life detection capabilities of LUVOIR and HabEx

... and WFIRST

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Meadows, 2016
<table>
<thead>
<tr>
<th>O₂ Generation Mechanism</th>
<th>Stellar Host</th>
<th>O₂ Column Depth (molecules/cm²)</th>
<th>O₃ Column Depth (molecules/cm²)</th>
<th>O₂ production rate (molecules/cm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern Earth Biology</td>
<td>G-type star</td>
<td>~5×10^{24}</td>
<td>~6×10^{18}</td>
<td>~1×10^{19}</td>
</tr>
<tr>
<td>Archean Earth Biology</td>
<td>G-type star</td>
<td>~4×10^{16}</td>
<td>~8×10^{11}</td>
<td>~3×10^{11}</td>
</tr>
<tr>
<td>Photochemistry (Harman et al.)</td>
<td>G-type star</td>
<td>~2×10^{19}</td>
<td>~7×10^{14}</td>
<td>~1×10^{12}</td>
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</tr>
<tr>
<td>H escape (Luger et al., Schwieterman et al.)</td>
<td>M-type star</td>
<td>~1×10^{26}</td>
<td>~2×10^{19}</td>
<td>~3×10^{12}</td>
</tr>
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</table>
LUVOIR/HabEx

- Up to 18 m diameter (254 m²)
- 15 m diameter
- 12 m diameter
- 9 m diameter
- 6 m diameter

Collecting areas based on possible mirror sizes and limited by the expected launch capabilities

JWST (25 m²)

HST (4.5 m²)

Wavelength [μm]

ULTRAVIOLET  OPTICAL  NEAR-INFRARED  MID-INFRARED
Difference between LUVOIR and HabEx?

Both LUVOIR and HabEx have two primary science goals:

- Habitable exoplanets & biosignatures
- Broad range of general astrophysics

The two architectures will be driven by difference in focus:

- For LUVOIR, both goals are on equal footing. LUVOIR will be a general purpose “great observatory”, a successor to HST and JWST in the ~ 8 – 16 m class.
- HabEx will be optimized for exoplanet imaging, but also enable a range of general astrophysics. It is a more focused mission in the ~ 4 – 8 m class.

Similar exoplanet goals, differing in quantitative levels of ambition:

- HabEx will *explore* the nearest stars to “search for” signs of habitability & biosignatures via direct detection of reflected light.
- LUVOIR will *survey* more stars to “constrain the frequency” of habitability & biosignatures and produce a statistically meaningful sample of exoEarths.

The two studies will provide a continuum of options for a range of futures.
HST/WFIRST
~2.4 m

HabEx
~4 m

JWST/HabEx
~6.5 m

LUVOIR
~9 m

LUVOIR
~16 m
UV oxygen emission from Europa water vapor jets observed with HST

For illustration ...

- **HST resolution**: 2.4-m
- **HabEx resolution**: 4-m, 6.5-m
- **LUVOIR resolution**: 9-m, 16-m
ExoEarth candidates as function of aperture

If frequency of habitable conditions is 10%, need 30 candidates to guarantee seeing one true exoEarth (at 95% confidence)

Stark et al. (2014)
C. Stark, Using SAG13 Occurrence Rates

Planet Diversity Yields

$D = 4 \text{ m}$

$D = 12 \text{ m}$
200 hr observations of Earth @ 10 pc

$D = 4 \text{ m}$

$D = 12 \text{ m}$

$R = 70$

$SNR \approx 10$

$R = 300$

$SNR \approx 17$

$200 \text{ hr observations of Earth @ 10 pc}$

J. Tumlinson’s Online Spectra Tool (Tumlinson, Robinson, Arney, et al)
Notional LUVOIR/HabEx instruments

**Observational challenge**
Faint planets next to bright stars

**Solution**
**OBSCURA**
Optical-IR Band Spectroscopy and Coronagraph for Rocky Atmospheres
Contrast < $10^{-10}$ to observe exoEarths
Low resolution spectroscopy ($R > 150$)
Baseline bandpass: 0.4 μm to 1.8 μm
Ambitious bandpass: 0.2 μm to 2.4 μm
No space-based analog
Notional LUVOIR/potential HabEx instruments

**Observational challenge**
No UV through Earth’s atmosphere

**Solution**
**LUMOS**  
(LUVOIR UV Multi-Object Spectrograph)

- Far-UV to near-UV spectroscopy
- High resolution ($R \sim 10^5$) spectroscopy
- Med. res. multi-object spectroscopy
- Near-UV imaging
- Major upgrade of HST STIS
Notional LUVOIR/potential HabEx instruments

**Observational challenge**
Imaging wide fields at high resolution

**Solution**

*High-Definition Imager*

4 – 6 arcmin field-of-view
Optical to near-IR bandpass
Possibly high precision astrometry to measure planet masses
Major upgrade of HST WFC3

HST Wide Field Camera 3
Notional LUVOIR instruments

**Observational challenge**
Measuring warm molecules present in Earth’s atmosphere

**Solution**

**Optical / Near-IR Spectrograph**
Multiple resolutions up to $R \sim 10^5$
High photometric precision for transits
Possibly high precision RV to measure planet masses
No space-based analog

Credit: Natasha Batalha

ESPRESSO spectrograph for VLT
(Credit: ESO)
## Technological challenges

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Details</th>
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<tr>
<td><strong>Need heavy lift launch vehicle with large fairing</strong></td>
<td>Suitable vehicles (SLS and commercial) in development</td>
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<td><strong>Compatibility of UV and coronagraphy</strong></td>
<td>New lab work shows UV reflective mirrors are just fine for coronagraphy</td>
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<td><strong>Ultra-high contrast observations with a segmented telescope</strong></td>
<td>Coronagraphs can be designed for segmented telescopes. Working hard to demonstrate needed system stability</td>
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<td><strong>Starshade Deployment, Edge Tolerance, and Formation Flying</strong></td>
<td>Lots of progress on deployment, both from JPL testbed and via JWST sunshield. Formation flying likely not limiting, but slewing of the starshade may limit # of observations. Edge tolerance currently the one of the biggest challenges for starshades.</td>
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