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PLOT meeting 2023
COTS coolers for Space

ROEL ARTS, 2023-06-22

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Content

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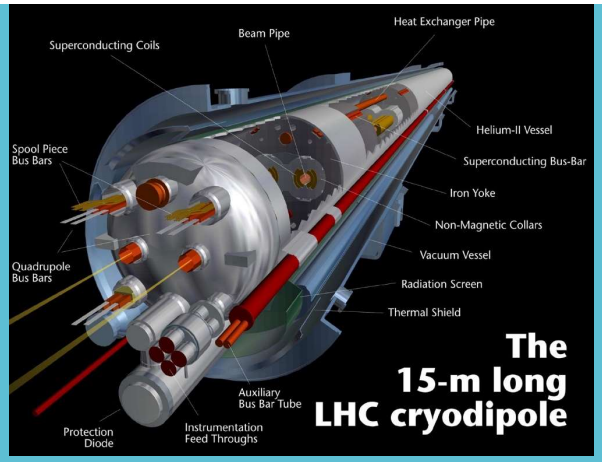
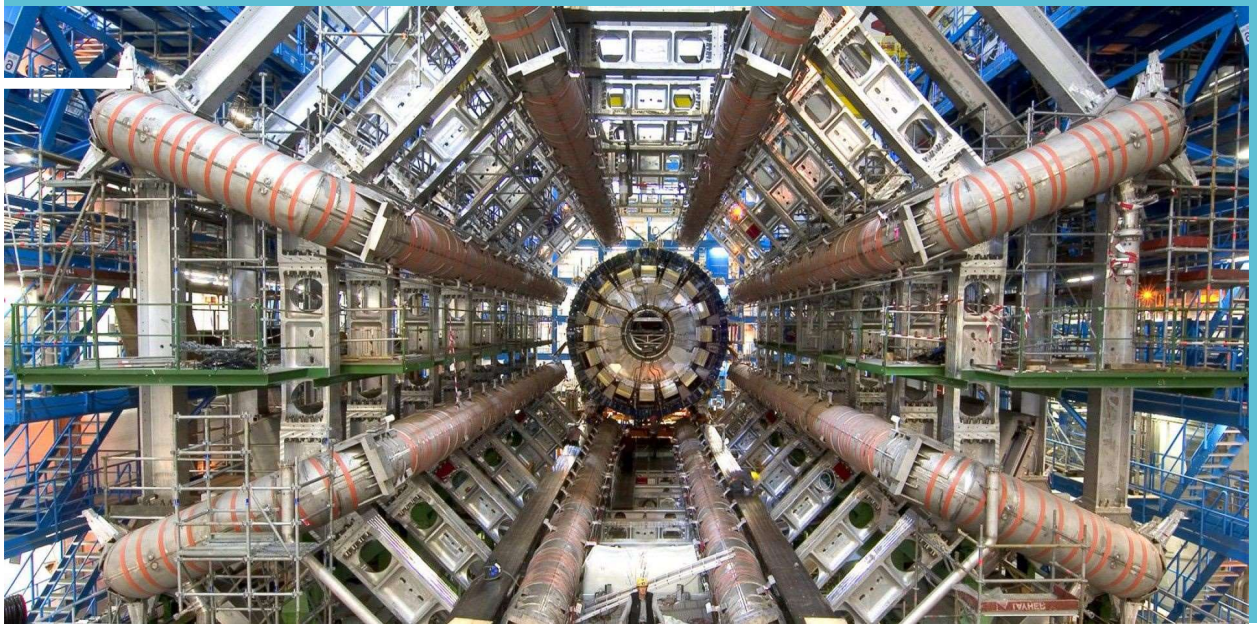

Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole Bus Bars
Radiation Screen
Thermal Shield
The 15-m long LHC cryodipole
Auxiliary Bus Bar Tube
Protection Diode
Instrumentation Feed Throughs

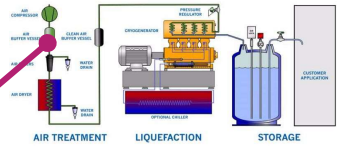

AUSTIN POWERS



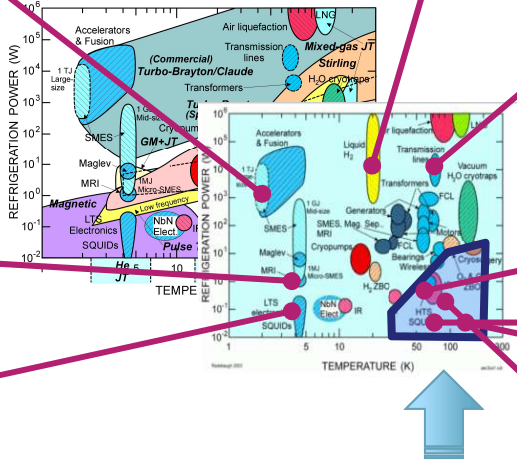
Cryogenic applications | Positioning of Thales Cryogenics

One of the eight 4.2K units @ CERN. Image CERN

Small liquefaction plant. Image: Cryotec



Principle of Air Liquefaction Image: Stirling Cryogenics (NL)



FCOSTRESS IR - Hyper Spectral analyzer: Image : NASA

3T MRI systems. Image Philips

4K Squid Brain imaging. Image: Elekta

THALES CRYOGENICS IS ACTIVE IN THE NICHE SEGMENT OF SMALL CRYOGENIC COOLERS

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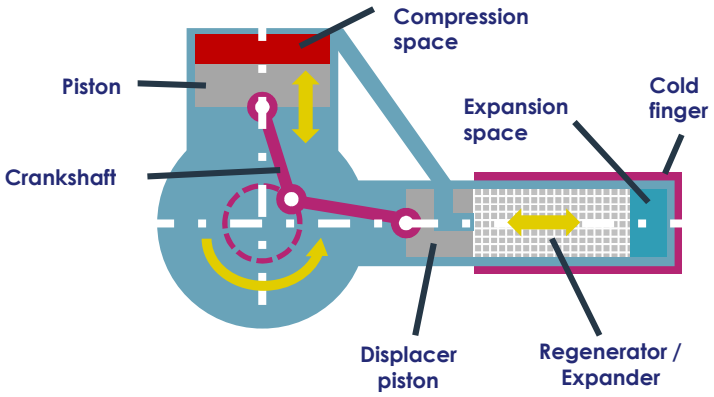
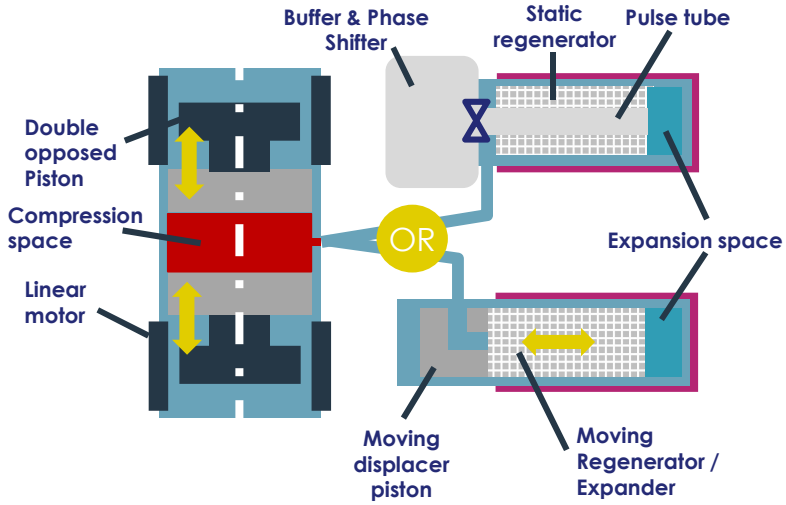
Existing products (← France // Netherlands →)

Rotary Stirling cooler



Linear Stirling and Pulse tube



Products (Thales LAS-France, Blagnac)

- RM2 - Best-seller rotary
- RM3 - Drop-in replacement for market leader K508
- RM4 - High lift
- RMs1 - Low SWaP, high performance

Products (Thales Cryo, Eindhoven)

- UP series: Linear Stirling (mainly tactical)
- LSF series: Linear Stirling with flexure compressor
- LPT series: Pulse-tube cooler with extreme lifetime
- Various space products

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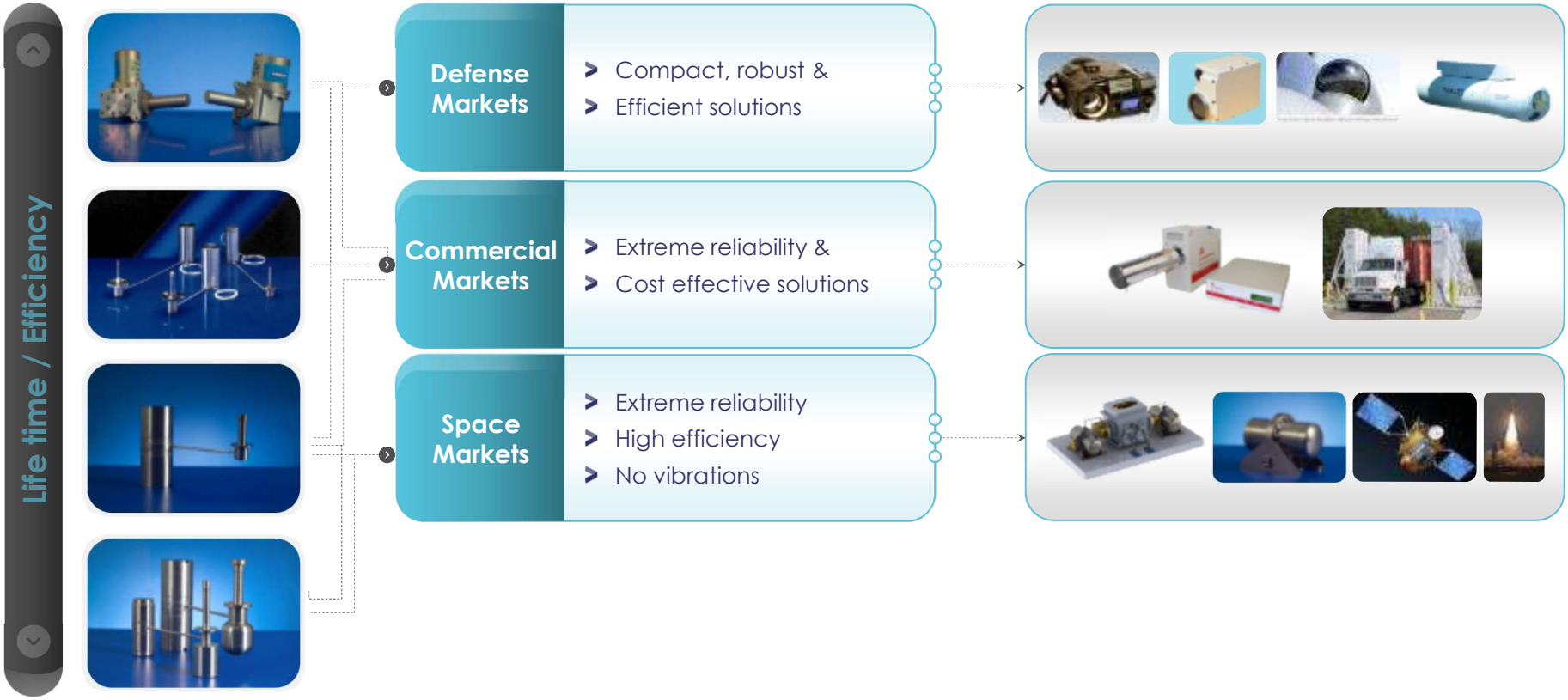
Main Requirements



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Cryocoolers: What are they for?

Cool down object to very low temperature

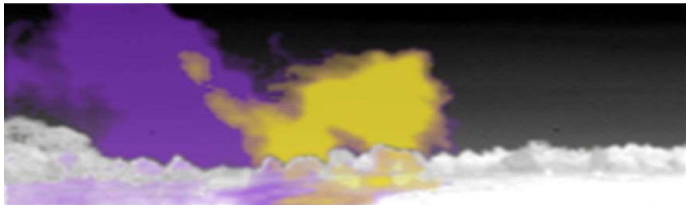
Typical operating range: Liquid Nitrogen temperature (77 K / -196°C)

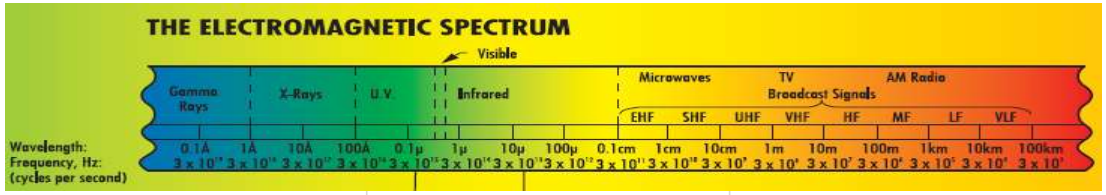
Various applications, but key market for Thales: Infrared sensing

Industrial applications (example: hazardous gas detection

Earth observation (example: Meteosat Third Generation)

Defense (example: sensors in and on fighter aircraft)





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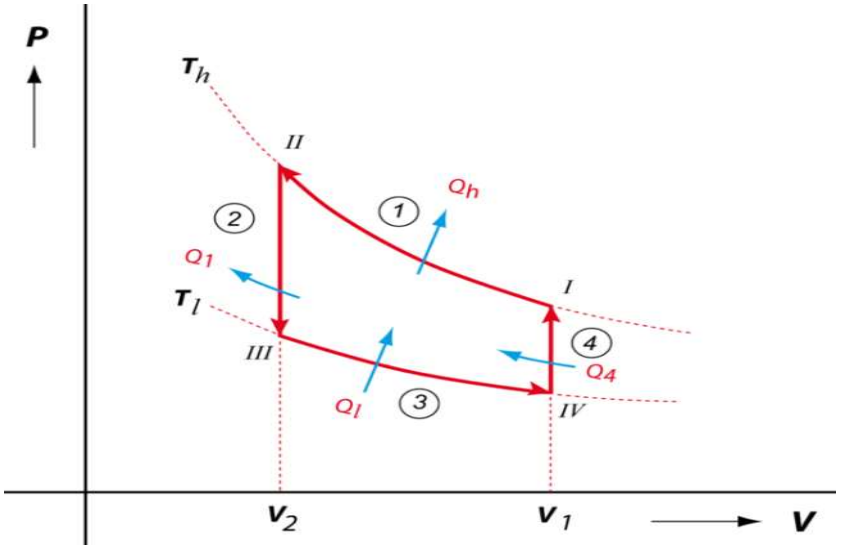
Detector cooling: the Stirling koeler



1. Isothermal compression
2. Gas cooled down (regenerative)
3. Isothermal expansion
4. Gas heats up (regenerative)

Reverse Stirling cycle :

Put in mechanical power, result in pumping of heat

Theoretically this cycle can reach the maximum efficiency (Carnot efficiency) of such a process:

$COP = (T_l/(T_h-T_l)$

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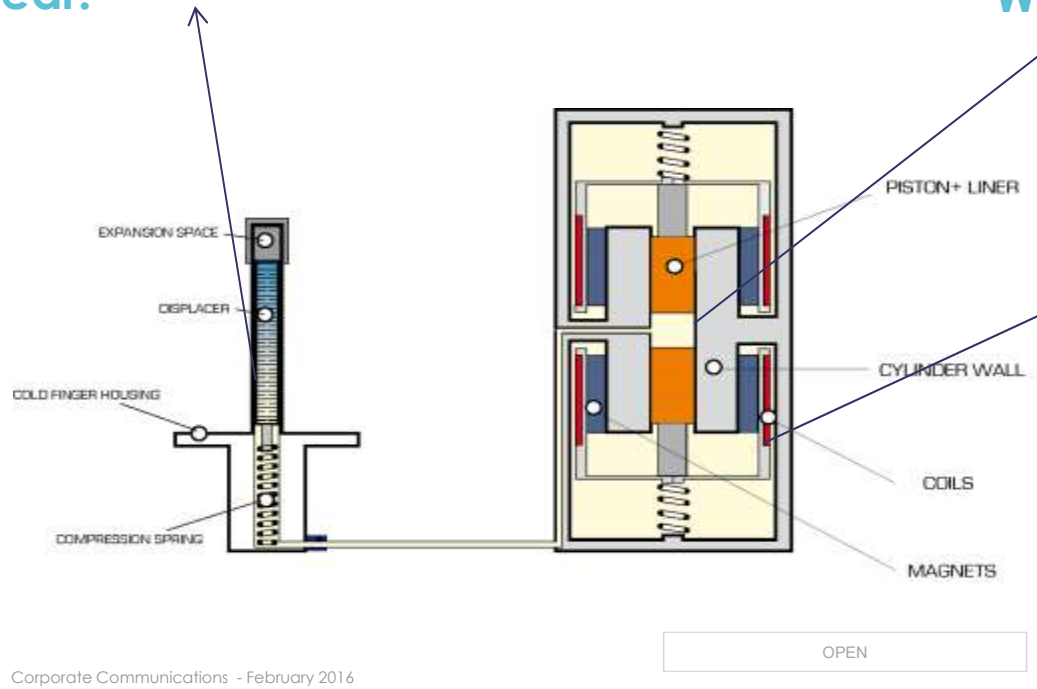
Cryocooler Reliability (Bread and butter of Thales Eindhoven)

Gap between moving displacer & wall: Wear!

Gap between piston and cylinder: Wear!



Motor coil in Helium
- **Leakage**
- **Outgassing**

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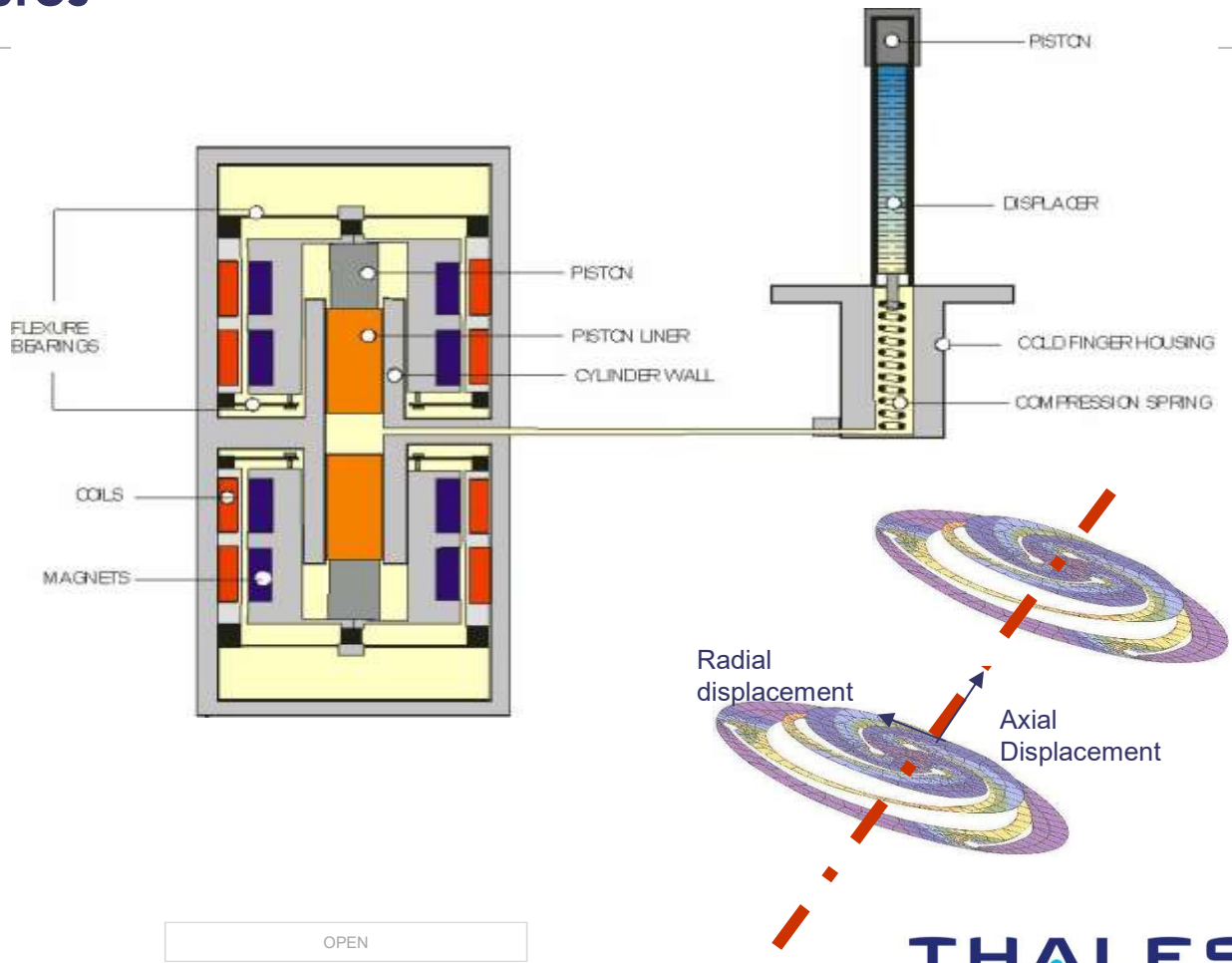
Compressor life: flexures



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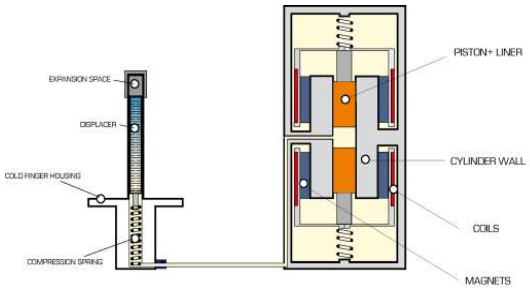
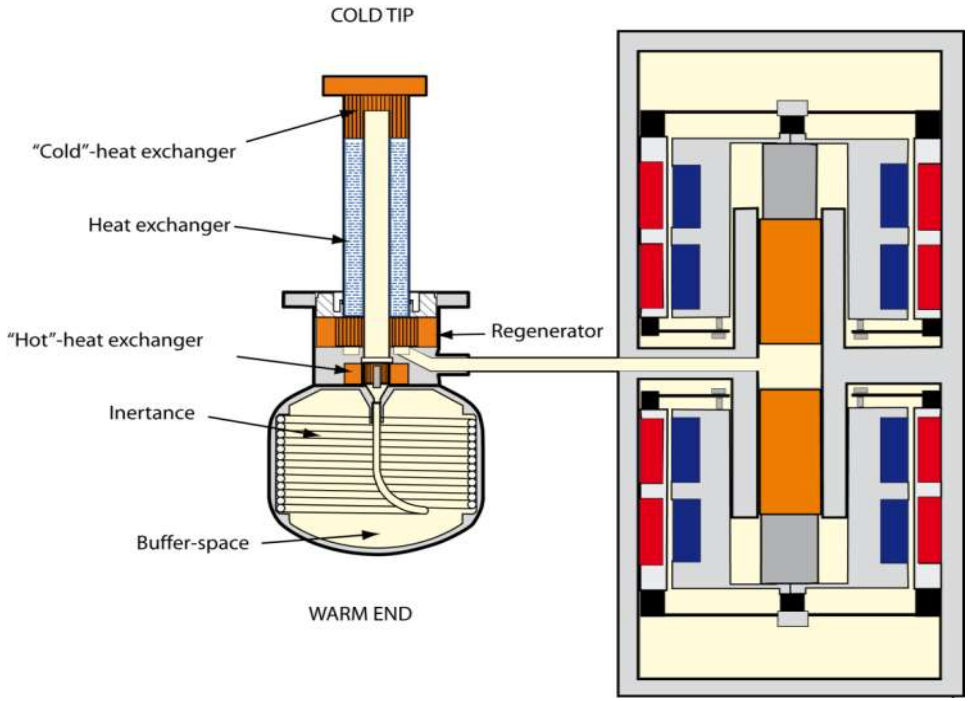
Cold finger life: Pulse tube





"Displacer" not needed:

- "Gas displacer"
- No moving solid parts in cold finger -> No wear, low vibration

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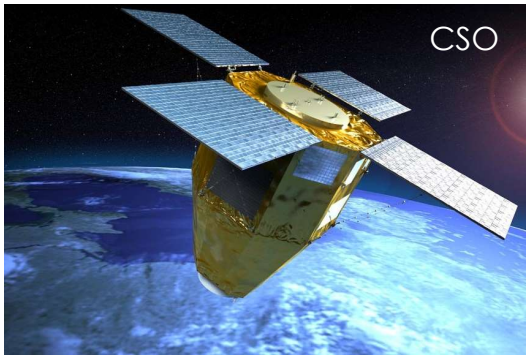
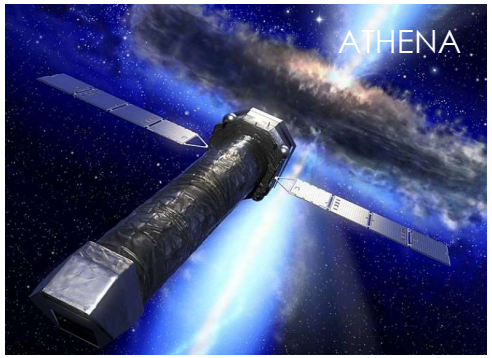
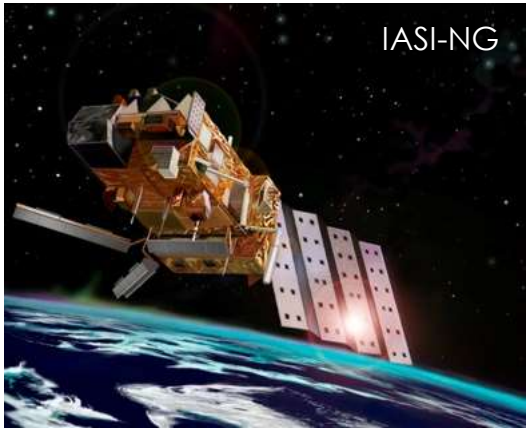
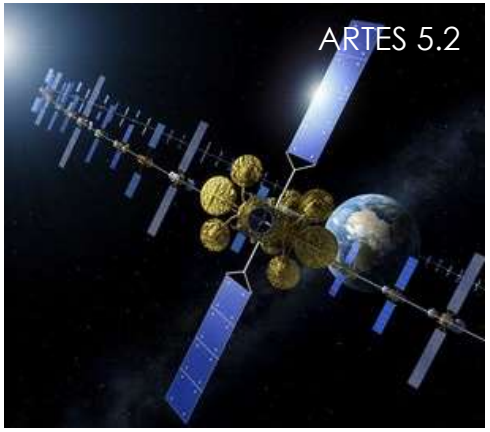
Our Space Footprint









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Space coolers: Product Line Perimeter

Thales Cryo: Diversified portfolio across MILITARY, CIVIL, SPACE markets

SPACE segmentation according to Customer Value:

- Full Space:
  - Compliant to ECSS or NASA standards
- New Space:
  - Designed to fully comply on technical requirements, but save(rationalize) on project cost
- COTS+:
  - Build it like a tactical product with some extra checks, design may not be fully compliant with space standards



1. FULL SPACE **2. NEW SPACE** **3. COTS+**



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Overall approach

General principle:

- Field-proven and life time test-proven reliability of many COTS/tactical cooler designs exceeds the R required for space

Take a commercial-grade high-reliability cryocooler and justify flight

- Example: the Thales LPT9310 series as used for ECOSTRESS and EMIT (JPL)

Or use proven design elements from tactical cryocoolers in a high-performance designed-for-space cryocooler

- Example: The Thales LSF9199/30 cooler

Use a rationalized set of testing to justify use as FM

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Typical additional tests done:

Additional batch-level inspections on critical parts

- Identify points where COTS-standard inspections are not sufficient

Additional burn-in

- Eliminate any workmanship or part-related infant mortality

Random Vibration Test

Thermal Vacuum Test

Additional compressor diagnostics (ring-down testing)

Extended drying/curing (100 C vacuum applied to cooler internals)

- Eliminate risk of contamination issues

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Case study: COTS cooler for NASA-JPL ECOSTRESS

- **Thales Cryogenics has built >3000 for non-space use**
- **Proven reliability of COTS coolers:**
  - In use 24/7
  - Proven high availability, >99% after 5 years of 24/7 use
- **COTS build standard is 1 or 2 orders of magnitude che grade" build standard**

- ***... That is why NASA JPL was anxious to try an "off-the-shelf" Thales cooler in an actual space mission***

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Standard LPT9310 – Specific ECOSTRESS validation

Leak test -> Proof test (reduced ratio) -> Leak test < $6x10^{-9}Pam^3/s$

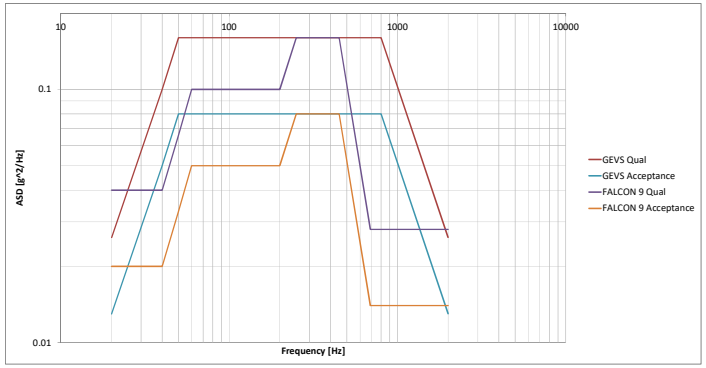
Random vibration tests with 100g additional mass on cold tip-> 10.1 grms

- Make sure the product survives launch!
- Notching of spectrum based on pulse tube deflection, in discussion with JPL

No performance degradation after tests

Burst test performed

- Pressurized hardware
- Tested for safety



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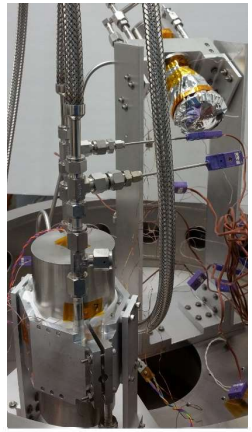
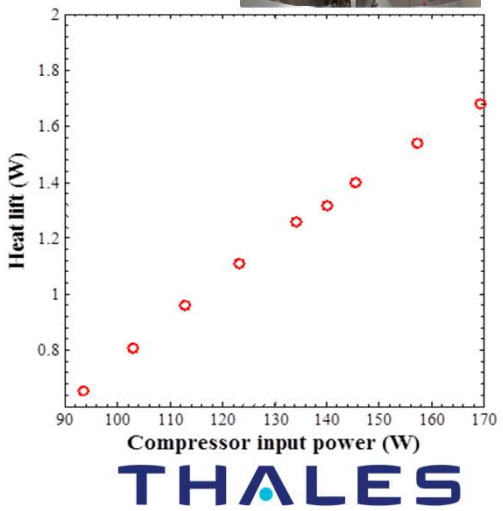
Standard LPT9310 – Test results at JPL

Conducted thermal performance tests assuming worst cased environmental conditions on the ISS

- 24°C fluid inlet temperature at 155 kg/hr delivery rate
- Compressor input power limit of 140 W
- At 65 K the estimated Ecostress focal plane thermal load is 1.3 W to each cooler; a 5K temperature gradient was assumed for the thermal strap to the 60 K coldtip
- At 140 W input power, the 60 K cold tip could deliver 1.3 W of cooling, leaving virtually zero margin in the cooling capability

Thales was contracted to execute a Form-Fit performance upgrade on a tight schedule





High performance LPT9310 – Trade-off results

Objective:

- Increased cooling performance
- Minimimise risks (design and schedule)
- No impact on interface

Approach

- Trade-off analysis of all pulse-tube redesign options that have been investigated by TCBV in the past:
- Contront each option to:
  - Improvement
  - Risk / heritage
  - Interface impact

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Trade-off results

Design option	Interface impact?	Process and schedule risk?	Selected ?
Optimized regenerator design	None	Low	Yes
Low conductance material between hot and cold	None	Medium -> heritage available	Yes
High-conductance material on warm side	None / Low	High -> impact on design, metal seals needed	No
Optimized cold heat exchanger	Medium	Medium – limited heritage	No
Optimized warm side heat exchange	Medium	High	No
Optimised inertance	High	High	No

Expected performance gain at 60K: ~700 mW

High performance LPT9310 – Process qualification approach

Approach:

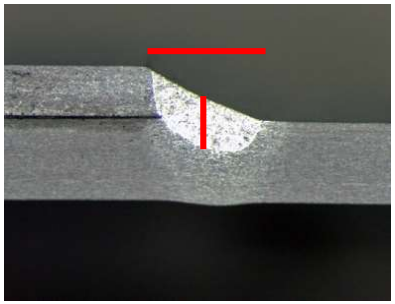
- Process delta qualification
- Pressure tests on product level

Involved processes

- Brazing process
- Welding process

Samples for

- Tensile test
- Micrographic inspection



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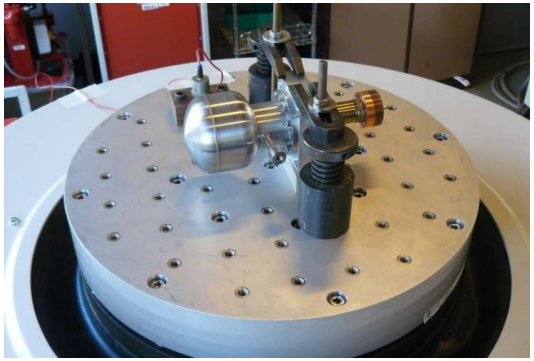
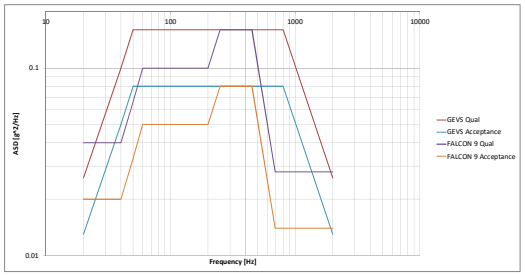
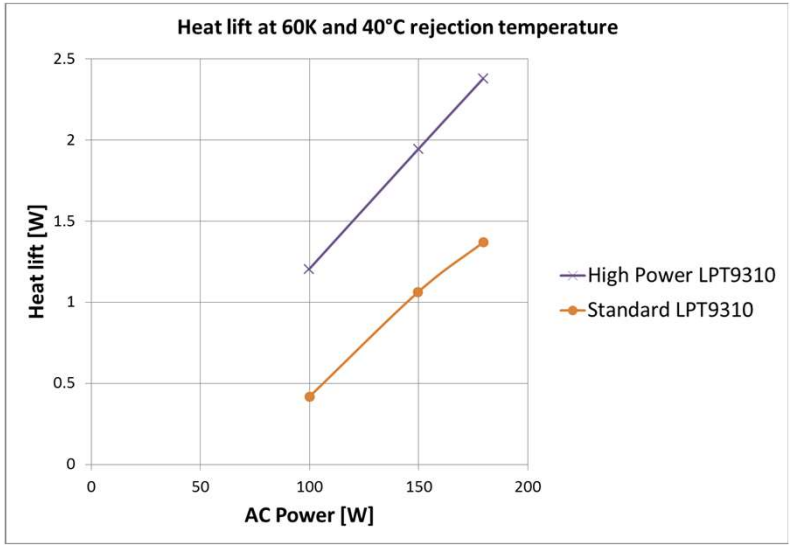
LPT9310-HP

- High-performance definition designed, built & Tested
  - Low-conductance tube
  - Optimized regenerator matrix
- Full test campaign, including:
  - Pressure cycling
  - Temperature cycling
  - Random vibration







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Development summary

- Off-the-shelf cooler initially selected for JPL-NASA ECOSTRESS mission
- Standard LPT9310 used as Engineering Model / Performance verification
- Updated interface requirements necessitate upgrade (no margin)
- Changes with minimal risk, maximal gain selected
- Delta qualification performed, >700 mW of performance gained at 60 K
- **Launched June 2018**

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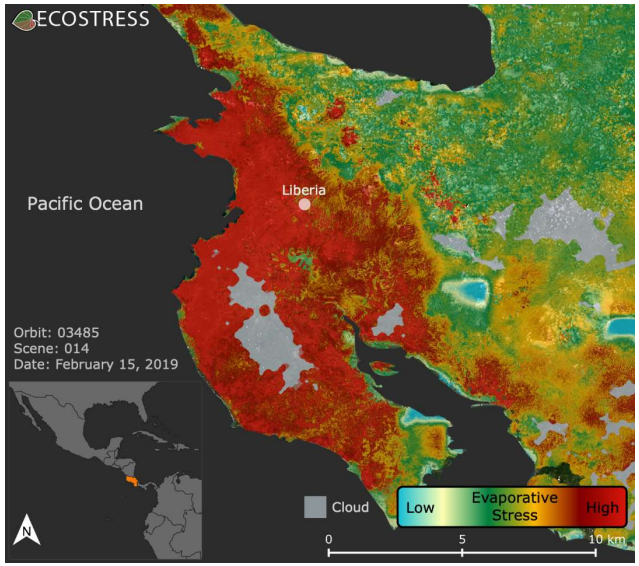
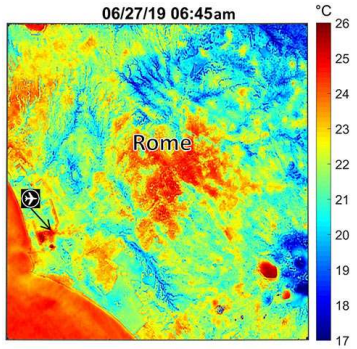
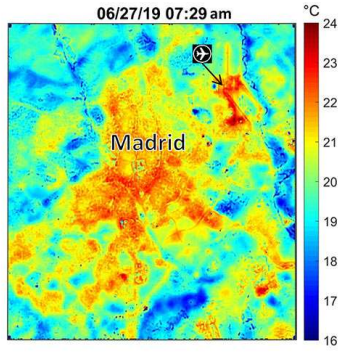
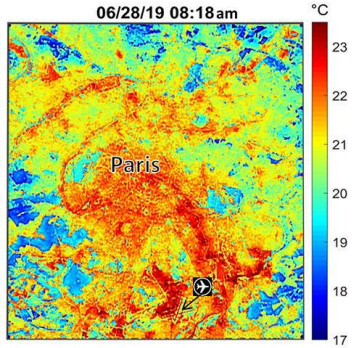
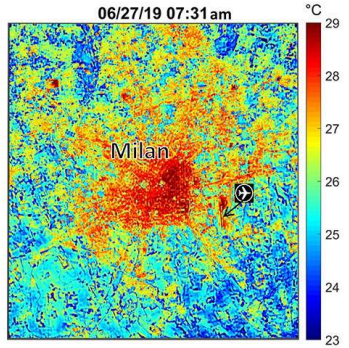


Jet Propulsion Laboratory
California Institute of Technology









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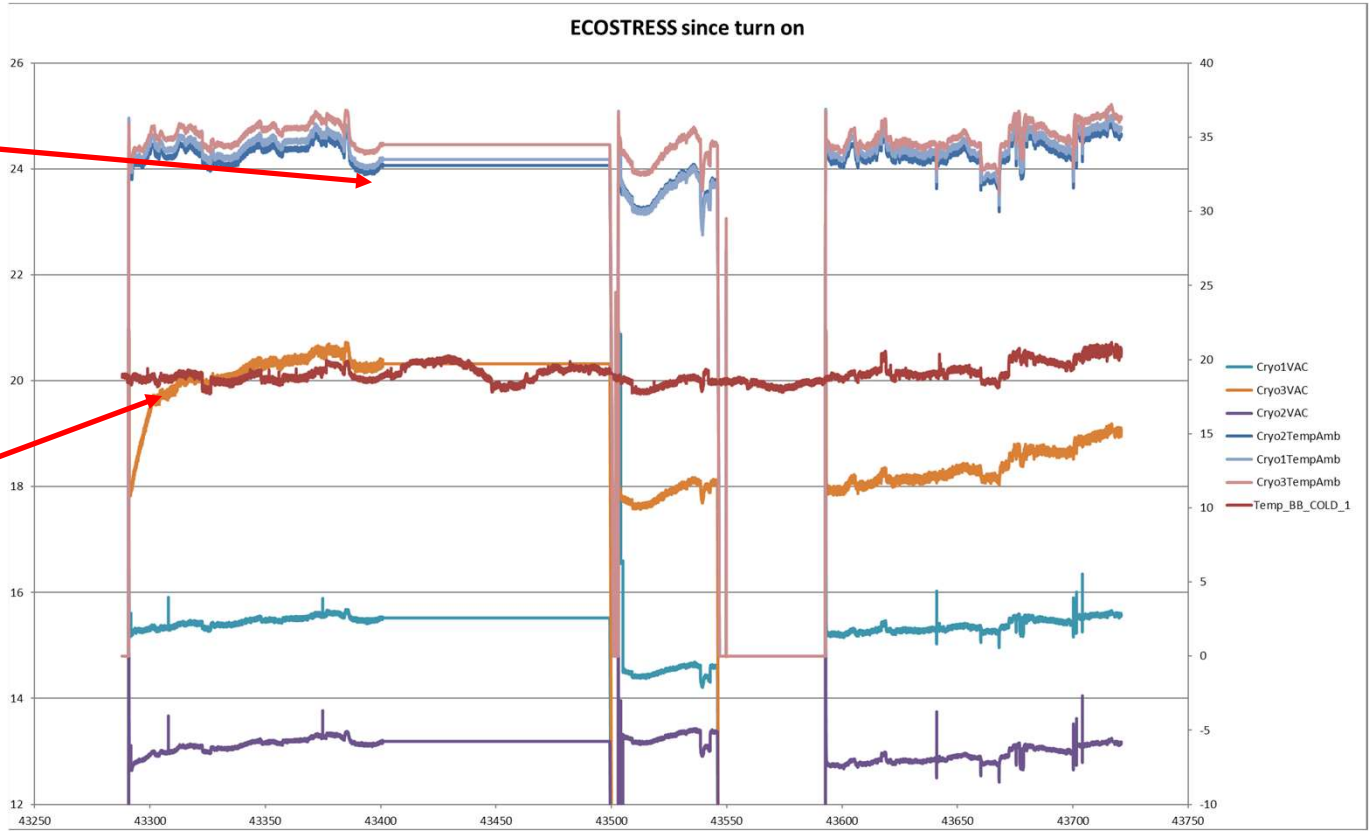
Telemetry since power-on

Comms issue (not caused by Thales hardware)

Slow deposition of contaminants on cold shield



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Happy customer! -> Two awards for Thales Cryo

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So why did we get these awards?

Pragmatic approach

- Both sides approached the project as a partnership rather than "supplier/customer"

Product has exceeded requirements & expectations

Quick support, answers to questions

Open and transparent communication -> also when facing problems

- Failure during testing (problem on Thales side)
- Failure during instrument integration (problem on JPL side)
- Failure on-orbit (problem on JPL side)

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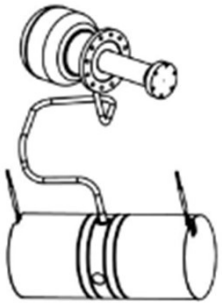
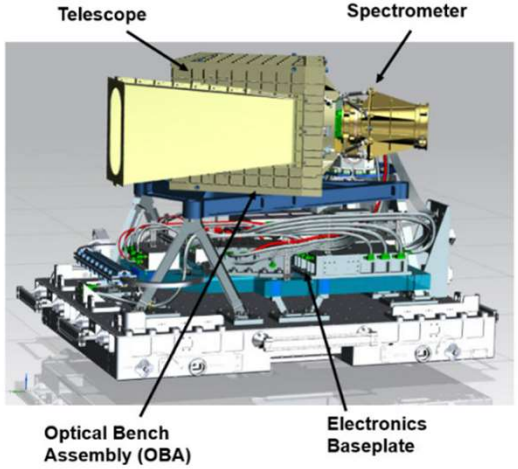
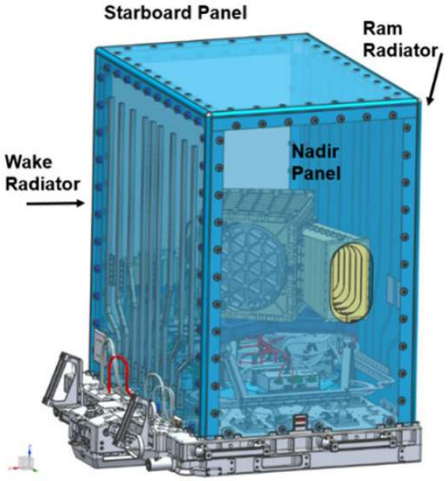
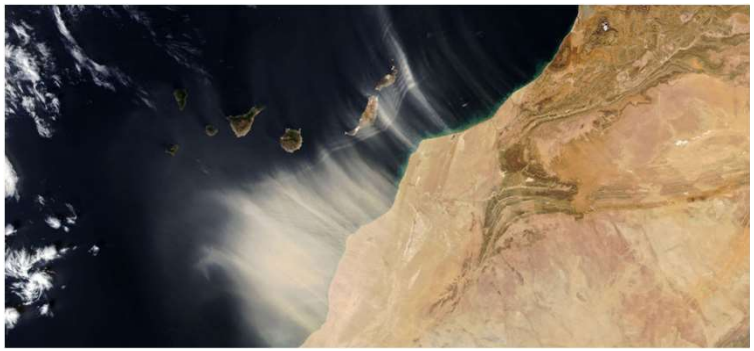
EMIT (NASA JPL) – Follow-up program, launched June 2022

- Earth Surface Mineral Dust Source Investigation
- 1x LPT9310 to provide cooling at 155 K
- IRIS HP-LCCE2 drive electronics used









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Thales LPT9510 & LPT9310: FM built and delivered

Cryocooler	Customer	Mission	Status
1x LPT9510 2x COTS CDE	Raytheon	TacSat-3 / Artemis	Launch May 2009, burn-up on re-entry after 3 years of nominal operation
3x LPT9310-HP 6x COTS CDE	NASA JPL	ECOSTRESS	Instrument turn-on July 2018, 3 units >40000 hours without any degradation.
1x LPT9310	NASA JPL	EMIT	Instrument turn-on July 2022, operation nominal to date
1x LPT9310	AIRS	Undisclosed	Launch date not disclosed to Thales
7x LPT9310	Undisclosed (USA)	Undisclosed	First unit launched 2023. Follow-up order received.
3x LPT9510	Undisclosed (USA)	Undisclosed	Delivered in 2020, launch date not disclosed to Thales
4x LPT9510	Undisclosed (USA)	Undisclosed	Delivered in 2022, launch date not disclosed to Thales

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Thank you for listening!

Questions?

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