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)
    - 5 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
Thermal Zones

- **Single Stage Radiator**: 30-35 K, 1.5-2.9W
- **Outer Barrel**: 32-35 K
- **Inner Baffle (4K)**
- **Room Temperature (Spacecraft, Instrument electronics)**
- **Sunshields**

NASA ORIGINS Space Telescope
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
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
Far IR Detectors-1
Focal Plane Array

• Require
  • $10^4$ scalable to $10^6$ pixels with $<3 \times 10^{-19}$ W/√Hz NEP (imaging) ($10^4$ pixels is enabling)
    • Reduce readout frequencies / electronics power dissipation
  • $<3 \times 10^{-20}$ W/√Hz NEP (spectroscopy) (enabling, OSS) with $3 \times 10^{-21}$ 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 $4 \times 10^{-17}$ W/√Hz NEP (TRL9 Herschel/SPIRE)
  • 5120 pixels with low $x10^{-16}$ W/√Hz NEP (TRL 5 SCUBA 2)
  • Sensitive (NEP low $10^{-19}$ W/√Hz), 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.
State-of-the-art NEP and Array Size

[Graph showing NEP vs. number of pixels for various instruments]
Far IR Detectors-2
Multiplexing and Amplification

• Require
  • 4 GHz Bandwidth per 2000 pixels
    • Microwave SQUIDs and/or discrete 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 0.3 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-3
Room Temperature Readout

- Require
  - Low dissipation at per readout channel
- SOA
  - FPGA requires 40 W per channel
  - Emerging RFSO Cs (specialized FPGAs) need ~10 W (mobile phone 5G technology)
- Path to get there
  - Hardware RFSO C 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
  • SHI 4.5 K Cryocoolers have flown on Hitomi (2106)

• 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
Sub-Kelvin Coolers

- Require: 6 µW of cooling power at 50 mK
- SOA: 0.4 µW@ 50 mK demonstrated on orbit by Hitomi. Lab demo 6 µW@50 mK of cooling power at TRL4. Electronics at TRL 6 (same cards have flown)
- Path to Get There: SAT-funded development to achieve TRL 6 for a continuous ADR cooling to 50 mK with 6 µW of cooling power. Use same electronics as Hitomi.

TRL 4 demonstrated, TRL 6 funded for 2019 demonstration. High cooling power at lower T also provides another path for meeting Far IR NEP resolution in TES.
Summary

• 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 based on previous development progress