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 2030’s
  – 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
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

- Lab coolers @ 4K, 6K in red
- RAL/Astrium 4K J-T/Stirling
- Sumitomo 4K J-T
- Lockheed ACTDP actuals
- Astrium 10K
- Astrium 20K
- Astrium 30K
- SMTS
- TRW 3563
- TRW 3565
- AIRS
- TRW 50-80K
- Creare 65K SSRB
- TRW 65K-80K
- Creare NICMOS
- TRW Kodak 130K
- LM MPT
- LM HiPwr MPT
- LM HiPwr MPT
- CARNOT (300-Tc) Te
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

Earth

OST

L2 Orbit

Moon

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

• Ideally the center of solar pressure (\(\sim 9 \ \mu\text{Pa}\)) 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
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

255 mm

~ 1K interface

4K 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