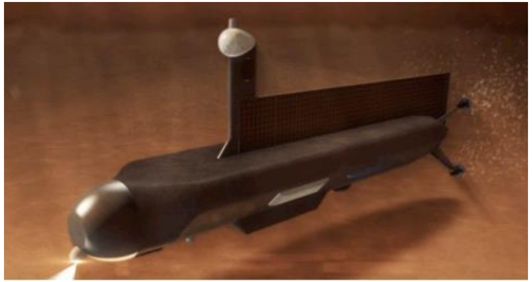
Air Liquide
creative oxygen

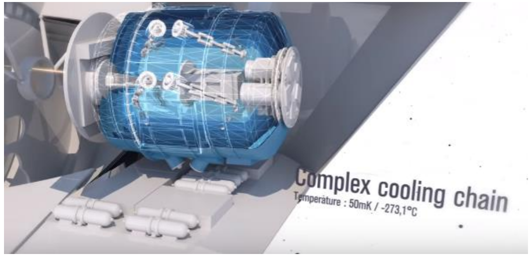
Pulse Tube Coolers for Earth Observation & Science

Introduction – why Space cryogenics ?

- Imposed by the environment
  - ❖ Example : explore Saturn's moon Titan



- For the purpose of observation performance
  - ❖ Detector cooling for IR in earth observation
  - ❖ Detector cooling for science payloads
  - ❖ Storage of biological samples

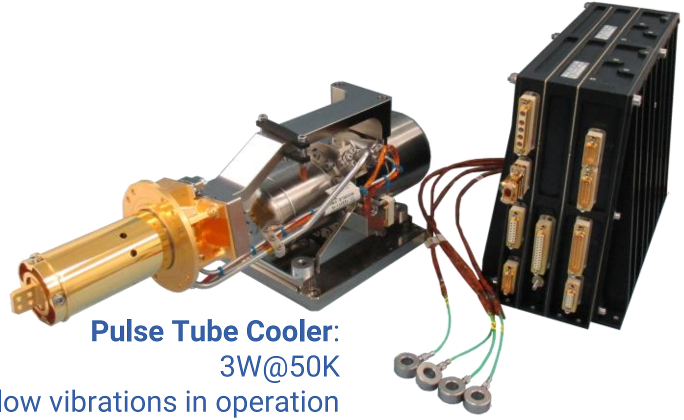


- For the purpose of propulsion optimization
  - ❖ Cryogenic propellant for launchers
  - ❖ Cryogenic propellant for deep space exploration

Air Liquide : A wolrd leader in Space Cryogenics

25 years experience

MELFI:
Turbo Brayton cooler 100W at -80°C for ISS
3 models operating in orbit with >80000 hour cumulated operation



Pulse Tube Cooler:
3W@50K
Very low vibrations in operation
Lifetime = 10 years in orbit
24 flight coolers for 4 instruments

HERSCHEL Superfluid Helium tank:
2400 L superfluid He
3.5 year autonomy
1.6K during all the mission

Planck Dilution Cooler:
From 1,6 K to 0,1 K
Launch lock mechanism using shape memory alloy
2.5 year autonomy (extended)
20,000 hours continuous operation : no failure!

Acknowledgements

Contributors to the work presented here :

ALAT team : René GARY, Diogo LOPES, Guillaume DARQUE, Jean-Michel NIOT, Simon CARPENTIER, Ian PENNEC, Guillaume BODOVILLE, Pascal BARBIER,…

Customer dream team : Thales Alenia Space, Airbus Defence & Space, OHB, CNES, ESA

Airbus CRISA, SITAEL : development of the electronics

Thales Cryogenics b.v. : development of the compressors

CEA SBT : cold fingers license

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Space coolers for Earth Observation projects

Air Liquide and Space Coolers

- Starting from 2009, The R&D effort started with the support of ESA and CNES concretised with orders from several programs:
  - French national : 6 flight coolers for Earth observation (delivered)
  - MTG: 12 flight coolers on two meteorological instruments (FCI and IRS)
  - METOP-SG: 6 flight coolers on IASI-NG instrument

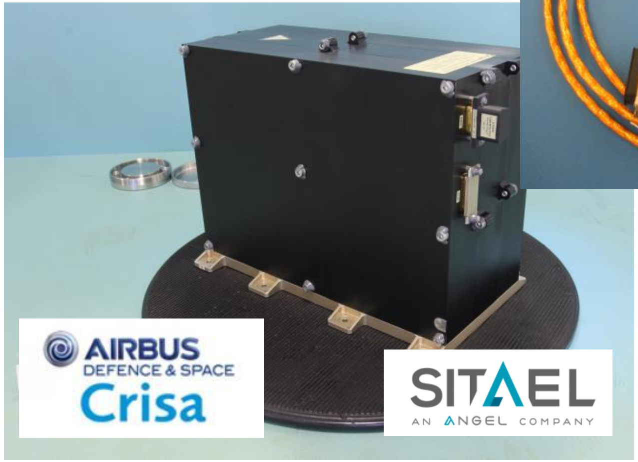
- Altogether, 24 flight coolers are to be manufactured, assembled, acceptance tested and delivered in a very short timeframe (3 years)

- To date, 10 flight coolers have been delivered, 2 are flying.

Air Liquide and Space Coolers
MTG Project & IASI-NG project

- A Large Pulse Tube Cooler (LPTC) is composed of

Cooler Control Electronics (CCE)



Telemetry and Power harness (TPH)

Cooler Mechanical assembly (CMA)

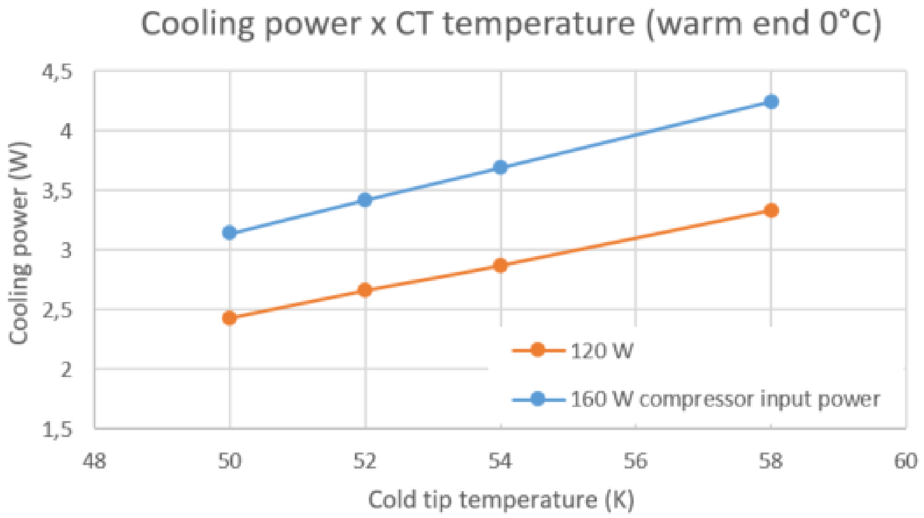
Air Liquide is responsible for the cooler system

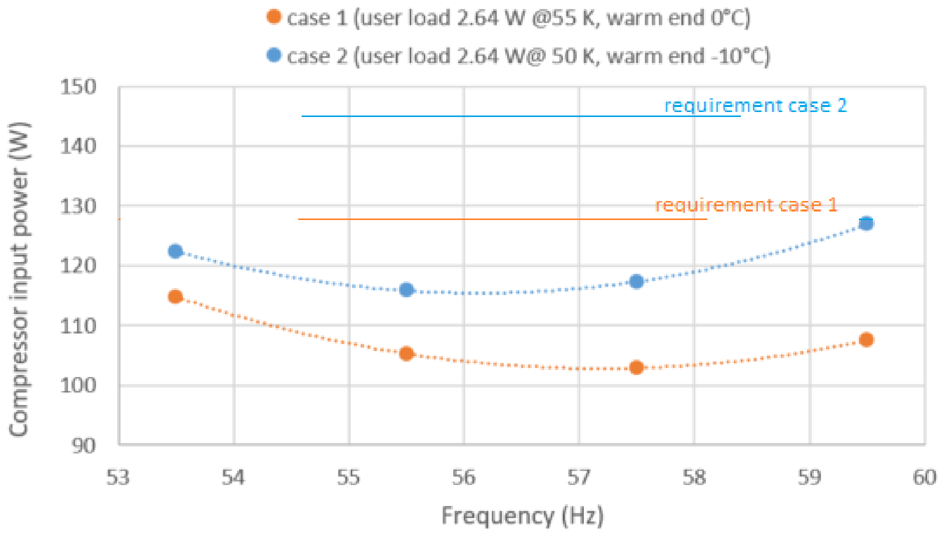
- Air Liquide handles the cooler technical specification, including electronics
  - Detailed design of the cold finger, buffer, inertance, split pipe
  - Flow down of specifications to compressor and electronics, follow up of development
  - Verification of all performances at system level

- Qualification of such cooler generally relies on several models
  - Engineering models, required for performance verification
  - Qualification models
  - Lifetime tests on some of these models

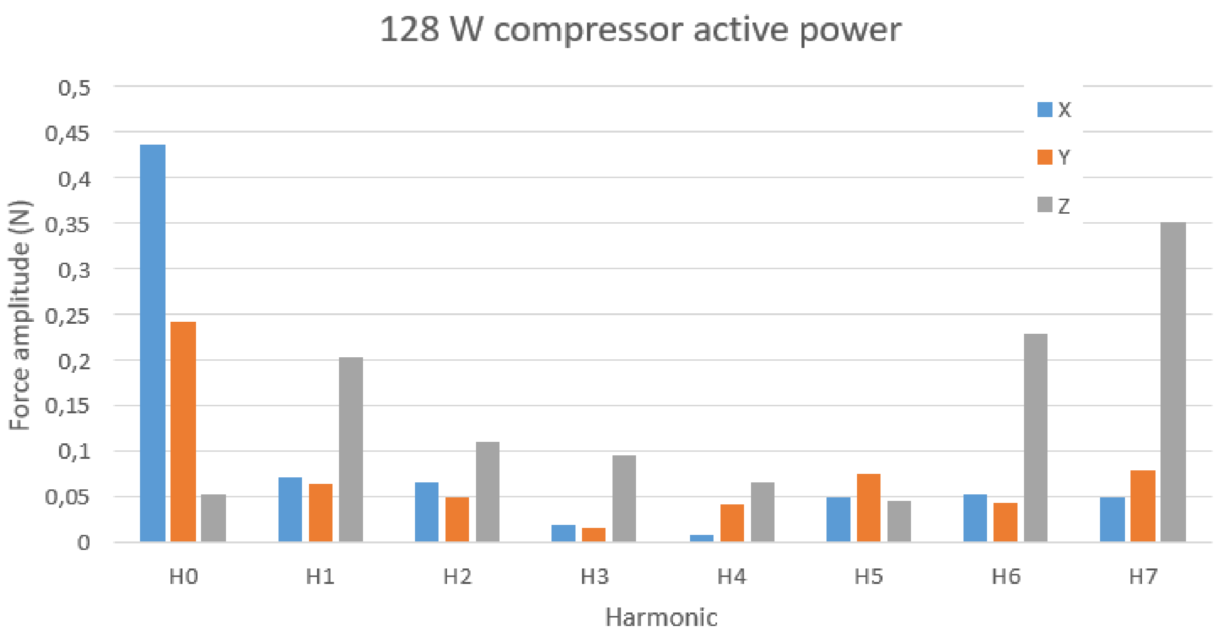
- Qualifications needed for some components, not initially space qualified
  - Temperature sensors, hermetic connectors, C-seals, vibration sensors

Typical cryogenic performances





Typical microvibrations performances



MTG instruments

Artist’s impression of MTG satellites

MTG satellites come in two brands : MTG-I and MTG-S

MTG-I : 4 satellites

IR imager called FCI (Flexible Combined Imager), instrument prime TAS-F

MTG-S : 2 satellites

IR sounder called IRS (InfraRed Sounder), instrument prime OHB Munich

One single Cryocooler requirement for both instruments

MTG instruments

FCI characteristics

Mass : 470 kg

Power : 530 W

Full earth imagery every 10 minutes

16 spectral channels

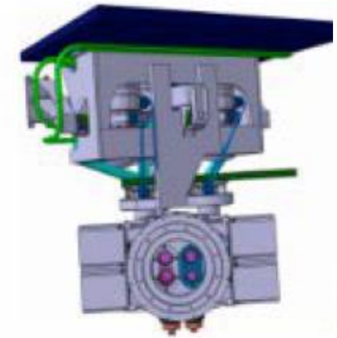
Resolution 1-2 km

Detailed imagery every 2.5 minutes

4 spectral channels

Resolution 0.5-1 km

Detector at 60K



MTG instruments

IRS characteristics

Mass : 470 kg

Power : 750 W

Michelson interferometer

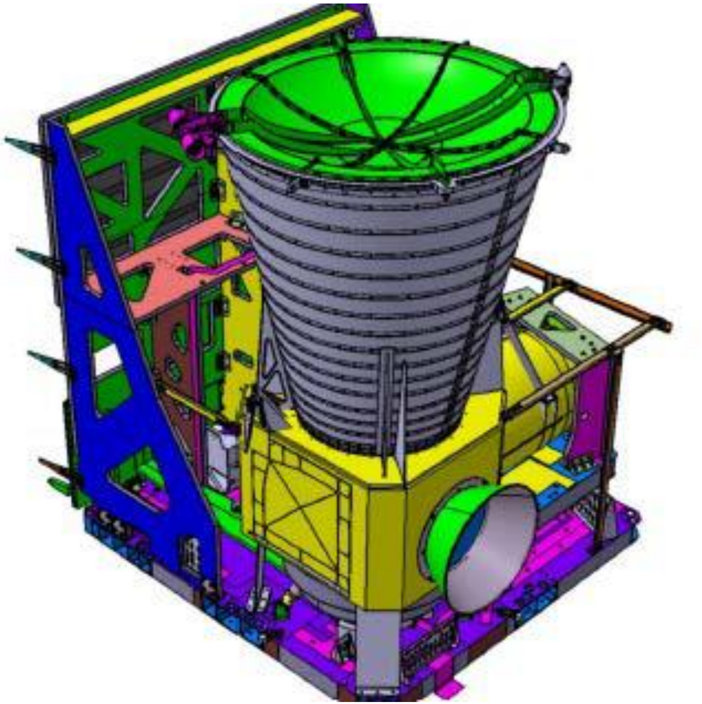
Full earth imagery every 10 minutes

2 spectral channels (LWIR & MWIR)

Resolution 4 km

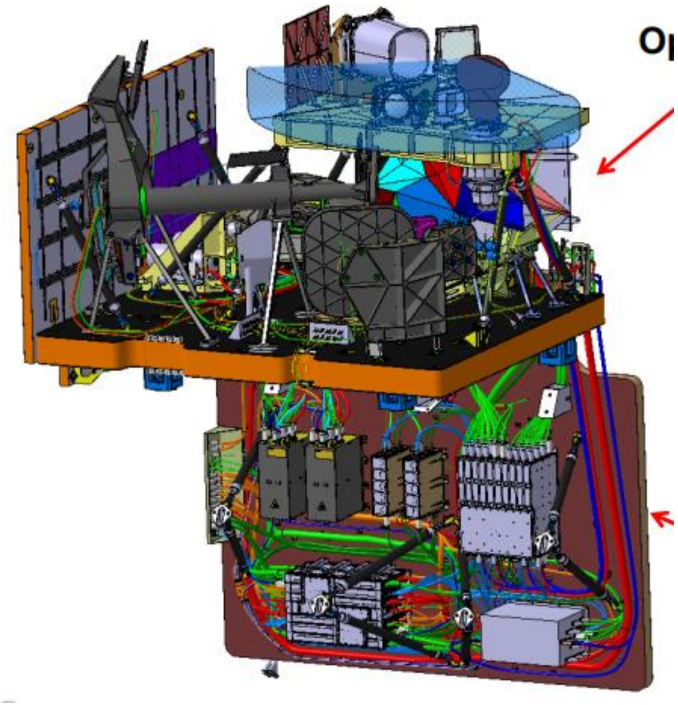
Provides atmospheric motion vectors

Detector at 55K



IASI-NG instrument (Source : WMO Oscar, CNES)

Acronym	IASI-NG				
Full name	Infrared Atmospheric Sounder Interferometer - New Generation				
Purpose	Temperature/humidity sounding, ozone profile and total-column or profiles of green-house gases (C2H2, C2H4, C2H6, CFC-11, CFC-12, CH3OH, CH4, CO, H2CO2, HCN, HNO2, HNO3, N2O, NH3, PAN, SO2)				
Short description	16,921 channels, range 645-2760 cm-1 (3.62-15.50 µm) split in 12 bands [see detailed characteristics below]. Spectral resolution 0.125 cm-1 (unapodised)				
Background	Evolution of IASI on MetOp A, MetOp-B, MetOp-C				
Scanning Technique	Step-and dwell cross-track: 28 Earth's FOV's plus two views, one of cold space and one of a blackbody. Swath 2000 km scanned in 15.6 s				
Resolution	Each FOV contains 4×4 IFOV's of 12 km size at s.s.p.				
Coverage / Cycle	Near-global coverage twice/day				
Mass	360 kg	**Power**	500 W	**Data Rate**	6 Mbps



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Space Coolers for Science projects

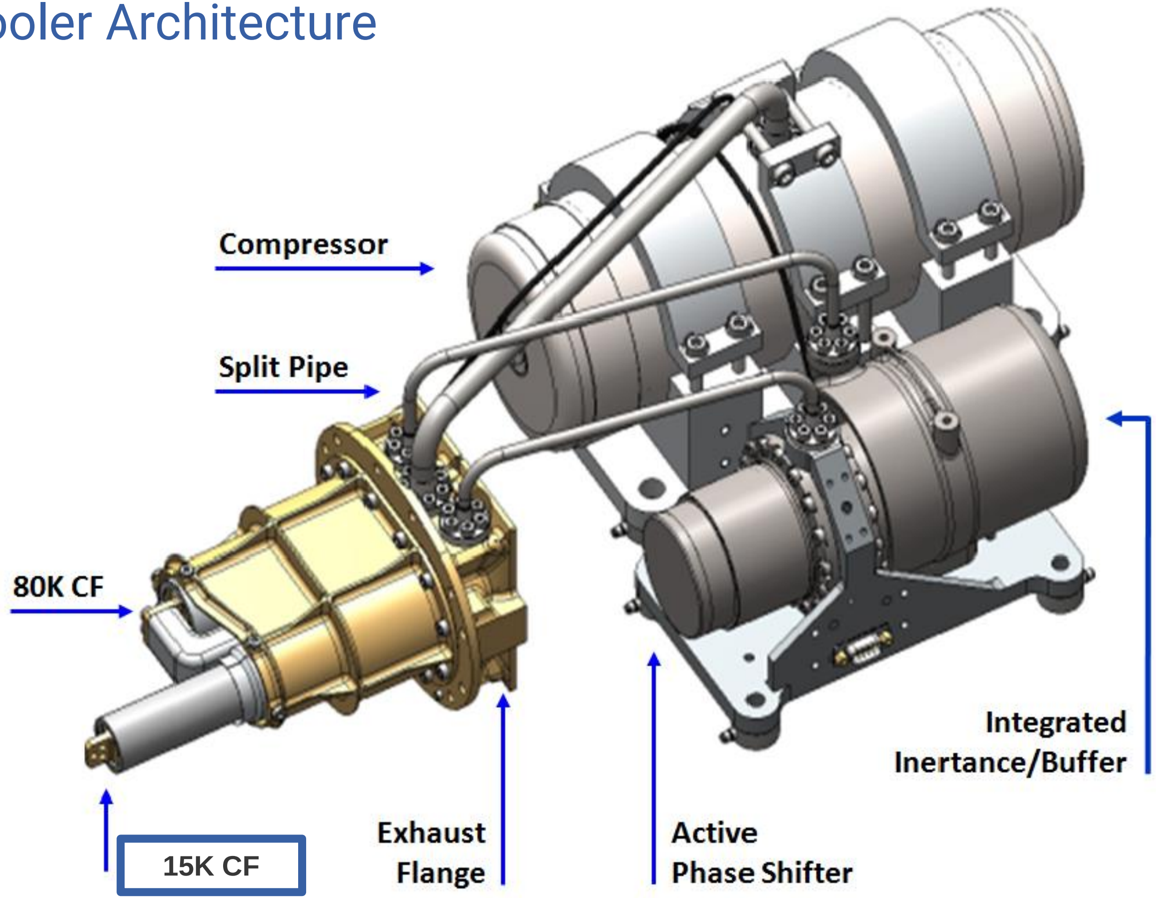
The ATHENA mission

- Advanced Telescope for High Energy Astrophysics

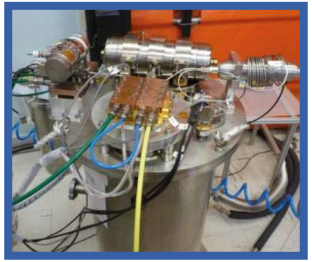
- X-IFU instrument presentation
  - https://www.youtube.com/watch?v=mOf6WIDmi30

- **Detectors : micro calorimeters, need to be cooled down at 0.05 K**
  - Complex cooling chain : Pulse Tube coolers, Joule Thomson coolers, Adiabatic Disimenation cooler
  - 15K stage, 3-4K stage, 50mK stage
  - Combination to coolers allowing redundancy

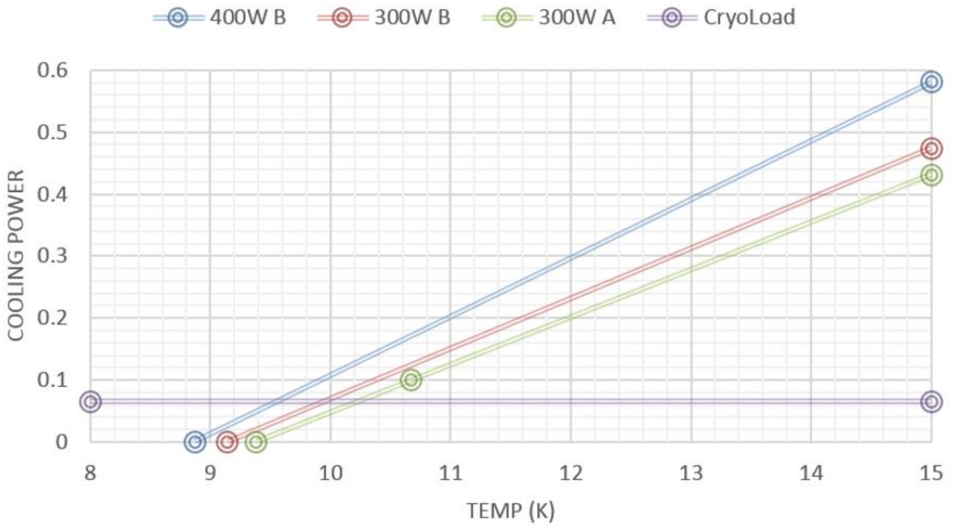
Hi-PTC Cryocooler Architecture



Hi-PTC Cooling Curve



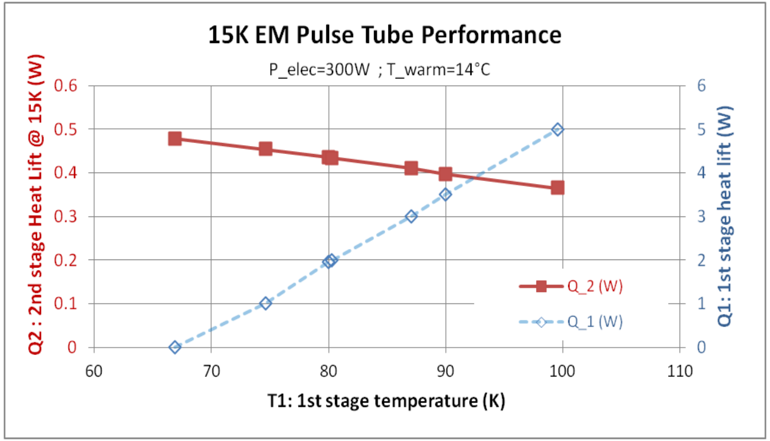
THALES Cryogenics

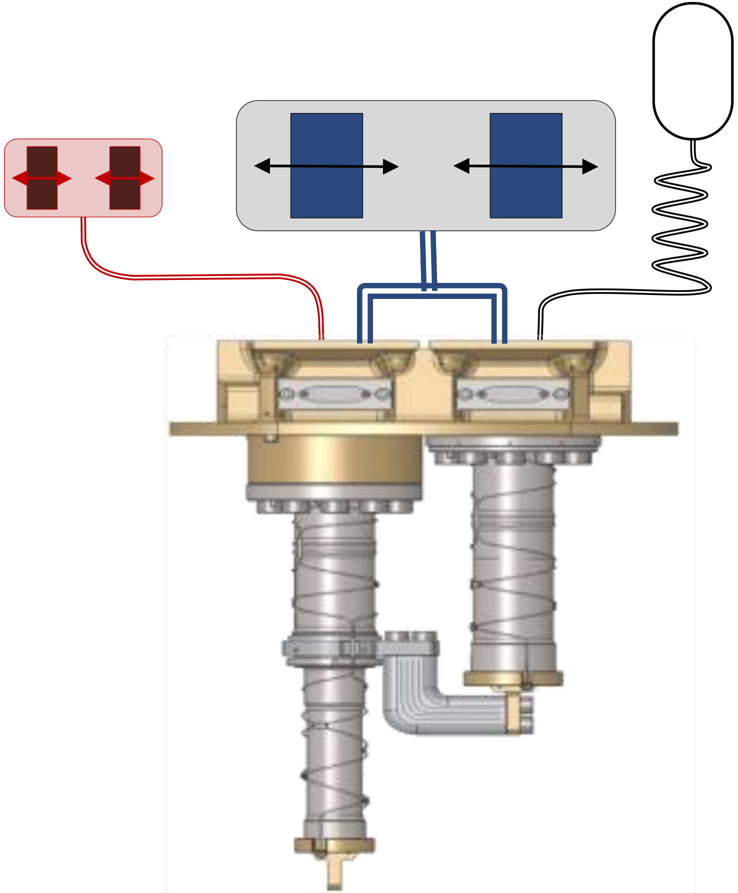


Cooling Power @ 10K: 80mW
Cooling Power @ 80K: 1,9W

HiPTC

- **EM for ATHENA preparation**
  - Performance target is met
  - Verification of environment for mechanical cooler
  - Development electronics





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Engineering Challenges

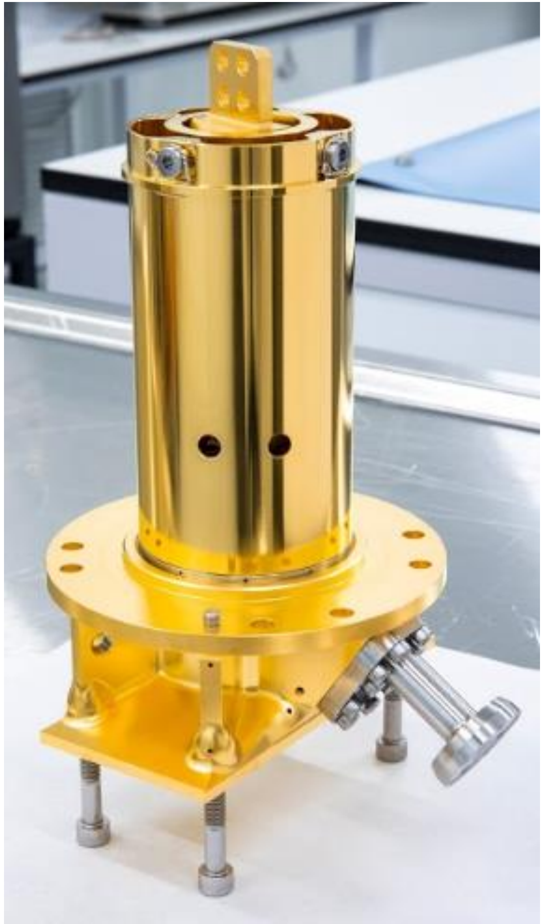
Cryocooler technology

- Technology and design in space cryogenics is always a question of compromise:
  - Mechanical strength / stiffness vs Thermal insulation / performance
  - Efficiency vs reliability, lifetime

- Pulse Tube technology is chosen:
  - Because it provides a good compromise between efficiency and reliability compared for example to Stirling with displacer
  - Good micro vibration performance
  - It is a suitable technology for 10K – 200K cooling
  - It is adapted to the required cold power

Cold finger challenges

- Efficiency
  - ❖ Most configurations are cold redundancy = two coolers connected to the same load, one active, one « spare » in case of failure of the first.
  - ❖ This induces a thermal loss through the second cold finger = parasitic heat loss
  - ❖ Design of the cold finger needs to be optimized for reducing the thermal loss
  - ❖ However, launch loads need to be sustained.

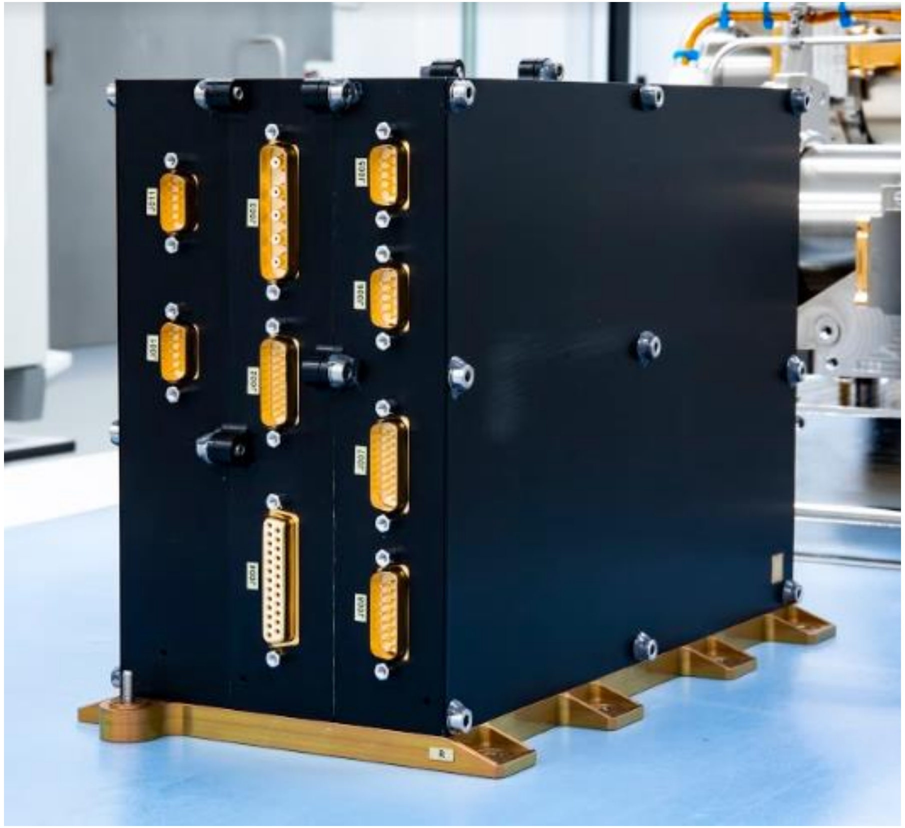


Compressor challenges

- Efficiency, EMC, micro vibrations
  - Efficiency of the compressor is key to global cooler efficiency, also, compressor needs to be correctly matched to the cold finger
  - Compressor technology is linear electro magnetic motors, motor architecture needs to be designed to avoid excessive radiated magnetic fields
  - Opposed motors and pistons need to be perfectly balanced in order to reduce exported micro vibrations.

Electronics challenges

- Multi disciplinary product
  - Power conversion for reacting load
  - Power generation
  - Sensitive analog circuits (temperature measurement, force measurement)
  - Control logic for temperature regulation and exported vibration reduction



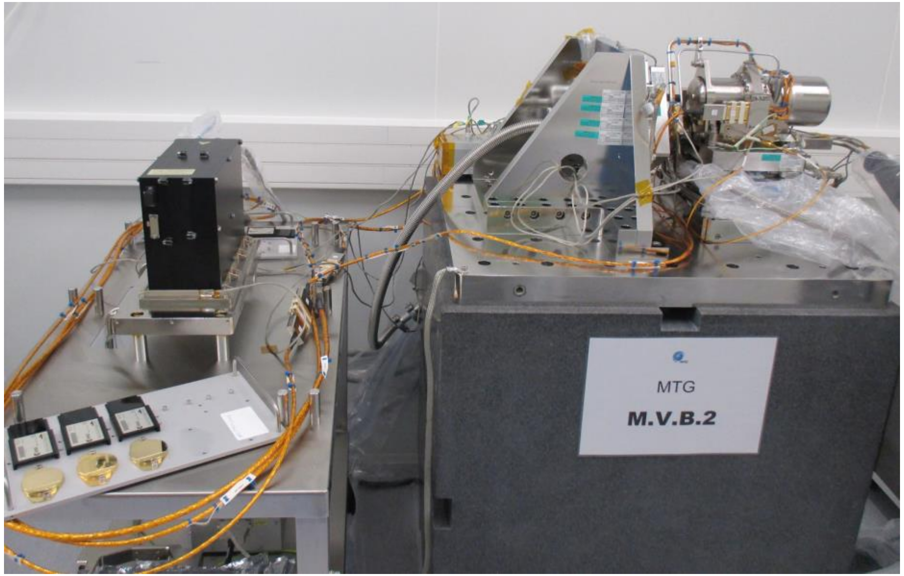
Manufacturing and Test

- 110m² of ISO 5 Clean Room for Manufacturing and Test

Manufacturing and Test

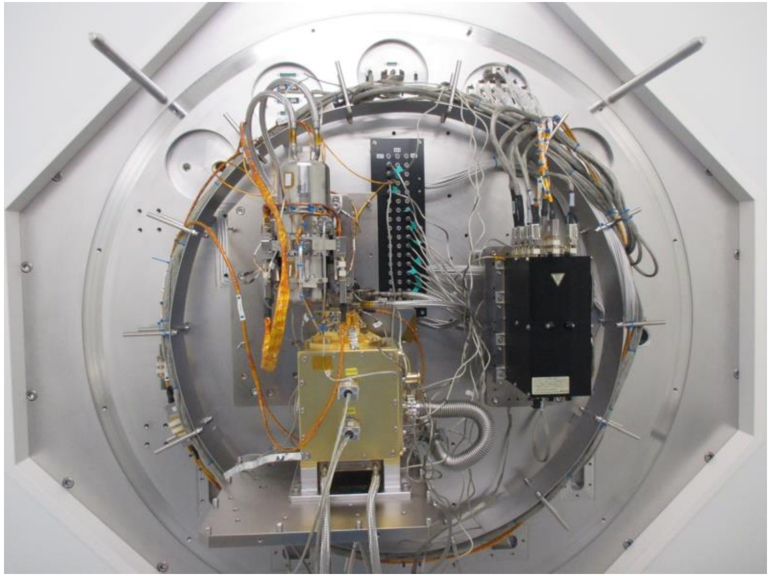
- Capability to run 4 CryoCooler test campaigns in parallel

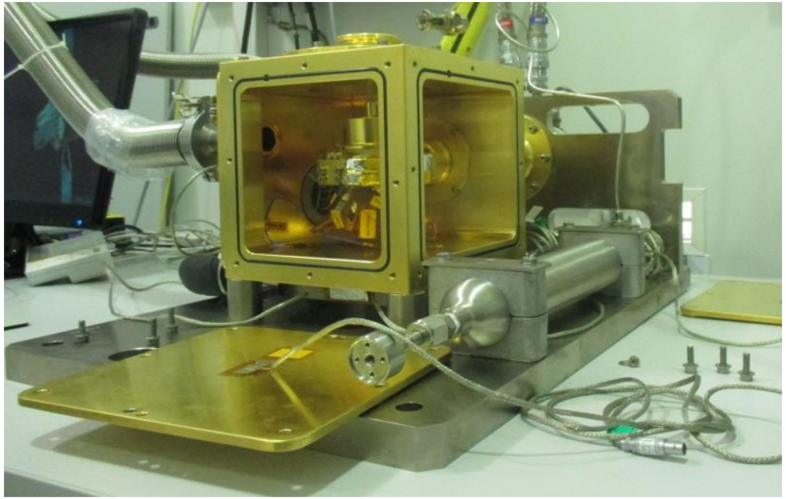
- Test bench development for exported µVibration measurement
    - Force Accuracy lower than 10mN up to 200Hz (and 25mN up to 400Hz)
    - Resolution (incl. noise) lower than 2mN
    - Torques Accuracy and resolution lower than resp. 1mN.m and 0.1mN.m



Manufacturing and Test

- Thermal Vacuum test bench for Cryogenic performances and thermal cycling of complete systems, Cold finger parasitic losses test bench





5
Technology and Science

Conclusions and Remarks

- Space cryocoolers are complex objects
- Design and qualification requires lots of skills
- Engineering and technology is not sufficient to solve the challenges posed by the development of such high performance products
    - Efficiency optimization : CFD, thermodynamics, complex modeling
    - Micro vibrations : electrodynamics, CFD, acoustics, multi-physics modeling
    - Sensitive sensors
    - Advanced materials
- We need science people to tackle all those challenges