The Planck Mission and its scientific goals

N. Mandolesi
IASF-BO/INAF

On behalf of the Planck Science Team

LFI

HFI

PLANCK

Mission Overview

Development Progress and Status

1 year to Launch – Major milestones

LFI - Low Frequency Instrument

HFI – High Frequency Instrument

Planck Scientific Objectives

Core Programme

Note: Some of the view graphs shown in the talk at the meeting have been removed in agreement with the Planck policy on publication

Mission Overview

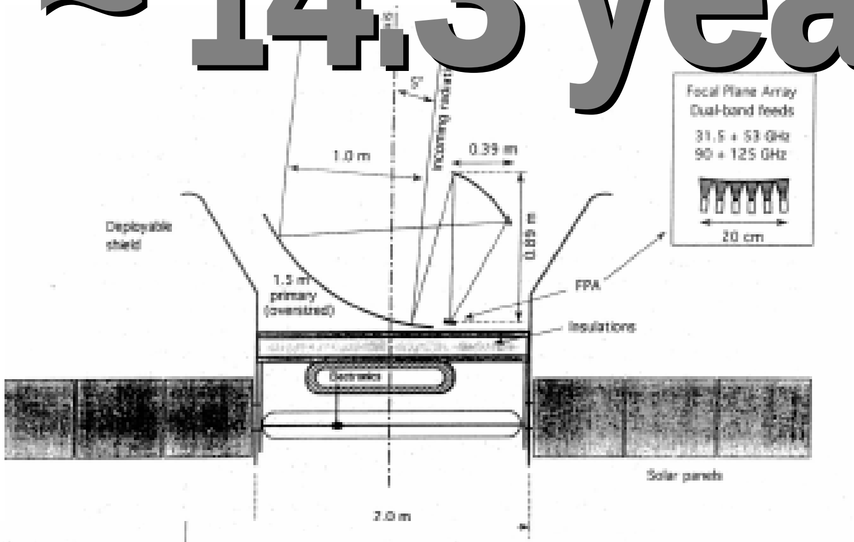
Programme Manager: T. Passvogel
Deputy PM: G. Crone

A proposal submitted in response to ESA M3 Call for Mission Ideas (May 1993)

COBRAS

COsmic Background Radiation Anisotropy Satellite

~ 14.3 years ago



ian optical system assumed in our
set from the spin axis (here assumed
the details of the scan strategy. The
lelobe pickup and cooling efficiency.
feeds. Placing their apertures on a

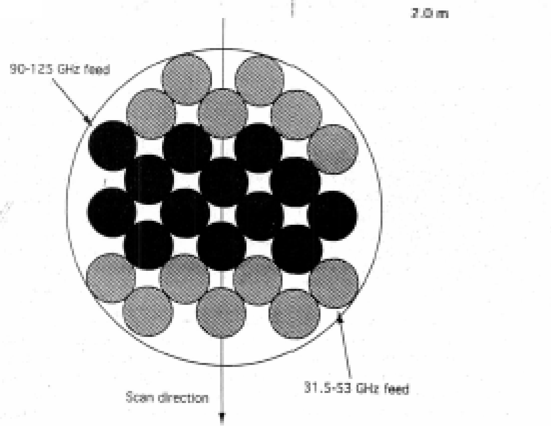
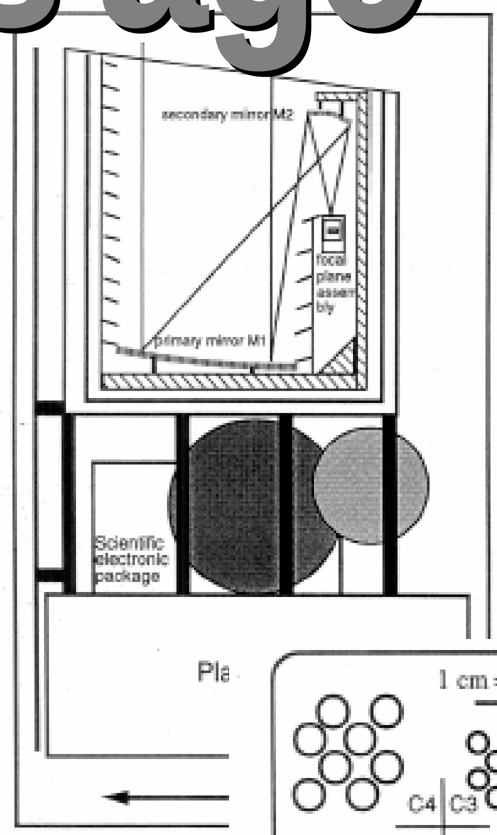
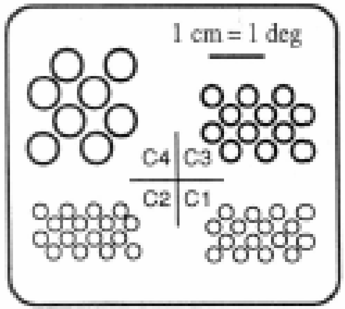


Figure 7 - The proposed geometrical disposition of the feed elements in the focal plane array is shown. The higher frequency elements (90–125 GHz) are more sensitive to beam distortion effects and have been clustered near the center of the array. Our preliminary study shows that coma lobes of the most de-centered elements are expected to be below -40 dB (10^{-4}) at 125 GHz and below -55 dB ($10^{-5.5}$) at 30 GHz.

SAMBA

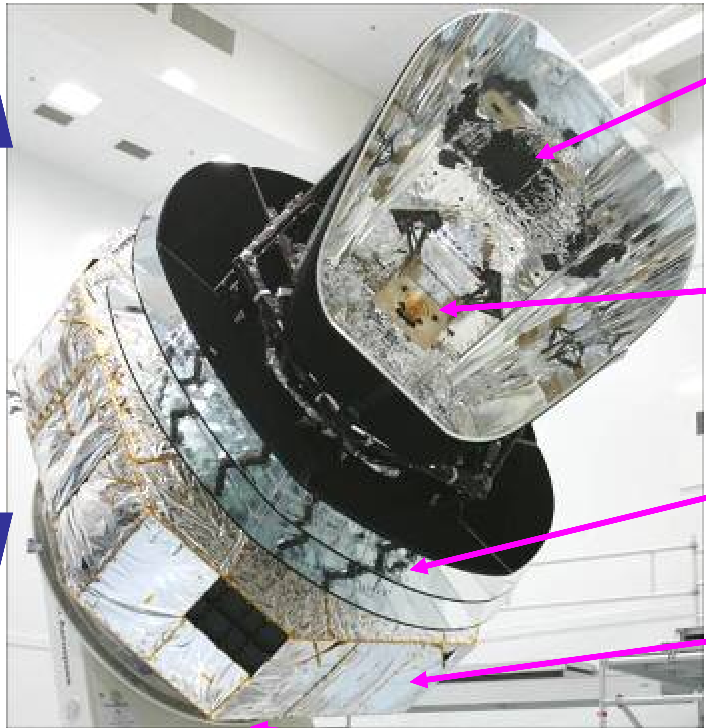
Satellite for Measurements of Background Anisotropies





Planck Satellite - Overview

4.1 m



1.5 m Telescope (30 – 60 K)

Telescope Baffle

Instruments (20 – 4 K- 100 mK)

V-Groove shields (150 - 60 K or better)

Service Module (300 K)

S/C units and Instrument electronics

Solar Array

1500kg 1800W

Development Progress and Status

Development Progress and Status

Industrial milestones:

Kick-off	April 2001
System Requirements Review	June-October 2001
Preliminary Design Review	October-December 2002 (Close-out)
Mission PDR	February 2003
CDR Space Segment	17th August- 12th October 2004
Mission CDR	11th March 2005
Module Qualification Reviews	SVM, PPLM, H-EPLM completed
System Qualification Review	February - April 2007
Flight Acceptance Review	April 2008
Launch	31st July 2008

Done

Planck Satellite - Status

- CQM test campaign successfully completed
- PFM 1 test campaign performed SVM + Sorption cooler
- LFI and HFI delivered end 2006 and integrated and mounted on Spacecraft
- Planck Payload Module integrated with SVM
- Telescope Mounted on Spacecraft
- Late availability of flight model 4K cooler being mitigated
  – use CQM electronics + FM compressors and CAU now
  – swap with FM later, when available
- Next major FM test - Mechanical testing

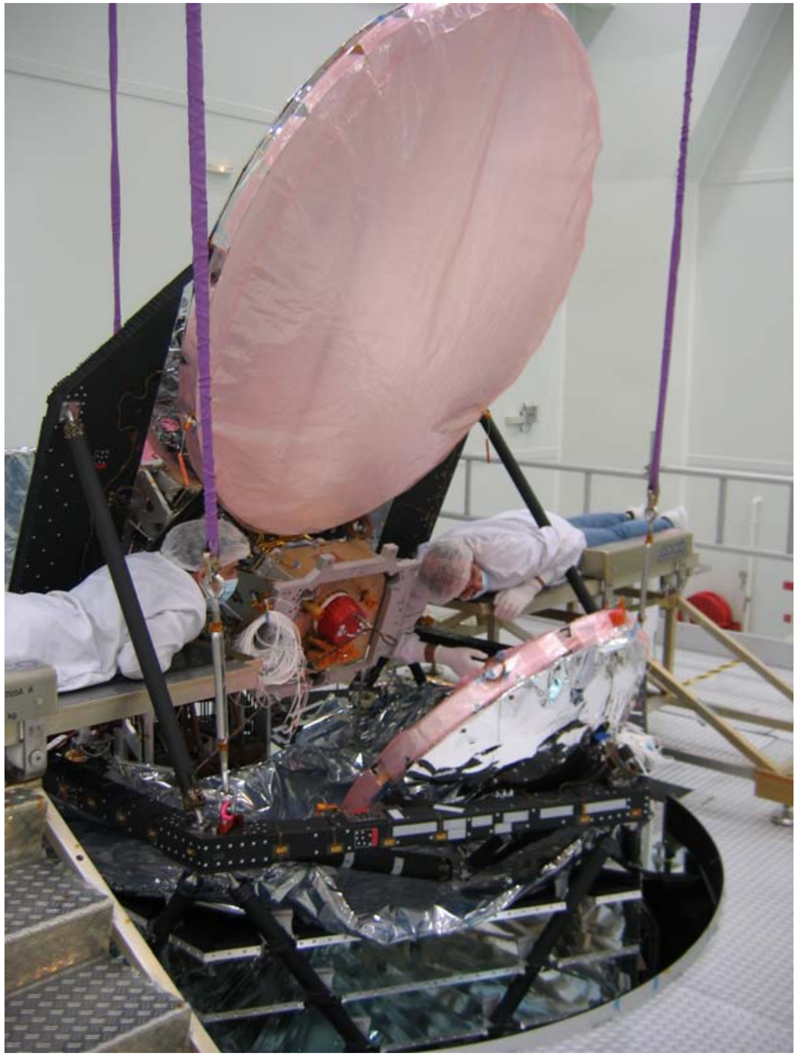
Mounting of RAA to Spacecraft

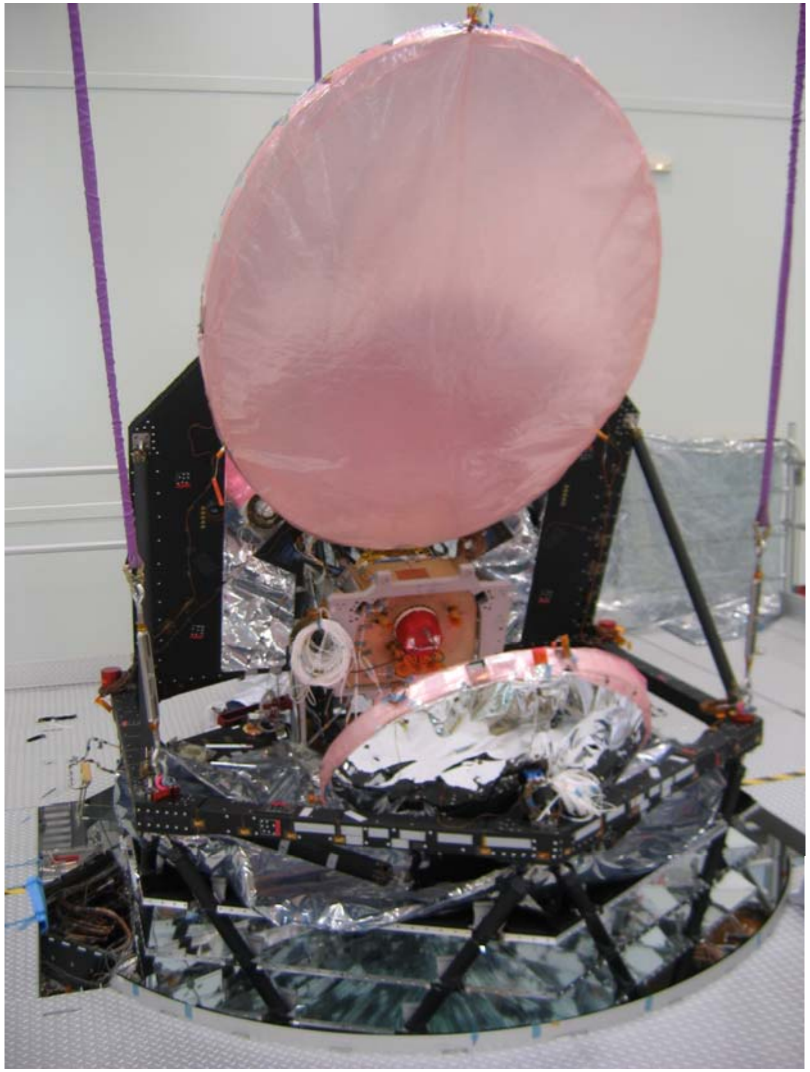
Mounting of RAA to Spacecraft

Planck Satellite - Status - Planck Telescope

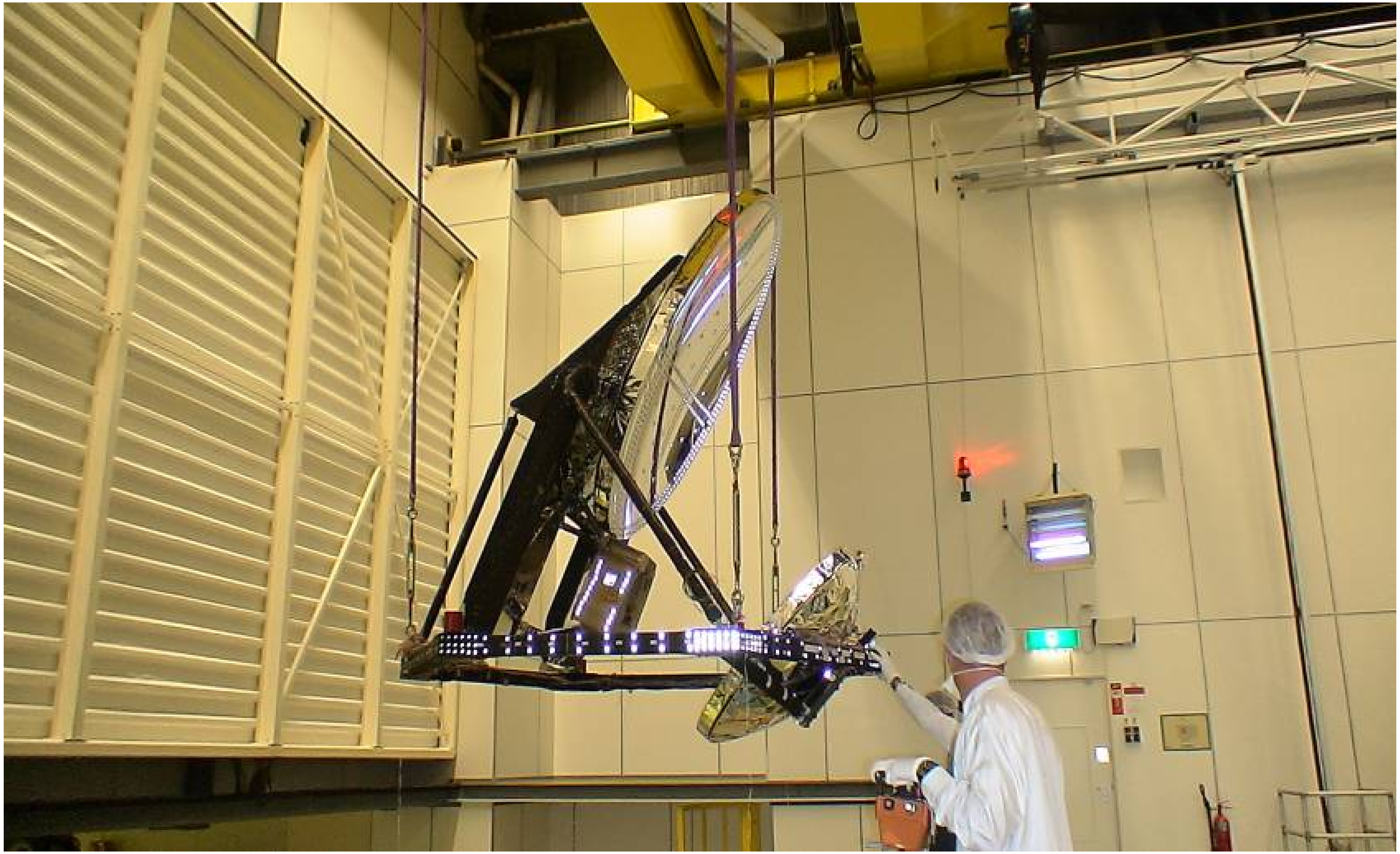
- **Final alignment settled with independent alignment verification team, set up beginning 2007**
- **Agreement reached with Instrument teams February 2007 on performance – Much work ahead**
- **Shift of secondary by about 1.5 mm to optimize performance + final shimming of focal unit**
- **Telescope re-aligned and now mounted on Spacecraft**
- **RFQM campaign completed – apart from Reference test horn**
- **Final updated RF in flight performance can now start**

Telescope integration





Planck Telescope



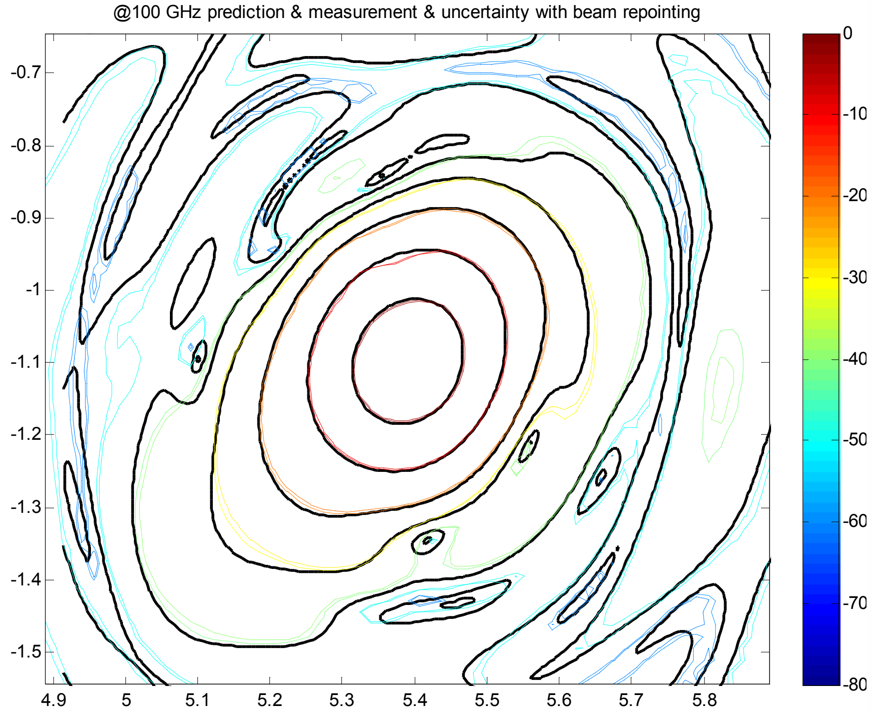
Planck Telescope

Planck Satellite - Status - RFQM

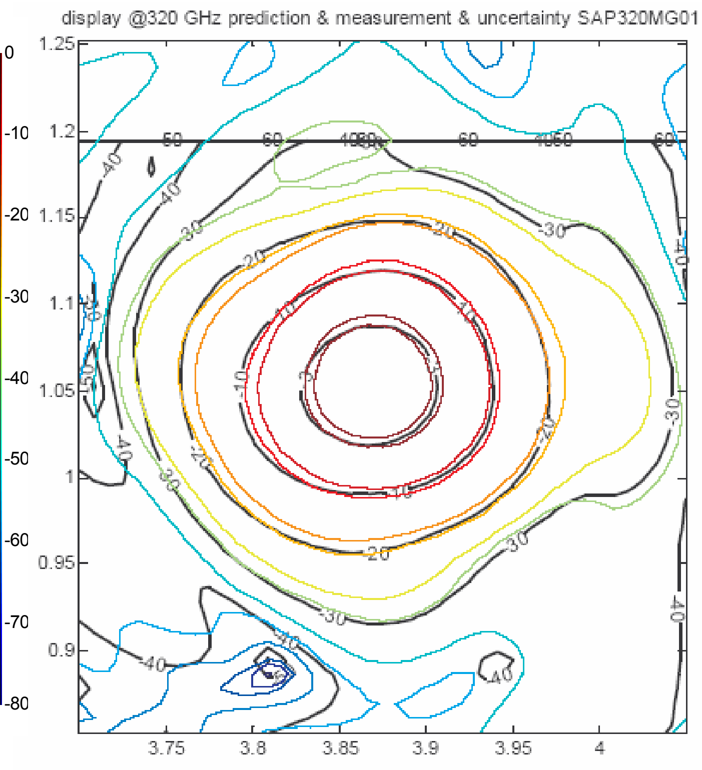
- First polarisation February 06, all frequencies

- Test Review Board held for test campaigns
  - Overall ok - some correlation activities to be completed
  - Excellent dynamic range-better than 100 dB at 320 GHz

Test results
Polarisation



100 GHz



320 GHz

RFQM - FPU

LFI

What **we know** about the **Telescope**

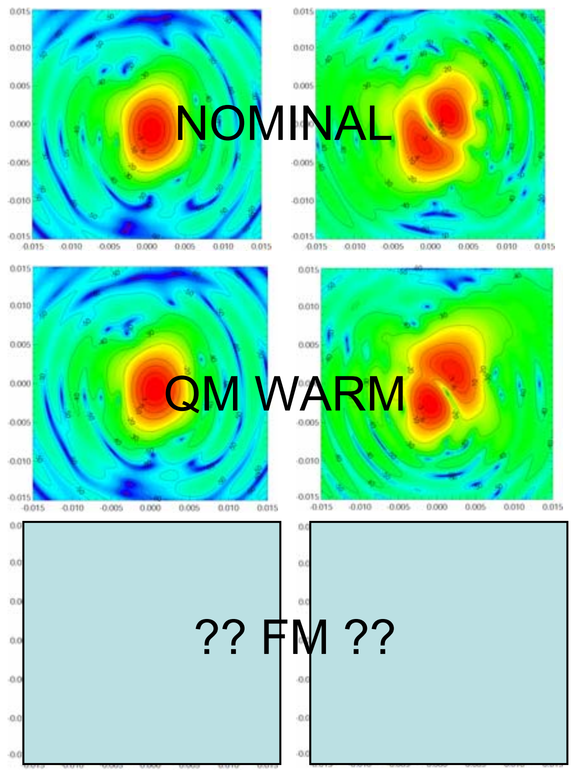
- **All beams with nominal telescope (theoretical surfaces and perfect alignment)**
  - Main beams
  - Intermediate beams
  - Full sky beams

- **RFQM measurement campaign**
  - At warm temperature
  - QM mirrors and representative FPU at a number of frequencies

M. Sandri's PHD thesis (LFI) and
J. Brossard's PHD thesis (HFI) are the most advanced knowledge of the Planck optics

What **we do not know yet** about the Telescope

- **Real alignment status**
  - Telescope has been aligned with FPU; availability of data urgent.
- **Real surfaces at operational condition**
  - Surfaces measured at ambient and 100K: extrapolation down to 50K needed (it should be not an issue)
- **All the Beam patterns at operational conditions**
  - Need to be calculated as soon as ESA delivers telescope data to instrument teams



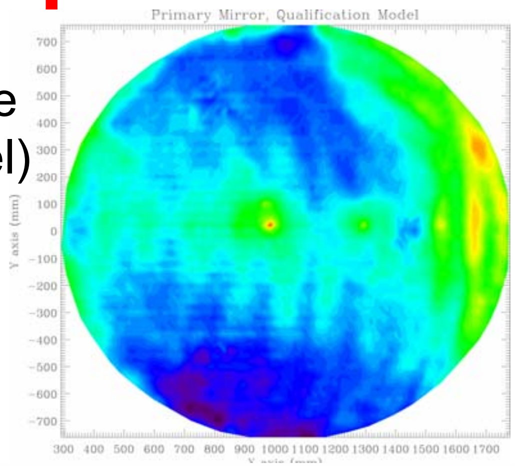
What **we will know** about the **Telescope**

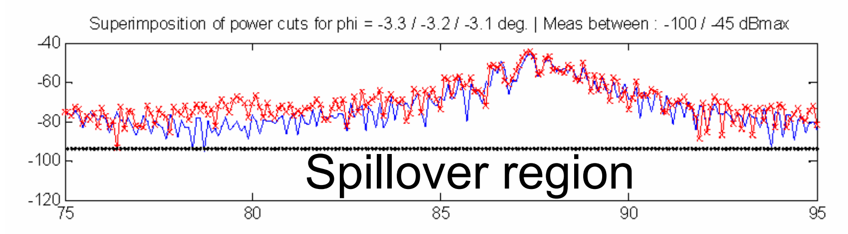
- **Main beam measurements with Jupiter**
  - Down to ~ 25 dB w.r.t. peak (E2E test)
- **Side lobe measurements with Moon**
  - Under study in the frame of ICWG if appropriate satellite movement will be appointed
- **Intermediate and side lobe beams**
  - Model under update by TAS(F) on the basis of RFQM measurements

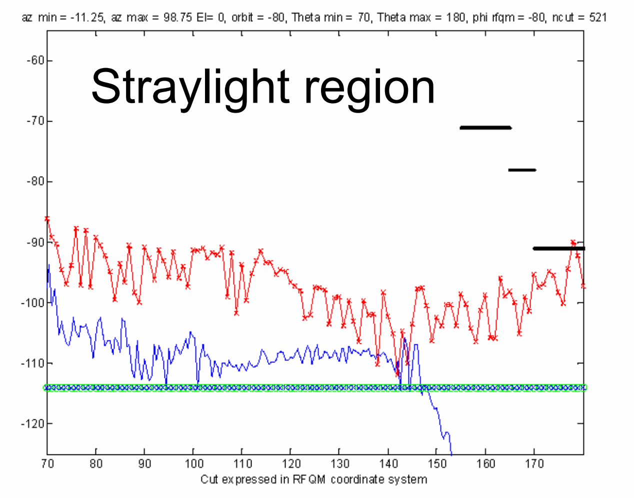
Needs about the **Telescope**

- **Knowledge of the telescope data at operational conditions**
  - Surfaces at 50K
  - Alignment
- **Side lobe model**
  - Since side lobes will not be extensively measured in flight, it is urgent to test the RFQM data wrt the model used for the nominal telescope

PR Surface
(QM model)







Meas (red) and sims (blue)

No major open issues

Only 1 year to Launch
Major milestones ahead

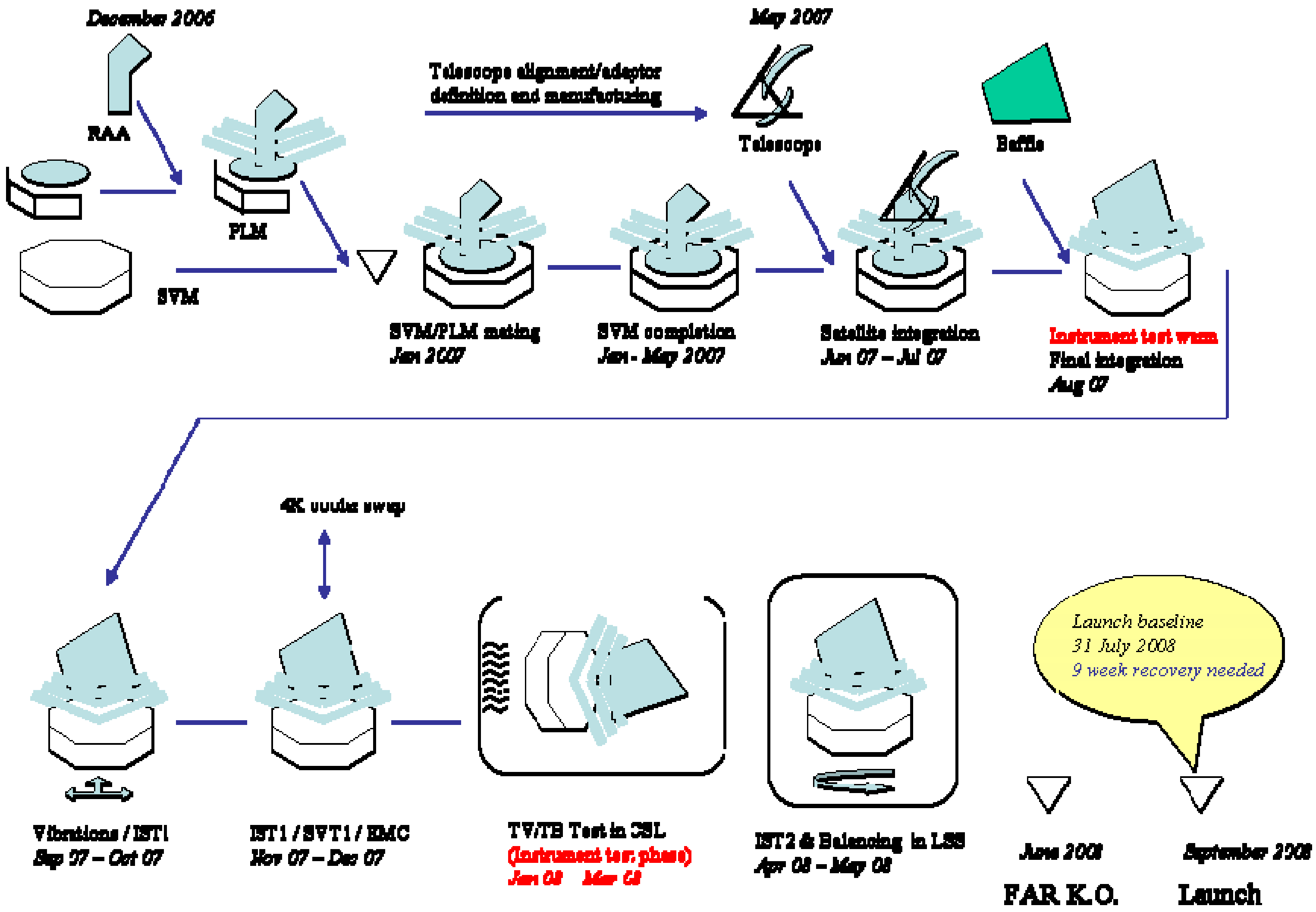
1 Year to Launch - Major milestones

– Instrument deliveries
  - Planck Instruments delivered
– Programme Qualification Review
  - Formal closure of qualification
  - ...cations
– Pl...
  -

No major open issues

– Planck 4K cooler FM should be available soon

Planck flow (status June 2007)



LFI

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Planck Fast L2 Transfer Strategy

- Objective
  - Earlier acquisition of final L2 orbit by Planck
  - Planck transfer orbit much better for early Science operations
  - Planck Spacecraft Earth + Sun vectors maintained within 15 degrees
  - Planck MGA use = "Science" from day 20 not day 100 !
- Made possible by
  - Residual Spacecraft δV
  - Residual mass budget
- How
  - Requires lower Ariane-5 perigee velocity
  - Revised spacecraft manoeuvre scheme
  - higher spacecraft δV contribution
- Implementation tbc some final verifications

Conclusions

- Most Development Risks mitigated
- System Qualification review held
- FM programmes well underway
- All known Open issues addressed
  - need full support and need full attention
  - will be settled in System level campaign
- ESA Project, Industry and Instrument Teams fully committed
- <1 year to come --> Launch on 31st July 2008

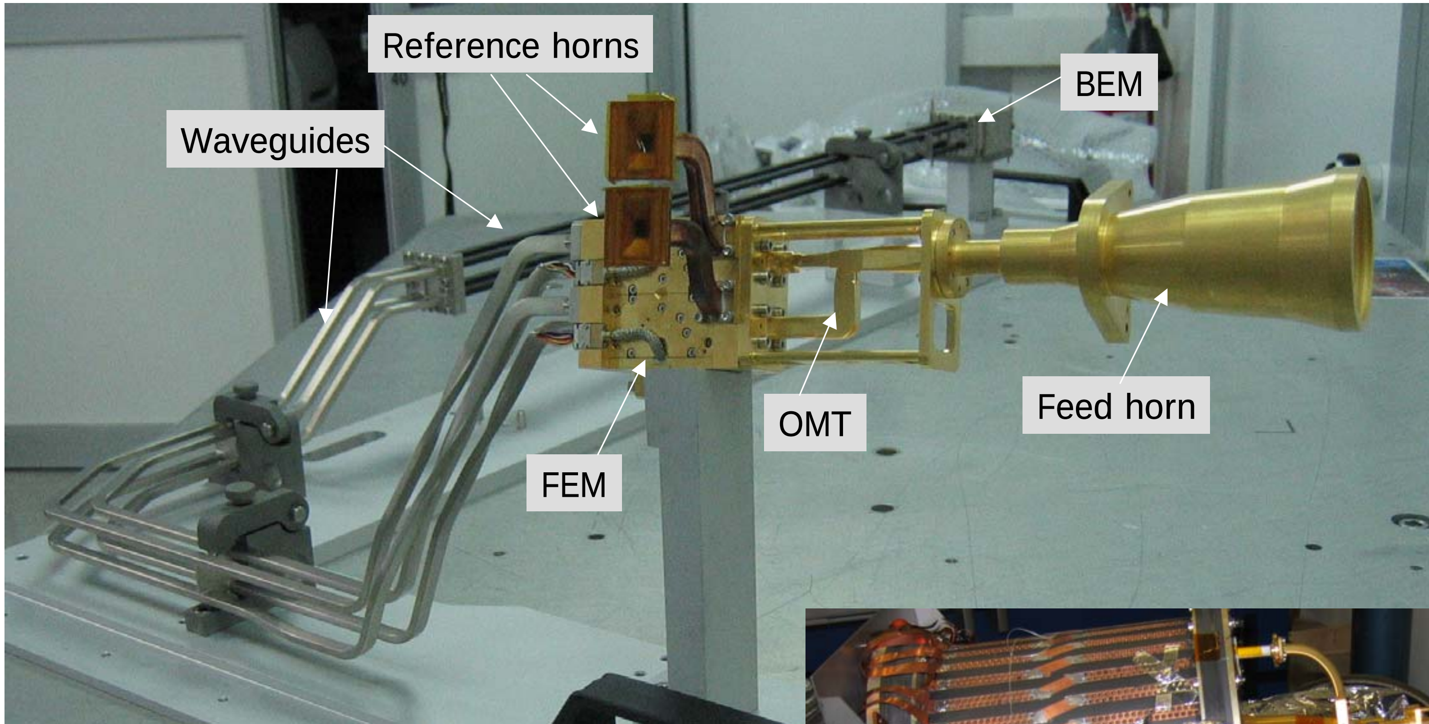
LFI - Low Frequency Instrument

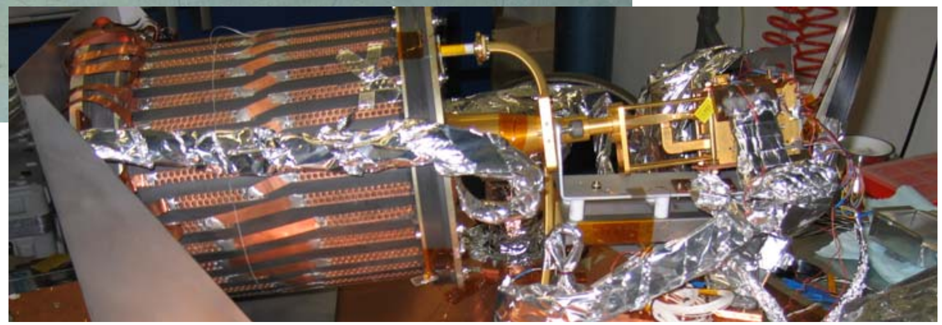
PI: N. Mandolesi
Project Manager: C. Butler
Instrument Scientist: M. Bersanelli
DPC Manager: A. Zacchei
Survey Scientist: C. Lawrence

Planck Low Frequency Instrument (LFI) status

30, 44, & 70 GHz channels

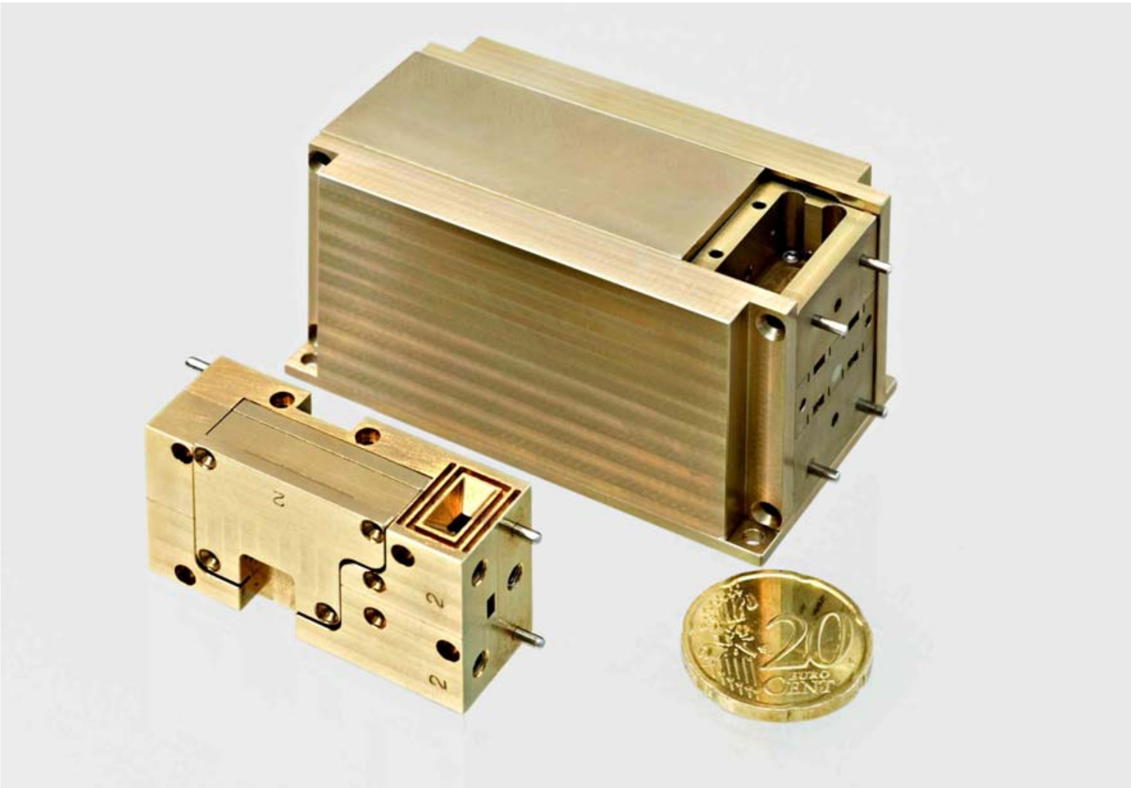
LFI contains 11 feed horns and 22 radiometers



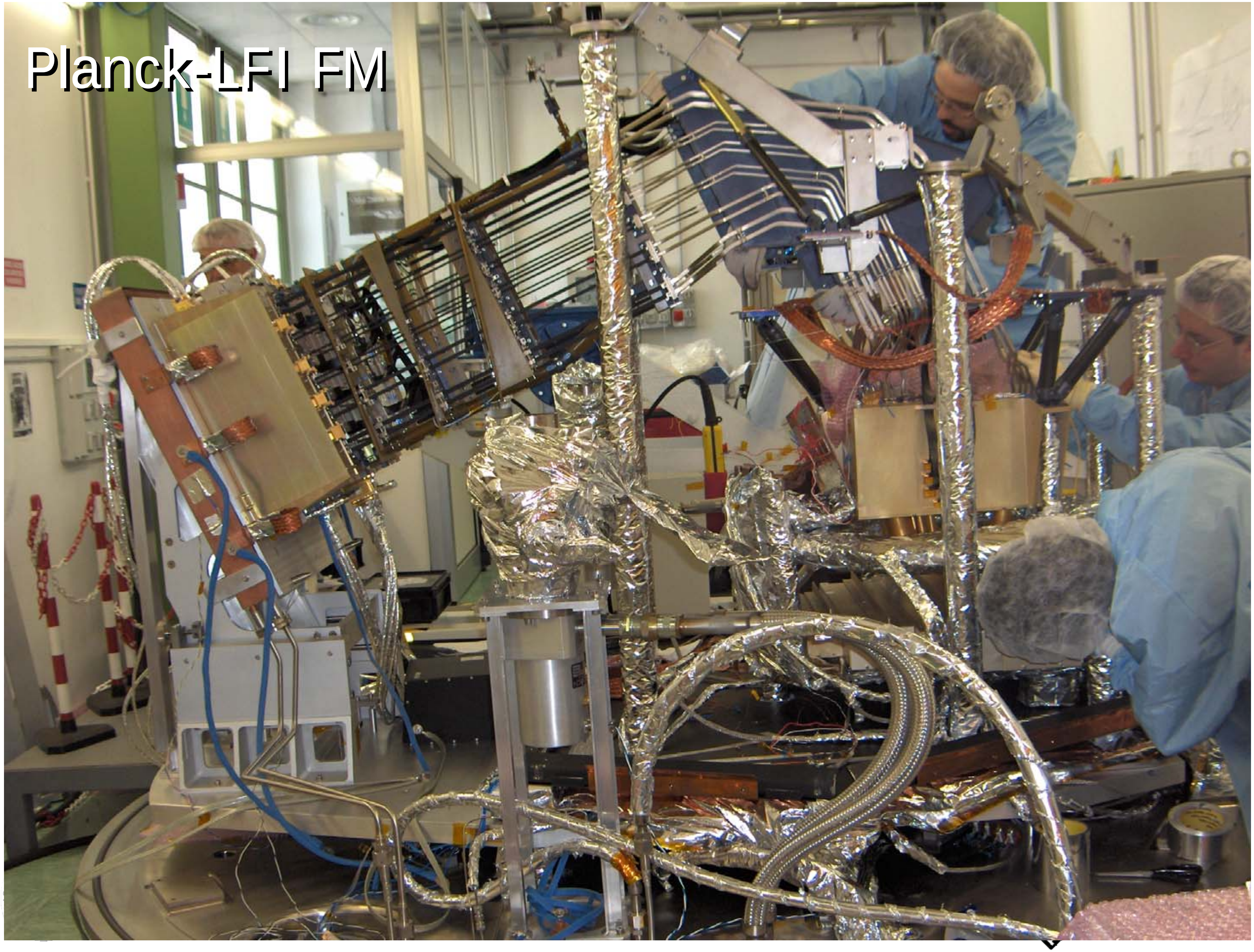


Radiometer chain at 30 GHZ

Radiometer Front End & Back End Modules
(70 GHz)



Most advanced cryogenic
Indium-Phosphide based
Millimeter wave receiver
technologies
developed in the programme


Planck-LFI FM

LFI Calibration Plan

1st version: Nov 1996

UniMi – IASF/CNR
LFI Project System Team

Planck LFI

TITLE: Planck-LFI Calibration Plan

DOC. TYPE: PLAN
PROJECT REF.: PL-LFI-PST-PL-008 **PAGE:** I of V, 64
ISSUE/REV.: 1.0 **DATE:** July 31st, 2003

Prepared by	M. BERSANELLI *On behalf of* THE PLANCK-LFI CALIBRATION TEAM (SEE FOREWARD FOR AUTHORSHIP)	Date: Signature:	July 31st, 2003 M. Bersanelli
Agreed by	C. BUTLER LFI Program Manager	Date: Signature:	July 31st, 2003 R.C. Butler
Approved by	N. MANDOLESI LFI Principal Investigator	Date: Signature:	July 31st, 2003

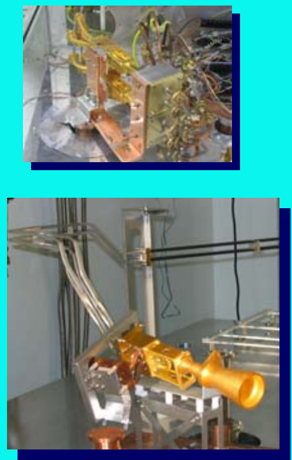
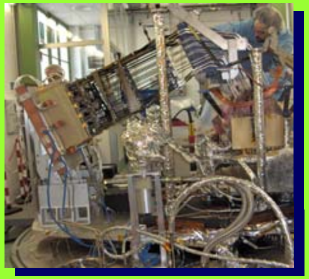
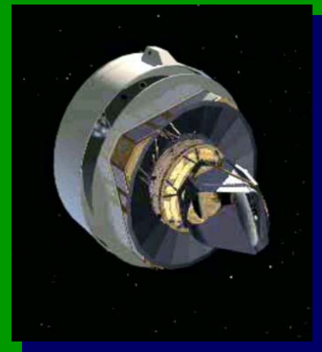
Detailed description of testing
- at various stages of integration (Unit, RCA, RAA, System, in-flight)

- Covering: Optical, Radiometric (*tuning, functionality & performance*), Thermal, Photometric, Attitude

Summary of Calibration tests

	Unit	RCA	RAA/LFI	RFQM Model	System	In-Flight
OPTICAL CALIBRATION						
Feed horn beam pattern	X Feed					
Feed-OMT cross-polarisation	X Feed+OMT					
Front-end Insertion Loss and Return Loss	X Feed+OMT					
LFI Main Beams				X (subset)		X
LFI Side Lobes				X (subset) TBC		X TBC
RF CALIBRATION						
Optimisation of bias settings and DC amp gain	X FEM,BEM	X	X			
Gain modulation factor		X	X		X	X
Noise spectrum measurement	X FEM	X	X		X	X
Noise temperature measurement	X FEM	X	X		X	X
Radiometer gain constant	X FEM	X	X		X	X
RF Spectral Response		X	X (TBC)			
Radiometer input offset		X		X		
RCA linearity		X				
Channel isolation		X				
Power consumption	X FEM,BEM	X	X		X	
Sensitivity to electrical instabilities		X	X			
Sensitivity to variation of thermal interface temperatures	X	X	X		X	
THERMAL CALIBRATION						
Temperature sensors calibration			X			
Thermal model calibration			X		X	X
PHOTOMETRIC CALIBRATION						
Photometric calibration (absolute calibration)		X	X		X	X
Calibration stability (relative calibration)					X	X
ATTITUDE						
Beam center direction				X (subset)		X
Pointing						X

LFI Calibration Plan

Unit	RCA	Instrument	Satellite	In-flight
				

Qualification Model (QM)

Unit	RCA	Instrument
Completed	*Completed*	*Completed*

Flight Model (FM)

Unit	RCA	Instrument	Satellite	In-flight
Completed	*Completed*	*Completed*	*In progress*	*In preparation*

LFI DPC Support

LFI HFI

PLANCK – LFI CALIBRATORS FOR GROUND TESTING

Planck-LFI ground tests required to power the feedhorns with a black-body signal at cryogenic temperature, to mimic the sky signal. Results from calibrations are strongly depending on ‘blackness’ of this source (and on modelling abilities).

Three calibrators (plus one?) have been developed to be used during the different phases of LFI calibration test campaign, depending on the test setup.

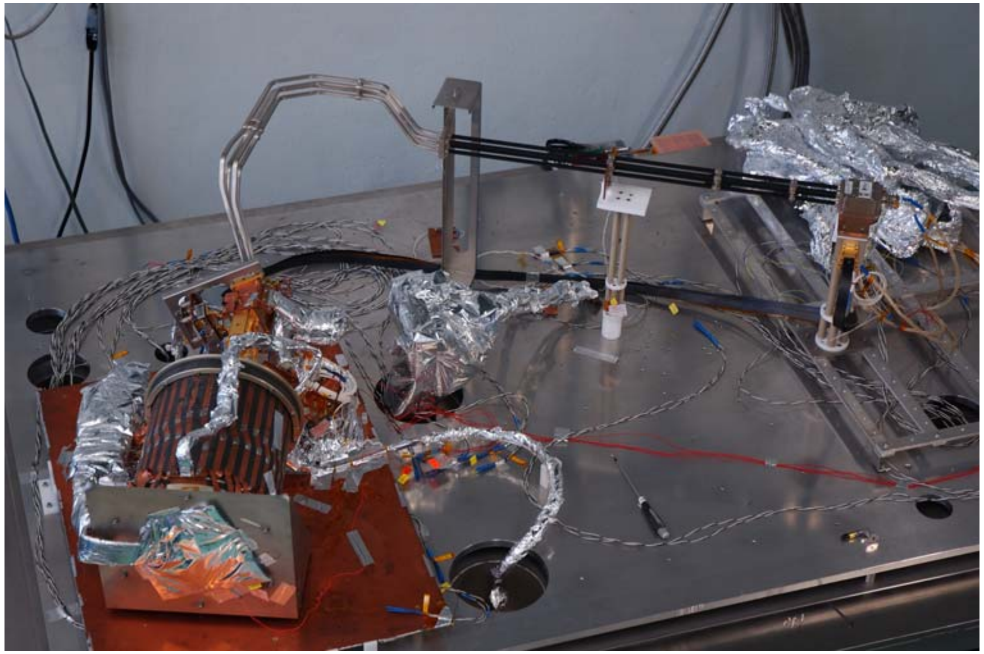
-RCA Sky load ➔ calibrations at Radiometer Chain level

-RAA Sky Load➔ calibrations at Instrument level

-Planck- Sky Load ➔ calibrations at System level (shared with HFI to be used in CSL at system level)

- Planck- Modified Sky load ➔calibration at system level to satisfy latest HFI requirements

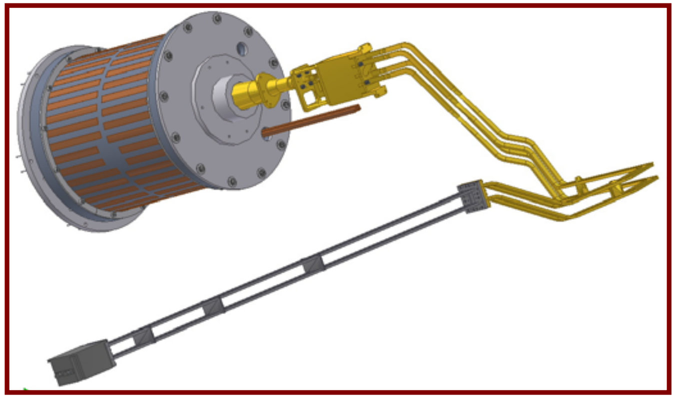
RCA SKY LOAD

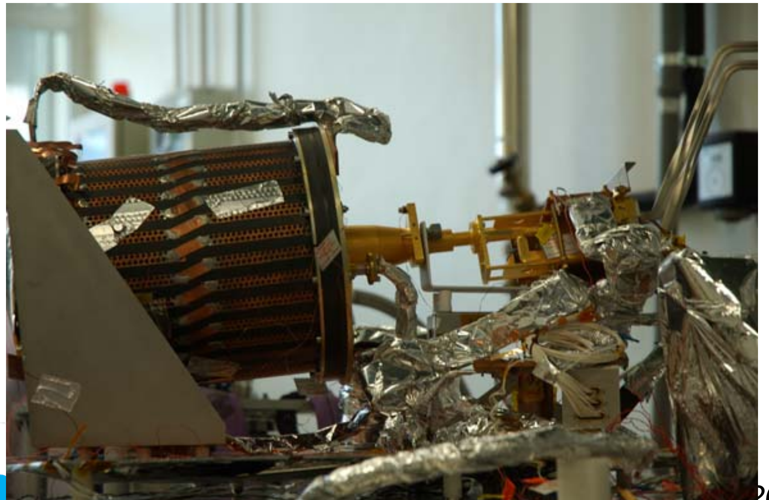


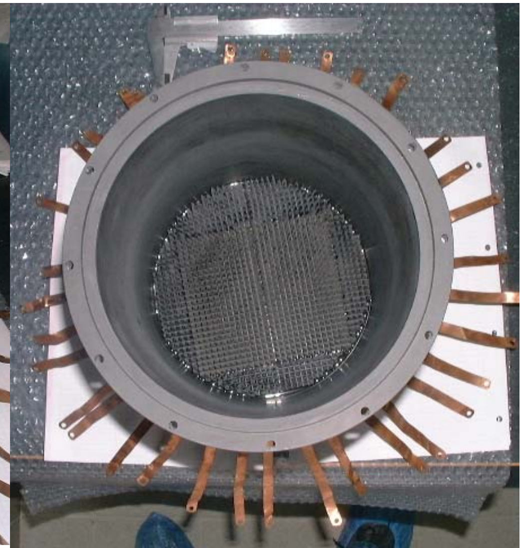
Reflectivity < -50 dB

Spillover ~ 0

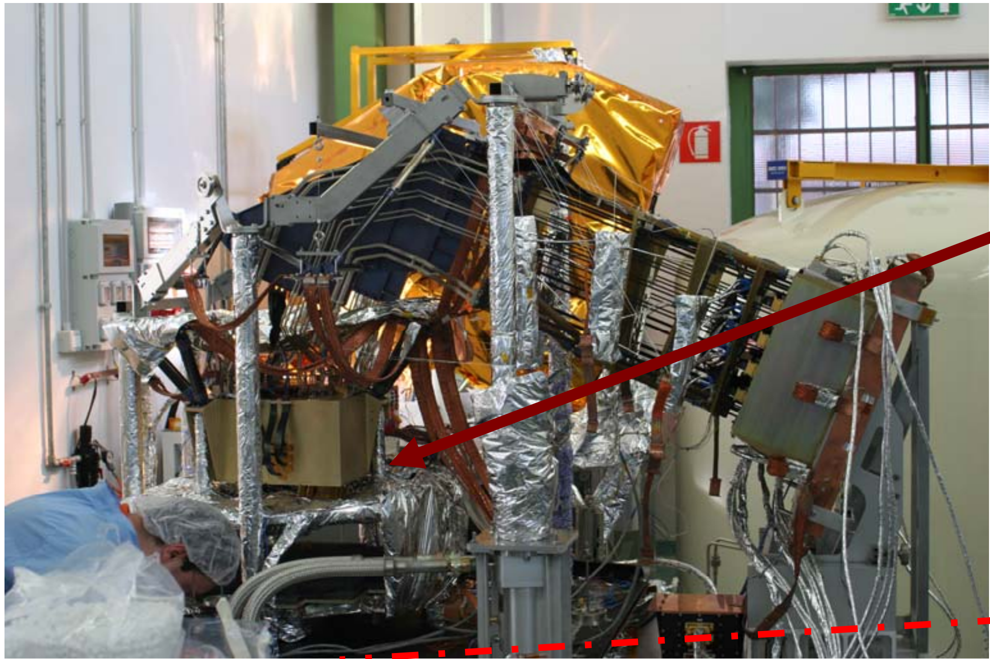
T_{min} ~ 8 K (RCA)

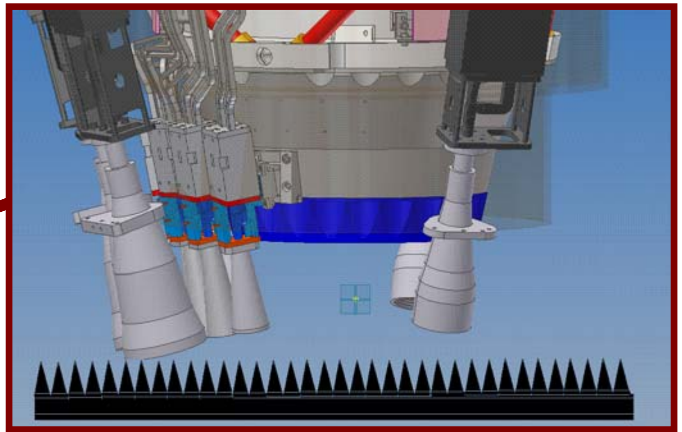


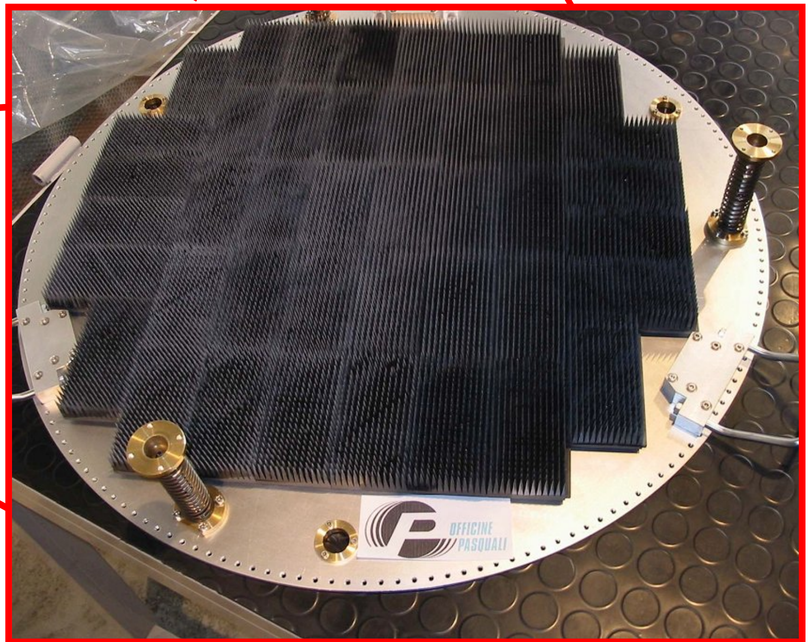




RAA SKY LOAD





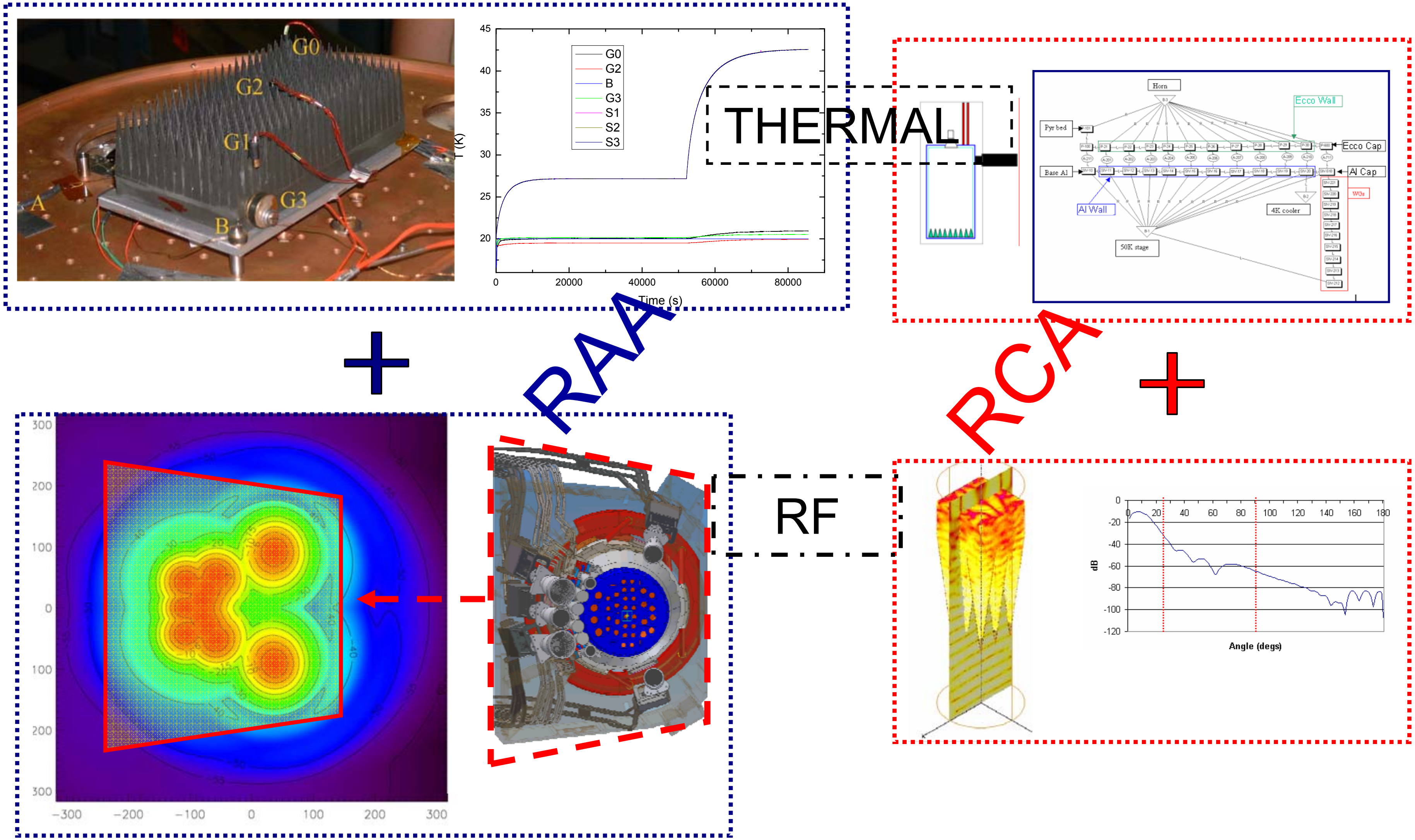


Reflectivity < -40 dB

Spillover < -40 dB

T_{min} ~ 22 K (RAA)

MODELLING



LFI

HFI

LFI scientific calibration analysis

Nearly completed

UniMi/UniTs/ESA/CNR-IFP/JBO/IASF-INAF/UCSB/OAT/SAN
LFI Project System Team

Planck LFI

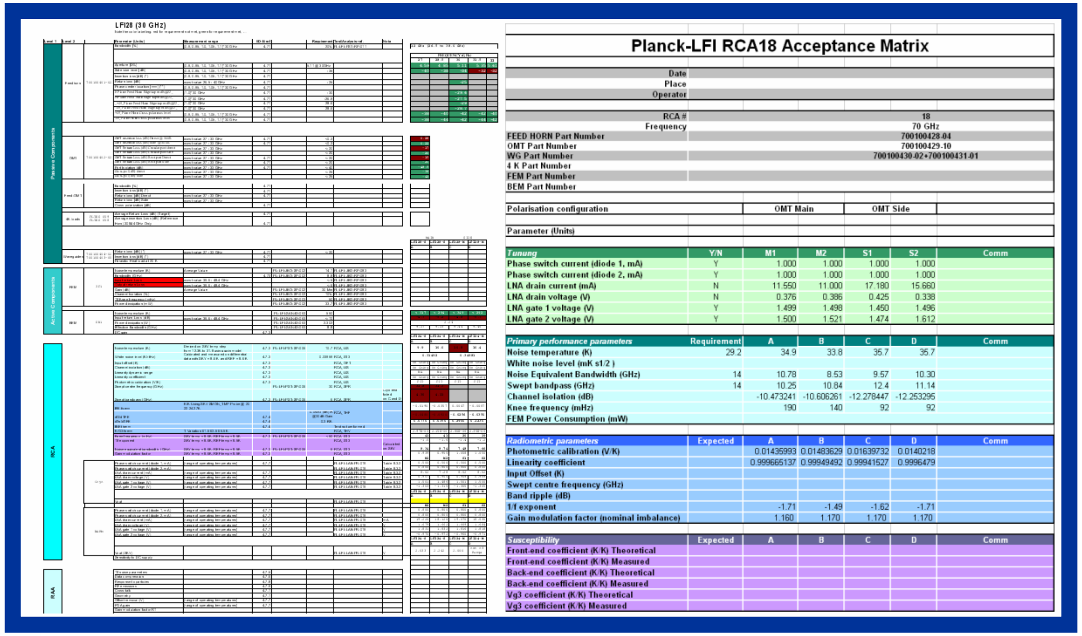
TITLE: Data analysis and scientific performances of the LFI FM instrument.

DOC. TYPE: Analysis document
PROJECT REF.: PL-LFI-PST-AN-006 PAGE: 1 of 68
ISSUE/REV.: 1.1 DATE: November 15, 2006

Prepared by	Aniello Mennella Marco Bersanelli Benedetta Cappellini Angel Colin Francesco Cuttaia Ocleto D'Arcangelo Samuele Galeotta Anna Gregorio Rodrigo Leonardi Stuart Lowe Michele Maris Luis Mendes Peter Meinhold Maria Salmon Maura Sandri Luca Stringhetti Luca Terenzi Maurizio Tomasi Luca Valenziano Fabrizio Villa	November 15, 2006
Agreed by	M. Bersanelli LFI Instrument Scientist C.R. Butler LFI Program Manager	30 October 2006
Approved by	N. Mandolesi LFI Principal Investigator	30 October 2006

- LFI FM analysis report
  Mennella et

- Calibration matrix (F. Villa et al.)



Planck-LFI RCA18 Acceptance Matrix

Date	
Place	
Operator	
RCA #	18
Frequency	70 GHz
FEED HORN Part Number	700100428-04
OMT Part Number	700100429-10
WG Part Number	700100430-02+700100431-01
4 K Part Number	
FEM Part Number	
BEM Part Number	

Polarisation configuration	OMT Main	OMT Side	

Parameter (Units)

Tunung	Y/N	M1	M2	S1	S2	Comm
Phase switch current (diode 1, mA)	Y	1.000	1.000	1.000	1.000	
Phase switch current (diode 2, mA)	Y	1.000	1.000	1.000	1.000	
LNA drain current (mA)	N	11.550	11.000	17.180	15.660	
LNA drain voltage (V)	N	0.376	0.386	0.425	0.338	
LNA gate 1 voltage (V)	Y	1.499	1.498	1.450	1.496	
LNA gate 2 voltage (V)	Y	1.500	1.521	1.474	1.612	

Primary performance parameters	Requirement	A	B	C	D	Comm
Noise temperature (K)	29.2	34.9	33.8	35.7	35.7	
White noise level (mK s1/2)						
Noise Equivalent Bandwidth (GHz)	14	10.78	8.53	9.57	10.30	
Swept bandpass (GHz)	14	10.25	10.84	12.4	11.14	
Channel isolation (dB)		-10.473241	-10.606261	-12.278447	-12.253295	
Knee frequency (mHz)		190	140	92	92	
FEM Power Consumption (mW)						

Radiometric parameters	Expected	A	B	C	D	Comm
Photometric calibration (V/K)		0.01435993	0.01483629	0.01639732	0.0140218	
Linearity coefficient		0.999665137	0.99949492	0.99941527	0.9996479	
Input Offset (K)						
Swept centre frequency (GHz)						
Band ripple (dB)						
1/f exponent		-1.71	-1.49	-1.62	-1.71	
Gain modulation factor (nominal imbalance)		1.160	1.170	1.170	1.170	

Susceptibility	Expected	A	B	C	D	Comm
Front-end coefficient (K/K) Theoretical						
Front-end coefficient (K/K) Measured						
Back-end coefficient (K/K) Theoretical						
Back-end coefficient (K/K) Measured						
Vg3 coefficient (K/K) Theoretical						
Vg3 coefficient (K/K) Measured						

EXAMPLE of VERIFICATION and CALIBRATION MATRIX

F.Villa et al.

LFI28 (30 GHz)

Note the color labelling: red for requirement not met, green for requirement met, …

Level 1	Level 2		Parameter (Units)	Measurement range	IID-B ref		Requirement	Test/Analysis ref.	Note	12 GHz (26.5 to 38.0 GHz)
Passive Components	Feedhorn	700100401-02	Bandwidth [%]	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71		20%	PL-LFI-PST-RP-011		
			Aperture [D/λ]	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71		5.11 @ 30GHz			4.59
			Side lobe level [dB]	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71		-35			-40
			Insertion loss [dB] (*)	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71					
			Return loss [dB]	worst value 26.5 - 40 GHz	4.71		-25			
			Phase center location [mm] (**)	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71					
			E Plane Feed Horn Edge taper dB@22_	{1.0}*30 GHz	4.71		-30			
			H Plane Feed Horn Edge taper dB@22_	{1.0}*30 GHz	4.71		-26.9			
			_+45_Plane Feed Horn Edge taper dB@22_	{1.0}*30 GHz	4.71		28.6			
			-45_Plane Feed Horn Edge taper dB@22_	{1.0}*30 GHz	4.71		28.6			
			+45_Plane Horn Cross polar max level	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71					-38
			-45_Plane Horn Cross polar max level	{0.9, 0.95, 1.0, 1.05, 1.1}*30 GHz	4.71					-38
	OMT	700100402-02	OMT insertion loss (dB) Direct @ 300K	worst value 27 - 33 GHz	4.71		<0.3			0.28
			OMT insertion loss (dB) Side @ 300K	worst value 27 - 33 GHz	4.71		<0.3			0.22
			OMT Return Loss (dB) Circular port direct	worst value 27 - 33 GHz			<-20			-17
			OMT Return Loss (dB) Circular port side	worst value 27 - 33 GHz			<-20			-20
			OMT Return Loss (dB) Rect port Direct	worst value 27 - 33 GHz	4.71		<-20			-15
			OMT Return Loss (dB) Rect port Side	worst value 27 - 33 GHz	4.71		<-20			-20
			Port Isolation (dB)	worst value 27 - 33 GHz	4.71		<-40			-48.5
			Cross pol (dB) direct	worst value 27 - 33 GHz			<-25			-38
			Cross pol (dB) Side	worst value 27 - 33 GHz			<-25			-42
	Feed-OMT		Bandwidth [%]		4.71					
			Insertion loss [dB] (*)		4.71					
			Return loss [dB] Direct	worst value 27 - 33 GHz	4.71					
			Return loss [dB] Side	worst value 27 - 33 GHz						
			Cross polarization [dB]		4.71					
	4K loads	PLTES 059 PLTES 058	Average Return Loss (dB) (Target)		4.71					
			Average insertion Loss (dB) (Reference Horn) 30&44 GHz Only		4.71					
	Waveguides	700100404-02 700100403-05	Return loss [dB] (*)	worst value 27 - 33 GHz	4.71		<-20			
			Insertion loss [dB] (*)		4.71					
			Parasitic Heat load at 20 K		4.71					
Active Components	FEM	3F1	Noise temperature (K)	Average Value		PL-LFI-JBO-SP-002	14.1	PL-LFI-JBO-RP-083		
			Bandwidth (GHz)		4.73	PL-LFI-JBO-SP-002	8.8	PL-LFI-JBO-RP-083		
			Input return Loss	worst value 39.6 - 48.4 GHz			<-5	PL-LFI-JBO-RP-083		
			Output return Loss	worst value 39.6 - 48.4 GHz			<-6	PL-LFI-JBO-RP-083		
			Gain (dB)	Average Value		PL-LFI-JBO-SP-002	30 Min	PL-LFI-JBO-RP-083		
			Channel Isolation (%)			PL-LFI-JBO-SP-002	10%	PL-LFI-JBO-RP-083		
			1/f Knee frequency (mHz)			PL-LFI-JBO-SP-003	50	PL-LFI-JBO-RP-083		
			Power dissipation (mW)			PL-LFI-JBO-SP-002	33.7	PL-LFI-JBO-RP-083		
	BEM	SN1	Noise temperature (K)			PL-LFI-SAN-ID-053	550			< 317
			Input return Loss (dB)	worst value 39.6 - 48.4 GHz		PL-LFI-SAN-ID-053	<-10			-4.7
			Power dissipation (W)			PL-LFI-SAN-ID-053	2.302			
			Effective Bandwidth (GHz)			PL-LFI-SAN-ID-053	8.8			9.27
			DC gain		4.7.3					
RCA			Noise temperature (K)	Derived on SKY temp step from 12.3K to 31.8 using gain model	4.7.3	PL-LFI-PST-SP-006	10.7	RCA_LIS		9.9
			White noise level (K/rtHz)	Calibrated and measured on differential data with SKY = 8.6 K and REF = 8.6 K	4.7.3		0.33959	RCA_ST3		
			Input offset (K)		4.7.3			RCA_OFT		On Going
			Channel isolation (dB)		4.7.3			RCA_LIS		On Going
			Linearity dynamic range		4.7.3			RCA_LIS		NA
			Linearity coefficient		4.7.3			RCA_LIS		On Going
			Photometric calibration (V/K)		4.7.3			RCA_LIS		FIT
			Swept centre frequency (GHz)			PL-LFI-PST-SP-006	30	RCA_SPR		31.8
			Swept bandpass (GHz)		4.7.3	PL-LFI-PST-SP-006	6	RCA_SPR	Cryo test failed on C and D	4.30
			fFE therm	K/K Using SKY SMON_TMP Probe @ 20 22 24 27K						-0.0190
			dG/dTFE		4.7.4		0.043G (dB)/K @30dB Gain	RCA_THF		-0.0480
			dTn/dTFE		4.7.4		0.3 K/K			0.0770
			fBE therm		4.7.4			Test not performed		
			fVG3 therm	T Variation 61.5 63.5 65.5 K				RCA_THV		2.97E-06
			Knee frequency (mHz)	SKY temp = 8.6K; REF temp= 8.5K	4.7.3	PL-LFI-PST-SP-006	<50	RCA_ST3		41
			1/f exponent	SKY temp = 8.6K; REF temp= 8.5K				RCA_ST3		-1.6
			Noise equivalent bandwidth (GHz)	SKY temp = 8.6K; REF temp= 8.5K	4.7.3	PL-LFI-PST-SP-006	6	RCA_ST3	Calculated on SKY	8.34
			Gain modulation factor	SKY temp = 8.6K; REF temp= 8.5K	4.7.3			RCA_ST3		0.939
		Cryo	Phase switch current (diode 1, mA)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	Table 8.3.2	0.500
			Phase switch current (diode 2, mA)					PL-LFI-LAB-PR-019	Table 8.3.2	0.800
			LNA drain current (mA)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	Table 8.3.2	8.02
			LNA drain voltage (V)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	Table 8.3.2	0.957
			LNA gate 1 voltage (V)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	Table 8.3.2	1.501
			LNA gate 2 voltage (V)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	Table 8.3.2	-1.303
			Vout					PL-LFI-LAB-PR-019		
		WARM	Phase switch current (diode 1, mA)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019		0.800
			Phase switch current (diode 2, mA)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019		0.800
			LNA drain current (mA)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	mA	19.220
			LNA drain voltage (V)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	V	1.679
			LNA gate 1 voltage (V)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	V	1.831
			LNA gate 2 voltage (V)	{range of operating temperatures}	4.7.7			PL-LFI-LAB-PR-019	V	-0.970
			Vout (SKY)					PL-LFI-LAB-PR-019	V	2.033
			Sensitivity to DC supply							
RAA			1/f noise parameters		4.7.5					
			Data compression		4.7.6					
			Response to particles		4.7.8					
			RF emissions		4.7.9					
			Cross-talk		4.7.1					
			Geometry		4.7.1					
			Offset removal (V)	{range of operating temperatures}	4.7.7					
			PGA gain	{range of operating temperatures}	4.7.7					
			Gain modulation factor R1							
			Gain modulation factor R2							

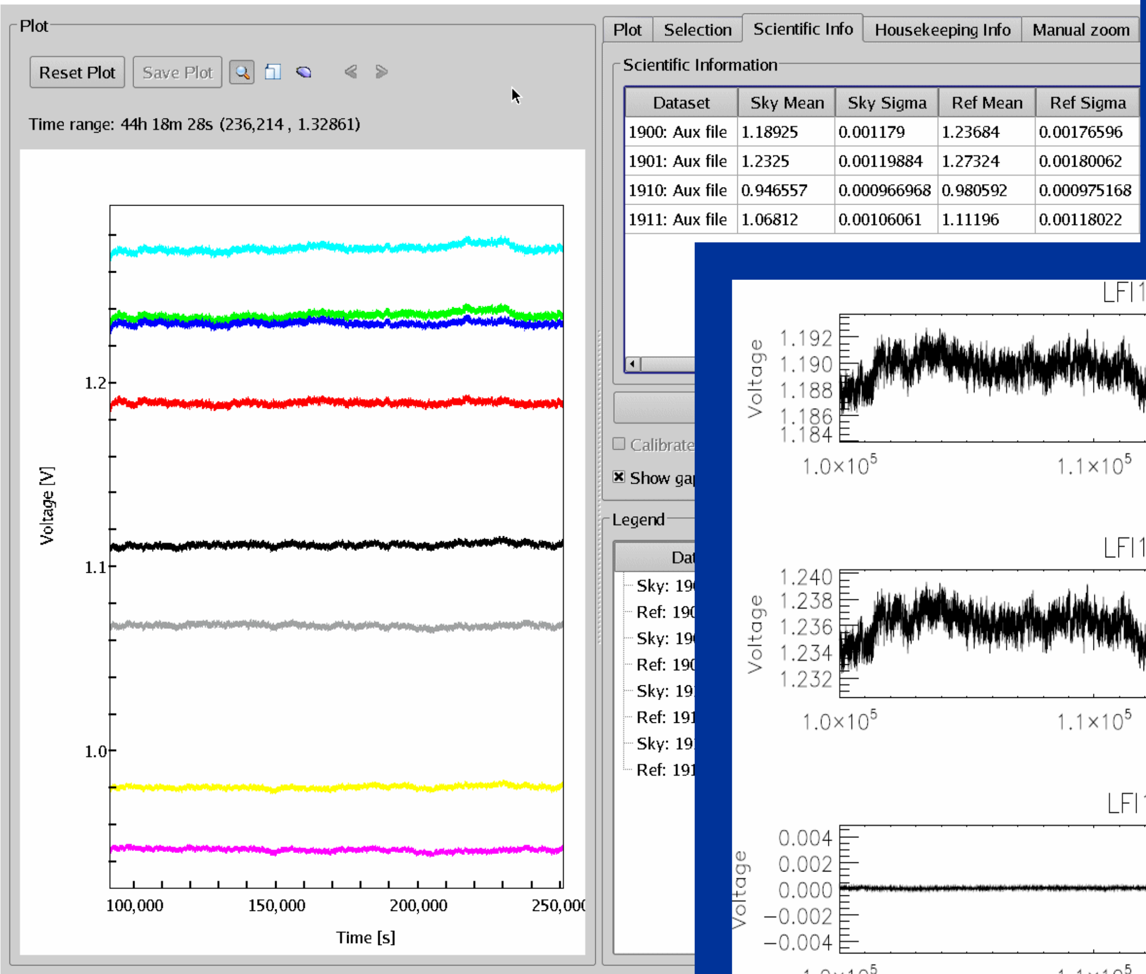
Planck-LFI RCA18 Acceptance Matrix

Date						
Place						
Operator						
RCA #	18					
Frequency	70 GHz					
FEED HORN Part Number	700100428-04					
OMT Part Number	700100429-10					
WG Part Number	700100430-02+700100431-01					
4 K Part Number						
FEM Part Number						
BEM Part Number						
Polarisation configuration		OMT Main		OMT Side		
Parameter (Units)						
Tunung	**Y/N**	**M1**	**M2**	**S1**	**S2**	**Comm**
Phase switch current (diode 1, mA)	Y	1.000	1.000	1.000	1.000	
Phase switch current (diode 2, mA)	Y	1.000	1.000	1.000	1.000	
LNA drain current (mA)	N	11.550	11.000	17.180	15.660	
LNA drain voltage (V)	N	0.376	0.386	0.425	0.338	
LNA gate 1 voltage (V)	Y	1.499	1.498	1.450	1.496	
LNA gate 2 voltage (V)	Y	1.500	1.521	1.474	1.612	
Primary performance parameters	**Requirement**	**A**	**B**	**C**	**D**	**Comm**
Noise temperature (K)	29.2	34.9	33.8	35.7	35.7	
White noise level (mK s1/2)						
Noise Equivalent Bandwidth (GHz)	14	10.78	8.53	9.57	10.30	
Swept bandpass (GHz)	14	10.25	10.84	12.4	11.14	
Channel isolation (dB)		-10.473241	-10.606261	-12.278447	-12.253295	
Knee frequency (mHz)		190	140	92	92	
FEM Power Consumption (mW)						
Radiometric parameters	**Expected**	**A**	**B**	**C**	**D**	**Comm**
Photometric calibration (V/K)		0.01435993	0.01483629	0.01639732	0.0140218	
Linearity coefficient		0.999665137	0.99949492	0.99941527	0.9996479	
Input Offset (K)						
Swept centre frequency (GHz)						
Band ripple (dB)						
1/f exponent		-1.71	-1.49	-1.62	-1.71	
Gain modulation factor (nominal imbalance)		1.160	1.170	1.170	1.170	
Susceptibility	**Expected**	**A**	**B**	**C**	**D**	**Comm**
Front-end coefficient (K/K) Theoretical						
Front-end coefficient (K/K) Measured						
Back-end coefficient (K/K) Theoretical						
Back-end coefficient (K/K) Measured						
Vg3 coefficient (K/K) Theoretical						
Vg3 coefficient (K/K) Measured						

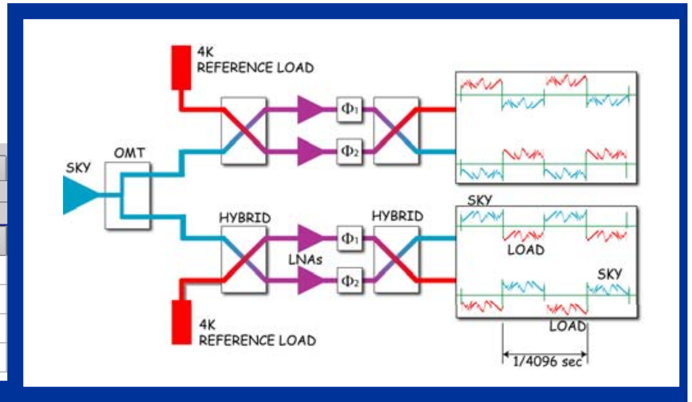
Long-duration RAA data set

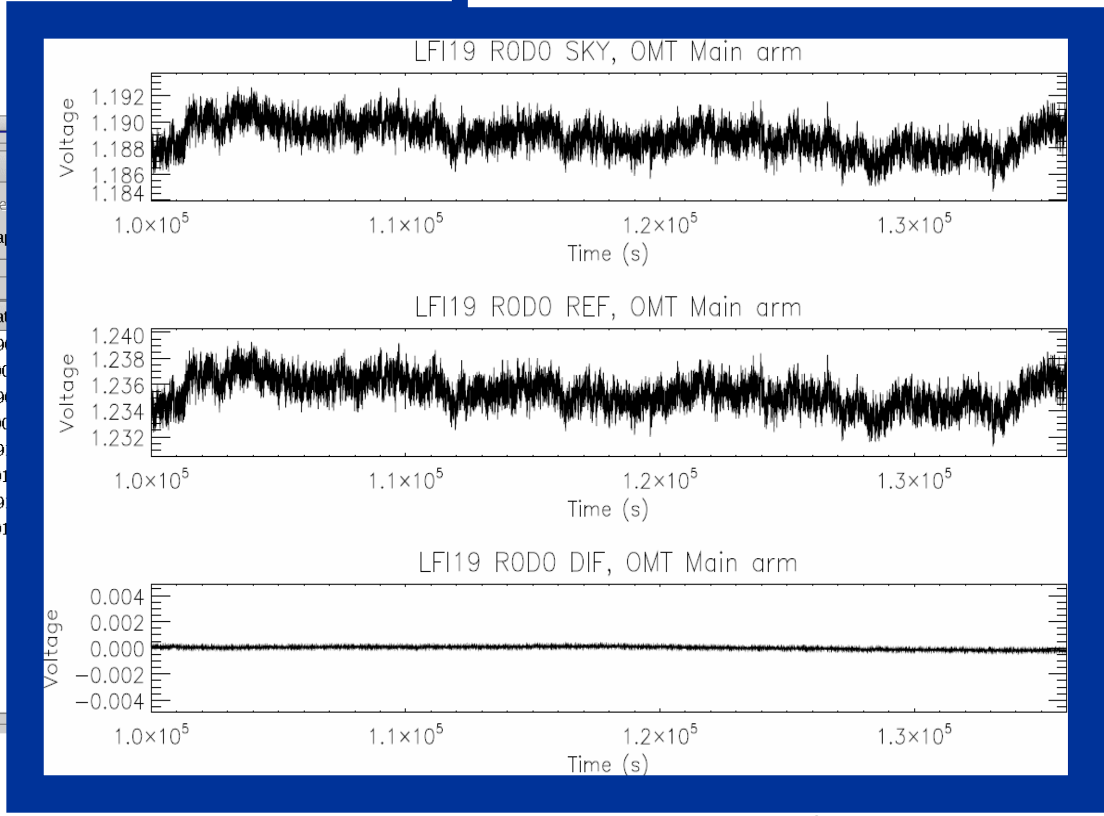
45 hours of undisturbed acquisition (MODE 5)

70 GHz LFI#19 02 Sep 2006



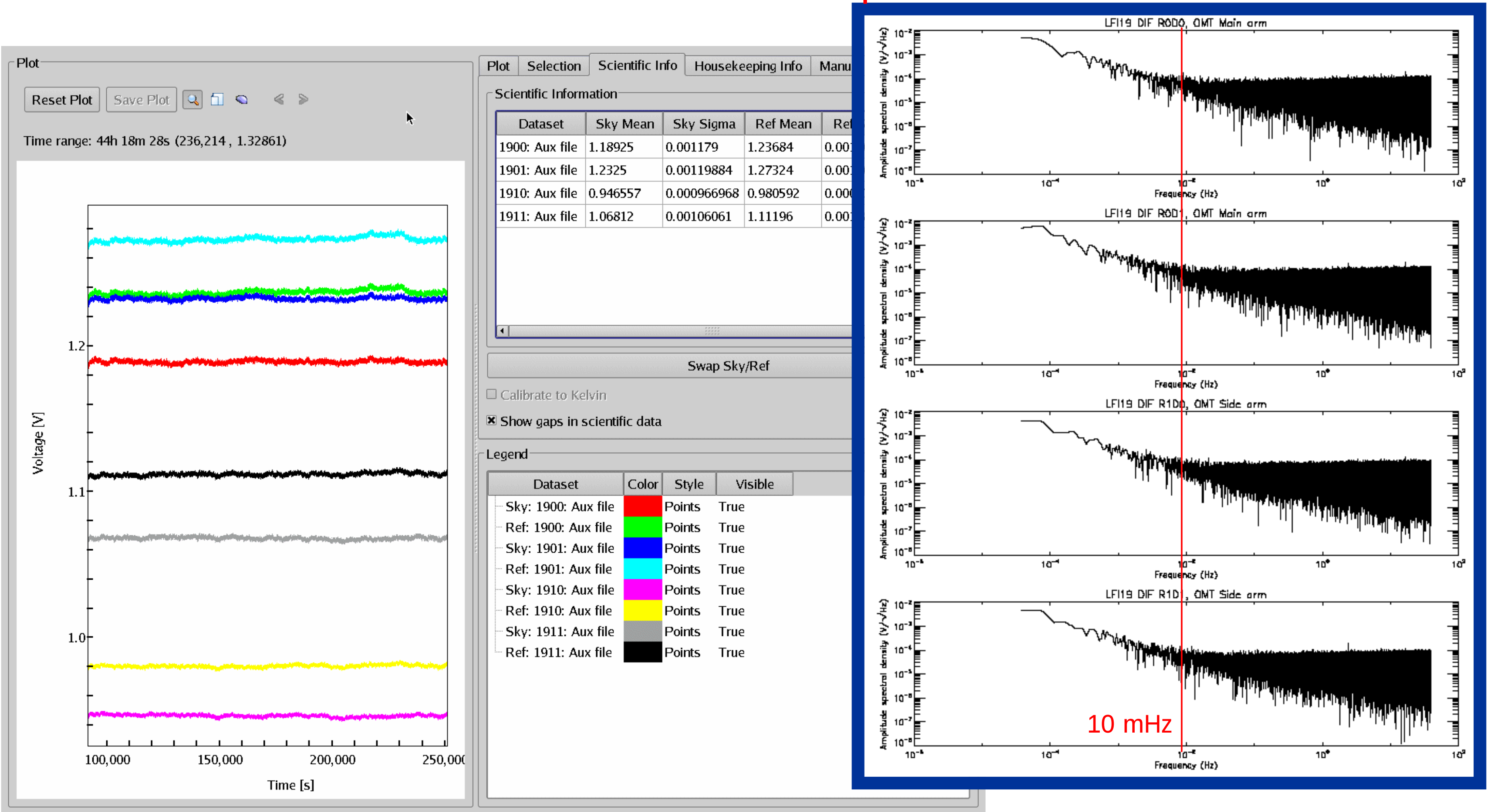
Dataset	Sky Mean	Sky Sigma	Ref Mean	Ref Sigma
1900: Aux file	1.18925	0.001179	1.23684	0.00176596
1901: Aux file	1.2325	0.00119884	1.27324	0.00180062
1910: Aux file	0.946557	0.000966968	0.980592	0.000975168
1911: Aux file	1.06812	0.00106061	1.11196	0.00118022





Long-duration RAA data set
45 hours of undisturbed acquisition (MODE 5)

70 GHz LFI#19 02 Sep 2006



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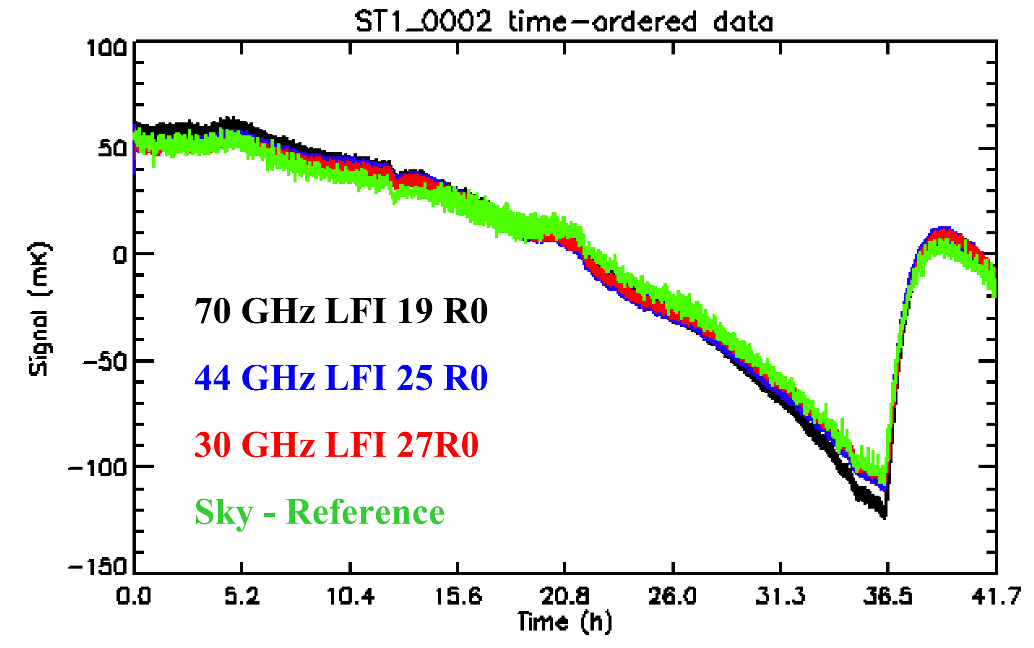
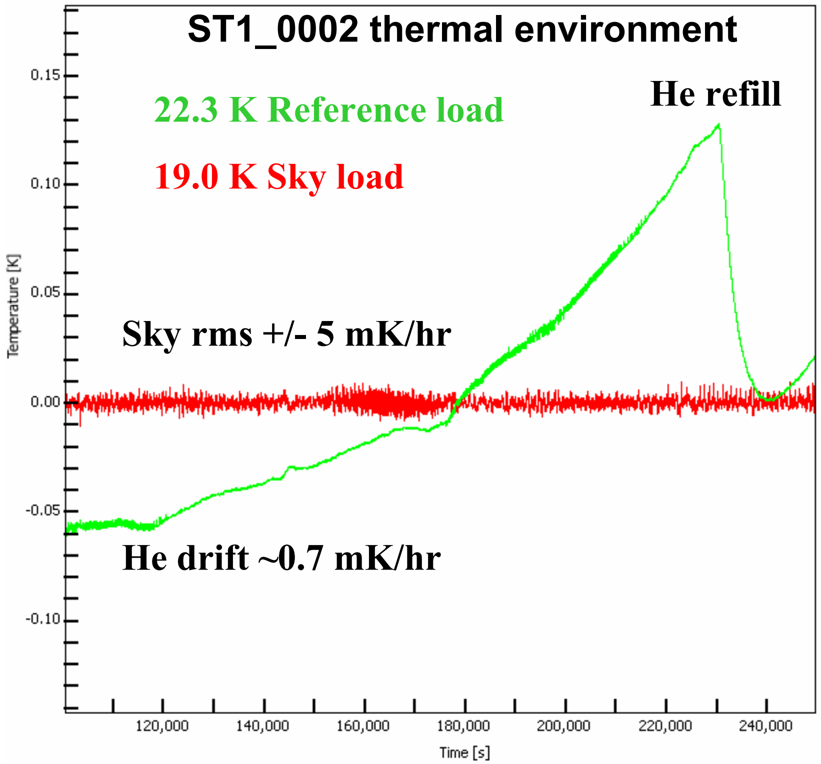
LFI

HFI

Long-duration RAA data set
45 hours of undisturbed acquisition (MODE 5)



Binned samples



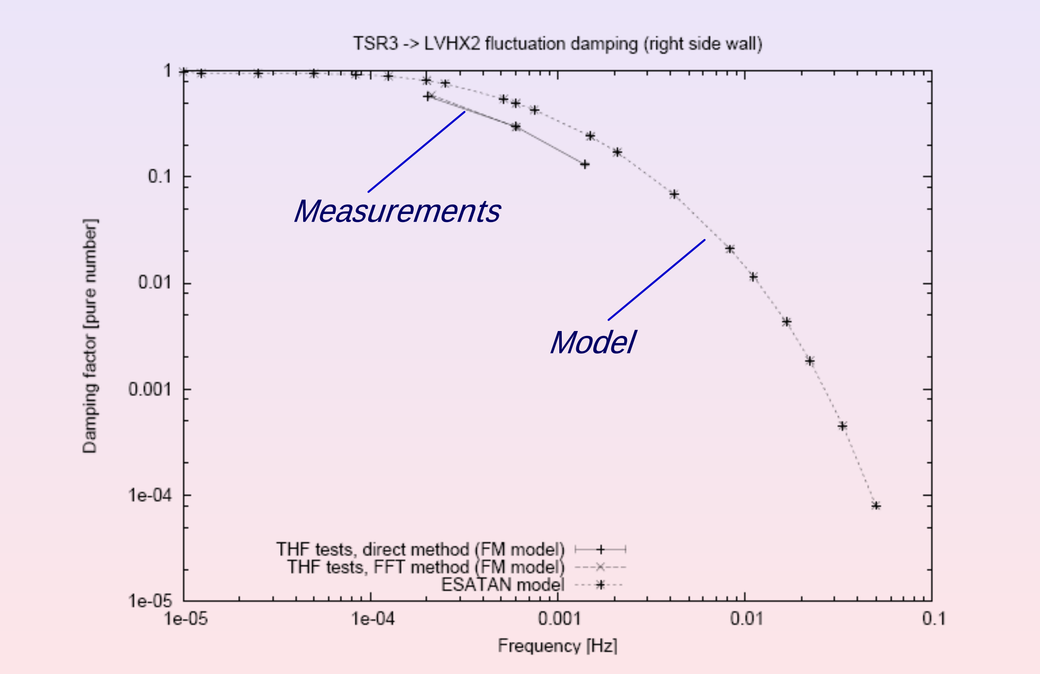
Measurements of thermal damping

(M.Tomasi et al)

LVHX2 stimulated with sinewave thermal input, different frequencies

12 temperature sensors on the FPU

Correspondence to relevant nodes in LFI thermal model



Results obtained for a number of interfaces/nodes

Example shown

General good agreement

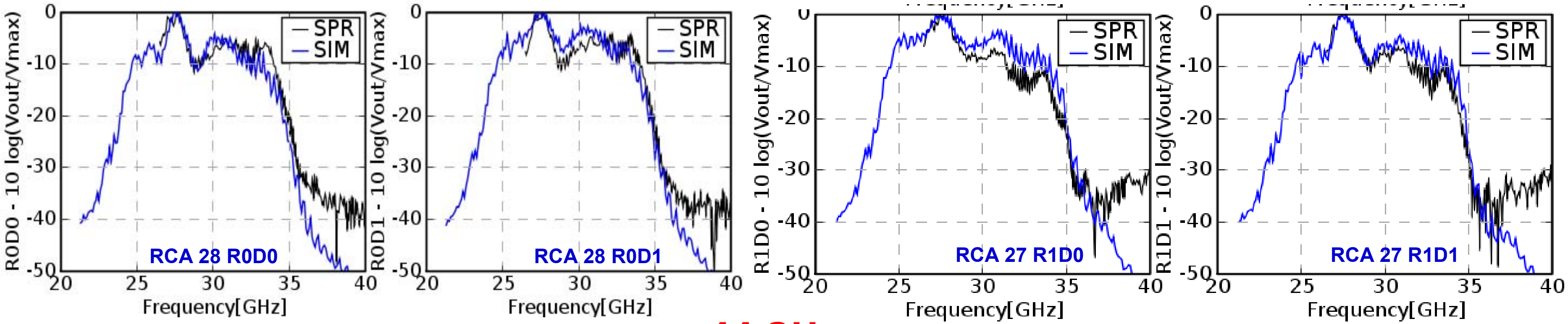
Damping factor slightly higher (good news!)

Investigate residual discrepancies (*SVR recommendation*)

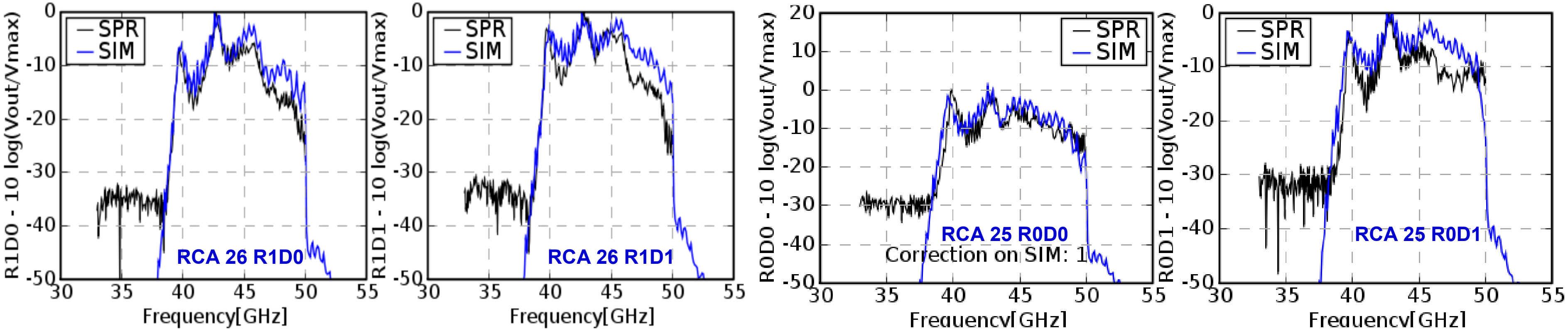
LFI Bandpasses (A. Zonca et al)

Examples at 30 and 44 GHz

30 GHz

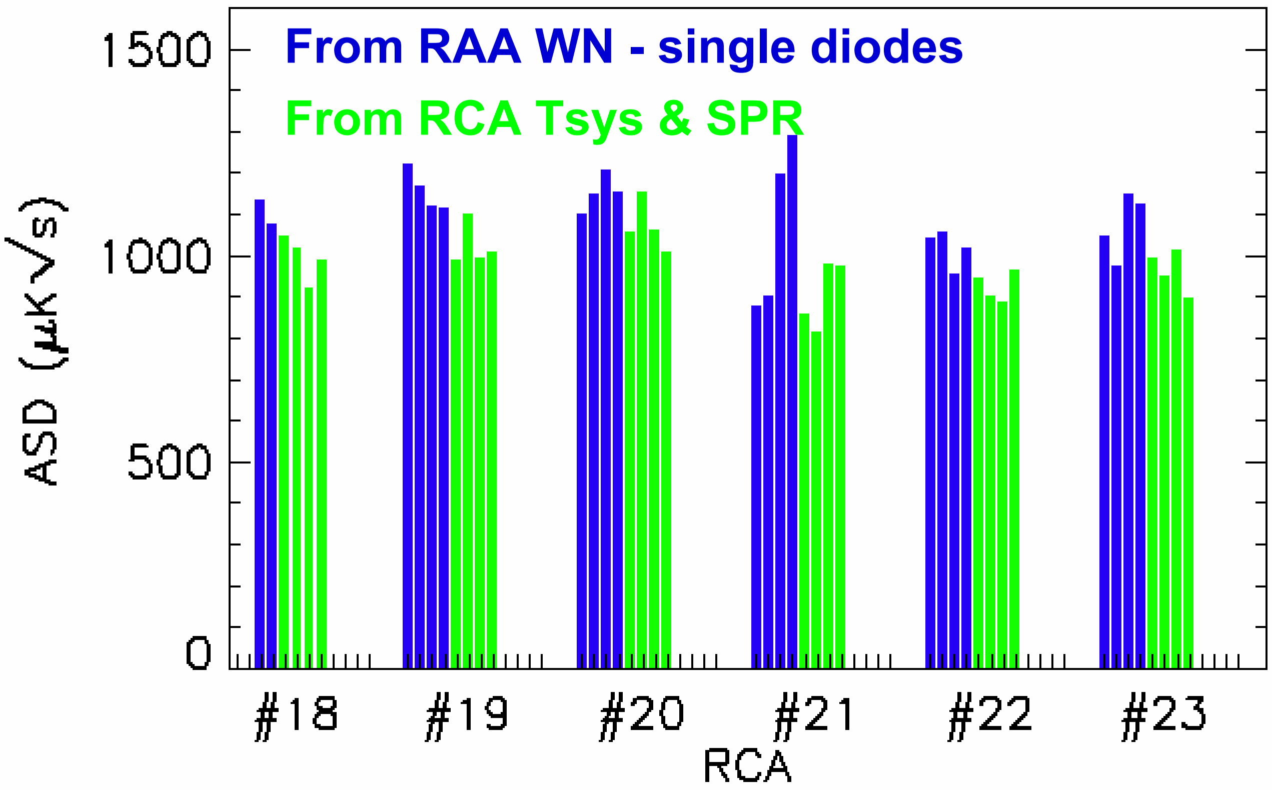


44 GHz



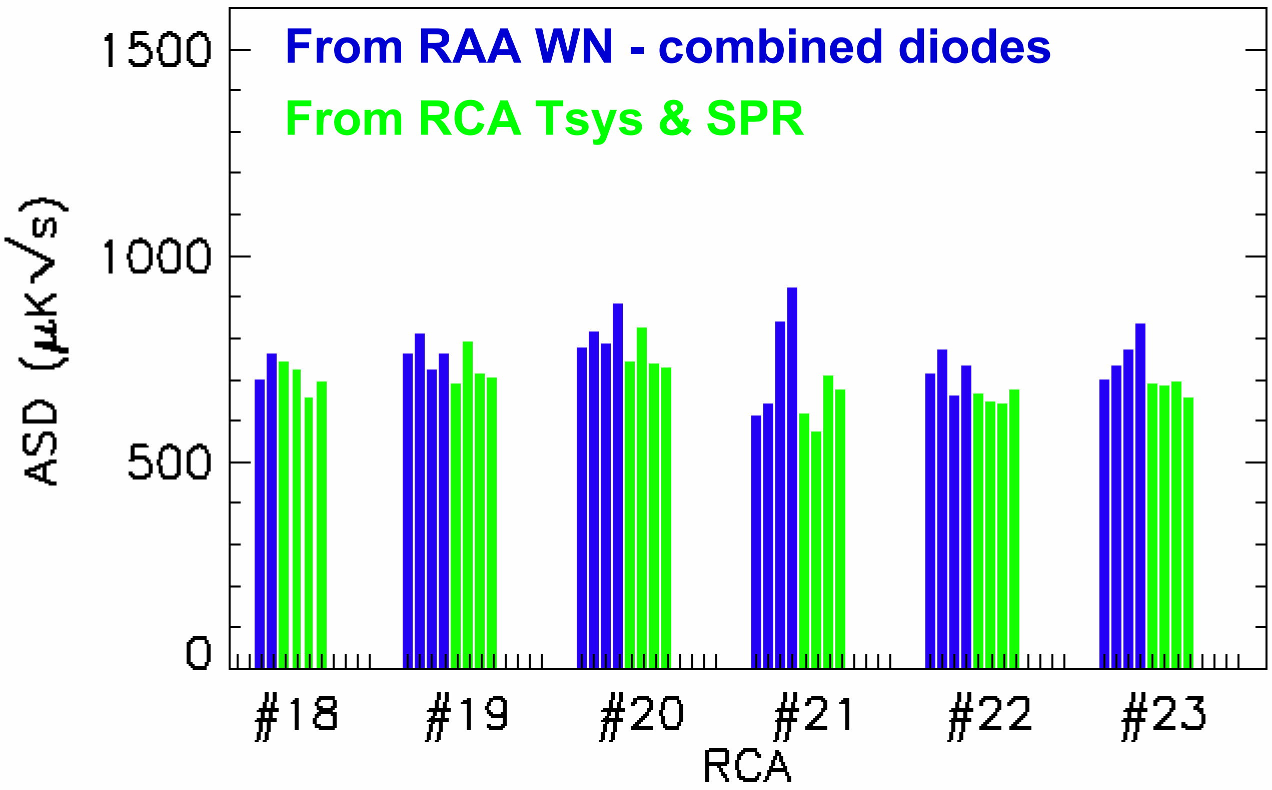
White noise - Consistency with basic model

Basic model: Radiometer Equation $\sigma_T = K\left(\frac{T_{\mathrm{sys}} + T_{\mathrm{sky}}}{\sqrt{\beta \cdot \tau}}\right)$



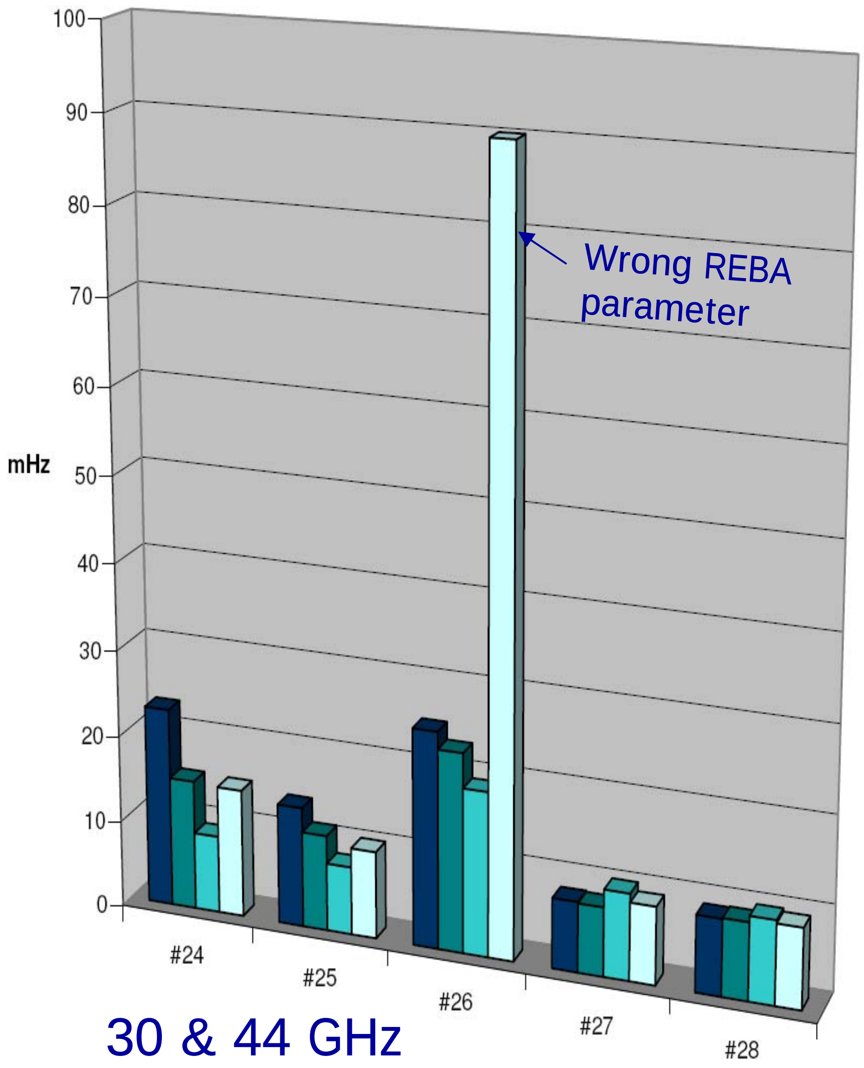
White noise - Consistency with basic model

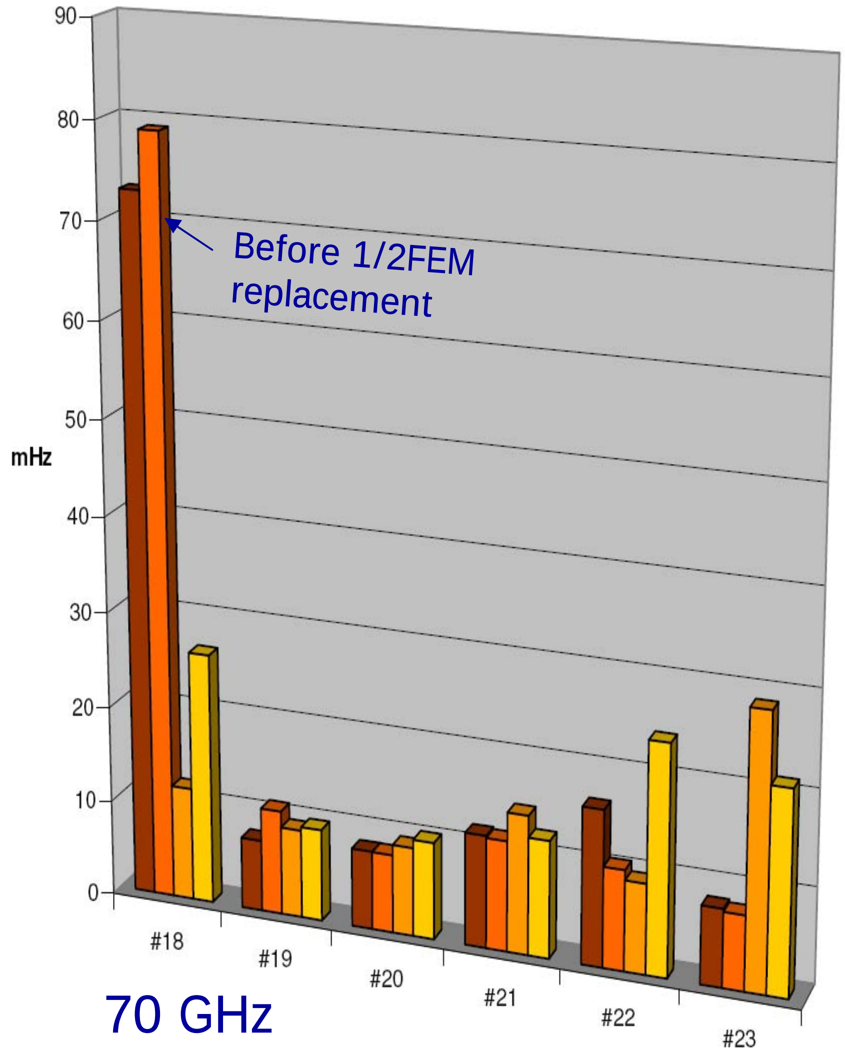
Basic model: Radiometer Equation $\sigma_T = K\left(\frac{T_{\rm sys} + T_{\rm sky}}{\sqrt{\beta \cdot \tau}}\right)$



sqrt(2) reduction as expected

KNEE FREQUENCY
REQ. < 50 mHz





LFI FM results summary

- Noise spectrum: generally clean
- Channel isolation: in spec (>13 dB)
- Sensitivity: near requirement (within -5/+20%)
- Knee frequency: 10-20 mHz level (better than goal)
- Bandpass shape: well reconstructed, ripple ±5dB
- Optical performances (main beam & sidelobes): as expected
  - Projected angular resolution at 70 GHz: ~13.5 arcmin
- Polarisation isolation: ~35dB (better than goal)
- Thermal damping: factor ~2 better than expected
- Thermal susceptibility: in line with model predictions

LFI flight instrument: unprecedented performances

Parameter	30 GHz		
	Meas	Req	Goal
Noise temperature (K)	12	10.7	7.5
Knee frequency (mHz)	18	50	50
Bandwidth (GHz)	8.1	6.0	6.0
Isolation (dB)	14	>13	>13
Sensitivity per frequency ($\mu K_{RJ}\ s^{1/2}$)	110	115	87
Average noise per 30' pixel (μK_{RJ})	7	8	6
Polarisation isolation (dB)	39	>25	>25

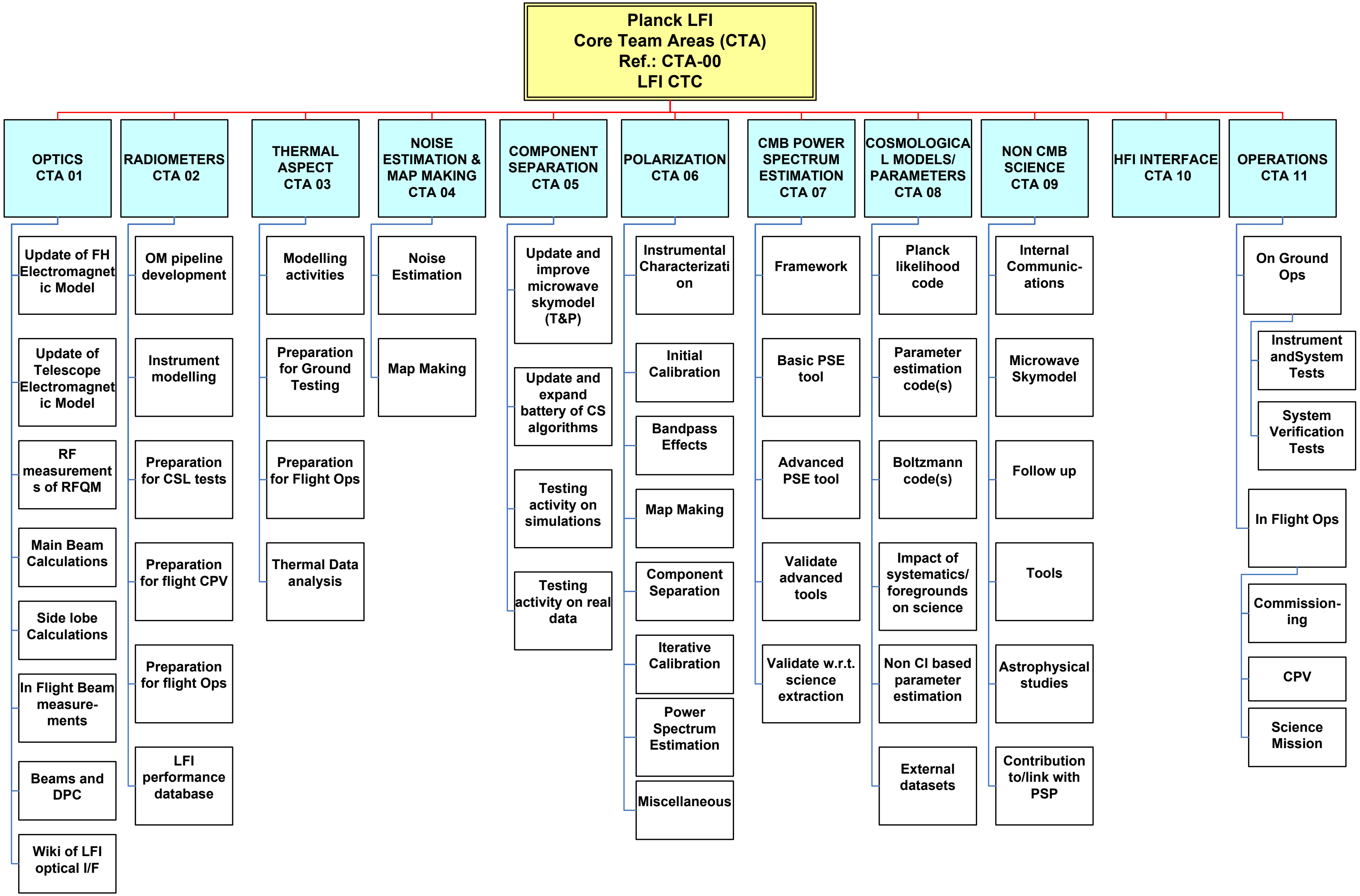
Example at 30 GHz

LFI Core Team

(90 people)

CT Areas	Coordinators/Deputies
Optics (Main beam, focal plane, far side lobes etc.)	F.Villa/S. Leach
Radiometers (calibration, model, noise, spikes EMI/EMC)	D. Mennella/P. Meinhold
Thermal aspects (includes SC)	G. Morgante/D. Pearson
Noise Estimation and Map Making	G. de Gasperis/ E. Keihanen
Component Separation	C. Baccigalupi/D. Maino
Polarization	P. Leahy/M. Sandri/H.K. Suonio (temp.)
CMB Power Spectrum Estimation	P. Natoli/G. Rocha
Cosmological Models/Parameters	A. Balbi/ F. Finelli/P.Vielva
Non CMB Science	C. Burigana/J. Gonzalez-Nuevo
HFI Interface	T.Banday/A. Zonca
Operations	A. Gregorio/L. Stringhetti

LFI CORE TEAM WBS



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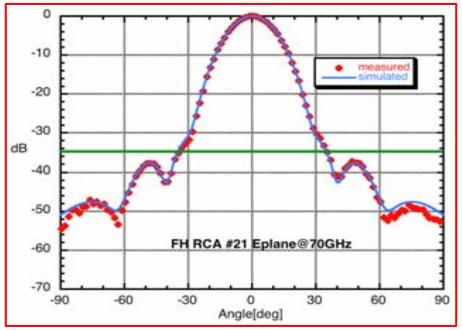
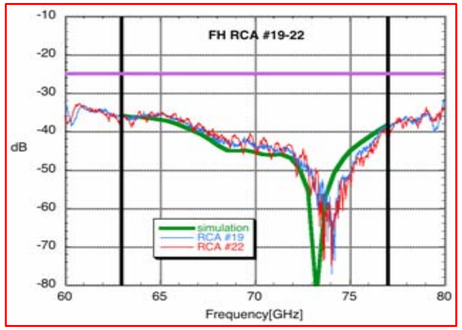
Additional CT activities

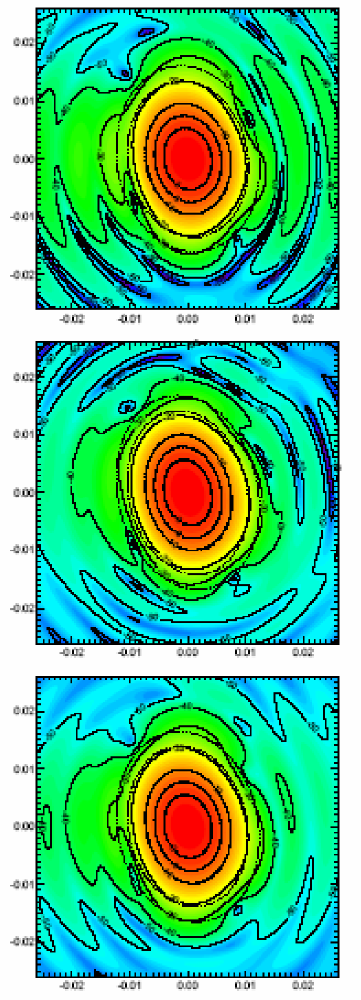
- **LFI additional tests on FS** (Investigate new tuning procedure to be used at CSL and during CPV, update of the bandshape knowledge (all freq), Thermo/optical model refinement, Thermo electrical model refinement
- **Preparation for CPV phase**
- **Instrument model**
- **Beams definition**
- **Systematics analysis**
- **LFI instrument analysis software**

LFI Optical design and analysis
coordinated by F. Villa

- Instrument level measurements and modeling
  - Feeds
  - Bandpasses
  - Coupling of optics with detector responses
  - Polarisation characterisation







- Telescope measurements and modeling
  - Reflectors properties (WFE, emissivity, cooldown, ...)
  - RFQM measurements
  - GRASP9 beams

Much work ahead !

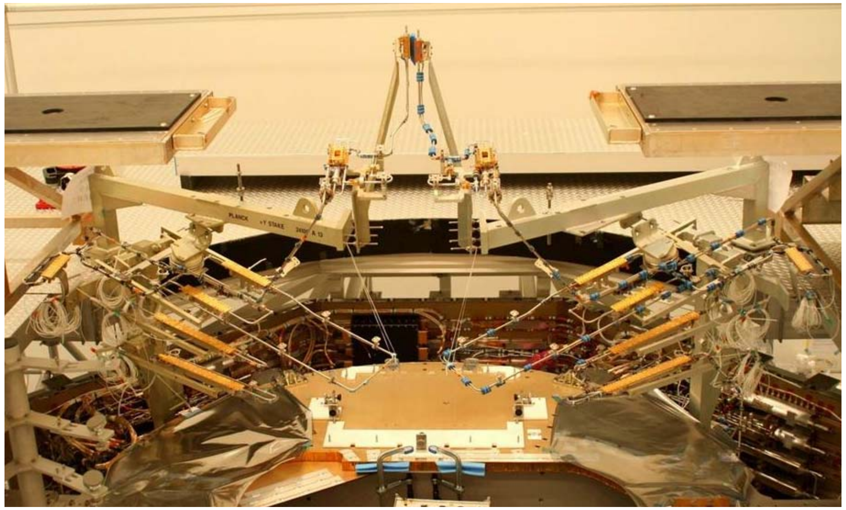
- Tuning procedure for CSL test and CPV phase
- Accurate flight beam pattern model (4π)
  - In-band coupling with radiometer response
- Polarisation:
  - Band shape effects
  - Gain relative calibration
- In-flight thermal conditions
  - 4KRL instability from HFI 4K cooler
  - Sorption cooler lifetime
- Instrument model
- LFI-HFI interaction
- LFI-HFI common analysis

Current launch date: 31 July 2008

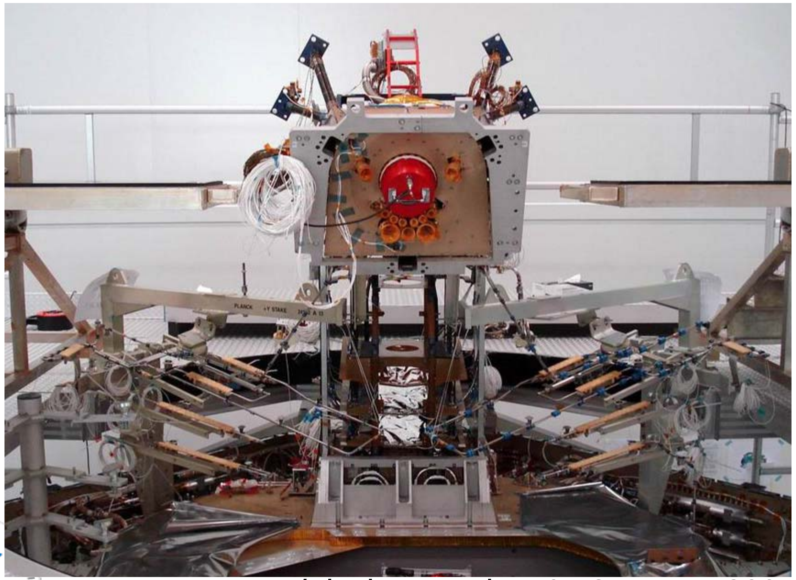
46 weeks
328 days

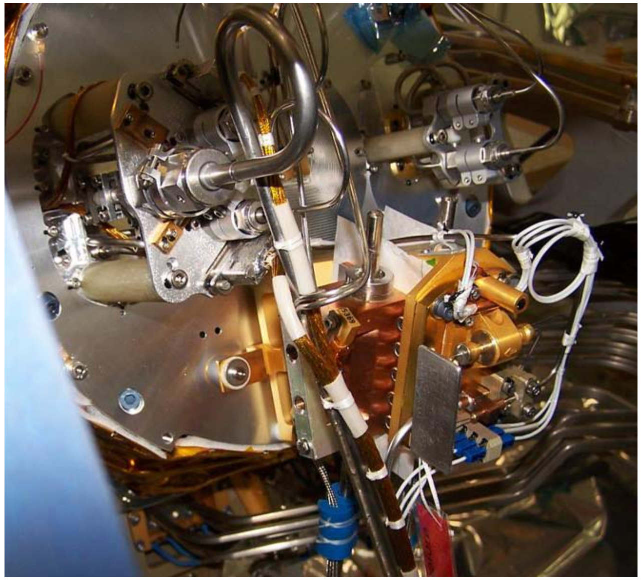
SORPTION COOLER

SCS compressors and Electronics boxes on radiator panel

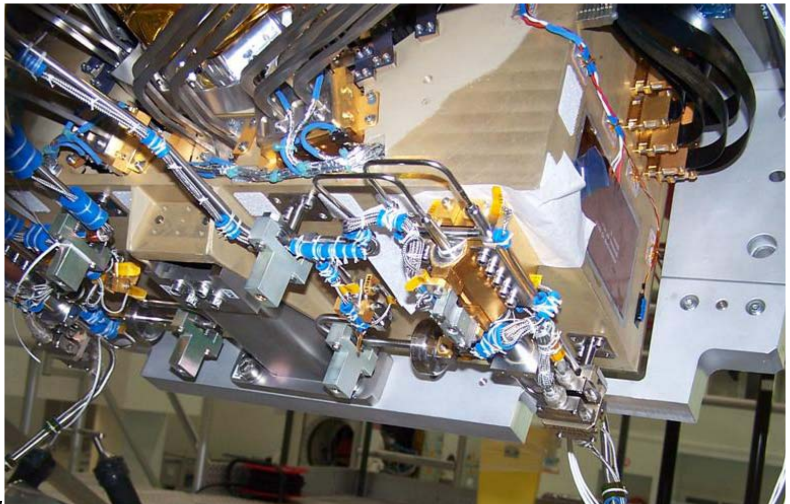


PACE before (up) and after (down) instruments integration





LVHX 1 (up) & 2 (down) pre-mating



LFI Cryogenic Critical Points 1/2

SCS Cold End T fluctuations – NOT A MAJOR OPEN ISSUE

One of thermal systematics main sources. Direct impact on LFI performance and HFI cryochain stability (including 4K ref load)

What we know

Two effects

- ❑ SCS Compressor driven peaks: low frequency, known, understood and measured, can be controlled by
  - compressor tuning for all boundaries flight allowable
  - TSA tuning (finalized after CSL PFM2 Test)
- ❑ SCS Cold End fluctuations: high-frequency, due to gravity effects, 0-g behavior known only by
  - analysis
  - experimental ground data in different orientations

Indications are that it will disappear in 0-g and TSA can control Cold End typical high-f even on ground

LFI 4K Reference Load T fluctations – OPEN ISSUE (4K COOLER availability)

4K reference load temperature is not measured (no sensors), fluctuations can be evaluated only by analysis/modeling. Their knowledge is essential to LFI because they affect instrument performance and precision of scientific measurement

What we know

- ❑ Requirements for 4K stage T stability
- ❑ Detailed thermal (and RF) model of reference load

What we need (requested to HFI)

- ❑ Actual 4K cooler stability data (on ground and in 0-g)
- ❑ Transfer functions from 4K cooler to 4K ref load IFs including effects of active control

LFI Cryogenic Critical Points 2/2

SCS Lifetime

Critical issue for the Planck mission duration

What we know

- ❑ Main limiting factor of SCS lifetime is hydrides degradation, function of cooler number of cycles (JPL analysis)
- ❑ Principal operational parameters having impact on lifetime are:
  - temperature of VG3 (the coldest the VG3, the longest the SCS life)
  - heat lift required
  - available input power
- ❑ Baseline for SCS flight operations is to maximize lifetime by reducing n of cycles
  - Operate cooler with max cycle time allowed by boundary conditions while meeting requirements

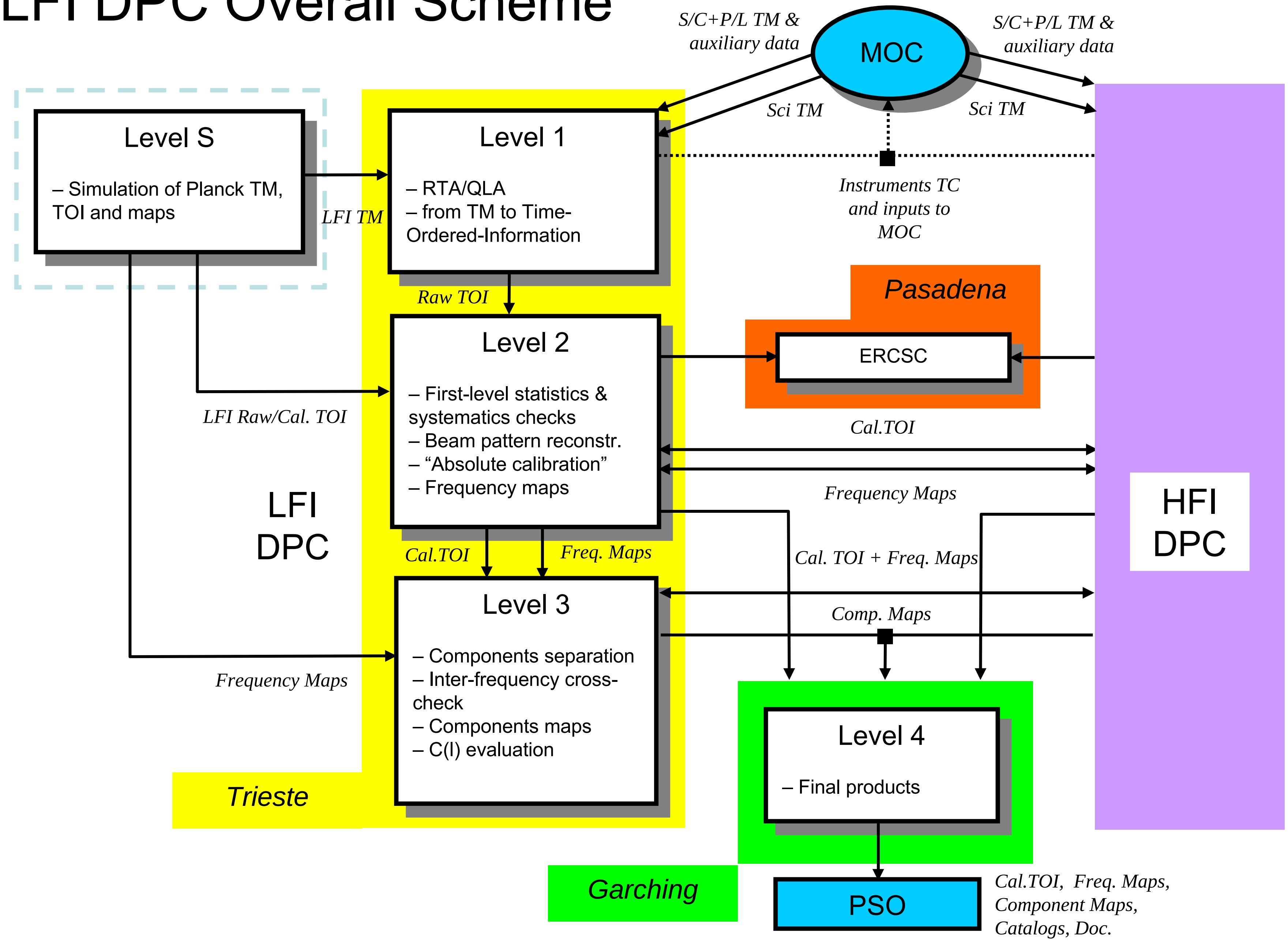
What we need

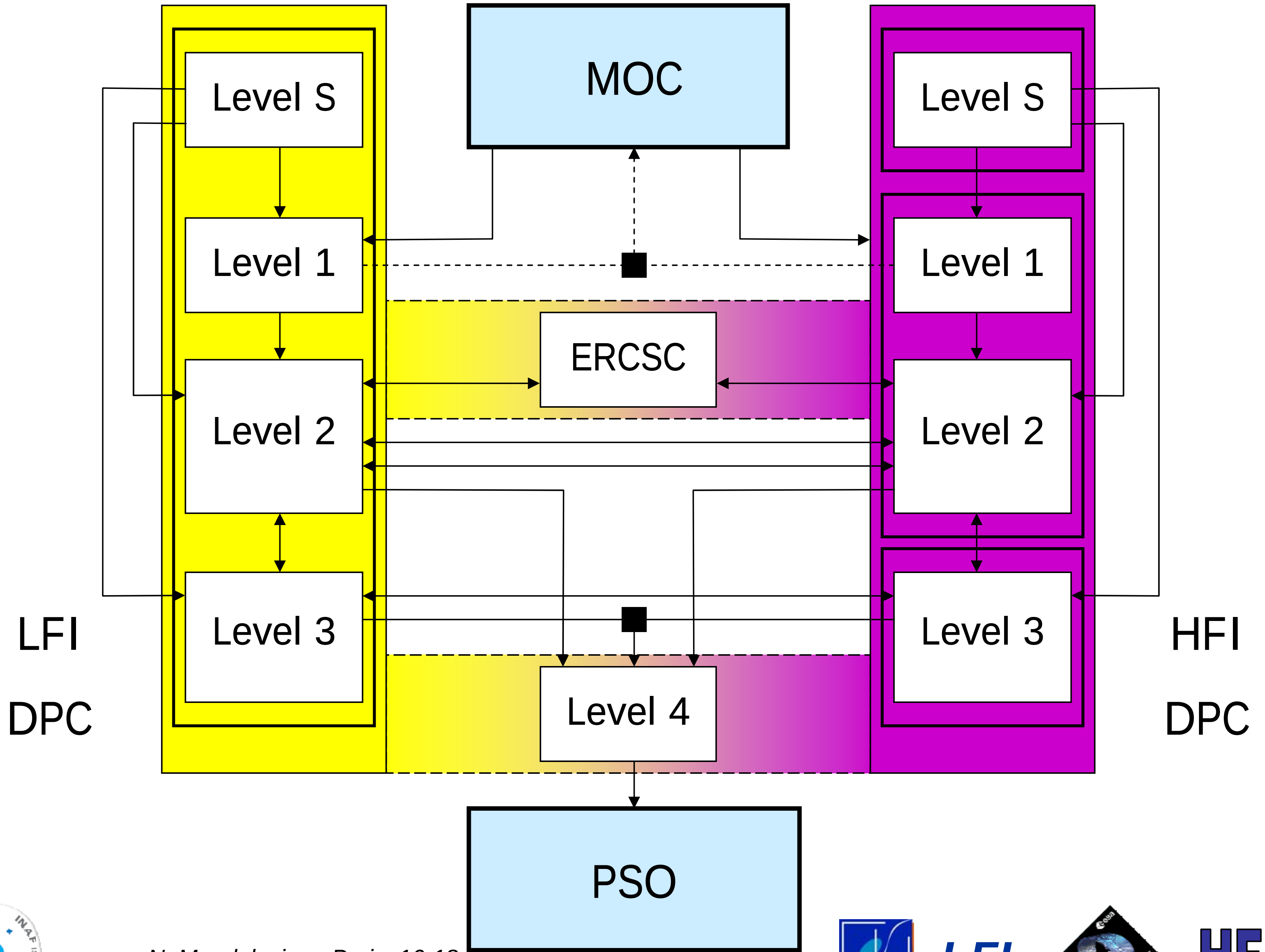
- ❑ SVM+PLM thermal model finalization after CSL test ⟶ SCS IFs best estimation for flight (from TAS-F)

Best Estimation: 4 surveys plus contingency

Planck-LFI DPC:
the data management

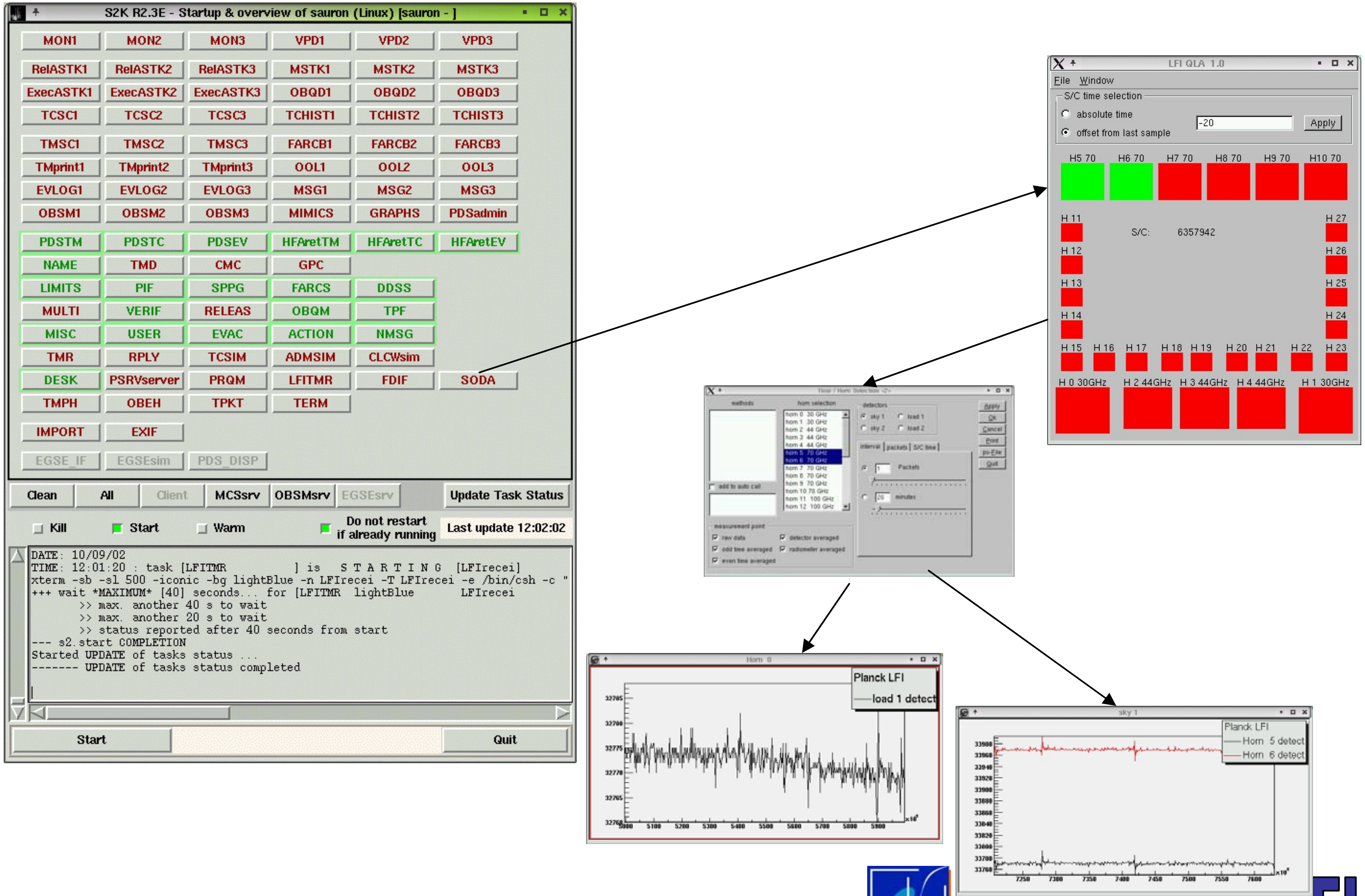
LFI DPC Overall Scheme



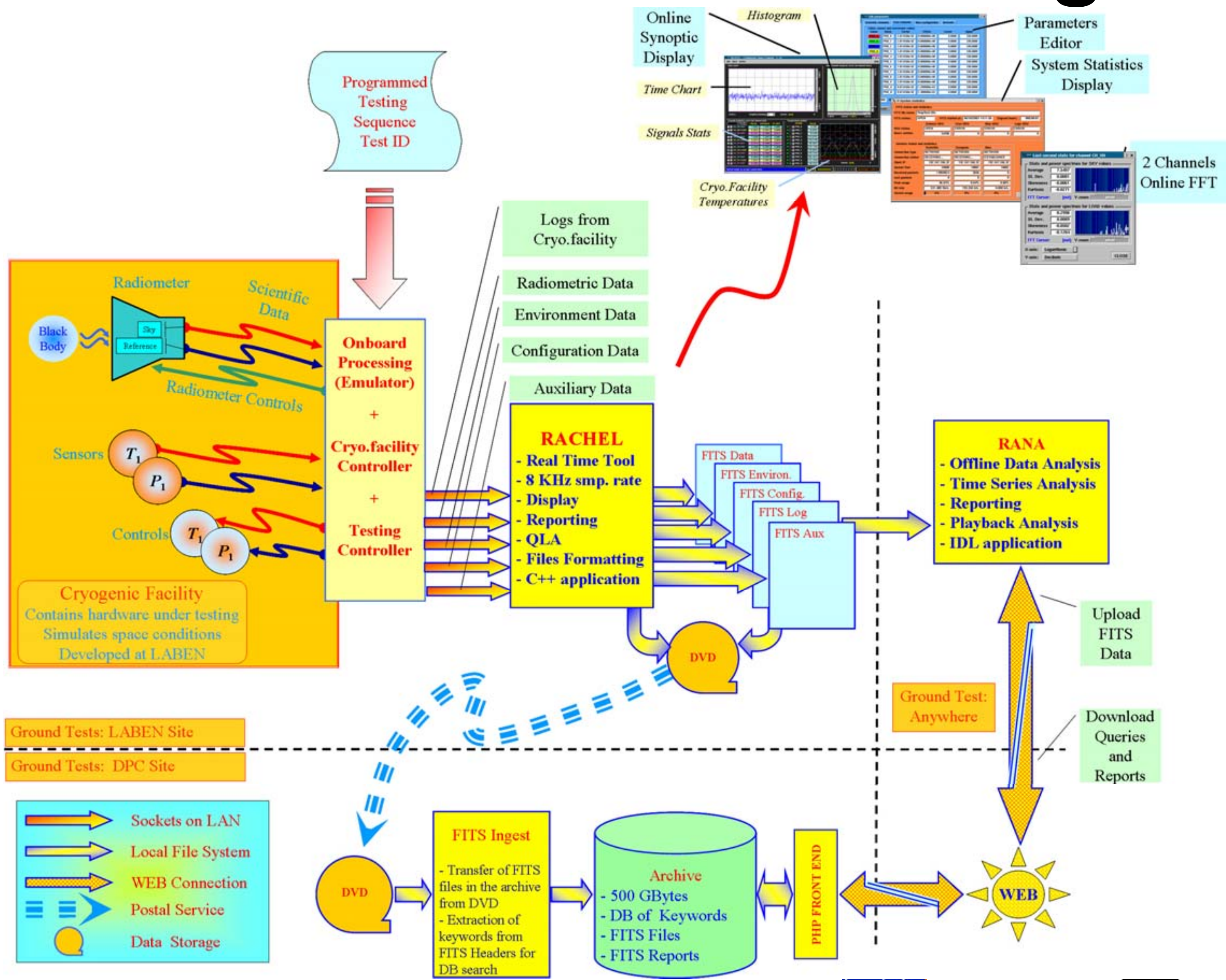


MOC
Level S
Level 1
Level 2
Level 3
ERCSC
Level 4
Level S
Level 1
Level 2
Level 3
LFI
DPC
HFI
DPC
PSO

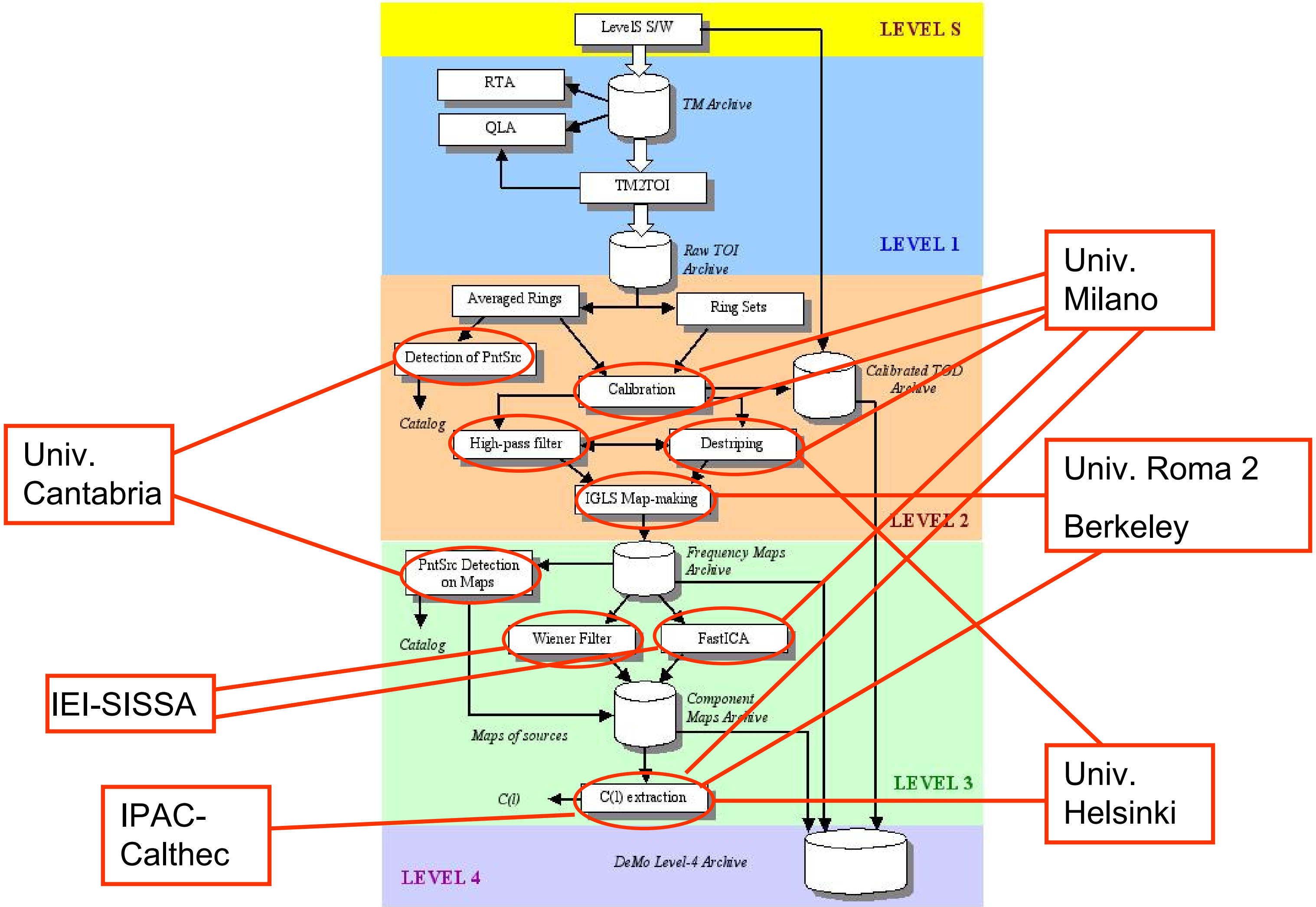
Level 1 Science Quick Look Analysis



Level 1 RCA TEST Design

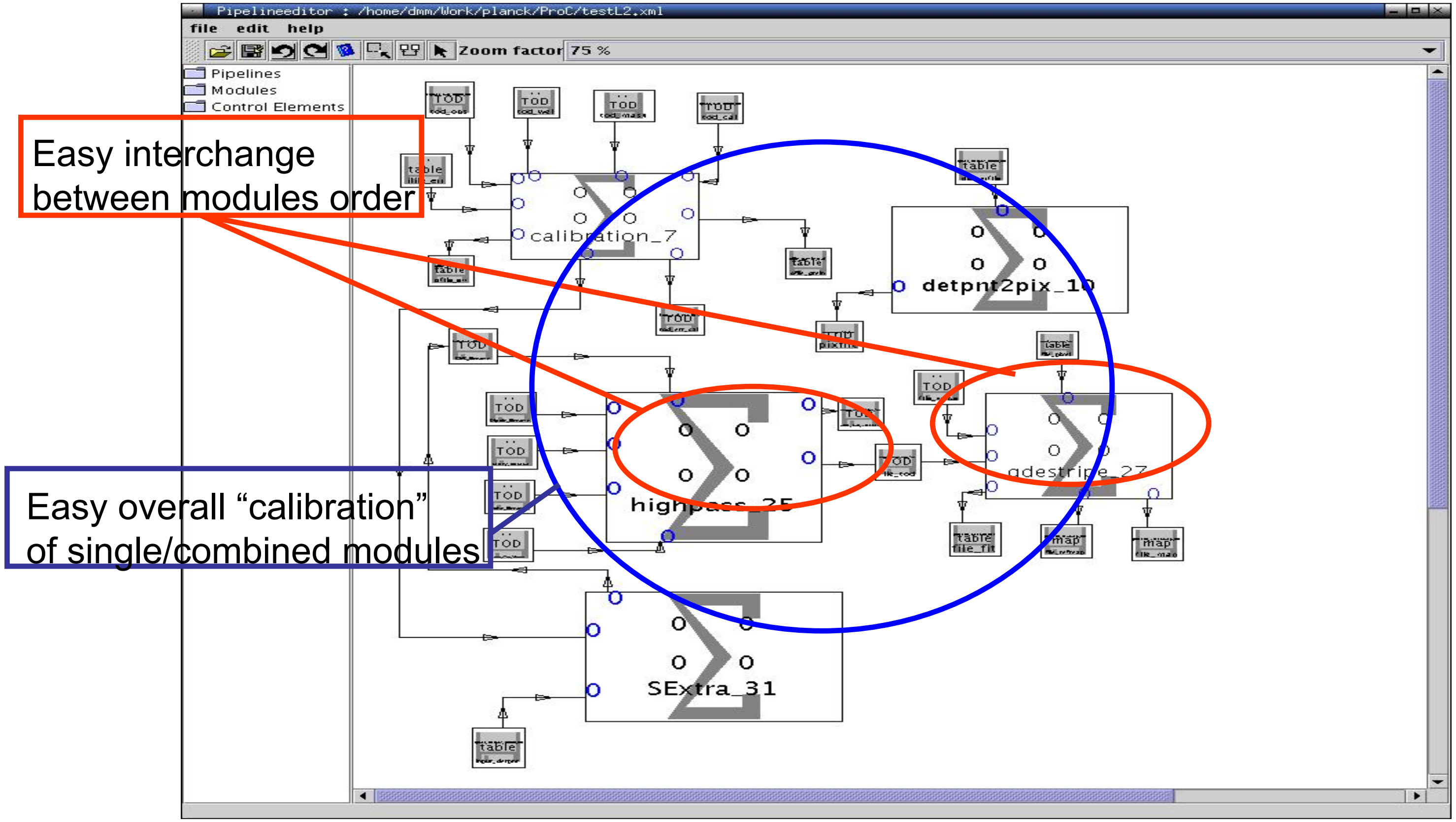


S/W design of the system Level 2/3



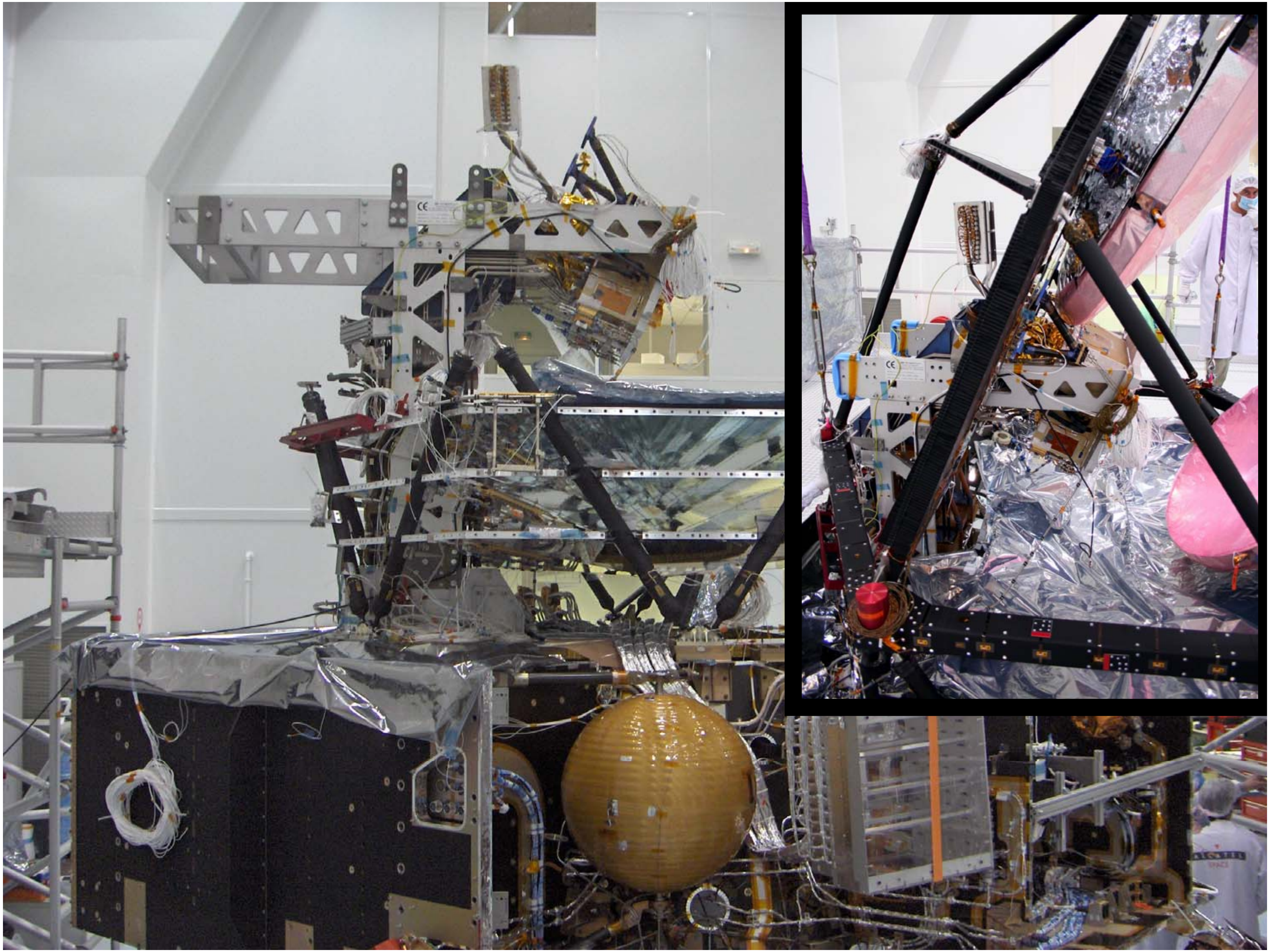
S/W design of the system

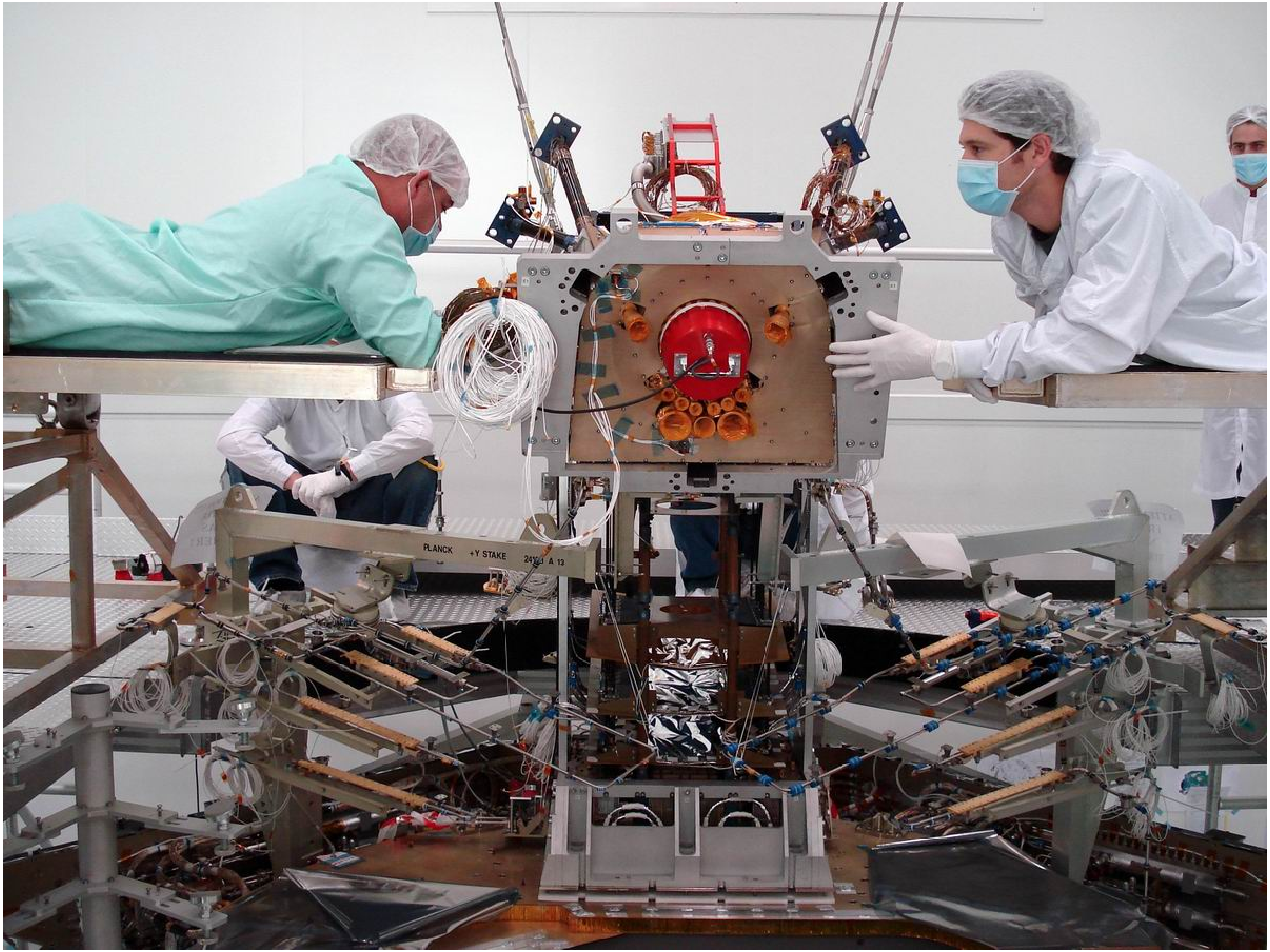
- Each pipeline is designed and controlled by the ProC
- Flexibility in pipeline design and optimisation

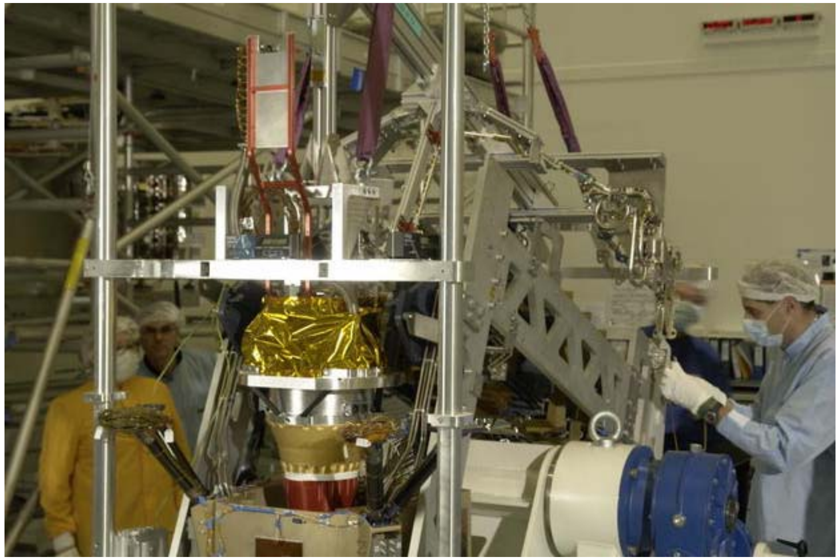


Testing of prototype system

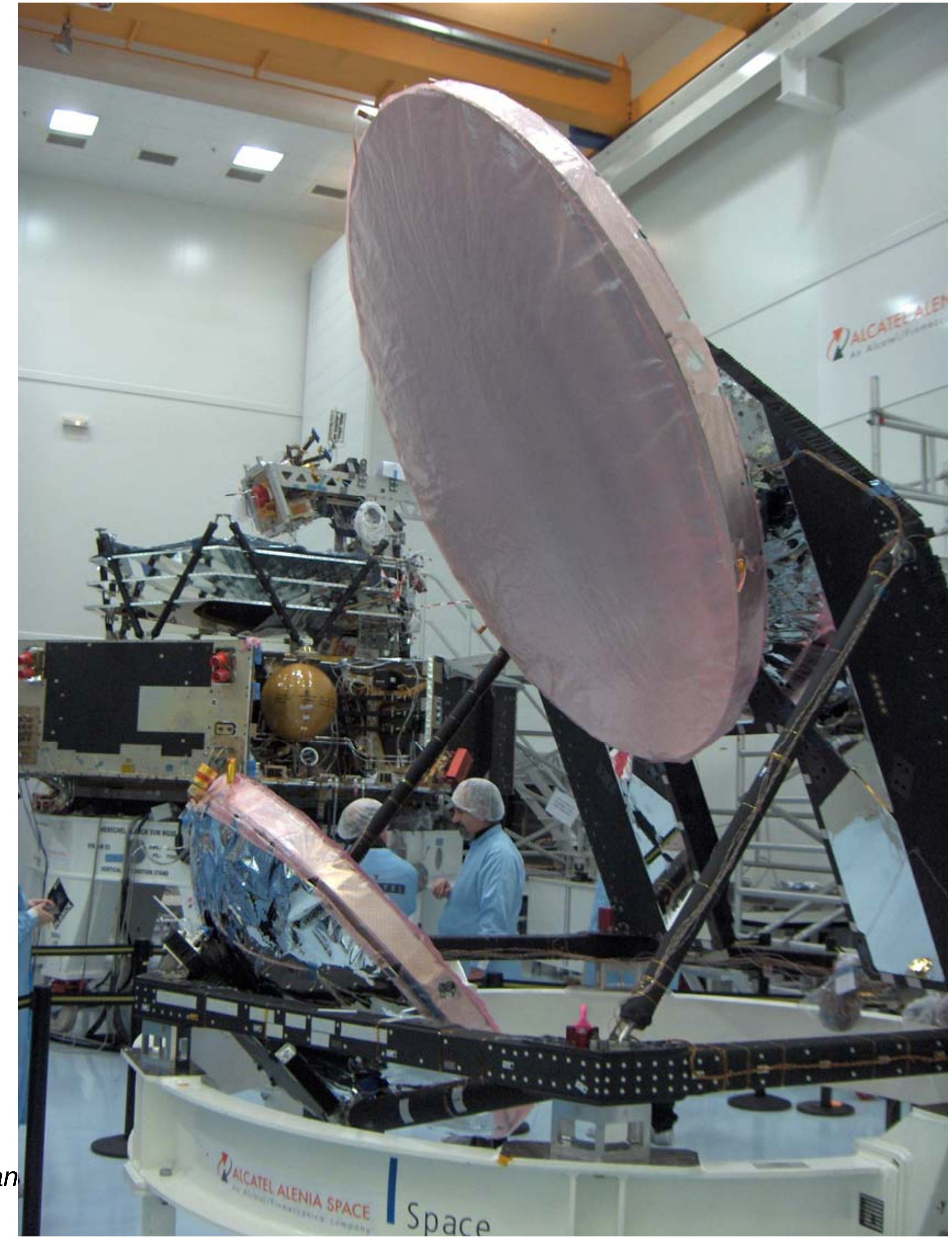
- The Level 2 / Level3 DeMo was released on February 2005
- The OM/0 model is expected was released on October 2006
- The OM/1 (Flight Model) is expected to be ready 6 month before launch.
- Hardware the will be used:
  - Beowulf system 128 CPUs (2GB Ram each CPU)
  - Storage element with 12 TB available
- Simulated data are being used to help developing the software of the data processing pipelines:
  - allowing the testing of algorithms needed to solve the critical reduction problems
  - evaluating the impact of systematic effects on the scientific results of the mission, before real data are obtained
- Need a large number of runs!
- Software is integrated into a coherent pipeline (Level S) by the MPA team and is resident in a single repository (at ESTEC)



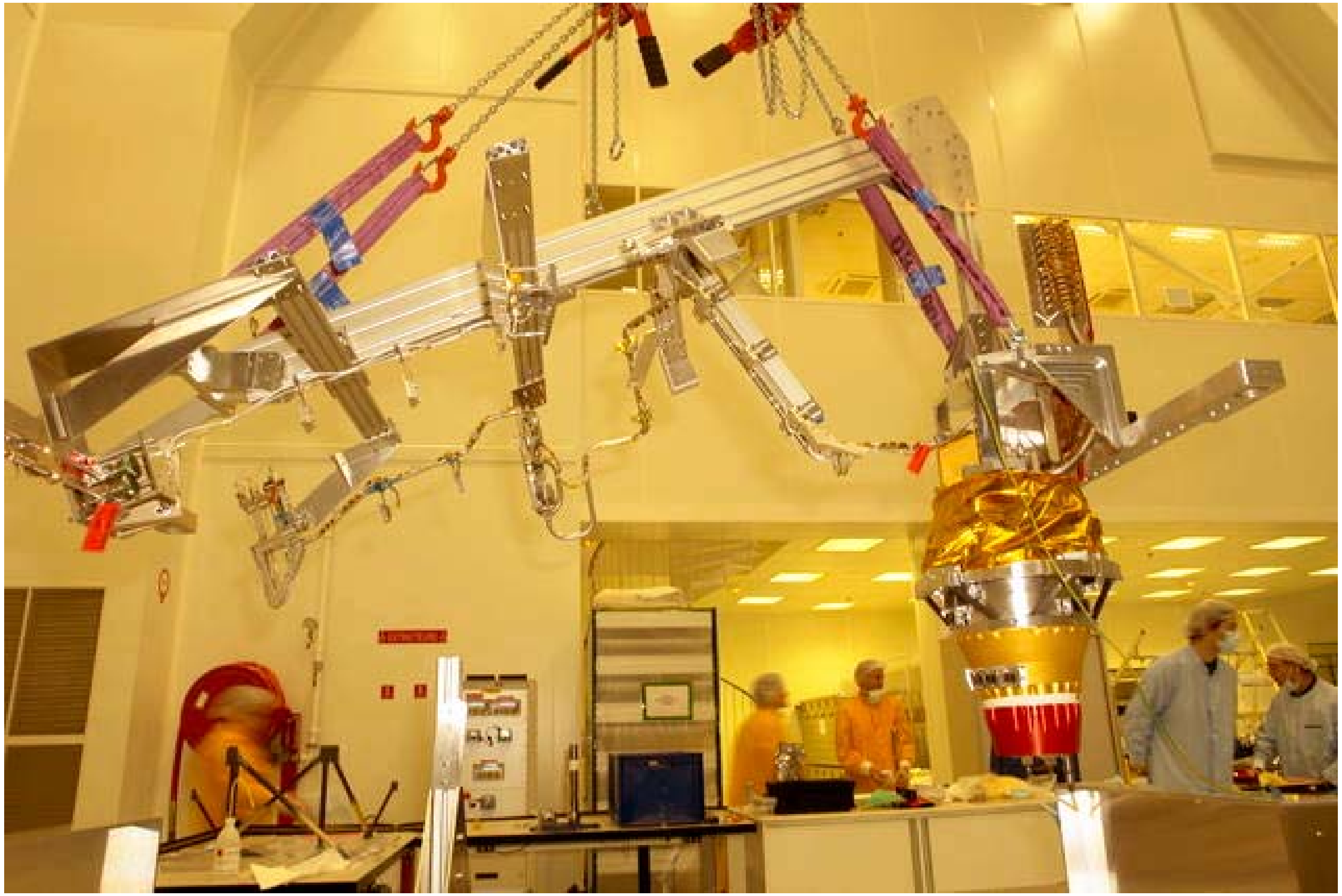

PLANCK
+Y STAKE
A 13



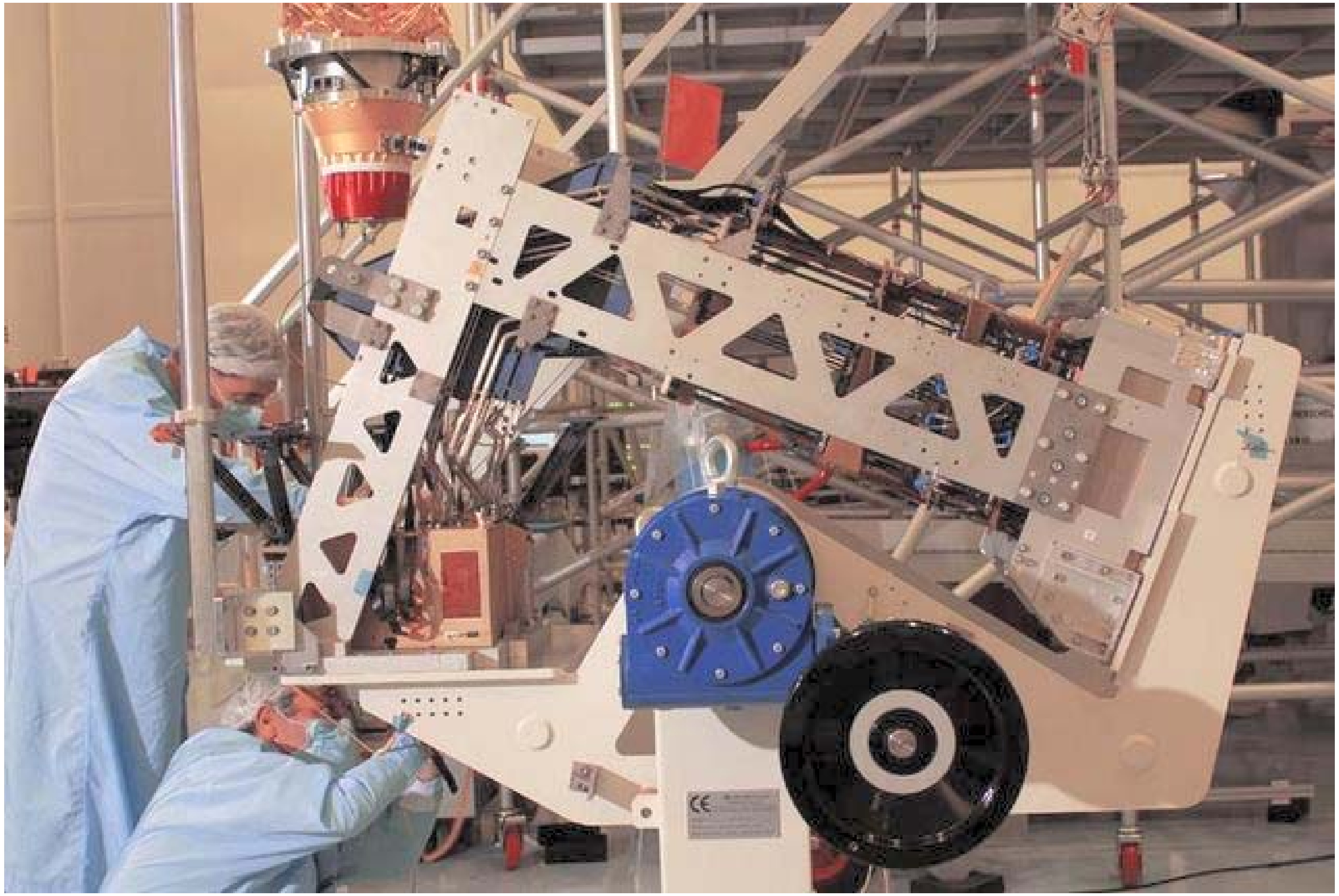
N.


ALCATEL ALENIA SPACE
Space

Integration LFI/HFI



Integration LFI/HFI



Integration LFI/HFI

Planck-LFI Instrument Team

Institutions & People Contributing to LFI Hardware Development & Calibration

Principal funding Agency

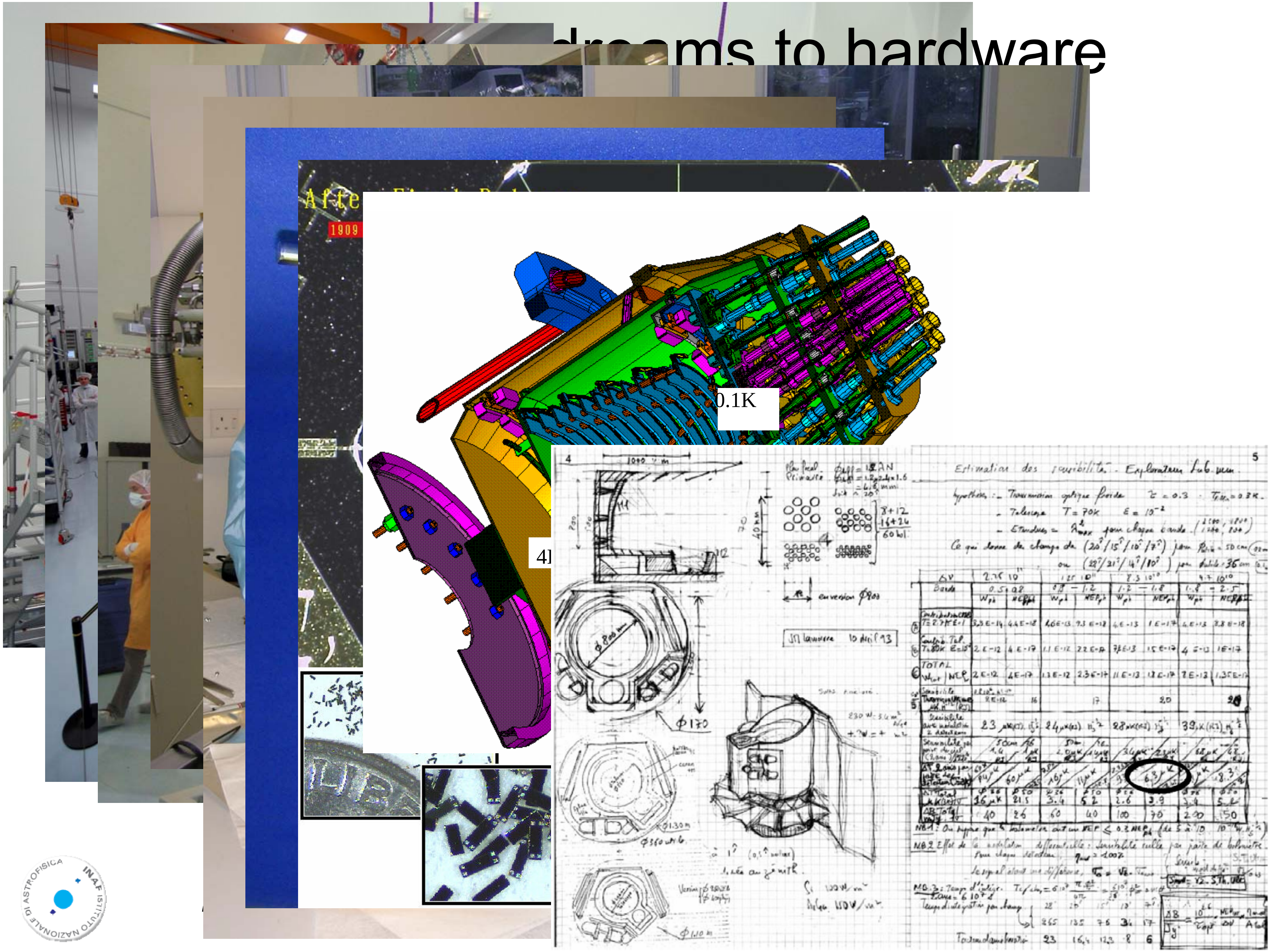
B.Aja, E.Artal, M.Balasini, G.Baldan, P.Battaglia, T.Bernardino, M.Bersanelli, P.Bhandari, E.Blackhurst, L.Boschini, R.Bowman, C.Burigana, R.C.Butler, B.Cappellini, F.Cavaliere, F.Colombo, F.Cuttaia, A.Colin, R.Davis, X.Dupac, J.Edgeley, O.D'Arcangelo,L. De Angelis, L.De La Fuente, A. De Rosa, M.C. Falvella, F.Ferrari, L.Figini, S.Fogliani, C.Franceschet, E.Franceschi, P.Jukkala, T.Gaier, S. Gallotta, A.Galtress, S.Garavaglia, A.Gregorio, J.M.Herreros, R.Hoyland, N.Hughes, D.Kettle, V.H.Kilpela, M.Laaninen, P.M.Lapolla, C.R.Lawrence, S.Lowe, D.Lawson, R.Leonardi, P.Leutenegger, S.Levin, P.B.Lilje, P.M.Lubin, D.Maino, M.Malaspina, N.Mandolesi, G.Mari, M.Maris, E.Martinez-Gonzalez, A.Mediavilla, P.Meinhold, L.Mendes, A.Mennella, M.Miccolis, G.Morgante, A.Nash, R.Nesti, L.Pagan, C.Paine, J.P.Pascual, F.Pasian, M.Pecora, S.Pezzati, M.Pospieszalski, P.Platania, M.Prina, R.Rebolo, N.Roddis, R. Rohlf, N.Sabatini, M.Sandri, M.J.Salmon, M.Seiffert, R.Silvestri, A.Simonetto, G.F.Smoot, C.Sozzi, L.Stringhetti, L.Terenzi, M.Tomasi, J.Tuovinen, L.Valenziano, J.Varis, F.Villa, L.Wade, A.Wilkinson, F.Winder, A.Zacchei, A.Zonca

HFI – High Frequency Instrument

PI: J.L. Puget
Co-PI and DPC Manager: F. Bouchet
Project Manager: G. Guyot
Instrument Scientist: J.M. Lamarre
Survey Scientist: G. Efstathiou

HFI Instrument
status after calibration and delivery

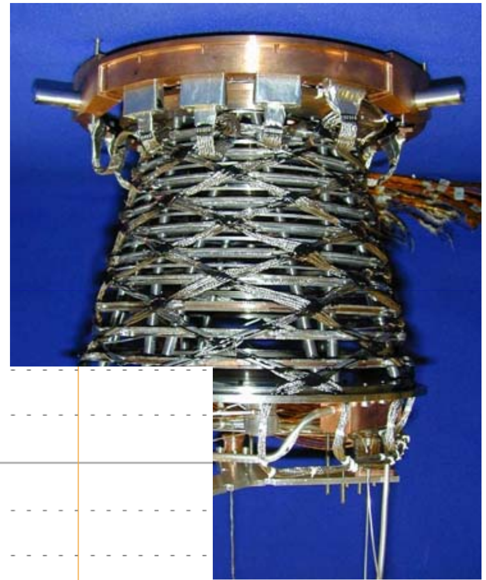
dreams to hardware



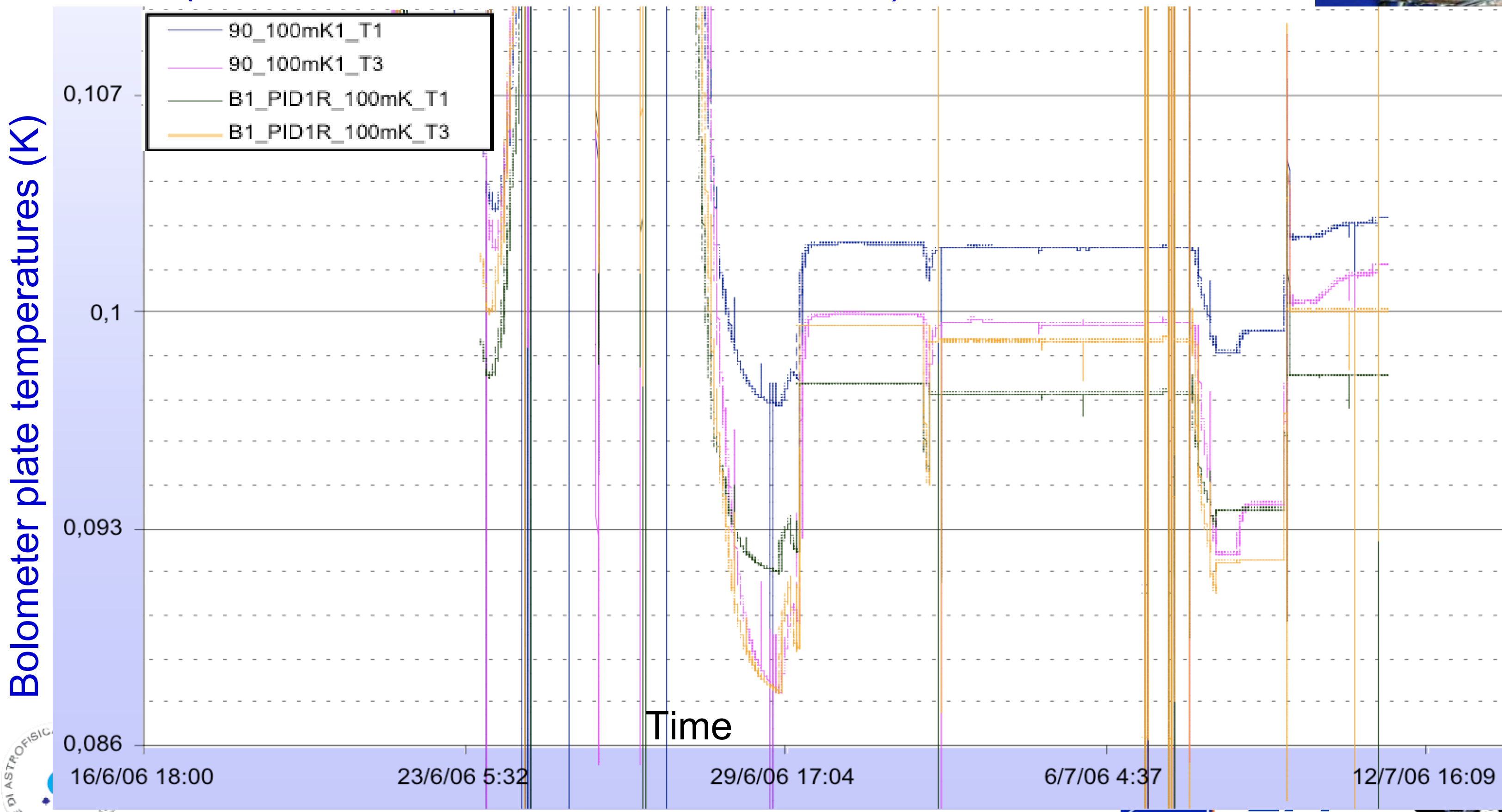
HFI Instrument challenge: An innovative architecture using brand new techniques

- Sensitivity
  - Goal: sensitivity limited by fundamental noises (2*photon noise)
  - Cooling chain down to 100mK in space
  - New 100mK bolometers
  - Unprecedented immunity to Electromagnetic interferences
- Stability needed for scanning strategy
  - Stable gain / No low frequency noises down to 0.016Hz
  - New readout electronics
  - New concepts for thermal stability
- Highly selective optics
  - Filtering with high rejection requirements
  - Use techniques from coherent detection : Low spillover taper Gaussian beams

100mK dilution cooler



- The dilution cooler is producing the needed cooling power at the required temperature and with the expected helium flows.
- Real time temperature chart during the calibration run . (Relative calibration to be corrected.)



HFI

Dilution Cooler

- Achieved temperatures

Flow rate (µmole/s)	FNOM2 7.7, 23.9	FNOM1 6.5, 19	FMIN 5.5, 17
4K I/F T	5.2 K	4.85 K	4.6 K
T JT	< 1.4 K	< 1.4 K	< 1.4 K
JT margin		100 < P < 200 µW	200 < P < 300 µW
Asymp. T		87 mK	~ 97 mK
Heat lift		164 nW @ 100 mK	24 nW @ 100 mK
		64 nW @ 92 mK	

In Flight autonomy (Months)

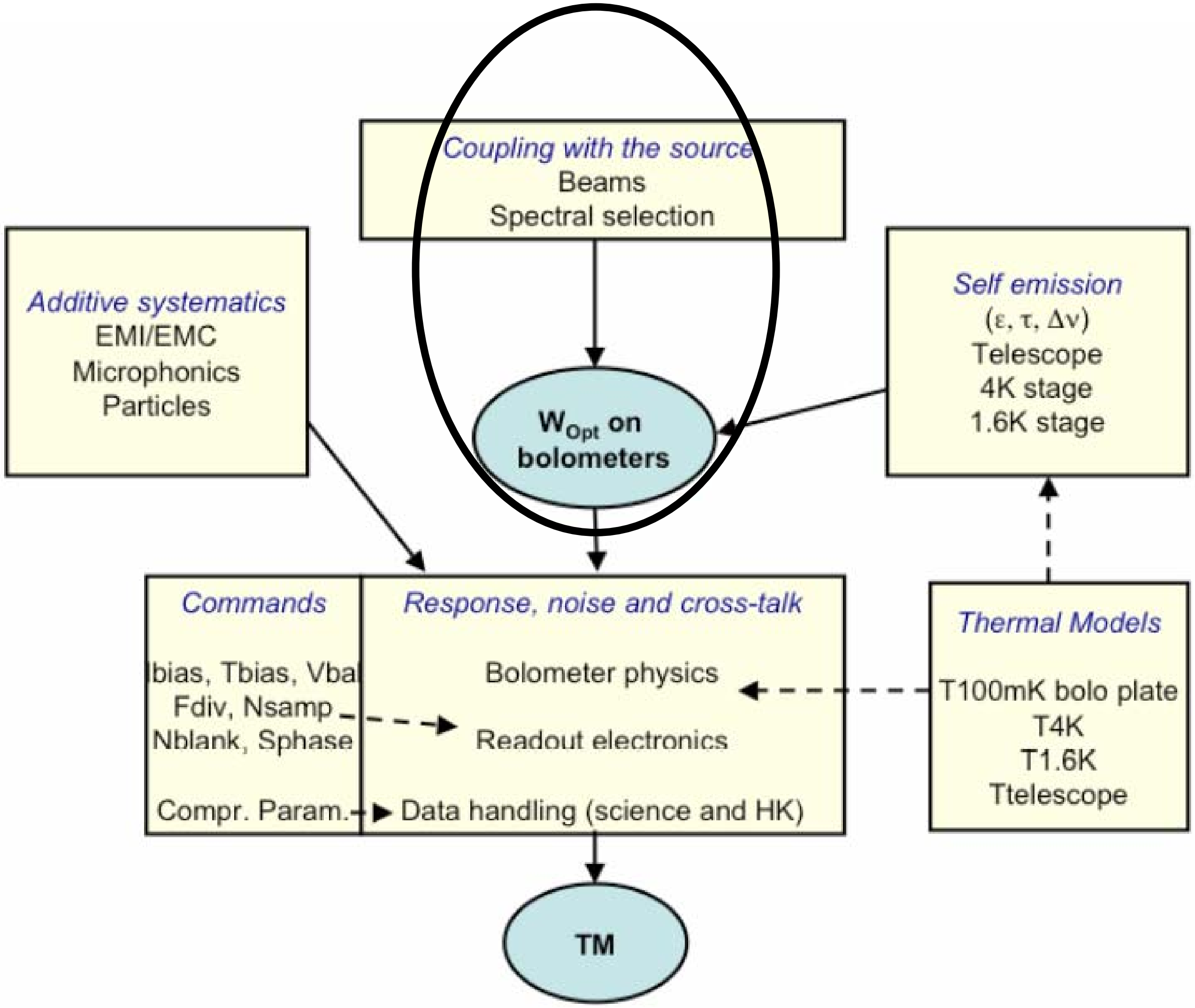
Full Tanks!

295 bar/40 °C	FMIN	FNOM1	F_AL_5K	FNOM2			
3He flow rate (µmole/s)	5,5	6,5	6,72	7,7	8,6	9,4	10,6
4He flow rate (µmole/s)	17	19,6	21,3	23,9	26,6	28,9	31,1
40°C_months with this flow rate	32,9	28,8	26,4	23,6	21,3	19,7	18,0
40°C_Months at L2 (observation)	27,9	23,8	21,4	18,6	16,3	14,7	13,0
40°C_Margin / 15 months+cd	12,9	8,8	6,4	3,6	1,3	-0,3	-2,0

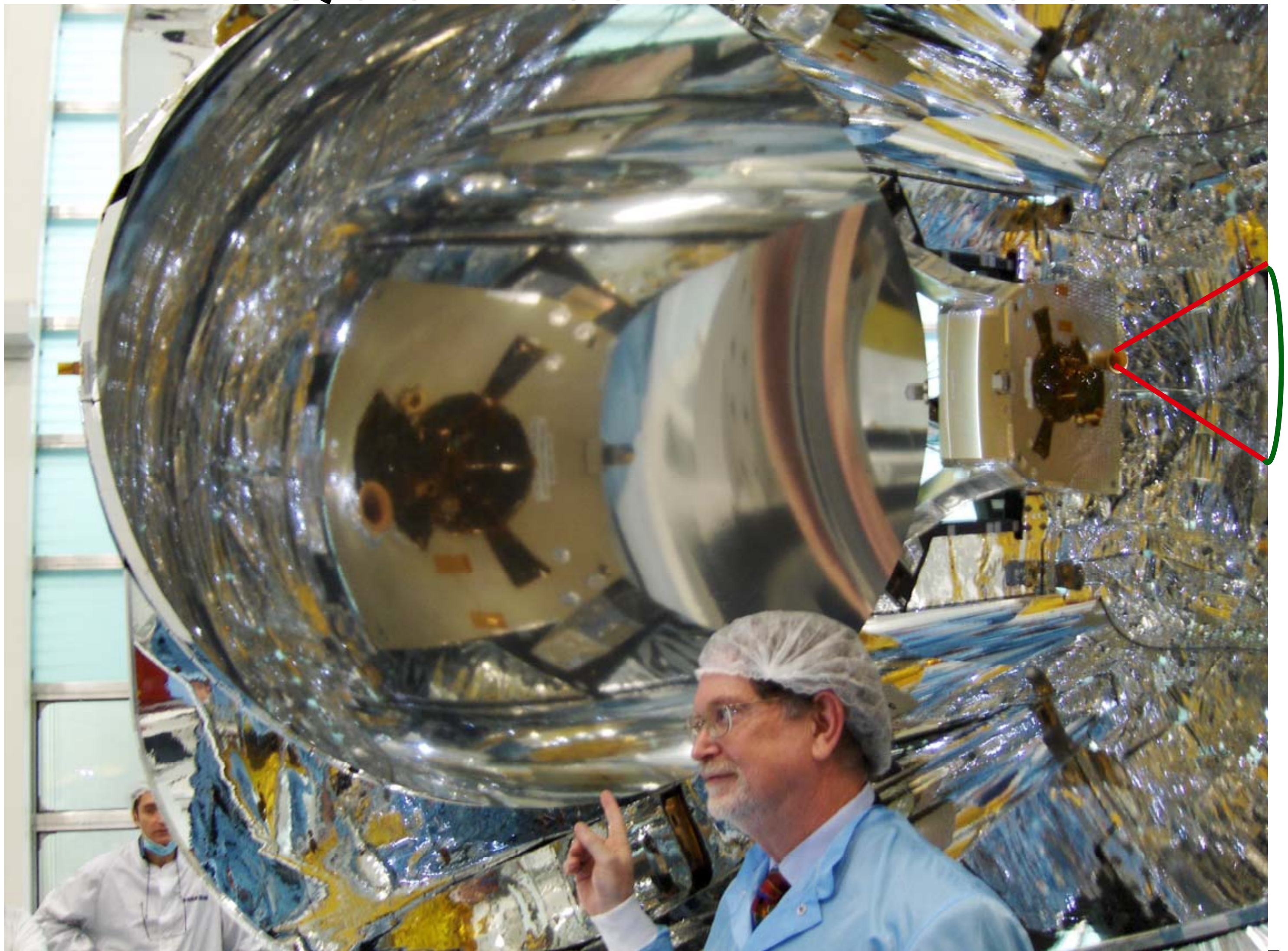
With FMIN Flow (which has demonstrated to work)
This makes four full surveys + margin with tanks full
Currently, only 3 surveys are guaranteed.
More funding needed.

- 5 months "nominal" flow rate from launch to observation phase.
- Taking into account the emptying of the tanks till the flow rate is maintained (~12 bars)

Signal formation in HFI



Optical system
RF Qualification Model

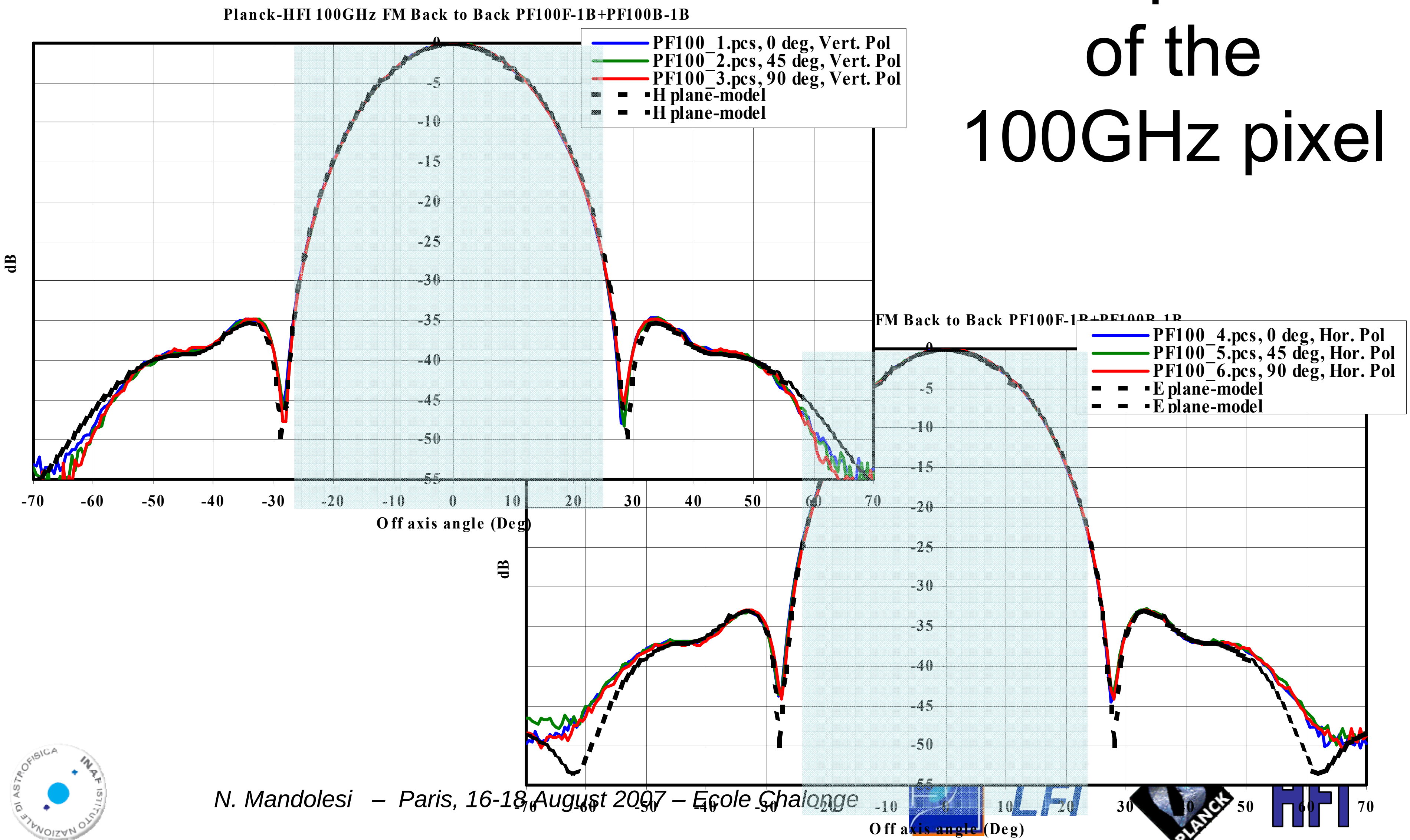


Single moded channel optical characteristics
(Does not take in account the aberrations)

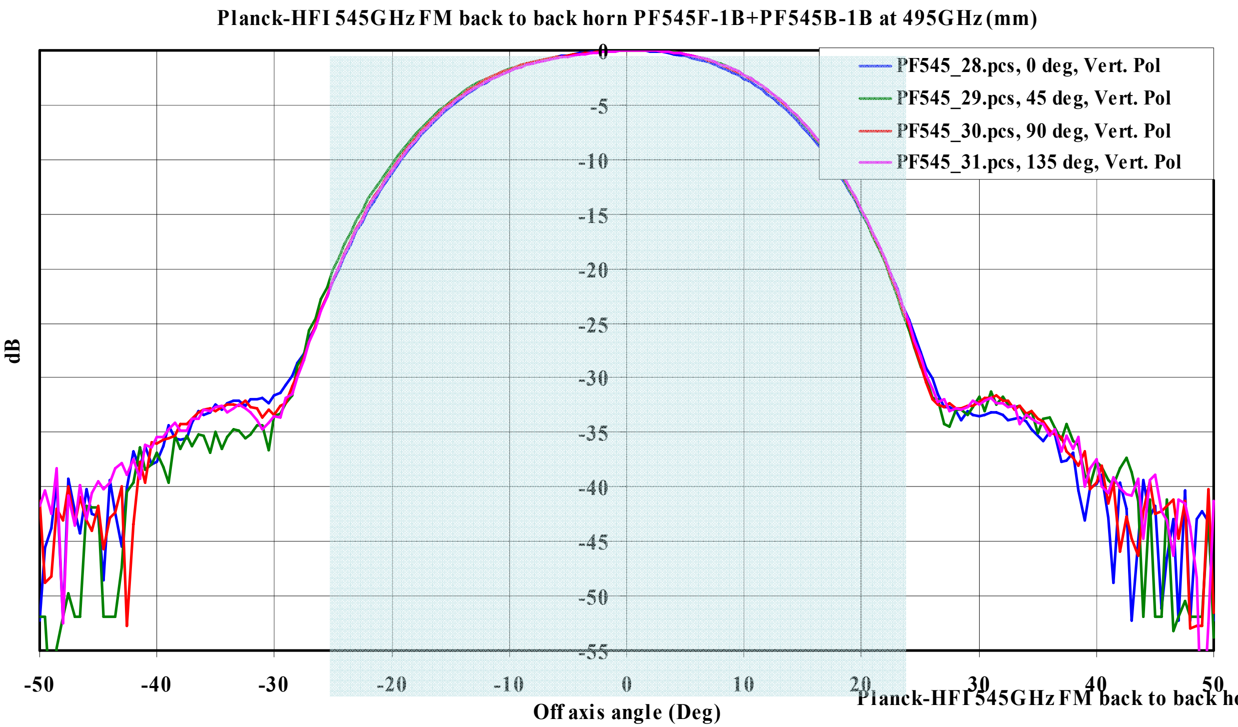
Frequency	Edge taper (at 25 deg)	Spillover	FWHM (horn)	FWHM (sky)
100	< -30 dB (-25)	< 0.5%	16.2 deg	8.9 (9.16)
143	< -28 dB (-28)	< 0.5%	16.6 deg	6.8 (7)
217	< -30 dB (-30)	< 0.3%	14 deg	5 (5)
353	< -35 dB (-32)	< 0.2%	9 deg	5 (5)

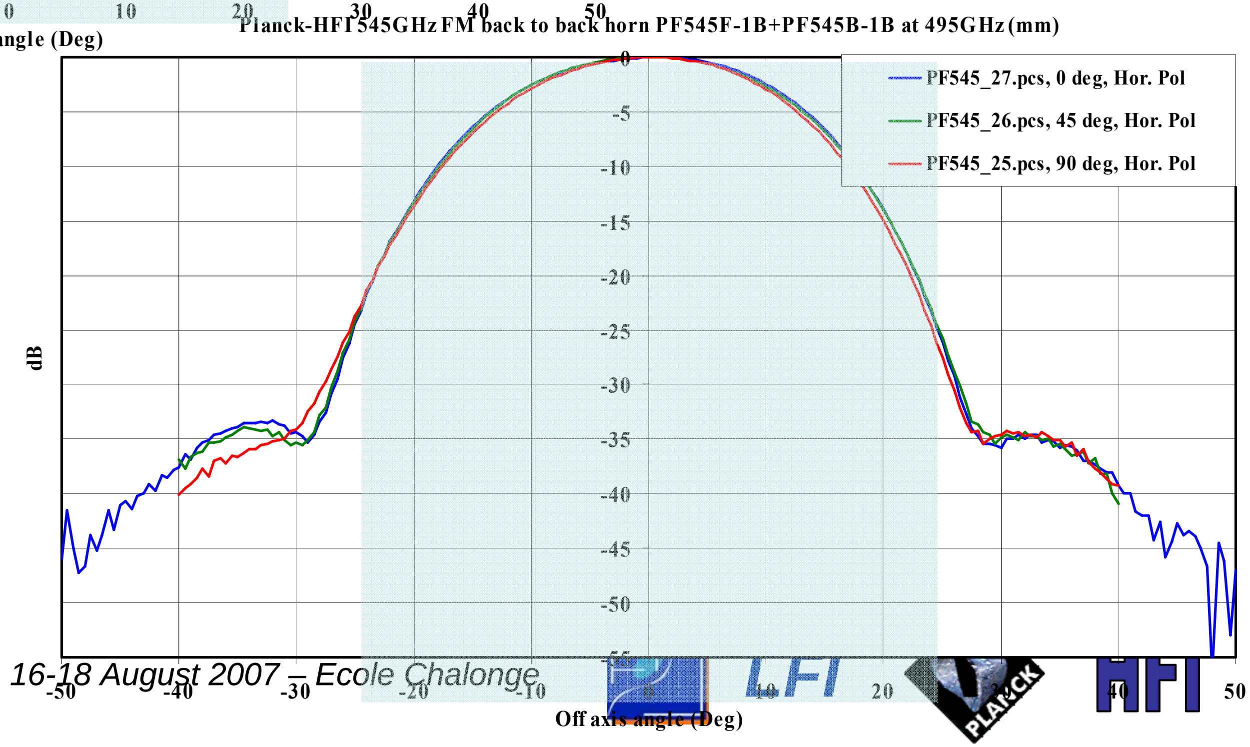
Beam patterns of the horns

Example one of the 100GHz pixel

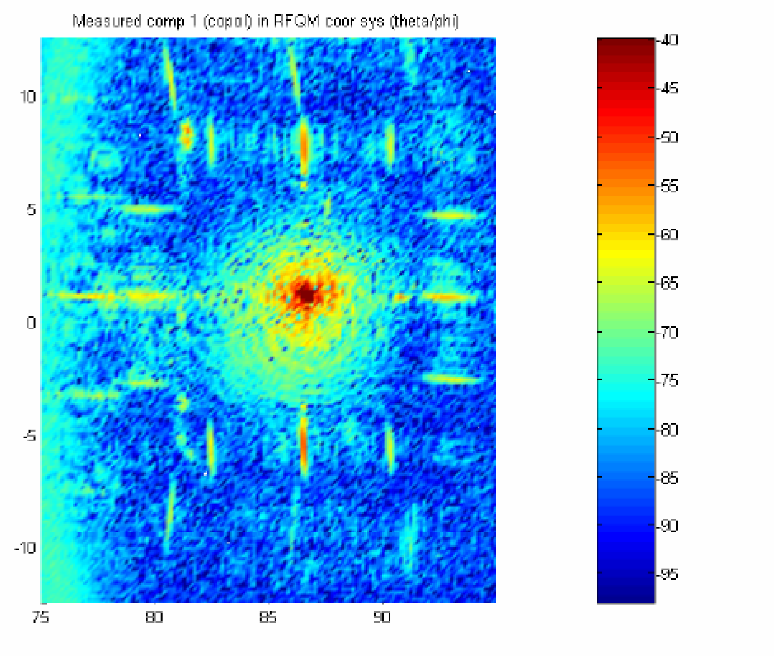


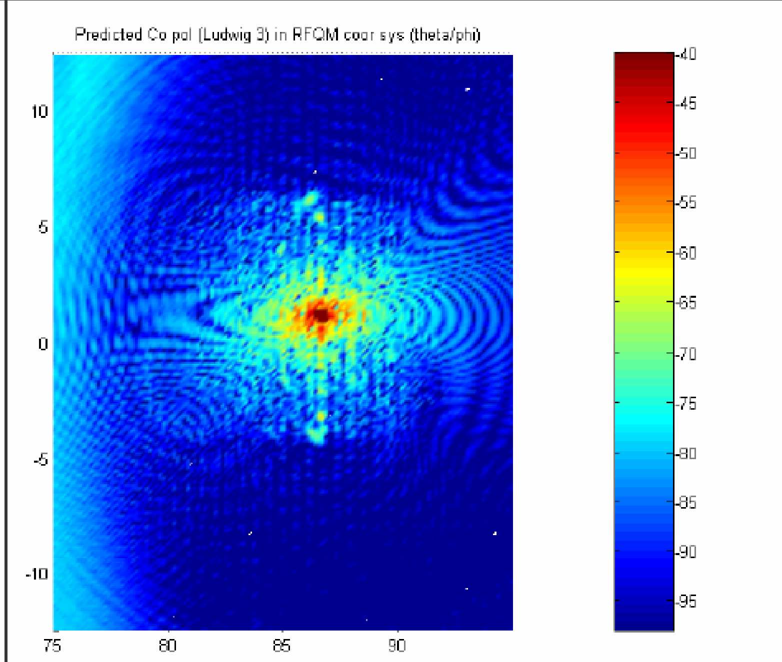
545GHz B2B horn multimoded test

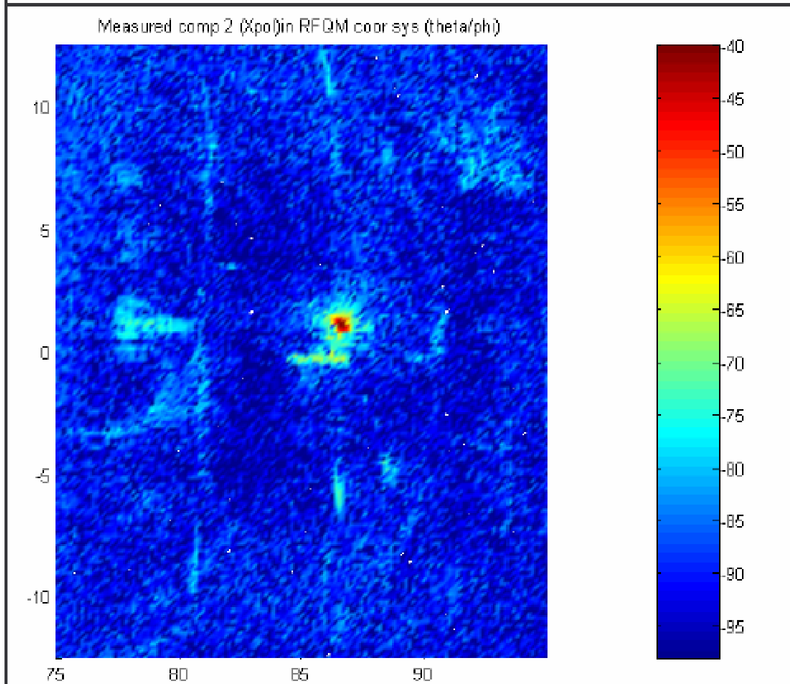


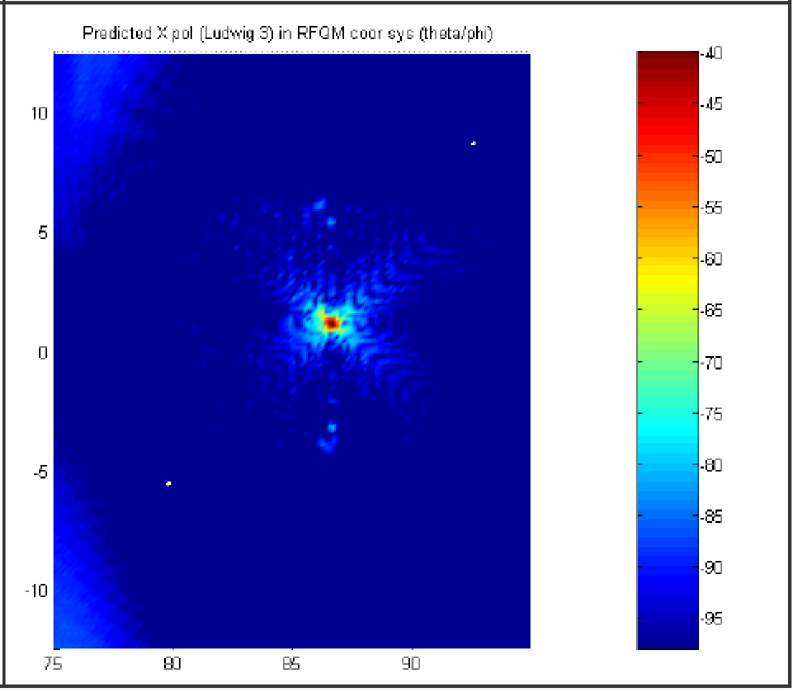


Measurement polarization 1	Prediction

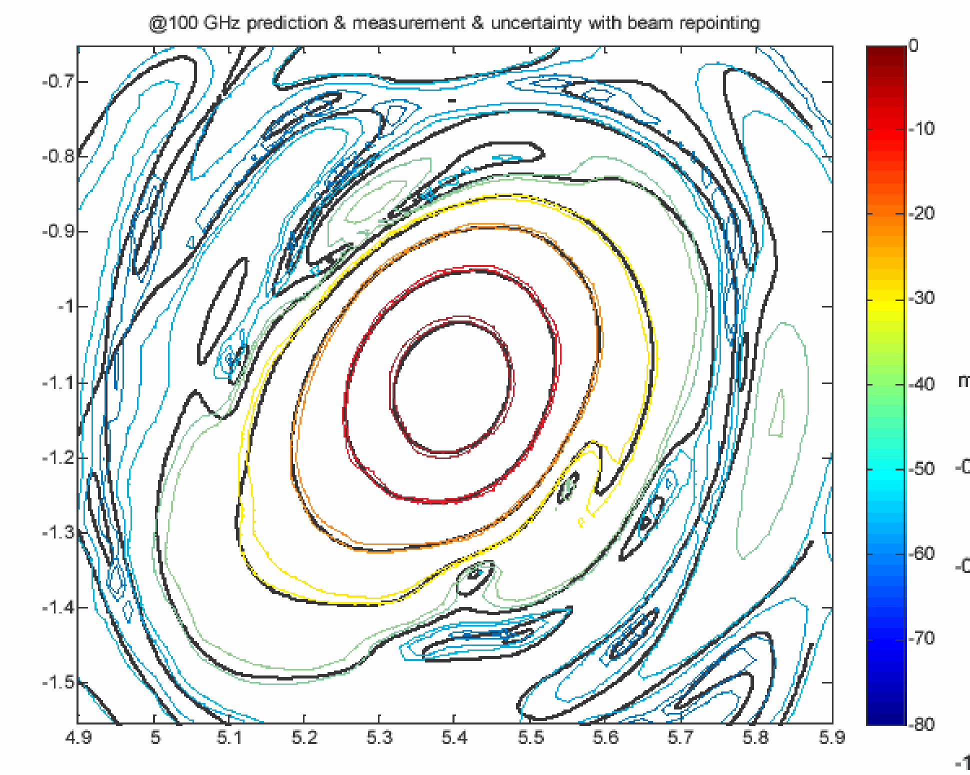








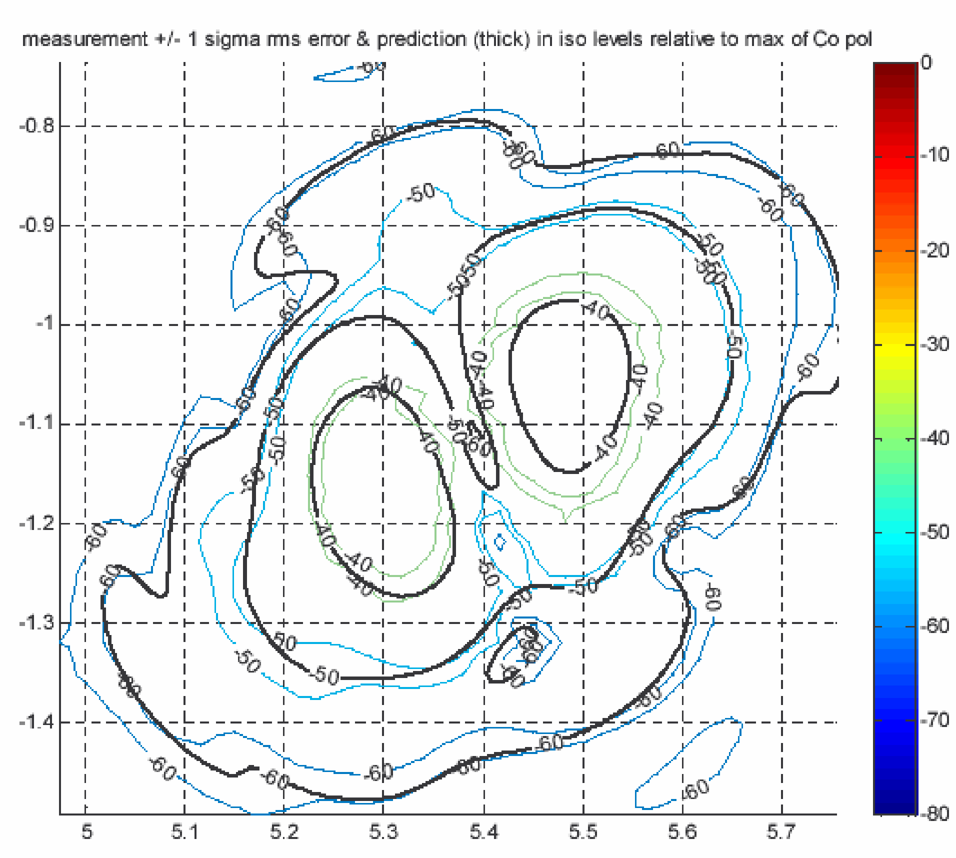
RFQM results at 100GHz



Co-polarisation beam at 100GHz

Alcatel-Alenia Space

X-polarisation beam at 100GHz



Main beam

The IAS Saturne cryostat

Spectral transmission has been measured with the Fourier Transform Spectrometer

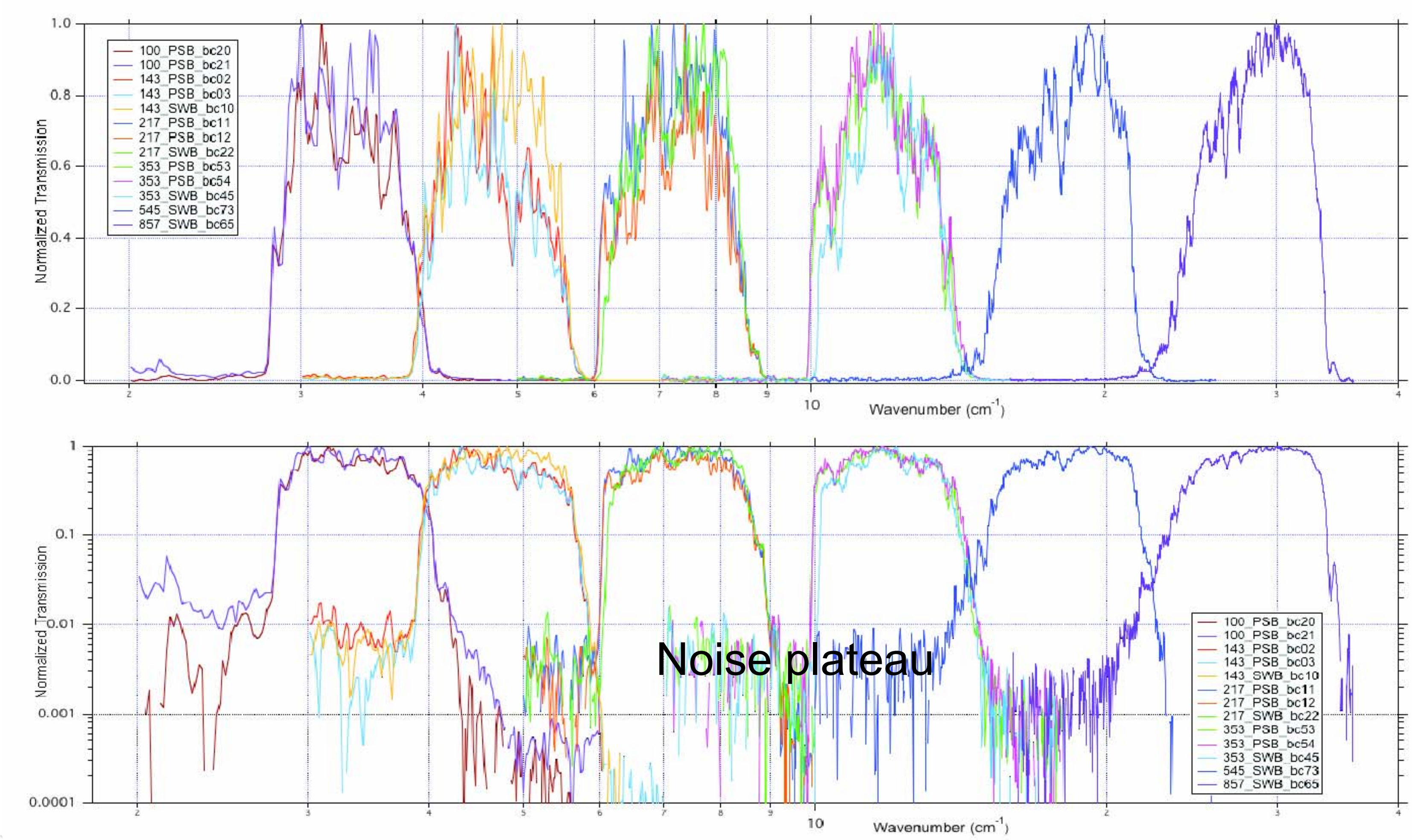
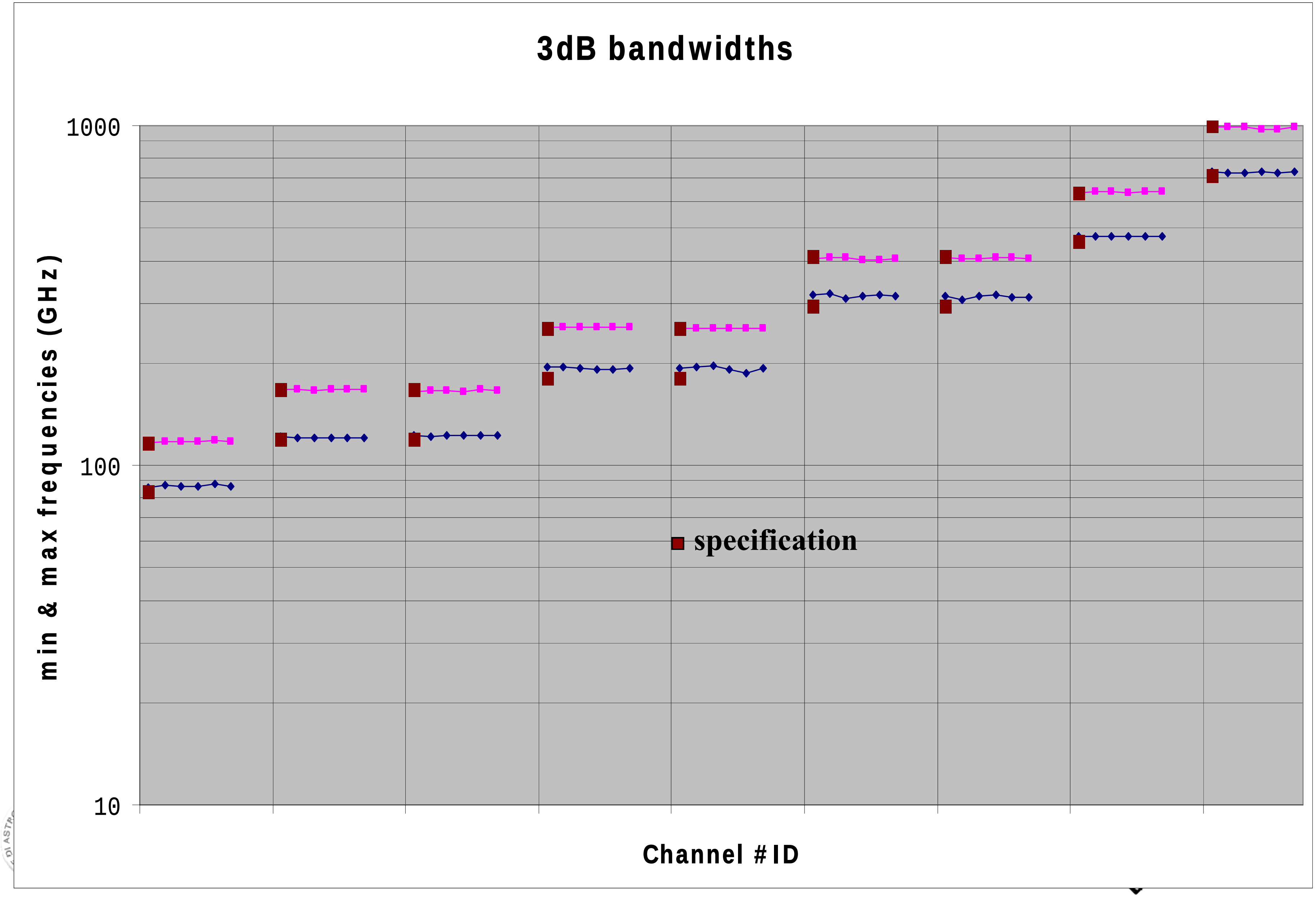


Figure 3.4 : Spectral transmission measured for one channel (SWB and PSB) of every HFI band.

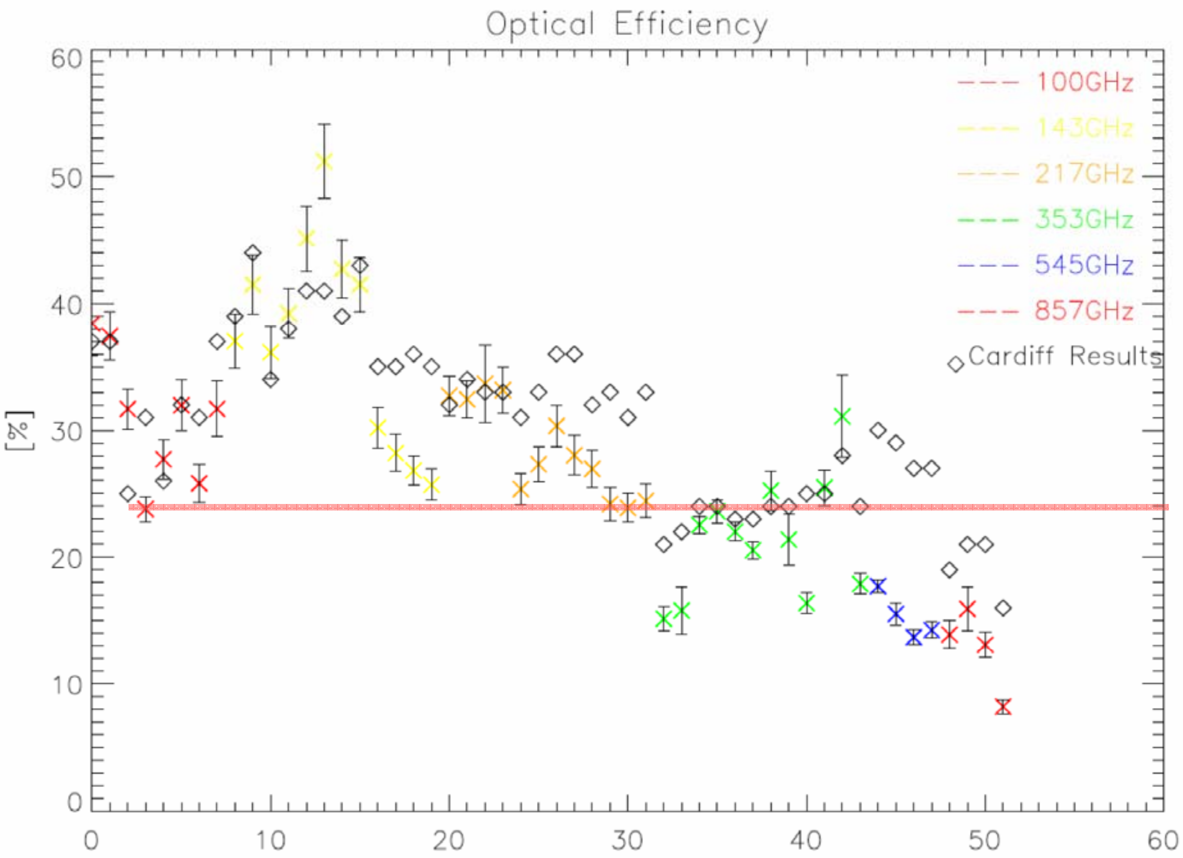
Measured bands (-3dB)



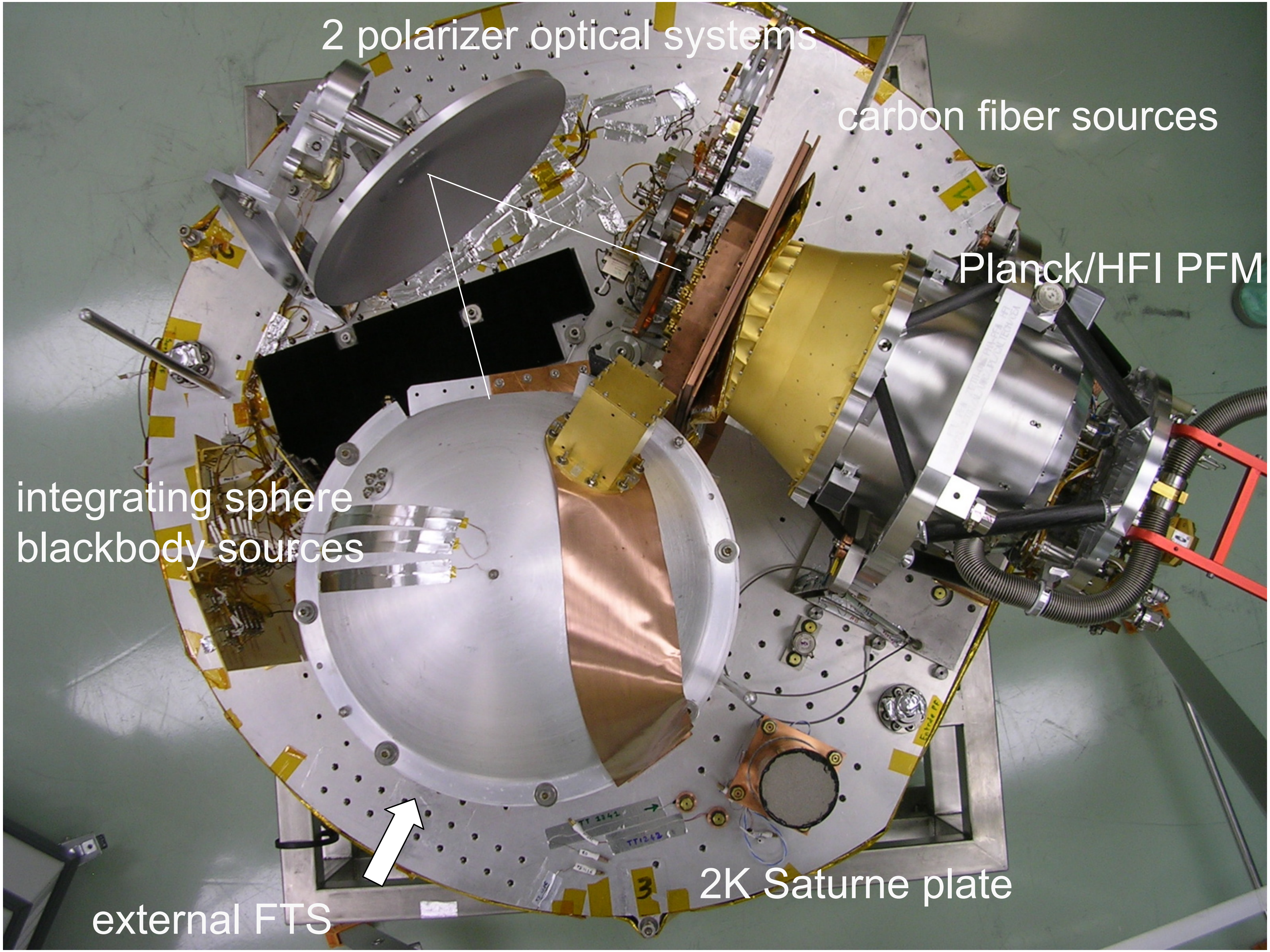
TOTAL OPTICAL EFFICIENCY

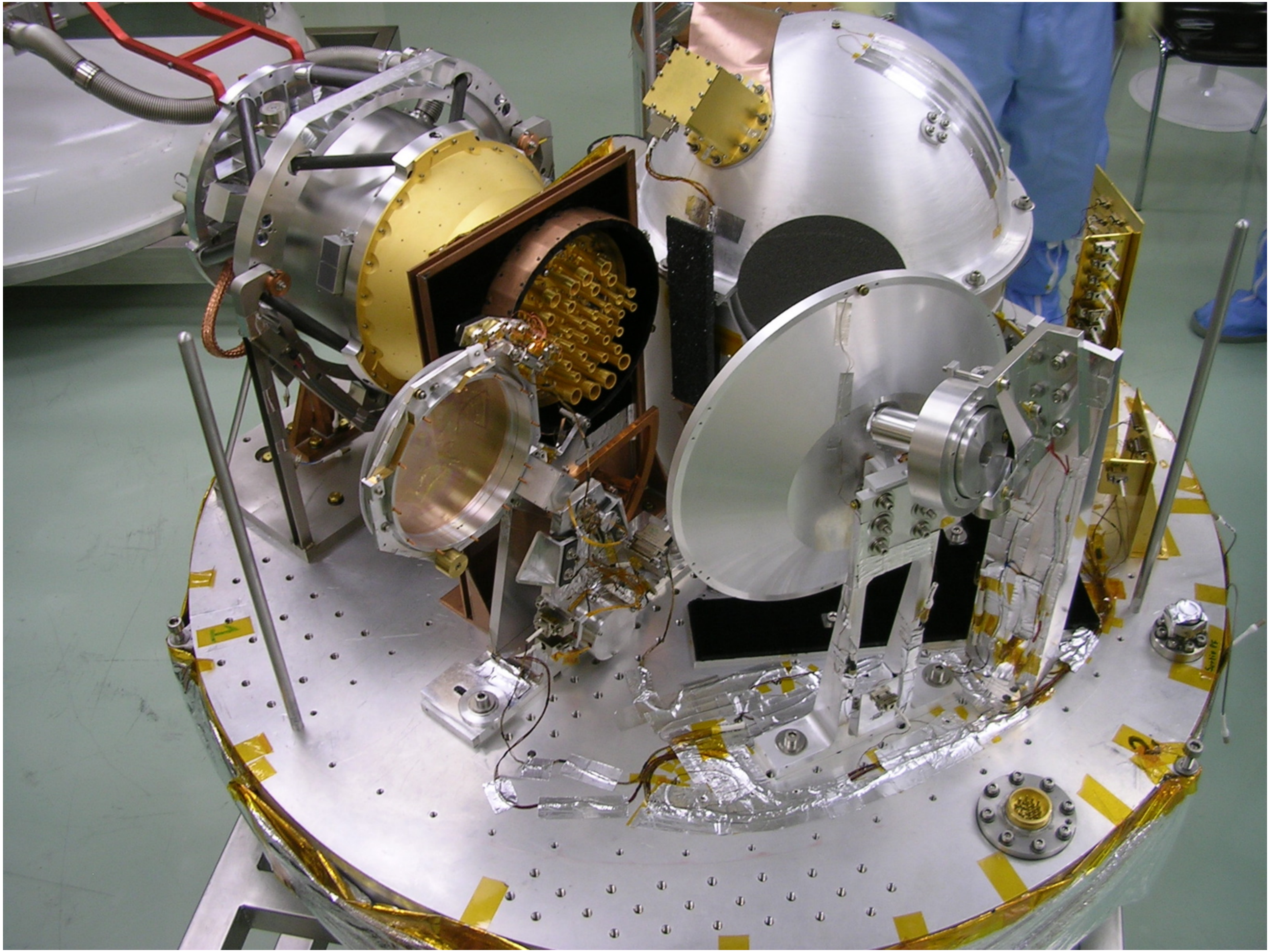
Total efficiency was measured in the SATURNE cryogenic calibration facility at IAS in a 2.7K environment.

Predicitons of sensitivity had been made assuming a 25% optical eficiency.



.5 : Optical efficiencies derived from ground calibration. The abscissa axis is the pixel number. A nominal top hat sion function (1 in-band, 0 out-of-band) is used in this determination.


2 polarizer optical systems
carbon fiber sources
Planck/HFI PFM
integrating sphere
blackbody sources
external FTS
2K Saturne plate

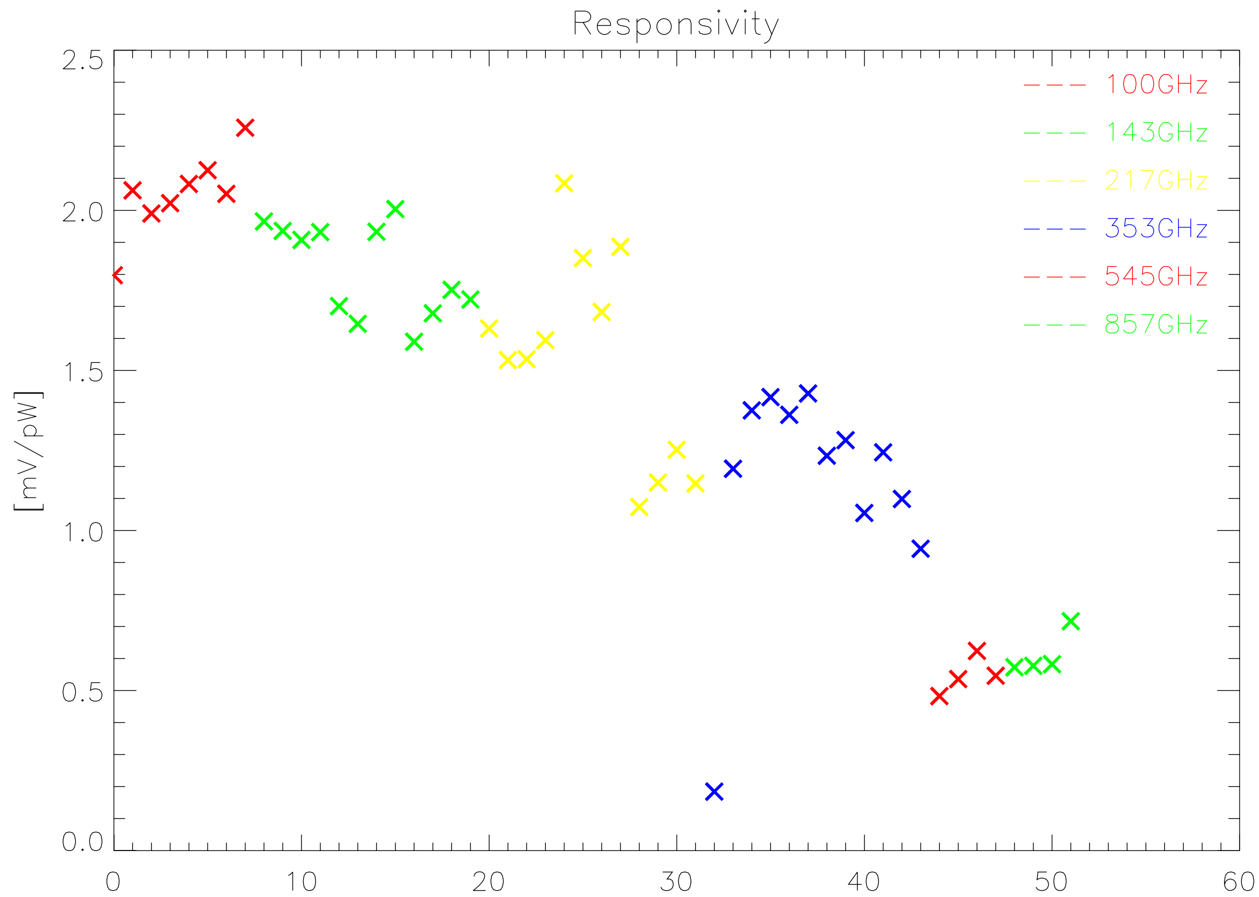


RESPONSIVITY

Responsivity from 4k sequence data with a background very close to the in-flight background.

(Tpl=2.2K, Tcs1=30K)

bolo 32 (BC=64) autobalance did not work



Instrument Performance near to Goals (Planck "Blue Book")

	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 $\Delta T/T_I{}^*$ per μK/K pixel[#] (μK/K)	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average $\Delta T/T_{U,Q}{}^*$ per pixel[#] (μK/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
ΔySZ per field of view ($x10^6$)				1.3	2.1	X	6.5	26	600

[*] Sensitivity (1σ) 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 (1σ) 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).

Conclusions

HFI is meeting the most optimistic expectations

Initial concept has proven to be robust and feasible

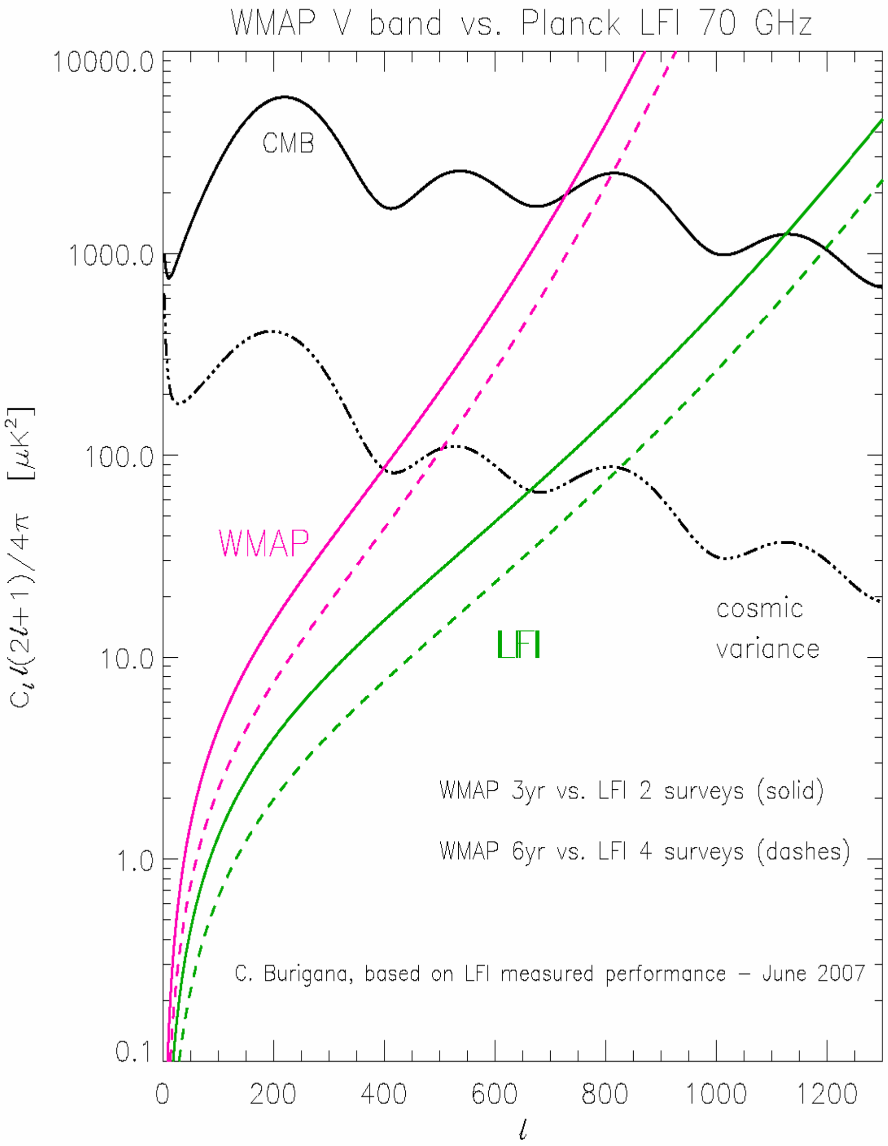
Planck Scientific Objectives

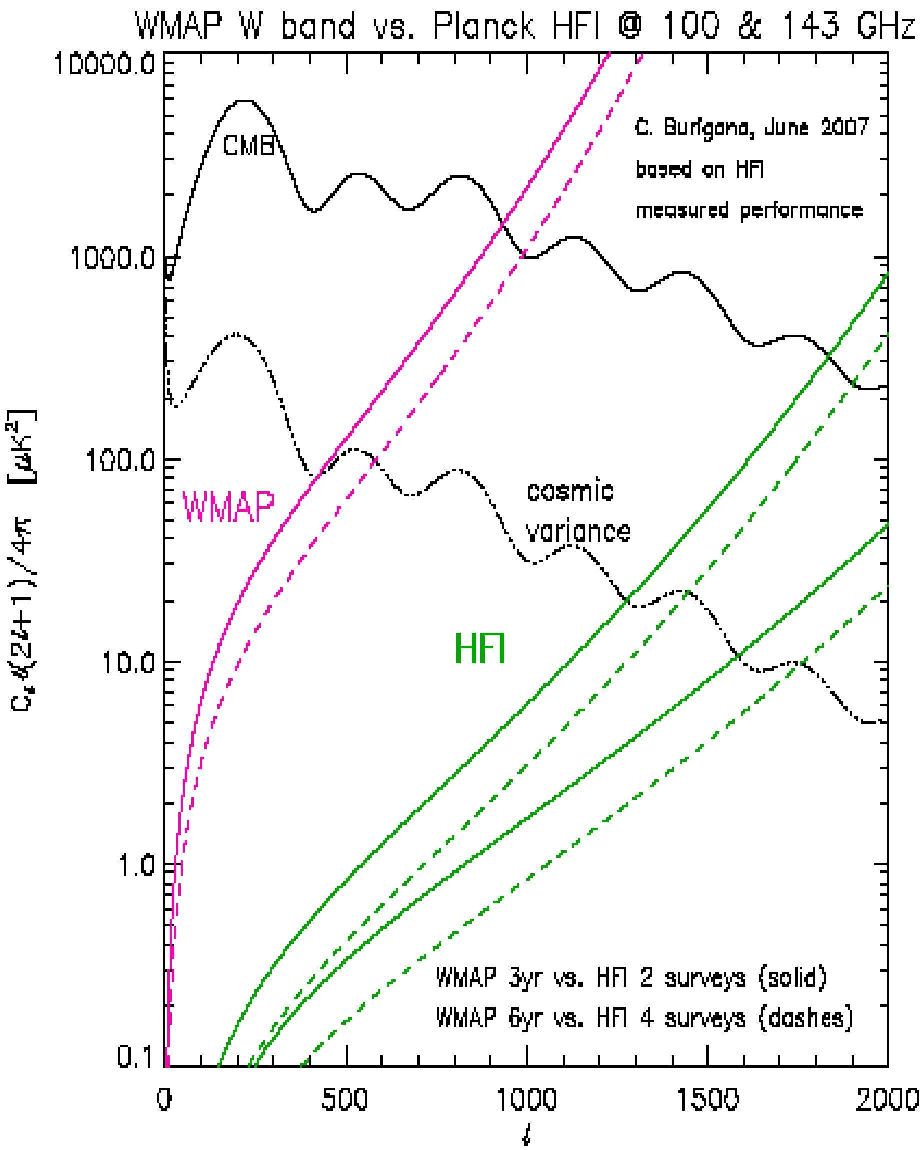
Planck vs WMAP

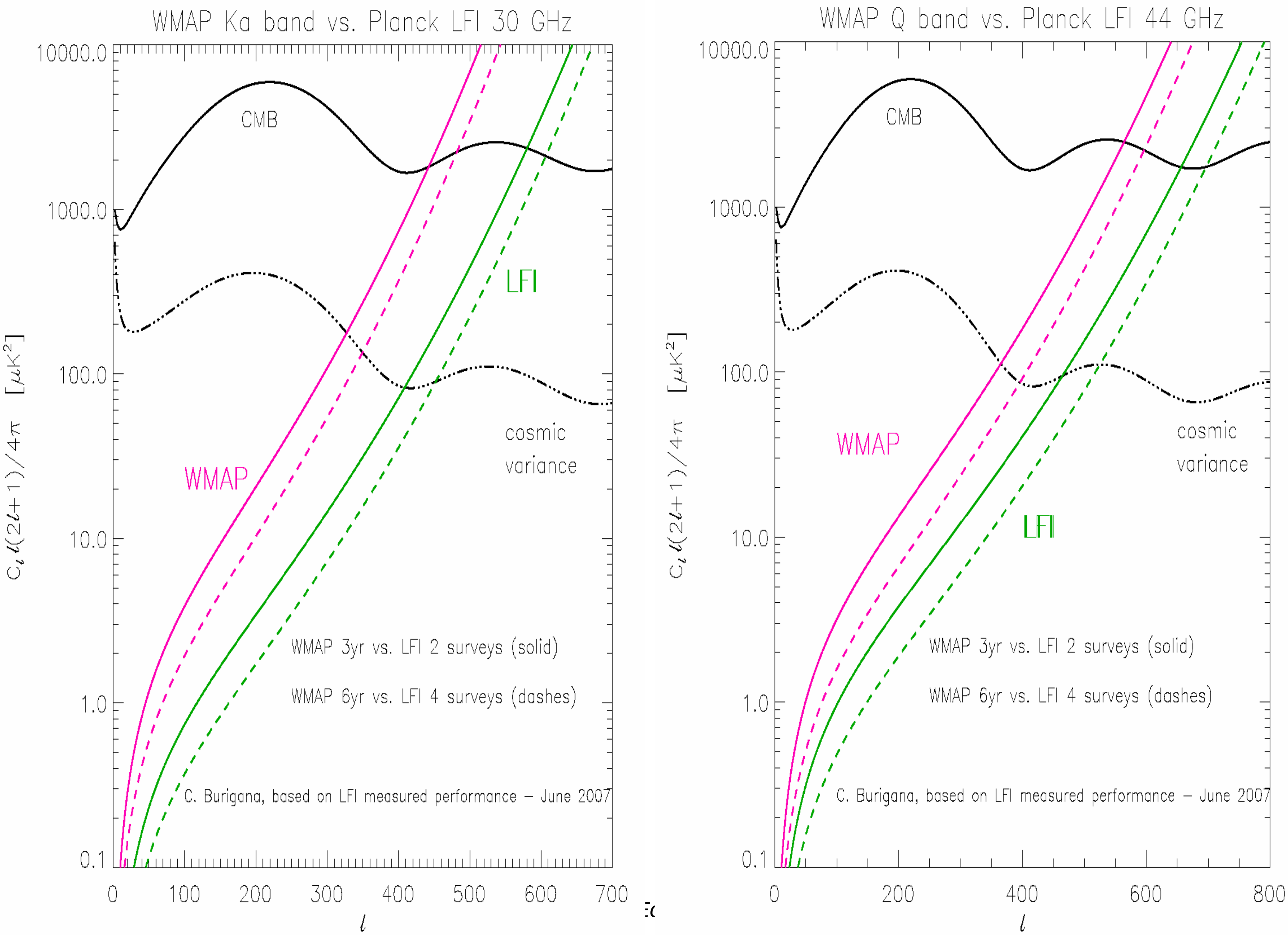
- **WMAP**
- **23, 33, 41, 61, 94 GHz**
- **0.88, 0.66, 0.51, 0.35, 0.22 deg (beam solid angle)$^{1/2}$ ~ FWHM**
- **20-30 uK on 20' side**

- ***Planck***
- **30, 44, 70, 100, 143, 217, 353, 545, 857 GHz**
- **35, 26, 13, 9.2, 7.1, 5, 5, 5, 5 arcmin (FWHM)**

→ **from 3 to 30 times sensitivity improvement**
→ **better resolution, better frequency coverage**
→ **essentially cosmic variance / astrophysical limited in T**


WMAP V band vs. Planck LFI 70 GHz
10000.0
1000.0
100.0
10.0
1.0
0.1
0
200
400
600
800
1000
1200
CMB
WMAP
LFI
cosmic
variance
WMAP 3yr vs. LFI 2 surveys (solid)
WMAP 6yr vs. LFI 4 surveys (dashes)
C. Burigana, based on LFI measured performance – June 2007


WMAP W band vs. Planck HFI @ 100 & 143 GHz
10000.0
1000.0
100.0
10.0
1.0
0.1
0
500
1000
1500
2000
CMB
C. Burigana, June 2007
based on HFI
measured performance
WMAP
cosmic
variance
HFI
WMAP 3yr vs. HFI 2 surveys (solid)
WMAP 6yr vs. HFI 4 surveys (dashes)



WMAP Ka band vs. Planck LFI 30 GHz
CMB
LFI
WMAP
cosmic variance
WMAP 3yr vs. LFI 2 surveys (solid)
WMAP 6yr vs. LFI 4 surveys (dashes)
C. Burigana, based on LFI measured performance – June 2007
WMAP Q band vs. Planck LFI 44 GHz
CMB
WMAP
LFI
cosmic variance
WMAP 3yr vs. LFI 2 surveys (solid)
WMAP 6yr vs. LFI 4 surveys (dashes)
C. Burigana, based on LFI measured performance – June 2007

- **Cosmological implicatons**

PARAMETER FORECASTS FOR WMAP AND PLANCK

Parameter	Input Value	June'03	June'03 +2dF	*WMAP*$_4$	*Planck*	*WMAP*$_4$ ACT/SPT
Flat+weak priors						
ω_b	0.2240	0.00095	0.00090	0.00047	0.00017	0.00025
ω_c	0.1180	0.011	0.007	0.0039	0.0016	0.0035
n_S	0.9570	0.026	0.024	0.0125	0.0045	0.0080
τ	0.108	0.059	0.056	0.020	0.005	0.021
+running						
ω_b	0.2240	0.00162	0.00090	0.00047	0.00017	0.00025
ω_c	0.1180	0.0158	0.007	0.0039	0.0016	0.0035
$n_S(k_n)$	0.9570	0.055	0.024	0.0125	0.0045	0.0080
n_{run}	0.0	0.033	0.029	0.025	0.005	0.0092
τ	0.108	0.112	0.074	0.019	0.006	0.0266

- **Implication for Dark Energy**

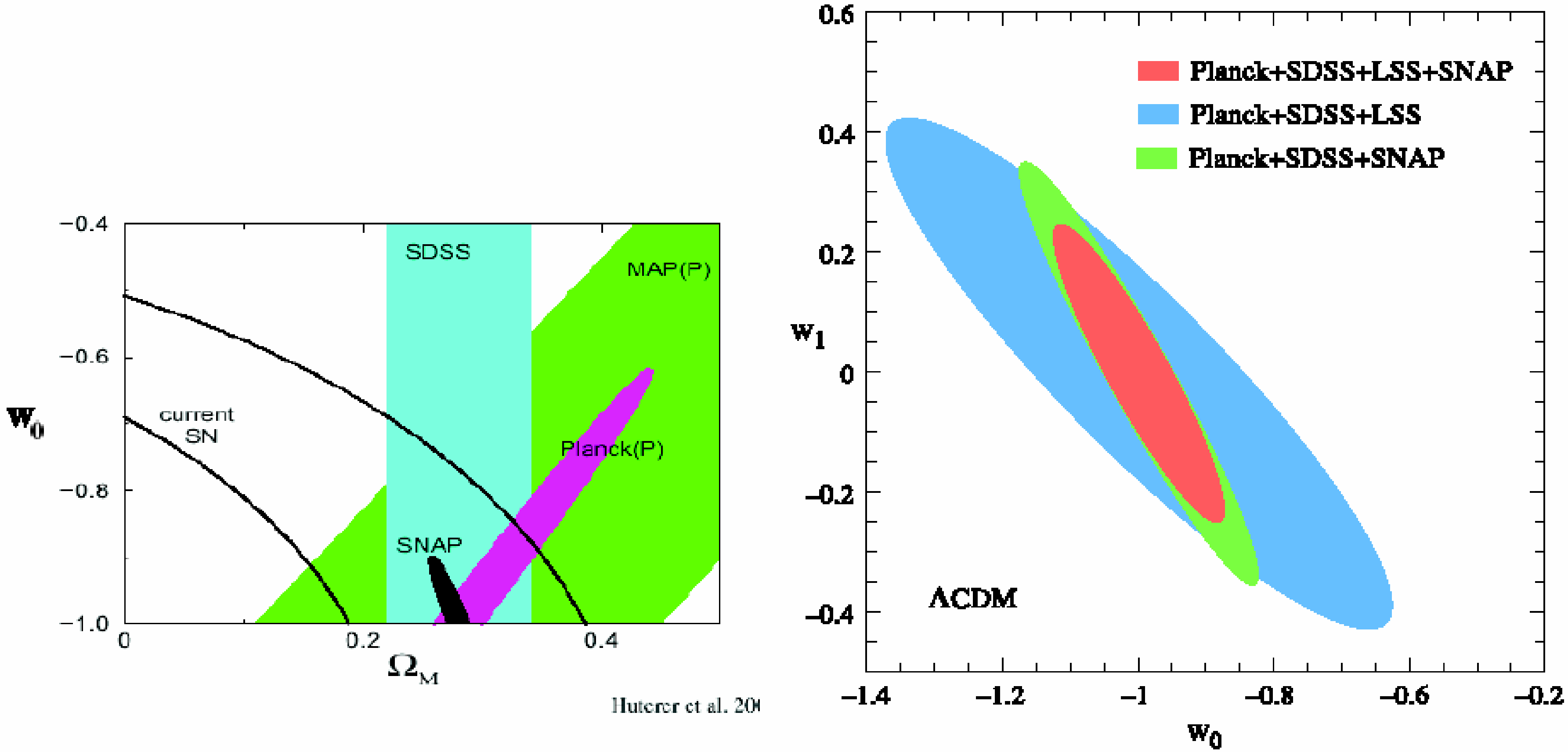
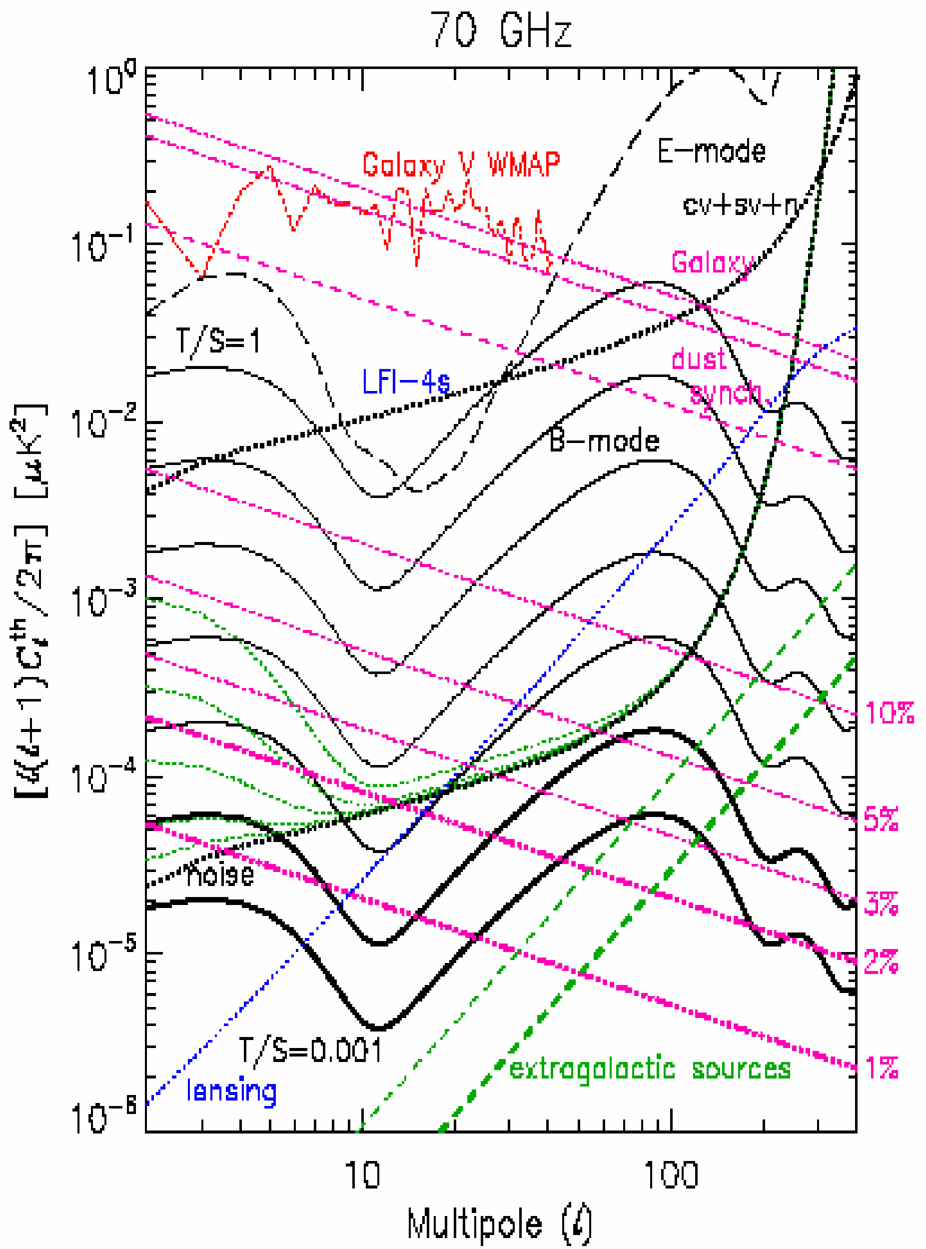


FIG 2.22.—The left panel (from Huterer & Turner 2001) shows forecasts of constraints on the dark energy equation of state parameter w and Ω_m for various experiments including *Planck*. The right panel (from Seo & Eisenstein 2003) shows forecasts of constraints on the time evolution of w, parameterised through $w \equiv w_0 + w_1 z$, for *Planck* combined with various redshift surveys and SNe observations from SNAP (see text for details).

B modes & E modes

Planck 4 surveys vs B-Pol



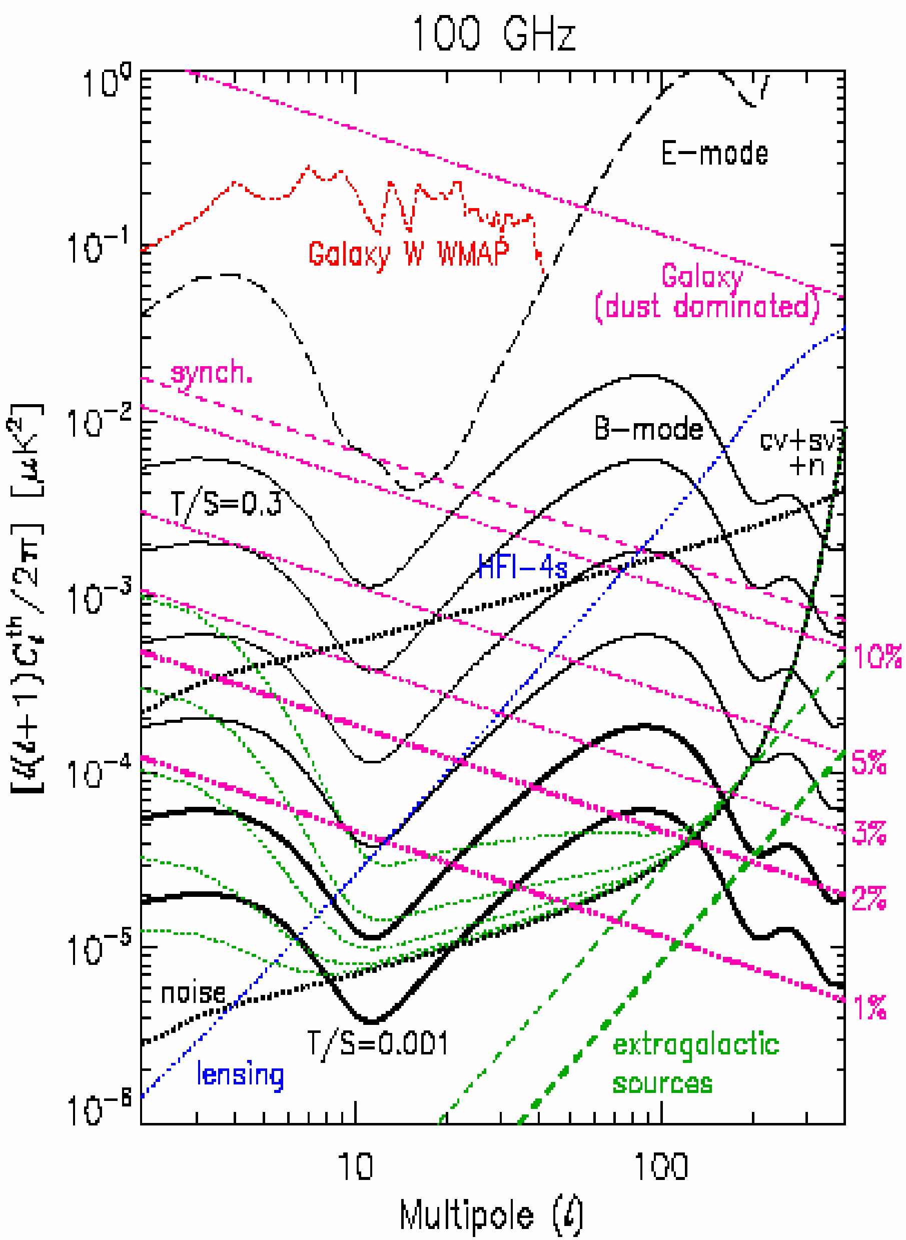


Figure 7: CMB E and B polarization modes compatible with WMAP 3-yr data compared to Galactic and extragalactic polarized (B-mode) foregrounds, the B-mode induced by lensing and their residuals and to the BPOL sensitivity including cosmic and sampling variance plus instrumental noise (black dotted lines labelled with cv+sv+n) assuming a multipole binning of 30%. Two different frequency are considered here. We display the E-mode (black long dashes); the B mode (black solid lines) is reported for different values of T/S (0.1, 0.03, 0.01, 0.003, 0.001 from top to bottom, at increasing thickness). Note that the cosmic and sampling (74% of sky coverage) variance implies a dependence of the overall sensitivity at low multipoles on T/S (again the black dotted lines refer to $T/S = 0.1$, 0.03, 0.01, 0.003, 0.001 from top to bottom). Galactic synchrotron (fuxia dashes) and dust (fuxia dot-dashes) polarized emissions produce the overall Galactic foreground (fuxia three dot-dashes) that is dominated by dust at 100 GHz. WMAP 3-yr power law approximations in the case of uncorrelated dust and synchrotron components are displayed here. For comparison, WMAP 3-yr results derived directly from the foreground maps are shown on a suitable multipole range: note that power law approximations provide (generous) upper limits of the power at low multipoles. Various level of residual contaminations by Galactic foregrounds (fuxia three dot-dashes) are shown for increasing capability to remove them (from 10% to 1% at map level at increasing thickness, labelled on the right). The contribution by extragalactic sources, $C_\ell^{\rm resPS}$, and the corresponding uncertainty, $\delta C_\ell^{\rm resPS}$, assuming $\delta\Pi/\Pi = \delta S_{\rm lim}/S_{\rm lim} = 10\%$ are reported (green dashes, thin and thick, respectively). The B-mode induced by lensing and its residual assuming a (conservative) 10% suppression accuracy at APS level are displayed (blue dots, thin and thick, respectively).

Generally …

- **Planck could in principle detect B modes for T/S above ~ 0.1 – (some × 0.01)**

- **In order to get info on B modes down to low T/S values (B-Pol goal) and on details of cosmological reionization we need extreme sensitivity and excellent separation/subtraction of foregrounds (at few % accuracy level)**

- **Clusters & SZ effect**

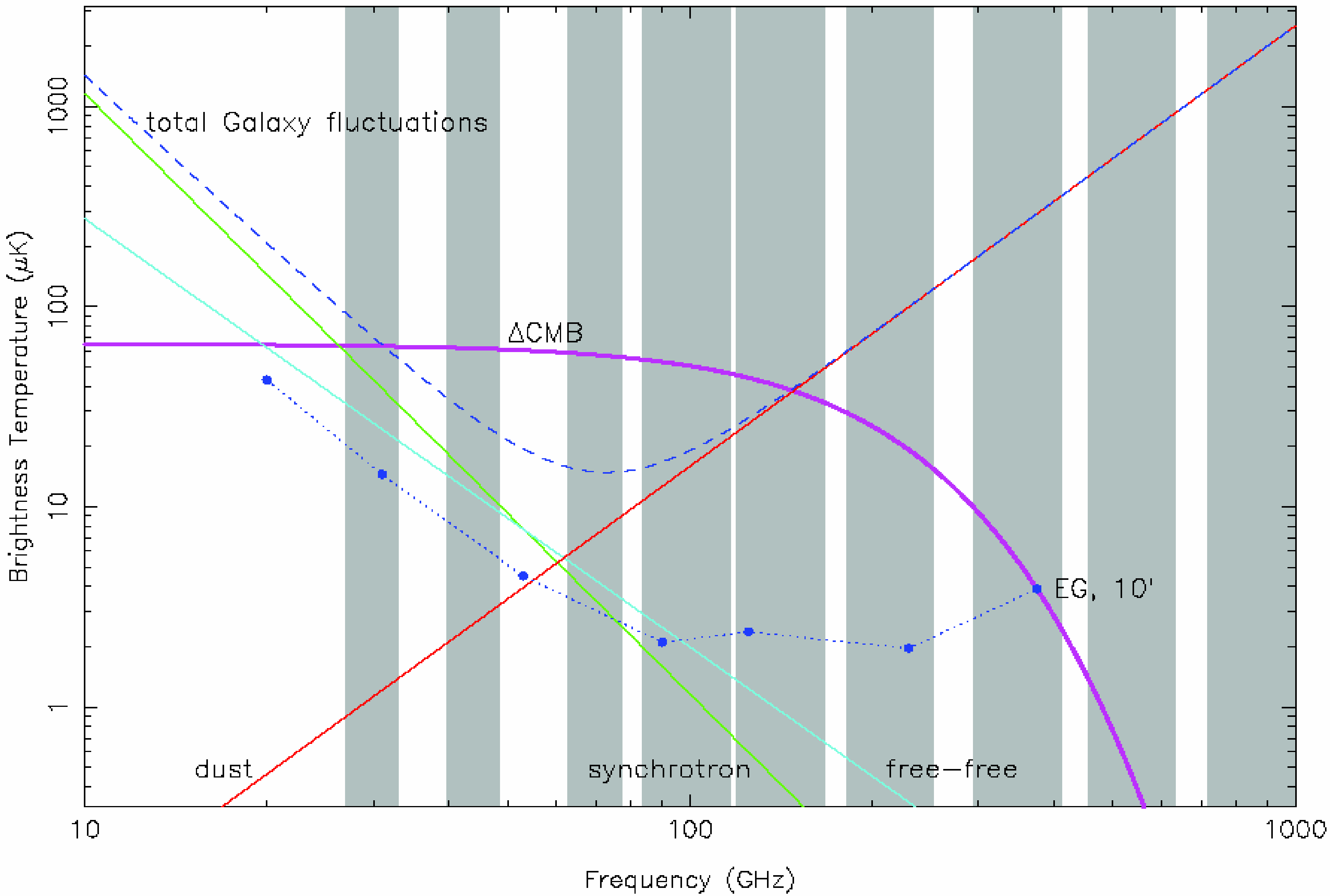


FIG 1.3.— Spectrum of the CMB, and the frequency coverage of the *Planck* channels. Also indicated are the spectra of other sources of fluctuations in the microwave sky. Dust, synchrotron, and free-free temperature fluctuation (i.e., unpolarized) levels correspond to the *WMAP* Kp2 levels (85% of the sky; Bennett et al. 2003). The CMB and Galactic fluctuation levels depend on angular scale, and are shown for $\sim 1°$. On small angular scales, extragalactic sources dominate. The minimum in diffuse foregrounds and the clearest window on CMB fluctuations occurs near 70 GHz. The highest HFI frequencies are primarily sensitive to dust.

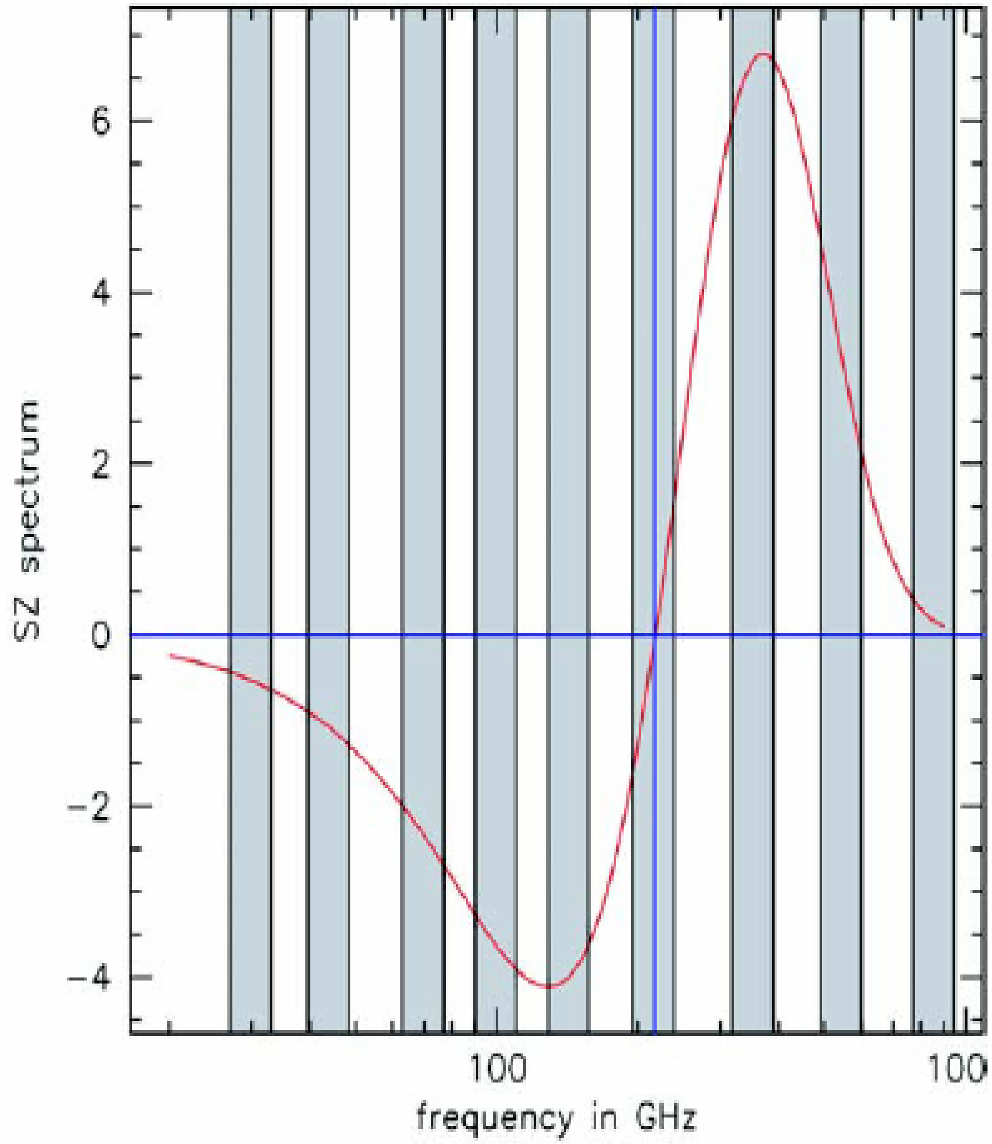


FIG 3.4.— Spectrum of the thermal Sunyaev-Zel'dovich effect (red curve, arbitrary units), overlaid with *Planck*'s frequency channels (grey bands). The CMB intensity is increased at frequencies above 217 GHz (i.e., to the right of the vertical blue line) at the expense of lower frequencies. In other words, galaxy clusters cast shadows below 217 GHz and shine above.

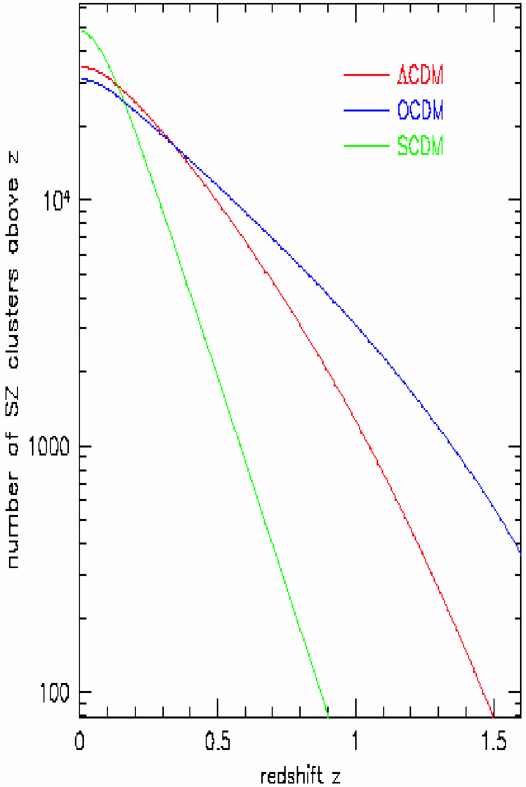


FIG 3.7.—The number of clusters *Planck* should detect at $\sim 3\sigma$ over the full sky at redshifts exceeding z, for three different cosmologies. For this calculation, the assumptions about the amount and structure of the intracluster medium were chosen to reproduce the SZ properties of observed low-redshift clusters. Abundance evolution is then based on large-scale numerical simulations (based on Bartelmann 2001).

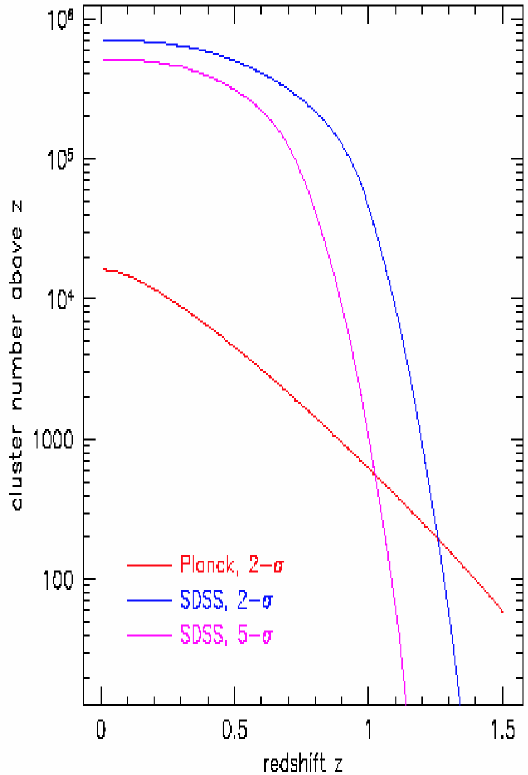


FIG 3.8.—The number of clusters expected to be visible in the optical for the Sloan Digital Sky Survey and in the microwave regime for *Planck* is shown as a function of cluster redshift. In the SDSS area, *Planck* should detect more than 10^4 clusters, almost all of which will also be detected by SDSS. Those *Planck* clusters which will not appear in the SDSS will be at high redshift (adapted from Bartelmann and White 2002).

- **Extragalactic radiosources (LFI)**

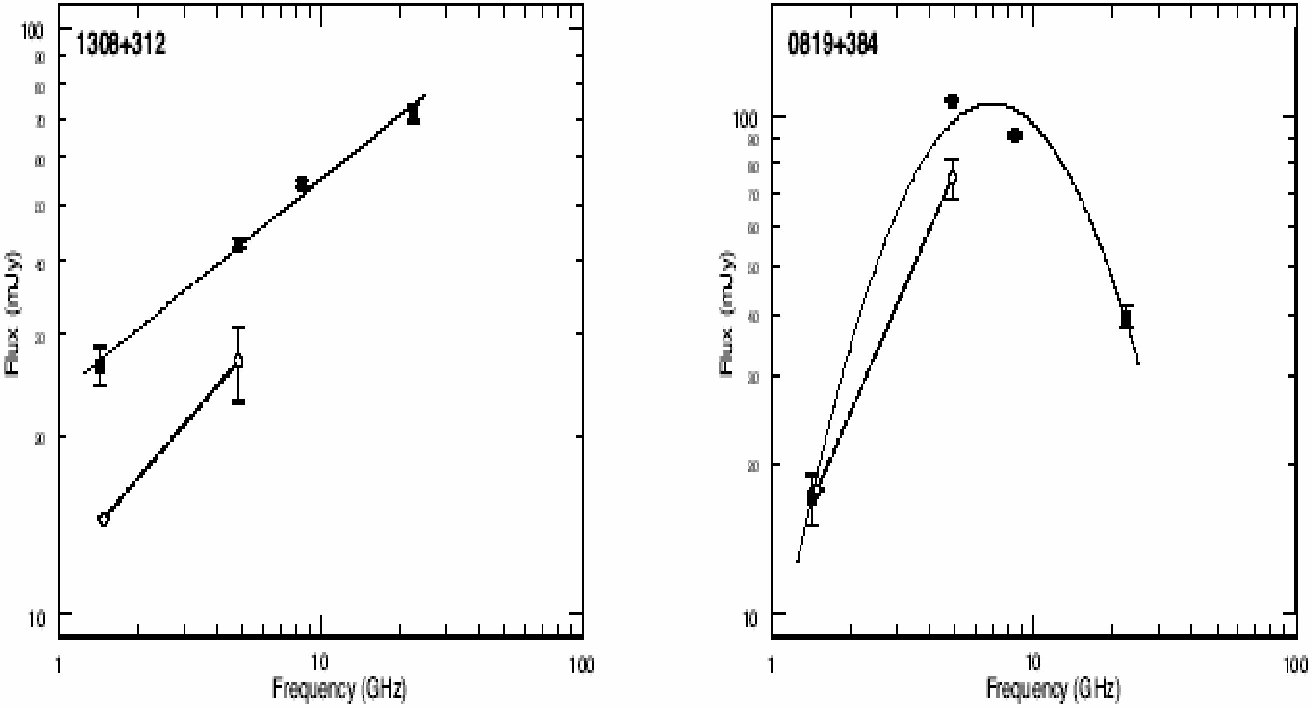
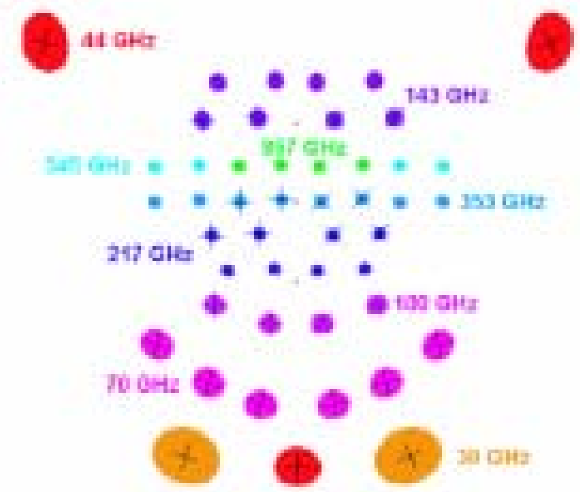


FIG 4.2.— Radio frequency spectra of two atypical radio sources. One is a GPS source.



gust 200

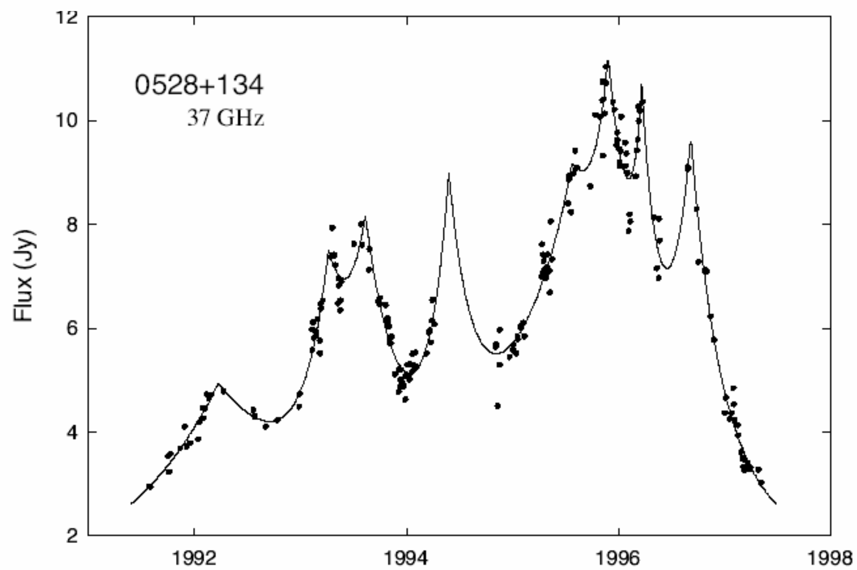


FIG 4.6.— Observations of a highly variable radio source, compared with a fitted model based on exponential flares. From Valtaoja et al. 1999.

- **Extragalactic far-IR sources (HFI)**

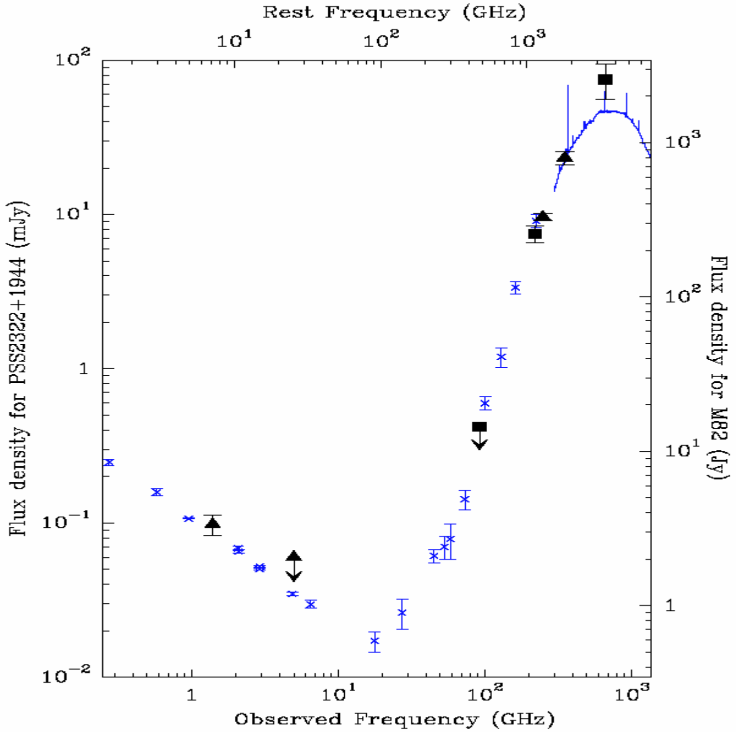


FIG 4.8.— Spectral energy distribution of PSS 2322+1944 (black points, from Cox et al. 2002). For comparison, the radio-to-infrared spectral energy distribution of the starburst galaxy M 82 is shown, redshifted to $z = 4.12$ and normalized to the flux density of PSS 2322+1944 at the observed wavelength of 850 μm. The crosses show all the currently available photometric data, and the continuous line represents the ISO LWS spectrum. The left- and right-hand flux density scale are adapted for PSS 2322+1944 and M 82, respectively.

PLANCK GALAXY SURVEYS

	FREQUENCY [GHz]				
	143	217	353	550	850
Confusion limit [mJy, 3σ]	6.3	14.1	44.7	112	251
Planck All Sky Survey sensitivity [mJy, 3σ]	26	37	75	180	300
Planck Deep Survey sensitivity [mJy, 3σ]	10	18.4	49	170	280
Number of galaxies [all sky]	570	860	1700	4400	35000

- **Galactic diffuse foreground maps**

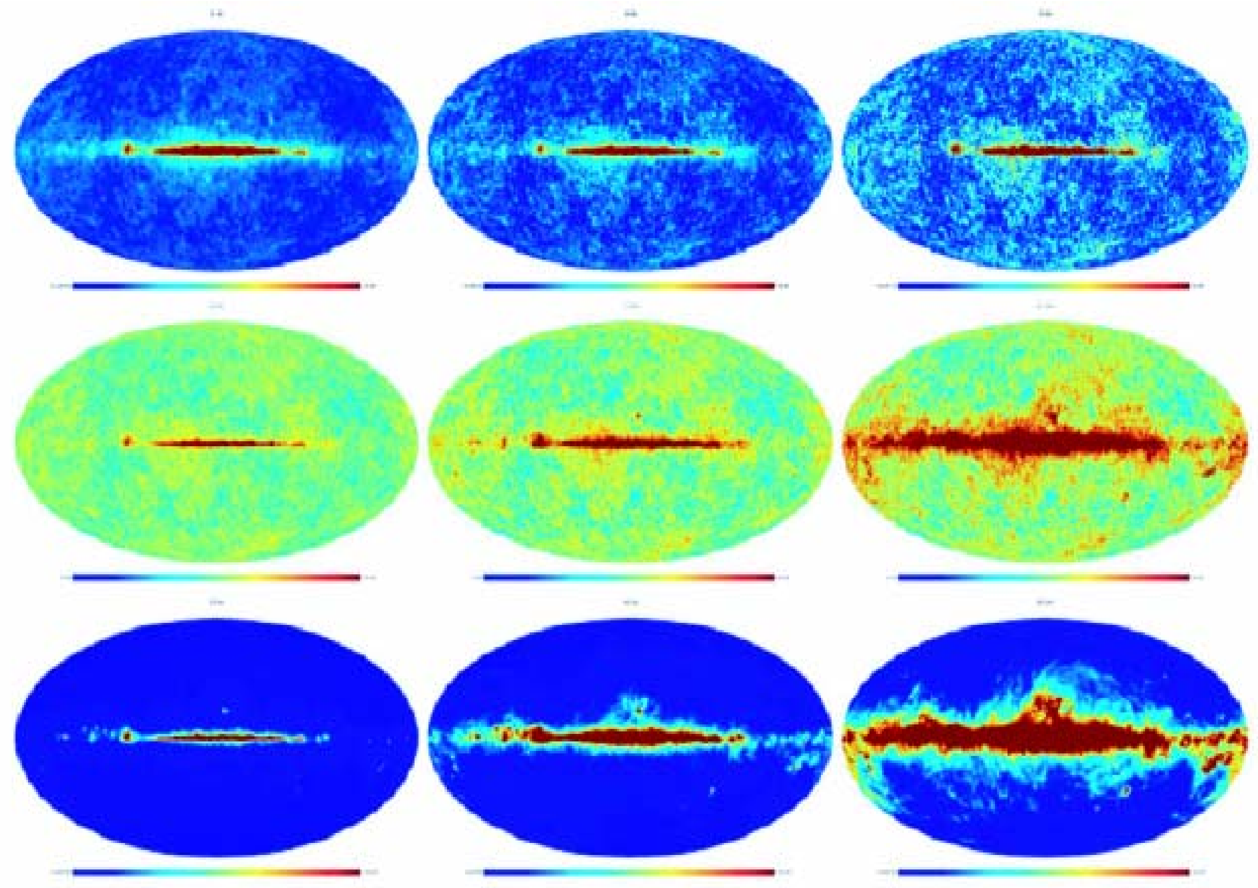


FIG 5.1.— False colour images of the simulated sky in the nine frequency channels of *Planck*, after subtraction of the monopole and dipole CMB components. From top left to bottom right: 30, 44, 70, 100, 143, 217, 353, 545, and 857 GHz channels.

- **Galactic sources**

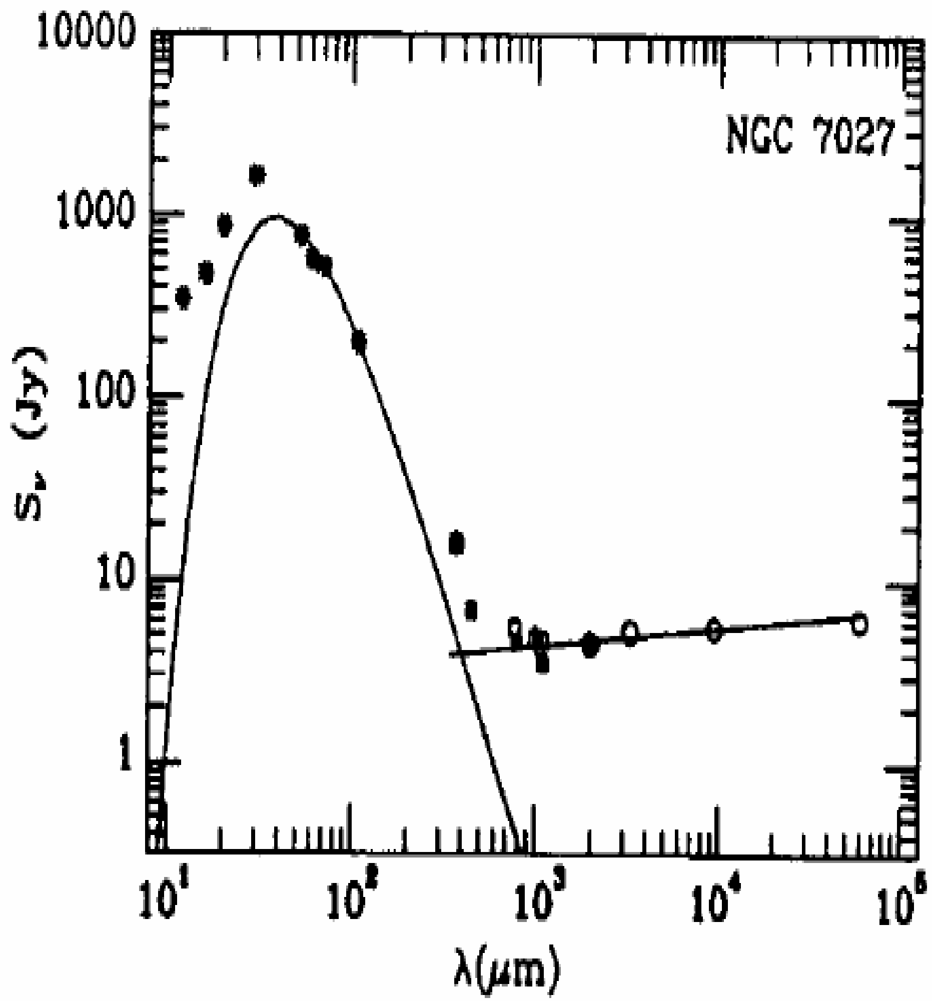


FIG 5.5.— The SED of the young planetary nebula NGC 7027 (reproduced from Hoare, Roche and Clegg, 1992). Thermal emission from dust dominates the IR-mm part of the spectrum, while the contribution of free-free emission from the ionized envelope is evident in the radio.

- **Solar System Science**

NUMBER OF DETECTABLE MAIN BELT ASTEROIDS[a]

R/d	Differential Number	Cumulative Number[b]
$1\text{–}2 \times 10^{-7}$	299	397
$2\text{–}3 \times 10^{-7}$	76	98
$3\text{–}4 \times 10^{-7}$	15	22
$4\text{–}5 \times 10^{-7}$	4	7
$R/d > 5 \times 10^{-7}$	0	3

[a] The lower threshold considered here for asteroid detection is set to a radius to distance ratio $R/d \sim 10^{-7}$, derived by assuming a typical asteroid temperature of $\sim 150\,\mathrm{K}$ and by taking into account the *Planck* sensitivity at different channels (see Cremonese et al. 2003 for details).

[b] The cumulative number is computed at the lower limit of the range listed for the differential number.

Planck deep fields

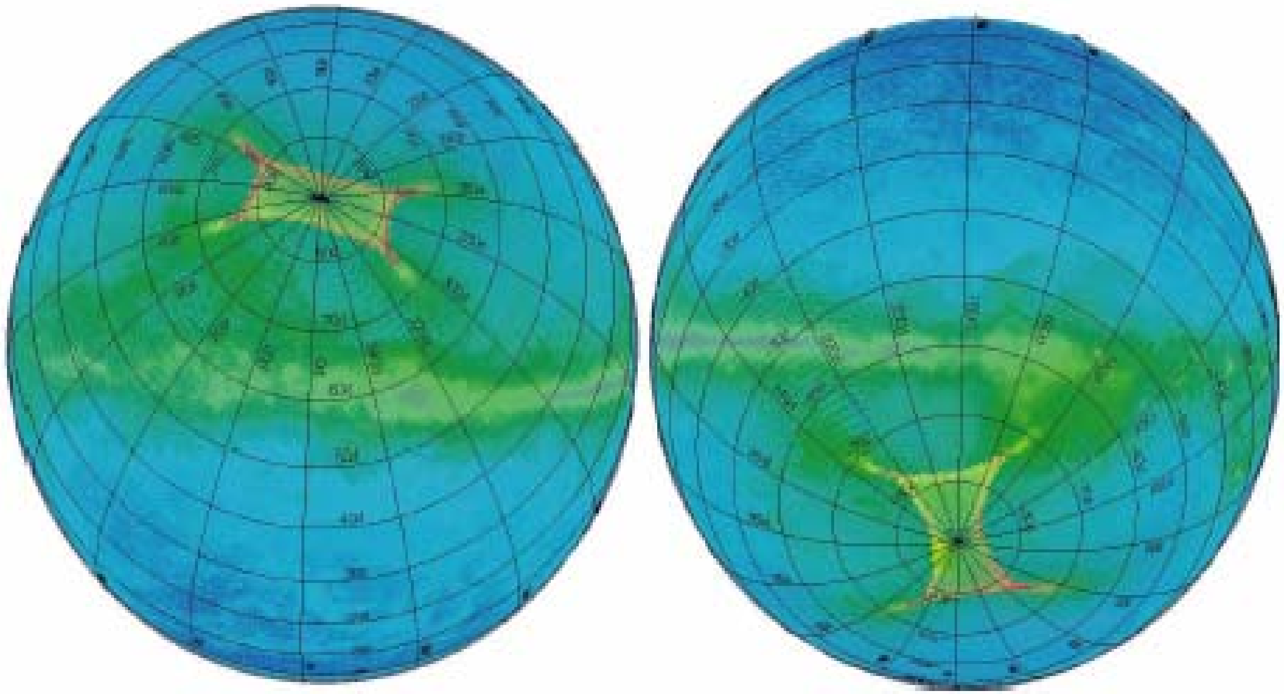


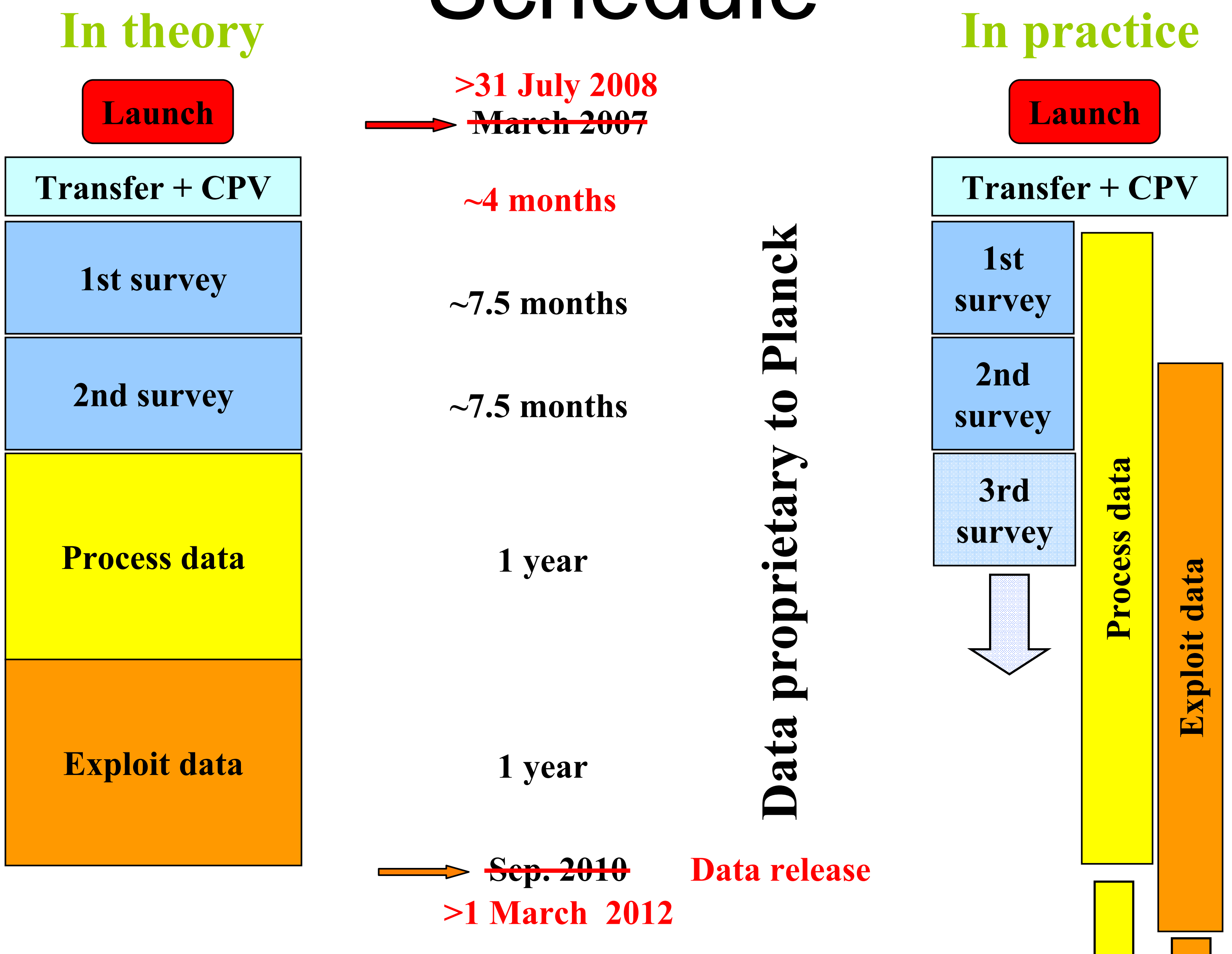
Figure 23: The coverage map at 100 GHz for the selected baseline SS is shown overlaid with the sky at 100 GHz as derived from the Galactic PLANCK sky model.

PLANCK

The Core Programme: status, context and approach

Planck Scientist: J. Tauber

Schedule


In theory
Launch
Transfer + CPV
1st survey
2nd survey
Process data
Exploit data
>31 July 2008
March 2007
~4 months
~7.5 months
~7.5 months
1 year
1 year
Sep. 2010
Data release
>1 March 2012
Data proprietary to Planck
In practice
Launch
Transfer + CPV
1st survey
2nd survey
3rd survey
Process data
Exploit data

The Scientific Programme

May 2001	2006-2007 ~~2005~~	2012 ~~2010~~
Baseline Core Programme General Projects Core Programme Teams Team Coordinators	**Core Programme** General Projects Special Projects Core Programme Teams Team Coordinators	**Publications** General papers Special papers Technical papers Conferences Invited seminars **Products**
✔	NOW !	

Core Programme: next milestones

- **Review by the Science Team and others [15 May – October]**
- **First and Preliminary Assessment by Science Team at this meeting [20 June]**
- **Opening of a period to re-submit work plans as needed [1 – 15 December]**
- **Consolidation & internal "publication" of the Core Programme [end January 2008]**

LFI

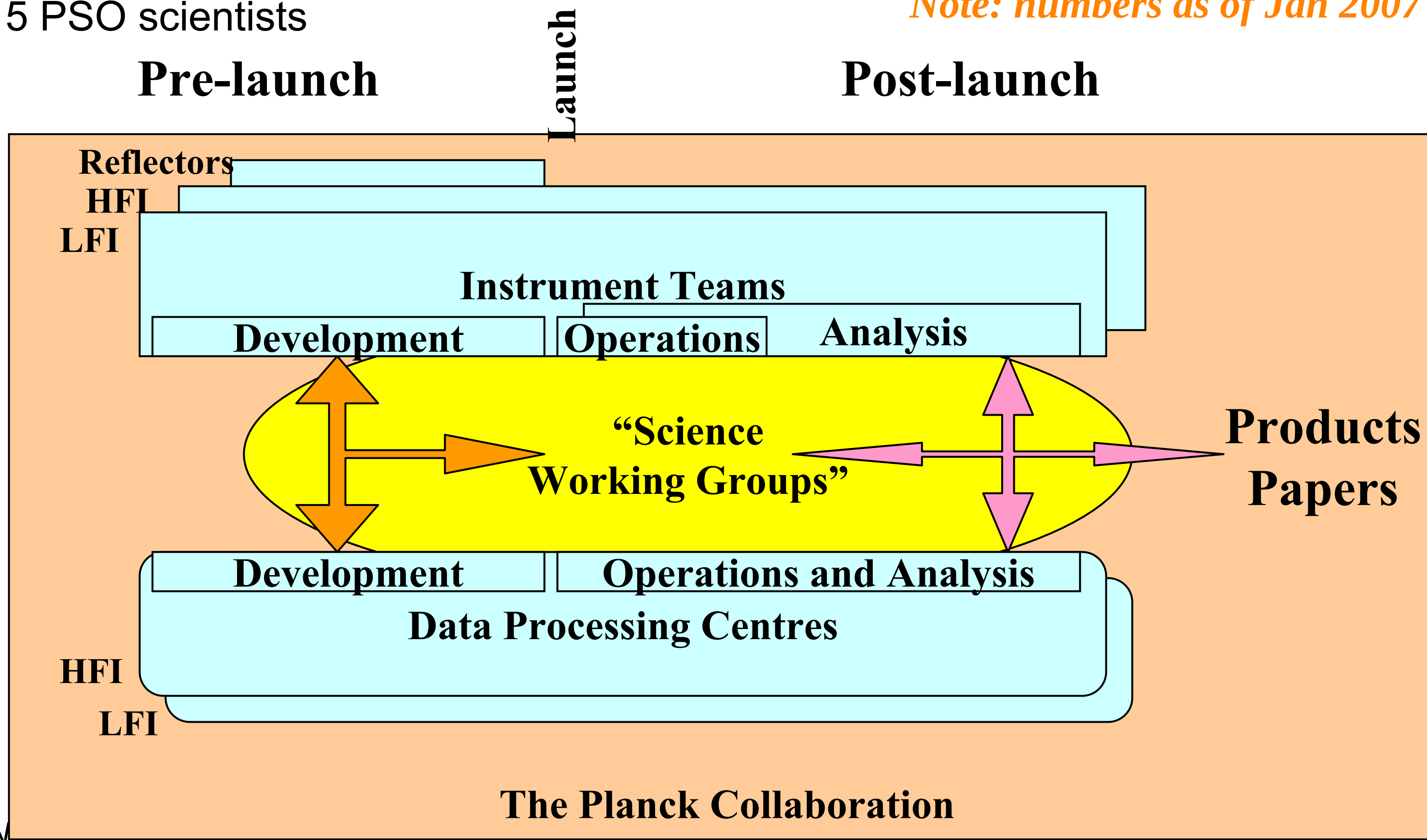
HFI

The Planck collaboration

- ~700 people in Planck database
  - 228 LFI scientists (Co-Is + Ass)
  - 172 HFI scientists (Co-Is + Ass)
  - ~30 common LFI-HFI scientists
  - 25 DK-Planck scientists (Co-Is + Ass)
  - 5 PSO scientists
- ~400 scientists who wish to exploit the data
- Consortia meetings are held jointly at roughly yearly intervals

Note: numbers as of Jan 2007

Scheme of 2001



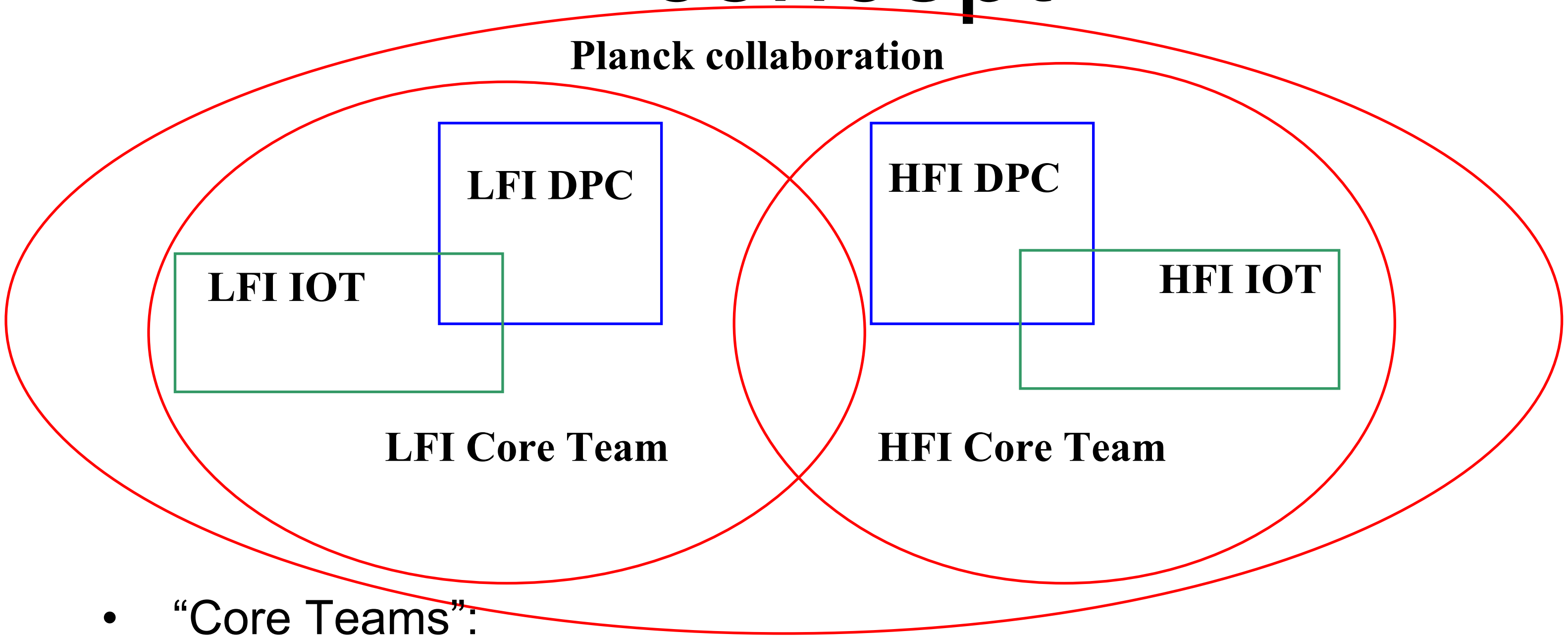
Planck Working Groups

- "Transverse Working Groups"
  - Systematic Effects (instrument related)
  - "CTP" (Cl, Temp & Pol extraction: map-making and power spectrum extraction techniques)
  - Component Separation techniques
- "Science Working Groups"
  - Non-gaussianity
  - Clusters and secondary anisotropies
  - Extragalactic sources
  - Galactic & solar system science
- Miscellaneous
  - Scanning strategy
  - Cryo-operations
  - Virtual observatory

Typical Tasks/Achievements

- Analysing the impact of systematic effects
- Comparison of map-making techniques
- Comparison of component separation techniques
- Development of point-source extraction algorithms
- Dev't of Reference Sky
- Gathering all kinds of sky templates
- Preparing Herschel-related proposals
- Comparing scanning strategies
- ….

Transition to operations concept



- "Core Teams":
  - Loose team of **dedicated** scientists to work on specific topics in **support** of operations and DPCs (organised into topical and ad-hoc sub-groups)
  - About 70 people for each of LFI and HFI
  - Meet every two months
  - Joint LFI/HFI meeting every ~6 months
- Core Teams are established, organised into sub-groups, working

Working Groups transition

- WG1 is already largely absorbed into Core Teams (topical teams)
- WGs 2 & 3 are still actively doing R&D work – near the end of 2007 the needed functions will start to be absorbed into the Core Teams (as WG1)
- WGs 4 to 7 will be reorganised along core programme lines (focussed on paper production).
  - Frame proposal coordinators will have an important coordination role in each area.

Science-Team coordinated proposals

Product description

The Planck Mission- first results
The Planck Optical System- In-flight Characterisation
In-flight Performances of the Planck-LFI Instrument
In-flight Performances of the PLANCK-HFI Instrument
The Thermal Performance of Planck
Time Ordered Information from LFI Radiometers
HFI TOIs
Planck temperature and polarisation frequency maps
The Planck Early Release Compact Source Catalogue
The Planck Component Separation

10 proposals

Cosmology

Isotropy and statistics of the CMB
Temperature and Polarization Power Spectra and Likelihood Functions
Cosmological Parameters from Planck/CMB data alone
Cosmological Parameters from Planck Combined with Astrophysical data sets
Constraints on inflationary models from Planck combined with astrophysical data sets
Constraints on B-mode polarization anisotropies

6 proposals

WG-coordinated proposals

Non-gaussianity (WG4)
Probing the Geometry and Topology of the Universe
Non-Standard Inflationary Models
Cosmic strings and other defects in the core program of Planck
Constraints on Primordial Magnetic Fields

Secondary anisotropies (WG5)
Planck WG 5 Proposals, cover proposal
Production and Exploitation of the SZ Cluster Catalog
Multi-wavelength Cluster Science
Gravitational lensing by large scale structures with Planck
Constraining the Ionisation History of the Universe
Cosmological constraints from the integrated Sachs-Wolfe effect
Studies of diffuse and kinetic Sunyaev-Zeldovich signals

Extragalactic sources (WG6)
WG6 Overview
Planck Survey of Extreme GPS and Inverted Spectrum Radio Sources
The astrophysics of quasars and BL Lac objects
The Planck View of Local Galaxies
High redshift dusty galaxies
Statistical Properties and Evolution of Radio and Submillimeter Sources
Far-Infrared Background and correlations- probing structure formation and evolution

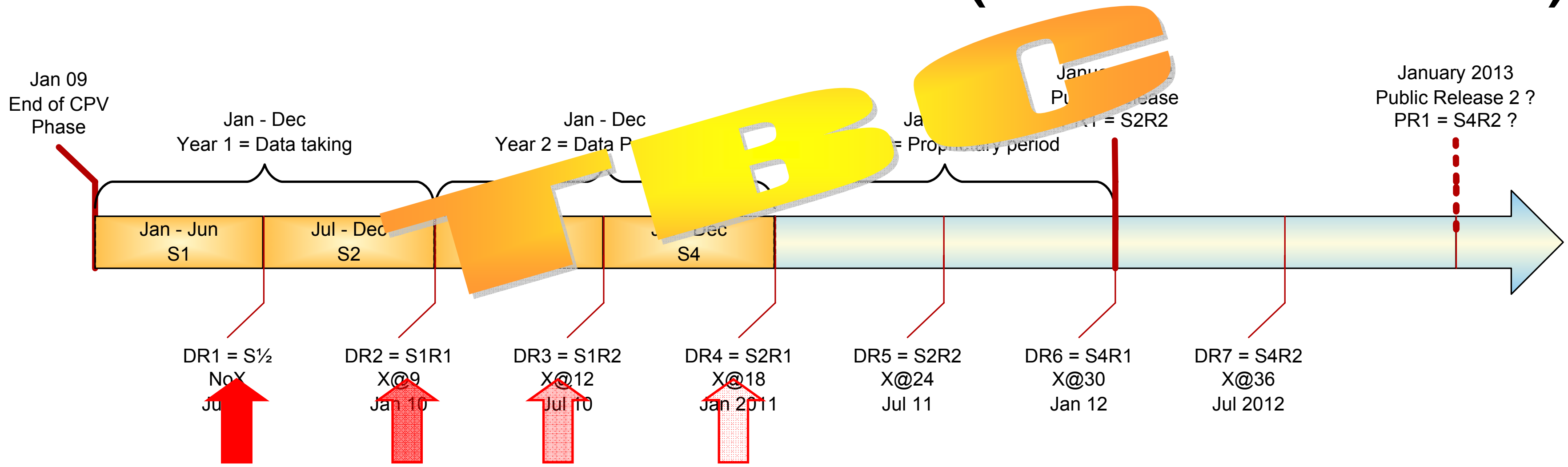
Galactic astrophysics (WG7)
Ancillary data and manipulation tools
The 3-D Galaxy
Relationship Between the Phases of the ISM
Diffuse Synchrotron Emission in the Planck survey
Studying the diffuse warm ionized gas in the Galaxy with Planck
Proposal to study the nature of the anomalous emission in the Planck Survey
Dust content in nearby molecular clouds
Dust at high Galactic latitude
Interstellar Clouds Polarization
Dust properties from Polarization
The Large-Scale Galactic Magnetic Field
Cold cores
Late stages of stellar evolution
Planck- an opportunity for the study of Massive Star Formation
Microwave Properties of Supernova Remnants
Solar System Diffuse Emission and Moving Objects

35 proposals

Science exploitation 2

- Data products for science exploitation will be generated by DPCs at roughly 6-month intervals (over the 2-3 year proprietary period)
  - Data access procedures concept is established
  - They will be distributed by “Level-4”
- DPCs will provide little or no specific support to scientific exploitation
  - Any product needed for scientific exploitation (other than the 6-monthlies) has to be provided by the programme teams themselves – by including Core Team scientists who can generate these products as part of their Core Team activity
  - There will be a knowledge & resource advantage to dedicated scientists within Core Teams (it is a “reward” & incentive for the very significant effort put in)

Internal data releases (“6-monthlies”)



First releases not useable for science !

Release contents will eventually cover (TBC):

- Calibrated timelines
- Detector maps
- Frequency maps
- Component maps
- Catalogues of sources

Release schedule (TBC):

- 1st release at End of First Survey (approx L+12 mo) based on the first 3 months of data
- 2nd release at End of Second Survey (approx L+18 mo) based on the First Survey data
- ERCSC available for internal validation (approx L+18 mo)
- 3rd release at End of Third Survey (approx L+24 mo) based on consolidated First Survey data
- 4th release at End of Operations (approx L+30 mo) based on First and Second Survey data
- Etc

Data rights & publication

- Policies are in place since 2000 including
  - Access to data & data security
    - See also *"Data Access Procedures "* document
  - Leadership of & participation in scientific efforts
  - Definition of types of papers
  - Authorship of papers (depends on type)

  "Policies for Planck Scientists, Data Rights and Publications" Nov 2005 – in Livelink

- The Planck Scientist List determines (a) the right to lead a scientific effort; (b) the right to author all General papers
  - Based on the integrated time spent on Planck

New policy elements 1/4

- Communications policy will be reinforced / reformulated to cover
  - Internal information flow
  - External information flow
  - Conferences, invited talks, seminars (including talks at home institutions) etc etc
- Information =
  - Data (including before launch)
  - Results
  - Press releases, Public relations materials
  - Corridor conversations (including within home institutions)
  - Web sites, newsletters, Etc etc
- Principle for now and from now on is:

No dissemination of any unpublished Planck information, in any form, to members outside the Planck collaboration, without express prior approval from the Science Team

New policy elements 2/4

- Publication process will be put in place
  - Data validation
  - Internal refereeing / reviewing
  - Criteria for publication
  - Approval for publication
- Principle for now is: **any publication based on Planck data (including pre-launch) will require express approval by the Science Team before being submitted to any journal or periodical**
- Notes:
  - This applies both to Science-Team-coordinated and WG-coordinated papers
  - Most of the major publications will occur in "waves"

Policy elements 3/4

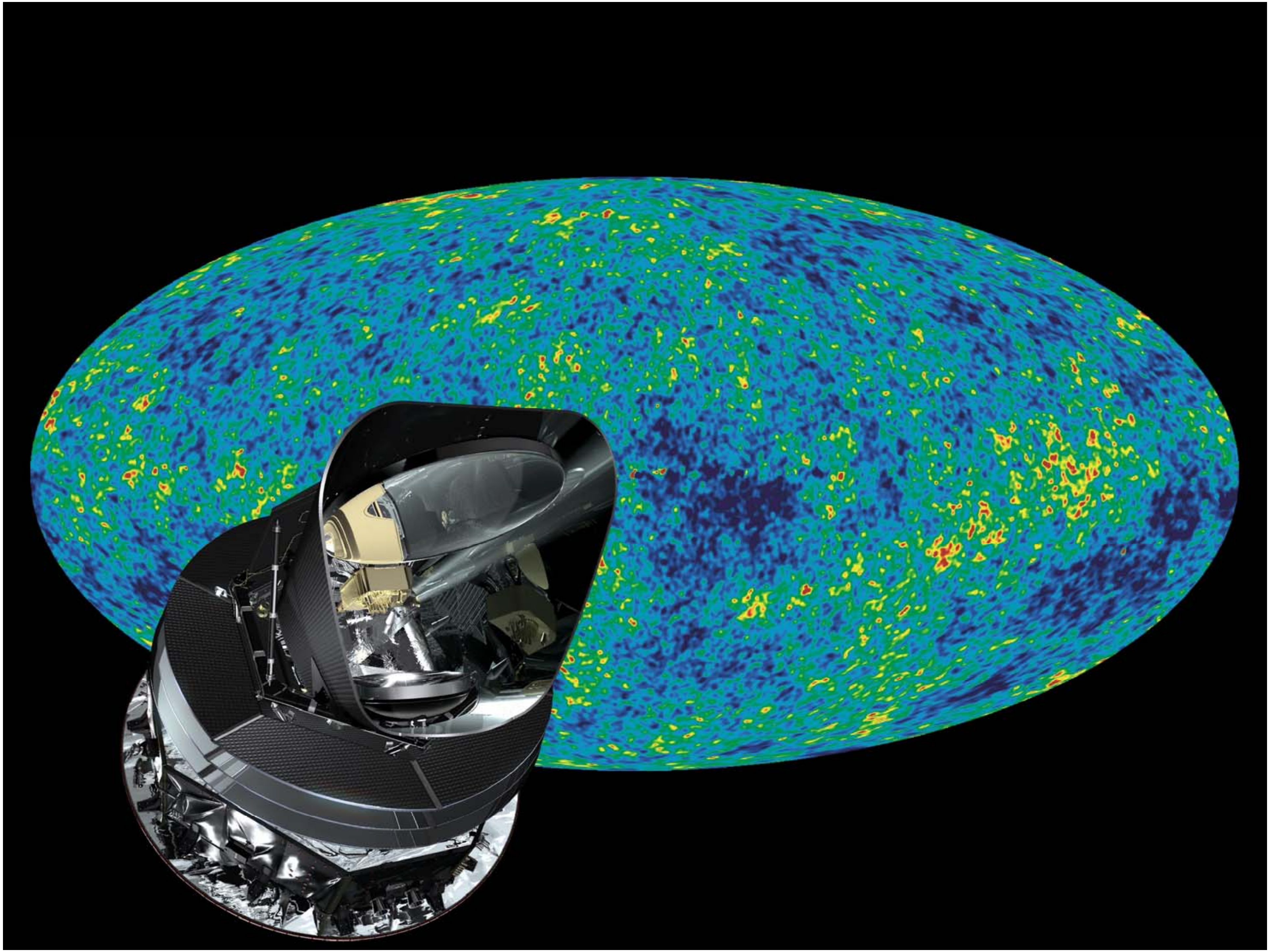
- **Restrictions on the use of unreleased Planck software and data products will also apply *after* the end of the proprietary period**

Violations of the Planck policies may result in individuals being ejected from the Planck Collaboration !

Science exploitation 4/4

External collaborators

- Any scientist wishing to use Planck data during the proprietary period, and bringing added value by doing that, shall apply to become an Associate by the usual means (via PI and then Science Team), and therefore will have to comply with the Planck Policies – *this applies also to Students, post-docs etc*
- Security policy shall be similar to that for Herschel/Planck collaborations (details on a case by case basis): “Each Planck/Herschel proposal shall have a PI or co-PI who is a Planck Co-Investigator or Planck Scientist. This person will be known as the “Planck PI” for the team, and shall be responsible for the security of Planck data inside the Planck/Herschel team according to the Policies for Planck Scientists. In particular, team members shall have access to Planck data as necessary through explicit written agreements with the Planck PI, which shall be signed by the team members, the Planck PI, and the Planck Project Scientist. Distribution during the proprietary period of Planck data to any other person without the express approval of the Science Team is forbidden. Similarly, discussion during the proprietary period of Planck data or results with anyone outside the Planck Collaboration without the express approval of the Science Team is forbidden, with the exception that the selection, characteristics, and positions of fields or sources detected by Planck and being investigated with Herschel can be described as necessary for Herschel proposals and observing plans. Dissemination of results in any form based on Planck data during the proprietary period requires advance approval of the Planck Science Team.”



Looking back in time

The End