The Origins Concept Study for the 2020 Decadal Survey

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For the OST Study Center and the OST STDT
Intro to OST

• Originally the Far-InfraRed Surveyor
• => Origins Space Telescope or Origins, when Mid-Infrared Instrument Added
  • Key to biosignatures in transiting exoplanets
• Follows Spitzer (0.85 m diameter, cold for 5.5 years) and Herschel (3.5 m diameter, but warm 80 K)
• General Observatory with 5 Year nominal mission duration with 10 years of consumables, designed for servicing
• Covers wavelengths from 3 microns to 600 microns
Top three themes

(I) 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.

(II) 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.

(III) Are we alone? OST question: How common are life bearing planets around M dwarf stars? 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.
Sensitivity Improvement

Spectral Line Sensitivity

Photometric performance, point source

5σ 1-hour Sensitivity (W/m²)

limiting flux density (Jy), $10^{-14}$

Wavelength ($\mu$m)

Wavelength ($\mu$m)
Mapping Speed

[Graph showing mapping speed across different wavelengths and survey times for various telescopes and instruments.]
Overall Architecture

- Spitzer-like rather than JWST-like
- Cold Baffle is more forgiving for stray light
- Cold radiator gives extra 35 K cooling
- Simple shield deployment that can be demonstrated on the ground

OST Concept 1
52 m²

OST Concept 2
25 m²

Spitzer
0.5 m²
Architecture Features

• Concept 1 (Open, JWST-like)
  • Pros: Easier to fold to stow for launch
  • Cons: stray light suppression is more difficult, Larger sunshield is more difficult to deploy and demonstrate on the ground

• Concept 2 (Closed, Spitzer-like)
  • Pros: suppression of stray light, ground demonstration of thermal performance, can be fully deployed at launch
  • Cons: limits the primary size to the fairing diameter

• Operating Temperature
  • 4.5 K, allows sky background-limited performance
  • Compatible with mechanical cryocooler and sub-Kelvin cooler technology
Why Do We Need a 4.5 K Telescope?

OST will cover the wavelength range from 5 µm to 600 µm. The goal is to be background limited – limited by the cosmos rather than self emission from the telescope.
View without Barrel

- Outer Sunshield
- Inner Sunshield
- 35 K Barrel
- 4.5 K Baffle
- 5.9 m diameter primary
- 4.5 K Instruments
- Spacecraft
Sunshield

- Very simple deployment with 4 actuators and spring-loaded mechanisms similar to those used in other missions
- Sunshield design minimizes distance between center of pressure and observatory center of mass
  - Decrease fuel and overhead required for momentum unloading
- Deployment can be demonstrated on the ground
  - Test-as-you-fly
Major Architecture Trades-1

- **Telescope size**
  - JWST collecting area to capture transit spectroscopy from enough Earth-like planets

- **Deployed vs. Non-deployed**
  - Non-deployed optics for simplicity
  - SLS (or BFR) required but viewed as less risky than deployment

- **On- vs. off-axis**
  - On axis for ease of packaging

- **Size of primary mirror segments**
  - JWST size, but forming circular aperture
    - 18 segment with only two prescriptions
    - Manufacturing facilities exist
Major Architecture Trades-2

• 3-mirror vs. 2-mirror design
  • 3 mirror allows use of Field Steering Mirror

• Beryllium vs. Silicon Carbide and other materials
  • Beryllium chosen over silicon carbide for mass savings and higher thermal conductivity (isothermal structure and mirrors)

• Instrument Complement (priority order)
  • OSS (Far IR Spectrometer)
  • MISC (Mid Infrared Transit Spectrometer)
  • FIP (Far-IR Imager and Polarimeter)
Cryogenic Design

- Staged cryogenic system provides immunity to external disturbances
  - 2 layer sunshield (~140 K)
  - Deep space radiator (35 K)
  - 3 stage cryocooler (70 K, 20 K, 4.5 K)
    - 4 TRL4-5 cryocoolers in parallel gives 100% margin over current heat loads
    - Higher TRL chosen over larger, somewhat more efficient cryocoolers
      - NASA has 20 years of technology development in this kind of cryocooler
      - Jitter requirement is met with standard soft-mount techniques
  - Nothing warmer on the colder side of a shield
    - Thermal analysis is simpler and more amenable to back-of-the-envelope calculations
  - Use cold amplifiers to bring low level signals to room temperature

Thermal analysis shows > factor of 2 margin at each cooling stage
Instruments

• Far IR Spectrometer (Origins Survey Spectrometer)
  • Wavelengths 25-588 µm
  • Resolution from 300 to 3x10^5 (lambda/delta lambda)

• Mid IR Transit Spectrometer
  • Wavelengths 2.8-28 µm
  • Densified Pupil Method purposely not focused on detector array – allows less stringent mirror focus quality

• Far IR Imager and Polarimeter
  • Wavelengths 50 and 250 µm
Testing/Verification

• JSC Chamber A, which was used for JWST, is large enough and cold enough to thoroughly test OST
• Full sunshield deployment will also be tested on ground
• Full end-to-end test of entire observatory in thermal/vac is planned – “test-as-you-fly”
• Shorter I&T overall than JWST because intermediate ISIM step is not needed
Enabling Technologies for OST

- Far IR Detectors -- FIP, OSS
- Mid IR Detectors -- MISC transit channel
- 4.5 K Cryocoolers -- FIP, OSS, HERO, telescope
  - Several qualified vendors (NGAS, Ball, Lockheed, and Creare)
  - SHI 4.5 K cryocooler with required specs has flown on Hitomi
- SubKelvin Coolers -- FIP, OSS
  - Ongoing SAT to develop continuous ADR from TRL 4->6
Enhancing Technologies for OST

• Lightweight, cryogenic-compatible, low cost optics
  • Actuators and new fabrication techniques

• Cryogenic Deformable Mirror for Wavelengths 2.8-11 microns
  • Would be needed for Mid-IR Imager
Summary

• OST addresses three astrophysics themes:
  • Are we alone? (biosignatures in transiting exoplanets)
  • How did conditions for life develop? ("follow the water")
  • How does the universe work? ("the rise of metals")
• OST’s architecture is simple, and is “test-as-you-fly”
• Cooling technology has rapidly evolved and will be ready by 2020
• Detector technology has a clear path to be ready by 2025
• Mirror technology needs are lighter cheaper cryogenic optics, and cryogenic deformable mirrors for the mid infrared

Questions?
Back Up
Far IR Detectors
Focal Plane Array

• Require
  • $10^4$ scalable to $10^6$ pixels with $<3\times10^{-19}$ W/\(\text{VHz}\) NEP (imaging) ($10^4$ pixels is enabling)
  • Reduce readout frequencies / electronics power dissipation
  • $<3\times10^{-20}$ W/\(\text{VHz}\) NEP (spectroscopy) (enabling, OSS) with $3\times10^{-21}$ background limited detection (enhancing)
  • Reaching enabling numbers decreases the observing time by factor of $\sim 100$ and increases areal coverage by 10-100 times

• SOA
  • 325 bolometers with $4\times10^{-17}$ W/\(\text{VHz}\) NEP (TRL9 Herschel/SPIRE)
  • 5120 pixels with low $10^{-16}$ W/\(\text{VHz}\) NEP (TRL 5 SCUBA 2)
  • Sensitive (NEP low $10^{-19}$ W/\(\text{VHz}\)), fast detectors (TES bolometers, and MKIDs in kilo pixel arrays) are at TRL 3.

• Path to get there: Develop MKID, TES, and QCD detector technologies in parallel

Three technologies offer multiple paths to required resolution and array size.
Far IR Detectors
Multiplexing and Amplification

• Require
  • 4 GHz Bandwidth per 2000 pixels
    • Microwave SQUIDs and/or discreet resonators for frequency domain multiplexing
    • Low dissipation at 4 K (0.3 mW per 2000 pixel amplifier)

• SOA
  • LNF HEMT is commercial part
  • SQUIDs under development at NIST and SRON have demonstrated necessary resonator spacing but for smaller total numbers (<200)
  • LNF HEMT shows proper noise and gain for 0.36 mW/channel

• Path to get there
  • Continue testing SQUID multiplexers and LNF HEMTs
  • X-ray microcalorimeters for Athena and Lynx require similar technology advances

Follow x-ray microcalorimeter SQUID developments and test LNF HEMTs
Far IR Detectors
Room Temperature Readout

• Require
  • Low dissipation at per readout channel

• SOA
  • FPGA requires 40 W per channel
  • Emerging RFSoCs (specialized FPGAs) need ~10 W (mobile phone 5G technology)

• Path to get there
  • Hardware RFSoC codes adapted for our use
  • Follow with ASICs to lower power by another >factor of 4

Leverage 5G technology to lower input power required
Mid IR Detectors

• Require: 5 ppm stability over 1-2 hours

• SOA:
  • 30 ppm (JWST/MIRI),
  • HgCdTe tests show good dark stability

• Path to get there: More HgCdTe testing, develop calibration sources with required stability

Excellent background stability measured in HgCdTe
4.5 K Cryocoolers

• Require: 200 mW cooling at 4.5 K + 400 mW cooling at 20 K + 20 W cooling at 70 K with input power of 2250 W
  • Includes 100% margin
  • Note that expected cryocooler-induced jitter has been shown to be not an issue even for the most sensitive instrument, MISC

• SOA: MIRI cooler has 65 mW cooling at 6 K + 203 mW cooling at 18 K 425 W input power

• Path to Get There: use 4 MIRI coolers with $^3$He as working fluid (to reach 4.5 K) or use Ball, Lockheed, or Creare coolers

Multiple manufacturers with TRL 4+ technology offer multiple paths to success