Cooling the Origins Space Telescope

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What is OST?

• NASA Headquarters Astrophysics Division commissioned 4 studies for one possible flagship mission to launch in the 2030s
  – Lynx (X-ray Surveyor)
  – LUVOIR (Large UV, Optical, and near InfraRed Observatory)
  – HabEx (Habitable Exoplanet mission)
  – Origins Space Telescope (OST) (Far IR Surveyor)
Why Do We need a 4.0 K Telescope?

- OST will cover the wavelength range from 6 µm to 600 µm
  - The goal is to be background limited – limited by the cosmos rather than self emission from the telescope
How Big is This Thing?

OST 9.1 m primary

JWST 6.7 m primary

16 m

25.4 m

14.4 m

19.8 m
One Question

• How can we do a 9 m diameter 4 K telescope when a 6.7 m 40 K telescope (JWST) was so difficult?
  – Cryocoolers are now more mature
    • Cryocoolers at low temperature have a huge advantage over radiative cooling at low T
  – OST has a longer wavelength so the optics are less challenging
  – Low temperature has advantages
    • Low thermal contraction with changing temperatures for one
  – The design is driven by cryo/thermal considerations
  – Cryogenics leads to solutions!!!
State of the Art for cooling

• ACTDP and follow up matured coolers from 3 different companies
• Approximately 10,000 W of input power per W of cooling power
• Space Cryocooler Reliability is Extremely High
  – From Ron Ross’s ongoing survey
Cooling Power Vs. T

Heat lift at all stages normalized to cold stage to determine specific power

Cooler Specific Power, W/K

Temperature, K

Lab coolers @ 4K,6K in red
RAL/Astrium 4K J-T/Stirling
Sumitomo 4K J-T

Lockheed ACTDP actuals

Astrium 10K
Astrium 20K
Astrium 50-80K
TRW 3503
TRW 3595
AIRS
SMTS

PLANCK goal
Ball 6K precooler
HIRLDS
Ball SB335
Lockheed HCC
Raytheon PSC
Ball SB235

TRW GIFTS
TES

LM MPT
LM HiPwr MPT
TRW Kodak130K

CREARE 65K SSRB
CREARE NICMOS

CARNOT (300-Tc) Te

ORIGINS
Space Telescope

NASA
Staged Cooling

• Utilize staged cooling to go from 300 to 0.05 K
  – Start with radiative cooling of the sunshield
  – Use 3 stages of cryocooler cooling
  – Finish with a subKelvin cooler to provide 50 mK
Nominal Heat Flows

• Rough calculation of the heat absorbed by the 4 K cryocooler stage is broken down as follows:
  – Telescope: radiation: 55 mW, conduction from structure 20 mW, conduction from harnesses 30 mW
  – Instrument dissipation: Maximum 100 mW mainly from low temperature preamplifiers

• Will use eight 50 mW cryocoolers in parallel which provides redundancy, 100% margin on the expected cooling load, and keeps size close to current technology
Sunshield Principle

• Radiate horizontally, block radiation perpendicular

• Practical Considerations
  – Solar pressure imbalance
  – Deployment
  – The Sun, Earth, and Moon do not stay in one place
Keep Out Angles

Moon

Earth

L2 Orbit

OST

Field of Regard adds to shield size
OST Pitch=+5°/-45°, Roll = ± 5°, Yaw = 360°

Sunshield Width vs. L2 radius

Layer 5 width (m)

Layer 5 angle (degrees)

L2 Radius (km)

Layer 5 width

Protection Angle

Selected for this study

No Earth Shadow

Occasional Moon Shadow
Solar Pressure

• Ideally the center of solar pressure (~9 µPa) and center of mass are in the same place
• Any offset must be overcome with momentum wheels and propulsion
  – Aside from mass, frequent propulsive maneuvers disrupt observing time
• [Two Cases]
Solar Torque - Two Cases

[Graphs of OST Sunshield Solar Pressure Torque and SRP Torque with time in seconds and torque in Nm]
Cryocooler Considerations

- Staged heat extraction
- Vibration issues
  - Not so much for image stabilization as for microphonics on detectors
- Packaging and distributing cooling
- 50 mW cooling at 4 K plus 20 K and 70 K cooling for 500 W of input power
Sub-Kelvin Cooling

- Instruments whose detectors require cooling to less than 1 K will be sized to accommodate a provisional sub-Kelvin cooler. Such a cooler is currently at TRL4 and will be at TRL6 by the end of the current SAT (end of 2019)
  - Up to 5 µW continuous cooling at 50 mK (max duty cycle)
  - Up to TBD mW cooling at ~1K
  - Heat rejection to 4 K
    - 6 mW (at max duty cycle), 3 mW at min duty cycle
  - Magnetic shielding to provide < 1µT at the boundary of the cooler
  - Mass ~ 21 kg
  - Volume (see graphic)
Multi-Stage ADR Sub-Kelvin Cooling

50 mK interface

4K Interface

255 mm

~ 1K interface

Superconducting Nb Shield
Summary and Conclusions

• The Origins Space Telescope is being studied as a flagship class astrophysics mission for the 2030’s
  – 9.1 m diameter primary operating at 4 K
    • Cooling is achieved by proper staging of radiative coolers (sunshields), mechanical cryocoolers
  – 4 K and lower instruments
    • 3 instruments require subKelvin (50 mK) temperatures which could be provided by new continuous adiabatic demagnetization refrigerator