UVOIR Space Astronomy for the Coming Decades

# The Advanced Technology Large-Aperture Space Telescope (ATLAST)

## Technology Roadmap


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Mirror Technology Days 2014

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# Key Messages

- Identified Technology Gaps and Priorities
- Open discussion with Tech Mirror Days community to provide input to technology roadmap and to explore opportunities for technology development

***Demonstrate readiness of key technologies by Astrophysics 2020 Decadal Survey so ATLAST mission concept will begin development in 2020s***

***(Five year plan: FY15 to FY19)***

# Science Requirements Flow-Down to Telescope and Instruments

**Telescope Design Parameters**

| Telescope Parameter | Consensus Requirement |
|---|---|
| Primary Mirror Aperture | ≥ 8 meters |
| Primary Mirror Temperature | ~20 C, pending detailed thermal design |
| UV Coverage | 100 nm (90 nm goal) – 300 nm |
| Vis/NIR Coverage | 300 nm – 2500 nm |
| Mid-IR Coverage | Under evaluation to ~ 8000 nm |
| Vis/NIR Image Quality | Diffraction-limited performance at 500 nm |
| Stray Light | Zodi-limited in 400 nm – 2000 nm wavelengths |
| Wavefront Error Stability for Exoplanet Imaging Using an Internal Coronagraph | 1 x $10^{-10}$ system contrast<br>< 10 pm rms residual system WFE for < 10 min<br>bandpass between λ/D and 10λ/D |

**Notional Science Instruments Design Parameters**

| Science Instrument Parameter | Consensus Requirement |
|---|---|
| UV Imager | 100 nm (90 nm goal) – 300 nm<br>FOV = 1 – 2 arcmin |
| UV Spectrograph | 100 nm (90 nm goal) – 300 nm<br>R = 20,000 – 300,000, multiple modes<br>FOV = 1 – 2 arcmin<br>Multi-object spectroscopy capability |
| Vis/NIR Imager | 300 – 2500 nm<br>FOV = 4 – 8 arcmin<br>Nyquist sampled at 500 nm |
| Vis/NIR Spectrograph | 300 – 2500 nm<br>R = 100, 500, 2000<br>FOV = 3 – 4 arcmin |
| Starlight Suppression System | $10^{-10}$ contrast (raw)<br>$10^{-11}$ contrast stability over several days<br>Inner working angle of ~ 40 mas |
| Exoplanet Imager | Near-UV and Visible channel<br>FOV~ 10 arcsec |
| Exoplanet Spectrograph | 300 – 2500 nm<br>R = 70, 500<br>FOV ~ 1 arcsec |

***NB:*** Mid-IR instrument TBD pending performance assessment

# Driving Capabilities

Faint/Distant Objects → Sensitivity; Resolution → Aperture

(D$^4$) ($\lambda$/D) ($\lambda$; D)

Starlight Suppression (High Contrast) → WFE → Mechanical, Thermal Stability

| Driving Capability | Need | Comparison to Current or Planned Space Missions |
|---|---|---|
| Sensitivity<br>Resolution | 10 m aperture | 300x HST, 6x JWST<br>4x HST, 6x JWST |
| Starlight Suppression (Contrast) | $10^{-10}$ | 10 – 100x WFIRST-AFTA |
| Wavefront Error Stability (WFE) (Using Internal Coronagraph) | 10 pm over 10 min | 1000x JWST |

# Technology Gap Areas

## Enabling Technologies

Starlight Suppression System

Vibration Isolation and Control System

Lightweight Mirror Segment

## Enhancing Technologies

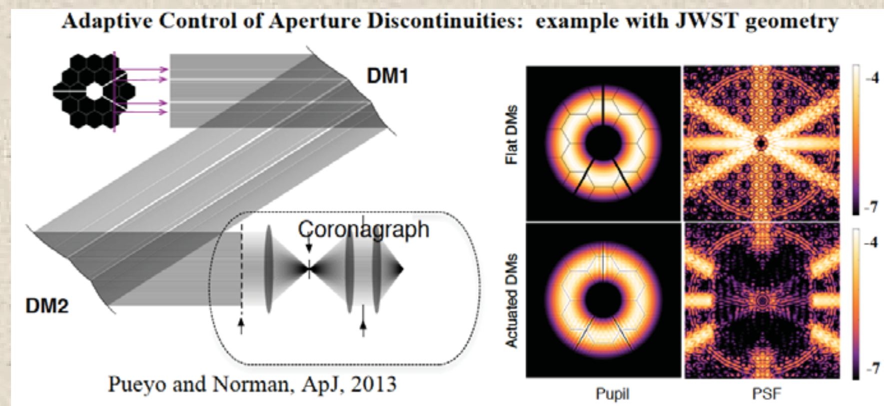
Detectors

Mirror Coatings

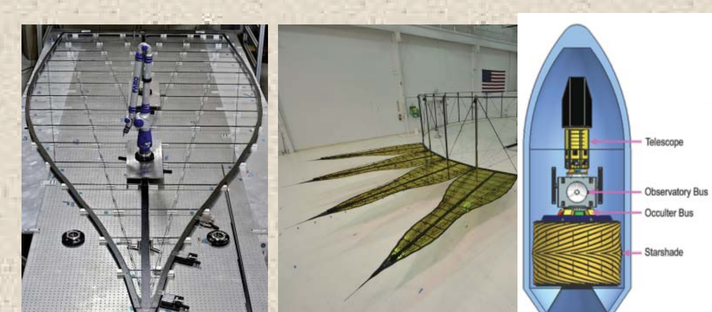
# Starlight Suppression System

- Key Challenges
  - $10^{-10}$ raw image contrast; $10^{-11}$ contrast stability
  - Compatible with segmented aperture geometry
  - 40 mas inner working angle
  - Broad Bandpass

- Approach
  - Develop both internal coronagraph and starshade
  - Identify technologies that relax stability requirements on telescope
  - Test coronagraphs on a vacuum segmented-aperture testbed




Coronagraph




Starshade

# Starlight Suppression System: Key Metrics/Need/SOA/TRL

| Technology | Key Metrics | Need | State of the Art | TRL |
|---|---|---|---|---|
| **Lightweight Mirror Segment** | Aperture Diameter (m) | ≥ 8 | 6.5 (JWST)<br>2.4 (HST) | 4 - 6 |
| | Areal Density ($kg/m^2$) | < 36 (EELV)<br>< 500 (SLS) | 70 (JWST)<br>460 (HST) | |
| | Areal Cost ($\$M/m^2$) | < 2 | 12 (JWST) | |
| | Surface Figure Error (nm rms) | < 7 | < 7 (HST)<br>25 (JWST) | |
| | Mechanical WFE Stability (pm rms/10 min) | < 7 | 50 nm/14 days (JWST) | |
| | Thermal WFE Stability (pm rms/10 min) | < 7 | 50 nm/14 days (JWST) | |
| | Areal Cost | < $\$2M/m^2$ | ~ $\$6M/m^2$ (JWST)<br>~ $\$12M/m^2$ (HST) | |
| | Areal Production Rate | > 10 $m^2$/year | ~ 4 $m^2$/yr (JWST)<br>~ 1 $m^2$/yr (HST) | |

# Vibration Isolation and Control System

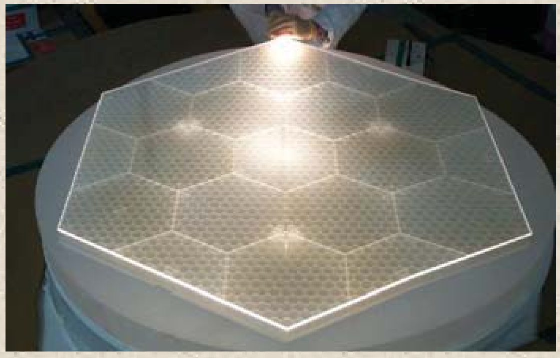
- Key Challenges
  - System wavefront stability < 10 pm over 10 min
  - Line-of-sight pointing stability < 1.0 milliarcsec
  - Total system vibration isolation of 140 dB (assuming JWST-like scaling)
  - Vibration-isolated mass of 5000 kg or more

- Approach
  - Develop system-integrated vibration isolation and control technologies
  - Establish capability to model/test vibration effects on segmented mirrors
  - Close partnership with industry

| Technology | Sub Areas | Key Metrics | Need | State of the Art | TRL |
|---|---|---|---|---|---|
| **Vibration Isolation and Control System** | Reaction wheels<br>Active Isolation System<br>Passive Isolation System | Attenuation > 40 Hz (dB) | 140 | 80 | 5 |

# Lightweight Mirror Segment

- Key Challenges
  - Diffraction-limited optical quality
  - Wavefront stability to 10 pm per 10 min
  - UV compatibility (microroughness, contamination)
  - Low cost, low mass, and rapid fabrication
- Approach
  - Optical system design and modeling
  - Segmented mirror system development
  - Active thermal control for stability
  - System-level vibration damping and isolation
  - High-precision actuation



*MMSD Lightweight ULE Segment Substrate*


*AHM SiC-based Segment Substrate*

# Lightweight Mirror Segment: Key Metrics/Need/SOA/TRL

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| | Areal Production Rate | > 10 $m^2$/year | ~ 4 $m^2$/yr (JWST)<br>~ 1 $m^2$/yr (HST) | |

# Detectors

- Key Challenges
  - Visible-blind, high quantum efficiency (> 50%) UV arrays
  - Photon counting Visible and NIR arrays
    - Coronagraphic spectroscopy for biosignature characterization
      - Read noise < 1 e- and dark current < 0.004 e-/s/pix
    - Starlight wavefront sensing and control
  - Deep full wells with low persistence and radiation tolerance to enable transit imaging and spectroscopy at all wavelengths
- Approach
  - Parallel development on a family of detectors: UV/Vis/NIR
  - Build on detector accomplishments of HST, JWST, and WFIRST-AFTA
  - Encourage innovative partnerships (university/industry/government)

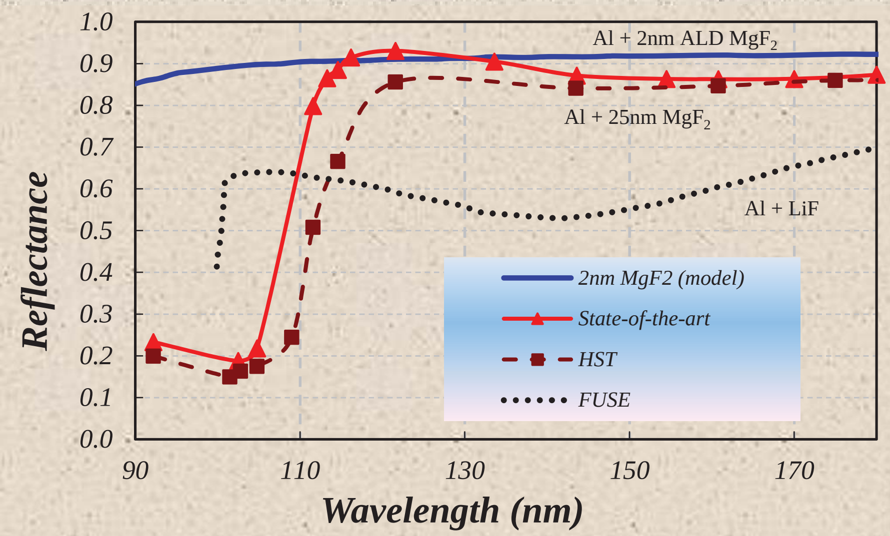
# Detectors:
# Key Metrics/Need/SOA/TRL

| Technology | Sub Areas | Key Metrics | Need | State of the Art | TRL |
|---|---|---|---|---|---|
| Detectors | UV (Visible Blind) | QE (%) | > 50 | 5 - 20 | 3 - 4 |
| | | Noise (elect rms) | < 5 | < 5 | |
| | | Format (Mpixel) | 4 | 1 | |
| | Vis/NIR | QE (%) | > 80 | > 80 | |
| | | Noise (elect rms) | < 5 | < 5 | |
| | | Format (Mpixel) | 16 | 16 | |
| | | Radiation Tolerance | Rad hard at L2 | Visible CCDs not rad hard at L2 | |
| | Photon Counting Vis/NIR | QE (%) | > 80 | > 60 (Visible only) | |
| | | Read Noise (elect rms)<br>Dark Current (e/s/pixel) | < 1<br><0.004 | EMCCDs have been used to count photons in the visible. Reducing clock induced charge would be beneficial.<br><br>HgCdTe arrays have been used to count photons at much higher dark count rates | |
| | | Format (Mpixel) | 4 | 1 | |

# Mirror Coatings

- Key Challenges
  - High reflectivity (> 90%) coatings to support starlight suppression and high-throughput UV observations
  - High uniformity (< 1%); large spectral range; low polarization (< 1%)
  - Scaling up coatings to large diameter (meters) mirror substrates

- Approach
  - Develop conventional technologies such as physical vapor deposition
  - Develop new coating technologies such as atomic layer deposition (ALD)



# Mirror Coatings:
# Key Metrics/Need/SOA/TRL

| Technology | Key Metrics | Need | State of the Art | TRL |
|---|---|---|---|---|
| Mirror Coatings | Wavelength (nm) | 90 - 2500 | 90 - 2500 | 3 - 4 |
| | Reflectivity (%) | > 90 | < 50; 90 – 120 nm<br>~ 85; 120 – 300 nm<br>> 90; 300 – 2500 nm | |
| | Uniformity (%) | < 1 | 2 | |
| | Polarization (%) | < 1 | 1 | |

See study team member presentations on Thursday – Optical Coating Technology:

- Bala (JPL): FUV to NIR mirror coatings development status
- Quijada (GSFC): Recent Progress on 2012 SAT for UVOIR Coatings

# Traceable to Cosmic Origins (COR) and Exoplanet Exploration (ExEP) Program Office Technology Gap Needs

| Technology Gap | Astrophysics Program Office | Past or Current Funding |
|---|---|---|
| Coronagraph | ExEP | X |
| Starshade | ExEP | X |
| Affordable, lightweight, large-aperture telescopes | COR | X |
| Sensing and control at the nanometer level or better | COR | |
| High-reflectivity mirror coatings for the UV/Vis/IR | COR | X |
| High-QE, large format UV detectors | COR | X |
| Very-large-format, high QE, low-noise, radiation tolerant detectors for the UV/Vis/IR | COR | X |
| Photon-counting visible and NIR detector arrays | ExEP, COR | X |

http://cor.gsfc.nasa.gov/docs/2014_COR_PATR.pdf

http://exep.jpl.nasa.gov/technology/http://exep.jpl.nasa.gov/technology/

# Connections to FY 15 SBIR Subtopics

| Subtopic # | Subtopic Title |
|---|---|
| S2.01 | Proximity Glare Suppression for Astronomical Coronagraphy |
| S2.02 | Precision Deployable Optical Structures and Metrology |
| S2.03 | Advanced Optical Systems and Fabrication/Testing/Control Technologies |
| S2.04 | X-ray Mirror Systems, Coating Technology for X-ray to UVOIR, and Free-Form Optics |
| S5.04 | Integrated Science Mission Modeling |
| S1.03 | Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter |
| S1.04 | Detector Technologies for UV, X-ray, Gamma-Ray and Cosmic-Ray Instruments |

# Path Forward

- Develop more detailed technology roadmap and technology investment plan for reference mission architectures
- Broaden input and collaboration with technical community

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# References

- **Science Drivers**


  - Postman et al., *Opt. Eng*. 51(1), 011007 (Jan 20, 2012). doi:10.1117/1.OE.51.1.011007


- **Telescope and Instrument Suites**


  - Stahl et al., *Proc. SPIE* 7731, Space Telescopes and Instrumentation 2010: Optical, Infrared, and Millimeter Wave, 77312N (August 09, 2010); doi:10.1117/12.856256
  - Feinberg et al., *Proc. SPIE* 9143, Space Telescopes and Instrumentation 2014: Optical, Infrared, and Millimeter Wave, 914316 (August 2, 2014); doi:10.1117/12.2054915
  - Redding et al., *Proc. SPIE* 9143, Space Telescopes and Instrumentation 2014: Optical, Infrared, and Millimeter Wave, 914333 (August 2, 2014)