IL TELESCOPIO DI PLANCK E LFI

Fabrizio Villa

INAF / IASF - Bologna

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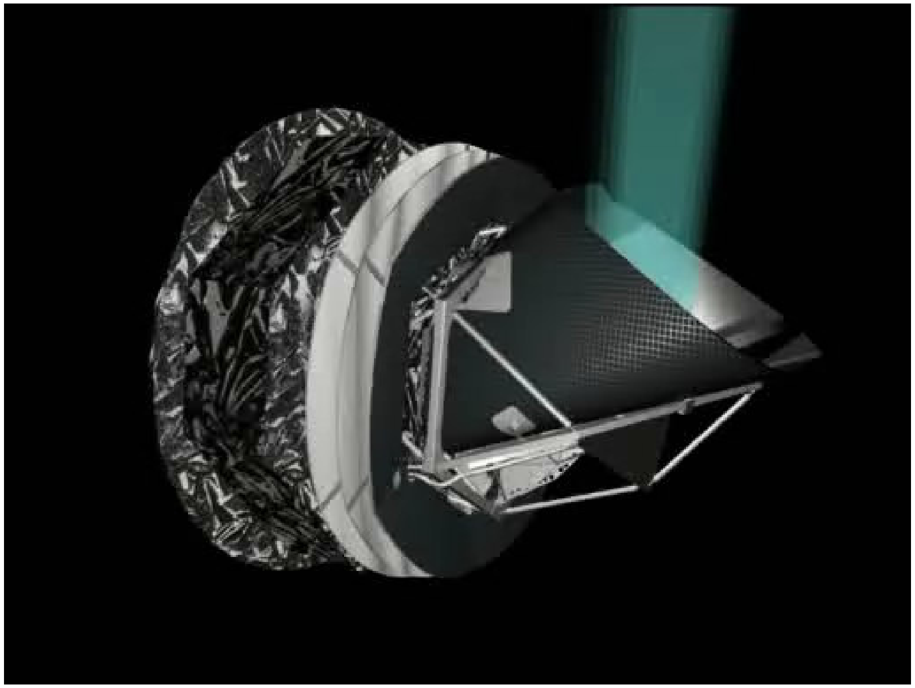
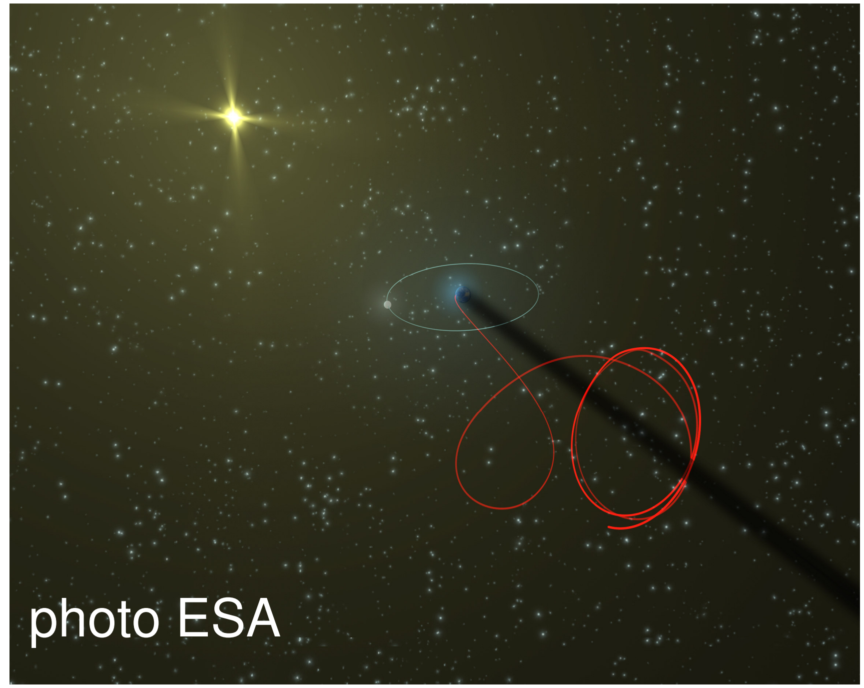
PLANCK e LFI (ESA media)





LAUNCH DATE: 31/10/2008

MISSION END: ~ 2010 (21 month baseline)

LAUNCH VEHICLE: Ariane 5

LAUNCH MASS: 1800 kg

ORBIT: Lissajous orbit about the second Lagrange point of the Earth-Sun system (L2)

OBJECTIVES: Mapping of Cosmic Microwave Background anisotropies with improved sensitivity and angular resolution (Temperature and Polarization)

COSTS: about 600 million Euros

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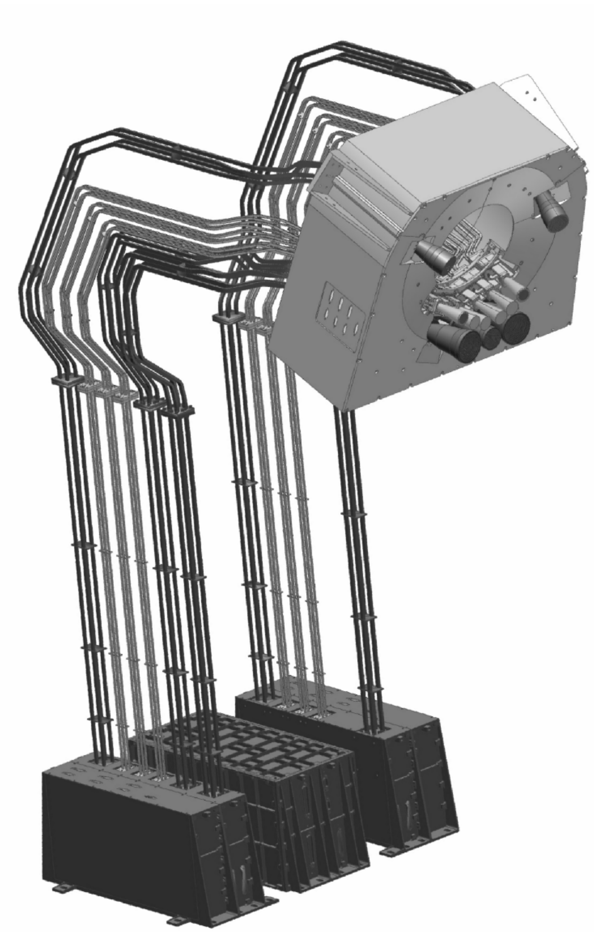
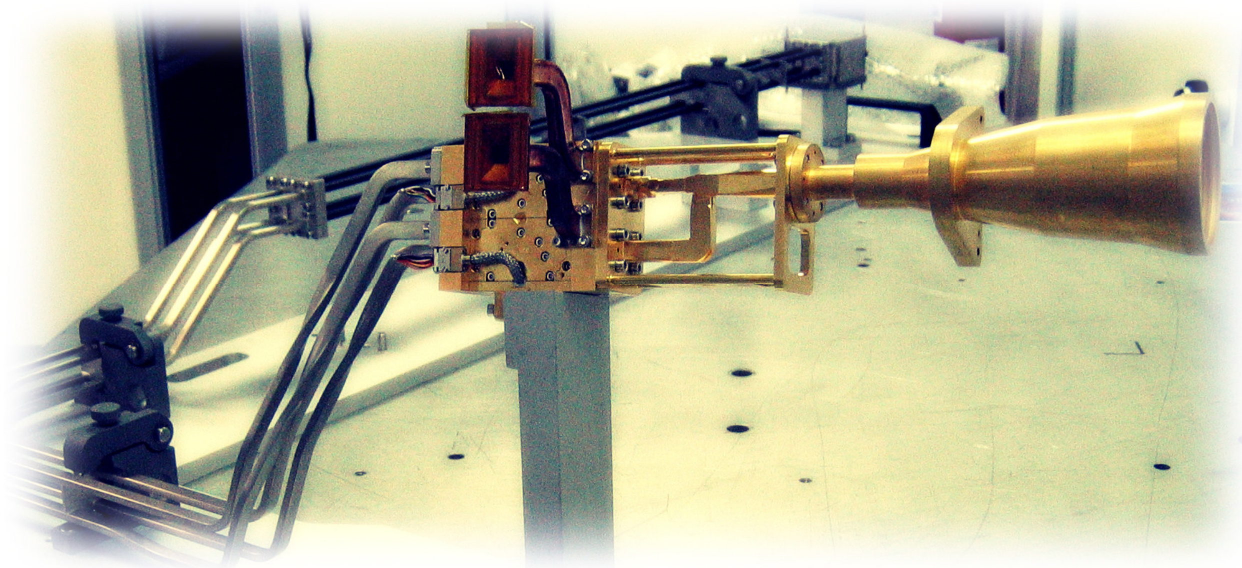
II Low Frequency Instrument



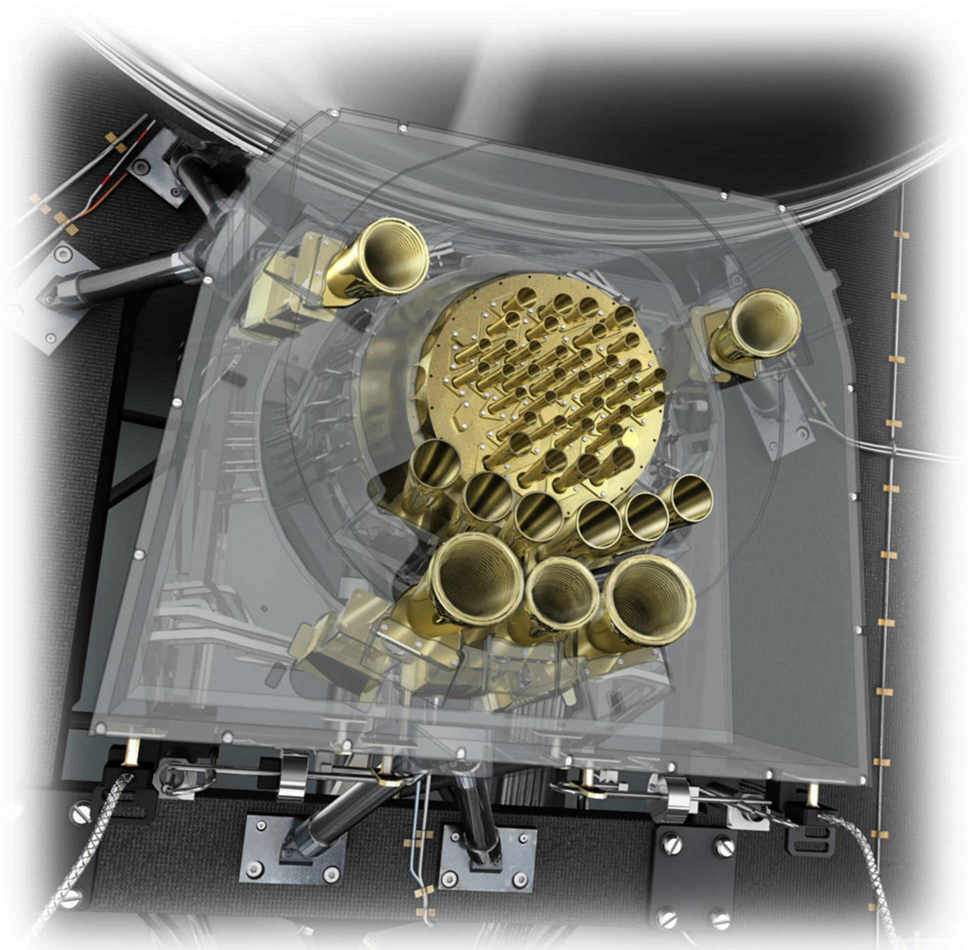


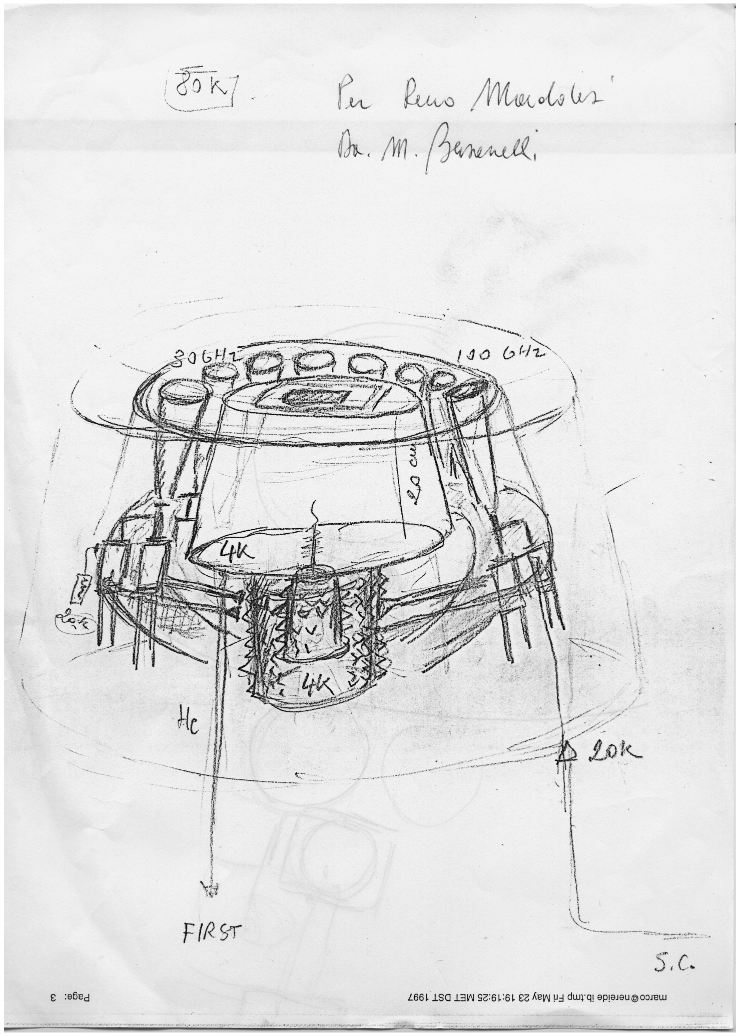
INSTRUMENT CHARACTERISTIC	CENTER FREQUENCY [GHz] 30	44	70
InP HEMT Detector technology	MIC	MIC	MMIC
Detector temperature		20 K	
Cooling system		H_2 Sorption Cooler	
Number of feeds	2	3	6
Angular resolution [arcminutes FWHM]	33	24	14
Effective bandwidth [GHz]	6	8.8	14
Sensitivity [$\mathrm{mK\,Hz}^{-1/2}$]	0.17	0.20	0.27
System temperature [K]	7.5	12	21.5
Noise per 30′ reference pixel [μK]	6	6	6
$\Delta T/T$ Intensity [b] [10^{-6} μK/K]	2.0	2.7	4.7
$(\Delta T/T)$ Polarisation (Q and U) [b] [μK/K]	2.8	3.9	6.7
Maximum systematic error per pixel [μK]	< 3	< 3	< 3

[a] All subsystems are designed to reach or exceed the performances of this table.

[b] Average 1σ sensitivity per pixel (a square whose side is the FWHM extent of the beam), in thermodynamic temperature units, achievable after 2 full sky surveys (14 months).

Focal Plane Unit (FPU)





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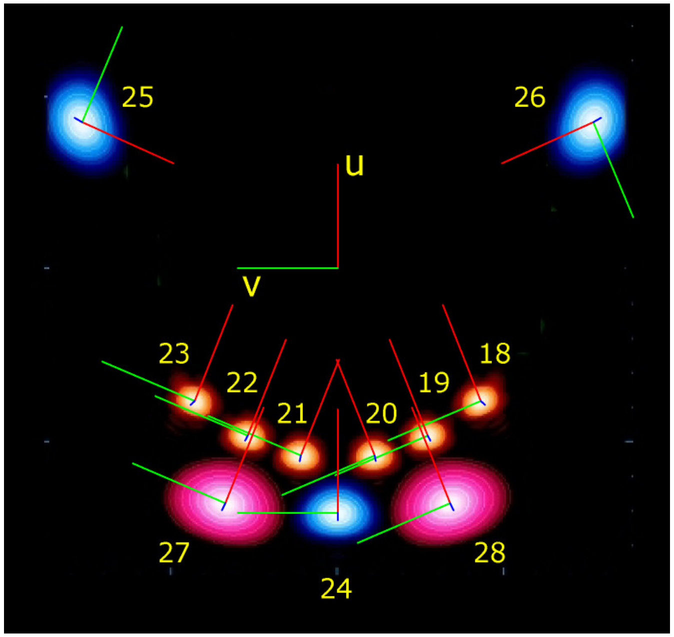

BEAM	ν_0 (GHz)	θ_{MB} (°)	ϕ_{MB} (°)	ψ_{MB} (°)	U_{MB}	V_{MB}
18	70	3.2975	−131.8147	22.3	−0.03835	−0.04287
19	70	3.1750	−150.8570	22.4	−0.04837	−0.02697
20	70	3.1649	−168.4438	22.4	−0.05409	−0.01106
21	70	3.1649	168.4438	−22.4	−0.05409	0.01106
22	70	3.1747	150.8570	−22.4	−0.04837	0.02697
23	70	3.2975	131.8147	−22.3	−0.03835	0.04287
24	44	4.0536	180.0000	0.0	−0.07069	0.00000
25	44	5.0186	61.1350	−113.5	0.04223	0.07661
26	44	5.0186	−61.1350	113.5	0.04223	−0.07661
27	30	4.3466	153.6074	−22.5	−0.06789	0.03369
28	30	4.3466	−153.6074	22.5	−0.06789	−0.03369

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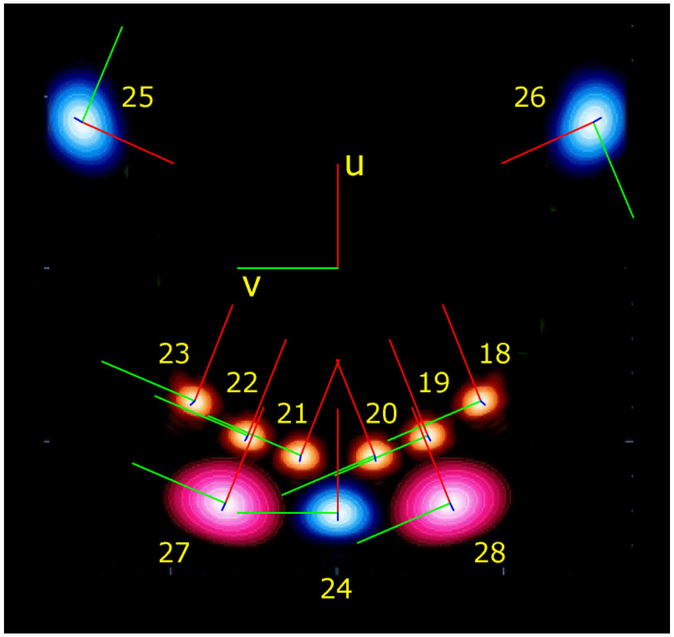

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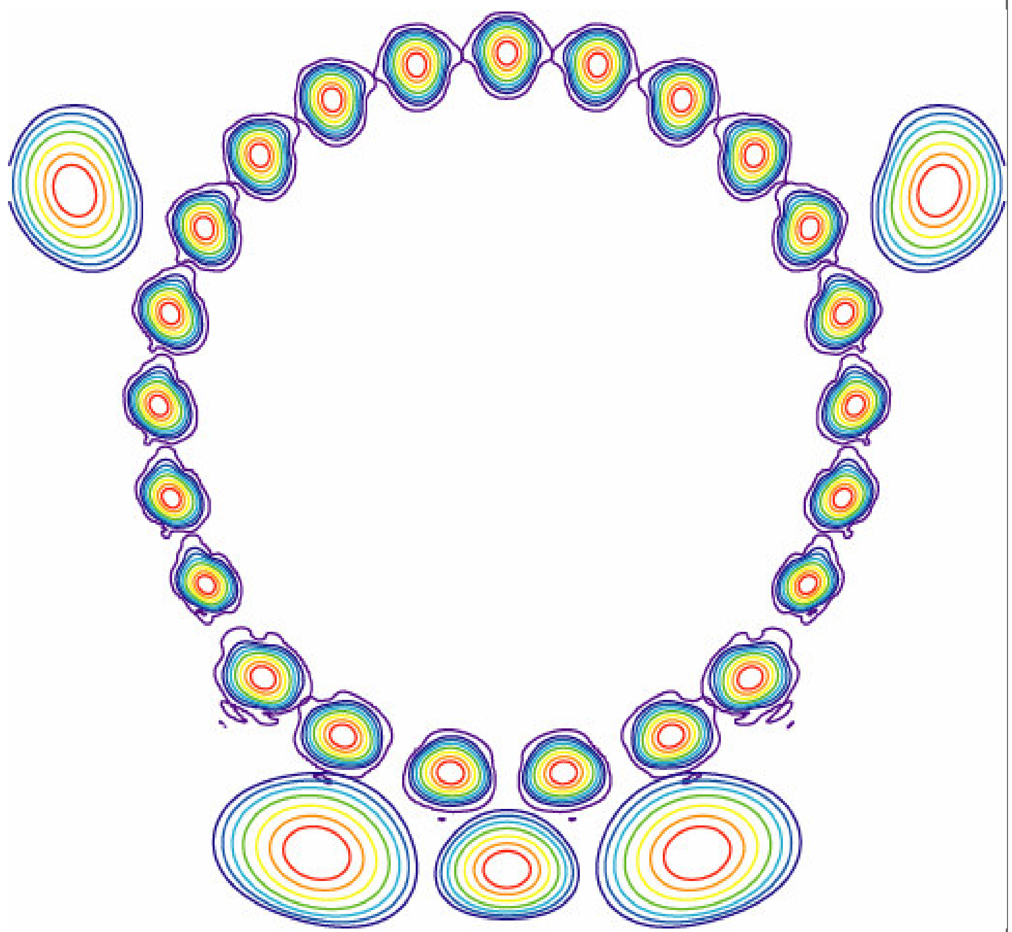

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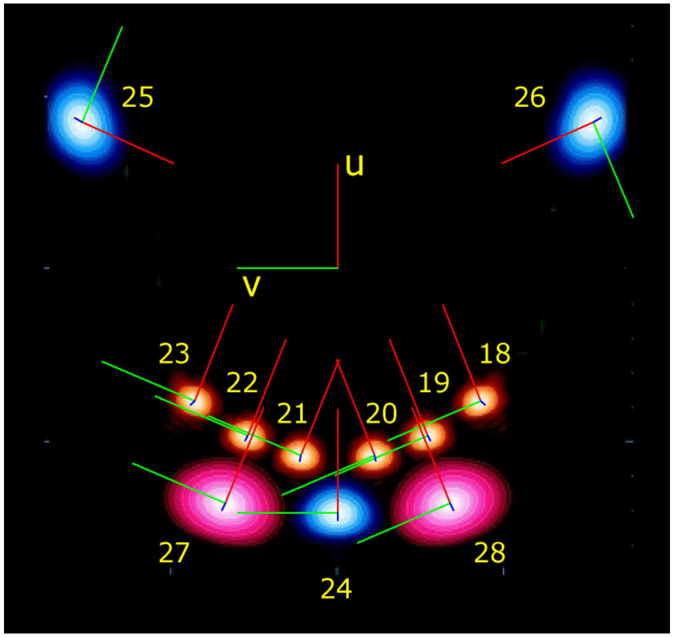

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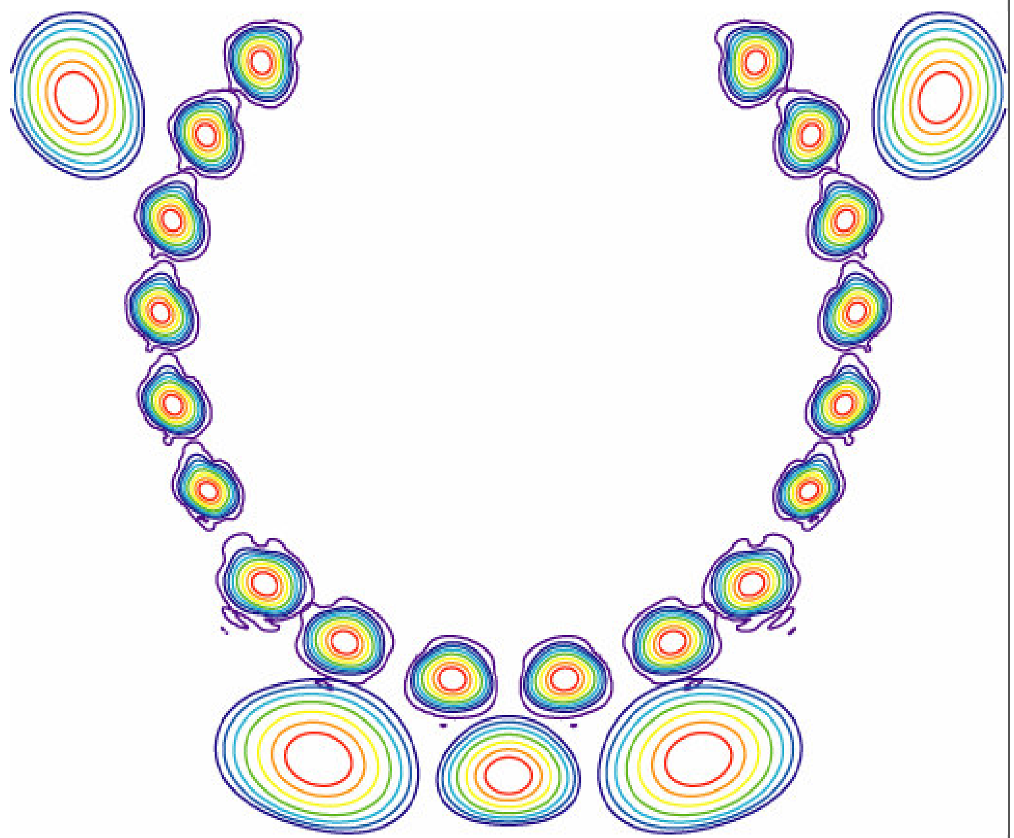

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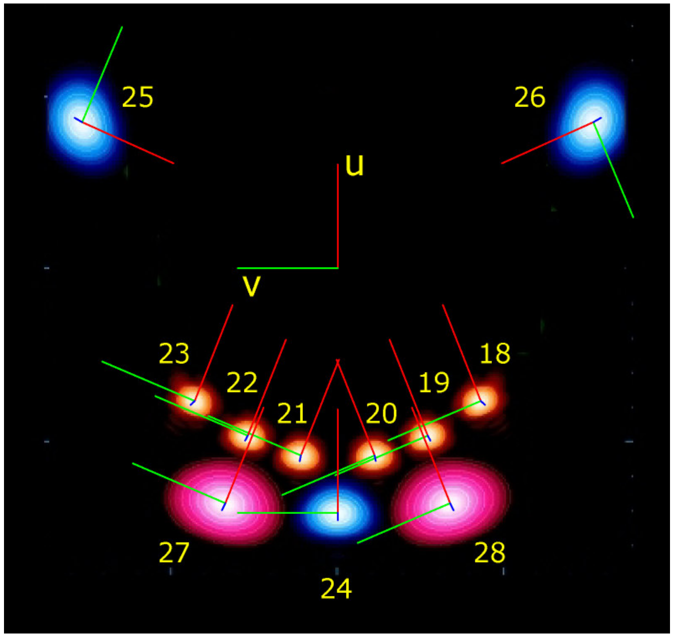

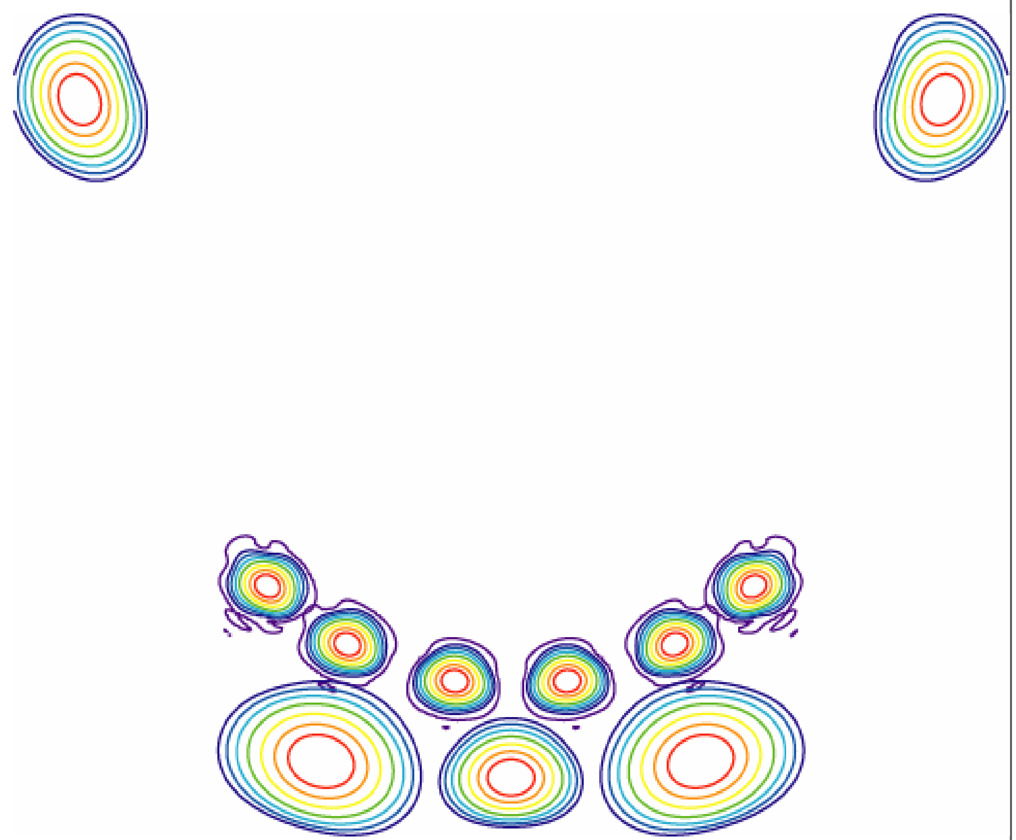

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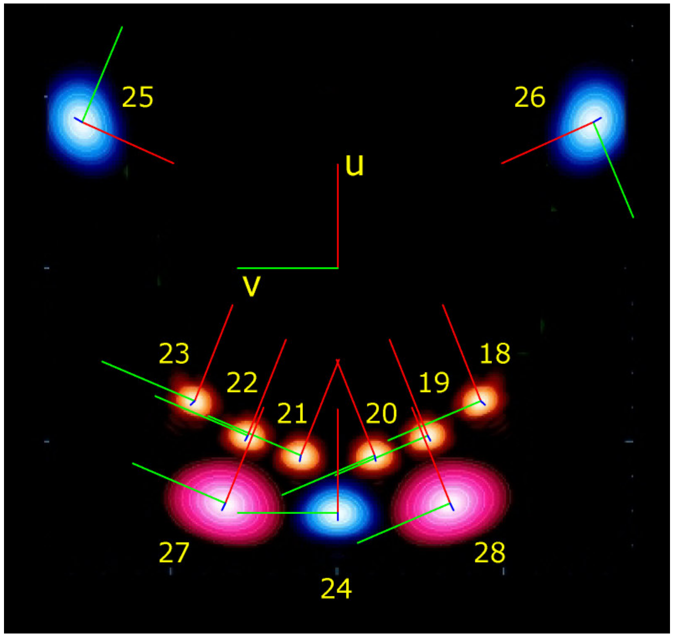

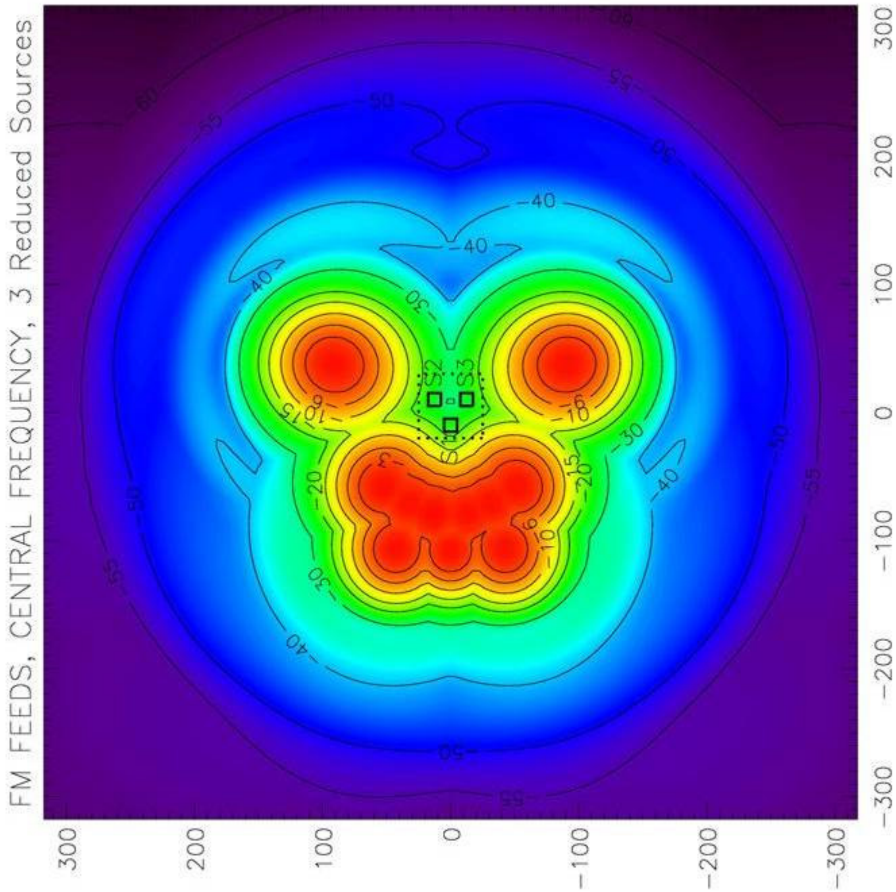

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L’Eredità di WMAP

THE ASTROPHYSICAL JOURNAL, 585:566–586, 2003 March 1

THE OPTICAL DESIGN AND CHARACTERIZATION OF THE *MICROWAVE ANISOTROPY PROBE*

L. PAGE,[1] C. JACKSON,[2] C. BARNES,[1] C. BENNETT,[3] M. HALPERN,[4] G. HINSHAW,[3] N. JAROSIK,[1] A. KOGUT,[3] M. LIMON,[1,]
S. S. MEYER,[5] D. N. SPERGEL,[6] G. S. TUCKER,[7] D. T. WILKINSON,[1] E. WOLLACK,[3] AND E. L. WRIGHT[8]
Received 2002 June 26; accepted 2002 November 12

ABSTRACT

The primary goal of the *MAP* satellite, now in orbit, is to make high-fidelity polarization-sensitive maps of the full sky in five frequency bands between 20 and 100 GHz. From these maps we will characterize the properties of the cosmic microwave background (CMB) anisotropy and Galactic and extragalactic emission on angular scales ranging from the effective beam size, less than 0°.23, to the full sky. *MAP* is a differential microwave radiometer. Two back-to-back shaped offset Gregorian telescopes feed two mirror symmetric arrays of 10 corrugated feeds. We describe the prelaunch design and characterization of the optical system, compare the optical models to the measurements, and consider multiple possible sources of systematic error.
Subject headings: cosmic microwave background — cosmology: observations — dark matter — early universe — space vehicles: instruments — telescopes

1. INTRODUCTION

The … produc… in micr… backgr… off fron… ized de… the CM… Experi… the CM… using differential or beam synthesis techniques. IAB (Piccirillo & Calisse 1993), PYTHON (Coble et al. 1999;

Radiometer (DMR) experiment on *COBE* (Smoot e… 1990). Of these, only DMR has produced a full sky map…

systematic error on any mode in the final map, *before* r…

response is quantified. To put the final design into perspective, some of the trade-offs are discussed. It is worth keeping in mind that our knowledge of the optics is one of the limiting uncertainties for *MAP*.

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 148:1–27, 2003 September

FIRST-YEAR *WILKINSON MICROWAVE ANISOTROPY PROBE* (*WMAP*)[1] OBSERVATIONS: PRELIMINARY MAPS AND BASIC RESULTS

C. L. BENNETT,[2] M. HALPERN,[3] G. HINSHAW,[2] N. JAROSIK,[4] A. KOGUT,[2] M. LIMON,[2,5] S. S. MEYER,[6] L. PAGE,[4]
D. N. SPERGEL,[7] G. S. TUCKER,[2,5,8] E. WOLLACK,[2] E. L. WRIGHT,[9] C. BARNES,[4] M. R. GREASON,[10]
R. S. HILL,[10] E. KOMATSU,[7] M. R. NOLTA,[4] N. ODEGARD,[10] H. V. PEIRIS,[7]
L. VERDE,[7] AND J. L. WEILAND[10]
Received 2003 February 11; accepted 2003 May 29

ABSTRACT

We present full-sky microwave maps in five frequency bands (23–94 GHz) from the *Wilkinson Microwave Anisotropy Probe* (*WMAP*) first-year sky survey. Calibration errors are less than 0.5%, and the low systematic error level is well specified. The cosmic microwave background (CMB) is separated from the foregrounds using multifrequency data. The sky maps are consistent with the 7° FWHM *Cosmic Background Explorer* (*COBE*) maps. We report more precise, but consistent, dipole and quadrupole values. The CMB anisotropy obeys Gaussian statistics with $-58 < f_{NL} < 134$ (95% confidence level [CL]). The $2 \le \ell \le 900$ anisotropy power spectrum is cosmic-variance–limited for $\ell < 354$, with a signal-to-noise ratio greater than 1 per mode to $\ell = 658$. The temperature-polarization cross-power spectrum reveals both acoustic features and a large-…gle correlation from reionization. The optical depth of reionization is $\tau = 0.17 \pm 0.04$, which implies a …onization epoch of $t_r = 180^{+220}_{-80}$ Myr (95% CL) after the big bang at a redshift of $z_r = 20^{+10}_{-9}$ (95% CL) for a …ge of ionization scenarios. This early reionization is incompatible with the presence of a significant warm …k matter density.

…A best-fit cosmological model to the CMB and other measures of large-scale structure works remarkably …ll with only a few parameters. The age of the best-fit universe is $t_0 = 13.7 \pm 0.2$ Gyr. Decoupling was … $= 379^{+8}_{-7}$ kyr after the big bang at a redshift of $z_{dec} = 1089 \pm 1$. The thickness of the decoupling surface …s $\Delta z_{dec} = 195 \pm 2$. The matter density of the universe is $\Omega_m h^2 = 0.135^{+0.008}_{-0.009}$, the baryon density is …$h^2 = 0.0224 \pm 0.0009$, and the total mass-energy of the universe is $\Omega_{tot} = 1.02 \pm 0.02$. It appears that there may be progressively less fluctuation power on smaller scales, from *WMAP* to fine-scale CMB measurements to galaxies and finally to the Lyα forest. This may be accounted for with a running spectral index of scalar fluctuations, fitted as $n_s = 0.93 \pm 0.03$ at wavenumber $k_0 = 0.05$ Mpc^{-1} ($\ell_{eff} \approx 700$), with a slope of $dn_s/d\ln k = -0.031^{+0.016}_{-0.018}$ in the best-fit model. (For *WMAP* data alone, $n_s = 0.99 \pm 0.04$.) This flat universe …

WMAP observes the sky convolved with the beam pattern. This is equivalent to the the spatial transform of the sky multiplied by the instrument’s “window function.” The beam patterns are measured in-flight from observations of Jupiter (Page et al. 2003a). Uncertainties in our knowledge of the beam pattern, although small, are a significant source of uncertainty for *WMAP* since they imply imperfect knowledge of the window function. A small difference between the A-side and B-side optical losses was derived based on dipole observations and corrected in the processing. Far

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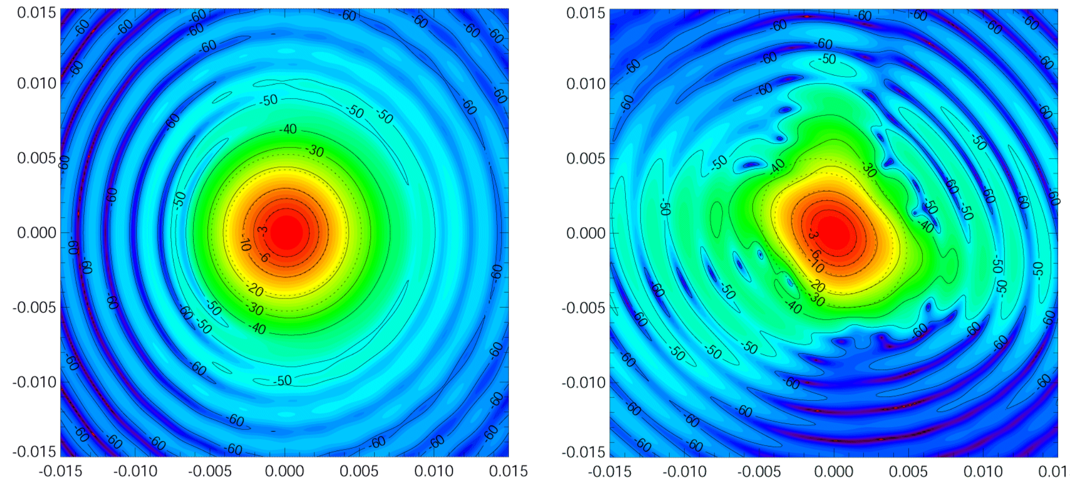
Aberrazioni “ottiche”



- **Degrado della risoluzione angolare**
- **Statistica falsata**
- **Degrado della polarizzazione**

Aberrazioni “non ottiche”

UNIVERSITA' DEGLI STUDI DI PADOVA

DIPARTIMENTO DI ASTRONOMIA

DOTTORATO DI RICERCA IN ASTRONOMIA

CICLO XVII

PLANCK Low Frequency Instrument:

optical performances and systematic effects

Coordinatore : Ch.mo Prof. Giampaolo Piotto

Supervisori : Ch.mo Prof. Giuseppe Tormen

Dott. Gianfranco De Zotti

Dott. Nazzareno Mandolesi

Dott. Fabrizio Villa

Dottorando: Maura Sandri

DATA CONSEGNA TESI

31 dicembre 2004

for the missing 100 GHz feed horns,

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Aberrazioni “non ottiche”

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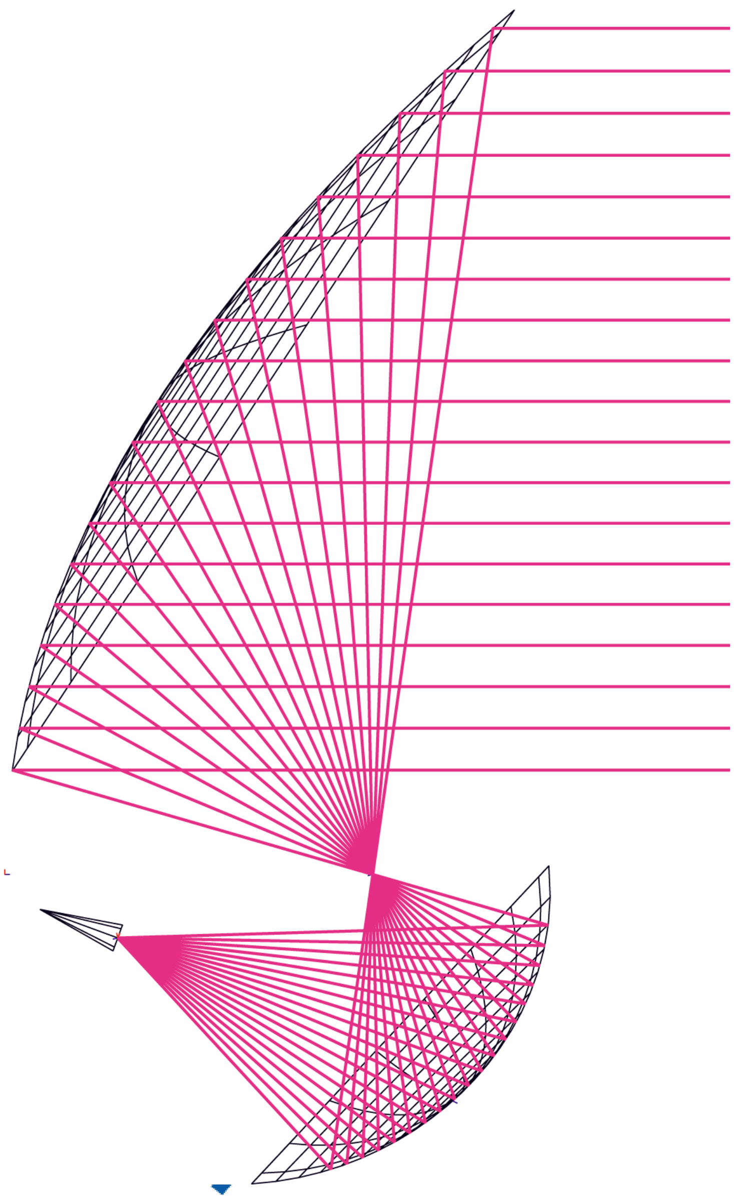
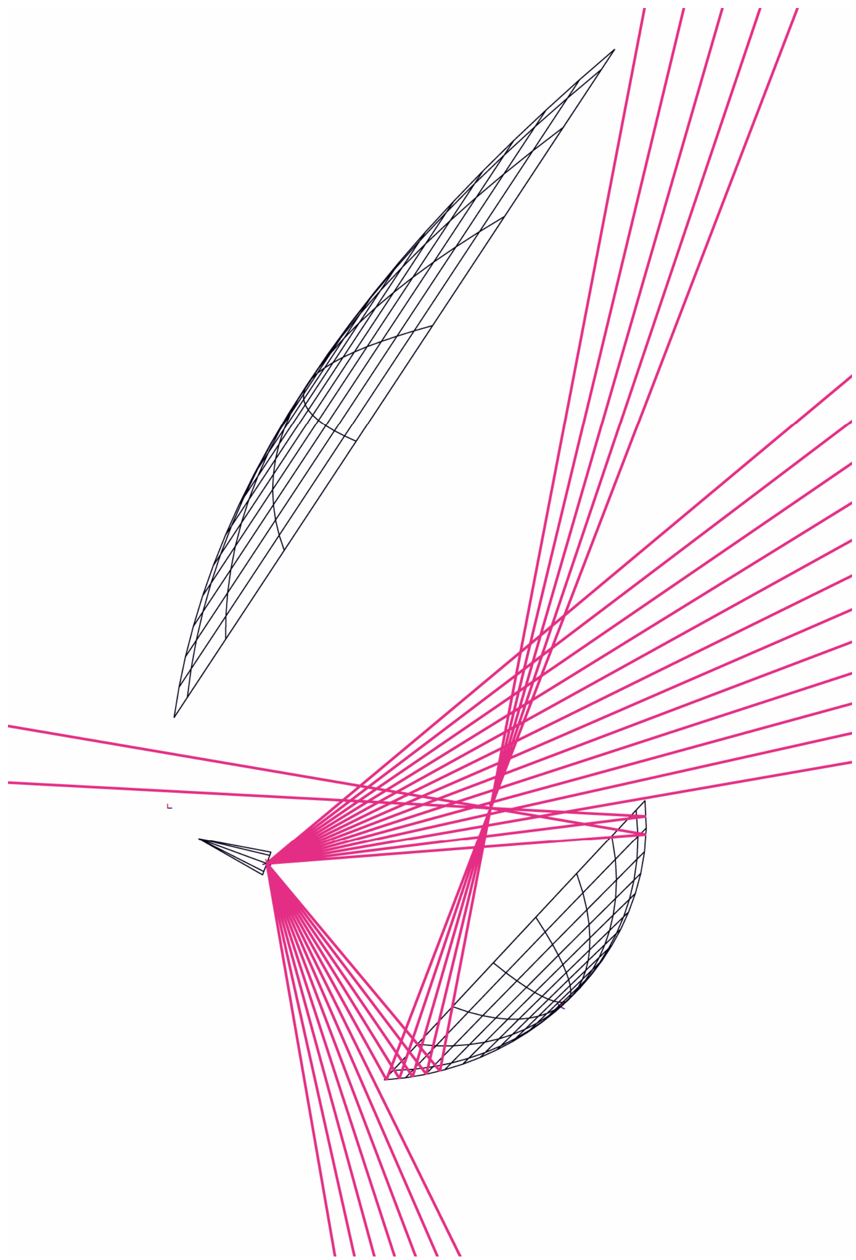
Off – Axis Configuration





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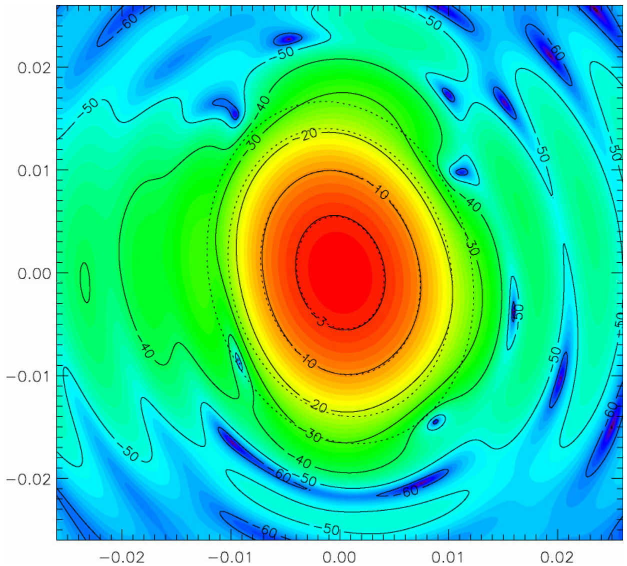
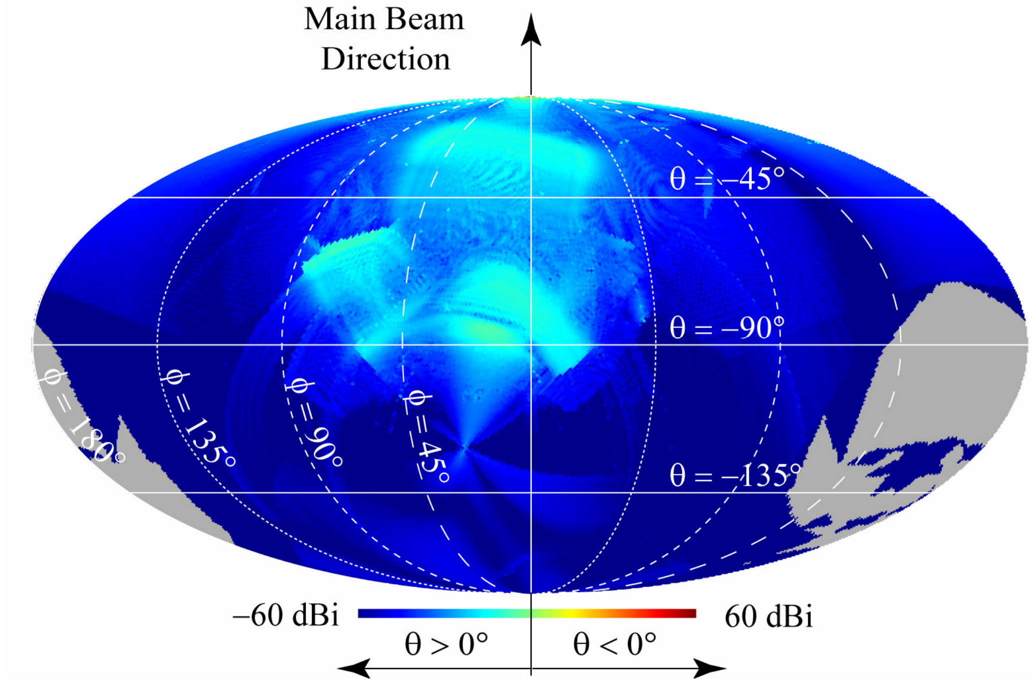
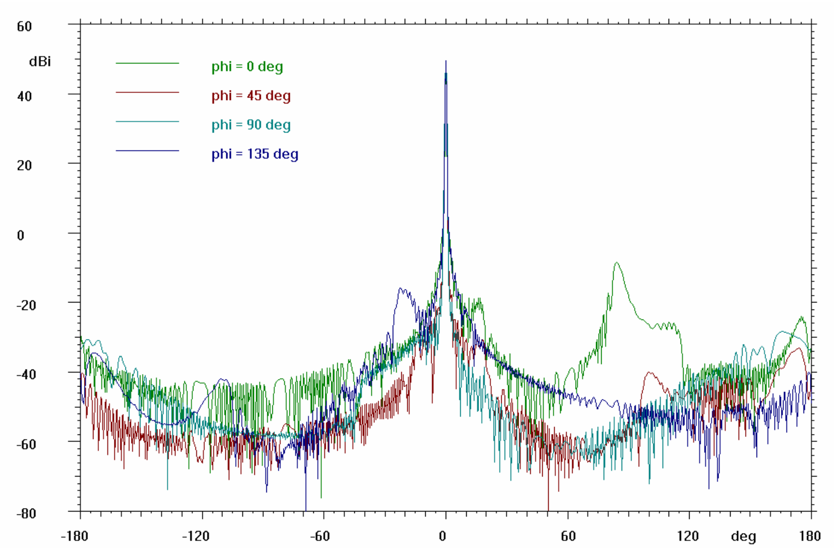
Full Sky Radiation Pattern







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Timeline

- (1992) COBRAS
- (1996) Phase A Telescope
  - 1.3 meter aperture
  - Dragone – Mizuguchi (minimizzazione della polarizzazione al centro del piano focale)
- (1998) Carrier Telescope
  - Phase A telescope + Extension of the primary mirror
  - 1.5 meter aperture
- (1999) Architect Study
  - Ottimizzazione del Telescopio

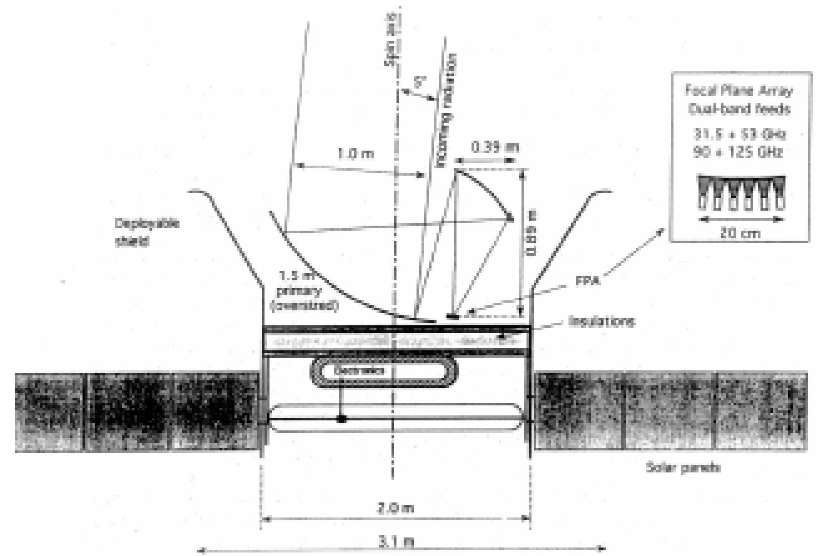
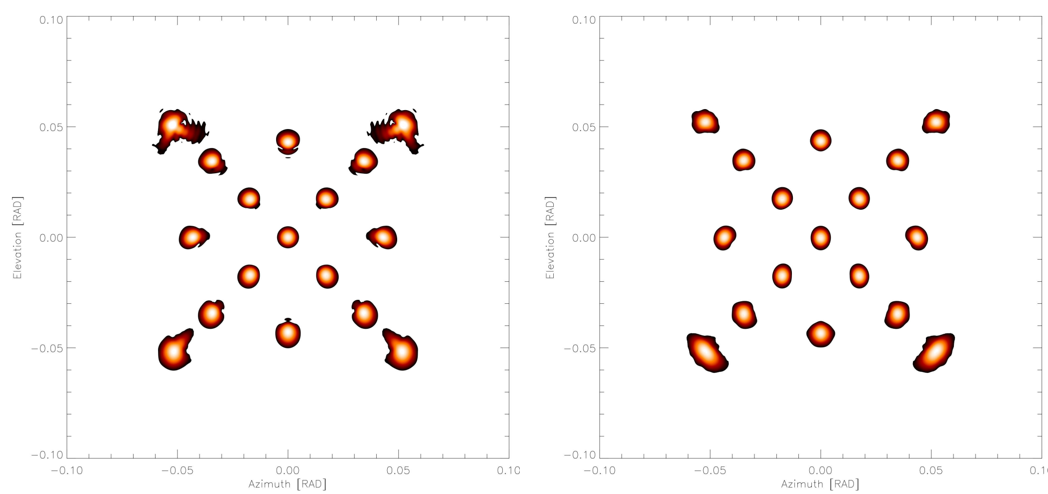


Figure 6 - Schematic COBRAS payload concept. The Gregorian optical system assumed in our preliminary simulation study is repesented in scale. The pointing offset from the spin axis (here assumed to be 5°) will be optimised during the assessment study together with the details of the scan strategy. The ground screens will flare out at an appropriate angle to optimise sidelobe pickup and cooling efficiency. The inset shows a schematic of the focal plane array of dual-band feeds. Placing their apertures on a spherical surface (~ 0.7 m radius) optimises beam symmetry.



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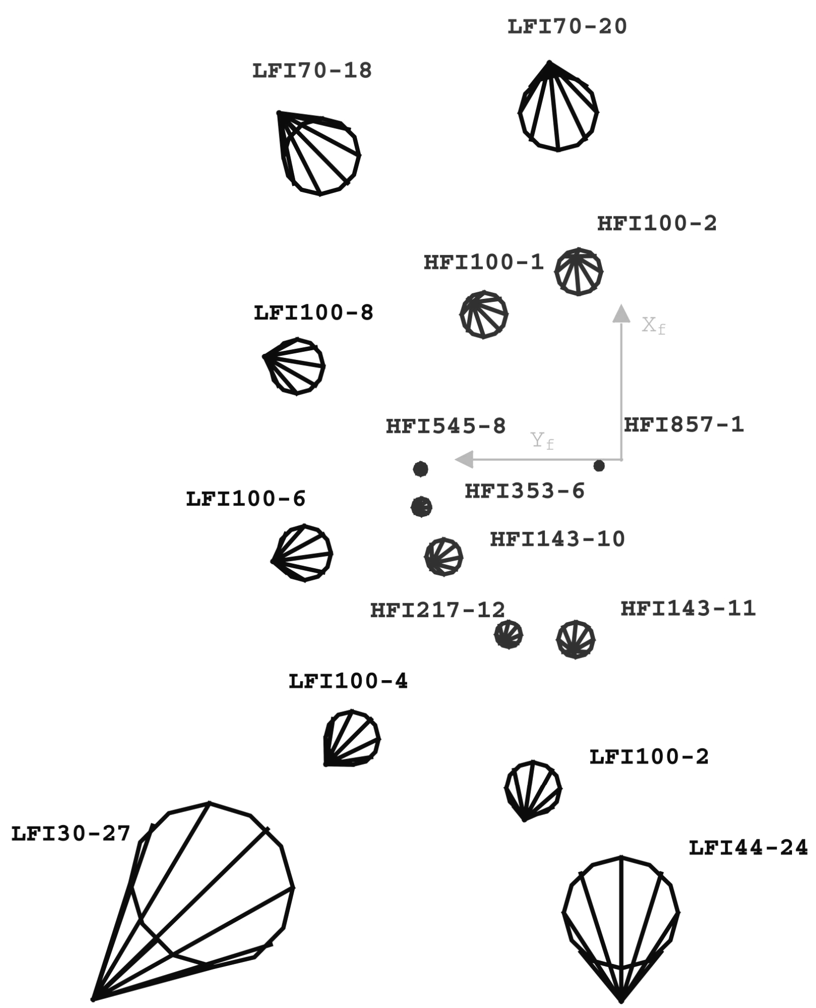
OTTIMIZZAZIONE (1999 – 2000)



- **CODE V** package and **GRASP8** software (partially **ASAP**)
- symmetric FPU
- 8 HFI Feeds
  - (1, 1, 2, 4)
- 8 LFI Feeds
  - (2, 2, 1, 1, 1, 1)
- Minimisation of the WFE at the aperture with gaussian illumination

OUTPUT

"*Case1*" Design

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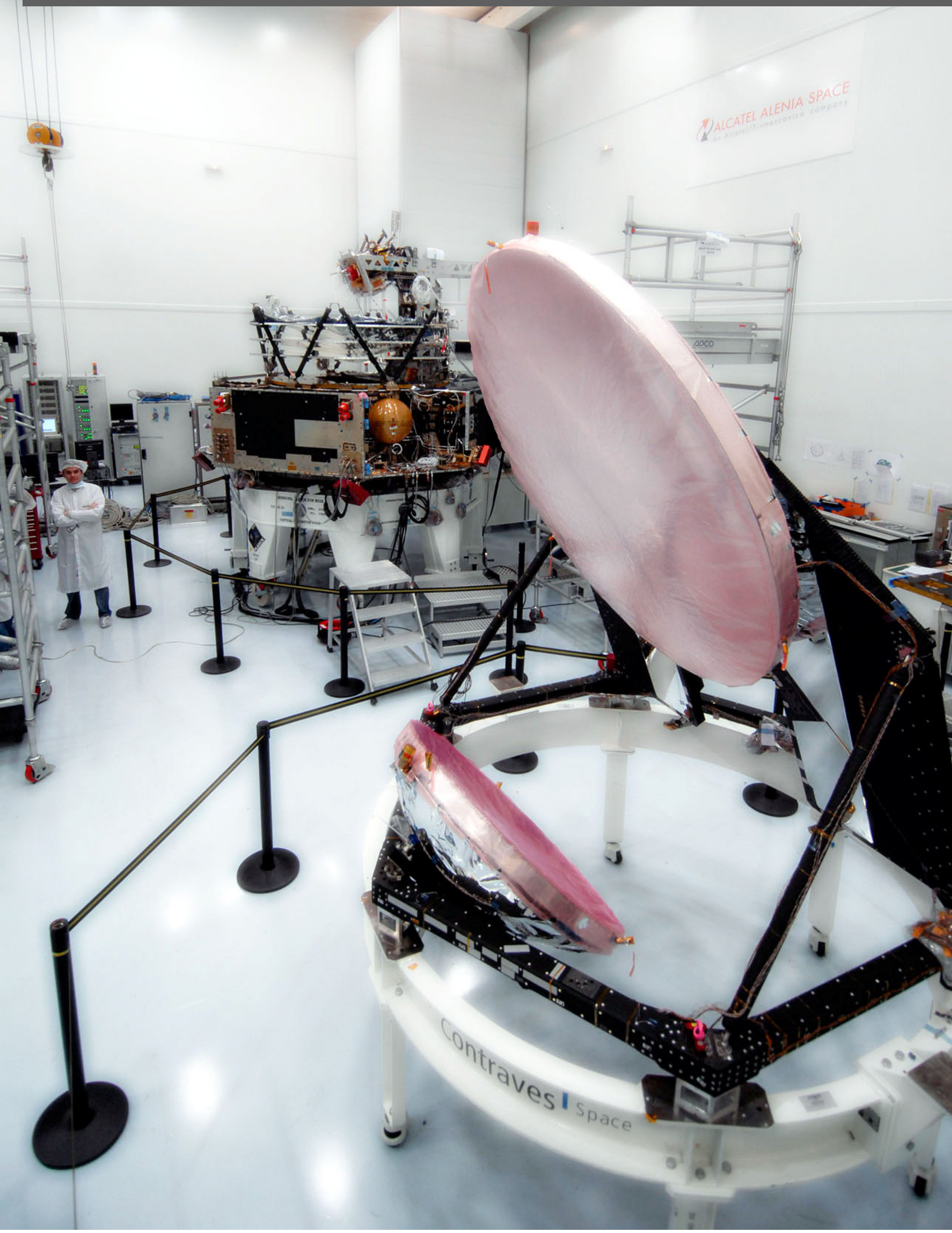
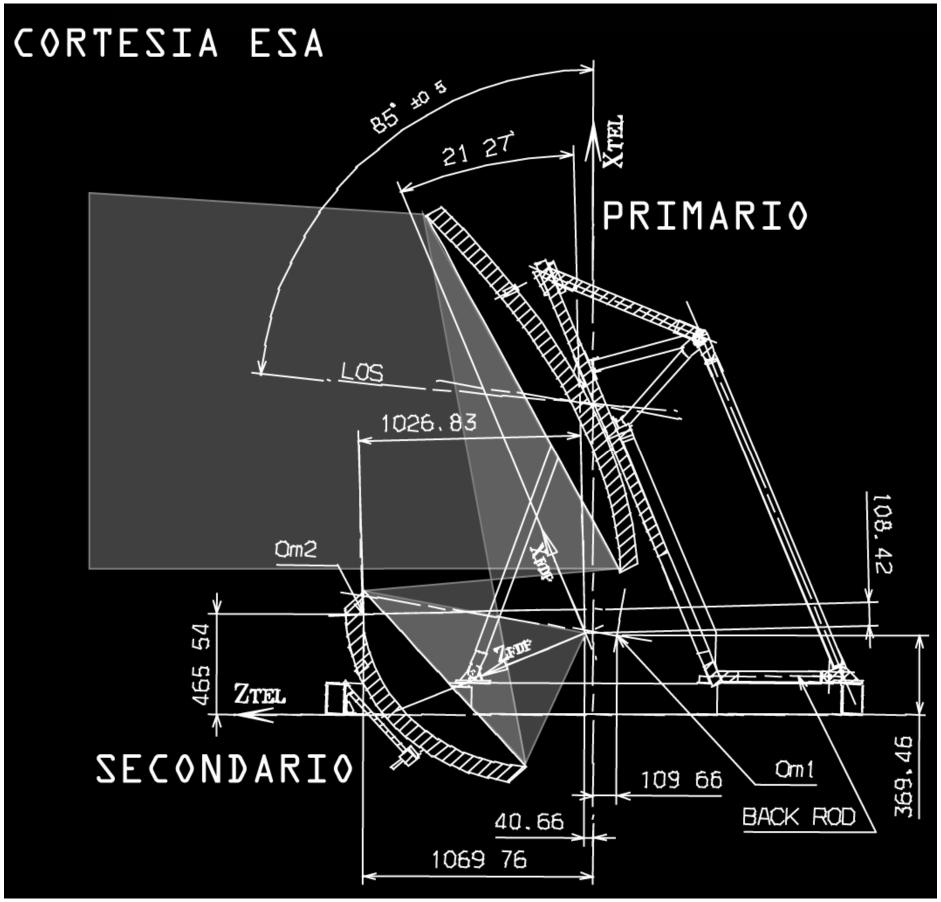
Il telescopio di Planck



- **Configurazione**
  - Gregoriano aplanatico ottimizzato
- **Frequenza**
  - 25 – 1000 GHz
- **Temperatura**
  - 40 K and 65 K
- **Massa totale**
  - < 120 Kg
- **Lifetime**
  - 6 years on the ground + 2 years in space

Caratteristiche Geometriche

- **Primary Mirror:**
  - Ellipsoidal , ~ 1.9m x 1.5m
- **Secondary Mirror:**
  - Ellipsoidal, ~1m x 1m
- **Overall Focal ratio:**
  - F# = 1.1
- **Field of View:**
  - ± 5°x5°



Telescope Models

- **Radio Frequency Demonstration Model (RFDM)**
  - Archeops experiment telescope
- **Qualification Model (QM)**
  - Qualifica ottica e meccanica (simile al FM)
- **Radio Frequency Qualification Model (RFQM)**
  - Qualifica a Radiofrequenza (misure di risposta)
- **Flight Model (FM)**

Timeline

- **(2000–2005) Sviluppo hardware**
- **(2006) Videogrammetria su FM**
- **(2006) Misura su RFQM (pol1)**
  - February / March 2006 (30 – 70 – 320 GHz)
  - June 2006 (100 GHz)
- **(2007) Misura su RFQM (pol2)**
  - October / November 2006 (30 – 70 – 320 GHz)
  - January 2007 (100 GHz)
- **(2007) ri-allineamento del telescopio**
  - Riallineamento del riflettore secondario
- **(2007) RF end2end test @320GHz su RFQM**
  - Check dell'allineamento tramite test con RCS
- **(2008) RF end2end test on FM**
  - Prossima settimana

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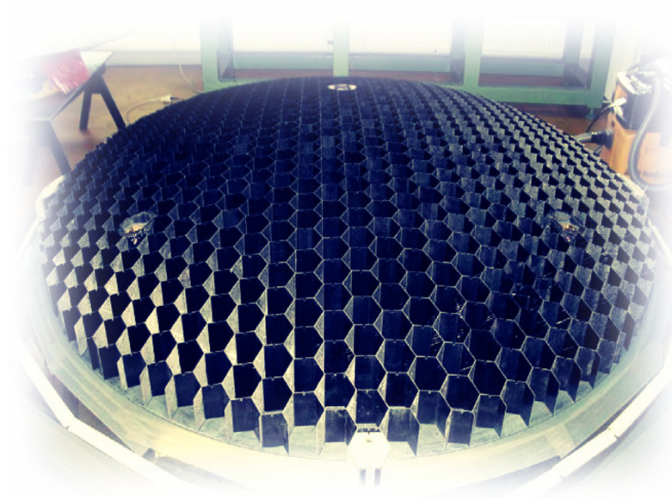
La tecnologia di fabbricazione

- **Core**
  - Celle esagonali di fibra di carbonio



- **Reflecting coating**
  - Adesivo: 5nm di NiCr
  - Riflettivo: 550nm di Al
  - Protettivo: 30nm PLASIL

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Caratteristiche dei riflettori

Earth Observation, Navigation & Science

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Measurement Results of the Planck Reflectors

	Residual Surface Errors [µm rms]					
	Spec	Goal	SR QM	SR FM	PR QM	PR FM
Ring 1	7.5	5	2.5	3.5	7.5	4.7
Ring 2	12	8	3.7	3.9	9.8	5.5
Ring 3	20	13	5.9	6.2	11.1	6.8
Ring 4	33	22	6.0	5.7	18.8	11.8
Ring 5	50	33	14.8	10.9	23.0	21.6
total	---	---	9.7	7.8	18.0	14.8

	QM	FM
Primary Reflector	27.90 kg	27.84 kg
Secondary Reflector	13.58 kg	13.54 kg

Optical Verification FM cryo tests

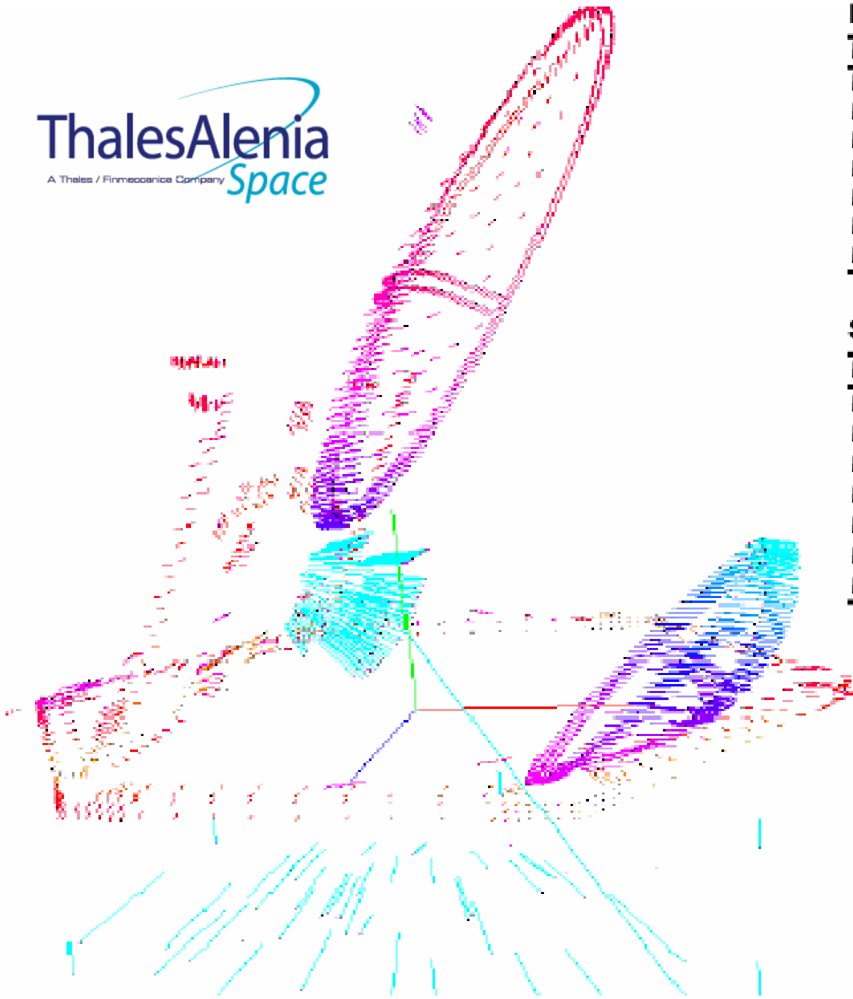
Telescope FM videogrammetry test sequence

- Mvt01: ambient temperature and pressure
- Mvt02: ambient temperature and vacuum
- Mvt04: 200 Kelvin (transient)
- Mvt05: 140 Kelvin (transient)
- Mvt06: 110 Kelvin (transient)
- Mvt07: 95 – 100 Kelvin (steady state)
- Mvt08: 110 Kelvin (transient)
- Mvt09: 140 Kelvin (transient)
- Mvt10: 200 Kelvin (transient)
- Mvt11: ambient temperature and vacuum
- Mvt12: ambient temperature and pressure

Optical Verification FM cryo tests

FM Cryo videogrammetry test results

ThalesAlenia
A Thales / Finmeccanica Company Space



PRIMARY REFLECTOR

Mesure	Xm (mm)	Ym (mm)	Zm (mm)	Rx m (dg)	Ry m (dg)
Mbvt 03	370,083	-0,355	-111,282	0,000	8,768
Mbvt 08	370,191	-0,188	-111,415	-0,002	8,759
Mvt 01	370,293	-0,237	-111,421	0,002	8,758
Mvt 02	370,154	-0,206	-111,477	0,003	8,757
Mvt 07	368,334	0,028	-112,192	0,006	8,765
Mvt 11	370,221	-0,217	-111,474	0,002	8,755
Mvt 12	370,327	-0,226	-111,427	0,001	8,754

SECONDARY REFLECTOR

Mesure	Xm (mm)	Ym (mm)	Zm (mm)	Rx m (dg)	Ry m (dg)
Mbvt 03	464,810	-0,476	1066,053	0,055	-1,390
Mbvt 08	464,609	-0,340	1066,143	0,050	-1,412
Mvt 01	464,409	-0,360	1066,131	0,046	-1,427
Mvt 02	464,206	-0,363	1066,219	0,046	-1,437
Mvt 07	463,453	-0,226	1067,127	0,031	-1,415
Mvt 11	464,260	-0,374	1066,215	0,046	-1,433
Mvt 12	464,664	-0,373	1066,138	0,047	-1,405

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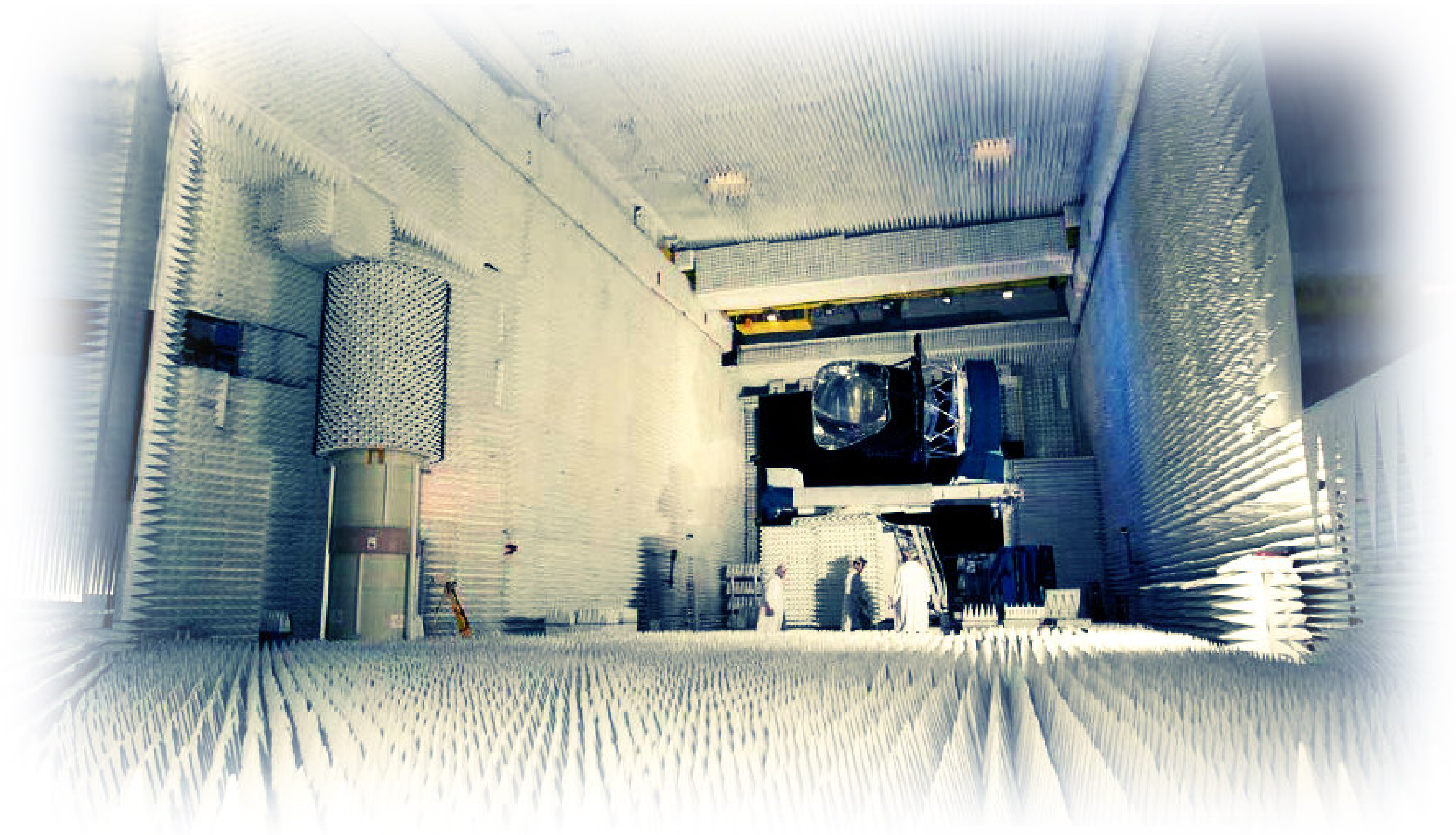
Compact Antenna Test Range



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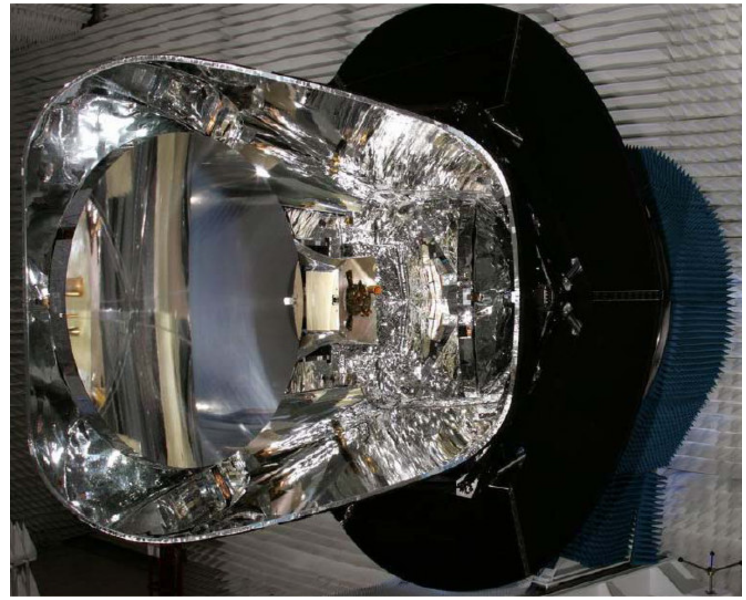
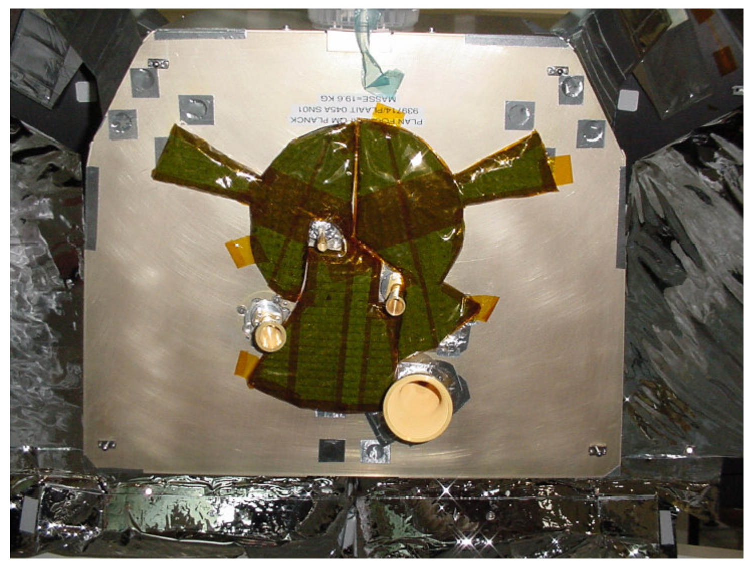
RFMQ Model

- QM reflectors
- QM baffle
- QM 3rd V-groove
- QM cryostructure
- Test FPU
- 1 x 30 GHz feed horn
- 1 x 70 GHz feed horn
- 1 x 100 GHz feed horn
- 1 x 320 GHz feed horn
- mm-wave instrumentation





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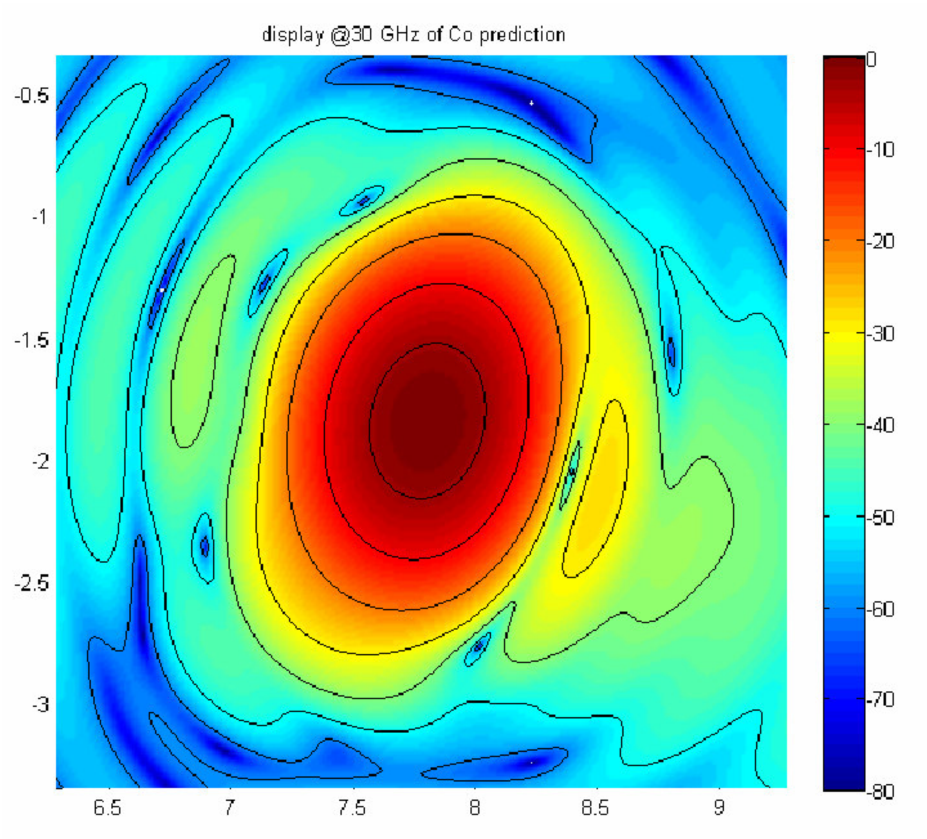
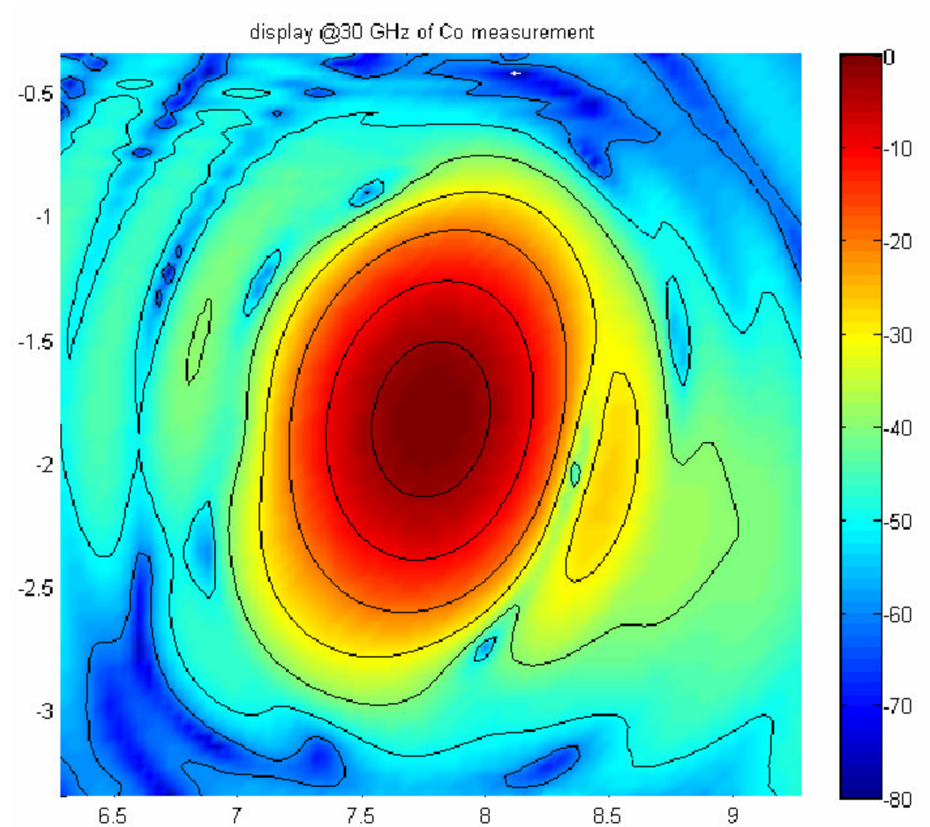
IL CONFRONTO

PREDICTION



MEASUREMENT



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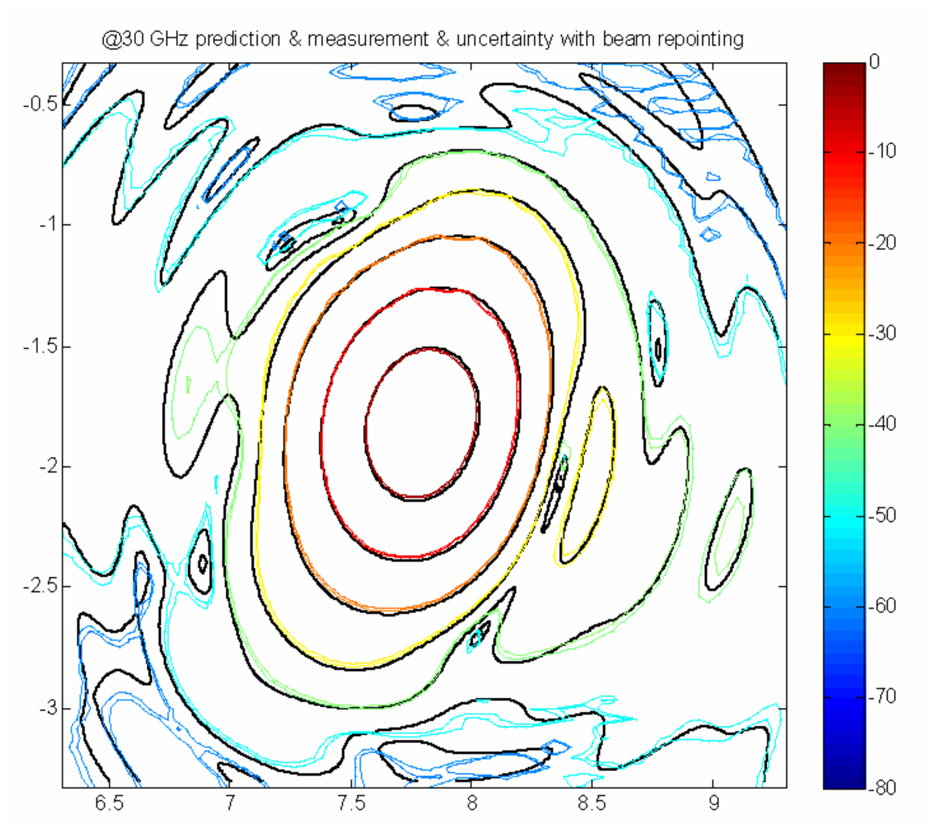
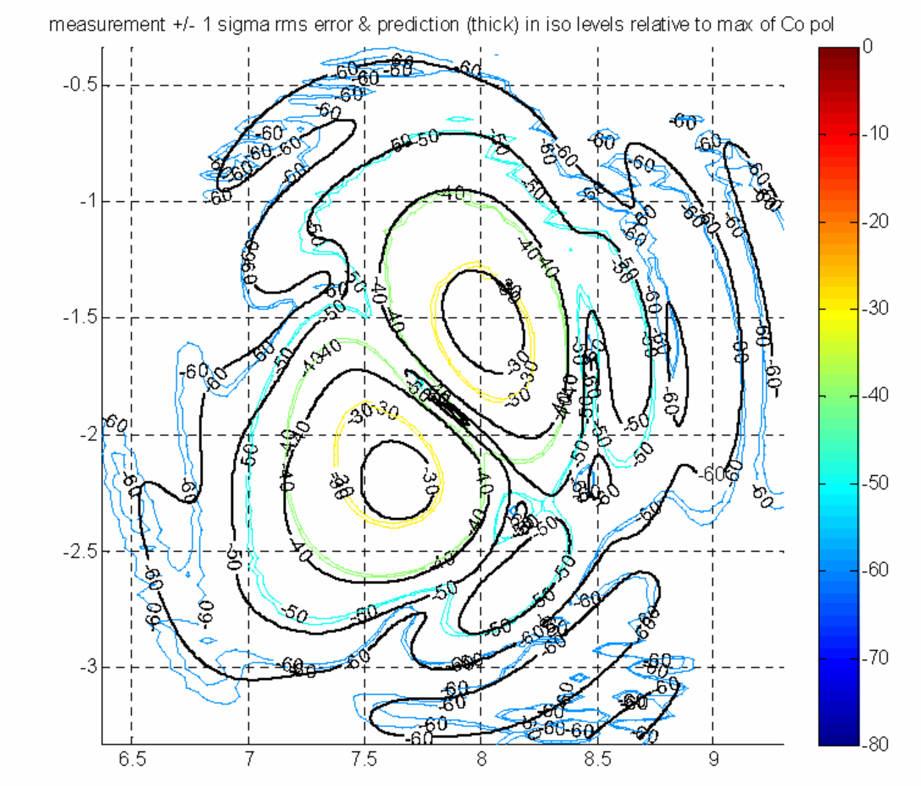
30 GHz slot3 pol2 MAIN BEAM





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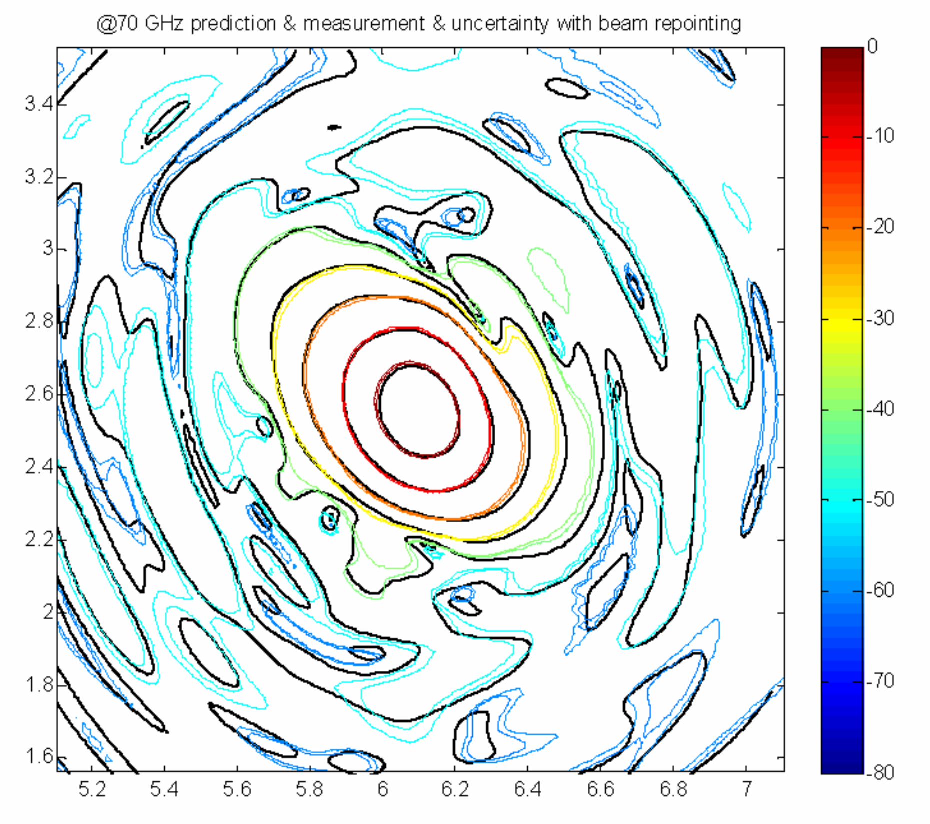
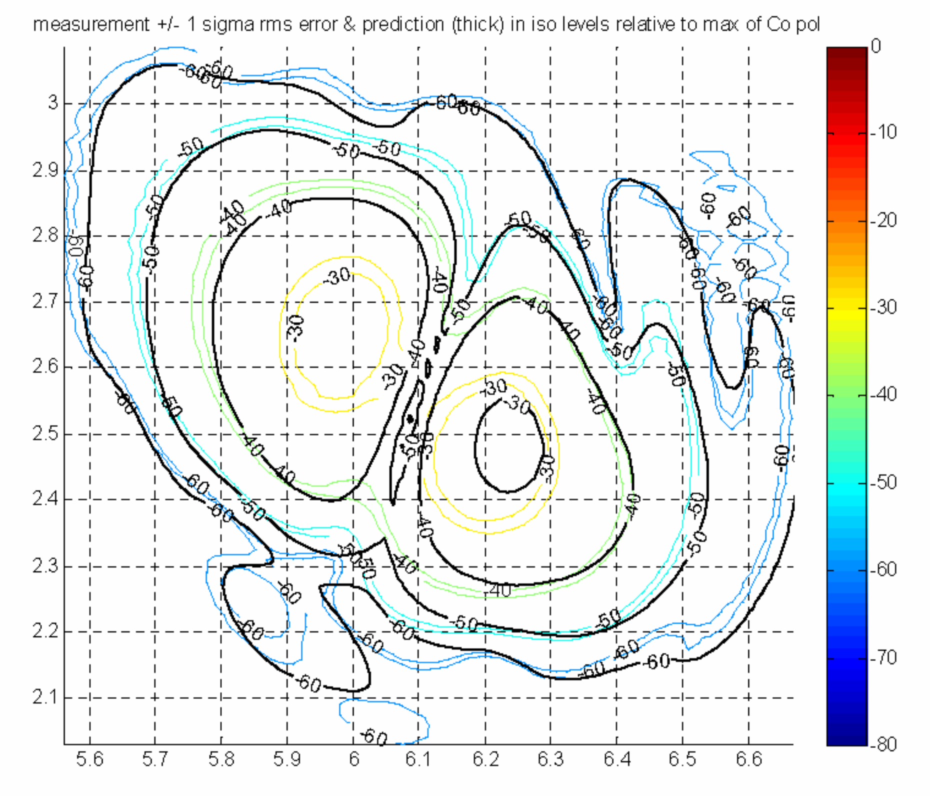
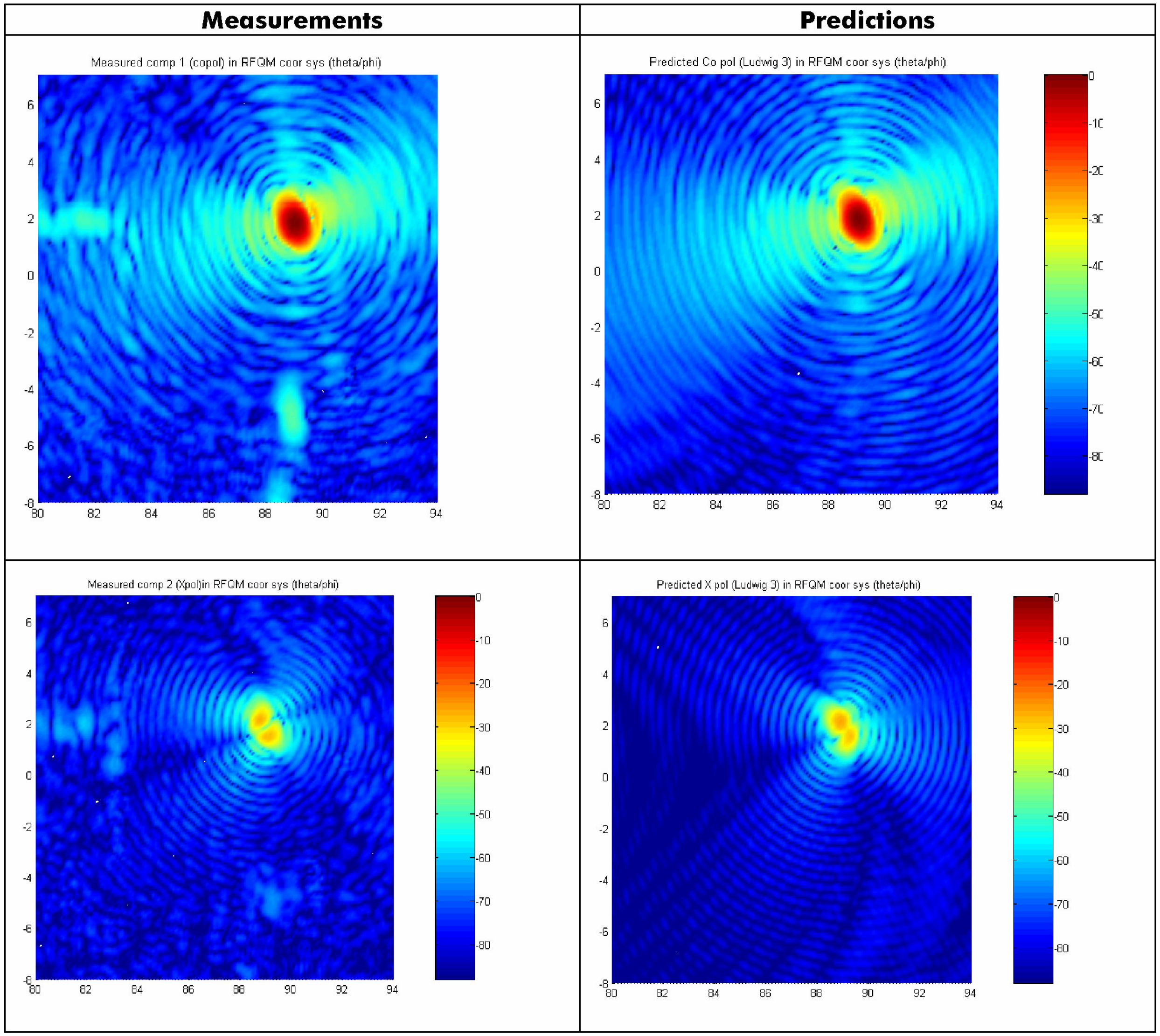
70 GHz slot3 pol2 MAIN BEAM





Inner intermediate region @ 30 GHz



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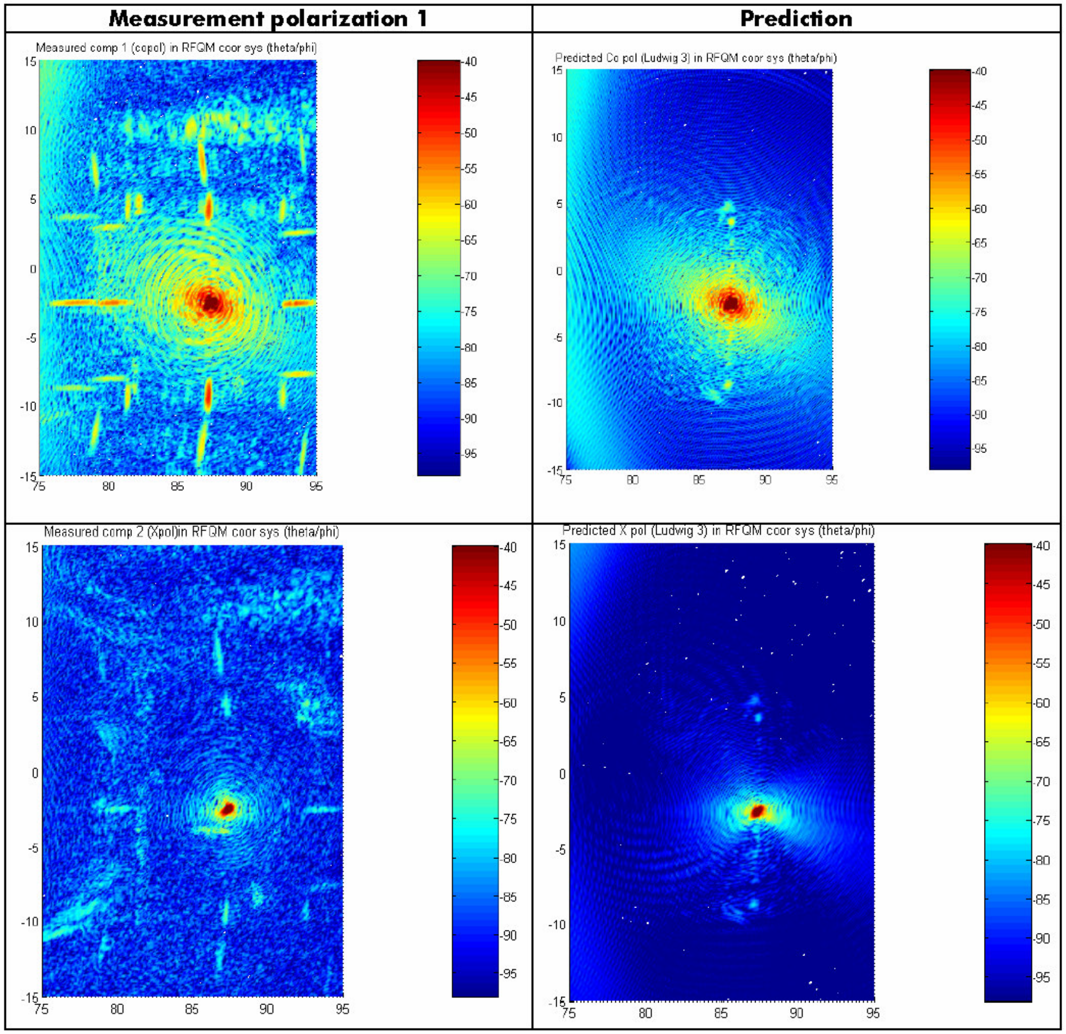
Inner intermediate region @ 70 GHz



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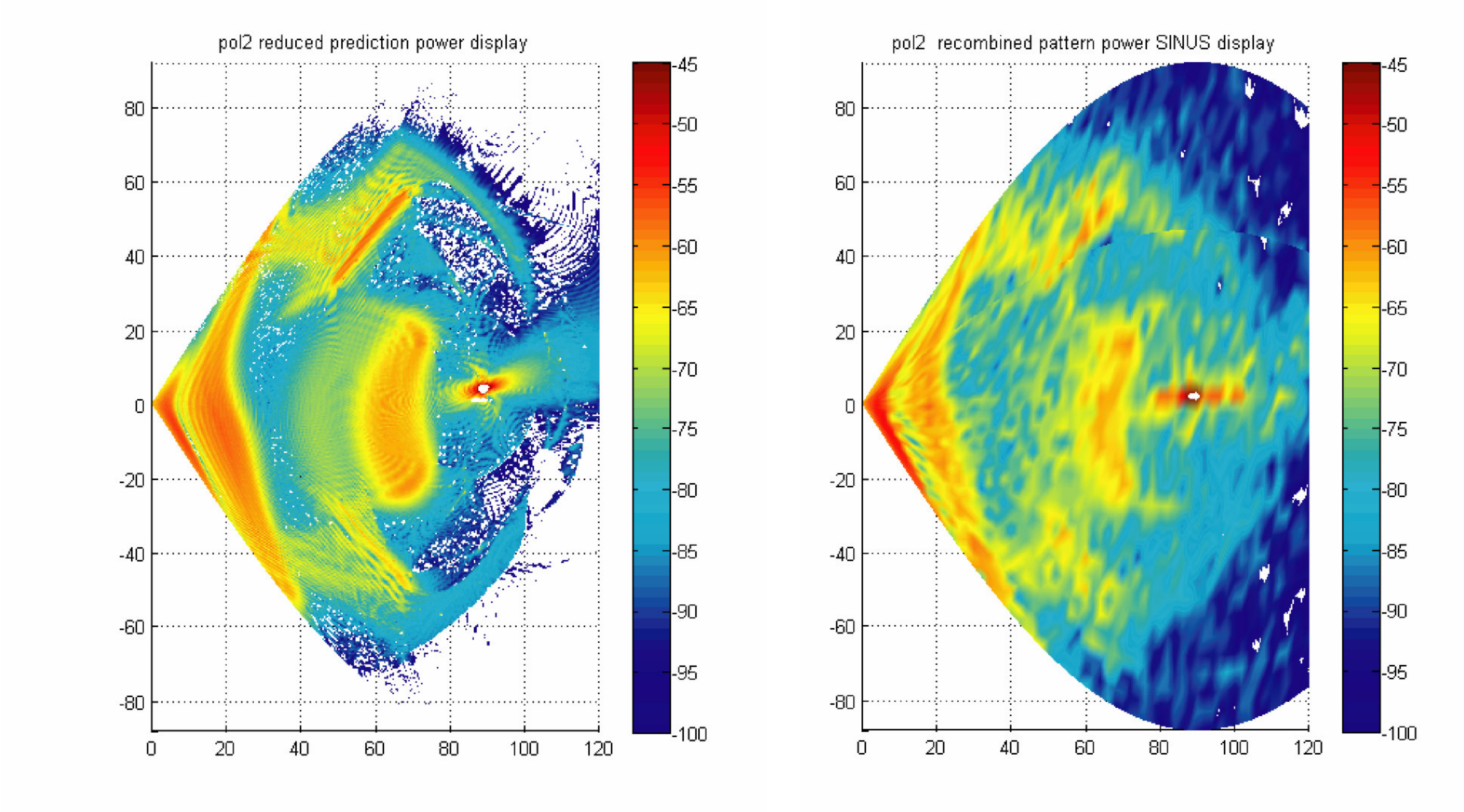
30 GHz spillover area



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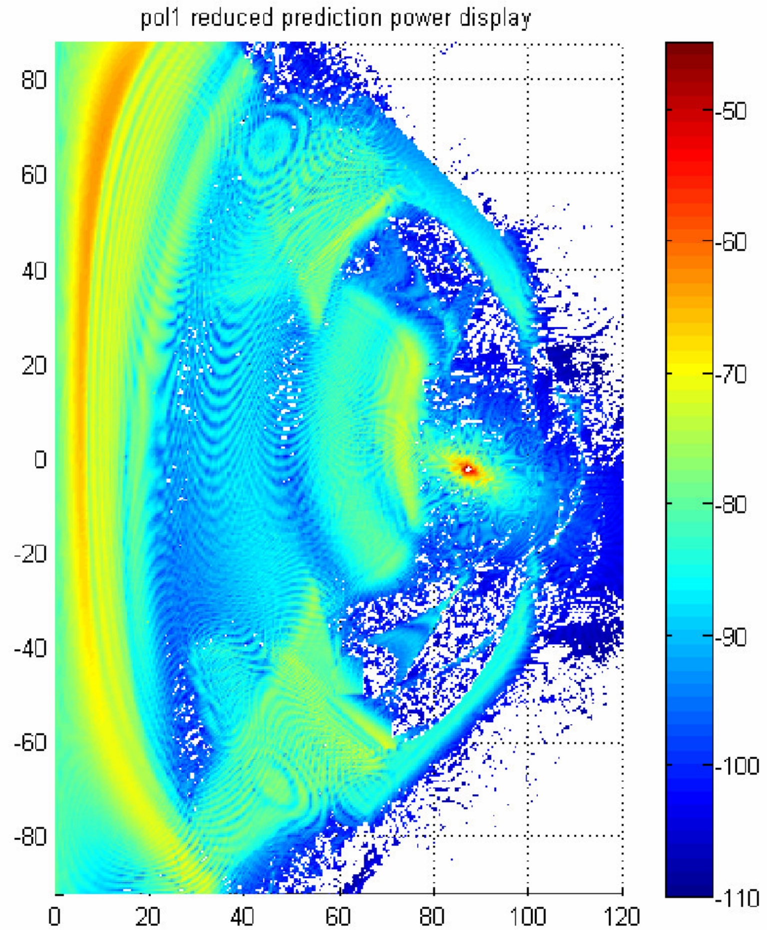
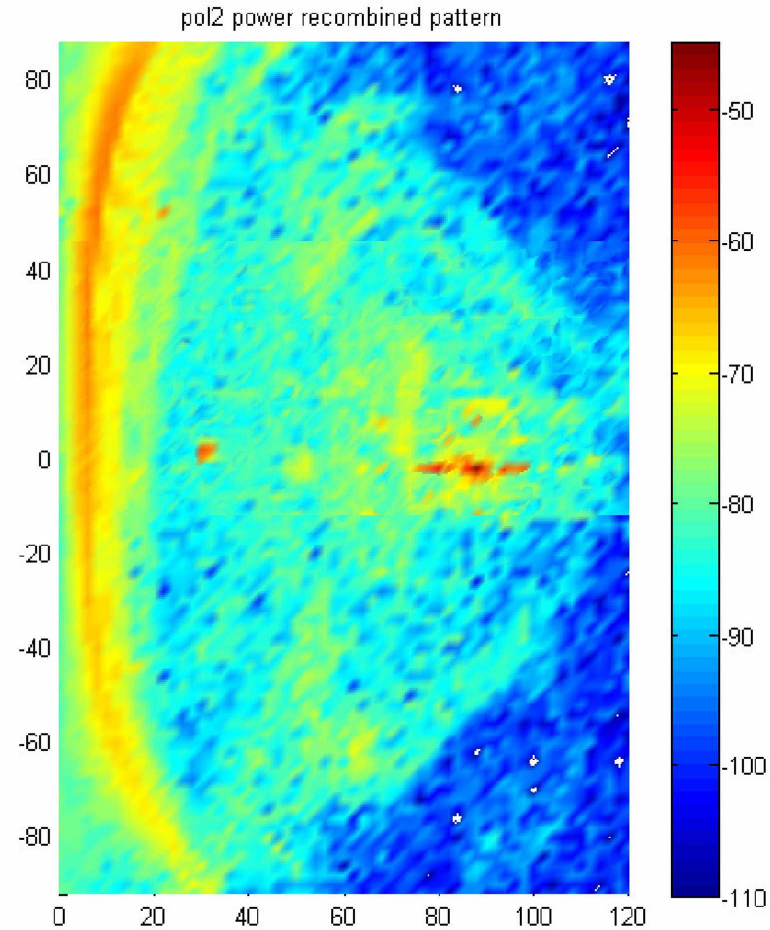
70 GHz spillover area





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Cosa Conosciamo del Telescopio

- **Charatteristiche Geometriche**
  - Videogrammetria a T ambiente e a freddo
  - Allineeamento 'ricavato' ma non misurato
- **Misure a Radio Frequenza (RFQM)**
  - A temperatura ambiente
  - Differente (ma simile) telescopio e FPU con pochi horn
- **Simulazioni Elettromagnetiche (LFI)**
  - Risposta di tutti i canali a tutto cielo
  - Telescopio con specchi ideali e perfettamente allineato

Il Telescopio di Planck e LFI

Table 4.5: Main beam characteristics, for both polarization channels: U_{peak} and V_{peak} represent the power peak location of the main beam computed in the UV– spherical polar grid defined with respect to the coordinate system reported in Tab. 4.2; the full width half maximum (FWHM), the ellipticity (e), the rotation angle of the polarisation ellipse (τ), the main beam directivity ($\mathcal{D}$), the cross polar discrimination factor (XPD), the main beam depolarization parameter (d), and the spillover ($\mathcal{S}$) are reported.

BEAM	U_{peak}	V_{peak}	FWHM (arcmin)	e	τ (°)	$\mathcal{D}$ (dBi)	XPD (dB)	d (%)	$\mathcal{S}$ (%)
18 X	0.00000	−0.00001	13.22	1.27	−0.1	58.80	28.01	0.38	0.55
Y	0.00000	−0.00001	13.25	1.23	−89.8	58.83	28.54	0.40	0.50
19 X	−0.00001	0.00000	13.13	1.26	0.0	59.02	29.73	0.26	0.64
Y	−0.00001	−0.00001	13.03	1.24	−90.0	59.06	30.21	0.28	0.58
20 X	0.00000	−0.00001	12.91	1.27	0.0	59.17	31.20	0.21	0.73
Y	−0.00001	−0.00001	12.82	1.25	89.9	59.22	30.99	0.23	0.69
21 X	0.00000	0.00001	12.91	1.27	0.0	59.17	31.20	0.21	0.73
Y	−0.00001	0.00001	12.82	1.25	−89.9	59.22	30.99	0.23	0.69
22 X	−0.00001	0.00001	13.13	1.26	0.0	59.02	29.73	0.26	0.64
Y	−0.00001	0.00002	12.94	1.22	90.0	59.06	30.21	0.28	0.58
23 X	0.00000	0.00001	13.22	1.27	0.1	58.80	28.01	0.38	0.55
Y	0.00000	0.00001	13.25	1.23	89.8	58.83	28.54	0.40	0.50
24 X	0.00002	0.00000	22.99	1.31	0.0	54.14	29.98	0.31	0.14
Y	0.00001	0.00000	23.09	1.38	90.0	54.09	29.97	0.29	0.16
25 X	0.00011	−0.00015	29.74	1.22	0.5	51.71	24.90	0.99	0.16
Y	0.00012	−0.00009	28.51	1.25	89.7	51.97	25.32	0.96	0.16
26 X	0.00011	0.00015	29.74	1.22	−0.5	51.71	24.90	0.99	0.16
Y	0.00012	0.00009	28.51	1.25	−89.7	51.97	25.32	0.96	0.16
27 X	0.00004	−0.00001	33.34	1.37	0.2	50.97	28.21	0.44	0.58
Y	0.00002	−0.00001	33.23	1.41	89.9	51.00	28.31	0.41	0.58
28 X	0.00004	0.00001	33.34	1.37	−0.2	50.97	28.21	0.44	0.58
Y	0.00002	0.00001	33.23	1.41	−89.9	51.00	28.31	0.41	0.58

Table 4.3: Half width at −3, −10, −20 dB for both polarizations.

BEAM	POL	HW at −3 dB (min, °)	HW at −3 dB (max, °)	HW at −10 dB (min, °)	HW at −10 dB (max, °)	HW at −20 dB (min, °)	HW at −20 dB (max, °)
18 and 23	X	0.0969	0.1235	0.1702	0.2212	0.2247	0.3147
	Y	0.0989	0.1219	0.1725	0.2176	0.2273	0.3096
19 and 22	X	0.0969	0.1219	0.1667	0.2167	0.2229	0.3013
	Y	0.0969	0.1203	0.1690	0.2131	0.2247	0.2967
20 and 21	X	0.0949	0.1203	0.1643	0.2140	0.2264	0.2981
	Y	0.0949	0.1187	0.1655	0.2112	0.2256	0.2941
24	X	0.1655	0.2176	0.2880	0.3927	0.3815	0.5539
	Y	0.1619	0.2229	0.2839	0.4025	0.3779	0.5654
25 and 26	X	0.2229	0.2727	0.4001	0.5260	0.5370	0.7923
	Y	0.2112	0.2639	0.3790	0.5170	0.5211	0.7948
27 and 28	X	0.2349	0.3208	0.4093	0.5706	0.5392	0.7808
	Y	0.2299	0.3239	0.4015	0.5757	0.5301	0.7891

Table 4.4: Solid angles (Ω) at −3, −10, −20 dB for both polarizations. The total area is $0.27 \cdot 10^{-02}$ ster for the 30 and 44 GHz channel, and $0.9 \cdot 10^{-02}$ for the 70 GHz channel.

BEAM	POL	Ω at −3 dB (ster)	Ω at −10 dB (ster)	Ω at −20 dB (ster)	FWHM$_{\Omega}$ (arcmin)
18 and 23	X	$0.116 \cdot 10^{-04}$	$0.373 \cdot 10^{-04}$	$0.743 \cdot 10^{-04}$	13.21
	Y	$0.115 \cdot 10^{-04}$	$0.370 \cdot 10^{-04}$	$0.737 \cdot 10^{-04}$	13.15
19 and 22	X	$0.111 \cdot 10^{-04}$	$0.353 \cdot 10^{-04}$	$0.679 \cdot 10^{-04}$	12.92
	Y	$0.111 \cdot 10^{-04}$	$0.350 \cdot 10^{-04}$	$0.672 \cdot 10^{-04}$	12.92
20 and 21	X	$0.108 \cdot 10^{-04}$	$0.340 \cdot 10^{-04}$	$0.644 \cdot 10^{-04}$	12.75
	Y	$0.107 \cdot 10^{-04}$	$0.337 \cdot 10^{-04}$	$0.635 \cdot 10^{-04}$	12.69
24	X	$0.346 \cdot 10^{-04}$	$0.110 \cdot 10^{-03}$	$0.207 \cdot 10^{-03}$	22.82
	Y	$0.349 \cdot 10^{-04}$	$0.111 \cdot 10^{-03}$	$0.209 \cdot 10^{-03}$	22.92
25 and 26	X	$0.578 \cdot 10^{-04}$	$0.196 \cdot 10^{-03}$	$0.397 \cdot 10^{-03}$	29.49
	Y	$0.534 \cdot 10^{-04}$	$0.185 \cdot 10^{-03}$	$0.387 \cdot 10^{-03}$	28.35
27 and 28	X	$0.722 \cdot 10^{-04}$	$0.227 \cdot 10^{-03}$	$0.416 \cdot 10^{-03}$	32.96
	Y	$0.717 \cdot 10^{-04}$	$0.225 \cdot 10^{-03}$	$0.415 \cdot 10^{-03}$	32.85

Timeline

- **(2008–2009) Calcolo dei beam pattern in condizioni operative**
  - Superfici misurate e estrapolazione a 50K
- **(2008–2009) misure del pattern in cielo**
  - Pianeti, sorgenti polarizzate (?)
  - Misura del campo del telscopio e geometria del piano focale
- **(2009–2010) Raffinamento dei modelli EM**
  - Correlazione misure in cielo / modelli

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