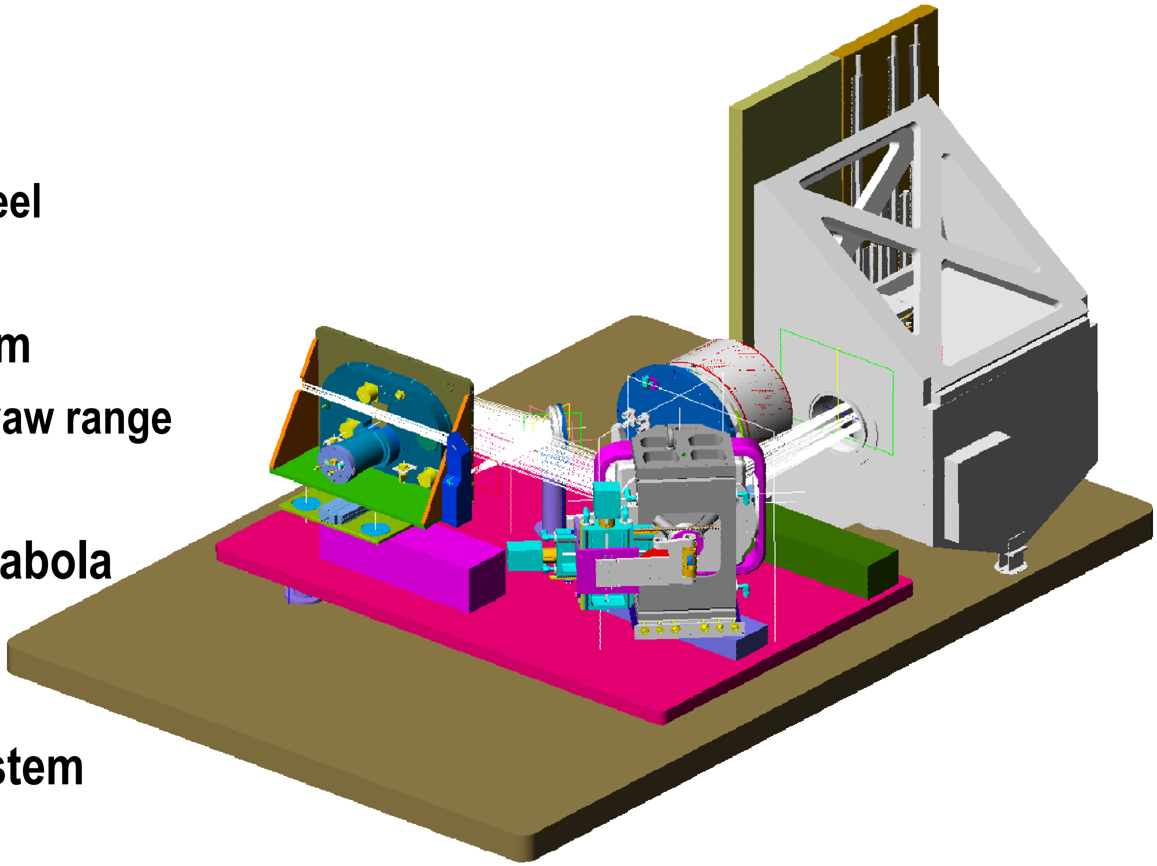
- **TIRS Project requested long term use of GSFC T-Vac Chamber Facility 225**
  - **Center has scheduled for TIRS use from 10/1/09 through 12/31/11**
  - **Chamber modification to incorporate window for spectral source**
  - **Chamber layout played role in calibration GSE design**
- **Vibration characterization required to determine possible impacts**
  - **Test completed with preliminary analysis 06/11**

10' X 15' CHAMBER (FACILITY 225)



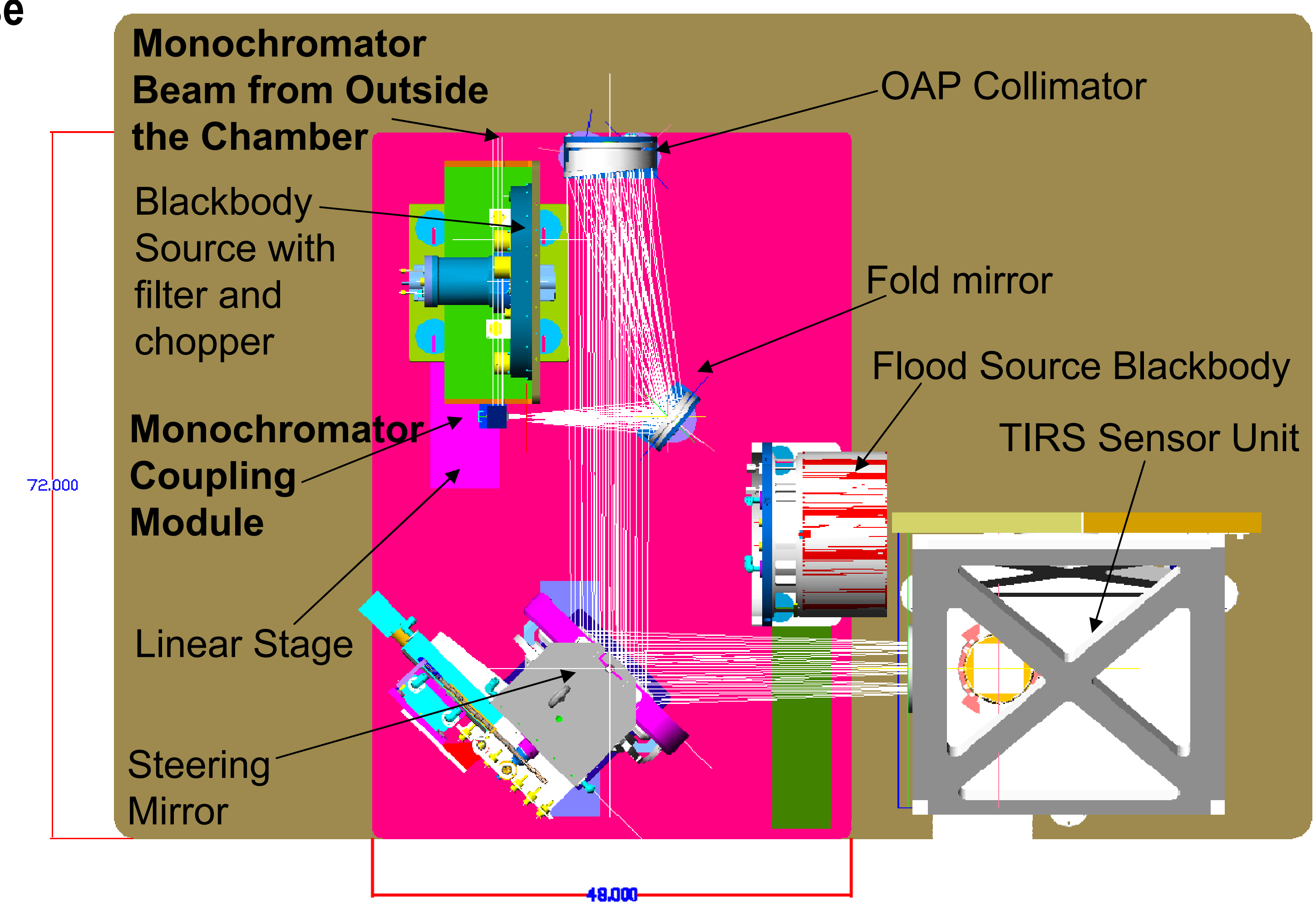
Major system components

- 16" Diameter Flood source
- Target Source Module
  - Blackbody
  - 16 position motorized target wheel
  - 8 position motorized filter Wheel
- 13" square steering mirror system
  - Linear stage expands effective yaw range
  - Pitch & yaw
- Folded, all reflective, off-axis parabola collimator
- Linear stages to move sources
- Cooled enclosure over entire system



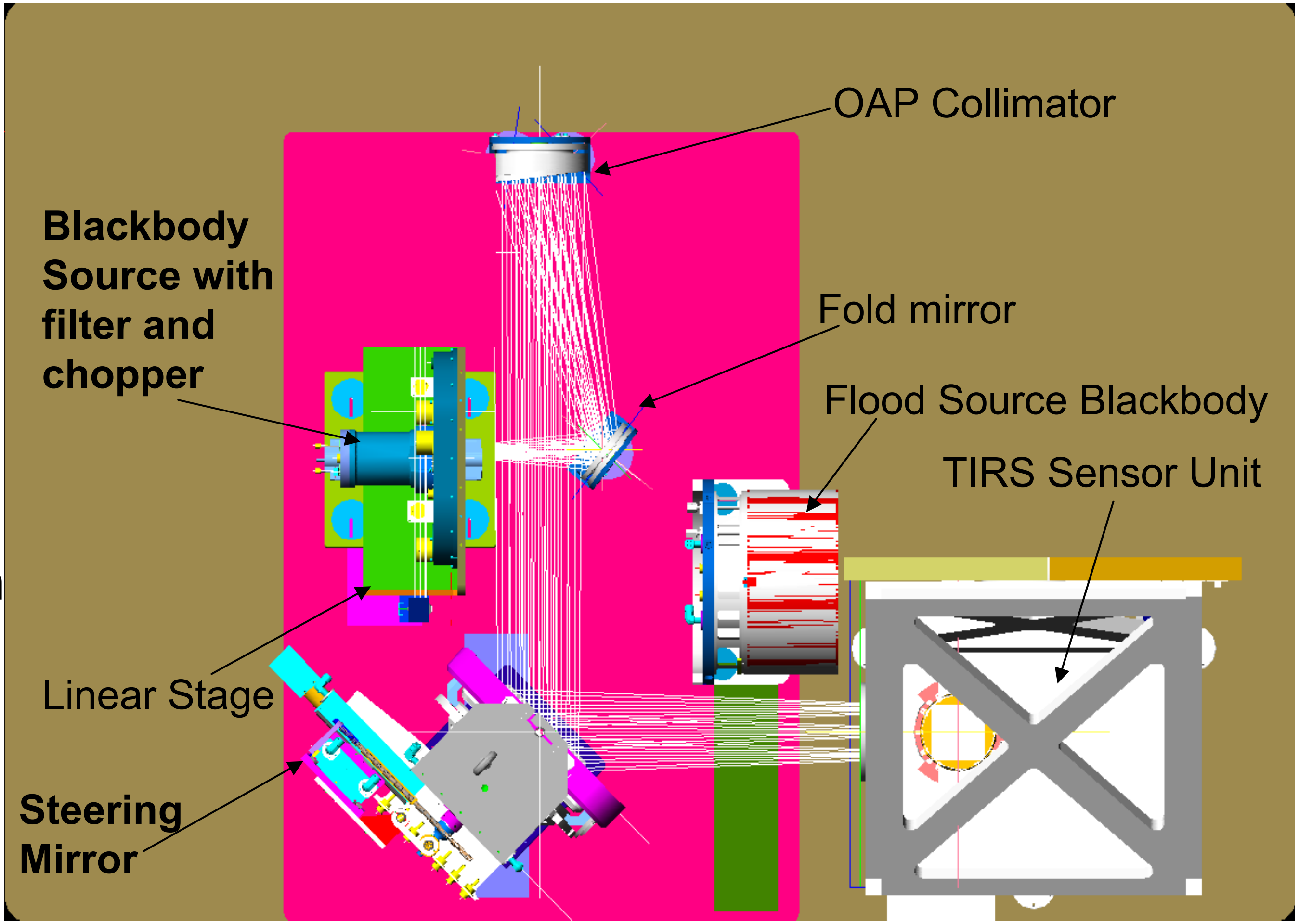
Spectral source configuration

- Spectral response
- Spectral shape
- Spectral shape uniformity
- In-band & out-of-band response



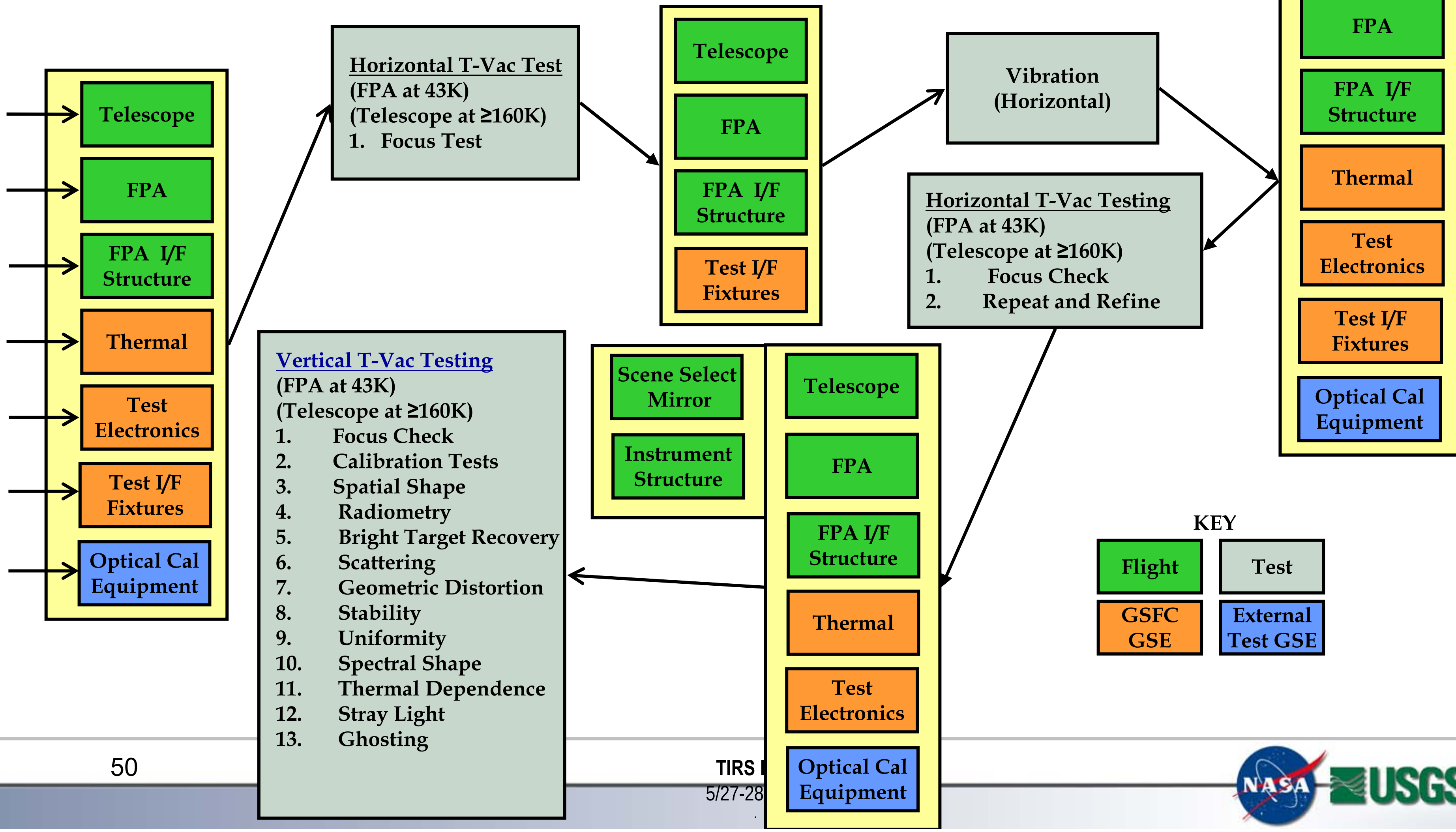
Radiometric source configuration

- Focus position
- Relative edge response
- NEΔL
- Linearity
- Ghosting
- Stray light
- Bright target recovery
- Saturation
- Geometric distortion
- Optical throughput
- Scattering

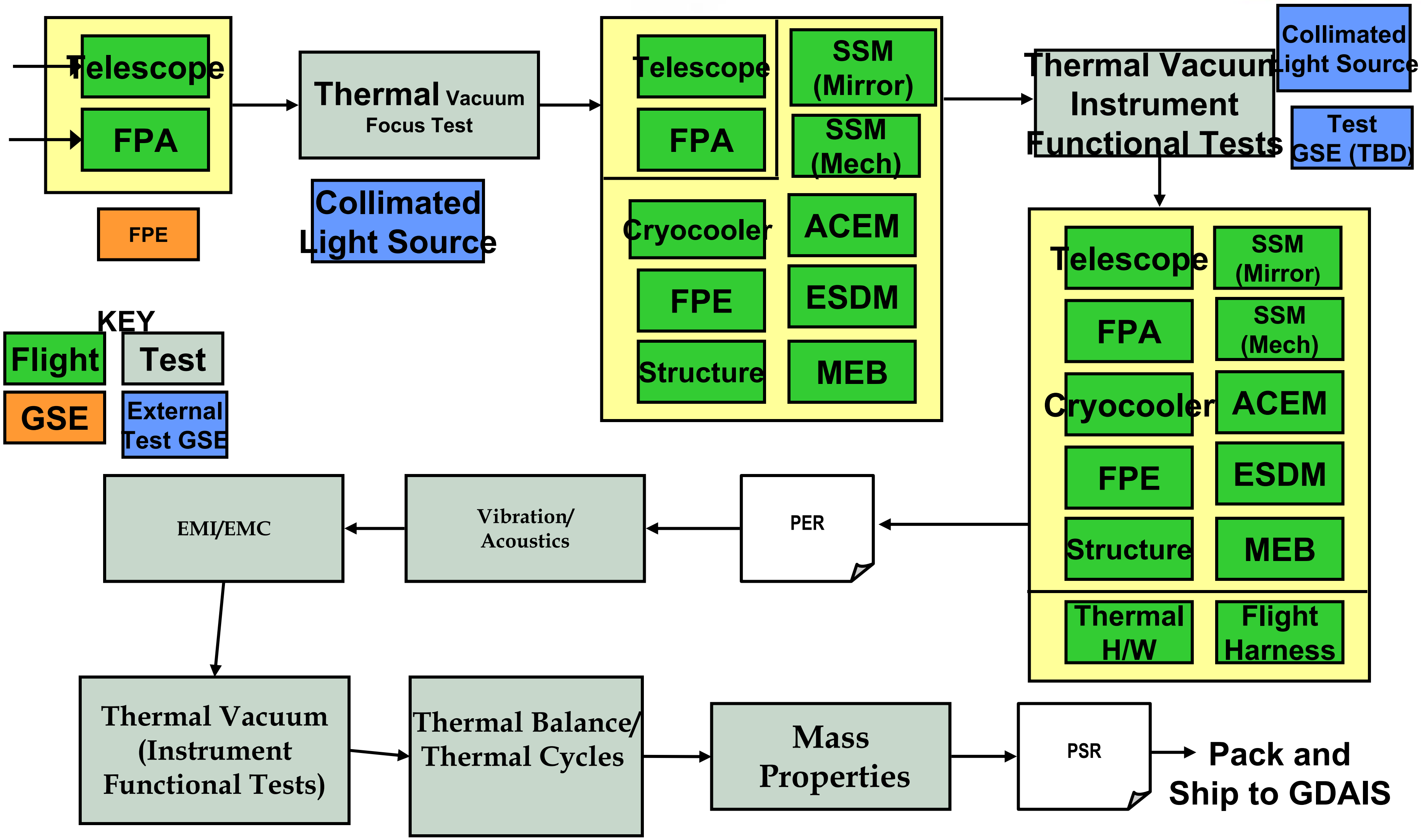


FPM test flow

- Assemble and test philosophy used
- Order may be altered to limit T/V chamber breaks and heating cycles on focal plane
- Final acceptance tests and calibrations done with scene-select mirror

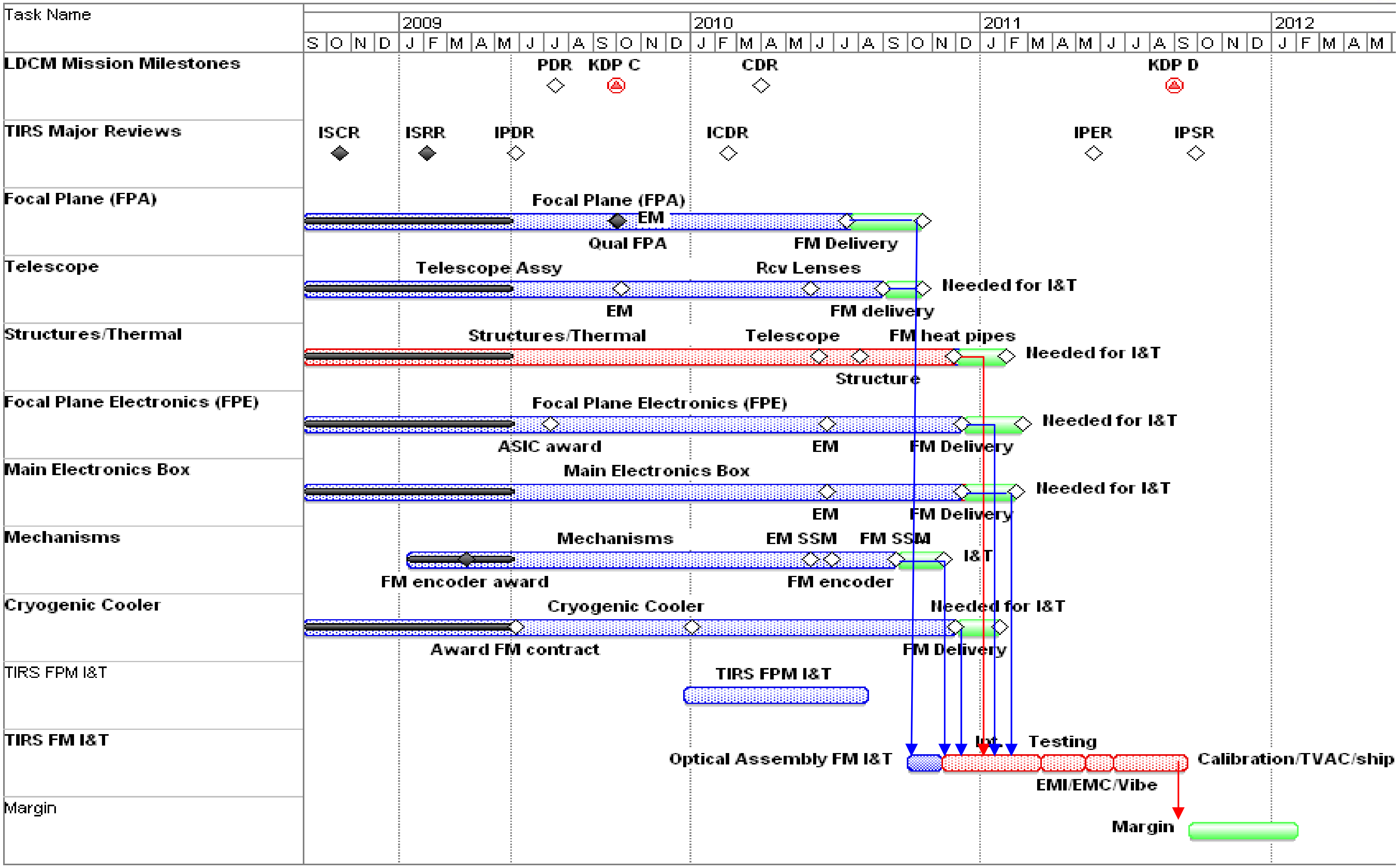


TIRS Flight Model I&T Flow



Master Schedule

TIRS LDCM



NASA USGS

Long Lead Procurement Status

- Procurements are on track to meet schedule
  - Schedule includes standard government procurement times for all government procurements
  - All procurements identified in schedule to provide tracking visibility
- Cryocooler Procurement awarded to BATC, 06/15/2009
  - Cooler efficiency expected to exceed requirement
- Calibration GSE contact in place 06/12/2009
- Encoder Procurement
  - Letter contract allowed BEI to start work on schedule on 4/6/2009
- ASIC Procurement
  - Procurement intentionally delayed to better define requirements
  - Additional updates to microcode procured on 5/13/2009 to maintain schedule.
- EEE Parts Procurements
  - Several parts already procured, many more identified. Critical long lead parts, such as FPGAs already on order.
  - Parts control board actively approving parts.

TIRS Has Received Outstanding Support from Partners

- Goddard institutional support has been consistently strong
  - Allocated Chamber 225 to TIRS for 2 years.
  - Provided office space for co-location of much of TIRS team.
  - Active involvement of upper management.
- LDCM Management, Science and Cal/Val Teams have been actively involved throughout.
  - Close interaction on requirements definition.
  - Valuable insights on calibration and algorithm development.
  - Management team has been very supportive
  - Science team support has been very helpful
- GDAIS has worked closely with TIRS to define spacecraft interface requirements
  - All issues related to TIRS mechanical interface resolved by TIRS/GDAIS Team.
- USGS has worked with TIRS to define algorithm requirements
  - TIRS involvement with all relevant TIMS and working groups
  - USGS personnel supported TIRS EPRs.
- HQ has provided necessary funding

Conclusion

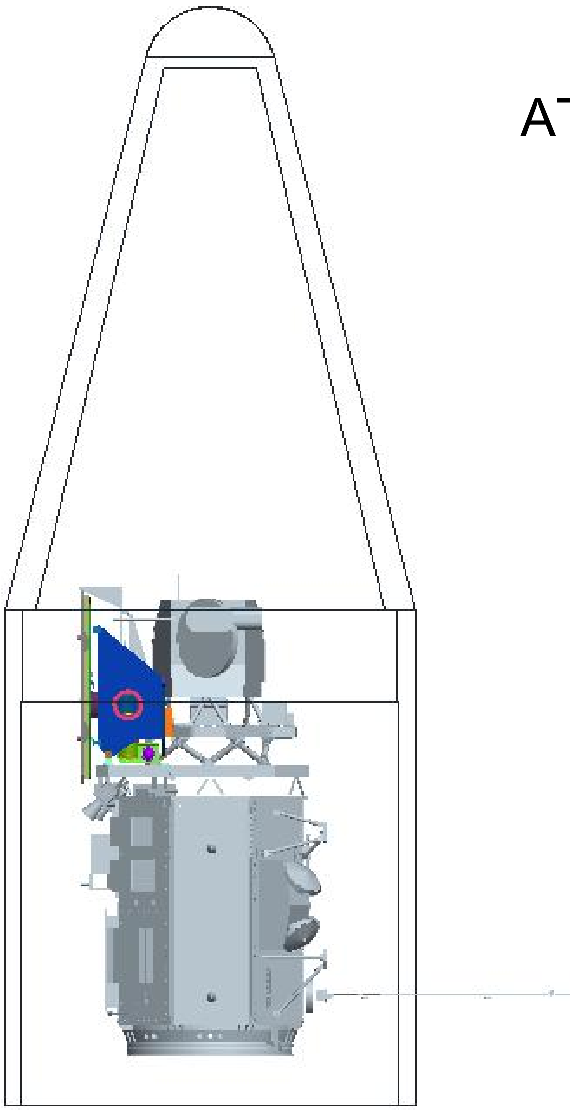
- TIRS has demonstrated that it is meeting its aggressive schedule
  - Preliminary designs and analyses complete.
  - FPA Technology demonstration on schedule.
  - Predicted instrument performance meets requirements.
  - Supporting spacecraft accommodations activities.
- Areas of concern are being agressively managed.
  - FPE and MEB rapidly addressing action items.
  - Increasing staffing.
  - Mass margin actively tracked
- GSFC demonstrating institutional support
  - Continue to staff with experienced personnel.
  - T/V chamber and clean rooms dedicated to TIRS.
- TIRS team working closely with LDCM and their contractors.

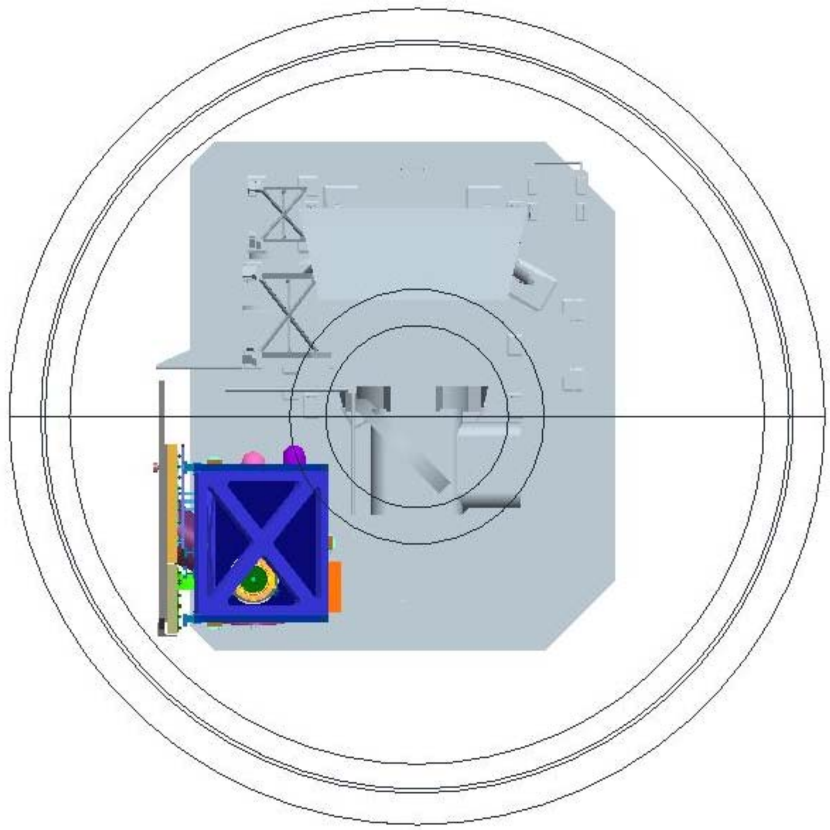
➢TIRS is ready to enter the Detailed Design Phase.

Backup

Launch Vehicle Configuration

ATLAS V - EELV





Alignment Knowledge Budget

TIRS Alignment Knowledge
27 μrad/axis
(2.5 second absolute stability, 40 minute knowledge)

- **Mechanism Knowledge/Stability 20 μrad/axis**
  - Basis for SSM encoder selection.
  - Most effects are in a single axis plane
  - Will review allocations post cooler selection
- **Thermal Knowledge/Stability 10 μrad/axis**
  - Post PDR STOP to refine allocations.
- **Jitter Knowledge/Stability 10 μrad/axis**
  - First order estimate.
  - Need final cooler selection and additional mechanical analysis.
- **Unallocated (Margin) Knowledge/Stability 11 μrad/axis**

TIRS Algorithm Requirements

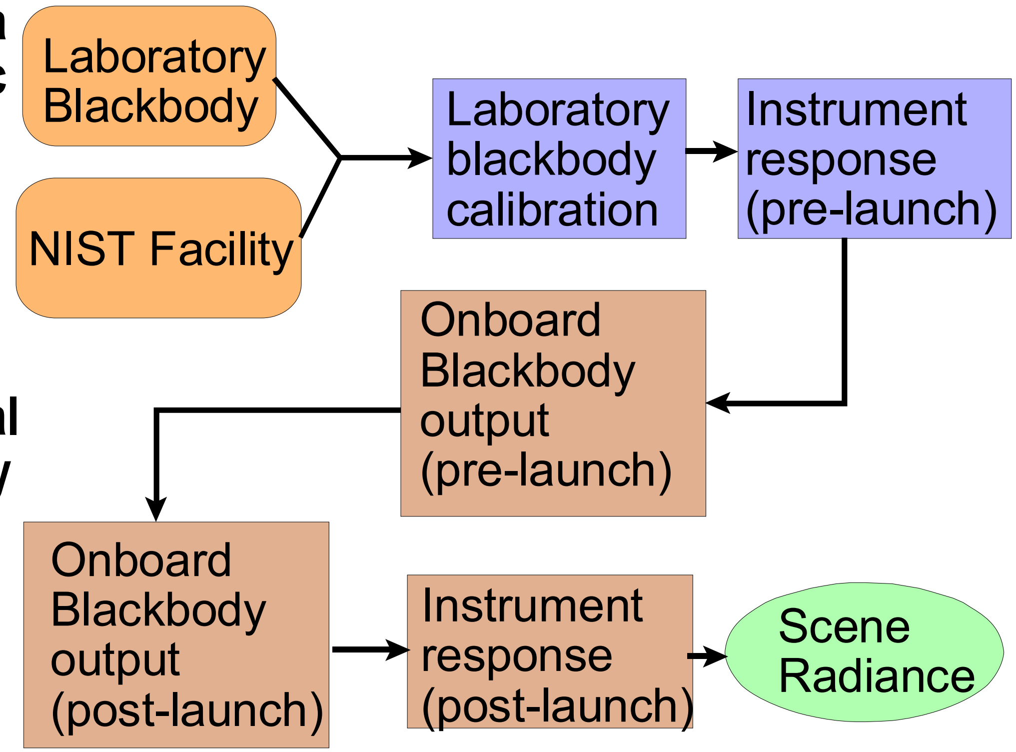
- Demonstrate the production of calibrated and registered WRS-2 scenes on the ground using TIRS data, TIRS data processing algorithms, and support data to correct residual errors in the LDCM TIRS data so that the resulting corrected LDCM TIRS data **meet the imagery requirements**
  - Radiometric Correction (RD 5.3.1)
    - Radiometric Response (Ground based characterization & in-flight cal sources)
    - Conversion to Radiance (cannot rely on scene data)
    - Conversion to Temperature
    - Inoperable Detector Replacement
  - Geometric Correction (RD 5.3.2)
    - Ancillary Data Preprocessing
    - Line Of Sight Model (cannot rely on scene data)
    - LOS Projections (cannot rely on scene data)
      - Ellipsoid
      - Terrain
  - Image Re-sampling (RD 5.3.3)
    - Cubic convolution interpolation to earth referenced coordinates
  - Performance (RD 5.3.4)
    - WRS-2 scene in 1/2 hour
  - Imagery Requirements (RD 5.6, 5.7)
    - Radiometry
    - Navigation and Registration

Test equipment characterization

- Further details of calibration facility discussed as part of test descriptions
- Characterization of test equipment is joint effort between MEI and TIRS team
  - Witness samples of components measured in GSFC facilities
  - Modeling/analysis of data to supply full range of operational configurations
- Laboratory blackbody will be sent to NIST for characterization after FPM testing
- Angular and spatial uniformity of the flood source
  - Model analysis
  - Measurements with independent IR camera
- Characterization of calibration GSE will take place during FPM testing

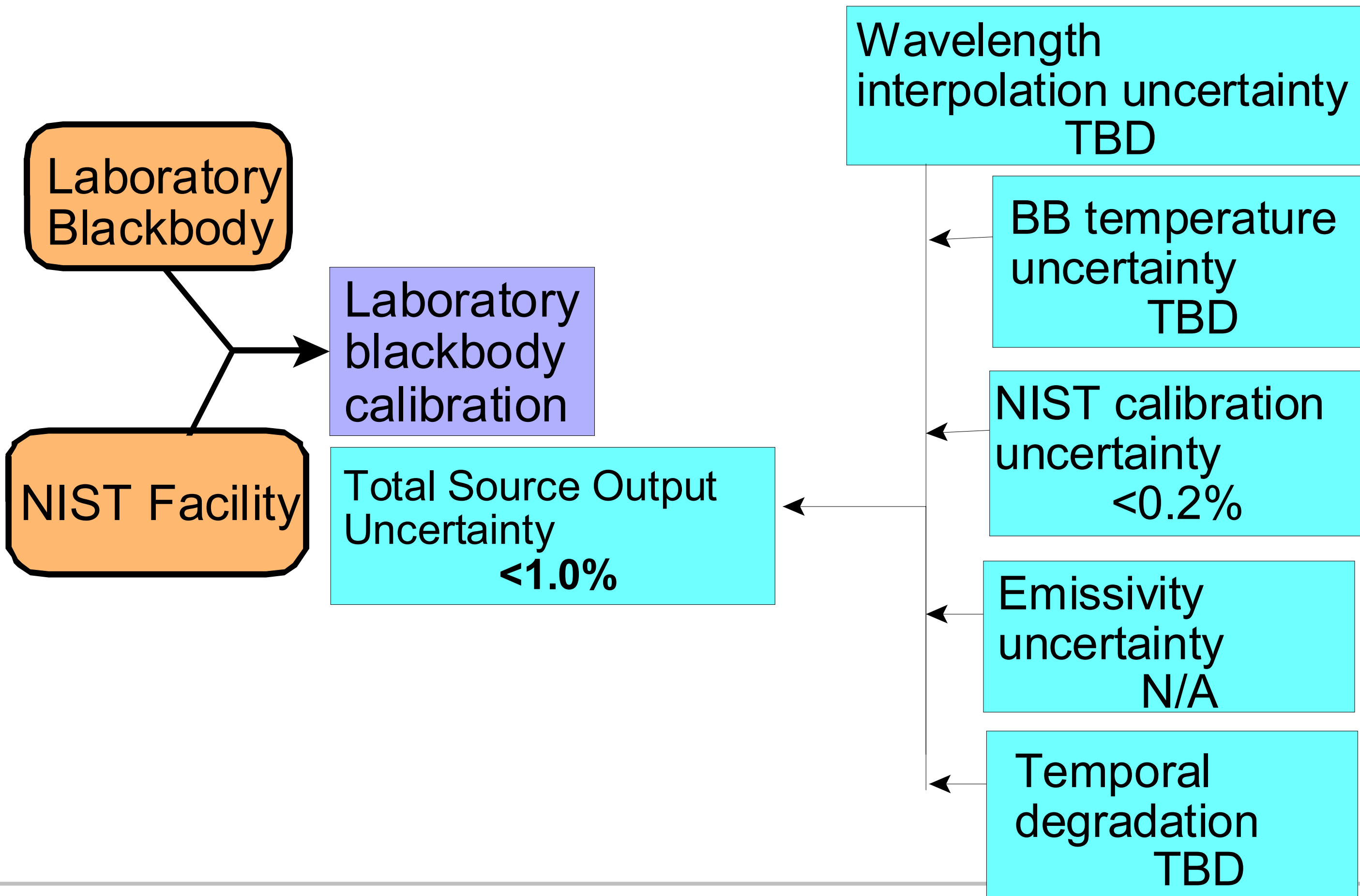
NIST-traceable absolute radiometry

- Blackbody source characterization is a key element in meeting the radiometric uncertainty requirement
  - ≤4% for 240 K to 260 K
  - ≤2% for 260 K to 330 K
  - ≤4% for 330 K to 360 K
- Must be established relative to National Institute for Standards and Technology (NIST) standards
- Send laboratory blackbody to NIST for calibration between FPM and flight testing



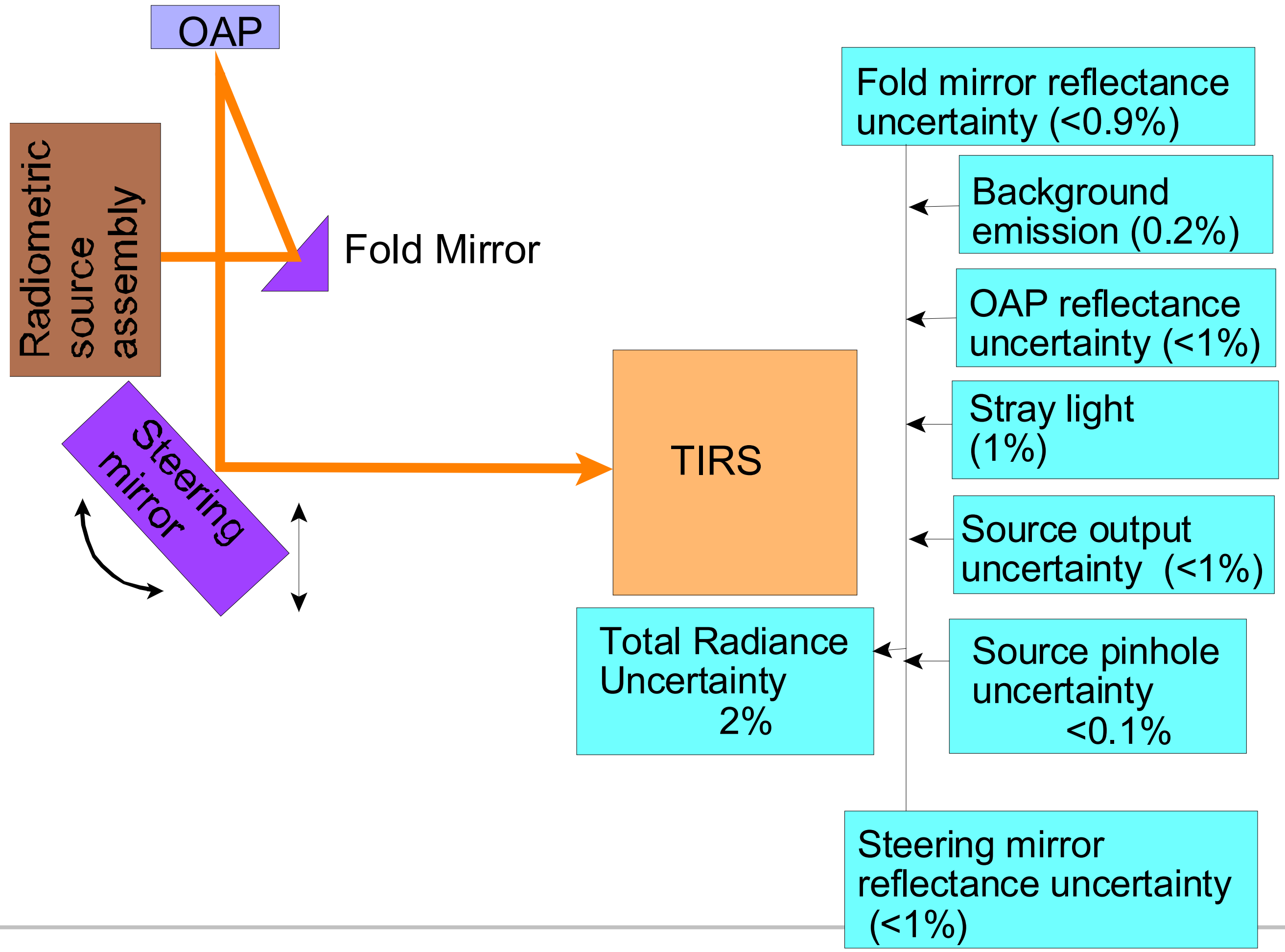
Radiometric source

- Laboratory blackbody source calibrated at NIST
- Uncertainty <1% sufficient to ensure radiometric calibration requirement is met

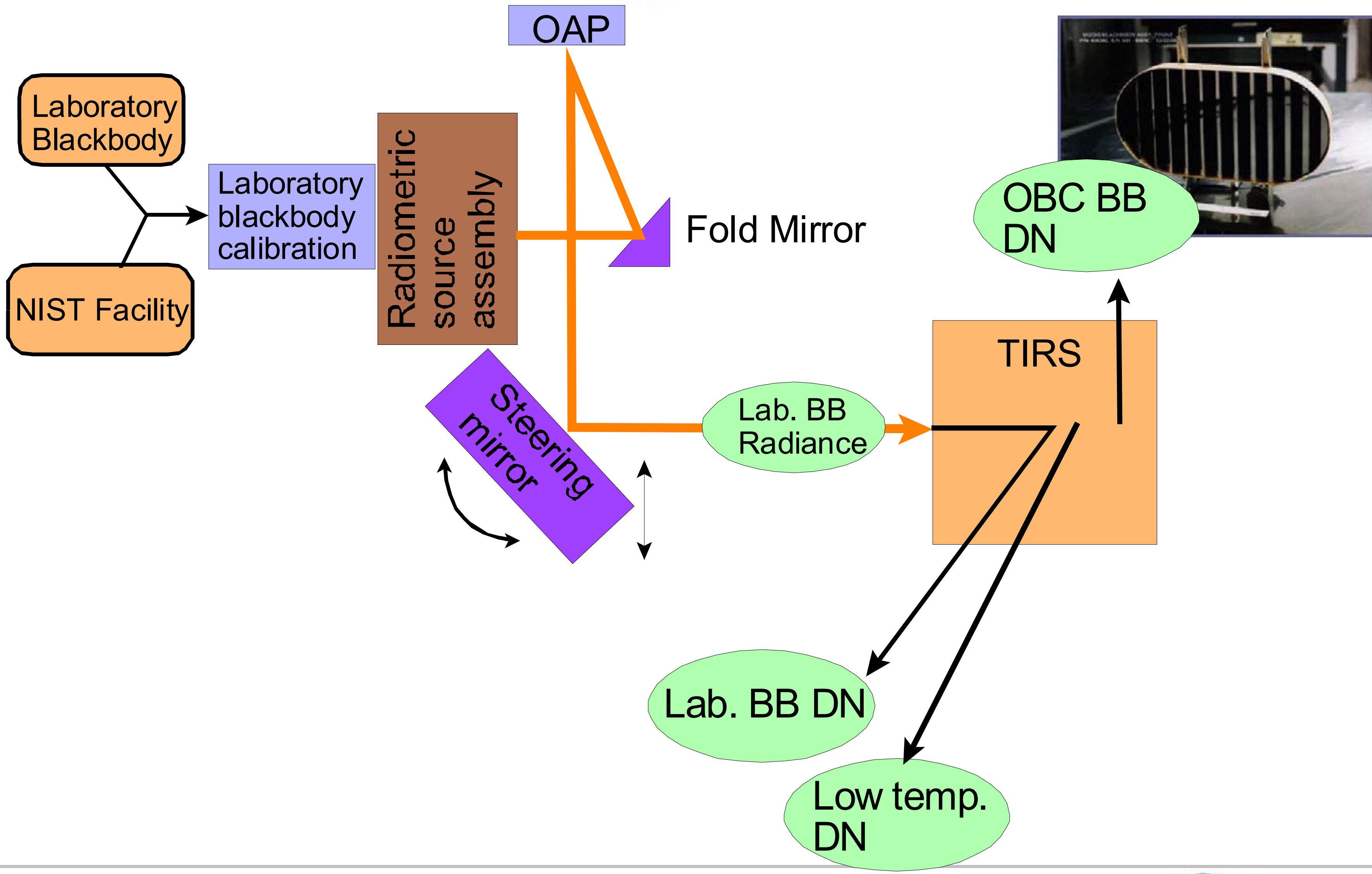


Radiometric uncertainty

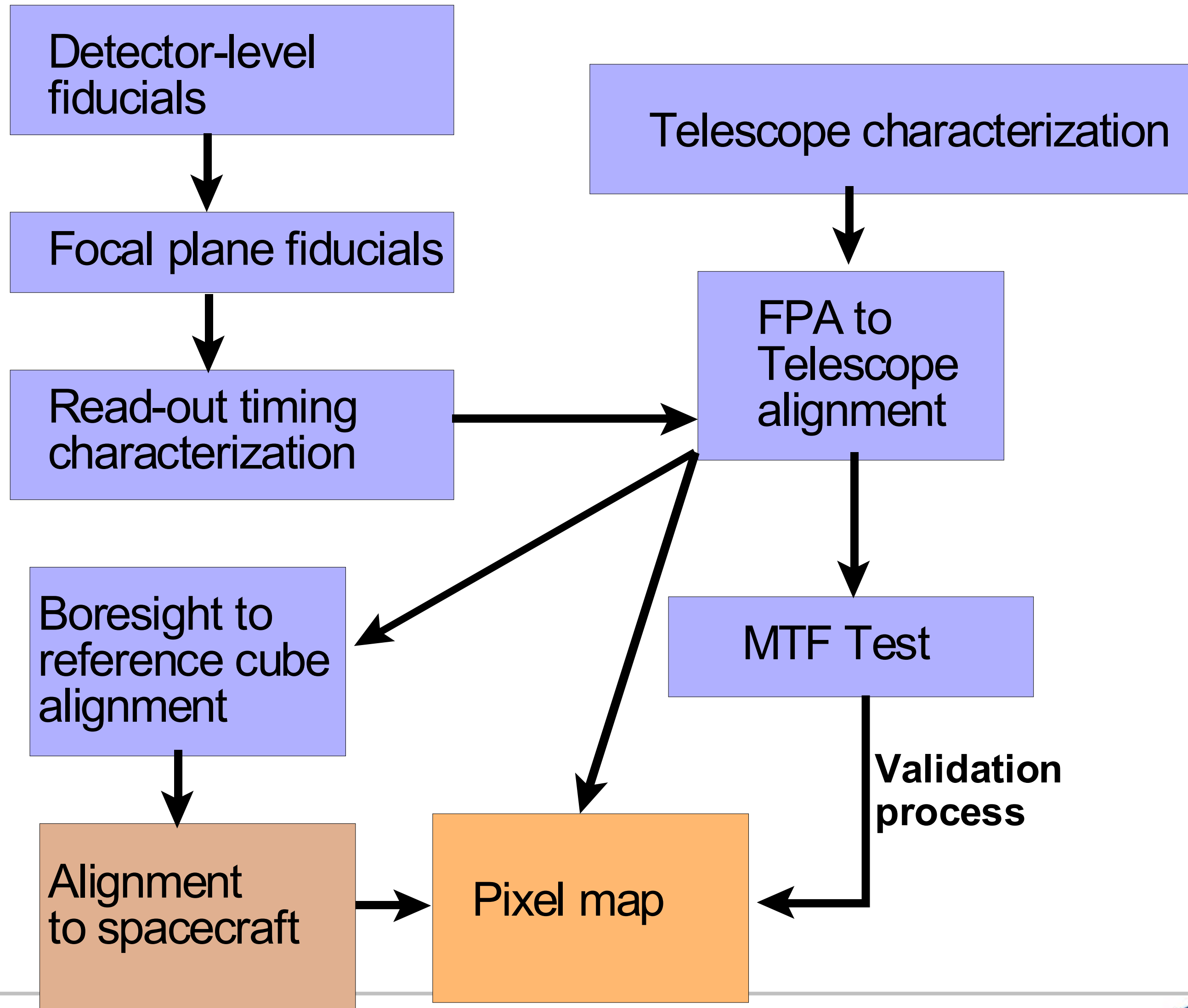
- **Nominal characterization of calibration GSE will satisfy radiometric requirements at launch**



Onboard blackbody characterization



Geometric calibration flow



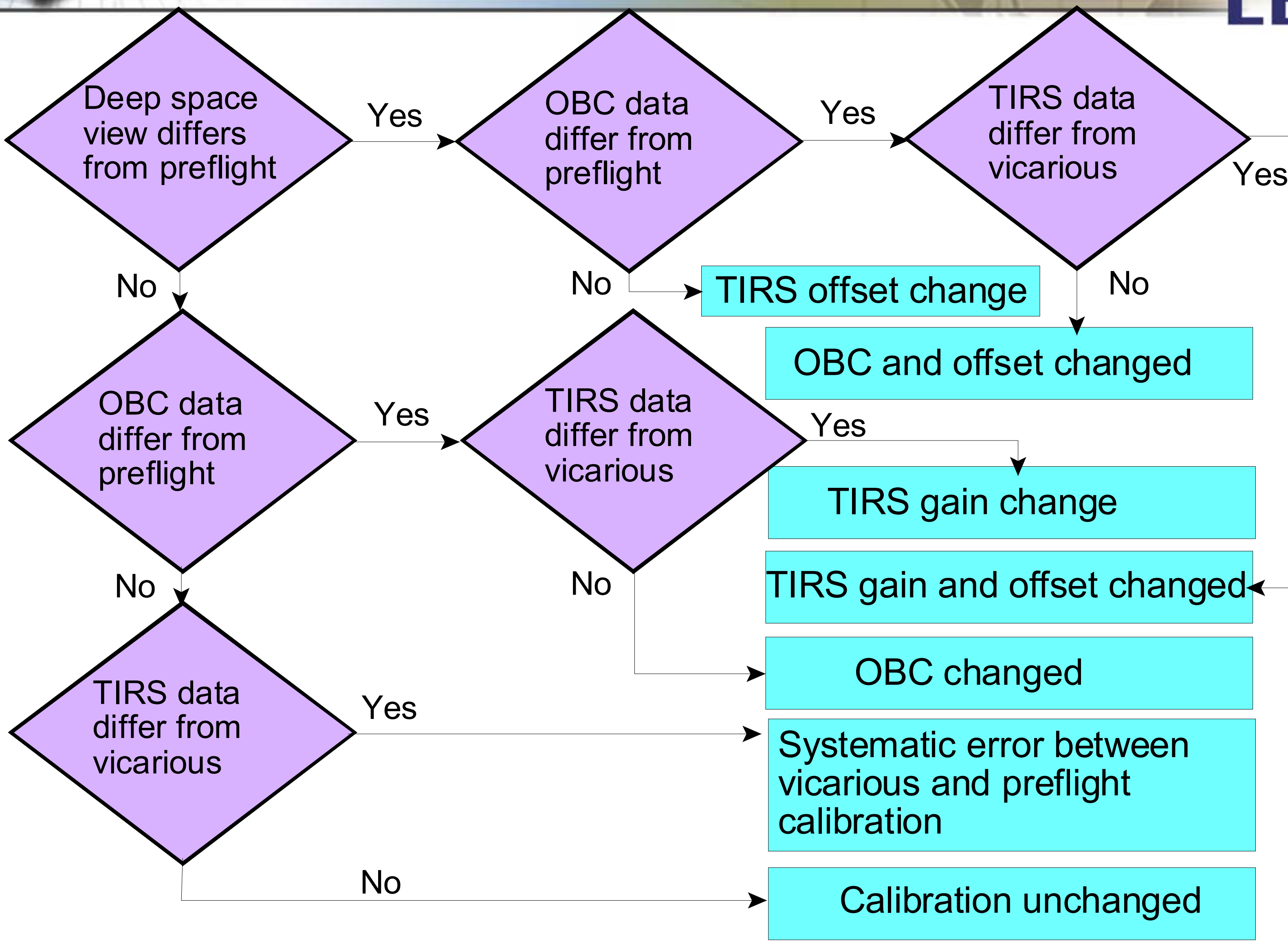
On orbit testing

- On-orbit testing will follow past efforts for similar sensors
  - Verify sensor calibration and noise performance on orbit
  - Evaluate onboard calibrator performance
- Radiometric approaches
  - Intercomparison with ETM+ per requirements
  - Ground sites
  - Intersensor comparisons
- Geometric approaches
  - Band-to-band registration
  - OLI comparison
  - Lunar approaches per requirements
- Three-month commissioning and checkout phase
  - Schedule is still under development
  - Transfer to orbit of calibration is one component

Radiometric calibration

- Methods will rely on well-understood ground scenes
  - Simultaneous nadir overpass (SNO) approach
  - Melt ponds
  - Sea-surface temperature retrievals
- Other sensors used in addition to ETM+
  - MODIS
  - VIIRS
  - GOES

Transfer to orbit



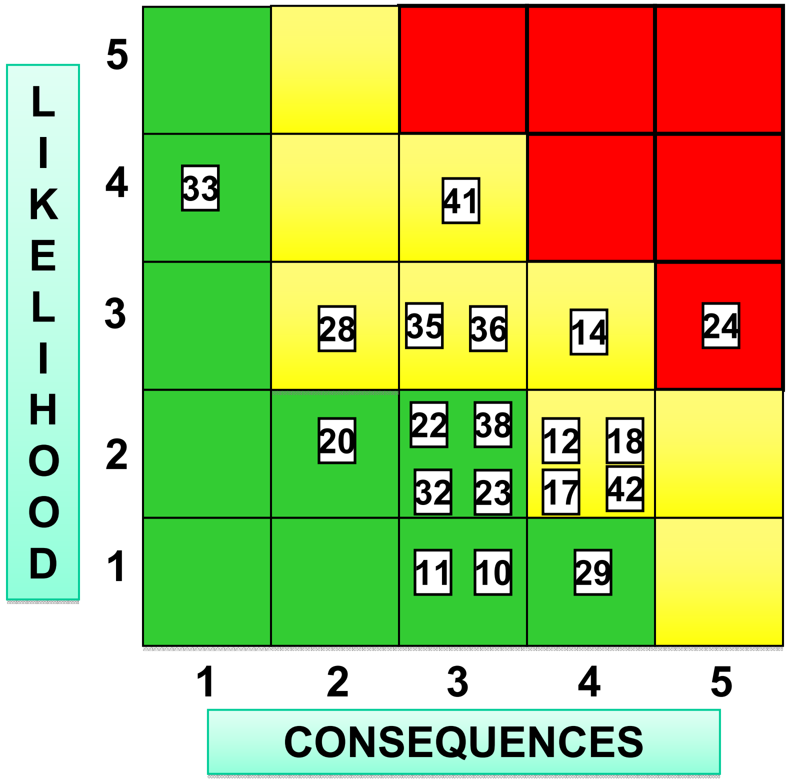
Geometric calibration

- Characterize instrument to Attitude Determination System Reference alignment.
- Characterize thermal band detector arrays lines of sight
  - Relative band to band
  - Relative to reflective bands
- Ground scenes
  - Cold deserts for OLI to TIRS registration
  - Hot spots for band-to-band
- Verify spatial characteristics via linear features
- Lunar views
  - OLI scheduled to use the moon for radiometric calibration
  - TIRS will also view the moon during the same maneuvers
  - Moon is high-temperature source
  - Examine data related to stray light and ghosting
  - Validate recovery time to return to nominal image performance

Summary

- Key requirements related to calibration/characterization have been identified
  - Driving requirements are known
  - Specific values still undergoing evaluation
- Impact of requirements on test equipment definition is understood
  - Test equipment based on off-the-shelf components
  - Test equipment specifications exceed what is needed from a measurement requirement
- Development of test procedures are being finalized
  - FPM testing will be used to evaluate procedures
  - Characterization of calibration GSE to take place during FPM testing
- Comments/action items from EPR have been addressed and awaiting comment from Review Committee

Top Risk List



LxC Trend	ID	Approach	Risk Title
⇨	24	M	TIRS Schedule
⇨	14	M	Detector Development
*	41	M	Mass
⇨	17	M	FPE development
⇨	36	M	I&T Planning
⇨	35	W	Potential loss of Key personnel
⇨	42	M	Jitter
⇨	18	M	Cryocooler Procurement
⇨	12	M	Requirements Baseline
⇨	28	M	ASIC Microcode Delivery

Criticality
- High
- Med
- Low

L x C Trend
- ⇩ Decreasing (Improving)
- ⇧ Increasing (Worsening)
- ⇨ Unchanged
- * New since last month

Approach
- M – Mitigate
- W – Watch
- A – Accept
- R - Research

Schedule Risk Mitigation

TIRS LDCM

	TIRS Organization	Systems Engineering	TIRS / LDCM Relationship
Mitigation Strategy	▪ Staff full time Instrument staff including IM, Deputy IM, CM, Scheduler, RA and Project Support ▪ Identify single point of contact for all TIRS procurements with Code 200. ▪ Co-locate Instrument Management team and Systems Engineering Team	▪ Increase Systems Engineering team, each with clear roles. ▪ Early documentation and traceability of requirements through level 5. ▪ SE team maintains control of Level 4 and 5 specifications ▪ SE team facilitates requirement development and management	▪ Establish role of TIRS Systems Engineer within LDCM to coordinate and communicate with TIRS team on a day to day basis. ▪ Establish interfaces between all disciplines of the LDCM / TIRS teams, as needed, including management, resources, systems engineering and mission assurance. ▪ Provide open access toLDCM to the TIRS CM system, meetings, peer reviews, etc.
Impact	▪ Provides support for reporting and review requirements. ▪ Allows for efficient communication between team management, including procurement. ▪ Results in higher Instrument Management costs than typical GSFC in-house instruments.	▪ Lessens burden of requirements documentation on leads, ▪ Increases communication within team. ▪ Provides high visibility by the SE team to potential requirements changes and their impacts across the system.	▪ Increases efficiency in documentation approvals, requirements changes, response time to action items. ▪ Allows for real time resolution of potential interface issues between TIRS evolving design and OLI or the spacecraft
Status	**Complete**	Complete	**Complete**

Schedule Risk Mitigation

	Review Process	Documentation	Schedule Management
Mitigation Strategy	▪ Establish early peer reviews on subsystems as soon as required based on the subsystem schedule.	▪ Eliminate or combine required documentation. ▪ Staff to respond to DRLs	▪ Create detailed schedule early. ▪ Maintain standard I&T durations ▪ Maintain required schedule reserve ▪ Track schedule performance
Impact	▪ Allows subsystems with longer development times to begin development and fabrication earlier, with reviewed designs. For example, FPA Pre-PDR Peer Review conducted prior to SRR. ▪ Cost estimate includes support for full review process.	▪ Documentation list is more demanding than many in-house missions due to being one of two instruments on an operational satellite. ▪ Cost estimate reflects documentation requirements.	▪ Provides insight early to identify design and/or testing priorities. ▪ Funded schedule reserve allows for issues and anomalies during I&T ▪ Allows early insight into schedule slips.
Status	Complete	Complete	Complete

Schedule Risk Mitigation

	Baseline Design	Engineering Model Philosophy	I&T
Mitigation Strategy	▪ Establish a baseline design allowing flexibility throughout preliminary design and critical design as issues arise.	▪ Develop a FPM including a FPA and telescope to verify system performance and calibration methodology. ▪ Parallel subsystem engineering models as needed for risk reduction at the subsystem level.	▪ Hold contingency to allow for additional shift throughout FM I&T. ▪ Reserve T/V chamber throughout the FPM and FM test duration, approximately 2 years. ▪ Staff full I&T team for FPM testing.
Impact	▪ Allows quick response to issues that arise during design and testing, with minimal impacts to the system design.	▪ Decreased risk at flight model integration.	▪ Allows parallel FPM Testing and FM development. ▪ Eliminates conflicts in T/V chamber with other projects. ▪ Additional cost.
Status	Complete	Planned	**In process:** **Contingency in cost estimate** **T/V chamber reserved** **Beginning FPM I&T staffing**