The Abdus Salam
International Centre
for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2474-2

School and Workshop on New Light in Cosmology from the CMB

22 July - 2 August, 2013

Planck Products: From the instrument to the data

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From intrument to data

A. Zacchei – INAF-OATs

LFI DPCM

on behalf of the Planck Collaboration

School on New Light in Cosmology from the CMB

ICTP

Summary

- From Instrument to data
  - Introduction
  - Previous Missions
  - Why one other mission ?
  - Planck instruments and its cooling system
  - Operations
  - Telemetry
- From timelines to frequency Maps
  - Pre-processing
  - Systematics
  - Calibration
  - Frequency Maps
  - Null Tests

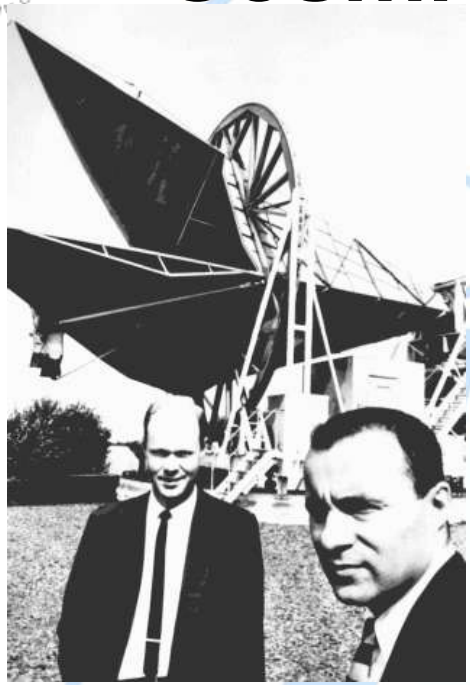
Cosmology

- Describe our univers at large scale.
- Actual model is based on:
  - Space and Ground Observations
  - The general relativity theory
  - Fundamental particle theory
  - The inflaction hypotesis
- It can be summarized in a very short number of parameters.

Main element to be observed

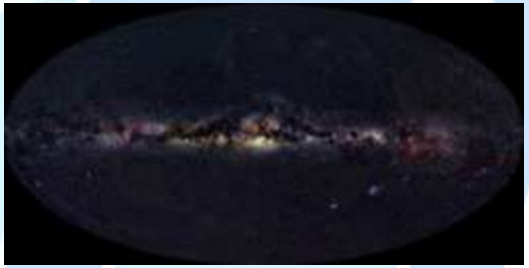
- Structure and dynamics of luminous matter
- Universe Expansion
- Abundance of light elements
- Age of the universe
- Cosmic Microwave Background (CMB)

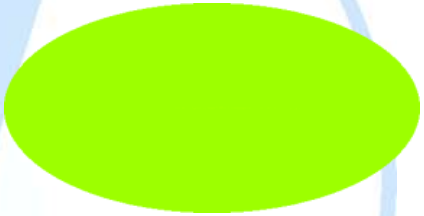
Cosmic Microwave Background



Penzias & Wilson 1965

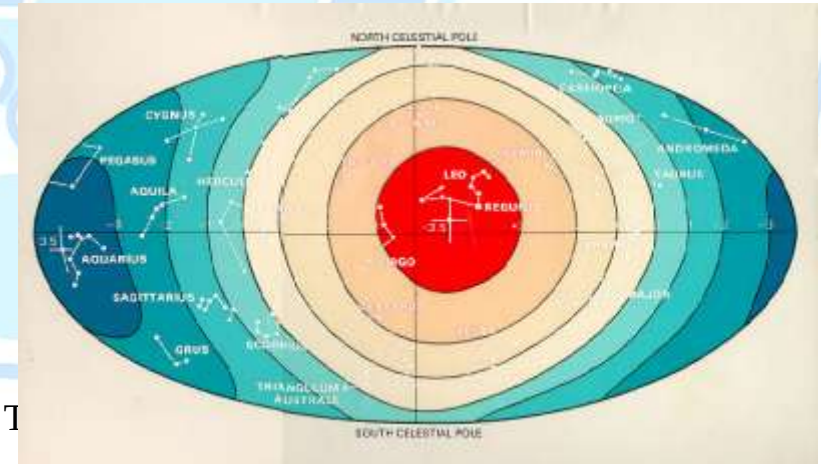
Discover of a isotropic signal in the sky
- Cosmological origin



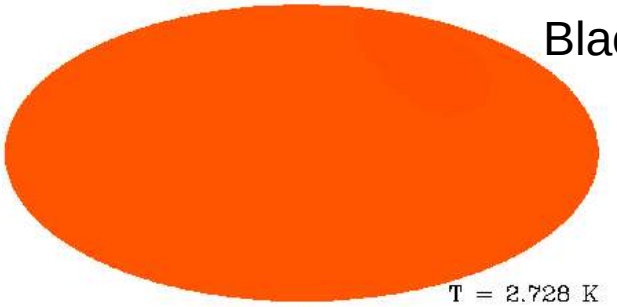


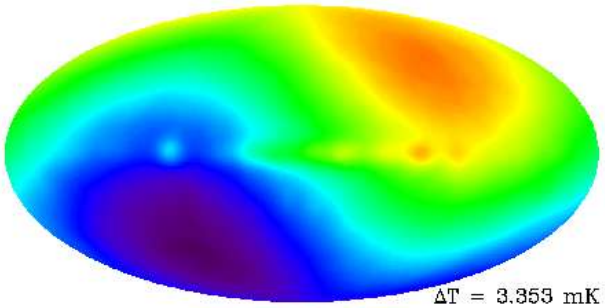
The dipole

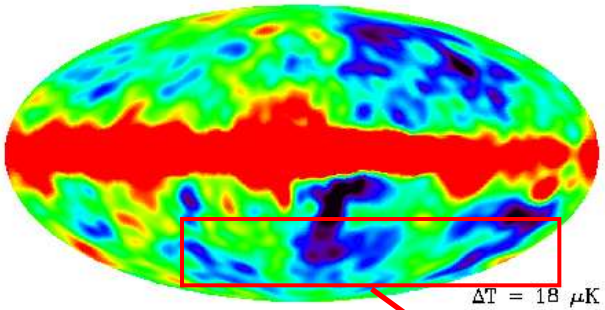
U2 experiment
1970's



Cosmic Microwave Background

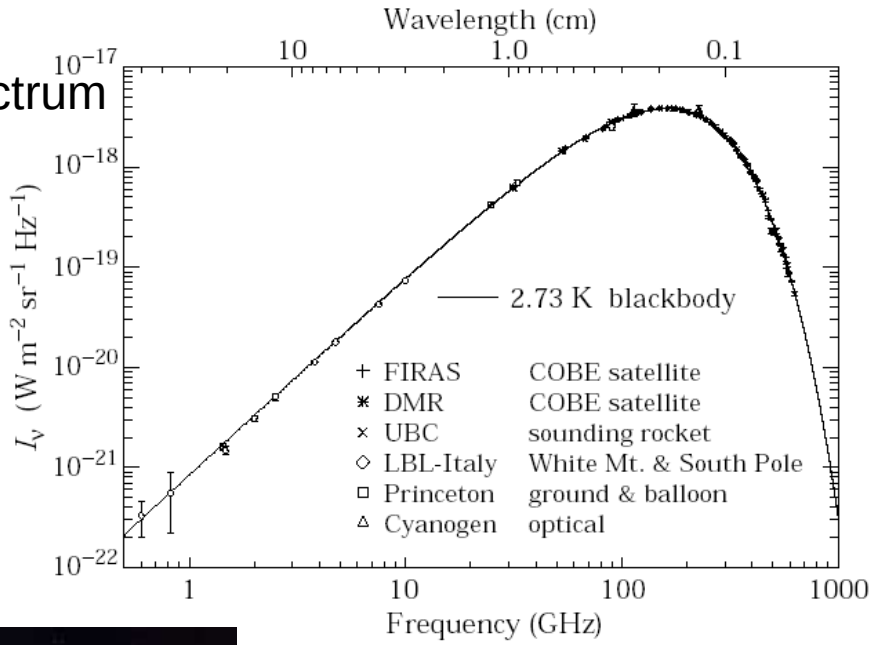






Those small CMB temperature fluctuation identify the origin of the light structure.

Black Body Spectrum



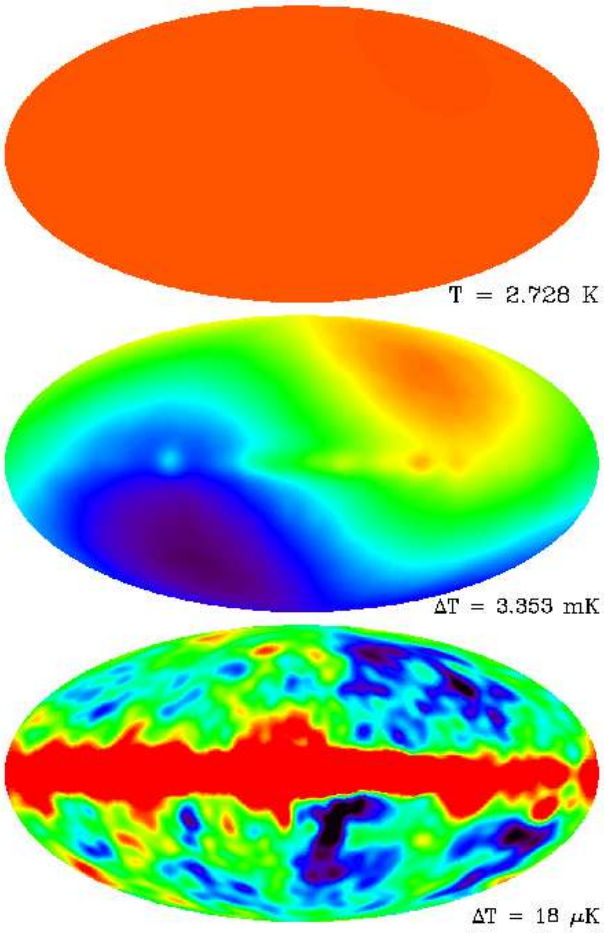
T ~ 2.7 K = -270.3 °C

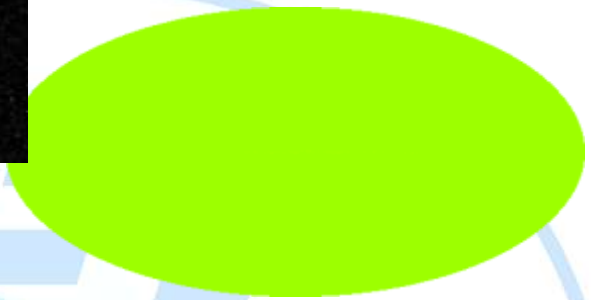
COBE
1992

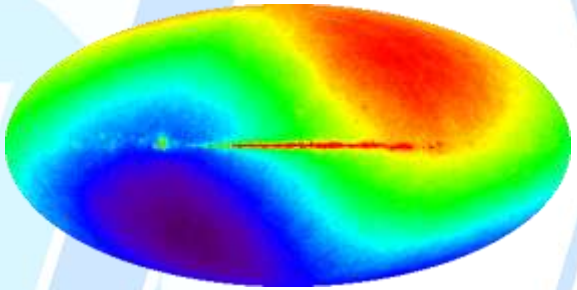
Cosmic Microwave Background

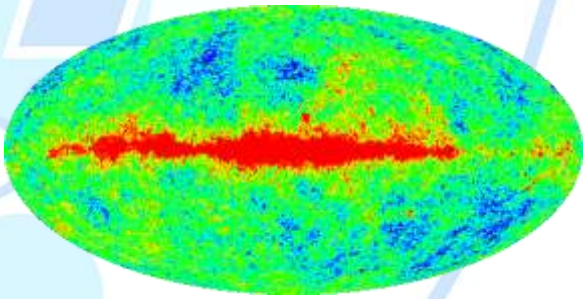
COBE 1992

WMAP 2003



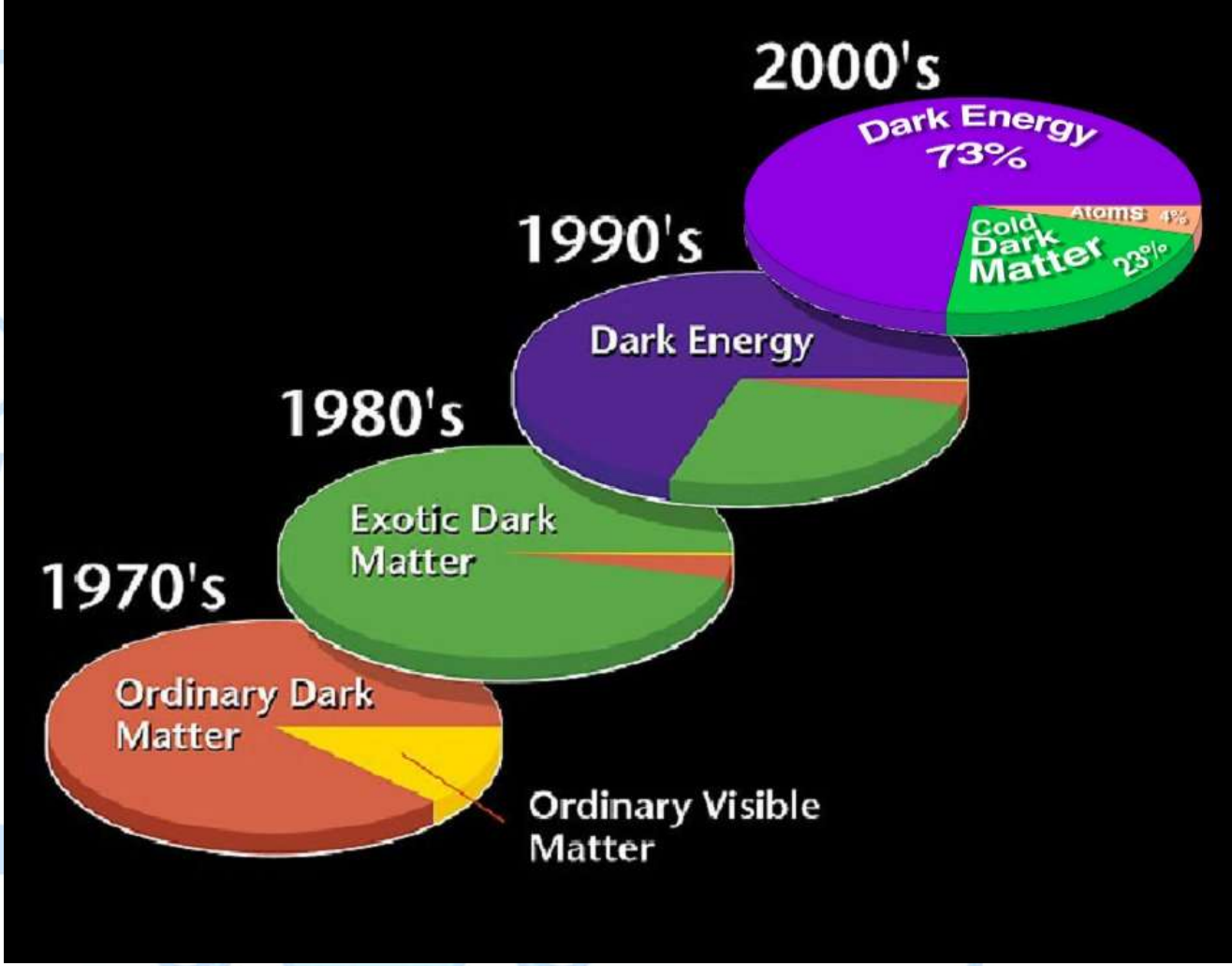






The search of the origin of the light structue

Universe based on WMAP observation



$\Omega_0 \sim 1$
Flat Geometry

Age ~ 13700 Mill. years

Pending Issue

- Characteristics of inflaction
- Origing of the vacuum energy
- What is Dark Matter ?
- What is Dark Energy ?
- Why do we live just around the time in which the expansion of the universe begins to accelerate ?
- How relevant are the neutrinos ?
- Are there magnetic monopoles, cosmic strings, etc ?
- .....

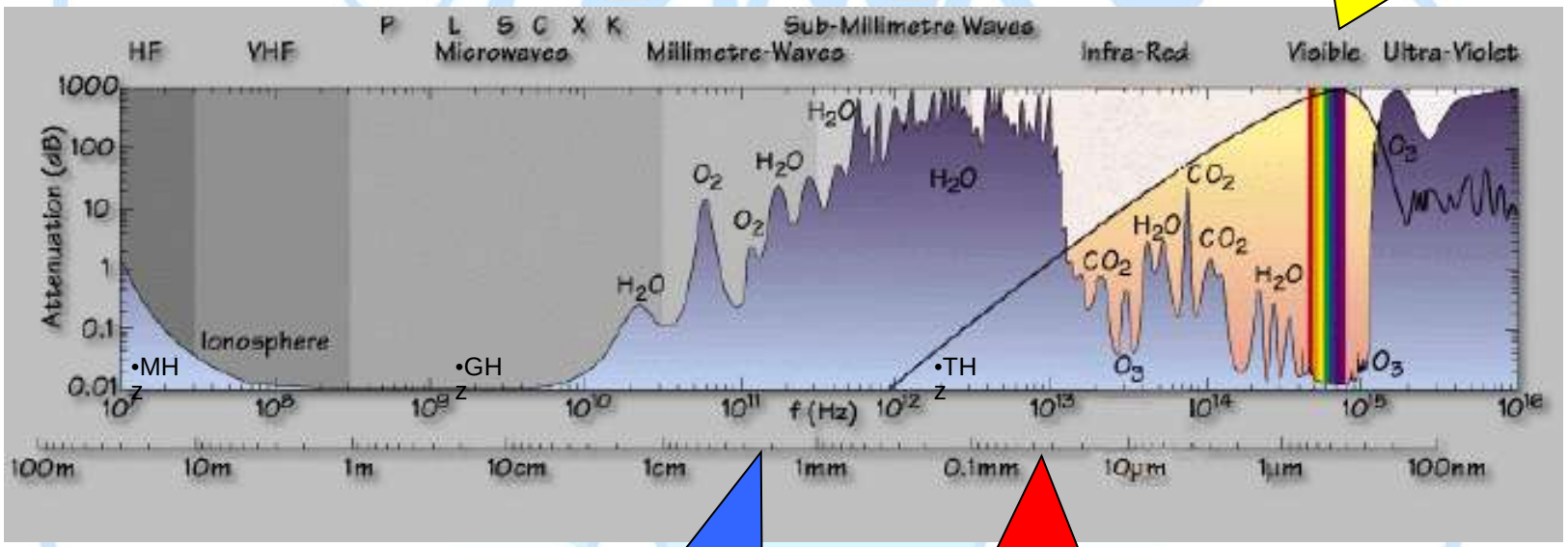
The CMB contains enough additional information to start answering some of those question.

To do that we need a space experiment that can:

- Detect smaller scale structure (resolution)
- Detect radiation 10 times weaker (sensibility) with respect what was done till now.
- Mapping the polarization.

Why from space?

Solar Radiation (6000 K, 0.5 μm)



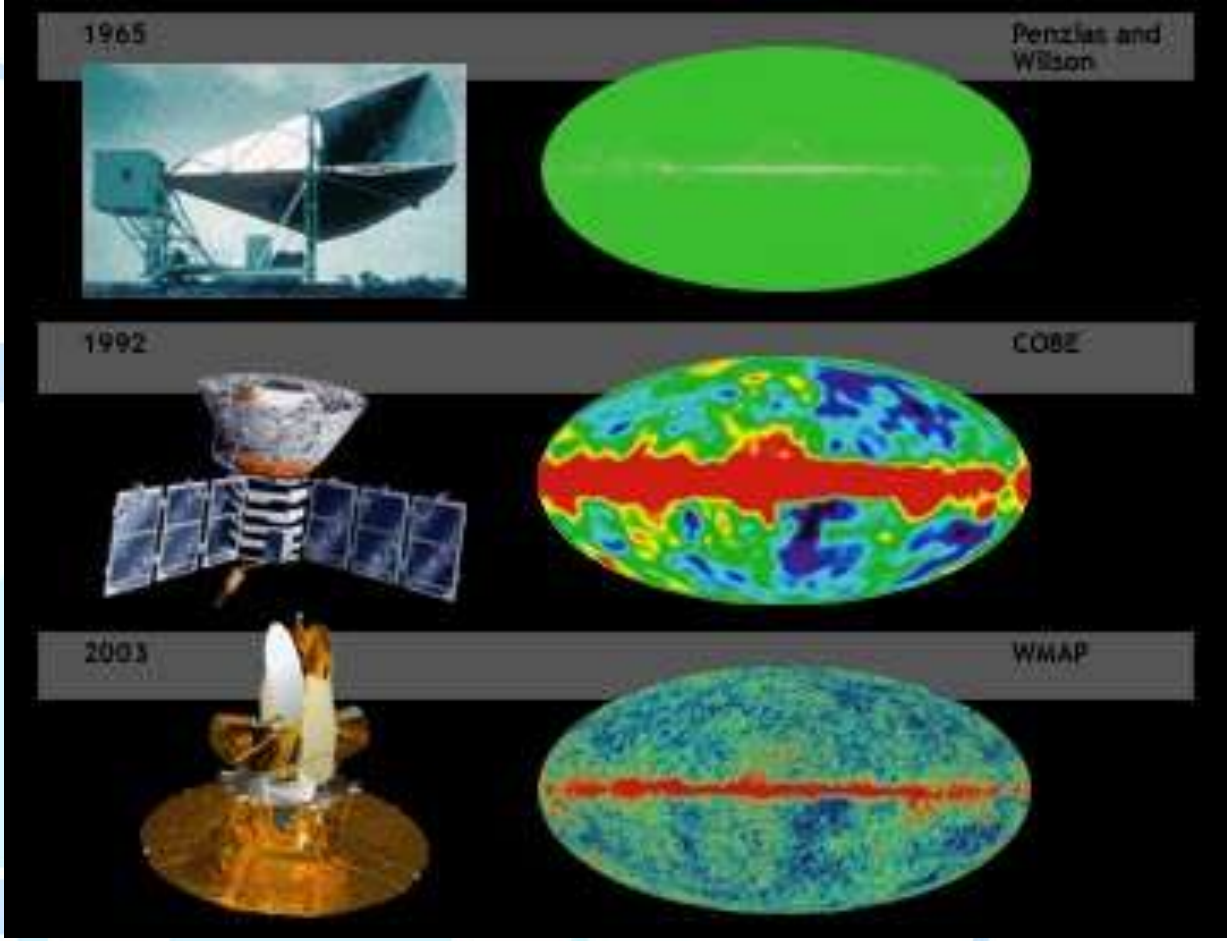
Microwave

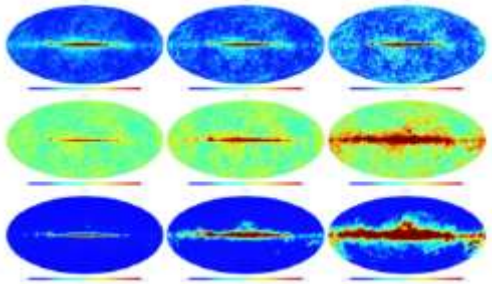
Visible Radiation

Earth Radiation (310 K, 9 μm)

CMB (2.7 K, 2 mm)

Planck: a third generation project

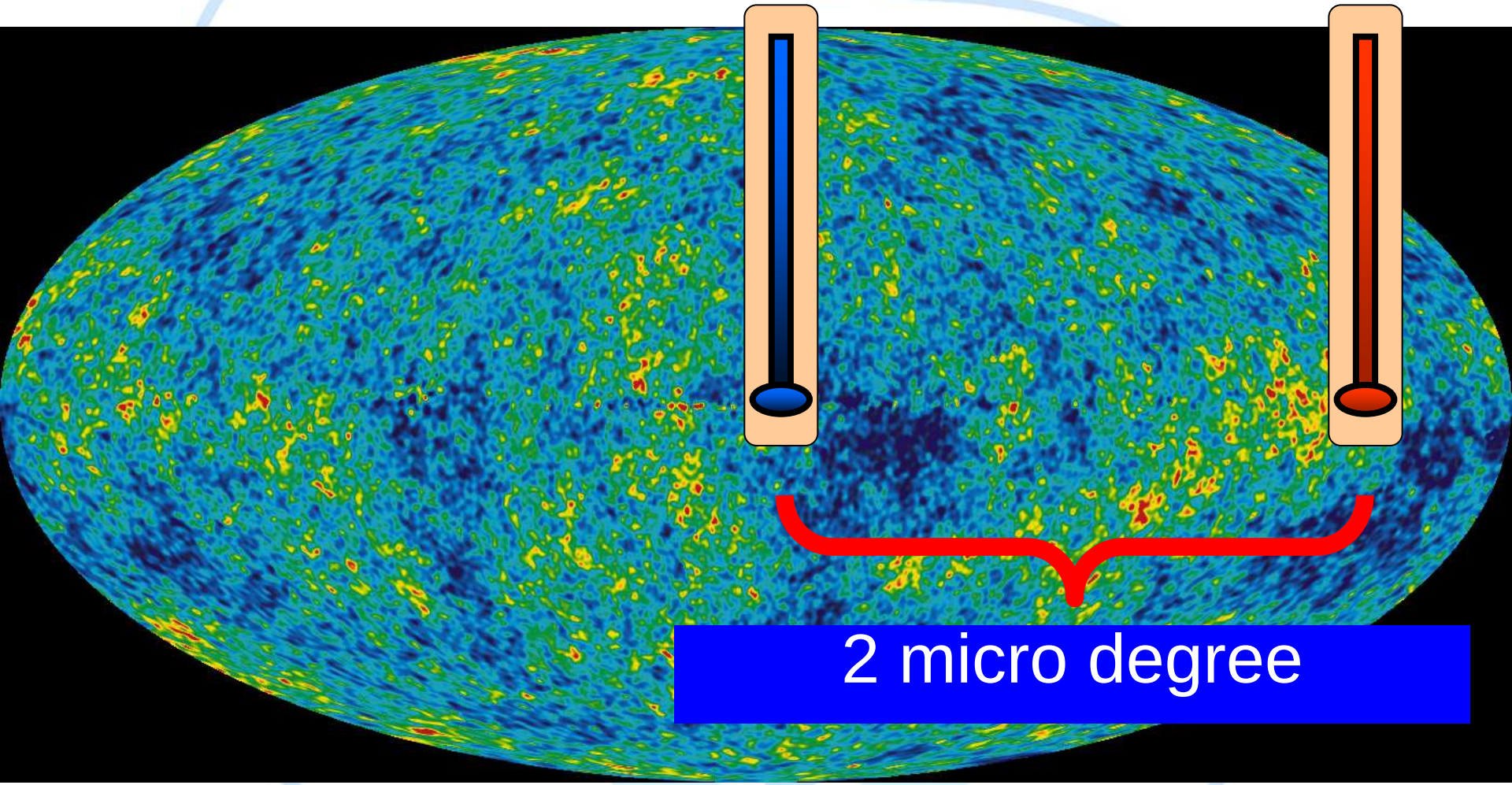




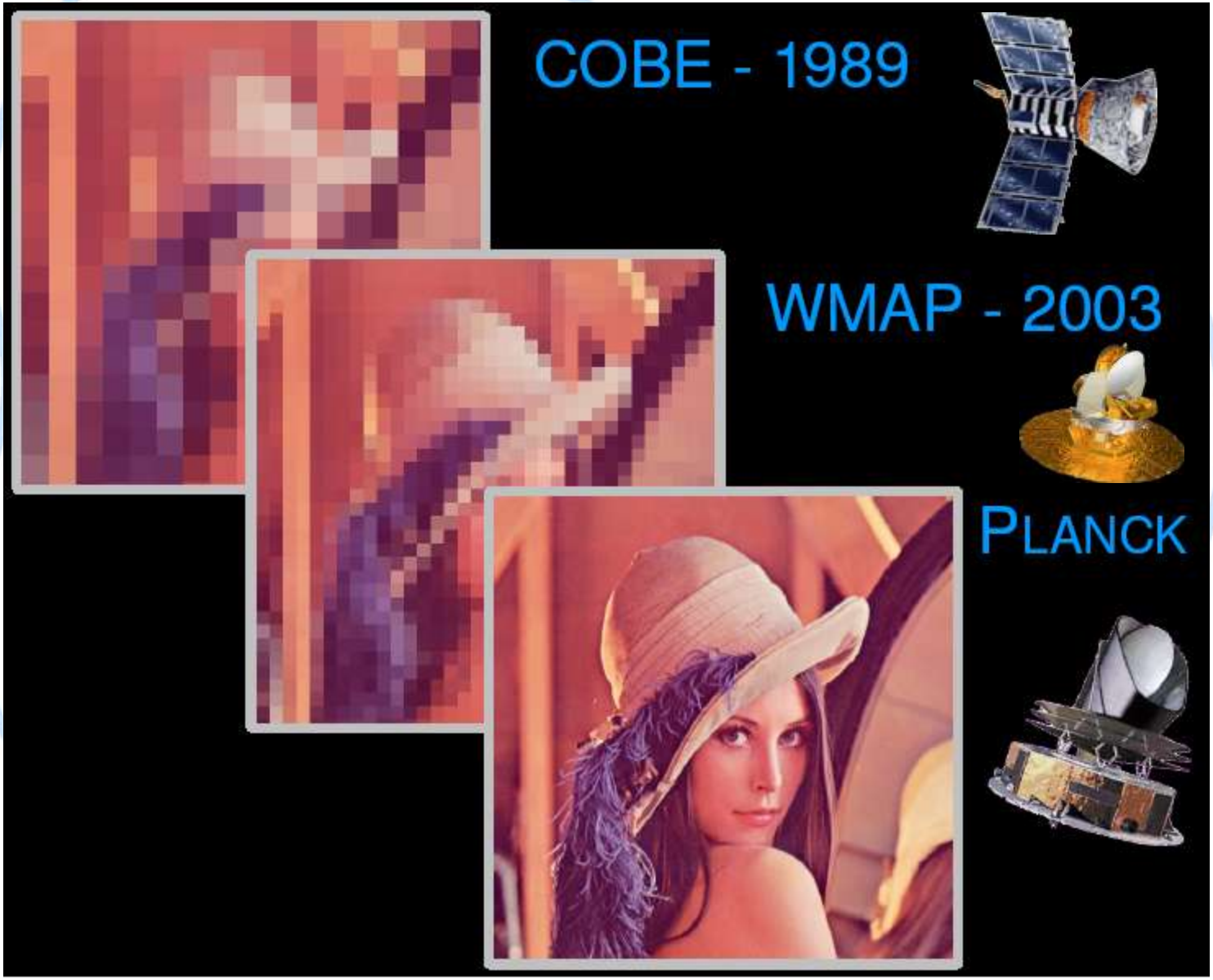
The Planck mission

- Two Consortia, each in charge of building an instrument and perform data processing (DPCs) :
  - LFI, tuned radiometers working at 3 frequencies (30 - 70 GHz), cooled to 20 K, PI: N.Mandolesi - INAF/IASF Bologna
  - HFI, array of bolometers working at 6 frequencies (100 - 850 GHz), cooled to 0.1 K, PI: J.L.Puget - IAS Orsay
    - Sorption Cooler System, device necessary to cool down until 0.1 K, PI: C Lawrence JPL USA
- The Nominal life was of 14 months after reaching L2 ⇒ Two complete sky survey; extension is ongoing and will allow at least 8 surveys, should end in October 2013.
- Total Cost was about 600 millions of Euro (instrument + Launch+ Ground Segment).

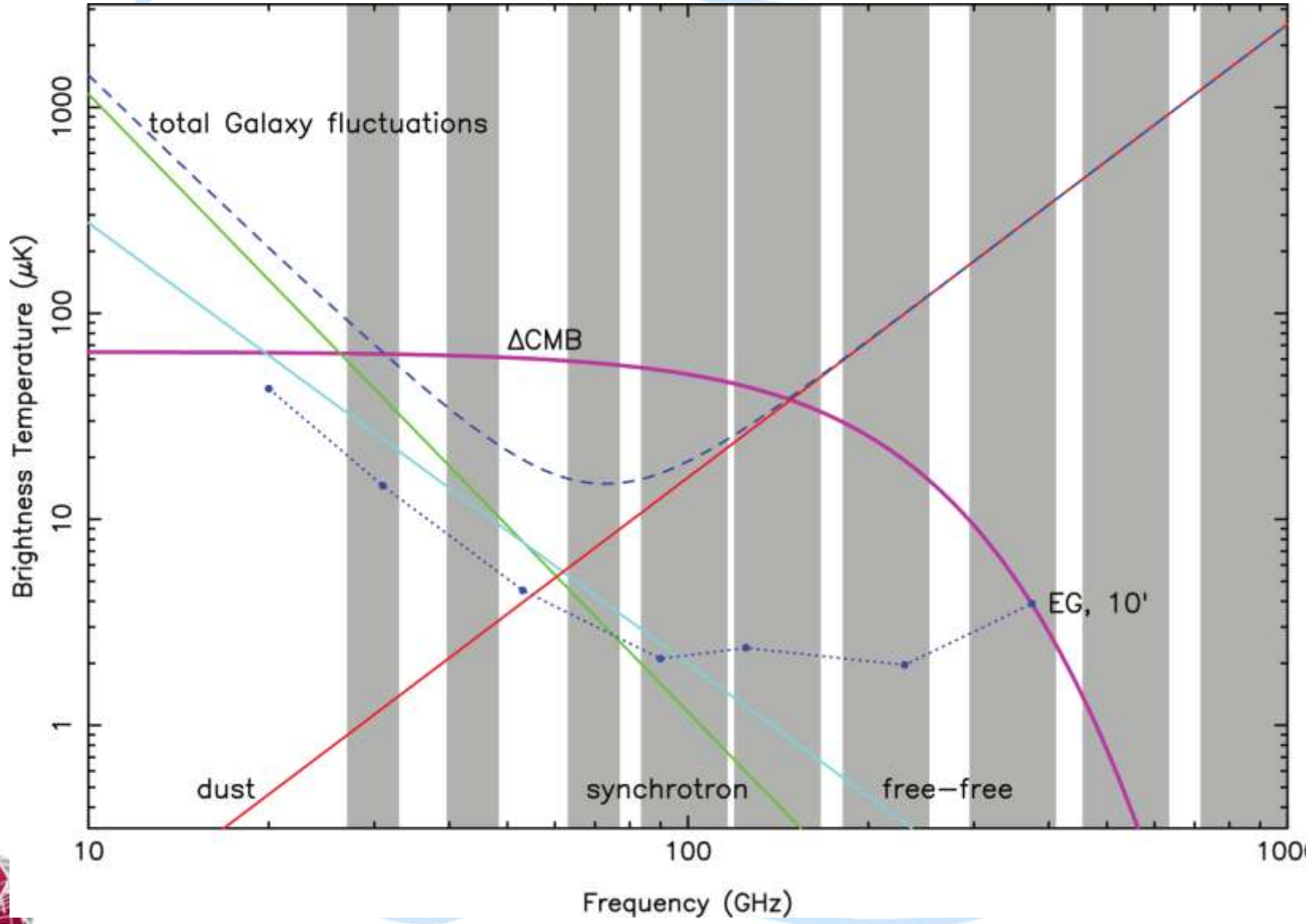
Sensibility



Resolution



Why so many frequencies?



Planck space mission

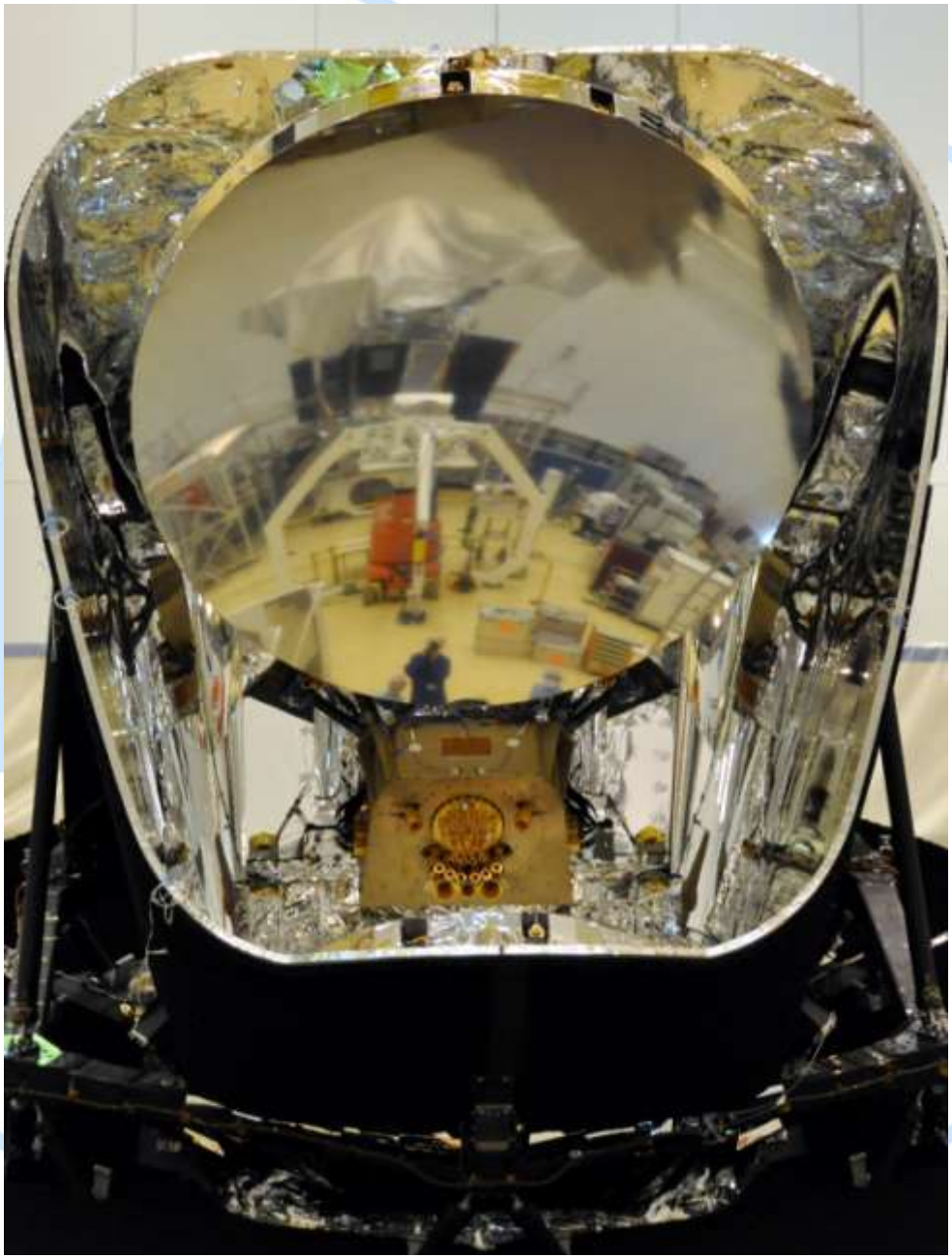
ESA mission
50000 Electronic components
36000 l ^{4}He
12000 l ^{3}He
11400 Documents
20 years between the first project and first results

2000 Kg
1600 W consumption
Dimension = 4.2 x 4.2 meter

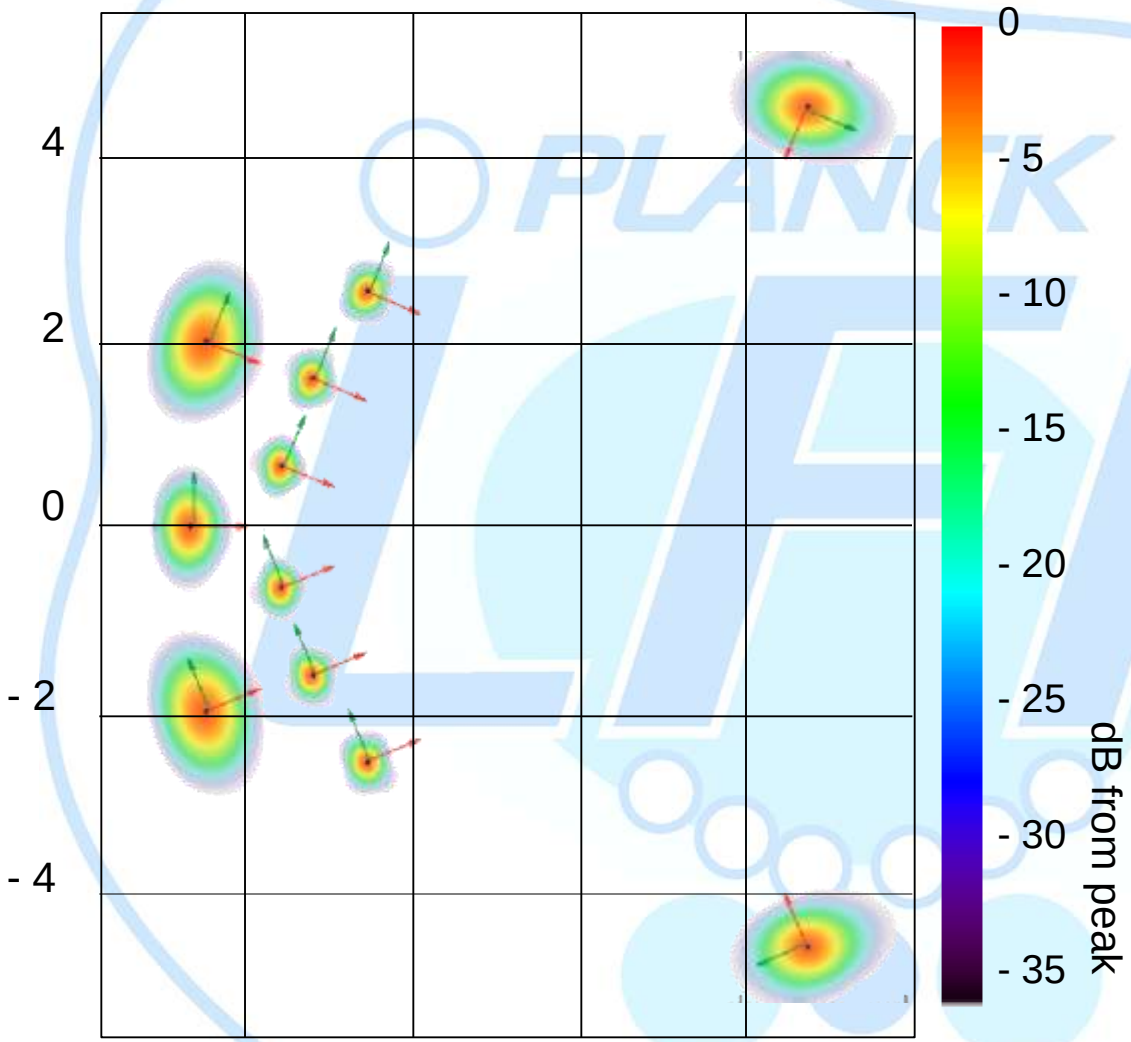
16 countries
400 researchers

Cost 600 millions euro

The eye of Planck

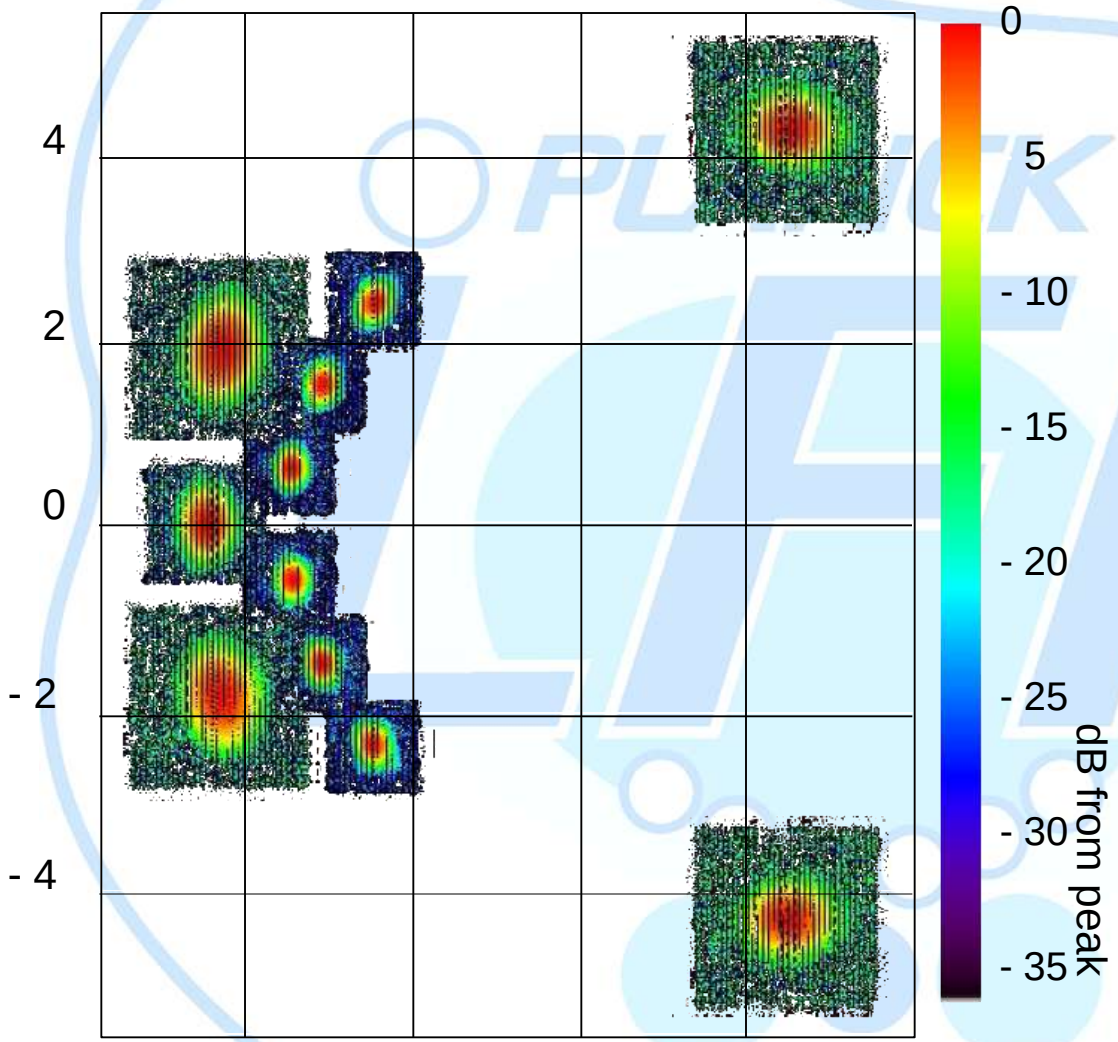


Planck's glimpse (LFI)



Simulations

Planck's glimpse (LFI)



Flight measurements

Thank you Jupiter!

The instruments

- Two instruments covering 9 frequencies [30 GHz, 1 THz]
  - LFI: Low Frequency Instrument, using HEMTS
  - HFI: High Frequency instrument, using bolometers

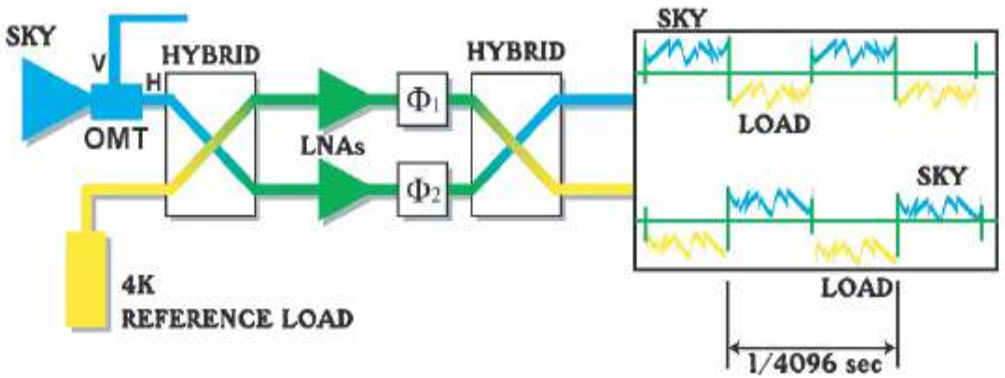
PLANCK	LFI			HFI					
Center freq (GHz)	30	44	70	100	143	217	353	545	857
Angular resolution (FWHM arcmin)	33	24	14	10	7.1	5.0	5.0	5.0	5.0
Sensitivity in I [μK.deg] [$\sigma_{pix}\Omega_{pix}^{1/2}$]	2.7	2.6	2.6	1.0	0.6	1.0	2.9		
Sensitivity in Q or U [μK.deg] [$\sigma_{pix}\Omega_{pix}^{1/2}$]	4.5	4.6	4.6	1.8	1.4	2.4	7.3		

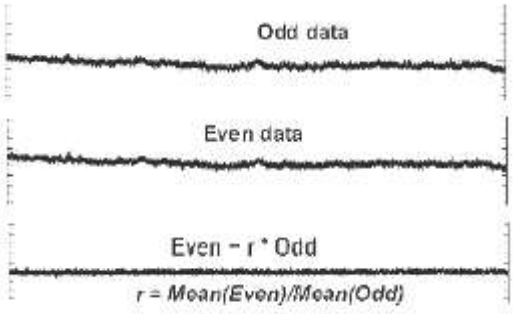
WMAP center freq.	23	33	41	61	94
Angular resolution (FWHM arcmin)	49	37	29	20	12.6
Sensitivity in I [μK.deg], 1 yr (8 yr)	12.6 (4.5)	12.9 (4.6)	13.3 (4.7)	15.6 (5.5)	15.0 (5.3)

Aggregated sensitivity of Planck core CMB channels is:
0.5 μK.deg in T, 1 μK.deg QU

LFI

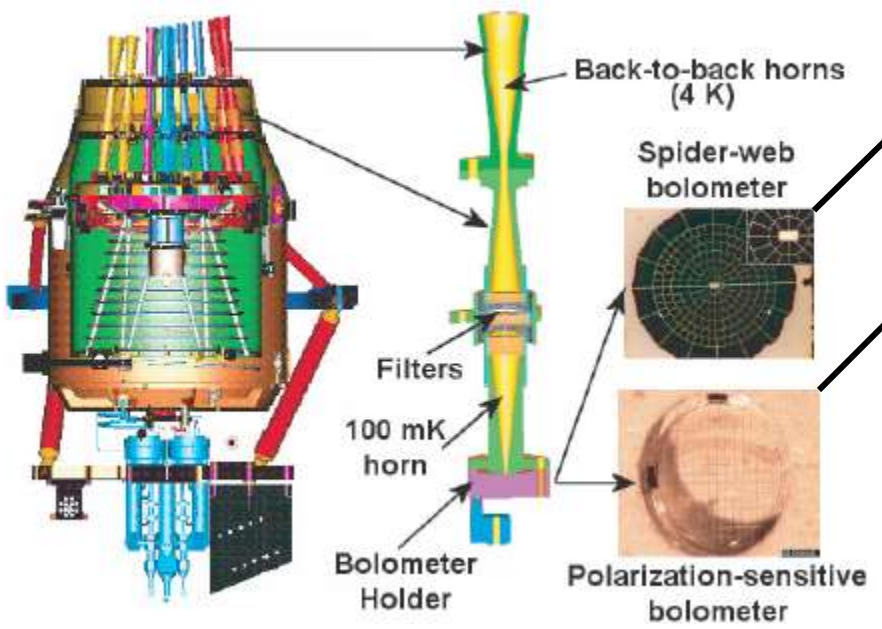
The radiometer design is driven by the need to suppress 1/*f*-type noise induced by gain and noise temperature fluctuations in the amplifiers, which would be unacceptably high for a simple total power system. A differential pseudo-correlation scheme is adopted, in which signals from the sky and from a blackbody reference load are combined by a hybrid coupler, amplified in two independent amplifier chains, and separated out by a second hybrid





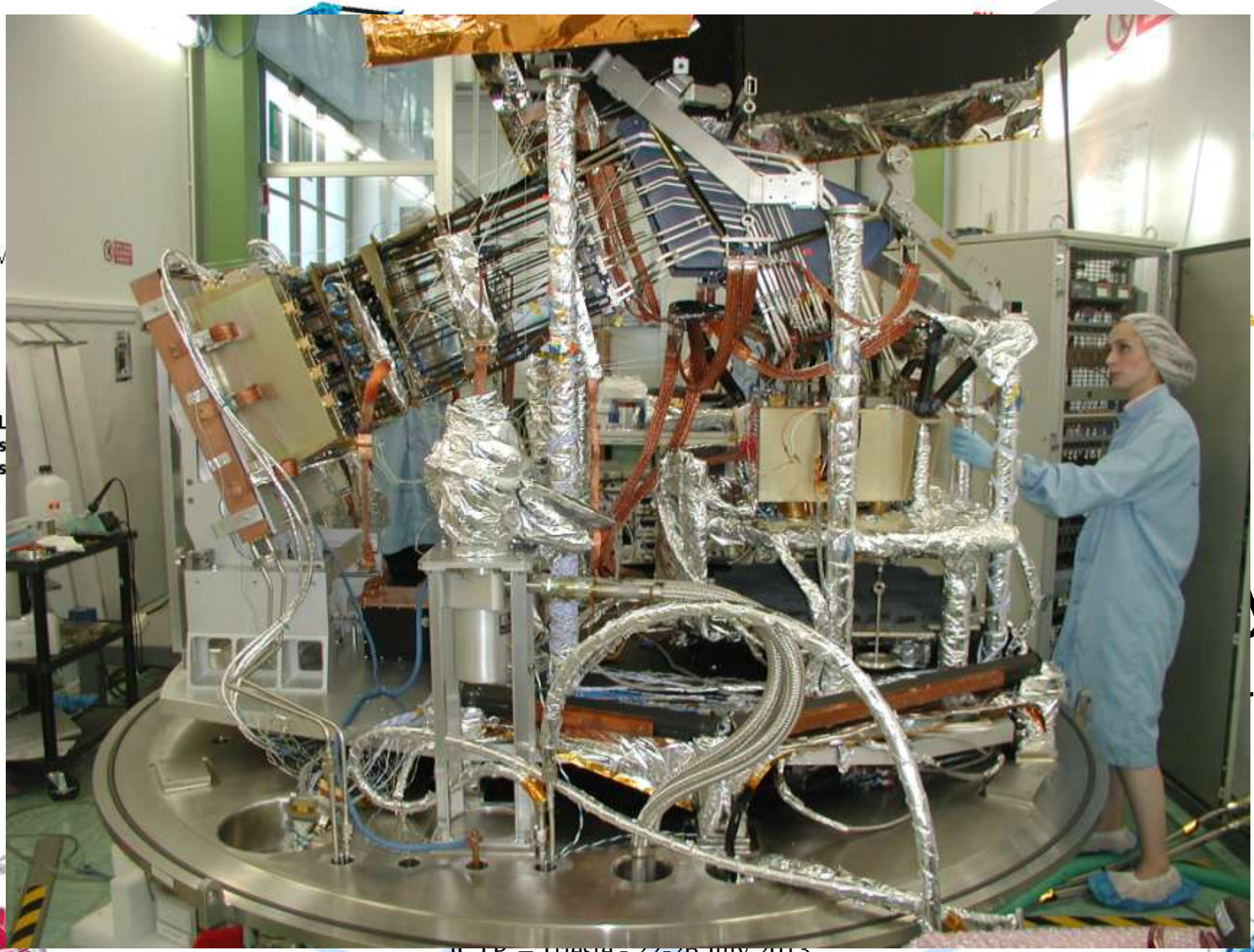
The signals from the two detector diodes ("odd and even samples"), correspond to the sky and the reference load (noise is highly non-white, 1/*f*-type component). The radiometer design, however, is such that the 1/*f* component is highly correlated in the two diodes, and the difference signal is extremely stable and insensitive to 1/*f* fluctuations.

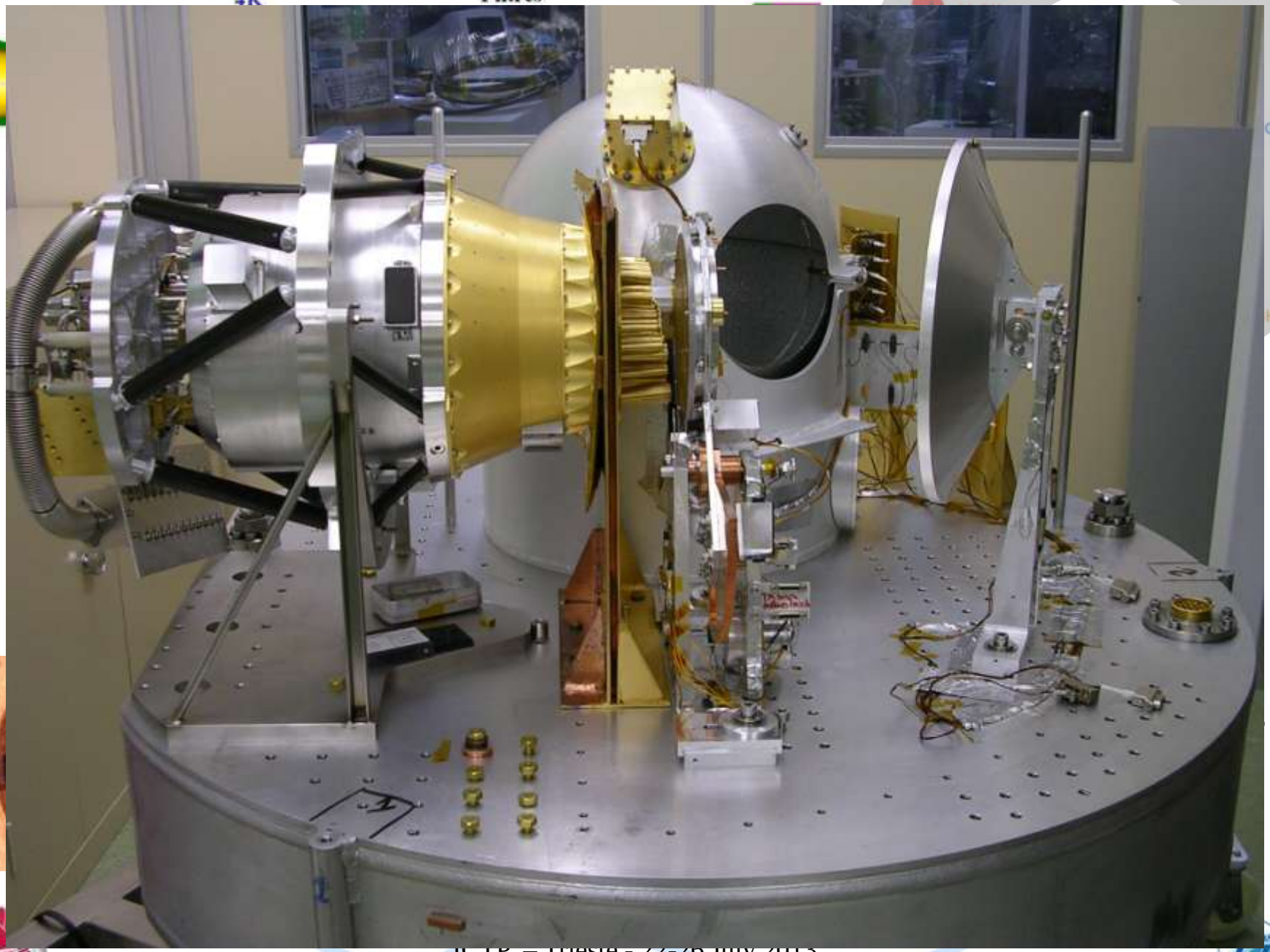
HFI



The HFI bolometers are of two kinds:
(a) spider-web bolometers are devices which absorb radiation via a spider-web-like antenna;
(b) about half of the HFI detectors are polarisation-sensitive bolometers: the spider-web is replaced with a linear grid which collects linearly polarised radiation only.

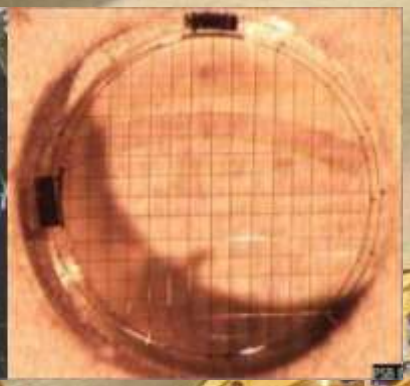
The HFI cooling chain includes: the common hydrogen sorption cooler, (18K stage); a closed-loop Joule-Thomson refrigerator (4K); a dilution refrigerator which provides the final operating temperature of the bolometers (0.1 K).




4K
Filtres
Bolometer


An ultra-sensitive retina

Spider-web



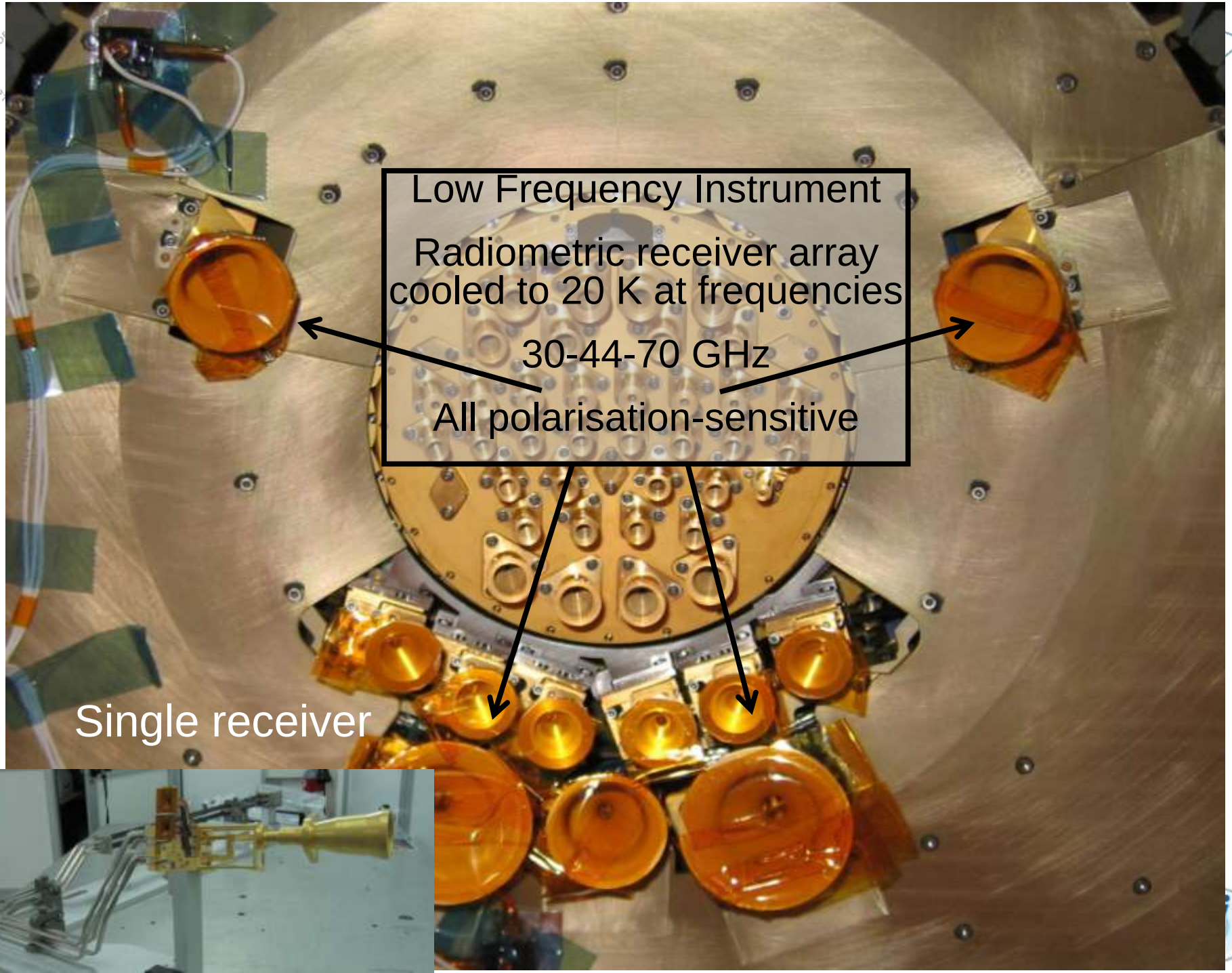
PSB

High Frequency Instrument

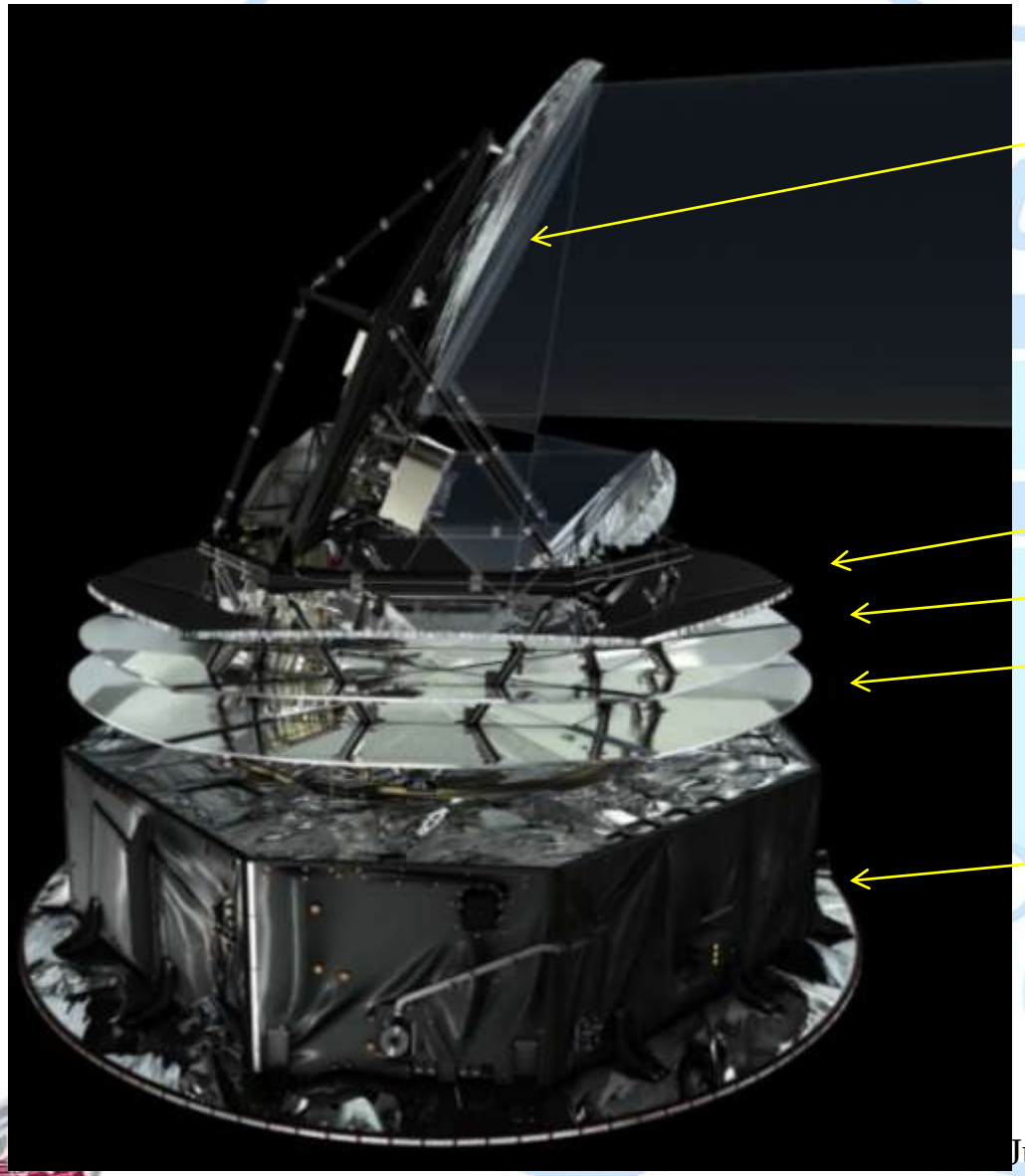
Bolometer array cooled at 0.1 K at frequencies

100-857 GHz

Polarisation sensitive at frequencies between 100 and 353 GHz


Low Frequency Instrument
Radiometric receiver array cooled to 20 K at frequencies
30-44-70 GHz
All polarisation-sensitive
Single receiver

Cold is “cool”



50 K (~ -223 ◦C)

~ 50 K

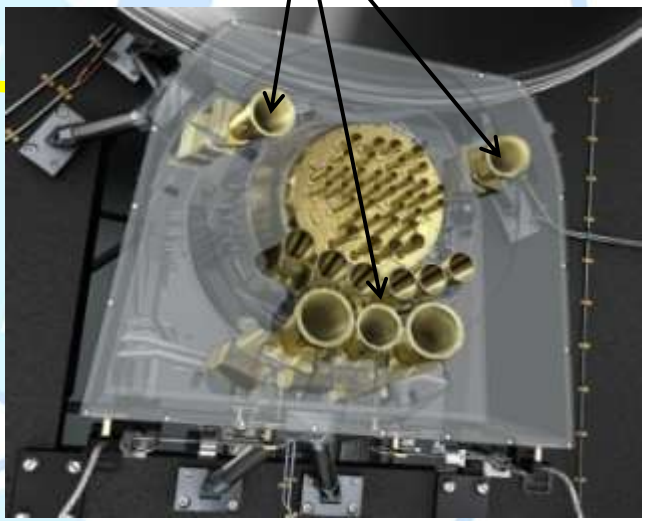
~ 100 K

~ 150 K

~ 300 K

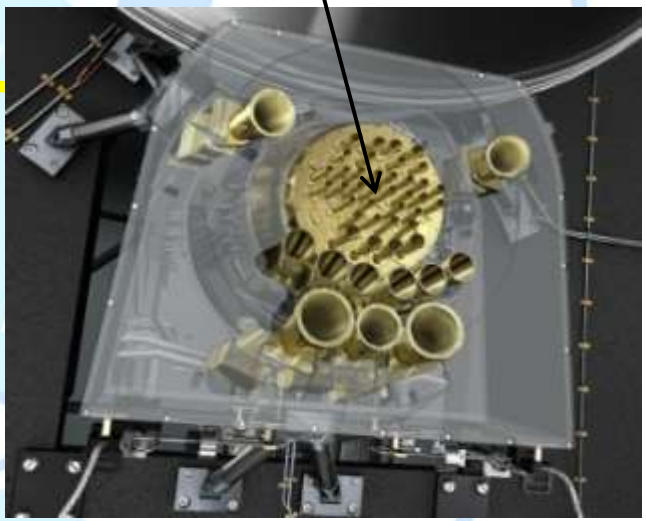
Cold is “cool”

20 K (LFI horns)



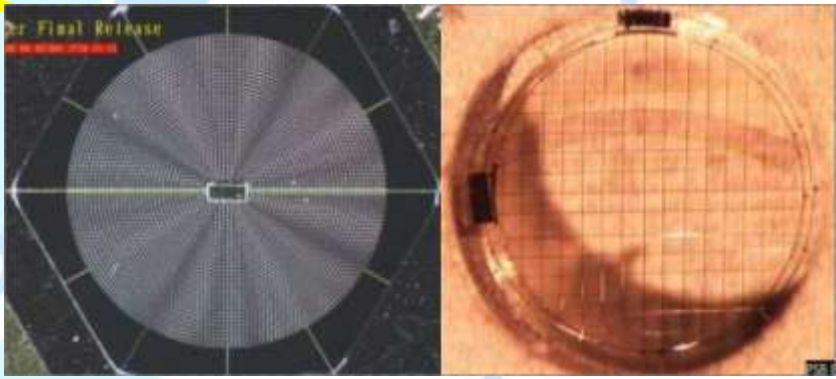
Cold is “cool”

4 K (HFI horns)

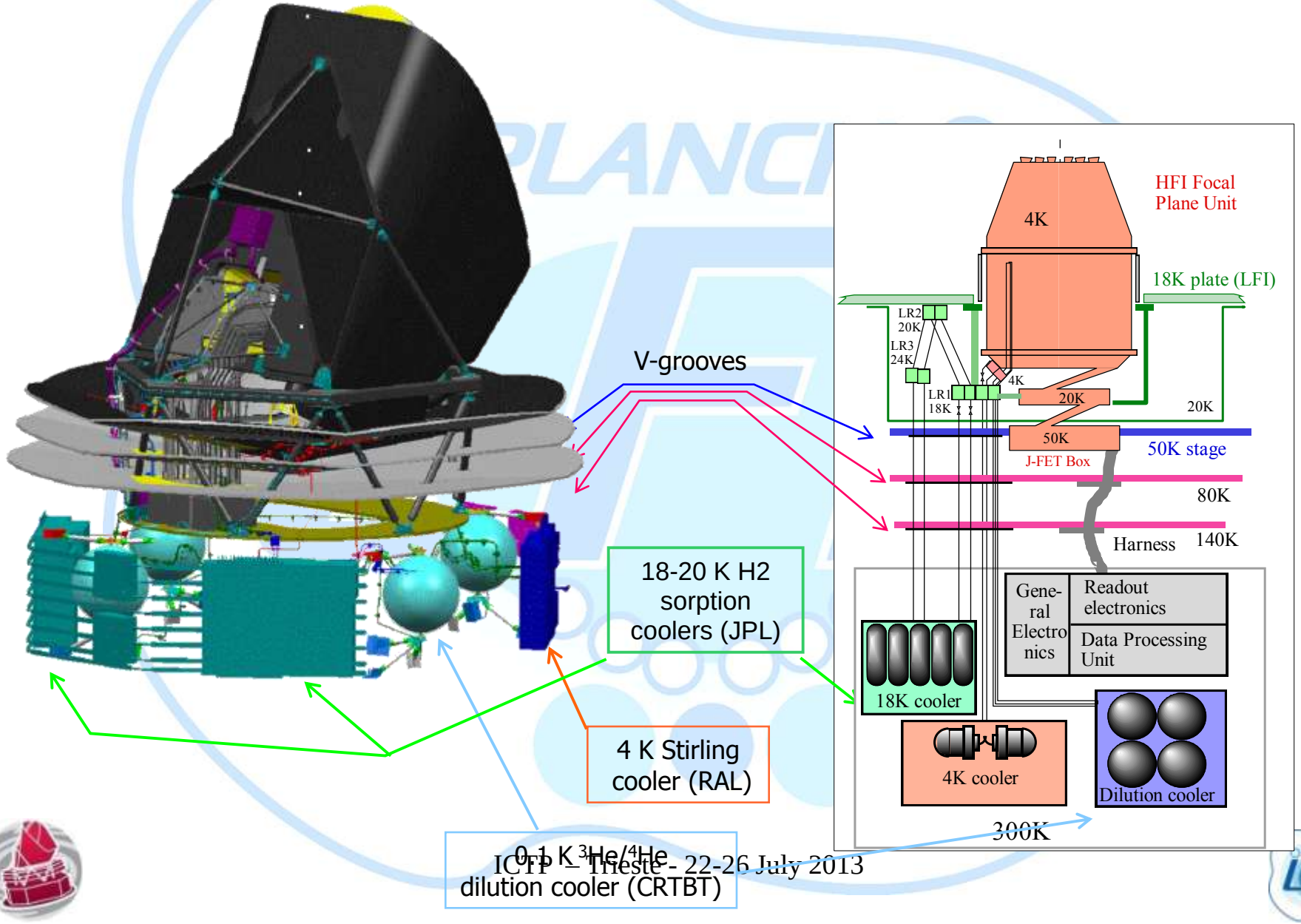


The coldest object in space

0.1 K (HFI bolometers)

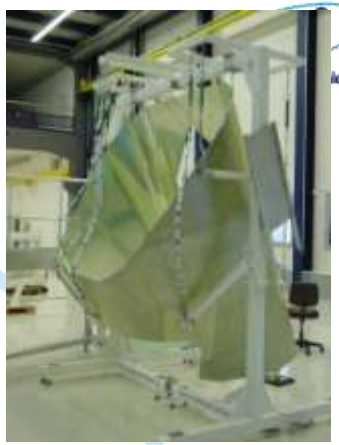


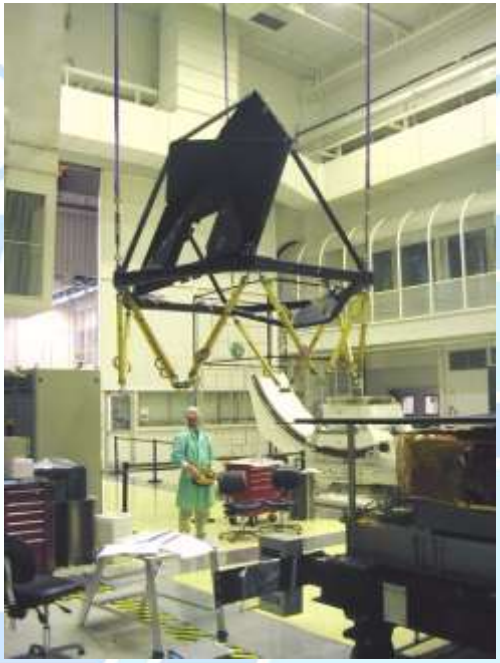
The Planck cryogenic system

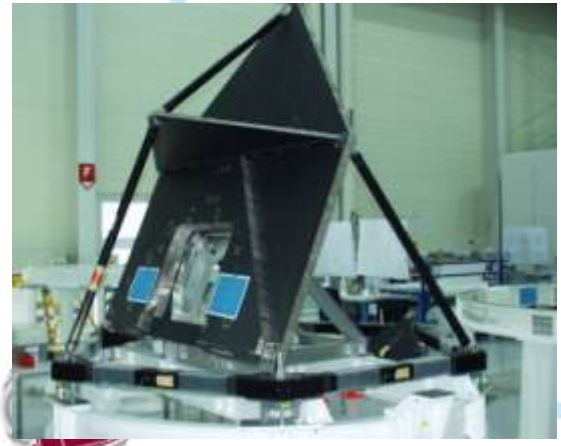


Build the satellite

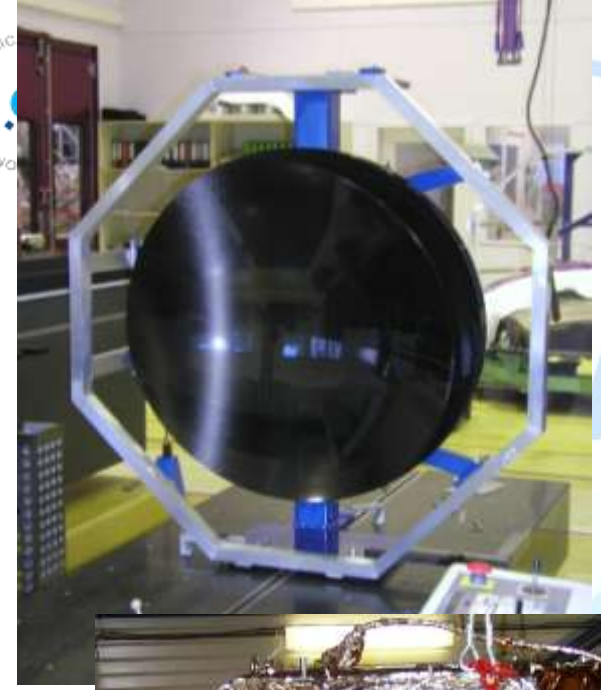
Prime contractor: Thales Alenia Space (Cannes)



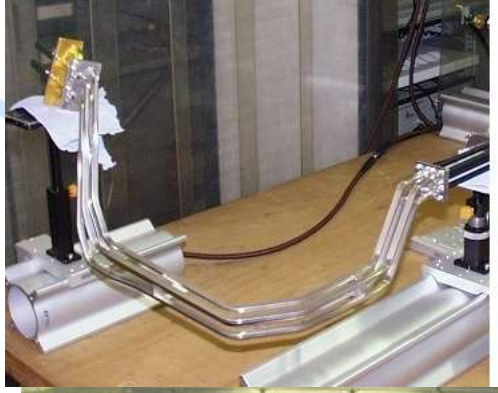




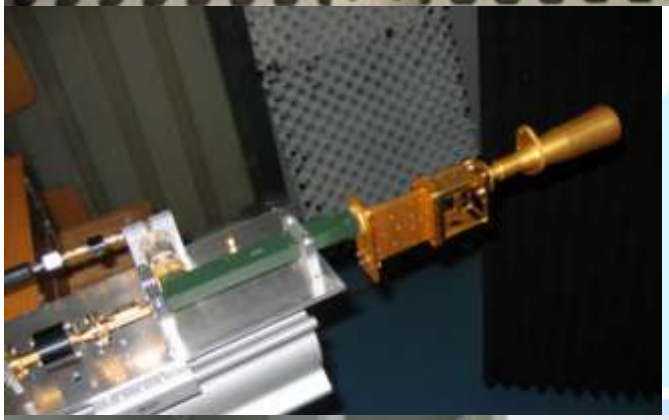
The telescope



Constructor: Astrium Gmbh (Friedrichshafen)

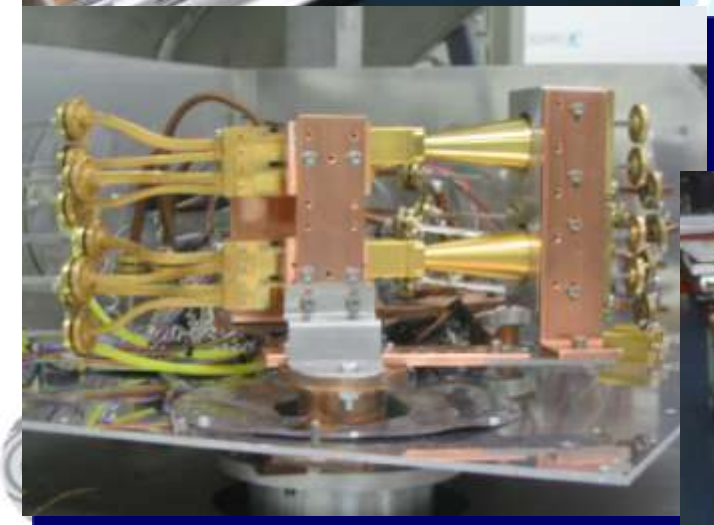





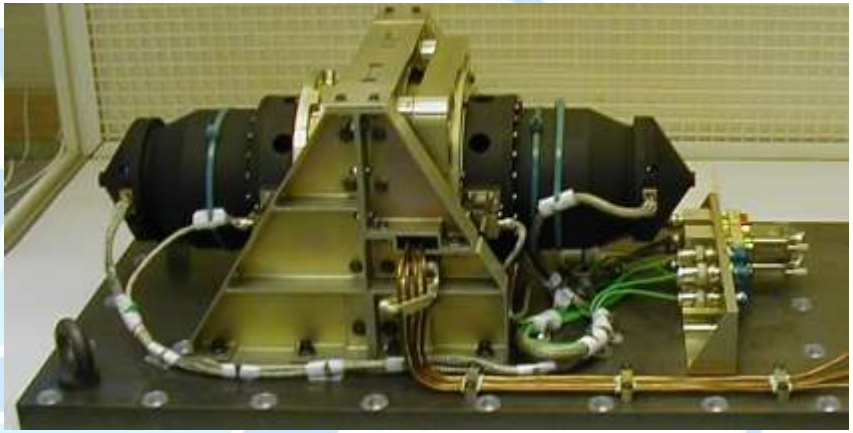


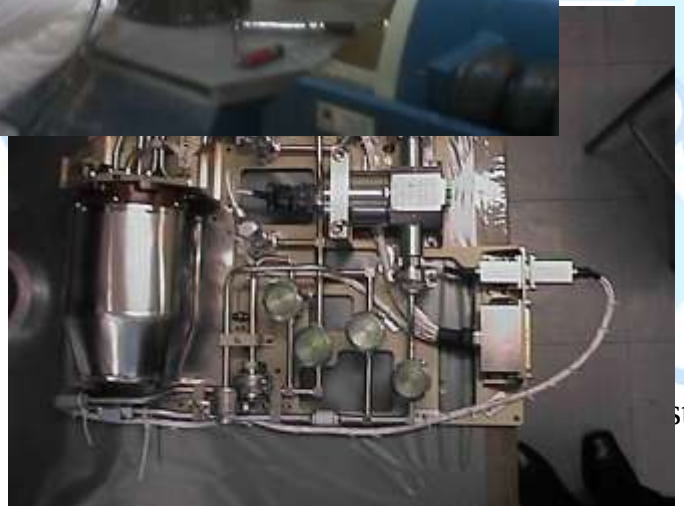
LFI



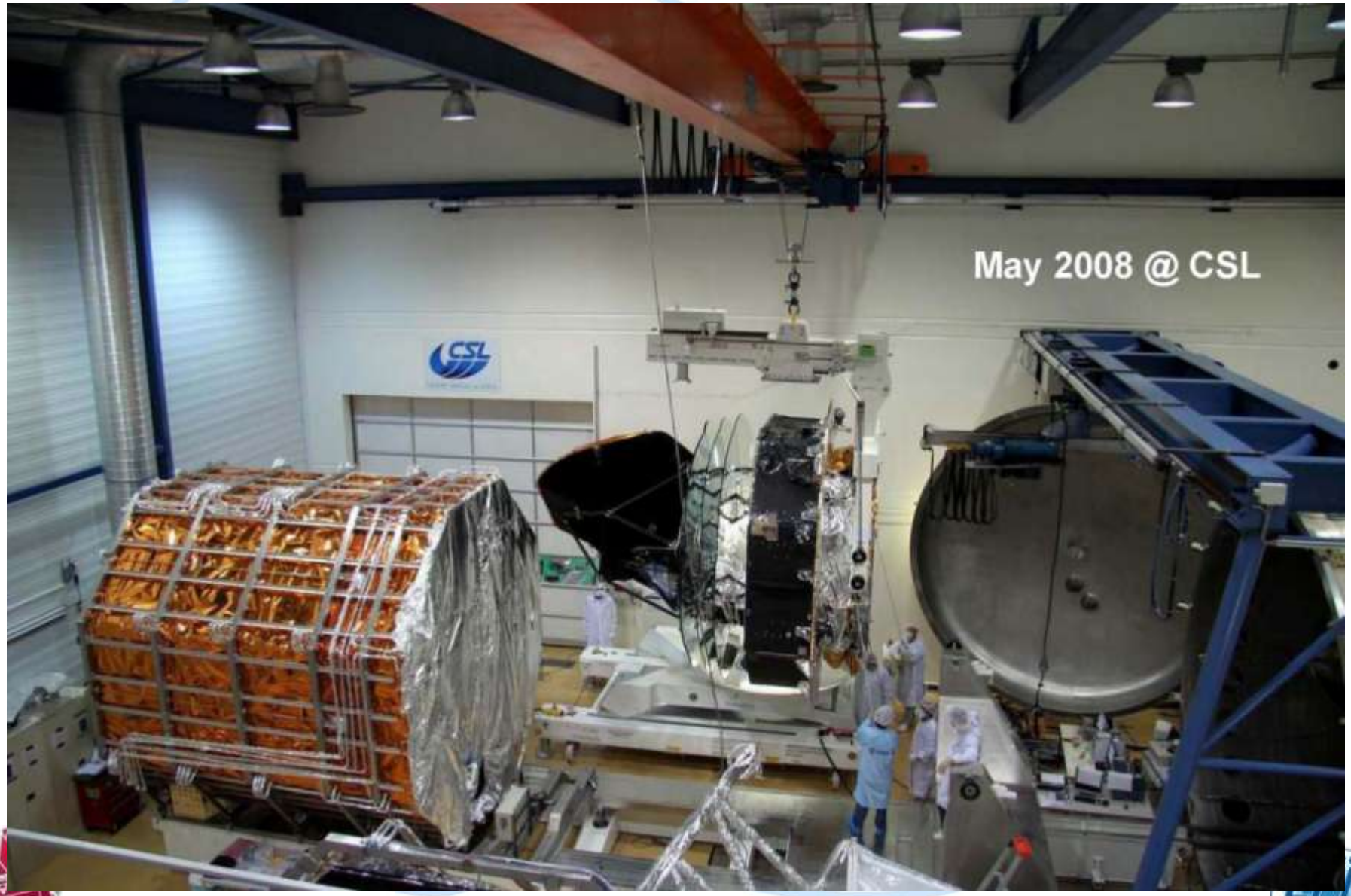



HFI





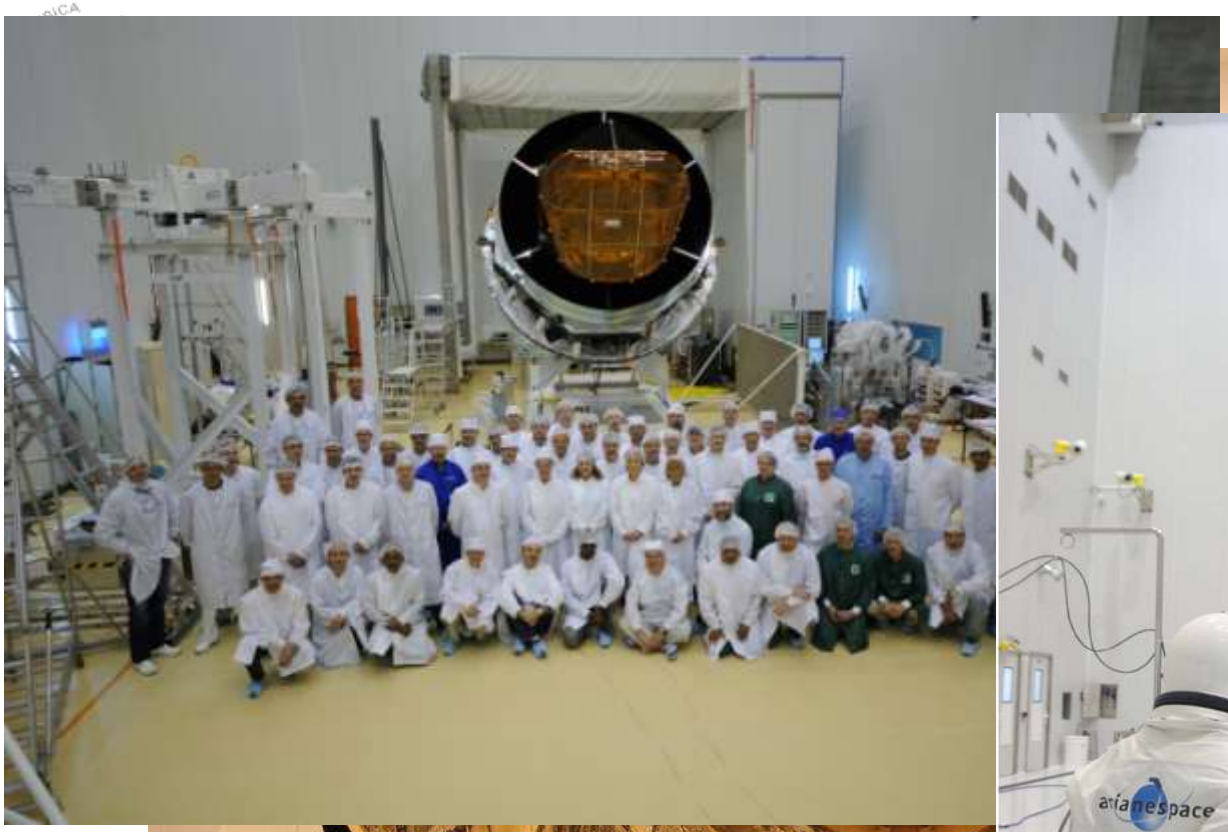
The Planck test



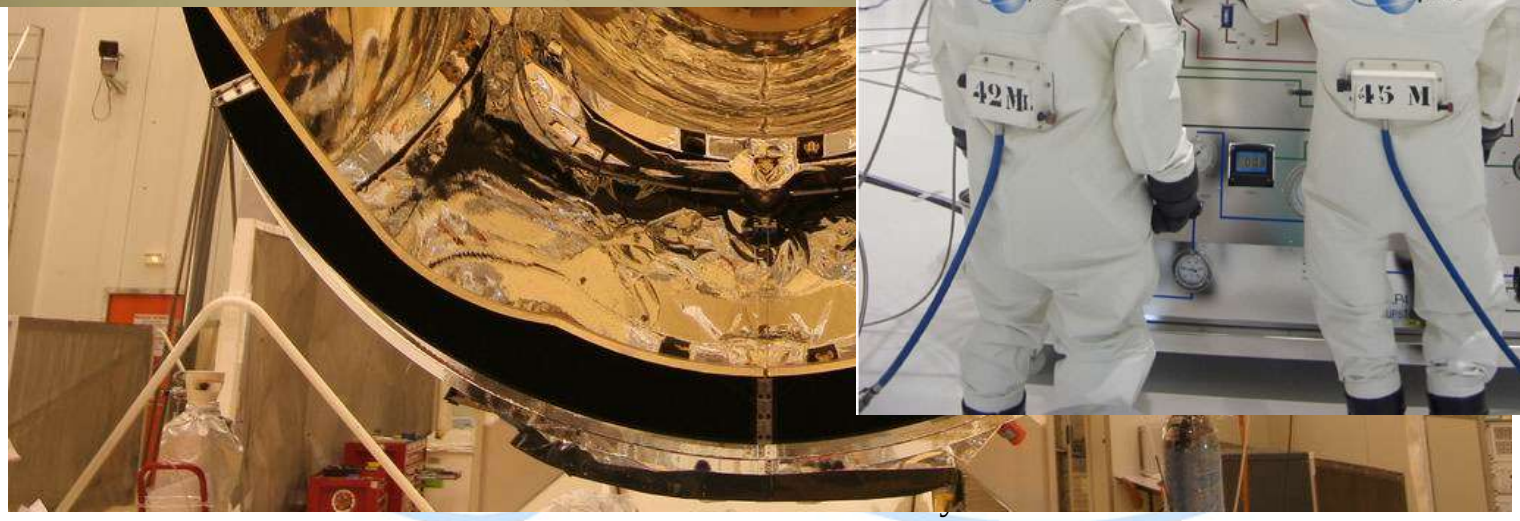
CSL Test in a nutshell

- 38 days of continuous work (24 h)
- All the flight procedure were tested (about 12000 telecommands)
- About 1 Tb of data was acquired during those test (to be used as reference point)
- The required thermal stability was reach (0.1 K)
- Instrument performance in the integrated system was verified.
- Vibration and Spinning test were successful

To Kourou




arianespace
arianespace
42 M.
45 M



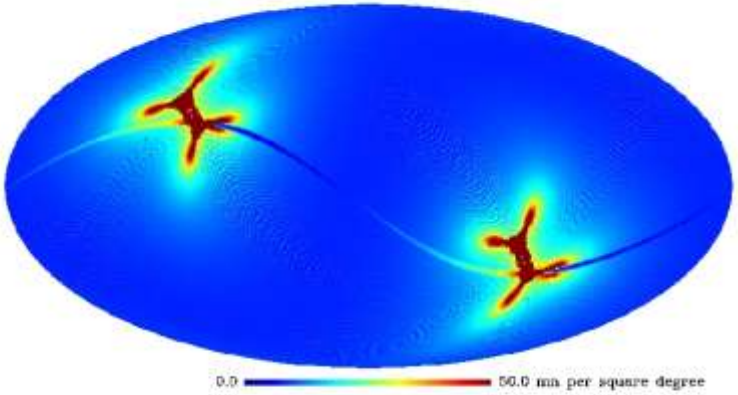
14 May 2009

HERSCHEL SPACE OBSERVATORY

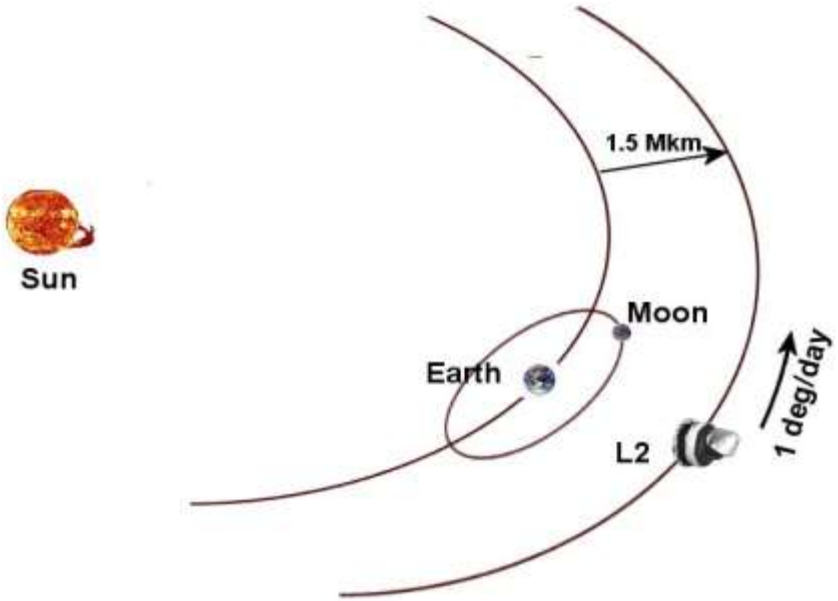
PLANCK

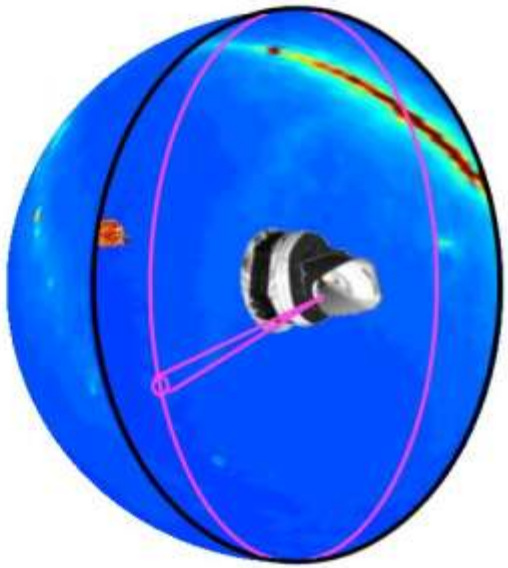
Planck o

- Planck is operating at the L2 Lag
- pointing at the anti-solar direction
- Baseline scanning strategy:
  - step size (slew): 2 arcmin
  - dwell time: 45 minutes
  - spin axis rotation rate: 1 rpm

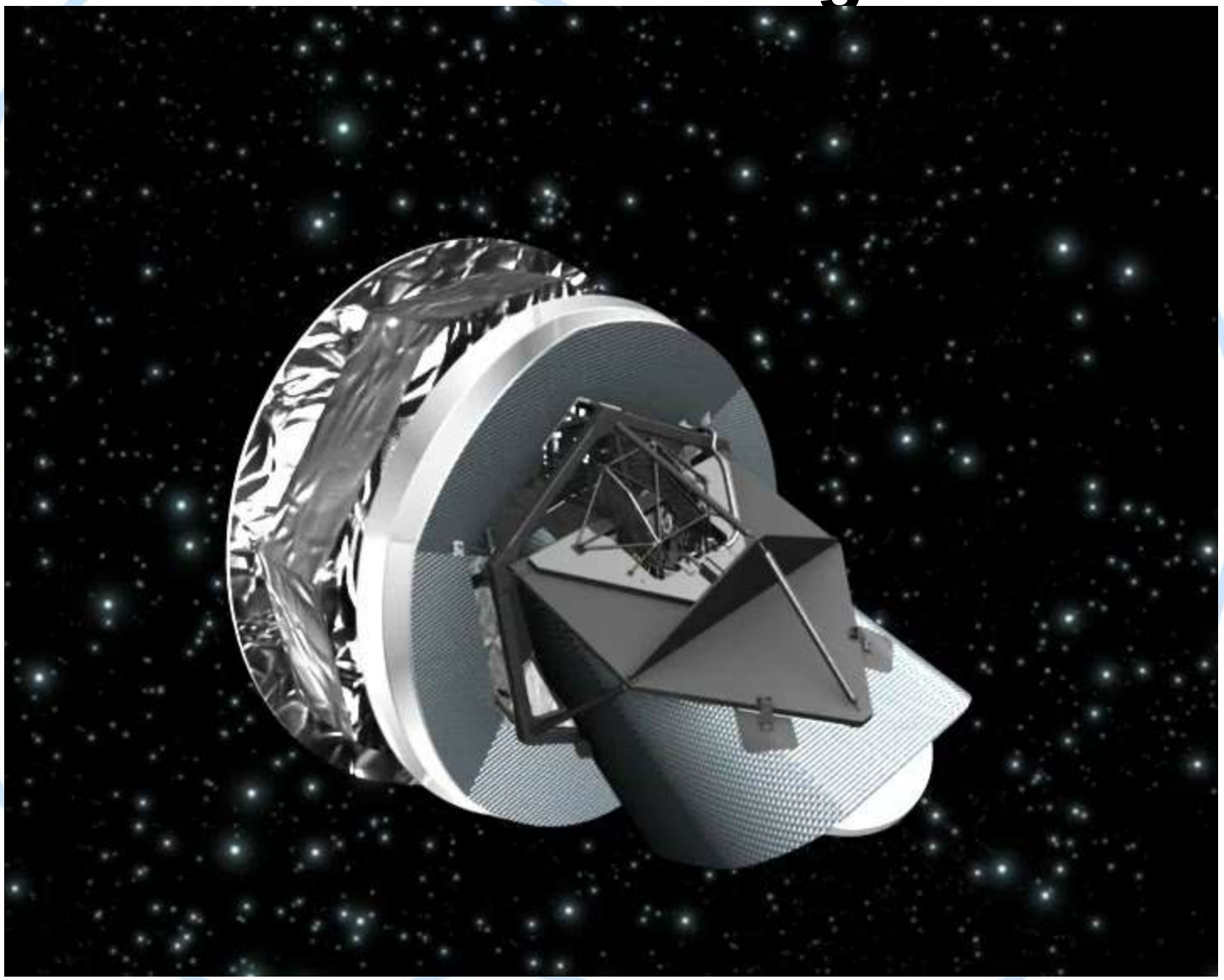


Cycloidal precession

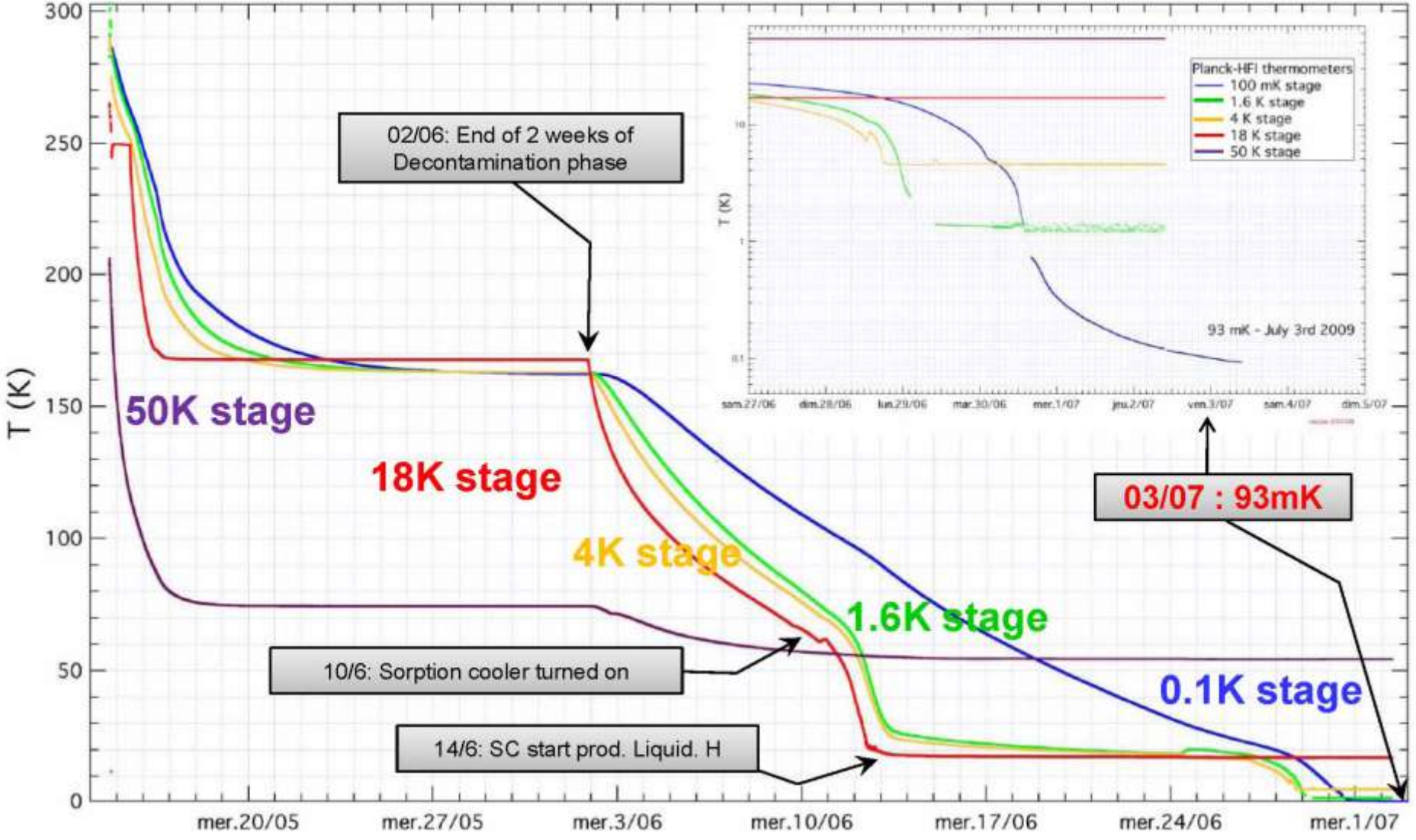




The scanning

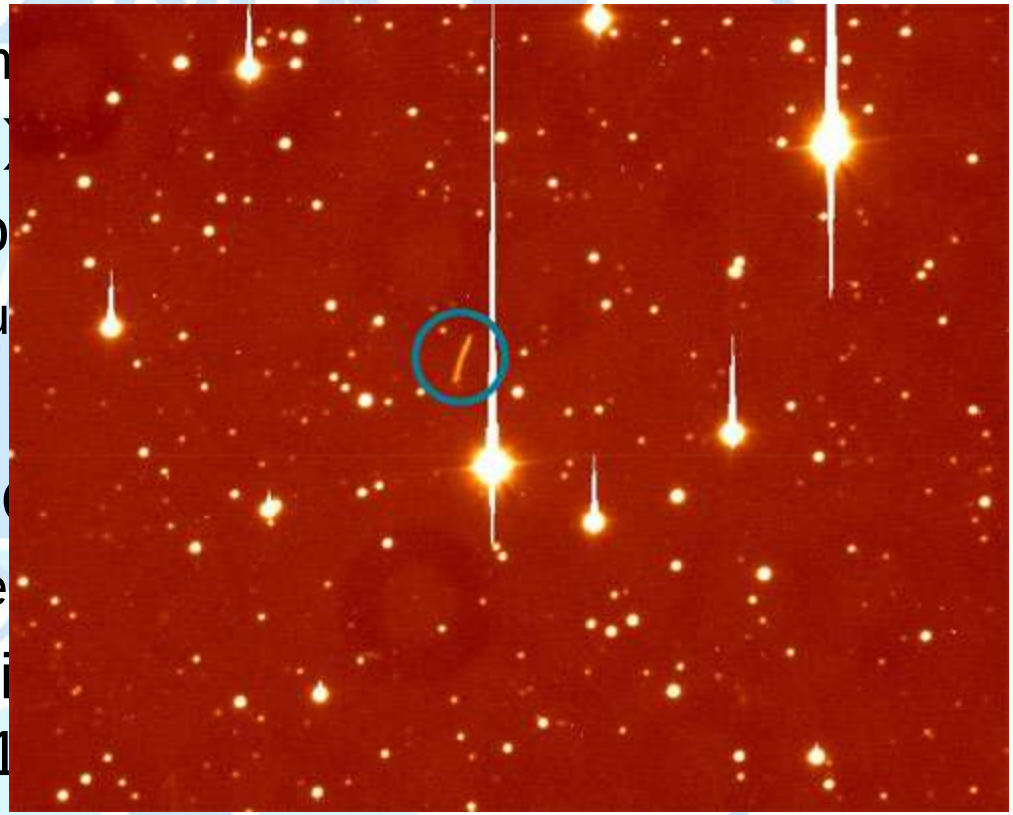


Planck Cooling



Overall Planck Status

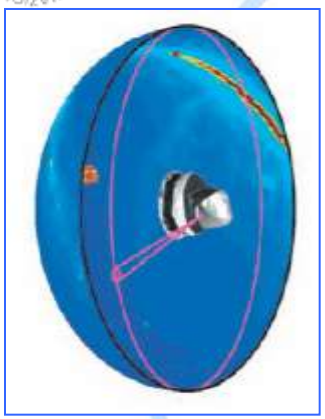
- 14/05/2009 Launch
  - Perfect launch together with Herschel (attitude < 0.1°, position of major axis <1,6%)
  - Transfer Trajectory ~2 m
  - Final Orbit (Sun-Earth L2)
- CPV starts first Week o
  - Instrument switch on / Tu
- Start of nominal Survey
- Sorption Cooler Switch
  - Change of sorption coole
- HFI terminate its operati continue till October 201



Communication and data flow

- ESA Ground Station
  - New Norcia – Cerberos (Australia or Spain)
- Mission Operations Centre (MOC)
  - Darmstadt (Germania)
- Contact: ~ 3 hours every day
- Data Transfer
  - MOC → DPC (data processing center in Trieste and Paris)

Communication and data flow

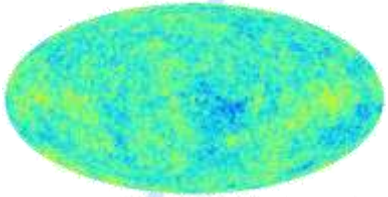


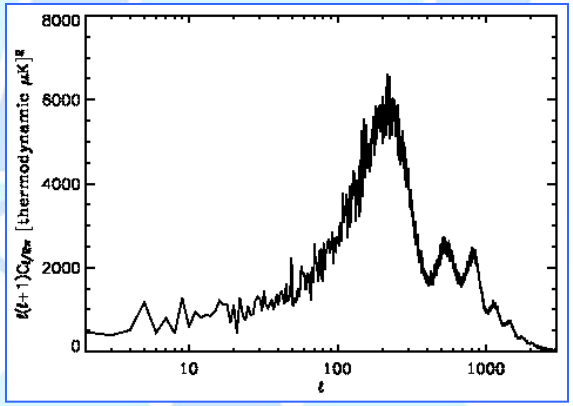
0110101

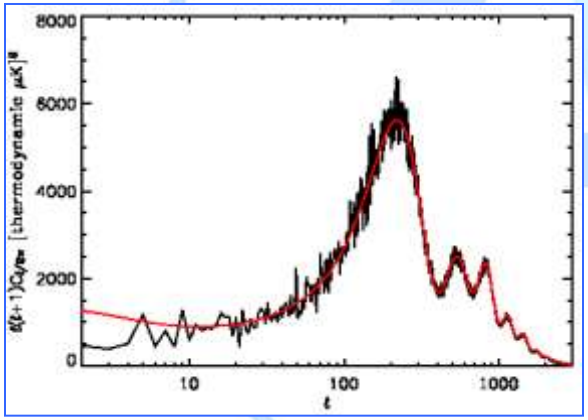
1110110

MOC

PARIS AND TRIESTE

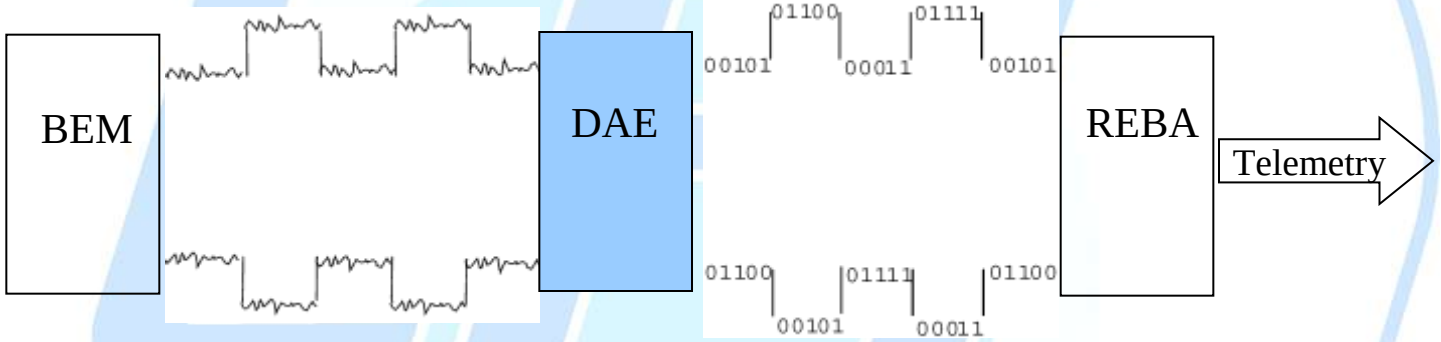






LFI on-board processing

- The Data Acquisition Eletronics (DAE) digitizes the scientific signal
  - It applies a programmable **offset** and **gain** to the signal in order to make full use of the resolution of the ADC (14 bits)



- The Radiometer Electronic Box Assembly (REBA) is in charge of processing the digitized scientific data and to manage the overall instrument

LFI on-board processing PROBLEM

"Spontaneous Gain Change"

- The gain and offset housekeeping value are stored onboard in two memory (*high* and *low*). The *High* memory is ONLY read internally by the electronics that apply the value to the data.
- The *Low* memory is read by the process that send to the ground the value applied.
- During the first period of the nominal mission we detect a very strange value on our science. After inspection, it was a pain …, the problem was identified due to cosmic ray that hits the high memory changing bits in a casual way. Special pipeline was triggered to recover at ground the gain and offset value IF the scientific data were not saturated.
- To minimize this possibility an automatic procedure was set-up to refresh the *high* memory reading the *low* memory.

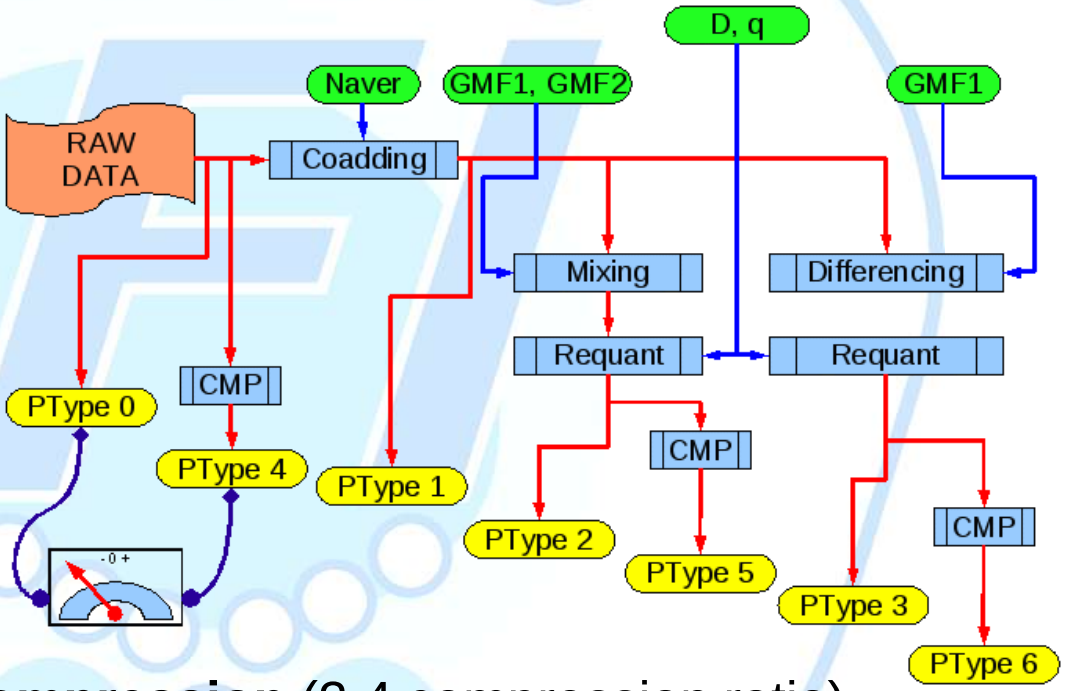
The REBA processing types

- The REBA processing steps:
  - **Data downsampling**: N_{Aver} samples are averaged in time to obtain the value of 1/3 of a pixel in the sky
  - **Double difference**:

$$\overline{S}_{sky} - GMF1 \cdot \overline{S}_{load}$$
$$\overline{S}_{sky} - GMF2 \cdot \overline{S}_{load}$$

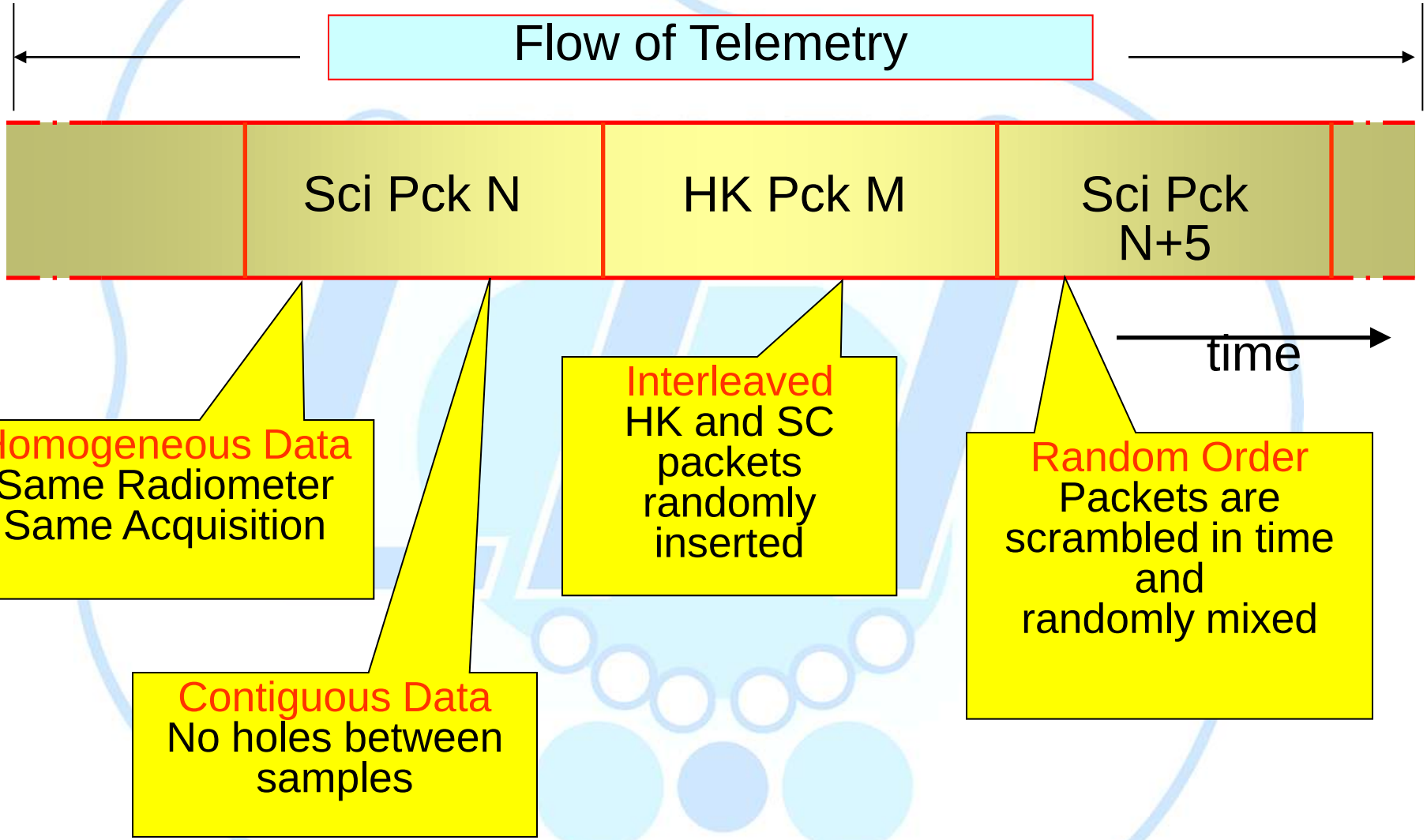
  - **Quantization**:

$$Q_i = [(\overline{S}_i + D) \cdot q]$$

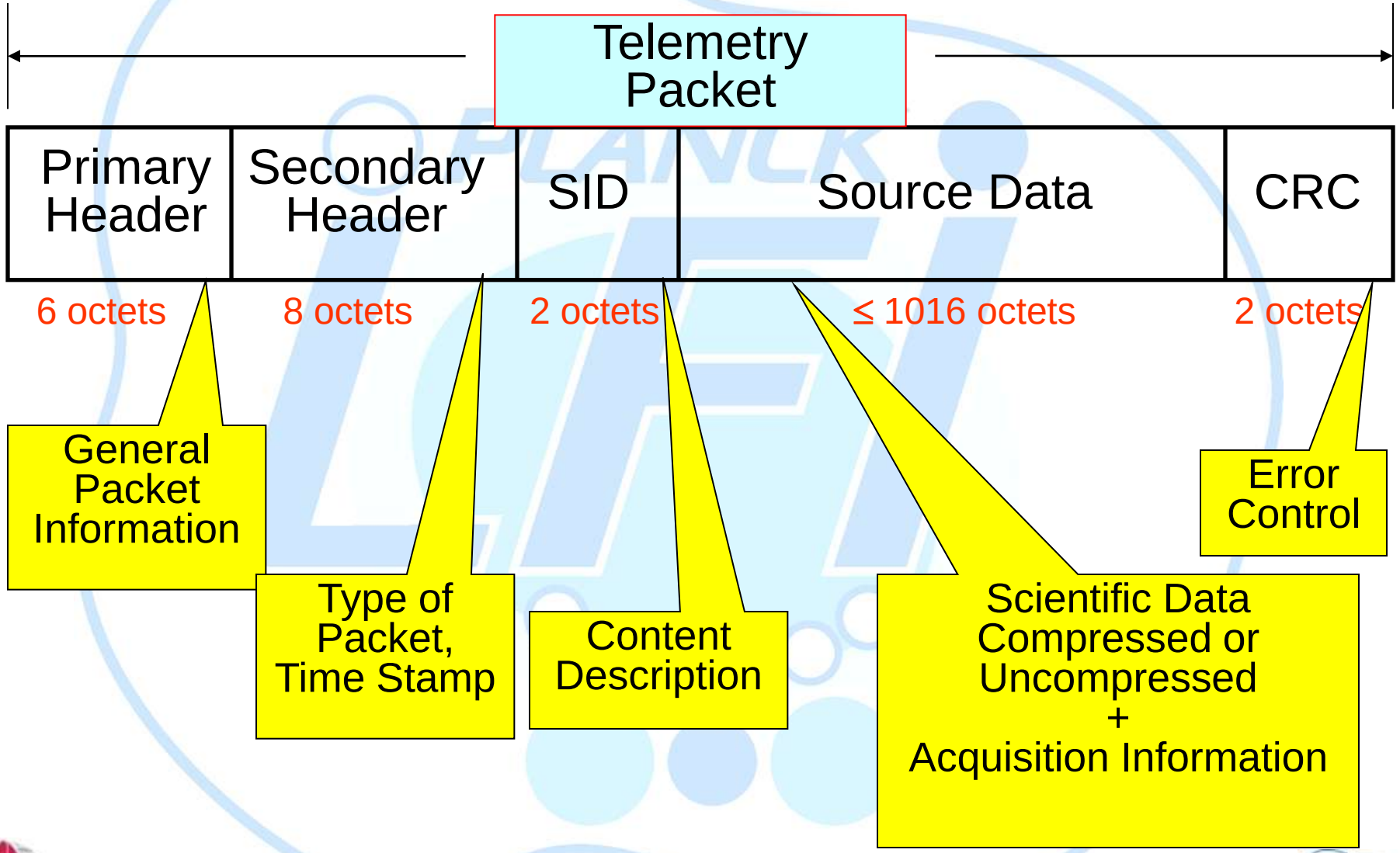


  - **Adaptive arithmetic compression** (2.4 compression ratio)

Level 1 Telemetry Flow



Structure of LFI Scientific Packet



LFI DPC Overall Scheme

S/C+P/L TM & auxiliary data

MOC

S/C+P/L TM & auxiliary data

Sci TM

Sci TM

Instruments TC and inputs to MOC

Level S

Simulation of Planck TM, TOI and maps

LFI TM

Level 1

RTA/QLA from TM to TOI

Raw TOI

Level 2

First-level statistics & systematics checks
Beam pattern reconstr.
"Absolute calibration"
Madam MapMaking
Frequency maps

Cal.TOI

Freq. Maps

Level 3

Components separation
Inter-frequency cross-check
Components maps
C(l) evaluation

LFI Raw/Cal. TOI

Frequency Maps

LFI DPC

Pasadena

ERCSC

Cal.TOI - RIMO

Frequency Maps

HFI DPC

CMB Removed maps

PIA/PLA

Final products

ESAC

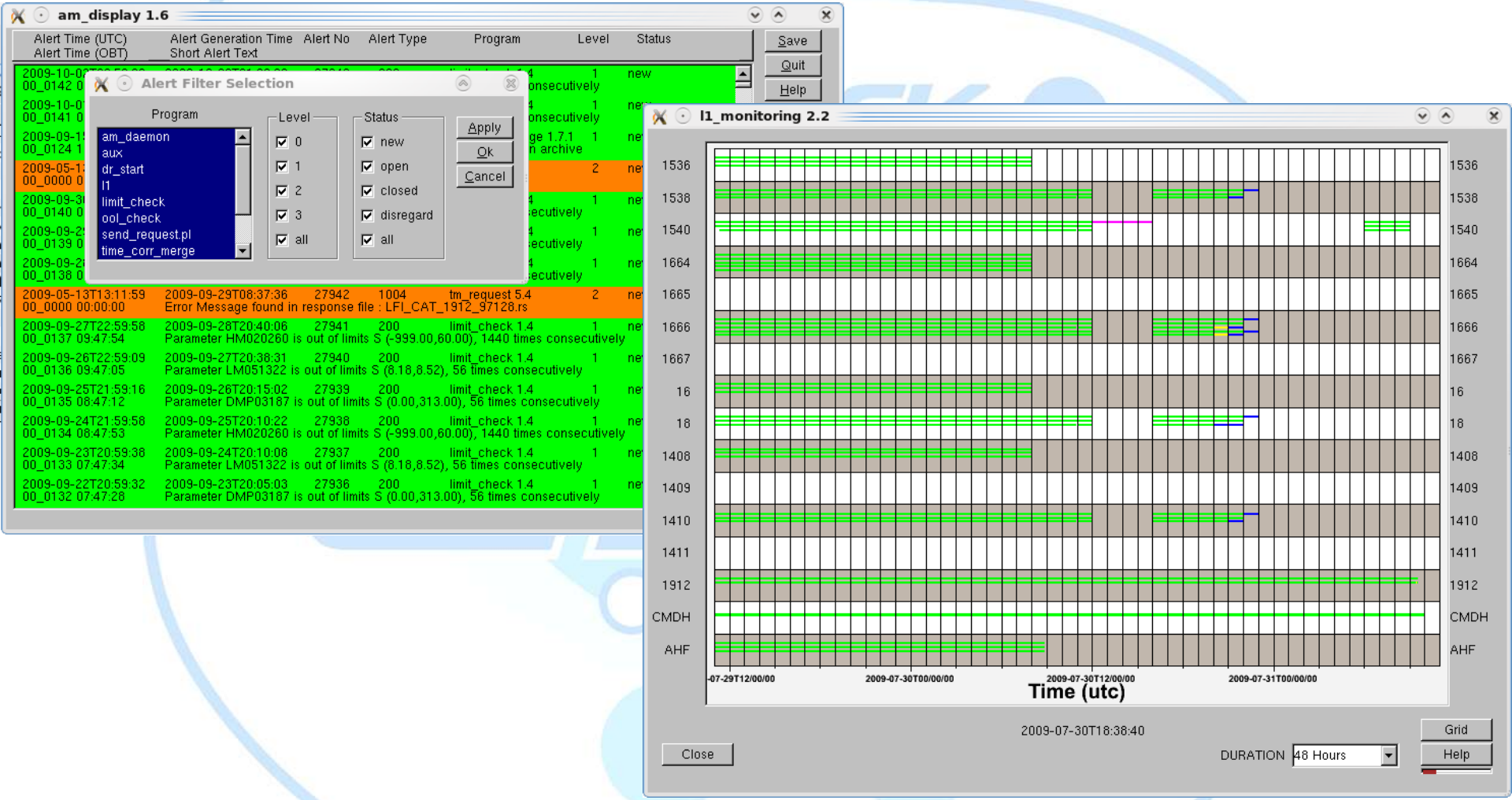
PSO

Freq. Maps, CMB Removed Maps, Catalogs, Doc.

Overall L1 Operations

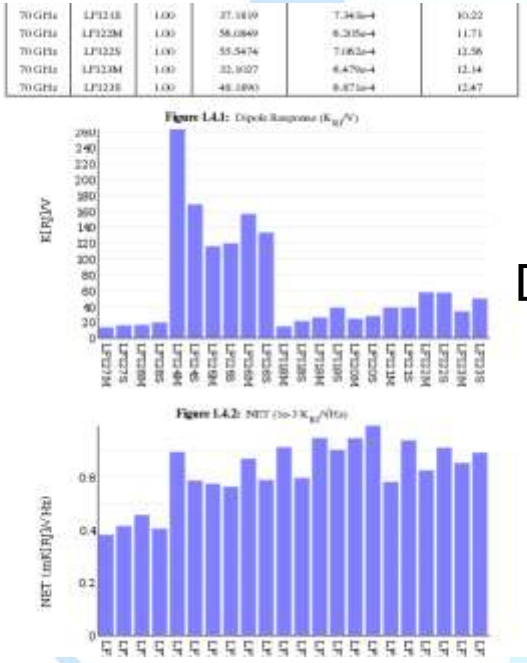
- Daily Telemetry download
  - Each day about 0.9 GB are downloaded from MOC
  - This telemetry is automatically decompressed
  - It is automatically de packetized (packet are in any case saved for security reason)
  - It is automatically transformed in timelines and scientific ADU are converted in VOLT using House keeping information (gain and offset)
  - It is check against Gain Change due to cosmic hit (in case special procedure is applied)
  - Timelines are then save in a Database (metadata) to be quickly retrieved during the processing
  - In total about ~ 23 GB of timelines are produced daily
  - Production and Check of DQR to be sent to ESA

The Pipeline Monitoring and Alert Display

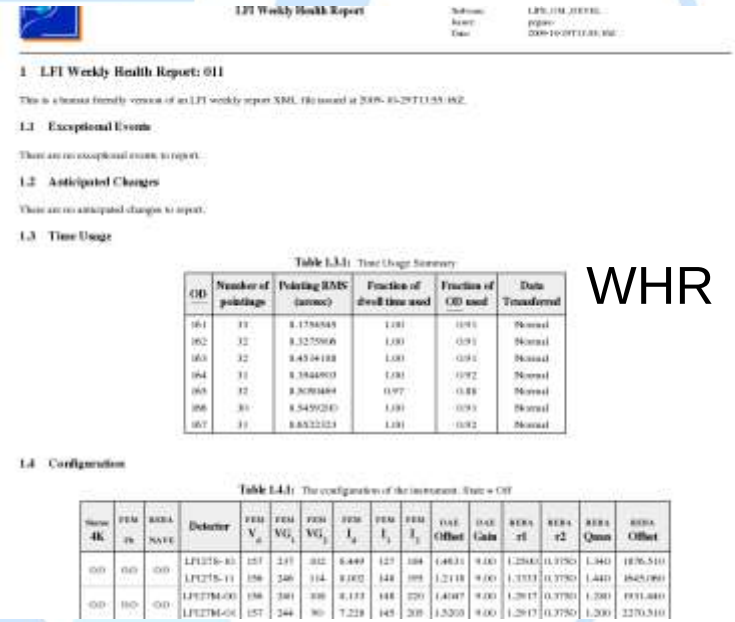


DQR-WHR

- Daily quality report and Weekly quality report are required by ESA to verify the instrument health and quality. DQR and WHR are XML file with summary statistics based on HouseKeeping and science data acquired daily (weekly).



DQR



WHR

Level 1

- The 13/08/2009 starts the Nominal Survey, till now we acquired about 1530 days of data this generates about 37 TB of data (Raw telemetry – TOI - Maps) and during all those days NO big problems where detected and no days were missed.
- To verify the goodness of the Instrument and quality of the LFI DPC level 1 software we extract this table to understand how much data was not used in the Science analysis till now.

	30 GHz	44 GHz	70 GHz
Missing [%]	0.00016	0.00027	0.00039
Anomalies [%]	0.41412	0.69726	0.41025
Maneuvers [%]	8.29798	8.29798	8.29798
Usable [%]	91.28774	91.0049	91.29138

  - Missing data: Real Gaps.
  - Anomalies: refers to the sample flagged as to not be used by the pipeline.
  - Manoeuvres: Science data acquired during dwell time (not used by the pipeline).

Hardware

- More than 10 machine used to telemetry control
- SGS1
  - L1 nominal Machine + Backup
  - 50 TB storage mirrored
  - Master L1 database mirrored
- SGS2 Operational environment
  - 240 Cores with 6 GB RAM each
  - 80 TB storage (mirrored)
  - Master L2 database mirrored
- SGS2 test environment
  - 100 CPUs with 8 GB each RAM
  - 24 TB storage
  - Master test database

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.