The Planck Mirror Dimpling

The Planck reflectors suffer from print-through of the honeycomb structures that support the carbon-fibre face sheets [1], [2], [3]. While the size of the deformation has been measured during tests below room temperature to be less than $20\,\mu$m, it is the strict periodicity of part of the deformation that contributes most to the additional beam-shape contribution. A simple grating equation has been shown to describe the angular positions of the resulting near side lobes very well:

$$\sin\theta_n = \frac{n\lambda}{Yd} \qquad (1)$$

where θ_n is the angular position of the n'th order lobe from the central beam peak; λ is the wavelength of the radiation; d is the grating spacing of the periodicity and Y is a factor that describes the position of the each reflector along the optical path. $Y = 1.00$ for the primary reflector and $Y = 1.80$ for the secondary reflector. Three possible periodicities (19.6 mm, 30 mm, 52 mm) in the honeycomb array dominate the Planck dimpling pattern for the 857 GHz detectors, though only those for the 52 mm can be seen for the 545 GHz and 353 GHz detectors. For the highest frequency detectors, only the weaker lobes due to the 19.6 mm and 30 mm periodicities are seen outside the 40 arcminute beam window, but they contribute at most $(0.05 \pm 0.008)\%$ to the integrated beam.

A map of Jupiter has been created for each 857 GHz detector, using the first four surveys, with the background subtracted using the same sky area for the survey taken 12 months before in which the planet is not present. The background-subtracted maps for each survey were then stacked to make a single map for each of the four detectors and these were further stacked to create a single 857 GHz band map, using the standard detector weightings proportional to $1/(NET)^2$ [Need public reference to the detector weightings here]. All the maps have 96 pixels per side, covering $\pm 1.4°$, and are scaled to the RMS noise of the background. Central beam values range from 205,000 to 256,000, depending on the noise of the detector.

For each of these five maps of Jupiter an elliptical gaussian main beam has been fitted, and the amount of saturation estimated by finding the peak increase that gives the best gaussian fit—typically 10–20%. A circular ruze envelope was also fitted together with a tilted gaussian component slightly offset from the beam in the cross-scan (optical X axis) direction, using data more than $0.13°$ from the beam, with the known positions of the dimpling lobes masked out. Once these strongest components were removed, a tilted elliptical gaussian was fitted for each visible dimpling lobe in up to 5 different sets of lobes, however the innermost lobe set (52 mm periodicity) is generally obscured by the ruze component and for the outermost set (19.6 mm periodicity) most lobes are too weak to be fitted for individual detectors. The contributing areas of the lobes were determined by three methods: from the fitted gaussians; from summation within boxed areas using offsets determined from surrounding boxed areas; from summation in the boxed areas using an offset determined from gaussian fitting. The uncertainties in the beam component areas given here include the spread in values from these different methods. Similarly, the lobe peaks in decibels are calculated using the raw, fitted and estimated desaturated beam peak values, and the uncertainties reflect the variations produced by the three methods. Averaged over the five map fittings, the dimpling lobes contribute $(0.47 \pm 0.13)\%$ of the beam area, while the ruze envelope accounts for $(9.2 \pm 0.7)\%$ of the beam with the main beam making up the remaining $(90.3 \pm 0.7)\%$. For lower frequencies the dimpling lobes are less visible and will not be discussed here. For example, the noise floor for the 545 GHz band map is about 47 dB below the observed Jupiter peak, so that no dimpling lobes are visible further out than the 52 mm lobes at $0.61°$. For 353 GHz the noise floor is at about 38 dB so that even the 52 mm lobes are not observed.

Figure 1 shows how the dimpling lobes seen for the 857 GHz band Jupiter map correspond to the contours calculated by the physical optics GRASP package, produced by TICRA, Denmark. The GRASP simulation was performed for the 857-1 detector and assumed a uniform dimpling distortion of 10 microns. The biggest departure from the simple grating model, is that the lobe pattern is elongated in the cross-scan (vertical) direction—lobes that should lie on a line $30°$ from the vertical are consistently found around $25°$ and those on the $60°$ line cluster around $53°$. This is due to the offset geometry of the mirror system, whereby the dimpling print-though is foreshortened along the optical x-axis due to the tilt of the mirrors, producing greater lobe spacing.

The amplitudes of the fitted dimpling lobes vary significantly within each set whereas the GRASP model shows a constant amplitude for lobes within a set, except for the 30 mm periodicity. Similar amplitudes are seen in lobes lying directly across the beam centre from each other, indicating that facesheet dimpling has not occurred uniformly in all directions as the GRASP model assumes. For the 30 mm periodicity the vertical lobes are significantly weaker than those at the sides just as the GRASP model also shows. Generally, the fitted lobes are somewhat stronger than those seen by GRASP, indicating that the dimpling is indeed larger than 10 microns.

While the dimpling lobes are measureable at the highest two frequencies, with a strong source (i.e. Jupiter), 90% of the dimpling lobe effect at 857 GHz, and 100% for all other frequencies, already appears in the beam functions described in this paper. However, the presence of the uniform dimpling lobes provides a useful window by which to investigate the mirror geometry.

References

[1] Dubruel D.˙ Planck flight radio frequency performances quilting analysis. Technical Report H-P-ASP-AN-1839, Thales Alenia Space, July 2009.

[2] Per Heighwood Nielsen. Rf effect of dimpling distortion on the planck telescope. Technical Report S-1281-01, TICRA, April 2004.

[3] Per Heighwood Nielsen. Planck telescope rf performance independent verification phase1. Technical Report S-1287-07, TICRA, February 2005.

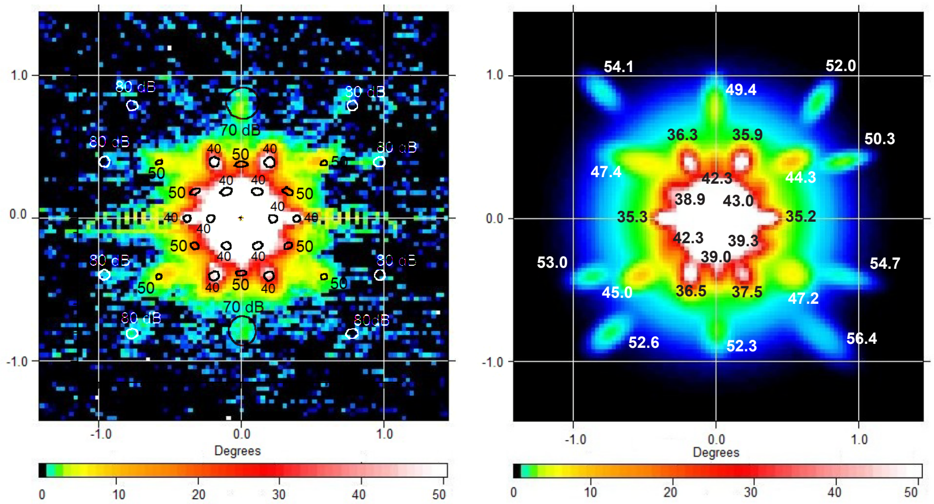

Figure 1: Dimpling lobes seen in the 857 GHz band map of Jupiter, with contours calculated by the GRASP physical optics package. Left: data map for 4 stacked surveys and 4 detectors, with the GRASP contours and peak values in decibels overlaid. Right: fitted components including main beam, ruze envelope and 4 sets of dimpling lobes with fitted peak values in dB below main beam peak, all values ± 0.3 dB, including the uncertainty due to peak saturation. Units are RMS background noise variation for both maps, with a logarithmic scale.