Initial Technology Assessment for the Large UV-Optical-Infrared (LUVOIR) Mission Concept Study

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With help from the LUVOIR Science & Technology Definition Team,
Study Office, and Technology Working Group

26 June 2016
Edinburgh, Scotland, UK
Paper 9904-18

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A ***Brief*** History of LUVOIR

- **pre-2010:** Advanced Technology Large Aperture Space Telescope (ATLAST) mission concept study
- **2010:** 2010 Decadal Survey, *New Worlds, New Horizons*
  - "...lay the technical and scientific foundations for a future space imaging and spectroscopy mission..." [page 20]
  - Recommended the definition of a future UV-optical space telescope
- **2013:** NASA Astrophysics 30-year Roadmap
  - First mention of LUVOIR as a "Formative Era" mission
- **2013+:** Additional work on ATLAST
  - Goddard, JPL, Marshall, Space Telescope Science Institute
- **2015:** AURA *From Cosmic Births to Living Earths*
  - Recommend the High Definition Space Telescope
- **2016:** Formation of LUVOIR Science & Technology Definition Team

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For a ***much*** more detailed history, see:

Thronson, *et al.*, "A path to a UV/optical/IR flagship: ATLAST and its predecessors", *JATIS*, **2**(4), 2016.

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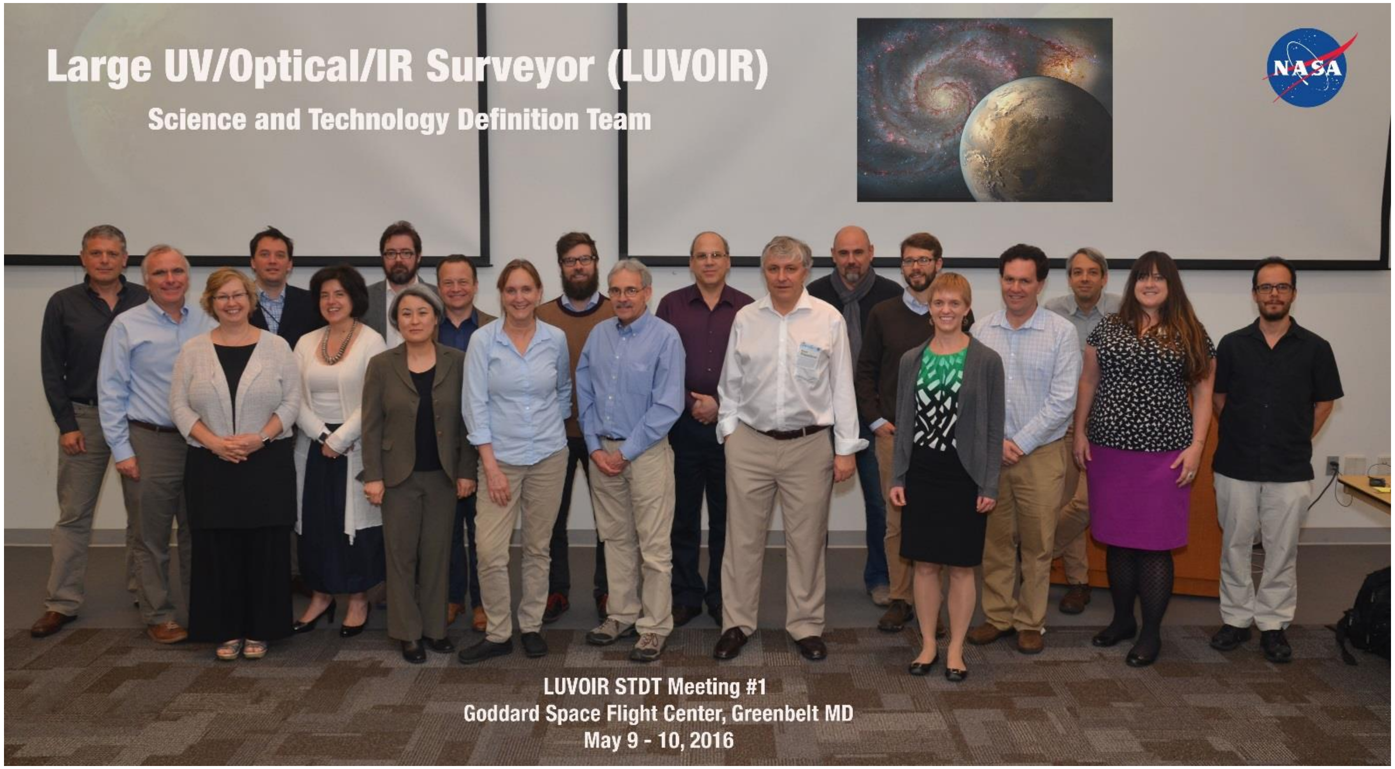
The LUVOIR STDT



- Tasked with:
  - Identify a compelling science case
  - Define a design reference mission with strawman payload
  - Prioritize and roadmap necessary technologies
- Supported by the Study Office at Goddard Space Flight Center

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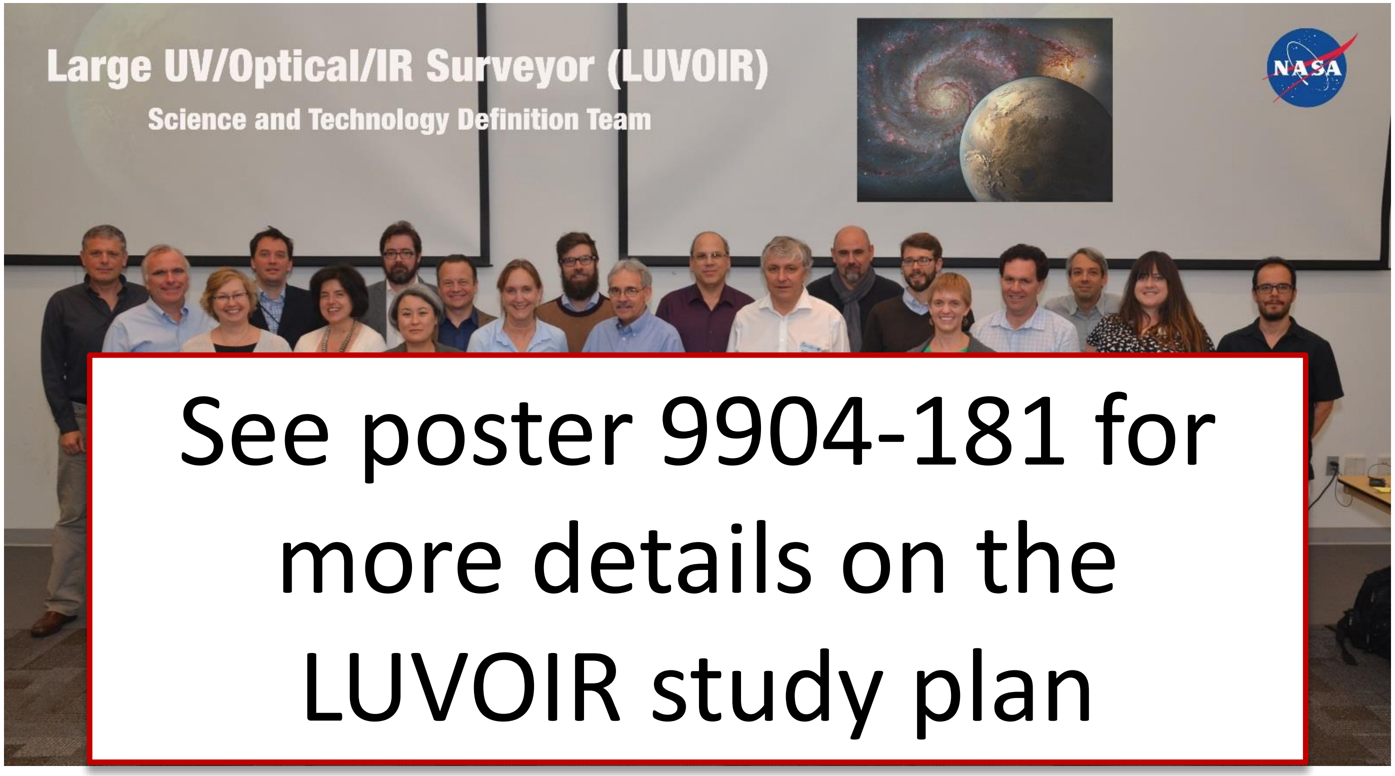

See poster 9904-181 for more details on the LUVOIR study plan

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LUVOIR Science*

- Broad array of general astrophysics
  - Wide-field of view, high-resolution imaging in the Hubble bandpass (UV – NIR)
  - Wide-field of view, multi-object UV spectroscopy
  - Sensitivity at wavelengths at least as short as 100 nm

- Direct imaging of dozens of habitable exoplanets
  - Spectroscopic search for biosignatures
  - High-precision astrometry and/or radial velocity
  - Comparative planetology

- Local solar system observations

*Subject to further definition by the STDT

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Implies a need for high-contrast imaging and ultra-stable optics.

- Local solar system observations

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Technology Prioritization for 2016 Cycle

Technology Area	**Difficulty**	**Urgency**
High-Contrast Segmented-Aperture Coronagraphy	**CRITICAL**	**CRITICAL**
Ultra-Stable Opto-mechanical Systems (includes Sensing, Control, Mirrors, and Structures)	**CRITICAL**	**CRITICAL**
Large Format, High Sensitivity, High-Dynamic Range UV Detectors	**HIGH**	**HIGH**
Vis/NIR Exoplanet Detectors	**HIGH**	**MED**
Starshade	**HIGH**	**MED**
Mirror Coatings	**MED**	**MED**
MIR (3–5 μm) Detectors	**LOW**	**LOW**

High-Contrast, Segmented-Aperture Coronagraphy

- Coronagraphy + large aperture (> 8m) provides high-yield exoEarth detection & characterization

Parameter	Goal	State-of-the-Art (WFIRST)
Aperture Type	Obscured, Segmented	Obscured, Monolith
Raw Contrast	1×10^{-10}	8.54×10^{-9}
Inner Working Angle	2 λ/D @ 1 μm	3 λ/D @ 0.55 μm
Bandpass (Instantaneous)	10 – 20%	10%
Bandpass (Total)	400 nm – 1.8 μm	523 nm – 578 nm
Throughput	> 10 %	< 5 %
LOWFSC Controllable Modes	Pointing, Z4-Z11	Pointing
LOWFSC Speed	> 1 kHz	~1 kHz
LOWFSC Accuracy	< 10 pm RMS	< 0.5 mas RMS per axis
Post-processing Contrast Gain	> 10×	3×

High-Contrast, Segmented-Aperture Coronagraphy

- Recommendations:
  - Continue the Segmented Coronagraph Design & Analysis study:
    - Improve model fidelity with dynamics, wavefront error, etc.
    - Continue “cross-pollination” and design collaboration
  - Viable candidates must be ***demonstrated*** on a UV-compatible, segmented aperture testbed prior to 2020 Decadal Survey
    - Need to establish credibility of segmented aperture coronagraphy

Ultra-Stable Opto-Mechanical Systems

- High-contrast imaging with a coronagraph requires wavefront stability ~10 pm RMS per wavefront control step

- Three general components to achieving wavefront stability:
  - Sensing Technologies
  - Control Technologies
  - Stable Structures & Mirrors

- An architecture involving all three is likely necessary to achieving the necessary stability

Sensing Technologies:

- Image-based techniques
  - Use the light from the object being observed
    - e.g. Zernike wavefront sensor, phase retrieval, etc.
  - Usually photon-starved, and therefore slower
    - Wavefront updates at 10s of minutes or hours

- External metrology
  - Use absolute metrology of optical system
    - e.g. laser trusses, edge sensors, etc.
  - Can be made arbitrarily fast, at the expense of added complexity
    - Provide wavefront updates at a few Hertz

- Use both:
  - Image-based techniques to control slow thermal drifts
  - External metrology to control faster dynamic drifts

Control Technologies:

- Primary Mirror Segments
  - Rigid body actuation in 6 degrees-of-freedom (*a la* JWST)
  - Higher-order control via warping harness or embedded actuators

- Macro-scale deformable mirrors
  - Currently used by most coronagraphs for speckle nulling
  - Continuous facesheets

- MEMs deformable mirrors
  - Continuous facesheet or segmented
  - Segmented can be mapped 1-to-1 to primary mirror segments for fast control of segment (tip/tilt)

- All require stable, precise, fast electronics

Stable Structures and Mirrors:

- Thermally stable mirror materials
  - ULE®, Zerodur® for low CTE at room temperature
  - SiC for high thermal conductivity, low CTE at colder temps

- Thermally stable structures
  - Composites with low CTE, CME
  - Better understanding of joints and lurches

- Requires better modeling and validation of linearity assumptions at picometer levels

Ultra-Stable Opto-Mechanical Systems

- Recommendations:
  - Systems-level approach to solving the problem
    - Mirrors, structures, sensors, actuators, materials, modeling, and the overall architecture must be developed together
    - Substantial participation of industry is necessary
  - Design and development activities to demonstrate closed-loop picometer-class stability for segmented apertures
  - Competitive development of picometer component sensing and control technologies and architecture feasibility demonstrations

Large Format, High Sensitivity, High Dynamic Range UV Detectors

- Micro-channel Plates (MCPs) are current state-of-the-art for UV detectors
  - Limited dynamic range (cannot view bright objects)
  - Limited lifetime (“gain-sag” issue)
  - Difficult to tile in large arrays

- EMCCD & sCMOS are of interest
  - *Must first be evaluated for radiation hardness and noise performance*
  - Could provide a path for large-format, high dynamic range
  - Need improvement in UV sensitivity

Large Format, High Sensitivity, High Dynamic Range UV Detectors

Parameter	Goal	State-of-the-Art (MCP)
Operational Bandpass	90 nm – 400 nm	90 nm – 300 nm
Read Noise	0	0
Dark Current	0	0
Spurious Count Rate	≤ 0.05 counts / cm^2 /s	0.05 counts / cm^2 /s
Quantum Efficiency (Peak)	75 % (FUV – NUV)	45 – 20% (FUV – NUV)
Resol Size	≤ 10 μm	20 μm
Dynamic Range	≥ 10^4 Hz / resol	40 Hz / resol; 5 MHz global
Time Resolution	≤ 100 ms	<< 1 ms
Format	≥ 8 – 16 k pixels per side	8k x 8k
Radiation Tolerance	Good	Good

Large Format, High Sensitivity, High Dynamic Range UV Detectors

- Recommendations:
  - Technology-only balloon/rocket programs and laboratory demonstration can accelerate development
    - Minimize time spent on science instrumentation; focus on detector evaluation
  - Evaluate/develop EMCCD and sCMOS for radiation hardness and noise performance
    - If acceptable, pursue δ-doping for UV sensitivity
    - Also benefits the Vis/IR Detectors for Exoplanet Science technology need

Vis/IR Detectors for Exoplanet Science

- For high exoEarth yields, require extremely low-noise detectors
  - < 1 e^-/pixel read noise; < 0.0010 counts/pixel/s dark current

- Candidate technologies:
  - EMCCD:
    - Must be made radiation hard
  - sCMOS:
    - Must be evaluated for read noise, dark current, and radiation hardness
  - MKID/TES:
    - Energy resolving detectors require cryogenic operation which may be incompatible with picometer stability requirement

Starshade

- Alternative means to starlight suppression for exoplanet science
  - Trades telescope stability for added complexity of additional space craft flying in precise formation with observatory
  - Risk reduction should coronagraphy or stability prove too challenging
  - Mission enhancing for NIR exoplanet characterization

- Starshade Readiness Working Group (SSWG) recently formed
  - Develop "a technical concept and risk reduction plan" for starshade validation

Mirror Coatings

- Require broadband, high-performance coatings that are compatible with coronagraphy:
  - Maintain high reflectivity over band between 90 nm and 2.5+ μm
  - High uniformity over 10-m class aperture
  - Minimize polarization aberration and cross-polarization leakage

- Need investigations in deposition processes to improve reflectivity and uniformity

- Demonstration of high-contrast imaging with UV-compatible coated segmented aperture is needed prior to 2020

MIR (3-5μm) Detectors

- Depending on operating temperature of LUVOIR, varying degrees of MIR science is possible
  - Observations are limited by telescope's thermal background
  - Even with a room-temperature telescope, cold instruments can enable some MIR transit spectroscopy

- Need to better understand needs of science observations relative to background limitations
  - Define detector needs and evaluate the technology gap

Conclusion

- Prioritized 7 technologies for LUVOIR, based on preliminary science case

- Three technologies elevated as urgent for 2016 investment:
  - High Contrast, Segmented Aperture Coronagraphy
  - Ultra-stable Opto-mechanical Systems
  - Large Format, High Sensitivity, High Dynamic Range UV Detectors

- Additional technologies will require development as
  - (a) the science case is further defined,
  - (b) the above gaps begin to narrow, and/or
  - (c) additional information is made available about current capabilities