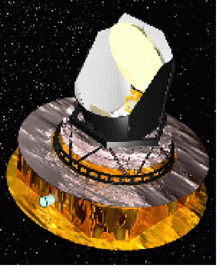


PLANCK HFI

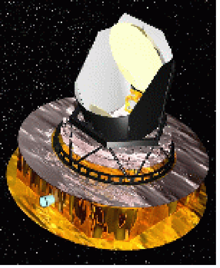
Planck-HFI, its Calibration and its connexions with HSO calibrations

*J.M. Lamarre**

*F. Pajot**, J.-L. Puget**, F-X. Desert***, G. Lagache**, M. Piat****, M. Giard*****,*
and the HFI calibration team

* LERMA, Observatoire de Paris
** IAS, Université d'Orsay
*** LAOG, Grenoble
**** CdF, Paris
***** CESR, Toulouse

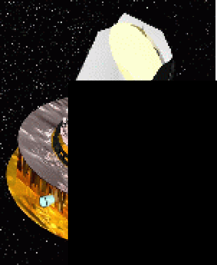
l'Observatoire de Paris – LERMA

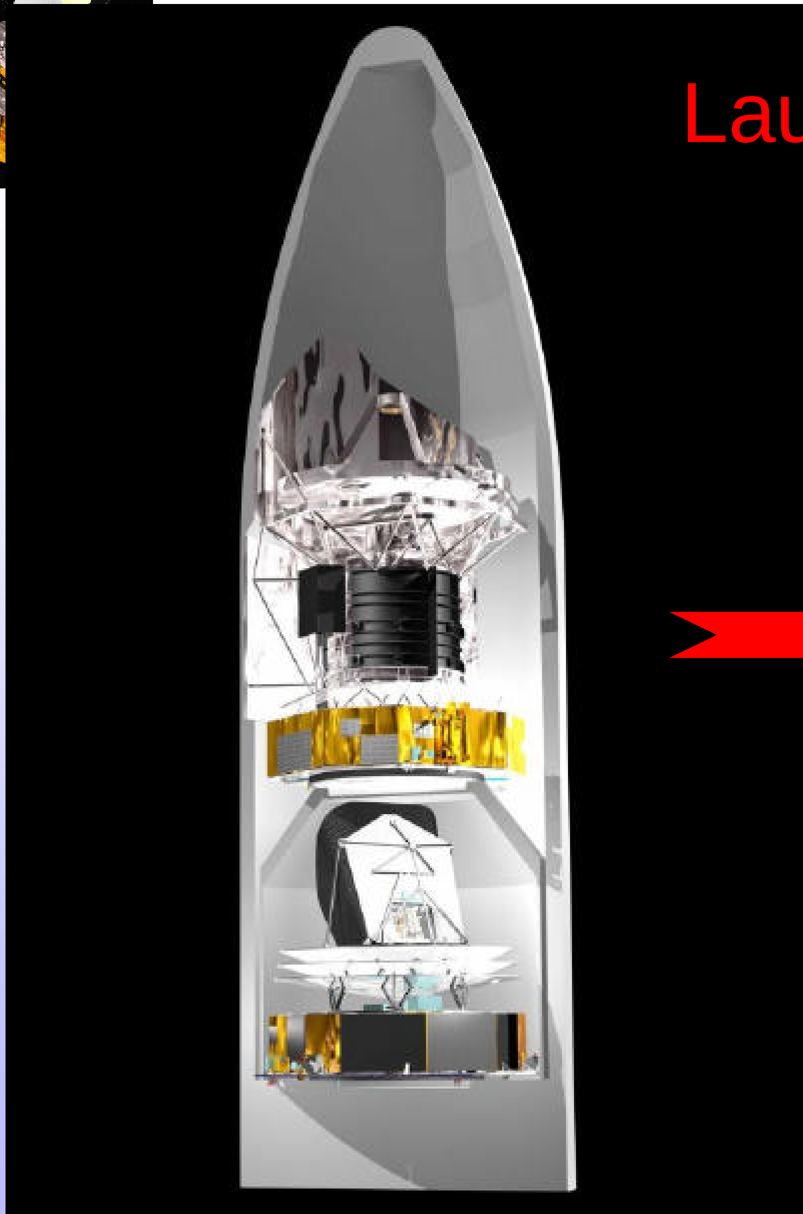


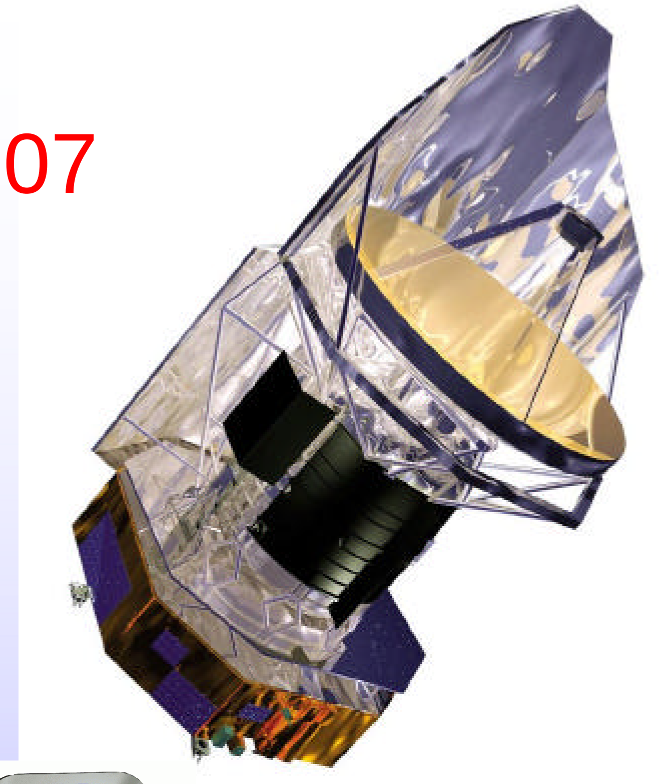
Overview

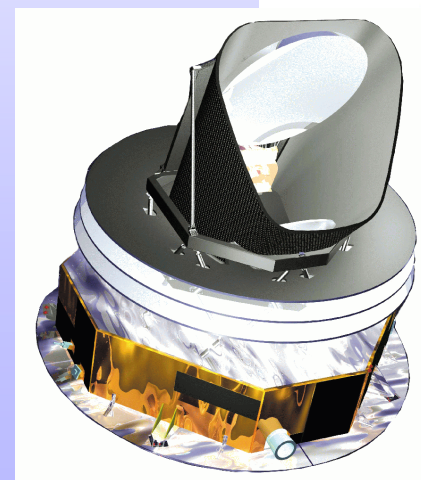
- Planck
- The High Frequency Instrument
- Performances of HFI
- Deliverables
- First calibration results of HFI-CQM
- Calibration philosophy of HFI
- Advantages of coupled observations Herschel/Planck

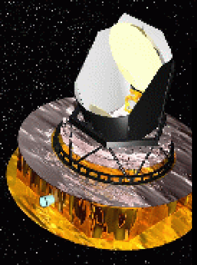
Launch in 2007



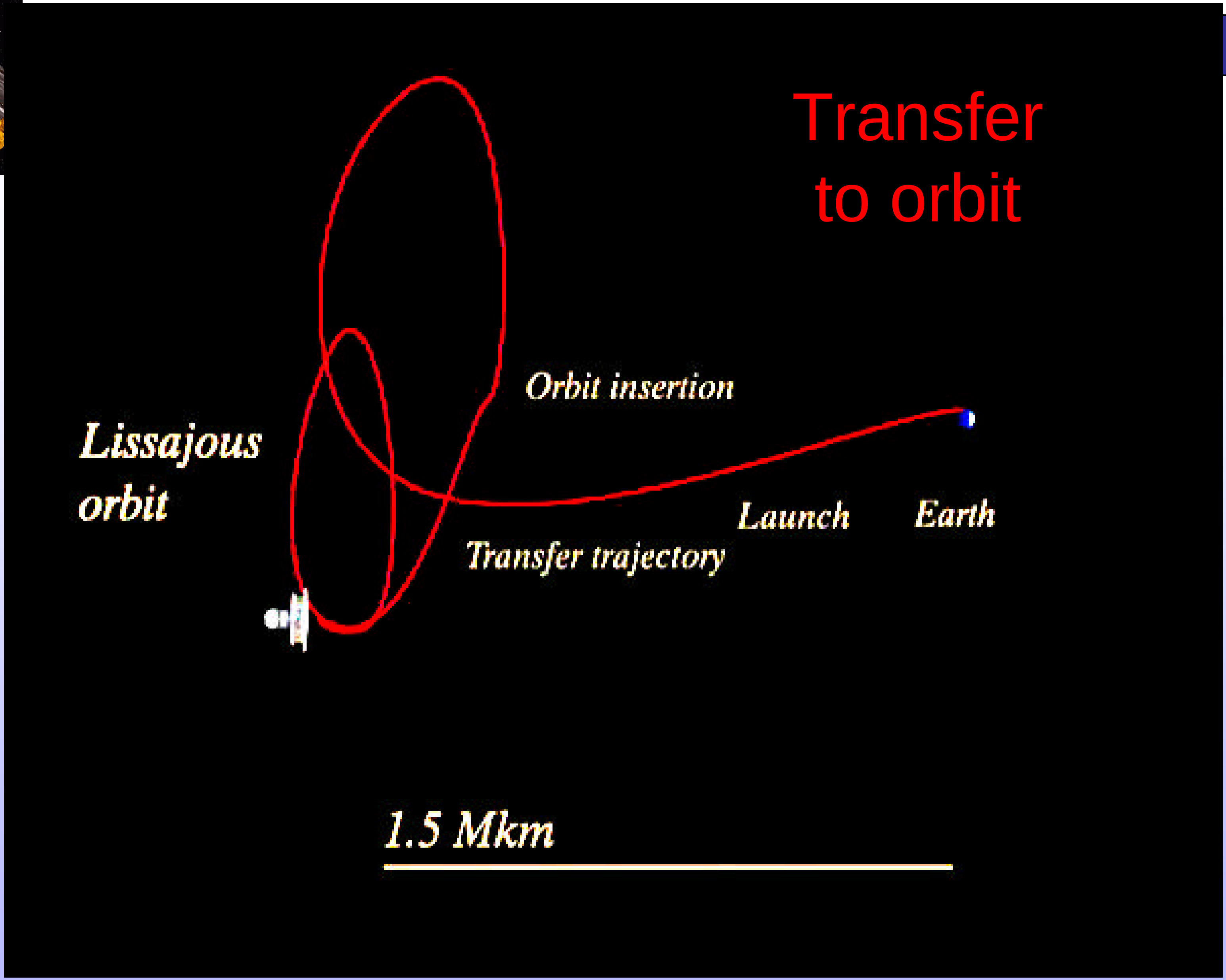


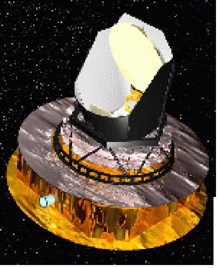






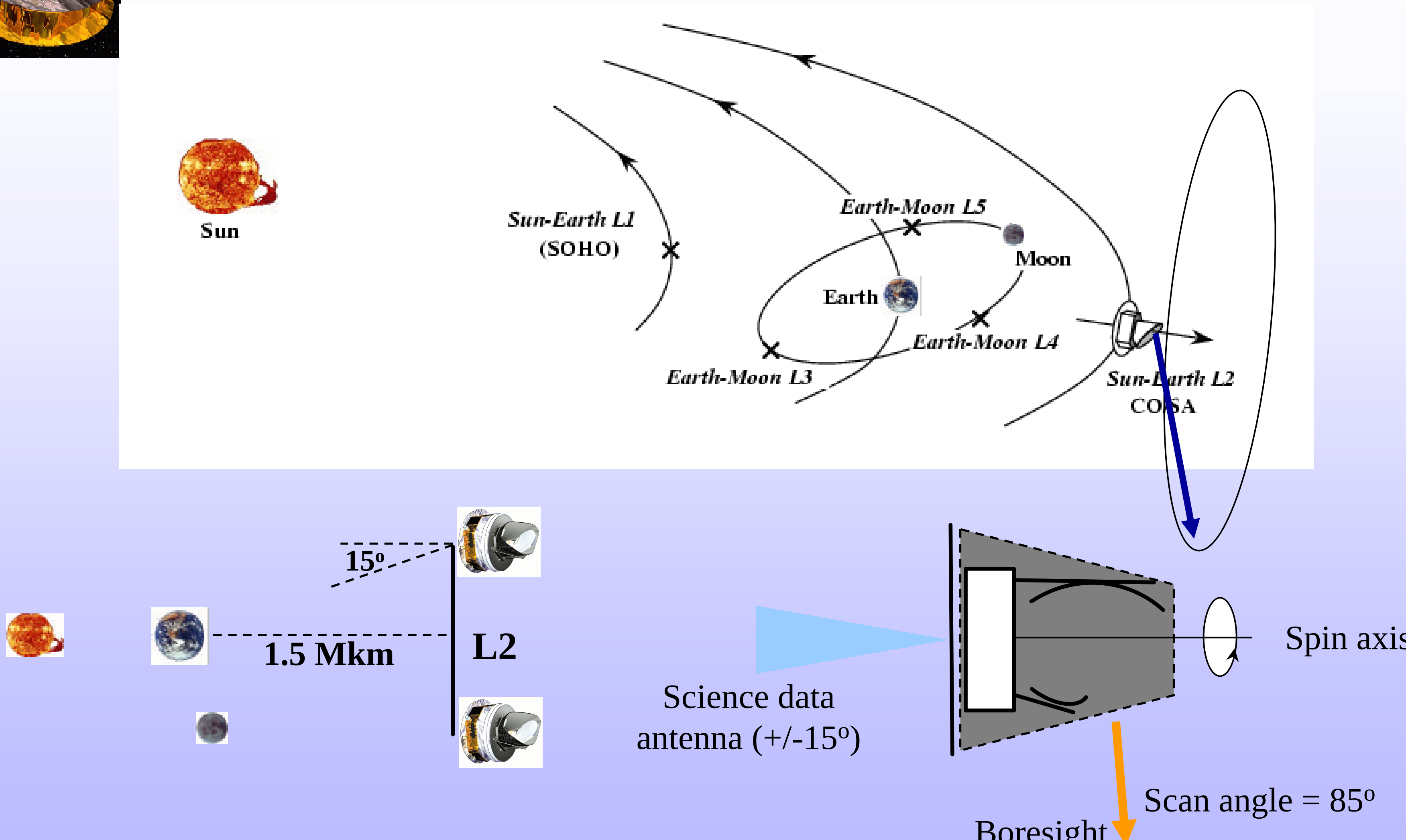
Transfer to orbit

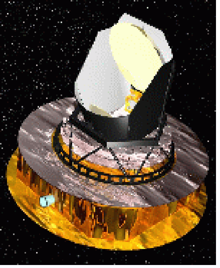




PLANCK HFI

Choice of orbit



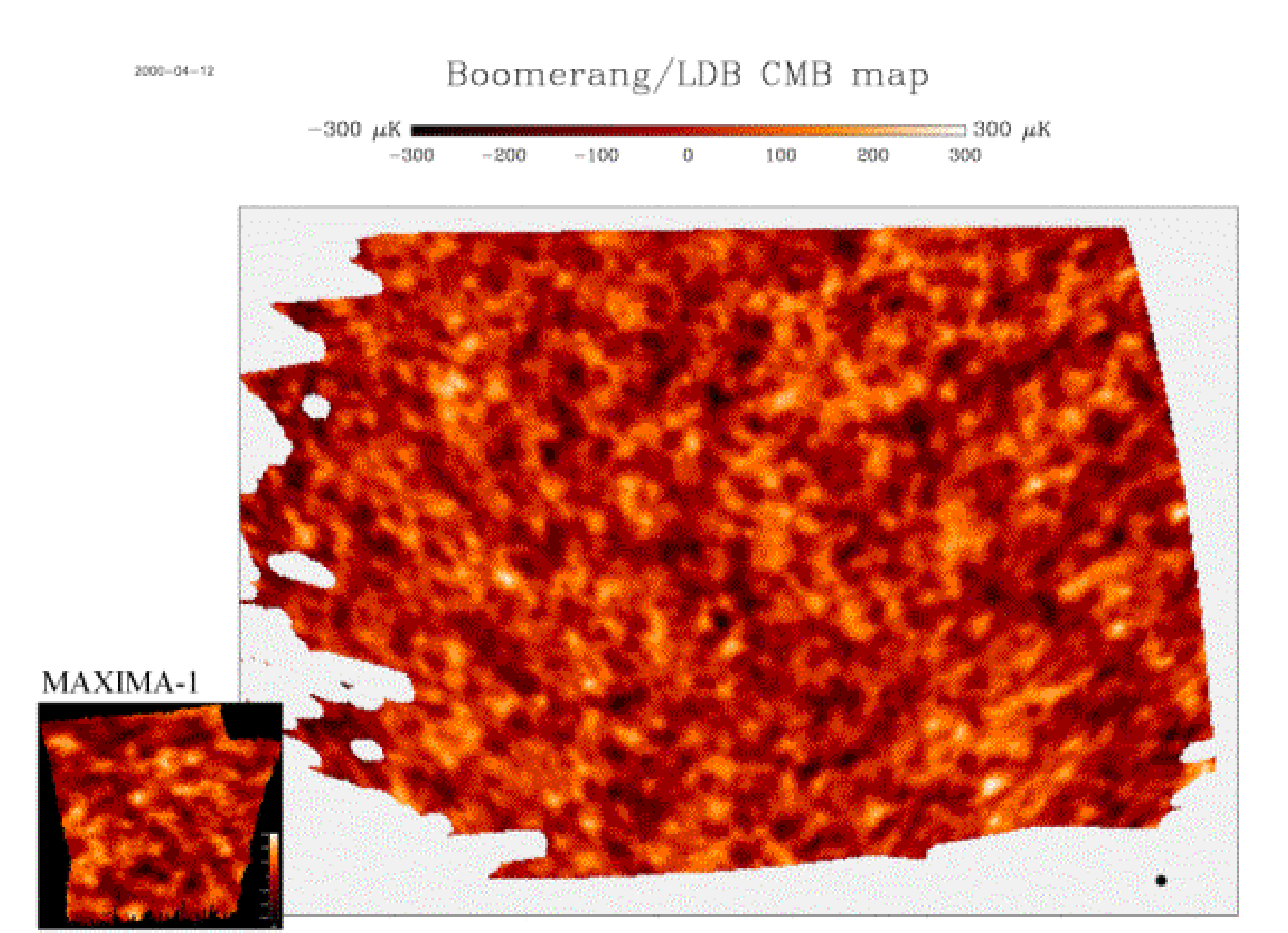


PLANCK HFI

Planck: 3rd generation of space CMB satellite

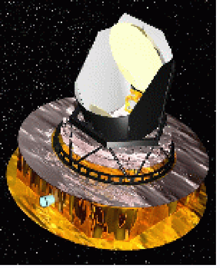
- Sensitivity limited mainly by CMB photon noise
- ˜1000 times more sensitive than COBE
- ˜ 20 to 30 times more sensitive than WMAP
- Used to:
  - increase number of pixels (5 arcmin instead of 7deg and 12 arcmin)
  - Increase signal to noise per pixel (x10 to a few)
  - Design it for polarization measurement

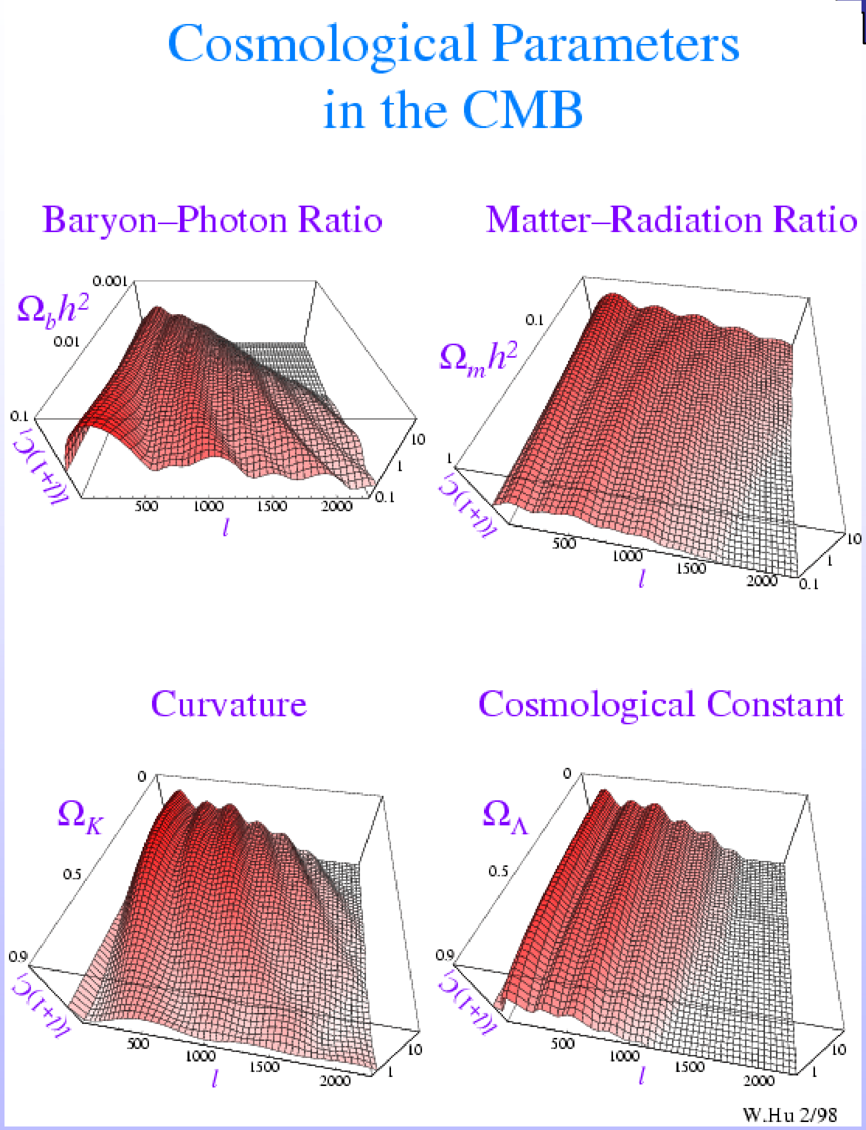
- The two maps observe completely independent sky regions, have been taken with different detectors and telescope, and show the same kind of structures !



Hanany et al. 2000

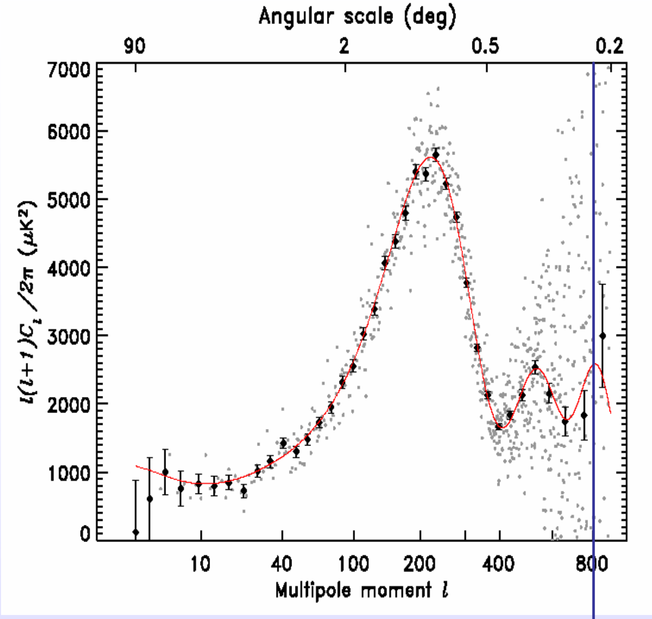
P. de Bernardis Oct. 2000





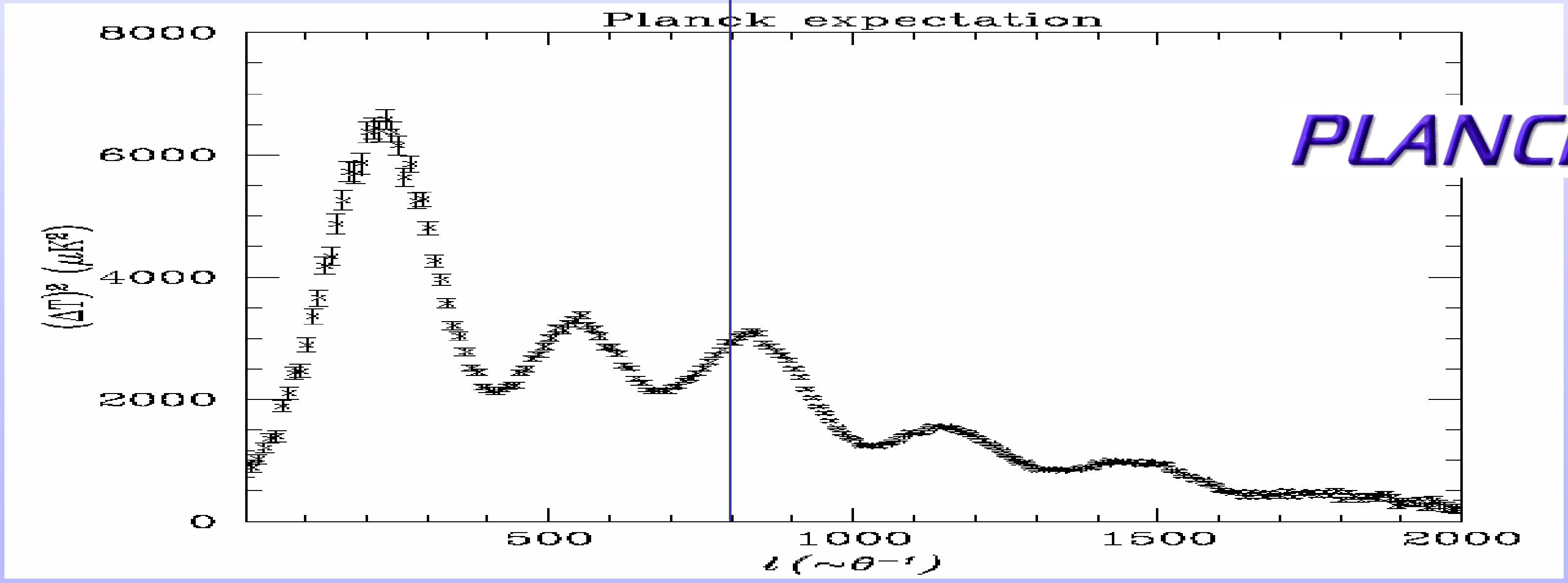
The shape of the power spectrum depends sensitively on the value of cosmological parameters

WMAP



Angular scale (deg)
90
2
0.5
0.2
7000
6000
5000
4000
3000
2000
1000
0
$l(l+1)C_l/2\pi$ (μK^2)
10
40
100
200
400
800
Multipole moment l

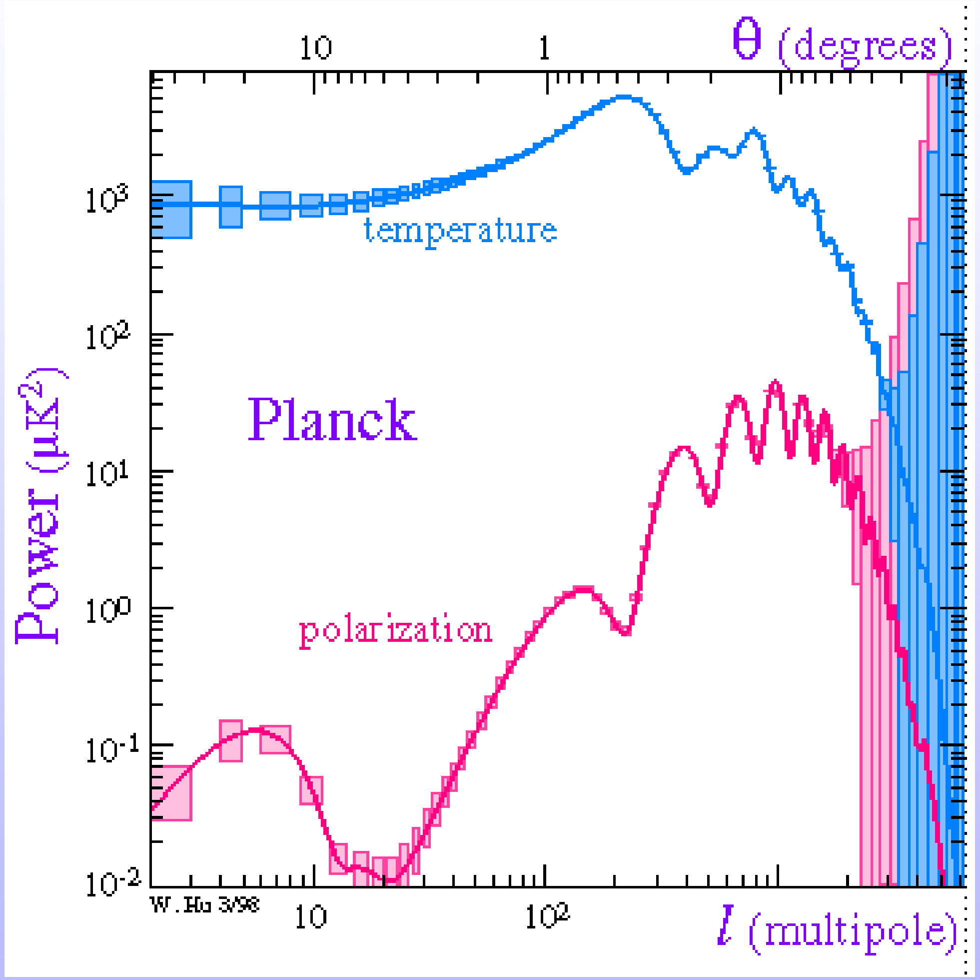
PLANCK

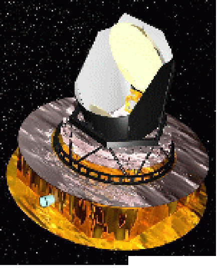


Planck expectation
8000
6000
4000
2000
0
$(\Delta T)^2$ (μK^2)
500
1000
1500
2000
l ($\sim\theta^{-1}$)

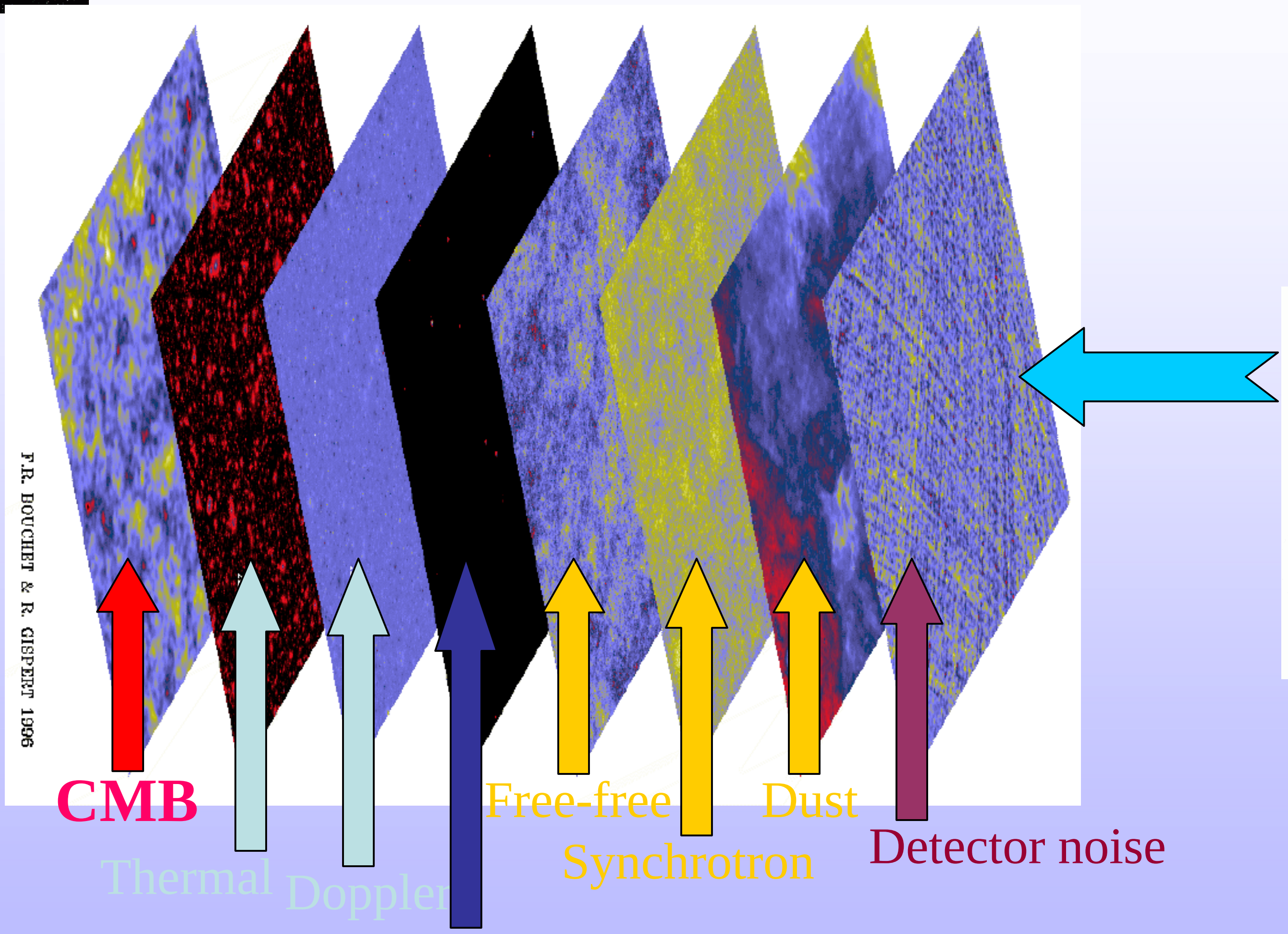
Predicted power spectrum recovery

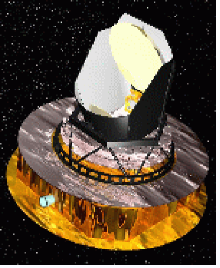
Both the temperature and the polarisation angular power spectra are accurately recovered





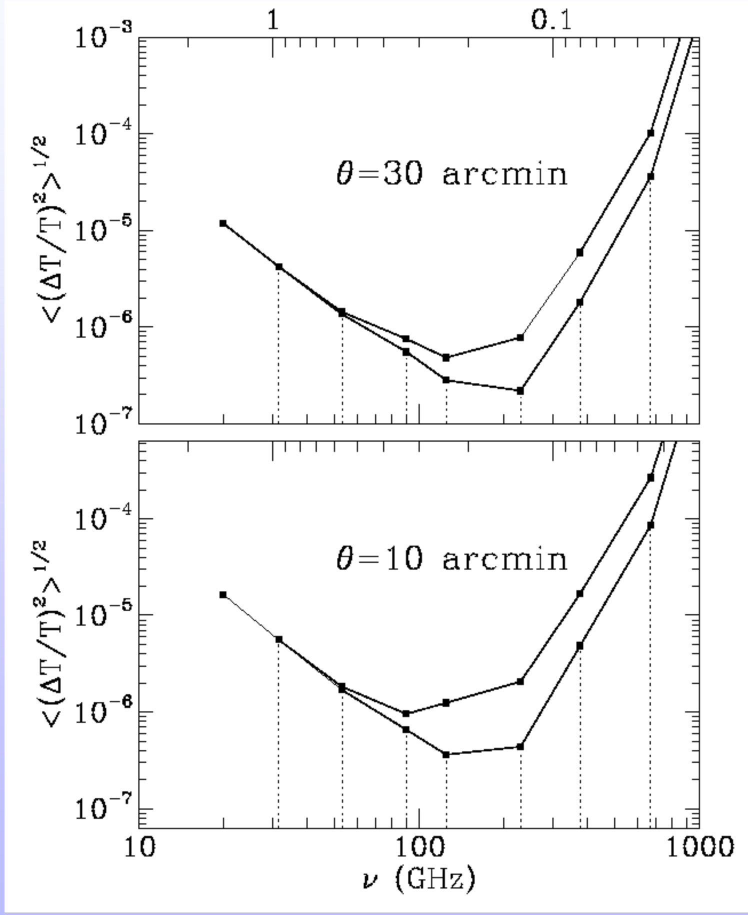
Foreground separation



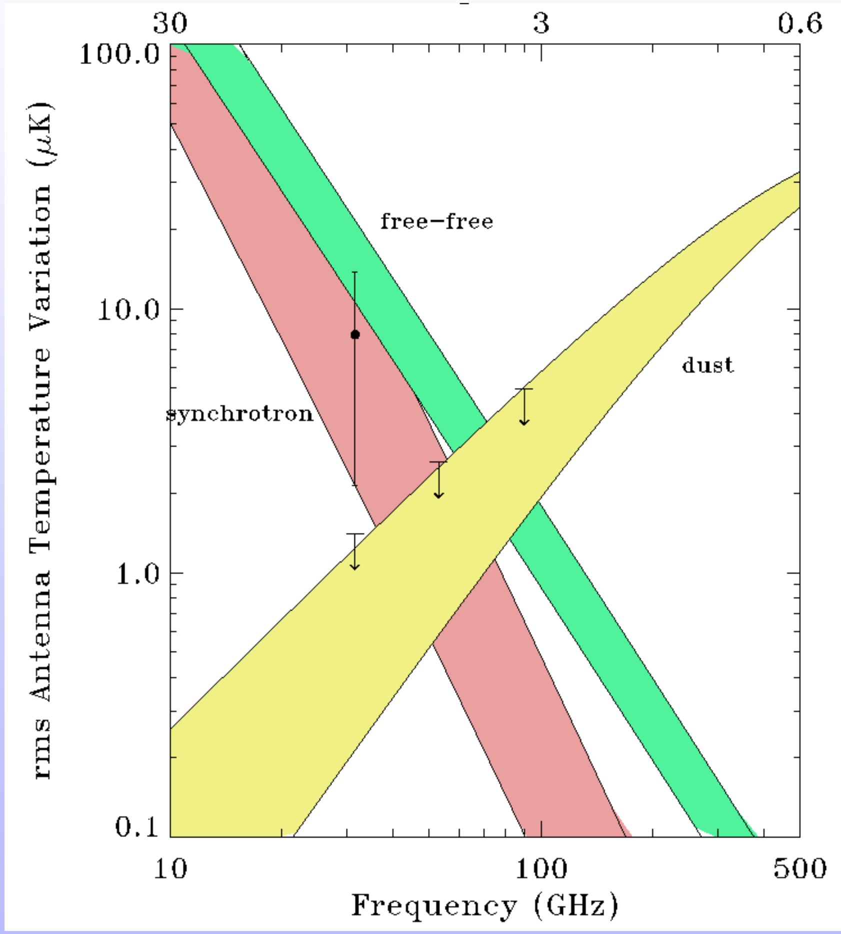


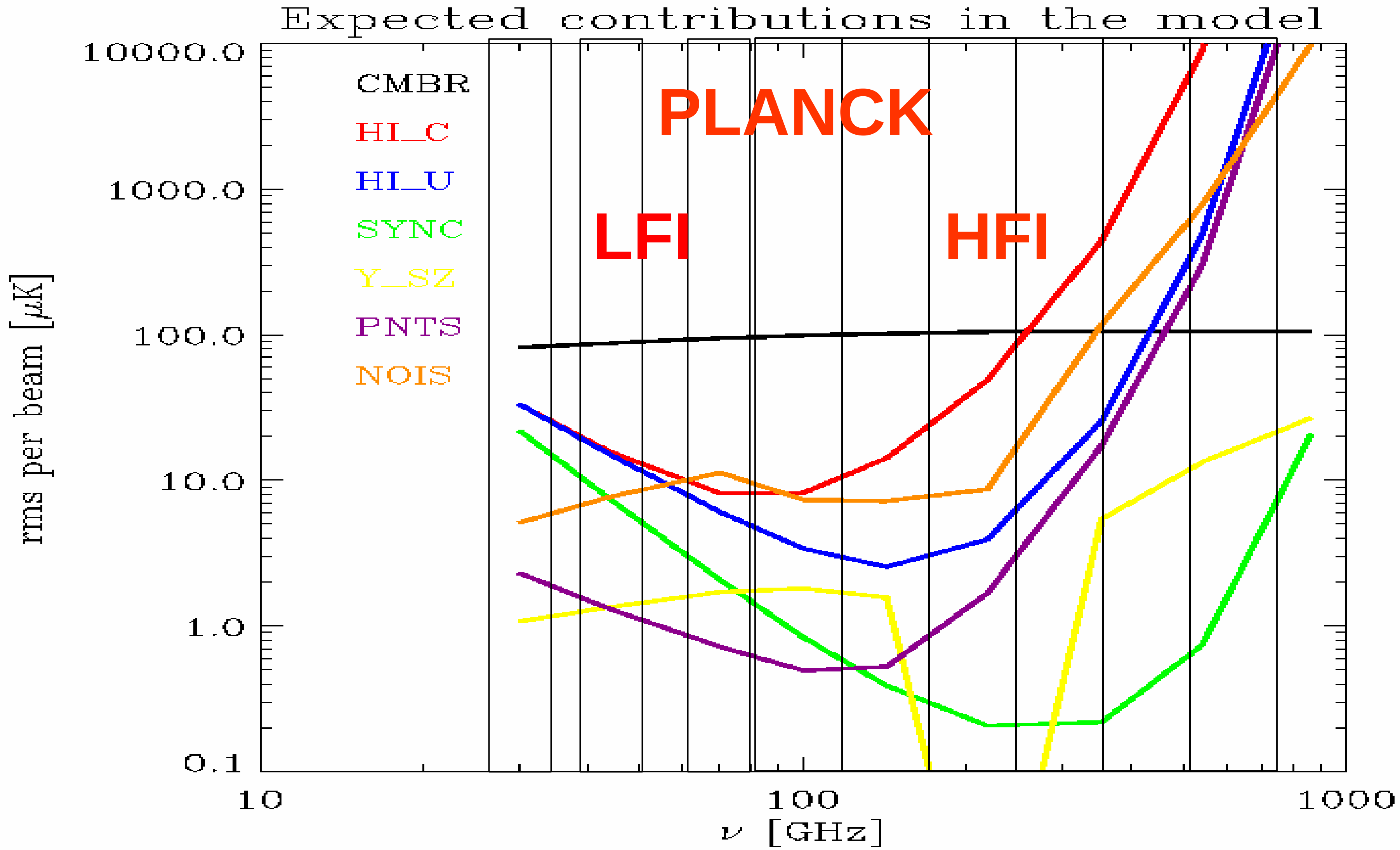
Foreground fluctuation levels

Extragalactic point sources

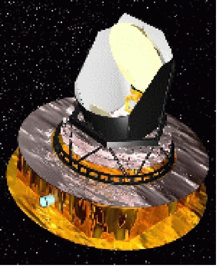


Galactic fluctuations at high latitudes





Identification and removal by spectral signature



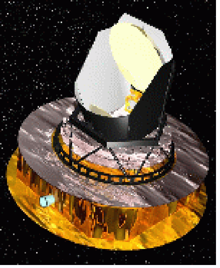
PLANCK HFI

Deliverables

The major scientific products of Planck will consist at the very least of:

- Whole-sky maps at each frequency channel present in Planck
- A whole-sky map of the temperature anisotropies of the CMB (and of their Stokes parameters)
- A whole-sky map of Galactic synchrotron, free-free and dust emission
- A whole-sky catalogue of extragalactic compact and point sources
- A whole-sky map of the S-Z effect from clusters of galaxies

+ Early release Compact Source Catalog useable by HSO



Performance Goals for a full sky survey

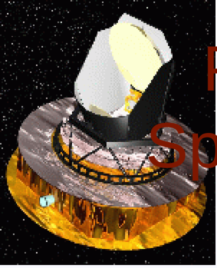
	Low Frequency Instrument			High Frequency Instrument					
Center Freq. (GHz)	30	44	70	100	143	217	353	545	857
Detector Technology	HEMT LNA arrays			Bolometer arrays					
Detector Temperature	~20 K			0.1 K					
Cooling Requirements	Sorption H_2 cooler			H_2 sorption + 4 K J-T stage + Dilution cooler					
Number of Unpol. Detectors	0	0	0	0	4	4	4	4	4
Number of Linearly Polarised Detectors	4	6	12	8	8	8	8	0	0
Angular Resolution (FWHM, arcmin)	33	24	14	9.2	7.1	5	5	5	5
Bandwidth (GHz)	6	8.8	14	33	47	72	116	180	283
Average DT/T_I* per mK/K pixel# (mK/K)	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average DT/$T_{U,Q}$* per pixel# (mK/K)	2.8	3.9	6.7	4.0	4.2	9.8	29.8	–	–
Flux sensitivity per pixel (mJy)				12	10	14	27	43	49
EySZ per field of view ($x10^6$)				1.3	2.1	X	6.5	26	600

* Sensitivity (1 s) to intensity (Stokes I) fluctuations observed on the sky, in thermodynamic temperature units, relative to 10^{-6} times the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months).

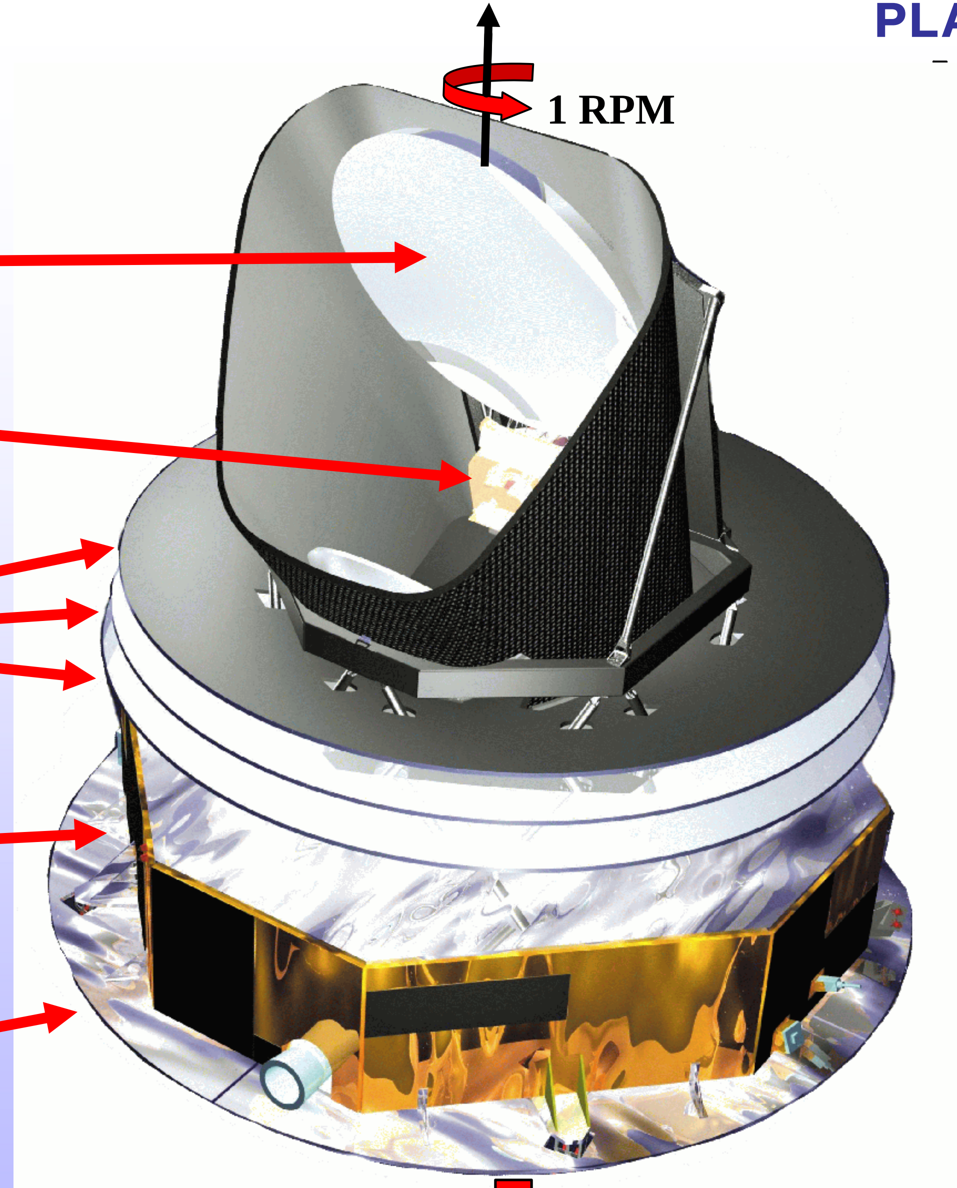
\# A pixel is a square whose side is the FWHM extent of the beam.

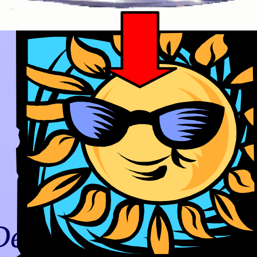
* Sensitivity (1 s) to polarised intensity (Stokes U and Q) fluctuations observed on the sky, in thermodynamic temperature units, relative to 10^{-6} times the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months).

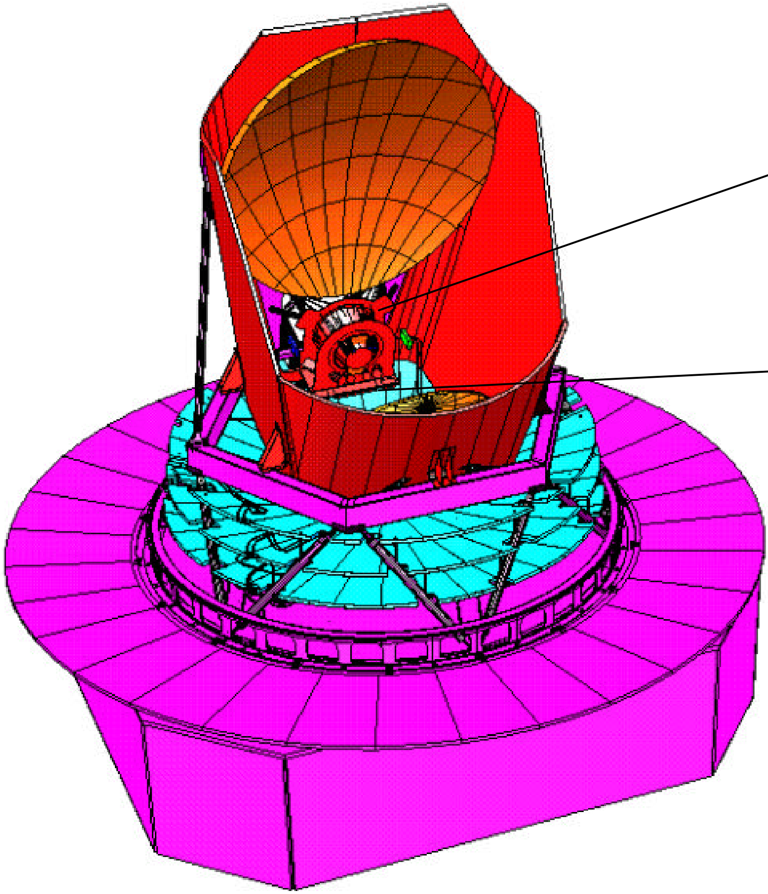
Table last updated 6/9/2002

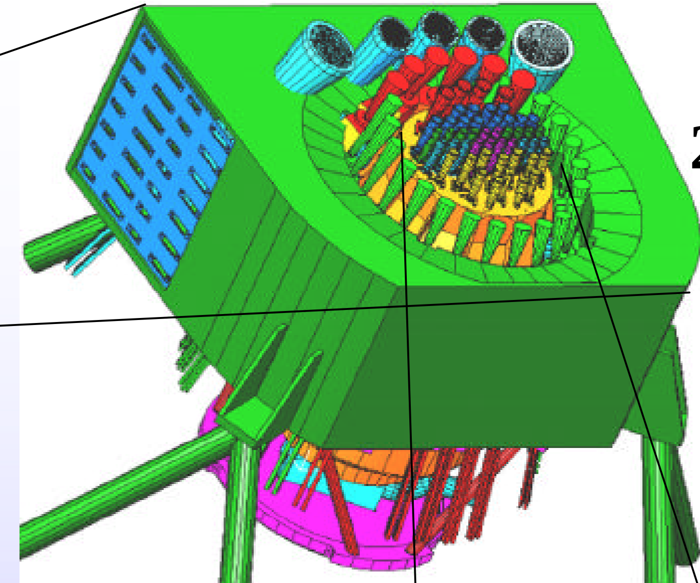


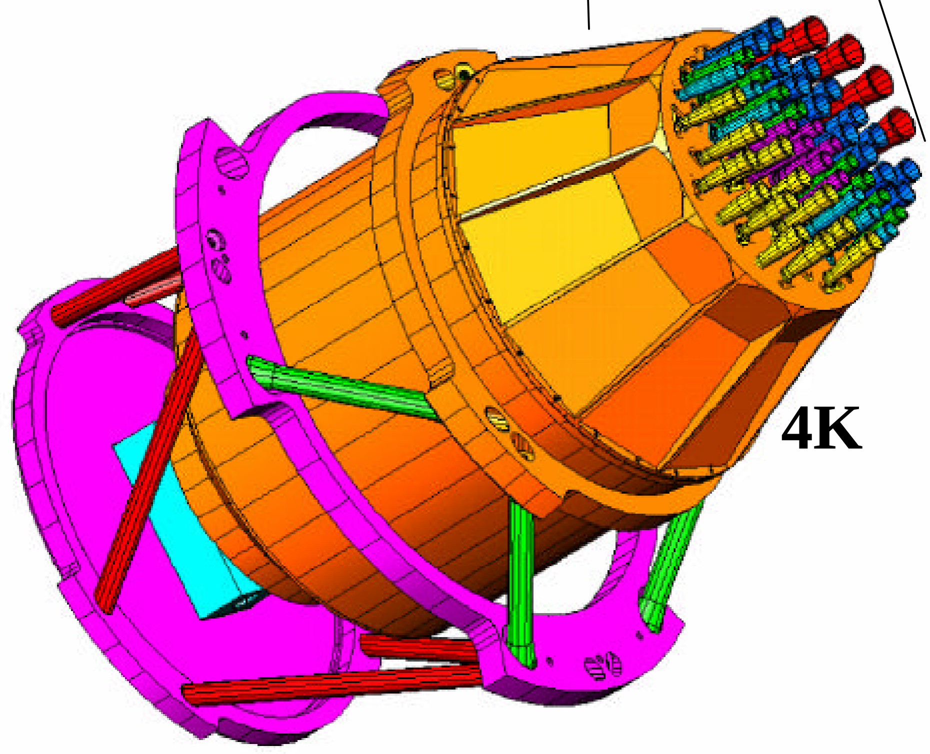
Planck Spacecraft

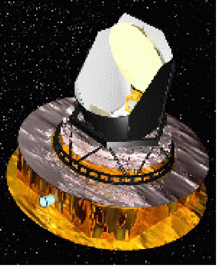






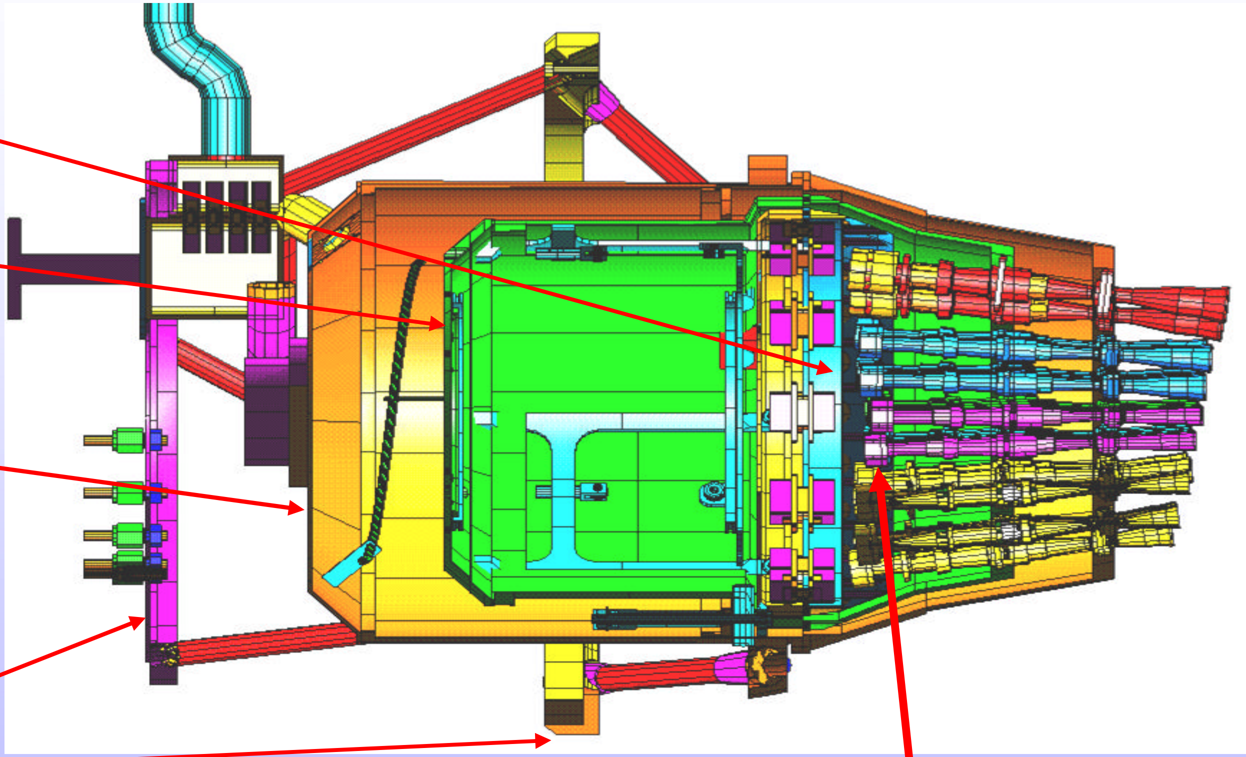

20K


4K



PLANCK HFI

HFI Focal Plane Unit



100 mK stage

1.6 K stage

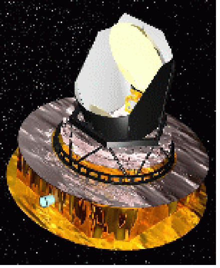
4 K stage

18 K plate

BOLOMETERS

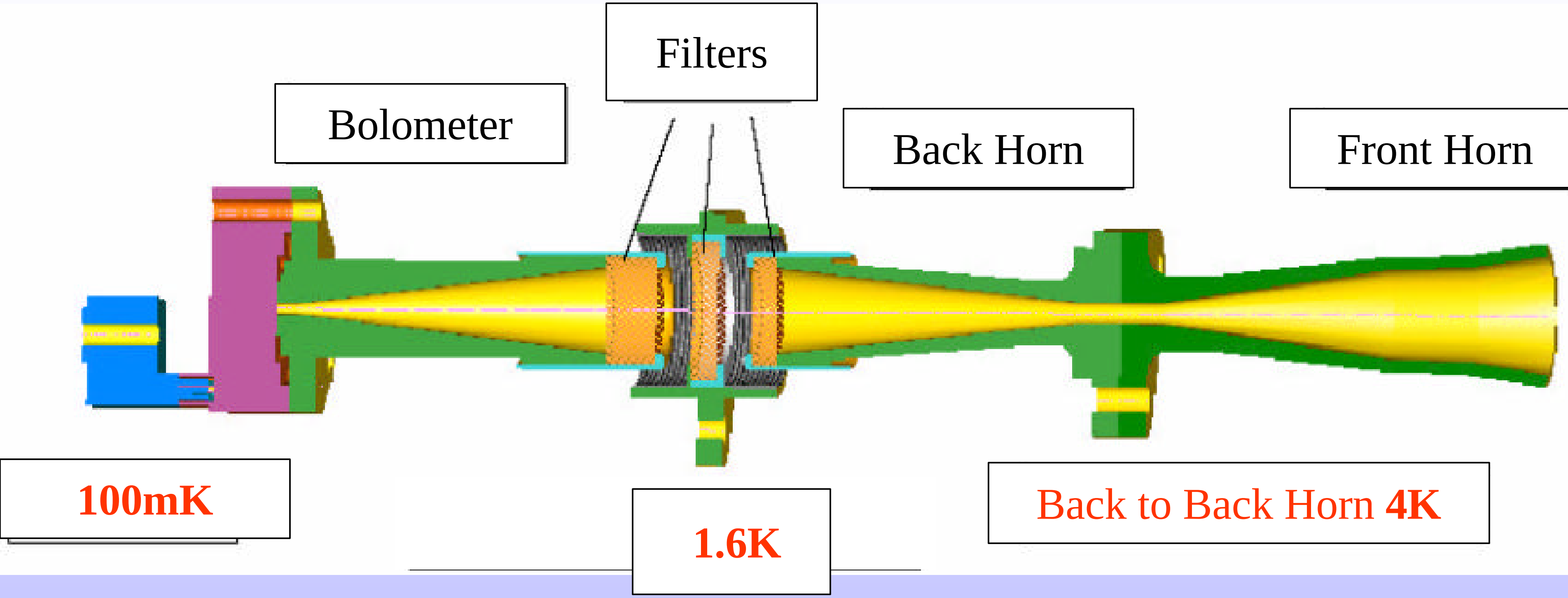
The HFI is built by a French-lead consortium

l'Observatoire de Paris – LERMA



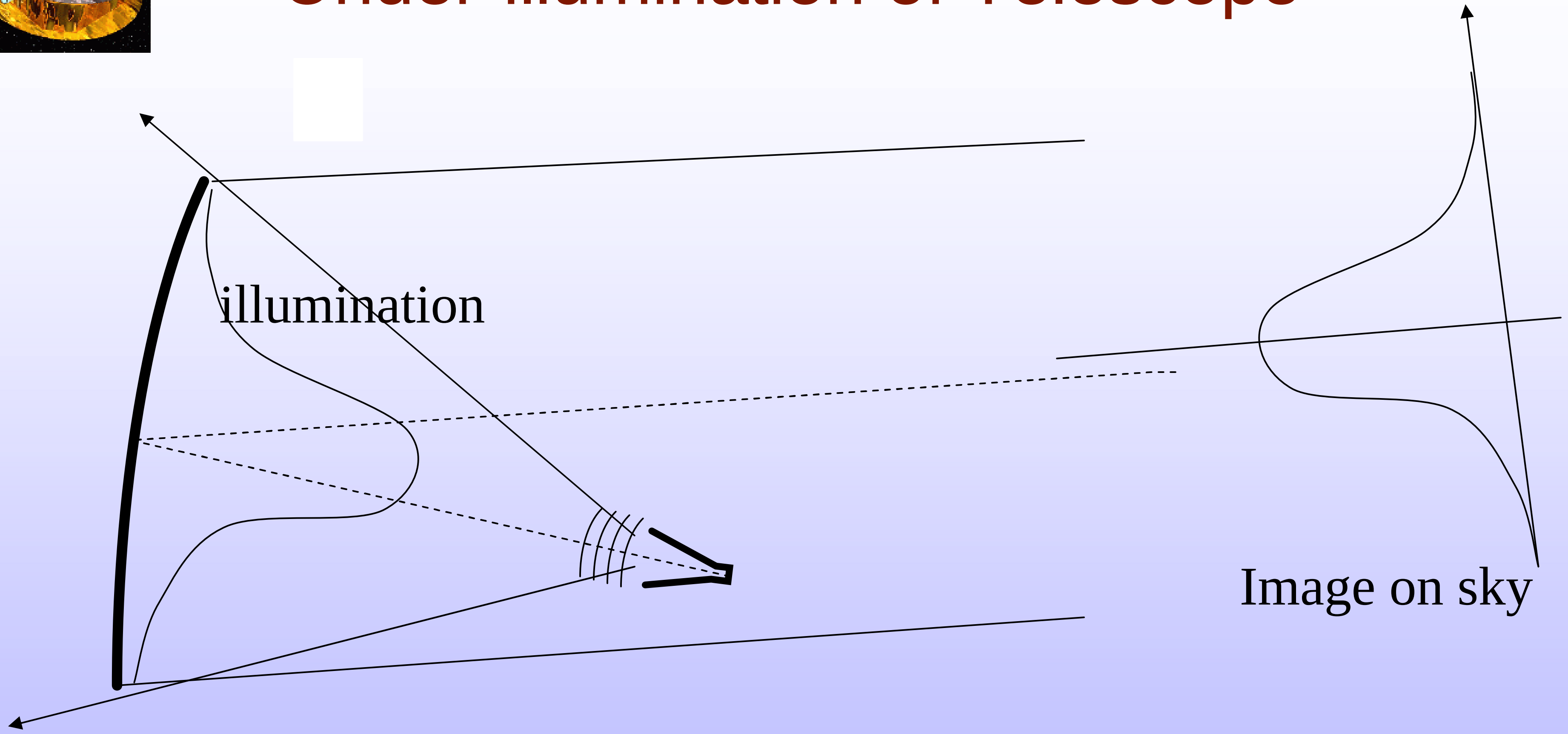
PLANCK HFI

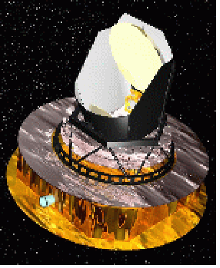
Optique focale



PLANCK HFI

Under-illumination of Telescope

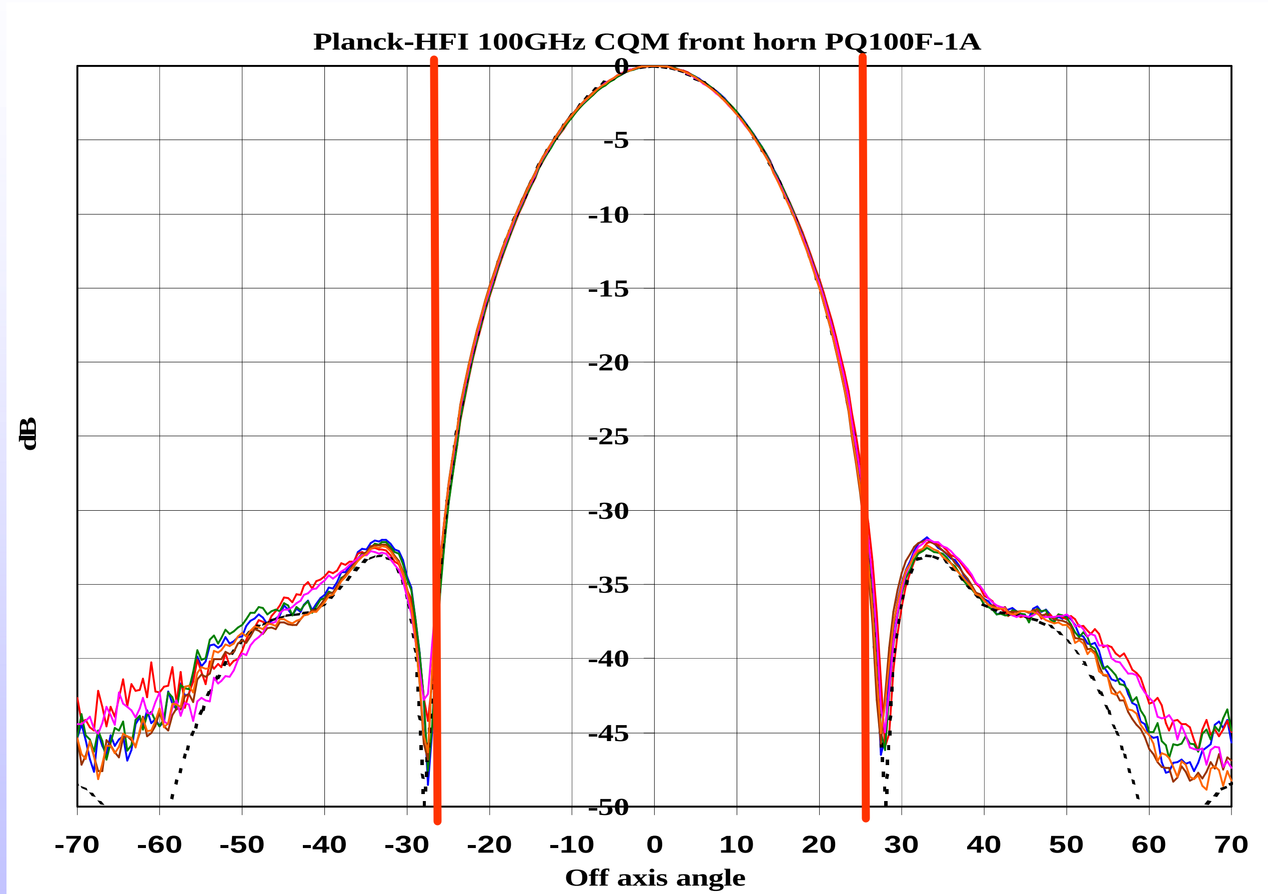




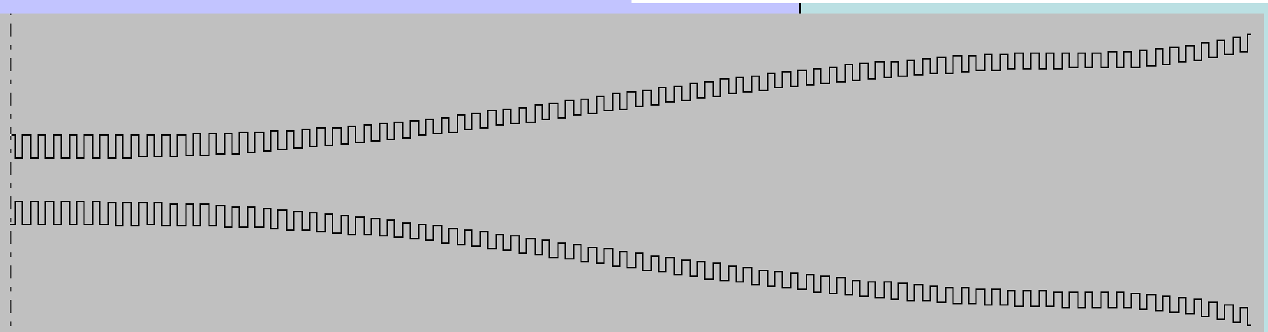
Coupling with the Telescope

PLANCK HFI

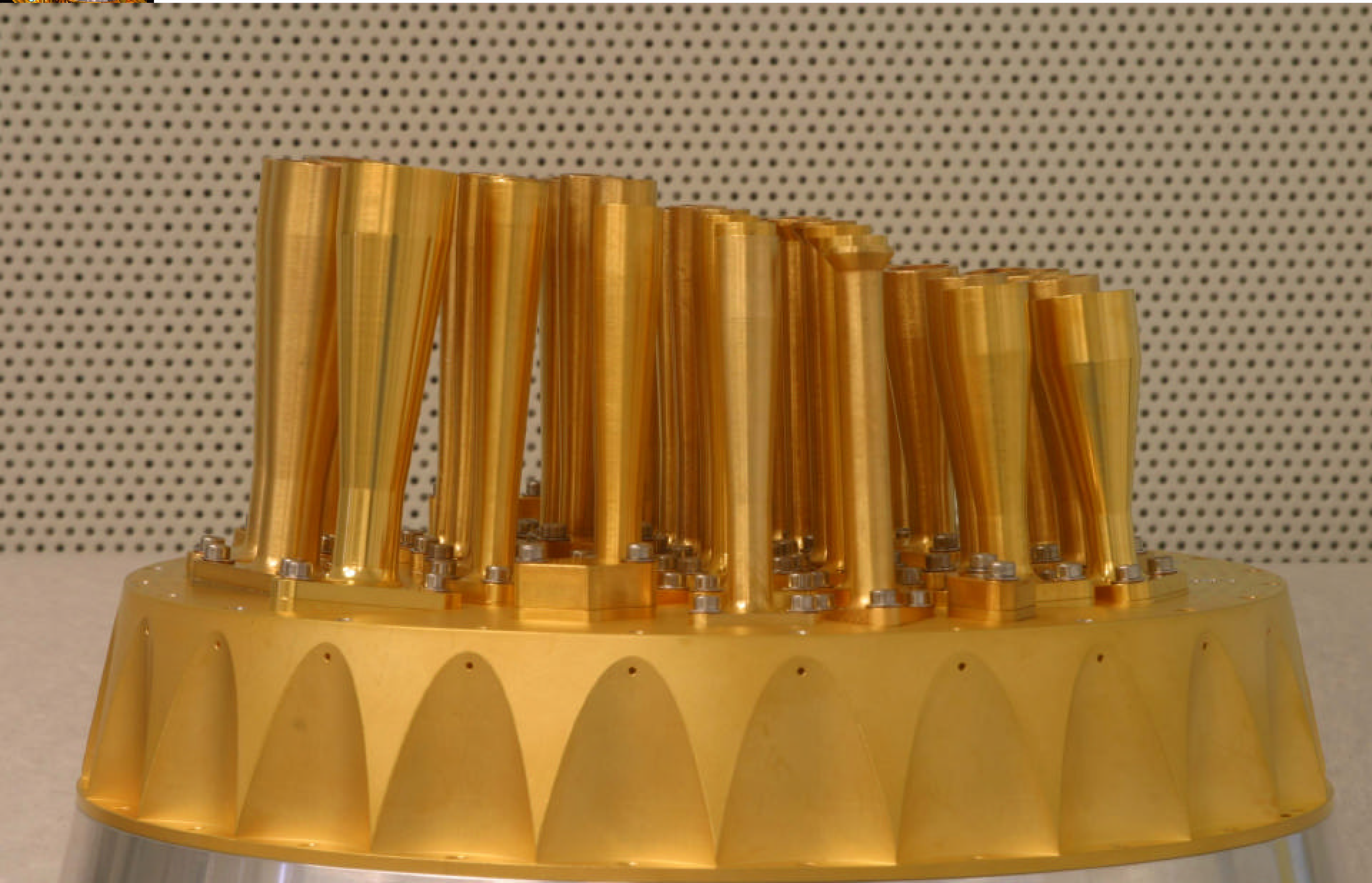
Profiled and flared corrugated horns insure the proper coupling of the detectors with the telescope

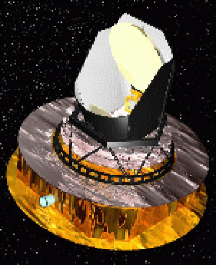


Front Horn



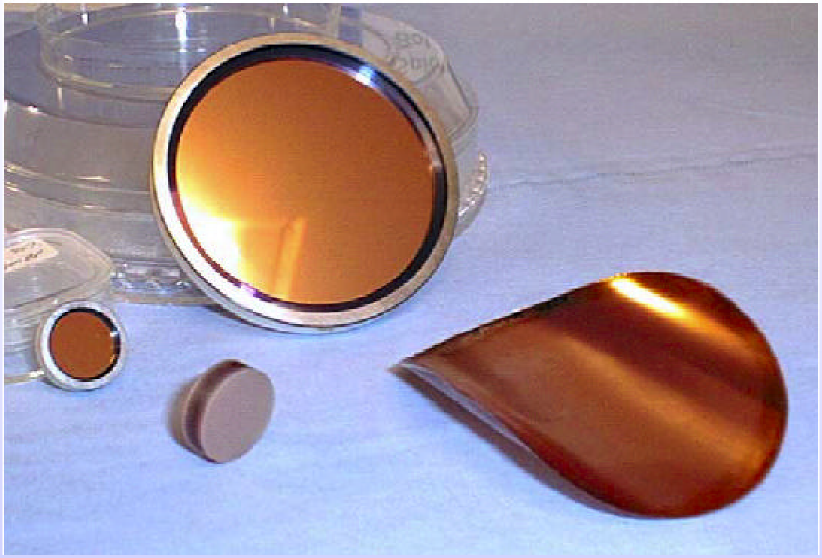
HFI CQM Focal Plane

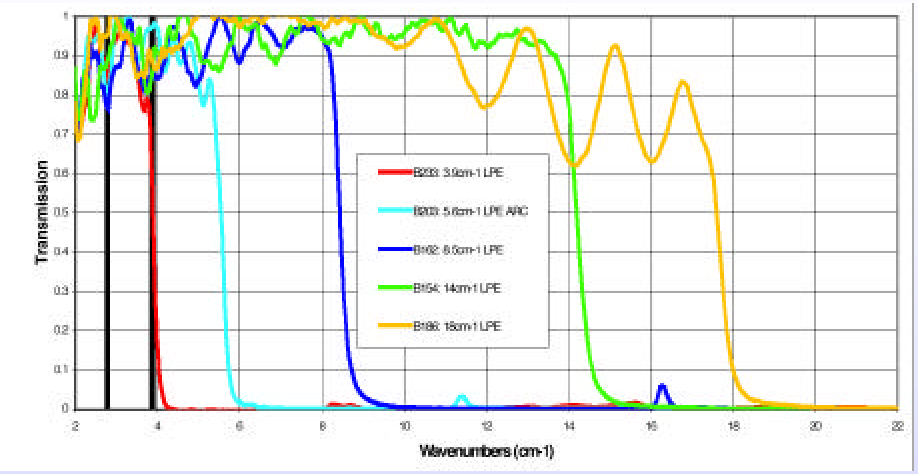


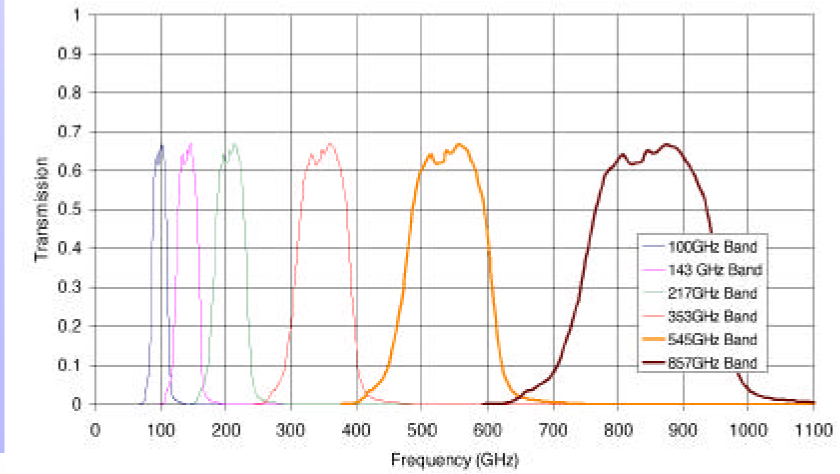


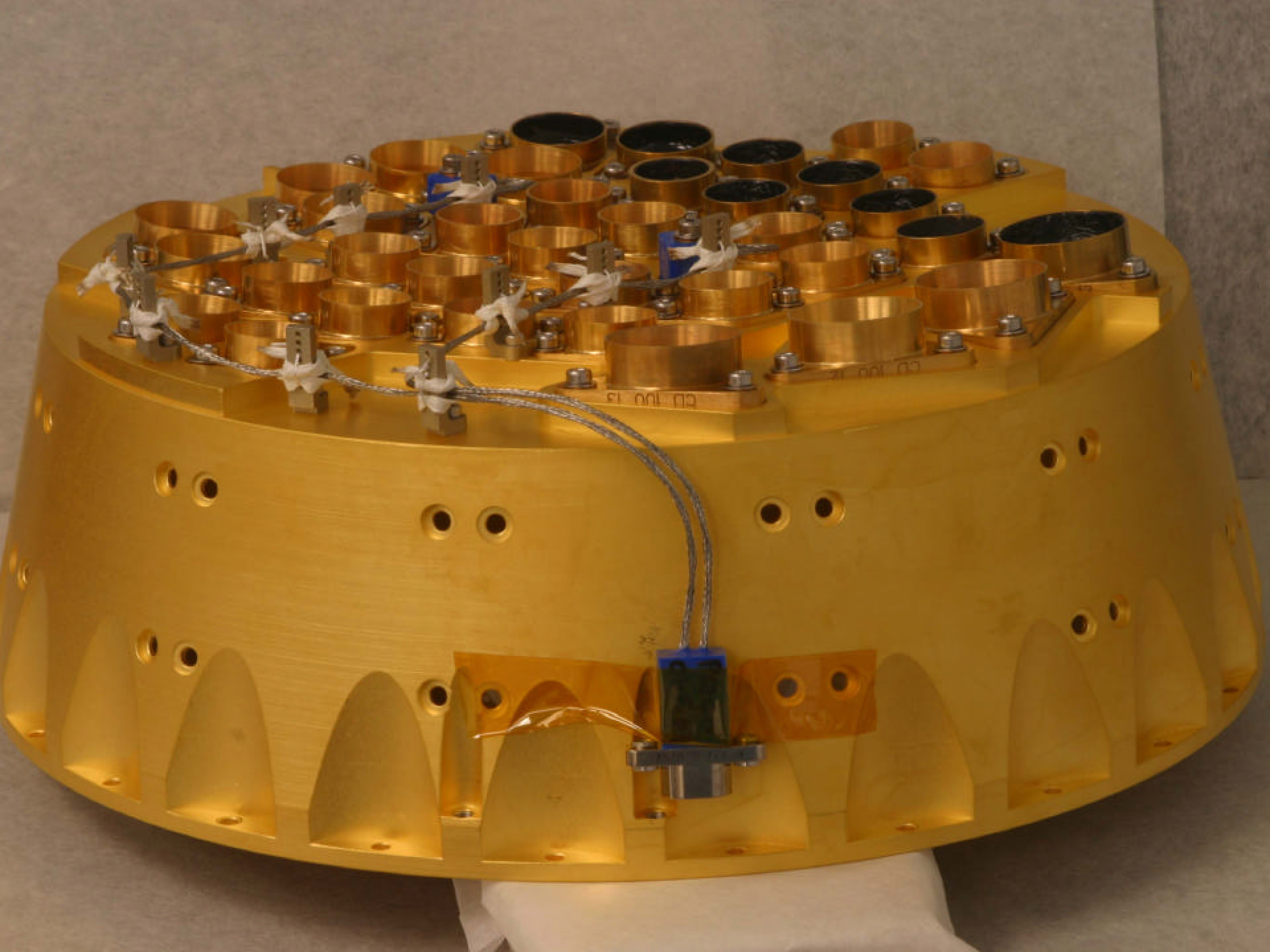
PLANCK HFI

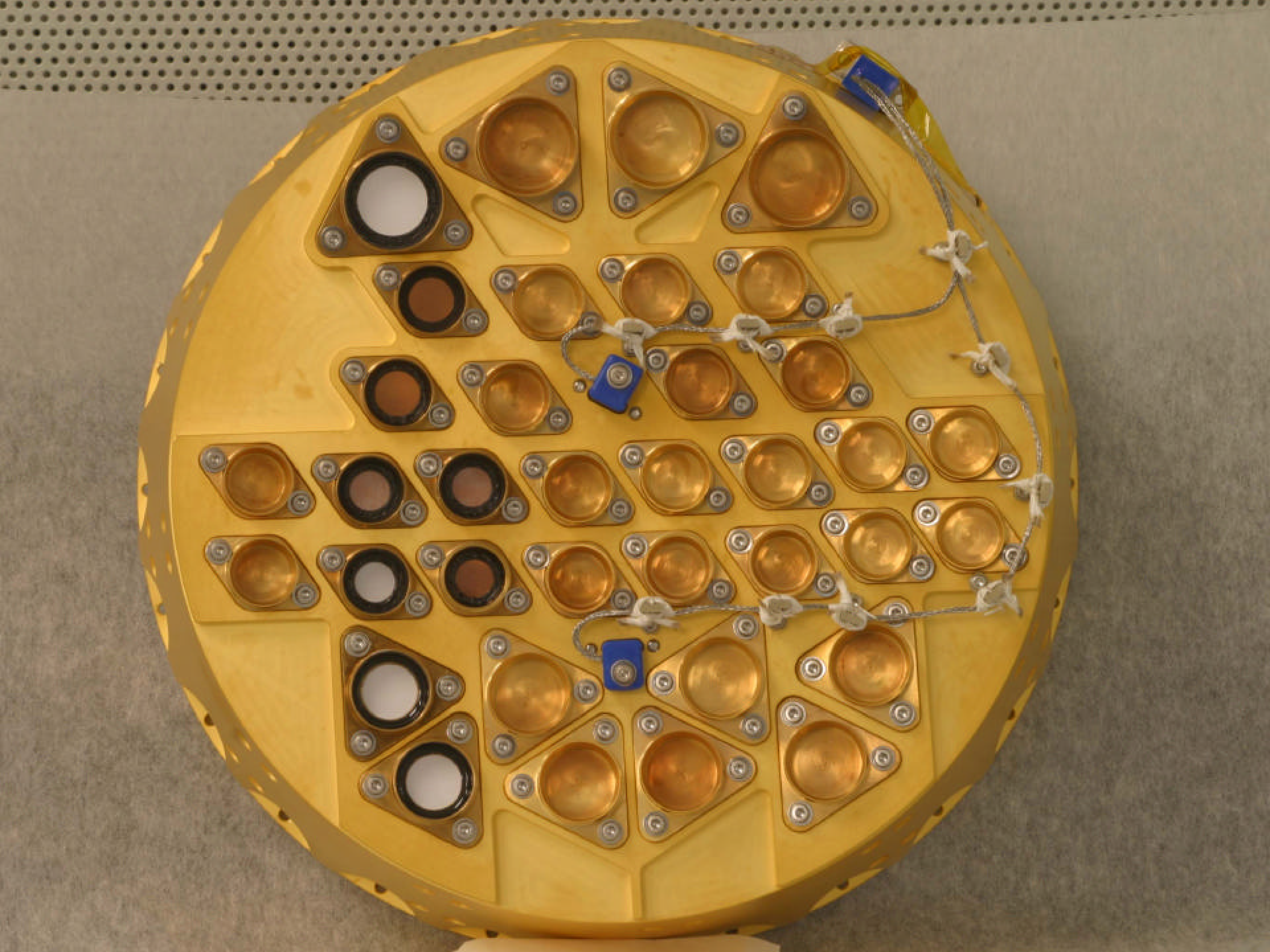
Filters (Cardiff group)



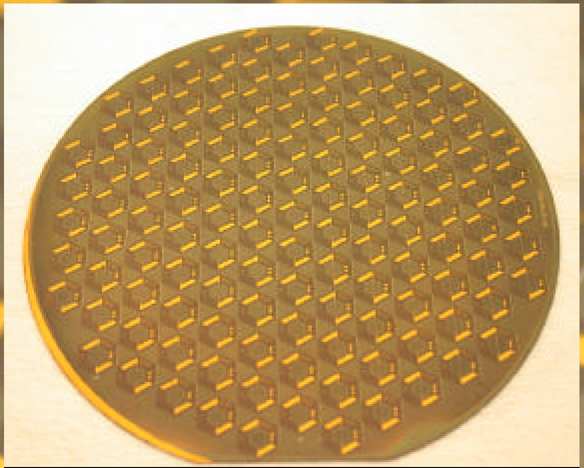




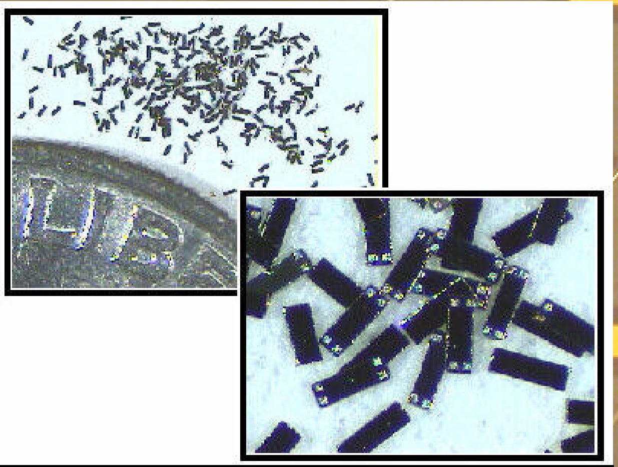




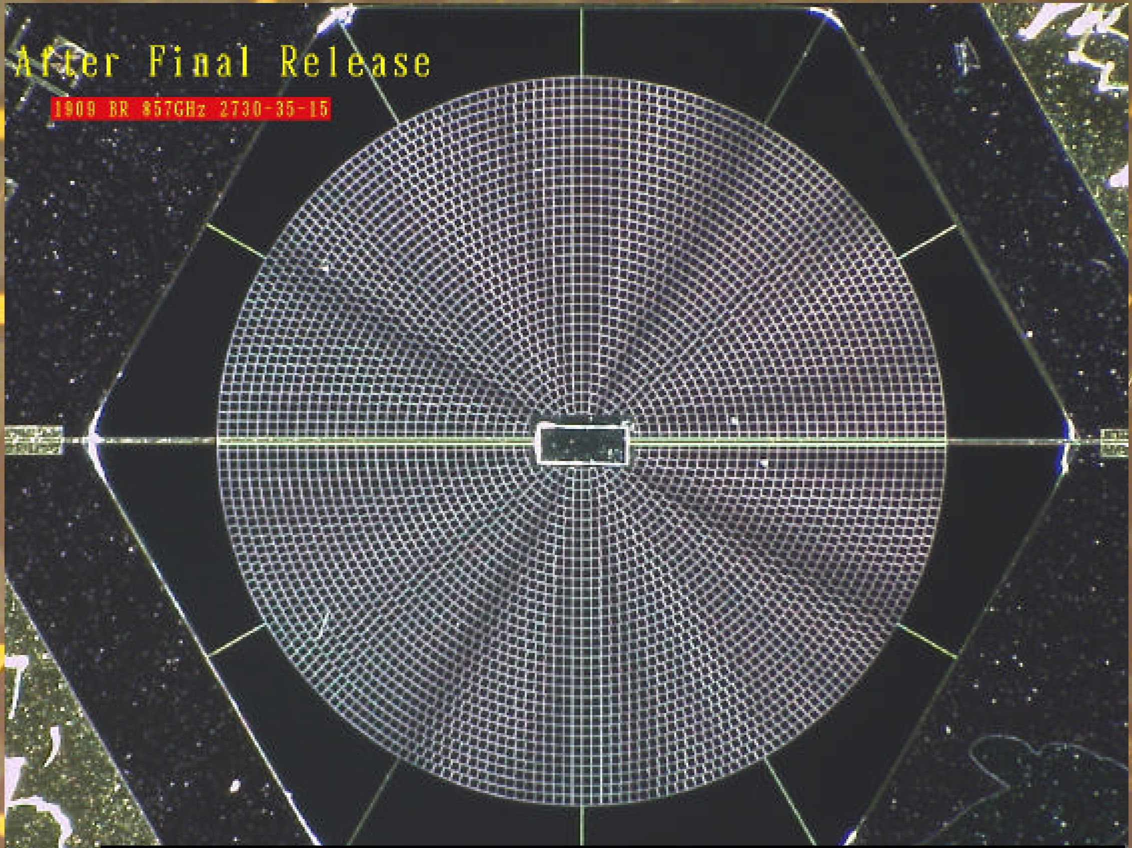
Spider Web Bolometers (Caltech/JPL)



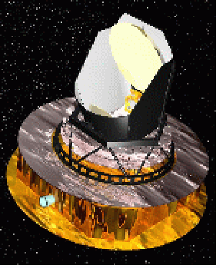
121 Bolometers on a Wafer



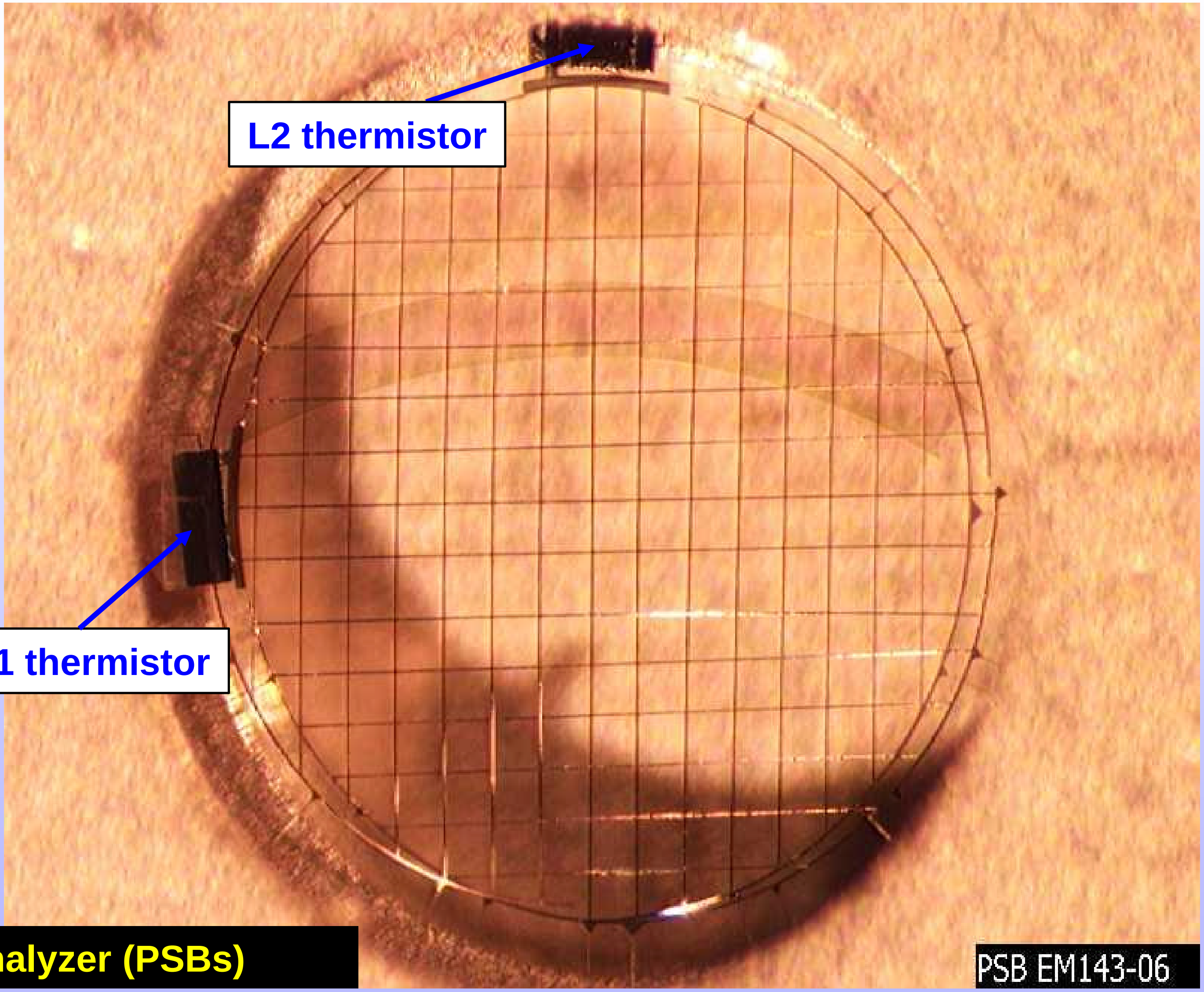
NTD Germanium



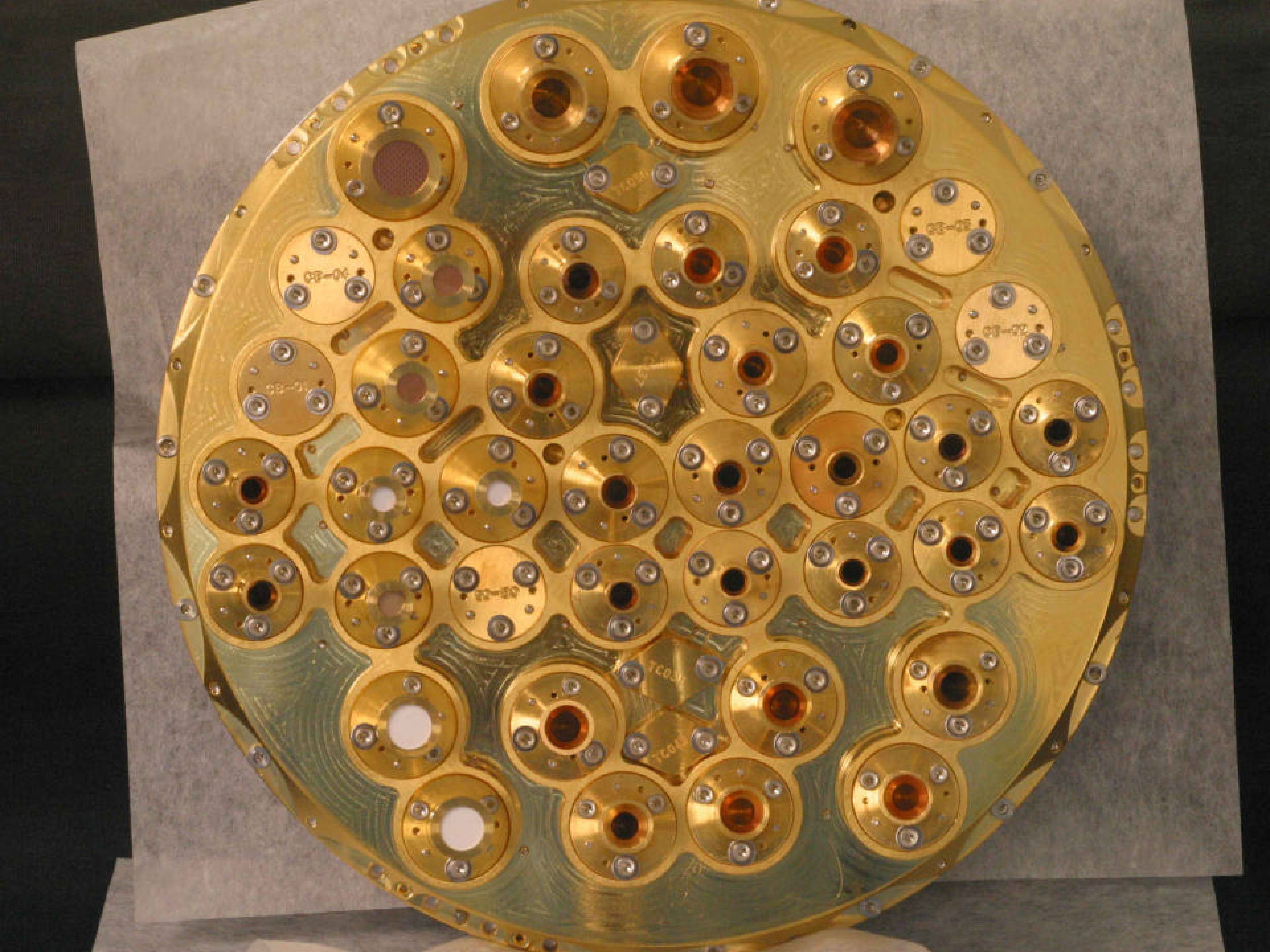
857 GHz Bolometer

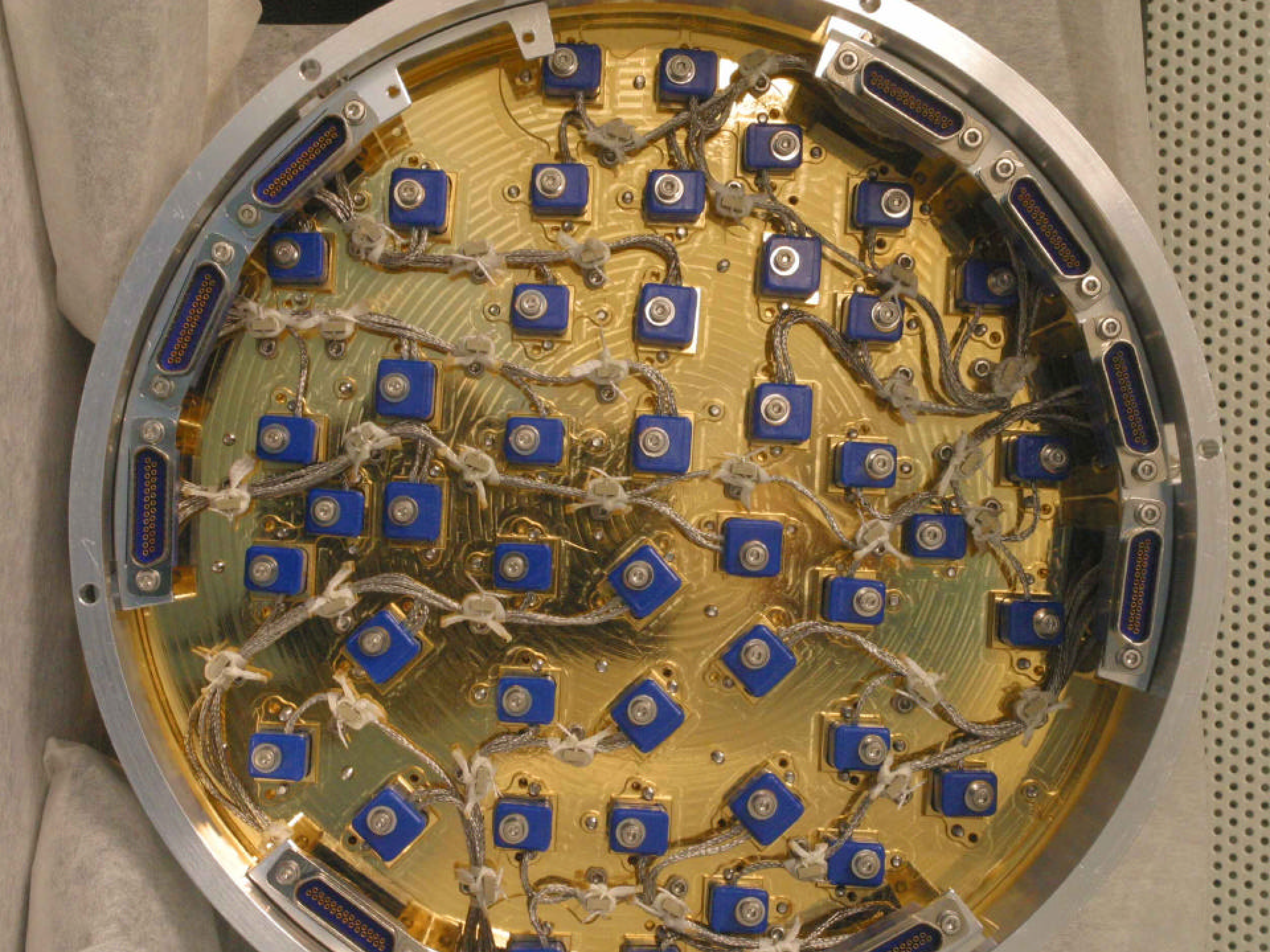


100GHz Polarization Sensitive Analysers



Dual Analyzer (PSBs)

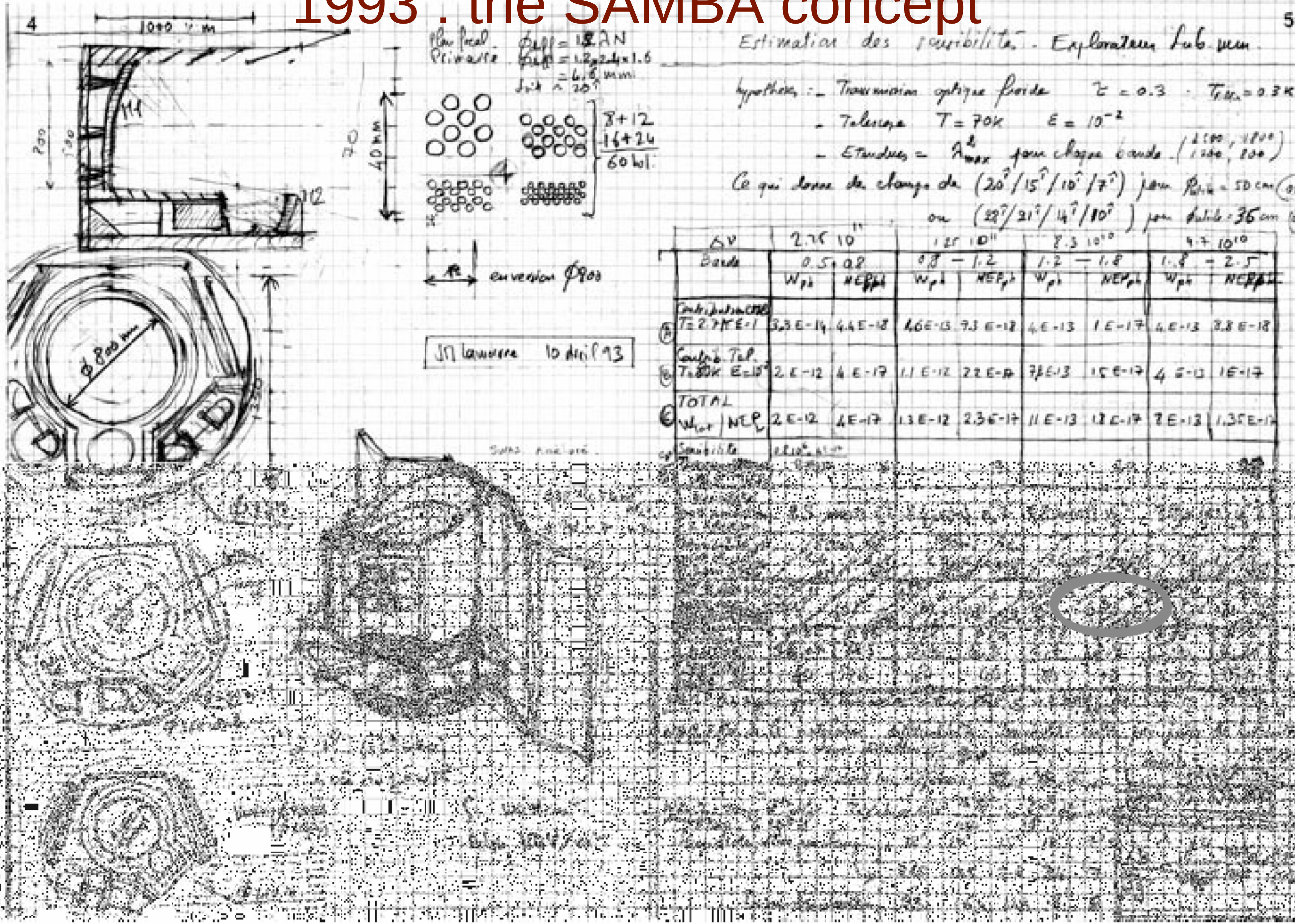


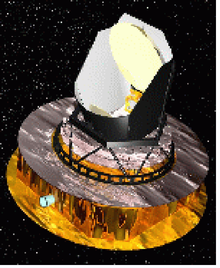


QuickTime™ et un
décompresseur TIFF (LZW)
sont requis pour visionner cette image.

HFI CQM in the calibration facility

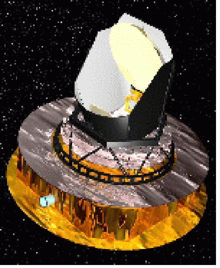
1993 : the SAMBA concept





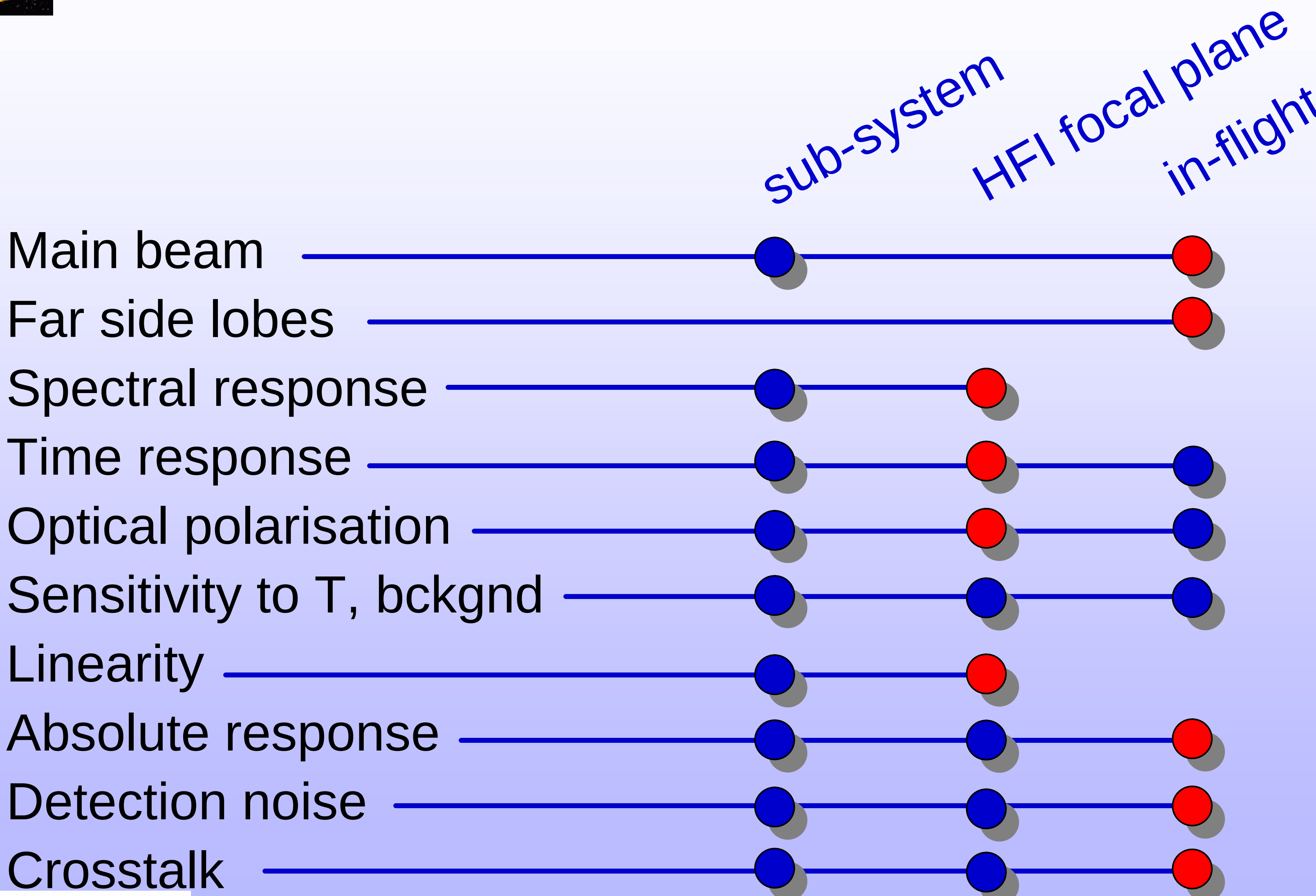
100GHz signal in calibration tank

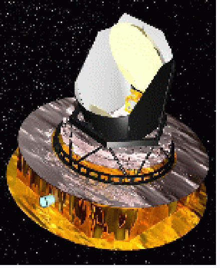
QuickTime™ et un
décompresseur TIFF (LZW)
sont requis pour visionner cette image.



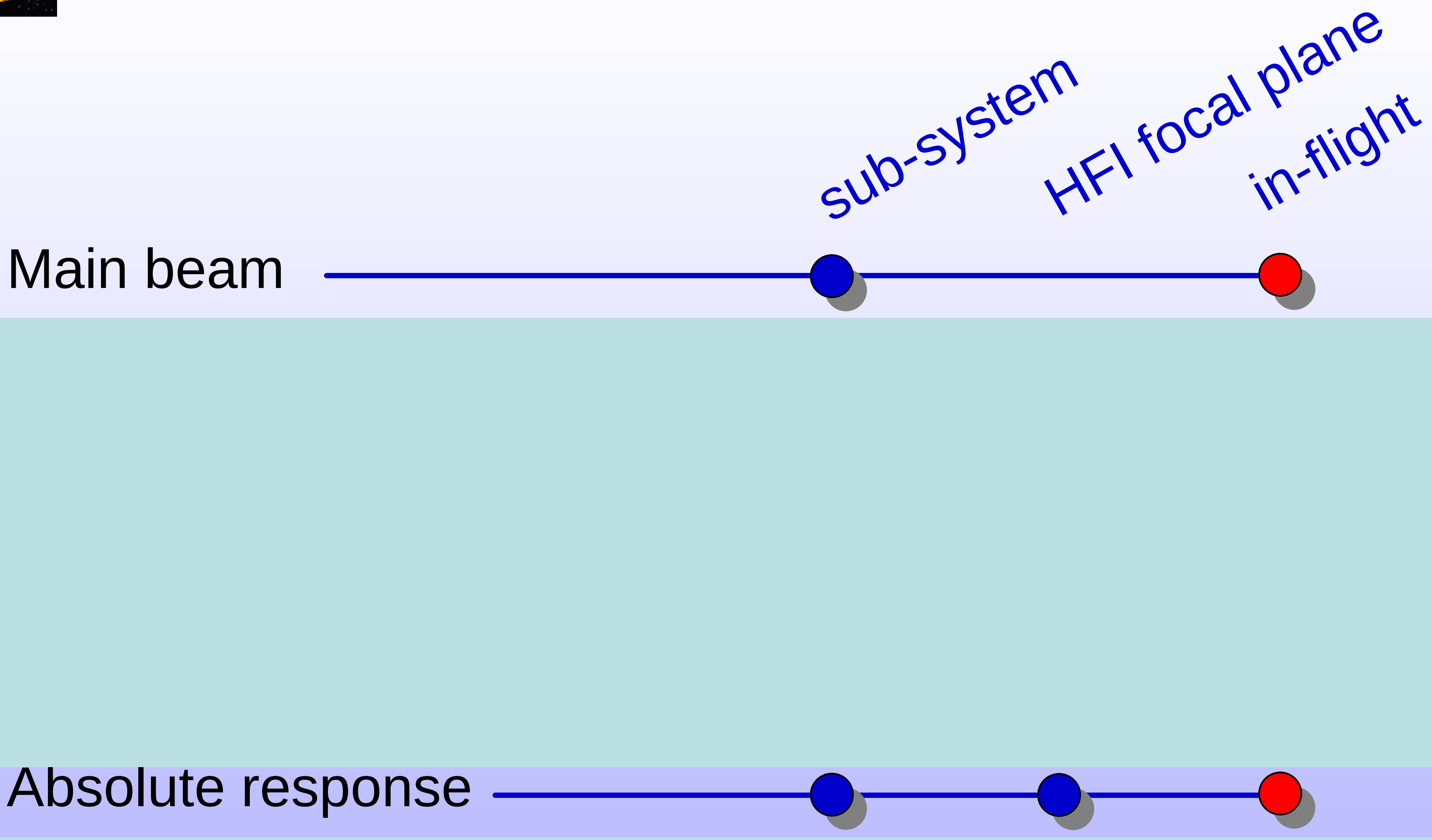
PLANCK HFI

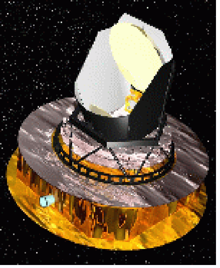
Calibration strategy outline





Calibration strategy outline

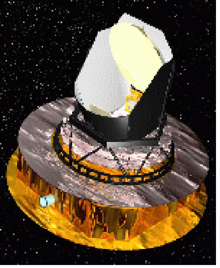




PLANCK HFI

Absolute calibration on extended sources (1)

- A very well calibrated source: the CMB temperature is known with accuracy better than 2.10^{-3} (Fixsen, 1996)
- Plank cannot measure accurately the monopole (uniform part of the emission) because many sources contribute (telescope, horns, filters,…)
- Our peculiar motion in a cosmological frame is well known and measured by COBE. This makes an absolute extended source of 3.36±0.024 mK (lineweaver et al, 1996). modulated at 1 period per minute by the satellite rotation
- It can be measured accurately by all HFI channels excepted the 350micorns channel (857GHz). This gives a calibration better than 1% on all but one HFI channels.



Absolute calibration on extended sources (2)

- The Doppler effect induced on CMB by the earth orbital movement is known with the accuracy of the CMB itself (better than $2.\ 10^{-3}$)
- It is possible that it can be measured accurately by Planck HFI on the 3 low frequency channels (100, 143, 217 GHz), that will therefore be calibrated to better than 0.5%, with a goal of $2.\ 10^{-3}$ or better.

- The COBE-FIRAS experiment has produced maps of the galaxy with an accuracy better than 3% in the high frequency channels of HFI. (see Piat et al, 2002).
- This can be used to calibrate the 857 GHz channel to 3%, and cross-check the calibration of the 545GHz channel.

Table 1. Required sensitivities of Planck-HFI per unpolarised detection chain (expected sensitivities are twice better). The last two lines give the sensitivities per channel for the full mission.

Frequency (GHz)	857	545	353	217	143	100
Resolution (arcmin)	5	5	5	5	7.1	9.2
Number of detector	4	4	4	4	4	4
NET_{CMB} ($\mu K\ Hz^{-0.5}$)	182000	3995	553	182	123	99
Thermo. temperature sensitivity per ring (μK)	199000	4370	605	200	113	80
NEI ($MJy\ sr^{-1}\ Hz^{-0.5}$)	269×10^{-3}	232×10^{-3}	165×10^{-3}	88×10^{-3}	47×10^{-3}	23×10^{-3}
Intensity sensitivity per ring ($MJy\ sr^{-1}$)	294×10^{-3}	253×10^{-3}	180×10^{-3}	96×10^{-3}	43×10^{-3}	19×10^{-3}
Thermo. temperature sensitivity full mission (μK)	36500	801	111	37	17	11
Intensity sensitivity full mission ($MJy\ sr^{-1}$)	54×10^{-3}	46×10^{-3}	33×10^{-3}	18×10^{-3}	6.6×10^{-3}	2.6×10^{-3}

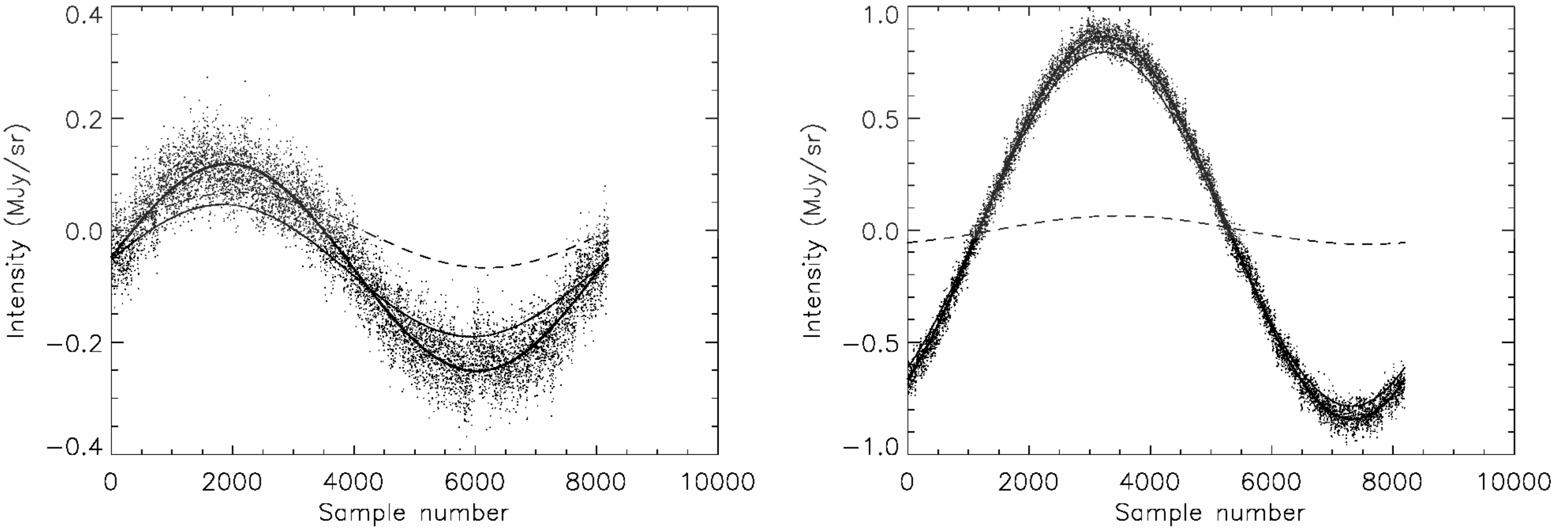


Fig. 3. Example of the analysis done at 100GHz on two rings (No. 0 and No. 20). The points represent the simulated signal. The PM and OM dipoles are represented by light solid and dashed curves respectively. The bold solid curve is the OM plus PM motion dipole fitted on the signal.

From Michel Piat et al. A&A, 2002

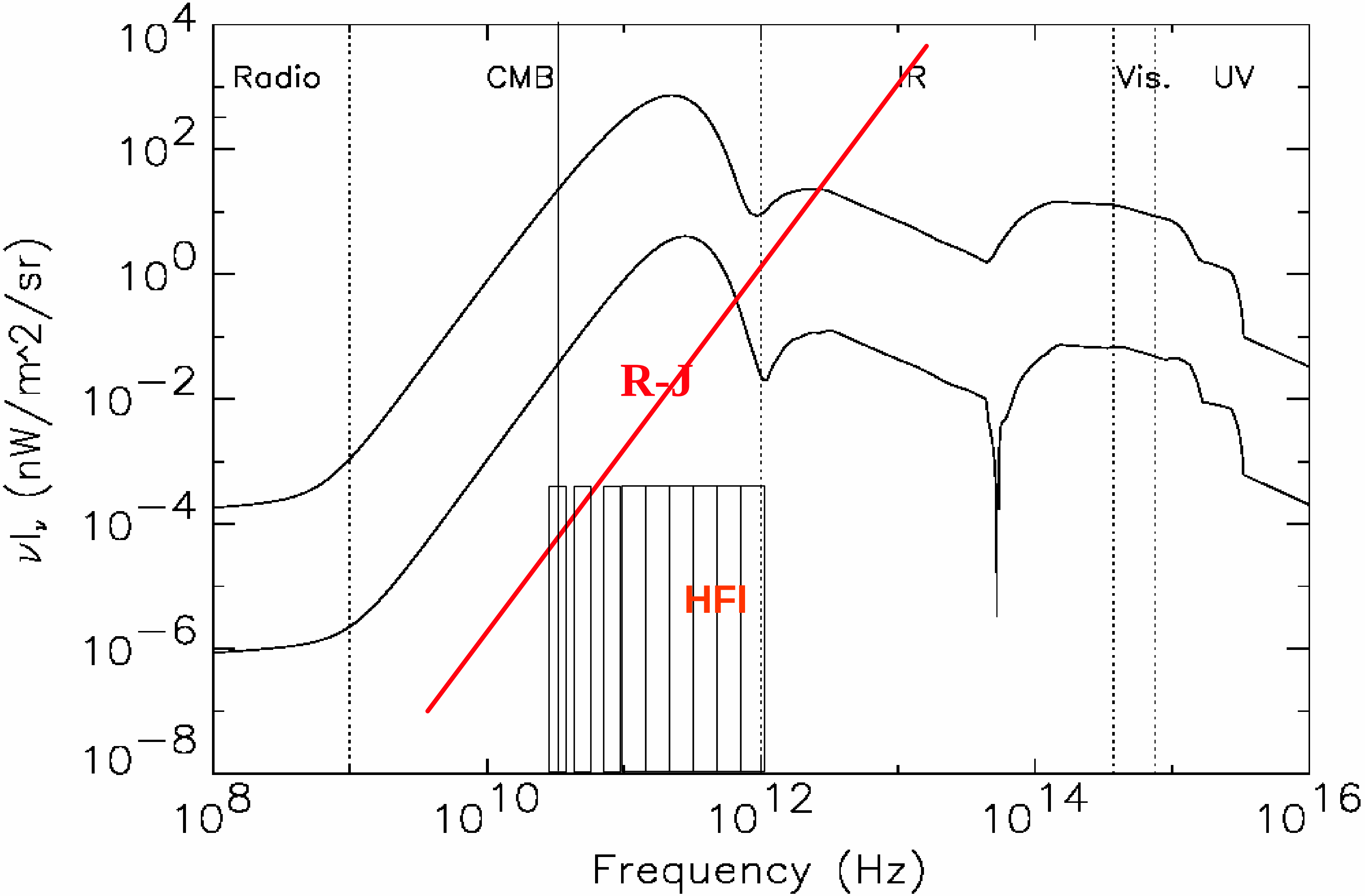
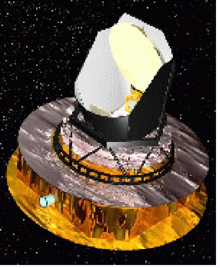


Fig. 1. Spectrum of the CB (top) and its dipole amplitude (bottom)

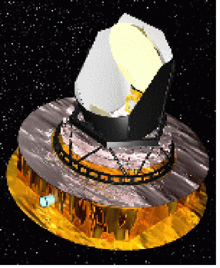
From M. Piat et al. A&A, 2002



PLANCK HFI

Absolute calibration on extended objects (3)

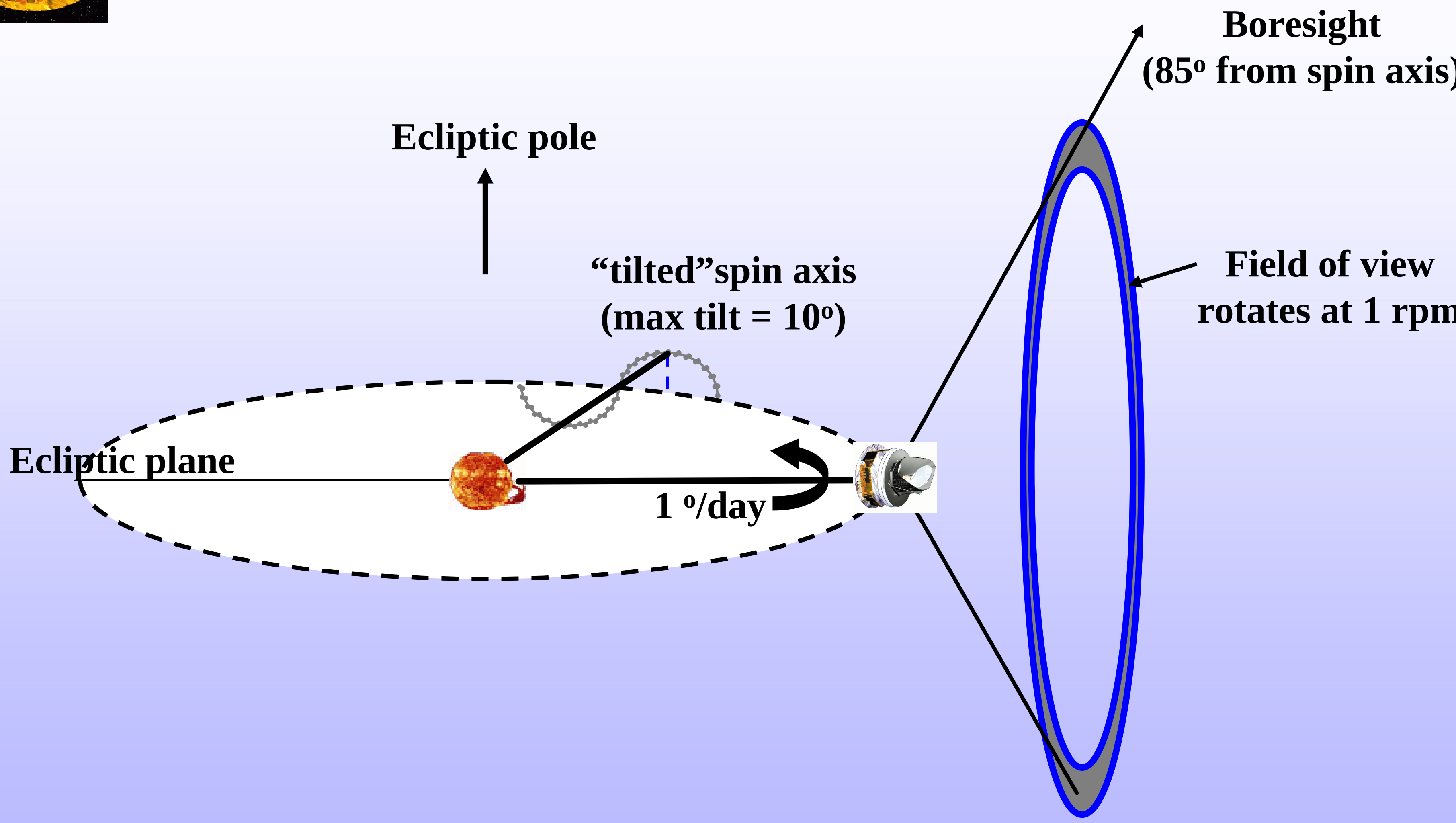
- Absolute calibration is excellent on HFI low frequency channels <0.5%. Goal <0.2%
- Calibration on 545GHz channel can be good (<1%) but depends on accuracy of spectral transmission knowledge. *Cousin channel to SPIRE*
- 857 GHz calibrated better than 3%. *Sister channel to Spire.*

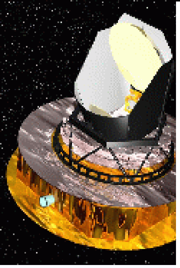


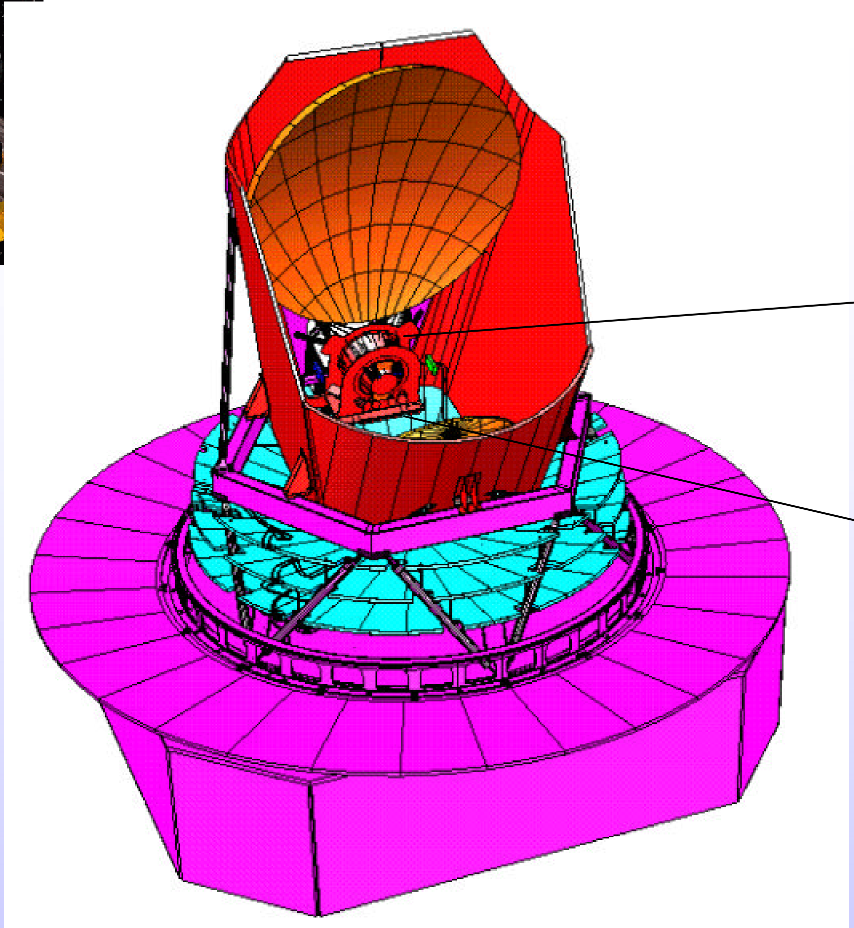
Beam calibration

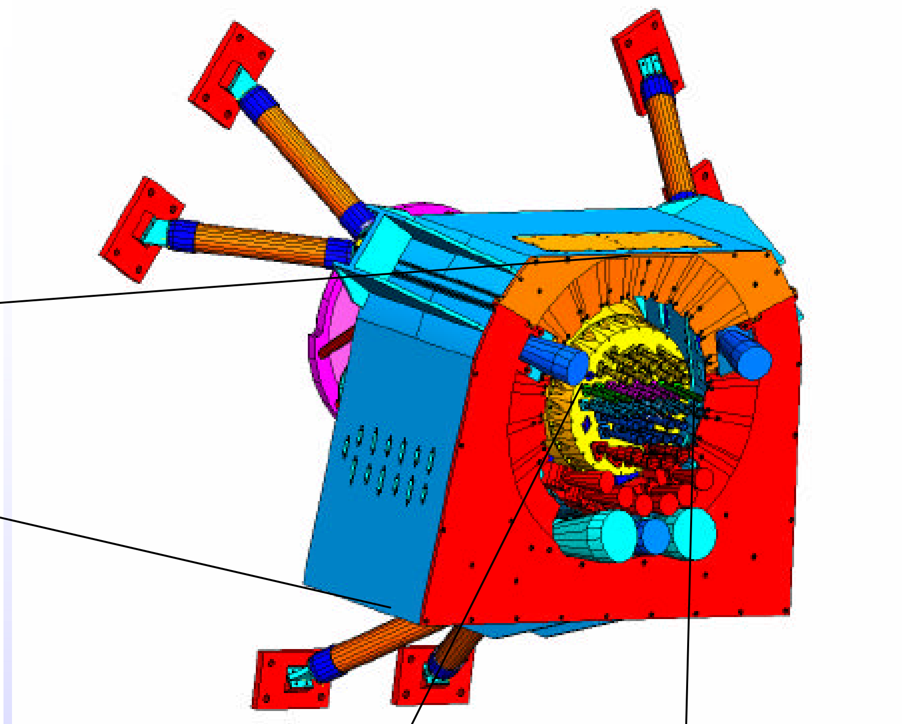
- Convolution by the beam defines the filter function for the C(l) measurement : Accurate calibration of the beam shape is mandatory for interpretation of CMB maps
- Accurate calibration of the beam is also the link between extended sources and point sources
- It will be performed mainly on planets
- Confusion by CMB is the main source of noise. Observation “without planet” is mandatory.

Observing strategy



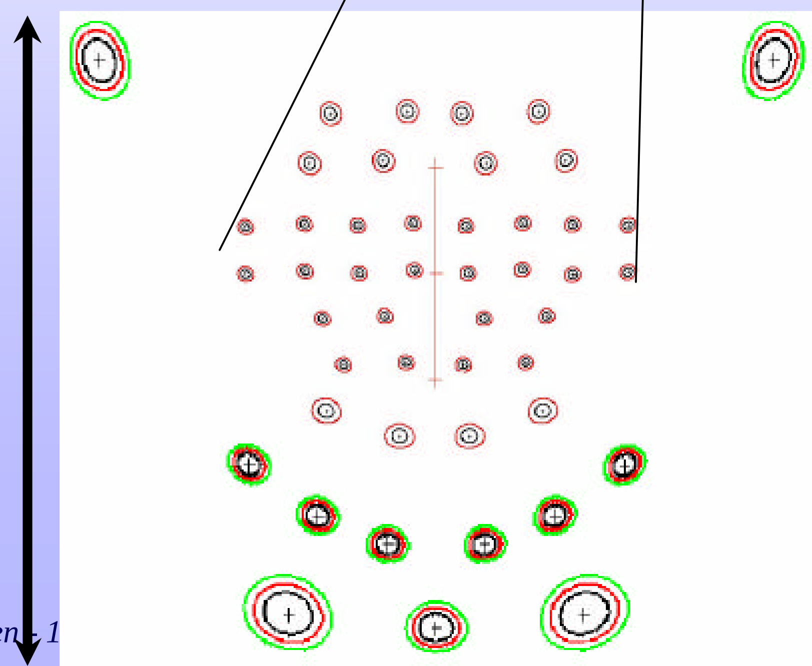


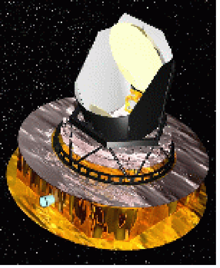




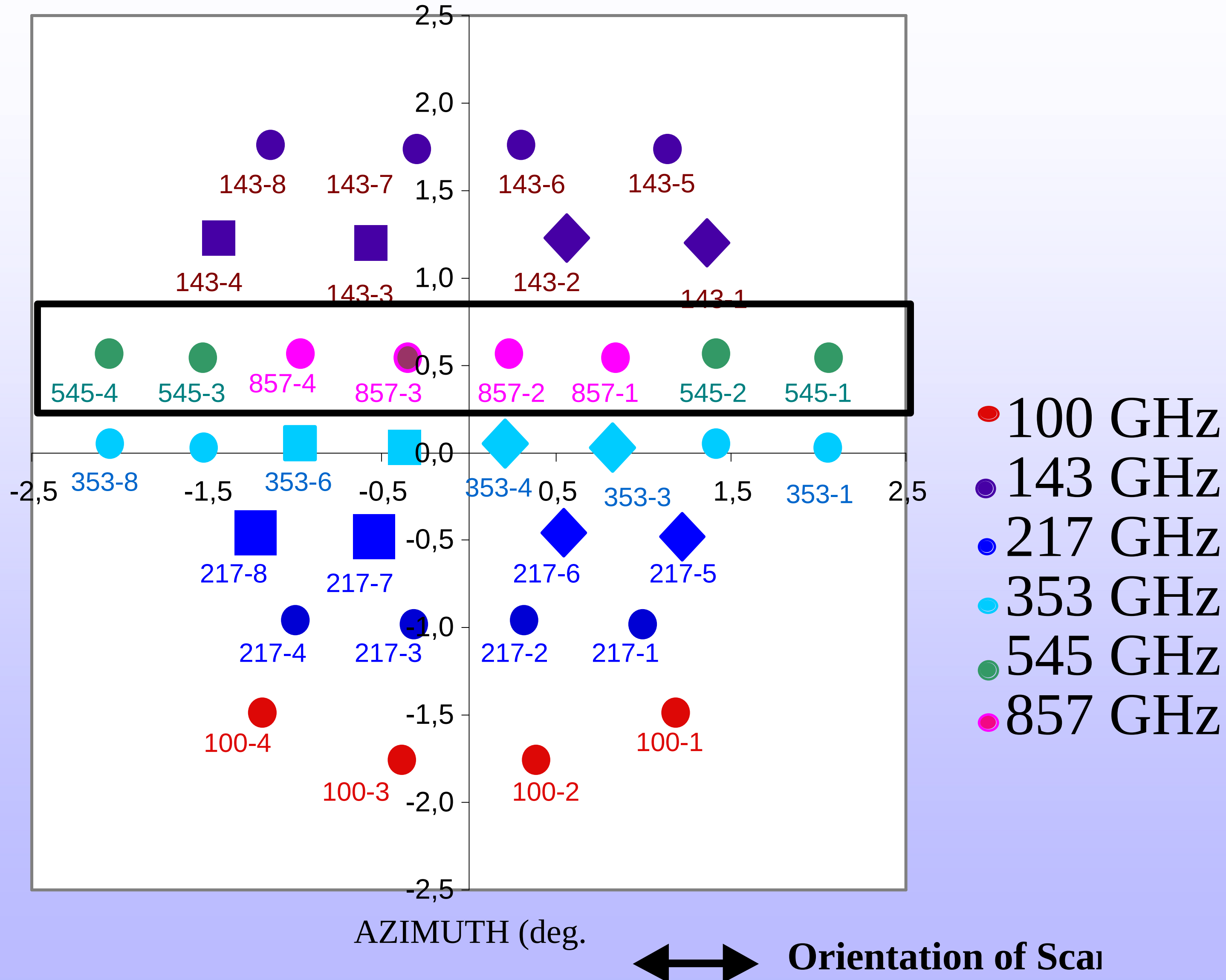
PLANCK Focal plane

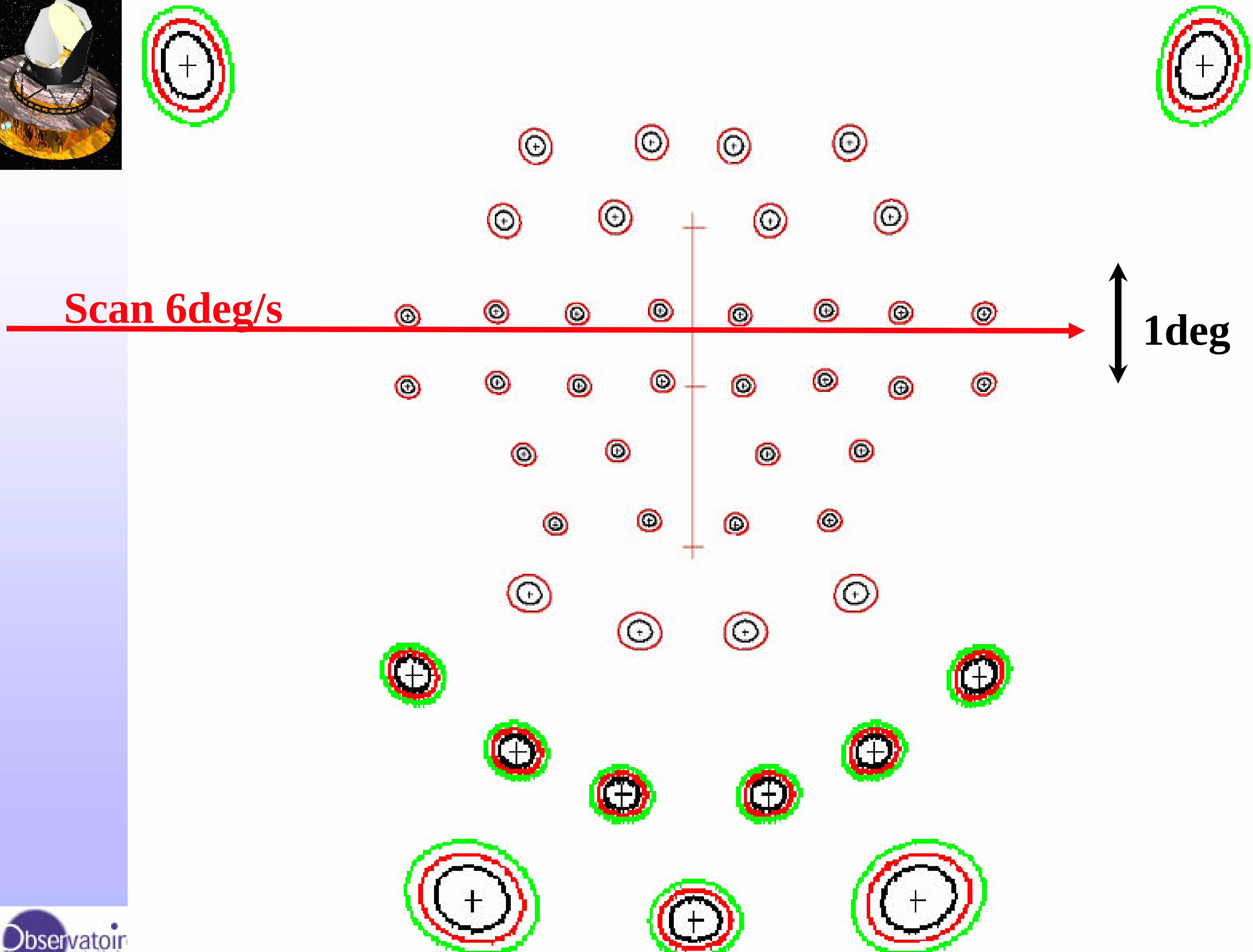
~8º

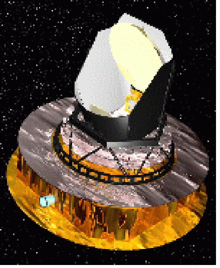




MAP OF LINES OF SIGHT

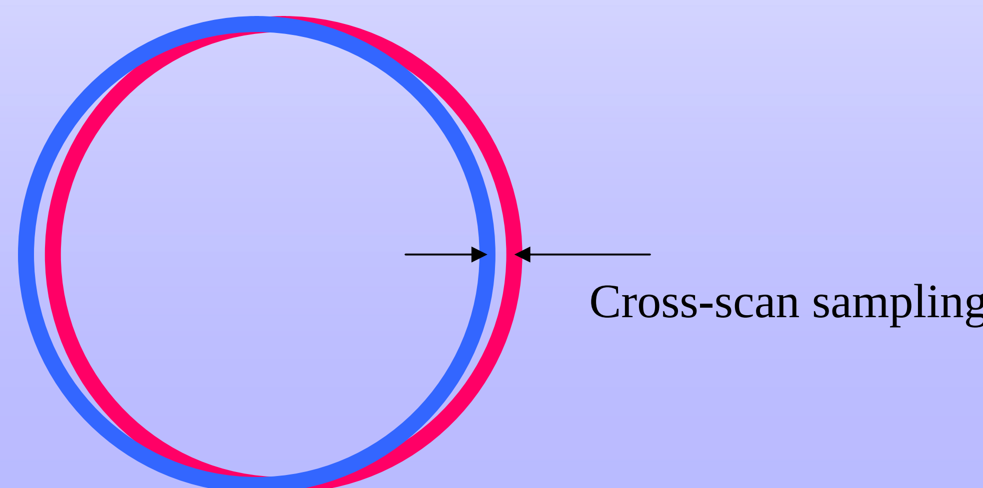


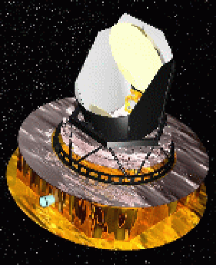

Scan 6deg/s
1deg



Scanning the sky

- Normal scanning:
  - Every 60mn, the rotation axis is shifted by 2.5arcmin (~1deg/day and ~360deg/year)
- Beam calibration scanning
  - Every ~60mn, the axis is shifted by 1.25arcmin, which gives a good beam cross-scan sampling.





PLANCK HFI

Cross-scan sampling

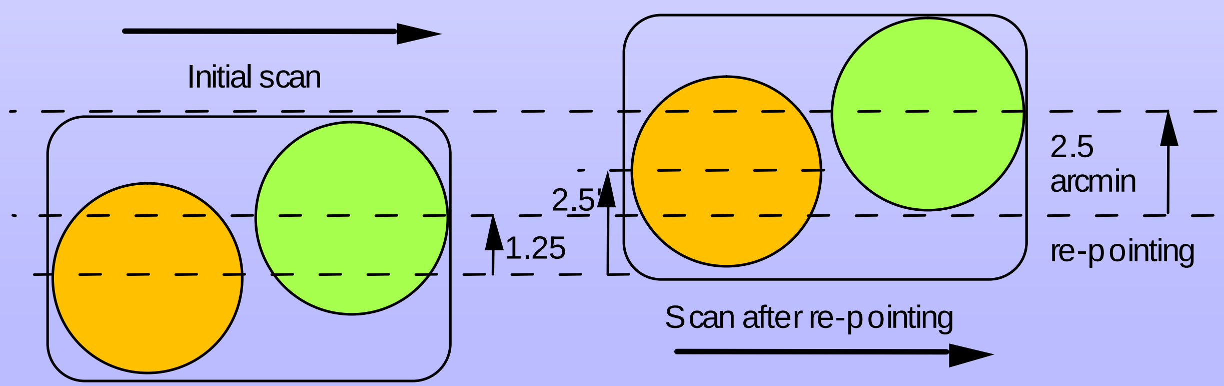
- Requirement: 2.4 sample per beam FWHM

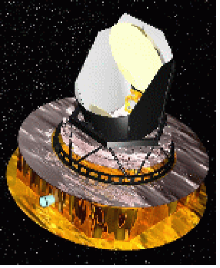
Beam FWHM	(arcmin)	9	7	5
Maximum sampling angle	(arcmin)	3.75	2.91	2.08

- Expected depointing: 2.5±0.4 arcmin < 2.9 arcmin (TBC…)

Acceptable for 9 and 7 arcmin (without margin for 7)

- 5 arcmin beams: pairs of detectors staggered by 1.25 arcmin



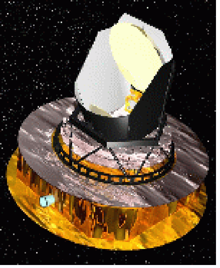


PLANCK HFI

Sensitivity for one detector, 1σ, 1.25x1.8 arcmin pixel

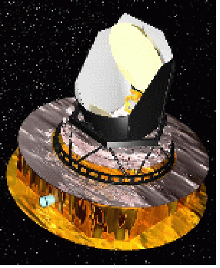
GHz	857	545	353	217	143	100
Jy	0.19	0.15	0.14	0.17	0.20	0.21
Beam (‘)	5	5	5	5	7.2	9.5

- Mars, Saturne, Uranus, Neptune, Ceres OK for main lobe
- Jupiter is too bright for main lobe (near to saturation) but required for scanning side-lobes down to -40dB
- Many point sources detected in one year in each band by co-adding detectors
  - 10^4 galaxies
  - SZ on thousands of clusters of galaxies



HFI as a calibration machine

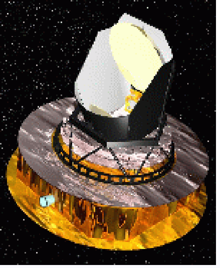
- HFI will have accurate absolute calibration by
  - Using very well known and bright extended sources, the CMB and its dipole components
  - Measuring accurately the beam on planets
- Planets or secondary calibrators can be used to pass this absolute calibration to HSO, and especially to SPIRE that has two channels very similar to Planck.
- The knowledge of the spectral transmission curves of all instruments is essential to this approach



Source variability

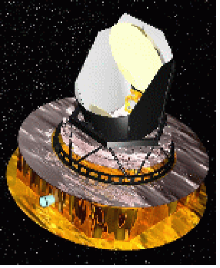
- Scanning the beam up to ±30arcmin takes 48h: *Source short term variability may be a problem*, (especially on Jupiter) if there is not a brightness monitoring when HFI is scanning planets

- Longer term variability may be a problem to use HFI data as a calibrator for Herschel



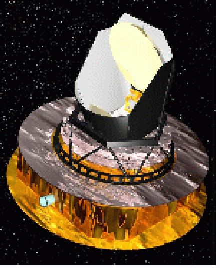
Advantages of a common programme (1)

- Observe planets simultaneously with HSO and Planck:
  - Secures Planck beam measurements by monitoring the planet short term changes
  - Provides HSO with a bootstrap to HFI's absolute calibration
  - Secures this bootstrap against any kind of source variability
- Compare models and/or use the best one



Advantages of a common programme (2)

- Absolute calibration with <1% accuracy will boost modelling submm emission of planet and other sources
- Observing the same objects with different instruments improves the knowledge of the sources and their usefulness as calibrators. Observe simultaneously sources with smoother spectra (asteroids?) would help to pass calibration on bands not exactly identical



Organise Planck HFI/Herschel cross-calibration