From Planck to LiteBIRD

Gerard Vermeulen, input from Philippe Camus and Sébastien Triqueneaux

Néel Institute (CNRS)

B mode from space, Kashiwa, 2015-12-15

References

- Plank collaboration: A&A 536, A2 (2011)
- design and performance of Planck dilution refrigerator: Cryogenics 46 (2006) 288-297
- current understanding this type of dilution refrigerator: Journal of Low Temperature Physics 169 (2012) 90-110

Outline

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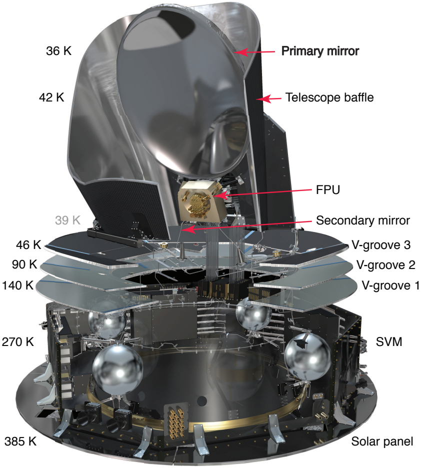
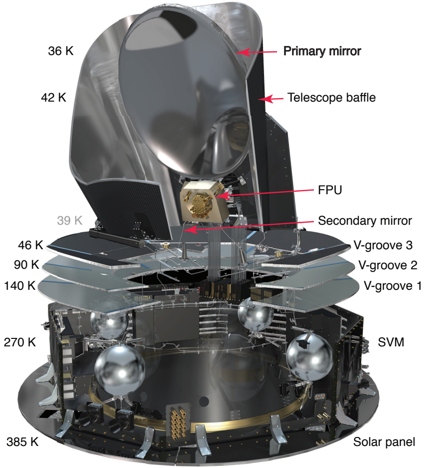
Planck thermal design



redundancy philosophy

LFI	300 K – 18 K: redundant
HFI	18 K – 0.1 K: not redundant

Planck thermal design



redundancy philosophy

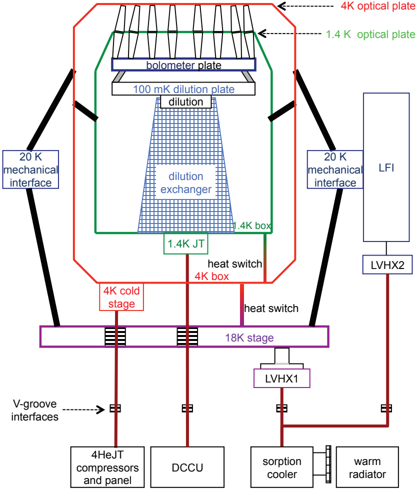
LFI 300 K – 18 K: redundant

HFI 18 K – 0.1 K: not redundant

cooling chain

- solar panel
- 3 V-groove radiators
- 2 18 K H_2 absorption coolers
  - not redundant due to aging
- 4 K ^{4}He JT cooler
- 0.1 K ^{3}He-^{4}He dilution cooler
  - 100 % duty cycle
  - 1.4 K – 1.6 K Joule-Thompson cooler for free
  - helium storage and cooling power set lifetime to 2.5 y

Planck thermal design



worked very well!

current cooling chains are very different!

redundancy philosophy

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1. Planck: tight integration of instrument with last cooling stage
   - Planck thermal design
   - HFI thermal design
   - Before HFI thermal design: minimization heating by micro-vibrations
   - Principal heat loads on 0.1 K stage in flight

HFI thermal design

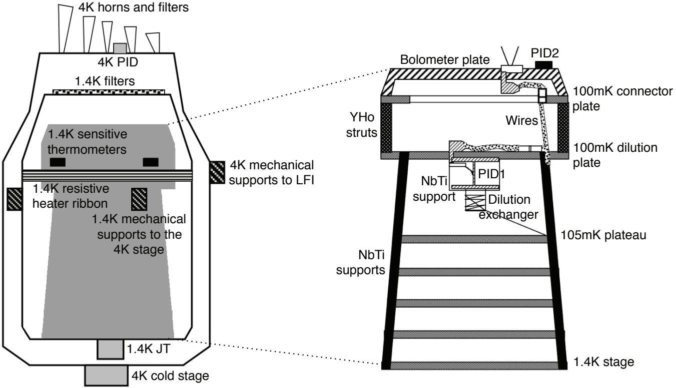
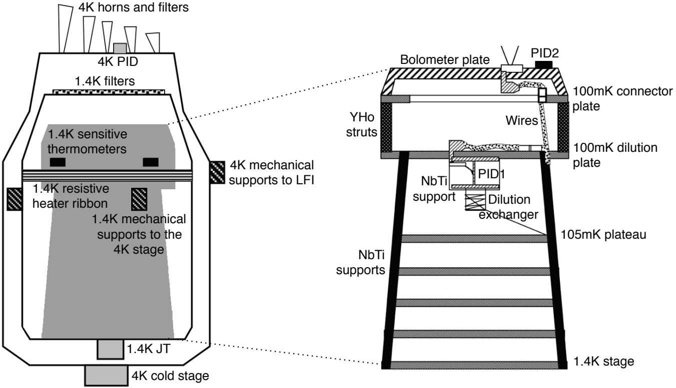


Table 5. Temperature stability requirements on HFI components, over the frequency range 16 mHz–100 Hz.

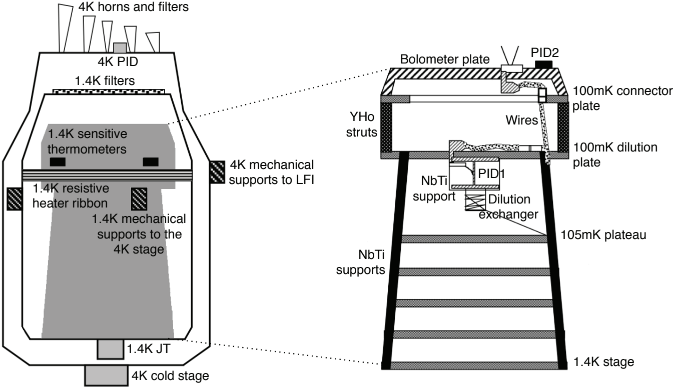
Component	Requirement
4 K horns and filters (30% emissivity)	$\leq 10\ \mu\mathrm{K\,Hz}^{-1/2}$
1.4 K filters (20% emissivity)	$\leq 28\ \mu\mathrm{K\,Hz}^{-1/2}$
0.1 K bolometer plate	$\leq 20\ \mathrm{nK\,Hz}^{-1/2}$

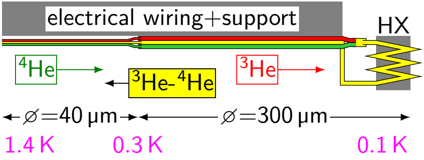
HFI thermal design



- 2 high sensitivity PID controls
- high C_p YHo struts for passive damping (time constant of hours)
- bolometer plate: stainless steel + 250 μm thick Cu + Au gold plating

HFI thermal design

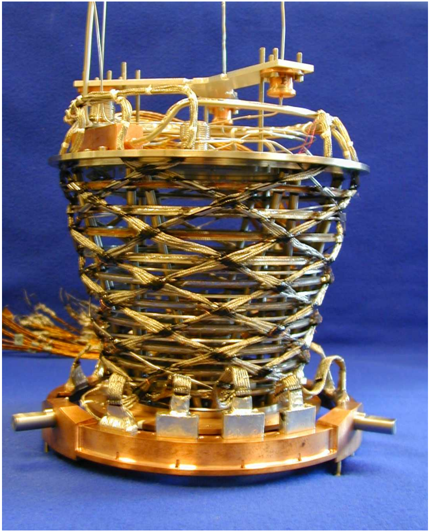




tightly integrated design

- heating 0.1 K stage due to vibrations of 4 K cooler?
- IAS+CRTBT: demonstration model with 20 K Stirling cooler

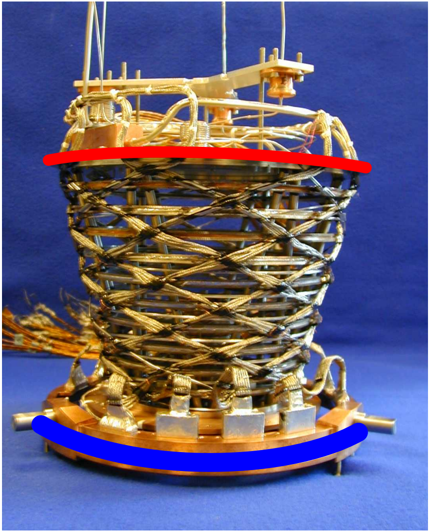
Low temperature thermal structure



tightly integrated design

developed in close collaboration between IAS and CRTBT (now part of Néel Institute):

Low temperature thermal structure



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- 1.6 K
- 0.1 K

Low temperature thermal structure

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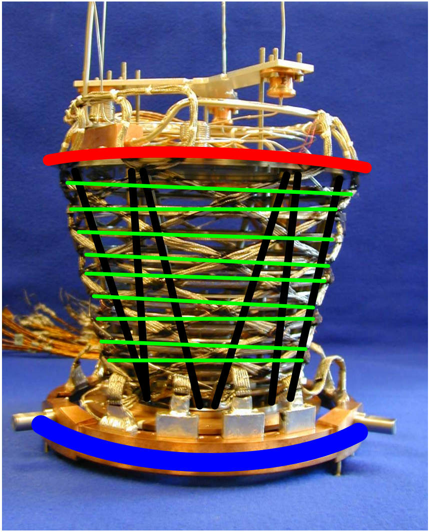
- 1.6 K
- 0.1 K
- NbTi support tubes

Low temperature thermal structure



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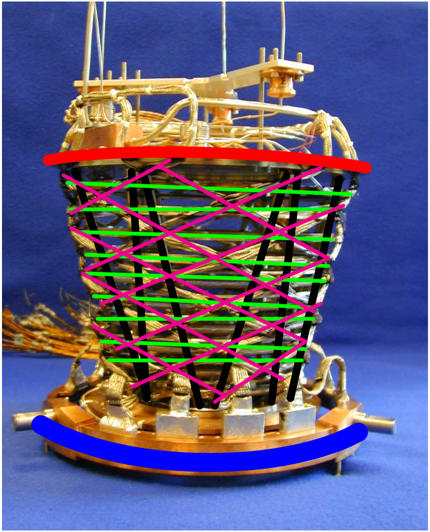
developed in close collaboration between IAS and CRTBT (now part of Néel Institute):

- 1.6 K
- 0.1 K
- NbTi support tubes
- DR HX thermal anchors

Low temperature thermal structure



tightly integrated design

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- 1.6 K
- 0.1 K
- NbTi support tubes
- DR HX thermal anchors
- electrical harness

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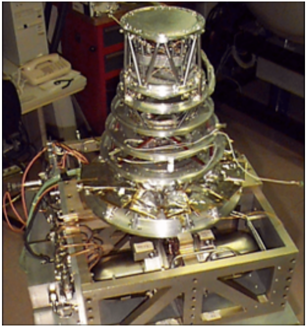
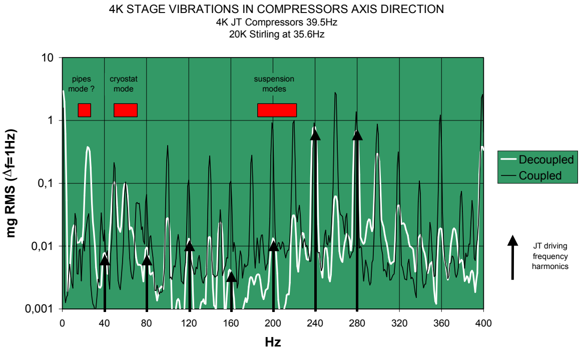
Demonstration model with 4 K and 20 K stages

September 2000

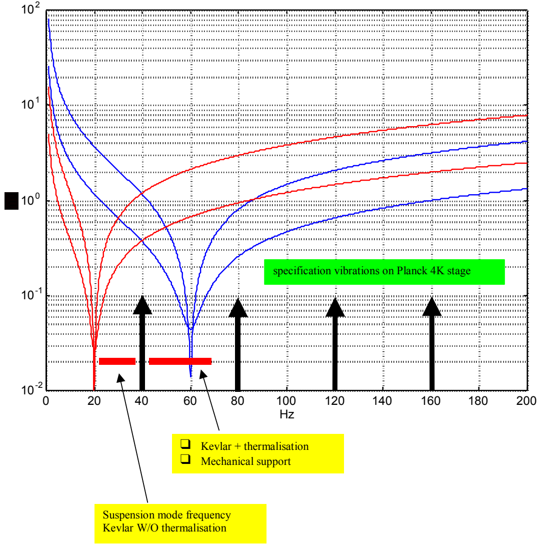


0.1 K demonstration model



up to 1 μW of vibrational heating

Micro-vibration specifications at the LFI/HFI interface



Philippe Camus: minimize micro-vibrations very early!

specifications

- 20 Hz – 70 Hz:
  - $< 30\,\mu\mathrm{g}\,\mathrm{Hz}^{-1/2}$
- 4 K JT:
  - < 1 mg rms
- Alcatel study 4 K JT:
  - (0.1 mg – 1 mg) rms

results heating FM

- IAS: 10 nW
  - 4 K and 18 K by IAS test tank
- CSL: 40 nW – 50 nW
  - 4 K ^{4}He JT and 18 K H_2 JT

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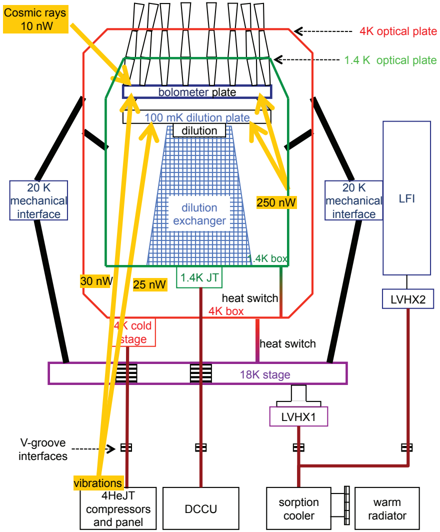

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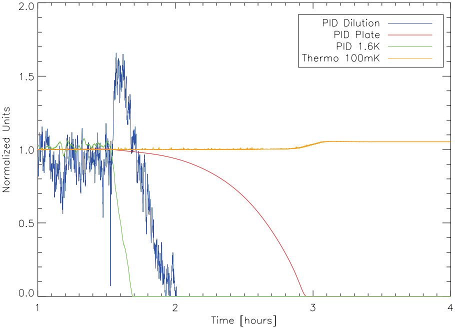
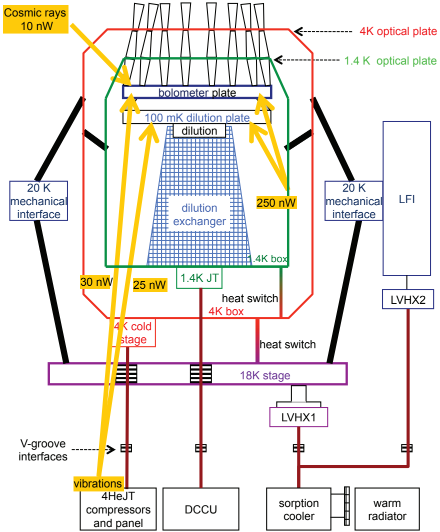
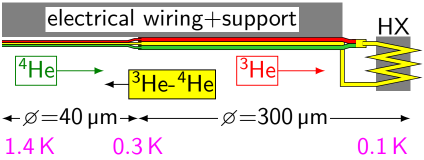




heat due to vibrations

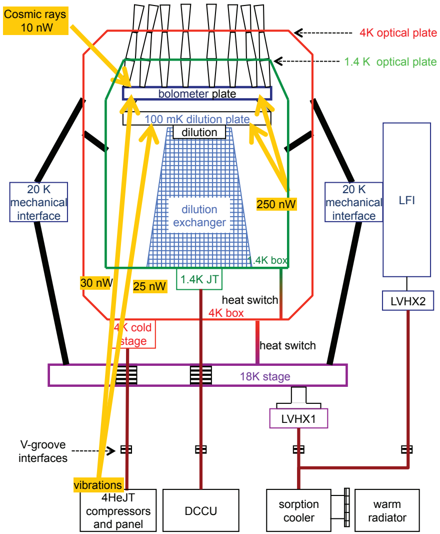
1. 4 K JT stopped once
   - fast decrease of 1.6 K PID
   - fast increase of dilution PID
   - slow decrease of plate PID
2. 4 K JT always OK after restart

Principal heat loads on 0.1 K stage in flight

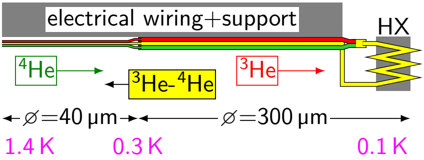


tightly integrated design

- without coolant in DR:
  - $\dot{Q}_{\text{conduction}} = 8\,\mu\text{W}$
- with coolant in DR:
  - $\dot{Q}_{\text{conduction}} = 250\,\text{nW}$
  - or $\dot{Q}_{\text{conduction}} = 100\,\text{nW}$?



Principal heat loads on 0.1 K stage in flight



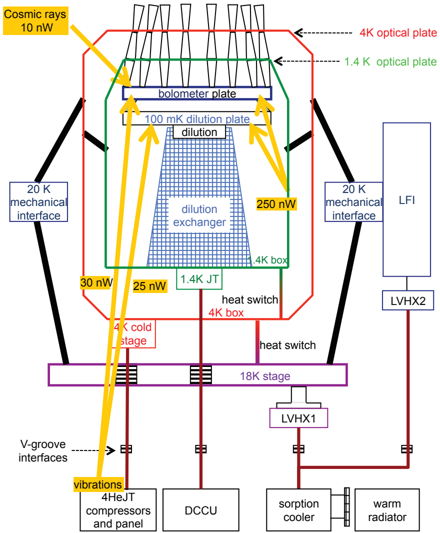
viscous dissipation for ⌀ HX

300 µm $\dot{Q}_{\text{viscosity}} = 150\,\text{nW}$

600 µm $\dot{Q}_{\text{viscosity}} = 10\,\text{nW}$

$\dot{Q}_{\text{viscosity}} \approx 50\,\%$ of total DR heat load

possibility to increase lifetime!



Outline

Dilution refrigerator proposal for X-IFU/Athena

X-ray Integral Field Unit of the Athena X-ray Observatory (click!)

- baseline: ADR built by SBT-CEA
- backup: closed cycle dilution refrigerator

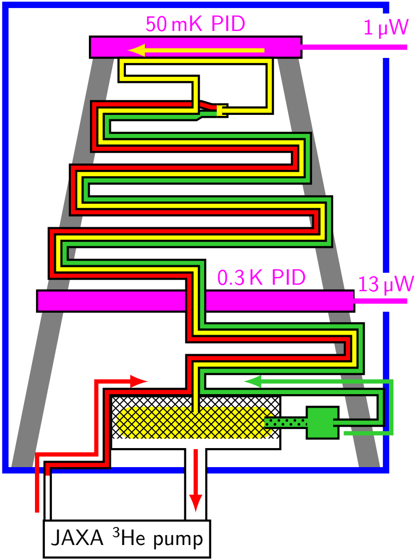
Specifications from ESA call for CTP cooling chain

- low temperature performance: $\leq 1\,\mu\mathrm{W}$ @ $50\,\mathrm{mK}$
  - primarely due TES dissipation at $50\,\mathrm{mK}$
- intermediate cooling requirements: $\leq 13\,\mu\mathrm{W}$ @ $0.3\,\mathrm{K}$
- temperature stability: $\leq 3\,\mu\mathrm{K}/600\,\mathrm{s}$
- thermal interfaces (TBC):
  - $5\,\mathrm{mW}$ @ $1.7\,\mathrm{K}$
  - TBD mW @ $4.5\,\mathrm{K}$ (TBC)
  - TBD mW @ $15\,\mathrm{K}$ (TBC)
  - TBD mW @ $100\,\mathrm{K}$ (TBC)

no funding yet – LiteBIRD and CORE+ are easier – happy to discuss

Dilution refrigerator proposal for X-IFU/Athena

cooled by 1.7 K JAXA ^{3}He JT expansion
SBT-CEA ADR geometry



loosely integrated design

- instrument outside 1.7 K box
- DR inside 1.7 K box
- Planck DR with ^{3}He/^{4}He separator at 1.1 K
    - liquid-vapor interface in sponge in negative gravity
- CFRP support structure
- 0.3 K I/F is not natural
- 0.1 mW @ 1.1 K unused

3 year dilution refrigerator development plan for X-IFU

Prototype (TRL4)

- recover 1 μW @ 50 mK in negative gravity
- work on 13 μW @ 0.3 K

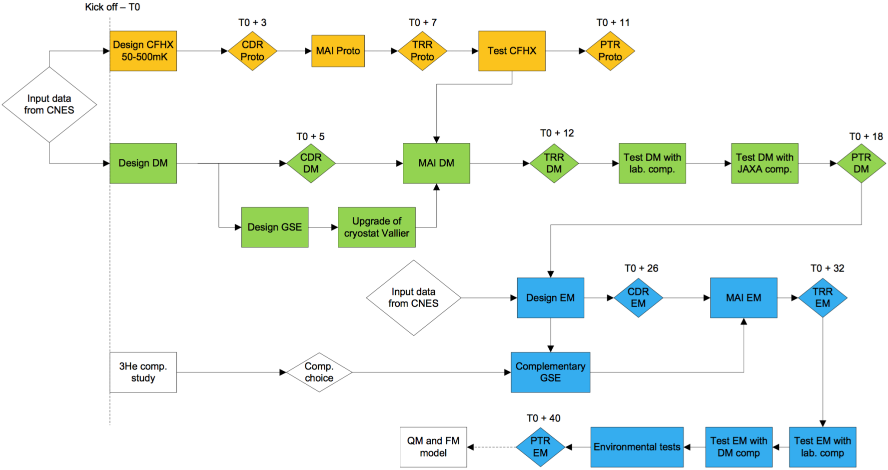
Demonstration Model (technology transfer to Air Liquide)

- validate 50 mK I/F and 0.3 K I/F (including thermal stability)
- validate launch support structure thermally
- validate plug-in compatibility with SBT-CEA ADR (cryostat #1)
- test with JAXA pump

Engineering Model (TRL5) by Air Liquide

- adapted to eventual changes in X-IFU specifications
- pre-qualification plan and procedure for all critical components
- mechanical testing

3 year dilution refrigerator development plan for X-IFU



Outline

Summary

Planck lessons

- cooling chain worked very well
  - but current pulse tube and Stirling cooler based cooling chains are very different
- work as early as possible on the mitigation of micro-vibrations
- 8 years from first DM with 4 K and 0.1 K coolers to FM tests

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design choice: loose or tight integration of instrument with DR

- tight: heat to FPU dominated by wiring+support
  - DR can intercept heat everywhere
- loose: heat to FPU dominated by detectors on FPU

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- loose: heat to FPU dominated by detectors on FPU

3 year dilution refrigerator development plan to EM

- no funding yet, therefore no commitment yet
- happy to discuss LiteBIRD, encouraged to do so by the CORE+ team