COrE/M5 proposal: e2e calibration plan

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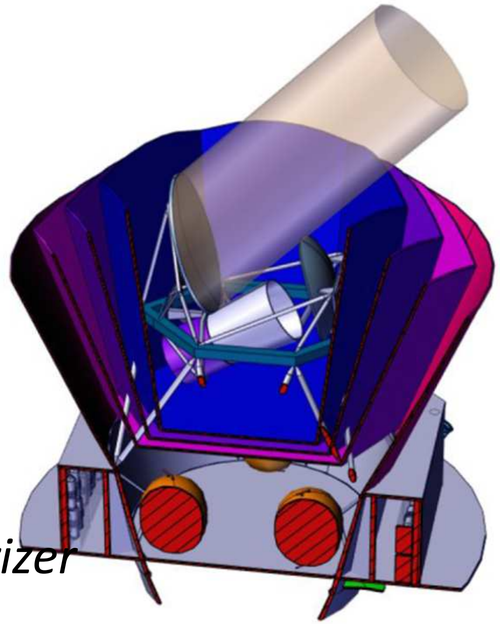
"Towards a next space probe for CMB observations and cosmic origins exploration"

COrE Instrument Baseline



Frequency range: 60 - 600 GHz, several bands

Adequate TRL
Simplicity, low cost
European technology
(depending on International collaboration)

Telescope: Gregorian 1.2m - 1.5m

Arranged in hexagonal modules following focal surface
Each module with a single band-selection filter and polarizer
Baffle: long, internally black, 1K shield, surrounding FPA.

FPA: 55 cm diameter array, 1000's pixels, *TES / KIDs*

Baseline: Planar technology (no horns)
Depending on beam quality and background level: add planar lenses arrays

Detectors: single-frequency pixels, unpolarized

Options: Dichroic, polarizer plate

Calibration

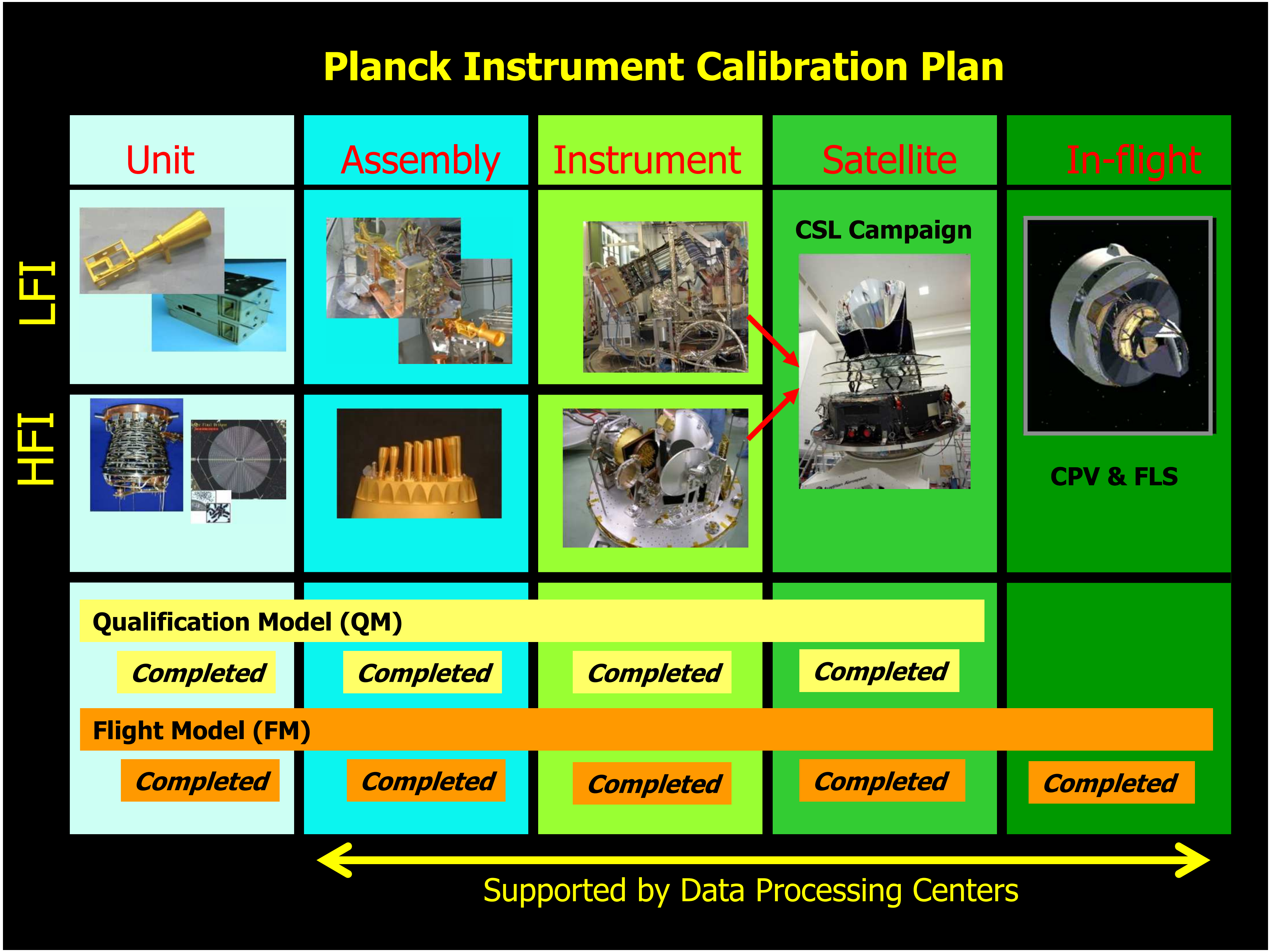
Large heritage from Planck
Challenge: ~100 times more channels, ~30 times deeper

In spite of the major calibration effort (ground + flight), some effects were not anticipated (cosmic ray hits for instance) and some other parameters could have benefited from a better characterization.

However the difficulty will be to adapt this calibration from 10s of pixels for Planck to 1000s of pixels for COrE+. It would be costly and time demanding to characterize all the pixels individually with extremely high accuracy.

The strategy:
- High requirement/control of performance homogeneity at the component level
- General tests on all components to check for anomalies, failures
- Thorough testing on a representative subset of channels across frequency bands.

The Planck data analysis has also shown the criticality of a detailed knowledge of beams and far sidelobes, particularly for polarization.
Clearly, even the extensive optical testing carried out for Planck [111][114] would be far insufficient forCOrE+ which requires RF calibration an order-of-magnitude deeper.
The COrE+ optical ground testing will include a highly representative focal plane system, closer to the real, and multiple in-band pattern measurements.


Planck Instrument Calibration Plan
Unit
Assembly
Instrument
Satellite
In-flight
LFI
HFI
CSL Campaign
CPV & FLS
Qualification Model (QM)
Completed
Completed
Completed
Completed
Flight Model (FM)
Completed
Completed
Completed
Completed
Completed
Supported by Data Processing Centers

Model Philosophy

- Structural Model
- Cryogenic Qualification Model (CQM)
  - P/L QM, with a full structure (as for Planck), SVM dummy with fittings for the PLM coolers and "PLM warm units", to be used for the cryogenic test qualifying the chain of cryo stages
- SVM Avionics Model (AVM)
- Protoflight Model (PFM)
  - New, no refurbishment from other models
- RFQM (refurbished CQM), tbd. depending on achievement of optical verification

- Mirror models:
  - QM, SM and FM: QM for the CQM and then the RFQM
- Flight spares

Integration and verification approach

- Based on Planck approach
- Cryogenic tests in CSL
- Optical test in CSL
  - As telescope configuration is different, the feasibility (required space) is still to be determined
- Videogrammetry test with PFM PLM and QM mirrors (tbc)
- Spin test in LSS
- PFM TB/TB

COrE Calibration

Classes of instrument parameters

1. **Photometric calibration:** Conversion of telemetry units to physical units (KCMB). Gain factors fwill be measured on the ground at several stages. The final calibration will be performed in-flight.

2. **Relative calibration:** stability of the gain, 1/f noise, noise spectra, zero-level stability. The redundancy of the scanning strategy will help on this.

3. **Thermal effects:** systematics induced by thermal fluctuations in the 0.1 K, 1.7 K, 4 K, 20 K, and 300 K stages; cooler induced microphonics. Thermal susceptibility of detector response. Verify that temperature sensors H/K provide sufficient monitoring of instrument thermal configuration and stability.

4. **Detector chain non-idealities:** detector (TES ot KIDs) characterization, detector time-response; non-linearity of the detector response; nonlinearity of ADC converters; impact of cosmic rays; sensitivity to microphonics, temperature susceptibility, cross-talk.

5. **Spectral calibration:** filter characterization (module level), detailed bandpass measurements. These measurements will be done on the ground, as no sweeping sources is planned on the satellite. In-flight verification of the measured bandpasses will be possible through observation of diffuse and point sources with steep spectra.

6. **Optical calibration:** main beam determination, near side-lobes, far side-lobes (both total intensity and polarization). Direct measurements of the main beams and near lobes in-flight from planets and strong polarization sources. Cross-polarization, reflection. Alignmant. Pointing.

7. **Polarization-specific calibration:** polarization efficiency and polarization angle of each detector; These will be measured both on-ground and in-flight.

8. **Noise characterization:** detailed measurements of the noise properties (noise power spectrum, 1/f noise, possible non-gaussianity) and their time evolution.

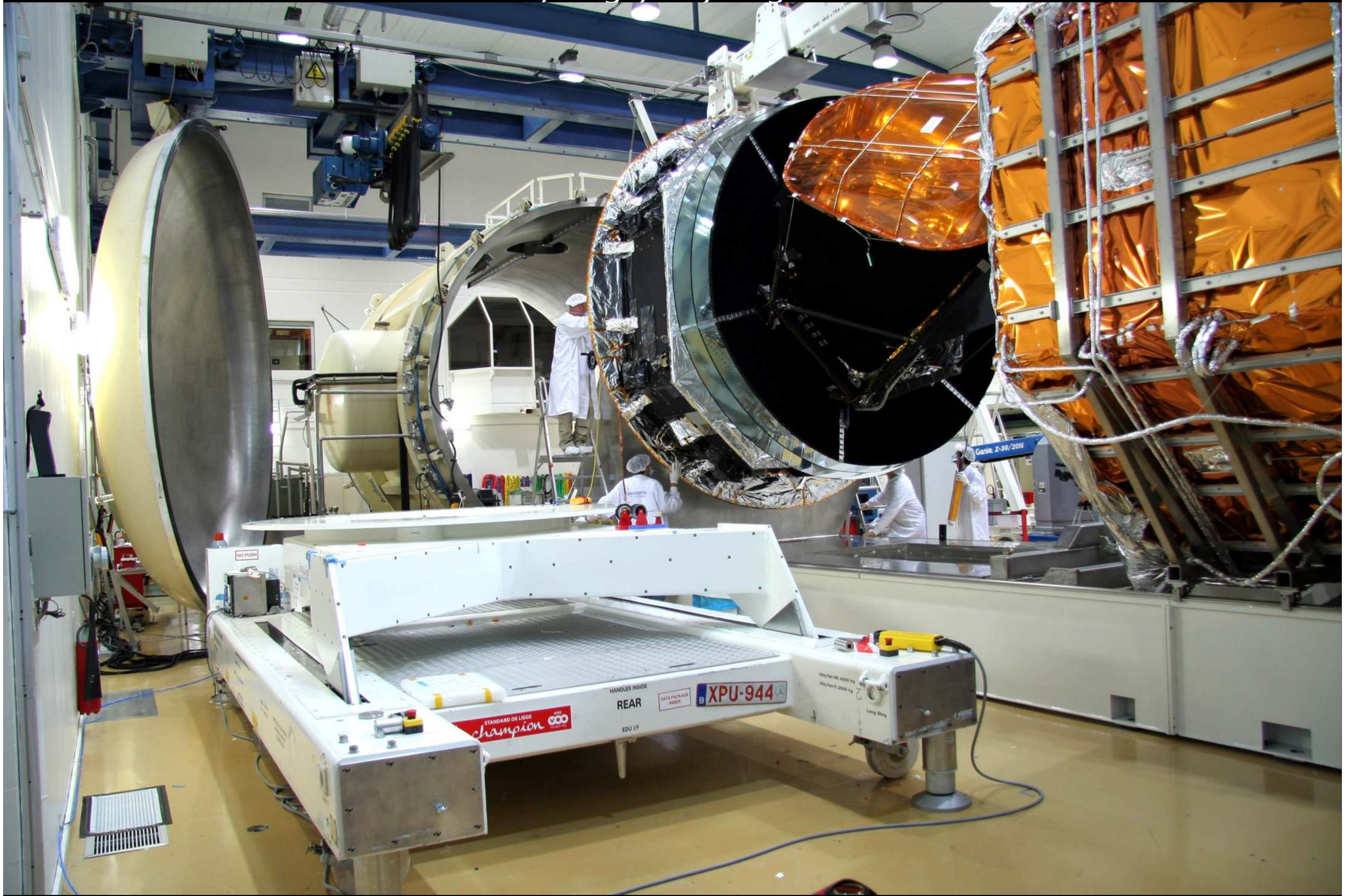
Overall calibration matrix

	CHANNEL /UNIT	MODULE	FPA/ INSTR.	RFQM Model	CQM	CSL	IN-FLIGHT	
OPTICAL CALIBRATION								Compare to Optical Model
Beam pattern at FPA level (feed, planar?)	X	X						
Cross-polarisation	X	X					X	
Front-end Insertion Loss and Return Loss	X	X						
Main Beams (full optics)				X (subset)			X	Optical Model
Side Lobes (full optics)				X (subset)			X	(Moon flyby?)
DETECTION CHAIN								Compare to Instr. Model
NEP	X	X	X			X	X	
Time constants	X	X	X			X	X	
Noise spectrum measurement	X	X	X			X	X	
Detector linearity	X		X			X	X	
Readout electronics	X		X					
RF Spectral Response		X	X					
ADC linearity		X	X			X	X	
Channel isolation / crosstalk		X	X					
Electrical susceptibility		X	X					
Thermal susceptibility	X	X	X		X	X	X	
Sensitivity to cosmic rays	X						X	
THERMAL CALIBRATION								Thermal Model
Power @ cold (0.1 K, 1.7 K, 4 K, 20 K, 300 K)					X		X	
Temperature sensors calibration			X		X			
Thermal model calibration			X		X	X	X	
PHOTOMETRIC CALIBRATION								
Photometric calibration (absolute calibration)		X	X			X	X	Dipole(s)
Calibration stability (relative calibration)						X	X	
ATTITUDE								Structural Model
Beam centre reconstruction / alignment				X (subset)	X		X	
Pointing reconstruction							X	

COrE Optical calibration

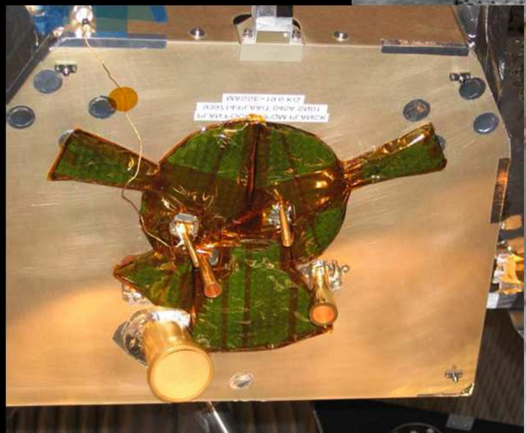
Objective of test/ measurement	Requirements	On-ground (at what stage)	In-flight	Instrument model verification
Optical coupling at FPA	*FWHM (Edge taper): 30dB* *Losses < 0.1dB* *Reflections: VSWR > 40dB* *Cross-polarization: <30dB*	*- Single detector* *- Module* *- Instrument*	*N/A*	*Compare to GRASP simulations* *Feeds/lenses prototypes*
Main beam determination *Both total intensity and polarization*	*FWHM per freq (value spread)* *Ellipticity <* ***1.1***	*- Single detector* *- Module* *RFQM (With telescope)*	*Direct measurements of main beam exploiting signals from ALL external planets* *Strong polarization sources: polarized beams*	*Compare to GRASP simulations* *Beam variation in-band*
Sidelobe determination *- near side-lobes,* *- far side-lobes* *Both total intensity and polarization*	*Rejection needed for: Galaxy,* *Sun, Earth, Moon* ***20dB lower than Planck***	*RFQM (With telescope)*	*Intermediate sidelobes down to -35 dB to -40 dB with Jupiter* *will be possible in-flight*	***Trade off edge taper with angular resolution*** *Compare to GRASP simulations* *Beam variation in-band*
Internal straylight	*Limit background on detectors from* *- FPA environment* *- P/L environment* *- Baffle*	*- Single detector* *- Module* *- Instrument* *- CQM* *- PFM (at CSL)*	*May be able to test during cooldown*	*Thermal model* *Emissivity* *Baffle*
Filter characterization	*- Band definition (from comp sep)* *- Bandwidth (sensitivity)* *- Consider CO lines (and other moloecules)*	*- Unit/Module level* *- CQM (cryo conditions)*	*N/A*	*Filter models* *Filters prototypes*

CSL, Liege, July-August 2008



Planck RFQM & Optical Calibration

Planck RFQM campaign:
QM mirrors and representative FPU and limited number of frequencies
At room temperature

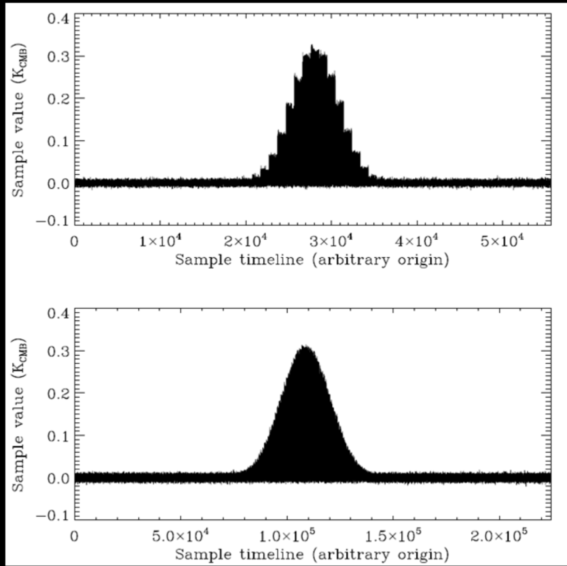


Frequency	AZ max RF (°)	EL max RF (°)
30	7.78	-1.85
70	6.09	2.53
100	5.40	-1.10
320	3.88	1.05

Table 1: Measured angular direction (main lobe)

Compare measured beam parameters with accurate optical model

Planck RFQM & Optical Calibration



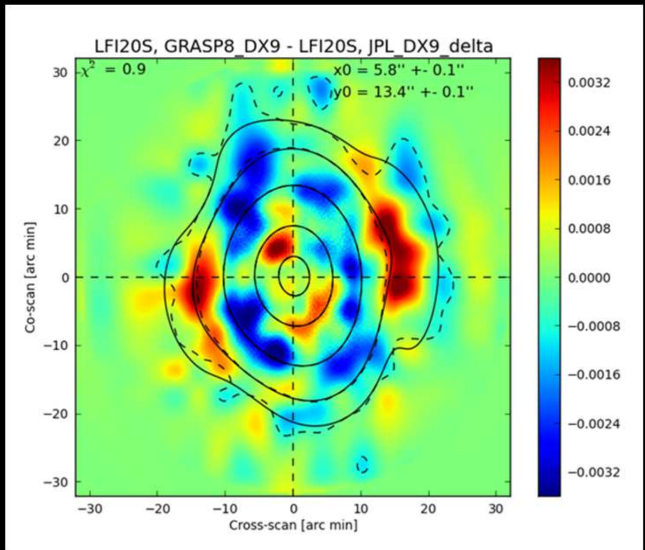
Raw data timelines during Jupiter crossing

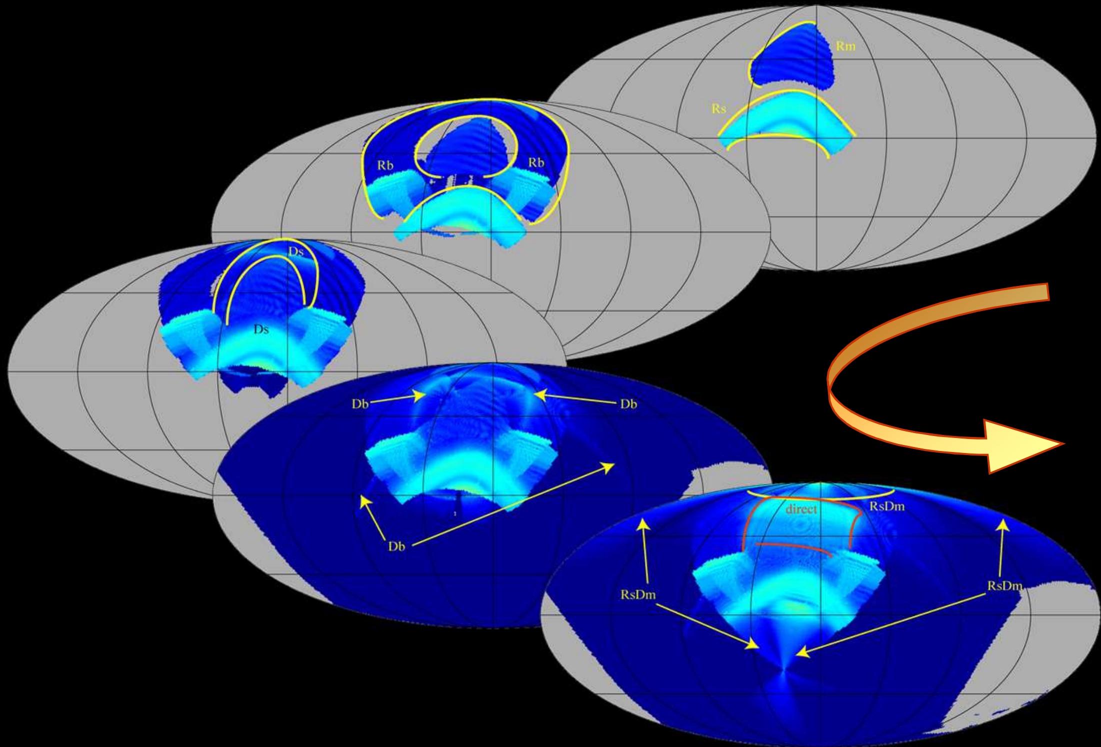
GRASP9 simulations:

– Main beams

– Intermediate beams

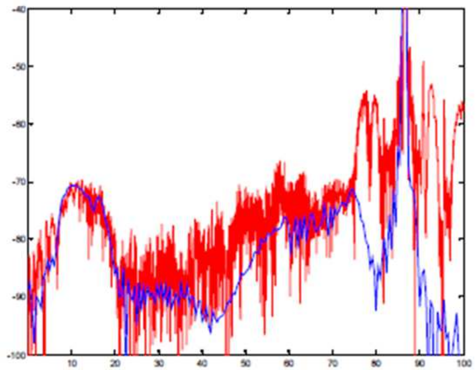
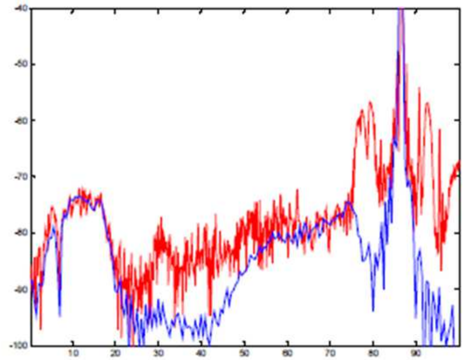
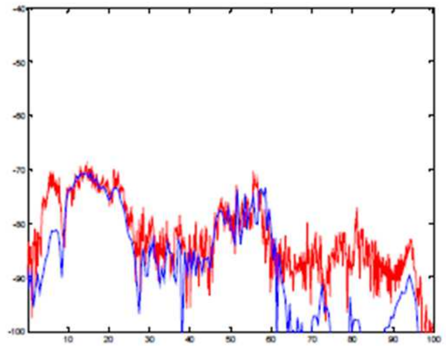
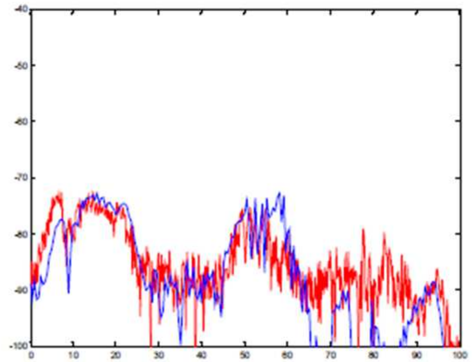
– Full sky beams



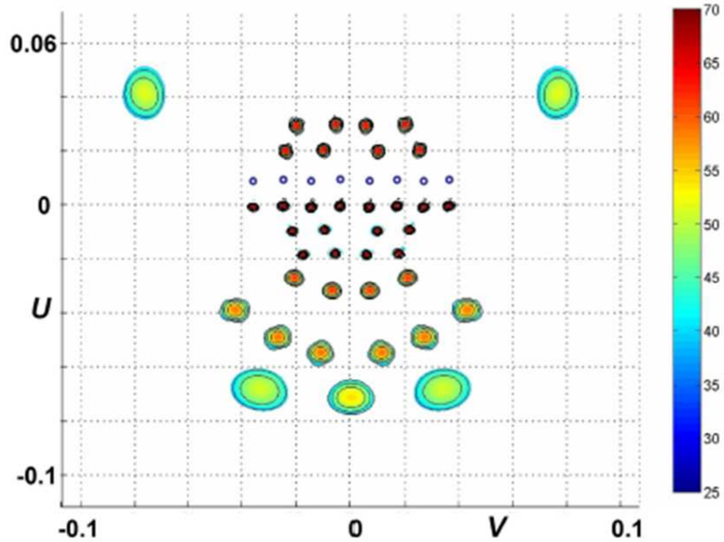


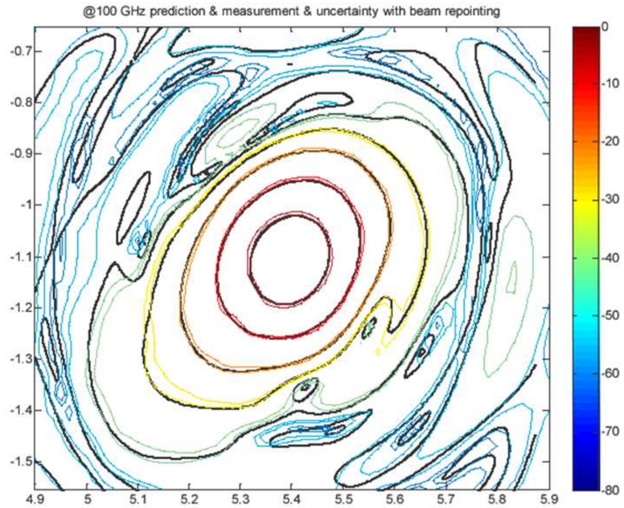
<1% match between in-flight measurement and GRASP beam models (<0.3% in the 70 GHz)

The nominal measurement for the high resolution cuts (phi=0° and phi=45°) are displayed and superimposed with the predictions in Table 5.3-2.

Polarization 1	Polarization 2
	
 Phi = -45	 Phi = -45

Main beams





Uncertainty in the main beam shape after ground test campaign (integrated power, in percent of total) as a function of angular radius from peak.
(70 GHz: horn 23); 100 GHz: horn 1; 353 GHz: horn 6).