LUVOIR ARCHITECTURE “A”
ENGINEERING STATUS

Presented to:
The LUVOIR STDT

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We will study two architectures in depth...

- **Architecture A (first half of 2017)**
  - 15-m diameter aperture
  - Five instrument bays:
    - Optical / NIR Coronagraph (A)
    - UV Multi-object Spectrograph (“LUMOS”)
    - High-definition Imager (will also perform guiding / wavefront sensing)
    - *UV Spectro-polarimeter* (*CNES Contributed*)
    - Empty Bay for future expansion / contribution

- **Architecture B (late 2017 into 2018)**
  - ~9-m diameter aperture
  - Three instrument bays:
    - Optical / NIR Coronagraph (B)
    - UV Multi-object Spectrograph (“LUMOS”)
    - Optical / NIR Multi-resolution Spectrograph
      - Will need to include guiding and wavefront sensing capabilities
Study Schedule (2017):

✓ 1/17–24 – Telescope Instrument Design Lab (IDL)
  • Pre-work 1/10
✓ 2/6–10 – HDI IDL
  • Pre-work 1/31
○ 3/20–24 – Coronagraph IDL
  • Pre-work 3/14
○ 5/15–19 – LUMOS IDL
  • Pre-work 5/9
○ 6/7–13 – Instrument Accommodation & DeltaTelescope IDL
  • Pre-work 6/1
○ 7/10–14 – LUVOIR “A” Mission Design Lab (MDL)
  
○ June – Dec.: Prepare Interim Report on Architecture A
○ Sept.: Kick-off Architecture B IDLs
Telescope Design
LUVOIR “A” Science Measurement Concept

- FOV: 10 arcmin x 8 arcmin
- Wavelength:
  - 100 nm – 2.5+ μm
  - 90 nm blue cutoff stretch goal (largely dependent on coating technology development)
  - Optics & coatings should not preclude observations as red as 5.0 μm
- Diffraction-limited at 500 nm
- Spatial resolution:
  - Limiting instrument (LUMOS) has a spatial resolution of 30 mas for an assumed 25 μm resolution element
  - Implies a telescope focal length \( \geq 172 \) m
- Aperture diameter:
  - Largest that can fit in an 8.4-meter x 27.4-meter fairing
  - Deemed to be 15-m by LUVOIR Engineering Team
- Operating temperature: 270 K
LUVOIR “A” Telescope Optical Design

FOV: 10’ x 8’
EFL: ~300 m
System F/#: ~20
PM F/#: 1.45
Obscuration: ~3 m
LUVOIR “A” Telescope Aperture

- 1.15-m flat-to-flat segments (120x)
- Central ring of array removed to accommodate Aft-optics & Secondary Mirror Obscuration
- Effective area is ~135 m²
- 15-m circumscribed diameter / 12.7-m inscribed diameter
- Assumes 6 mm gaps
Mechanical Design Details (1)

- Tertiary mirror support structure
- Strut cross-sections 0.05 m x 0.15 m
- ~20 m
- 15 m
Stowed Telescoping Boom is 1.5 m deep

Folded segments of SMSS
Footprint for Backplane Support Frame (BSF) and Instruments, given OTE stowed arrangement
Mechanical Design Details (4)

Not Shown:
- Sunshield and deployment system
- Spacecraft bus
- Primary Mirror “frill”
Mechanical Design Details (5)

**Deployed Boom**
- Fine Steering Mirror Assembly
- Tertiary Mirror

**Stowed Boom**
- STEM deployers (retractable if desired)

Dimensions:
- Deployed Boom:
  - Aperture: 5 m
  - Fine Steering Mirror Assembly: 1.3 m
  - Tertiary Mirror: 2 m

- Stowed Boom:
  - 1.5 m
Control System Block Diagram (So Far)

Subject of LUVOIR “A” 1st IDL Study

Control System Processor (CSP)

- Image Data
- Signal Data
- Commands
- Commands w/ Actuator Feedback / Positional Information

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Concept for PM Segment Phasing (1)

- Introduced a closed-loop control system at the primary mirror segments to maintain segment-to-segment phasing.
- Edge sensors on each segment measure picometer-level rigid-body motions at high speeds.
- In response, piezoelectric (PZT) actuators move PM segments at picometer level.
- Closed-loop system creates a “virtual monolith.”
Concept for PM Segment Phasing (2)

Edge Sensors

- Capacitive edge sensors
  - Two sensors per edge shared between segments: 622 sensors total
  - Provide 6-degree of freedom motion of each segment

- Similar sensors are being developed for ground-based systems (TMT, EELT, GMT) and have been used on Keck

- Challenge for LUVOIR is in the electronics
  - Need high speed (~450 Hz) readout with picometer-level accuracy at low power

- Lab-based system has demonstrated ~10 pm sensing at lower speeds with custom electronics
Concept for PM Segment Phasing (3)

Segment Actuators

- Average the 450 Hz edge sensor measurements at a rate of 5:1 to generate a 90 Hz control signal for PM segments

- LUVOIR PM segments use exact same actuator design as JWST, except fine stage mechanical actuator is replaced with a PZT actuator
  - One PZT per actuator → 6 PZTs per PM segment for fine control of six degrees of freedom

- On JWST, a mechanical linkage is used to “step-down” physical actuator displacement to PM segment motion
  - i.e. if actuator moves 100 microns, the mirror only moves ~1 micron

- We will use the same linkage for the PZTs such that a 0.250 nm PZT step (which is easy) corresponds to ~2 pm motion of the mirror segment
Priority Telescope “To-Do”

- Add mechanical design fidelity to:
  - Primary mirror backplane
  - Primary mirror segment mechanical structure (heater, whiffles, delta frame, actuators, mounting points)

- Perform dynamic stability analysis
  - For launch loads on stowed configuration
  - For jitter disturbance on deployed configuration

- Re-visit thermal control system
  - Incorporating new backplane wing sections
  - Incorporating actuator drive electronics in each primary mirror segment assembly

- Add fidelity to mechanisms
  - Launch locks, deployment motors, latches, snubbers, etc.

- Perform straylight analysis and size baffling
High Definition Imager Design
HDI Technical Overview (1/2)

- **Two-channel Imaging Instrument:**
  - UV/Vis Imaging (200 nm - ~1.0 µm)
    - Diffraction-limited performance at 500 nm
    - Nyquist sampled at 400 nm
  - NIR Imaging (~1.0 µm – 2.5 µm)
    - Diffraction-limited performance at 1.2 µm
    - Nyquist sampled at 1.2 µm

- Each channel will contain a suite of spectral filters:
  - Narrow (R ~50-100)
  - Medium (R ~20-40)
  - Broadband (R ~3-5)
  - At least one slitless grism/prism option with R ~200-500

- **Field-of-view:** 2 x 3 arcmin
  - Both channels view the same patch of sky
HDI Technical Overview (2/2)

- **Exposure times:**
  - For most extragalactic sources and stellar population observations:
    - Total observation times of up to 200 hrs.
    - Composed of many exposures of 500-1000 s each
  - High-speed photometry will require exposures of 50 – 100 ms
    - Will only be required over a small area of the focal plane array (perhaps a single SCA of the entire FPA)

- **Dynamic Range:**
  - Desire the ability to define a region of the focal plane with reduced sensitivity (or faster readout) for both astrometry and solar system observations
HDI Special Modes:

- **High-Precision Astrometry (for measuring exoplanet mass):**
  - Astrometric precision of $< 5 \times 10^{-4}$ pixels
  - Requires a Pixel Calibration System to calibrate pixel geometry

- **Fine-guiding:**
  - HDI is the primary fine-guidance sensor for the LUVOIR observatory
  - Similar to WFIRST operation
    - Requires ability to define regions of focal plane with faster readout
    - Should have capability in both UV/Vis and NIR channels

- **Image-based Wavefront Sensing (i.e. phase retrieval) for telescope commissioning and maintenance:**
  - Similar to role played by NIRCam on JWST
  - Requires inclusion of:
    - Weak-lenses for generating defocused images
    - Dispersed Hartmann Sensor (DHS) gratings for coarse piston sensing
    - Pupil Imaging Lens (PIL) subsystem
HDI Detector Concept – UV/Vis Channel

- **CMOS Detector**
  - Pixel size = 5 µm
  - Nyquist sampled at 400 nm
    - Defined as: 1 pixel = $\lambda / (2*D)$
    - $\lambda = 400$ nm; $D = 15.08$ m; $\diamond$ 1 pixel = 2.74 mas
  - Read noise: ~2.5 e-
  - Dark Current: Assume 0.001 e-/pix/s
  - Assume same QE as WFC3 UVIS CCD detector
  - Operating temperature ~120 K
  - Pixel sensitivity to be stable to ~1% over 14 days

- **For an 8k x 8k detector technology**:
  - Use 5 x 8 tiling of arrays:
    - FOV = 1.90 x 3.12 arcmin
    - 40,960 x 65,536 pixels = 2.68 Gpix
    - 209 x 342 mm focal plane array (including gaps)
    - 205 pixel gap (~1 mm)
  - Gaps are as shown at right:

- **Assume 16 bits/pixel: 5.4 Gbytes per image**
HDI Detector Concept – NIR Channel

- **H4RG Detector**
  - Pixel size = 10 $\mu$m
  - Nyquist sampled at 1200 nm
    - Defined as: 1 pixel = $\lambda$ / (2*D)
    - $\lambda$ = 1200 nm; D = 15.08 m; $\Diamond$ 1 pixel = 8.2 mas
  - Read noise, dark current, QE adopted from WFIRST H4RG specs
  - Operating temperature ~70 K
  - Pixel sensitivity to be stable to ~1% over 14 days

- For an 4k x 4k detector technology:
  - Use 4 x 5 tiling of arrays:
    - FOV = 2.28 x 2.91 arcmin
    - 16,384 x 20,480 pixels = 335 Mpix
    - 167 x 213 mm focal plane array (including gaps)
  - Gaps are as shown at right:

- Assume 16 bits/pixel: 0.671 Gbytes per image
HDI Thermal Design

- Three thermal zones within the instrument using passive cooling:
  - 260 K
    - Instrument housing
    - Pupil relay optics
    - UVIS channel optics
  - 120 K
    - NIR channel optics
    - UVIS focal plane
  - 70 K
    - NIR focal plane
Priority HDI “To-Do”

- Resolve a small volume allocation violation
  - A few millimeters of the NIR channel thermal shroud encroaches beyond the allocated instrument volume

- Finalize optical design
  - Grisms, weak lenses, pupil imaging lens, etc.
  - Investigate optimizing the design for UVIS throughput

- Re-visit thermal design and radiator sizing for the three thermal zones
  - 120 K may be colder than is needed for UVIS detector

- Re-visit number of elements and element type in the channel select mechanism