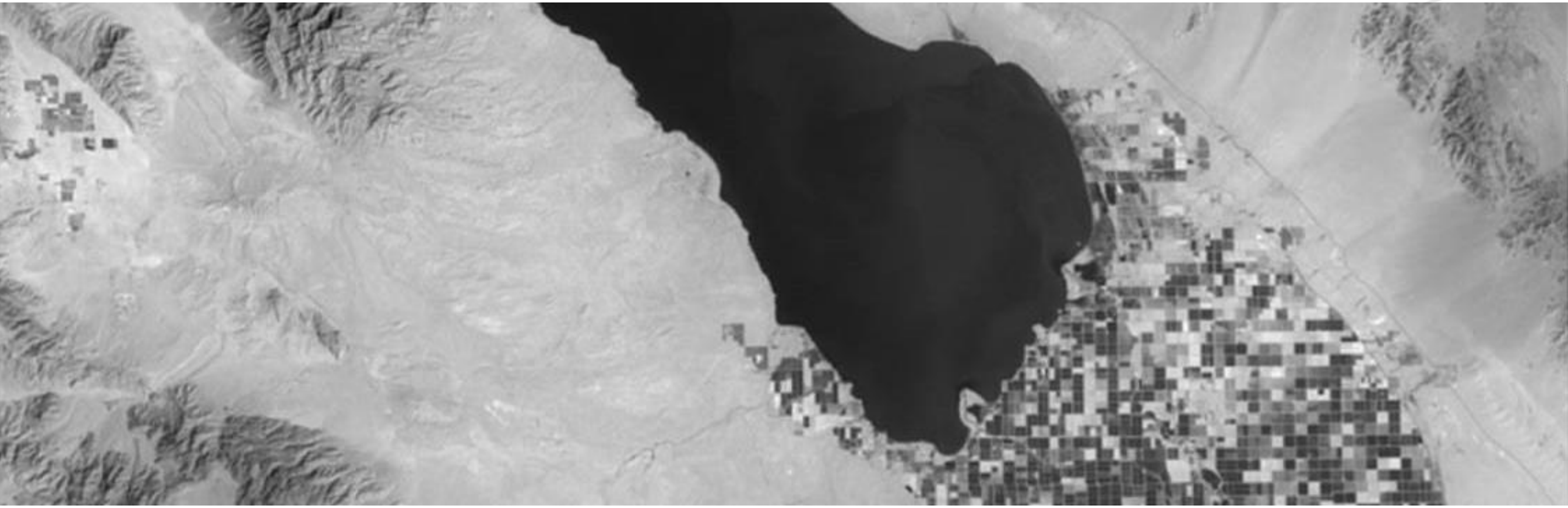

Thermal Infrared Earth Resource Monitoring Instrument (THERMI) Size Weight & Power (SWaP) Reduction Study

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SDL/15-420

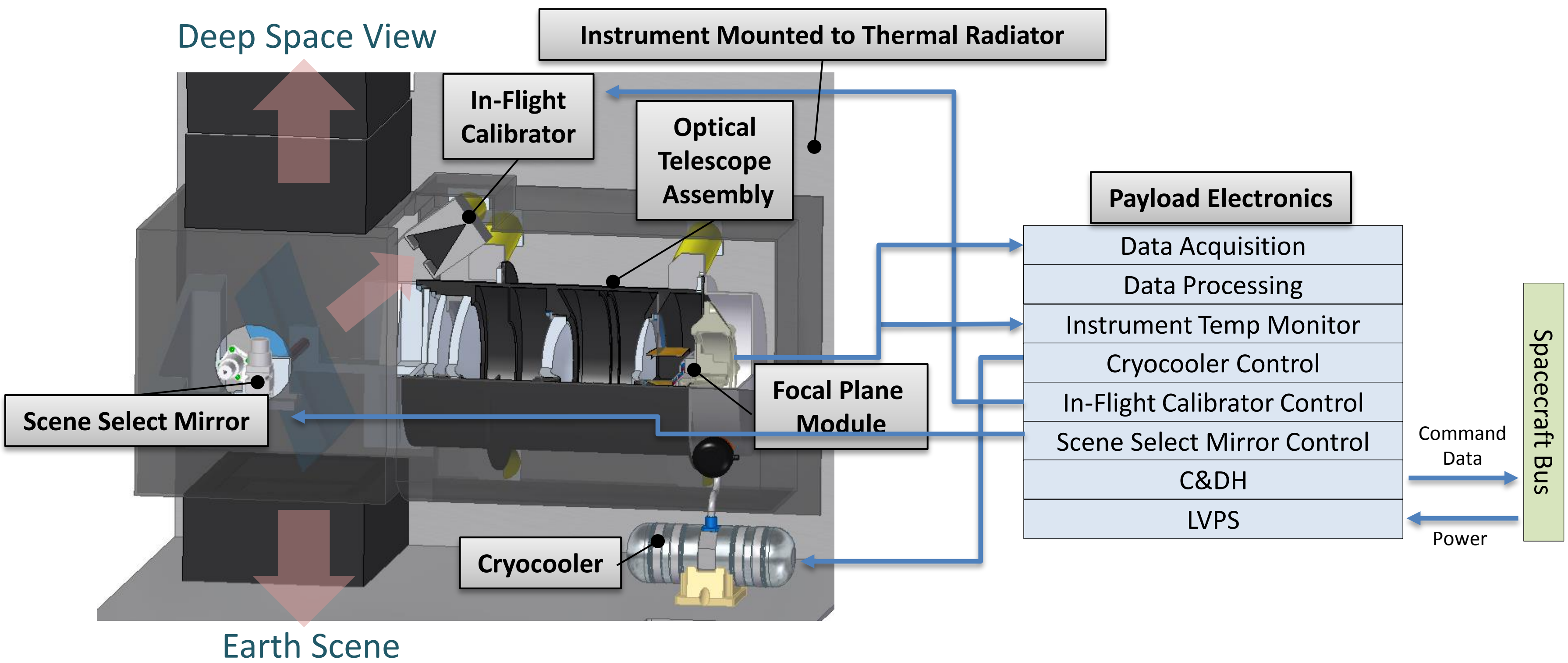
Landsat Heritage Performance Requirements

- Earth resource monitoring
  - Measurement of the land surface temperatures in two long-wave infrared bands
- Requirements include spectral, spatial, and radiometry performance
- Requirements driving Size Weight and Power (SWaP)
  - Radiometry
    - Cryogenic operating temperatures
      - Multiple temperature zones
    - On-board calibration system
    - Straylight rejection
  - Spatial resolution
    - Ground sample distance
    - Relative Edge Response (RER) slope
    - RER edge extent

Objective: Minimize SWAP and meet performance requirements

THERMI Overview

- 3 scene select operational modes
  - View Earth
  - View in-flight calibrator
  - View deep space



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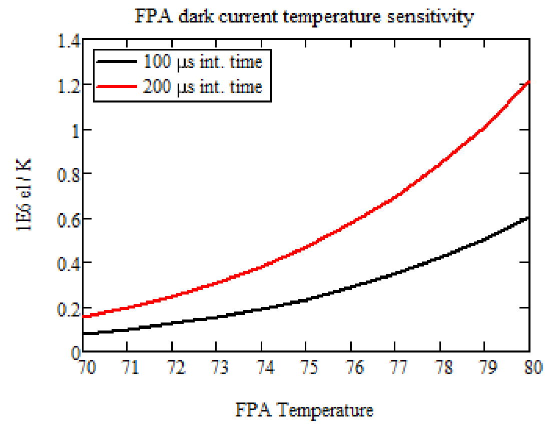
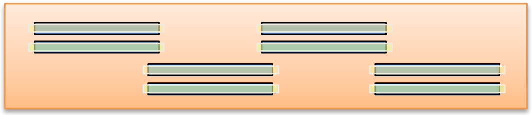
Focal Plane Module

- **Driving requirements:**
  - **60 m GSD**
  - **185 km swath width**
  - **2 spectral bands**

- MCT detector
  - Maximize operating temperature (reduce SWaP)
  - MCT dark current is highly temperature dependent
- MCT performance drives focal plane thermal control
  - Minimize temperature to minimize dark current
  - Stabilize temperature to minimize dark offset drift (50 mK stability required for 0.5% radiance uncertainty)



25 micron pixels



10.8 and 12.0 µm spectral filters bezel-mounted over SCAs

DETECTOR CHIP		ROIC	
Pixel pitch	25 µm	Well capacity	> 5 Me-
Spectral cutoff	12.9 µm	Read noise	< 2500 e-
QE	40 – 60 %	Nonlinearity	< 0.8%
Dark current	<1E10 e-/s	Line rate	up to 1 kHz
Nonlinearity	< 0.6 %	Power	<200 mW / chip
Operating Temperature: 70 K			

- Long linear array of ~3080 detectors
  - Multiple overlapping sensor chip assemblies
- Sensor Chip Assembly (SCA)
  - Readout Integrated Circuit (ROIC)
  - 2 wavelength bands (2 sets of 4 X 1024 format)
- Four SCAs form one FPA module
  - Custom development / adaptation of existing MCT designs
  - <1 W power dissipation

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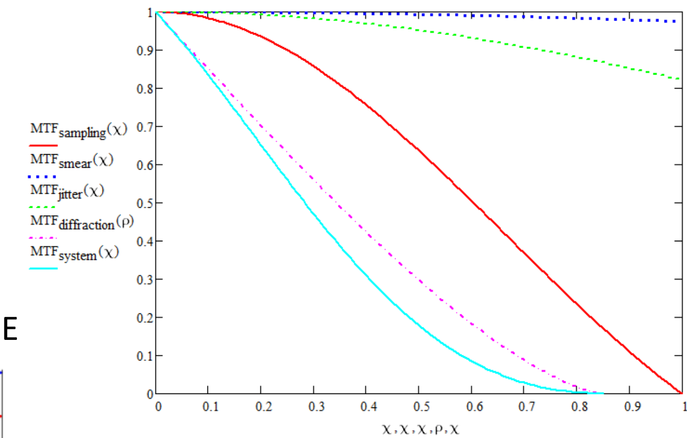
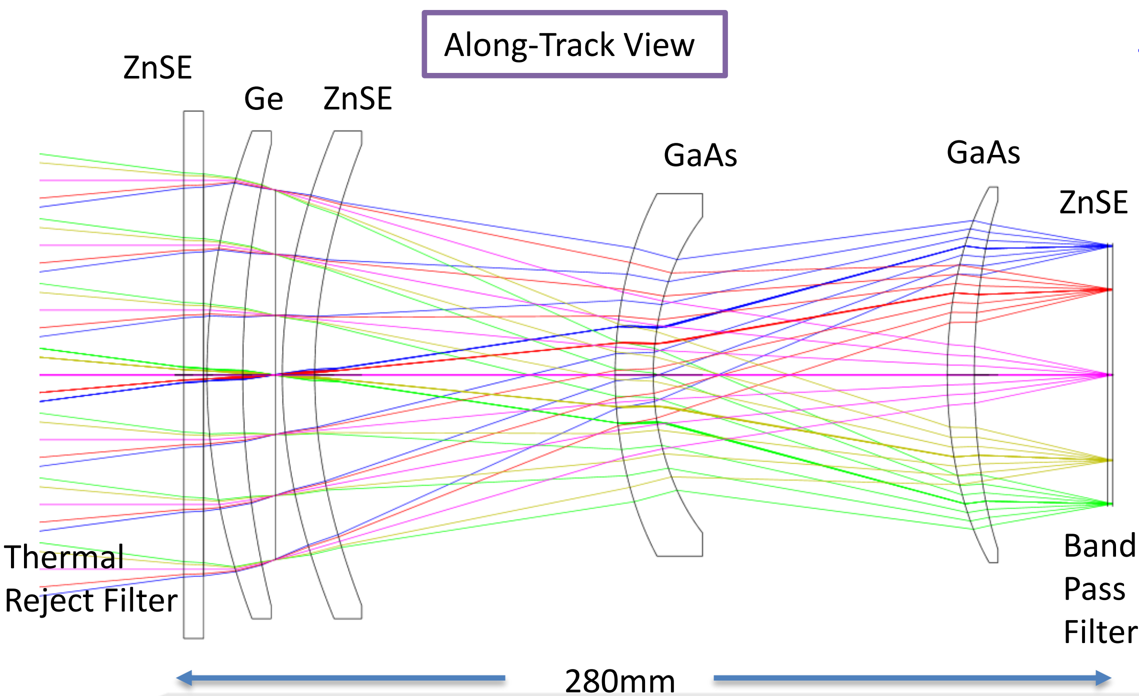
OTA Optical Design

- Aperture 120 mm (F/2.46)
  - Positioned to reduce lens size
- Low emissivity high transmittance materials
- Thermal reject filter tilted 1˚to reduce ghosting

- Focal length 295 mm
- FOV 15˚X 2˚
- Telecentric within 2 degrees
- Uniform F/# across FOV within 0.1





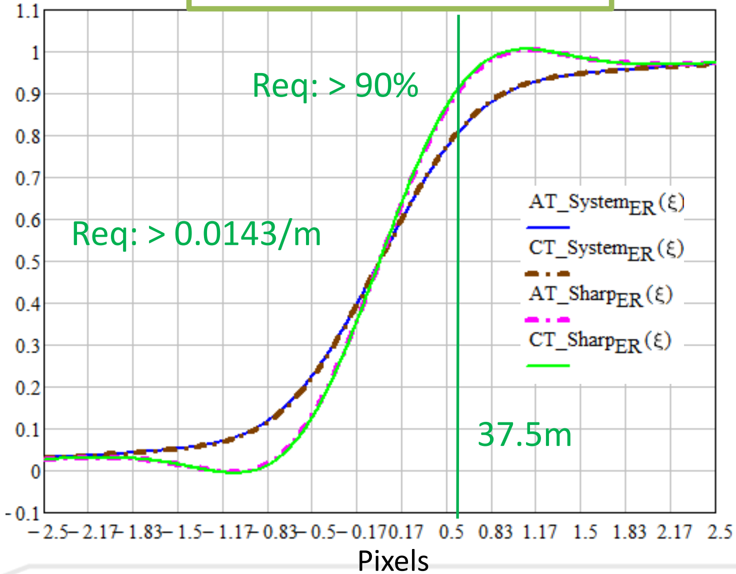
MTF normalized on sampling frequency

- Diffraction
- Detector sampling
- Along track velocity smear
- Jitter

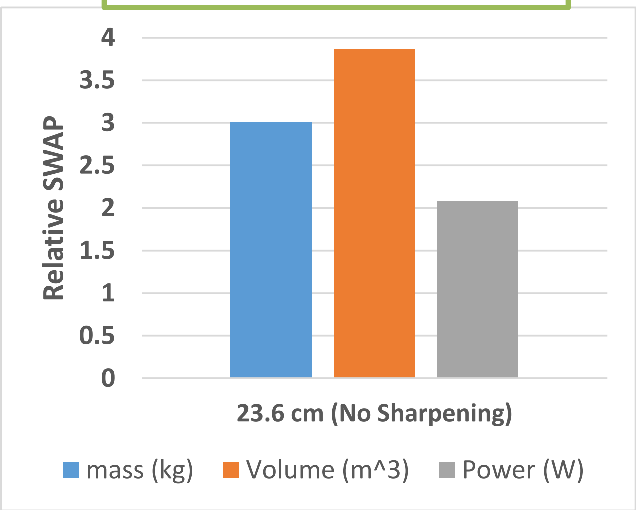
Edge Response Performance Requirements Met with Sharpening

- Relative edge response (RER) analysis includes: diffraction, aberrations, detector sampling, smear along track, jitter
  - Sharpened with low gain 3x3 kernel
- RER requirements are met with sharpening with a slower lens system
  - Overshoot <3% (requirement <5%); Ripple <1% (requirement <5%)
- Benefit of sharpening: RER requirements require 23.6-cm diameter lens with 60 m GSD
  - Larger lens requires ~3X mass, ~4X vol. and ~2X power (compared to 12cm lens)

Relative Edge Response



23.6cm Lens Relative SWaP (w.r.t. 12cm Lens)



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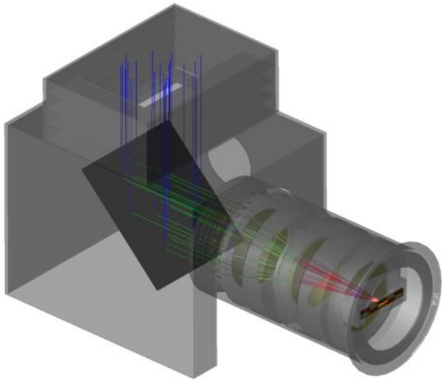
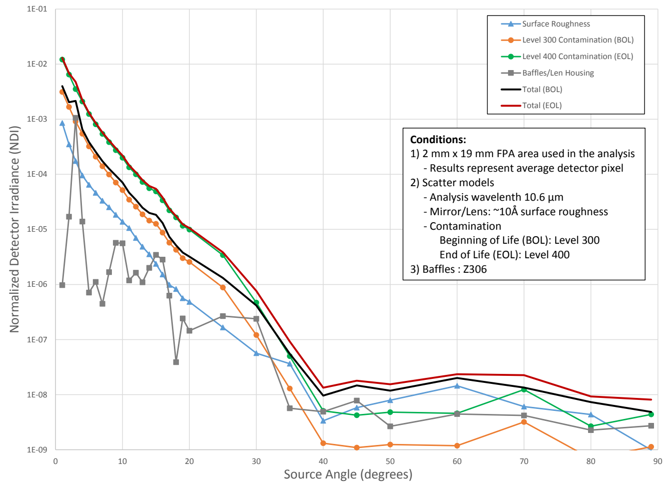
Stray Light Analysis Predicts Low Impact

- Analysis completed in non-sequential Zemax
- Rays traced from simulated point source to detector
  - Collimated beam at 1° to 89°
  - Azimuthal angles of 0°and 90°
- Scatter off of optical element surfaces due to:
  - Surface roughness
  - Particulate contamination
- Scatter off of baffling and structure



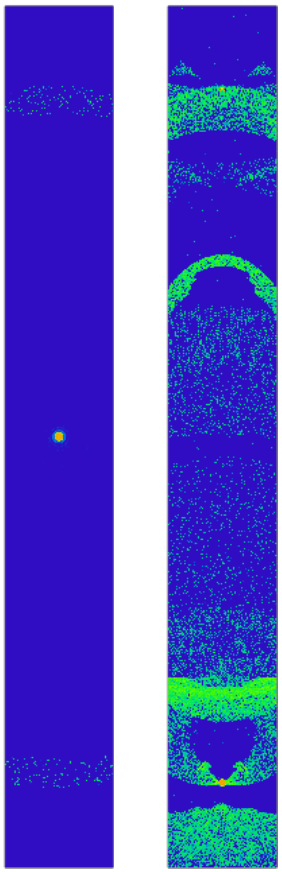
Results: Normalized Detector Irradiance (NDI)



- Predicted stray-light fraction from off-axis earth radiance
  - Beginning of life (BOL) 0.06%
  - End of life (EOL) 0.18%
- Assumptions
  - Off-axis scatter from entire visible earth (64.2° half angle)
  - Scene temperature: Target 300 K; Off-axis 330 K

Results: Ghost Analysis

- Ghost magnitude <0.001%



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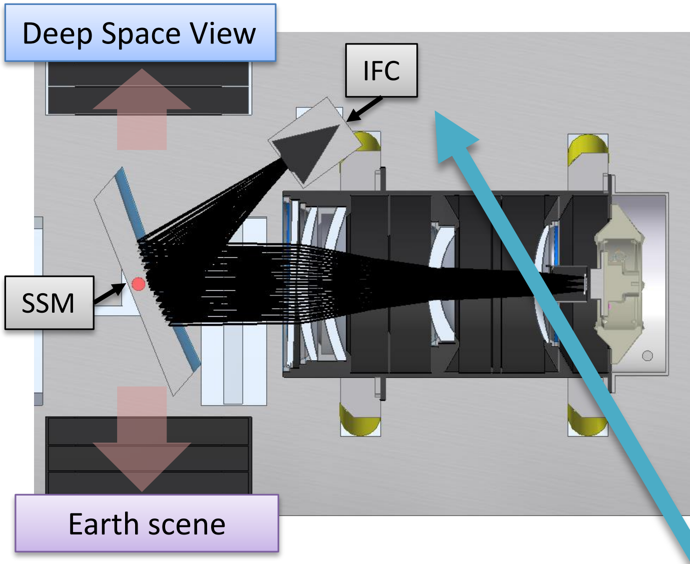
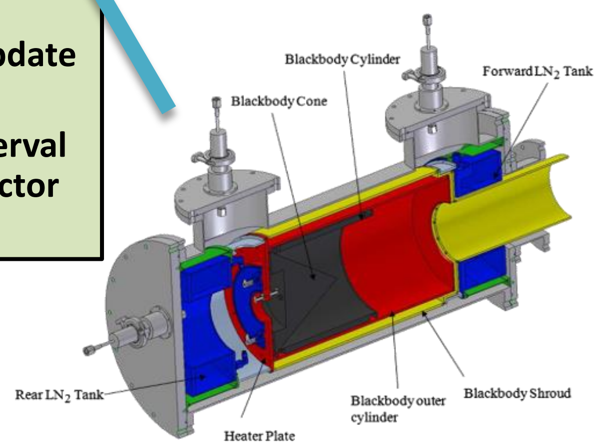
In-Flight Calibration System



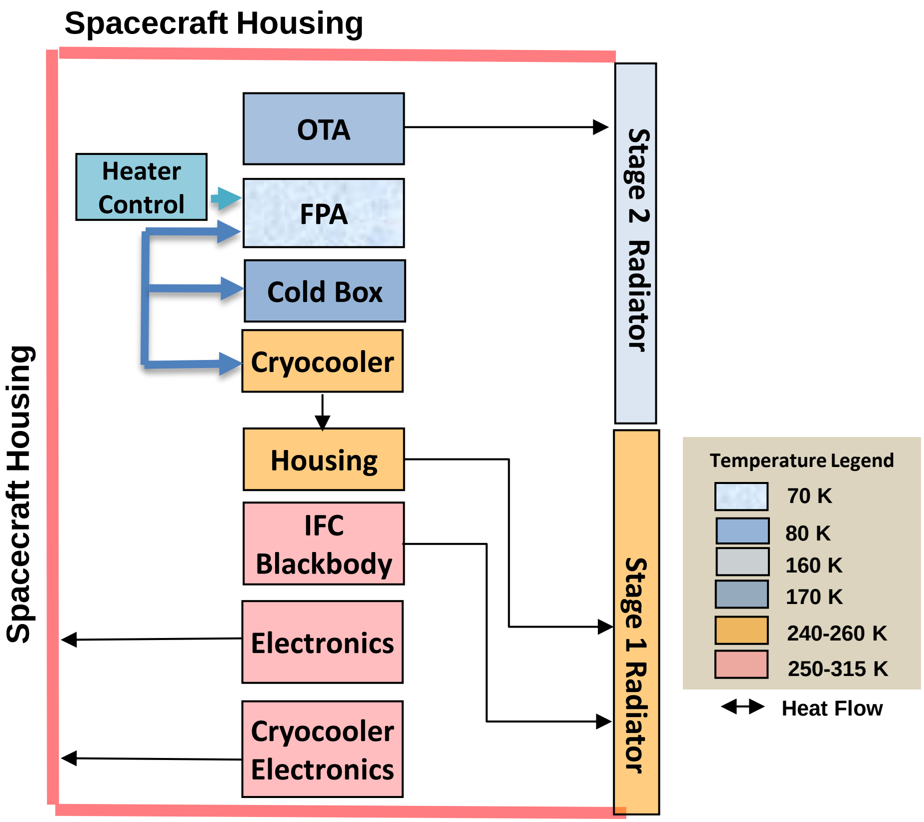
- 2-sided Scene Select Mirror (SSM)
  - Front side flat for normal operation
  - Powered back side mirror reduces IFC from 250 mm diameter to 80 X 15 mm rectangular slit
- In-Flight Calibrator (IFC)
  - Hg & Ga phase-change cells provide absolute temperature calibration standards
- Absolute radiometric uncertainty < 2% (260 K to 330 K)
- Radiance transfer from high-fidelity (NIST traceable) laboratory blackbody REQUIRED

- **Concept of Operation**
  - **Deep space viewed once per orbit to update dark offset correction**
  - **Calibration source viewed at longer interval to update calibration of individual detector elements**



Thermal Management Overview

- **OTA**
  - Cooled to <170 K with passive cold radiator
- **FPA**
  - Active cooling with compact pulse-tube cryocooler to 70 K +/- 50 mK
  - Trim heater control
- **Cold Box**
  - Cryocooler cooled to <80 K
- **Mini Pulse Tube Cryocooler**
  - Coldhead temperature 68 K
  - Lift 1.67 W
- **Housing**
  - Cryocooler heat reject <260 K
- **In Flight Calibrator (IFC)**
  - Controlled at 260 K and 310 K
- **Electronics**
  - Temperatures ~ 290 K, stabilized as required
  - Heat rejected to spacecraft radiators



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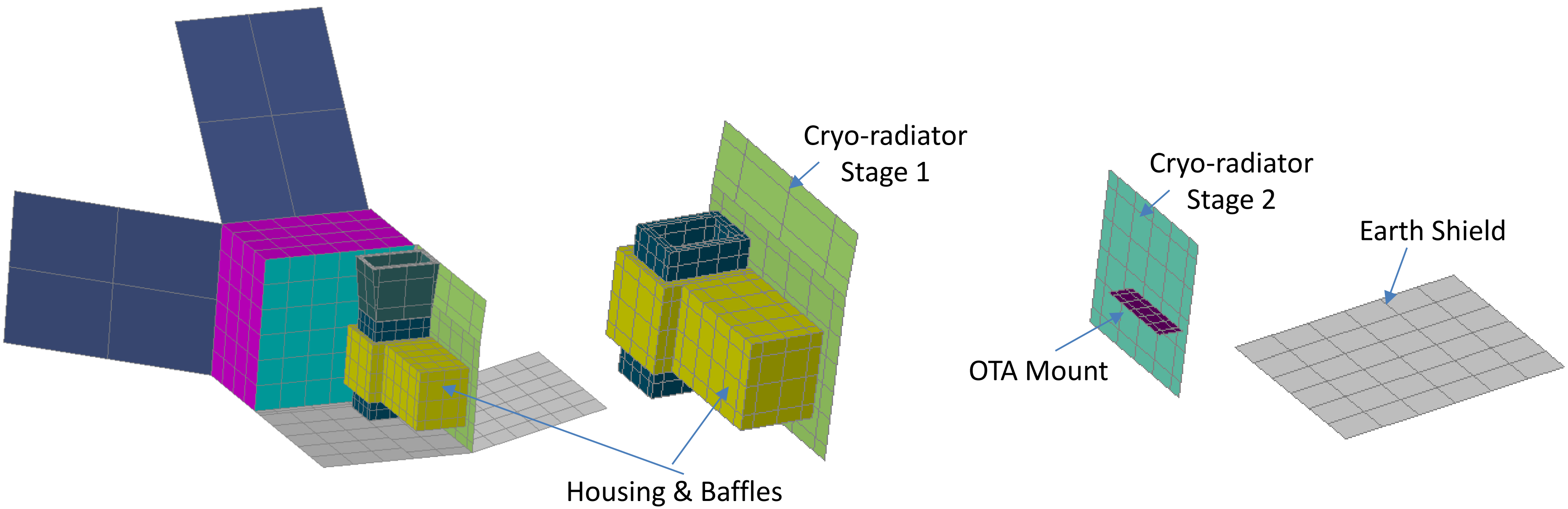
Thermal Analysis

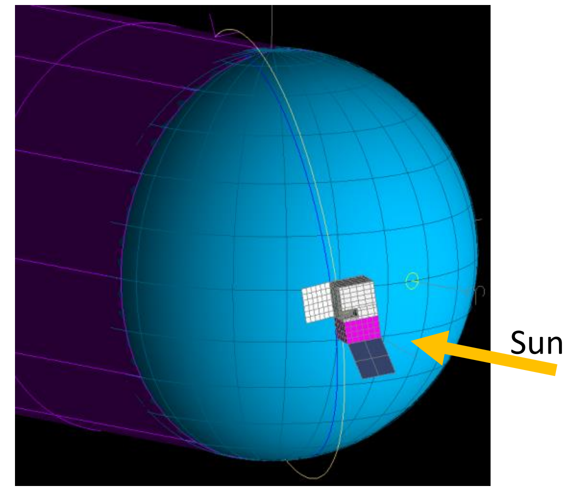
- THERMI mounts on cryo-radiator panel
- Uses Z93 paint and Vapor Deposited Aluminum (VDA)
- Heat reject window filter reduces OTA parasitic
- Fiber isolation mount reduces FPA parasitic

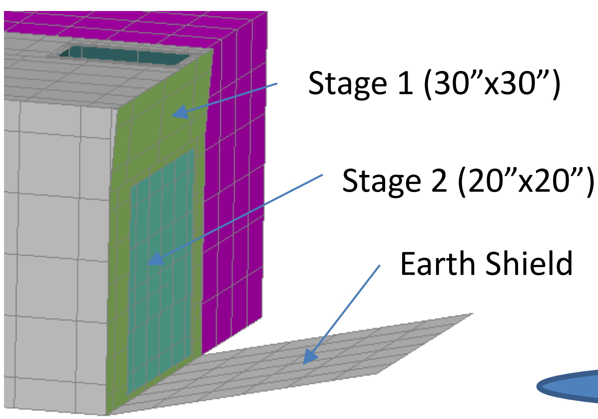
Component	Heat Origin	Heat Rejection Panel	Nominal (W)	Margined (W)
Cryocooler Reject	Elect	Cryo-Radiator Stage 1	19.73	23.68
FPA Tape Cable at SS Housing	Parasitic	Cryo-Radiator Stage 1	0.016	0.02
IFC (Phase Change)	Elect	Cryo-Radiator Stage 1	7.50	9.00
Mirror Motor	Elect	Cryo-Radiator Stage 1	5.80	6.96
OTA Heat Load	Parasitic/ Elect	Cryo-Radiator Stage 2	1.74	2.09
Cryocooler Compressor	Elect	Nadir Panel	29.60	35.52

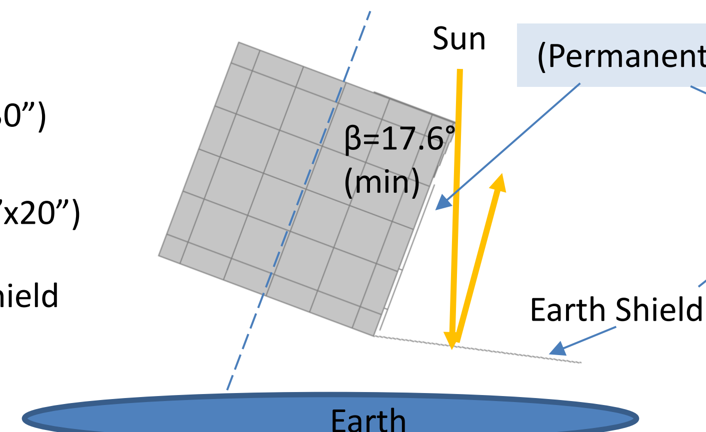


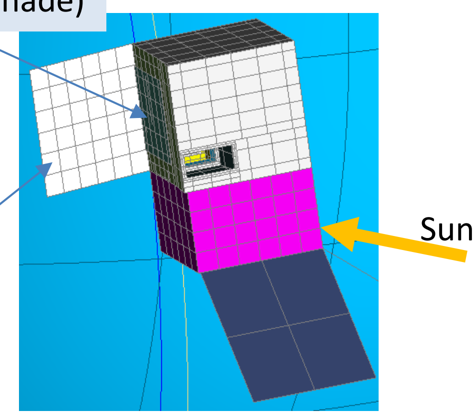
Cryo-Radiator Design

- Two-stage cryo-radiator
  - Stage 1 rejects housing heat loads including cryocooler reject power
  - Stage 2 rejects OTA heat loads
  - Stages mounted with thermal isolating structure
- Earth shield
  - Protects Stage 1 and Stage 2 from significant view of earth
  - Minimum beta angle determines canted angle to specularly reflect sunlight away from cryo-radiator



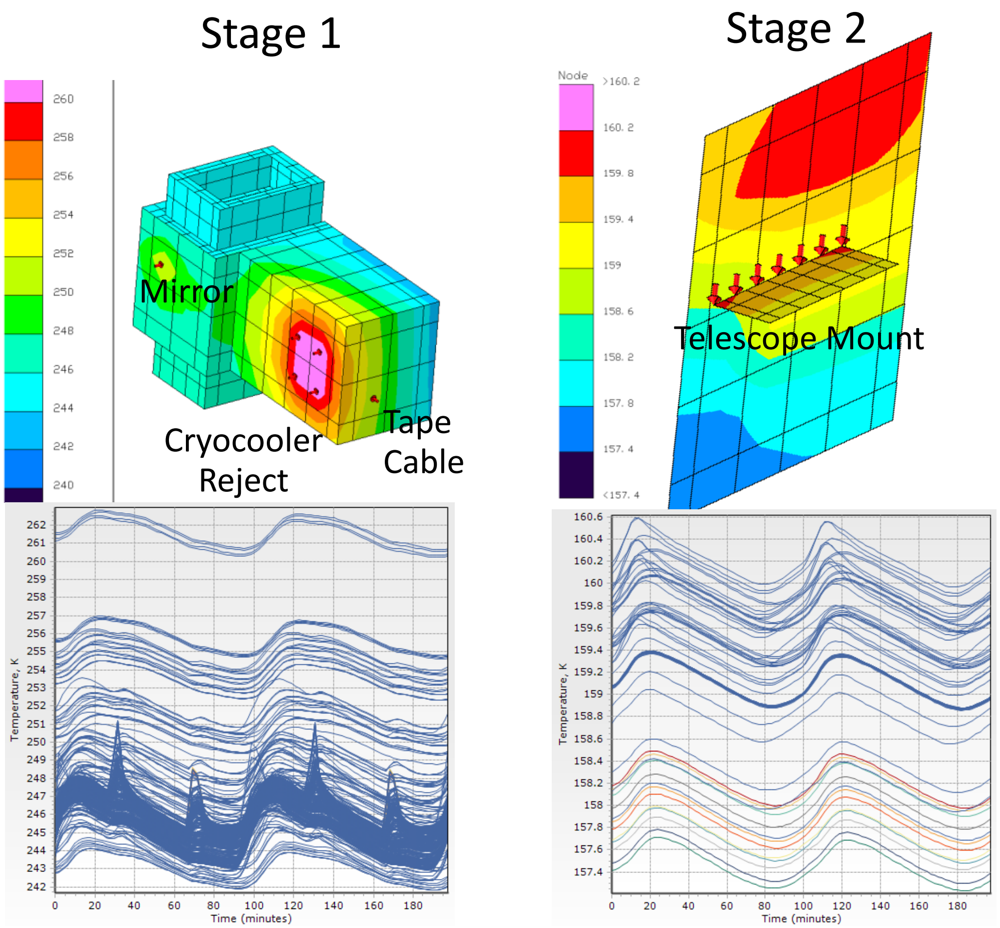






Cryo-Radiator Thermal Predictions

- Stage 1 required to maintain SS housing to bulk-average temperature <260 K
  - With ~243 K operation, Stage 1 maintains the SS housing average temperature ~250 K
- Stage 2 required to maintain telescope <170 K
  - Telescope mount base ~160 K under margined loads



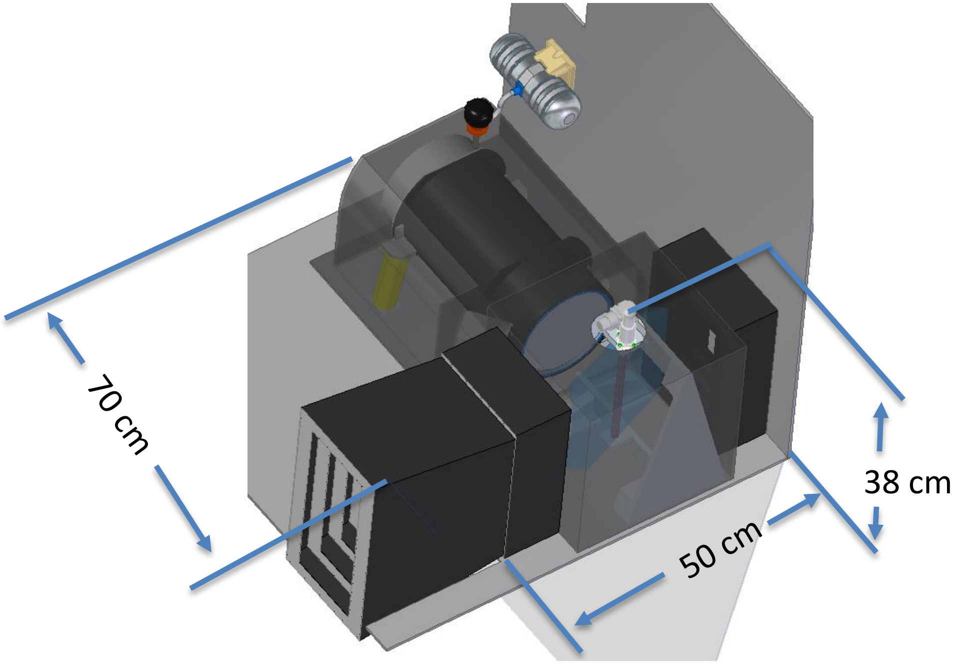
Reductions in SWaP allow THERMI to Fit on a Small Satellite Bus

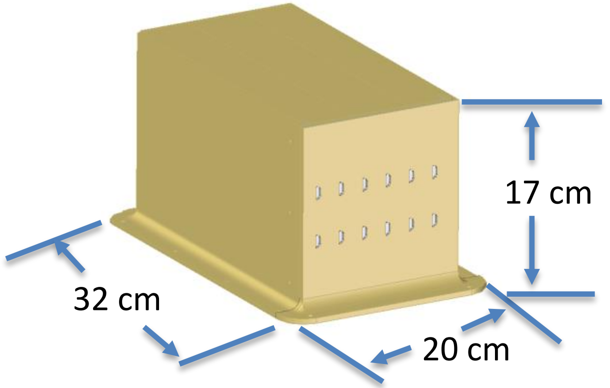
Mass with Margin		
Payload Electronics	13.1	kg
OTA	8.3	kg
In Flight Calibrator	6.5	kg
Thermal Management	3.8	kg
Covers and Baffles	6.5	kg
Housing and Mounts	18.6	kg
Total	**57**	**kg**

Power with Efficiencies and Margin		
Payload Electronics	32	W
Thermal Management	76	W
In Flight Calibrator	15	W
Total	123	W

SSTL-300 Small Satellite Payload Limits		
Power	140	W
Mass	300	kg
Volume	60 x 70 x 97	cm

*SSTL-150 customized for additional power





Conclusion

- Conformance
  - Predict conformance to Landsat heritage requirements
- SWAP Reduction Efforts
  - MCT SCM selected for higher detector operating temperature
  - Radiator for passive cooling of OTA eliminates need for 2 stage cryocooler
    - Detector cold box shielding allows for hotter OTA
    - Thermal energy reject filter reduces power lift requirement on radiator
  - Optical design to reduce first lens diameter, number of lenses, and OTA length
  - Edge sharpening in software to minimize aperture size and accompanying mass and power
  - SSM focuses light onto one small in-flight calibrator (IFC)
    - Maintain radiometric accuracy using phase change cells
- SWaP reduction allows THERMI to fit on a small satellite bus
- Mission cost historically correlates well with mass and power on-orbit

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Thanks!

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