

CRYOGENIC INTEGRATION IN SATELLITES

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1: CRYOCOOLERS IN SATELLITES

/// 1.1 Why using Cryogenics & Cryocoolers in Satellites and Instruments?

/ Main SL application (95%) is to cool detectors and proximity Electronics for Observation instruments, to operate detector at optimum performances

- Earth Observation instrument (Infrared)
- Instruments for Astronomy (all wavelength range)

/ + Potential applications, but never really used :

- Telecommunication amplifiers (use of supra-conductors)

/ Other space-related applications :

- For Launcher Cryogenics Engines
- In space Station, to preserve biological samples (freezers)



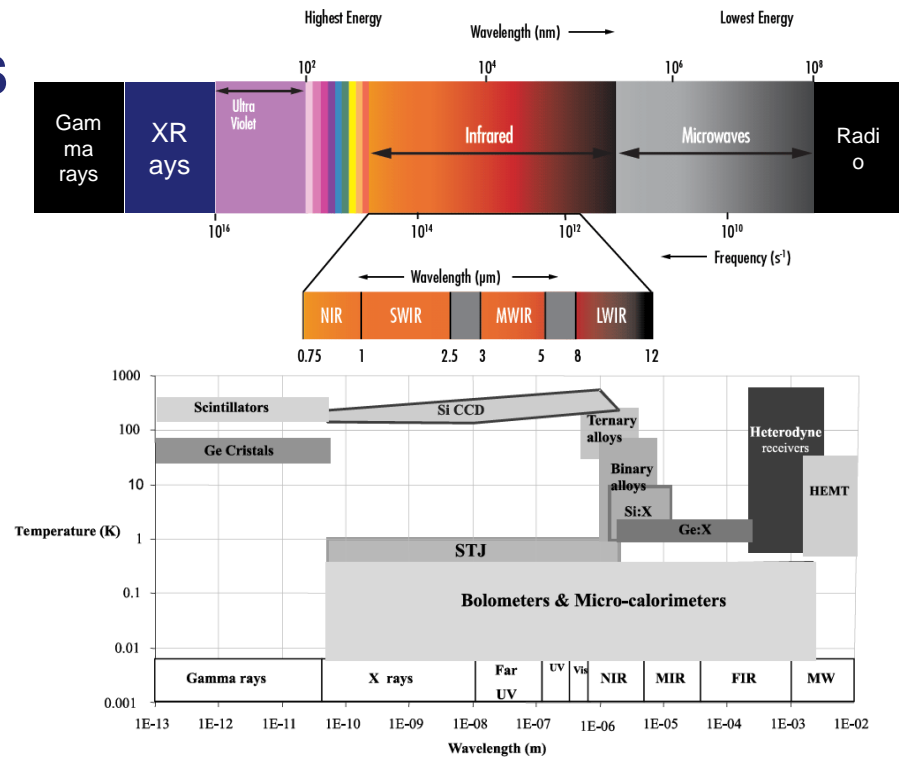
1: CRYOCOOLERS IN SATELLITES

/// 1.2: Detector Frequency Ranges and associated detector Temperatures

In principle, the longer the wavelength (corresponding to colder blackbody), the colder the detector should be

However, this depends also on detector technology

- Infrared detectors :
 - 100-200K for SWIR
 - 50-80K for TIR
 - Low temperature for FIR (0.05..20K)
- But very Low temperature also for Xrays (micro calorimeter) & gamma rays (80K)



Division name	Abbreviation	Wavelength	Temperature (Planck)	Temperature detector	Type of Cooler
Near-infrared	NIR	0.75–1.4 μm	3864–2070 K	ambient	
Short-wavelength infrared	SWIR	1.4–3 μm	2,070–966 K	100-200K	Radiator, Small Stirling or PT
Mid-wavelength infrared	MWIR (MidIR)	3–8 μm	966–362 K	50-80K	High Power Stirling or PT
Long-wavelength infrared	LWIR				
Far infrared	FIR	15–1000 μm	193–3 K	0.05..20K	Low temperature cooler System: ADR, Dilution, JT

1: CRYOCOOLERS IN SATELLITES

/// 1.3: Types of Coolers used in Space

/ Cryogenic Radiator

Radiation to Space

/ Cryogen Storage

Evaporation to space provide heat lift at vapour pressure temperature

/ Mechanical coolers

- Regenerative cycles (Pulse Tube, Stirling)
“Heat pump” based on Stirling Cycle
- Recuperative cycles (Joule-Thomson, Turbo-Brayton)
Pressurized gas expansion in an orifice (JT) or micro turbine (Brayton)

/ Low temperature coolers

Last stage of complex cryogenic chain

- Sorption cooler
- Dilution Cooler ,
Open or closed cycle
- Adiabatic Demagnetization Refrigerator



HERSCHEL © ESA

1: CRYOCOOLERS IN SATELLITES

/// 1.3: Type of Coolers used in Space

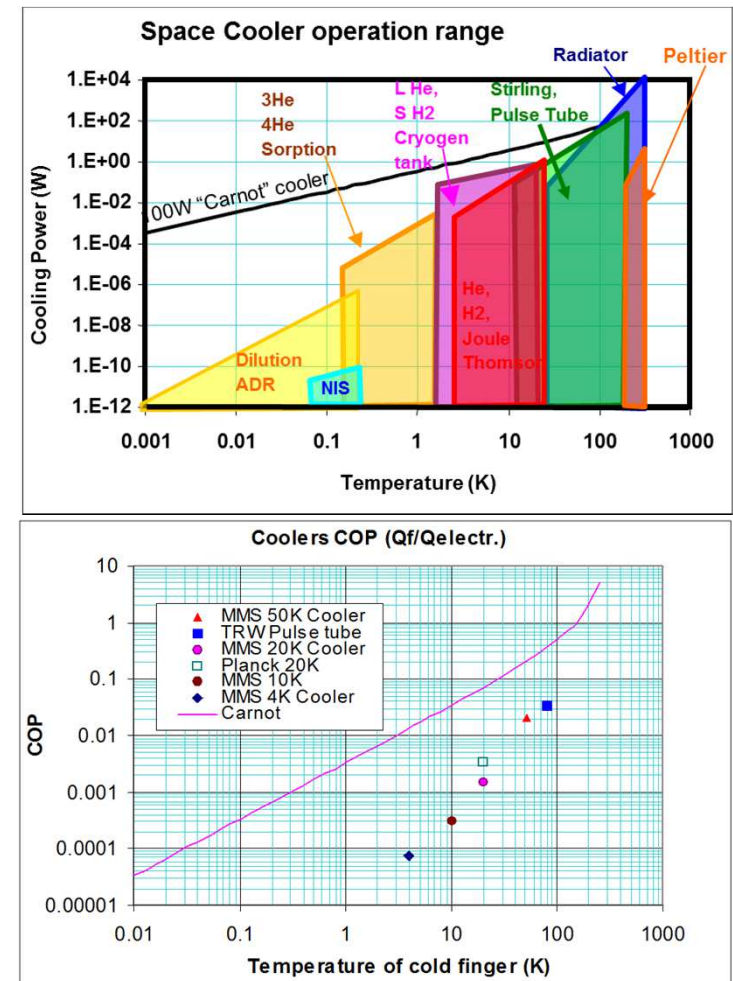
/ Synthesis of coolers to be used in Space

- Single coolers for $T > 20\text{K}$
- Cryogenic chains for lower temperatures
- Cryogenics budget from W at 50K to μW below 0.1K

/ Cooler efficiency

- Coolers efficiency \ll Carnot efficiency.
- Temperature \downarrow Efficiency \downarrow Electrical power \uparrow

$$\text{Efficiency} \quad \eta = \frac{COP}{COP_{carnot}} = \frac{Q_f}{Q_{el}} \cdot \frac{T_w - T_c}{T_c}$$

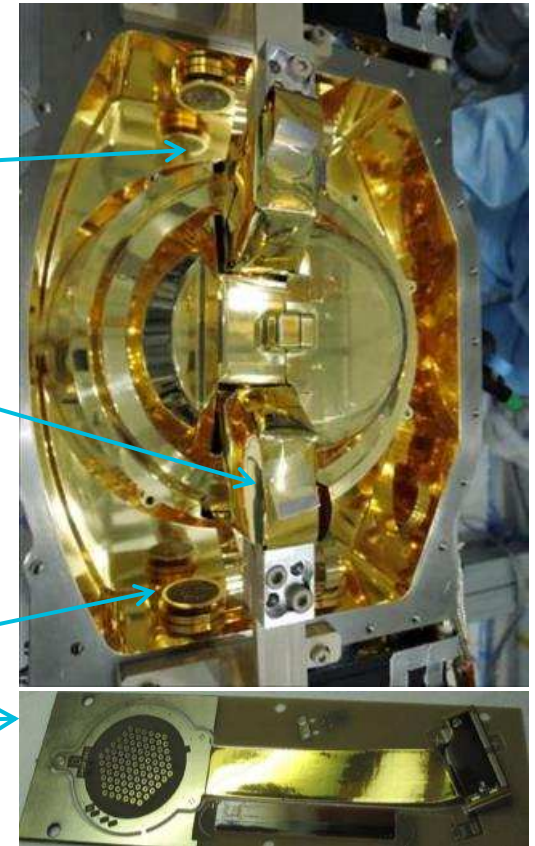


2: DESIGN & ACCOMMODATION OF CRYOGENICS IN SATELLITE

/// 2.1: Cryostat design

/ Cryogenic detectors will (generally) be

- Insulated from the warm parts of the instrument / Satellite
 - Radiative shields (gold coating, MLI,...)
 - Passive or cooled by vapour in case of Cryogen or by 2nd warmer stage of cooler if any
 - Low conductive stiff supports (GFRP, kevlar ropes, ..) with low CTE (defocus at ope T°)
- Thermally linked to the cryogenic sink (cooler cold tip)
 - Flexible cryogenic links (pure Aluminium/Copper, Graphite, ... stacked foils or braids)
 - Allow thermo-elastic and relative dynamic displacements and provide vibration insulation
- Optically linked to the Telescope
 - Germanium IR windows for closed Cryostats
- Electrically linked to external video units
 - Use of thermo-electrically optimised flexprints to Cryostat feedthroughs
 - Thin & narrow (copper) tracks engraved on Kapton
- Insulated from atmospheric environment (ground)
 - Cryostat housing may be vacuum tight to allow ground testing with local vacuum



2: DESIGN & ACCOMMODATION OF CRYOGENICS IN SATELLITE

/// 2.1: Cryostat design

/ Cryostat may be :

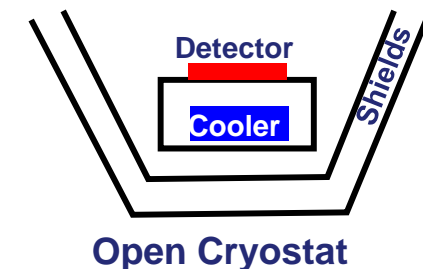
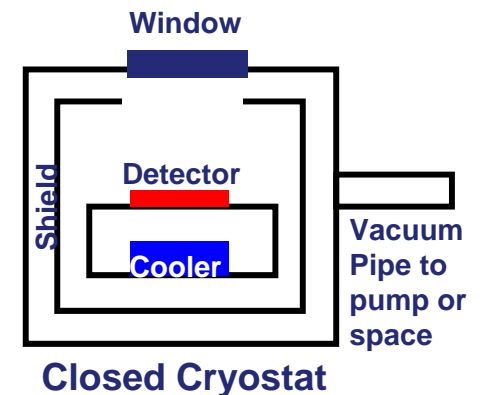
- Closed (most of earth observation instruments, and Instruments with cryogen storage)
 - Vessel is vacuum tight and can be evacuated (pumping line interface) for ground testing
 - A window or jettison cover is implemented to allow optical or signal path
- Open to Space
 - Need baffling & insulation from instrument
 - Often associated to radiator
 - Need for evacuated test chamber on ground

/ Design may include ancillary equipment

- Instrumentation (temperature sensors, heaters, with associated harness)
- Cold optics, cold baffle
- Detectors Proximity Electronics

/ Additional devices might be used to improve thermal performances

- Heat switch to disconnect redundant cooler (↓ parasitic loads)
- Energy Storage Unit (ESU) to level temporal heat load or cooling rate temporal fluctuations



2: DESIGN & ACCOMMODATION OF CRYOGENICS IN SATELLITE

/// 2.2: Coolers accommodation (thermal control)

/ Cooler & Electronic dissipative elements are heat-sunk to radiators

- Outer space = ultimate heat sink (radiative)

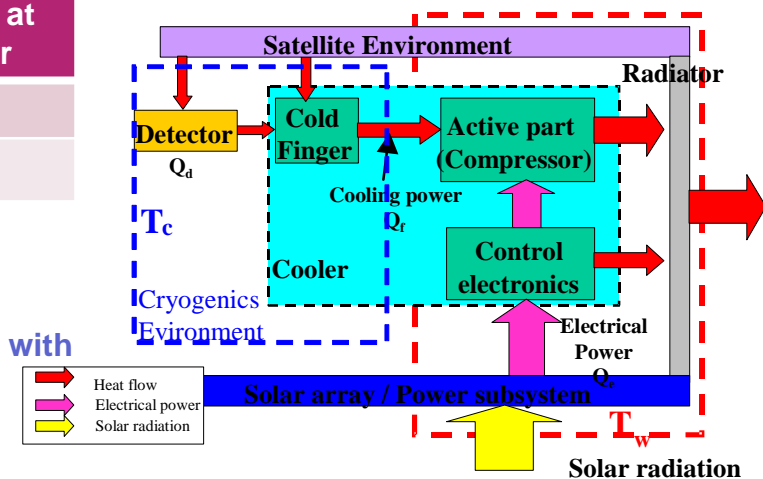
Input power # 160W	% dissipated at Cold Head warm flange	% dissipated at Compressor
Pulse Tube cooler	60%	40%
Stirling cooler	40%	60%

- For recuperative coolers (JT, RTB) input power dissipated mainly by Compressor, but precooling may be needed along the counterflow hx

/ Coolers must present efficient thermal drain interfaces compatible with system thermal control devices

/ Dissipative components may be :

- Mounted directly on radiator
 - Possible mainly for JT cooler compressors, electronic units (# 50W)
- Linked to radiator by
 - Two-phase heat transport components (heat pipes or loop heat pipes), Gradient warm/cold dominated by the contact surfaces along thermal path
 - Conductive links (less efficient, only for low dissipations)

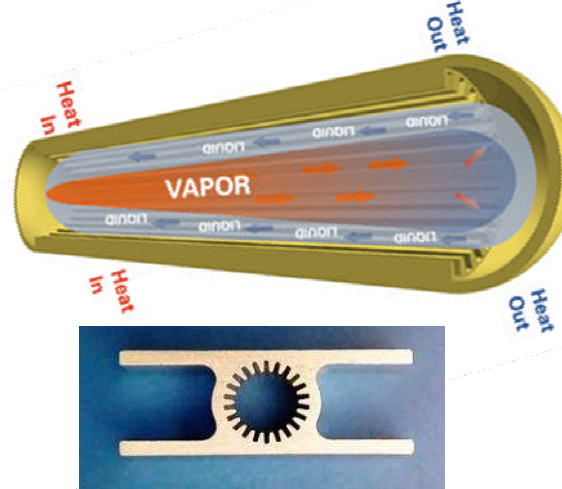


2: DESIGN & ACCOMMODATION OF CRYOGENICS IN SATELLITE

/// 2.2: Coolers accommodation (thermal control)

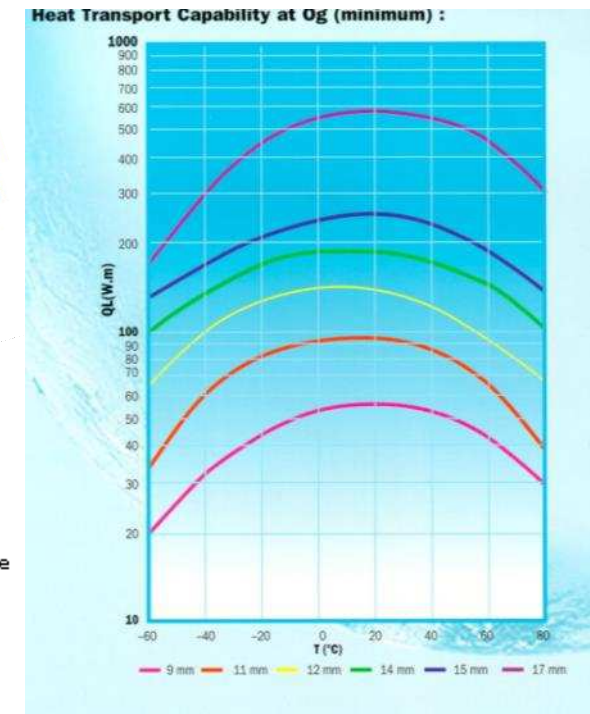
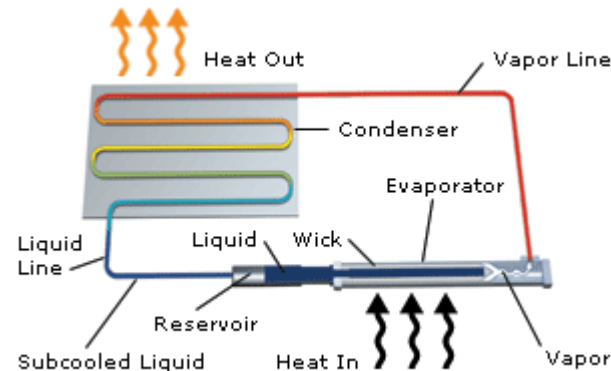
/ Heat Pipes

- Passive devices
- Extruded axially grooved Al pipes for liquid return by capillarity
- Evaporator/condenser areas adapt to system heat load and sinks
- Filled with ammonia for ambient T°
- Very high transport efficiency



/ Loop Heat Pipes

- Same principle, with capillary pump located at evaporator
- Fixed evaporator & condenser areas
- Liquid reservoir + start-up heater
- Flexible heat transport lines
- Thermal link can be switched off
- But more complex & costly



2: DESIGN & ACCOMMODATION OF CRYOGENICS IN SATELLITE

/// 2.3: Coolers accommodation (mechanical)

/ Cooler vibration sources (compressor , ..) may need to be mechanically insulated from the Instrument by reducing the transmissibility of the fixation system :

- Controlling the natural frequency of the cooler structure assembly by using elastic suspensions ($f < f_{0\text{cooler}}$, -40dB/decade)
- Dissipating vibration energy by increasing structural damping (use of elastomeric pads)

/ Mechanical insulation may require the use of

- Flexible heat transport devices
 - Thermal Straps (only for <few W)
 - Long & flexible heat pipes, LHP
- Launch clamping device (especially in case of pure elastic control)

/ Mechanical insulation needs (according to Instrument sensitivity !)

- Will be likely for regenerative coolers (PT, Stirling) because vibrations sources must be close to detection
- May be less useful for recuperative coolers (JT, RTB) because the compressor can be accommodated out of Instrument (on platform)

2: DESIGN & ACCOMMODATION OF CRYOGENICS IN SATELLITE

/// 2.4: Cooler accommodation in Instrument / Platform

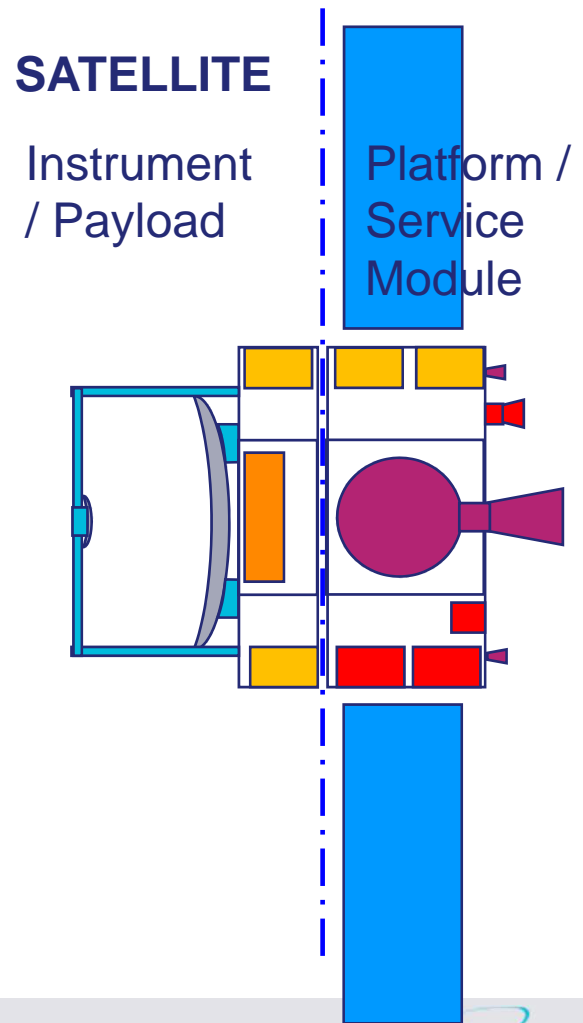
/ Satellites generally composed of 2 independent modules

- Instrument or Payload with telescope & instrument(s)
- Platform with avionics (command and data handling, communications, power system, orbit & attitude control, ..)

/ Cooler elements may be distributed :

- In Payload (thermo-mechanical unit)
- In Platform (electronics if possible)

/ In specific cases (JWST) pre-coolers may need to be accommodated in Platform



3: CONSTRAINTS FROM SPACE & LAUNCH ENVIRONMENT

/// 3.1 Vacuum

Mandatory for Cryogenics ! Need for heat transport devices (no convection) such as thermal links, HP, ...

/// 3.2 No Gravity

- / Important when liquids are used : containment by capillarity or phase separator to force location evaporation interface (case of Cryogen storage)**
- / May cause coolers ground-flight performance representativeness issues (and may induce ground-testing orientation constraints to limit ground-flight performance deviations)**

/// 3.3 Radiation

- / According to the orbits, satellites are subjected to various radiation environments originating from solar flares, radiation belt or cosmic rays**

High energy proton, heavy ions, electrons may cause severe damages on satellite equipment

- / Electronics need to be hardened against high energy particles**

- Metallic shielding, specific hardened components (more resistant to radiation), auto correction for memories (EDAC)
- Threats are analysed from radiation environment models, estimation of transport and simulation of effect on circuit
- Specific components are qualified against radiation doses (cobalt 60 for ageing, particles accelerators for heavy ions and protons SEE)

3: CONSTRAINTS FROM SPACE & LAUNCH ENVIRONMENT

/// 3.4 Thermal environment

/ SL external environment

- Outer space (~3K)
- External loads (solar, planet IR & albedo)
 - Limit the radiators W/m² rejection and may cause orbital thermal stability issues (eclipses)
 - Must be accounted for in both Beginning of Life (cold cases) and End of Life conditions (hot cases)
Coatings degradations mainly due to UV radiation (sides facing sun) and atomic oxygen erosion (for low Earth orbits, velocity side)
- Also constituted by SL external elements (solar arrays)

/ SL internal environment

Other equipment close to cryostat/coolers with varying dissipation modes (switch on telecom, observation phase)

/// 3.5 Resources limitation

/ Limited by satellite size:

- Electrical power : generated from solar array (1 to few KW for observation SL, few 10kW for Telecom SM)
- Power rejection : size of radiators limited by satellite surface (few m²)

3: CONSTRAINTS FROM SPACE & LAUNCH ENVIRONMENT

/// 3.6 Orbits:

/ The mission imposes the Orbit

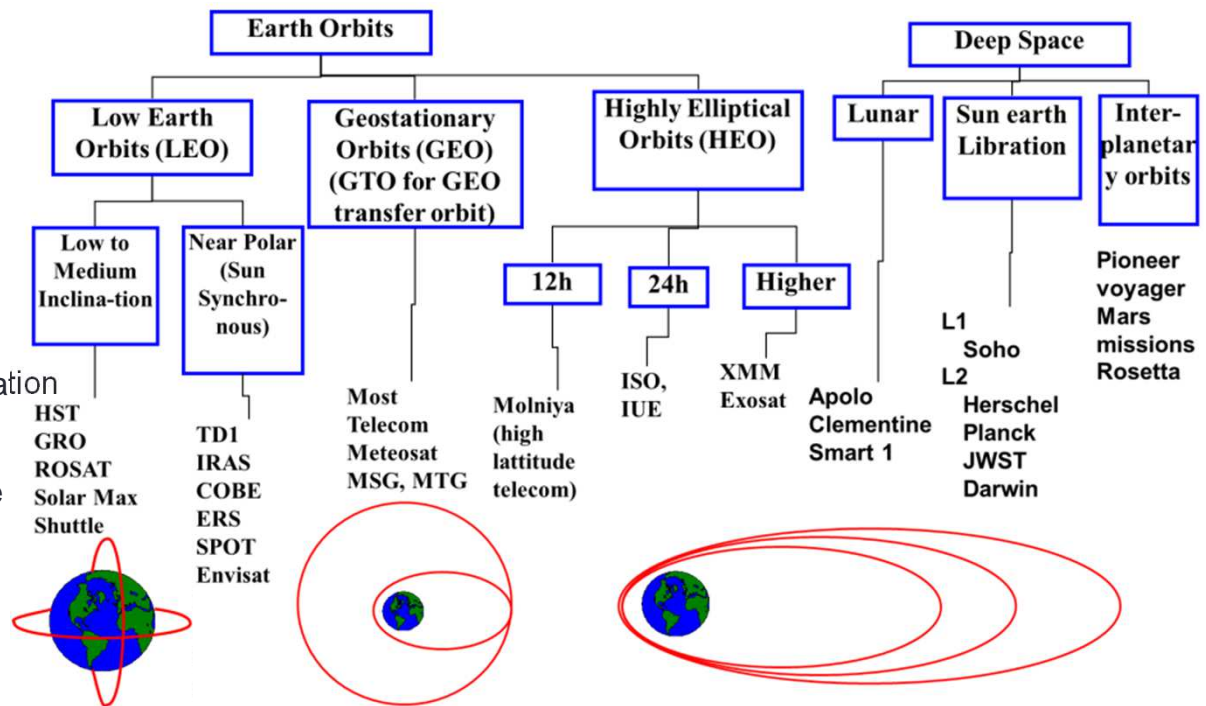
/ 3 types are more often used:

- GEO (Meteosat, telecom):
 - Period 24h
 - Radiators North & south
 - Earth within field of view
 - SL fixed vs ground
- LEO (earth observation, near polar),
 - Sun-synchronised by adjustment of inclination
 - Typical period 1h30
 - 1 side w/o direct sun flux for cold radiator
 - Revisit period (few d) adjusted by altitude
- Lagrange2 (deep sky observation)
 - Period 1y
 - Sun & earth can be shielded (no sun on radiators)

/ For Earth orbits, presence of Eclipse (36mn for LEO, 72mn for GEO)

Switch to batteries

/ On Orbit, satellite can be stabilized (MTG, Herschel) or spin (MSG, Planck)



3: CONSTRAINTS FROM SPACE & LAUNCH ENVIRONMENT

/// 3.7 Launch loads

/ Launch loads qualification based on equivalent environments :

- Sine equivalent [5 to 100Hz]
 - Simulation of sustained sine or transient events during propulsion phases or transients
 - Engines vibrations, structural elastic modes
 - Sweep rate [2 oct/min for Q] ~25g , amplitude-limited for lower frequencies
- Random [20 to 2000Hz]
 - Engines vibration, aerodynamics, acoustic
 - 3mn/axis for qualification
- Acoustic (often covered by random) [20 to 10000Hz]
 - Lift-off and transsonic flight
 - Noise generated by engines and aerodynamic phenomena (shock waves, turbulences)
- Shocks [100 to 10000Hz]
 - Stage separation, fairing jettisoning, SL separation & SL inner mechanisms activations
 - Several times for each axis during Q

/ Loads qualification levels specified at equipment I/F

/ Pistons launch lock system may be required for mechanical coolers

- Either passive by short circuit of motor coils
- Or active with control at position 0 (requires cooler assembly to be “ON” during launch)



4: CONSTRAINTS FROM MISSION

/// 4.1 Instrument type and associated performances

- / The Instrument is designed
- / The type of detector is chosen
- / The detector/optics temperature levels are defined and the associated thermal stability are specified
- / Examples :

	Detector type	Temperature & stability	Cold Optics	Cooler type
Earth Obs. TIR	Photo detector HgCdTe	~60K \pm 10mK	~150K	Large PT/Stirling
Earth Obs. SWIR	Photo detector HgCdTe	~170K \pm 20mK	No	Radiator or medium PT/Stirling wrt SL agility needs
Science Obs. FIR	Bolometers	~0,XK \pm few μ K	Telescope 50-90K	He Dewar + Sorption Cooler (Herschel) Dilution Cooler + 4K JT + 20K Sorption Cooler + 50K radiator (Planck)

Evolutions for Herschel:

- Design started with many coolers (50K + 20K Stirling + 4K JT) & Dilution
- Switch to He Dewar & sorption cooler because of complexity & ISO heritage

/ Influential cooler performances are specified

- Thermal stability (detectors thermal stability is ensured by cooler + potential addition of heating power)
- Exported vibrations by cooler (other potential sources such as reaction wheels)
- EMI-EMC (ac and dc magnetic fields generated by Stirling-type linear motors)

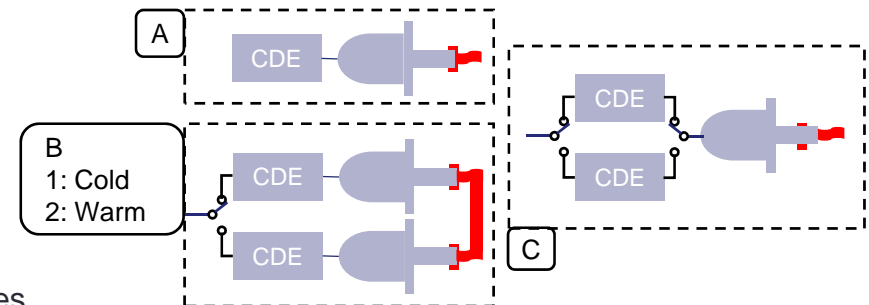
Regenerative cooler will likely be in vicinity of Detectors and proximity electronics

4: CONSTRAINTS FROM MISSION

/// 4.2 Reliability & lifetime

/ Cooler redundancy scheme

- System
 - Cooler redundancy is defined against required reliability figures
 - The customer can impose solutions (no SPF, ..)
- Different options
 - Typical trade-off for Earth observation Instrument



	Cooler mode	Redundancy	Cooler load	Design complexity	Budgets (mass, ..)	Risk
A	Single	None	Medium	Low	Low	High
B1	Single	Full cooler	High (wo th switch)	Low	High	Low
B1	Single	Full cooler	Medium (w th switch)	High	High	Medium
B2	Dual	Partial	Low	Low	High	Medium (degr.mission)
C	Single	Full CDE	Medium	Medium	Medium	Medium

- B1 preferred generally : depends of cooler maturity / Generate orientation constraint vs gravity for ground testing
- Significant part of non-reliability is due to CDE : C may be used with Coolers increasing maturity

/ Mission lifetime

- Satellite typical lifetime = 10 to 15y (contactless mechanical coolers designed for typical 10y)
- Low temperature Coolers in open cycles have limited lifetime (2 to 5y)

5: CONSTRAINTS FROM COOLER

/// 5.1: Microvibrations

/ Microvibration generated from

Mobile masses / Fluid circulation / Pressure oscillations

/ Coolers with linear motors (PT, Stirling, ..)

Moving piston $|F| = M \cdot \omega^2 \cdot x$ (40N/1 piston/100g/3mm-56Hz)

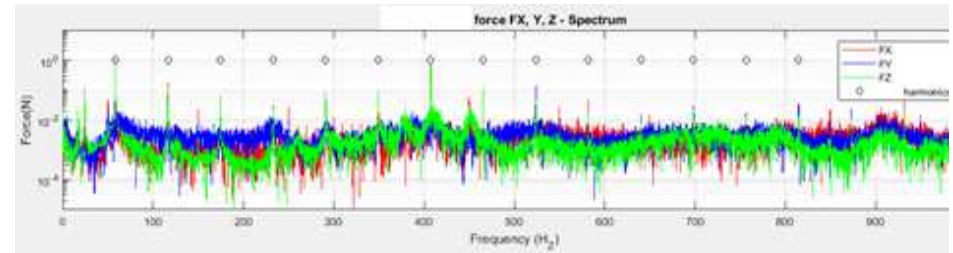
- Cancellation on-axis with mass balanced head-to-head pistons
- Increased on-axis performance with active feedback control with residual forces nulling (slave piston driven with harmonic –amplitude/phase-correction)
- Lateral forces remain not compensated (0.01 to <1N)

/ Impact of Microvibrations may be dramatic for Instrument

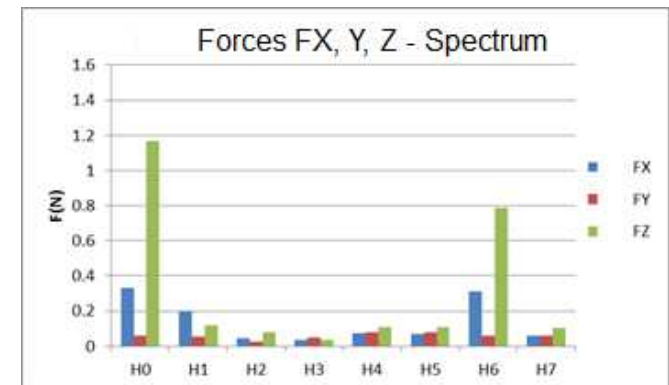
- Alteration of Instrument Line of Sight (LOS) stability → degrade image quality
- Thermal impact for very low temperature cooler (dilution & ADR), with dissipation of μ vibration damping at focal plane → increase cryogenic heat budget

/ Risks mitigations

- Cooler operating frequency tuneable (typ ± 4 Hz) to avoid mechanical resonances
- μ vibration sources properly characterised at Cooler level
- Impact of microvibrations on instrument performance is analysed at system level (specific and complex analyses)
- Potential use of filtering devices



No significant levels out of harmonics →
Harmonics diagram representation



5: CONSTRAINTS FROM COOLER

/// 5.2: Parasitic loads from Cold Head (Stirling & PT coolers)

For Cold redundancy, the off-state loads from the non-op cold head increase the cryo budget

- Conduction in cold head tubes and in the gas (best if vertical) ~ -25% in cooling power for PT
- Off-state loads might be reduced by use of thermal heat switch

/// 5.3: Distance Cold/ Warm

Stirling & Pulse tube cooler have a very short distance between Cold tip & Warm end (10-15cm)

Adapted to compact cryostats

/// 5.4: Distance Compressor to Cold Head

/ For Stirling & PT coolers, the length of compressor & cold head connecting lines (Split Pipe & Inertance) is limited to ~30cm

/ Distance can be longer for JT or TB coolers

- Few meters possible
- Length limited by pressure drops which affect the efficiency

5: CONSTRAINTS FROM COOLER

/// 5.5: EMI / Stray magnetic field

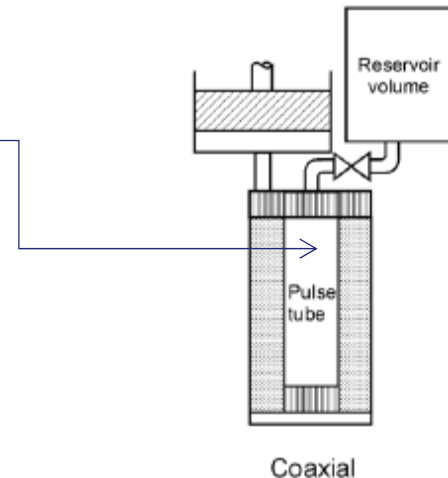
Compressor coils & magnets generate magnetic fields

When sensitive electronic devices (detection electronics) must be accommodated in the vicinity of compressors, Mu-metal magnetic shielding is implemented.

/// 5.6: Testing Orientations

Pulse tube coolers have orientation constraints with gravity (not Stirling coolers)

- Origin = convection in pulsation tube
- Operating cooler performance is slightly affected (<10%), minor concern
- Off-state loads increase dramatically (from 0,7W to 6W) due to convection cells
 - Operating cooler may not sustain such extra loads
 - Preferred testing orientation is cold tip downward in vertical position



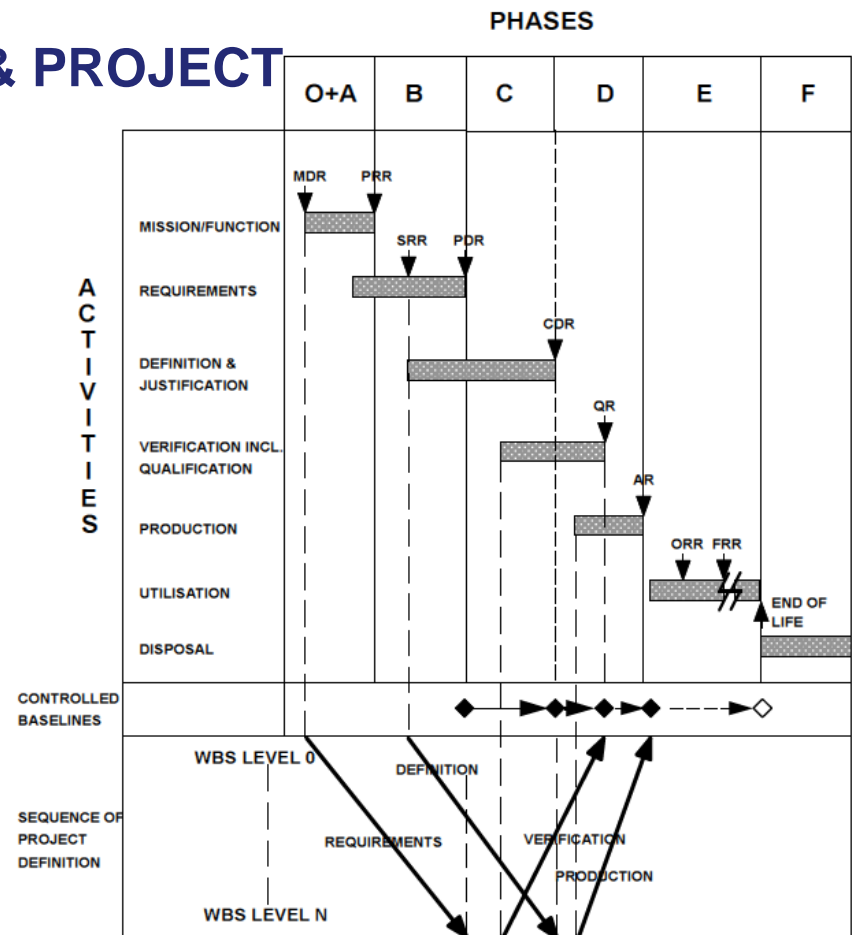
6: CONSTRAINTS FROM SATELLITE & PROJECT

/// 6.1: Project Organisation

/ Satellite, Instrument & Cooler project Organisation will have to match

- Project Organisation
- Project Phases
- Project Reviews

AR = Acceptance Review
 CDR = Critical Design Review
 FRR = Flight Readiness Review
 MDR = Mission Definition Review
 ORR = Operational Readiness Review
 PDR = Preliminary Design Review
 PRR = Preliminary Requirements Review
 QR = Qualification Review
 SRR = System Requirements Review
 WBS = Work Breakdown Structure



From ECSS-M-30A - Space Project Management – Project Phasing and Planning

6: CONSTRAINTS FROM SATELLITE & PROJECT

/// 6.1: Project Organisation

/ Satellite Project Phases

- **Phase A : Feasibility and concept studies** (several years for scientific missions)
 - Concepts trade off – System requirements and interfaces
 - Collaboration customer, industry, (competitive studies) instruments pre-consortium
 - Pre-definition of cost & schedule for satellite, instruments, launch, and mission operation
- **Phase B : Preliminary definition** (~1 year)
 - Technology developments completion - Baseline definition and design/justification activities
 - Set project organisation & contracts – Development plan - Quality assurance plan –
 - Specifications and SOW for Sub-Systems
- **Phase C : Detailed Definition** (~1 year)
 - Final design detailed definition
 - Start qualification & procurement
 - Development models production
- **Phase D : Qualification, Production and Launch** (few years)
 - Production of Qualification & Flight models - Qualification of Processes, Units, subsystems, modules & satellites
 - Acceptance of Flight models of units, subsystems, modules & satellite
- **Phase E : Utilisation** (< 1 to 15y)
- **Phase F: End-of mission Disposal**

6: CONSTRAINTS FROM SATELLITE & PROJECT

/// 6.2: Documentation & Configuration

/ Massive documentation required before delivery, at all levels (SL, Instrument , Cooler) for production & tests

- Management documents (management plan, schedule, product tree, risk management plan, development plan)
- Engineering documents (specification & compliance Mx, design justification&description, budgets, ICD, math. models)
- AIV/AIT documents (tests plan, test procedures, test reports, verification matrices, logbooks, user manual, databases)
- PA documents (material, components & process lists, NCRs, RFD/RFWs, reliability/safety)

/ Documentation is under configuration control (issues management, approval forms, doc.database updates)

/ Requirements managed & organized through all Project levels

- Flow down of requirements Satellite → Module → Subsystem → Units, with origin and filiation tracking by links
- Use of leading requirements management tool (DOORS) / Generation of compliance & verification Mx

/// 6.3: Product & Quality Assurance

/ SL projects are supported by Product Assurance (Project & Engineering level) & Quality Assurance (AIT level)

- Independent organisation (from the project) to ensure quality workmanship, processes and materials at all levels
- PA/QA engineers verify the respect of the company methodology, manage non-conformances & deviations, follow material, components & processes qualification

/ PA/QA activities are co-ordinated among the project levels & subsystems

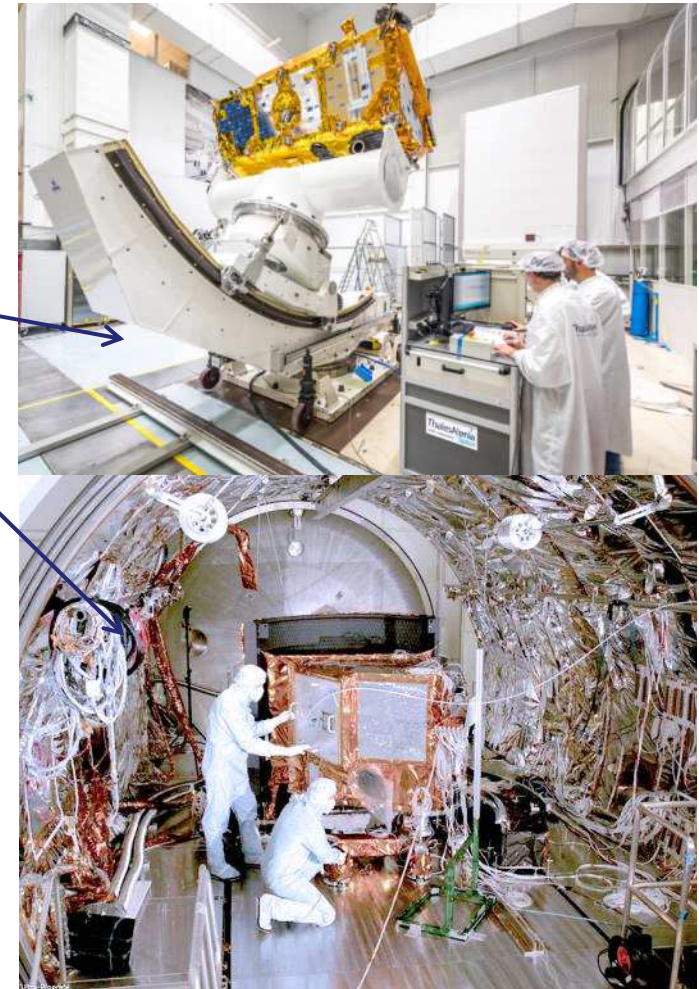
/ Cost of PA/QA activities can be significant in a project

So can be un-quality cost !

6: CONSTRAINTS FROM SATELLITE & PROJECT

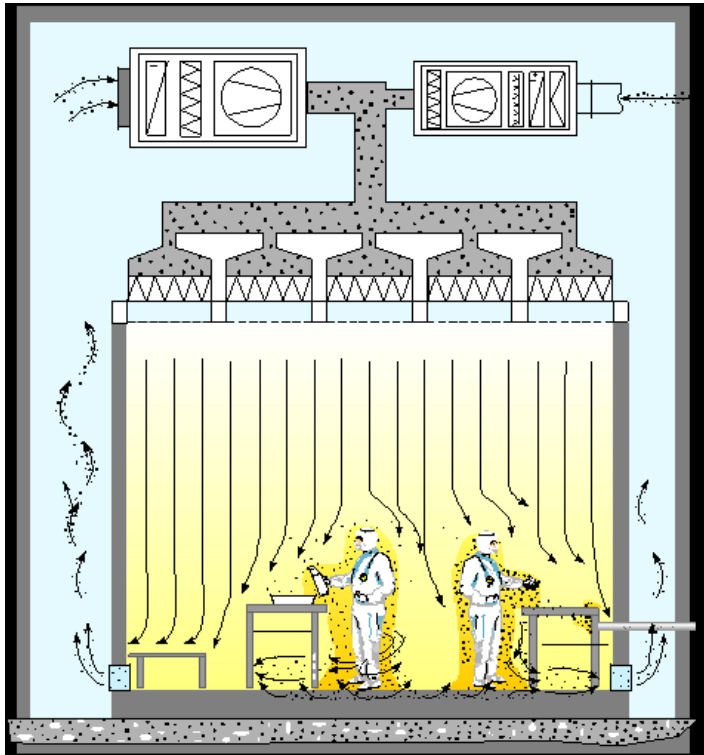
/// 6.4: Cleanliness

- Satellite usually integrated & tested in Cleanliness class 100 000 (ISO8)
- Optical Instruments usually integrated & tested in class 100 (ISO5)
- Such cleanliness standards propagate to manufacturing & testing of equipment (coolers, cryostats)
- Significant impact on facilities (clean room investments) and cost of manufacturing, integration & testing
- Requires management of particulate & molecular contamination of equipment (trace exposure time to different cleanliness levels)
- Requires validated cleaning procedures



6: CONSTRAINTS FROM SATELLITE / PROJECT

Cleanliness class & clean rooms



Class	Maximum particles/m ^{3 a}						FED STD 209E
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	equivalent
ISO 1	10						
ISO 2	100	24	10				
ISO 3	1,000	237	102	35			Class 1
ISO 4	10,000	2,370	1,020	352	83		Class 10
ISO 5	100,000	23,700	10,200	3,520	832		Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7				352,000	83,200	2,930	Class 10,000
ISO 8				3,520,000	832,000	29,300	Class 100,000
ISO 9				35,200,000	8,320,000	293,000	Room air

7: CONSTRAINTS FROM GROUND TESTING

/// 7.1 Satellite or Instrument test orientation for functional tests

/ Satellites have orientation constraints due to test facilities

Optical tests with GSE / TV test chamber / EMC test facilities

/ Coolers operated with 1g may have orientation constraints

PT (mainly OFF-state loads), Sorption Coolers, Cryogen Dewars (location of phase separator)

/ Heat pipes work in specific orientations (evaporator below condenser)

/ Overall design must meet all constraints and ensure test feasibility

/// 7.2 Icing of cryogenic surfaces

/ Water sources

- Outgassing of organics materials inside cryostat (Kapton, resins, ...) [also flight but with lower kinetics]
- Residual air leak within vacuum chamber or Cryostat [N/A for flight]

/ Effects are increase of radiative exchanges and cryogenic optics transmission reduction

Observation of temporal drift as ice thickness increases

/ Design rules

- Minimize the quantity of organic materials inside Cryostat
- Minimize leaks of Cryostat ($<1\text{E-}7\text{mb.l/s}$)
- Allow “quick” cryogenic elements decontamination (evacuate water vapour)
- Size Cooler capacity including icing extra-budget to allow power drift during tests

8: EXAMPLES

/// 8.1: Meteosat Second Generation

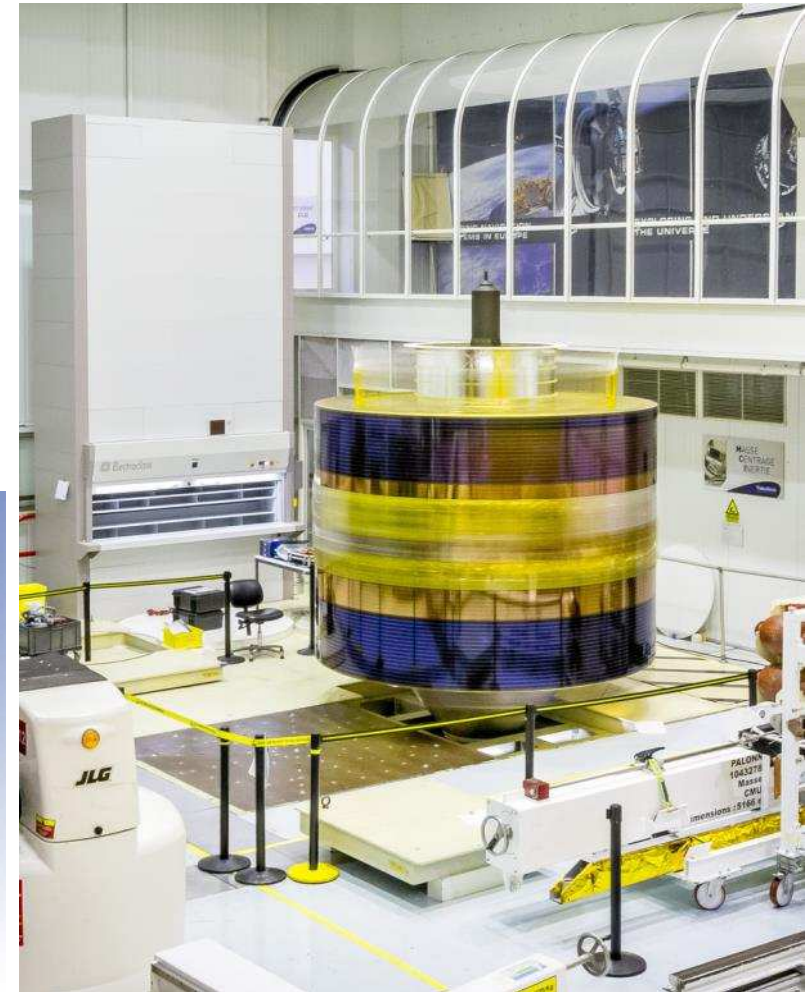
Instrument : SEVIRI / Cryogenic Radiator

- / Map of the atmosphere for meteorology
- / Spin Satellite (100rpm along North axis)
- / GEO Orbit, Lifetime 15y, 4 SL (2004-now)
- / 2-stage radiator (90K-130K)
 - 50mW detector dissipation
 - 200mW parasitics

SEVIRI



© EUMETSAT

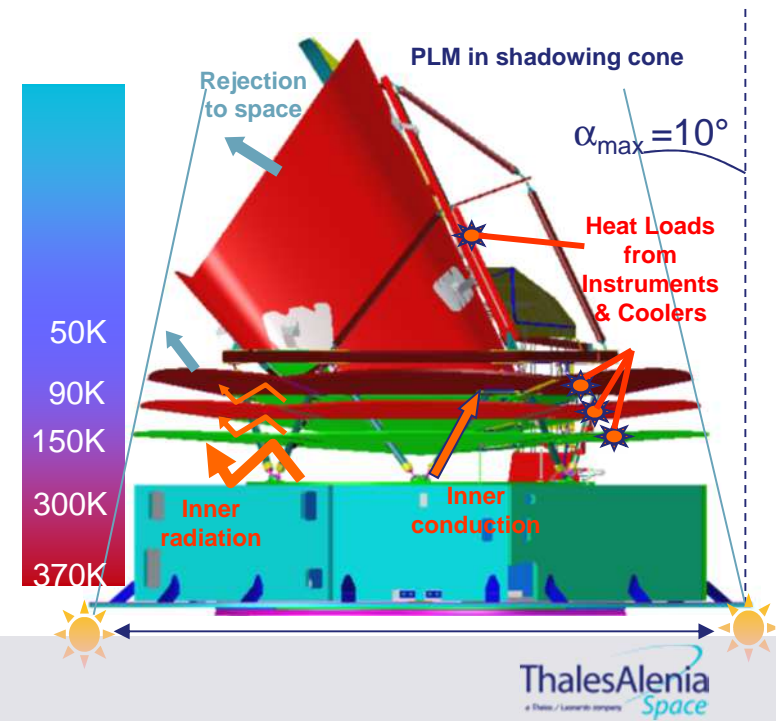


8: EXAMPLES

/// 8.2. Planck

- / Mapping of the CMB (Microwave / FIR)
- / Spin satellite (1rpm, Solar array = Sunshield)
- / Orbit = L2, Lifetime 2years, 1 SL (2009, terminated)
- / Complex cryogenic chain :
 - Passive Cooler (16m² radiator) [3W@50K]
 - 20K cooler 2x(H₂ JT, sorption compressor) [1W@20K with 600W input]
 - 4K cooler (4He JT, mechanical compressor) [15mW@4.5K with 100W]
 - 0.1K dilution cooler (μW@0.1K)
3He + 4He Helium gas quantities limit the lifetime
- / Insulation PLM / SVM → 3 V-Groove shields (tilt 5° + specular reflexion)

50K Radiator with black open honeycomb



8: EXAMPLES

/// 8.2. Planck



8: EXAMPLES

/// 8.3: Meteosat Third Generation

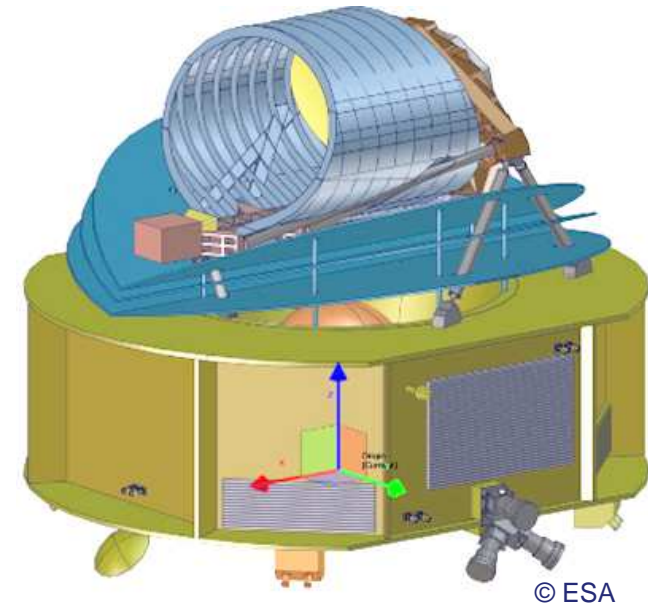
- / **Meteorology Mission**
- / **3-axis stabilized Satellite**
- / **Orbit =GEO, Lifetime = 8,5 years per SL (20y all), 4 Imaging and 2 Sounding missions**
- / **Currently in phase CD (manufacturing & test)**
- / **Detectors : Visible to TIR**
- / **Active cooling with Pulse Tube Cooler**
 - Cryostat power Budget : $\approx 2,5\text{W}@55\text{K}$
 - Coolers integrated on rigid structure mechanically insulated by elastomeric pads (μ vibration)
 - Heat pipes between radiator and coolers



8: EXAMPLES

/// 8.4: Ariel (Atmospheric Remote-sensing Infrared Exoplanet Large-survey)

- / Exoplanets atmospheric spectroscopy (M class)
- / 3-axis stabilized Satellite (Planck was spin)
- / Orbit = L2, launch planed in 2028 (TBC)
- / Currently competitive B1 phase (preliminary design)
 - Cryogenics payload provided by scientific Consortium
 - Industry in charge of Platform & Satellite
- / Architecture similar to Planck :
 - <50K Cryogenic radiator insulated by V-Groove Shields
 - 30K Neon JT cooler, for detector with mechanical compressor in platform
Counter-flow Heat exchanger pipes between Compressor & JT expansion
Precooled on V-Grooves shields and on 50K radiator
 - Solar attitude constraint = +/-30° around Y (was 10° for Planck)



THANK YOU FOR YOUR ATTENTION!