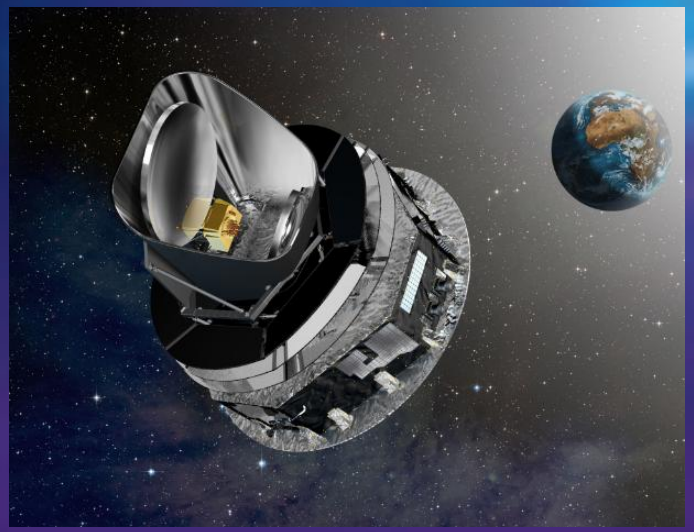
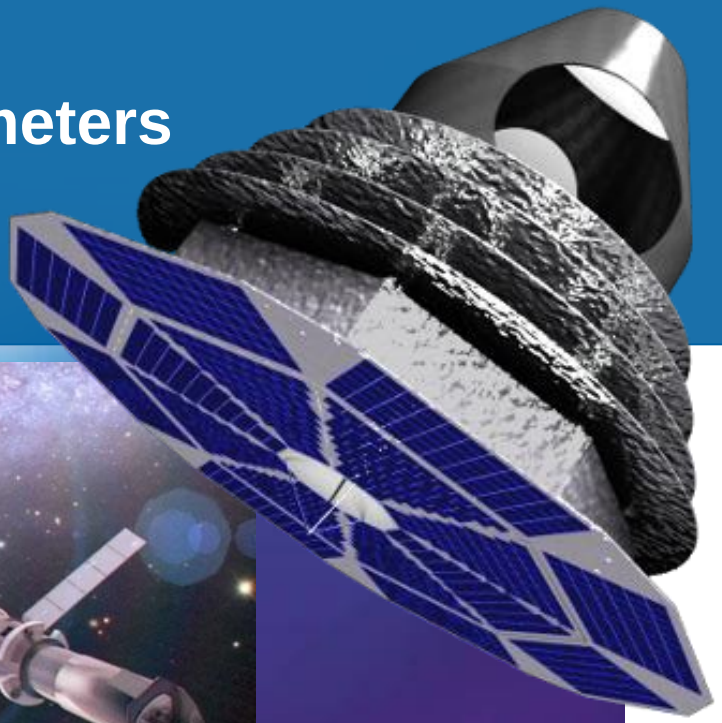
Spatial Cryogenics for Ultra Low Temperature Spectrometers

Y. Pennec, J. Butterworth, P Crespi





CERN-CMB- Mai 2016

Outline

ALAT space cryogenics overview
Planck Cryochain
Core + Cryochain
ALAT X-IFU Cryostat preliminary design
ALAT 15K High power Pulse Tube
ALAT-CNRS 50mK Dilution

Air liquide Space Cryogenics

Launchers

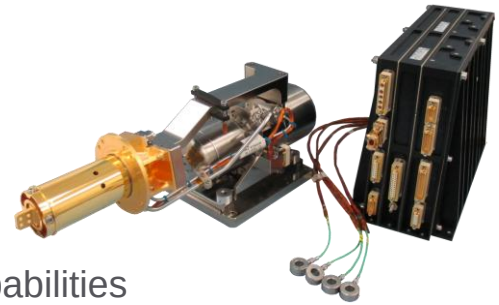
- Official Supplier of Ariane 5
- Cryogenic tanks (O2, H2, He)
- Thermal shielding
- Cryo Fluid and Gas distribution (lines, valves, control)

Orbital systems and Satellites

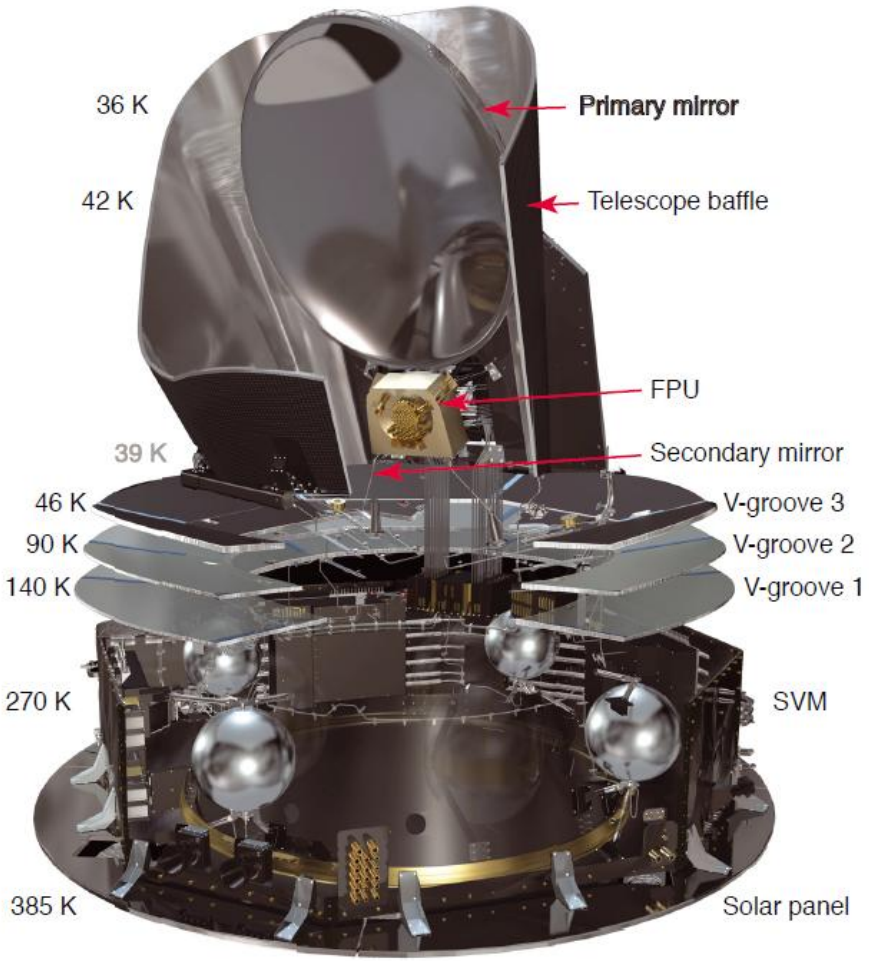
- Ultra Low Temperature 100mK-1.6K
- Pulse Tube CryoFingers 10K-150K
- Turbo-Brayton Coolers 200K
- Thermal Shielding
- Frames and supports
- Cryo Fluid and Gas distribution (lines, valves, control)

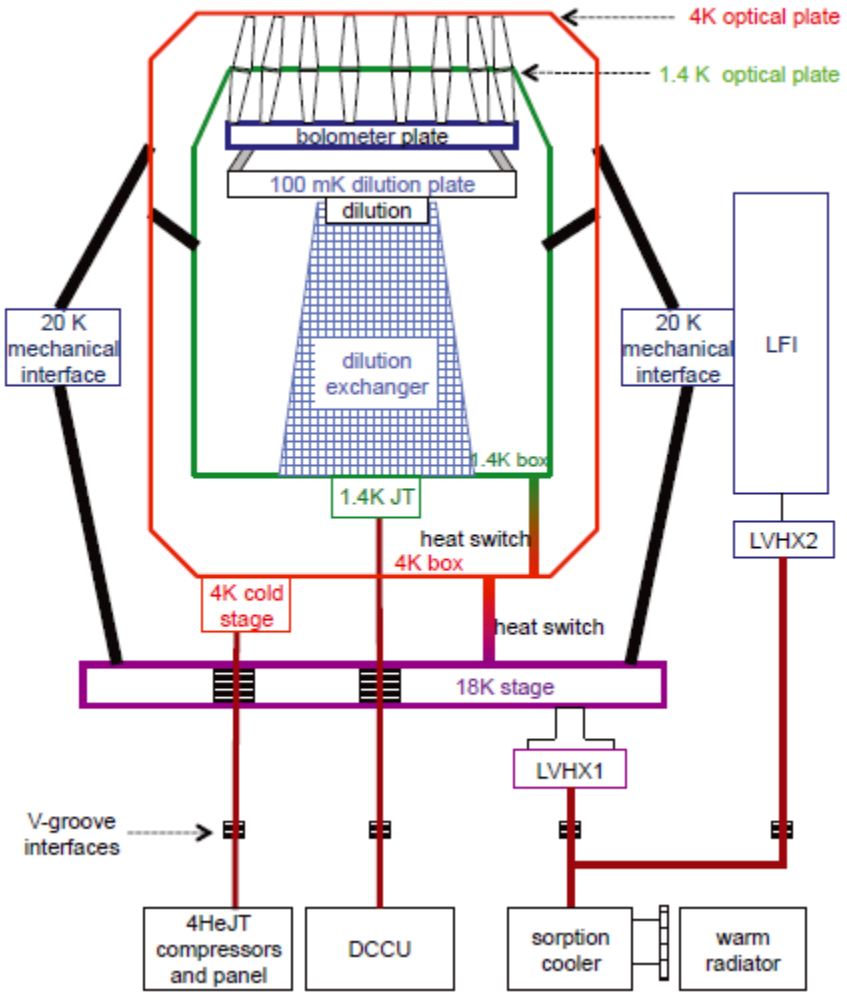
Ground resources

- Space Simulation Chambers
- Launch Simulation Test Benches
- Gas and CryoFluid distribution equipment
- Extensive R&D, engineering and manufacturing capabilities

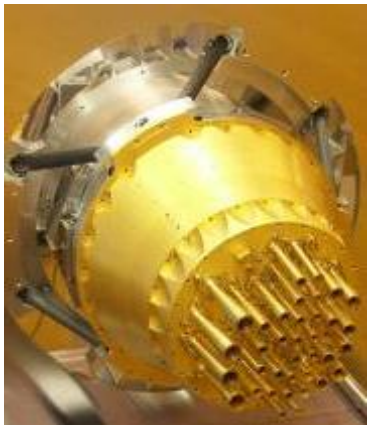


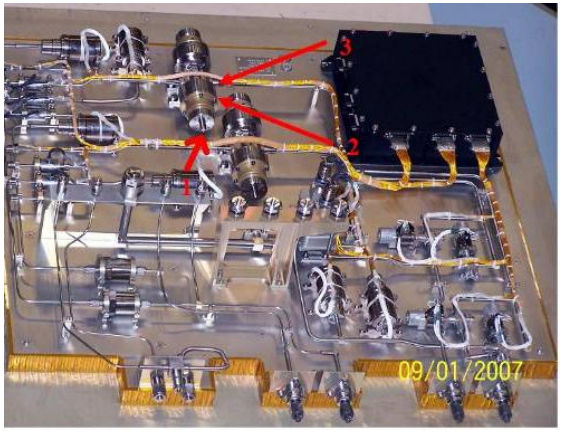
Planck Cryochain





ALAT-CNRS 100mK dilution cooler and cryogenic frame for Planck

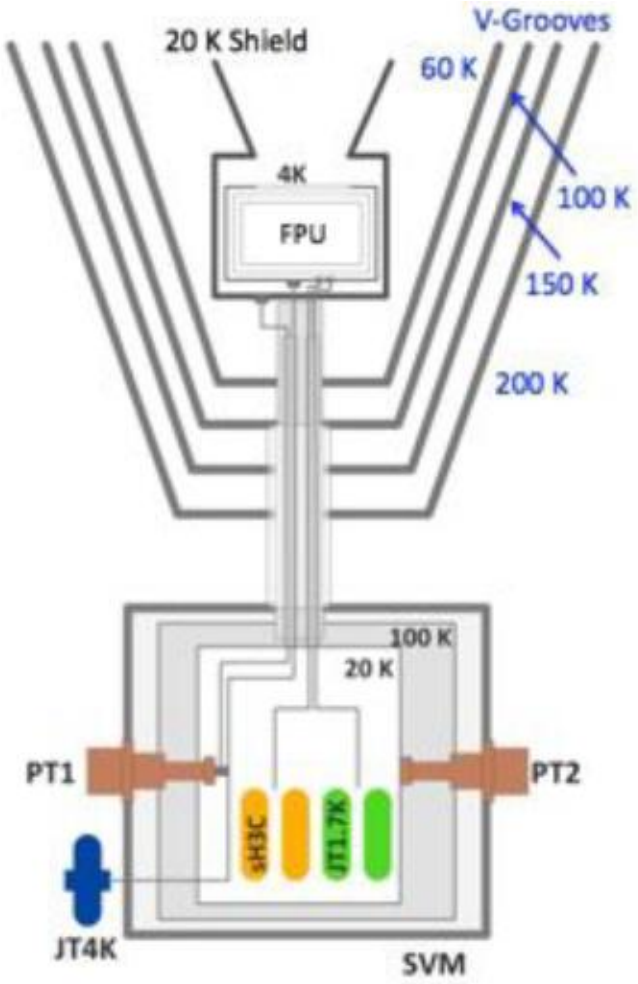




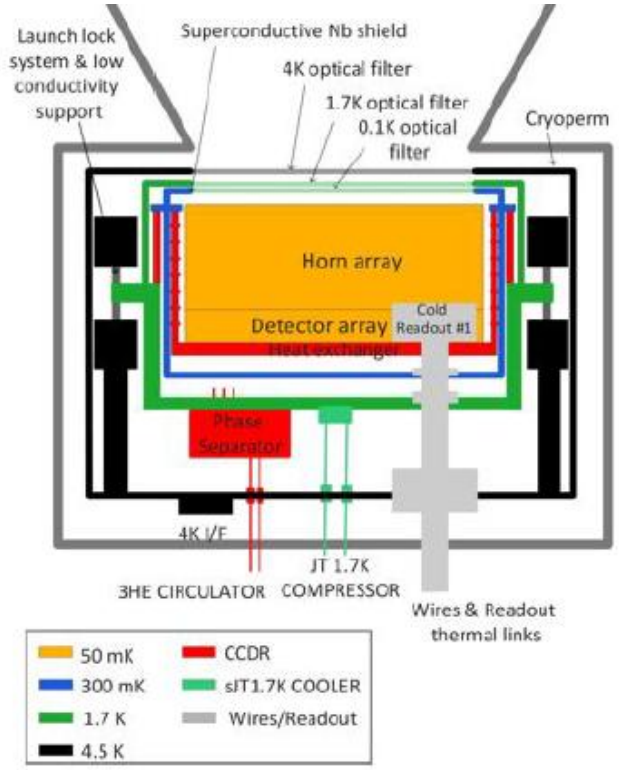
Zero Gravity ^{3}He/ ^{4}He Dilution

- Shape memory alloy Launch lock
- Wiring Harness Thermalization 0.1K
- Damping of thermal fluctuations with rare earths material
- 4 He storage @300bar / 51 L
- 2,5 year autonomy
- Fluidic Plate

CORE + M4 Cryochain - DESIGN



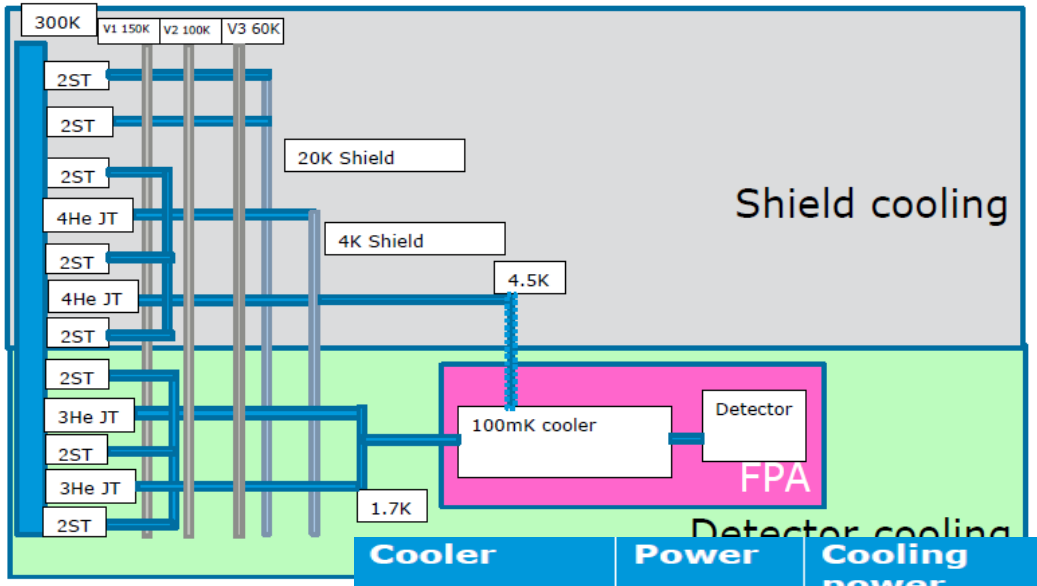
Cryogenic architecture



Entry requirements

Passive Cooling to 60K with V-Grooves
Optics below 60K (Passive and/or Active)
Mechanical coolers to ~20K, ~4K, ~2K
Active cooling of ~20K, ~4K Shields
Sub-K cooler to <100mK
Extended operating time

CORE + M4 Cryochain – Cooling Margins

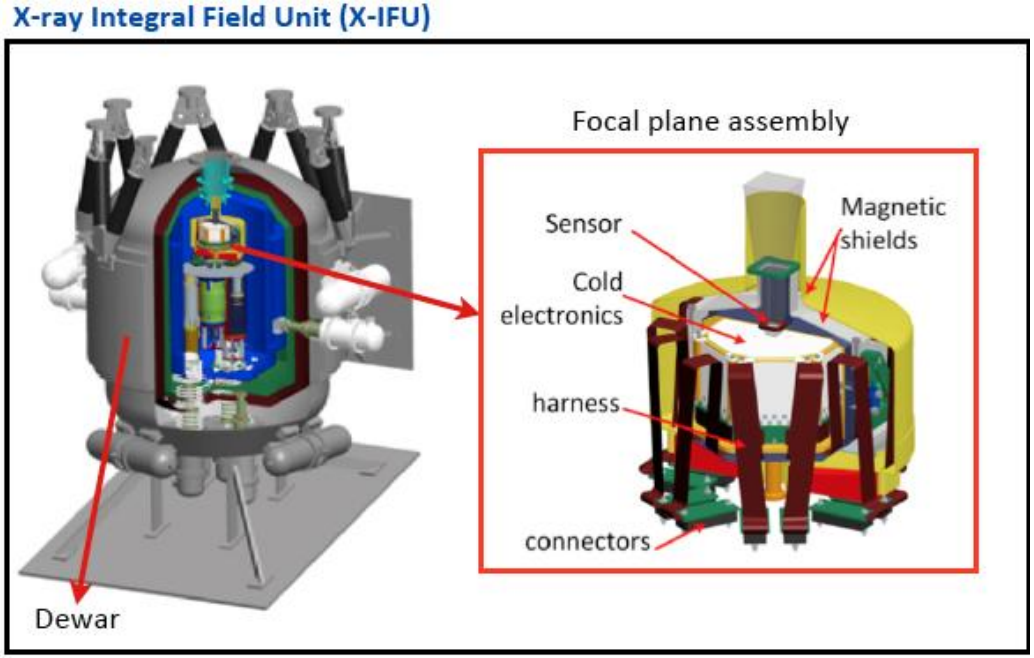


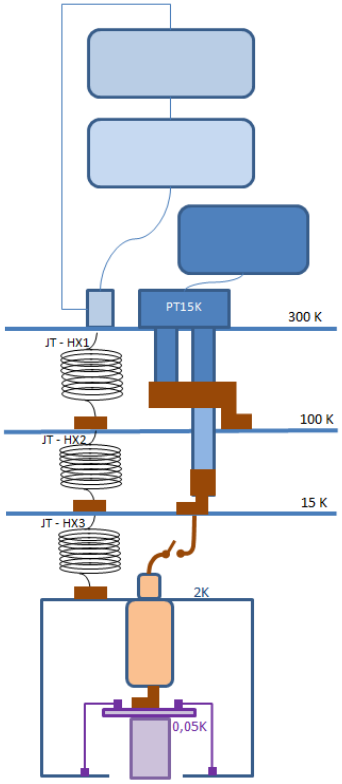
ALAT suggested path forward for Core+
Implement preliminary Cryostat/Support Design
Use High Power Low Temp Pulse Tube
Push CCDR to EM Level

Cooler	Power	Cooling power	Support/ Radiative	Cable	Dissip ation (FPA)	Total	Margin
Shield cooler	2x50 = 100W	200-450mW (17-25K)	132 mW	60mW	30mW	220 mW at 20K	33%
4K JT pre-cooler	3x50 = 150W	N/A					
4K JT cooler	2x100 = 200W	40mW at 4K	10.3 + 2.3 mW	14mW	10mW	36mW	11%
1.7K JT pre-cooler	3x60 = 180W	N/A					
1.7K JT cooler	2x70 = 140W	10mW at 2K	2 + 1mW	0.7 mW	5mW	8.7mW	15%
CCDR (LOW TRL)		**2uW @100mK**	**0.2uW**	**1uW**		**1.2uW**	**60%**

ALAT Athena Cryostat preliminary design I

X-IFU : X-ray spectrometer at 50 mK
Prime contractor : CNES & CEA



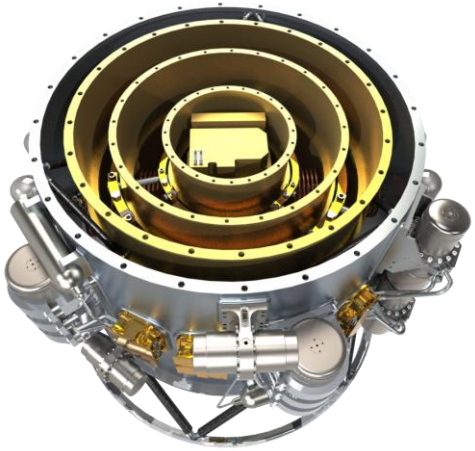


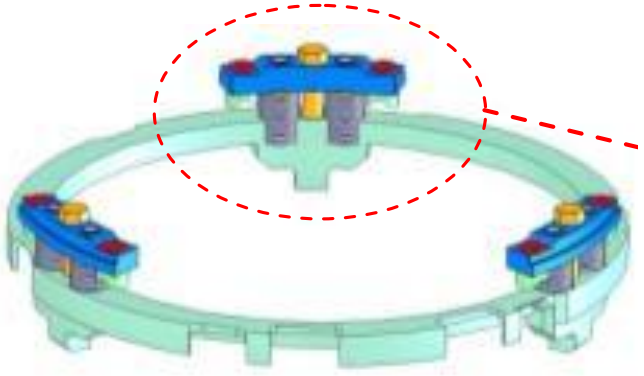
one 15 K-80 K PT
430 mW@ 15 K
+ 2 W@ 80 K

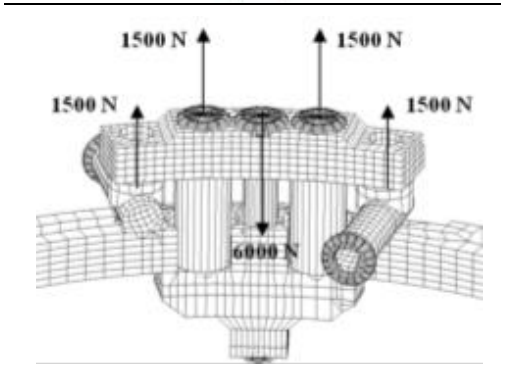
one 1.7K JT (RAL/JAXA)
20 mW@2K

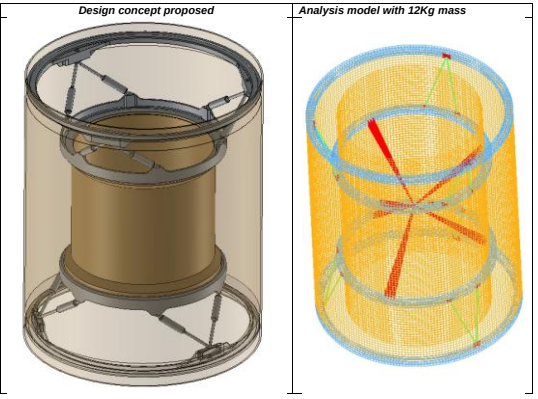
one 50 mK ADR/CCDR
1 µW@50 mK

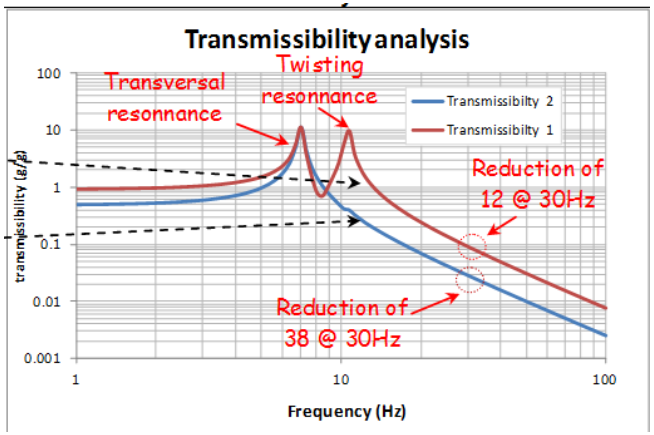
ALAT Athena Cryostat preliminary design II











Mechanics matter!

Integration

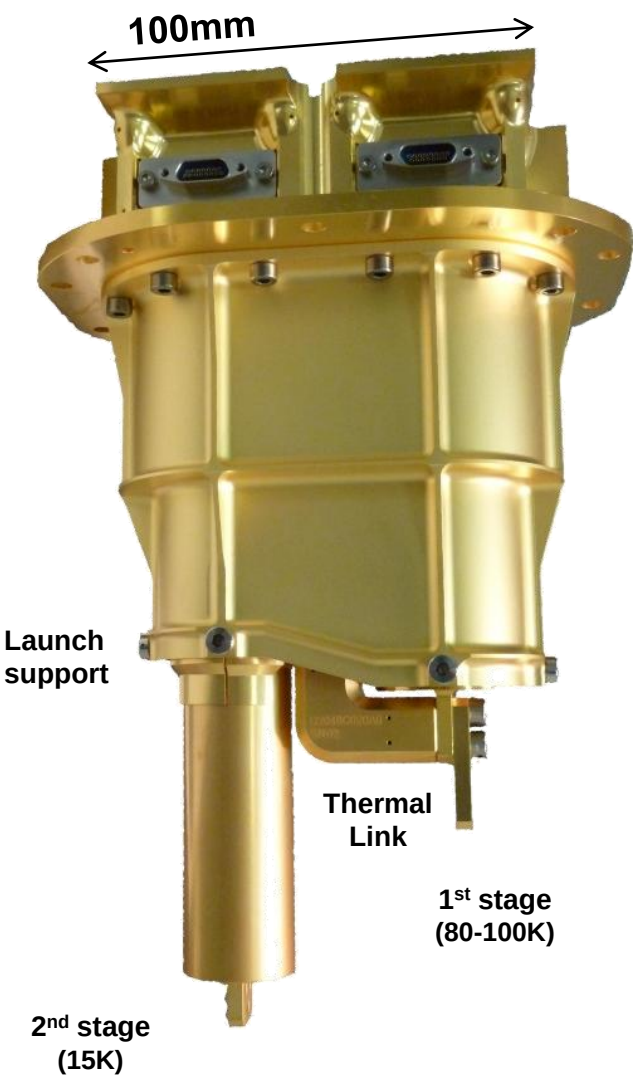
Mechanical resonance

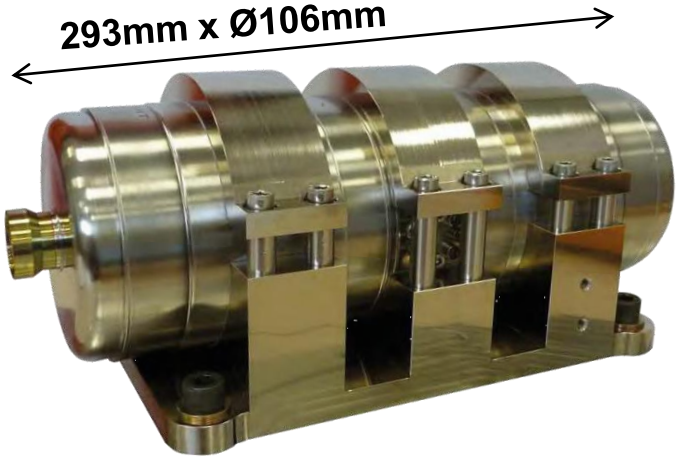
Launch support dimensioning

Direct Action on Thermal load

1mW with CFRP: 15K to 2K

ALAT 15K PTC

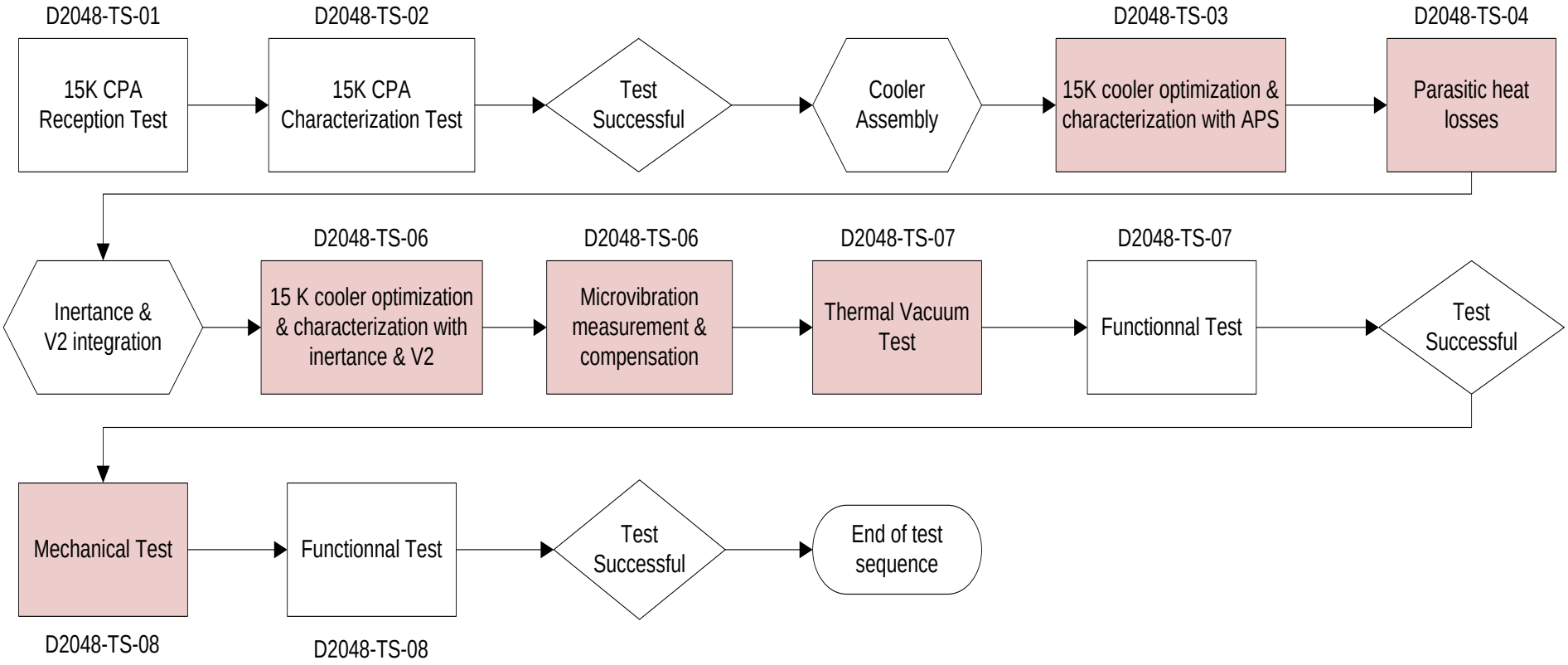




Leveraging on ALAT long heritage

- 1st stage based on TRL8-LPTC
- 2nd stage cold finger based on the 20-50K
- Novel low temp regenerator
- Mass 2.5 Kg CFA + 10 Kg Compressor
- TRL 5
- 450mW @ 15K + 5W at 100K

PT 15K: Test plan



TRL 5: Performance Summary

PT 15K Cryocooler Performance summary

Thermal performances		
Stage 1		
Cooling	> 400mW @ 15K	Best. 450mW
Parasitic Loss	< 180mW	Best. 160mW
Stability	10mK/Hrs	
Stage 2		
Cooling	> 4W @ 100K	Best. 5W
Parasitic Loss	< 2W	Best. 2W
Stability	30mK/Hrs	

microVibrations	
Pistons axis	< 250 mN
Off pistons axis	< 2 N

Environment		
Operating temperature	[-30C, 60C] Storage: [-50C, 90C]	
EMC	<300uT, <20uT at 30cm	
Vacuum proofness	Yes	
Mechanical (transverse axis)	25g sine +12 grms	Notch 1st Res.
Mechanical (piston axis)	15g sine + 12 grms	(Launch lock)
Horizontal configuration	Non working	

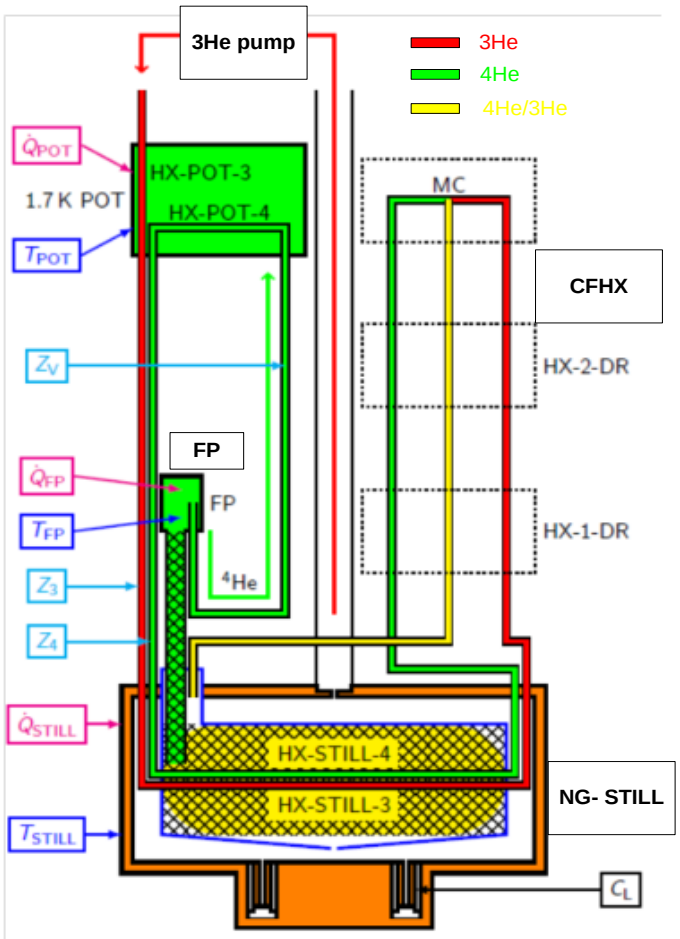
Compressor	
Dimensions	~ DIA 120 x 320mm
Weight	< 12 kg
Electrical Power	300W

APS	
Dimensions	~ DIA 80 x 180mm
Weight	< 3 kg
Electrical Power	< 20W

CFA	
Dimensions	~ 100 x 150 x225mm
Weight	< 2.5 Kg
1st Resonance	184Hz

Operating Parameters	
He filling pressure	21 Bar
Frequency	41Hz
APS Phase	312 Deg
Heat Sink Temp	15 C

CNRS CCDR: OPERATING PRINCIPLES



CCDR is composed of 4 main sub-systems:

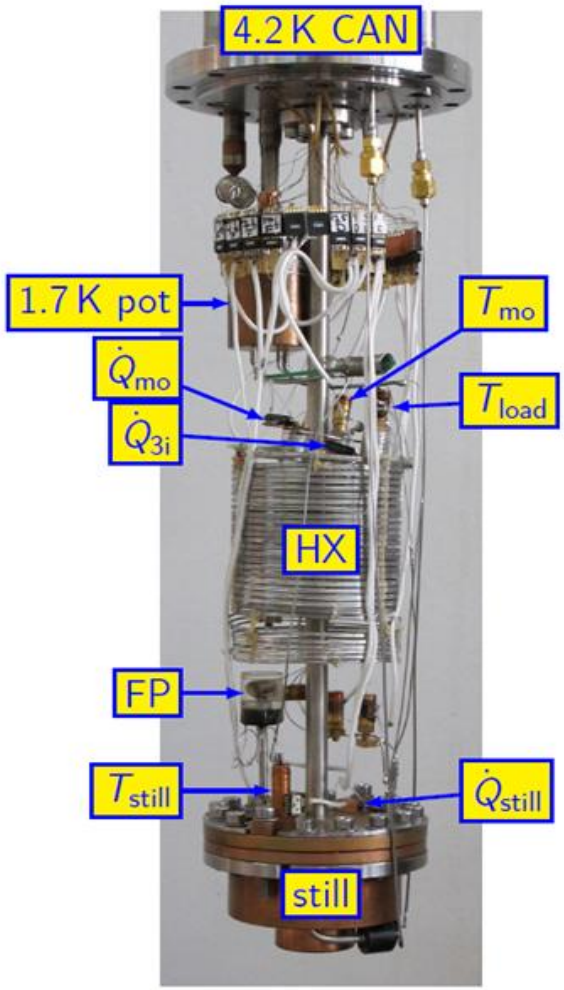
A Counter Flow Heat Exchanger and mixing junction (**CFHX+MC**) allows the dilution of 3He in 4He.

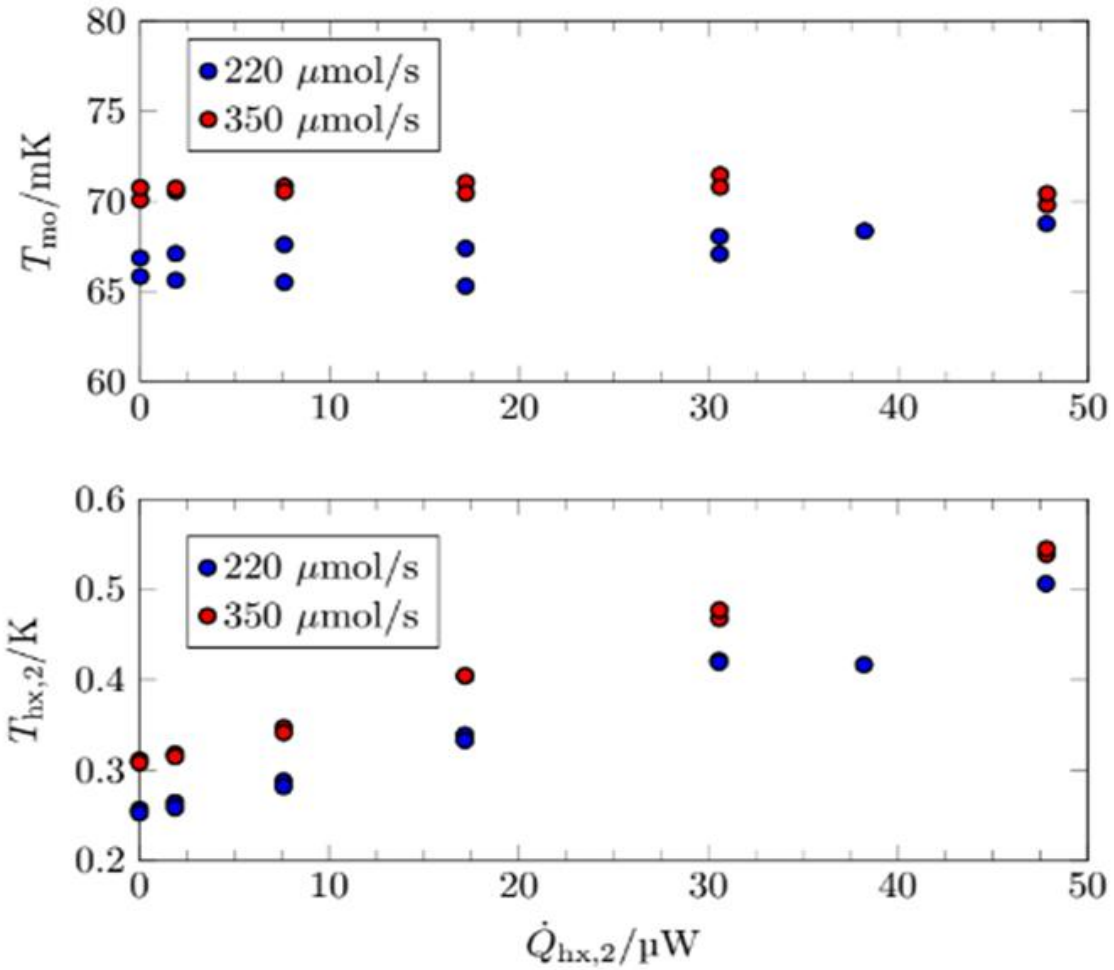
A porous material confines 3HE/He4 mixture (**NG-STILL**)

A superfluid fountain pump (**FP**) extracts the 4He from the NG-STILL and re-injects it into the CFHX.

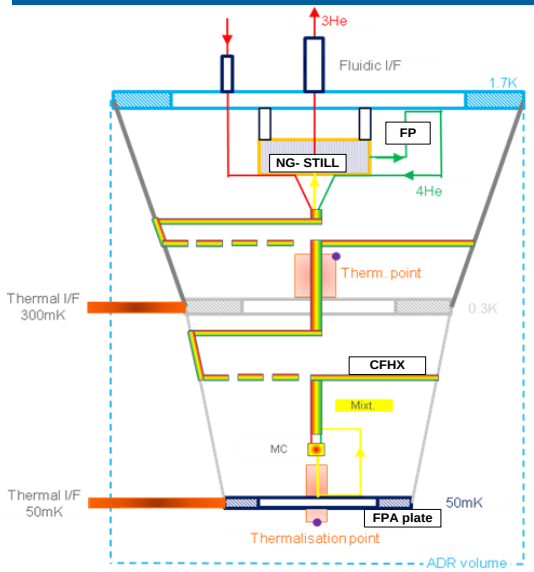
An external 3He compressor (**3H-COMP**) extracts the gaseous 3He from the NG-STILL and re-injects it into the CFHX.

CNRS CCDR TRL 4 UNIT

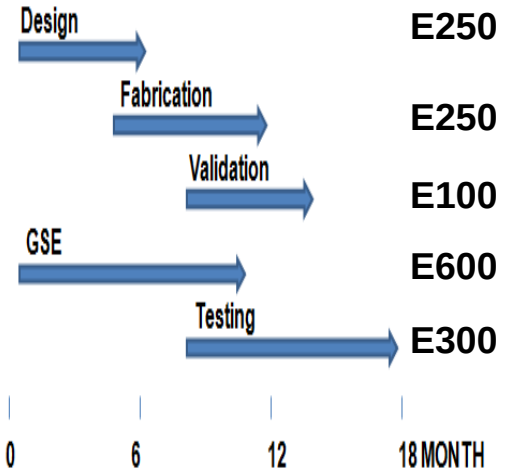




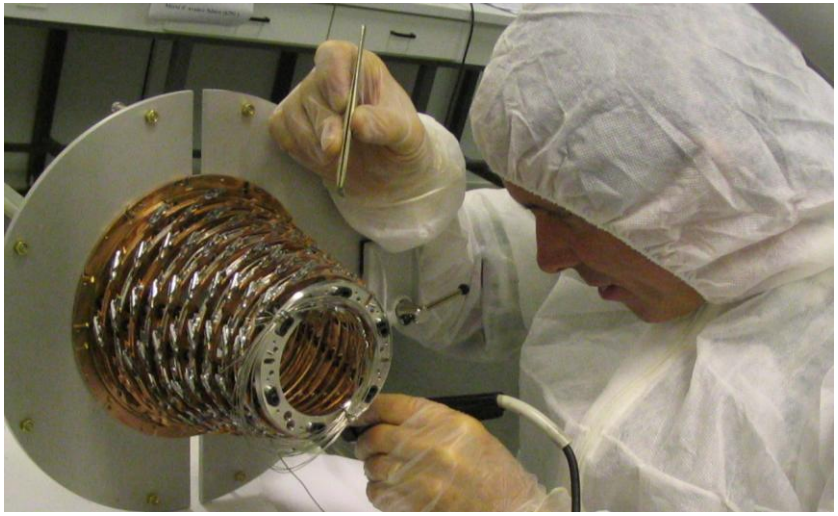
ALAT-CNRS CCDR: ROAD TO EM TRL 5/6



1	Dimensions	Less than 350x200x150mm^3
2	Weight	TBD
3	Mechanical Interface	X-IFU
4	Base Temperature	50mK/100mK
5	Cooling Power at Base Temperature	600nW
6	Base Temperature Stability	< 3uK/10mn
7	Intermediate Stage Temperature	300mK
8	Intermediate Stage Temperature Stability	TBD
9	Cooling Power at Intermediate Stage	13uW
10	Reject Stage operating temperature	1.7K
11	Reject Stage Power Consumption	<8mW
12	Magnetic Straight Field radiated	<10^-4 T
13	Thermal and Vacuum stress range	-50C -> 60C
14	Launch Vibration stress range	Ariane Standard



Project Lead and Scientist: Dr. Yan Pennec
Project Manager: Pascal Barbier
Scientific Advisor: Dr. James Butterworth (Planck Alumni)
Senior Mechanical Engineer: Gerald Fruh (Planck Alumni)
Mechanical Engineer: Eric Patras
Mechanical Engineer: Gaetan Coleiro
Structural Engineer: Samuel Ducarouge
Fabrication Technician: Dominique Chazot (Planck Alumni)
Fabrication and Test Technician: Guillaume Dorel
Engineer PA/QA: Benoit Barthélemy
Expert System Engineer: Thierry Wiertz (Planck Alumni)
Director: Pierre Crespi (Planck Alumni)



Conclusions

Spatial Cryogenics for Ultra Low Temperature Spectrometers is feasible but extremely challenging

Heritage from Planck is invaluable (V-Groove + Dilution + Structure)

Cryostat preliminary design adds critical inputs defining the thermal loads

Do not underestimate mechanical design constraints (launch locks/Isolators/Dampers/Supports)

Novel High Power Low Temp Cryocooler available

Primary shield thermalization + high efficiency JT

CCDR is ready for an EM level development

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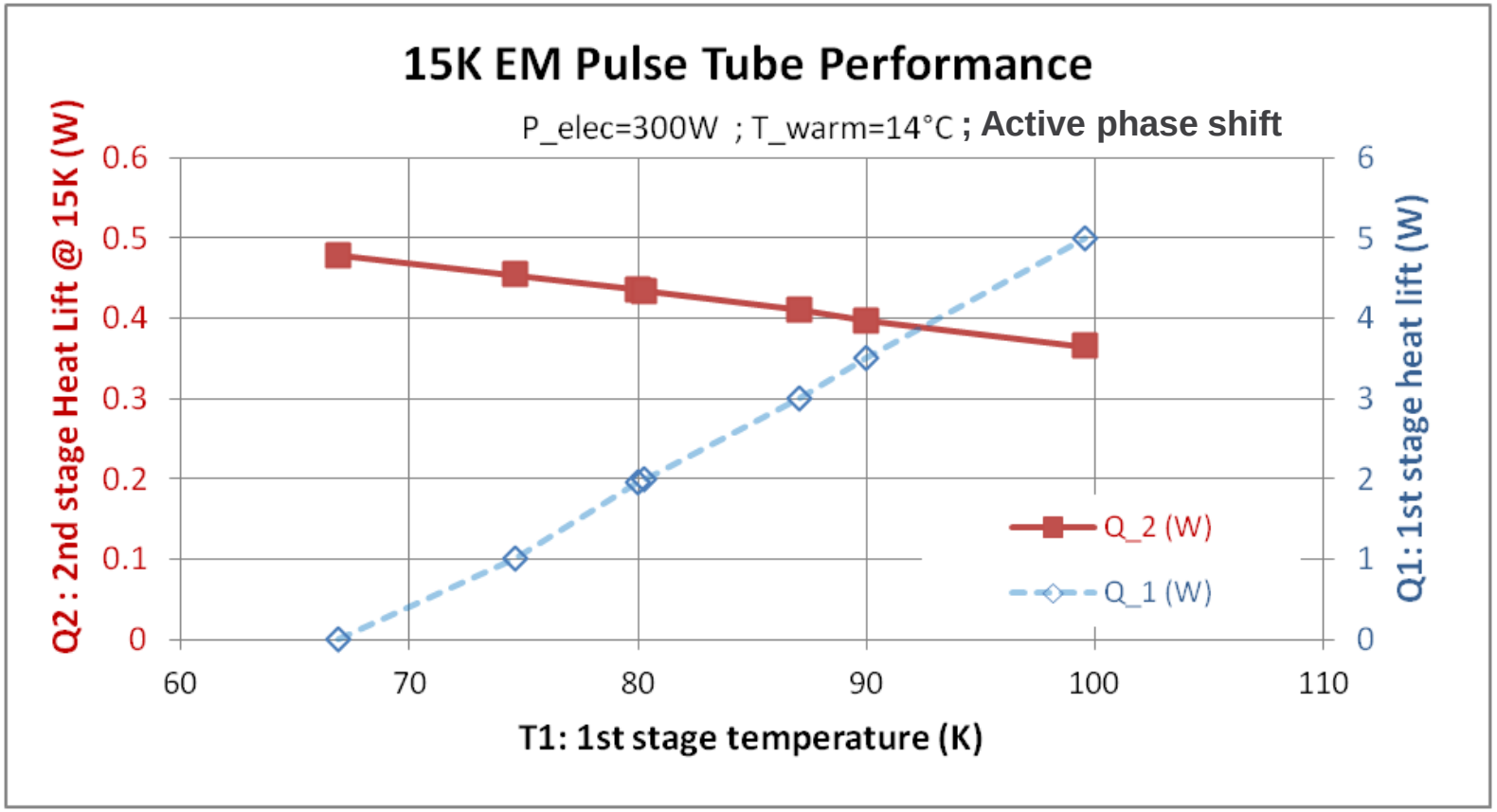
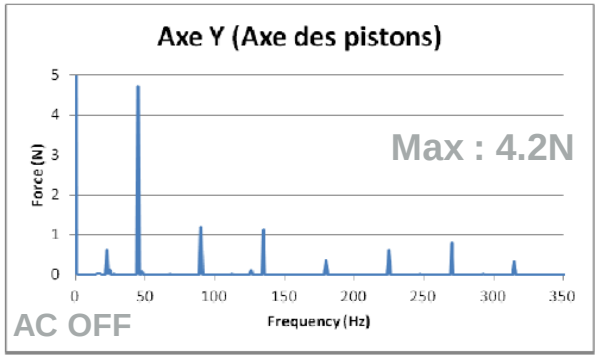
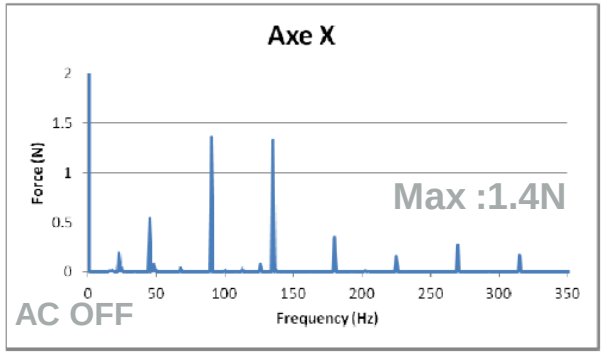
ALAT 15K PTC: Thermal

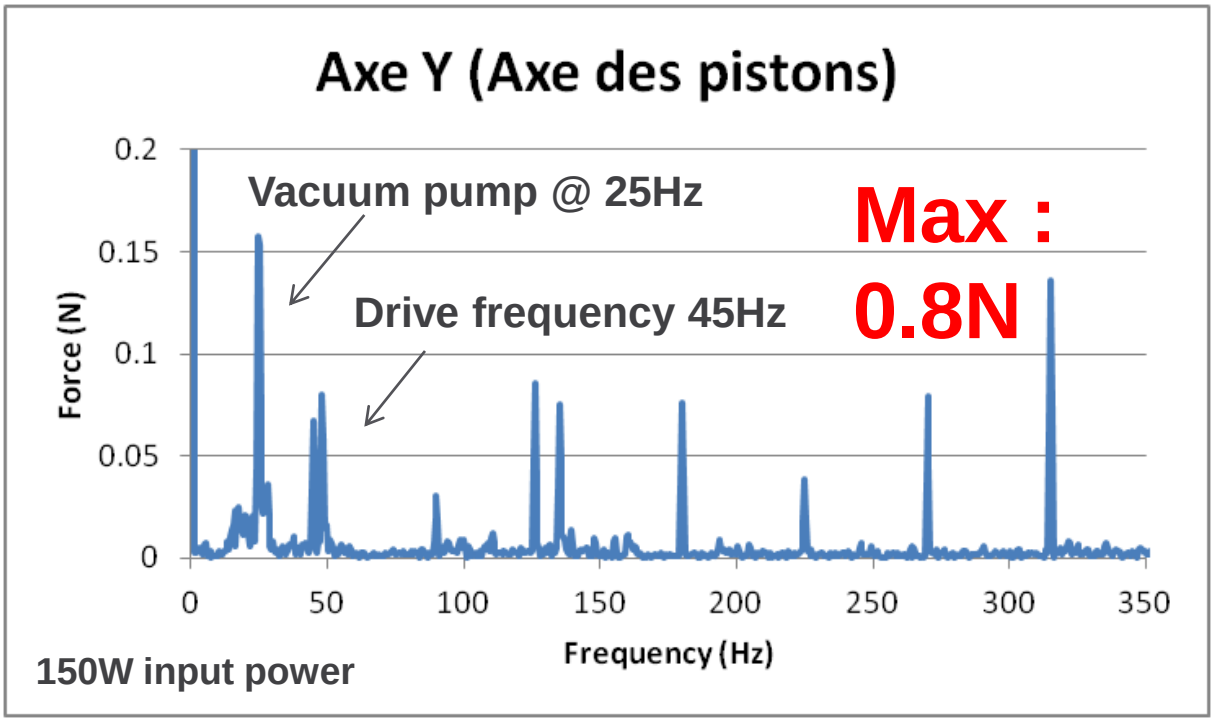


Q_1	T1	Q_2	T2
0.0	67	479	15.0
3.5 W	**90 K**	**0.4 W**	**15 K**
5.0	100	365	15.0

ALAT 15K PTC: Induced Vibrations

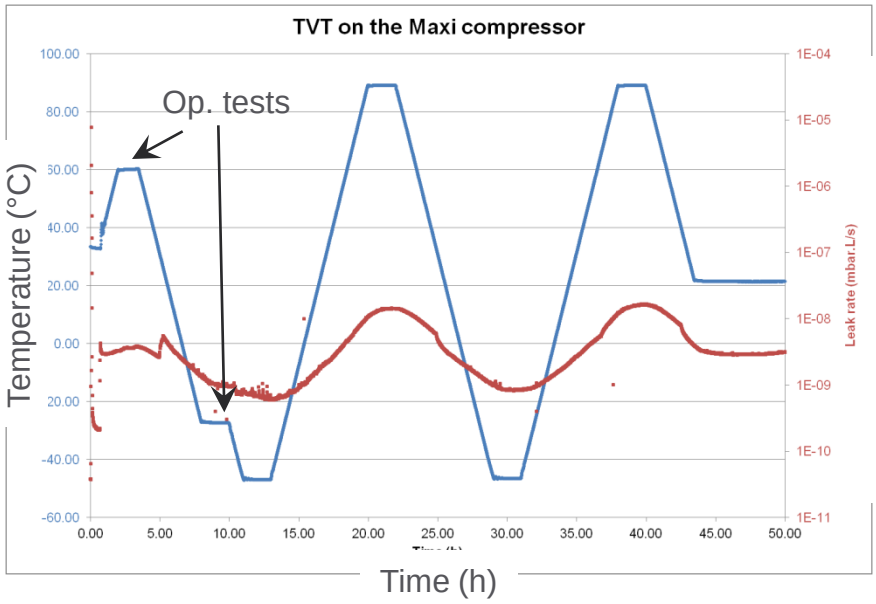


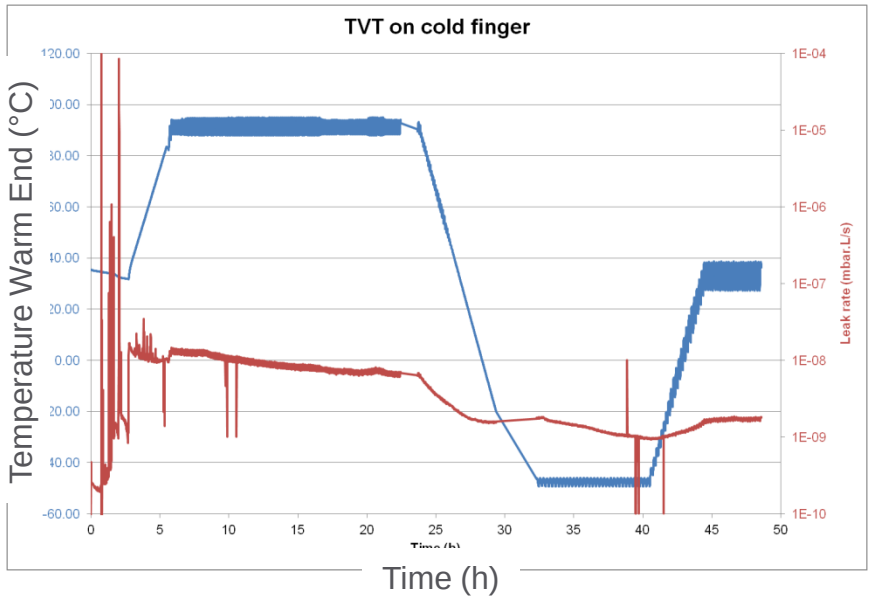




- Piston axis vibrations well compensated over 7 harmonics
  - Parasitic vibrations @ 25Hz from Vacuum pump.
- Peak Off-axis vibrations above 1N
  - Will be addressed for next EM
  - Target at 0.1N level with improved centering and balancing tolerances.

ALAT 15K PTC: Stress test I thermal and vacuum





- Thermal Vacuum Tests performed on both compressor and cold finger
  - T_{min} (non operating) = -50°C
  - T_{max} (non operating) = 90°C

  T_{min} (operating) = -30°C

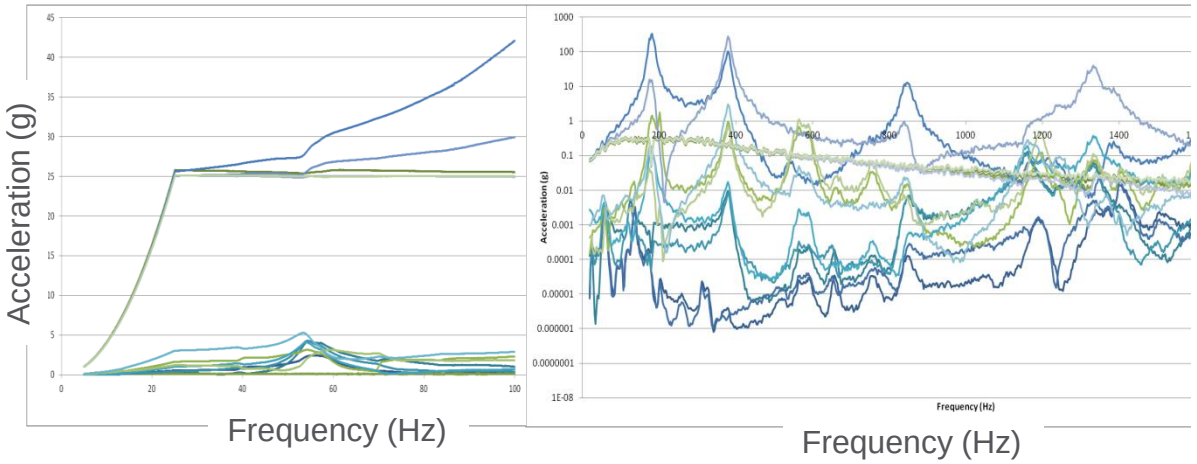
  T_{max} (operating) = 60°C

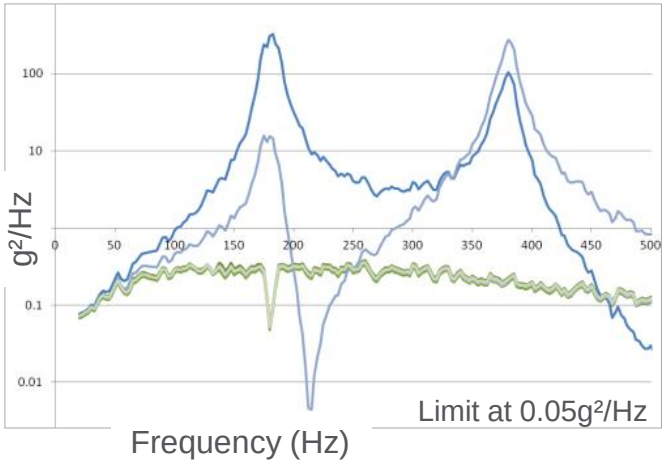
Performances after stress test

- **No performance loss**
- **No indication of leak**

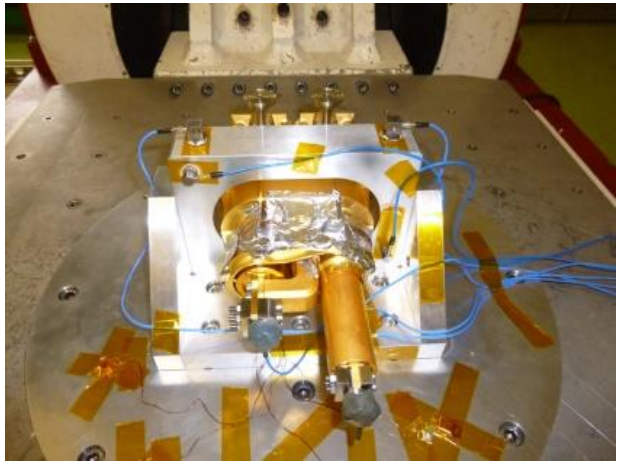
Q_1	T1	Q_2	T2
2 W	80 K	0.4 W	15 K

ALAT 15K PTC: Stress Test II Launch Vibration





- Standard Mechanical Vibration test run (Ariane launch)
  - 5->100 Hz 25g sine sweep
  - 20->2k Hz 0.3g^2/Hz random, composite 12.1 g rms
  - First resonant mode of cold finger > 180Hz,
  - Automatic notching implemented at resonance.



Performances after stress test

Q_1	T1	Q_2	T2
2 W	80 K	0.4 W	15 K

CORE + M4 Cryochain – HEAT LOAD

Detector, MUX	100mK	4K	20K	# wires 100mK-4K	# wires 4K - 300K
TES, TDM	0.7 nW	0 nW	300 mW	169	493
TES, FDM	0.9 nW	640 nW	0 nW	64	256
KID, FDM	0.5 nW	0 nW	30 mW	12	12

	Operation temperature	Conduction struds	Radiation	Optical filter	Harness conduction	R/O Electronics & detectors	JT4K	sJT1K7	sCCDR	TOTAL	Available	Unit
PT1	16K	100	50			31	151			332,0	400	mW
PT2	21K	70	10					350	150	580,0	700	mW
4K JT	4.5K	12	1,1	0,05		5		5	0,48	23,6	31	mW
1.7K sJT	1.65K	1			0,003				3	4,0	6	mW
0.3K CCDR	0.3-0.5K	10			-					10,0	20	µW
0.1K CCDR	0.1K	0,2			-	1				1,2	2	µW

	Temp	dia [mm]	height [mm]	thickness [mm]	Surface [m2]	Mass [kg]	Radiative load [mW]	Conductive load [mW]	Harness [mW]	FPA dissipation [mW]	Total [mW]
2K	1.7	500	500	0.8	1.18	2.55	0.0	2	0.7	5	7.7
4K	4	520	1500	0.8	2.88	6.23	1.3	9	14	10	34.3
25K	20	560	1500	0.8	3.13	6.78	56.8	75	60	30	221.8
60K	60										
Note							Au coating/ 2Layer SLI (20K)	Planck +50%	12 coax +100%	dissipation sub_K + LNA	