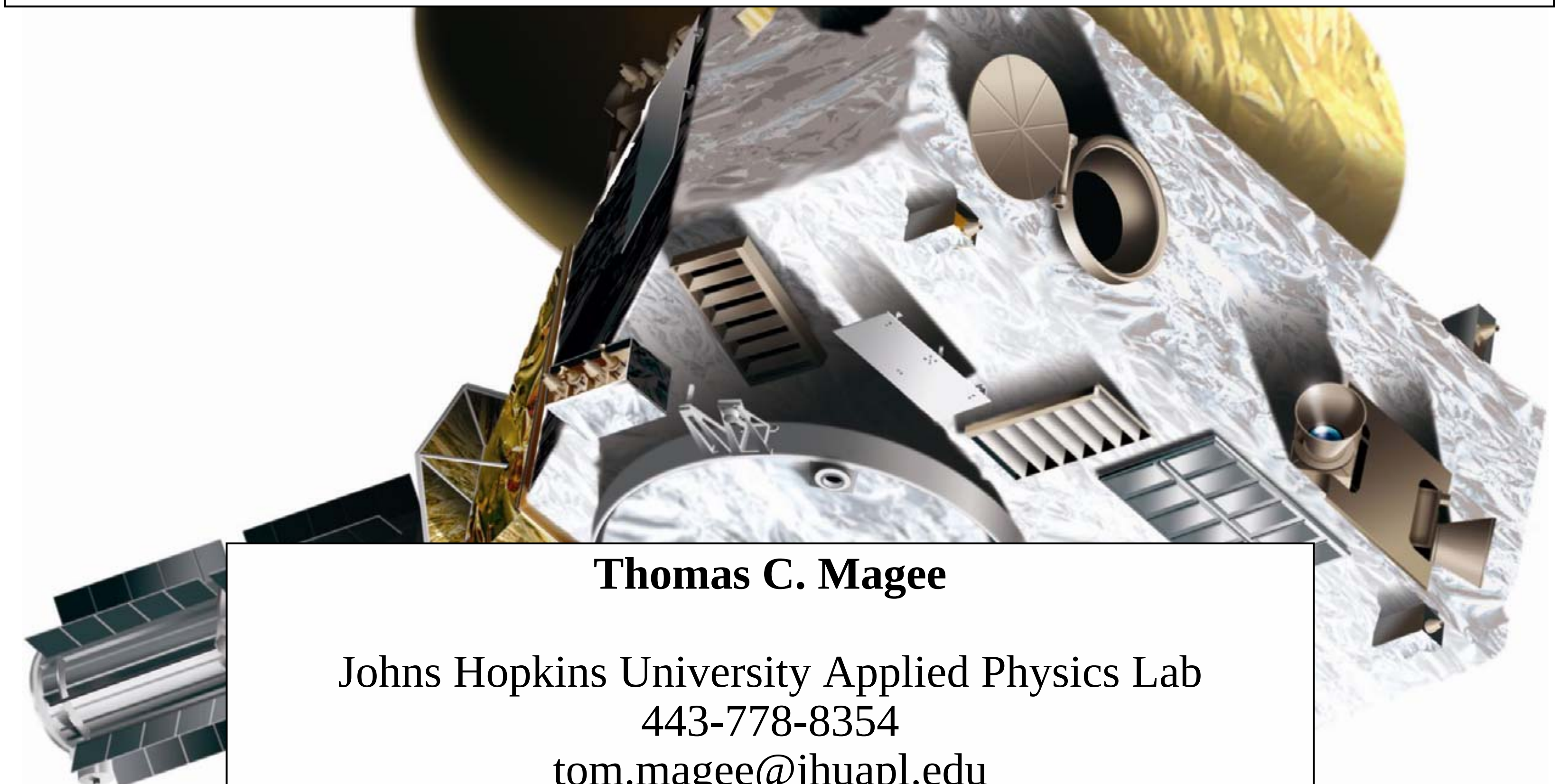
Thermal Modeling and Model Correlation of the LORRI Telescope



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Introduction

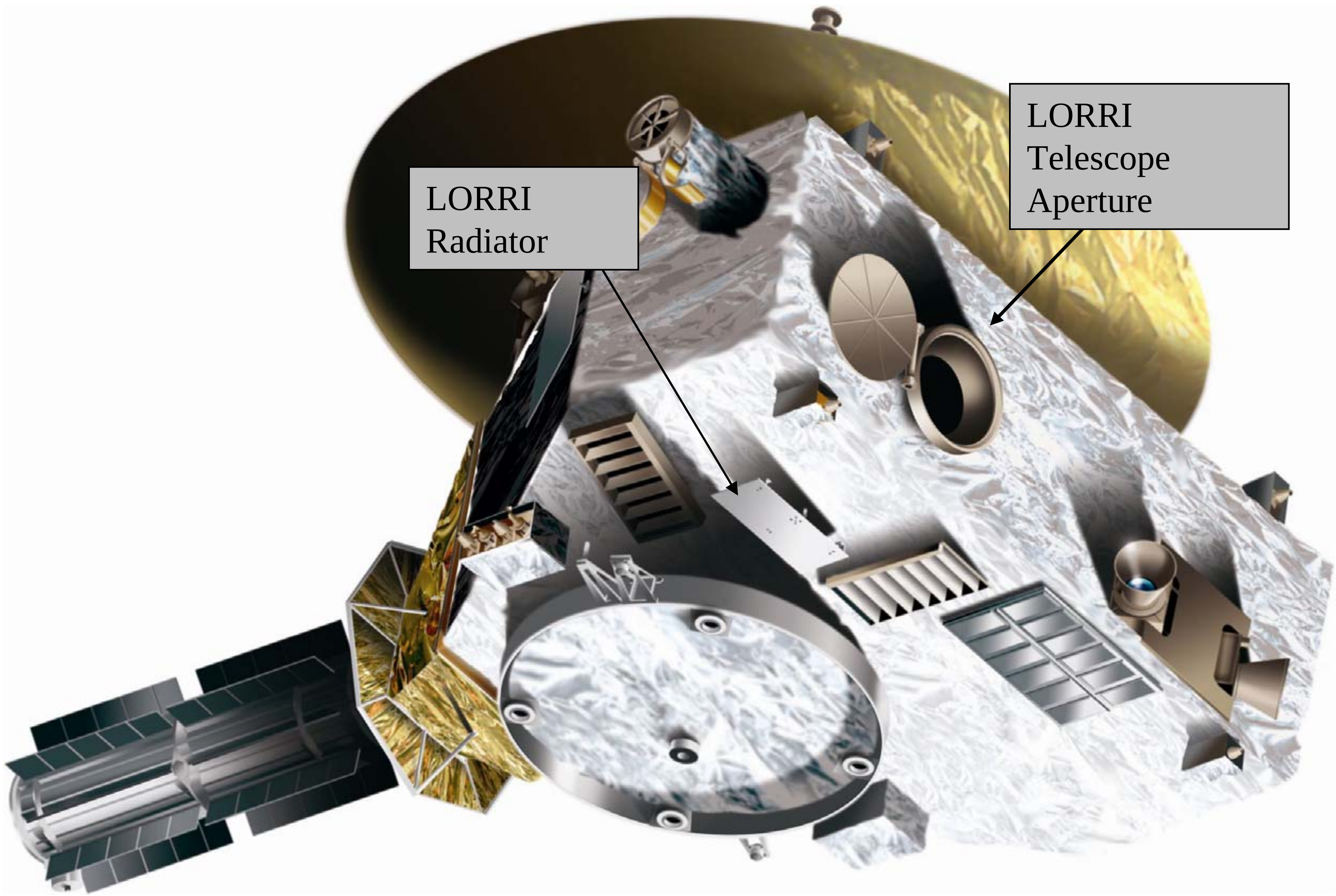
- The LOng-Range Reconnaissance Imager (LORRI) is a telescope that was designed, fabricated, and qualified for the New Horizons Pluto mission.

- LORRI was designed and fabricated by a combined effort of The Johns Hopkins University Applied Physics Laboratory and SSG Precision Optronics.

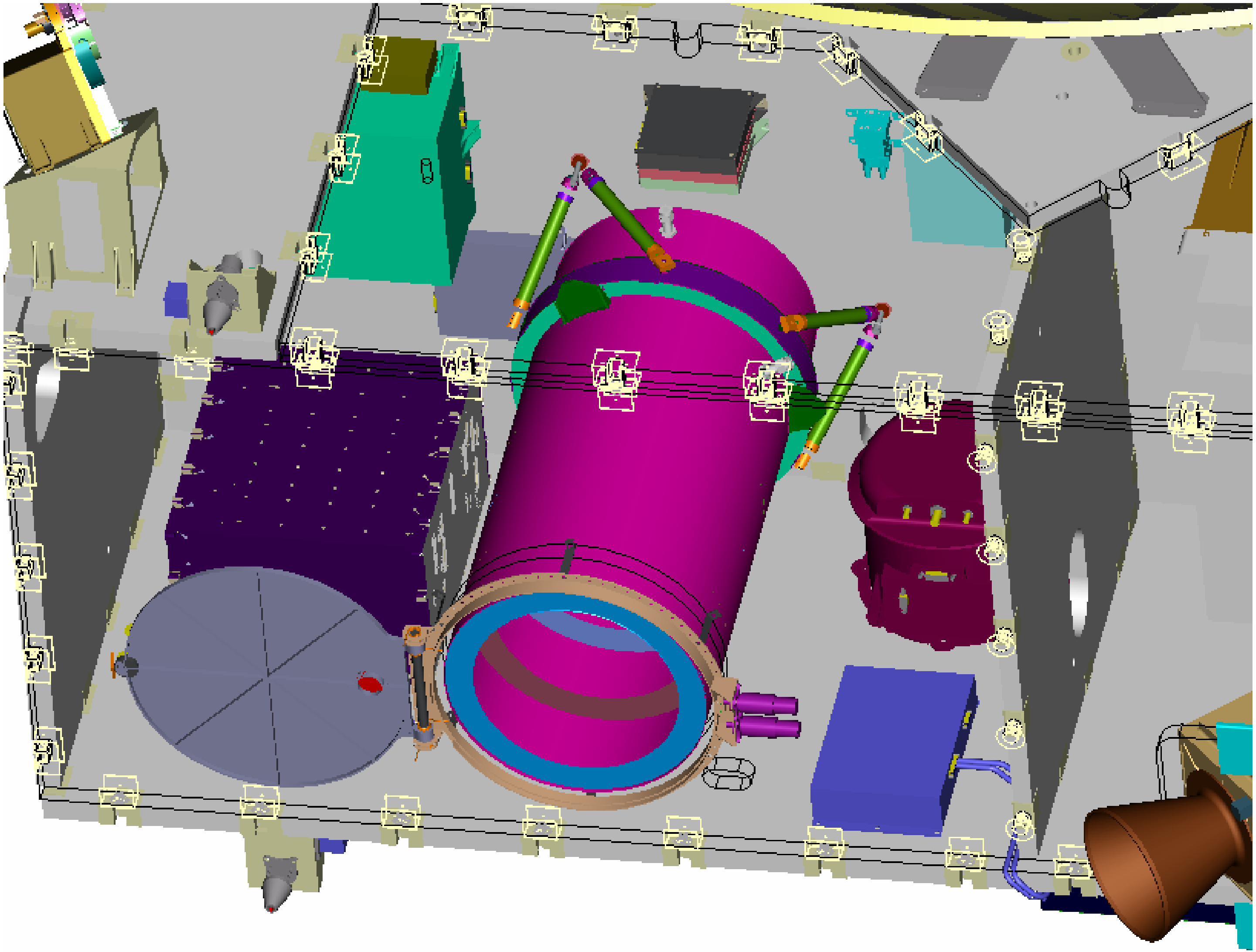
- LORRI is a narrow angle (FOV=0.29°), high resolution (IFOV = 5 μrad), Ritchey-Chrétien telescope with a 20.8 cm diameter primary mirror

- Purpose of the telescope is detailed imaging of Pluto (flyby in 2015)

Artists Depiction of the New Horizons Spacecraft



View of LORRI Inside the Spacecraft

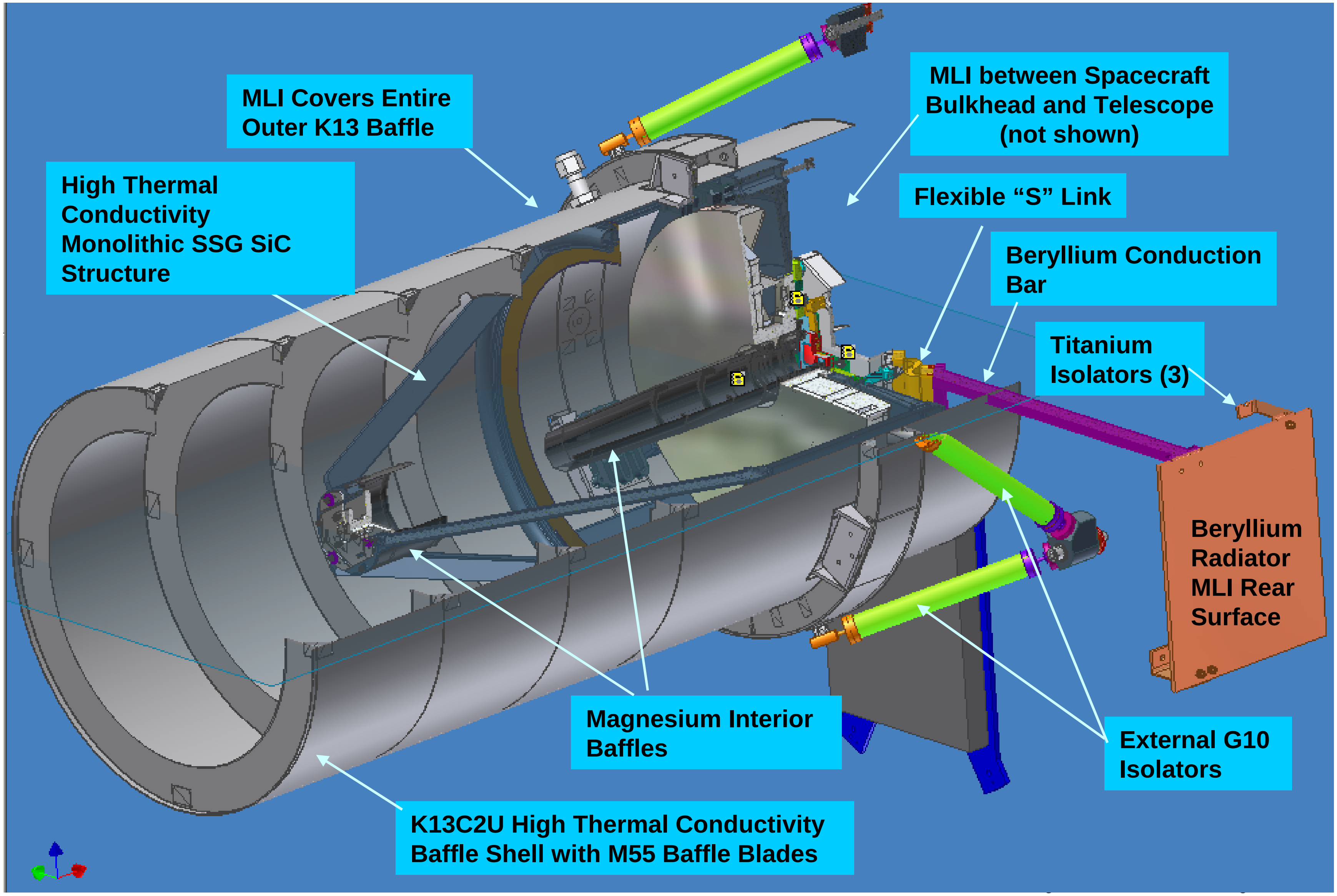


Thermal Challenges

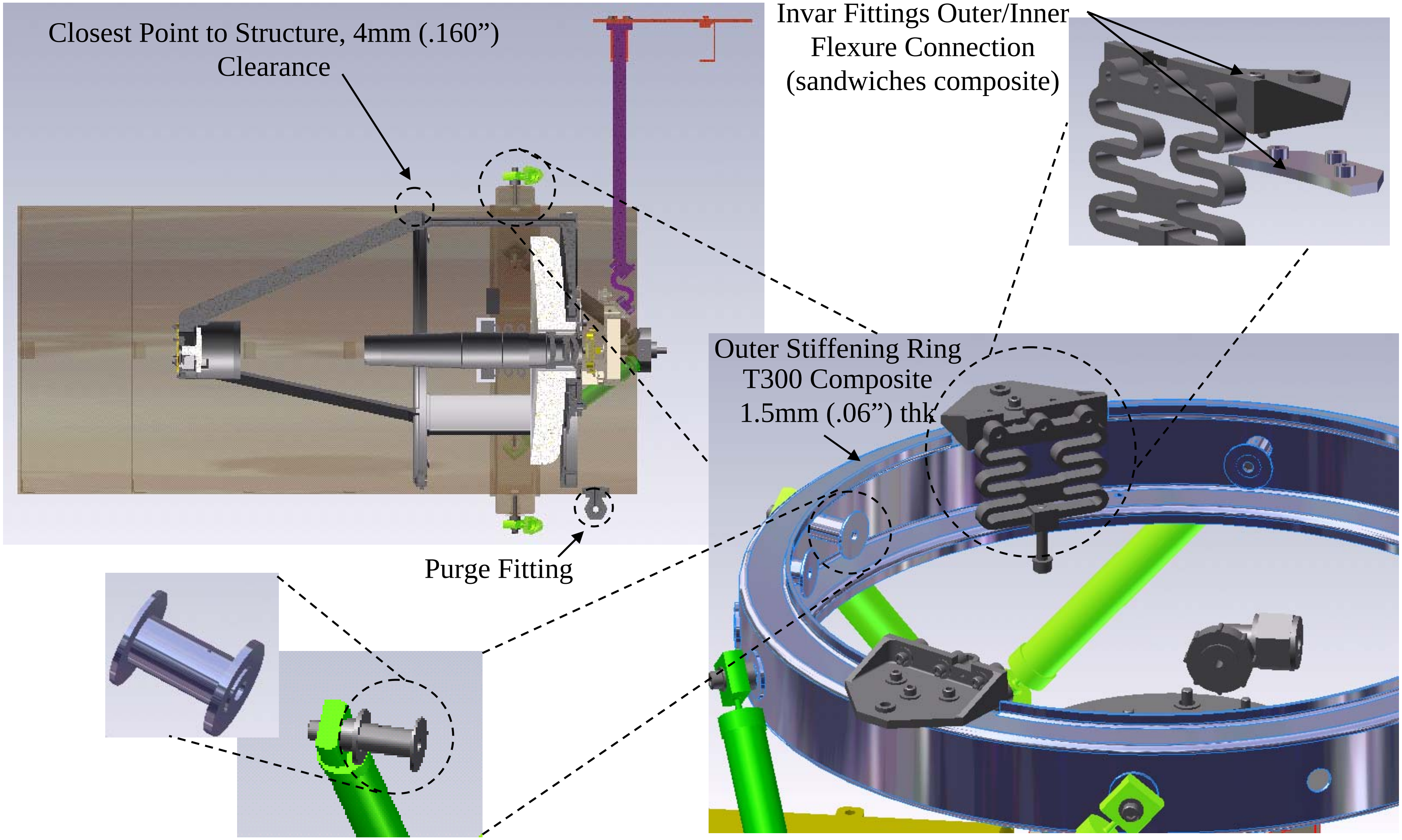
- Maintain focus without a focusing mechanism over a wide temperature range (-125ºC to 40ºC)
  – gradient from M1 to M2 must be less than 2.5ºC
  – requires a low CTE material with high thermal conductivity

- Maintain the CCD temperature below -70ºC while mounted deep inside a spacecraft which is at +40ºC
  – requires good thermal isolation

LORRI Mechanical/Thermal Concept Design

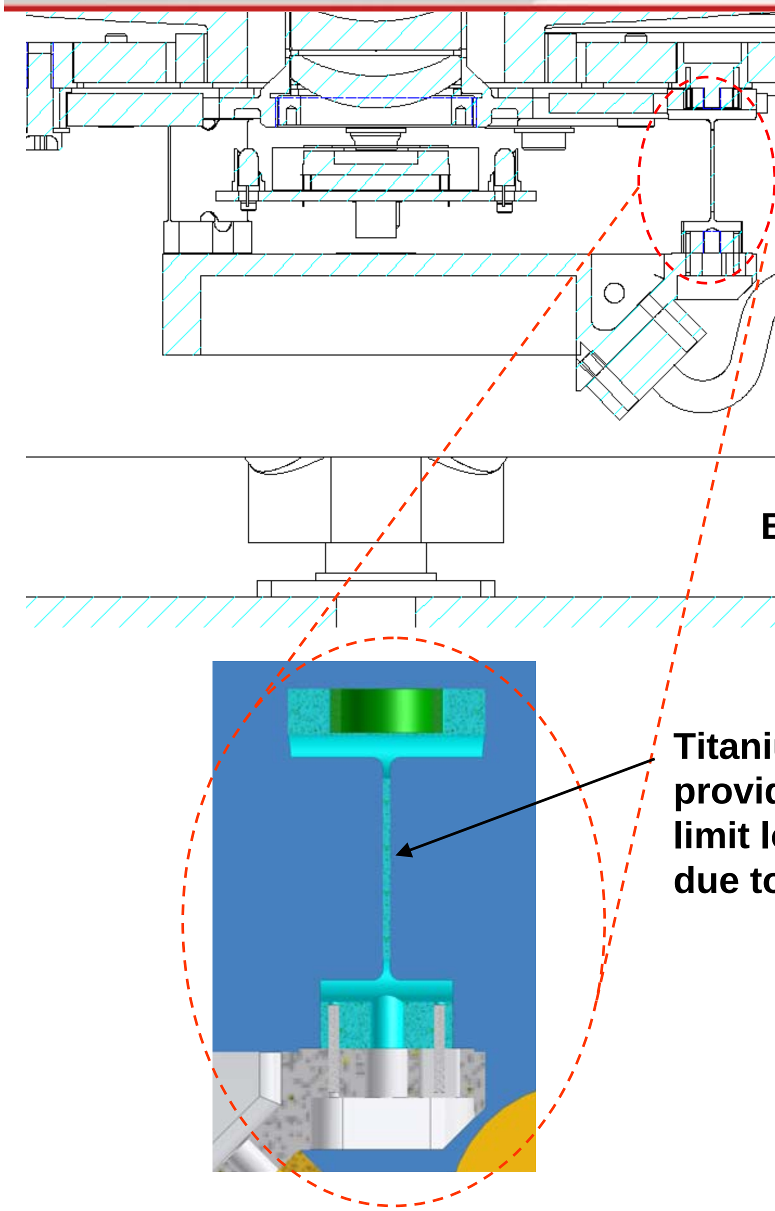


LORRI Mechanical Design (Outer Shell)



Invar Fittings for Outer Mounts and E-Box Transfer
Bonded to Both Outer Ring and Baffle Shell

CCD Mounting Detail

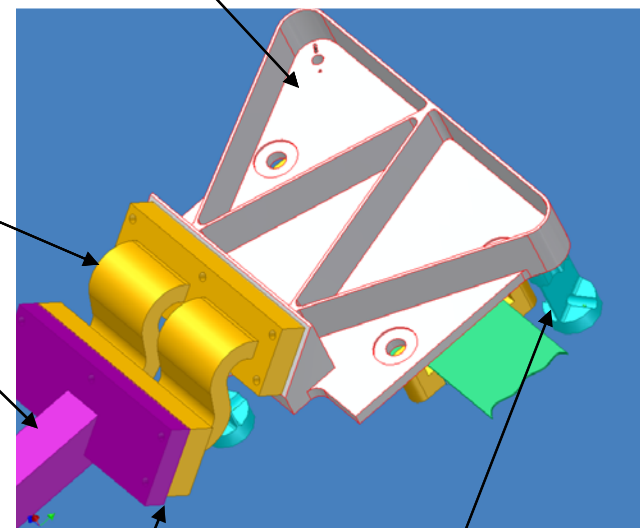


Titanium flexure (3 pls) provide thermal isolation and limit load transmitted to telescope due to CTE mismatch

CCD Mount Plate

S-Link
flexible thermal strap

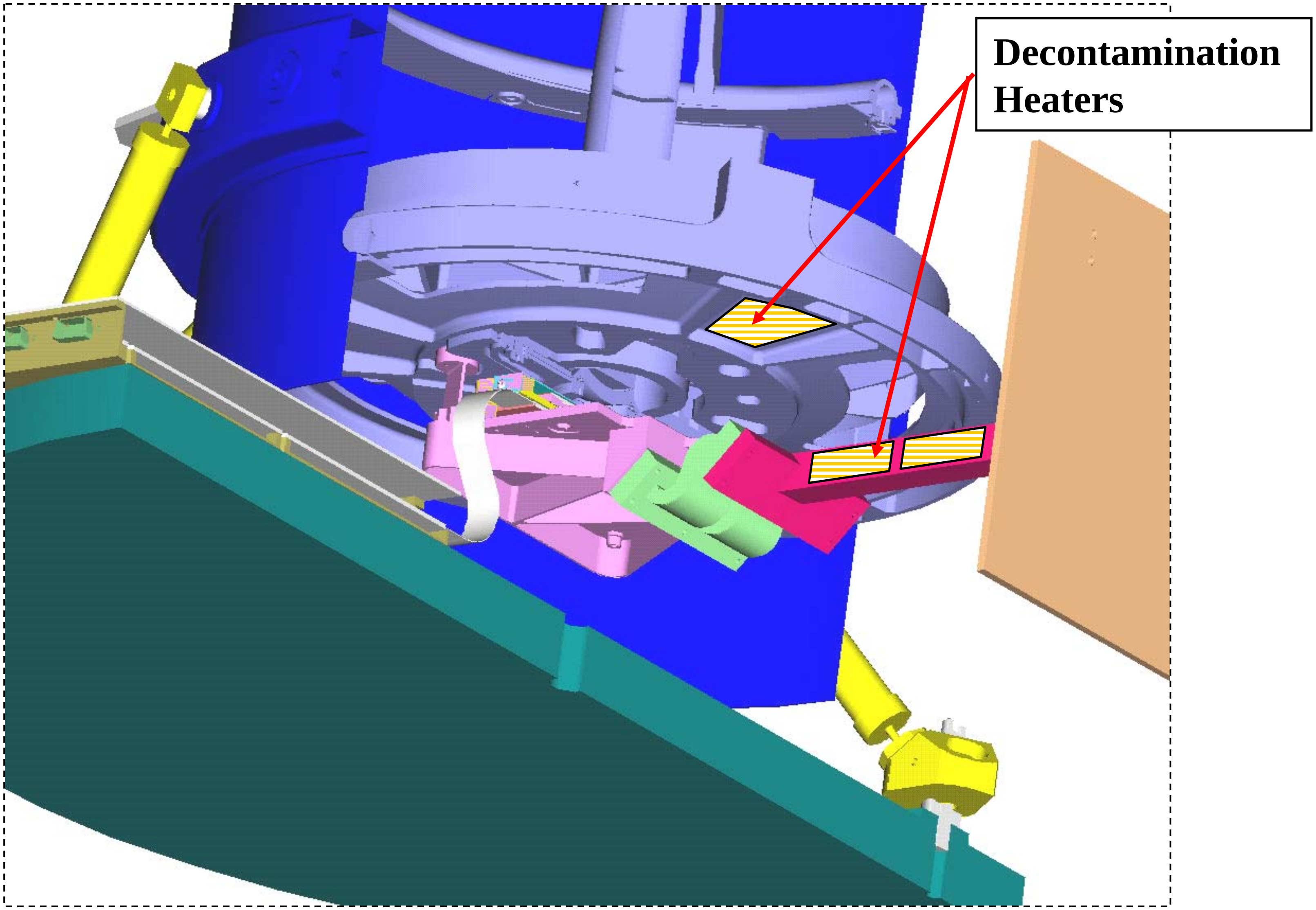
Beryllium Conduction Bar



Titanium flexure (3 pls)

“Thermabond” provides electrical isolation and thermal conduction

Radiator Connection Detail

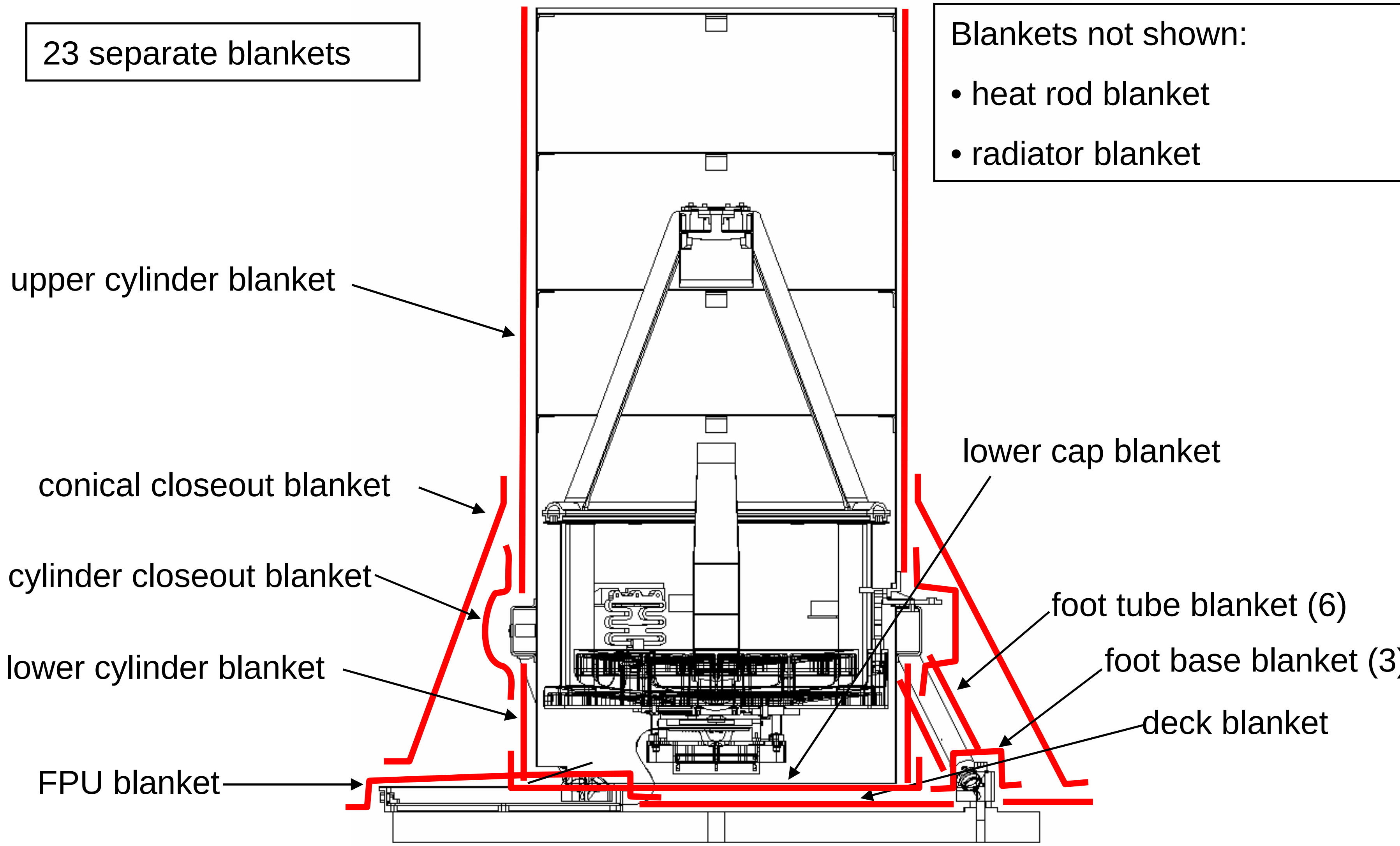


Thermal Blanket Design Concept

23 separate blankets

Blankets not shown:

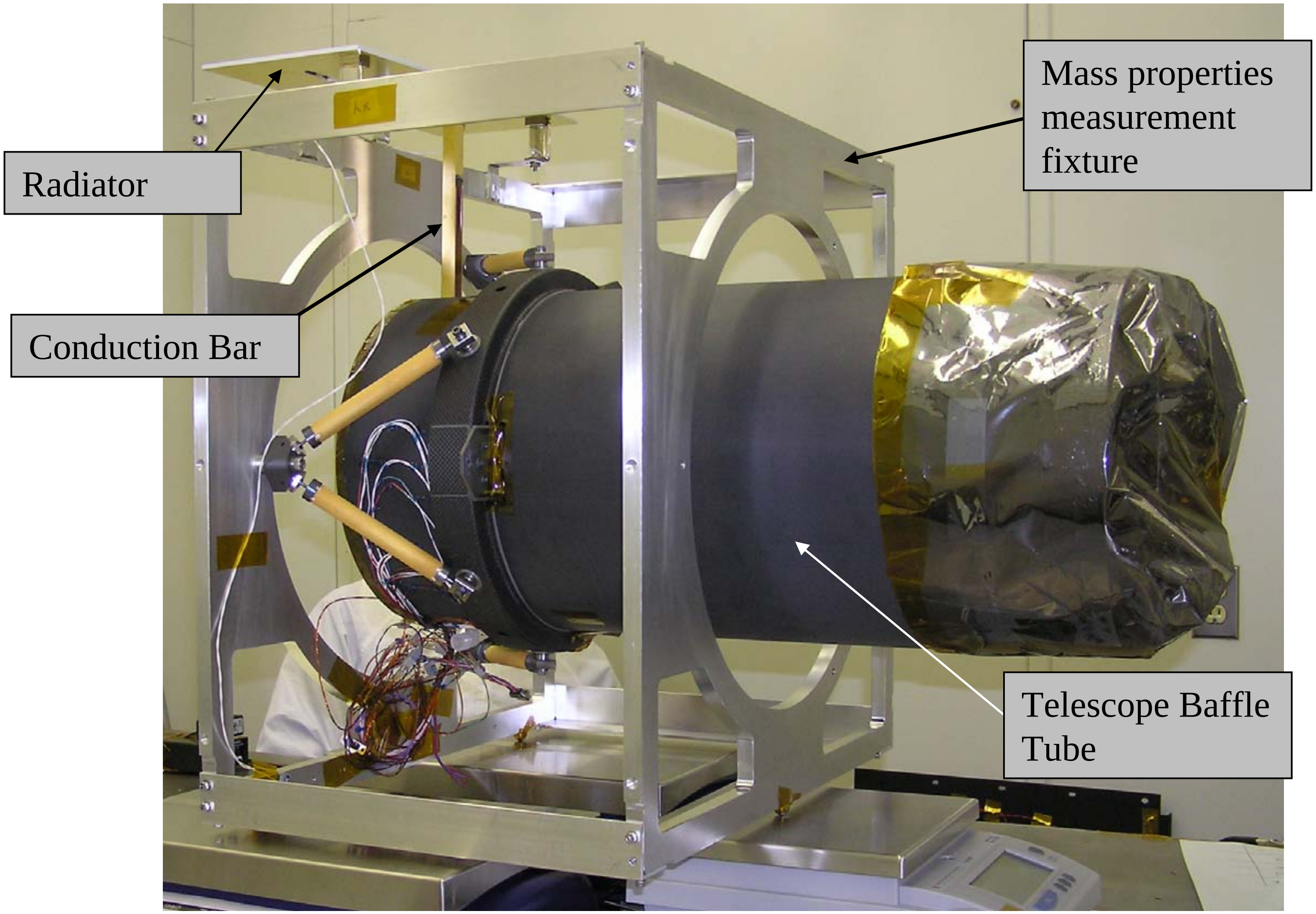
- heat rod blanket
- radiator blanket



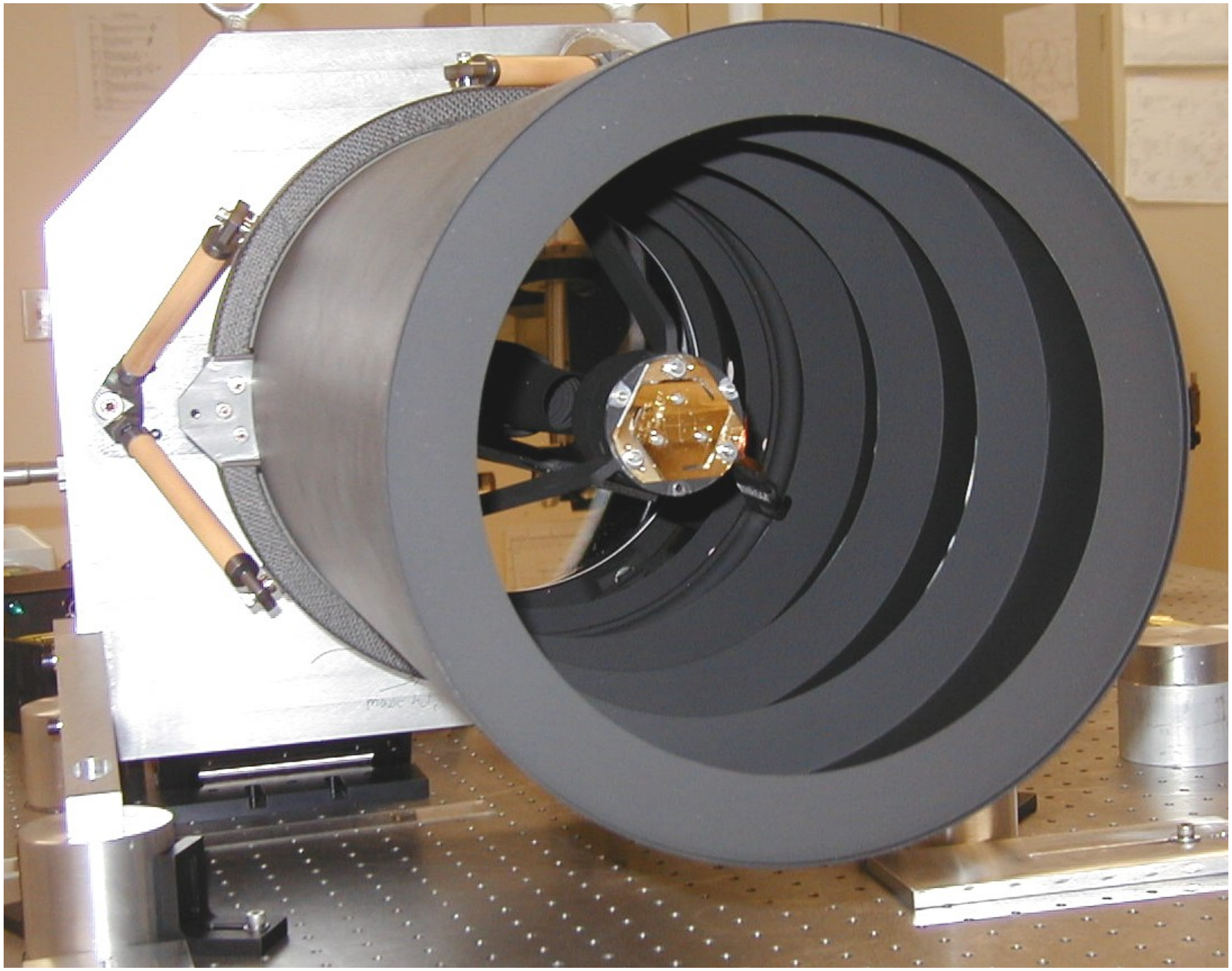
Summary of Thermal Design Features

- Conductive Isolation
  - G10 legs
  - Titanium Flexures
  - heater/sensor wires are bonded to the baffle tube
- Radiative Isolation
  - Thermal Blankets (15% of the total instrument mass)
  - Gold Coatings
    - back side of the M2 support
    - radiator, conduction bar, CCD mounting plate
    - G10 legs
- Thermally conductive optics metering structure
  - minimizes thermal gradients
- Thermally conductive Baffle Tube
  - provides a uniform radiative sink for the optics which helps minimize thermal gradients
- External Radiator
  - coupled to the CCD via a conduction bar and an S-Link thermal strap

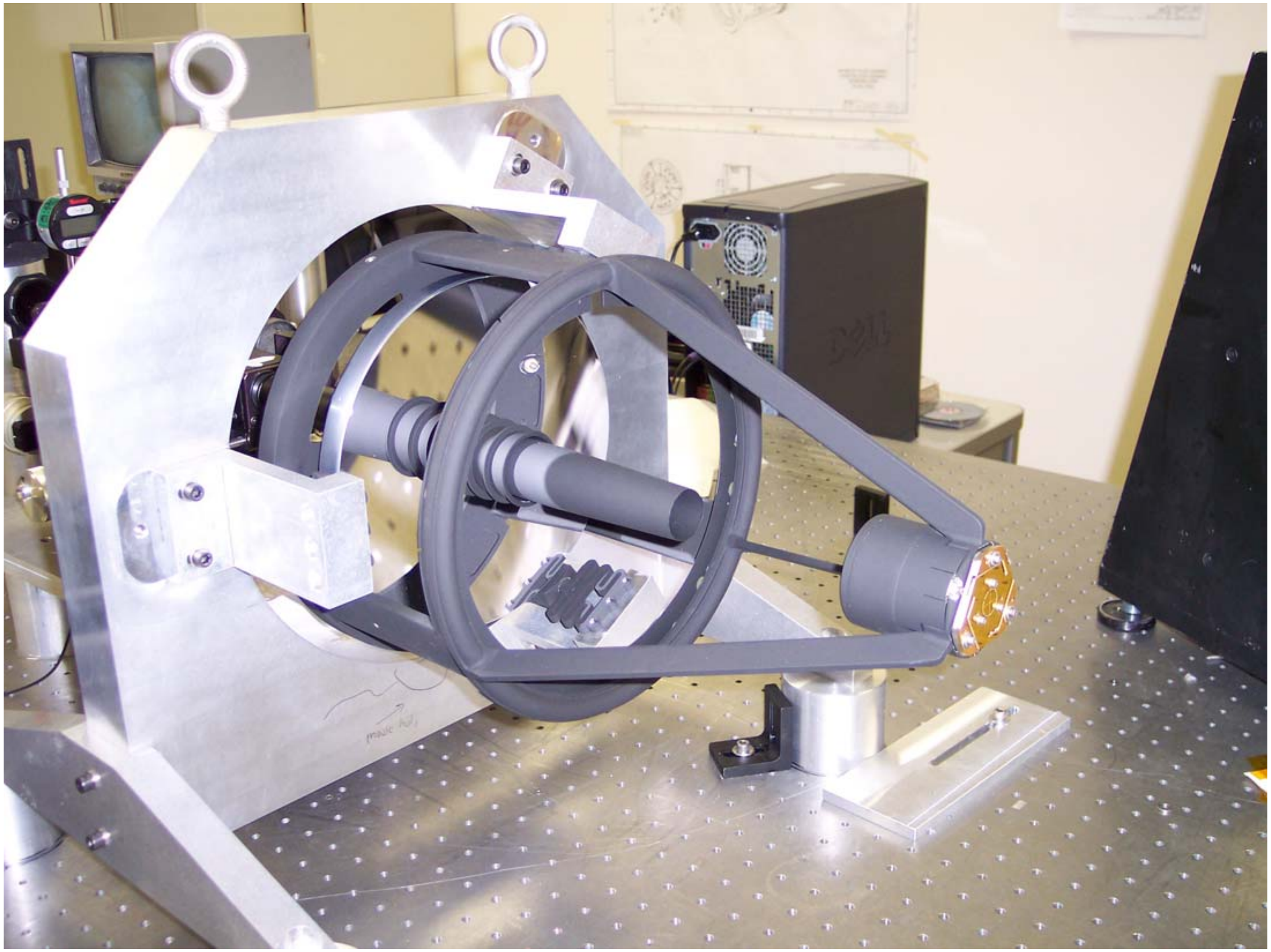
LORRI Telescope in Mass Properties Fixture



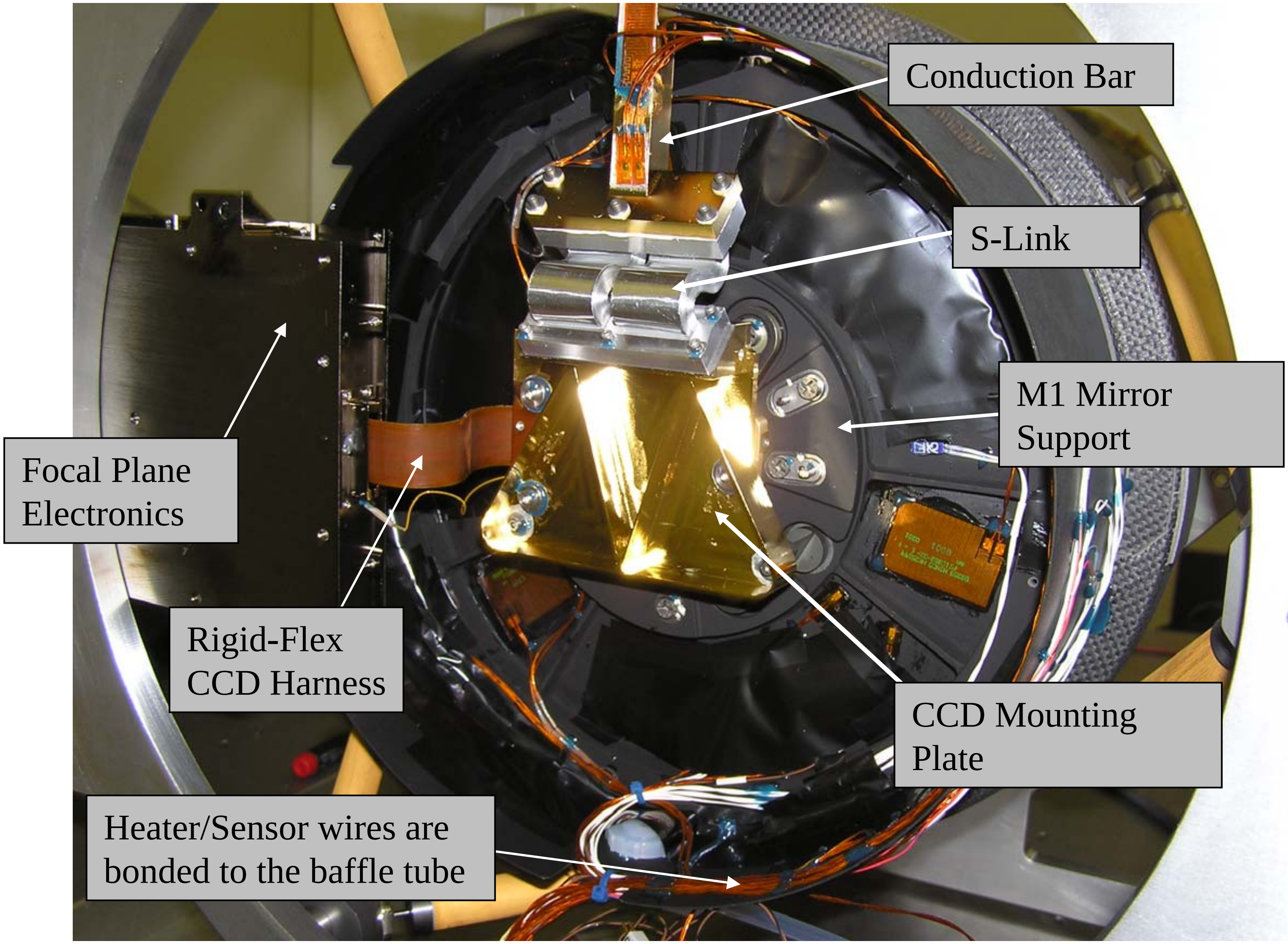
LORRI Telescope in Optical Test Fixture



LORRI Telescope Optics



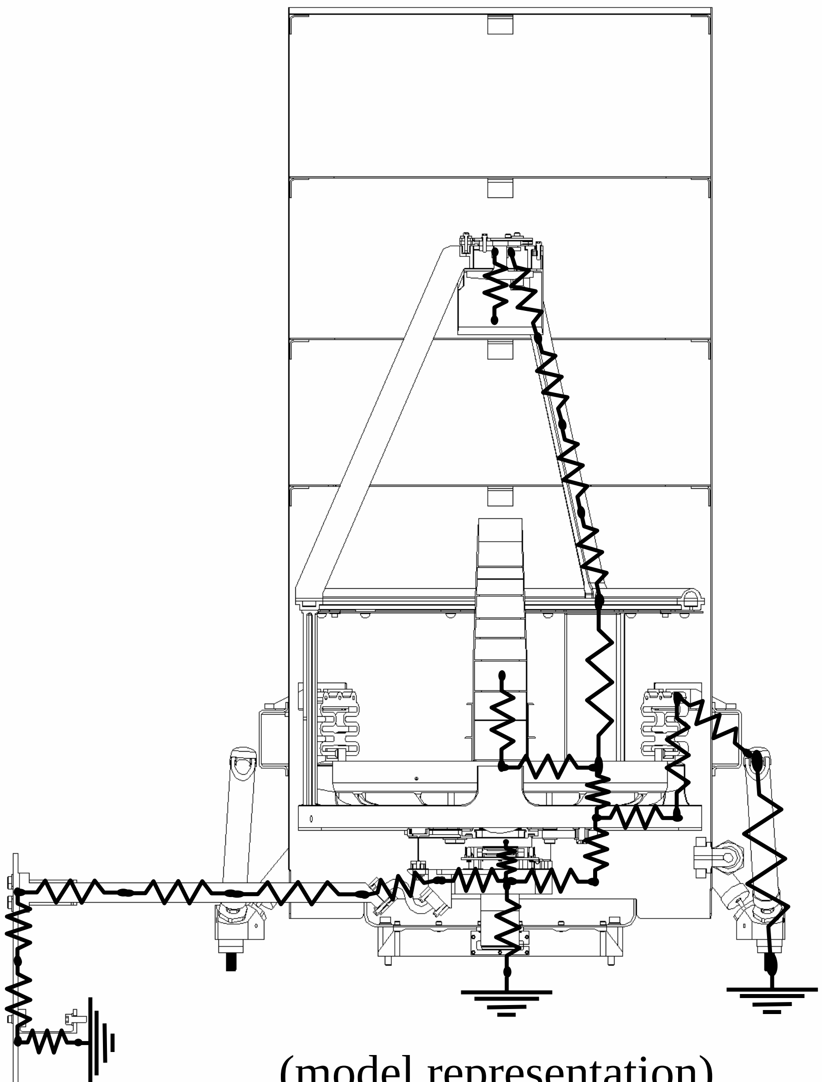
Rear View of LORRI Telescope



Thermal Analysis Techniques

- Finite Difference model is required
  - hand calculations using lump masses and conductors
    - finite element techniques create too many nodes to be compatible with ray trace modeling
  - execution in TAK (SINDA)
- Radiation view factors are calculated between surfaces using a ray-tracing technique (TSS software)
- FEA techniques were used to support the finite difference model for complex structures

Finite Difference Thermal Model


(model representation)

- Thermal resistance network
  - -lumped masses (nodes)
  - -conductors
- Most are calculated by hand
- 380 nodes
- 410 Linear Conductors
- 14,100 Radiation Conductors
  - -generated by TSS
  - -goes as $N^2/2$

Model Definition

Node Definition

```
c
     121,  T_init,  0.3037   $ M1
     101,  T_init,  0.2520   $ M1 Support
     131,  T_init,  0.0603   $ lens cell
     161,  T_init,  0.1014   $ SAS Ring
c
     201,  T_init,  0.0081   $ M2
     202,  T_init,  0.0308   $ M2 Support
     203,  T_init,  0.0072   $ M2 Baffle
c
     1811,  T_init,  0.0052 $ spider
     1812,  T_init,  0.0052 $ spider
     1813,  T_init,  0.0052 $ spider
     1814,  T_init,  0.0052 $ spider
c
     1821,  T_init,  0.0052 $ spider
     1822,  T_init,  0.0052 $ spider
     1823,  T_init,  0.0052 $ spider
     1824,  T_init,  0.0052 $ spider
c
     1831,  T_init,  0.0052 $ spider
     1832,  T_init,  0.0052 $ spider
     1833,  T_init,  0.0052 $ spider
     1834,  T_init,  0.0052 $ spider
c
     141,  T_init,  0.0303  $ strut
     142,  T_init,  0.0303  $ strut
     143,  T_init,  0.0303  $ strut
c
c Titanium Squiggly Isolators
c

     51,   T_init,  0.0068
     52,   T_init,  0.0068
```

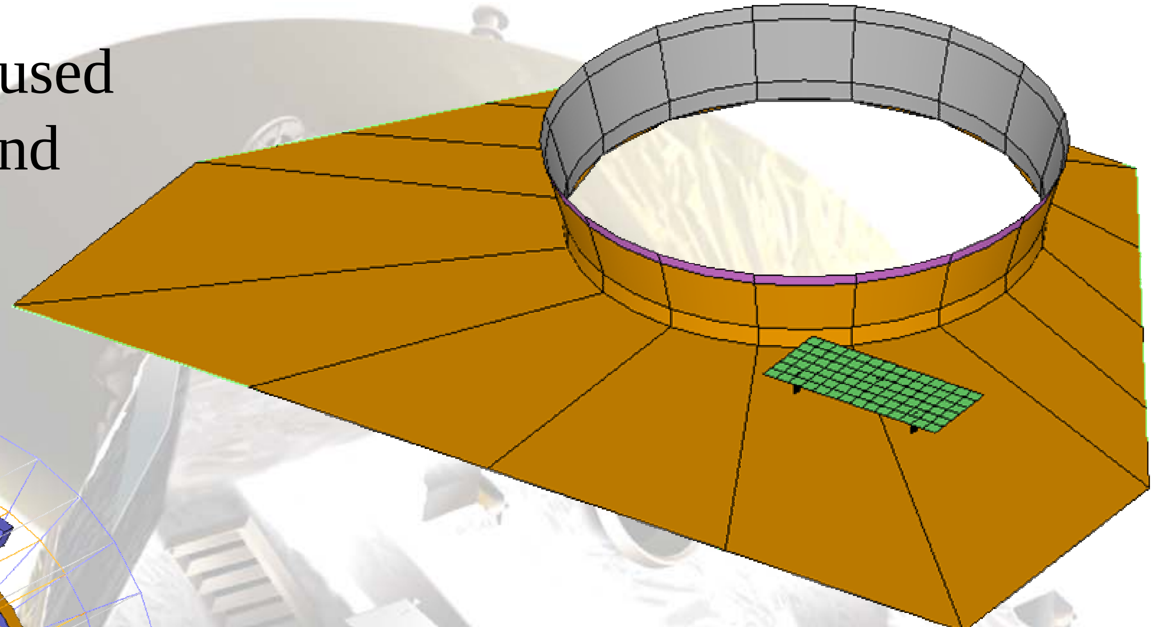
Conductor Definition

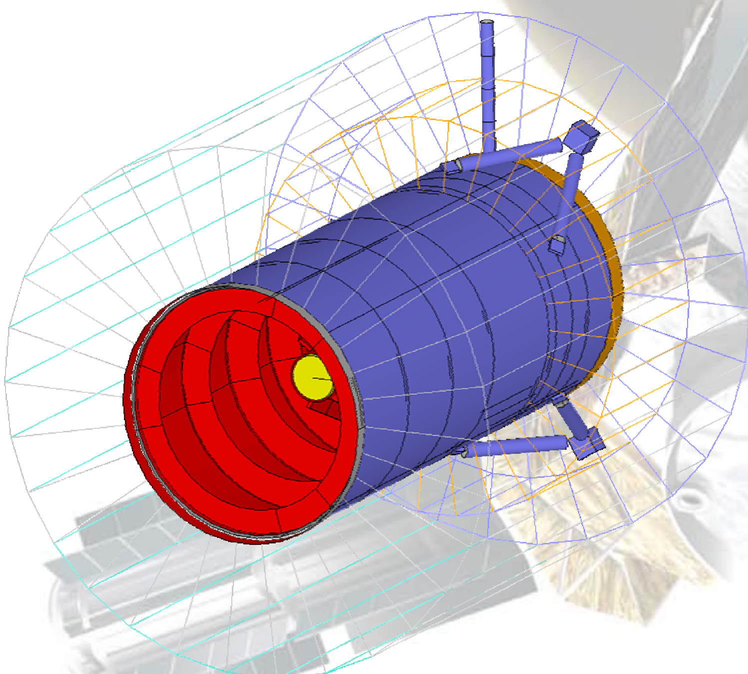
```
c  hand calc linear conductors for structure
c
     101,  121,  101,  1.5        $ M1 support to M1 (copy from Mike, 3/27/2003)
     131,  131,  101,  0.070      $ Lens Cell to M1 Support (copy from Mike)
c
     SIV 102,    101,  141,  10082,   0.00866       $ support to Strut
     SIV 103,    141,  161,  10082,   0.00866       $ strut to SAS
c
     SIV 104,    101,  142,  10082,   0.00866       $ support to Strut
     SIV 105,    142,  161,  10082,   0.00866       $ strut to SAS
c
     SIV 106,    101,  143,  10082,   0.00866       $ support to Strut
     SIV 107,    143,  161,  10082,   0.00866       $ strut to SAS
c
     SIV 108,  161, 1811,  10082,  0.00826

     SIV 109, 1811, 1812,  10082,  0.00413
     SIV 110, 1812, 1813,  10082,  0.00413
     SIV 111, 1813, 1814,  10082,  0.00413
     SIV 112, 1814,  202,  10082,  0.00826
c
     SIV 113,  161, 1821,  10082,  0.00826
     SIV 114, 1821, 1822,  10082,  0.00413
     SIV 115, 1822, 1823,  10082,  0.00413
     SIV 116, 1823, 1824,  10082,  0.00413
     SIV 117, 1824,  202,  10082,  0.00826
c
     SIV 118,  161, 1831,  10082,  0.00826
     SIV 119, 1831, 1832,  10082,  0.00413
     SIV 120, 1832, 1833,  10082,  0.00413
     SIV 121, 1833, 1834,  10082,  0.00413
     SIV 122, 1834,  202,  10082,  0.00826
c
         123,  201,  202,   0.0691   $ M2 to Support
         124,  203,  202,   0.5250   $ M2 baffle to Support
```

The user must keep track of all node numbers

Flight Interior and Exterior Radiation Model

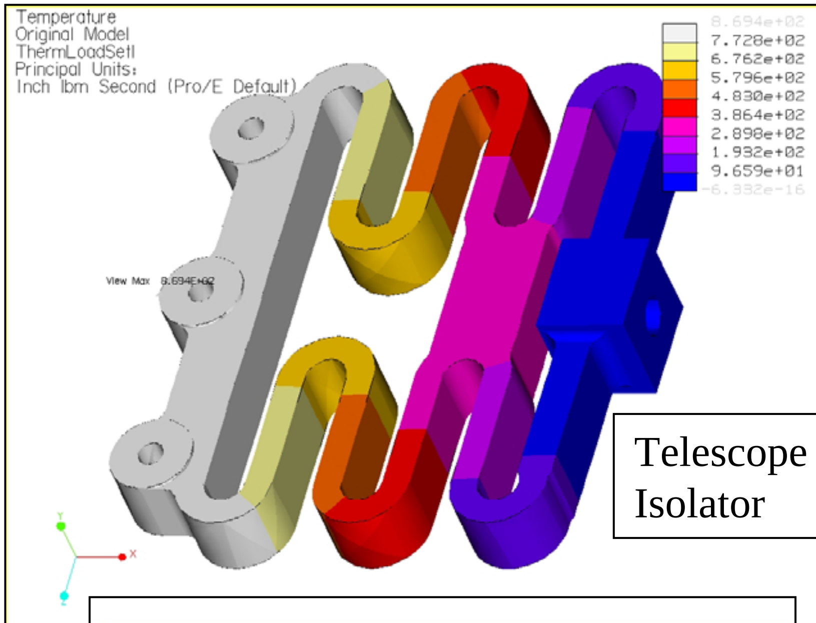
A separate model was used to model the radiator and the exterior of the spacecraft



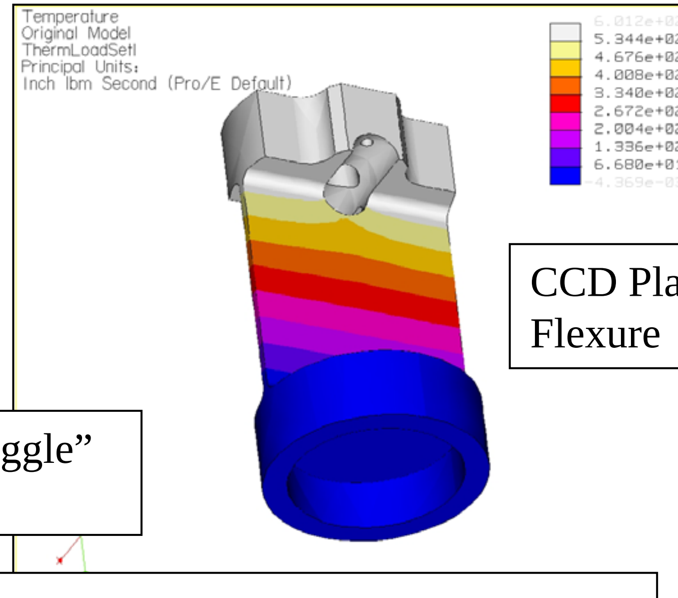


The node numbers in the radiation model must match the node numbers in the finite difference model

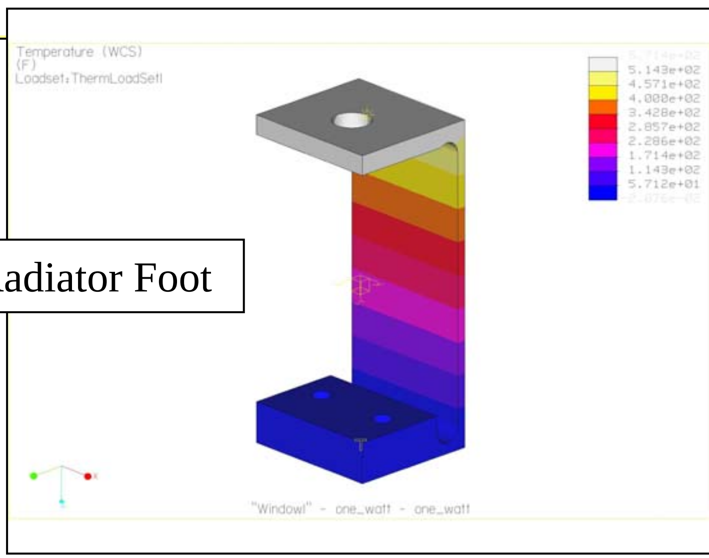
FEA Analyses to Support Finite Difference Analyses



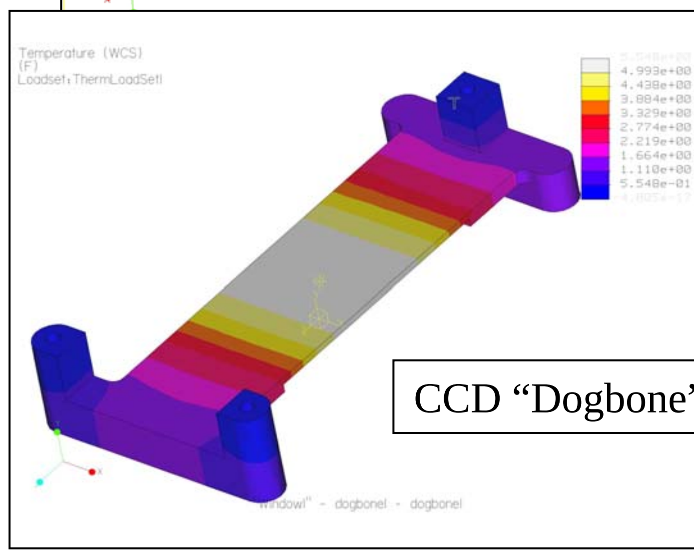
Telescope “squiggle” Isolator



CCD Plate Flexure

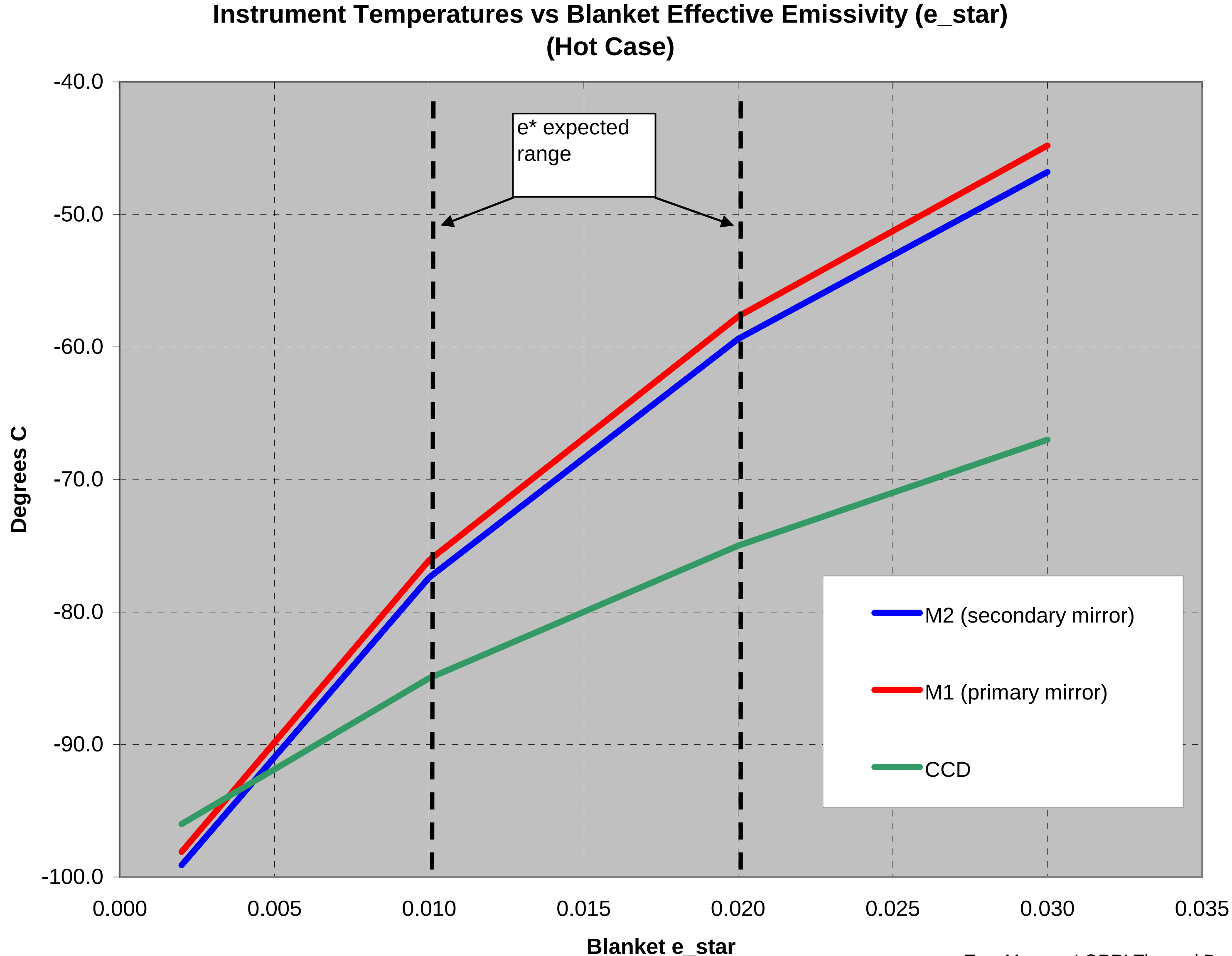


Radiator Foot



CCD “Dogbone”

Predicted Temperatures vs E_star

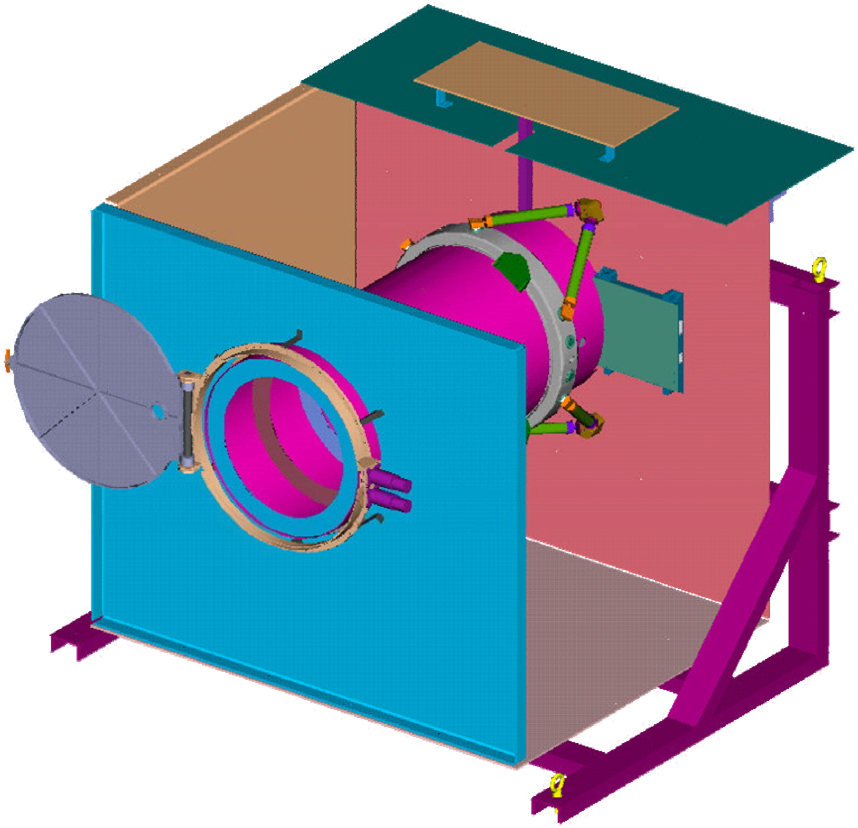


LORRI Thermal Balance Test

- The purpose of a thermal balance test is to simulate the flight conditions and to correlate the thermal model

- LORRI is mounted in a shroud that simulates the spacecraft interface (0ºC to 40ºC)
- Flight blankets were installed
- Chamber liner was flooded with LN2 to simulate radiation to deep space
- 5 separate test cases
  - a “good” model should correlate under varying conditions

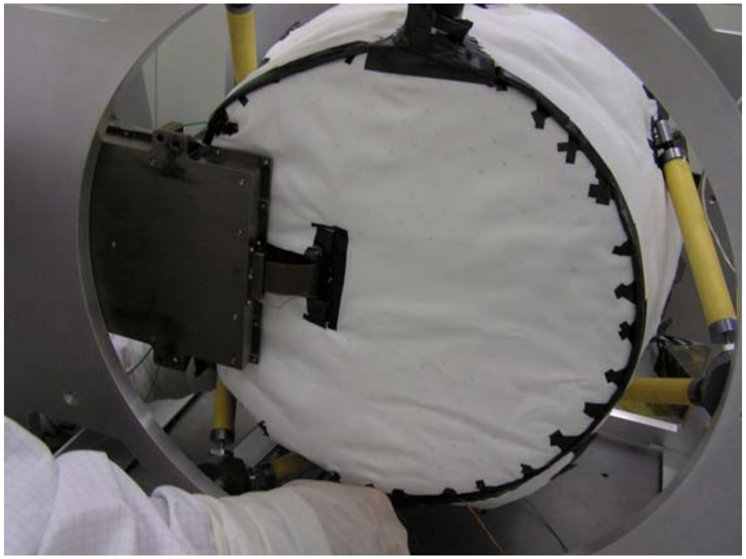
Thermal Balance Test Fixture

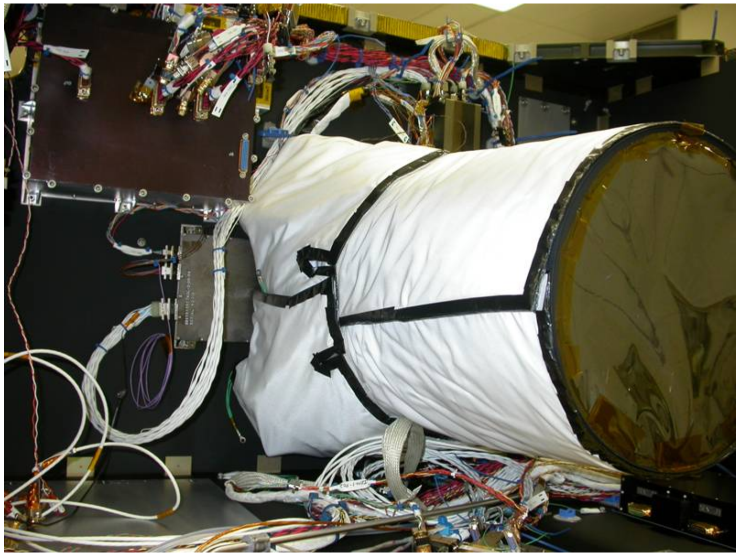


CAD model of shroud

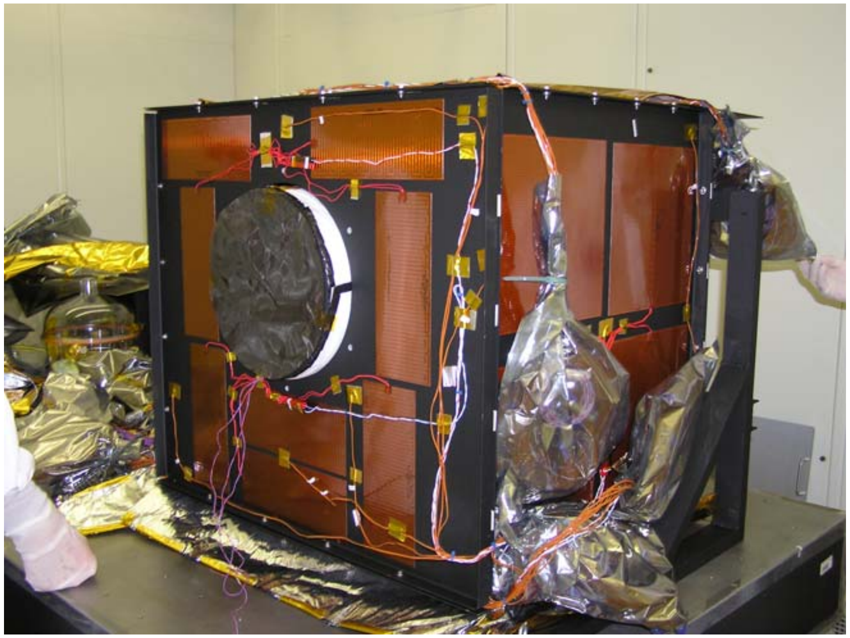
Photo of actual shroud

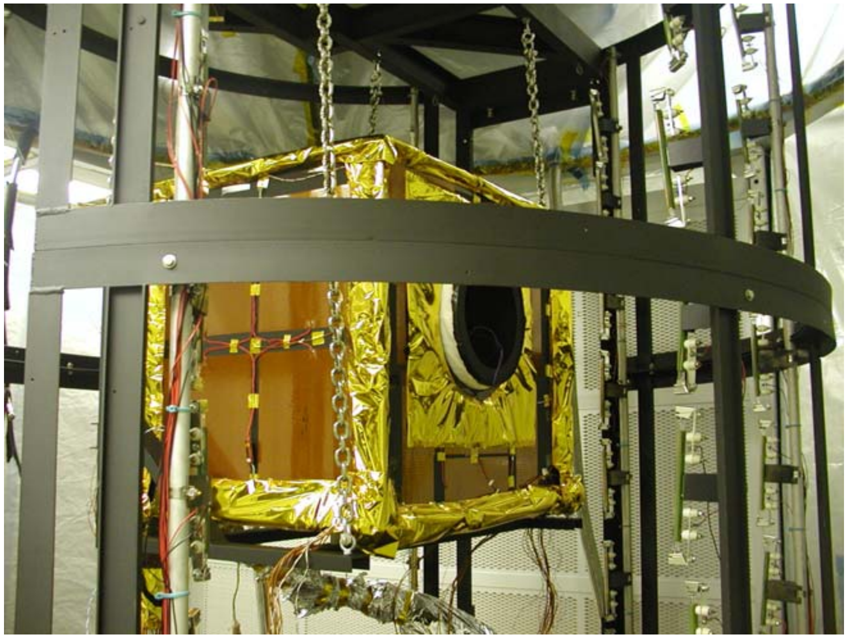
Thermal Blanket Installation



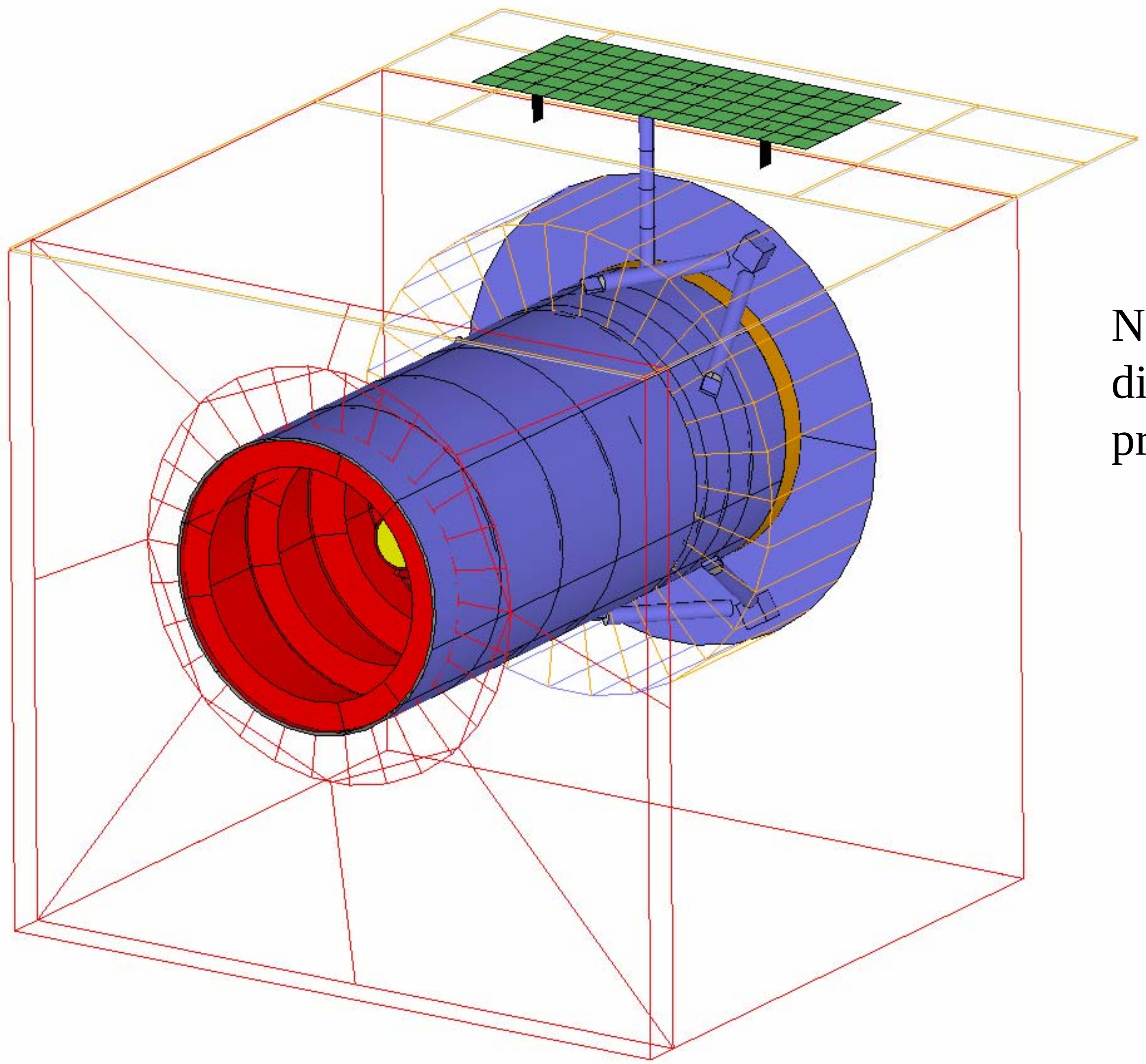


Thermal Shroud Photos



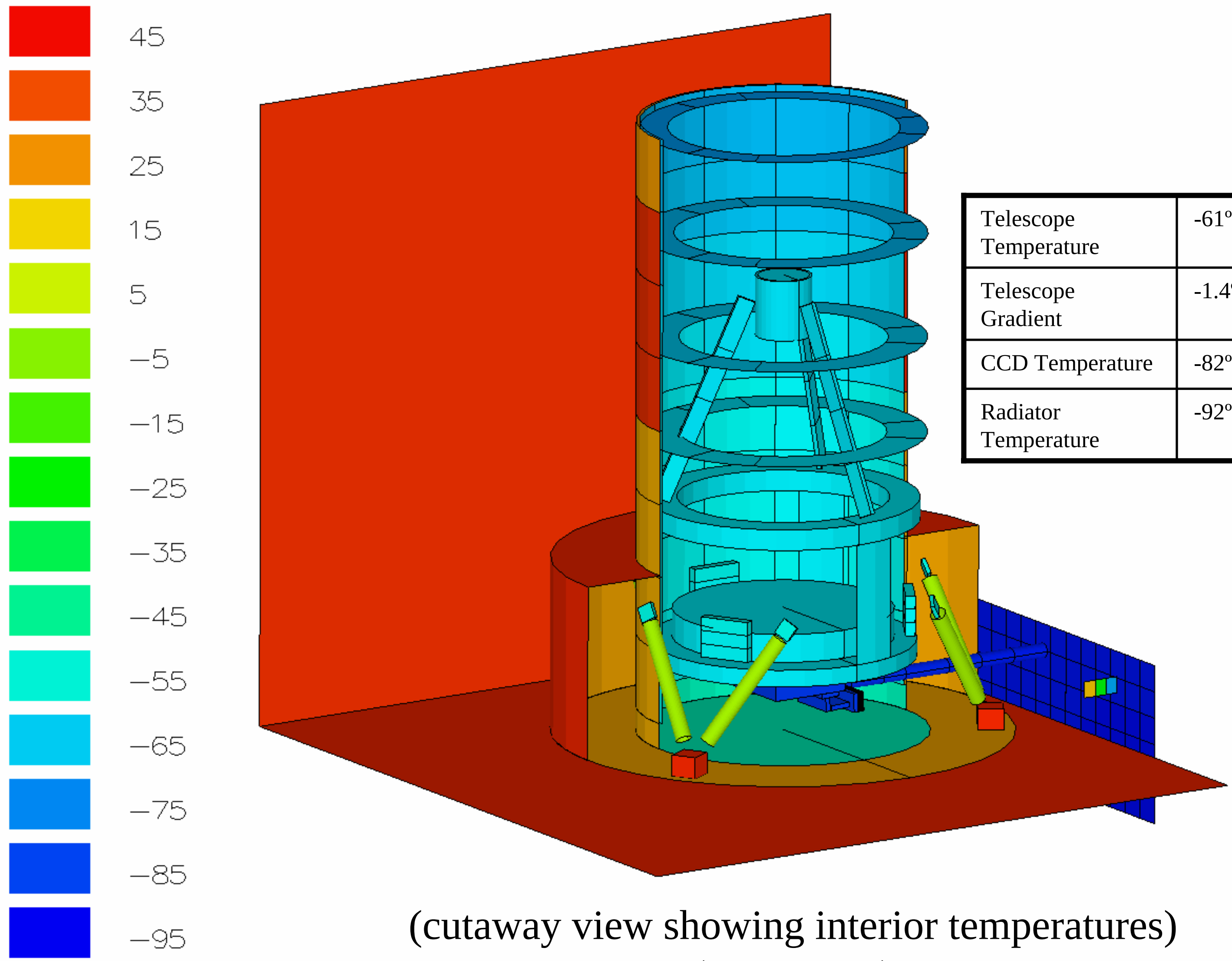


Thermal Balance Test Radiation Model



Note: colors depict different optical properties

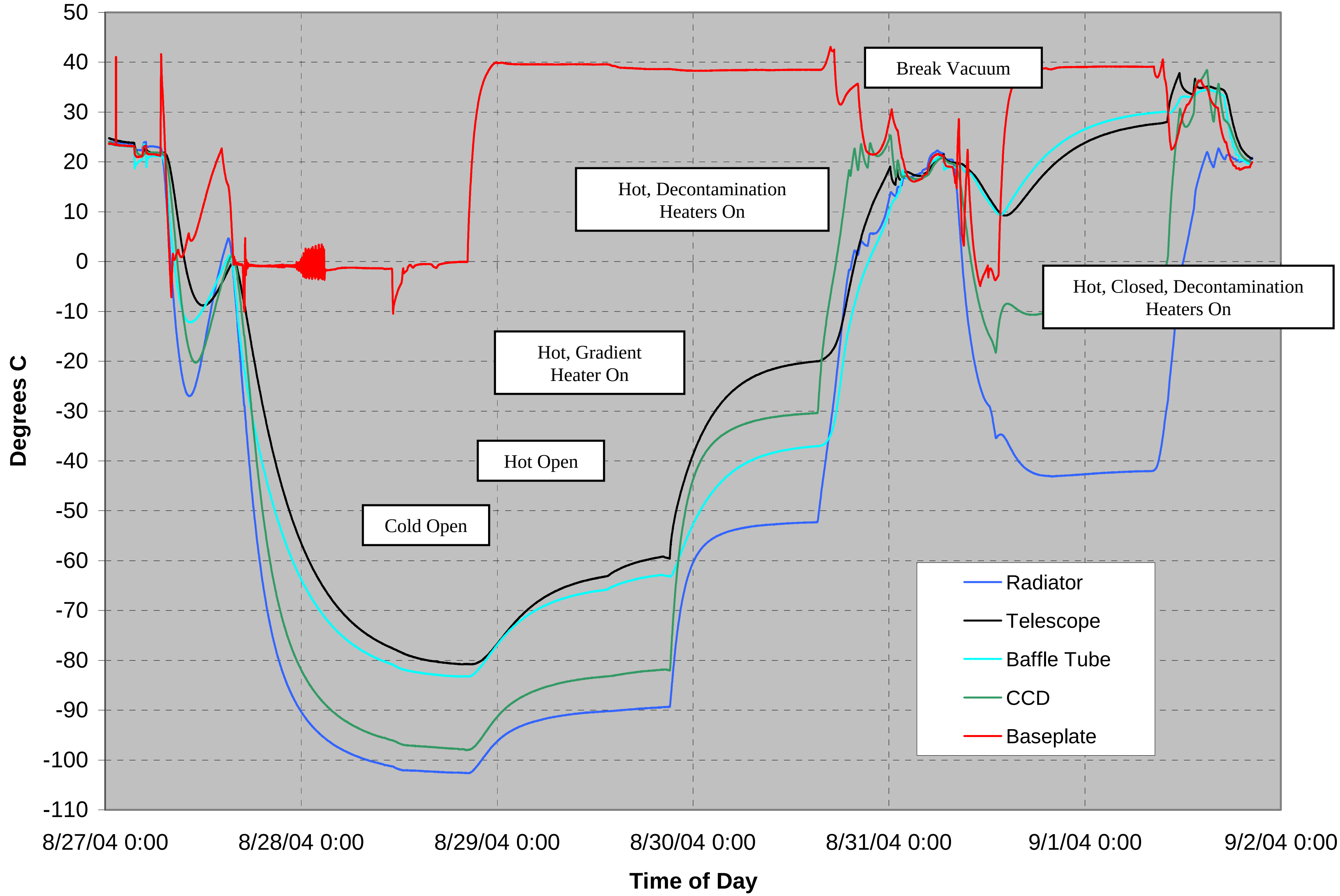
Thermal Balance Test Model (Hot Case)



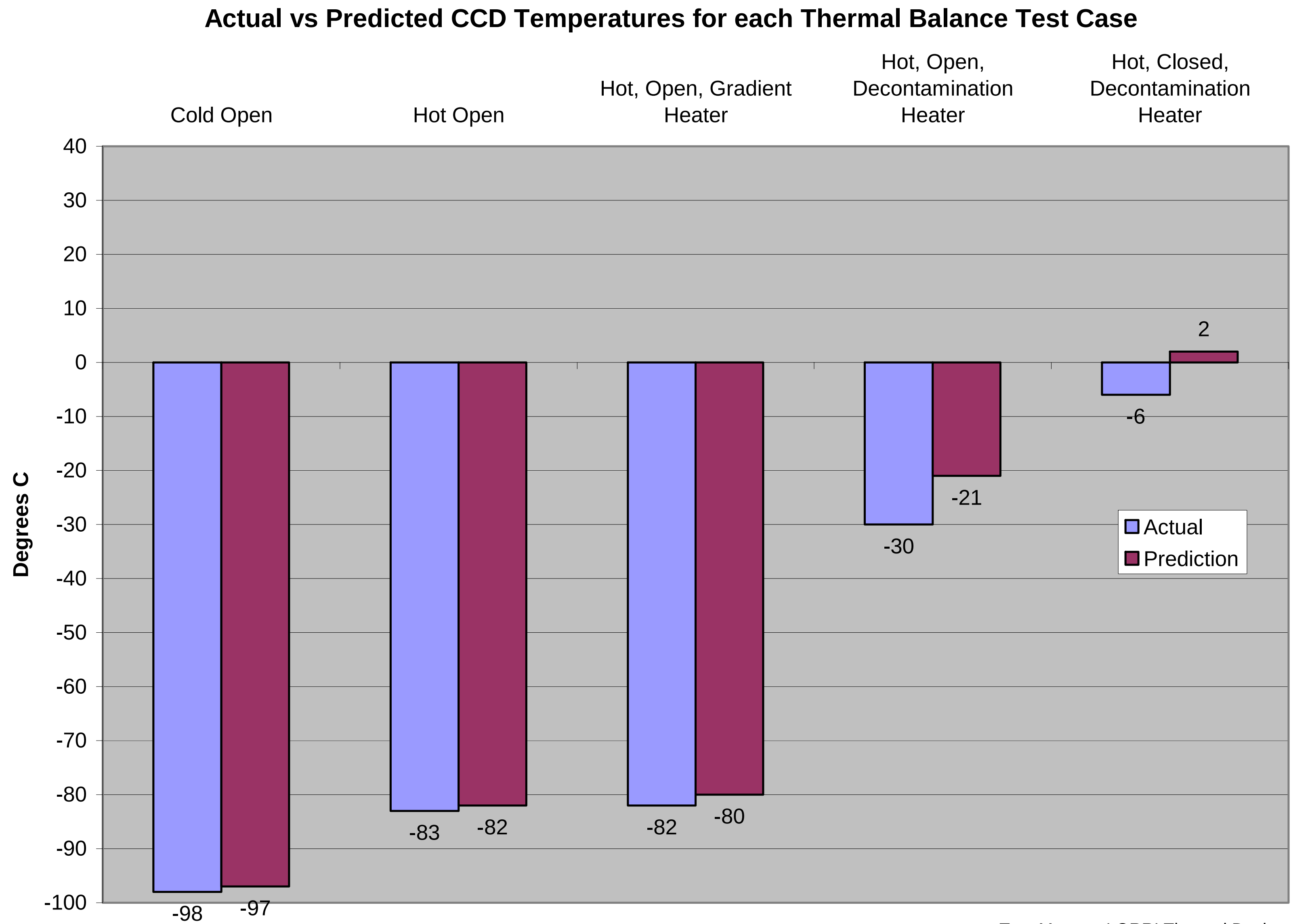
Telescope Temperature	-61ºC
Telescope Gradient	-1.4ºC
CCD Temperature	-82ºC
Radiator Temperature	-92ºC

(cutaway view showing interior temperatures)
(Degrees C)

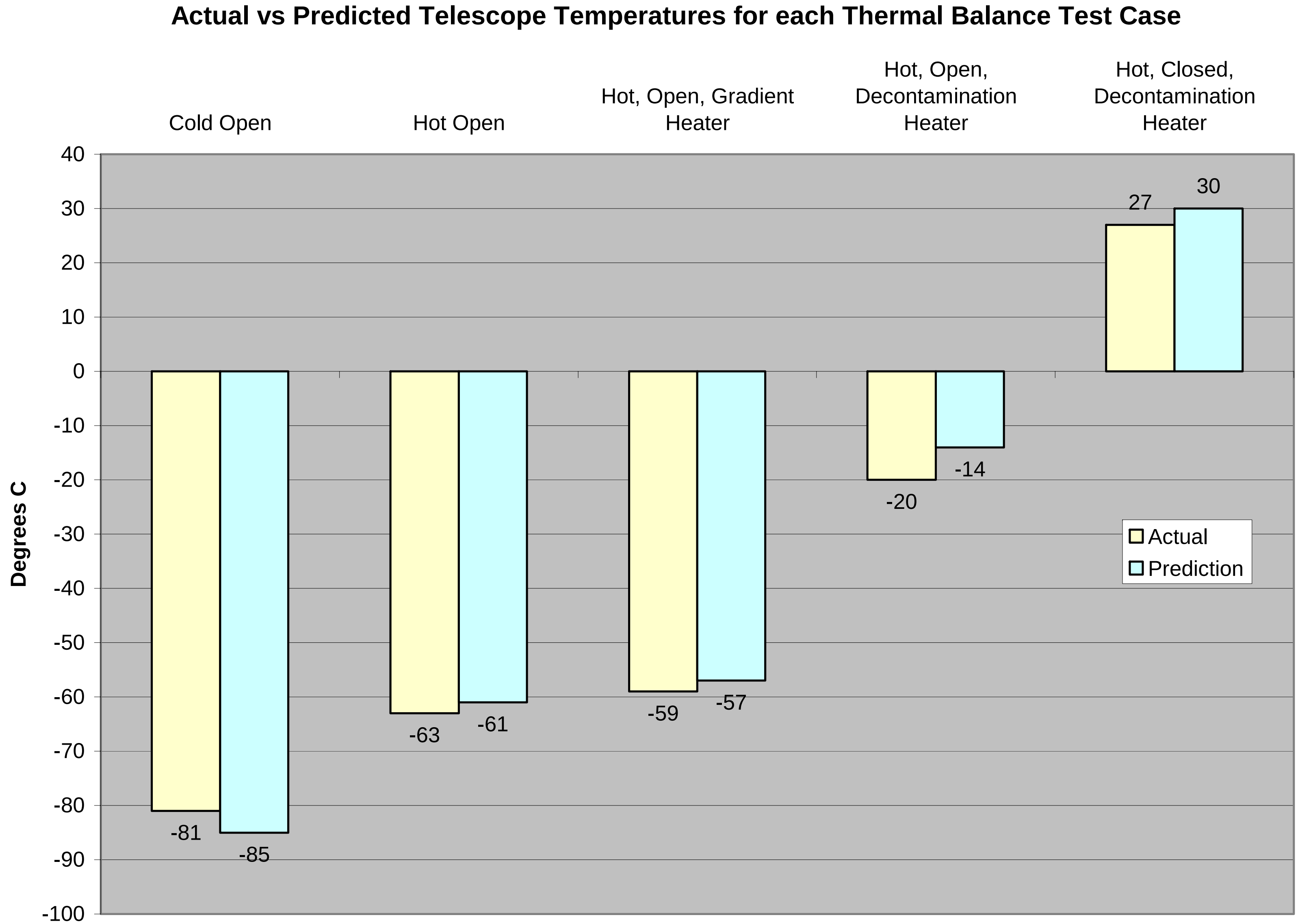
LORRI Thermal Balance Test Data



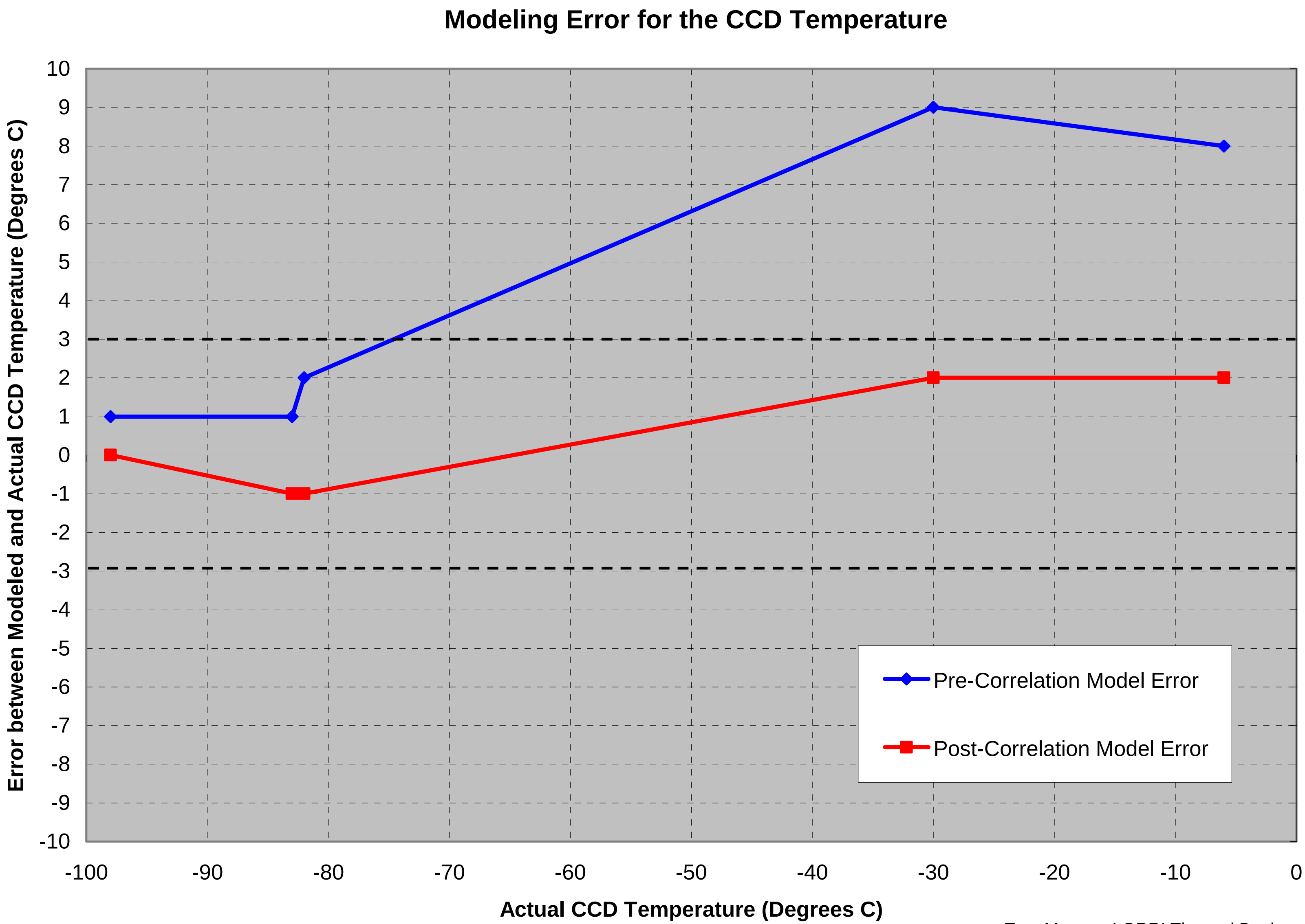
Comparison Between Test Results and Model Predictions



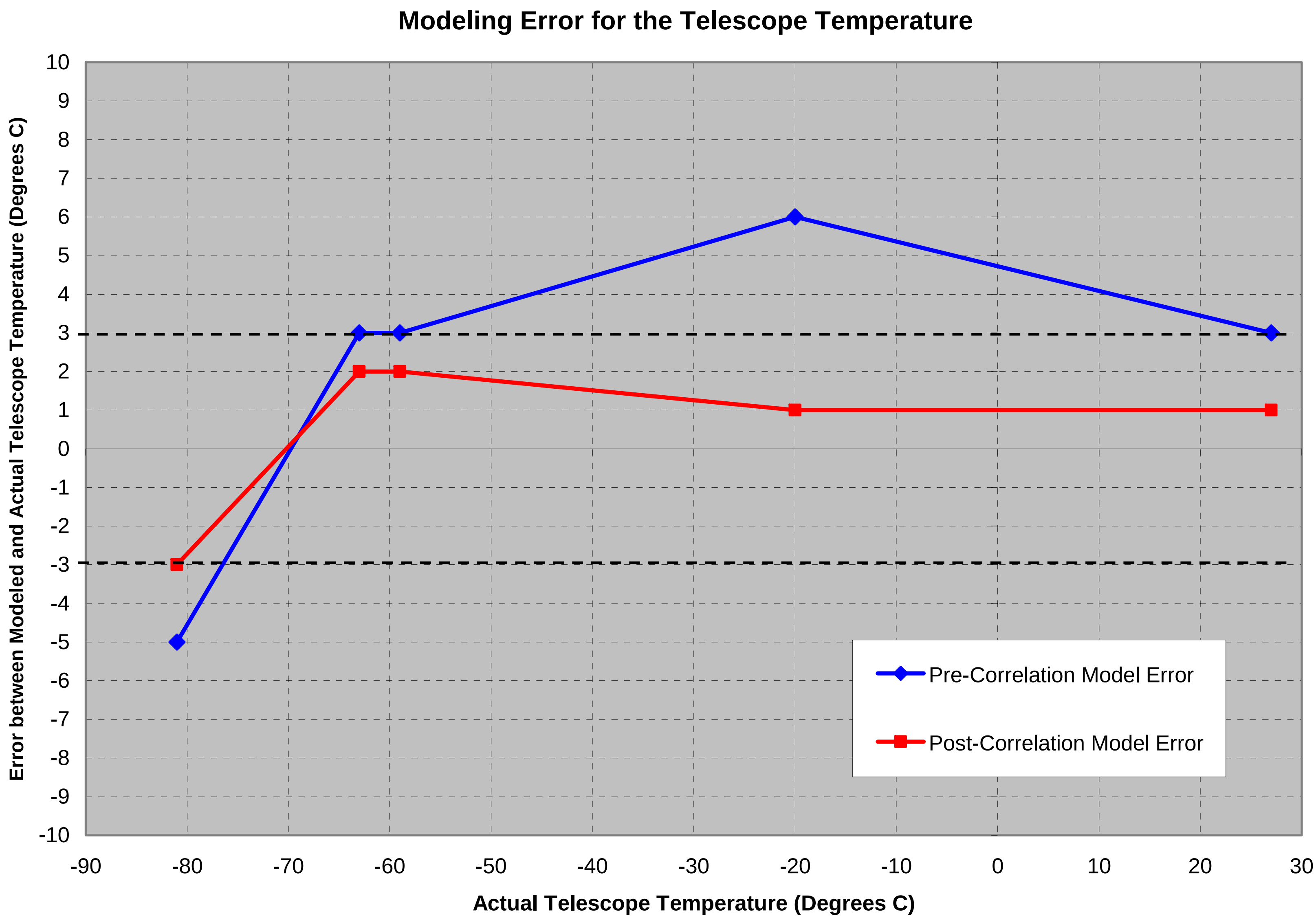
Comparison Between Test Results and Model Predictions



Modeling Error for the CCD Temperature



Modeling Error for the Telescope Temperature



Model Correlation Changes

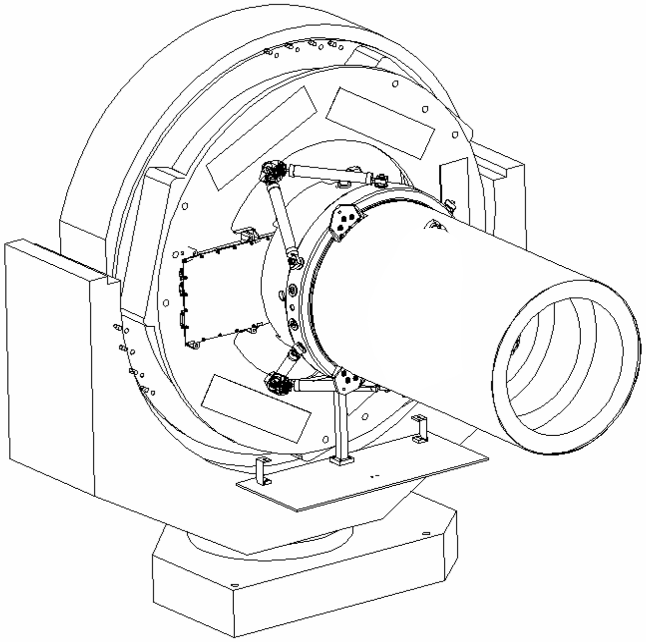
- Radiation Changes
  - adjust blanket effective emissivity to 0.020 (0.015 on the upper cylinder)
  - increase the aperture area by 5%
    - account for the fit of the blankets
  - increase the radiator area 10%
    - account for the edges
  - increase the emissivity of the mirror surfaces to 0.85
    - energy is focused
- Conduction Changes
  - recalculate the conductance of the "squiggle" isolators based on FEA modeling results
  - adjust the effect length of the wires (heat leak from the wires)
  - increase the conductance in the baffle tube wall
  - increase the conductance from the baffle annuli to the main tube
  - increase the conductance of the telescope legs
  - increase the conductance from the CCD to the radiator

Gradient from M1 to M2

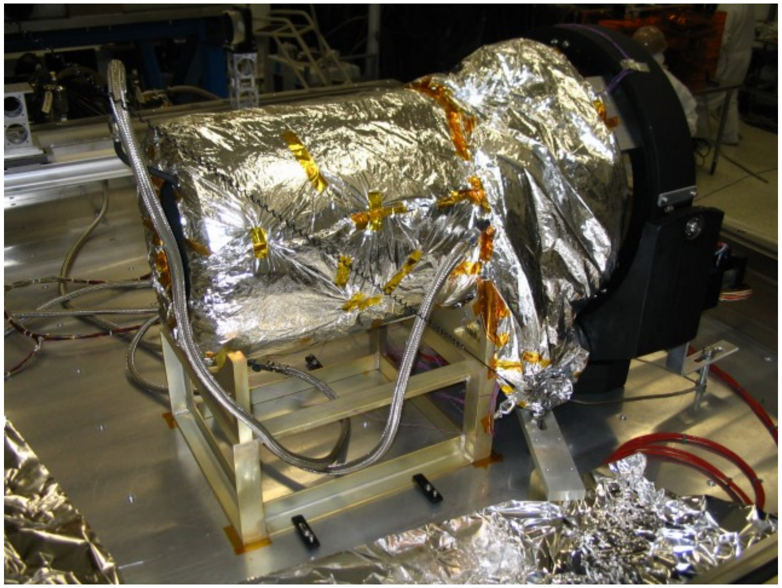
- Thermal Gradients in the optics structure in the balance test were less than predicted by the model
  - the in-flight thermal gradients will be comparable
  - The predicted gradients were less than the 2.5 C requirement and the actual gradients should be less than predicted

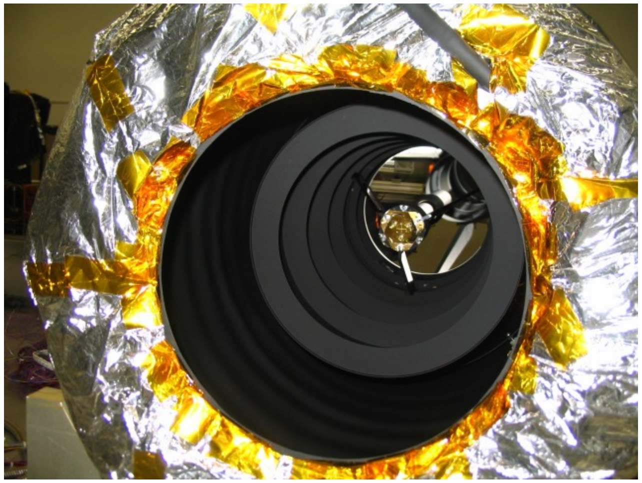
Actual Balance Test Gradient	Predicted Gradient in the Balance Test	Predicted Gradient in Flight
-0.6ºC	-1.3ºC	-1.1ºC

Optical Testing



- Optical Testing at cold temperature was confirmed at the Goddard DGEF





Summary

- A combination of modeling techniques was used to predict instrument temperatures
  - finite difference (overall model)
    - hand calculations (nodes and conductors)
  - finite element analysis (for complex structures)
    - used to support the finite difference model
  - ray-trace software (for radiation modeling)
- A thermal balance test was performed to validate the thermal model
  - slight changes were required to correlate the model in all 5 test cases
- The flight version of the model was then updated with the same changes and revised flight predictions were made
  - the CCD should be colder than the requirement of -70ºC
  - The thermal gradient in the optics structure should be less than the requirement of 2.5ºC
- The LORRI telescope has been integrated with the New Horizons Spacecraft and is awaiting launch in 2006 for a 2015 flyby.