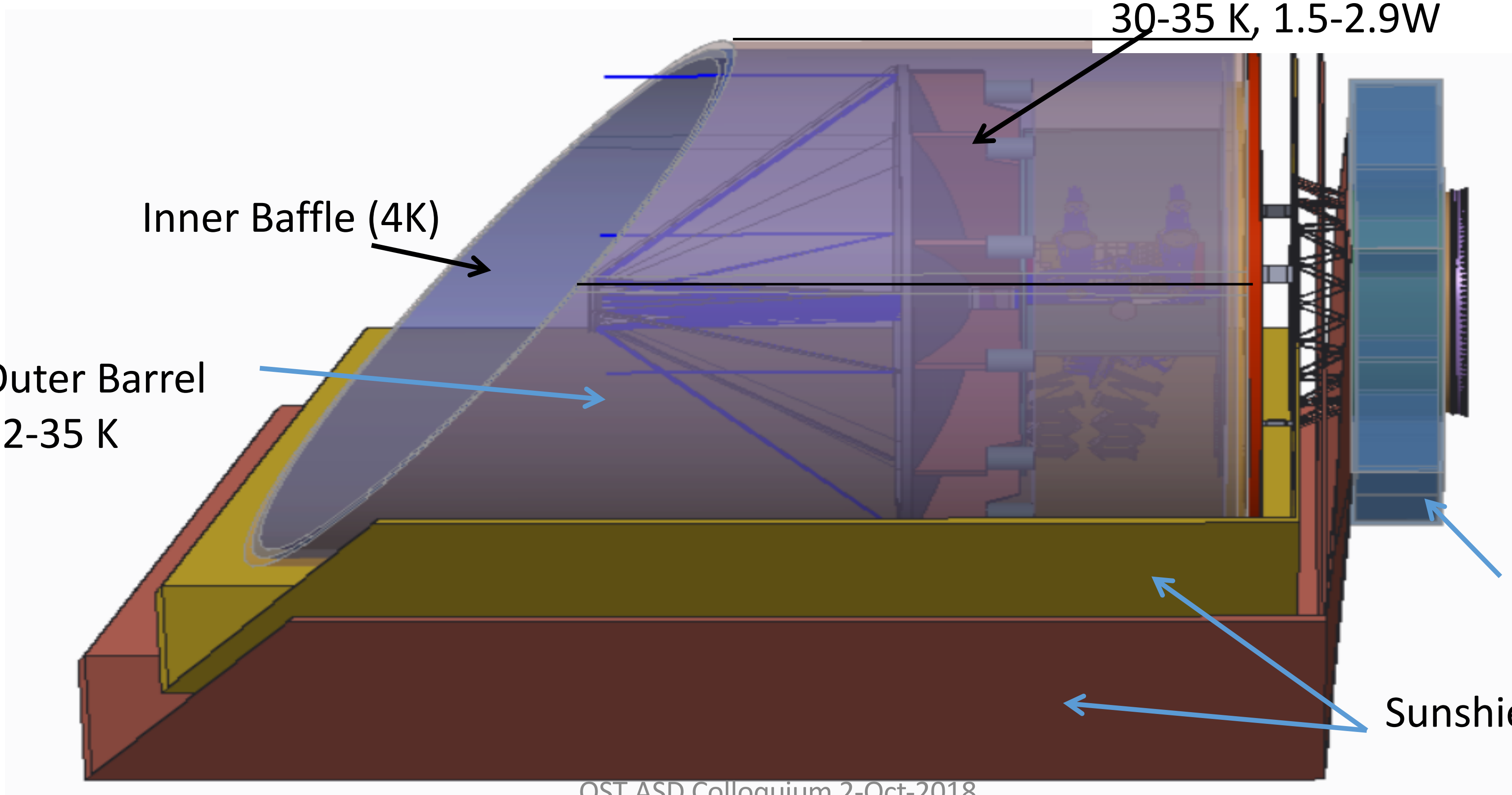
Cryogenic Design

- 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



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

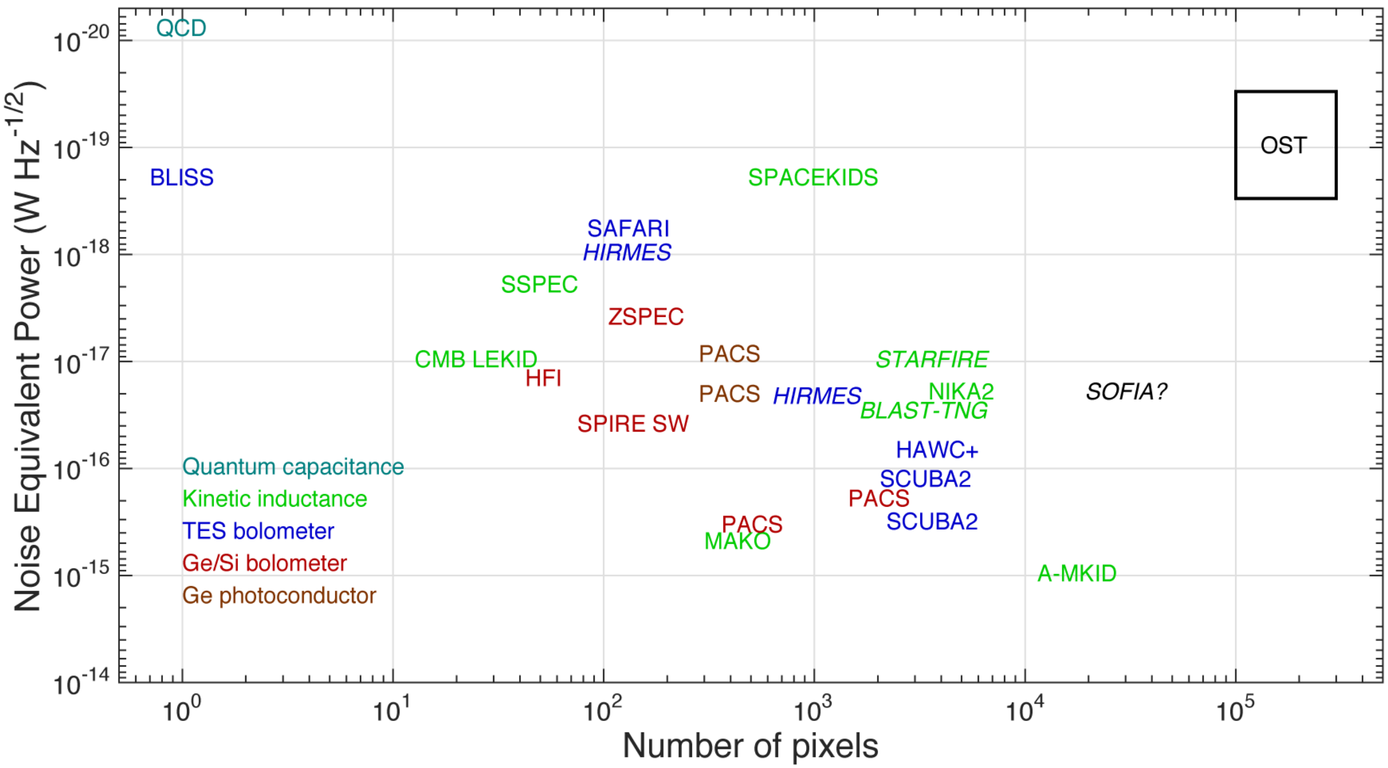
Far IR Detectors-1

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 3×10^{-21} background limited detection (enhancing)
  - Reaching enabling numbers decreases the observing time by factor of ~100 and increases areal coverage by 10-100 times
- SOA
  - 325 bolometers with 4×10^{-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



Far IR Detectors-2

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 0.3 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 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

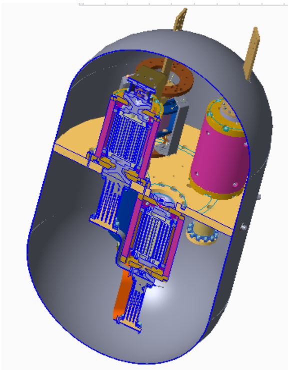
4.5 K Cryocoolers

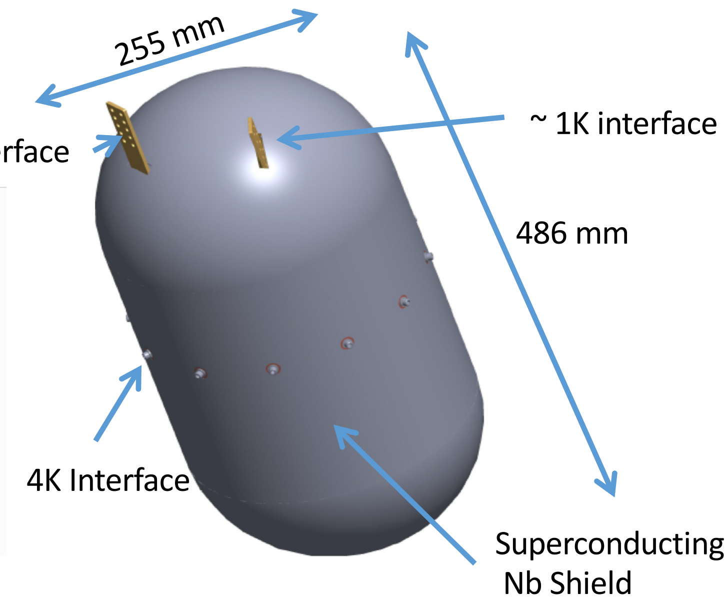
- Require: 200 mW cooling at 4.5 K + 400 mW cooling at 20 K + 20 W cooling at 70 K with input power of 2250 W
  - Includes 100% margin
  - Note that expected cryocooler-induced jitter has been shown to be not an issue even for the most sensitive instrument, MISC
- SOA: MIRI cooler has 65 mW cooling at 6 K + 203 mW cooling at 18 K 425 W input power
  - SHI 4.5 K Cryocoolers have flown on Hitomi (2106)
- Path to Get There: use 4 MIRI coolers with ^3He 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