Simulations of the Sunyaev-Zel'dovich Effect

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Virtual Sky Simulations

We create simulations of the 30 GHz sky using three components: the Cosmic Microwave Background (CMB), the Sunyaev-Zel'dovich Effect from the scattering of CMB photons by hot gas in groups and clusters of galaxies, and foreground point sources.

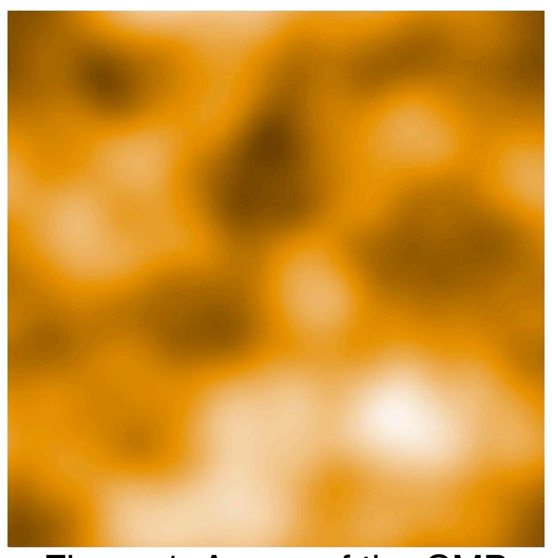

Figure 1: A map of the CMB

Cosmic Microwave Background

Maps of the CMB are created using a power spectrum generated by CAMB (Lewis, Challinor & Lasenby, 2000) under the assumption that the CMB is a Gaussian random field. An example 1x1 degree realisation of the CMB is shown in Figure 1.

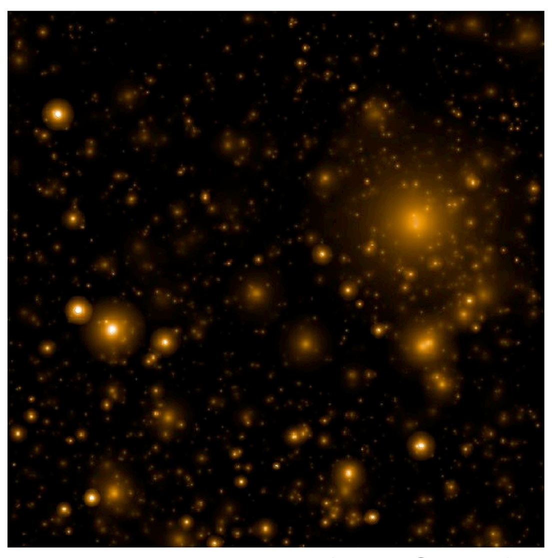

Figure 2: A map of the SZ effect (1x1 degree)

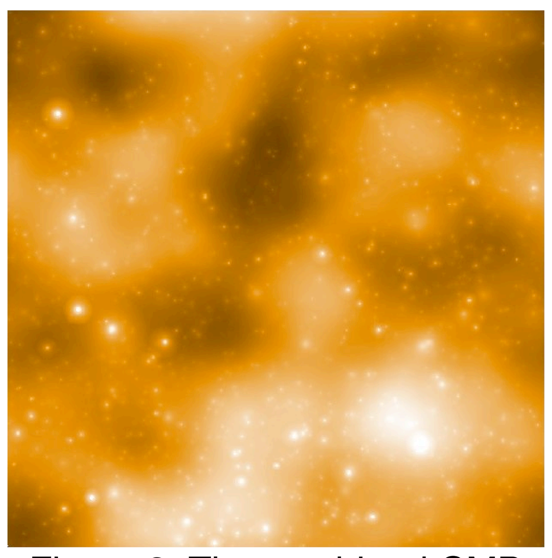

Figure 3: The combined CMB and SZ effect maps

The Sunyaev-Zel'dovich Effect

Two models are required to create maps of the SZ effect: the distribution of the groups and clusters, and a model of the cluster profile. The former is generated using Pinocchio (Monaco, Theuns & Taffoni), which uses Lagrangian perturbation theory to collapse large-scale matter into clusters and groups of galaxies. We create 1000 cluster catalogues each of 3x3 degrees from 100 Pinocchio runs for each of three values of σ_8: 0.75, 0.825 and 0.9.

We use a simple, spherically symmetric cluster model using an isothermal beta model and a power law relation for the normalization as a function of mass, choosing parameters comparable to those from recent cosmological gas simulations.

Figure 2 shows an example realisation of the SZ effect for σ_8=0.825, containing nearly 2000 groups and clusters within a 1x1 degree area (6 arcsecond resolution). The combination with the CMB is shown in Figure 3.

Point Sources

We introduce point sources into the realisations using number counts as a function of flux from the model by Toffolatti et al. (1998; see Figure 4) normalised to agree with observations by WMAP (Bennett et al. 2003; pink in Figure 4), DASI (Kovac et al. 2002, blue), VSA (Cleary et al. 2005, green), CBI (Mason et al. 2003, red) and GBT (Mason et al. 2009, grey). The point sources are either randomly positioned on the maps or clustered according to the surface mass distribution from the galaxy groups and clusters.

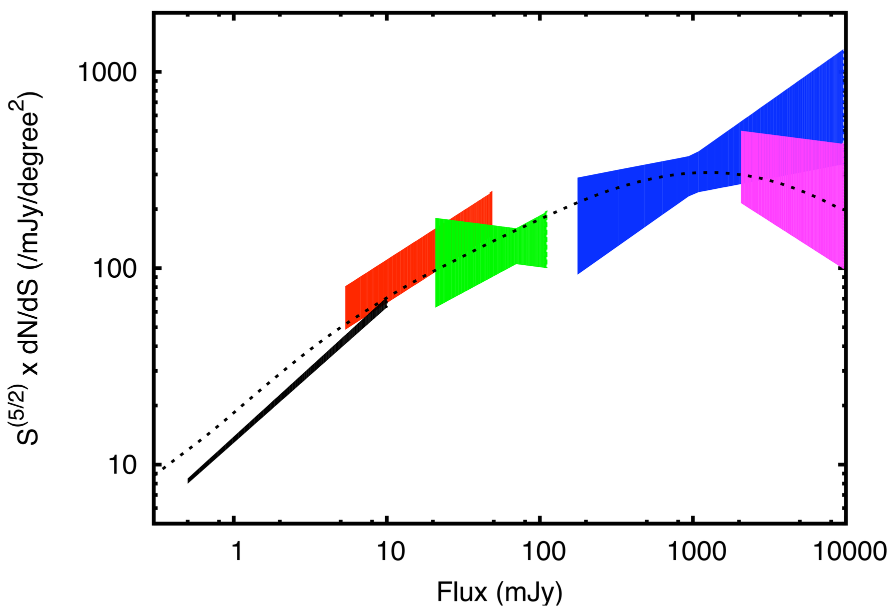

Figure 4: Differential point source number counts.

Power Spectrum Statistics

Binning the power spectra from the sets of 1000 realisations, we look at the statistics of the SZ power spectrum. We find that the distribution is wider than expected from Gaussian statistics by a factor of 3 and broadens an extra 10-15% due to clustering. The distribution is also positively skewed, especially for small maps.

Non-gaussian and skewed histograms

Figure 5 shows the histogram of the power spectra within a multipole bin of l=3000-4000 for nine thousand 1x1 degree maps of the CMB and SZ effect. The red line shows the expected distribution from Gaussian realisations with the same mean power spectrum. The blue line shows the best Gaussian fit. The histogram is clearly broader than Gaussian, and is skewed towards higher values.

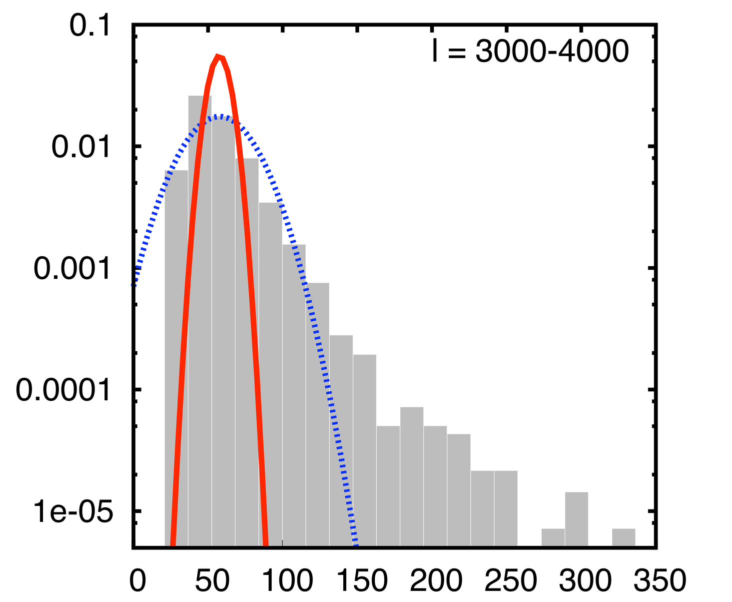

Figure 5: Histogram of the binned CMB+SZ effect

Effects of gas physics

We investigate the effect of gas physics on the statistics by changing the parameters within their allowed range. This leads to changes in the mean power spectra that are comparable to those from the range of σ_8 and can significantly increase the standard deviation. Figure 6 shows the effect of changing the profile of the SZ effect, β, on the mean power spectrum; changing from β=2/3 to 1 doubles the mean power spectrum and triples the standard deviation at l=2000-4000.

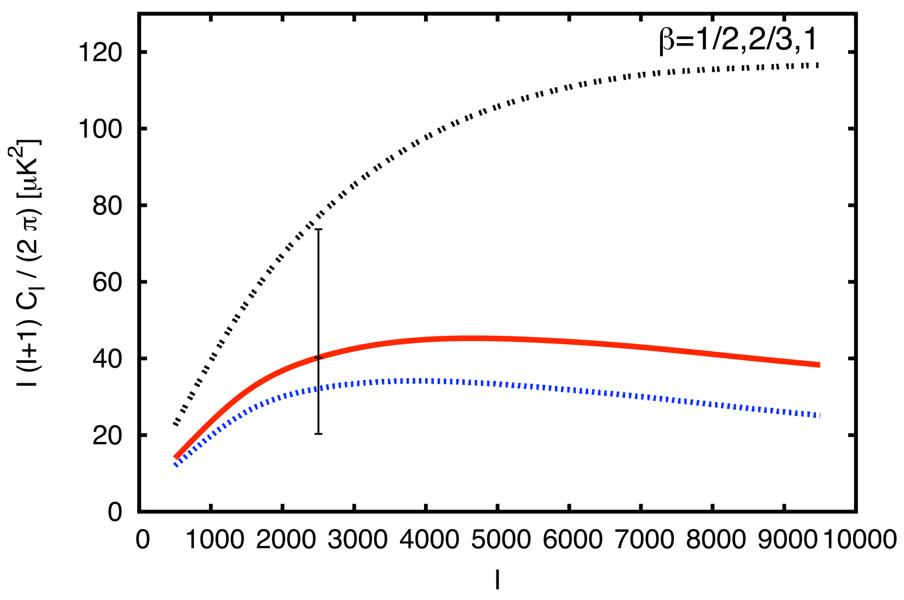

Figure 6: Changing the cluster profile results in changes in the mean power spectra (solid lines) comparable to that from different σ_8 (error bar)

Implications for the high multipole excess

An excess of power has been measured at high multipoles by the Cosmic Background Imager (CBI; Sievers et al. 2009), BIMA (Dawson et al. 2006) and weakly by ACBAR (Reichardt et al. 2008), although curiously observations by the SZA (Sharp et al. 2009) and QUAD (Friedman et al. 2009) do not detect this excess.

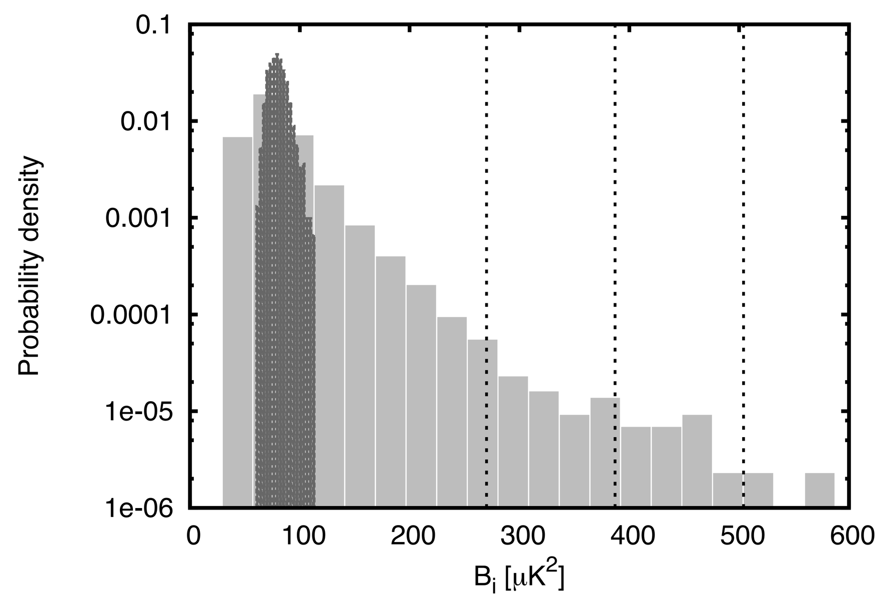

Figure 7: Statistics within the highest CBI multipole bin for σ_8=0.825.

Figure 7 shows the statistics from 0.75x0.75 (light grey) and 3x3 degree (dark grey) realisations in the highest CBI multipole bin along with the central and 1 sigma values measured by CBI; the distributions are skewed sufficiently for some realisations to match the measured power, but these are rare (0.36%). These become more likely when the mean power spectra is increased by using a different value of σ_8 (2.4% for σ_8=0.9), using different gas physics (2.4% for β=1; see Figure 6) or adding point sources (10.3% for 1mJy point sources).

Bennett C.L. et al., 2003, ApJS, 148, 97
Cleary K.A. et al., 2005, MNRAS, 360, 340
Dawson K.S. et al., 2006, ApJ, 647, 13
Friedman R. B., et al., 2009, preprint (arXiv 0901.4334)
Kovac J.M. et al., 2002, Nature, 420, 772
Lewis A., Challinor A., Lasenby A., 2000, ApJ, 538, 473
Mason B.S. et al., 2003, ApJ, 591, 540
Mason B.S. et al., 2009, preprint (arXiv 0901.4330)
Monaco P., Theuns T., Taffoni G., 2002, MNRAS, 331, 587
Sharp M.K. et al., 2009, preprint (arXiv 0901.4342)
Sievers J.L. et al., 2009, preprint (arXiv 0901.4540)
Reichardt B.S. et al., 2008, preprint (arXiv 0801.1491)
Toffolatti L. et al., 1998, MNRAS, 297, 117

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