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 world leader in Space Cryogenics

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

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

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

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!

25 years experience
Acknowledgements

Contributors to the work presented here:

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

Airbus CRISA, SITAEI: 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

Cooling power x CT temperature (warm end 0°C)

- Cooling power (W)
  - 120 W
  - 160 W compressor input power

Cold tip temperature (K)

- Frequency (Hz)
  - case 1: 2.64 W @55 K, warm end 0°C
  - case 2: 2.64 W @ 50 K, warm end -10°C

 requirement case 2

 requirement case 1
Typical microvibrations performances

128 W compressor active power

![Graph showing force amplitude vs harmonic for X, Y, and Z axes.]

- H0
- H1
- H2
- H3
- H4
- H5
- H6
- H7
MTG instruments

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)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>IASI-NG</th>
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<tbody>
<tr>
<td>Full name</td>
<td>Infrared Atmospheric Sounder Interferometer - New Generation</td>
</tr>
<tr>
<td>Purpose</td>
<td>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)</td>
</tr>
<tr>
<td>Short description</td>
<td>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)</td>
</tr>
<tr>
<td>Background</td>
<td>Evolution of IASI on MetOp A, MetOp-B, MetOp-C</td>
</tr>
<tr>
<td>Scanning Technique</td>
<td>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</td>
</tr>
<tr>
<td>Resolution</td>
<td>Each FOV contains 4×4 IFOV's of 12 km size at s.s.p.</td>
</tr>
<tr>
<td>Coverage / Cycle</td>
<td>Near-global coverage twice/day</td>
</tr>
<tr>
<td>Mass</td>
<td>360 kg  Power  500 W  Data Rate  6 Mbps</td>
</tr>
</tbody>
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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 Disimination cooler
  - 15K stage, 3-4K stage, 50mK stage
  - Combination to coolers allowing redundancy
Hi-PTC Cryocooler Architecture

- Compressor
- Split Pipe
- 80K CF
- 15K CF
- Exhaust Flange
- Active Phase Shifter
- Integrated Inertance/Buffer
Hi-PTC Cooling Curve

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
3

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 electromagnetic 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
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