ATLAST and JWST Segmented Telescope Design Considerations

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Contributions from ATLAST Team (GSFC, MSFC, JPL, StScI, SAO)
General Approach taken since 2009

- To the extent it makes sense, leverage JWST knowledge, designs, architectures, GSE
  - Good starting point
  - Develop a full end to end architecture that closes
  - Try to avoid recreating the wheel except where needed
  - Optimize from there (mainly for stability and coronagraphy)

- Develop a scalable design reference mission (9.2 meter)
  - Do just enough work to understand launch break points in aperture size

- Demonstrate 10 pm stability is achievable on a design reference mission
  - A really key design driver is the most robust stability possible!!!

- Make design compatible with starshades

- While segmented coronagraphs with high throughput and large bandpasses are important, make the system serviceable so you can evolve the instruments

- Keep it room temperature to minimize the costs associated with cryo
  - Focus resources on the contrast problem

- Start with the architecture and connect it to the technology needs
### General ATLAST Requirements

<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>≥8.0 meters</td>
<td>&gt;12.0 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 UV</td>
<td>100 nm – 300 nm</td>
<td>90 nm – 300 nm</td>
<td></td>
</tr>
<tr>
<td>Wavelength Coverage Visible</td>
<td>300 nm – 950 nm</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Wavelength Coverage NIR</td>
<td>950 nm – 1.8 µm</td>
<td>950 nm – 2.5 µm</td>
<td></td>
</tr>
<tr>
<td>Wavelength Coverage MIR</td>
<td>Sensitivity to 8.0 µm**</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Image Quality 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>
</tr>
<tr>
<td>Wavefront Error Stability</td>
<td>~10 pm RMS uncorrected system WFE per wavefront control step</td>
<td>-</td>
<td>Starlight Suppression via Internal Coronagraph</td>
</tr>
<tr>
<td>Pointing Spacecraft</td>
<td>≤1 milli-arcsec</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Coronagraph</td>
<td>&lt;0.4 milli-arcsec</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

| Science Instrument            | Parameter                      | Requirement                     |
| UV Multi-Object Spectrograph  | Wavelength Range               | 100 nm – 300 nm                 |
|                               | Field-of-View                   | 1 – 2 arcmin                    |
|                               | Spectral Resolution             | R = 20,000 – 300,000 (selectable) |
| Visible-NIR Imager            | Wavelength Range               | 300 nm – 1.8 µm                 |
|                               | Field-of-View                   | 4 – 8 arcmin                    |
|                               | Image Resolution                | Nyquist sampled at 500 nm       |
| Visible-NIR Spectrograph      | Wavelength Range               | 300 nm – 1.8 µm                 |
|                               | Field-of-View                   | 4 – 8 arcmin                    |
|                               | Spectral Resolution             | R = 100 – 10,000 (selectable)   |
| MIR Imager / Spectrograph     | Wavelength Range               | 1.8 µm – 8 µm                   |
|                               | Field-of-View                   | 3 – 4 arcmin                    |
|                               | Image Resolution                | Nyquist sampled at 3 µm         |
|                               | Spectral Resolution             | R = 5 – 500 (selectable)        |
| Starlight Suppression System  | Wavelength Range               | 400 nm – 1.8 µm                 |
|                               | Raw Contrast                    | 1×10⁻¹⁰                        |
|                               | Contrast Stability              | 1×10⁻¹¹ over science observation |
|                               | Inner-working angle             | 34 milli-arcsec @ 1 µm          |
|                               | Outer-working angle             | >0.5 arcsec @ 1 µm              |
| Multi-Band Exoplanet Imager   | Field-of-View                   | 0.5 arcsec                      |
|                               | Resolution                      | Nyquist sampled at 500 nm       |
| Exoplanet Spectrograph        | Field-of-View                   | 0.5 arcsec                      |
|                               | Resolution                      | R = 70 – 500 (selectable)       |

Rioux, et al, 2016, SPIE/JATIS, in review
Aperture Sizes Studies since 2009
Using JWST Hex Segment Architectures

- 9.2m in Delta IVH: Circular Geometry JWST SM deployment, 3 JWST-wings per side
- 11.9m in Delta IVH Clamshell SMSS
- 12m is SLS, Dual Fold Wing
- 18m is Block 2 SLS, 16m deemed feasible

Figure 2: Notional 20m Telescope Robot/Astronaut Installation in Panels
20m Assembled
Mass Considerations

Approximate Launch Mass to Sun-Earth L2 Orbit (C3 = -0.5 km²/sec²)

Representative Launch Vehicle Fairing Diameters (meters)
Scalable Segmented Design Reference Mission

- 36 JWST-Size Segments
- 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
  - Near Zero-Q over Field of Regard
- Deployable Baffle
- Serviceable Instruments are Externally Accessible
- 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
- Stowed Configuration

90 degree pitch plus roll
## Multi-layer stability approach:
**Add layers based on performance and cost**

<table>
<thead>
<tr>
<th>Layer 1: Minimum observatory (active heater, non-contact isolation)</th>
<th>Layer 2: Use internal coronagraph sensing and control methods</th>
<th>Layer 3: Use telescope metrology systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Segment Thermal Stability</strong></td>
<td>Low Q architecture, Active PM heater control, material choice</td>
<td>Zernike Sensor with continuous DM control</td>
</tr>
<tr>
<td><strong>Segment to Segment Thermal Stability</strong></td>
<td>Active heater and MLI control, material choice, joint design</td>
<td>Zernike Sensor with Continuous or Segmented DM control (piston, tip/tilt), Use bright star (reduce 10 minute update rates)</td>
</tr>
<tr>
<td><strong>Segment Dynamics Stability</strong></td>
<td>Stiffness and Design, Possibly smaller segments, materials</td>
<td></td>
</tr>
<tr>
<td><strong>Segment to Segment Dynamic Stability</strong></td>
<td>Reaction Wheel isolators, Non-contact Isolation between SC and telescope, Design, TMD's (if needed), material choice</td>
<td>Zernike Sensor, Feed forward DM control, Use bright star (reduce update rate)</td>
</tr>
<tr>
<td><strong>Line of Sight/SM Thermal Stability</strong></td>
<td>Low Q architecture, Heater</td>
<td>LOS sensor and control mirror, MIMF for SM alignment</td>
</tr>
<tr>
<td><strong>Line of Sight/SM Dynamic Stability</strong></td>
<td>Reaction wheel isolators, Non-contact isolation, Design, TMD (if needed)</td>
<td>LOS sensor and control with feed forward control</td>
</tr>
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</table>
Notional End to End Architecture?

12-meter telescope:
1.98 m Tip-to-tip
1.71 m flat-to-flat, stiff

12m diameter
PM to SM spacing: 13m
SM obscuration is 19.5% area
Design for 8x12 arcminutes
TMA
Coronagraph uses PM-SM

Stability:
Backplane motions removed with Segmented DM (speed?)
Segments Stable

Segmented Coronagraph Channels
- Band 1
  - S Pol
  - P Pol

Segmented Coronagraph Channels
- Band 2
  - S Pol
  - P Pol

Segmented Coronagraph Channels
- Band 3
  - S Pol
  - P Pol

Out of band Sensor

PIAA CMC, APLC, VNC/POVNC, Vector Vortex, etc
Defeatable Mirrors
Lyot Stops
Masks
Rejected starlight LOWFS

Deformable Mirrors
Lyot Stops
Masks
Rejected starlight LOWFS

Laser
Truss for SM

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Backplane motions removed with Segmented DM (speed?)
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Mirror stability demonstrated

AMSD: Lightweight Closed Back ULE Heritage

- See paper by M. Eisenhower/SAO on mirror thermal control architecture
  - Next generation ULE 1.2m flat to flat, 12Kg mass
- Single segment design is optimized for high thermal and dynamic stability (each segment is like a smallish ExoC or TPFC mirror)
- Mass production is similar to TMT, multiple parallel lines
- Silicon Carbide and Zerodur also assessed and each has advantages, expect mirror material trade in the future
Integrated Modeling Results

• Based on published non-contact isolation values, passive reaction wheel isolation

• Caveats:
  • Results include NO MUF and damping knock-down factor.
  • Mechanical and finite element models are at preliminary stages of development.
  • All isolation systems are implemented as idealized analytical filters.
  • Assumes system behaves linearly down to picometer scale (plan to validate this at joint/interface level, Ultra-Stable technology effort underway)

Total WFE: Vibe+RW Isolators, 1” Strut

LOS Results: Vibe+RW Isolators
Mirror dynamics and deformations

- Mirrors will have tilt modes that dominate WFE along with deformation modes
  - Deformations also result from tilts (induced by the inertia), see below
- One path to minimizing mirror tilt and mirror deformation is to minimize the tilts using isolation – initial modeling of tilts using traditional linear models is promising but hard to verify full scale at the picometer level
- A more robust solution and simpler verification strategy for mirror tilt is an active control loop between segment edge sensors and a segmented DM. In this approach, larger tilts can be tolerated but only if they do not deform the mirror.
- See induced deformation (see “nanometer characterization of the JWST optomechanical systems using high-speed interferometry", Saif et al, Applied Optics May 1st 2015 Vol 54, No. 13")
Changes in Consideration

• Narrower struts
  • Already included in modeling (1” wide)
  • Initial results promising but needs more vetting

• Alternative strut geometries
  • The 12m in an SLS Block 1A or 2 has plenty of volume to accommodate this
  • Need to carefully assess heritage and 1-G deployment and integration
  • We’ll see if this is a differentiator in the SCD modeling

• Even stiffer mirrors
  • Requires slightly deeper mirrors
  • Minimize gravity error (and thus uncertainty on gravity) – very tight requirement of about 2nm RMS surface!
  • Conceptually: Remove large scale backplane changes actively, make very, very stable mirrors (thermal, dynamics, lurch)
Large Aperture UVOIR Telescope Can leverage JWST Technology and Design Heritage
Large Aperture UVOIR Telescope Can Leverage JWST Integration and Testing
Conclusion

• A scalable segmented telescope architecture that achieves high stability continues to evolve

• JWST segment geometry and size has given us a good starting point for a reference design
  • Continue to evaluate improvements like strut size on a case by case basis

• Some key technologies that enable this:
  • High contrast segmented coronagraphs
  • Low power picometer edge sensors
  • Picometer class Segmented DM’s
  • Lower cost picometer DM’s that can be made using economies of scale (including electronics and hybridizations)
  • Ultra-stable structures and latches (note: metrology to characterize these is being funded)
  • Optical components for high contrast (dichroics, beamsplitters, polarization)
  • Picometer stable mirrors (milli-Kelvin class thermal control)
  • Low power laser truss for secondary mirror