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MAIN BEAM SIMULATIONS FOR THE PLANCK TELESCOPE

F.Villa[1], L.Valenziano[1], N.Mandolesi[1], M.Bersanelli[2]

[1]*Istituto TESRE, CNR, Bologna, Italy*
[2]*Istituto di Fisica Cosmica, CNR, Milano, Italy*

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SUMMARY — A study of the properties of the main beam of the Planck telescope is presented. Three optical configurations have been analyzed: the Phase A 1.3m design, the Enlarged 1.55m and Enlarged 1.75m designs. For each configuration the Far-Field main beam has been calculated in a regular grid in the Elevation (EL) — Azimuth (AZ) plane inside the Field of View (FOV) of the telescopes. The corresponding response of each Planck/LFI feedhorn for the baseline Focal Plane Unit (FPU) has been also calculated. These results will be used to calculate the impact of the beam distortions on the CMB anisotropy measurements.

1 Introduction

Multi-feed telescope are suitable for reducing the noise in CMB measurements by combining observations with different detectors placed on the focal region of the telescope. the associated systematic effects of such combination can be negligible if the beams on the sky are similar and symmetrical.

Future space missions like Planck Surveyor (ESA M3 mission) will use a multi-feed dual reflector off-axis telescope. Although this kind of telescope is free of blockage (resulting in a pattern without diffraction from struts and directivity losses by obscuration), optical aberration effects can be important, especially for detectors placed far from the center of the focal surface of the telescope.

The Low Frequency Instrument (LFI) and the High Frequency Instrument (HFI) on board the Planck Surveyor share the focal region of an off-axis telescope which for the phase A configuration (Bersanelli et. al, 1996) is a "compensated" gregorian design and has a projected aperture of 1292.4 millimeters. This design introduces significant optical aberrations, especially for the Planck/LFI instrument, which, in the new focal plane arrangement, has its corrugated feedhorns located in a ring around the Planck/HFI cryostat. The aberrations play

Parameters	Phase A	Enlarged 1.55	Enlarged 1.75
MR Aperture (mm)	1292.4	1550.0	1750.0
MR Focal lenght (mm)	720.00	836.51	974.30
SR Focal lenght (mm)	514.29	514.29	514.29
SR axial magnification	2.5	2.5	2.5
offset angle (deg)	14.0	14.0	14.0

Table 1: Characteristics of the three telescope configurations. MR is referred to the Main Reflector, while SR to the Sub Reflector.

a fundamental role on the systematic effects on the CMB anisotropy measurements by LFI. The present study has been performed in order to calculate the main beam profiles which are used as inputs to successive analysis steps (e.g. Mandolesi et al., 1997, Burigana et al., 1998a and 1998b), in order to quantify the scientific loss associated with the observation effects.

Three different configurations have been analyzed: the Phase A telescope (P.H.Nielsen, 1996), and two other, "Enlarged", configurations designed with the same subreflector of the Phase A telescope but different aperture diameters and focal length of the main reflector. All the configurations have the same overall $F_{\#}$, in order to maintain the same illumination properties. The geometrical characteristics of the three telescopes analyzed are reported in Table 1.

2 Technical Approach

The calculations have been done by using the *antenna* approach: telescope performances are calculated in the "transmitting mode". Starting from the electromagnetic properties of the detector, the far field radiation pattern on the sky is found. The method is based on GO scattering on the sub-reflector to calculate the amplitude and phase of the grading function $g(x, y)$ on the aperture plane. The far-field pattern has been evaluated by Fourier Transforming the grading function.

The code (Sletten, 1988), running only for gregorian or cassegrain Dragone-Mizuguchi telescopes, has been used to make a preliminary study of the Planck telescope. Because the simple ray-tracing code and integration routine the calculations have been applied for circular aperture and symmetrical illumination only. However, these results have been validated with the calculation done with the GRASP8 software package (TICRA, 1997), finding a good agreement for scan angles below 4° from the optical axis.

The original FORTRAN 77 routines have been modified to automatically calculate the beams inside the Field of View of the Planck Telescope.

3 Calculation Strategy

Starting from a regular grid (from $-5°$, $-5°$ to $+5°$, $+5°$ step 1°) on the Elevation-Azimuth plane the focal surface has been calculated (Valenziano, et. al, 1998). For each Elevation and Azimuth point (EL, AZ) and corresponding focal position (x, y, z), the amplitude and phase on the tilted aperture plane have been obtained. The feed pattern function was selected as a $\cos^N(\theta)$ pattern with $N = 91$ to give an aperture amplitude distribution with and Edge

Taper (ET) of −30dB at 22° of angle. Calculating the Fourier Transform of the aperture current distribution the far-field main beam pattern has been calculated. Data were stored in 121×3 files (three file for each EL,AZ position) as a $\theta, \phi, Amplitude$ ASCII data file (*.tf), $U, V, Amplitude$ ASCII data file (*.uv), and $\theta, \phi, Amplitude$ binary matrix stored data file (*.tfc). The *.tf files are used to plot ϕ–cut patterns, while the *.uv files are utilized for contour plot visualization.

Calculation have been done at 30GHz and 100GHz for the Phase A Planck telescope, the Enlarged 1.55 meter and the Enlarged 1.75 meter Planck telescope (Villa et al., 1998). For each telescope configuration, the 121 beams in the FOV of the telescope have been calculated. The sampling interval for the 100GHz and 30GHz beams was 0.01 and 0.03 degree respectively for the θ angle and 5 degree for the ϕ angle, in a local θ and ϕ coordinate system, centered on the each beam axis (data are available on request for members of the LFI Consortium).

In addition, the response of each telescope has been calculated in the same way for the baseline Planck/LFI Focal Plane Unit arrangement (Villa et al., 1998) shown in figure 1, where the feedhorns are labeled with a progressive number ($1 \div 17$ for the 100GHz, $18 \div 23$ for the 70GHz, $24 \div 26$ for the 44GHz and 27 and 28 for the 30GHz feedhorns). Contour plots of these calculations for the 100GHz feeds are shown in figures 2 and 3 for the phase A telescope (`st`), in Figures 4 and 5 for the Enlarged 1.55 meter telescope (`e1`), and in Figure 6 and 7 for the Enlarged 1.75 meter telescope (`e2`). The corresponding number of the feedhorn is indicated on the top of each plate in the file name (for example `st_01_100ghz_tp-30.uv` is referring to the feedhorn at 100GHz number 1 for the phase A telescope).

4 Conclusions

A simple code in FORTRAN 77 has been modified in order to simulate the beam response of the Planck Telescope. This code, originally written by Sletten, allows to obtain a calculation of the telescope response in the entire Field of View. The calculations have been performed for three different optical designs of the Planck Telescope (Phase A, Enlarged 1.55 meter, and Enlarged 1.75 meter) in order to quantify the beam distortions as a function of telescope diameter. We reported in figures the calculation done for the 100GHz feeds in the baseline Focal Plane Unit arrangement. The conclusions are summarized in the following points:

- As expected, for the three configuration analyzed here, the beam shape is symmetrical for the central beam only (this is a consequence of the Dragone-Mizuguchi compensated design).
- Because of the beam distortion, the Phase A telescope does not meet the nominal angular resolution in the LFI channels, including the 10 arcmin requirement at 100 GHz which is considered critical for the scientific objective.
- Increasing the aperture diameter, the angular resolution is obviously better but the distortions are mainly the same. This means that in order to reduce the aberrations a different design is required.

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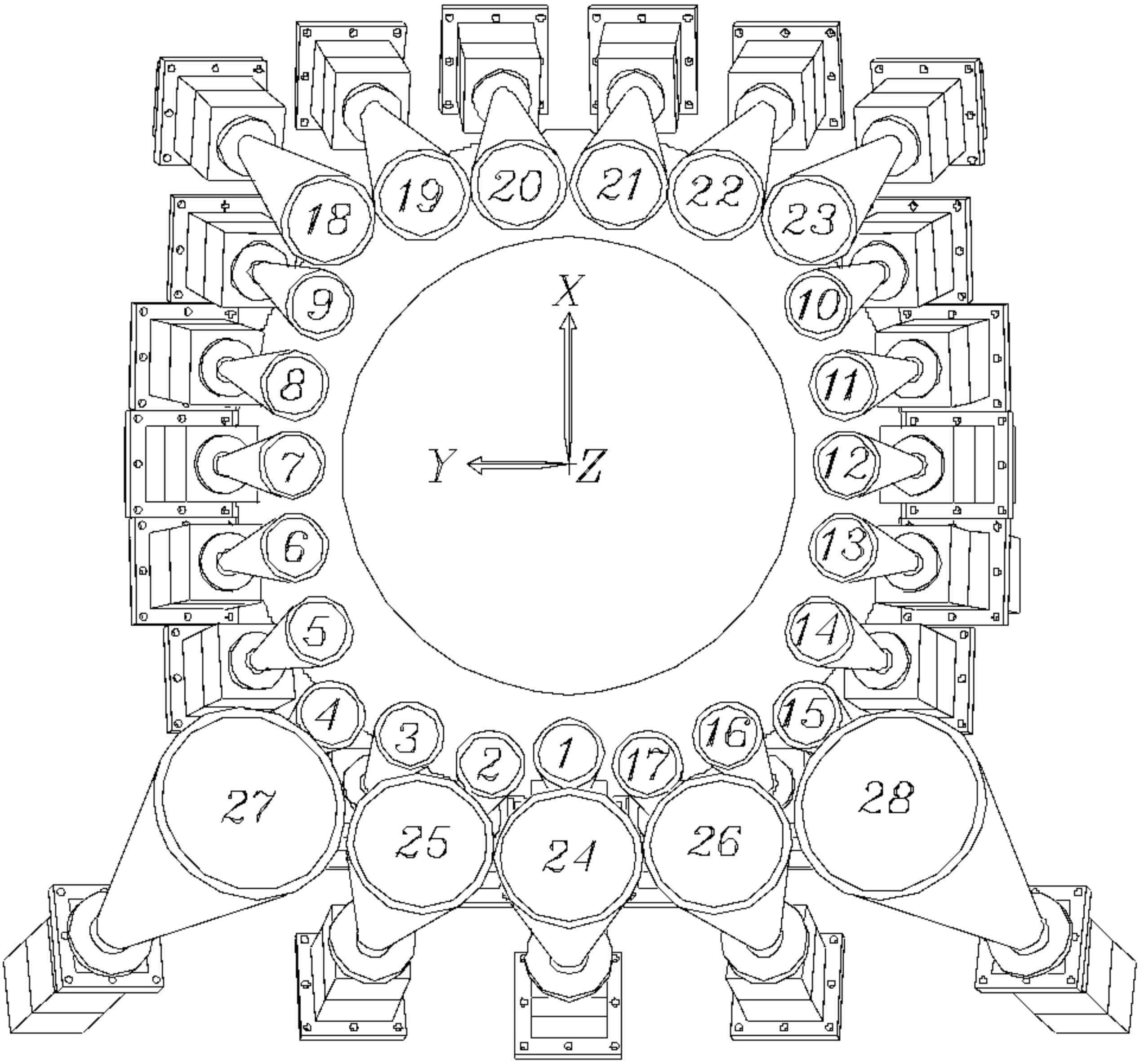

Figure 1: Planck/LFI Focal Plane Unit: baseline configuration.

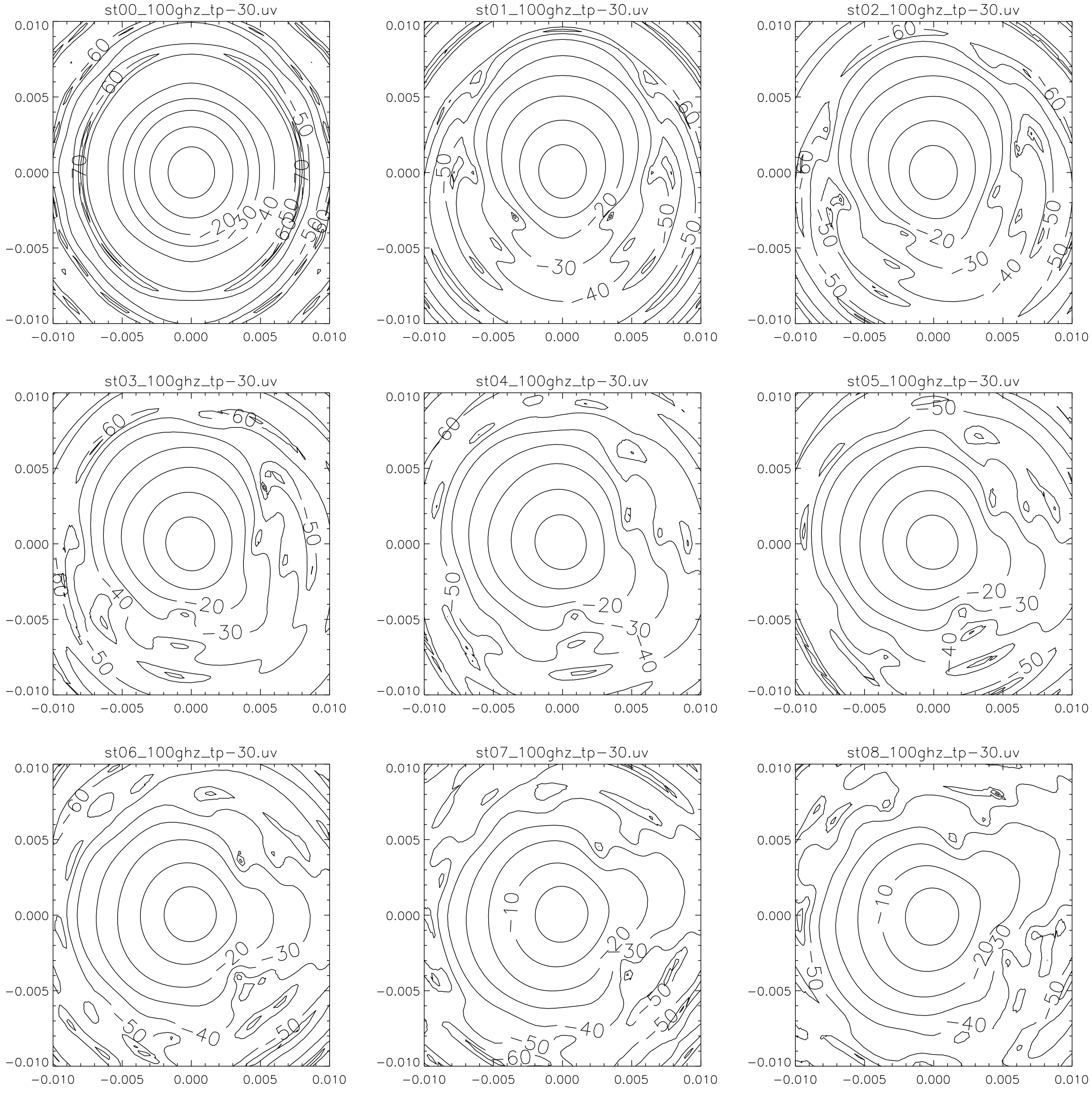

Figure 2: Phase A telescope main beam response for the Planck/LFI 100 GHz feedhorns. The labeled '00' beam is for a feed located at the center of the focal surface.

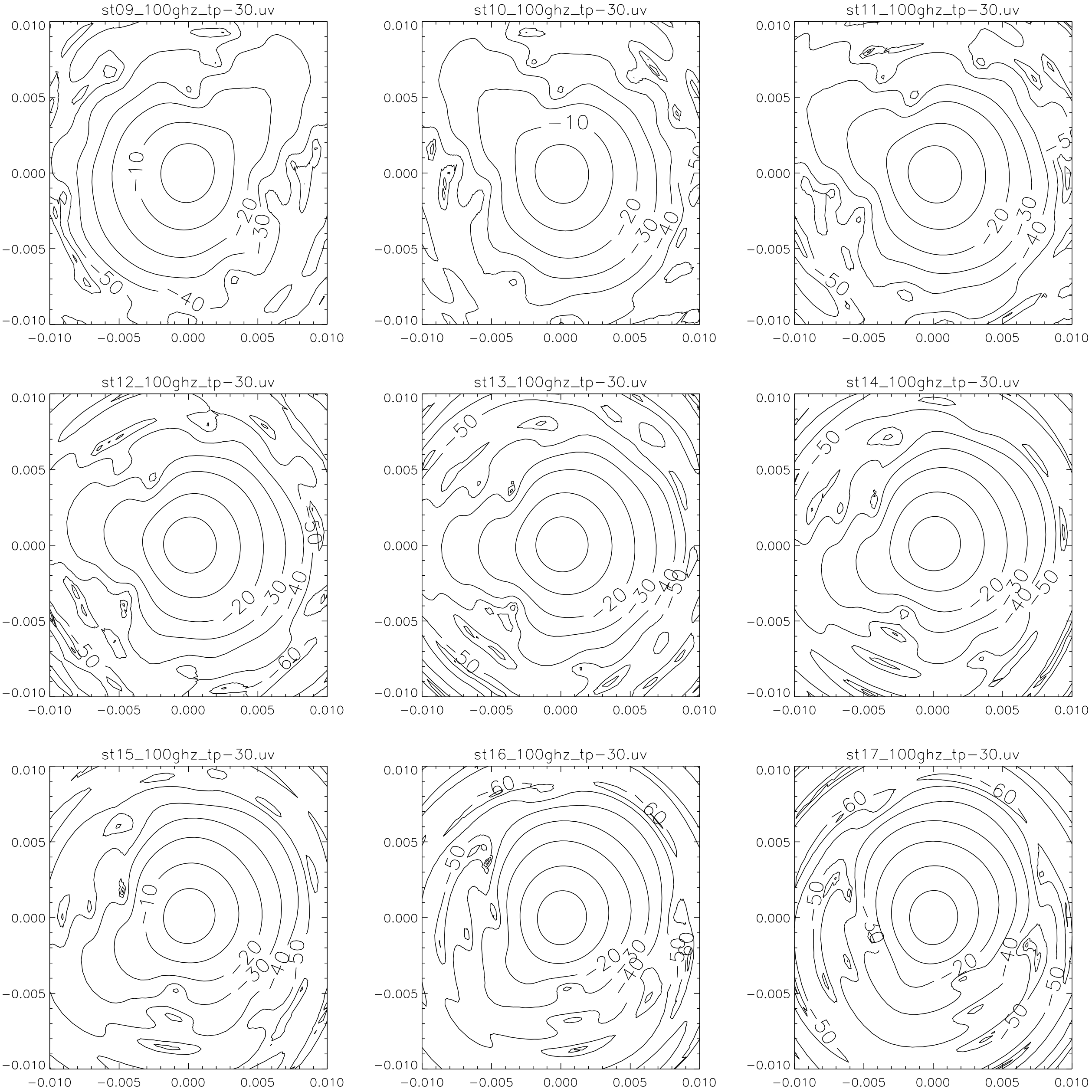

Figure 3: Phase A telescope main beam response for the Planck/LFI 100 GHz feedhorns. The labeled '00' beam is for a feed located at the center of the focal surface.

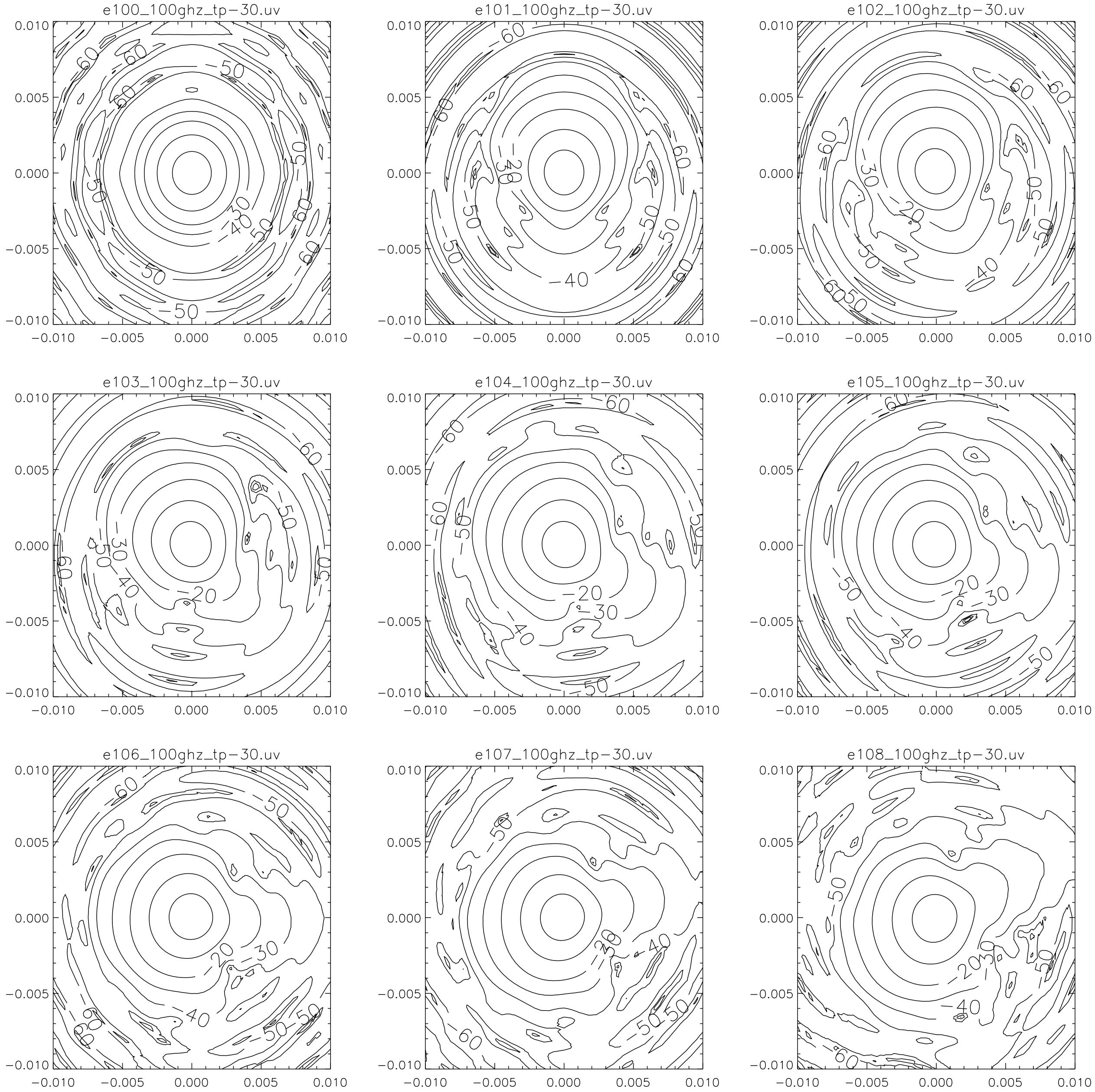

Figure 4: Enlarged 1.55 meter telescope main beam response for the Planck/LFI 100 GHz feedhorns. The labeled '00' beam is for a feed located at the center of the focal surface.

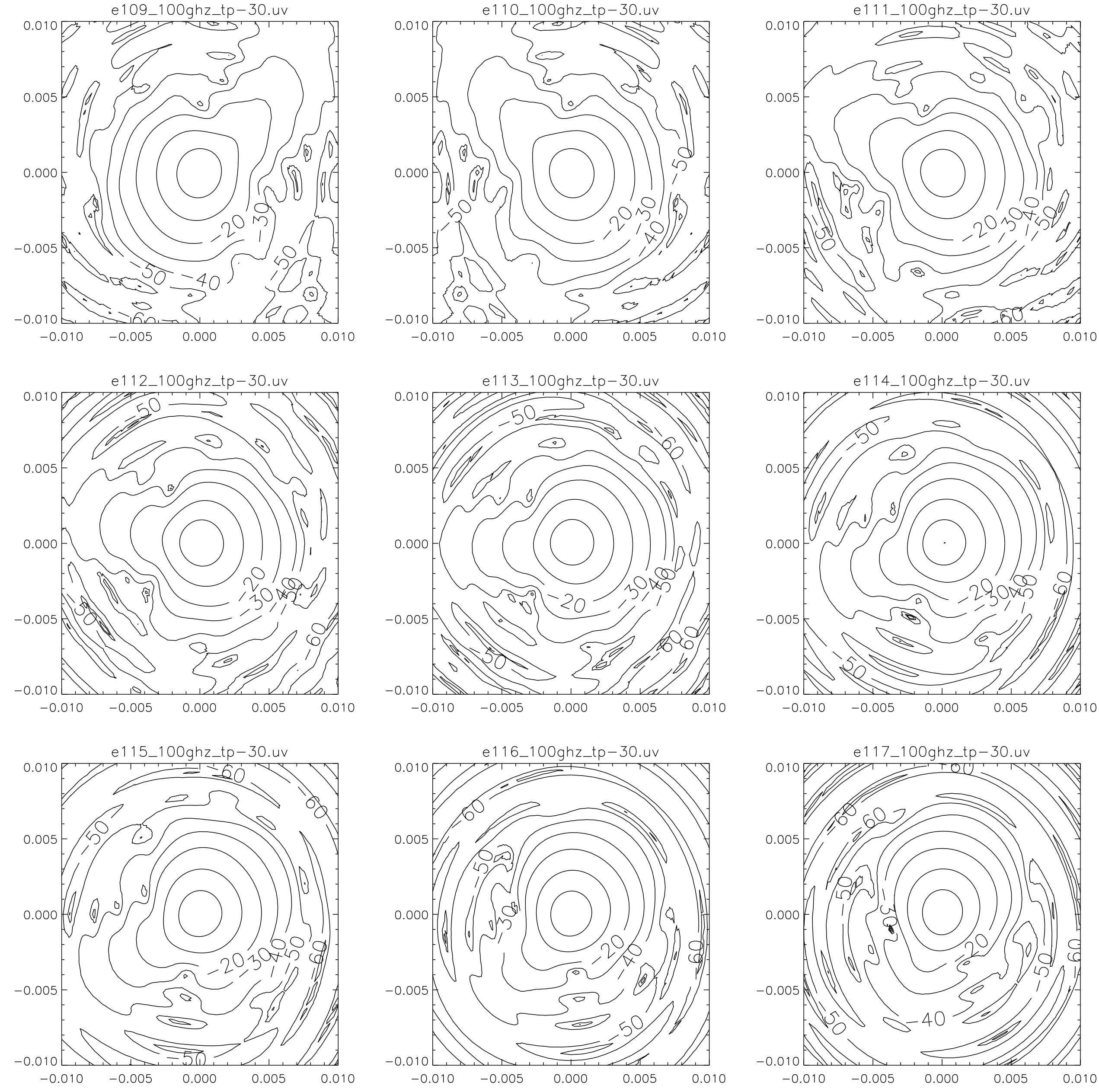

Figure 5: Enlarged 1.55 meter telescope main beam response for the Planck/LFI 100 GHz feedhorns. The labeled '00' beam is for a feed located at the center of the focal surface.

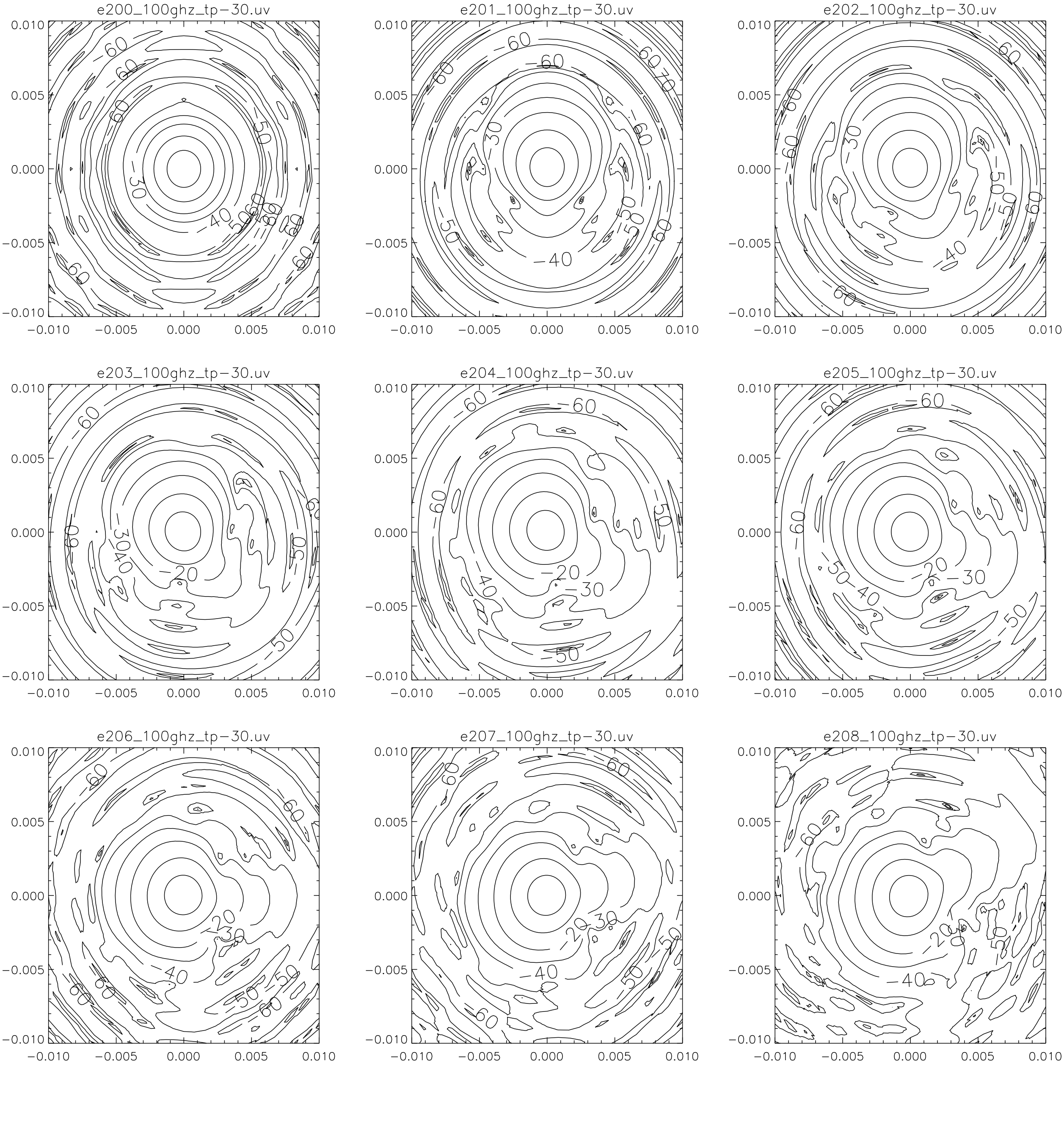

Figure 6: Enlarged 1.75 meter telescope main beam response for the Planck/LFI 100 GHz feedhorns. The labeled '00' beam is for a feed located at the center of the focal surface.

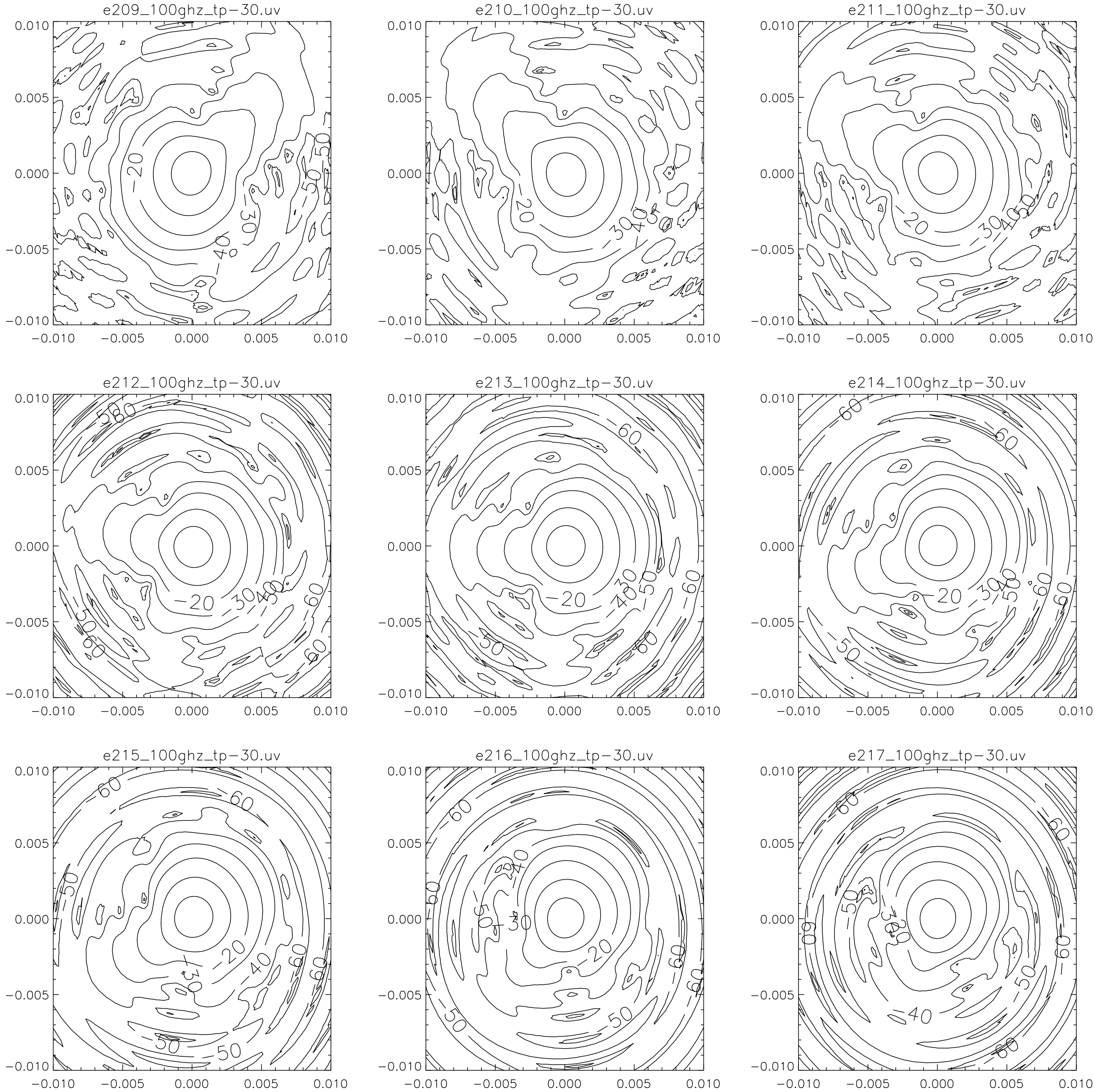

Figure 7: Enlarged 1.75 meter telescope main beam response for the Planck/LFI 100 GHz feedhorns. The labeled '00' beam is for a feed located at the center of the focal surface.