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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

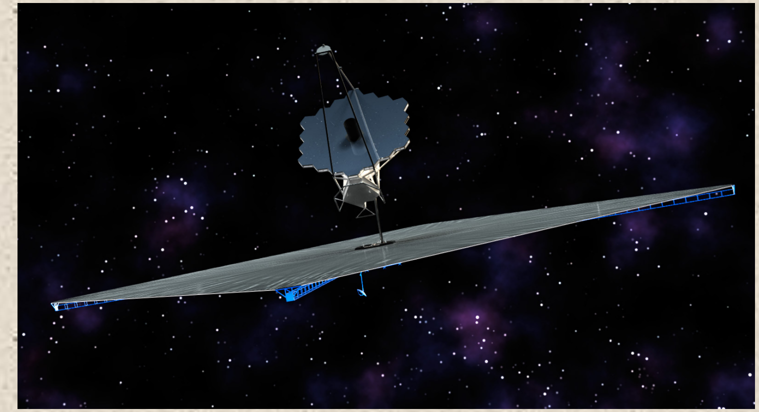
(Five year plan: FY15 to FY19)

ATLAST Mission Concept Summary

- Driving requirements
  - Large aperture: a *10 meter-class space telescope*
  - UV to NIR with a wide range of notional instrumentation
  - Diffraction limited, with outstanding wavefront stability
  - High contrast imaging and spectroscopy

Approach: Build on experience

- Segmented architecture using technologies developed by NASA and others
- JWST deployment system, WF sensing and control – but no cryogenic systems
- Serviceable on orbit



Science Requirements Flow-Down to Telescope

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 < 10 pm rms residual system WFE for < 10 min bandpass between λ/D and $10\lambda/D$

Science Requirements Flow-Down to Instruments

Notional Science Instruments Design Parameters

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

NB: Mid-IR instrument TBD pending performance assessment

Driving Capabilities

Driving Capability	Need	Comparison to Current or Planned Space Missions
Sensitivity Resolution	10 m aperture	300x HST, 6x JWST 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:

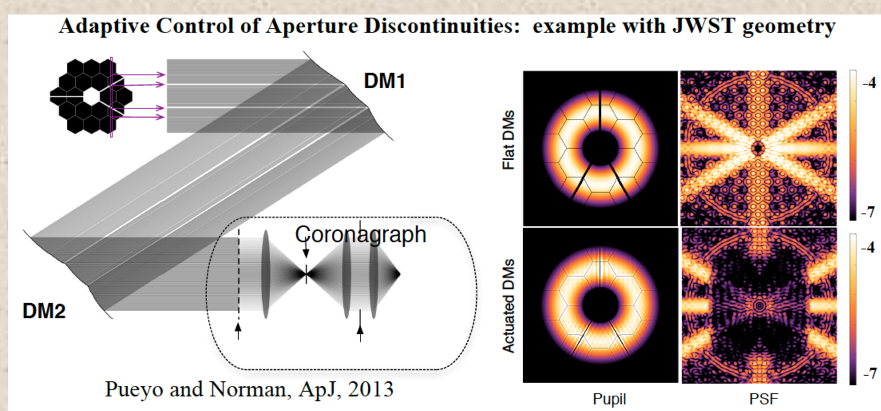
Detectors

Mirror Coatings

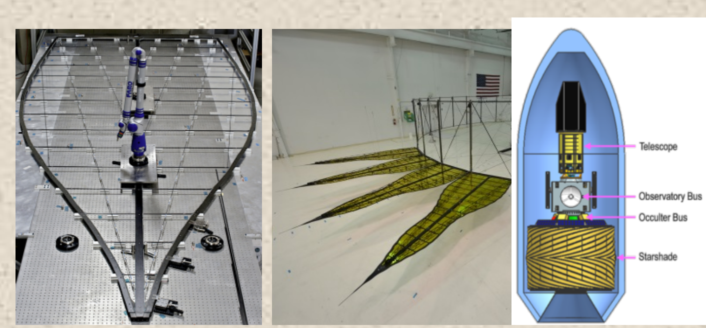
Starlight Suppression System

- 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	Sub Areas	Key Metrics	Need	State of the Art	TRL
Starlight Suppression System	Internal Coronagraph	Contrast (raw)	1×10^{-10}	5×10^{-10} (unobscured pupil) 1×10^{-8} (obscured pupil, monochromatic)	2 - 4
		IWA (λ/D)	2 - 3	4	
		Bandpass	Broad	2% – 20%	
	External Starshade	Contrast (raw)	1×10^{-10}	1×10^{-7}	
		IWA (λ/D)	2 - 3	Few	
		Bandpass	Broad	Broad	

Vibration Isolation and Control System

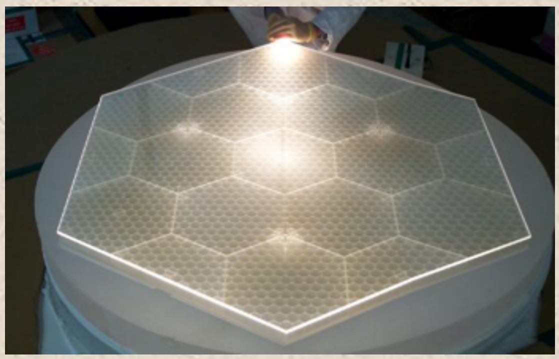
- Key Challenges
  - System wavefront stability < 10 pm over 10 min
  - Line-of-sight pointing stability < 1.0 milliarcsec
  - Total system vibration isolation of 140 dB (assuming JWST-like scaling)
  - Vibration-isolated mass of 5000 kg or more

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

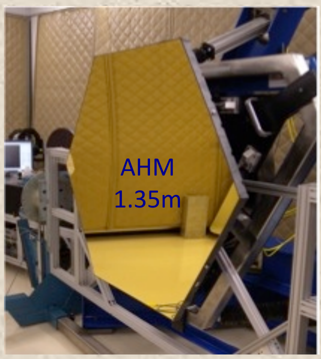
Technology	Sub Areas	Key Metrics	Need	State of the Art	TRL
Vibration Isolation and Control System	Reaction wheels	Attenuation > 40 Hz (dB)	140	80	5 - 6
	Active Isolation System				
	Passive Isolation System				

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

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

TRL is architecture dependent

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

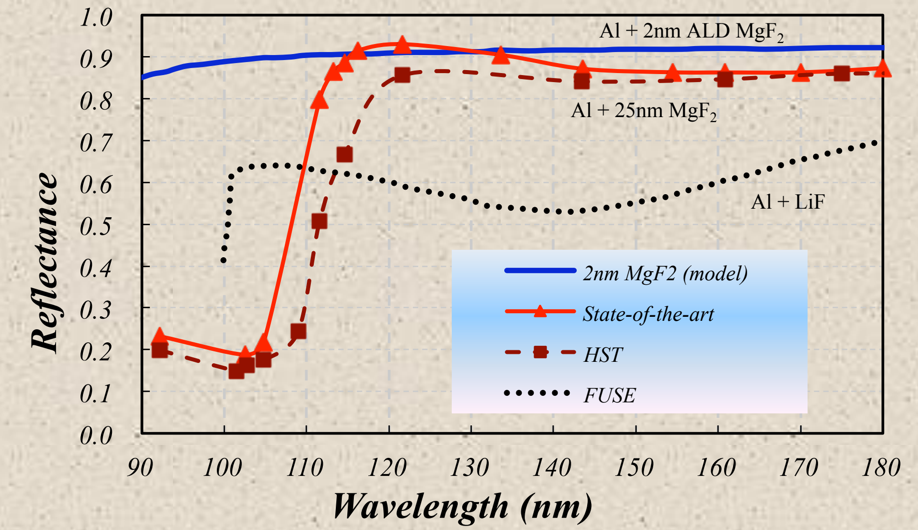
Technology	Sub Areas	Key Metrics	Need	State of the Art	TRL
Detectors	UV (Visible Blind)	QE (%)	> 50	5 - 20	3 - 4
		Noise (elect rms)	< 5	< 5	
		Format (Mpixel)	4	1	
	Vis/NIR	QE (%)	> 80	> 80	
		Noise (elect rms)	< 5	< 5	
		Format (Mpixel)	16	16	
		Radiation Tolerance	Rad hard at L2	Visible CCDs not rad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

TRL is for enhancing capabilities

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 ~ 85; 120 – 300 nm > 90; 300 – 2500 nm	
	Uniformity (%)	< 1	2	
	Polarization (%)	< 1	1	

TRL is for enhancing capabilities

See 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
- Sheikh (ZeCoat): Broadband Reflective Coating Process for Large FUVOIR Mirrors

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

http://sbir.nasa.gov/

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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  - 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)

- Roadmap
  - "Enduring Quests, Daring Visions: NASA Astrophysics in the Next Three Decades" http://science.nasa.gov/media/medialibrary/2013/12/20/secure-Astrophysics_Roadmap_2013.pdf