

Cryogenics in Space Missions

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Summary



- 1. A bit of History
- 2. Typical Challenges
- 3. Examples of Cryogenic Space Missions
 - a) Planck
 - b) Meteosat Third Generation
- 4. Wrap-Up and Future Trends





























A bit of History



- Cryogenic <u>for</u> Space is as old as the space era itself:
 LOX was used to launch Sputnik 1 in 1957.
- Cryogenic <u>in</u> Space is almost as old as the space era itself:
 - First Dewar on Apollo missions in 1968.
 - First Cryocooler (open cycle H2/N2 JT) in space in 1969 on Mariner 6 and 7 (50 years anniversary!)
- From that moment on, the quest of long-lifetime space cryogenics begun.





Courtesy of NASA









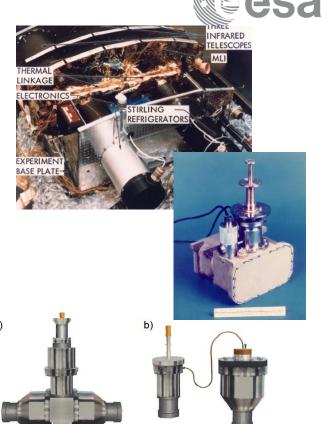






A bit of History

- (some of) The Firsts*:
 - First Closed-Cycle mechanical cooler (1971): Malaker Stirling Cooler (LMSC, US) on-board RM-19 (DoD).
 - First Multi-Year Cryogenic Mission (1979):
 Rhombic Drive Stirling (Philips Lab., NL) on-board a DoD Gamma Ray mission.
 - First Oxford-Style Coolers in Space (1991):
 RAL-version (UK) onboard ERS-1, Oxford- a)
 version (UK) onboard UARS

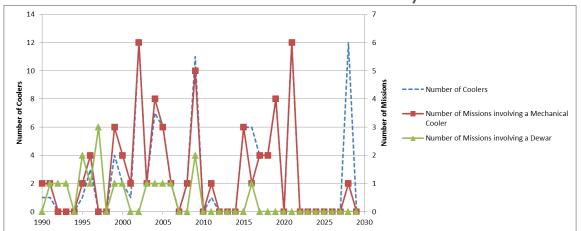


^{*} Most info come from the excellent R.Ross paper "Aerospace Coolers: a 50-Year Quest for Long-life Cryogenic Cooling in Space"

A bit of History



- Since the 90's and including the missions under development right now >50 instruments required/are requiring mechanical cryocoolers.
 - It represents a total of ~ 110 flight coolers 'worldwide' between the early 90's and ~ 2025 .
- In the meanwhile, Liquid or Solid Cryogen dewars which were popular in the 80's and first half of the 90's are not considered anymore.



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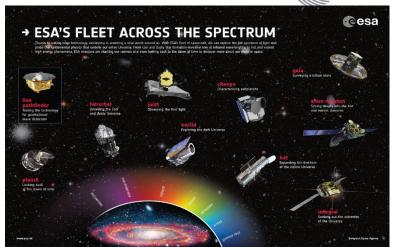


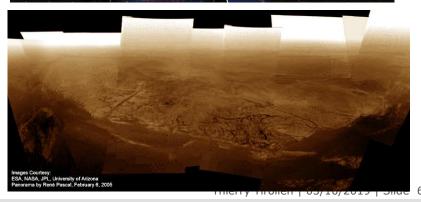




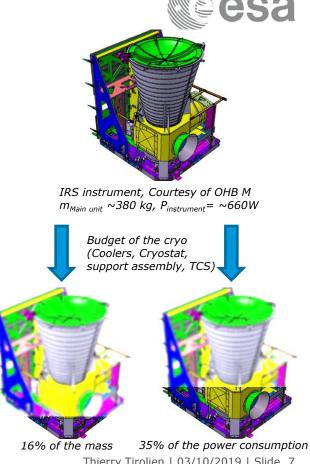
- But first, why Space Cryogenics?
- Cryogenics in Space mainly used for Focal Plane Cooling...
 - Earth Observation
 - Imagery (Civil or Military)
 - Monitoring of lands (fires etc.)
 - Meteorology
 - Atmospheric Chemistry
 - Science
 - Black hole studies
 - Gamma ray studies
 - **CMB**
 - Chemistry of exoplanets
- But other applications (can) exist:
 - · Sample collect and conservation
 - Zero-Boil Off for long cryogenic propulsion missions
 - High Temperature Superconductors
 - In Situ Ressource utilization
 - Cryogenically cooled Low Noise Amplifiers

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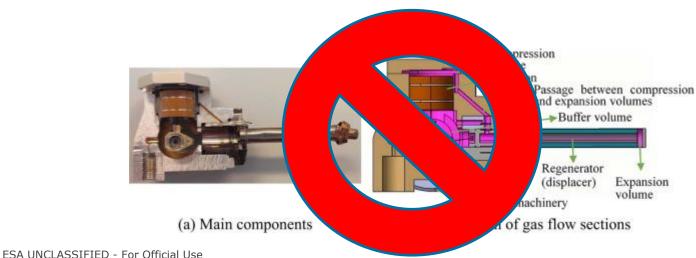


- By essence, resources (mass, volume, power) are limited:
 - → Thermo-mechanical design of the Cryo systems are critical (i.e. we are chasing fractions of Watts, milliwats or microwatts).
 - → We use coolers which are light and performance driven.
- The classical uncertainty/margin approach that prevails in all Space system developments and designs need to be clearly defined.





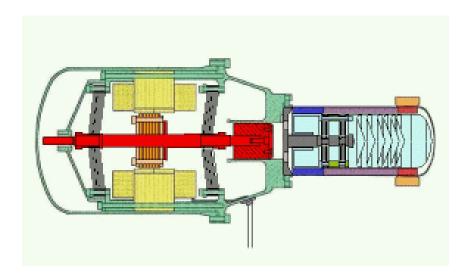
- Lifetime Requirements are stringent. Typical requirements is to fulfil the performance during more than 8 years of continuous operations. It impacts:
 - The Design of the refrigeration solution.







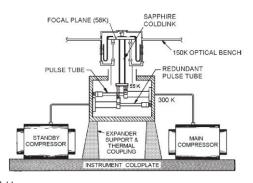
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 - The architecture of the Cryogenic System (redundancy scheme).





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- Lifetime Requirements are stringent. Typical requirements is to fulfil the performance during more than 8 years of continuous operations. It impacts:
 - The Design of the refrigeration solution.
 - The architecture of the Cryogenic System (redundancy scheme).
 - The lifetime demonstration approach.



Accelerated tests at components level (court. Oxford Un.)

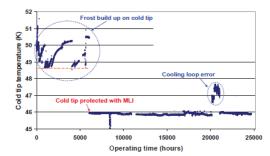
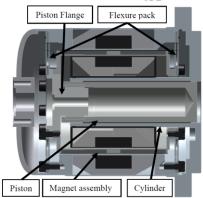


FIGURE 4. LPTC EMMS endurance text data

Non-accelerated tests at machine level
(court. ALAT)
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- Most instruments that need Cryocoolers (optical instruments) are also often requiring stringent pointing requirements (for image quality)
 - → Exported microvibrations are an important performance parameter of Space Coolers
 - It has impacts on:
 - The manufacturing of the cooler (e.g. alignment of moving parts).
 - The Cryocooler Electronics (Active Microvibration control system)
 - The Thermo-mechanical assembly of the cooler and instrument (use of Thermal links assembly, vibration reduction structure necessary, thermal control solution of the cooler affected).
 - 'Vibration Free Cooling' is an important topic in the Space Sector.





Cross-section of a Compressor (court. TCBV)

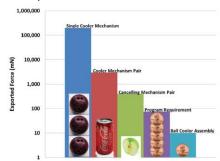


Illustration of the different levels of microvibes for a CCS (courtesy of Ball)

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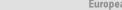














- Offgassing and Outgassing affect the performances of a Space Cryogenic systems in 3 different ways:
 - Contamination is detrimental for optical instrument.
 - Pollution of low ϵ surfaces impair the thermal performance of the system.
 - Outgassing inside the working fluid may lead to degradation or failure of the cooler.
 - Needs to be accounted for in the design: limiting the offgassing materials in the vicinity of the cold parts, allowing the pollutants to be evacuated (snorkel design), plan for decontamination hardware and outages.
- Launch loads impact not only the thermo-mechanical design of Cryostats, but impose the use of launch-locking solutions for Cryocoolers.

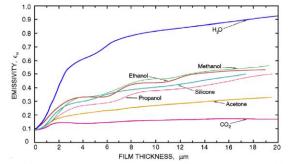


Figure 29. Emissivity of polished stainless steel to 300 K blackbody radiation versus film thickness.

Courtesy NASA/JPL

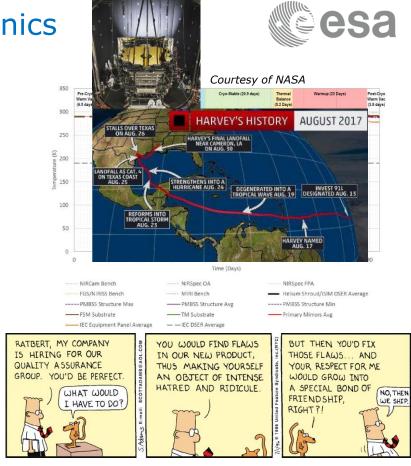


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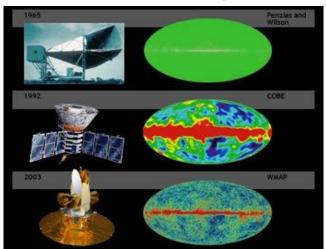
- Thermal Testing is an indispensable and crucial event of Spacecraft with Cryogenic applications:
 - Everything must be testable on ground:
 - Gravity dependency must be tackled.
 - Sink Temperatures can be less favorable than in Flight.
 - Cryogenic Testing is time consuming (=expensive).
- Last but not least: Cryogenics usually being a critical domain in (operational) space missions, it requires a significant PA/QA effort that shall be taken into account technically (heritage...) and programmatically.



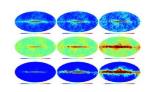
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- The phase A of Planck (along with Herschel) began in \sim 1985 with the objective of being the 3^{rd} generation of CMB Space experiments.
- The main drivers for the Cryogenic system were:
 - The very broad frequency coverage (30 to 857 GHz) imposes the use of two detector technologies that require vastly different temperatures (20K and 0.1K).
 - The scanning strategy based on a spinning satellite (1rpm).
 - The minimum lifetime required of 1.5y.
 - The 60K required temperature for the telescope.
 - The L2 orbit.



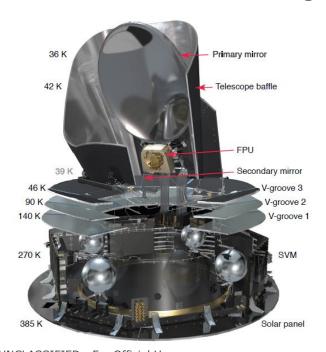


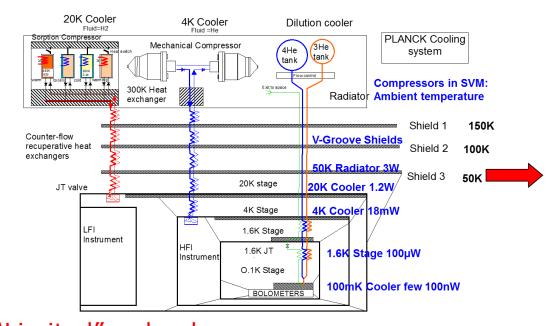


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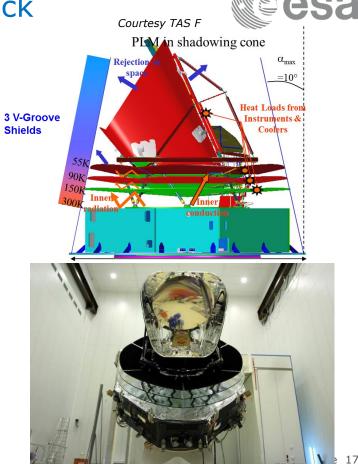
 Those requirements impose a sophisticated architecture based on a combination of Passive Cooling (V-Grooves) and Cryocoolers

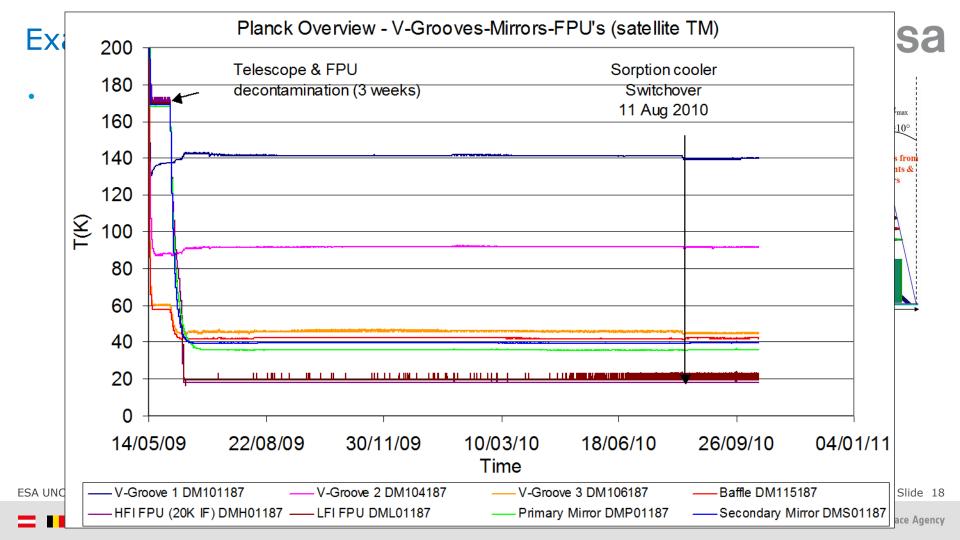




"Limited" redundancy

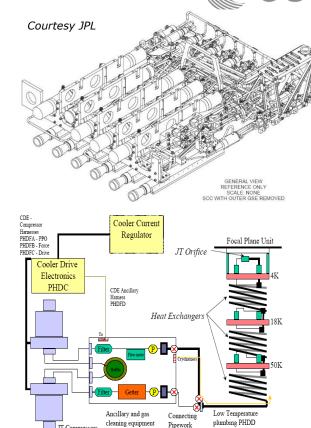
- Passive Cooling
 - Based on the V-Grooves solution that radiatively insulate from the hot SVM (insulation function) and intercept heat from the supports and harness (rejection function).
 - Last V-Grooves + Baffle in black open honeycomb (16m2 of radiative area with $\epsilon_{\text{equivalent}} \sim 0.98$)





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- 20K Stage (JPL):
 - 1.1W@17K, for about 600W Electrical
 - Mass: 56kg (x2)
 - absorption Compressor (Metal Hydride cycled between 200°C and -10 °C) located on SVM
 - Managed by gas gap heat switches around the beds
 - Long pipes (few m) between beds & JT.
 - Subject to ageing (switched to redundant after ~1y of operation)
- 4K Cooler (RAL):
 - 4He JT Cooler with 2 compressors based on the 50-80K cooler (large heritage)+reed valves.
 - Ancillary panel for gas management and getter
 - 'Cold plumbing' dismountable intercepted on the V-Grooves
 - Electronics provided by TAS UK (ex-SEA)
 - 18mW@4.3K 140W input power (60W compressors), ~40kg



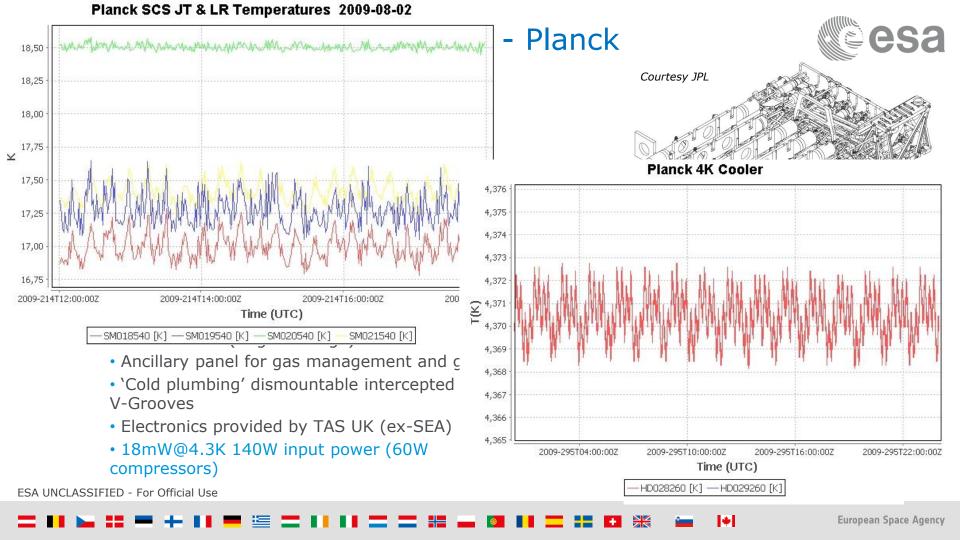


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(Includes cryoharness)

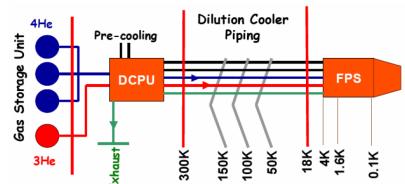
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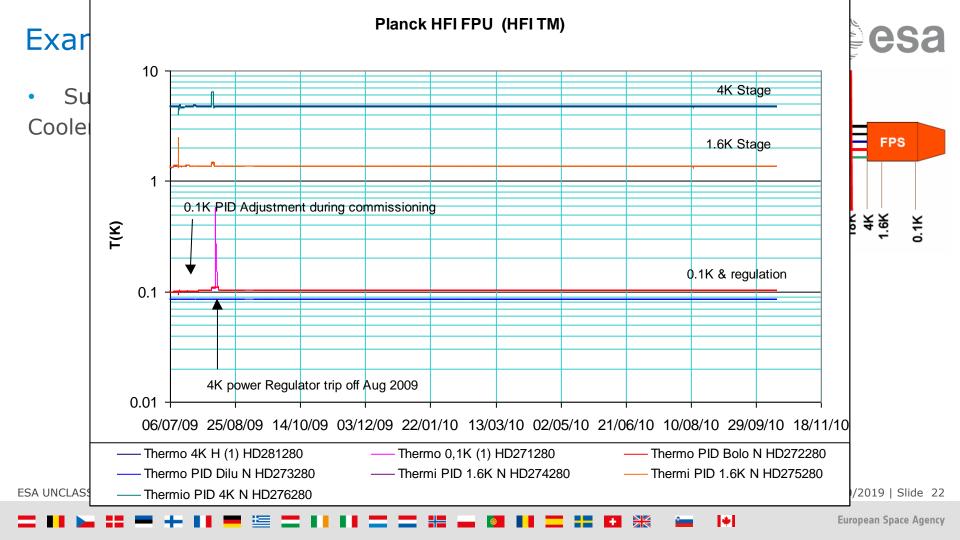




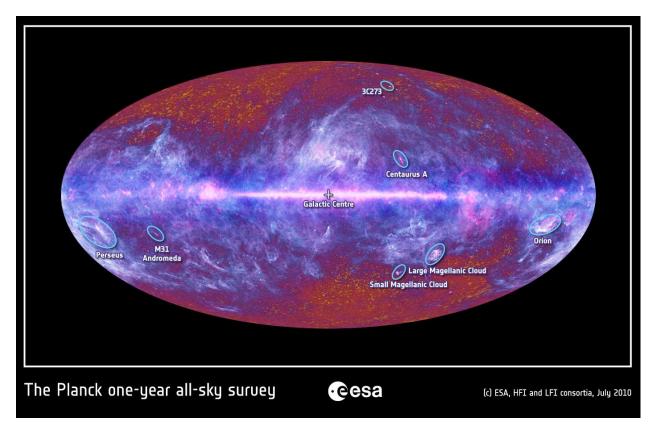
- Sub-Kelvin Cooler: Open cycle Dilution
 Cooler (Institut Néel/ALAT)
 - 4 * 51l tanks pressurized at ~300 b and located at 300K
 - Dilution Cooler Pneumatic Unit used to provide optimised isotope flows
 - Piping (heat exchangers) at every cold stage
 - 1.6K and 0.1K provided by the dilution cooler embedded with the FPA
 - 100nW@100mK for 27 months
 - 400microW@1.4K











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- What is Meteosat Third Generation
 - MTG-I mission
 - Four flight models
 - Two imaging P/L (FCI and LI)
 - One communication P/L (DCS & SAR)
 - MTG-S mission
 - Two flight models
 - Two sounding P/L (IRS and GMES-S4 UVN)
- MTG-I FCI and DCS & SAR missions are continuation of MSG mission
- 3-axis geostationary satellites with -Ys side never Sun illuminated thanks to yaw flip performed twice a year at Equinox period



Artist impression of MTG satellites

















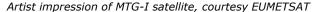














- Mass ~450 kg
- Power ~500W
- ~2mx1.6mx1m

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Full Disc



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High Resolution

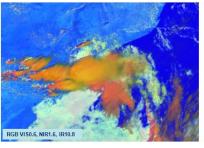
		Hyper-Spectral Imagery		Fast Imagery	
Spectral		16 channels		4 channels	
Repeat cycle		10 min		2.5 min	
SSD VNIR	SSD IR	1 km	2 km	500 m	1 km
MTF @ Nyquist		0.15 < MTF < 0.3		~ 0.3	
SNR @ ρ=0.01 VNIR	NEdT @ Tref IR	> 20 > 12 for VIS0.9	0.1-0.3 K 1 K for Fire	> 12	0.2 K @ IR3.8 & IR10.5
Radiometric accuracy		< 5 %	< 0.7 K	VIS0.6 & NIR2.2 < 10%	IR3.8 & IR10.5 < 1K
Lifetime & Availability		8.5 years & > 96%		8.5 years & > 96%	

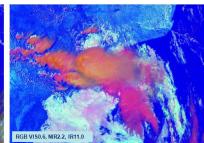
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- Improvement compared to the SEVERI instrument: Better spatial, temporal and radiometric resolution.
- Expected benefits:
 - Improved meteorological information.
 - True color imagery
 - Improved aerosol retrieval
 - etc.
- Part of those improvements are due to the 3 axis stabilization and IR/NIR Channels to 13.3 microns.

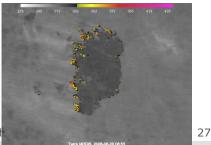






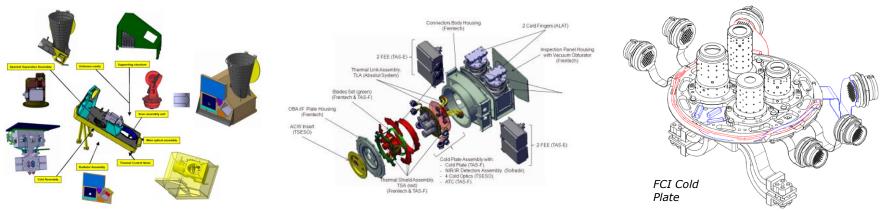






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- Temperature related requirements:
 - Detectors: Temperature at the TRP 58K +/-0.5K, 0.05K thermal stability over 10mins
 - Cold Plate: Temperature [80, 100K], stability +/-0.5K over the lifetime, gradient on CO mounting points 7.5K with a stability of 0.05K over 10 minutes

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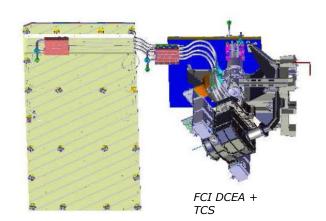






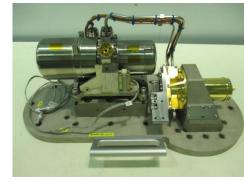


- Other types of requirements and Challenges
 - Long storage and operational lifetime (respectively 10 and 8.5 years) with high reliability requirements.
 - Extremely low Microvibrations are requested (initial requirement at the base of the support structure: <50mN in all axis and all harmonics)
 - Minimize the outages due to contamination: Effect on the radiometric and cryogenic performances.
 - Cryostat shall be testable 'on the table'



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- To achieve the required detector temperature and stabilities:
 - Cryocooler system + associated thermal control:
 - 2 LPTC in Cold Redundancy
 - Regulation loop of the cold finger temperature.
 - 1 Cryocooler Support Assembly
 - A CPA radiator with its Heat Pipe link and network
 - A CFA radiator with its Heat Pipe link and network
 - An Equipped Cryostat with its ancillary equipments:
 - A Cryostat Structure using PVD gold coating on nickel plated titanium (Frentech, CZ) $\rightarrow \epsilon$ < 0.027
 - Bellows
 - Thermal Link Assemblies 140 High purity aluminum 50 microns foils (Al5N) + Al 1080A endfitting (Absolut System, F)



LPTC MTG version















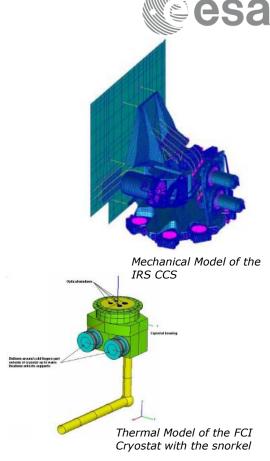








- Reduce the impact of Microvibrations:
 - Challenging requirements at Cryocooler level (<~400mN and lower in all axis and harmonics)
 - Dedicated support structures with damping solution.
 - Microvibration simulations and early characterization tests to assess the margins in the design.
- Limit the decontamination outage:
 - Limit the amount of outgassing material inside the cryostat (hence the absence of MLI).
 - Use of a dedicated "Snorkel" to evacuate contaminants during the commissioning.
 - Numerical analysis at every stage of the design of the Cryostat to evaluate the contamination pattern.
- Cryostat Testable on the 'Table'
 - Leak tight cryostat
 - Work around solutions for the higher I/F temperature

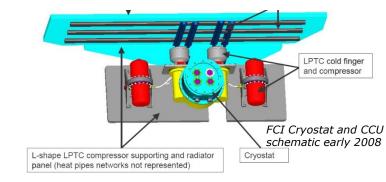


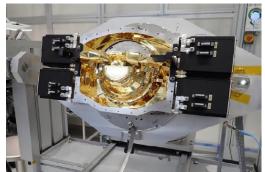


After 10 years of development, the Cryogenic parts of MTG-I have been Thermally validated and the performance of the first PFM look extremely promising

Performances at sub-element level (Cryocoolers, TLA, Gold Coating etc.) exceed the requirements.

FCI & MTGI STM qualification, TAS-F





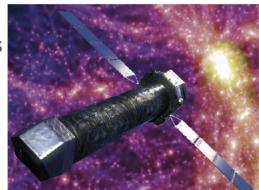
FCI Cryostat EM in

integration March 2018

Wrap-Up and Future Trends

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- After the revolution that represented the invention of Long Lifetime coolers at the beginning of the 90's, the Space Cryogenics field evolved to become a mature domain. There are many major missions finishing their development (e.g. MTG, MetOp SG, JWST) and even more to come (e.g. Athena, Ariel, Copernicus expansion and next generation, SPICA, LiteBird etc.).
- Compared to other domain of Cryogenics, Spacecraft Cryogenics is characterized by:
 - Relatively low cooling needs but scarce resources (mass, power, volume).
 - Extremely stringent lifetime and reliability requirements.
 - The fact that microvibrations are a driver in the Thermomechanical architecture of an instrument.





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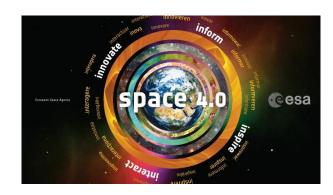




Wrap-Up and Future Trends



- Beside those classical missions (that are here to stay), future applications will shake the sector:
 - The rise of Low Cost, High Volume and Lower reliability missions ('New Space' or Space 4.0 concept) will require a new range of coolers: cost optimized, but efficient and reliable enough*.
 - In Situ Resource Utilization and other ambitious exploration applications (RBO/ZBO for long term manned missions) will call not only for bigger cooling needs, but a set of skills (e.g. Cryogenic Fluids management) not classical in Spacecraft Cryogenics.





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Shameless Self-Promotion

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- If you are interested in Space
 Cryogenics, do not hesitate to sign-up for the 8th European Space Cryogenics
 Workshop!
- It will take place from the 15/04/20 to the 17/04/20 in ESTEC (Noordwijk, NL)
- First Announcement due in the coming days, in the meanwhile get in touch with me (<u>Thierry.Tirolien@esa.int</u>) for information.



























References



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