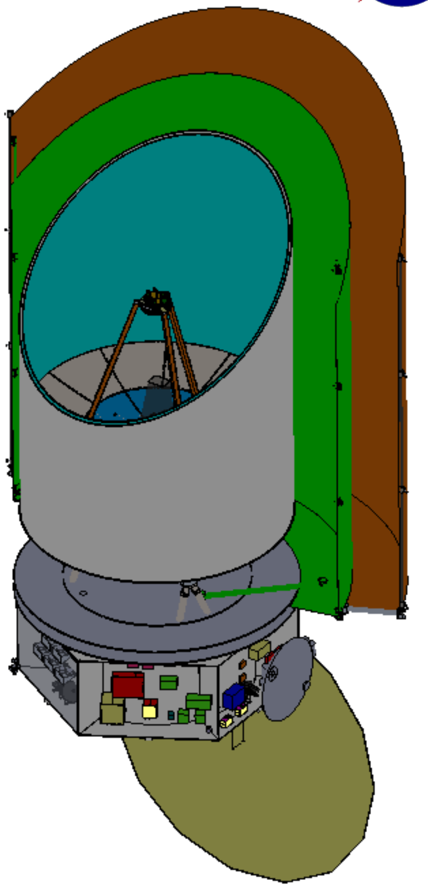
# The Origins
# Concept Study for the 2020 Decadal Survey


Mike DiPirro/NASA-GSFC

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

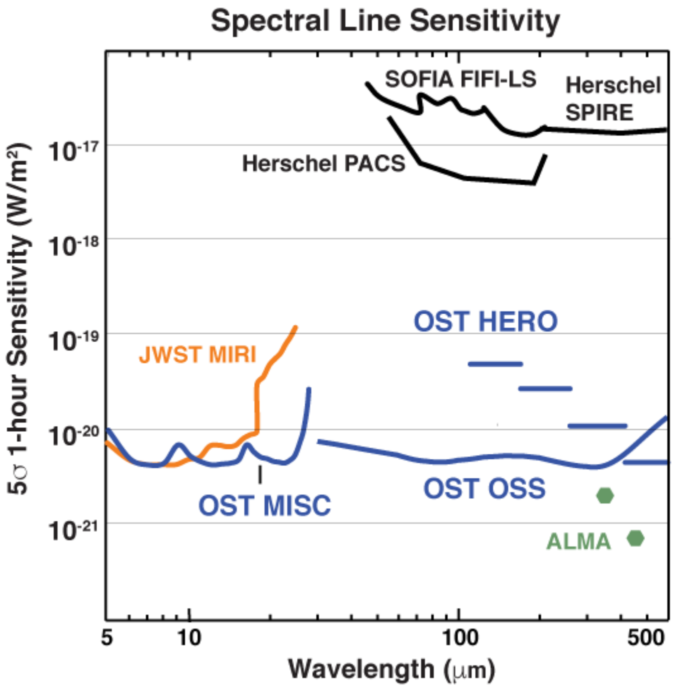
# Top three themes

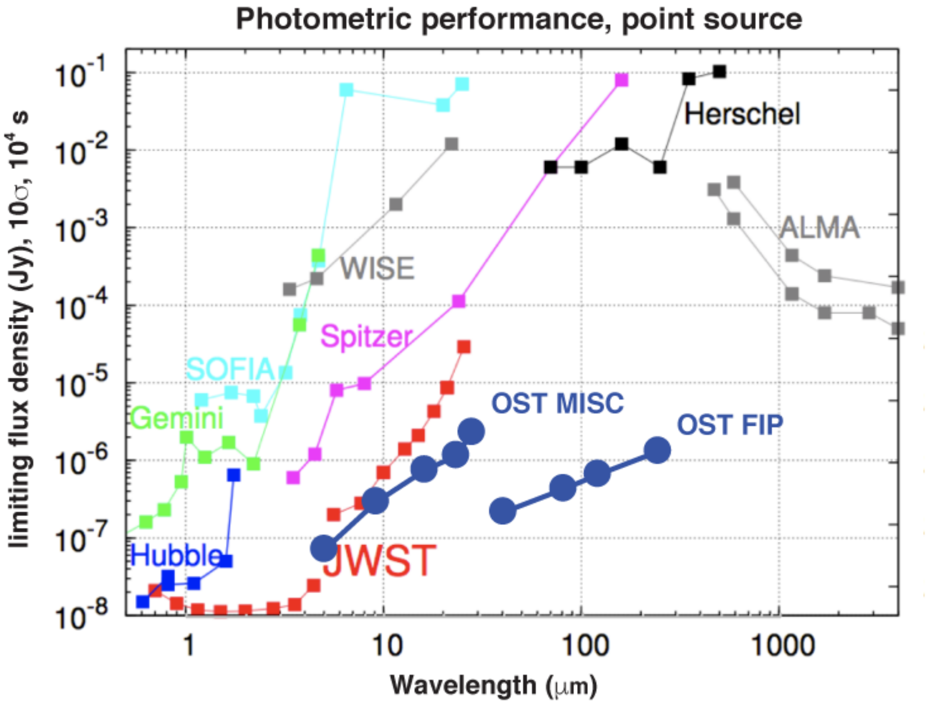
(I) How does the Universe work? OST question: How do galaxies form stars, make metals, and grow their central supermassive blackholes from reionization to today? *OST will spectroscopically 3D map wide extragalactic fields to measure simultaneously properties of growing super-massive blackholes and their 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.*

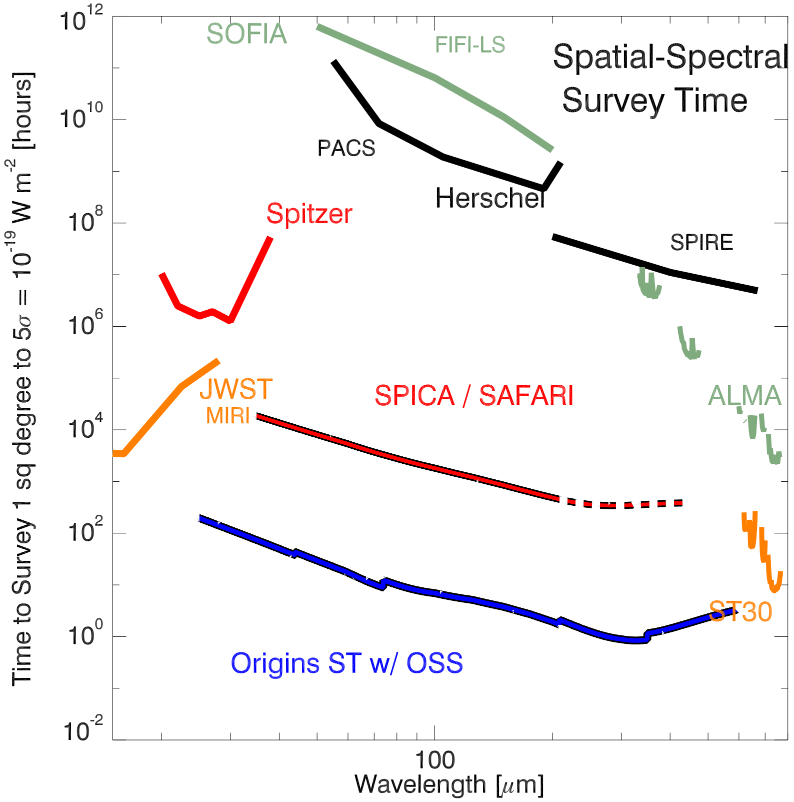
(III) Are we alone? OST question: How common are life bearing planets around M dwarf stars? *With sensitive mid-infrared transit spectroscopy, OST will measure biosignatures, including ozone, carbon-dioxide, water, and methane in the atmospheres of Earth-sized habitable exoplanets.*

# Sensitivity Improvement



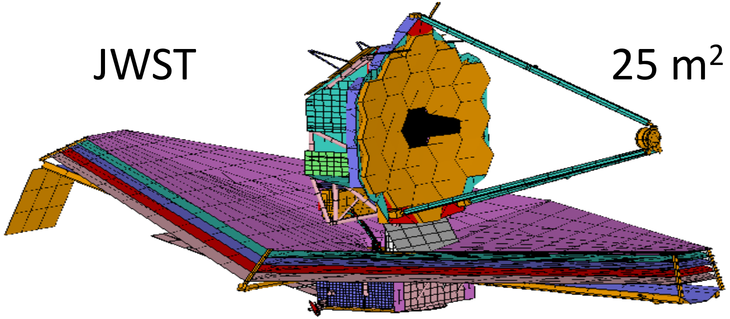



# Mapping Speed

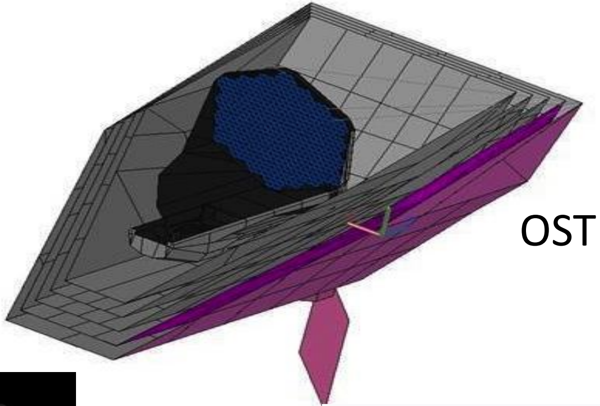


# Overall Architecture

JWST



25 $m^2$



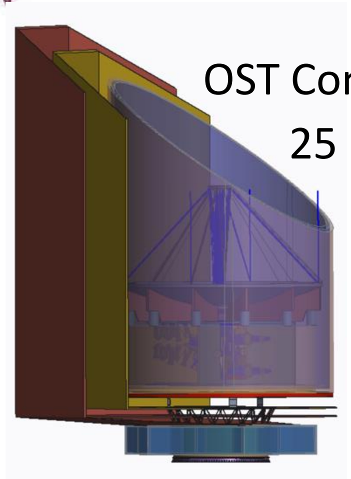
OST Concept 1

52 $m^2$

- 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

Spitzer

0.5 $m^2$



OST Concept 2

25 $m^2$

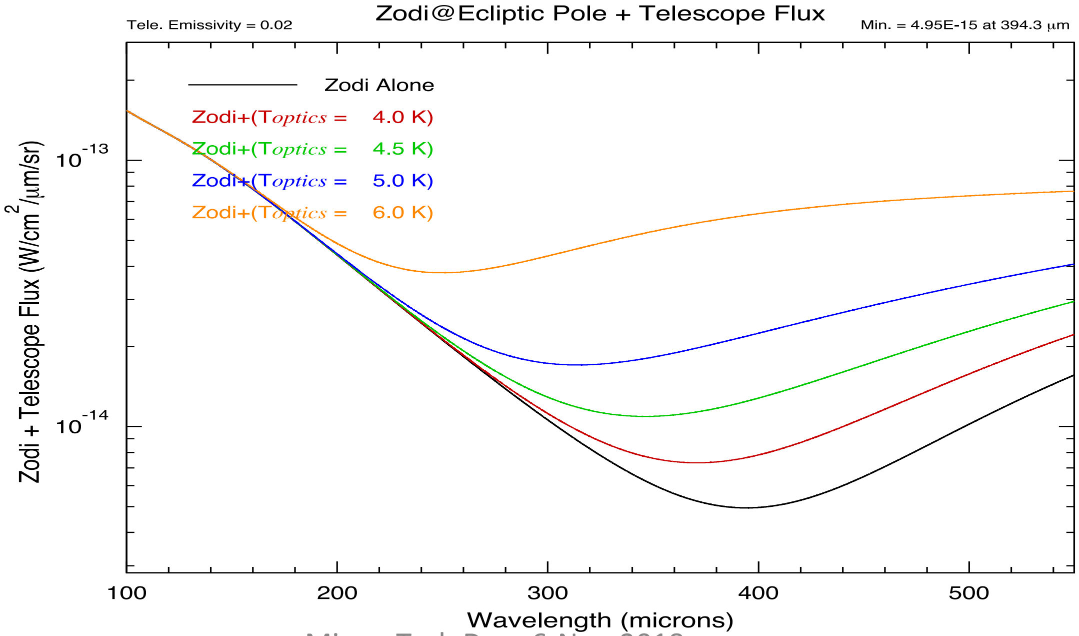
# Architecture Features

- 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

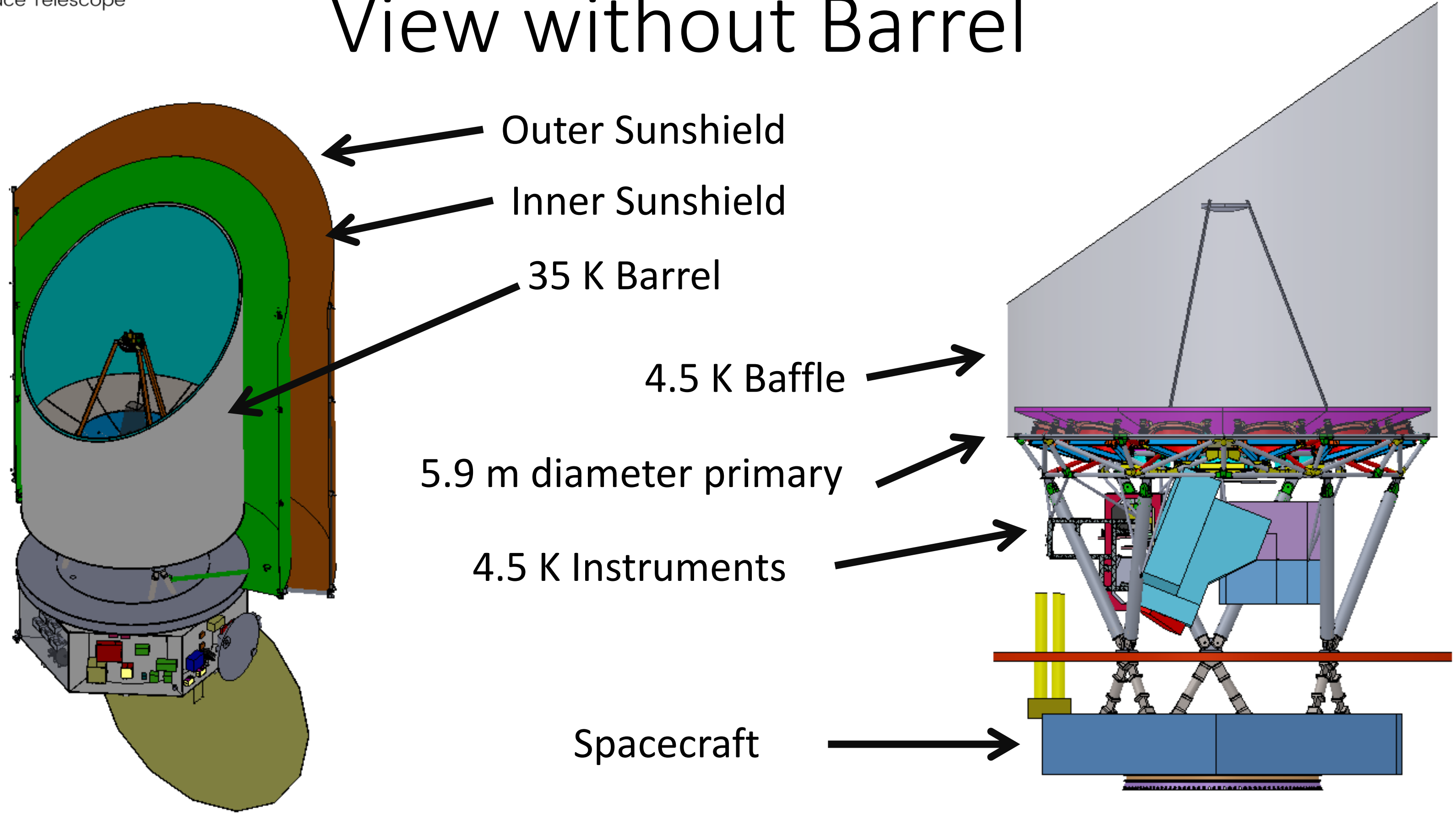
# Why Do We Need a 4.5 K Telescope?

## 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

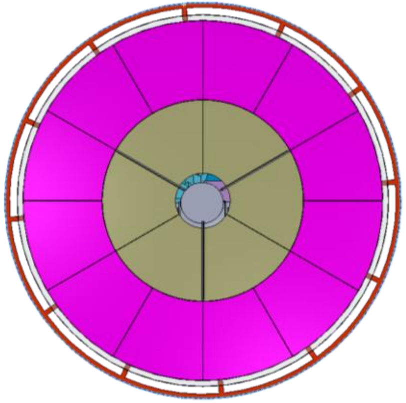


# Sunshield

- 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)

ORIGINS Space Telescope

NASA

# 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 $3\times10^5$ (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

ORIGINS Space Telescope

# 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 $<3 \times 10^{-19}$ 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 ~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 $\times 10^{-16}$ 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.

# 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 $^3He$ 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