DEGREE-SCALE ANOMALIES IN THE CMB:
LOCALIZING THE FIRST PEAK DIP TO A SMALL PATCH OF THE NORTH ECLIPTIC SKY

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Abstract

Noticeable deviations from the prediction of the fiducial ΛCDM cosmology are found in the angular power spectrum of the CMB. Besides large-angle anomalies, the WMAP 1st year data revealed a dip in the power spectra at $l \sim 200$, which was more evident in the ecliptic poles region. Using the latest WMAP 3-year data release, we study the intensity and spatial distribution of this feature in order to unveil its origin and its implications for the cosmological parameters. We show that in both first and third year WMAP data there is a substantial suppression of the first Doppler peak in a region near the north ecliptic pole.

Introduction

The angular power spectrum derived from the Wilkinson Microwave Anisotropy Probe (WMAP) sky maps provides a striking confirmation of the concordance ΛCDM cosmological model.

The pattern of acoustic peaks and troughs imprinted on the angular power spectrum by the post-inflationary evolution of the primordial fluctuations in the inflationary field has been mapped with certainty [1, 2, 3]. A global fit to the data has enabled to determine the handful of parameters of the ΛCDM model, which does a remarkably good job at describing the spectrum.

Nevertheless, the expectation that the anisotropies should be statistically isotropic and Gaussian has been challenged by the discovery of several anomalies [4, 5, 6]:

- lack of large angle correlations and violations of statistical isotropy at $l = 2$, 3 and 6.
- anomalous values of C_l in at least three bins: $l \sim 22$, 44 and 200.
- hemispheric asymmetries extending over a wide range of angular scales.

These anomalies are still present in the three year data release [7, 8], although the WMAP team claims that the though around the first peak is no longer present when the newly adopted weighting scheme is used to extract the best fit power spectrum. The anomaly was, thus, attributed to a noise fluctuation [3].

Surprisingly, the dip in the power spectrum around $l \sim 200$ disappears when data from the *ecliptic* poles is not included in the analysis of the 1st year WMAP data [1]. The fact that previous experiments like Archeops observing the north ecliptic pole regions differed in their estimates of the power spectrum in these angular scales from others, like e.g. Boomerang, that had access only to southern ecliptic regions, suggests that the differences might not steam from the ecliptic plane region.

Here we study the 1st and 3rd year WMAP data in different regions of the ecliptic sky, using the two different weighting schemes on both datasets to assess the likelihood of noise fluctuations. We find that the power is reduced upon including data around the northern ecliptic pole irrespective of the noise or the dataset considered. With the 1st year weighting scheme this decreased power manifests as the known dip.

Ongoing work is underway to establish whether this effect is of cosmological origin, an unknown systematic error or due to foreground contamination [10].

Power spectrum calculation and data selection

The usual decomposition of a sky map $\Delta T(\mathbf{n})$ in spherical harmonics can be generalised to the case of partial sky coverage by introducing a position-dependent weight, $W(\mathbf{n})$, which is set to zero in the regions where the sky is contaminated:

$$\tilde{a}^i_{lm} = \Omega_p \sum_p \Delta T^i(p) W^i(p) Y^*_{lm}(p), \tag{1}$$

where the map, corresponding to the DA i, has been discretized in pixels sub-tending a solid angle Ω_p.

In a multichannel experiment like WMAP the noise between two different DAs is uncorrelated. Using cross-power spectra instead of auto-power spectra we obtain an optimal estimate of the true power spectrum that is independent of the noise model. Even though the pseudo-power spectrum, $\tilde{C}_l$, derived from weighted maps (1), differ from the full-sky C_l^{sky}, their ensemble averages are simply related by a mode coupling matrix, $G_{ll'}$. We thus obtain the following estimate for the power spectrum [1]:

$$C_l^{\text{sky}} = \sum_{l'} G^{-1}_{ll'} \tilde{C}_{l'}, \tag{2}$$

where $\tilde{C}_l = \frac{1}{2l+1} \sum_{m=-l}^{l} \tilde{a}^i_{lm} \tilde{a}^{j*}_{lm}$, and the details of the coupling matrix, which is a function of the weights, can be found in [9].

The WMAP team obtained its best estimate power spectrum by optimally weighting all the possible pairings of Q, V and W DAs, although the Q band was dropped in the 3rd year estimate, since it is the most prone to foreground and diffuse source contamination. Our aim here is not to obtain the best power spectrum estimate, but to study how it changes when looking at different parts of the sky or when using different weighting schemes. We thus obtain our power spectrum estimate by applying Eq. (2) to the foreground reduced V and W frequency band maps for both the 1st year and averaged 3 year maps. We perform our analysis using the 1st and 3rd year weighting [1, 3] schemes for both datasets.

Results

Oddly enough, some of the anomalies found at large angular scales correlate with the ecliptic [5], and the WMAP team 1st year data gives a different spectrum around $l \sim 200$ in the ecliptic plane than in the poles [1]. Even though, a random search in all directions could potentially reveal a more significant region, the statistical penalty factor associated with the scanning is difficult to estimate, and when such an analysis is performed for the 1st year data the results also point to the ecliptic poles [6]. We, thus, choose to start with a few *a priori* selected regions associated with the ecliptic.

Estimating the *real* power spectrum from observations of a limited region in the sky, introduces errors that increase as we shrink the patch. To minimise this effect we use *complementary masks*. For instance, *to check the influence of the northern ecliptic pole region, we just remove the cap around the pole and keep the rest of the sky.*

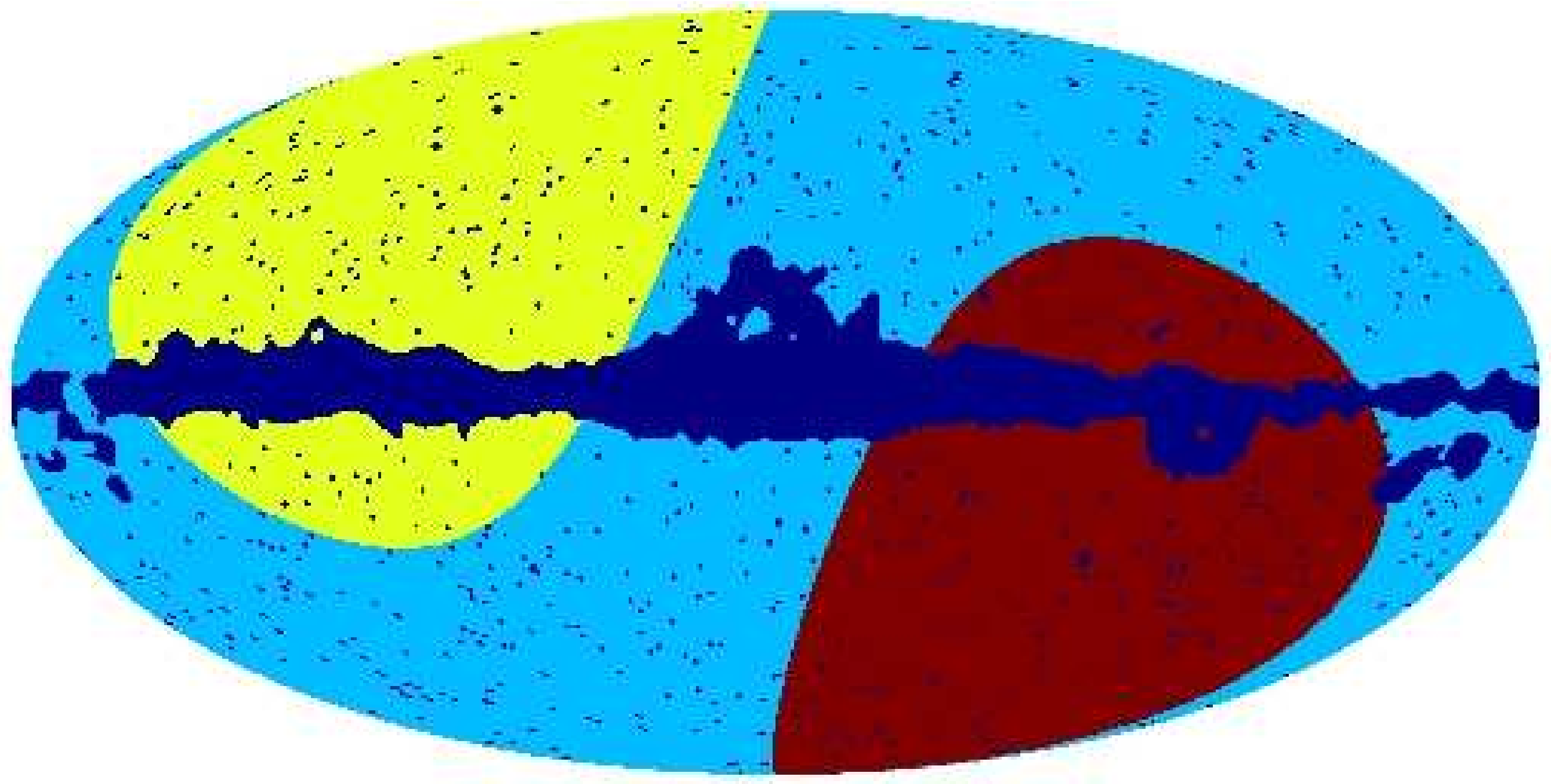

FIGURE 1: Ecliptic masks in galactic coordinates. We test the influence of a particular region by masking a cap in that direction, while keeping the rest of the sky. The Kp2 region is always masked out.

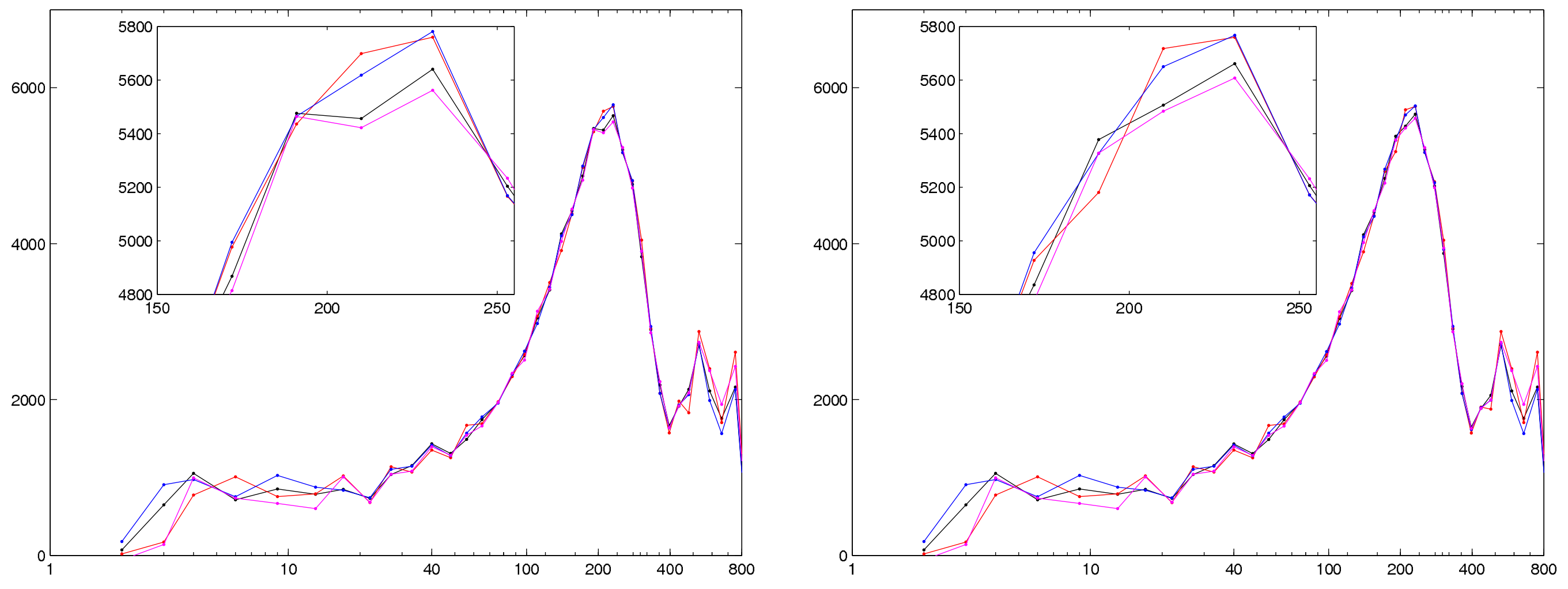

FIGURE 2: Power spectrum estimated from the regions shown in Fig. 1 for the 1st year WMAP data release. The 1st (3) year weighting scheme has been used in the left (right) column.

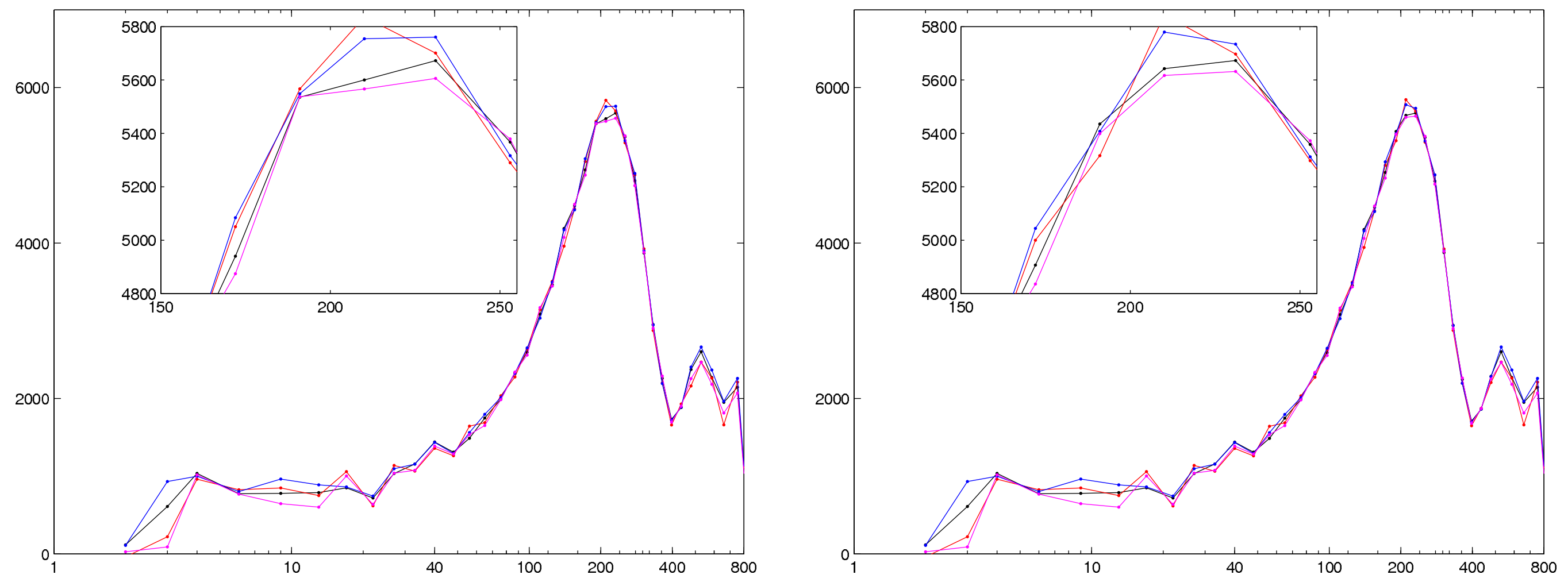

FIGURE 3: The same as in Fig. 2, but using 3 year WMAP data.

The observed power spectrum in the 1st year WMAP data for scales $l \sim 200$ was ∼10% smaller than what the best fit ΛCDM model would indicate. If this dip originated in a particular region in the sky, we can then estimate the dimension of the patch involved to be $\sim 30°$.

Outlook

As shown in Fig. 2, *the power around* $l \sim 200$ *is reduced if data in the region of the north ecliptic pole is used* to estimate the spectrum. The black line was obtained with the Kp2 mask only, and for the magenta we left out, in addition, the southern ecliptic pole. When leaving out the northern ecliptic pole (red) or keeping just the ecliptic plane (blue) the value of $C_{l\sim 200}$ is roughly 10% higher. The effect is seen *for both the 1st and 3 year WMAP data regardless of the chosen weighting scheme*, although the dip-like shape is more obvious when the 1st year data and weights are used. Its significance can only be assessed with a detailed likelihood analysis that is underway [10].

The process of foreground cleaning was overhauled in the 3 year WMAP data release, yet the reduction in power due to northern ecliptic pole data can still be appreciated. This would argue against an unaccounted foreground contamination as the origin of these variations.

As for possible systematic effects, it should be noted that the WMAP surveys the ecliptic plane more scarcely as compared to the poles, and the different beam ellipticity could bias the result.

If these variations are of cosmological origin, they cannot be explained within the standard ΛCDM model, since it predicts an isotropic and Gaussian spectrum, and would demand a modification of the basic principles that are used to describe our Universe.

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