Hardware Summary

• Available Flight Hardware
  > Two, 2.4m, two-mirror telescopes
    > One completed with full thermal hardware
    > Electronics & Actuators have been harvested but can be rebuilt to existing drawings
  > Two outer barrel assemblies
    > One fully completed with thermal blankets and butterfly doors
  > One hardware radiator/electronics bays
    > Aluminum structures for radiator and electronic attachment
  > Acted as a “spacer” between the spacecraft and the outer barrel assembly
• All ground support equipment for alignment, integration, and test
• Miscellaneous parts for a third system

Robust traceability has been retained for all flight hardware
Hardware

- **Outer Barrel Assembly (OBA)**
  - 2 Assemblies Available

- **Telescope Subsystem (TSS)**
  - 2 Assemblies Available

- **Payload Radiator Subsystem (PLRSS)**
  - 1 Assembly Available
2.4m Space Telescope Form

- Optical Form: 2 Mirror, f/8
- Aperture: 2.37m
- Unvignetted Field of View: ~ 1.8° Dia.
- Wavefront Quality: <60 nm rms
- Secondary Mirror Assembly Control –
  - 6 DOF plus fine focus
  - 6 DOF Actuators are at the base of the secondary struts
  - Focus actuator is behind the SMA
- Mass: 840kg
- Back Focus: 1.2m behind PM Vertex

~ 5.8 m³ Volume Available for Instruments, Sensors, Electronics
Outer Barrel Assembly

- Thermal Protective Enclosure *including Two Actuated Thermal Butterfly Doors*
- Composite Structure
- Full MLI blanket set also completed
- Mass: 280kg (without blankets)
- Mounting: Requires Interim Structure connected to Spacecraft Interface
System Obstruction

Seven coating artifacts correctable by recoating

On Axis Pupil
17% Obstructed
Strut Mean Width: 41mm
Strut Obstruction Length: 881mm
Mirror Quality and Coating

**Primary Mirror (~40kg/m²)**

- **Clear Aperture:** 2.37m OD, 0.7m ID
- **Surface Quality:** 12nm RMS
- **Form:** Concave, F/1.2
- **Mirror Coating:** Protected Silver

![Primary Mirror Diagram]

**Secondary Mirror**

- **Clear Aperture:** 0.53m OD, 0.02m ID
- **Surface Quality:** 16nm rms
- **Form:** Convex
- **Mirror Coating:** Protected Silver

![Secondary Mirror Diagram]
Telescope Thermal Configuration

- Cold biased design - Outer Barrel Assembly (OBA) serves as a passively cooled radiative enclosure to attenuate environment changes.
- Heaters control telescope: Aft Metering Structure (AMS), Forward Metering Structure (FMS), Secondary Mirror Assembly (SMA), Secondary Mirror Support Tubes (SMST)
  - Minimize radial and diametrical gradients near PMA
  - Independent prime, redundant, and survival heaters
  - Control telemetry for each heater zone
  - Prime & redundant for computer-based control
  - Autonomous hybrid heater controllers (HHC) for survival
  - OBA heater control located on door mechanism only
  - MLI on FMS, SMA, OBA OD, SMST surfaces away from PM

<table>
<thead>
<tr>
<th>Heater Location</th>
<th># of Zones</th>
<th>Capacity (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS</td>
<td>24</td>
<td>102</td>
</tr>
<tr>
<td>FMS</td>
<td>21</td>
<td>100</td>
</tr>
<tr>
<td>SMST</td>
<td>12</td>
<td>106</td>
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<tr>
<td>SMA</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>

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Hybrid Laminates with low CTE, low CME, and high modulus *(patented)*

- 0 CTE (0.0 ± 0.1 µin/in°F) in all inplane directions

Cyanate Siloxane Resin with low moisture uptake *(ITT/Hexcel development)*

Hygro strain < 15 µin/in

Invar Fittings where required for stability

- CTE: < 0.4 µin/in°F
- Temporal Stability (Invar growth): < 2 ± 1 µin/in/yr

Neat Resin Equilibrium at 50%RH

<table>
<thead>
<tr>
<th>% Moisture</th>
<th>Time</th>
</tr>
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<tbody>
<tr>
<td>Epoxy</td>
<td>√t1</td>
</tr>
<tr>
<td>Cyanate Ester</td>
<td>√t1*14</td>
</tr>
<tr>
<td>Cyanate Siloxane</td>
<td>√t1*14</td>
</tr>
</tbody>
</table>
**Thermal Operating Considerations**

- Telescope system was designed to operate around 293K (Room Temperature)
  - Does not require requalification for warm launch
- Various material considerations influence using the system at colder temperatures
  - **Mirror Materials**
    - Corning ULE™ is optimized for room temperature applications
    - ULE™ has been tested at 20K with degraded CTE characteristics
  - **Structures**
    - Laminate also optimized for room temperature use
    - CTE characteristics degrade slowly so some level of off-nominal conditions would be acceptable
  - **Bonding Materials**
    - GE RTV-566 used to attach mirrors to mounts would need qualification at off-nominal temperatures
  - **Mechanisms**
    - Precision mechanisms would be a concern

<table>
<thead>
<tr>
<th>OPERATING TEMPERATURE (K)</th>
<th>LOW RISK</th>
<th>MINOR RISK</th>
<th>MAJOR REWORK</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>Minor Mat’l Testing</td>
<td>Refigure Mirrors/Qual Composites &amp; Adhesives/Modify some mechanisms</td>
<td>Major redesign of system</td>
</tr>
<tr>
<td>275</td>
<td>250</td>
<td>225</td>
<td>150</td>
</tr>
</tbody>
</table>

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Summary

- Telescope system designed for room temperature operation
  - Off optimal thermal configuration is possible with some level of analysis and retest
  - We do not recommend operating temperatures below 200K due to numerous material, electronic, and optical considerations
- Some minor rework on the telescope is very low risk
  - Telescopes were designed to be taken apart and refurbished
  - Ion figuring and recoating would be considered very low risk for example
- Instrument section is the most doubtful of the configuration
  - Aluminum and heavy
  - Designed for a specific instrument accommodation
  - Not a cost driver to replace with a better form factor
- Outer Barrel Assembly is probably shorter than desired for NASA mission
  - Extension and repositioning is low cost and low risk
- Point of Contact
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