Cryogenics for future Space missions

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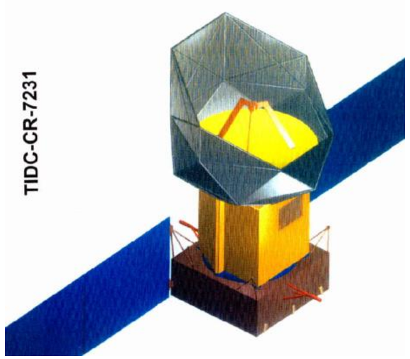
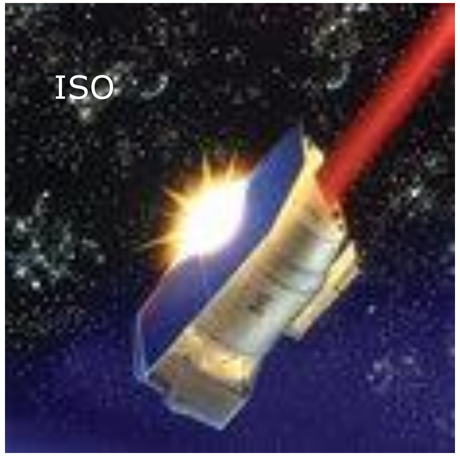
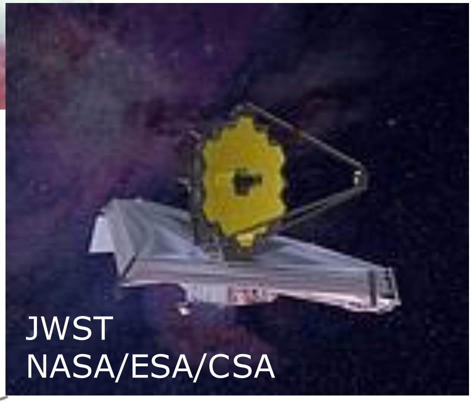
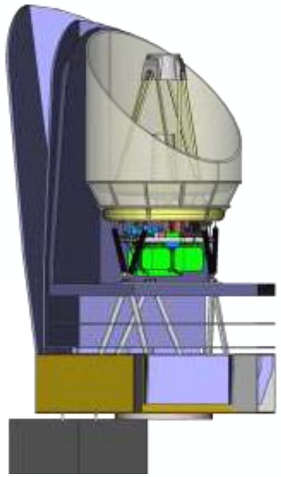
History of ESA cryogenic Science studies and missions



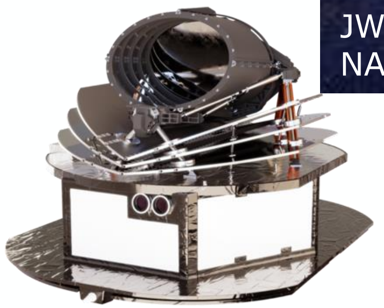
FIRST







SPICA
ESA/JAXA



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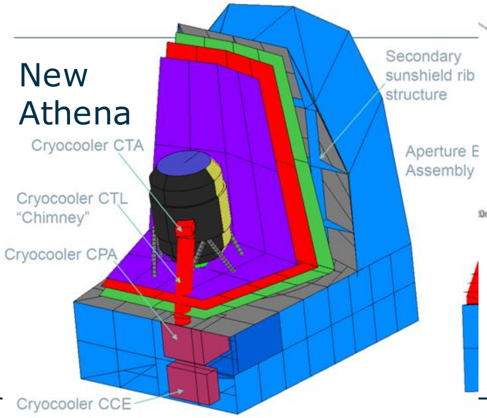
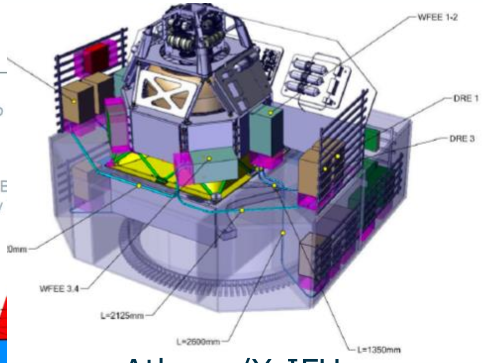




Athena/X-IFU

History of space cryogenics in ESA

- Space Cryogenics first used on ISO in 1995
- Development of long life mechanical coolers by Oxford University/RAL end 80’s
  - Enabled long life cryogenic missions for Earth Observation and Science
  - Commercial products developed in Europe and USA
- Herschel/Planck in the 2000-2010 timeframe were 2 major cryogenic missions at their time
  - Employing CEA 300mK sorption cooler and 100mK open loop diluton cooler from Institut Neel/AL
- Several missions have been studied since the 2010’s in ESA Science
  - SPICA
  - Athena
  - CMB missions
  - EChO/Ariel
- Ariel is now in implementation Phase for a launch in 2029
- **Athena was meant as the next big space cryo mission, boosting the technologies for other M-class missions**

Why did Old Athena fail in Phase B1

Athena was meant to be the next big space cryo mission,qualifying the next generation of coolers
➔ this should have provided commercial products for M-class cryogenic missions

- Cryostat and cooler were transferred from CNES/JAXA to ESA
  - H/W and responsibility of cooler procurement under prime
  - 15K cooler and 4K cooler from different industrial entities ➔ doubled non-recurrent costs from the cooler suppliers
  - AIV of integrated X-IFU instrument including long verification/calibration

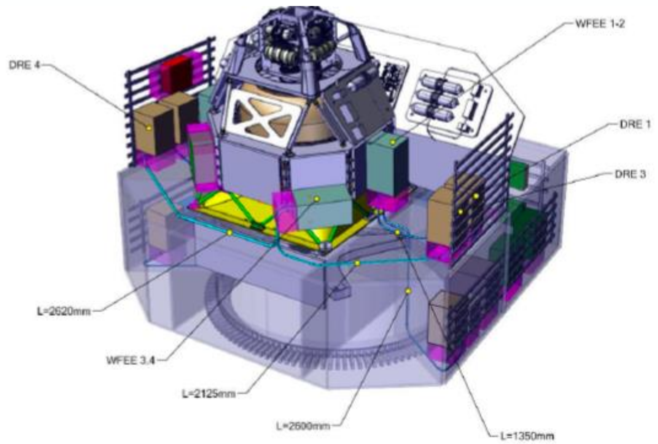
  ➔ Increased responsibility on prime side

- µ-vib and EMC responsibility of the cryogenics under Prime
  - 14 compressors in close proximity to the FPA

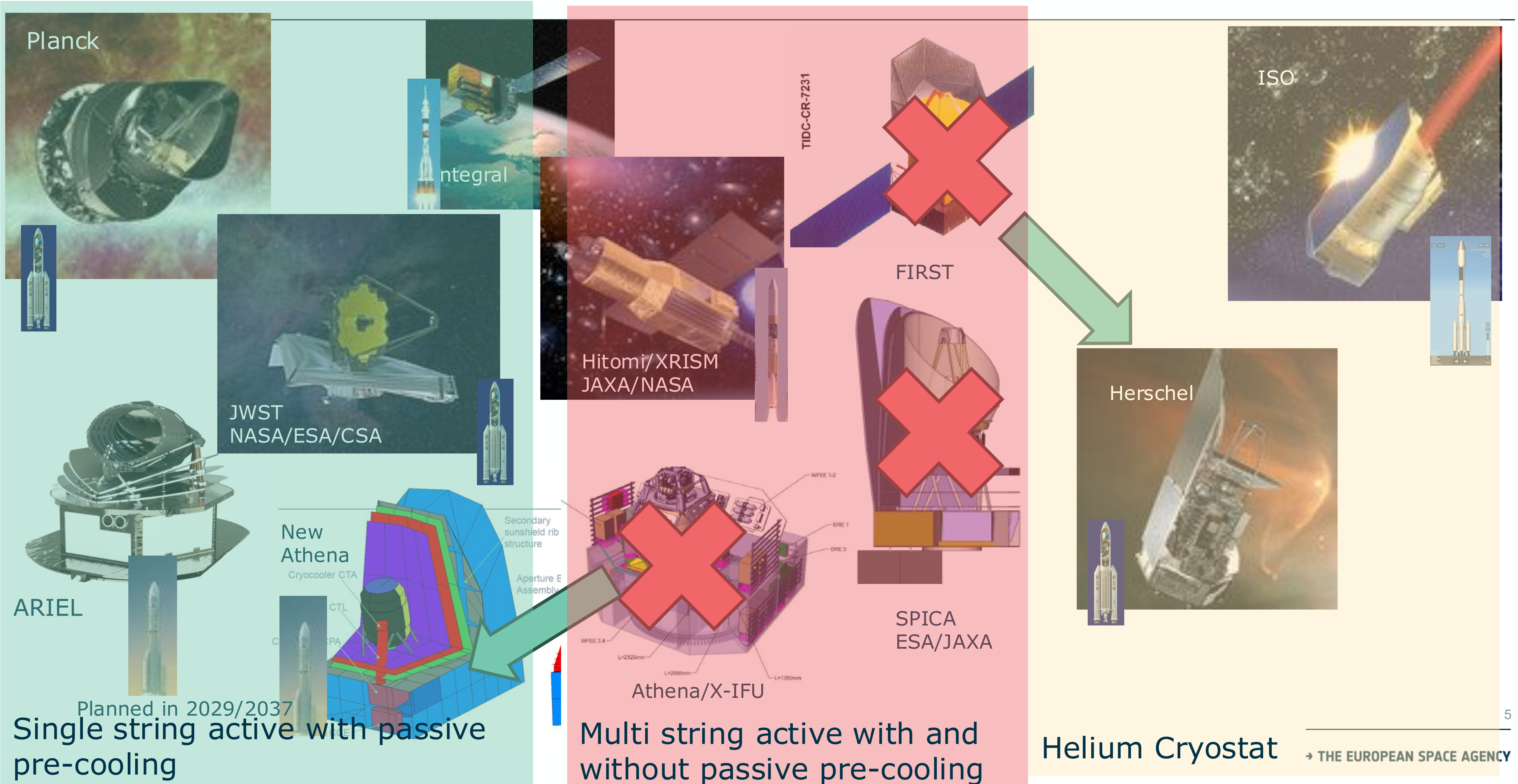
  ➔ High risk on feasibility, only de-risk at EM late in the programme

- Schedule increased by 3 years partly due to cryogenics and X-IFU
  - As planned schedule was 2 years longer than as run Herschel-Planck

- Significant risks moved from instrument to ESA/Prime



History of ESA cryogenic Science studies and missions



How to succeed with a New Athena payload

- Remove non-recurrent coolers from the system ➔ ask NASA for the JWST cooler
- Limit the number of coolers to the bare minimum (but keeping high reliability)
  - Passive cooling down to 50-60K required
  - 4K I/F instead of 2K I/F
- Move coolers far away from FPA to simplify EMC/µ-vibs as done on Planck
  - Avoid disturbances rather than try to control them, minimising engineering and verification
  - Enables to verify/calibrate X-IFU at Instrument level rather than on system level
- Simplify/accelerate AIVT at system level ➔ reduce schedule
- Reduce performance requirements to better manage risks at System level
  - Enables a simplified verification at system level
  - Still guarantying best engineering practises to minimise impact on instrument level and enabling the best performance in orbit

A V-Groove solution for Athena

A V-Groove solution was favoured by ESA in the beginning enabling:

😃 A quiet environment for X-IFU by providing 50K passive and remote active cooling, building on the heritage of Planck and Ariel

😃 X-IFU performance tests can be performed at instrument level only because of the quiet environment

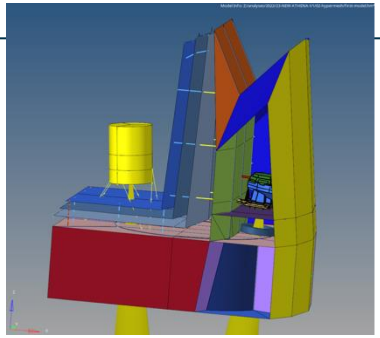
- Only functional end-to-end test required during TBTV
- No long performance tests at S/C level required

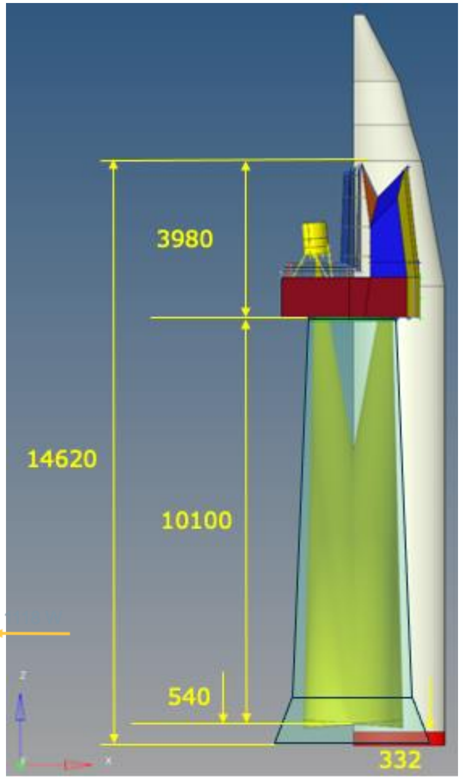
😃 Only a limited de-scope of instruments required (mainly to limit the thermal dissipation)

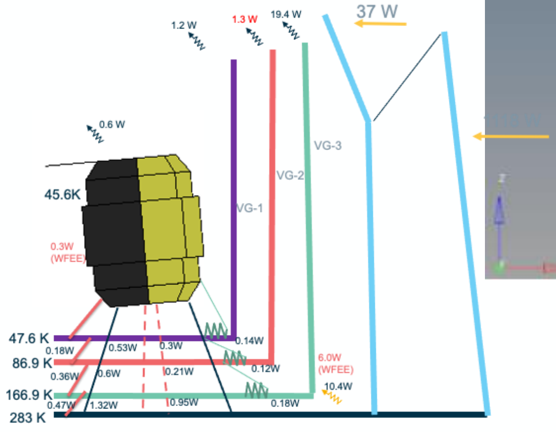
😃 Still a better performance than Hitomi/XRISM or eRosita

😃 Reduced number of active coolers

😡 More complex TB/TV test at S/C level required, special test facilities required ➔ heritage is available from Planck

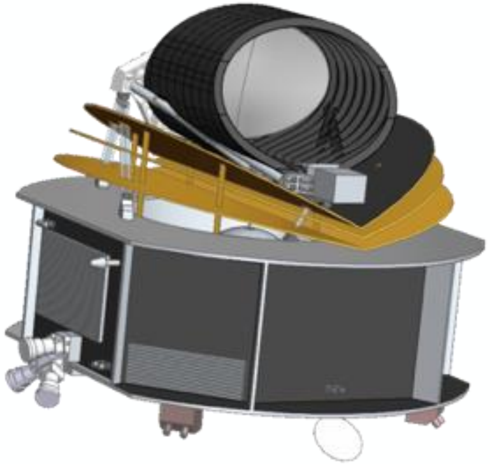




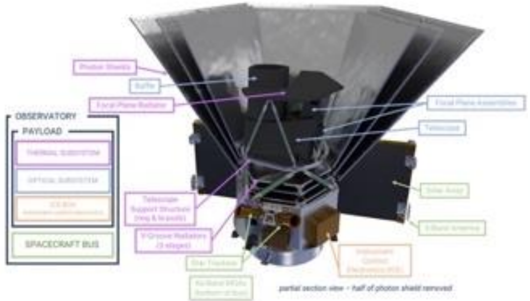


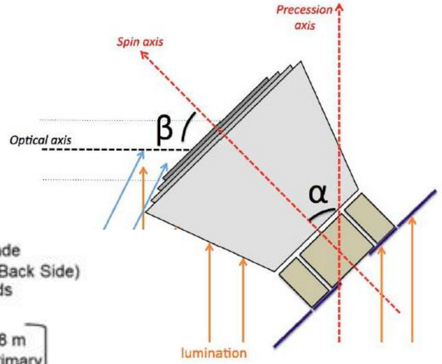
Early V-Groove configuration

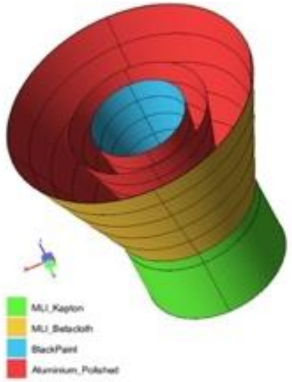
Alternative V-Groove systems

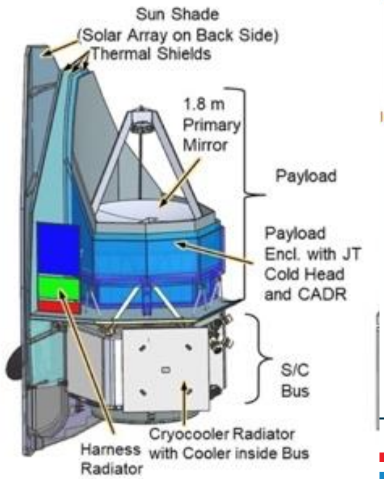


Mission /Study	Comment
Planck	➢ Slow spinner, full sky survey in L2 ➢ VGroove-3 passive cooling in orbit below 50K ➢ Tested in CSL with Helium shrouds ➢ Cold Payload mass (Instruments incl. coolers and reflector): ~180kg ➢ Shared launch and development with Herschel ➢ 20 K sorption cooler from JPL (US) ➢ 4K JT cooler from RAL (UK) ➢ 0.1K dilution from ALAT (FR)
Ariel	➢ 3-axis stabilised SC in L2 ➢ PLM to be provided by consortium ➢ PLM mass: ~500 kg ➢ To be tested in RAL Space using dedicated facility under development ➢ 32 K Ne-JT cooler from RAL (UK) ➢ Optics and FGS passively cooled to 60-80 K
CMB Polarisation Mission CDF study	➢ CDF study: https://sci.esa.int/s/AGdG7lw ➢ Spinner, Full sky survey
SphereX	➢ Small US mission in LEO (sun-synchronous) ➢ Full sky survey, always pointing away from the earth ➢ Temperature achieved 50-80 K ➢ https://spherex.caltech.edu
Modified SphereX concept	➢ Derived concept from SphereX in LEO (SSO 895km, dusk dawn) within the limits of Vega ➢ Limited pointing (±10deg away from anti-Earth) for ~ 15min ➢ 60-80K passive cooling for ~100kg cold payload
PRIMA (Astrophysics probe candidate for NASA)	➢ NASA/APEX mission candidate under study ➢ All Aluminum 1.8m Telescope at 4.5K ➢ Passive and active cooling ➢ https://prima.ipac.caltech.edu









An affordable 4K European cooler system

1. Non redundant system
    - Redundant cooler sizes the heat budget and drives the # cooler in the system
    - No failure observed in orbit, all workmanship/design problems on coolers detected during gorund test ➔ minimum cycles during ground testing required
2. Synergies with EO coolers
    - Large 15K PT cooler for Athena driven by the need to pre-cool at 15K a ^{3}He-JT cooler for a 2K I/F
    - 4K JT using ^{4}He only requires 20K pre-cooling, achievable with LPTC type compressors from EO
    - This also enables the re-use of qualified drive electronics
3. Provision of a 4K system instead of individual cooler
    - No duplication of system engineering and management at provider level
    - No duplication of tests at provider level
    - No I/F management at prime level
    - No repetition of cooler level tests at integrated system level by the prime

➔ An activity for a 4K cooler system has been added to the Science technology plan and ESA plans to start the activity in Q3/Q4 2025

A 4K system for M8

The overall costs of the 4K cooling system is driven by:

- Cryogenic support structure: as a guideline, the cold payload should not exceed 300kg
- V-Groove panels number and size: deployable systems should be excluded
- Active cooling system: The active 4K cooler is a significant contributor. Cooling down to 20-30K can be achieved with cheaper single stage systems (next chapter)
- Cryogenic testing: specific test facilities (e.g. need for Helium-cooled shrouds in vacuum chambers) and test duration are significant cost contributors. To limit these costs, it is assumed that only functional tests are performed at instrument system level (i.e. full performance and calibration is performed by the instrument provider prior to delivery) and that cooldown accelerators are implemented at instrument level
- System complexity: Additional requirements on the cryogenic system (e.g. EMC, microvibration, pointing) need to be critically assessed

Assuming a successful development of the 4K cooler system, the provision by ESA of a 4K cryogenic system for the payload will consume a significant part of the ESA CaC (e.g. in the range of ~8%) and hence excludes the provision of other payload elements by ESA (e.g. telescope, detectors).