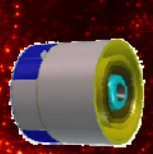
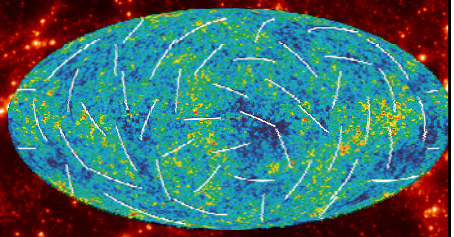
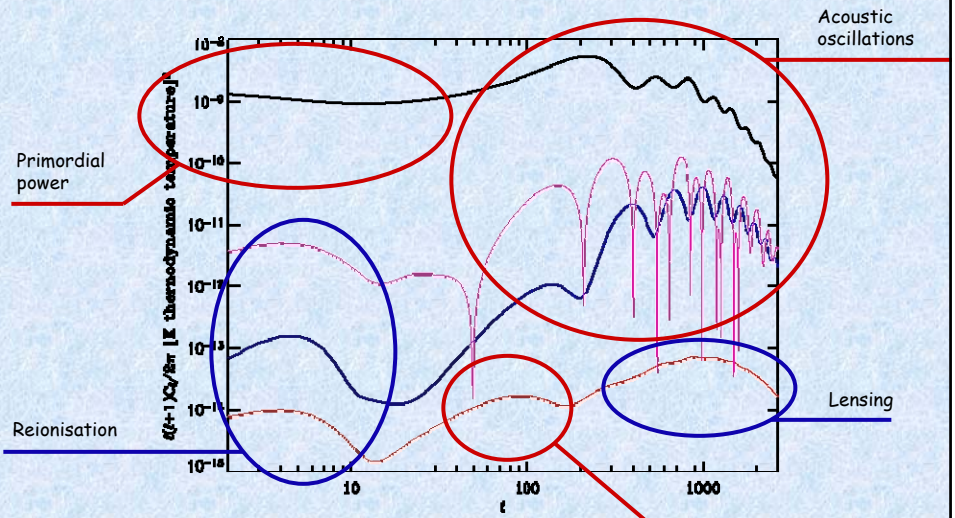
THE PLANCK SATELLITE: STATUS & PERSPECTIVES





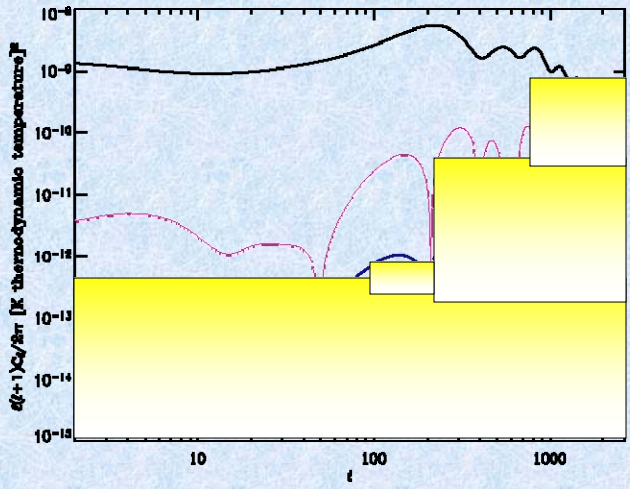
F. R. BOUCHET
INSTITUT D'ASTROPHYSIQUE DE PARIS, CNRS
COSPA, TAIPEH, NOVEMBER 15TH, 2006

CMB INFORMATION MINE (SOME)



+ all non-gaussian information

KNOWN CMB ANGULAR POWER SPECTRUM



Angle ≈ 200/l degrees

BLESSED WITH MUCH MORE TO EXTRACT

THE PLANCK CONCEPT

- An Instrument able to perform the "ultimate" measurement of the CMB temperature anisotropies:
  - full sky coverage and angular resolution covering all scales at which the CMB primary anisotropies contain information (~5')
  - sensitivity essentially limited by ability to remove the astrophysical foregrounds, implying enough sensitivity combined with a large frequency coverage from 30 GHz to 1 THz (provided by the two instruments: HFI+LFI)
- get the best performances possible on the polarization of the CMB with the technology available

⇒ Selected by ESA en 1996 as 3rd Medium size mission

⇒ Goal can be achieved with a small number of detectors in each frequency band, limited by the photon noise of the background (for the CMB ones)

PLANCK VS WMAP: 1 YEAR SENSITIVITY GOALS

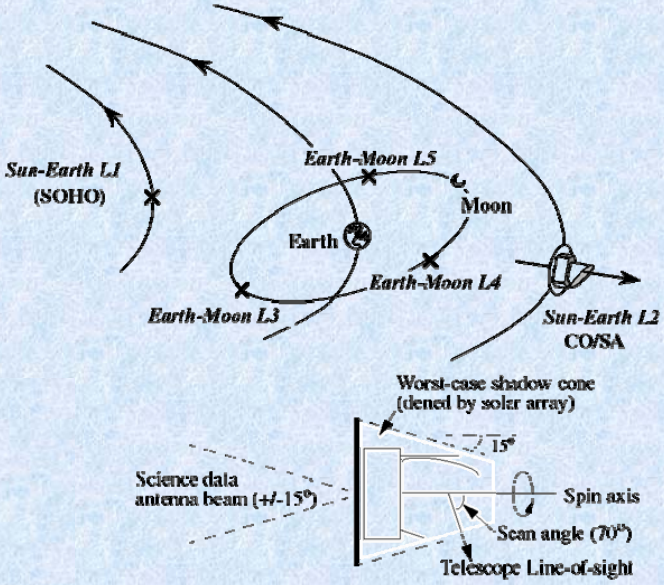
(extracted from the "Blue book" (2005), cf. www.rssd.esa.int/Planck)

Center Freq. (GHz)	30	44	70	100	143	217	353	545	857
Angular Resolution (FWHM, arcmin)	33	24	14	9.5	7.1	5	5	5	5
Average $\Delta T/T_I$ per pixel#	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average $\Delta T/T_{U,Q}$ per pixel#	2.8	3.9	6.7	4.0	4.2	9.8	29.8		
Sensibilité in I [μK] per pixel (FWHM)	5.5	7.4	12.8	6.8	6.0	13,1	40,14		
Sensibilité in I [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	2.7	2.6	2.6	0,96	0,63	0,97	2,9		
Sensibilité in Q or U [μK.deg] [$\sigma_{pix}\ \Omega_{pix}^{1/2}$]	4.5	4.6	4.6	1.85	1.45	2.39	7.26		

WMAP Center Freq.	23	33	41	61	94
Angular resolution (FWFM arcmin)	49	37	29	20	12,6
μK per 3,2 10^{-5} sr pixel (22'x 22')	38.9	39,9	41	48	46
Sensibilité en 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)

The aggregated sensitivity of the 3 core CMB channels of Planck, @ 100, 143, 217GHz (~0.5μK.deg in T, 1 μK.deg QU) will be unprecedented and quite challenging in terms of control of systematics

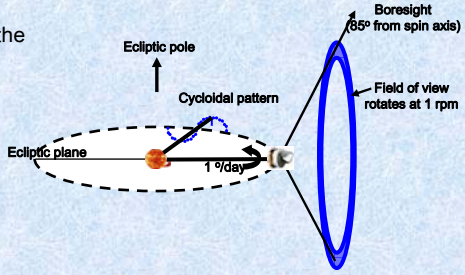
OBSERVATIONAL SITE



BASELINE SCANNING STRATEGY (WG9)

Slow Precession: circular motion of the spin axis around anti-Sun direction, inclination of the solar array remains fixed

- precession circle 7.5 degrees
- period of 6 months
- phase depends on launch date, determines the position of the deep fields as well as the alignment w.r.t. the dipole



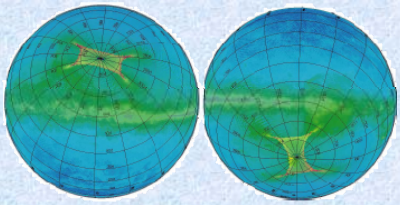
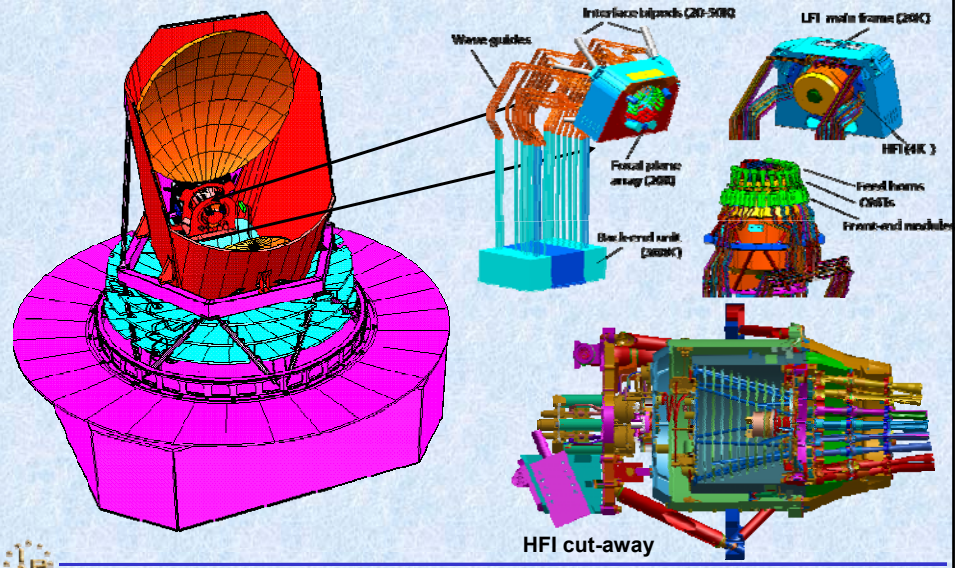


Figure 23: The coverage map at 100 GHz for the selected baseline SS is shown overlaid with the sky at 100 GHz as derived from the Galactic PLANCK sky model.

Operational details still to be investigated:
- maximum stepsize 2.5 arcmin
- fixed dwell time of 45 min

Coverage (hit map) - courtesy WG9 J.-P. Bernard, C. Burigana, B. Capellini, X. Dupac, J. Tauber and others.

ON THE DRAWING BOARD...

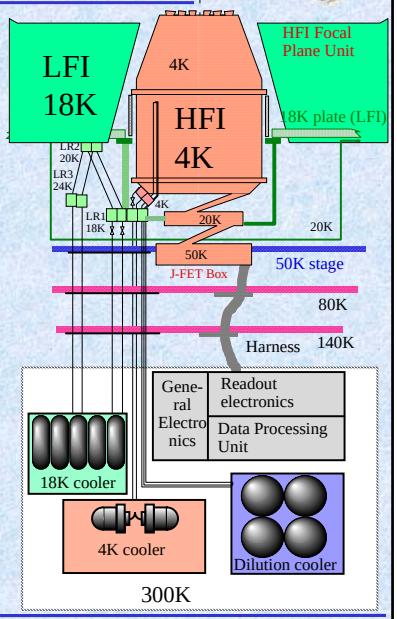


HFI cut-away

PLANCK COOLING CHAIN

To Bring
- ❑ LFI HEMTS to 18K
- ❑ HFI Bolometers to 0.1K

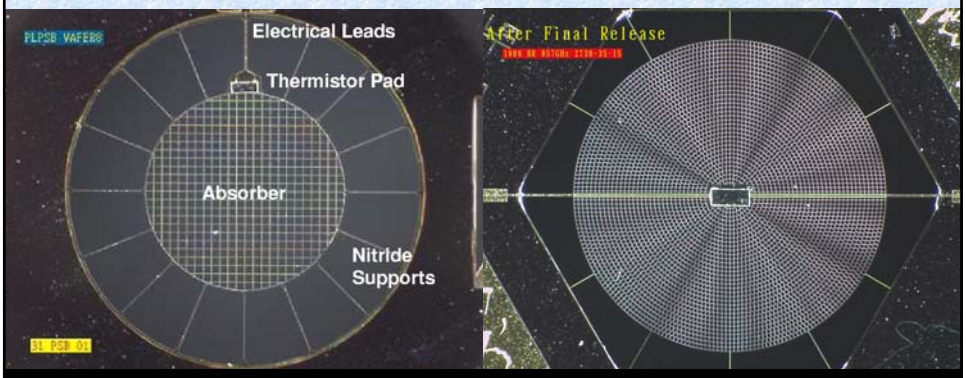
40K: passive cooling	≈2W
18K: H_2 J-T Sorption pumps (JPL, *USA*)	≈1W
4K: He J-T Mech. Pump (RAL, *UK*)	≈15mW
1.6K: J-T expansion	0.5mW
0.1K 3He/4He dilution (AL, CRTBT, IAS, *France*)	0.2μW



PLANCK NEEDED BREAKTHROUGHS

- The sensitivity goals of Planck requires several technological performance never achieved in space before
  - Sensitive & fast bolometers with
    - NEP< 2 10^{-17} W/Hz$^{1/2}$ & time constants typically < 5 msec
    (thus cooling them to 100 mK, very low heat capacity & charged particles sensitivity)
  - total power read out electronics with very low noise
    - < 6nV/Hz$^{1/2}$ from 10 mHz to 100 Hz
  - Excellent temperature stability, from 10 mHz (1 rpm) to 100 Hz (cf Lamarre etal. 04)
    - < 10 μK/Hz$^{1/2}$ for 4K box (30% emissivity)
    - < 30 μK/Hz$^{1/2}$ on 1.6K filter plate (20% emissivity)
    - < 20 nK/Hz$^{1/2}$ for detector plate (~5000 damping factor needed)
  - low noise HEMT amplifiers (⇒ cooled to 20K) & very stable cold reference loads (4K)
- Additionally:
  - low emissivity, very low side lobes, telescope (strongly under-illuminated)
  - no windows, minimum warm surfaces between detectors and telescope
  - Complex cryogenic cooling chain (50K passive+20K+4K+0.1K)
    - 20K for LFI with large cooling power K (0.7W)
    - 4K, 1.6K and 100mK for HFI
    - Thermal architecture optimised to damp thermal fluctuations (active+passive)
  - NB: 100mK cooling by dilution cooler does not tolerate micro-vibrations at sub-mg level or 7.10^{10} He atoms accumulated on dilution heat exchanger (typically He pressure 1.10^{-10} mb)

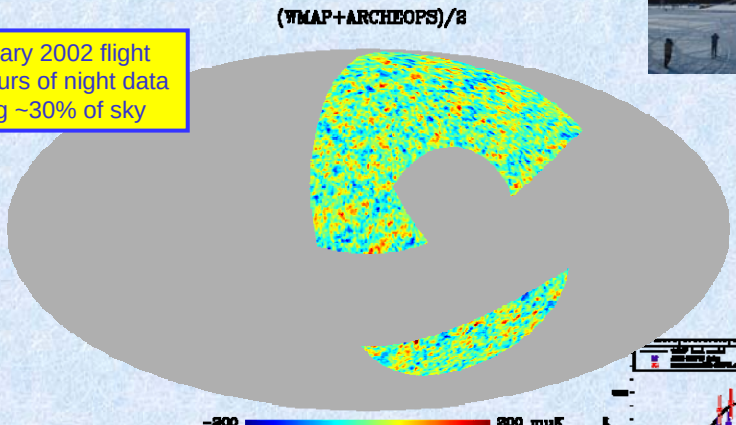
SPIDER WEB BOLOMETERS & PSBS



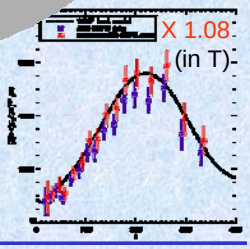
145 GHz PSBolometers | 857 GHz SWB Bolometer

All HFI flight bolometers have been built by Caltech/JPL, integrated into pixels and tested in Cardiff, integrated into HFI @ IAS and are now tested at instrument level. NB: the Flight Model includes 4 PSB pairs @ 100 GHz (following the descoping of the 100 GHz receivers from the LFI)

ARCHEOPS & WMAP

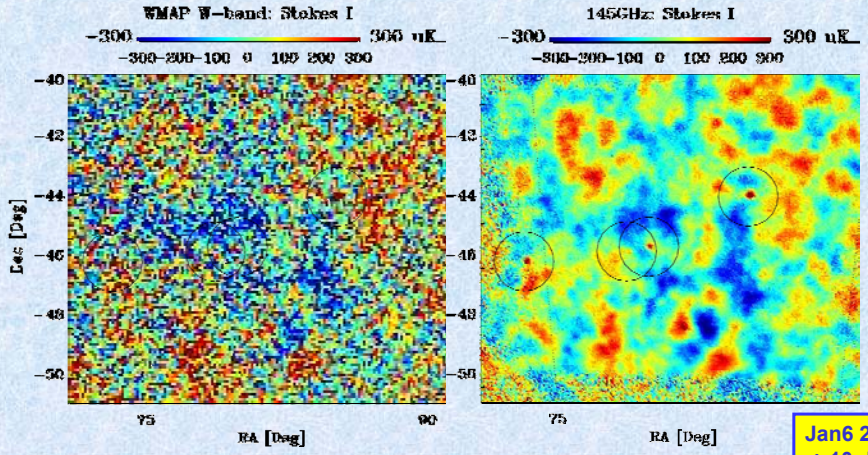


7 February 2002 flight
12.5 hours of night data
covering ~30% of sky



Archeops: 2 best bolos (143k03, 217k06) v3.2
Galactic cut |b|> 20 deg -> 19% of Sky
WMAP: 94 GHz freq map

B03 DEEP SURVEY



Masi et al. astroph/0507509

Jan6 2003
+ 10 days

A foretaste of Planck-HFI @ 145 GHz but:

- w_I =82μK.arcmin, while HFI goal is w_I =42μK.arcmin @ 143GHz (OK FM bolos delivered~36)
- Planck has matching sensitivities in 9 frequency bands, e.g. ~60 μK.arcmin @ 100 & 217 GHz
- 90 deg², i.e. 0.2% of the sky covered, instead of 100% (and deep surveys in Planck too)

PLANCK-HFI PERFORMANCE

Tested flight bolometers

		100	143	217	353
beam size	arcmin	9,5	7,1	5	5
n pixels		1,65E+06	2,95E+06	5,94E+06	5,94E+06
system sensitivity to T	μK rt s	28,8	16,4	26,1	93,9
system sensitivity to Q,U	μK rt s	43,8	38,1	58,9	262
avg time/pixel	s	19,2	10,7	5,3	5,3
ΔT/pixel	μK	6,587279	5,021682	11,32264	40,76182
ΔT/T/pixel	10^{-6}	**2,4**	**1,9**	**4,2**	**15,0**
ΔT/T/pixel bluebook	10^{-6}	2,5	2,2	4,8	14,7
Δ(Q,U)/pixel	μK	10,0	11,6	25,6	114
Δ(Q,U)/T/pixel	10^{-6}	**3,7**	**4,3**	**9,4**	**41,9**
Δ(Q,U)/T/pixel bluebook	10^{-6}	4	4,2	9,8	29,8

Survey Time	years	1			
T Sens (muK.arcmn)		63	36	57	204
T Goals Blue Book		65	42	65	200
Q, U Sens (muk.arcmin)		95	83	128	568
Q, U Goals Blue Book		104	81	134	406

As of 17 February 2006

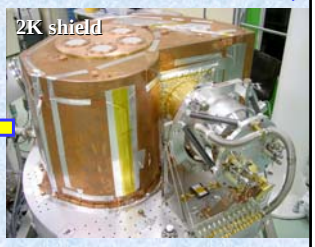
PLANCK HFI CURRENT STATUS

- Flight Model (FM) Calibration took place between April and end of July 2006;
- 19 days of science data;
- 250 GB Acquired;
- ***ongoing*** analyses, but main conclusions already available.
- See some examples below.

- NB: FM is the last model in a long series (follows the CQM which was in IAS in Nov 2004, in CSL mid 2005)

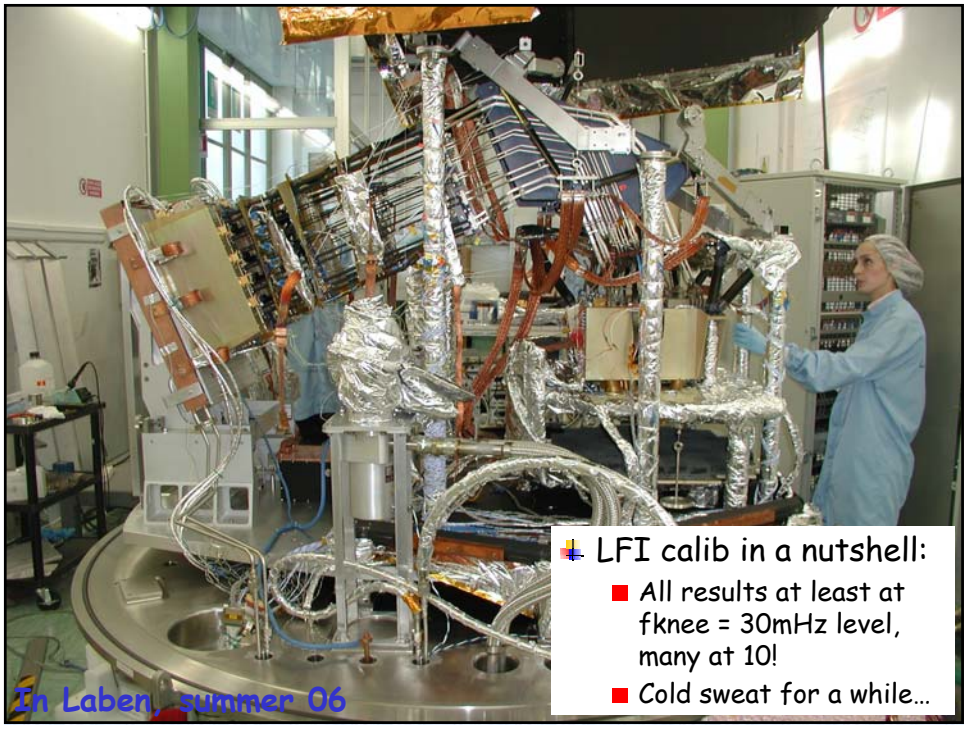
CQM INTEGRATION & CALIBRATION @ IAS

(CQM = Cryogenic Qualification Model)



MANY OTHER ANALYSES ARE ONGOING

- Total optical efficiency assessed and satisfactory.
- Detailed modelling of the detection chain (bolos+electronics) has been validated and is being used to forecast best parameters combinations (linear at 10% level including Jupiter, higher order polynomials otherwise)
- Thermal transfer functions evaluations indicate that passive thermal control of Sorption cooler should be enough to reach the temp. stability requirements on HFI Stages (4K, 1.6K, 0.1K)
- Optical cross-talk appears negligible
- Negligible Current cross talk, Weak Intensity cross-talk
- Well defined main beams, quite well described by model.
- Polarisation measurements confirm expectations from pixel level.
- …
- **Overall, the behaviour of the instrument appears to be well understood and all necessary data is now in hand.**
- So far, this confirms, at this instrument testing level (system level tests are next), that requirements will be globally met, quite possibly reaching or exceeding the goals.



- LFI calib in a nutshell:
  - All results at least at fknee = 30mHz level, many at 10!
  - Cold sweat for a while…

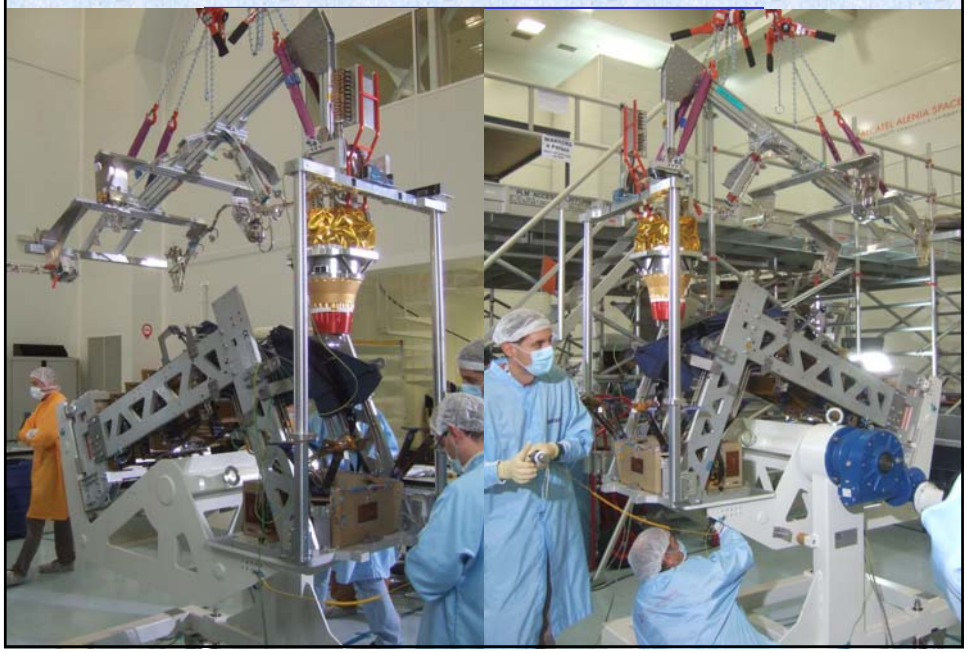
WHAT'S NEXT?

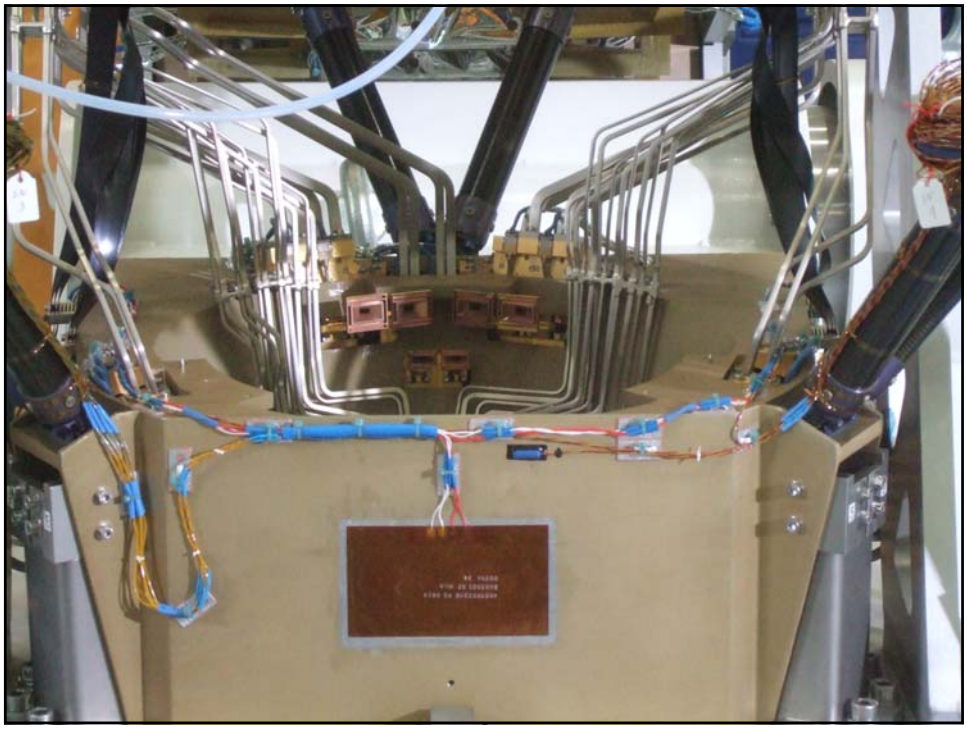
- HFI FM has been delivered to industry. Finalize HFI + LFI integration with the satellite at ALCATEL.
- Then CSL system level tests
- Current launch date is ~ mid 2008

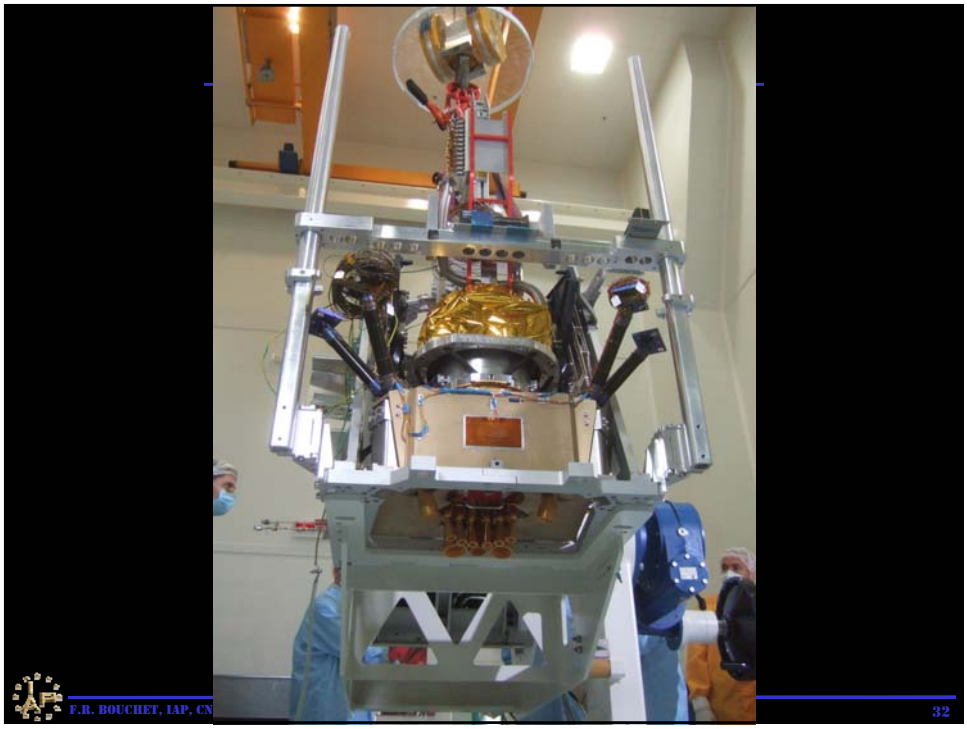
- Then 4 month to go to L2
- 2 month of PV phase
  (> survey starts in ~ 2009)
- 1 year nominal operation
- 1 year Data analysis
- 1 year proprietary > Public data deliveries ~ end of 2011

- Another year of cryogenic operations might be possible, given the performances reached so far.

LAST MONDAY @ ALCATEL-CANNES…





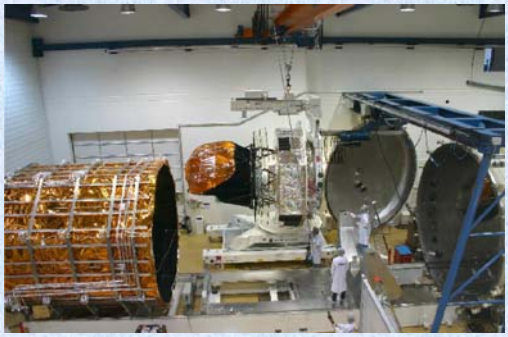


CQM@ALCATEL-CANNES

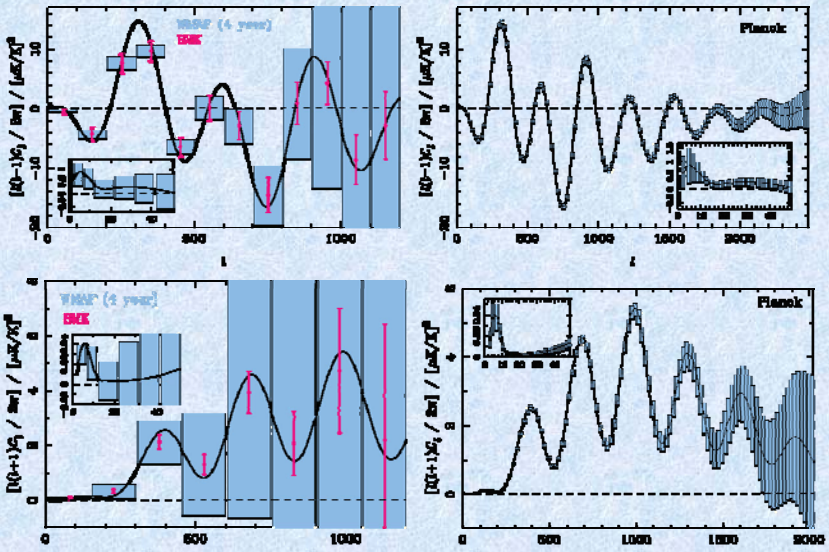
Out of acoustic chamber

CQM @ CSL (SUMMER 2005)

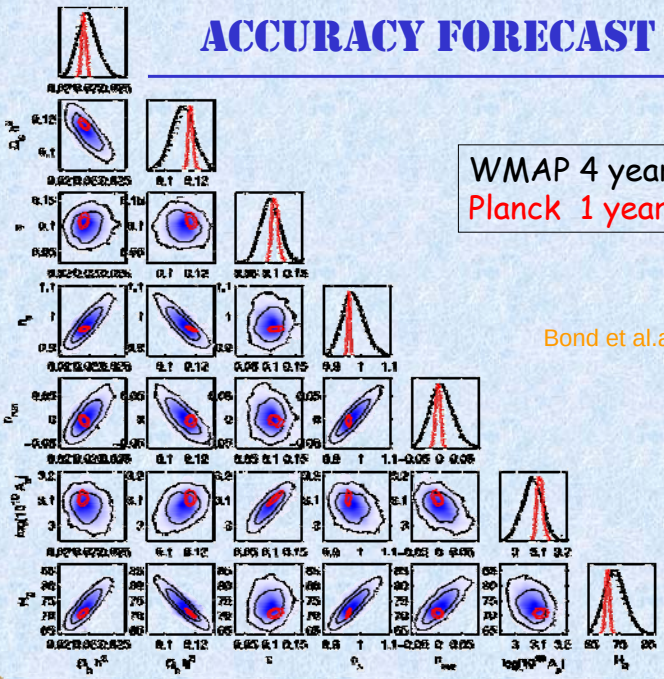
Validation of most of the cooling chain, with many points being followed up to prepare for the FM @ CSL…



TE & EE FORECASTS



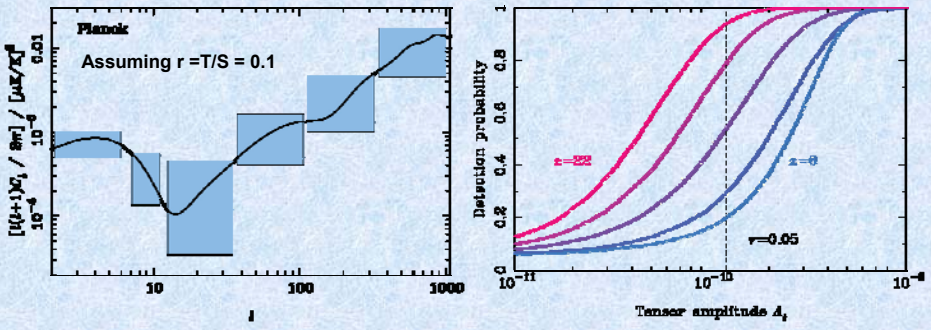
ACCURACY FORECAST



WMAP 4 years (94 GHz)
Planck 1 year (143 GHz)

Bond et al.astroph/0406195

B POLARISATION FORECASTS



Planck will be limited by its (polarisation) sensitivity (~60 µK.arcmin at best)

Indeed, it was conceived to be limited by unpolarised foregrounds confusion

CONCLUSIONS

- CMB remains unique in tightening together so many fundamental elements (Fundamental laws, cosmography and cosmogony, i.e. the cosmological paradigm for the Universe content, evolution, structuring, and it's parameters).
- Mining polarisation will surely be challenging, but in proportion to the potential pay-offs in addressing such topics as
  - Does the concordance cosmological model survive a new round of tests` , to an unprecedented accuracy level which can easily falsify it
  - does fluctuations originates during an inflation period or in some pre big bang era ?
  - find if the inflation energy scale is the Grand Unification one (~3 x 10^{15} to 3 x 10^{16} GeV)
  - do we see any evidence for extra dimensions (branes) ?
  - measure the neutrino mass with high accuracy
  - contribute to improve much the accuracy of astrophysical measurements (for ex of the dark energy equation of state with lensing in the optical)
  - …
- It will ultimately provide a unique set of maps of the microwave polarized sky, with all induced spin-offs "à la IRAS or, soon, à la Planck"
- But other probes needed
  - To confirm paradigm
  - Break degeneracies, and in particular low-z possible variations of w