NASA flagship class mission concept for the 2020 Decadal review. Comes from the NASA Astrophysics Roadmap.

- $5 \mu m - 600 \mu m$ (diffraction limit around $30 \mu m$)
- $4.5K$ actively-cooled large aperture operating at L2
- factor of 10,000 improvement in sensitivity over previous (driven primarily by cooling not aperture size).
- ultra-sensitive detector arrays $\Rightarrow$ new spectroscopic capabilities
- exoplanet studies via a coronagraph and transit spectroscopy
- modular instrument suite with robotic serviceability
- Mission aimed at mid 2030s: post JWST, concurrent with WFIRST, Athena, LISA, and 25m-35m ground-based optical/IR facilities.
- Science goals and measurement requirements in 2030+
From first stars to life

Study Team

- **Community Chairs**: A. R. Cooray, UCI; M. Meixner, STSCI/JHU
- **Study Scientist**: D. Leisawitz, GSFC
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**NASA Study Center (Goddard Space Flight Center) Team**: C. Wu (Mission Systems Engr), E. Amatucci (Instrument Systems Engr), M. DiPirro (Chief Technologist), J. Staguhn (Instrument Scientist)

**Study Advisory Board**: J. Arenberg, Northrup Grumman; J. Carlstrom, Chicago, H. Ferguson, STScI; T. Greene, Ames; G. Helou, IPAC; L. Kaltenegger, Cornell; C. Lawrence, JPL; S. Lipsky, Ball; J. Mather, GSFC; H. Moseley, GSFC; G. Rieke, Arizona; M. Rieke, Arizona; J. Turner, UCLA; M. Urry, Yale.
- **Are we alone? OST question: How common are life bearing planets?** With sensitive mid-infrared transit spectroscopy, OST will measure biosignatures, including ozone, carbon-dioxide, water, and methane in the atmospheres of Earth-sized habitable exoplanets.

- **How did we get here? OST question: How do the conditions for habitability develop during the process of planet formation?** With the sensitive and high-resolution far-IR spectroscopy OST will map the water trail in our Galaxy.

- **How does the Universe work? OST question: How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today?** OST will spectroscopically 3D map wide extragalactic fields to measure simultaneously properties of growing super-massive blackholes and their galaxy hosts across cosmic time.
From first stars to life
Are we alone?

OST question: How common are life bearing planets?
To detect biosignatures:

- Spectral resolving power ($\lambda/\Delta\lambda$) of 100-300
- Noise floors $< 5$ ppm (requirement)
  - (M3V@20 pc – 2 hr at 7 μm)
- Key spectral signatures of Earth-size planets that Origins will detect:
  - $H_2O$, $CO_2$, $O_3$, $N_2O$, $CH_4$
  - bio-signatures: $O_3$ or $N_2O$ plus $CH_4$
  - bio-indicators: $H_2O$, $CO_2$

*Origins Space Telescope will have mid-IR capability down to 5 μm; noise floor will be due to mid-IR detector stability.*
From first stars to life
How did we get here?

Following the formation of planetary systems from the interstellar medium to life-bearing worlds

- Interstellar medium
- Protoplanetary disks
- Planetary systems
- Exoplanets
From first stars to life

How did we Get Here? The Water Trail

- Water’s birth in star-less cores: tracing water vapor in the beginnings of star formation.
- Supply to a young disk in protostars: follow water during collapse and the early stages of disk formation.
- Early planet formation in protoplanetary disks: survey water and HD in > 1000 disks, all disks out to 500 pc - trace snowline and water/ice content.
- Late planet formation in debris disks: OST can detect water and O I from evaporating planetesimals and determine whether disks are primordial or secondary.
- Supply of life’s ingredients to terrestrial worlds: detect water D/H in > 100 comets!
From first stars to life

How does the Universe work?

Infrared is rich in key spectral lines!
From first stars to life

Spitzer/MIPS

Origins Space Telescope (9m)
From first stars to life

GO Sciences: examples

- **Time-domain sciences**: fast-scanning (100 arcsec/second) allows follow-up of LISA error boxes!
- **Direct coronagraphic imaging** of true Jupiters and Saturns
- **Methane sources** on Mars, map out methane distribution. Also **temporal monitoring** of Titan atmosphere.
- **KBO survey to study the albedo distribution** by mapping 100 sq. degrees 2-4 times in parallel with LSST or its successor in 2030s.
- **Image cold dust in exo-zodi/exo-KBO clouds** in TESS, Ariel and other targets.
- Map **crystalline water ice** via the 43 micron emission feature in proto-stellar outflows.
- **Polarization mapping** of the Milky-Way to connect magnetic fields and Galactic star-formation.
- Determine the **cosmic-ray flux in Milky-Way** and other near-by galaxies.
- Spectral line and continuum mapping of local volume galaxies to study feedback processes; see bubbles, outflows and fountains in lines such as CII, NII.
- Find **first AGN**; first dust sources.
- Dusty star-formation in **large-scale structure**, clustering measurements. Resolve **Cosmic Infrared Background**.
• **Telescope type**: three mirror anastigmat (TMA); unobstructed primary mirror

• **Primary mirror**: 9.1 meters in diameter; 37 hexagonal segments

• **Five instruments housed in an Instrument Accommodation Module (IAM)**
  – Medium Resolution Survey Spectrometer (MRSS) – JPL
  – Hi Res (Far-IR) Spectrometer (HRS) – GSFC
  – Heterodyne Instrument (HERO) – CNES
  – FIR Imager/ Polarimeter (FIP) – GSFC
  – MID-IR Imager Spectrometer/ Coronagraph (MISC) – ARC/JAXA

• **Instrument Wavelength Coverage**: 5 to 600 μm

• **MISC serves as guider for the spacecraft attitude control system**

• **Telescope and instrument operating temperature**: ~4.5 K

• **Cryocoolers used for cooling**, not expendable cryogen

• **Instrument warm electronics housed in the spacecraft bus (270 K)**
From first stars to life

Concept 1 configuration

Deployed

Stowed
From first stars to life
Concept 1 Requirements

- **Mission Life**: 5 Years with 10-year consumables (Once a decade serviceability extends life-time > 30 years).
- **Launch Vehicle**: SLS Block 2, 8.4m x 27.4m fairing
- **LRR**: September 1, 2035
- **OST Observatory Size**:
  - 14.75 x 21.6 x 33.5 m (deployed), 19L x 7.5D m (stowed)
- **Mission Orbit**: Sun-Earth L2 (Sun, Earth, Moon avoidance, No eclipses)
- **Service plan**: Earth-Moon L1, robotic/human
- **Pointing Control** – 44 mas; **Pointing Knowledge** – 30 mas; **Jitter** – 22 mas
- **Folded/scooped sunshade to minimize size** (size fixed for this study)
- **IAM** is to be on-orbit serviceable (underside)
- **Science Observation**: > 70% efficiency
- **Field-of-Regard (FOR)**: -5°- +45° Pitch off Sun Line, 360° Yaw about Sun Line, ±5° Roll about Line of Sight (LOS)
- **Communication**: 2 optical terminals, 1 S-band OMNI Pair, 1 S-band HGA
- **Observatory Mass**: ~30000 kg (CBE)
- **Observatory Power**: ~7500 W (CBE)
- **Peak Data Rate**: ~350 Mbit/sec
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Wavelength Coverage</th>
<th>Spectral Resolving Power (λ/Δλ)</th>
<th>Number of spatial pixels or sky beams</th>
<th>Typical Required Sensitivity (1-hr)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Infrared coronagraph/imager/IFU</td>
<td>6 to 40 μm</td>
<td>imager: R~10; IFU R&gt;3000</td>
<td>~10⁷</td>
<td>photometric: 1 μJy @10 μm</td>
<td>coronagraph 10⁻⁵-10⁻⁶ IWA=2λ/D</td>
</tr>
<tr>
<td>Imager + Polarimeter</td>
<td>40, 80, 120, 240 μm</td>
<td>R~3</td>
<td>~100,000</td>
<td>1 μJy - 100 μJy (confusion limit)</td>
<td>polarimetry</td>
</tr>
<tr>
<td>Mid-Res Spectrometer</td>
<td>50 to 600 μm</td>
<td>low-res<del>500 high-res</del>1x10⁵</td>
<td>100 per channel</td>
<td>10⁻²¹ W/m² 5σ (any spectral line across full band)</td>
<td>full-band instantaneous with 6 channels</td>
</tr>
<tr>
<td>High-Res Spectrometer</td>
<td>35 to 250 μm</td>
<td>low-res<del>10⁴ high-res</del>few 10⁵</td>
<td>10</td>
<td>few 10⁻²² W/m² (for a single spectral line)</td>
<td>photon-counting; full band requires scanning</td>
</tr>
<tr>
<td>High-Res Heterodyne Spectrometer</td>
<td>63 to 66 μm and 111 to 641 μm</td>
<td>up to ~10⁷</td>
<td>10-100</td>
<td>2 mK in 0.2 km/s @ 1 THz</td>
<td>polarization sensitive, near quantum limit</td>
</tr>
</tbody>
</table>
A factor of 10,000 (!) improvement in sensitivity. An immense discovery potential. Origins Space Telescope will not be extending what we know already. **It will be a true revolution in astronomy.**
From first stars to life

OST Concept 2 Design

- Spitzer-like configuration
- No on-orbit deployments, other than sun-shade and solar array.
- Lower complexity and mass relative to both JWST and Concept 1
- On-Axis Telescope
- Telescope and instrument module cooled and maintained at 4-4.5 Kelvin

- Instrument Module accommodates 4 instruments (scaled down from Concept 1)
  - OST Survey Spectrometer (OSS): JPL
  - Far-IR Imaging Polarimeter (FIP): GSFC
  - Mid-IR Imager Spectrometer Coronagraph (MISC): JAXA
  - Heterodyne Receiver (HERO): CNES

- Design to total mass 5,000 kg, including 30% contingency
- Total flight system mass ~3,850 kg allowed
From first stars to life

OST Concept 2 Configuration

- Secondary Mirror (SM) (non-deployable)
- Two-layer deployable Sunshield
- UltraFlex Solar Array
- Telescope Baffle Assembly
- Instrument Module (IM)
- Spacecraft Bus
OST Concept 2 Collecting Area

- Goal: match JWST collecting area
  - ~25m²
- Current design:
  - On-axis, three-mirror anastigmat (TMA)
  - 5.9m diameter circle
  - 0.9m diameter hole
  - Assume 5% areal loss due to secondary supports/segment gaps
Technology Gaps

- Large-format, high-sensitivity far-IR direct detectors, multiplexers, and readout electronics
- Compact Far-IR spectrometers
- Heterodyne focal plane arrays
- Sub-Kelvin cooling
- Large cryogenic optics and actuators
- 4.5 K cryocoolers
- Ultra-stable Mid-IR detectors and coronagraphy
Where we are:

• Concept 1 study complete - STDT delivered interim report to NASA last week

• STDT completed Concept 2 definition
  – Engineering design study has started
    • Spitzer-like configurations under study, 5.9m with a non-deployable mirrors
  – Instrument requirements and performances in iterations with the STDT

• Concept 2 criteria: 5000 kg weight limit (with 30% mass contingency) and fit into a 7m-diameter fairing for the launch vehicle.

Concept 2 will be “simpler” than Concept 1, while still being efficient, capable, less complex and preserving the immense gain in sensitivity and greatly expanding discovery space.