The Planck-LFI programme

Reno Mandolesi
INAF/IASF Bologna
On behalf of the LFI Consortium

Planck

- *Planck* is a project of the European Space Agency - ESA – 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 collaboration between ESA and a scientific Consortium led and funded by Denmark
- *This talk is supported also by information provided by HFI and ESA*

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- Marco Bersanelli – LFI Instrument Scientist
- Chris Butler – LFI Project Manager
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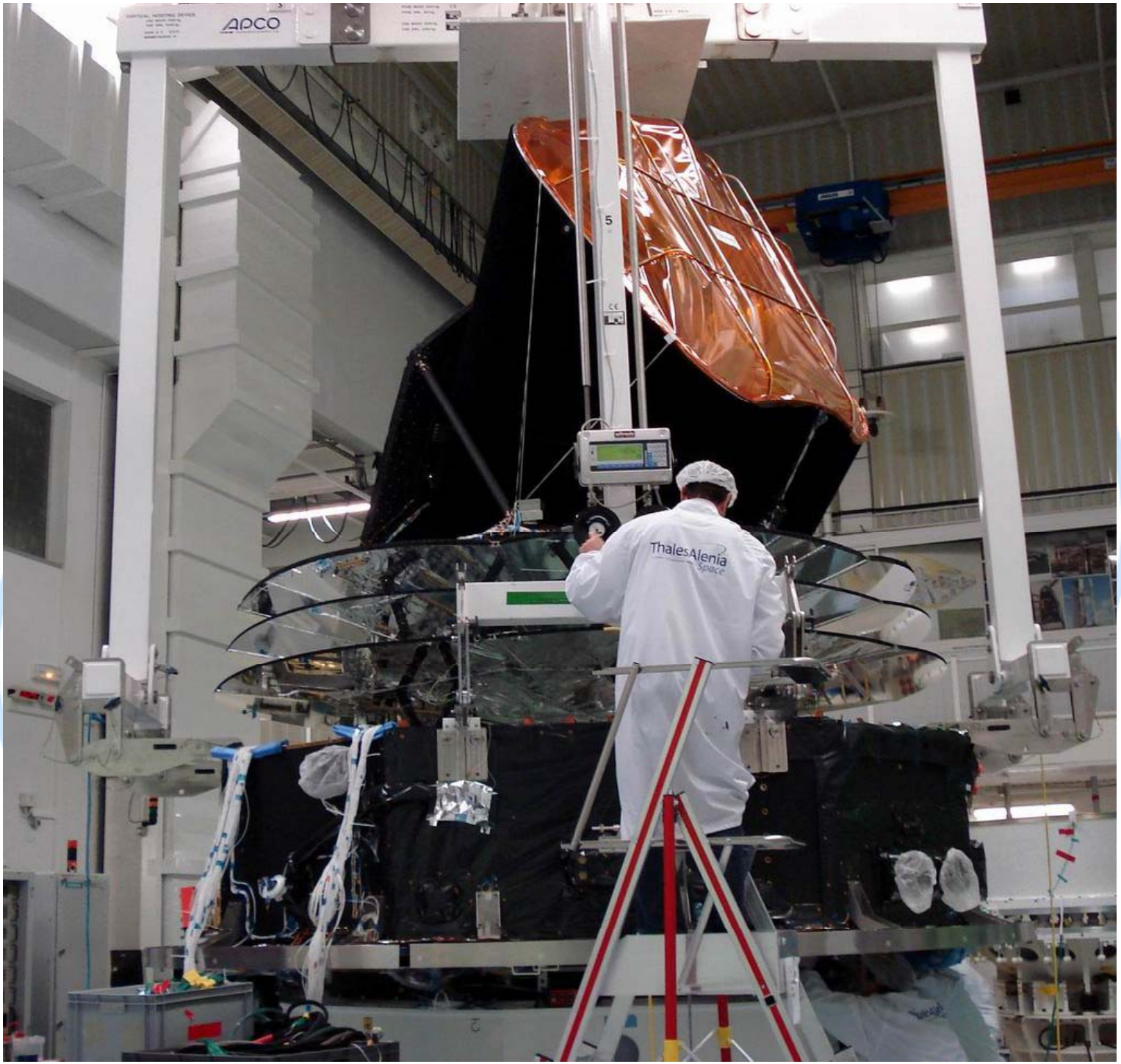
- Anna Gregorio – LFI IOT Manager
- Charles Lawrence – LFI Survey Scientist
- Jan Tauber – Planck Project Scientist
- Thomas Passvogel – H-P Project Manager
- Gerry Crone – H-P P/L Manager
- Funding Agencies (for Italy: INAF & ASI – M.C. Falvella) & ESA
- Industries (Thales Alenia Space)
- Over 1000 people (scientist, engineers, managers, technical staff) who have been deepley involved in Planck in the past 17 years

Outline

- Planck Status
- Cosmology and Astrophysics with LFI and Planck
- The Instrument
- The LFI Programme
- Conclusions

Planck Status

- Launched from Europe's spaceport in Kourou, French Guiana.
- Launch time: 14 May 2009 at 13:12 UTC
- Rocket Ariane 5 ECA. Also Herschel was on board.
- Commissioning, Performance & Verification (CPV) phase begun shortly after separation.
- CPV expected to end by 7th August
- First Light Survey (2 weeks) will begin August 8th (TBC) followed by the beginning of the nominal operation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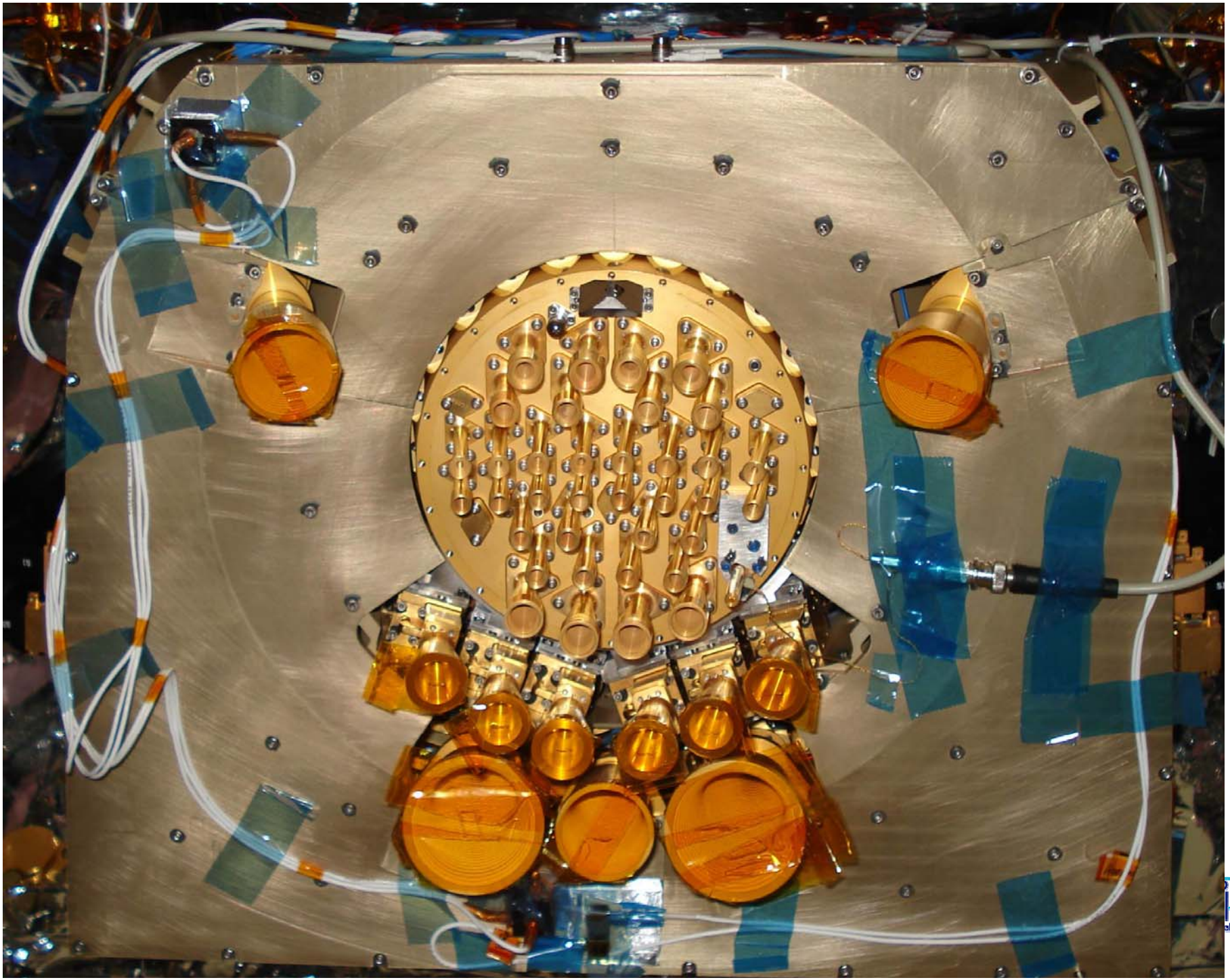

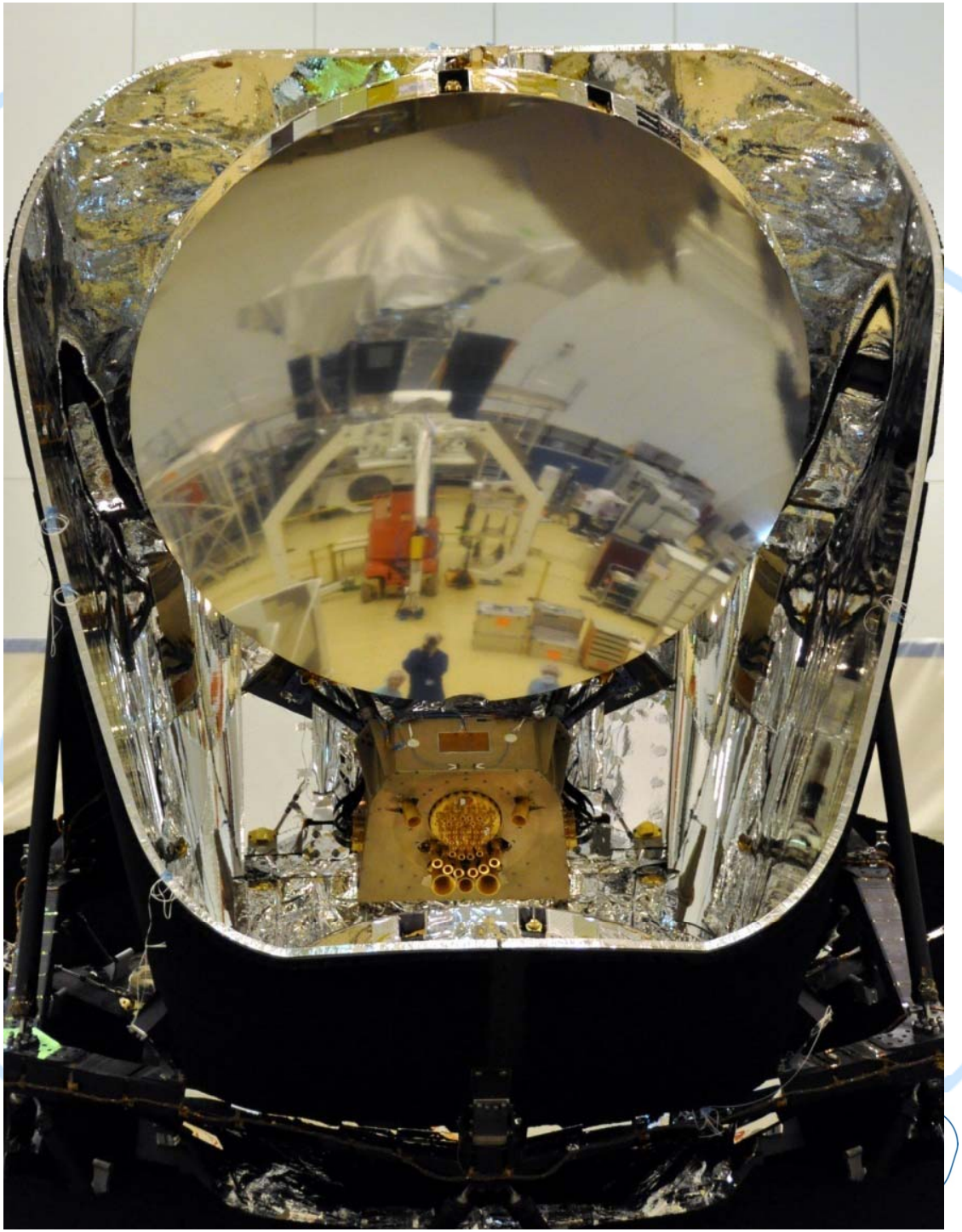

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Planck Pre-launch Status: the Planck-LFI Programme

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Abstract

This paper provides an overview of the Low Frequency Instrument (LFI) programme within the ESA *Planck* mission. The LFI instrument has been developed to produce high precision maps of the microwave sky at frequencies in the 27–77 GHz range, below the peak of the Cosmic Microwave Background (CMB) radiation spectrum. The scientific goals are described, ranging from fundamental cosmology to Galactic and extragalactic astrophysics. The instrument design and development are outlined, together with the model philosophy and testing strategy. The instrument is presented in the context of the *Planck* mission. The LFI approach to on-ground and in-flight calibration is described. We also provide a description of the LFI ground segment. We present results of a number of tests that demonstrate the capability of the LFI Data Processing Centre (DPC) to properly reduce and analyse LFI flight data, from telemetry information to sky maps and other scientific products. The organization of the LFI Consortium is briefly presented as well as the role of the Core Team. All tests carried out on the LFI flight model show excellent performance of the instrument and its various sub-units. The data analysis pipeline has been tested and its main functionalities proven. In the first three months after launch, the commissioning, calibration, performance, and verification phases will be completed, after which *Planck* will begin its operational life, with LFI ready to be an integral part.

Key words. (Cosmology): Cosmic Microwave Background – Galactic and extragalactic astrophysics – Space vehicles – Calibration – Data analysis

1. Introduction

In 1992 the Cosmic Background Explorer (*COBE*) team announced the discovery of intrinsic temperature fluctuations in the cosmic microwave background radiation (CMB; see appendix A for a list of the acronyms appearing in this paper) on angular scales larger than 7° and at a level of a few tens of μK (Smoot et al. 1992). One year later two space-borne CMB experiments were proposed to the European Space Agency (ESA) in the framework of the Horizon 2000 Scientific Programme: the Cosmic Background Radiation Anisotropy Satellite (COBRAS; Mandolesi et al. 1994), an array of receivers based on High Electron Mobility Transistor (HEMT) amplifiers; and the SAtellite for Measurement of Background Anisotropies (SAMBA), an array of detectors based on bolometers (Tauber et al. 1994). The two proposals were accepted for an assessment study with the recommendation to merge. In 1996 ESA selected a combined mission called COBRAS/SAMBA, subsequently renamed *Planck*, as the third Horizon 2000 Medium-Sized Mission. Today *Planck* forms part of "Horizon 2000" ESA Programme.

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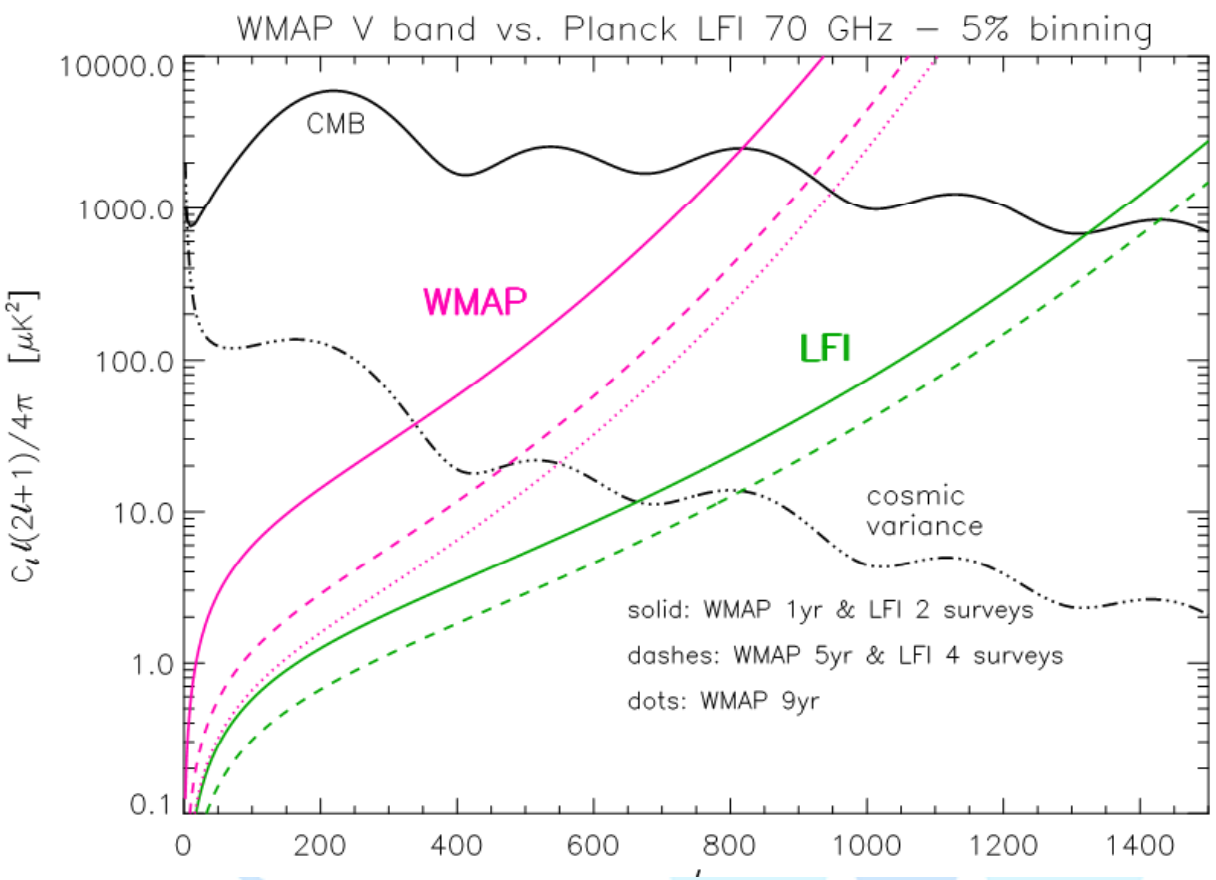
- Mandolesi et al., submitted to A&A
- Member of a series of > 40 papers
- Will establish the pre-launch status of Planck.

Planck: the 3rd generation space CMB experiment

- Planck gains a factor 2.5 in angular resolution and up to10 in instantaneous sensitivity with respect to WMAP
- LFI uses coherent detection and HEMTS based amplifiers in 3 bands 30 to 70 GHz, photometric reference loads on the 4K box of the HFI FPU. LFI is cooled at 18 K, read in total power (22 polarized channels, 44 tot power signals). Small 1/f noise.
- HFI bolometers are cooled to 100 mK, 6 bands 100 to 857 GHz, read in total power mode with a white noise from 10 mHz to 100 Hz (no 1/f noise in the signal range), nearly photon noise limited in the CMB channels (100-200 GHz)
- Temperature power spectrum sensitivity is limited by the ability to remove foregrounds (supported by the broad frequency coverage: 30 GHz-1 THz)

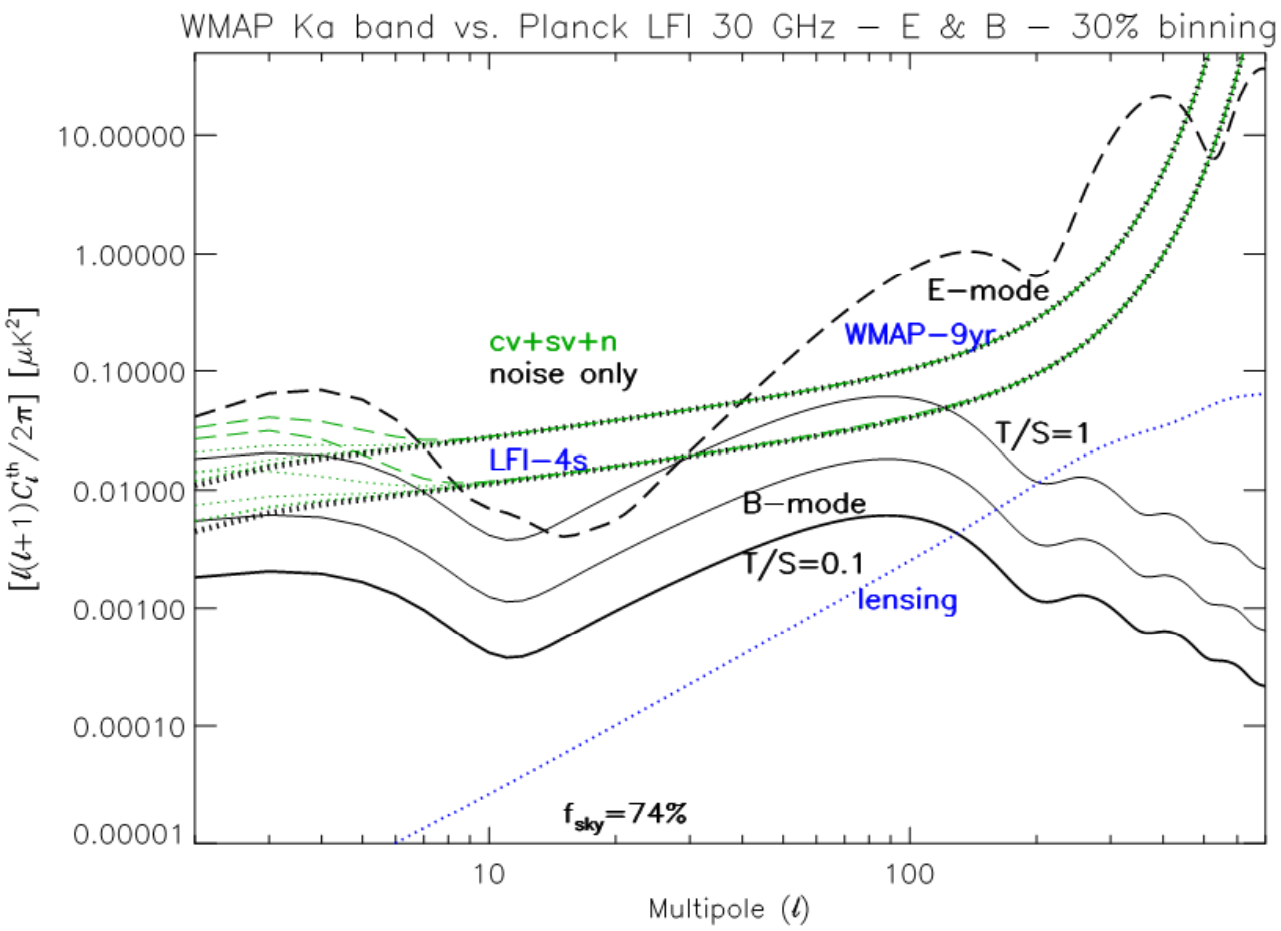
Cosmology with LFI: CMB Intensity



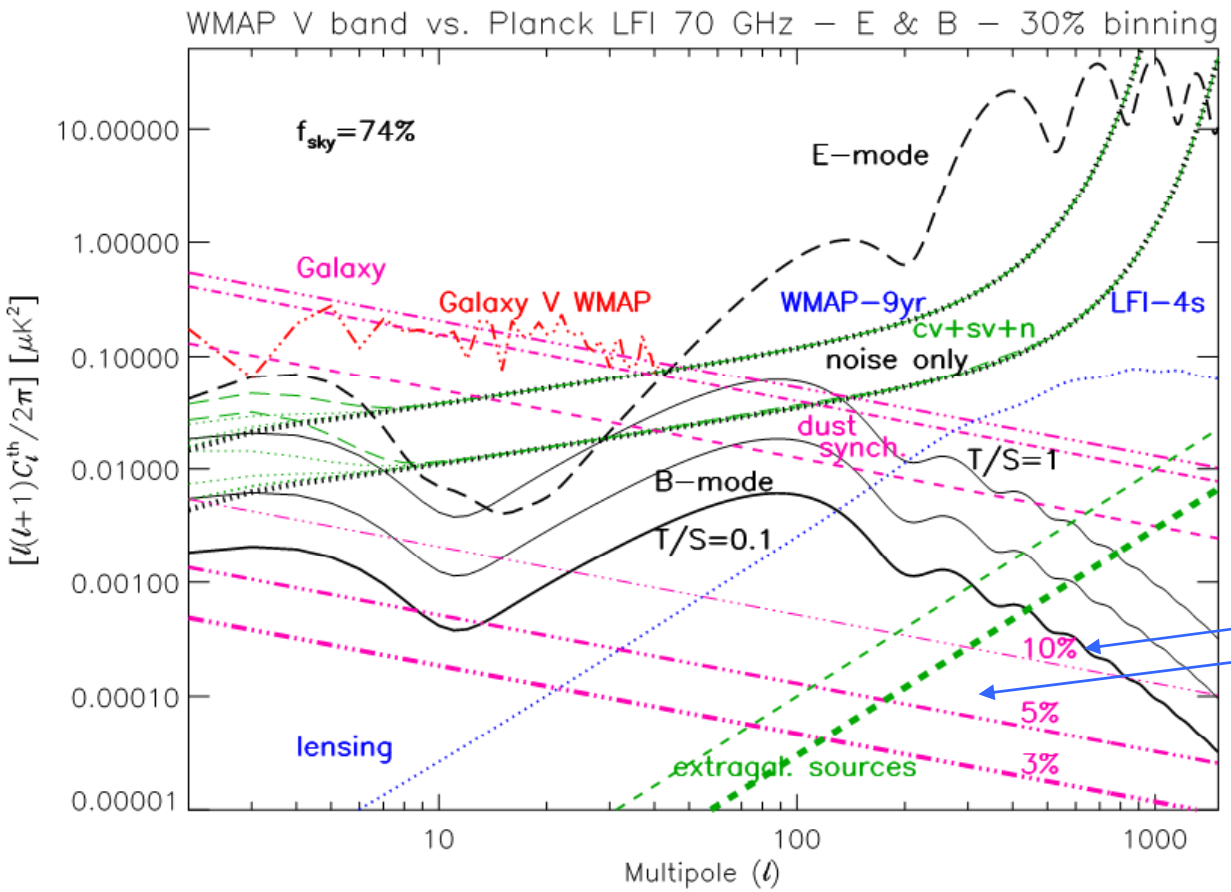
$$\frac{\delta C_\ell}{C_\ell} \simeq \sqrt{\frac{2}{f_{\rm sky}(2\ell+1)}}\left[1+\frac{A\sigma^2}{NC_\ell W_\ell}\right]$$

- 2 acoustic peaks above WMAP V band

Cosmology with LFI: CMB Polarization

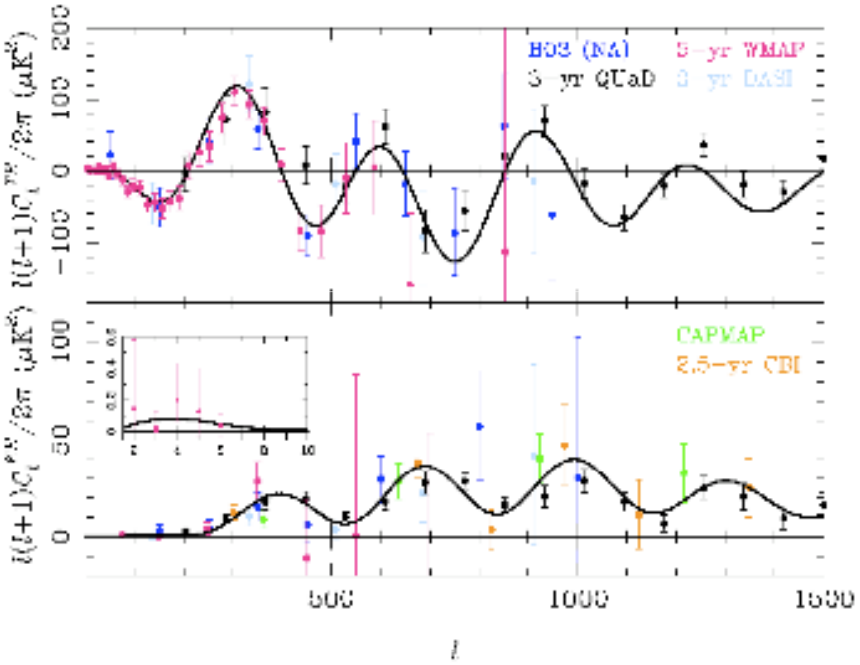


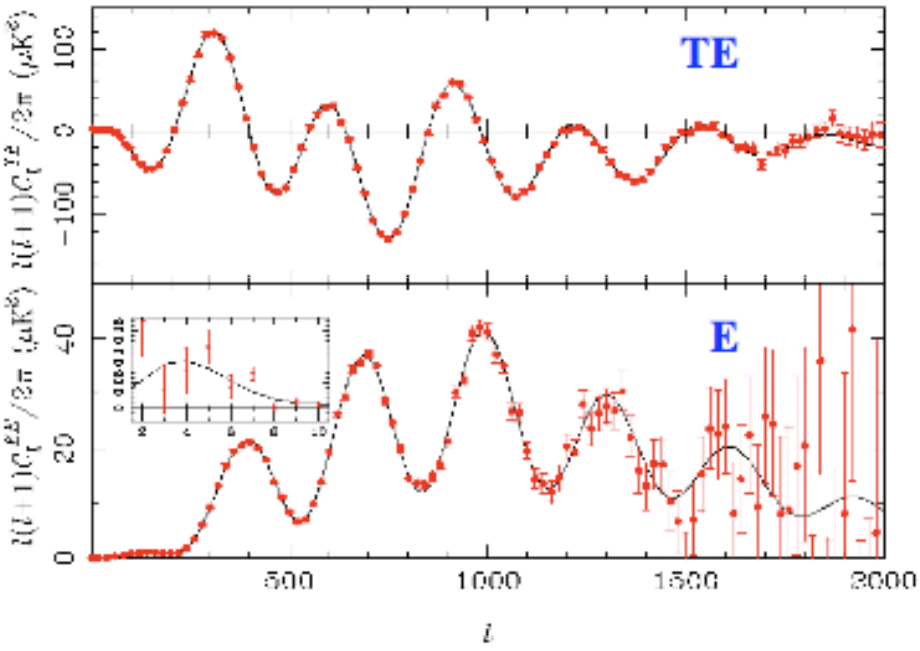
CMB Polarization vs foreground emission



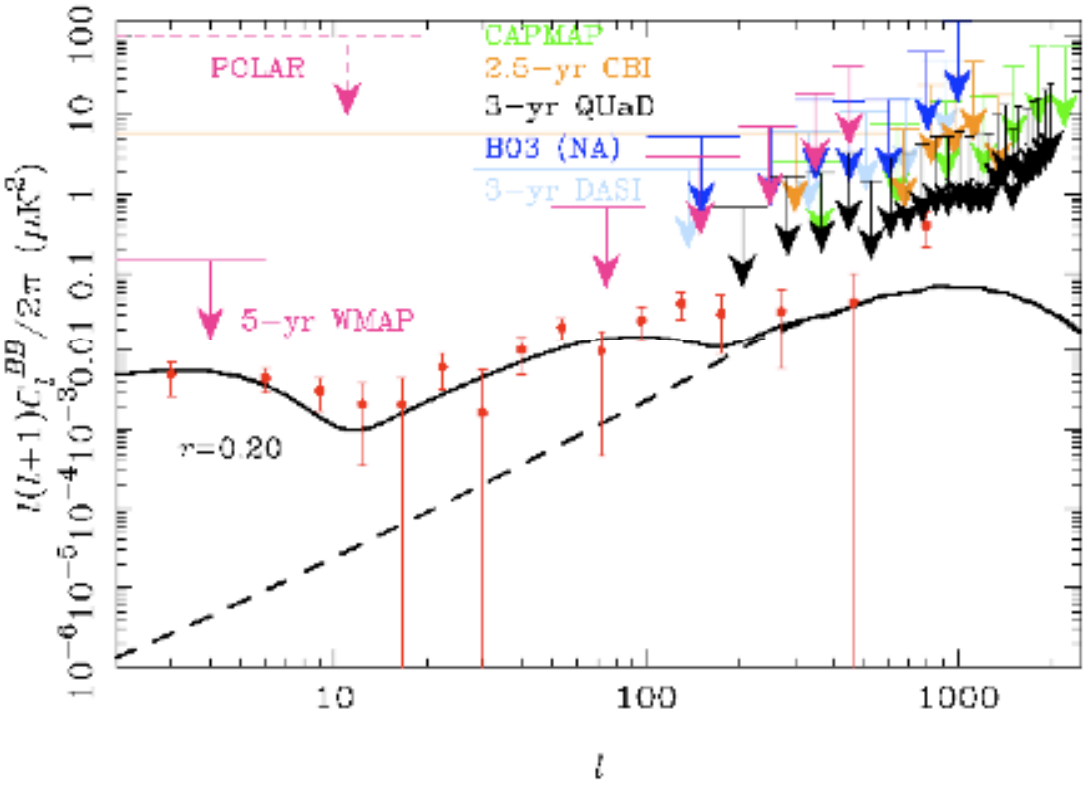
- Minimum in polarized Galactic emission around 70 GHZ
- Impact of residual contamination after foreground cleaning

E mode polarization

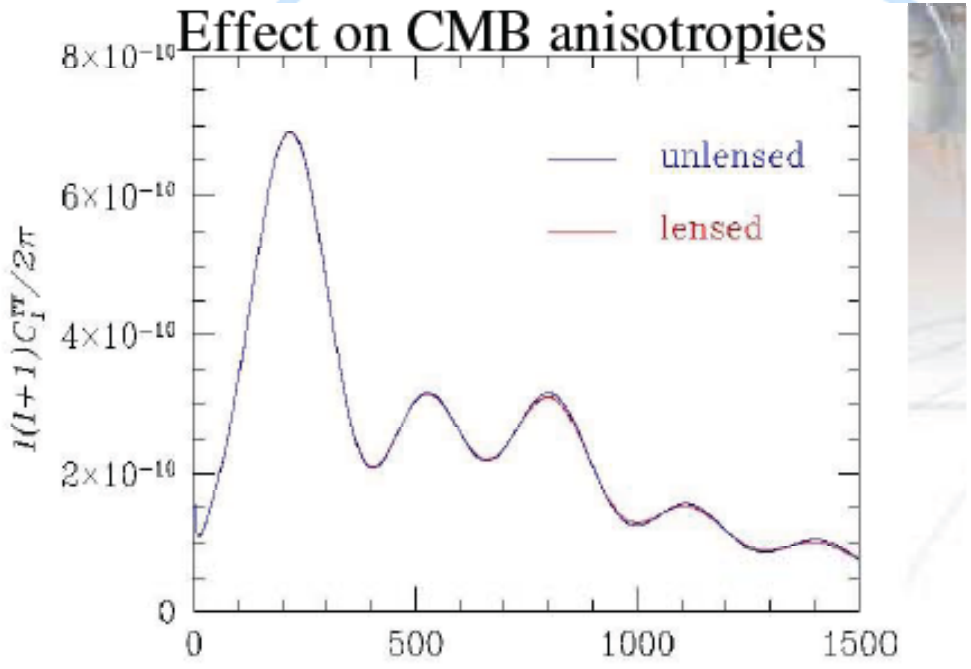


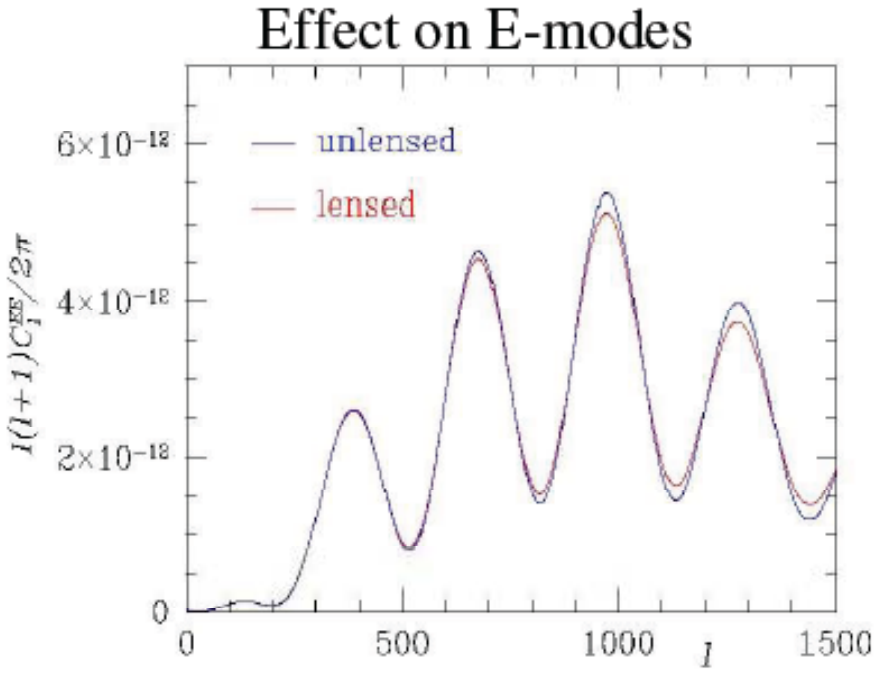


B-modes: present limits and Planck prospects

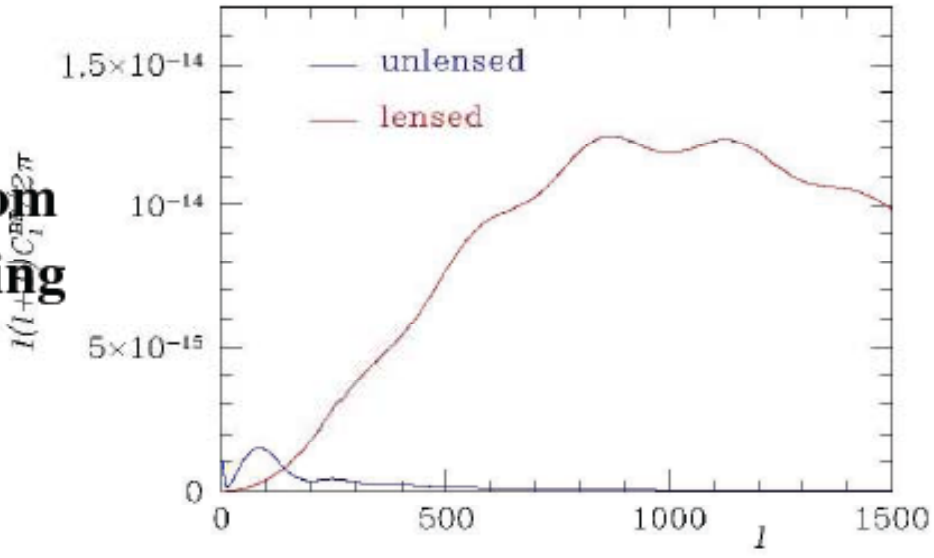


Polarization from lensing



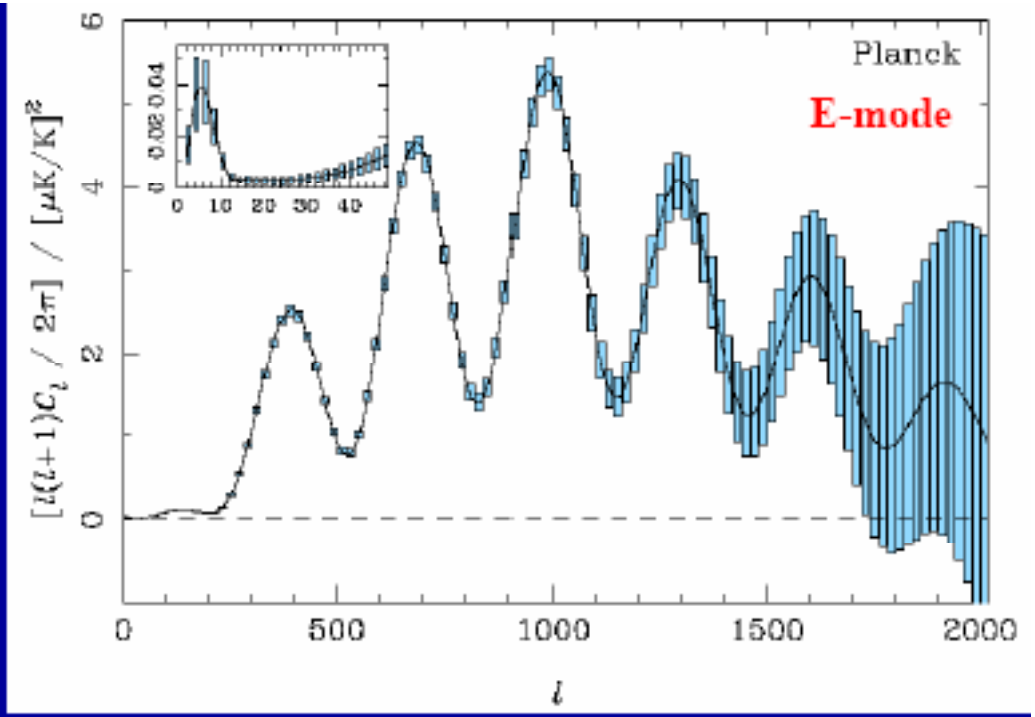


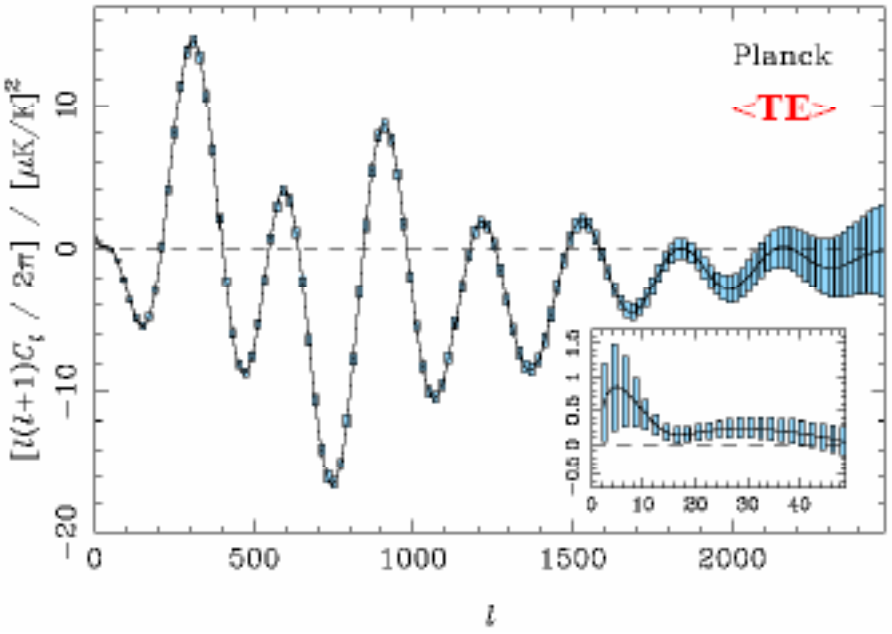
B-modes converted from E-modes through lensing

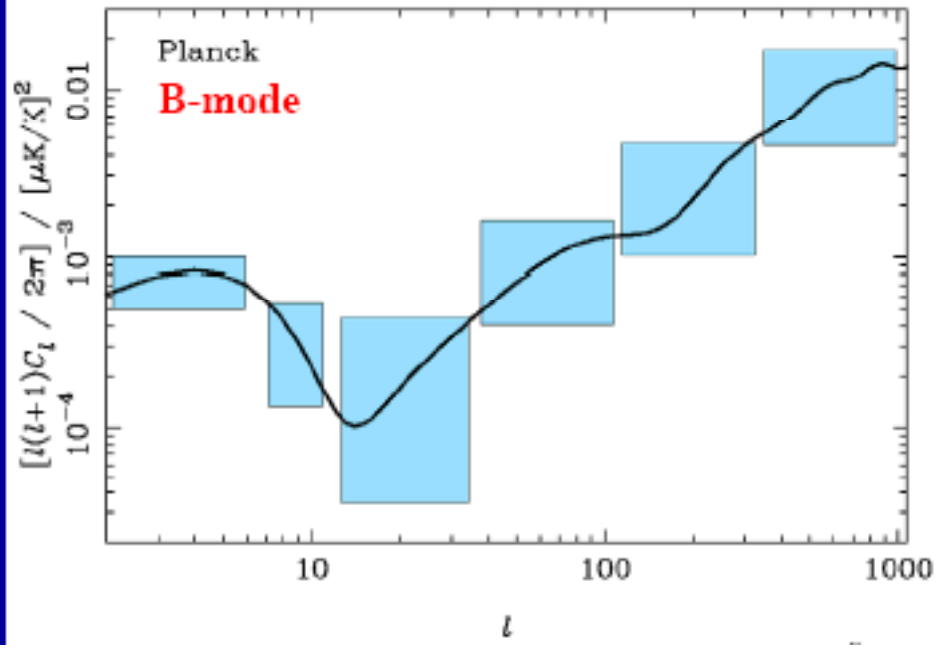


The Planck results (in a few years' time)

Predicted power spectrum recovery for Planck

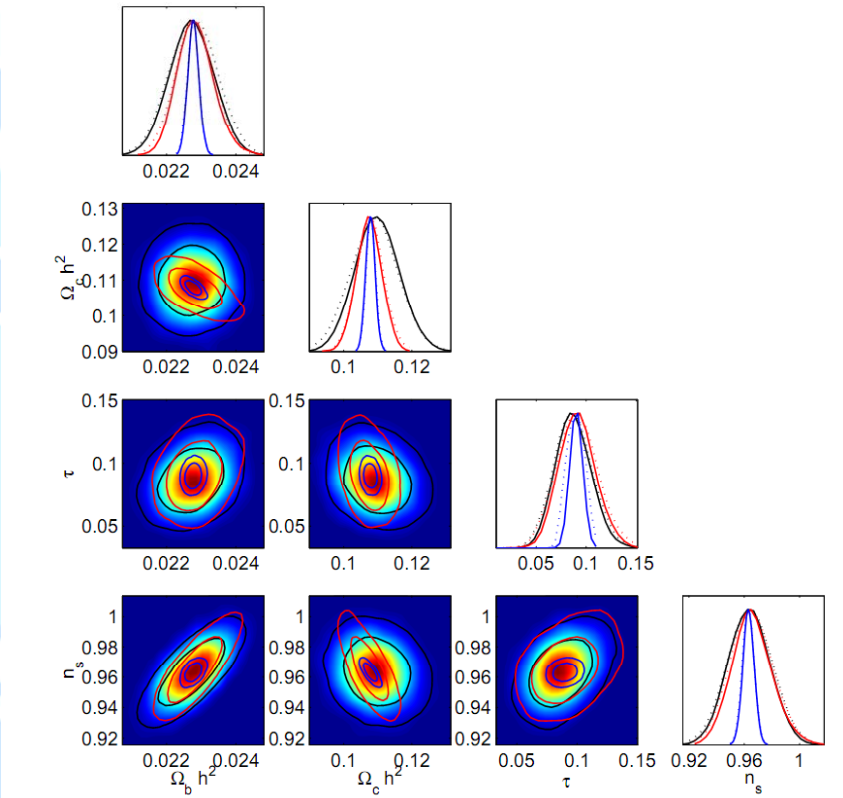






Cosmological parameters from Planck

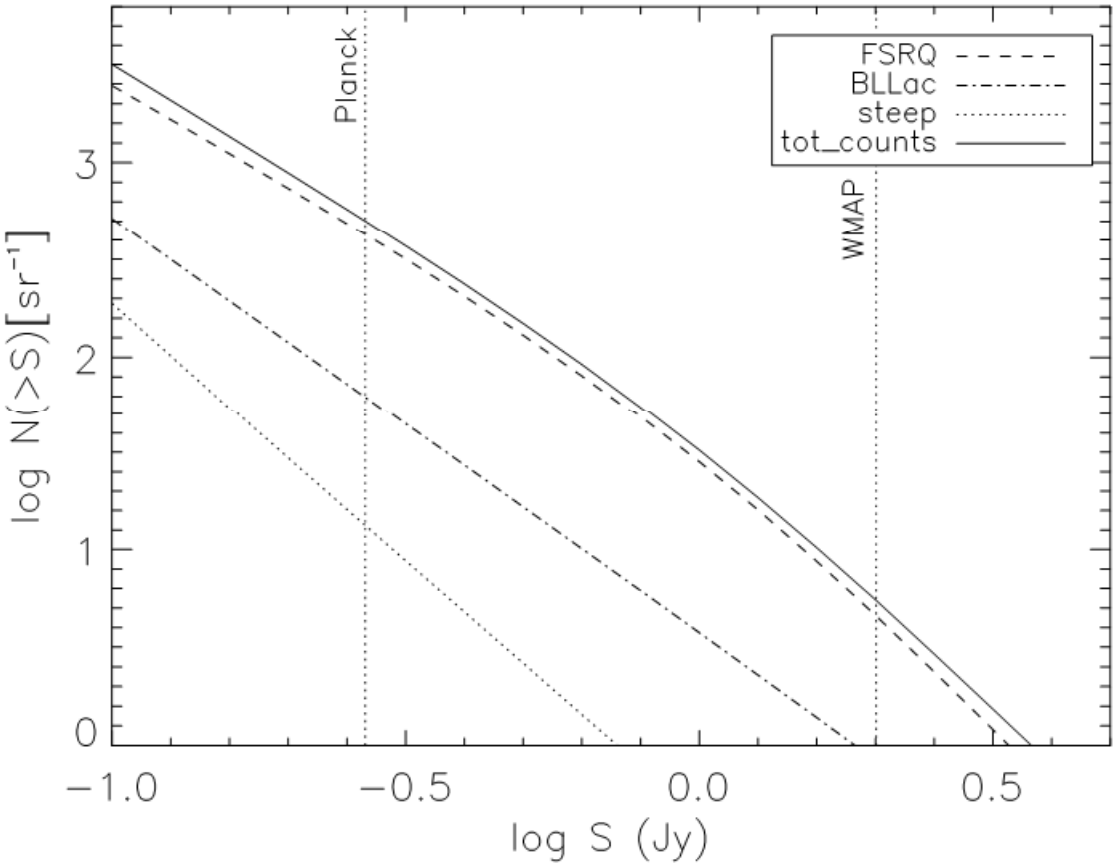
- Black: WMAP
- Red: Planck LFI
- Blue: Planck LFI + HFI (assuming foreground removal)



Galactic astrophysics

- Planck with the 9 frequency bands all sky surveys of the fluctuations of the galactic emission will provide a major improvement on large scale dust emission (mainly above 100 GHz with HFI), poorly known, particularly in polarization
- However since dust emission still dominates over free-free and synchrotron at 70 GHz, LFI will provide crucial information on the low frequency tail of this component
- The LFI frequency channels at 30 & 44 GHz will be relevant for the study of the diffuse polarized synchrotron emission and for the essentially unpolarized free-free emission

Extragalactic astrophysics 1/2



- Integral counts for several radio sources @ 70 GHz

- LFI expects to detect between1000 and 1500 sources at each of the 3 freq.s with completeness fluxes of 540,340, 270mJy (@ 30, 44, 70 GHz)

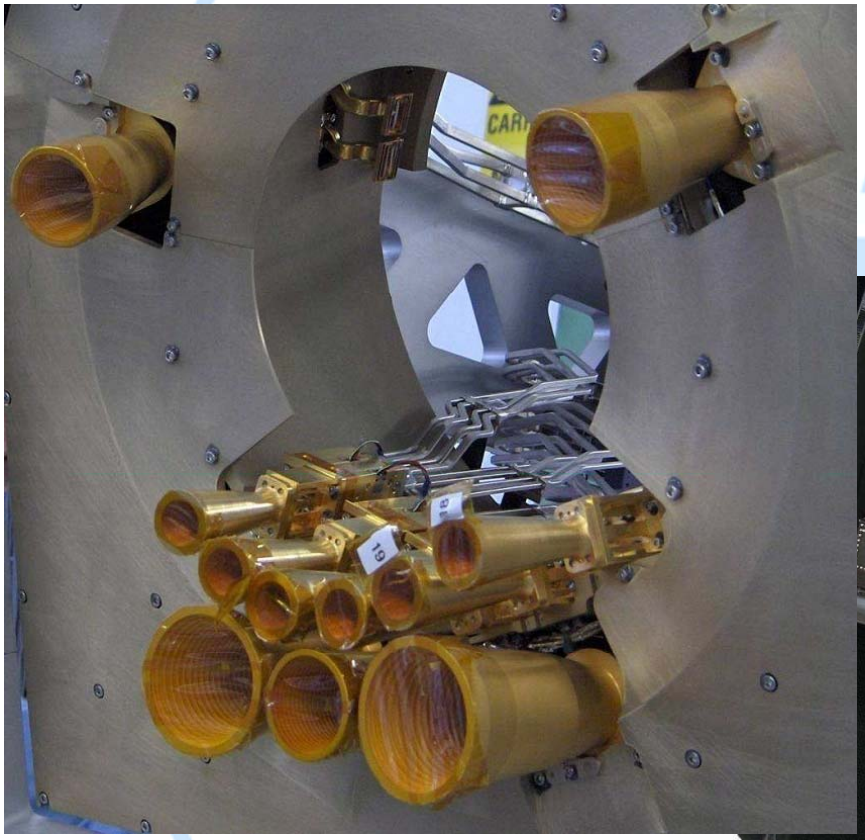
- Most of the sources will be FSRQ

- The no. of expected blazars and BLLac is similar to those expected from Fermi-GLAST. For those common expect relashionship beween radio and gamma ray properties

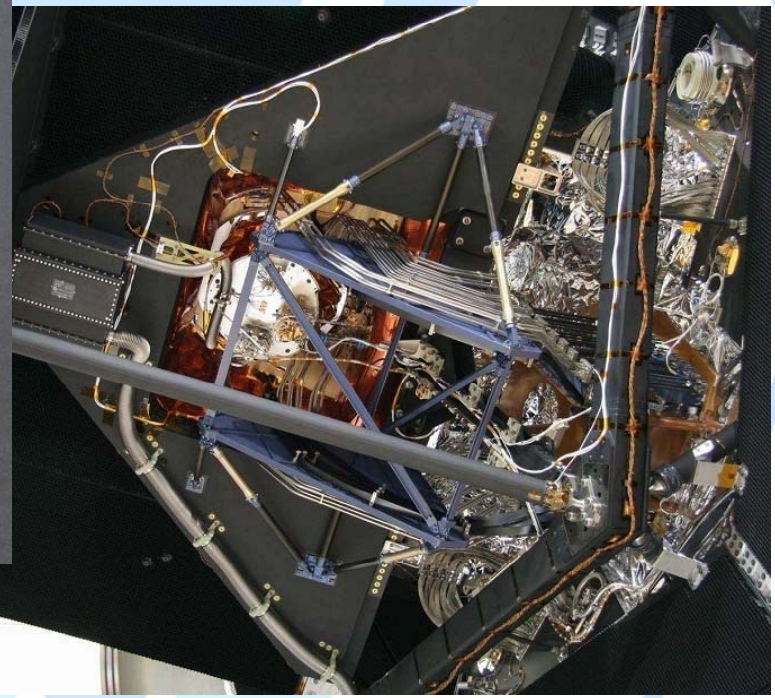
Planck Extragalactic astrophysics 2/2

- Polarization measurements
- Flaring objects & High Frequency Peakers
- Astrophysics of Clusters (mainly HFI): over 1000 clusters will be detected out to z of the order of unity via their thermal Sunyaev-Zel'dovich effect

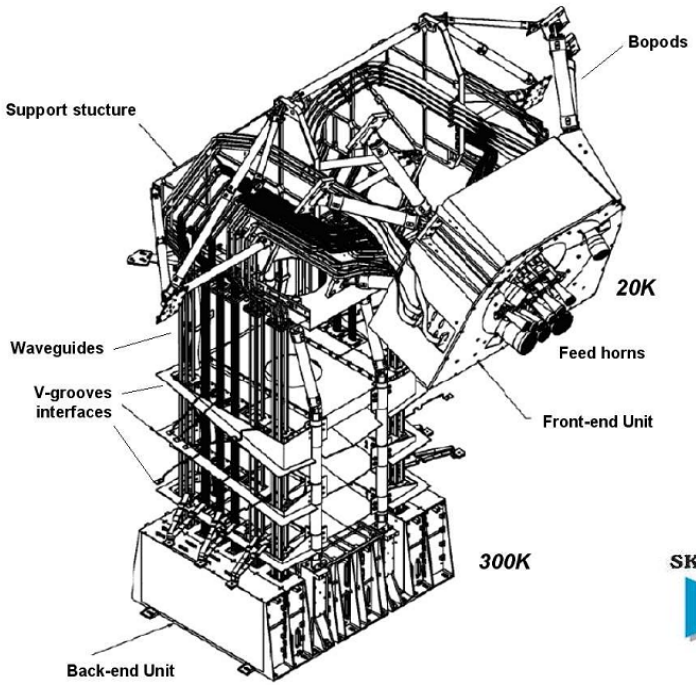
The focal plane

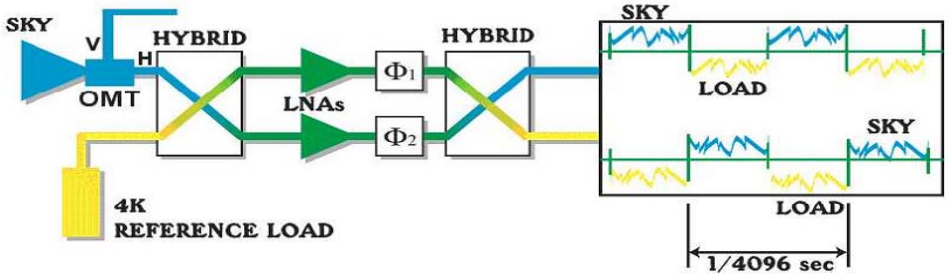


•Back view



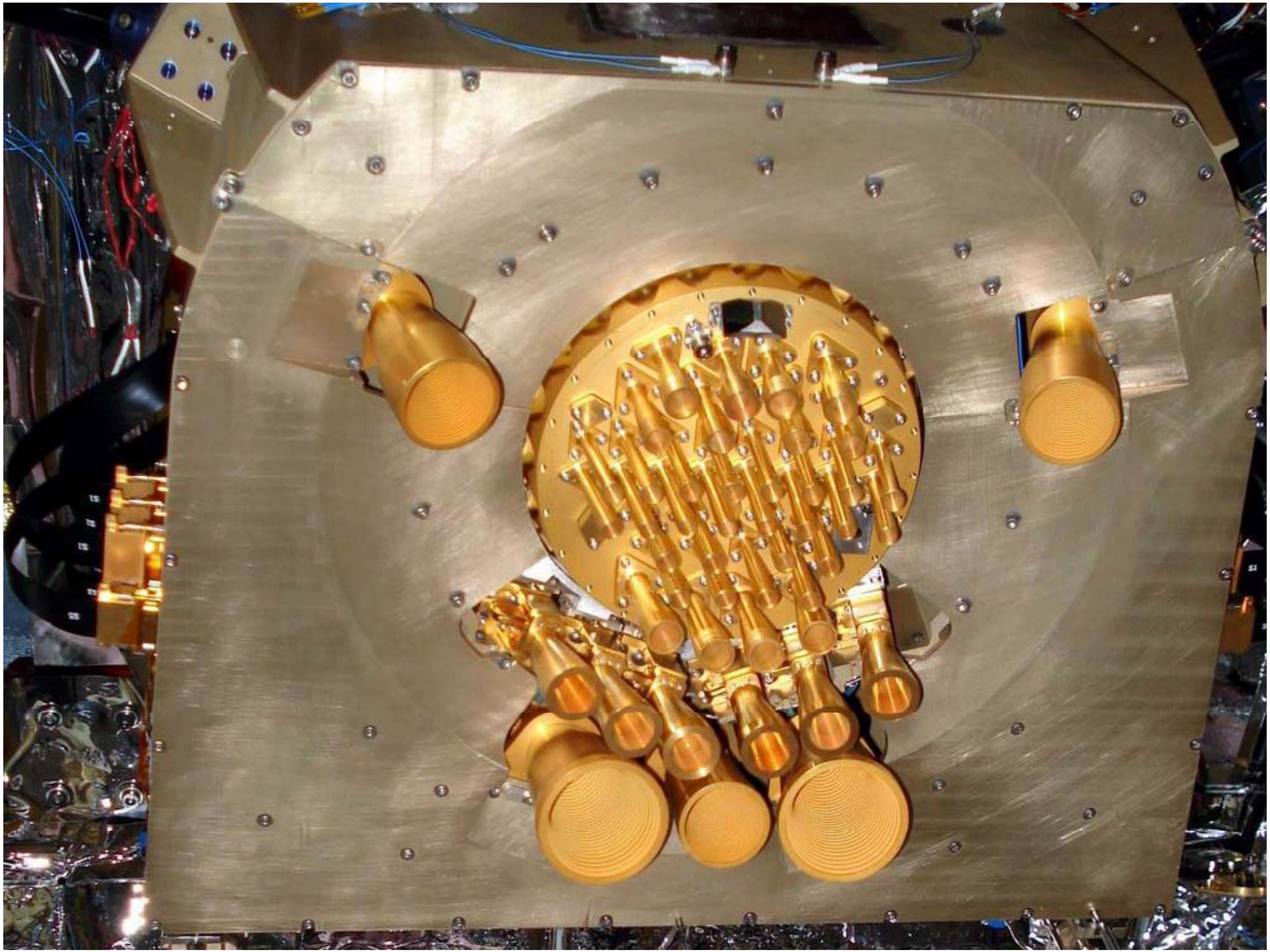
The Instrument

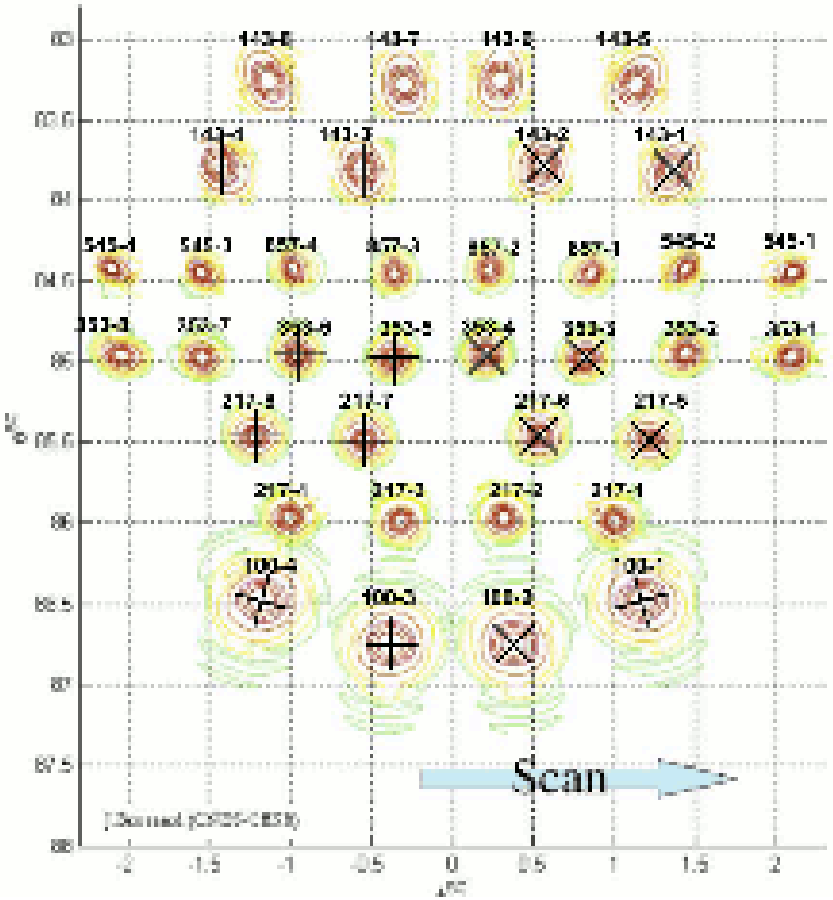




Performances

Frequency channel	30 GHz	44 GHz	70 GHz
InP detector technology	MIC	MIC	MMIC
Angular resolution [arcmin]	33	24	14
δT per 30′ pixel [μK]	8	8	8
δT/T per pixel [μK/K]	2.67	3.67	6.29
Number of radiometers (or feeds)	4 (2)	6 (3)	12 (6)
Effective bandwidth [GHz]	6	8.8	14
System noise temperature [K]	10.7	16.6	29.2
White noise per channel [μK $\cdot \sqrt{s}$]	116	113	105
Systematic effects [μK]	< 3	< 3	< 3





Centre Freq. (GHz)	100	143	217	353	545	857
ΔT/T per pixel (I Stokes parameter)	**3**	**2.2**	**4.8**	**20**	**150**	**6000**
Proposal goal	*2.5*	*2.2*	*4.8*	*14.7*	*147*	*6700*
ΔT/T per pixel (Q and U Stokes parameters)	**4.8**	**4.1**	**9**	**38**	–	–
Proposal goal	*4.0*	*4.2*	*9.8*	*29.8*	–	–

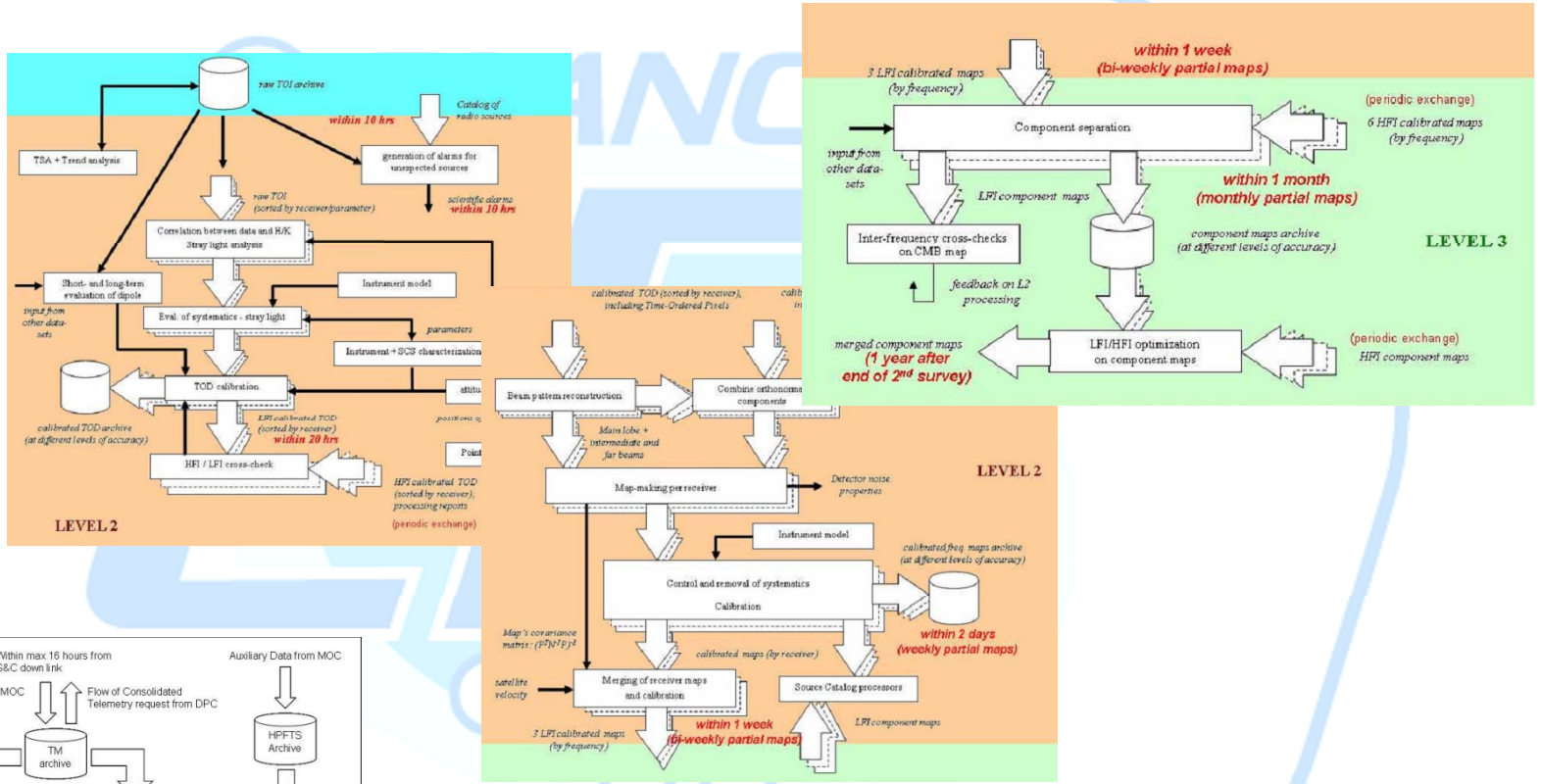
The LFI Programme

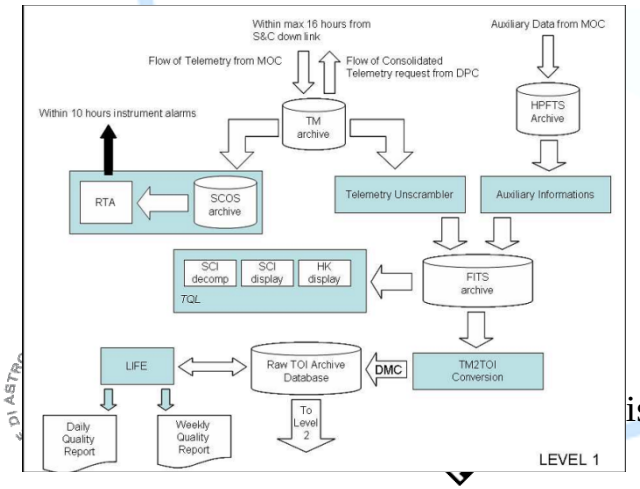
- The Planck Avionics Model (AVM) in which the System Bus was shared with the Herschel satellite, and allowed basic electrical interface testing of all units and communications protocol and software interface verification.
- The Planck Qualification Model (QM) which was limited to the Planck Payload Module (PPLM) containing QMs of LFI, instead of LFI, HFI, and the Planck telescope and structure that would allow a qualification vibration test campaign to be performed at payload level, as well as alignment checks, and would, in particular, allow a cryogenic qualification test campaign to be performed on all the advanced instrumentation of the payload that had to fully perform in cryogenic conditions.
- The Planck Protoflight Model (PFM) which contained all the Flight Model (FM) hardware and software that would undergo the PFM environmental test campaign, culminating in extended thermal and cryogenic functional performance tests.

Scientific Data Analysis

- Most accurate microwave experiment to date in terms of control, reduction and correction of systematic and stochastic noise.
- Will deliver the most accurate and complete maps per frequency (in the range 30 GHz to > 900 GHz) and per astrophysical component thanks to a very ambitious component separation engine.
- Will make heavy use of computational resources, setting a new tier for the field (NERSC-LBNL, CINECA in Bologna, CSC in Finland, MARE NOSTRUM in Spain and DEISA)

DPC Pipelines





The LFI DPC is in Trieste

LFI DPC Processing

Level 1

Monitoring of instrument health and generation of Time Ordered Information (TOI);

Real Time Asessment (RTA); Telemetry Quick Look (TQM)

Day to day basis operations: telecommands etc.

Level 2

Differenced data (sky-load), balancing the radiometers&reduce impact of 1/f noise

Calibration of data sets (of each detector)

Instrumental performance and properties, systematic effects

Sky Maps for each channel (Iterative process)

Level 3

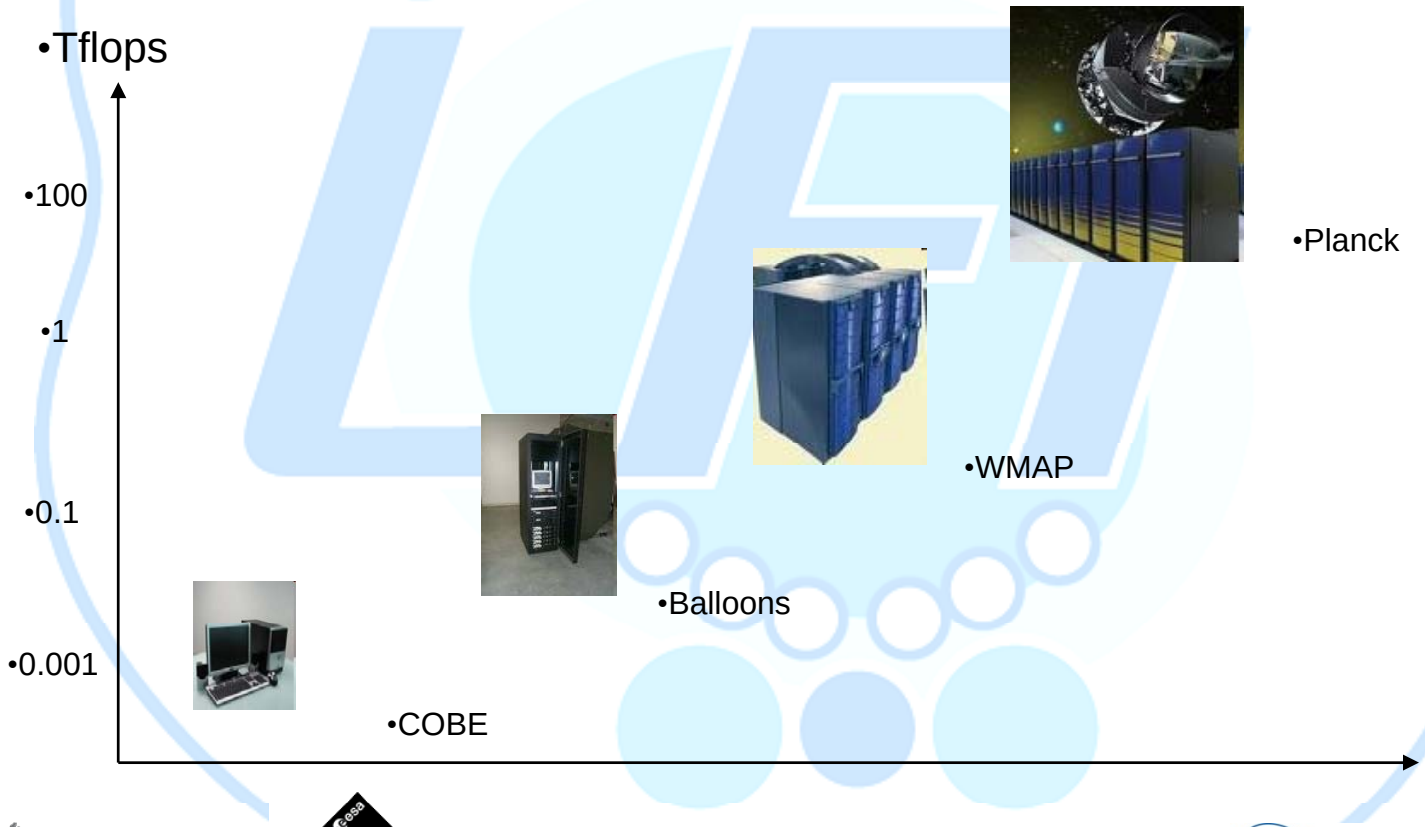
Component separation

Angular Power spectra

Montecarlo's

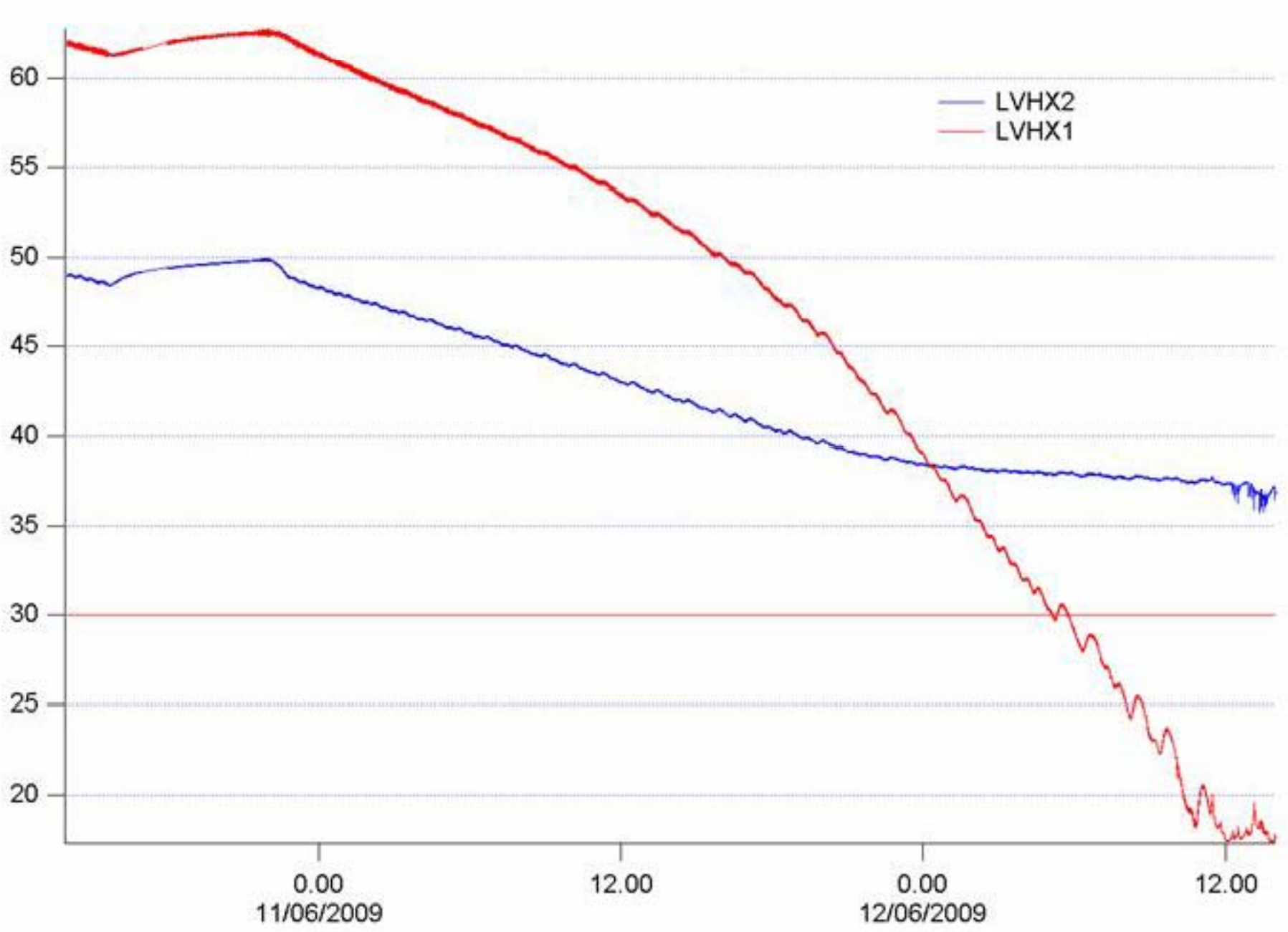
Cosmological parameters

Escalation in computer power



….and much more….

- Optics (telescope, beams, RFQM tests, modelling using GRASP, Thermo-mechanical model
- Beams and calibration of the focal plane (planets, dipole, Crab, sources)
- Systematic effects
- DPC Level S, E2E tests etc.
- Component separation methods
- Extensive use on Montecarlo's
- Cryogenic chain (coldest satellite in the sky)
- Sorption Cooler (20K,>1W, long life time, H2 J-T expansion)
- Scanning strategy (spinning, 85 deg, 2' spacing each repointing, cycloidal modulation around spin axis – 6 month period- with ½ cone of 7.5 deg for a better sky coverage of all detectors)
- Organisation of the Consortia (e.g. Core Teams. WG's etc..)
- Product delivery and Planck Legacy Archive
- ERCSC (Early Release Compact Source Catalogue) – IPAC
- Science: non gaussianity, large scale anomalies etc..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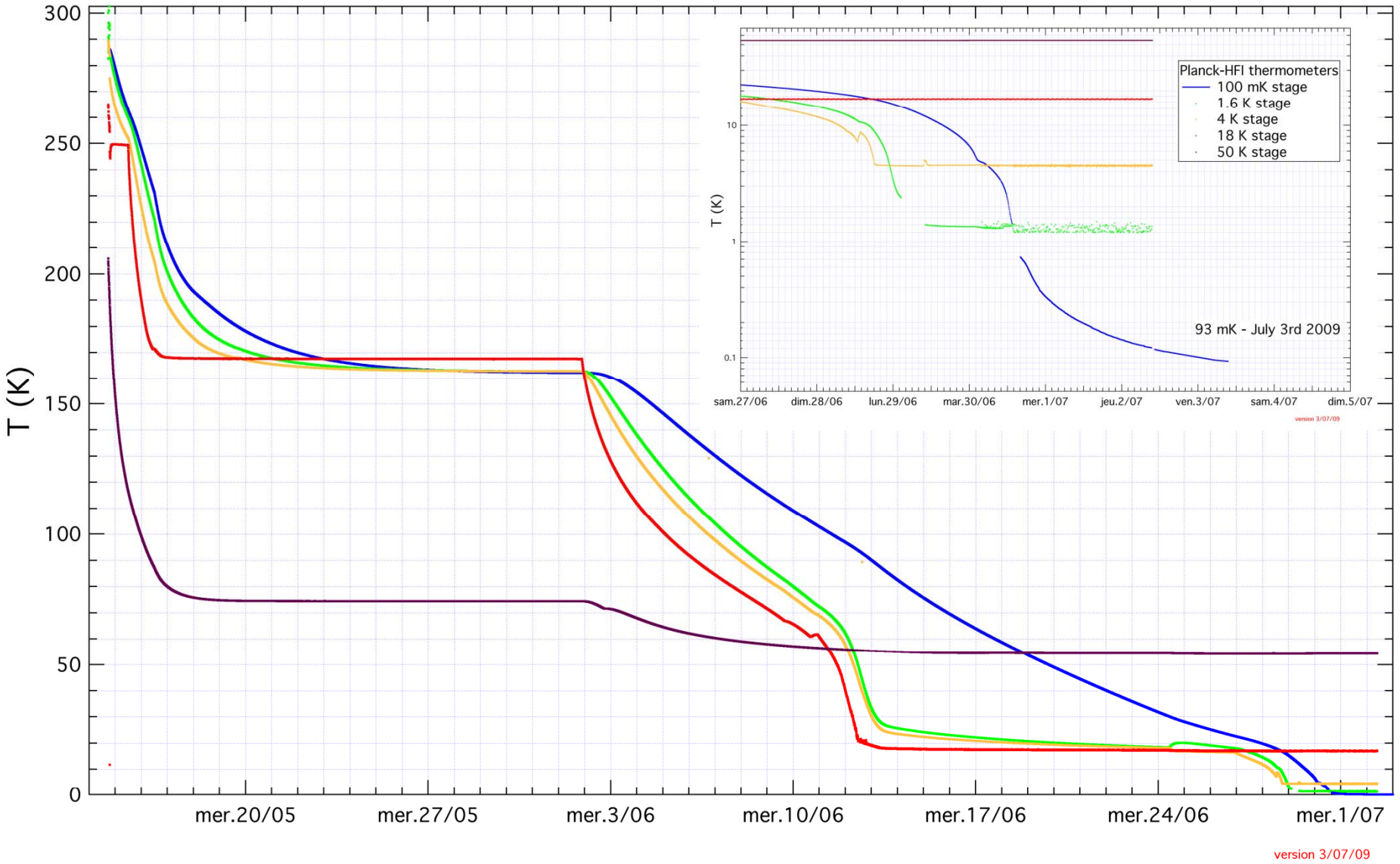
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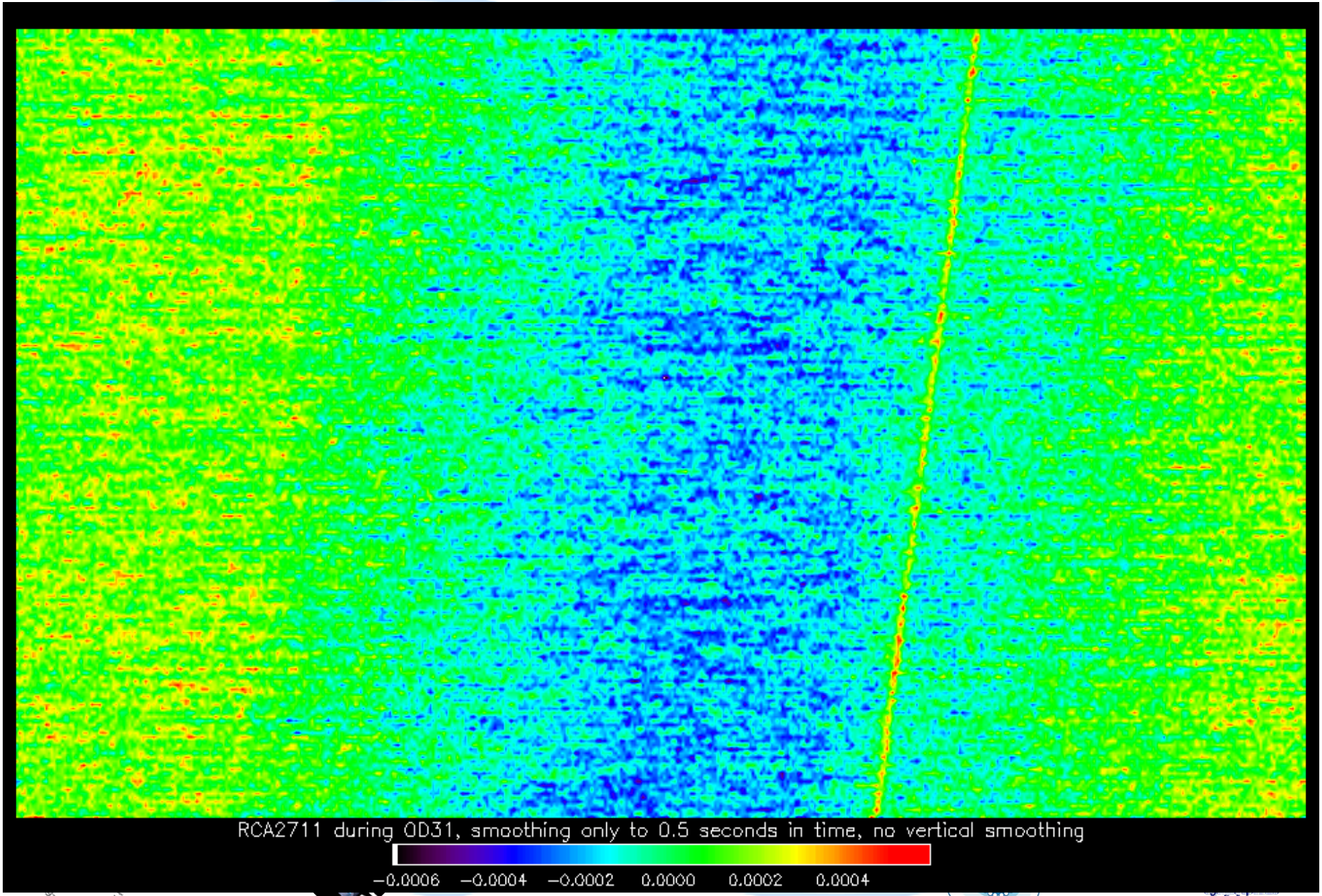
mer.1/07
jeu.2/07
ven.3/07
sam.4/07
dim.5/07
version 3/07/09


RCA2711 during OD31, smoothing only to 0.5 seconds in time, no vertical smoothing
−0.0006
−0.0004
−0.0002
0.0000
0.0002
0.0004

Conclusions

- All tests carried out on the flight model (CSL vs CPV) show excellent performance of Planck
- Minor problems encountered and solved
- Planck has begun its operational life with the CPV
- Almost ready to start

Years of exciting science to come