Planck cryochain heritage: alternative 15-20K stage and lessons learned

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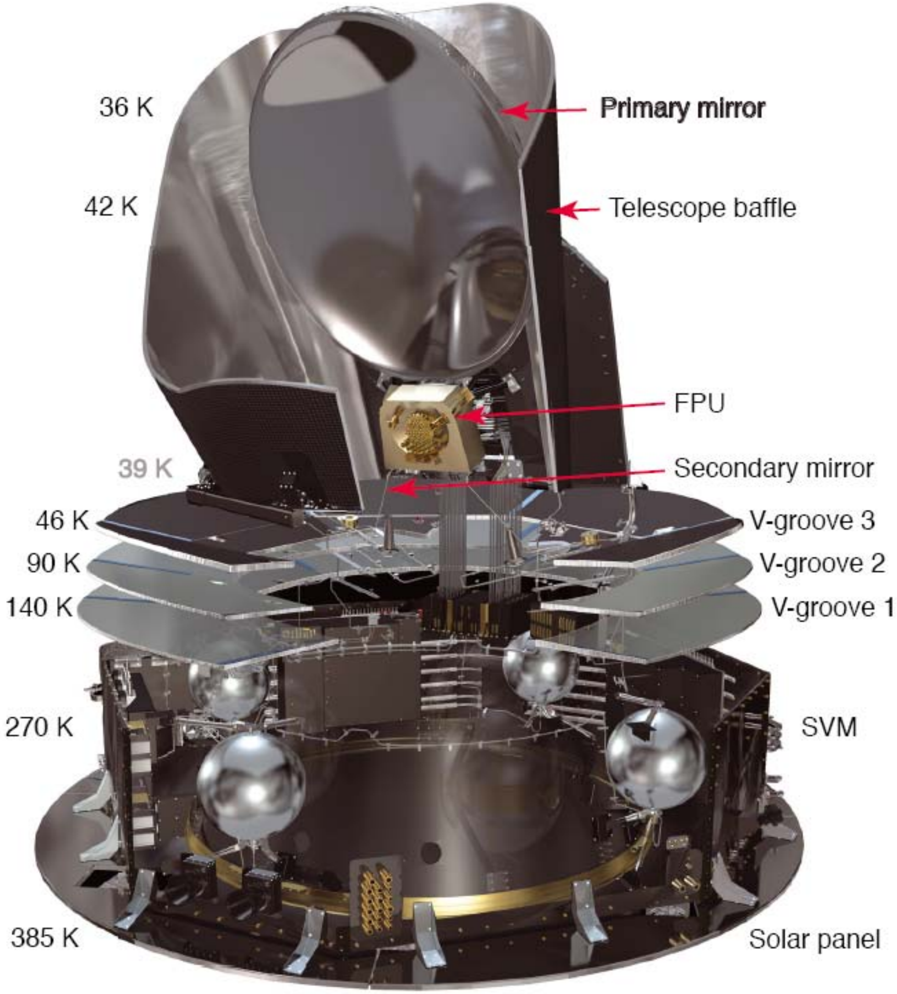
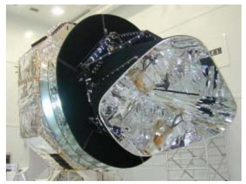
Planck Thermal & Cryo Architecture



- Thermal architecture based on a passive and active systems combination
- The most complex cryogenic mission to date
- Overall cryo-chain performances are among the biggest technological achievement of the Planck mission
- **Planck leaves a large heritage and a wealth of lessons learned for future cryo missions**

Aggressive passive design, VGrooves-based:

- Sunshield at 300K with Solar Panels
- VGroove3 at < 50 K
- VG2 at ~100 K
- VG3 at ~140 K

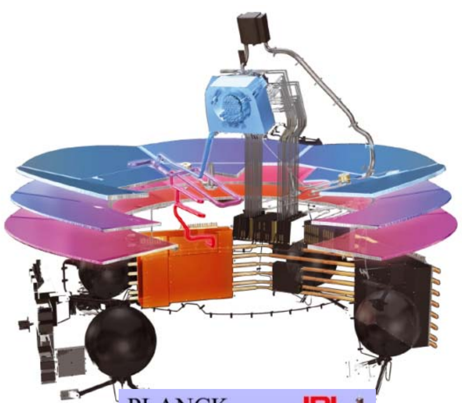


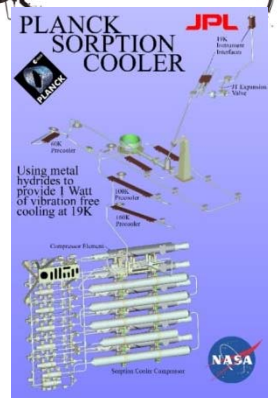
- 14kW incident on the solar panel less than 1W reaches the FPU
- Passive cooling and thermal insulations were the keys for the overall cryo performances of Planck

Planck cryochain: 3-stages active cooling chain

3 refrigerators in cascade:

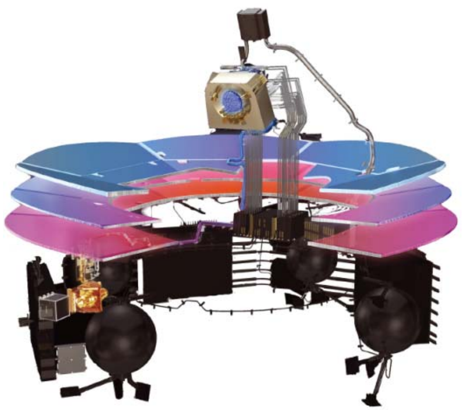
Sorption Cooler at 18K

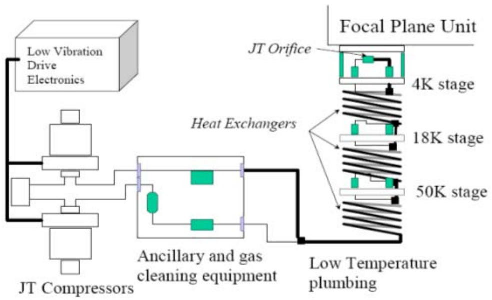




- Nom unit lifetime ≈10500 hrs
- Red unit lifetime > 27500 hrs
- Regeneration test in flight at EOL

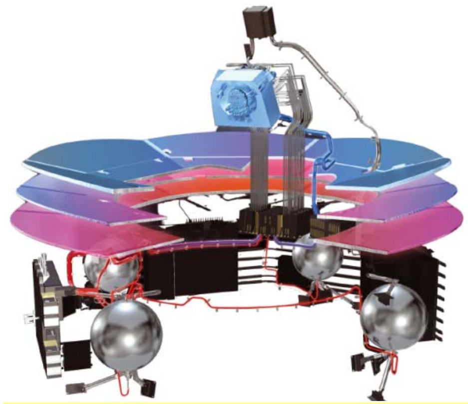
He JT Cooler at 4K

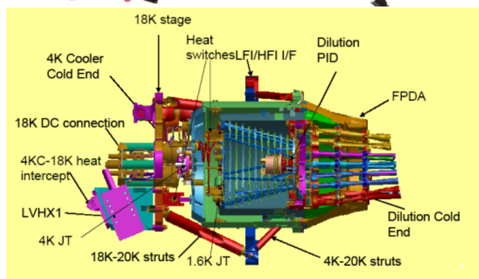




- Lifetime > 38000hrs
- No sign of degradation

Dilution at 0.1K





- ^3He duration > 2.5 yrs
- Smooth continuous ops
- The coldest thing in Universe until Jan 2012

Overall excellent performances

Planck cryochain lessons learned

Planck cryochain "complexity record" can and will be beaten by ATHENA, NGCryoIRTel, liteBIRD, COrE,…

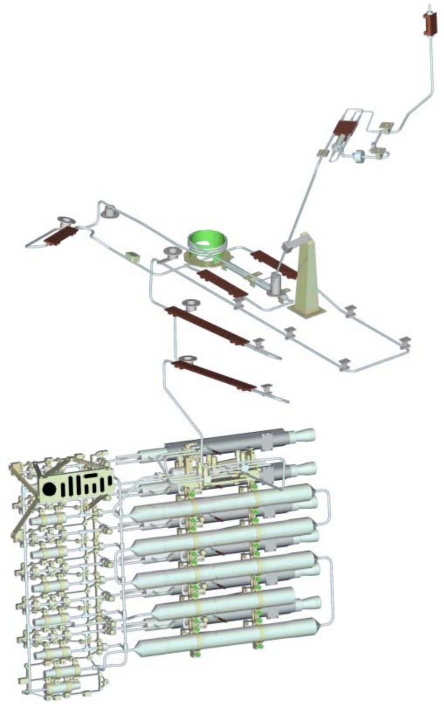
- Future complex cryochains shall build on this success and take advantage of Planck lessons learned in the design, implementation, testing and operation of multiple passive/active cryogenic systems working in cascade as a single system
- A key document on Planck lessons learned is in preparation at ESA: thermal/cryo section is one of the most important. To be released in the next future
- No anticipations (wait for the doc) but in my opinion two issues are fundamental in general:

1. The need of a reference subject for managing the cryochain as a "whole system" from a technical point of view since the design phases. A System Engineering Team not only to ensure correct requirements flow-down, interfaces and allocations management, etc. but also to have a continuous overview of the development process and a communication link between cooler teams
   - In Planck everything worked out very well because each team was assuming margins over margins. The problem with this approach is that you may end up with the cooling chain coldest stages "too cold" (this happened at some level in Planck)
2. Testing is critical: test as much and as long as possible
   - Anticipate testing at system level even with earlier models (QM's, EBB's, etc.) is really important to highlight possible issue that don't show up at subsystem level. This was a key to Planck success

Sorption coolers

Sorption refrigerators have **many advantages** over mechanical coolers:

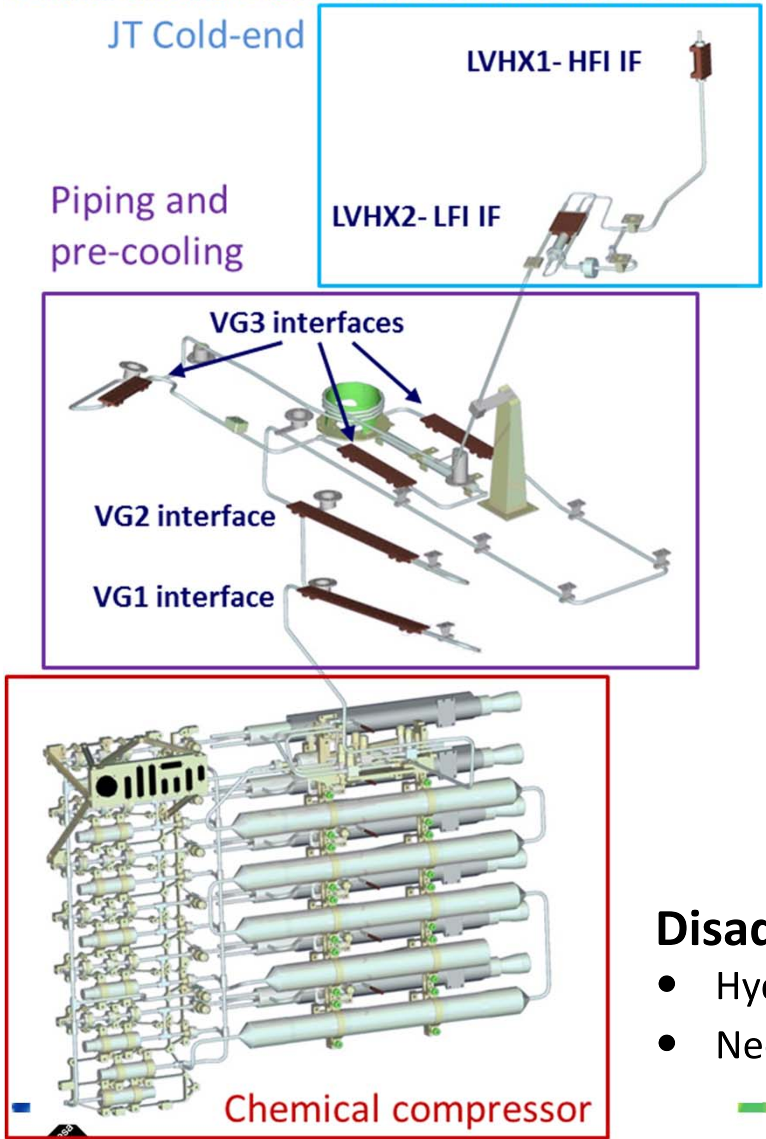
- no moving parts, compression/decompression only by heating/cooling chemi/physi-sorption material
- high reliability and long-life (if you know how your sorbent material ages and how to operate it)
- virtually vibration-free and with no electromagnetic interference (EMI) effects
- readily scaled to match a wide range of cooling loads by simply adding/removing (increasing/decreasing) compressor modules (beds)
- cold end temperature is defined by gas selection
- JT cooling allows for remote location of cold end from warm end (flexibility in integration)



Planck H_2 sorption cooler:

- Chemi-sorption compressor with a JT cold end
- Continuous closed cycle system
- T reference for the LFI and precooling stage for the HFI 4K cooler
- **The first continuous closed cycle H_2 sorption cooler to be operated in space**

Planck H_2 Sorption Cooler System



Design Features and Advantages

- Chemi-sorption compressor with a JT cold end (sintered plug)
  - $La_{1.01}Ni_{4.78}Sn_{0.22}$ Hydride sorbent
  - H_2 refrigerant
- Passive precooling (VGrooves & tube-in-tube HXCG)
- Compression achieved thermally by electric heaters
- Sorbent cooling by radiator and thermal switches
- No moving parts in the compressor or in the cold end
- Compressor remotely located from cold stages
- Cooler produces no vibration
- Input Power Rejected at Warm Radiator (SVM)
- Low P H_2 absorbed at ~270 K
- High P H_2 desorbed at ~470 K
- Beds staggered cycling allows continuous refrigeration
- Two full units for redundancy

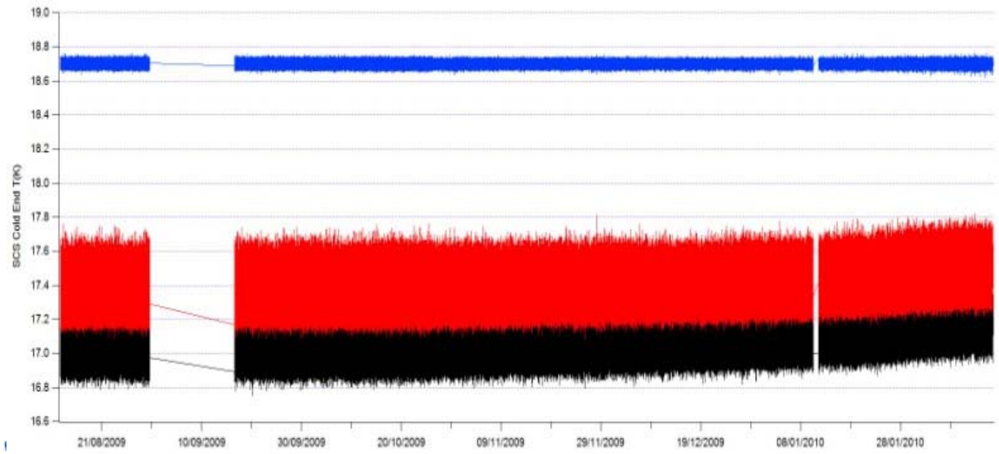
Disadvantages

- Hydrides age with time loosing capacity of absorbing/desorbing H_2
- Need to characterize and properly operate the sorbent material

Planck sorption cooler performances

The Planck H2 Sorption Cooler overall performances were extremely good:

- Planck satellite launched on 14 May 2009: Nominal cooler started on 10 June 2009 and met/exceeded all requirements until first Planck completed 100% sky coverage (May 2010)
- Stopped Nom cryocooler in August 2010 due to excessive power usage (unexpected sorbent materials & thermal switches degradation) & switched to redundant cooler
- Redundant cooler met flight cooling requirements for 3 Years (August 2010 to October 2013) until the end of the extended Planck mission
- Hydrides regeneration process successfully tested at mission EOL
- Nom + Red coolers allowed 50 months of continuous observations
- No component (e.g. heaters, sensors) failures and no leaks or clogs (e.g. in JT restriction) observed in any of the models developed



Main performances:

- more than 1100mW of heat lift
- 17.1 K cold end temperature
- 0.5 K pp fluctuations, 0.35 K rms
- 0.1 K pp at temperature control stage
- 300W of input power (BOL)

Planck sorption cooler main issues & lessons learned

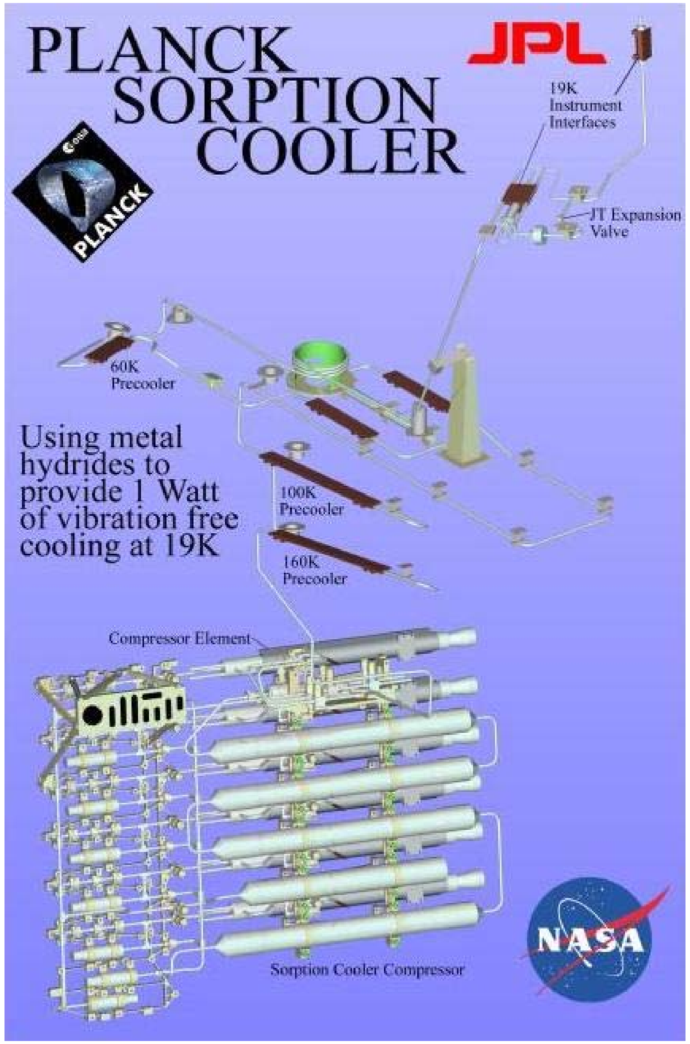
- Being the first cooler of its kind, a lot was learned during the long run of the actual flight ops
  - La-Ni-Sn hydrides demonstrated great performances but only actual operations over years gave us the insight of the hydrides evolution with time and how to cope with this evolution
- Both coolers were operated in flight (as expected) but as it turned out their individual performances were quite different (15 months vs more than 36 months)
  - This was due to hydride powder distribution inside the sorbent beds: different teams with different procedures. Uniformity of beds is a key to a successful cooler, specific requirements to be verified need to be specified:
    - check uniformity of beds on ground (X-rays analysis, dedicated test runs to select beds)
    - use of separators to keep powder confined
- This in the end led to lower capacity and to an accelerated degradation of the first unit sorbent materials: regeneration process was successfully tested in flight. This process is capable of recovering more than 90% of the original capacity. Any future user of similar coolers should design this operational feature in.
- Gas Gap Heat Switches limited the operating life of PSC, mainly due to H2 permeation exceeding switch capacity:
  - over sized to be more robust to gas accumulation
  - ventable to space for periodical cleaning
- Presence of two redundant coolers had an impact, even if only at EOL in degraded conditions, on working unit in term of temperature oscillations of the cold end
  - add extra spare beds (2-4) in a single system for redundancy instead of a full unit

Possible alternative 20K stage for a future CMB mission

20K stage main specifications, features and characteristics derived from Planck heritage

- Temperature in the 16 - 20K range (depends on warm radiator temperature)
- Heat lift > 1W with cold end at 17K (depends on precooling efficiency, mass flow and input power)
  - If less / more heat lift is required the system can be easily scaled to meet requirement
- Compressor in the SVM with cold end remotely located in cryo stages (Planck SC piping ~10m)
- Cooling can be distributed in several liquid-vapor heat exchangers to distribute cooling for T uniformity (e.g. on a shield)
- Pre-cooling needs
  - Heat exchangers on VG's, expected load on coldest VGroove is < 690 mW
  - Enthalpy recovery by tube-in-tube HXCG
- Total input power BOL 300W – EOL 470W (excluding electronics, that is around 90W)
- Cooler mass <55 kg (excluding electronics box) for a six compressor beds system
  - < 70 kg for 8 or 10 beds cooler for redundancy (to avoid second unit)
- Compressor volume allocation approx. < 0.7 x 0.65 x 0.4 m^3 (for a six beds system)
- Gas gap thermal switch actuators re-designed for improved robustness to H2 permeation
- Regeneration process designed into the system, to be executed at hydrides EOL (typically after 3-5 years of operations depending on cooler pace) to fully restore their capacity
- Redundancy ensured by compressor with extra beds (2-4)

Conclusions



Thank you for your attention

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