Thermal InfraRed Sensor TIRS-2 Instrument Development

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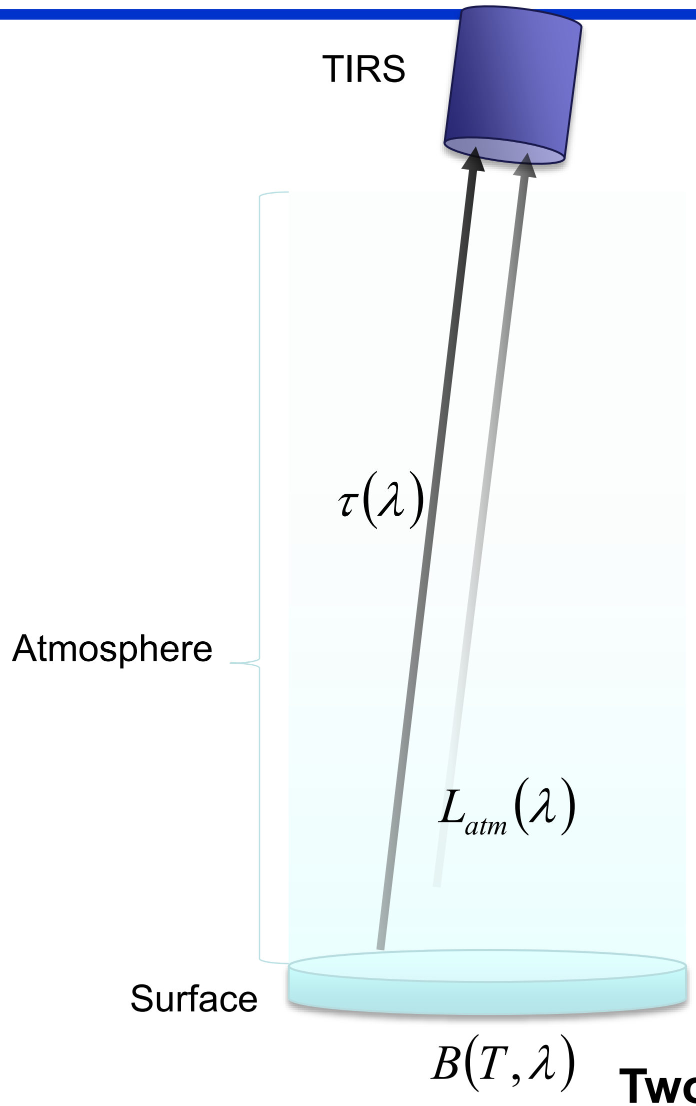
TIRS-2 Project Overview

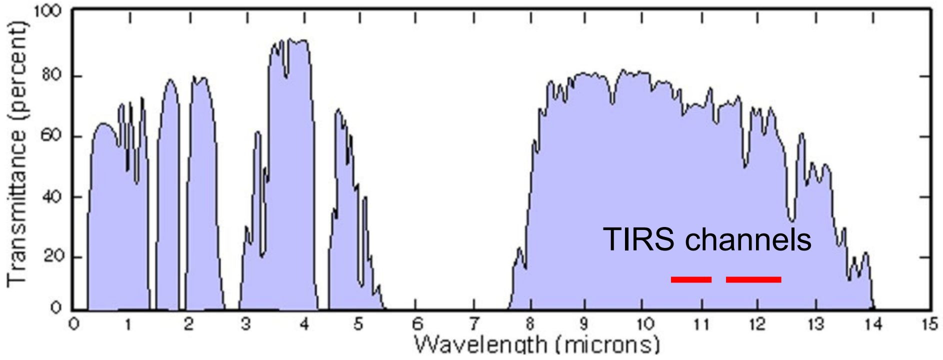
- TIRS-2 will fly on the LandSat 9
  - 16 day re-visit cycle
- Like TIRS on Landsat 8, TIRS-2 will produce radiometrically calibrated, geo-located thermal image data
  - TIRS-2 operates in concert with, but independent of, the Operational Land Imager (OLI-2)
  - Final scene data generated as part of 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 code
  - TIRS-2 will deliver algorithms and parameters necessary to evaluate data and produce required outputs
  - No changes expected from process used for TIRS on Landsat 8
- TIRS-2 image data will have the same performance characteristics as that of TIRS on Landsat 8
  - Except better in some cases

Thermal Radiance Detected by TIRS-2 from Surface and Atmosphere



$$L_s = \frac{\int \left(B(T,\lambda)\cdot\tau(\lambda) + L_{atm}(\lambda)\right)\cdot R'(\lambda)\cdot d\lambda}{\int R'(\lambda)\cdot d\lambda}$$

- $B(T,\lambda)$ • Emitted and reflected surface radiance
- $\tau(\lambda)$ • Transmission of atmosphere
- $L_{atm}(\lambda)$ • Emitted and scattered radiance of atmosphere
- $R'(\lambda)$ • Spectral response of pixel
- L_s • Pixel integrated radiance



Two channel "split window" techniques correct for atmosphere and improve retrieved surface temperature

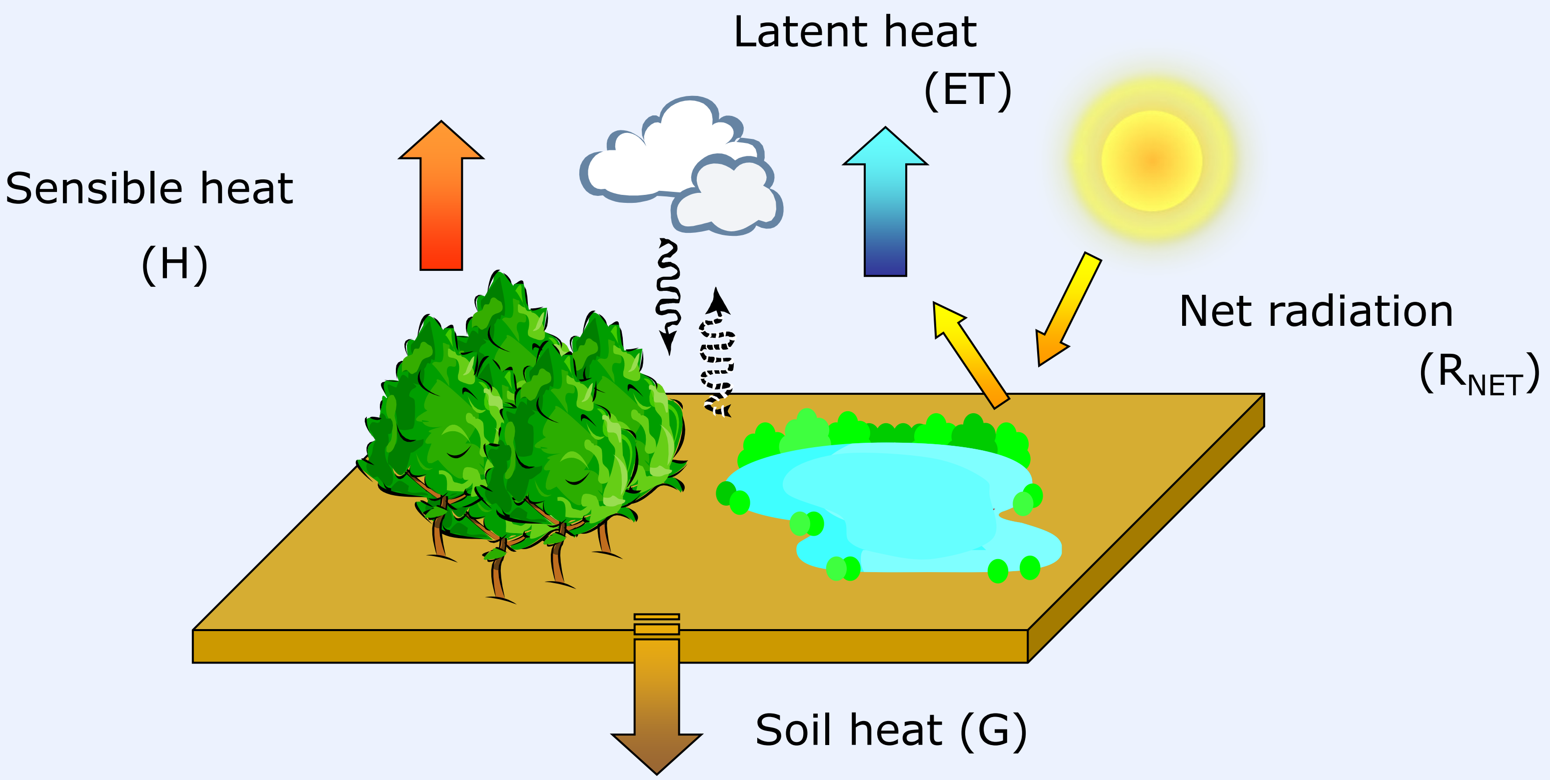
TIRS-2 Science Overview

- Landsat satellites have acquired single-band thermal images since 1978
  - – Landsat 3 (1978 -1983) afforded 240 m spatial resolution in the thermal band
  - – Landsat 4 (1982 - 1989) and Landsat 5 (1984 – 2003) afford 120 m resolution
  - – Landsat 7 (1999 - present) affords 60 m resolution
- TIRS on Landsat 8 (launched 2/11/2013) produces 100 m thermal data in 2 bands
  - – 2 bands allows use of split-window technique to correct for atmospheric absorption
  - – TIRS-2 on Landsat 9 will do the same
- Landsat thermal data are now used operationally to monitor water consumption on a field-by-field basis in the U.S. West and internationally
  - – Evapotranspiration cools vegetation
  - – 120 meter resolution (or better) sufficient
  - – Allowed by development of operational energy balanced-based evapotranspiration models
    - Parametric models use measured vis/NIR and thermal radiation, surface classification and estimates of soil thermal transport

Example: Water Management Using Surface Energy Balance

$$R_{NET} = G + ET + H$$

$$R_{NET} = (SW_{dn} - SW_{up}) + (LW_{dn} - LW_{up})$$



- Net Radiation is the balance between incoming minus outgoing radiation
  - OLI required to calculate the SWup (short wave albedo)
  - TIRS data required to calculate the LWup from surface temperature

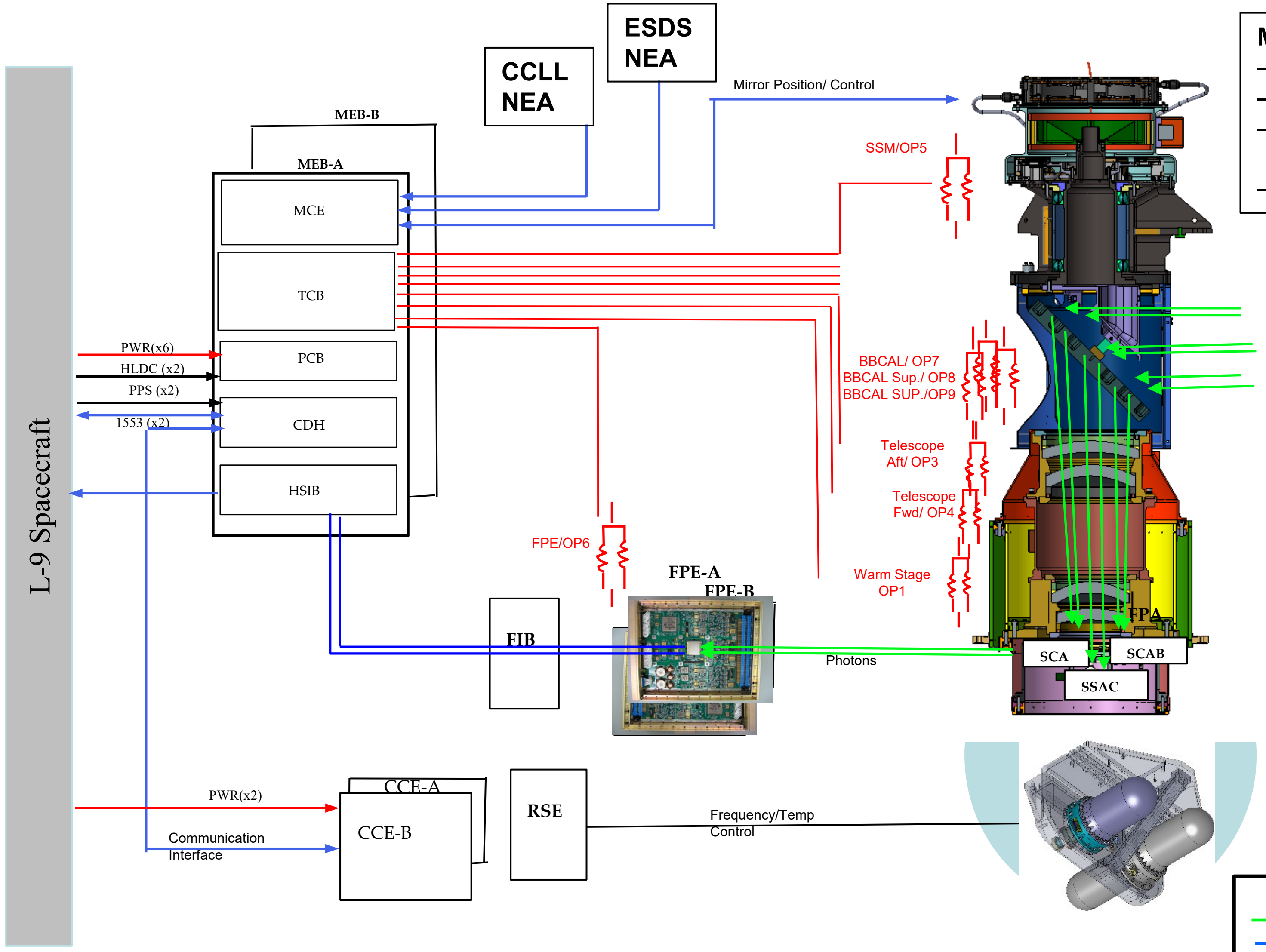
Driving Requirements

	Title	Requirement	Expected Compliance
Spectral	Thermal Spectral Band and Width	Band 10.8 Center 10.8 +/- .2, min/max edge 10.3/11.3 um Band 12.0 Center 12.0 +/-.2, min/max edge 11.5/12.5 um Waiver Approved for 12.5 um Level 3 Requirement	= 10.9 nm center, 10.6 um to 11.2 um = 12.05 nm center, 11.5 um to 12.6 um Model shows band edge around 12.55 um, analysis shows negligible impact on science
Radiometry	Absolute Radiometric Accuracy	Absolute radiometric uncertainty relative to a NIST traceable standard < 2% (1-sigma)	CBE = 1.8% (1-sigma)
	Radiometric Stability	12.0 um < 0.70% (1-sigma) 10.8 um < 0.70% (1-sigma)	= 0.53% (1-sigma) = 0.51% (1-sigma)
	Noise Equivalent Delta Radiance -NEΔL	10.8um 0.059 W/m2 sr µm 12um 0.049 W/m2 sr µm	Radiance < 0.008 (360K, flood source) Radiance < 0.008 (360K, flood source)
Spatial	Ground Sample Distance	185 km cross track swath width 120 m cross and in track for each detector element	185 km 100 m per detector element
	Relative Edge Response	AT > 0.047/m (originally > 0.007/m) XT > 0.047/m (originally > 0.007/m) Deviation Approved for Level 3 Requirement	10.9 um: XT: .0059 m AT: .0058m 12um: XT: .0059 m, AT: .0060 m TIRS-2 performance same as TIRS, which met science objectives.
	Edge Extent (10 to 90%)	AT < 245m (originally <150m) XT < 245m (originally <150m) Deviation Approved for Level 3 requirement	10.9 urn: XT: 215.6 m, AT: 222.9 m 12um: XT: 214.9 m, AT: 205.5 m TIRS-2 performance same as TIRS, which met science objectives.
Pointing	Absolute Pointing	2 mrad (3-sigma, per axis)	XT= 556.6 urad, AT= 688.0 urad
	Alignment Knowledge	< 600 urad each axis	XT= 279.3 urad, AT= 400.0 urad
	Pointing Stability	< 27 urad (3-sigma, per axis) over 16 days	XT= 7.16 urad, AT= 4.14 urad
	Timing Accuracy	Timing of each detector column shall be known < 1.5 ms	CBE < 1.5 ms

Driving Requirements

Title	Requirement	CBE / MEV
	Engineering	
Science Data Rate	< 15Mbps	= 9.747Mbps
Power	Imaging / Calibration (Operational PWR) MEB < 150 W CCE < 225 W	MEB CBE = 97.0 W CCE CBE = 190.0 W
	Survival PWR< 255 W	CBE = 197.0 W
	Fault Mode (Operational PWR) MEB <150W CCE <225W	MEB CBE = 81.0 W CCE CBE = 190.0 W
Mass	Total < 350kg Instrument Deck Total <210kg	MEV = 326.0 kg MEV = 201.1 kg
Availability	> 0.95	> 0.95
Mission Life	5.25 Years = ops + commissioning	= 6 years (mission life + ground ops)

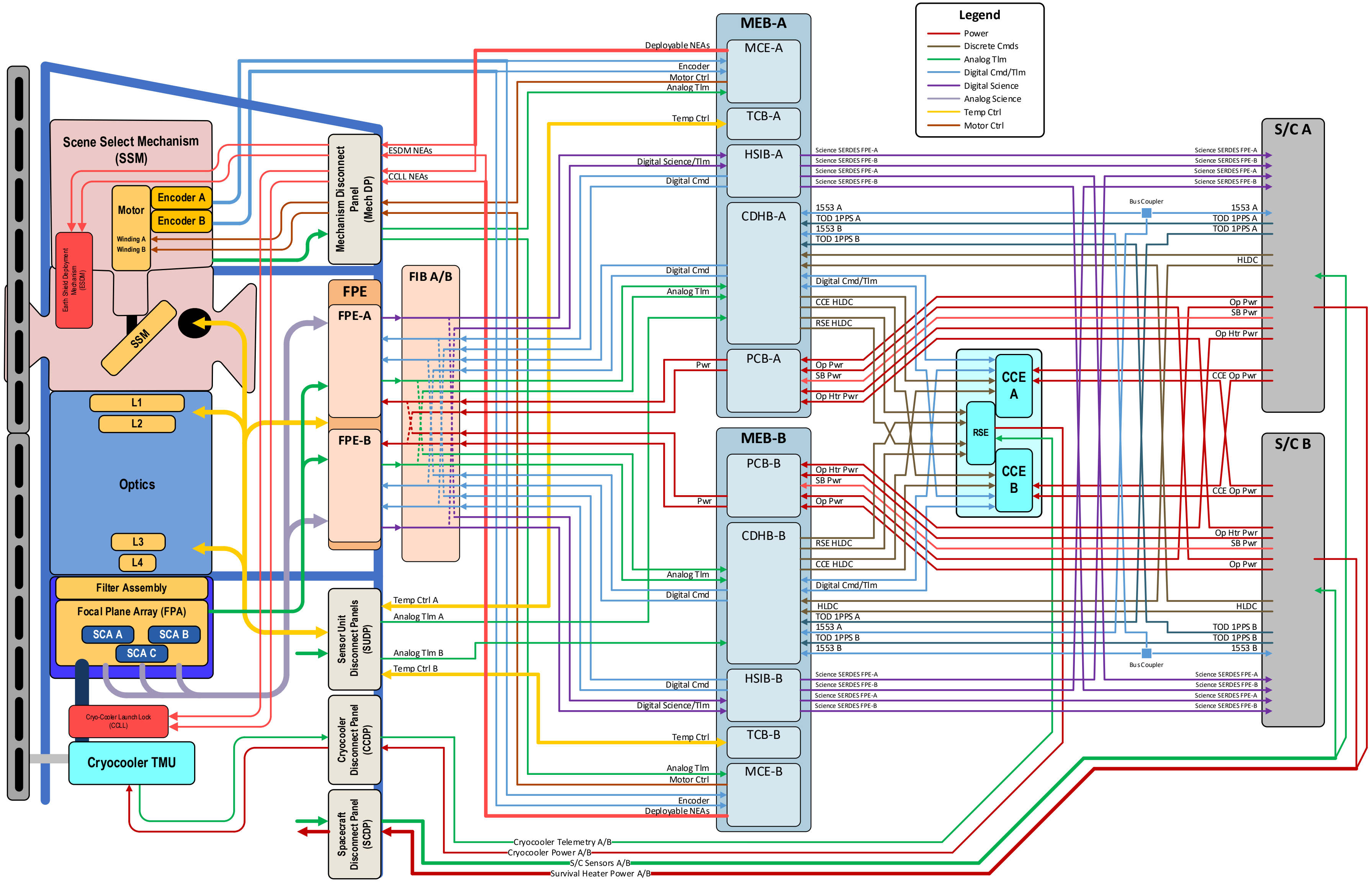
Instrument System Block Diagram



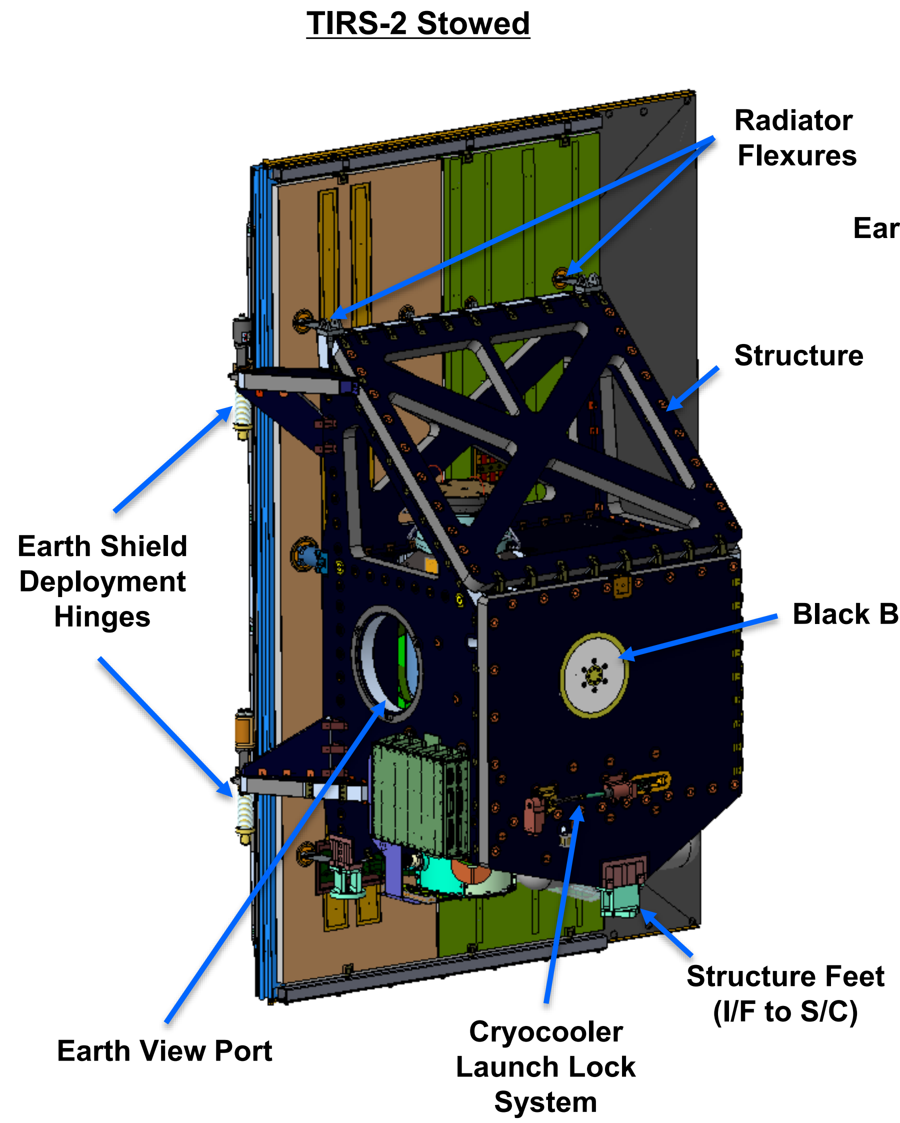
Major Functions:
– Cryocooler
– Science Data Path
– Mechanisms Control/Deployables
– Thermal Control

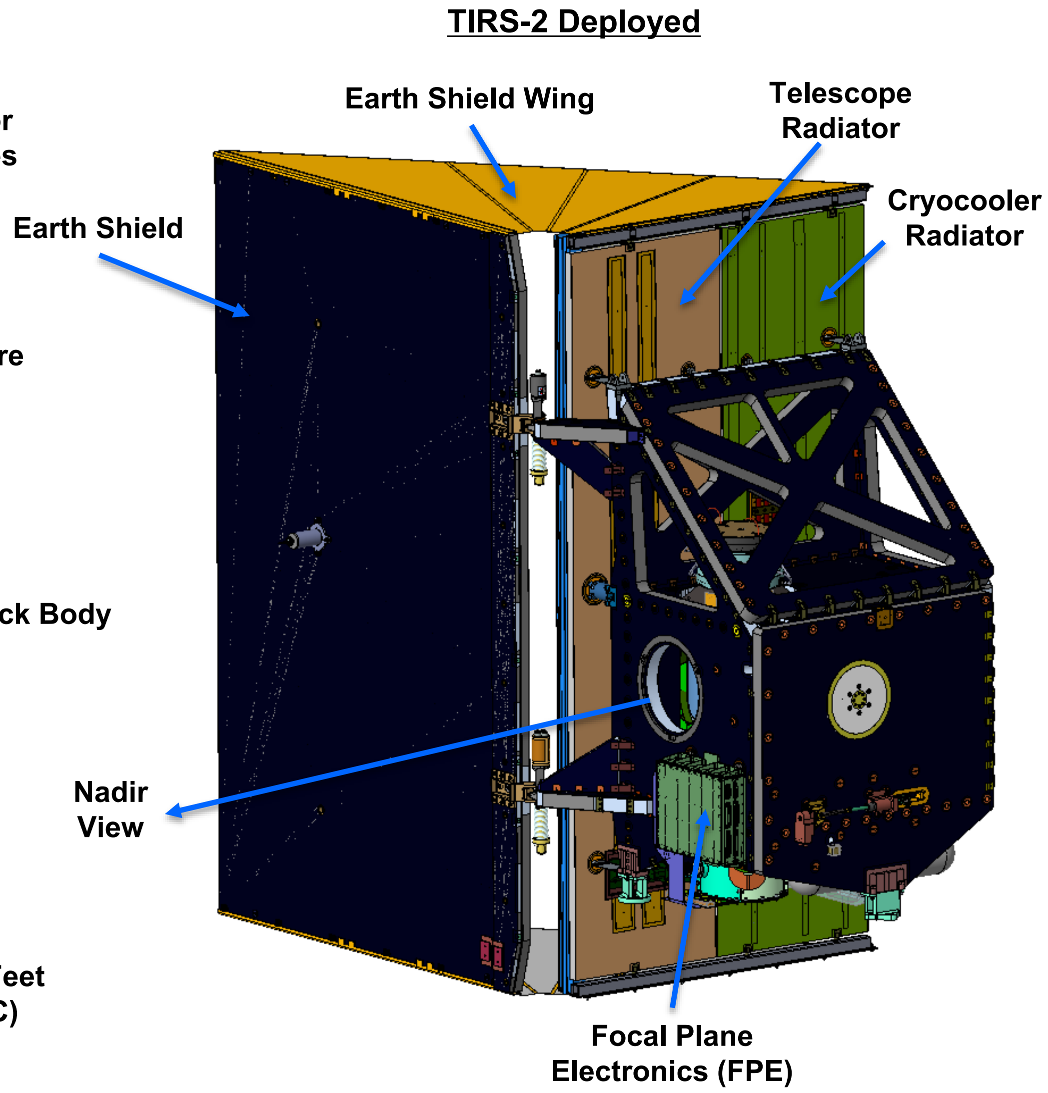
Key
- Optical Path
- Communication
- Power

TIRS-2 System Block Diagram

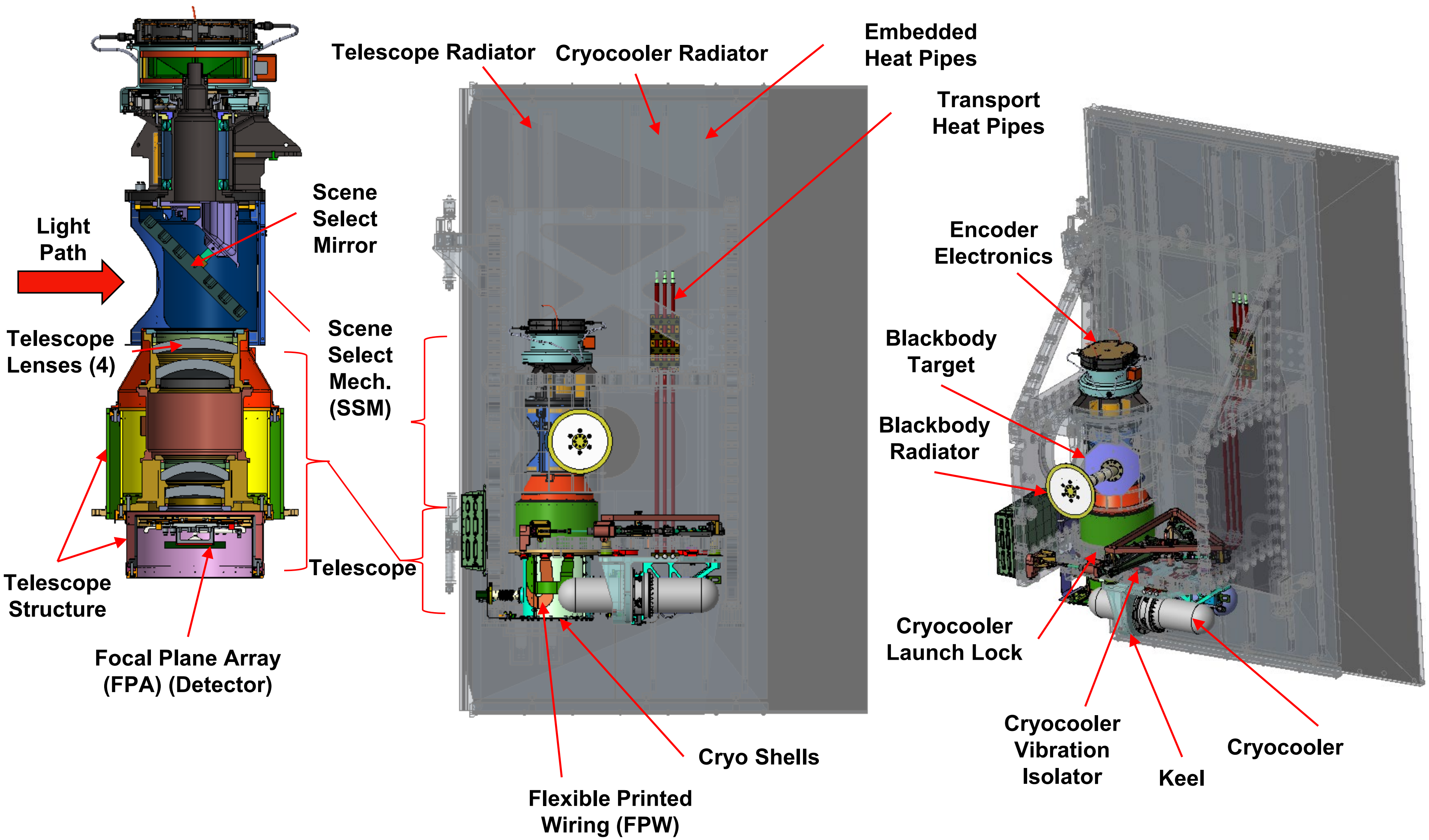


TIRS-2 Sensor Unit Design Overview

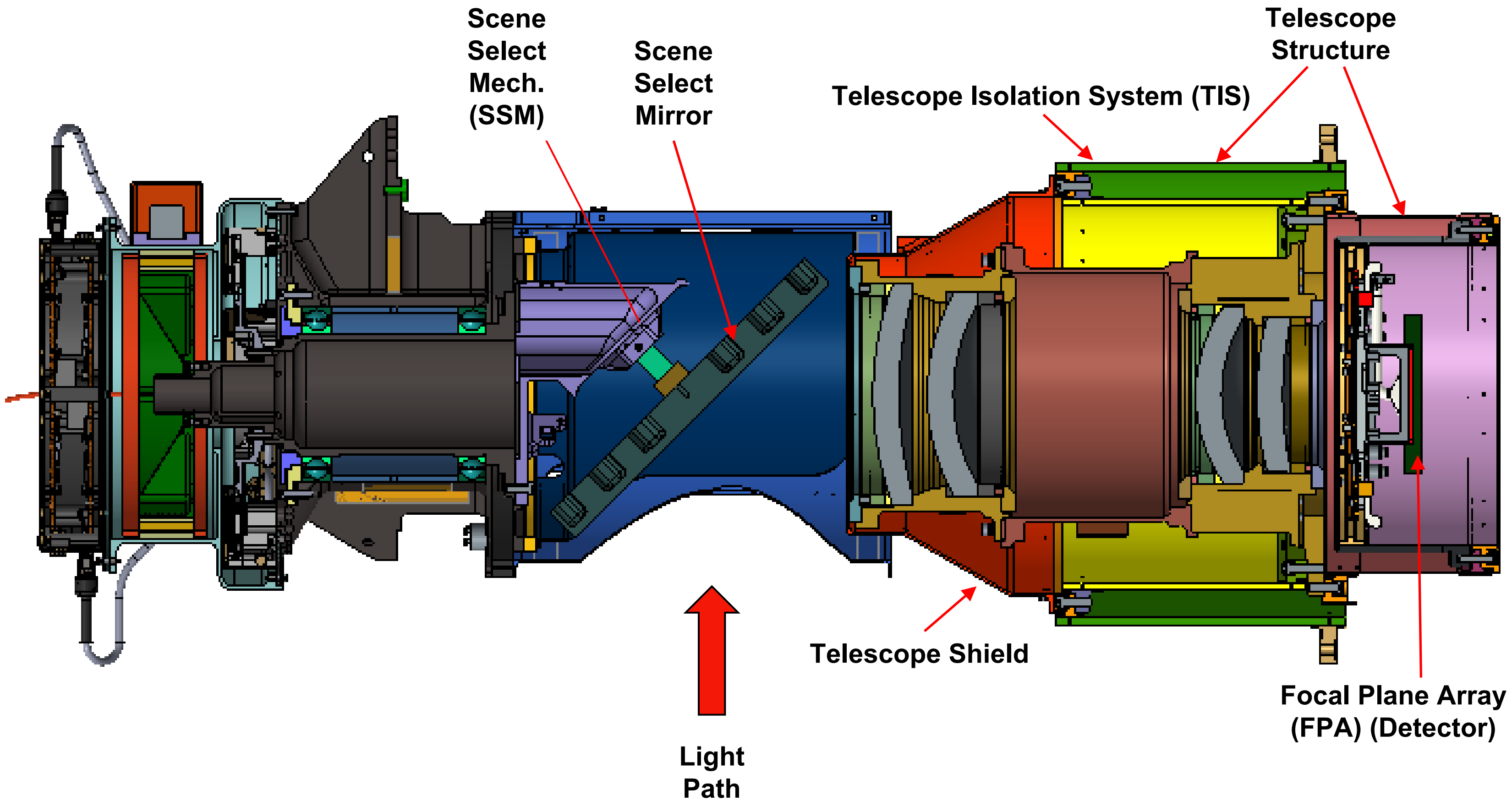




TIRS-2 Sensor Unit Design Overview

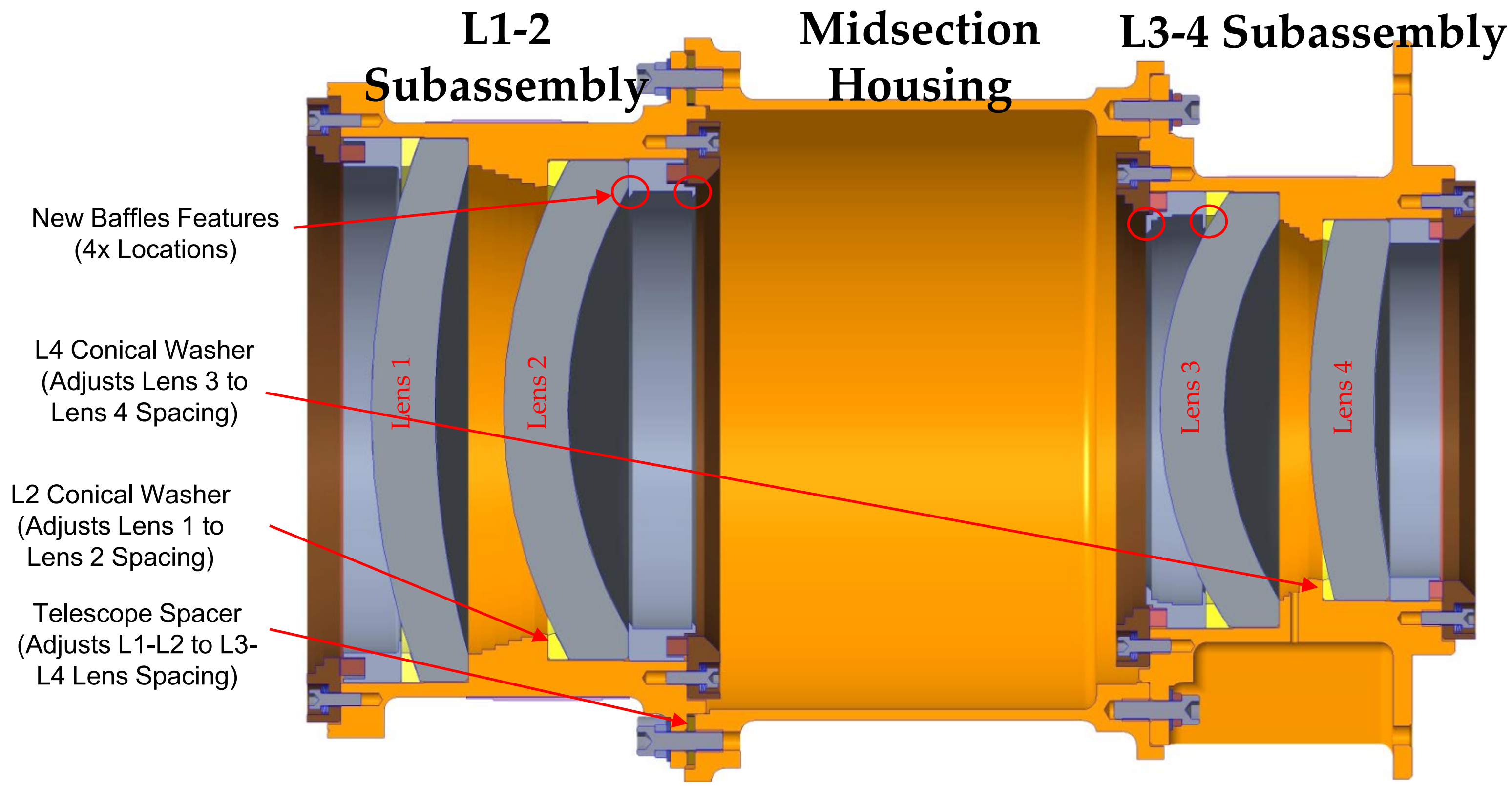


Overview of TIRS Sensor, con't



Barrel & Optics Subassembly

- Lenses mount to L1-L2 & L3-L4 Subassemblies
- Stray light baffles added to Lens 2 & 3 Preload Spreaders
- Lens Axial Positioning: performed with Telescope Spacer & Conical Washers



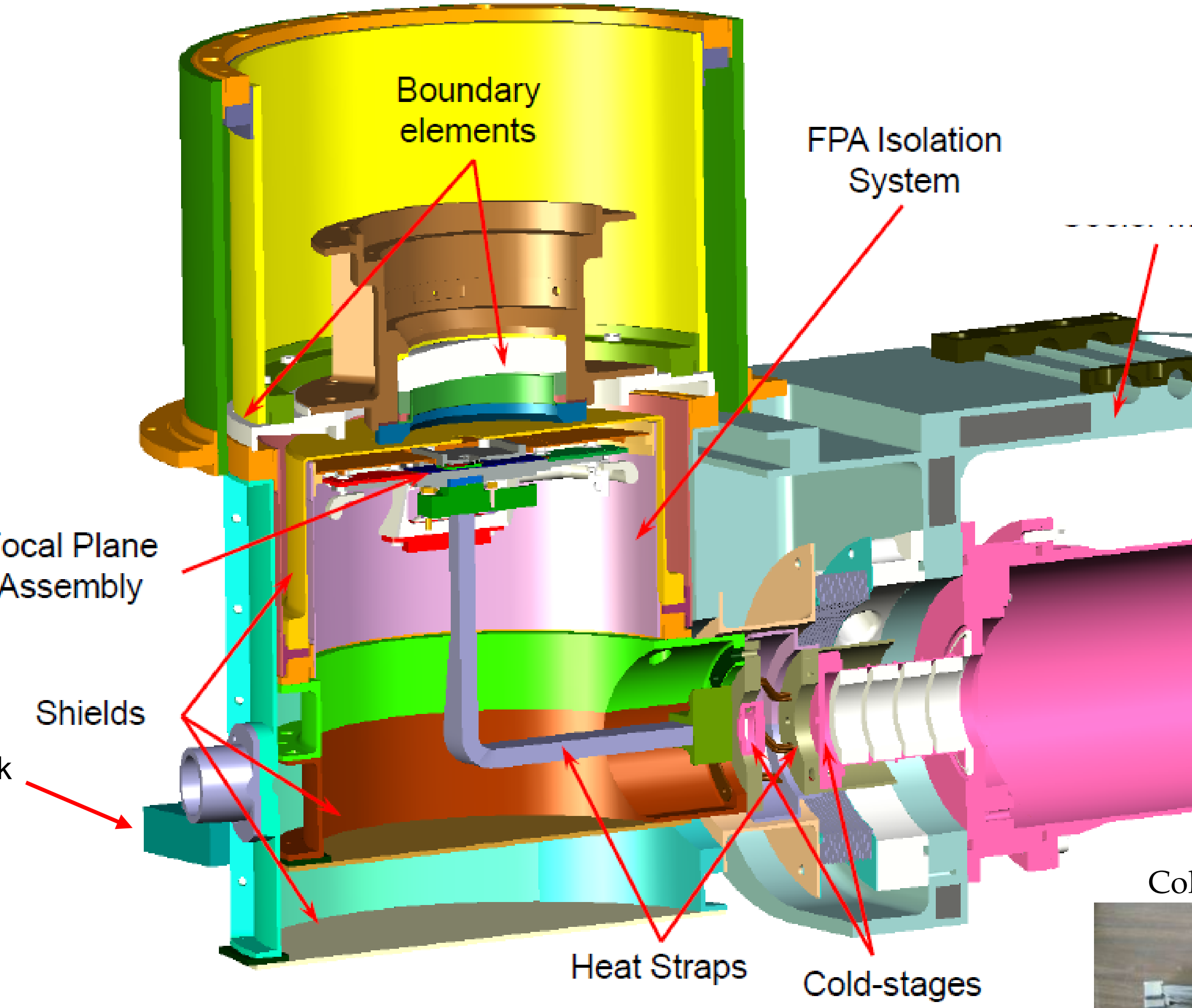
Barrel & Optics X-Section

Cryo Subsystem Overview

Tel Stage FCL

Tel APG Bar

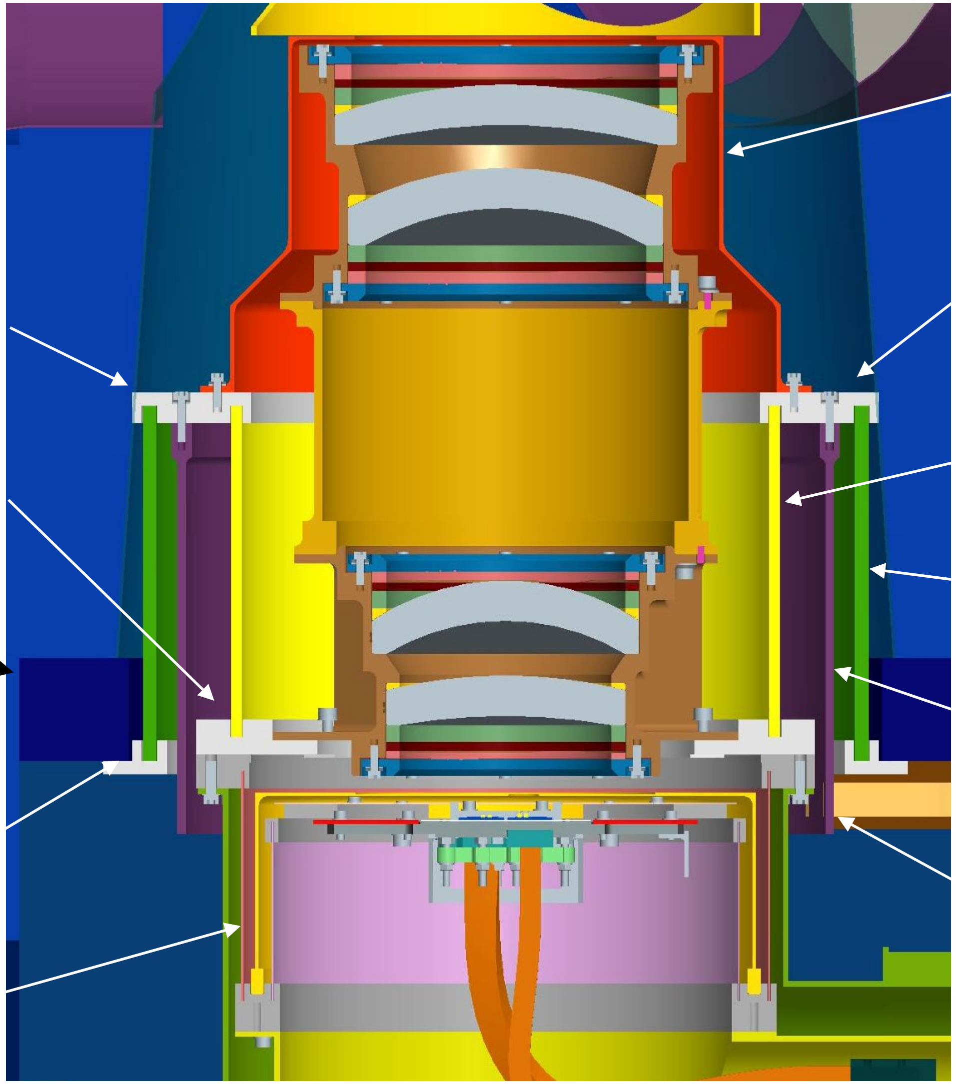
Warm Stage FCL



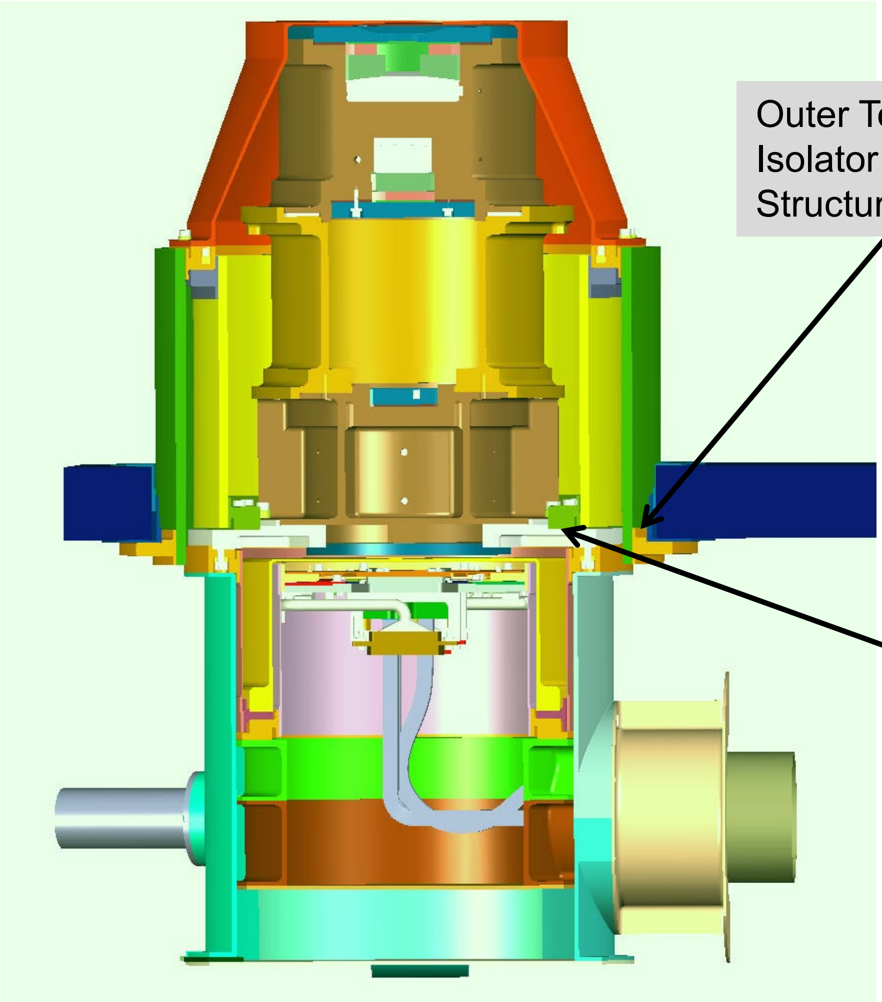
CC Mount (keel)

Cold Stage FCL

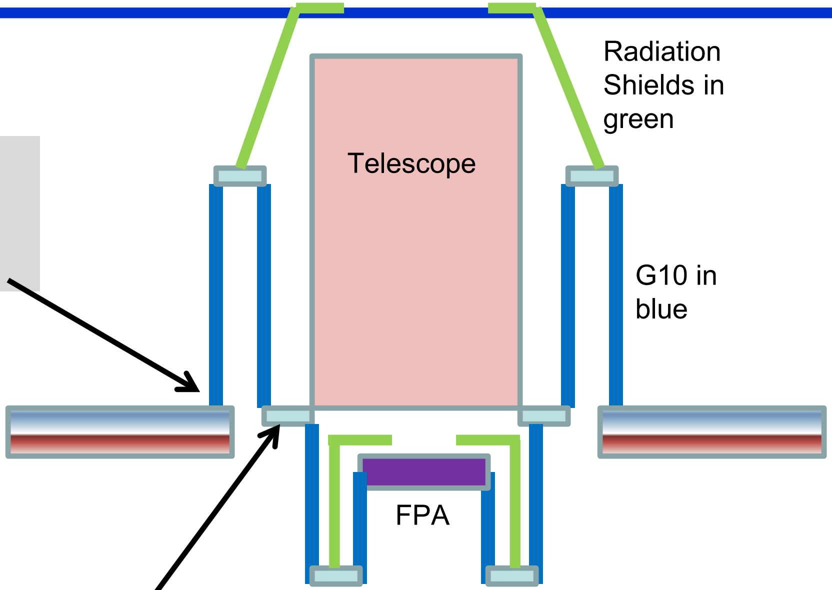
Telescope Structural Thermal Isolation Mount



Isolation System Overview



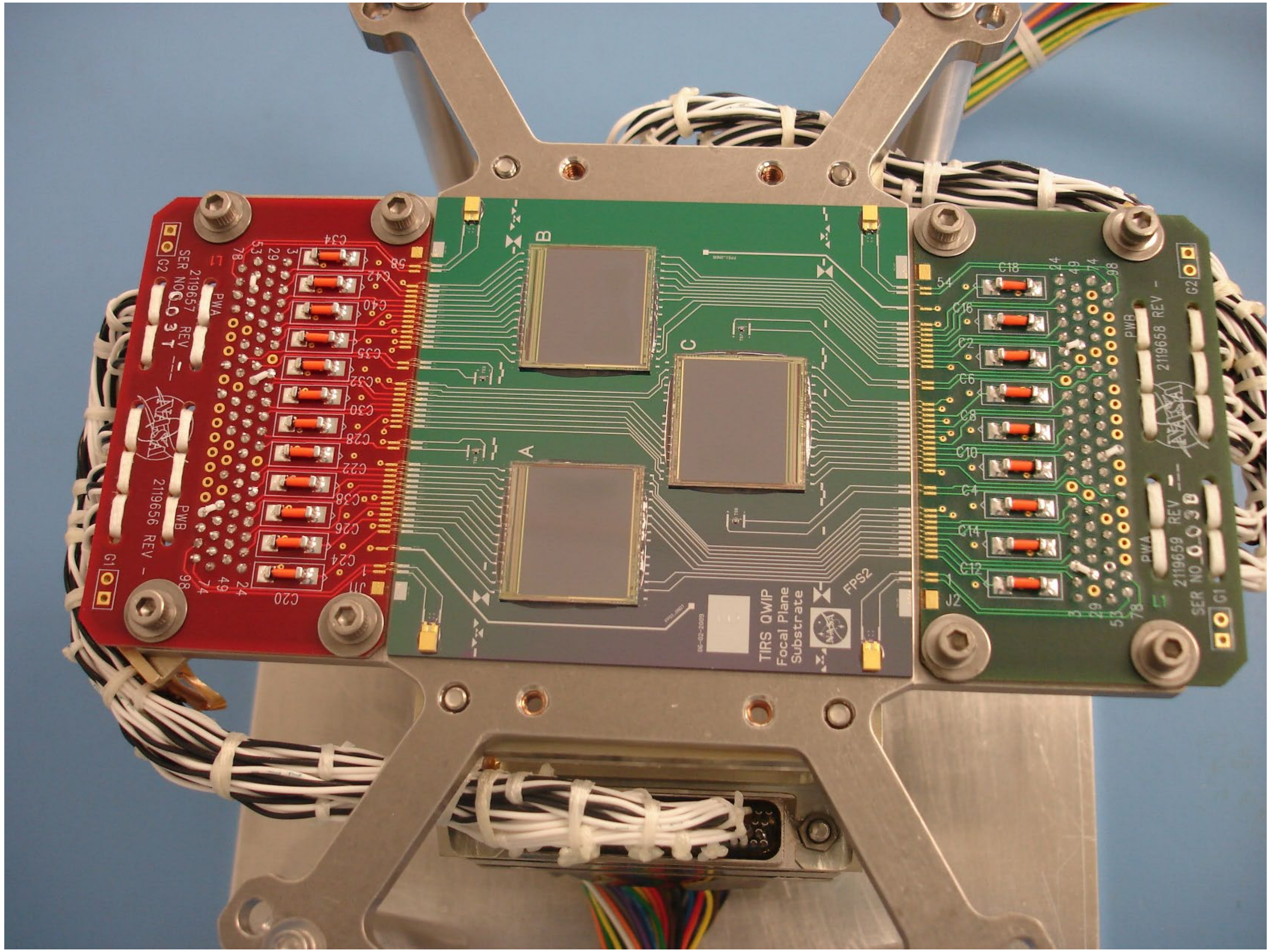
Outer Telescope Isolator I/F with Structure



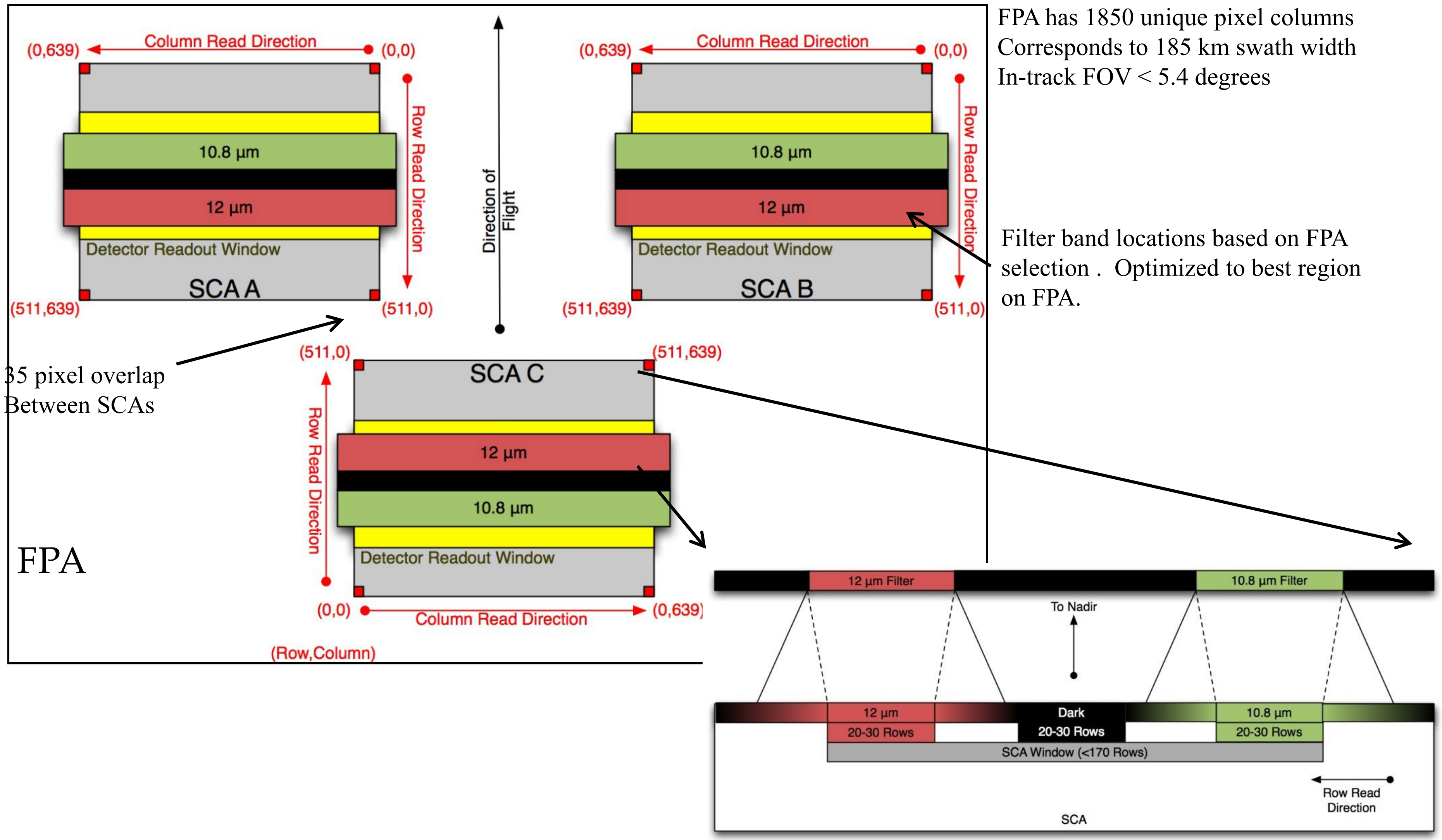
I/F: Inner Telescope Isolator, Outer FPA Isolator, and Telescope

FPA has physical separation from telescope

TIRS-2 Flight Focal Plane Assembly



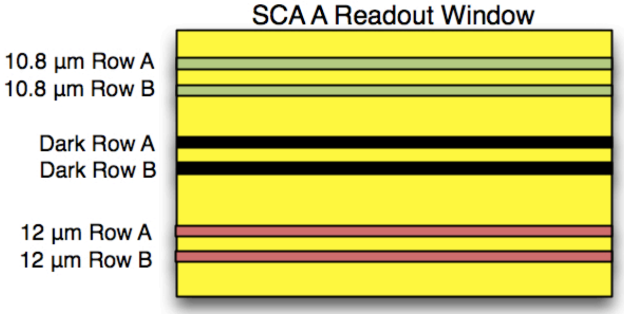
FPA Architecture

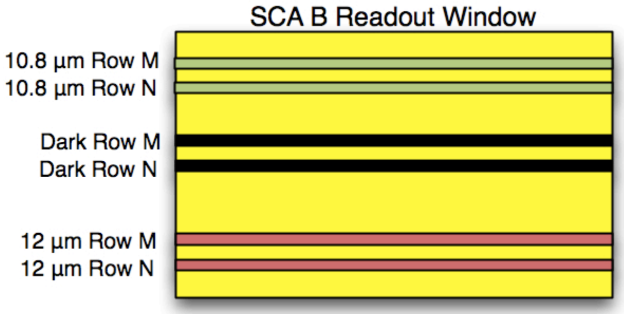


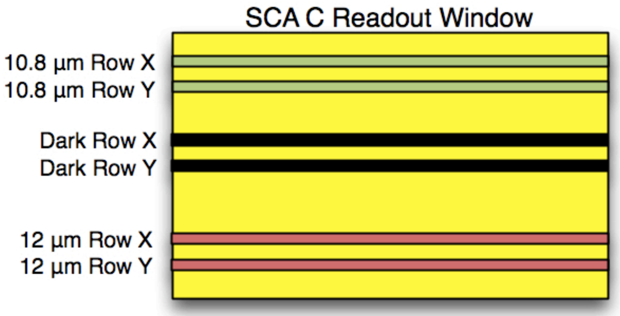
FPA has 1850 unique pixel columns
Corresponds to 185 km swath width
In-track FOV < 5.4 degrees

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

SCA Readout Paterns



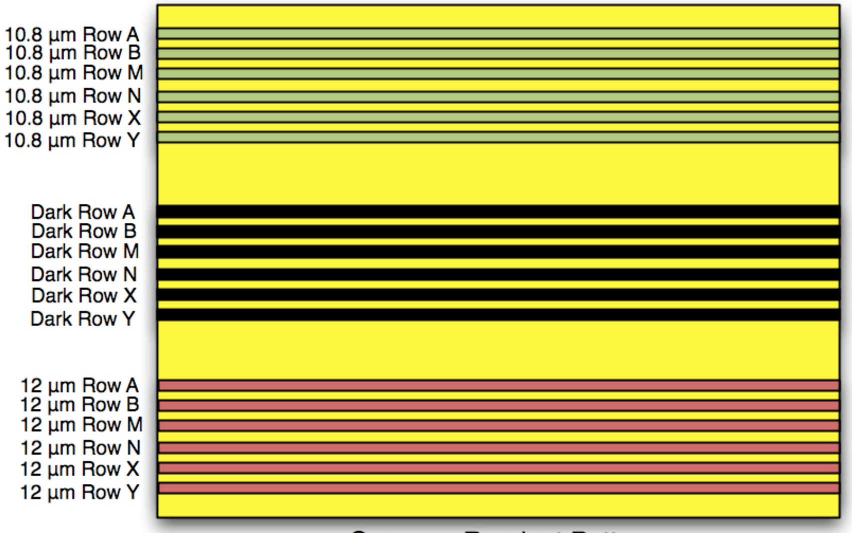




Readout from through the FPE at 2 clock rates:

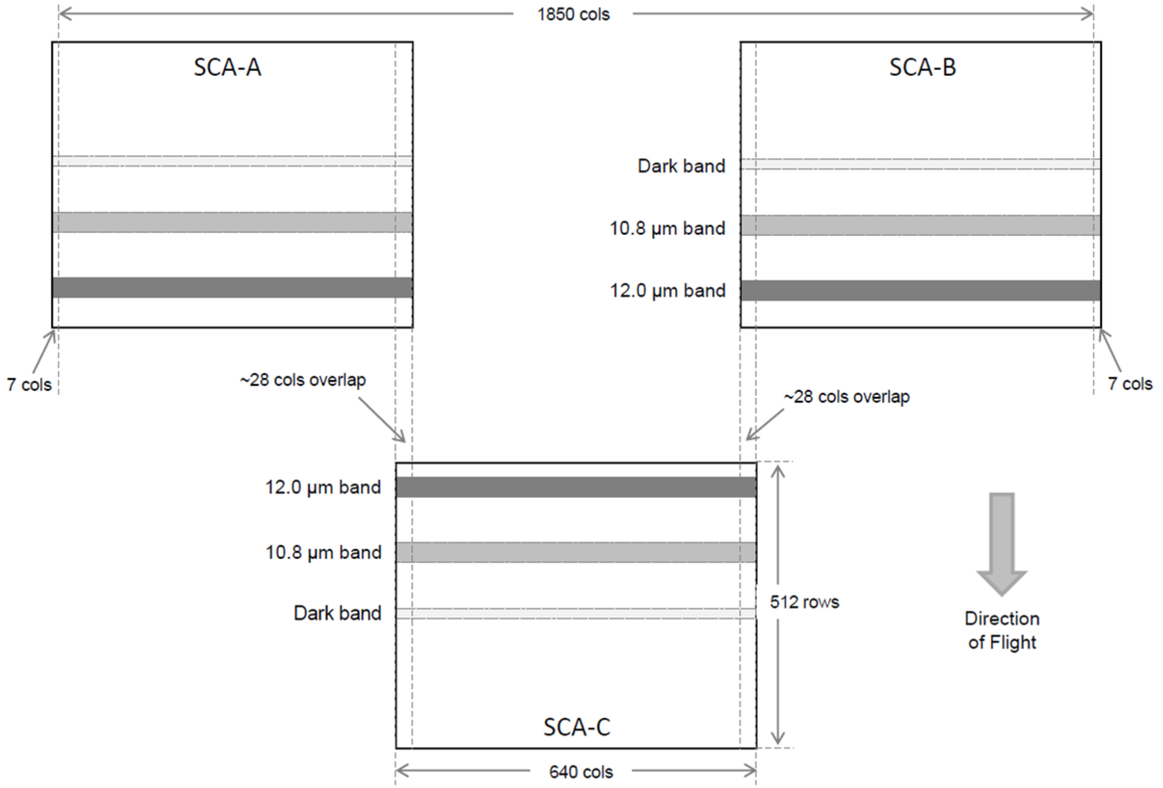
- 500 kpixel/second "Read"
- 1 mpixel/second "Skip"

Row mask will be set prelaunch but can be changed through microcode updates on orbit if too many pixels from a row are lost on orbit



Common Readout Pattern

Image Formed on Focal Plane Assembly



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

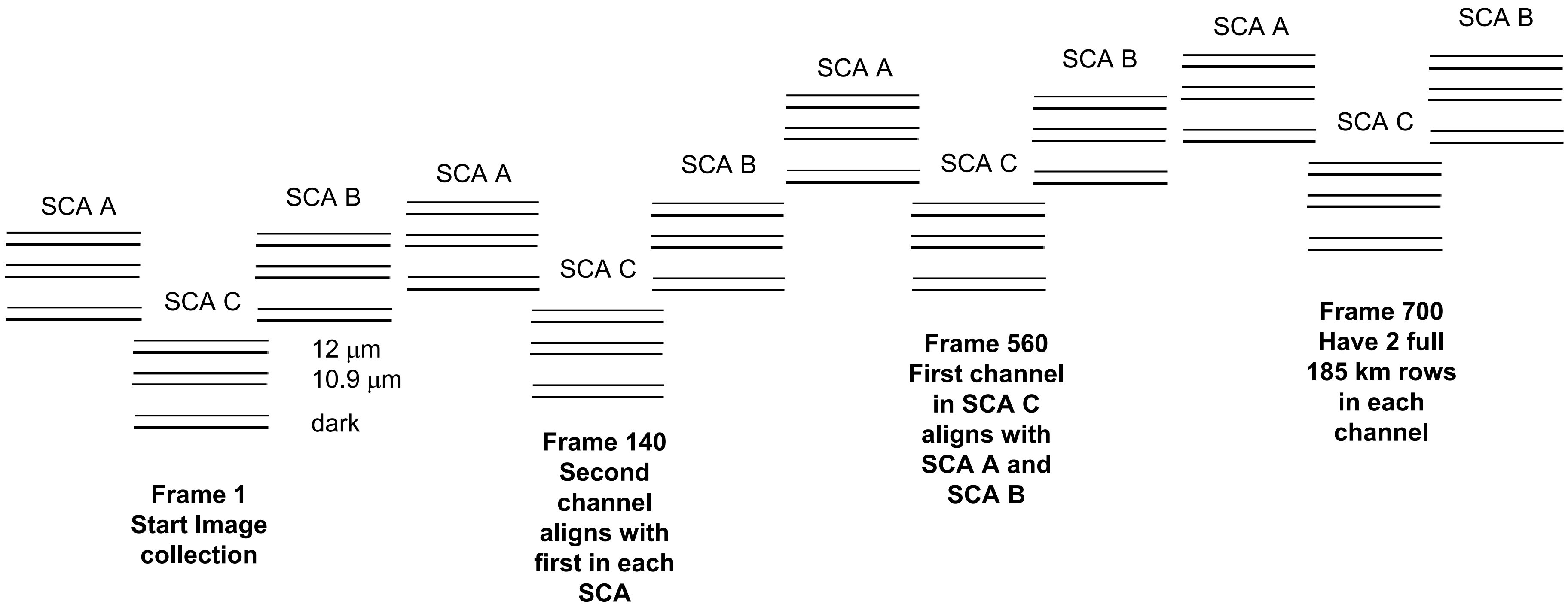
Filter band locations based on FPA selection . Optimized to be in best region on FPA.

- Up to 140 rows between channels on a single detector
- 700 rows before data produced by SCA C aligns with SCAs A and B

- Read 2 rows from the central 30 rows for each filter on each array and for dark region (far from filters)
- Dark region is an area covered by the filter holder
- Combine data on ground to get single best row
- Row selection can be changed in flight

How do we make an image?

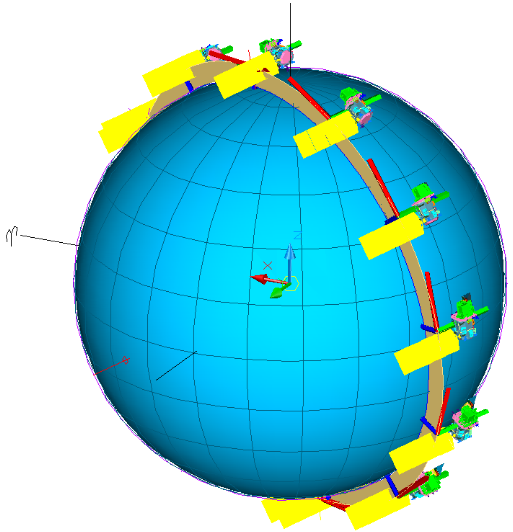
- 2 rows of data taken in each channel and in dark area
  - Combined into a single effective row on the ground
    - Generally all pixels in each row are good.
  - Dark only used if detector temperature is not stable – Dark has never been used



- Each frame from 700 on gives another full 185 km row in each channel
- Frame integration time is ~3.23 milliseconds
  - Allows excellent Signal-to-Noise Ratio without significant spatial broadening
- Non-science rows are skipped – allows science rows to be read out @ 235 kilopixels/sec

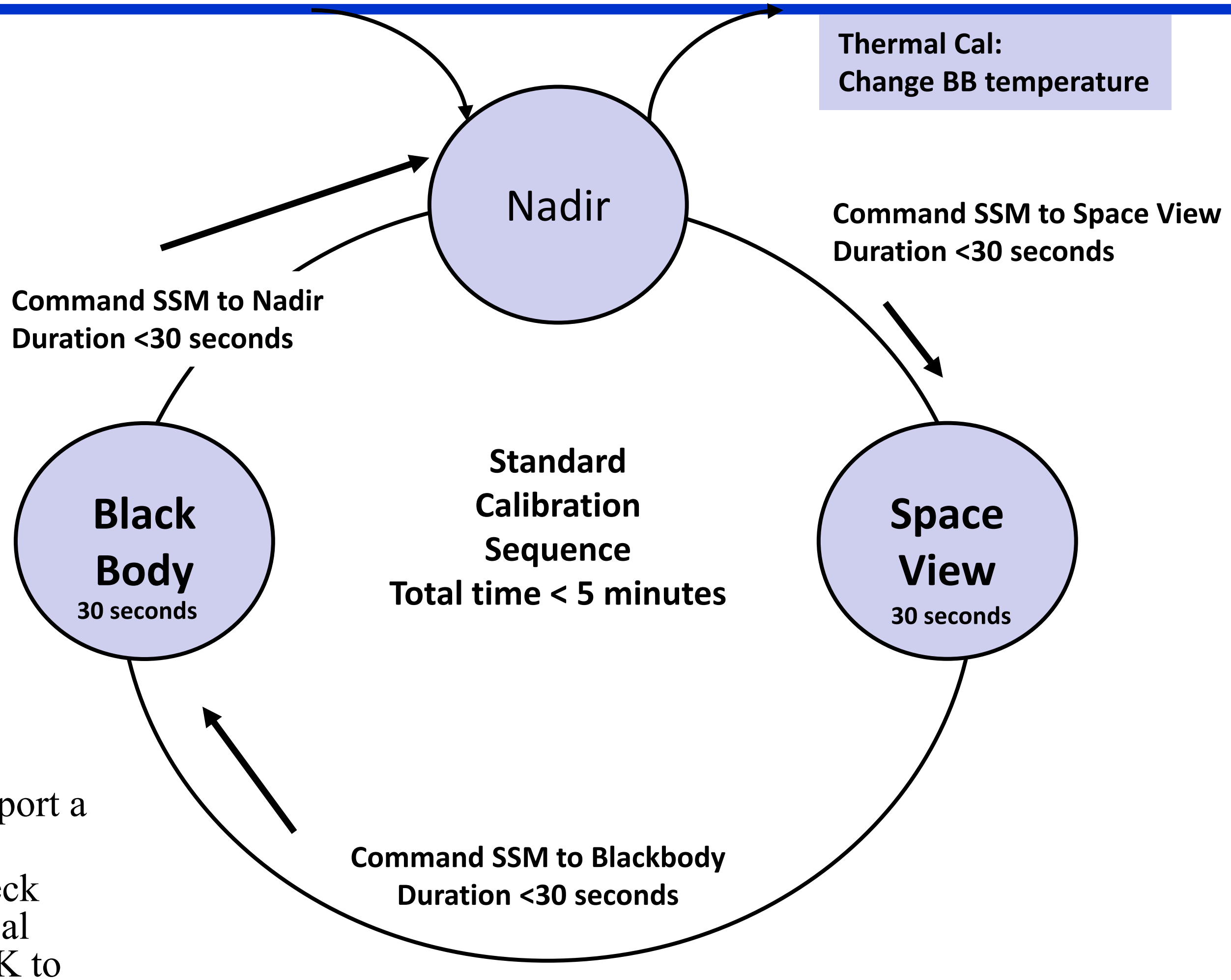
Top Level Operations Requirements

- Imaging
  - 400 WRS-2 scenes/24 hour period
  - Image up to 15 degrees off-nadir
  - Acquire up to 83 contiguous sun-lit scenes per orbit
  - Acquire up to 38 contiguous night scenes per orbit
- Calibration Operations
  - Onboard calibration capability
    - Spaceview and onboard NIST Traceable Black Body
  - No calibration maneuvers required
  - No planned vicarious calibration sources
- Orbit
  - 705 (-1/+27) km altitude
  - 98.2 $\pm$ 0.015 degrees inclination
  - 10:00 $\pm$ 15 minutes AM equatorial crossing descending node



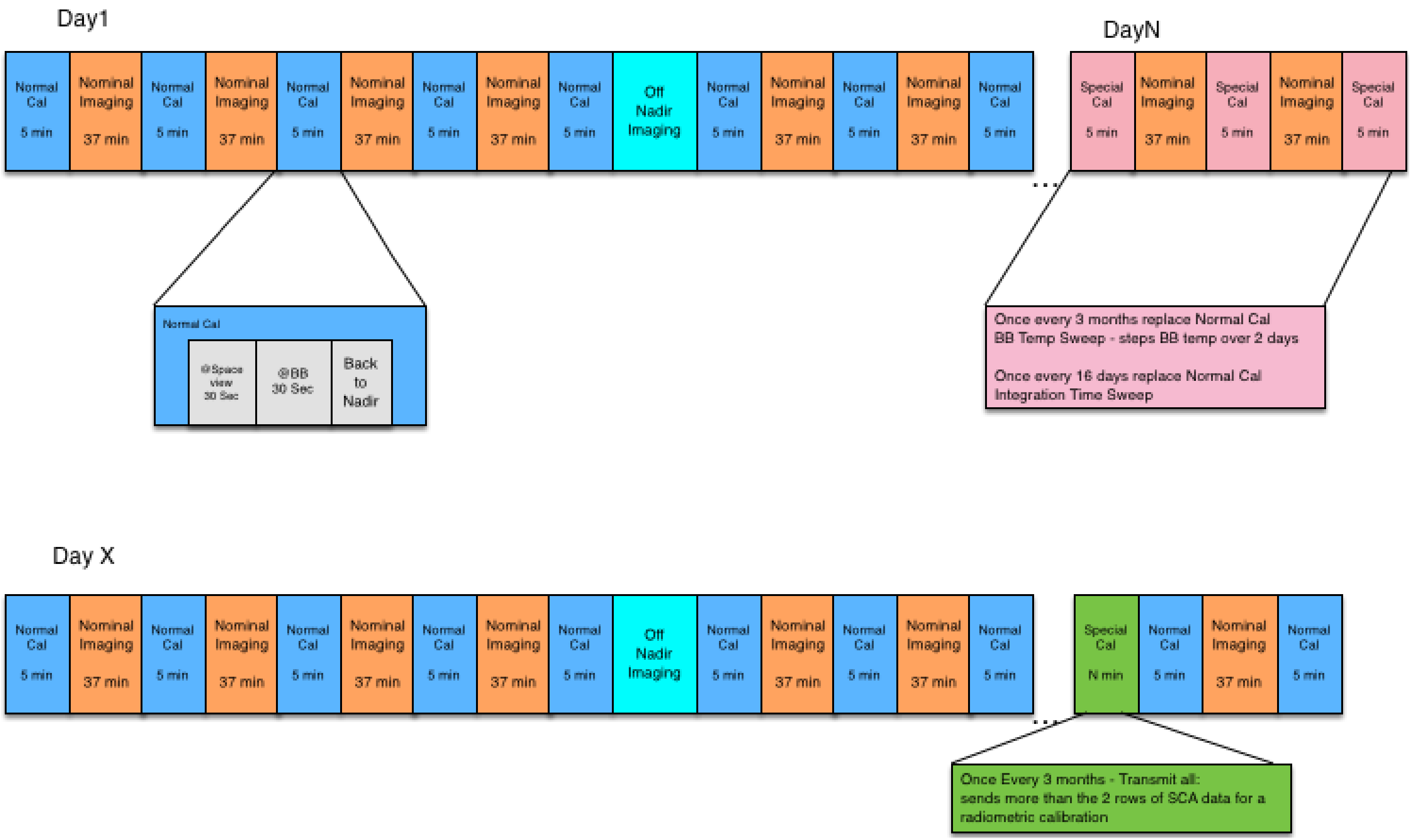
Calibration

Blackbody		
Cal. Type	**Temp.**	**Integration Time**
Normal Radiometric (twice per orbit)	Constant	Constant
Integration Time Sweep	Constant	Vary 0.1 to 5.5 msec in 0.1 msec steps
BB Temperature Sweep (every 3 months)	Gradually vary across entire range w/in 24 hours	Constant



- BB Temp Sweep
  - BBCal setpoint is varied to support a linearity calibration sequence
  - Plan to complete a linearity check every 3 months where the BBCal temperature is varied from 270K to 320K within a single day
  - Calibration sequences are separated by 37 minute imaging intervals

TIRS-2
On-Orbit Operations



- Repeating Cycle 16 (governed by the DRC-16)
- Up to 37 minutes total imaging bounded by calibrations
- Mission planners coordinate Imaging Periods and Calibrations with WRS-2 and OLI-2
- Frequent calibrations at least once per orbit repeat cycle

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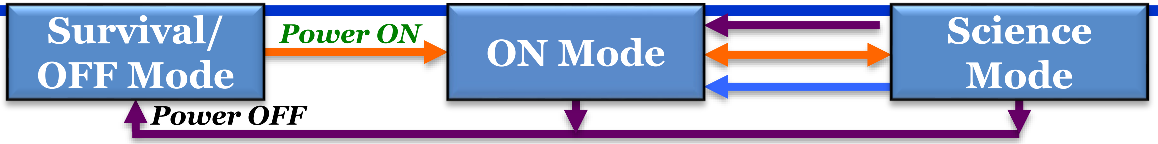
TIRS-2 Modes and States



On Submode States:
Standby
Dry-out
Deployment
De-ice
CSS Cool Down
Safe
Fault

Science Mode States:
Normal Imaging Calibration

Mode	Configuration
Survival	Only Survival heaters active
ON Mode	
Standby	MEB ON. Other electronics OFF
Dry-out	Prior to Earth Shield deploy: SU components warm
Deployment	S/C Safe Bus enabled for ES dployment
De-ice	Post ES deploy: warm temps, Initial state for CSS cooldown.
CSS Cooldown	Transition to operational temperatures.
Safe	MEB On, FPE and TCB reset, SSM – Nadir, Cryo-retain state
Fault	TIRS-2 Fault Management component safing,
Science	
Imaging	Op temperatures. FPE/FPA On
Calibration	Nominal: SSM to Nadir, BB and Space views. BB at 295K Other: BB Calibrator step 270-320 K. Integration Time Sweep 0.1 to 5.5 msec

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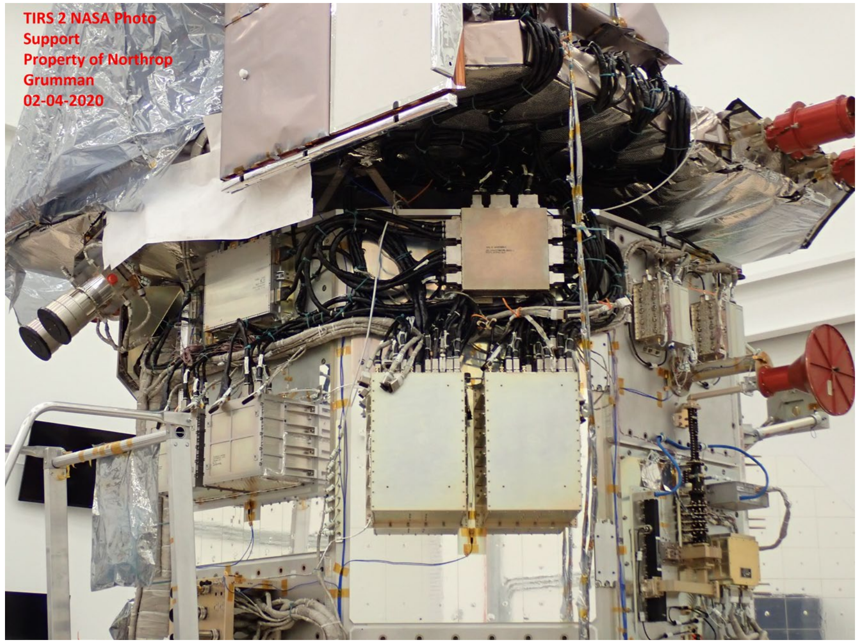
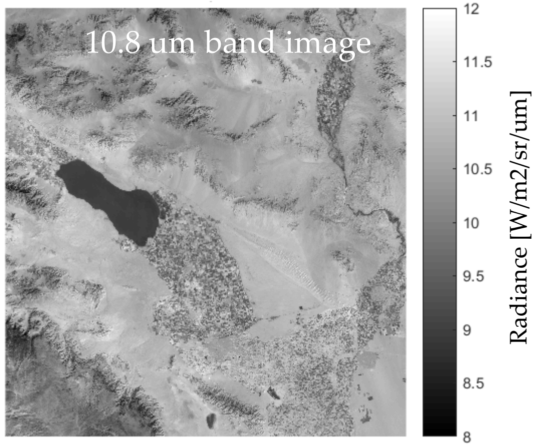
TIRS2 Hardware Photos

"Photos have been approved for public view by the GSFC Export Control Office"

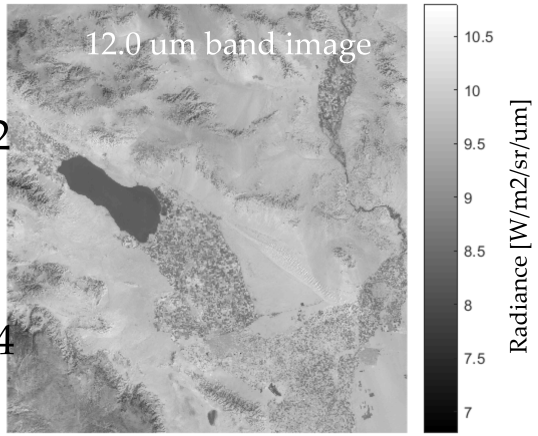


TIRS-2 Dual Thermal Infrared Spectral Bands

- TIRS-2 first imaging started 21-301 (Oct 28 2021)
- First Obs image (with OLI) started day 21-304 (Oct 31st)

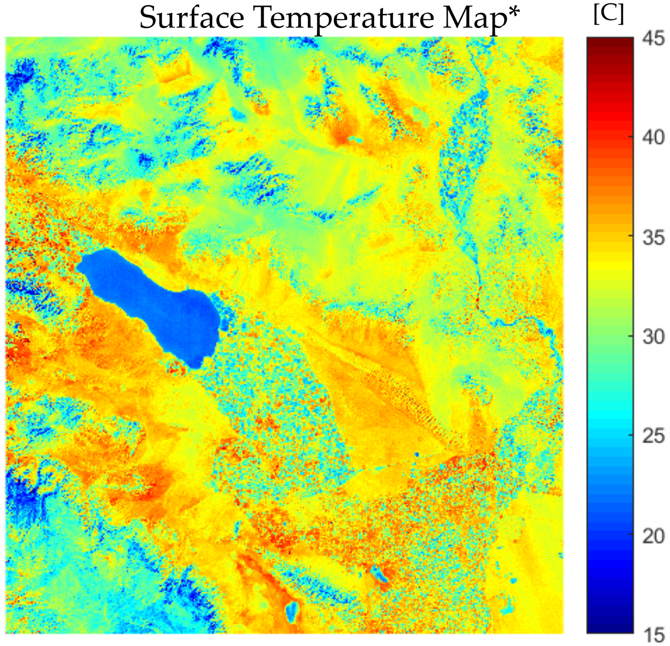


Salton Sea, CA, USA
Approx Lat/Lon: 33.213027 / -115.585342
Acquired: Wed 2021 Nov 03 18:05:19
RFID: 0780000.2021307193014633.SGS



Using the Split Window technique, image data from the two thermal bands are used to compensate for the atmosphere and derive surface temperature

Surface Temperature Map*

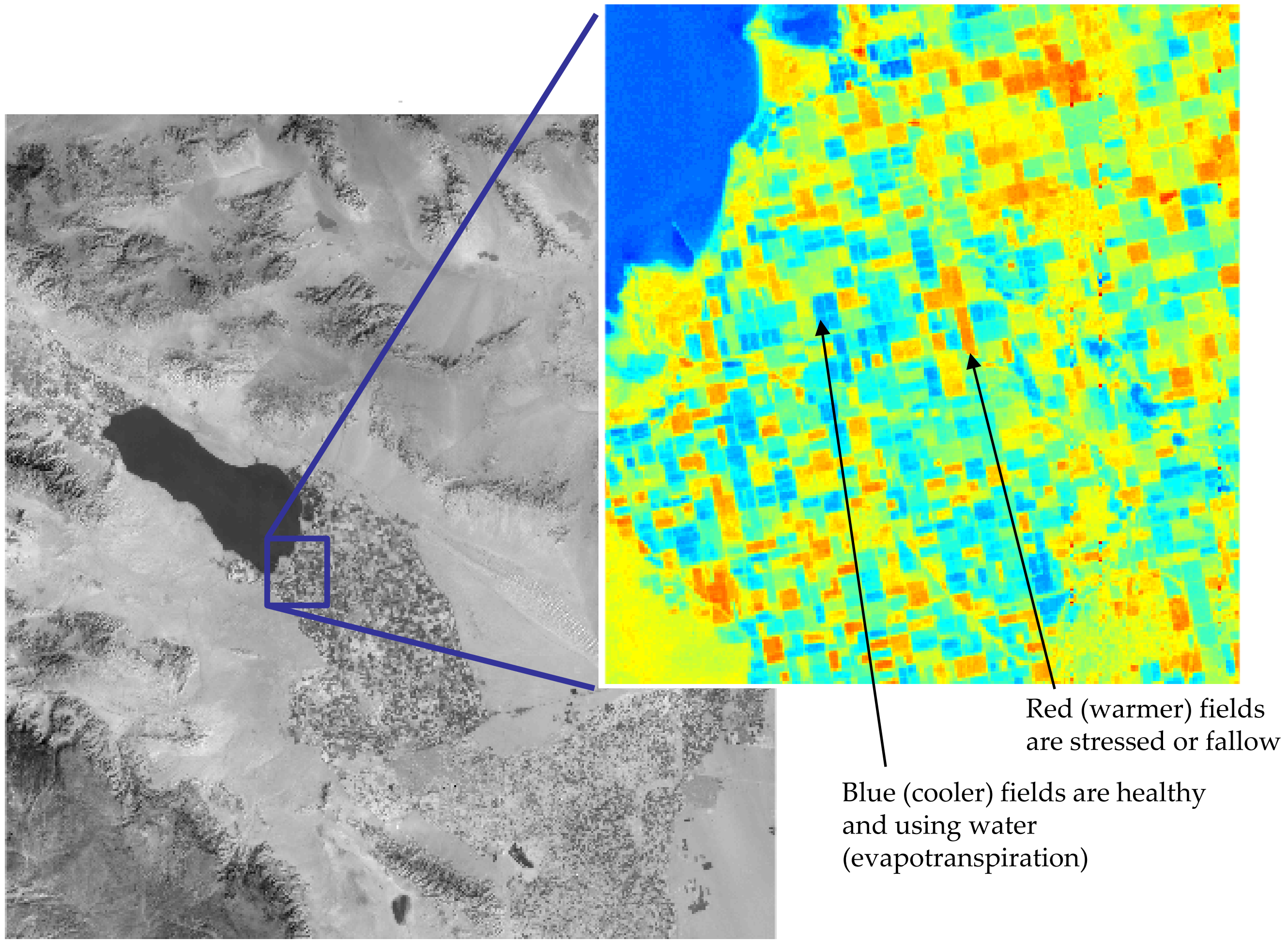


$$ST = b_0 + \left(b_1 + b_2\frac{1-\epsilon}{\epsilon} + b_3\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_i + T_j}{2} + \left(b_4 + b_5\frac{1-\epsilon}{\epsilon} + b_6\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_i - T_j}{2} + b_7(T_i - T_j)^2$$

*Split window coefficients supplied by Tania Kleynhans and Aaron Gerace of RIT

TIRS-2 Plant Health/ Water Use

Salton Sea, CA, USA
Approx Lat/Lon: 33.213027 / -115.585342
Acquired: Wed 2021 Nov 03 18:05:19
RFID: 0780000.2021307193014633.SGS



This plant health/water use measurement ability is a major motivation for the TIRS instrument