A Future Large-Aperture UVOIR Space Observatory: Reference Designs

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NASA Goddard Space Flight Center
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SPIE Optical Engineering + Applications Symposium
Broad Consensus -
Large Telescope Aperture Enables Breakthrough Science

- **ATLAST** – Advanced Technology Large Aperture Space Telescope
  - Proposals submitted to 2010 NRC Decadal Survey
  - GSFC, MSFC, JPL, STScI
    - 8m monolith, 9.2m deployed, 16m deployed
    - 2010 Decadal Survey elevated technology investment for a mission to search for exo-Earths as its highest-priority “Medium Activity” for the decade

- **LUVOIR** – Large Ultraviolet Optical Infra-Red telescope
  - NASA’s 30-year vision for astrophysics
    - Enduring Quests, Daring Visions
    - Highlighted a Large UV/Optical/IR observatory as a priority mission for the 2020s.

- **HDST** – High Definition Space Telescope
  - Associated Universities for Research in Astronomy (AURA)
  - Report - From Cosmic Birth to Living Earth
The Advanced Technology Large-Aperture Telescope (ATLAST)
The Next Great Leap In Astrophysics

A powerful, general-purpose non-cryogenic observatory operating from 0.1 µm to 1.8+ µm.

Detection of Biosignatures in Habitable Zone Planets

Breakthrough in UVOIR Resolution and Sensitivity throughout the Universe

Tracing the History of Star Formation in all Types of Galaxies up to 10 Mpc

Resolve 100 pc Star-Forming Regions Everywhere in the Universe
## ATLAST Telescope Parameter Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Stretch Goal</th>
<th>Traceability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Mirror Aperture</td>
<td>≥ 8 meters</td>
<td>12 meters</td>
<td>Resolution, Sensitivity, Exoplanet Yield</td>
</tr>
<tr>
<td>Telescope Temperature</td>
<td>273 K – 293 K</td>
<td>-</td>
<td>Thermal Stability, Integration &amp; Test, Contamination, IR Sensitivity</td>
</tr>
<tr>
<td>Wavelength Coverage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>100 nm– 300 nm</td>
<td>90 nm – 300 nm</td>
<td></td>
</tr>
<tr>
<td>Visible</td>
<td>300 nm – 950 nm</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>NIR</td>
<td>950 nm – 1.8 µm</td>
<td>950 nm – 2.5 µm</td>
<td></td>
</tr>
<tr>
<td>MIR</td>
<td>-</td>
<td>Sensitivity to 5.0 µm under evaluation</td>
<td>Transit Spectroscopy</td>
</tr>
<tr>
<td>Image Quality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UV</td>
<td>&lt; 0.20 arcsec at 150 nm</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Vis/NIR/MIR</td>
<td>Diffraction-limited at 500 nm</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Stray Light</td>
<td>Zodi-limited between 400 nm – 1.8 µm</td>
<td>Zodi-limited between 200 nm – 2.5 µm</td>
<td>Exoplanet Imaging &amp; Spectroscopy SNR</td>
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<tr>
<td>Wavefront Error Stability</td>
<td>~ 10 pm RMS uncorrected system WFE per control step</td>
<td>-</td>
<td>Starlight Suppression via Internal Coronagraph</td>
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<tr>
<td>Pointing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spacecraft</td>
<td>≤ 1 milli-arcsec</td>
<td>-</td>
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<tr>
<td>Coronagraph</td>
<td>&lt; 0.4 milli-arcsec</td>
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<tr>
<td>Science Instrument</td>
<td>Parameter</td>
<td>Requirement</td>
<td>Stretch Goal</td>
</tr>
<tr>
<td>------------------------------------</td>
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<td>----------------------</td>
</tr>
<tr>
<td>UV Multi-Object Spectrograph</td>
<td>Wavelength Range</td>
<td>100 nm – 300 nm</td>
<td>90 nm – 300 nm</td>
</tr>
<tr>
<td></td>
<td>Field-of-View</td>
<td>1 – 2 arcmin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spectral Resolution</td>
<td>R = 20,000 – 300,000 (selectable)</td>
<td></td>
</tr>
<tr>
<td>Visible-NIR Imager</td>
<td>Wavelength Range</td>
<td>300 nm – 1.8 µm</td>
<td>300 nm – 2.5 µm</td>
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<tr>
<td></td>
<td>Field-of-View</td>
<td>4 – 8 arcmin</td>
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</tr>
<tr>
<td></td>
<td>Image Resolution</td>
<td>Nyquist sampled at 500 nm</td>
<td></td>
</tr>
<tr>
<td>Visible-NIR Spectrograph</td>
<td>Wavelength Range</td>
<td>300 nm – 1.8 µm</td>
<td>300 nm – 2.5 µm</td>
</tr>
<tr>
<td></td>
<td>Field-of-View</td>
<td>3 – 4 arcmin</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spectral Resolution</td>
<td>R = 100 – 10,000 (selectable)</td>
<td></td>
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<tr>
<td>MIR Imager / Spectrograph</td>
<td>Wavelength Range</td>
<td>2.5 µm – 8 µm</td>
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<tr>
<td></td>
<td>Field-of-View</td>
<td>3 – 4 arcmin</td>
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</tr>
<tr>
<td></td>
<td>Image Resolution</td>
<td>Nyquist sampled at 3 µm</td>
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</tr>
<tr>
<td></td>
<td>Spectral Resolution</td>
<td>R = 5 – 500 (selectable)</td>
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<tr>
<td>Starlight Suppression System</td>
<td>Wavelength Range</td>
<td>400 nm – 1.8 µm</td>
<td>200 nm – 2.5 µm</td>
</tr>
<tr>
<td></td>
<td>Raw Contrast</td>
<td>1×10^{-10}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contrast Stability</td>
<td>1×10^{-11} over integration</td>
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<td></td>
<td>Inner-working angle</td>
<td>34 milli-arcsec @ 1 µm</td>
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</tr>
<tr>
<td></td>
<td>Outer-working angle</td>
<td>&gt; 0.5 arcsec @ 1 µm</td>
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<tr>
<td>Multi-Band Exoplanet Imager</td>
<td>Field-of-View</td>
<td>~0.5 arcsec</td>
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</tr>
<tr>
<td></td>
<td>Resolution</td>
<td>Nyquist sampled at 500 nm</td>
<td></td>
</tr>
<tr>
<td>Exoplanet Spectrograph</td>
<td>Field-of-View</td>
<td>~0.5 arcsec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resolution</td>
<td>R = 70 – 500 (selectable)</td>
<td></td>
</tr>
</tbody>
</table>
# Launch Vehicle Capabilities

## Approximate Mass to Sun-Earth L2 Orbit in Thousands of kg

<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>Approximate Mass (in Thousands of kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falcon 9 v1.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Atlas V (551)</td>
<td>6.1</td>
</tr>
<tr>
<td>Ariane</td>
<td>6.6</td>
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<tr>
<td>Delta IV H</td>
<td>9.8</td>
</tr>
<tr>
<td>Falcon H</td>
<td>14</td>
</tr>
<tr>
<td>SLS Block 1</td>
<td>25</td>
</tr>
<tr>
<td>SLS Block 1B</td>
<td>36</td>
</tr>
<tr>
<td>SLS Block 2B</td>
<td>50</td>
</tr>
</tbody>
</table>

### Delta IV H

C3 = 0.5 (km²/sec²)

## Fairing Diameters (m)

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<tr>
<th>Launch Vehicle</th>
<th>Fairing Diameter (m)</th>
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<tbody>
<tr>
<td>Falcon 9 v1.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Atlas V (551)</td>
<td>5</td>
</tr>
<tr>
<td>Ariane</td>
<td>4.57</td>
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<tr>
<td>Delta IV H</td>
<td>4.57</td>
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<tr>
<td>Falcon H</td>
<td>5.2</td>
</tr>
<tr>
<td>SLS Block 1</td>
<td>5</td>
</tr>
<tr>
<td>SLS Block 1B</td>
<td>8.4</td>
</tr>
<tr>
<td>SLS Block 2B</td>
<td>10</td>
</tr>
</tbody>
</table>

### ATLAST Candidates

ATLAST is compatible with:
- Delta IV Heavy
- Falcon Heavy
- SLS

ATLAST and SLS engineer-to-engineer conceptual interface development meetings underway

Multiple vehicle candidates mitigate risks and associated costs
ATLAST System Formulation

- Role of Conceptual Design
  - Derive and validate requirements
  - Enable balanced, cost effective, end to end system
Engineering Design Reference Missions (EDRM)s

- Key design driver - Coronagraphy of exo-planets
- Multiple simultaneous science parameters
  - IWA, throughput, band pass, contrast, survey integration time, aperture, yield
  - WFE stability
    - Mechanical dynamics, jitter
    - Thermal stability
- Analyze engineering design trade space in depth and detail
  - Identify stressing requirements
  - Identify opportunities for margin against requirements
- Enable implementation trade studies to formulate most effective, well balanced, and lowest risk designs.
SLS, Block II 10m Fairing Enabled EDRMs

Stahl et al., SLS - launched missions concept studies for LUVOIR Mission

- 8-m monolith EDRM
  - Submitted to 2010 Decadal Survey
  - Largest possible monolith for space application

- 12.7 m deployed EDRM
  - Central monolith, deployed petals
  - Leverages depth in axis of primary mirror for mechanical stability
Scalable Segmented EDRM

36 JWST-Size Segments (Glass or SiC, Heater Plates)

Deployable Baffle

Serviceable Instruments are Externally Accessible

9.2 m Aperture

Actively controlled SM 6-dof control metrology to SI

Telescope Isolated from SC - 6-dof magnetic isolation - Signal and power fully isolated

Three-layer sunshield, Constant angle to sun, warm, stable sink Sunshield deployed from below using four booms

Pointing gimbal maintains constant sun angle; Single pointing axis enhances stiffness
Mechanical Dynamic Stability

- 3 deployable mirror “wings” on each side of central strip
- Design for stiffness
- Iteration and optimization

5m fairing packaging

Backplane Design

Modal Analysis

Axial View in Fairing
Jitter Stability

- Initiation of integrated modelling process - preliminary analysis
- Single RWA worst case forcing function
- No model uncertainty factor (MUF)
- Includes model of contact-free isolation system – 4 decades of isolation

Future improvements - Include gimbal and telescope pointing boom, MUF
Thermal Stability

• Preliminary analysis focused on feasibility of achieving picometer wave front error on individual mirror segment

• Eisenhower, Park, et al. “ATLAST ULE Mirror Segment Performance Analytical Predictions Based on Thermally Induced Distortions”
  – Analysis on a mirror segment with a high precision active heater control

• Initial results are encouraging
  – Future plans extend analysis to include the backplane
Cost Control

• Fundamental mission priorities:
  – Deliver revolutionary science that unites the science community
  – Control cost and cost uncertainty

• Develop technologies early
  – Robust technology development plan already in place
    • Bolcar et al., Technology development for the Advanced Technology Large Aperture Space Telescope (ATLAST) as a candidate large UV-Optical-Infrared (LUVOIR) surveyor
      – Actively pursuing early funding for key technologies

• Non-cryogenic telescope

• Focus on TRL-9 implementations unless mission enabling
Cost Control

• Scalable Segmented EDRM
  – Compatibility with multiple launch vehicles and fairing configurations
  – Departs from an extrapolation of previous segmented telescopes

• Parallelization of telescope schedule
• Economies of scale
• High technology readiness, existing facilities and MGSE
• Designs, hardware, mechanisms, personnel, ground support equipment, facilities, and experience with JWST