Overview of Pathfinder Data: Correlated Noise

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1 Introduction

This is an overview of the different components of correlated noise we have found in the analysis of the data here in Oslo. By correlated noise, we here mean noise that is correlated in time (e.g. 1/f noise etc.). The good news is that all the components of correlated noise we have found are also correlated between frequencies, which makes it easier to identify and filter the correlated noise out, or in the worst case identify and mask "bad channels".

We will start with a short overview of the main analysis steps currently performed on the data in the Oslo pipeline. We will then go through and discuss each of the identified components of correlated noise.

The data show in this document all comes from the obsid 2062, a CES (squashed lissajous) scan of the co2 field. This is a fairly old dataset, but the different correlated noise components seem to be essentially the same in more recent data.

2 Analysis Procedures

The main steps of the Oslo analysis pipeline that the raw data goes through are as follows (in order):

1. Normalization: We divide the time-ordered-data (TOD) by its running mean (on a timescale of $1/0.003\,\mathrm{Hz} \sim 5.5\,\mathrm{min}$), and subtract 1. We can look at this as a normalization and a weak highpass-filter. The normalization is such that in the absence of correlated noise the timestreams after this procedure would be white noise with a variance of $1/B\tau$.

2. Mask "bad" frequency channels: The "bad" channels are found by applying the poly- and PCA-filters (described below) on a copy of the original dataset and then identifying which channels are outliers in various diagnostics, indicating that they still have a large amount of correlated noise in them. Throw away the copied data, and go on with the analysis of the original data but now with the "bad" channels (that we have just identified) masked out.

3. Polyfilter: At each timestep subtract a best fit first order polynomial in frequency across each sideband.

4. PCA-filter: Find the functions of time which explains the largest amount of the variance between the different frequencies across all

the different detectors. Find the amplitude of these PCA-components for each frequency (take the dot product in the n_{samp} dimensional vector space of possible time-streams), and subtract each component multiplied by the corresponding amplitude from each frequency. We subtract the 3 leading PCA-components this way.

3 Correlated Noise

3.1 Detector Noise

The main contributor to the correlated noise is the noise from the detectors themselves. The good thing about this contribution is that it is extremely correlated within each detector, making it easier to separate out and remove (see top Figure 1). Calculating the mean value within each sideband at each timestep we get the common mode that we can subtract from the TOD to significantly reduce the correlated noise (see bottom Figure 1).

3.2 Global Common-Mode

Another important contribution to the correlated noise is the global common-mode, this is found in all of the detectors, and becomes apparent after we have performed the polynomial filter in frequency (see top Figure 2).

Performing a global PCA analysis picks out the common mode. We see that removing this component will, in many cases, leave the TOD almost completely uncorrelated (see bottom Figure 2). The amplitude of this common mode changes quite a bit between different frequencies and detectors (see Figure 3).

The origin of the common mode is not clear, but we can at least say some things:

- It affects all detectors, although to varying degrees. detectors 11 and 12 seem least affected.
- It is not simply adding power, it leads to both positive and negative fluctuations. The main spikes in the signal tends to go in the same direction, but since the amplitude of the mode is as likely to be positive or negative, these spikes can add or subtract power depending on what frequency we are looking at (see Figure 4).
- It is very well, but not completely (as we will see), filtered out by removing a single PCA-mode.

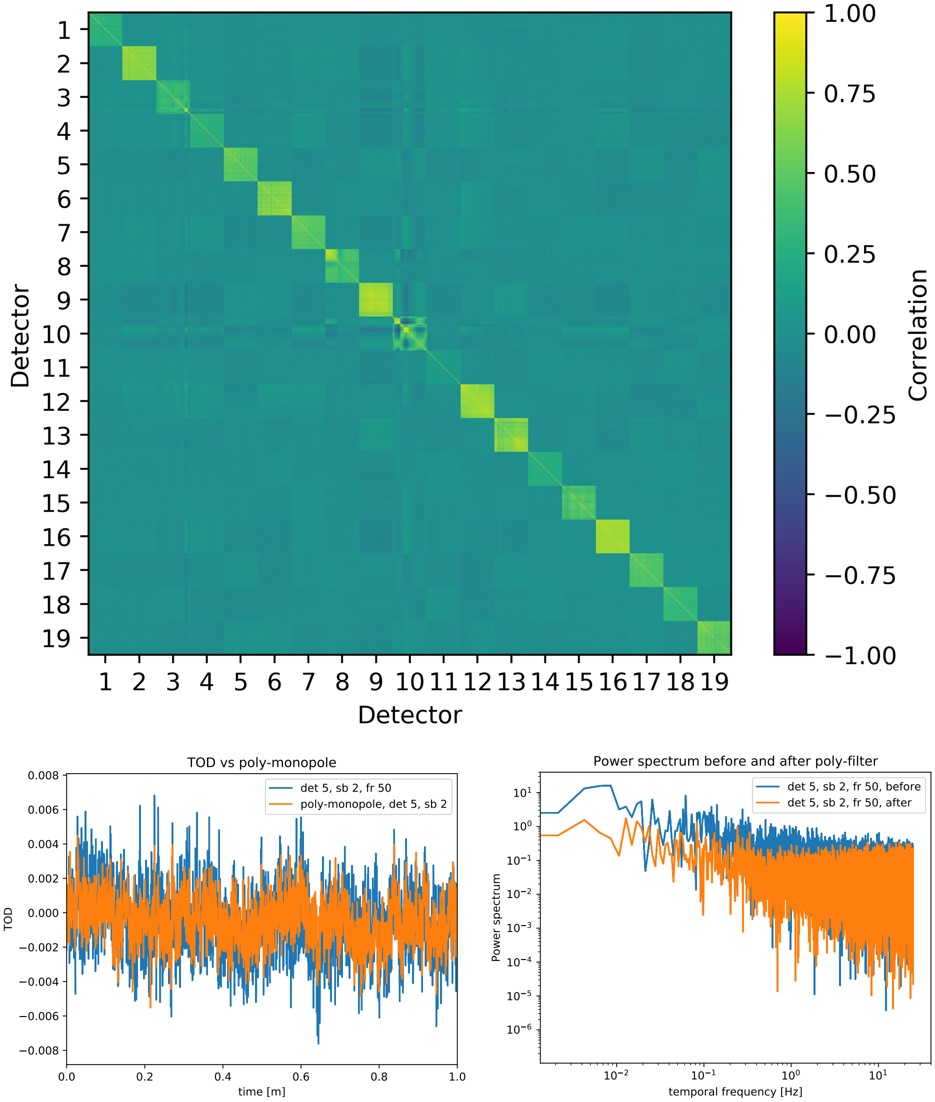

Figure 1: Top: Correlation between frequency channels on different detectors, after the raw TOD has been divided by its running mean. We see that the main correlations are between frequencies within detectors. These are typically correlated at levels from around 20 - 60 %. Bottom left: Comparison between a single frequency TOD and the average TOD across the whole sideband. Bottom right: Corresponding power spectrum before and after the polynomial filter in frequency.

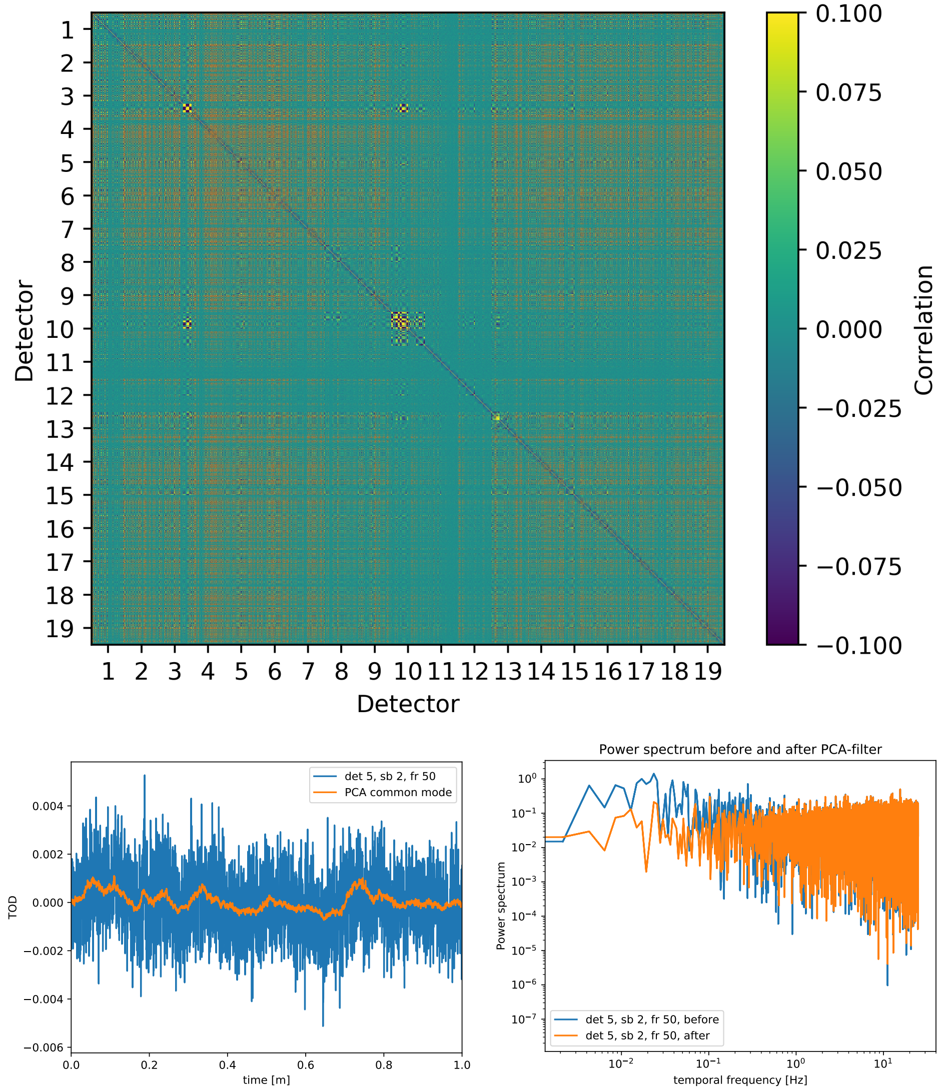

Figure 2: Top: Correlation between frequency channels on different detectors, after applying the polyfilter (note the color scale here is different from Figure 1). We see various levels of correlation between frequencies at different detectors. Bottom left: Comparison between a single frequency TOD and the PCA-component corresponding to the global common mode. Bottom right: Corresponding power spectrum before and after the PCA filter. Note that after the PCA-filter the power spectrum looks almost completely white.

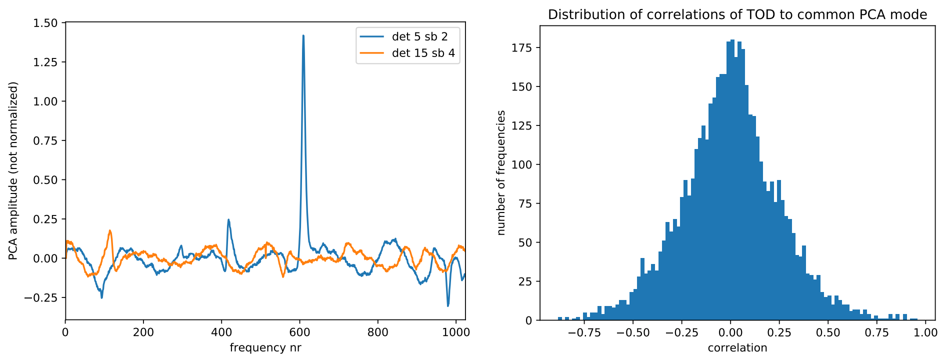

Figure 3: Left: Example of PCA amplitudes for different frequencies within a sideband. Right: Distribution of correlations between single frequencies and the global common mode. We see that we have roughly as many negative amplitudes as we have positive.

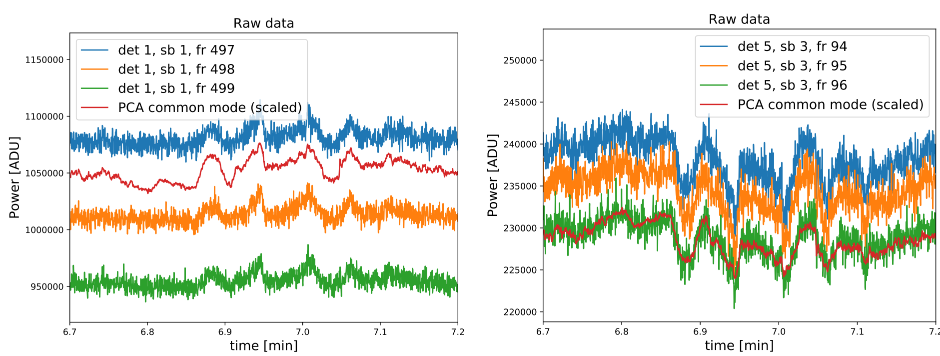

Figure 4: Examples of the common mode in the raw data. Left: Frequencies where the main spikes add power. Right: Frequencies where the main spikes remove power.

3.3 Residual Common Mode

There are individual or groups of nearby frequencies that have a large amount of correlated noise (see top Figure 5). This effect seems highly correlated to, although linearly independent of, the PCA - common mode (see bottom left Figure 5). This effect is only clear in detectors 1-7, and not in the detectors on the outer layer of the focal plane. I am not sure what, if anything that means, but it should at least be noted. The timestream of the signal was extracted by taking the average of many of channels recogniced by eye to have this effect. The signal looks to be essentially the same in all of these frequencies and groups of frequencies, and it also seems also to be present in the other frequencies of the affected detectors (at least detectors 2-7), where the median correlation to the signal was roughly 4-6 % (compared to 20-70 % correlations in the channels identified by eye).

The residual signal in any given frequency is generally in the opposite direction of the common mode that was previously present in this frequency, suggesting that the PCA filter oversubtracted this common mode. However, the medium-sized peaks in the signal (in the same direction as the main spikes) seem to be subtracted correctly, while the largest peaks are undersubtracted (Hence the residual is in the same direction as the original signal).

The sinplest way to explain this pattern is for there to be some non-linear effect that makes these frequencies respond stronger to whatever causes the global common mode when there is a large spike and respond less strong when there are smaller fluctuations (as compared to the average response of the other frequencies to ths same cause). The best fit PCA amplitude will then be a compromise between trying to fit the really large peaks (where we need a large amplitude), and trying to fit the regular fluctuations (where we need a small amplitude). Using the ampltude resulting from this compromise to subtract the PCA common mode will then tend to oversubtract the small fluctuations and undersubtract the large fluctuations leading to exactly the observed pattern.

3.4 Roach 1 Edge Effects

The most prominent feature in the correlation plots once the PCA-filter has been applied, except fore some detectors with serious problems, are the correlations between roach 1 on each detector. These correlations are most prominent at the edge frequencies, but are also present in the other frequencies (see top Figure 6).

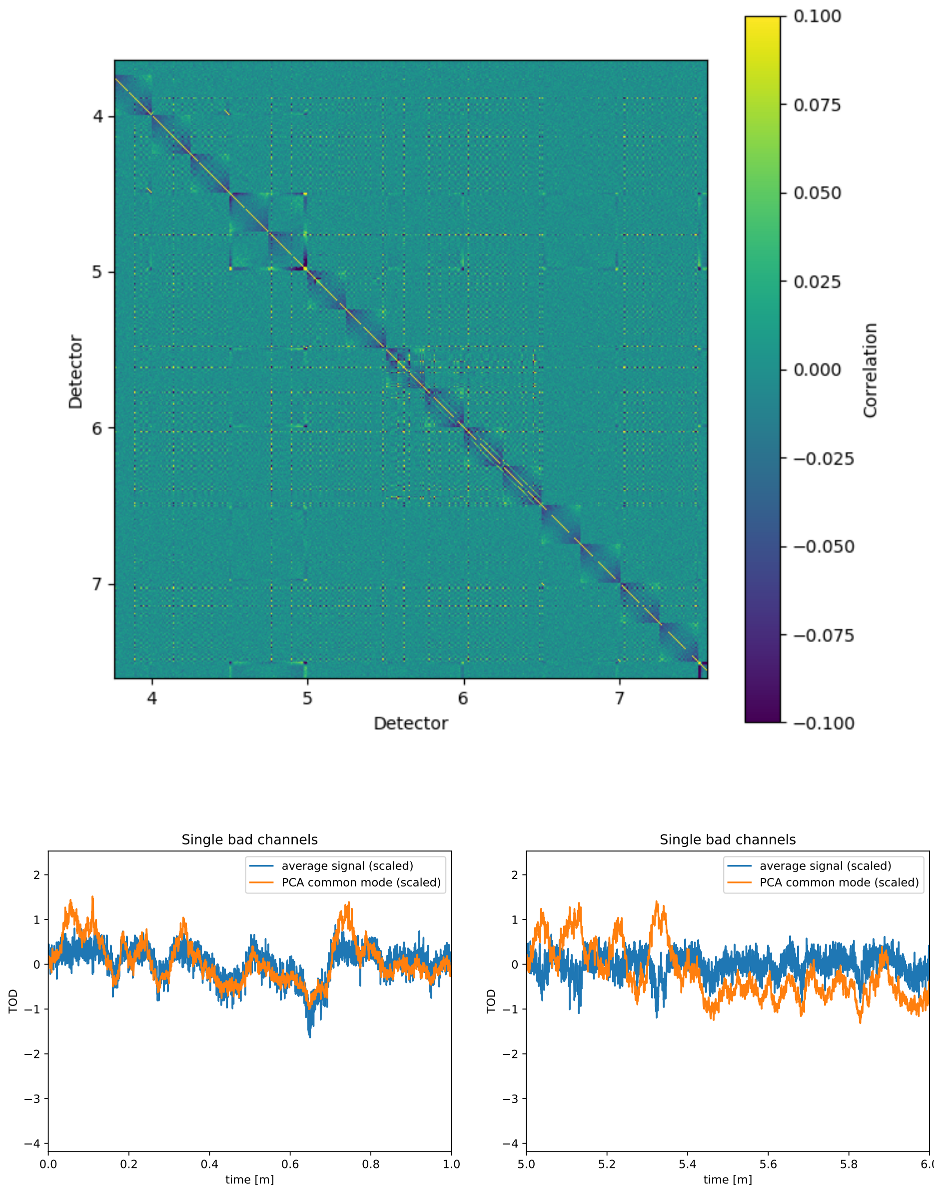

Figure 5: Top: Correlation between frequency channels on different detectors, after applying the polynomial and the PCA-filter. Individual and groups of frequencies show large correlations since they contain a common signal. Bottom left: Comparison of signal to the PCA common mode. The two timestreams are clearly connected but it seems like the signal from the individual frequencies seems to saturate, meaning that the positive peaks are removed. Bottom right: Same as left only some time later. We scaled the two timelines to fit for the first minute, however, here we see that the relative sign is changed when there is a large peak in the PCA common mode.

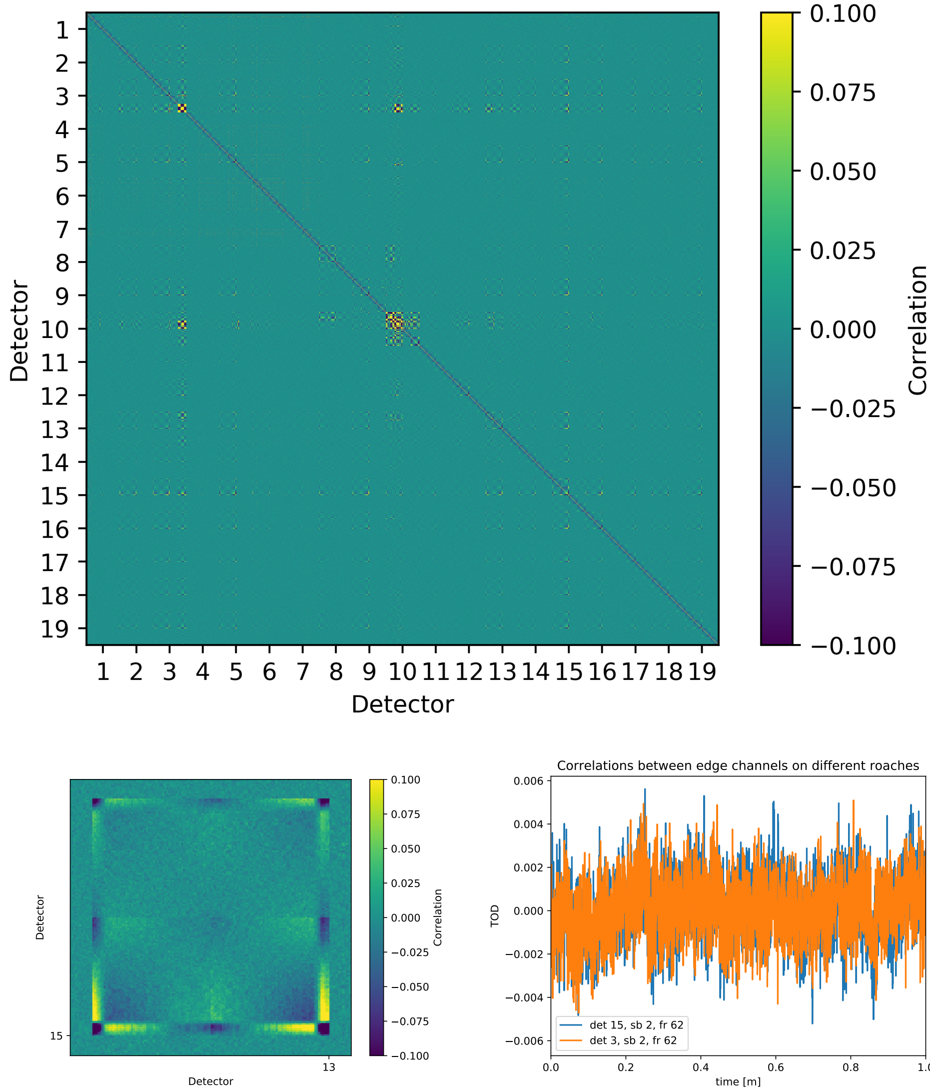

Figure 6: Top: Correlation between frequency channels on different detectors, after applying the polynomial and the PCA-filter. The main features are the correlations between roach 1 on each detector. Bottom left: Zoom-in on the correlation structure of 1 roach. Bottom right: Comparison between TOD for two frequencies on different detectors.

3.5 Specific Separations

In detector 6 we see clear correlations on the 2-4% level between channels with a separation of 9 and 10 channels (see Figure 7).

In order to understand this effect better we can look at the high resolution correlation plot, before we co-add frequencies from 1024 to 64 channels per sideband. In Figure 8 we see that it is not just affecting channels at a single specific separation, but that channels separated by roughly 150 channels tend to be more correlated than other channels, and that this effect adds up when we co-add channels to the low resolution grid. Where the number 150 comes from, and why this only shows up in detector 6 is still unclear.

When looking at other data the specific separation where the excess correlation happens can change (see Figure 9), note also that here we can see a higher harmonic at twice the separation of the main off-diagonal stripe.

One more point should be noted in the high-resolution correlation plot. We see small correlations (2-4%) between neighbouring channels. This is also found in the other detectors, not just in detector 6. Is this rougly the level we should expect?

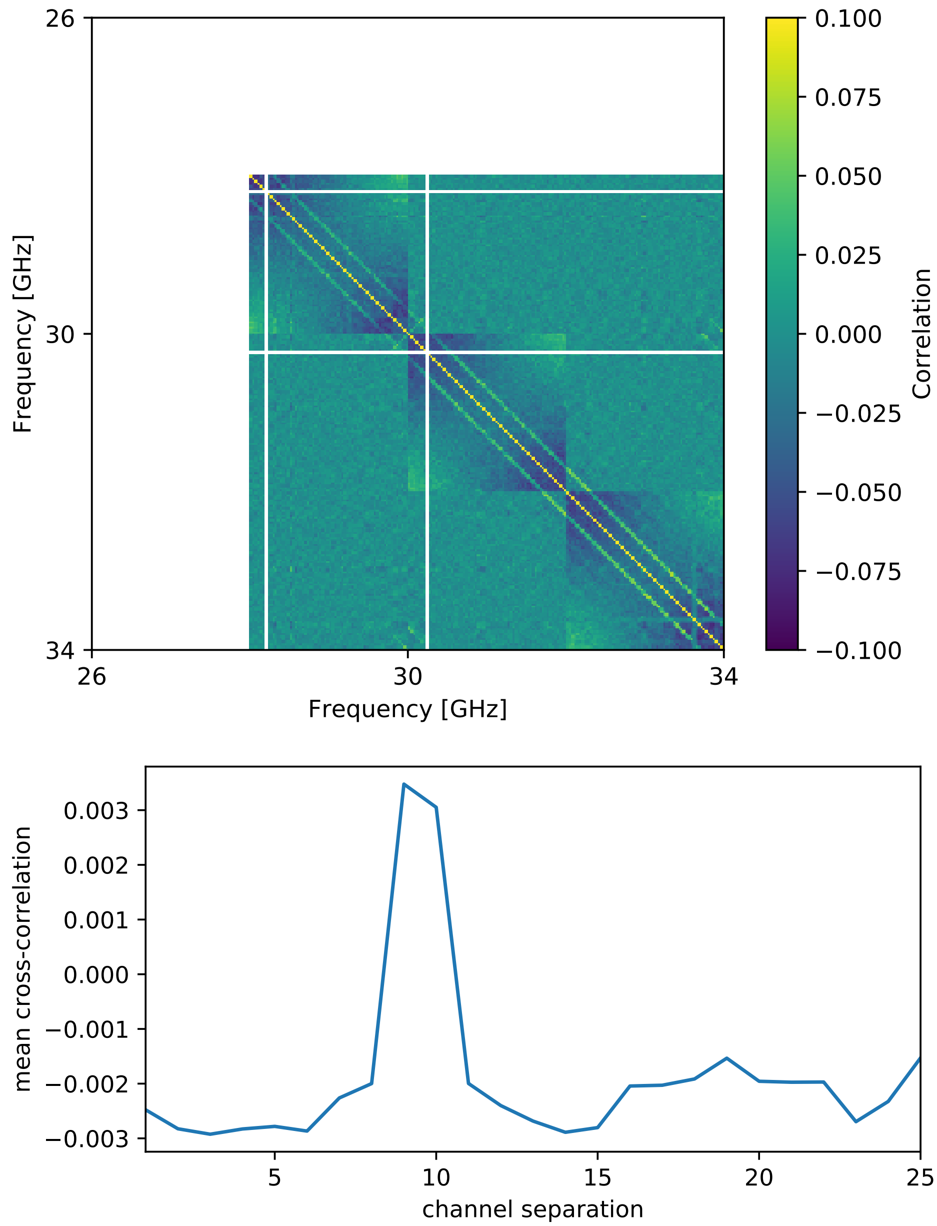

Figure 7: Top: Correlation between frequency channels on detector 6, after applying the polynomial and PCA-filters as well as the frequency mask. We see clear off-diagonal stripes at a separation of 9-10 channels. Bottom: Mean cross correlation between channels separated by different number of channels on detector 6.

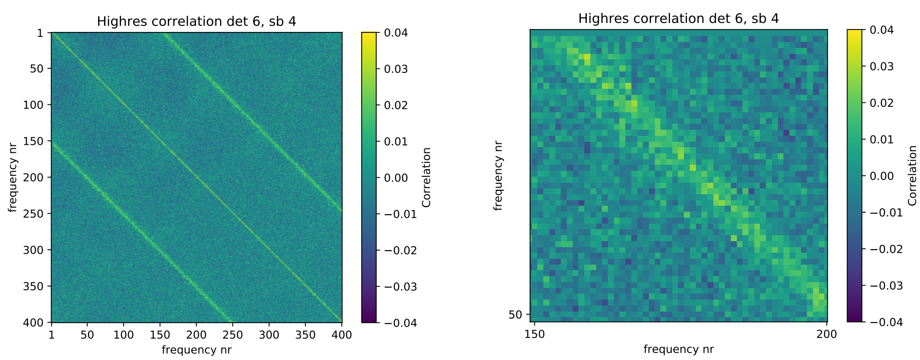

Figure 8: Left: Correlation between high resolution frequency channels on detector 6 sideband 4, after applying the polynomial and PCA-filters. Right: Same as left but zoomed in on the correlation stripe.

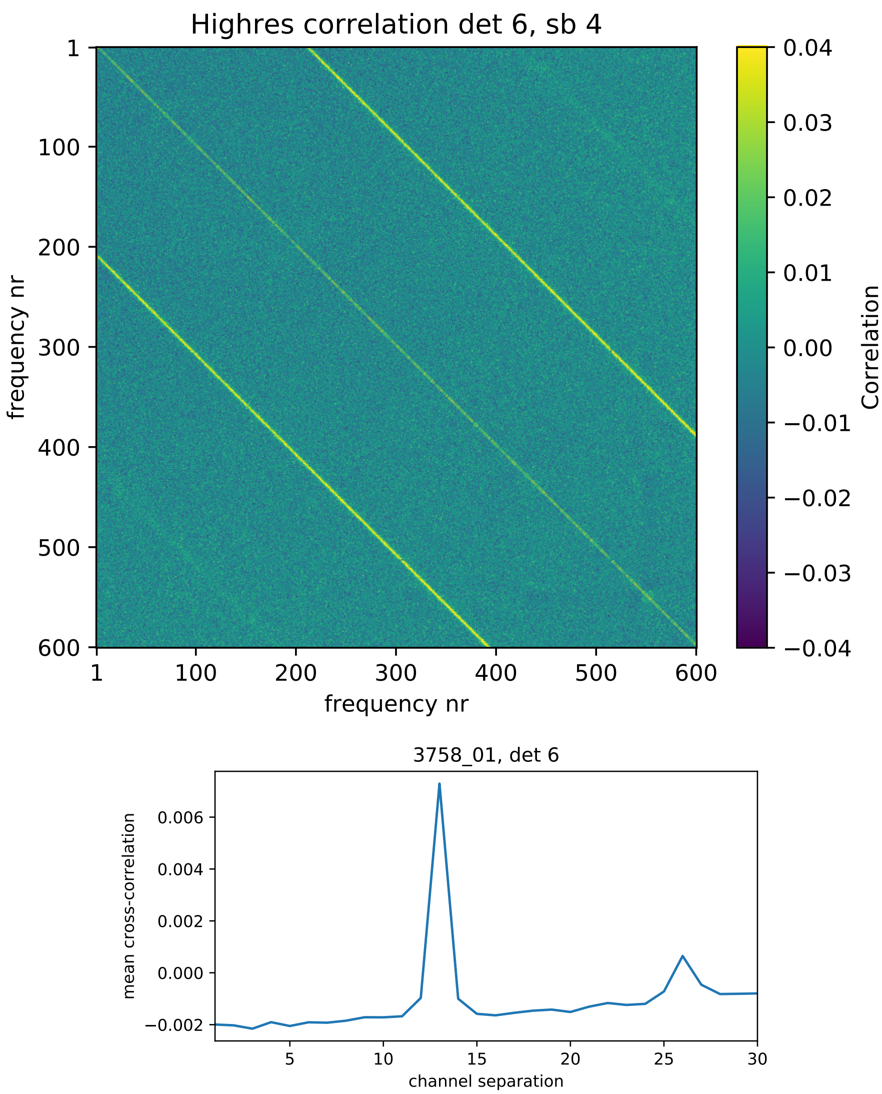

Figure 9: Top: Correlation between high resolution frequency channels on detector 6 sideband 4, after applying the polynomial and PCA-filters. This is in newer data, obsid 3758. Bottom: Mean cross correlation between channels separated by different number of channels on detector 6.