Use of SZ effect to reconstruct clusters in patches of Planck maps

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Abstract

The goal of the project is to reconstruct clusters of galaxies using the SZ effect on patches of the sky. As a starting point, we use maps given by the six highest frequencies measurements of Planck. Using an internal linear combination method, we extract clusters' signatures.

1 Introduction

1.1 The SZ (Sunyaev-Zel'dovich effect

Photons of the CMB can be accelerated by means of inverse Compton scattering when travelling through a galaxy cluster. Electrons in the cluster, much more energetic than the fossil photons, are shifting them towards higher frequencies : we observe hence a deficit at low energies and a excess at high energies in a pattern characteristic of the SZ effect.

This effect can thus be used as a complementary method to characterize clusters : its angular resolution is not sufficient to discern much details but it has led to the discovery of a supercluster for the first time in 2010. [4]

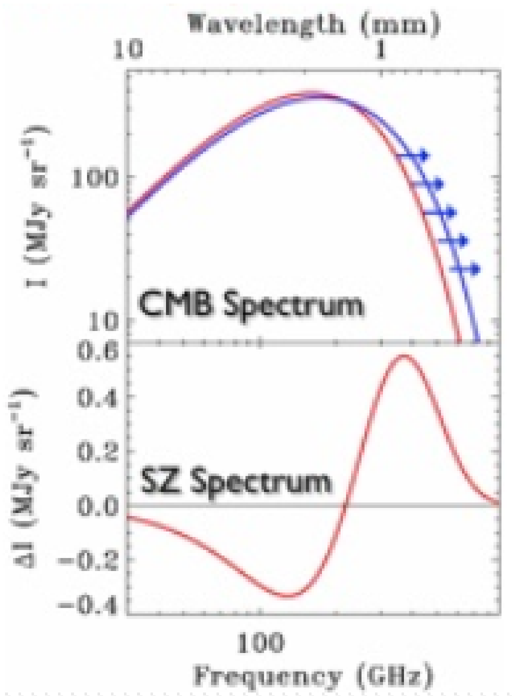


Figure 1: Shift of the SZ effect leading to a negative difference (a deficit) at low energy and a positive at higher energies.

1.2 Internal Linear Combination

At Planck frequencies, the main signals are : emissions from Galactic and inter-Galactic sources, CMB, thermal dust, diffuse free-free, synchrotron, molecular emissions (mainly ^{12}CO), SZ effect for clusters of galaxies. These sources are frequency-dependent, as shown in Fig 2.

Therefore we apply an internal linear combination method as described in [1], allowing us to substract signals other than the cluster's signature.

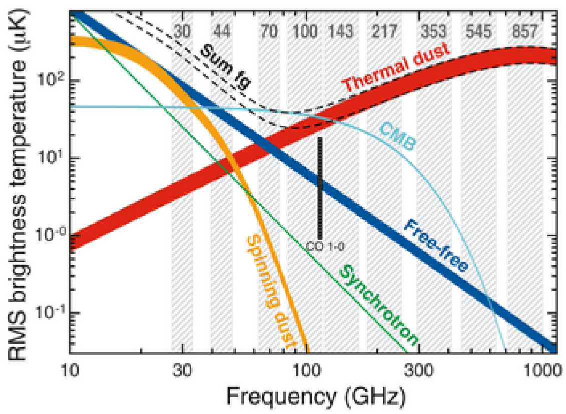


Figure 2: Different signals of the sky as a function of the frequency.

1.3 Focus on patches of the sky

Our project is to apply the linear combination only on patches of the sky, which is of course less suitable for a global first search than on the whole sky. On the other hand, we hope to reach a higher sensitivity to the presence of clusters.

2 Method

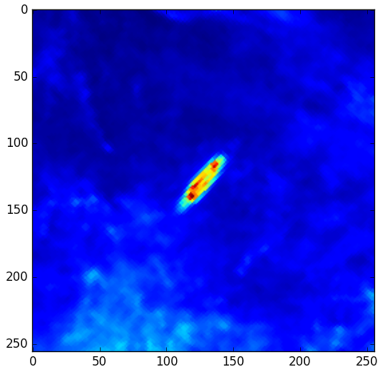
2.1 Smoothing the maps

As we do a linear combination, we need the maps to be at the same resolution. Otherwise, we wouldn't obtain zero by substracting the same object at different resolutions, but extra details brought by higher resolution.

The lowest frequency we use is 100 GHz and its angular precision is 9.7 arcmin, so we smooth every map at this precision, and we degrade each map to 12×512^2 pixels (which was actually more necessary for the global search project than for ours).

2.2 Patch creation

We build patches with a preselected cluster in the middle; to test that our zoom on the sky map works, we tried it on Andromeda (at 857 GHz, hence the higher resolution) :



In principle, since we want to reconstruct clusters, we should be blind to their positions; however, in order to make sure that we have something to reconstruct, we choose clusters, and with high SNR values, for a start.

2.3 Internal Linear Combination

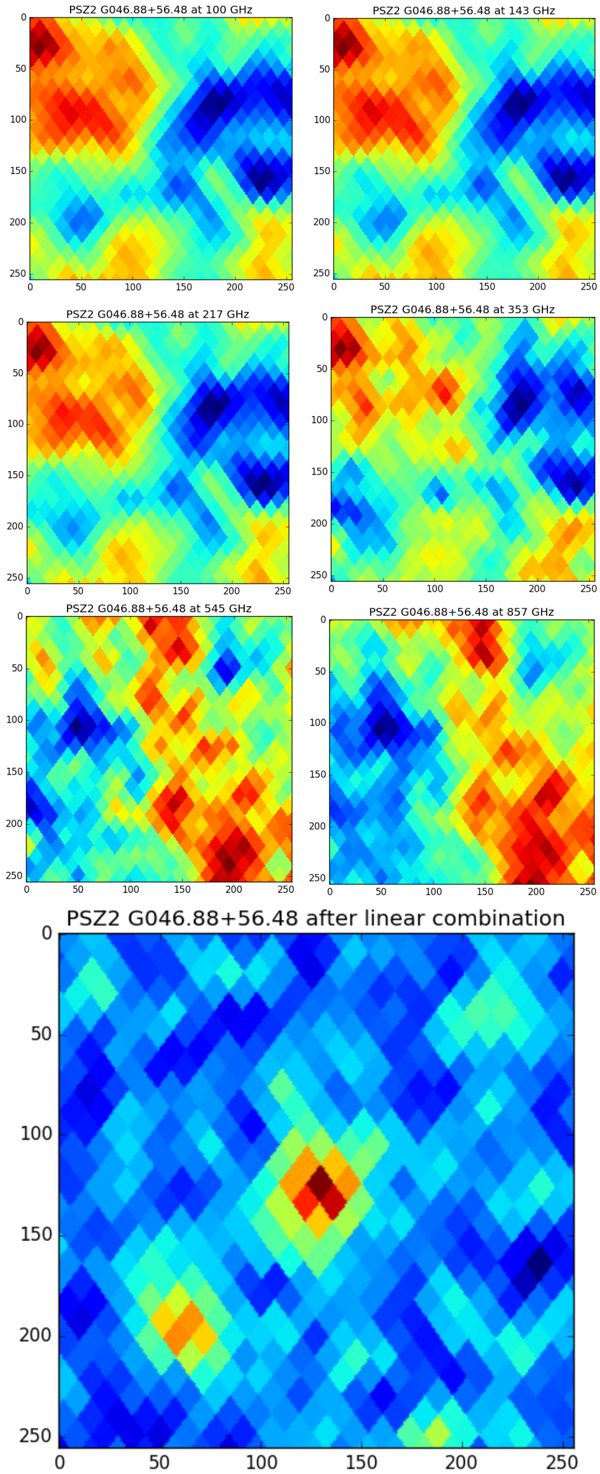
We now want to compute coefficients for each map (each frequency). As a first step, we convert the maps in y_{SZ} units (given in [3], table 6) – since we want to use the SZ effect to extract the signature of the cluster.

We compute the map-to-map covariance matrix whose element [i,j] quantifies the correlation between maps i and j :

$$C_{ij} = \langle \Delta T_i \Delta T_j \rangle = \frac{1}{N_{\text{pix}}} \sum_{p=i}^{N_{\text{pix}}} (T^i(p) - \bar{T^i})(T^j(p) - \bar{T^j}). \tag{1}$$

The weights for the linear combination are then computed as follows :

$$w_i = \frac{\sum_{j=1}^{k} C_{ij}^{-1}}{\sum_{jk} C_{jk}^{-1}}, \tag{2}$$



The six maps of Planck around a cluster and the result of their linear combination.

3 Comparisons

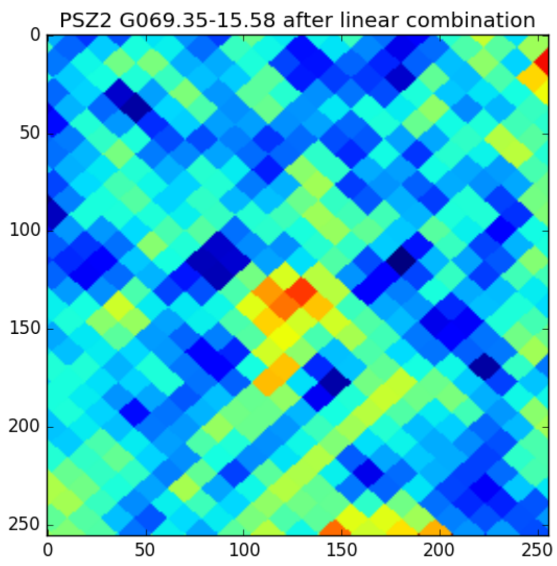
3.1 Different SNR

The previously described method is known to be less accurate at low SNR; we tested it for decreasing SNR values and found that it does actually work until an SNR of 4.5 (almost the lowest of the Planck catalog) :

Cluster	SNR	Detected
PSZ2 G006.76+30.45	35.01	Yes
PSZ2 G006.49+50.56	23.17	Yes
PSZ2 G003.93-59.41	17.36	Yes
PSZ2 G046.88+56.48	12.93	Yes
PSZ2 G008.47-56.34	10.05	Yes
PSZ2 G004.45-19.55	9.07	Yes
PSZ2 G029.80-17.40	9.01	No
PSZ2 G028.77-33.56	8.74	Yes
PSZ2 G044.77-51.30	8.27	Yes
PSZ2 G002.82+39.23	8.07	Yes
PSZ2 G028.89+60.13	7.52	Yes
PSZ2 G012.59-20.10	7.01	Yes
PSZ2 G049.09+25.23	6.10	Yes
PSZ2 G029.55-60.16	5.03	Yes
PSZ2 G069.35-15.58	4.57	Yes

Table 1: Results of cluster identification when taking decreasing SNR.

The contrast naturally diminishes with the SNR, but we can still recognize the cluster's signal :



Region of the sky around cluster PSZ2 G069.35-15.58 after linear combination on this patch

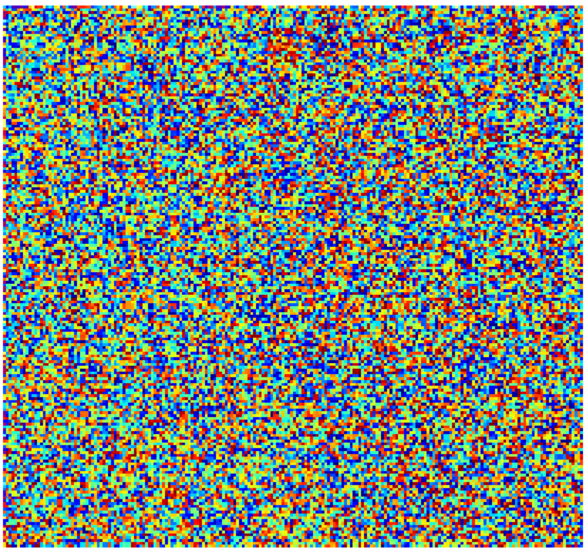
3.2 Comparison with the whole sky method

We compare our results with the team that did the same work but on the whole sky.

Cluster	SNR	Local (us)	Global
PSZ2 G006.76+30.45	35.01	Yes	Yes
PSZ2 G006.49+50.56	23.17	Yes	Yes
PSZ2 G003.93-59.41	17.36	Yes	Yes
PSZ2 G046.88+56.48	12.93	Yes	Yes
PSZ2 G008.47-56.34	10.05	Yes	Yes
PSZ2 G004.45-19.55	9.07	Yes	Yes
PSZ2 G029.80-17.40	9.01	No	No
PSZ2 G028.77-33.56	8.74	Yes	No
PSZ2 G044.77-51.30	8.27	Yes	No
PSZ2 G002.82+39.23	8.07	Yes	Yes
PSZ2 G028.89+60.13	7.52	Yes	No
PSZ2 G012.59-20.10	7.01	Yes	No
PSZ2 G049.09+25.23	6.10	Yes	No
PSZ2 G029.55-60.16	5.03	Yes	No
PSZ2 G069.35-15.58	4.57	Yes	No

Table 2: Results of the global method on the same clusters.

As we can see, the global method stops working at higher SNR values, of about 10. If we look at the linear combination carried out on the whole sky, and then zoom on our 4.57-SNR-cluster, we cannot distinguish the cluster anymore :



Same region of the sky, around cluster PSZ2 G069.35-15.58, after linear combination on the whole sky

4 Conclusion

By a set of nine frequency channels, spanning the range from 30 to 857 GHz, chosen with the SZ effect in mind, Planck enables us to identify new clusters and superclusters, even if its primary goal is to study the CMB.

For our project, we used only the six highest frequencies of Planck. Among the 1653 clusters of the Planck SZ database, the global method could reconstruct 58, until an SNR of about 10. The local method enables us to reconstruct signals until lower values of SNR. The next steps would have been to check the percentage of clusters it's able to identify over the 1653 in the Planck database, and to do some photometry in order to quantify better the results.

References

[1] H. K. Eriksen, A. J. Banday, K. M. Gorski and P. B. Lilje, *On foreground removal from the Wilkinson Microwave Anisotropy Probe data by an internal linear combination method: limitations and implications*, 2008.

[2] G. Hurier, J. F. Macias Perez, S. Hildebrandt, *MILCA, a Modified Internal Linear Combination Algorithm to extract astrophysical emissions from multi-frequency sky maps*, 2013.

[3] `planck.caltech.edu/pub/2013results/Planck_2013_results_09.pdf`

[4] `sci.esa.int/planck/47692-planck-s-first-glimpse-at-galaxy-clusters-a-new-supercluster/`