CMB-S4 Summer Meeting

Mandelli

Simulating and Mitigating the Atmospheric Effects for CMB ground-based Observations

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Presentation overview

Introduction

CMB observation approaches

- Satellite mission
- Balloon-Based telescope
- Ground-Based telescope

Analysis approach

- **The B-modes detection**: limited by the control of the systematic effects
  - Requires to use a **sinergistic approach** between all of these philosophies
- The systematic contributions has to be **characterized** and **modelized** as better as we can.

Systematic Effects

The atmosphere

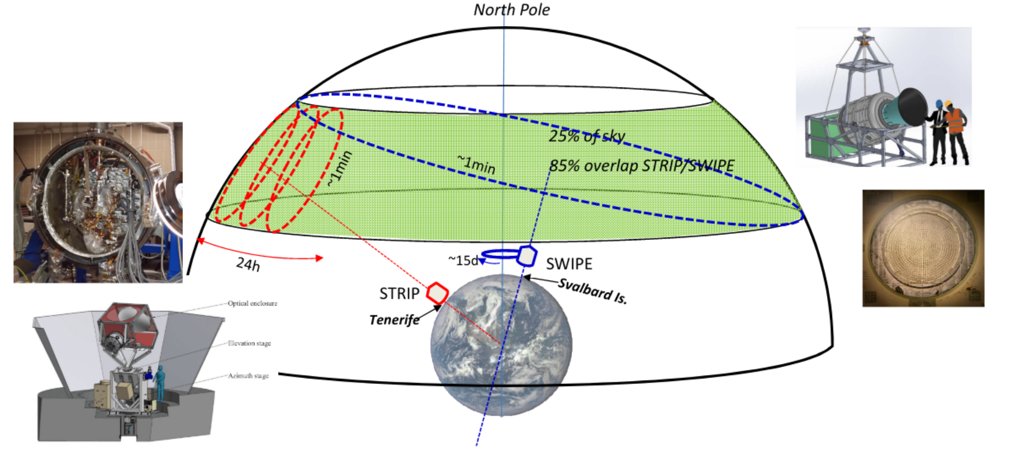
The atmospheric spurious contribution

The atmospheric load represents the **main contribution** of noise for CMB ground-based telescope.

- We have considered the atmospheric emission **unpolarized**.
- The main contribution (if we exclude the O_2 Zeeman's emission) is due to the **instrumental leakage** from I to P channel.
- In this context, the atmospheric pattern that we can find in the I channel, is the **same** that is present in the **P channel** (with a rescale factor due to the leakage parameter, 1% for LSPE/Strip Q-band focalplane).
- I have studied the atmospheric effects in temperature, and I created an adaptive mapmaker to mitigate its fluctuations.

LSPE Experiment

The main features of the LSPE experiment[1]



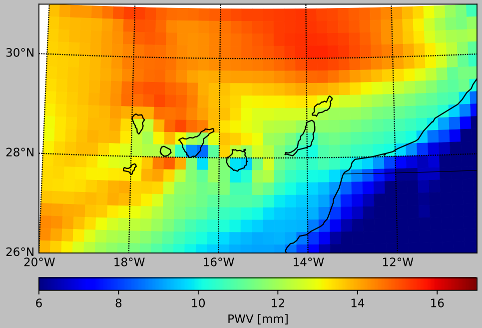
[1] 10.1088/1475-7516/2021/08/008 JCAP

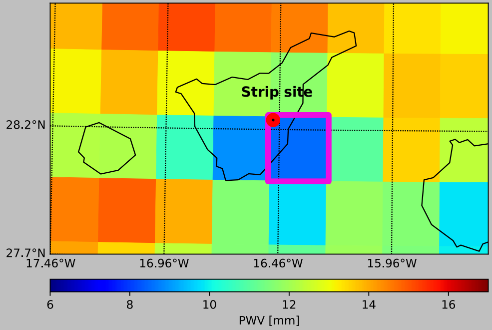
The Atmospheric Statistical Picture

The white noise estimation

Collect the wheater history of the site

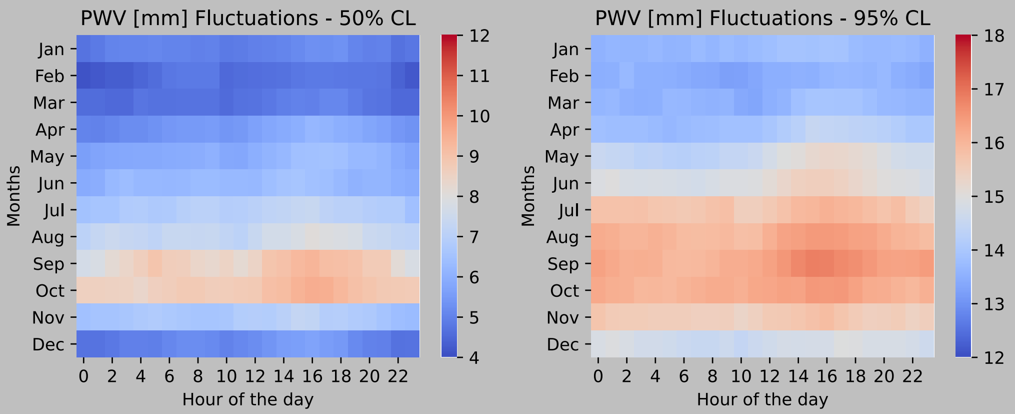
ERA-5 graphical representation





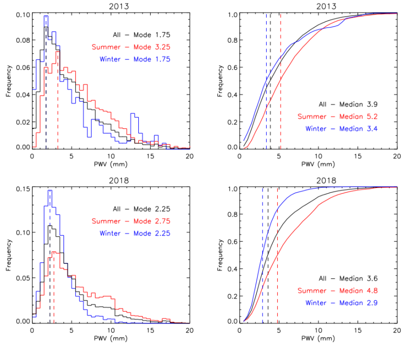
White noise seasonal fluctuations

White noise



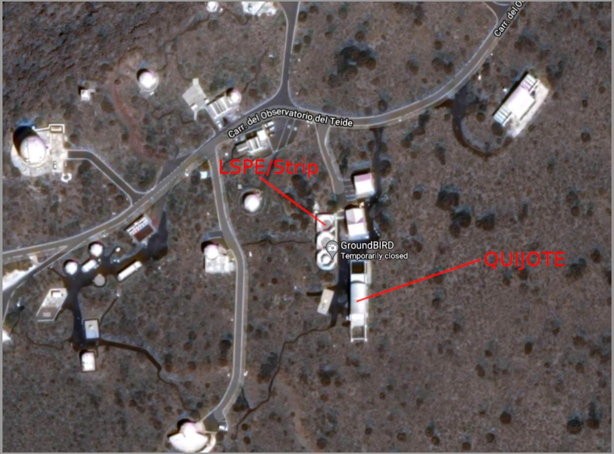
The actual atmospheric quality from Teide Observatory

PWV Observed by QUIJOTE



- Median PWV = 3.7mm
- During the good weather condition (the 20% of the observations) the PWV was below 2mm.
- **We have to find a way to correct/calibrate the ERA-5 data**

Comparison with QUIJOTE MFI



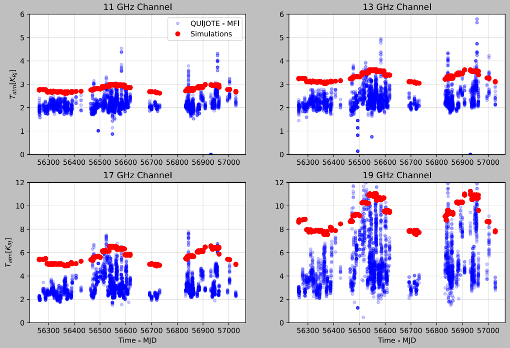
The QUIJOTE telescope is located at Observatorio del Teide (2400 m), near the LSPE/Strip site. We can share data about

- **Instrumental systematics**
- **Atmospheric fluctuations**.

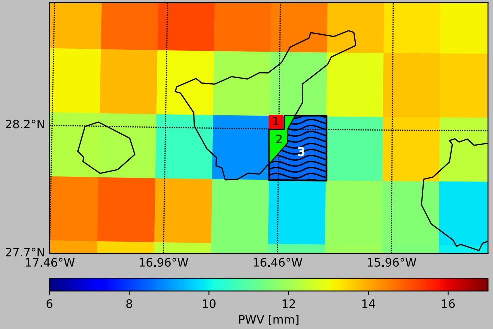
The site location represent a great opportunity to approach a joint data analysis

Comparison with QUIJOTE MFI

Simulations and measurements



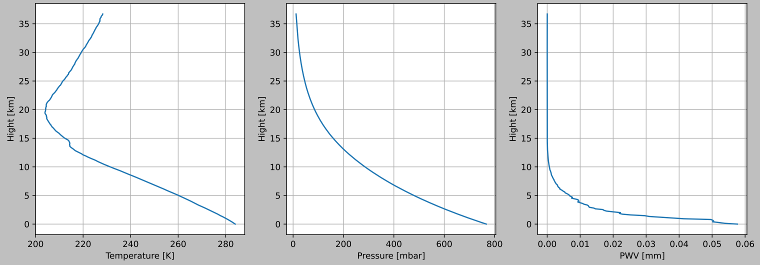
Contribute of the ocean



Balloon measurements

To mitigate the spatial resolution issue, we used the atmospheric profiles measured from Izaña by balloon probes

Profiles

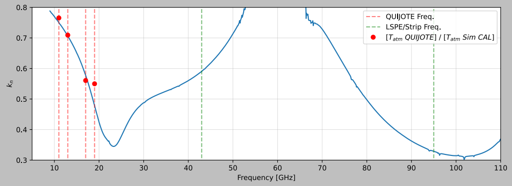


- Point like spatial resolution
- Poor temporal resolution
- Annual median profiles

Pixel calibration

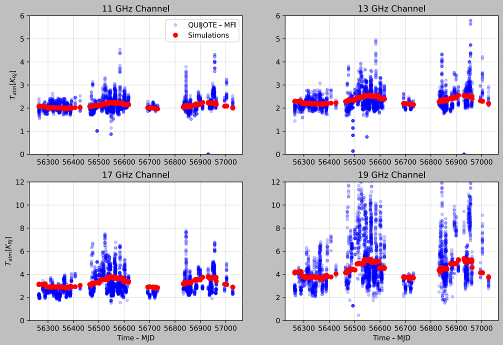
Using CAL[2] and AM we have estimated the contribute of the ocean.

Correction factor



- **Blue line:** represents k_ν evaluated with simulated T_{atm}
- **Red points:** k_ν out of QUIJOTE measurements and CAL simulation

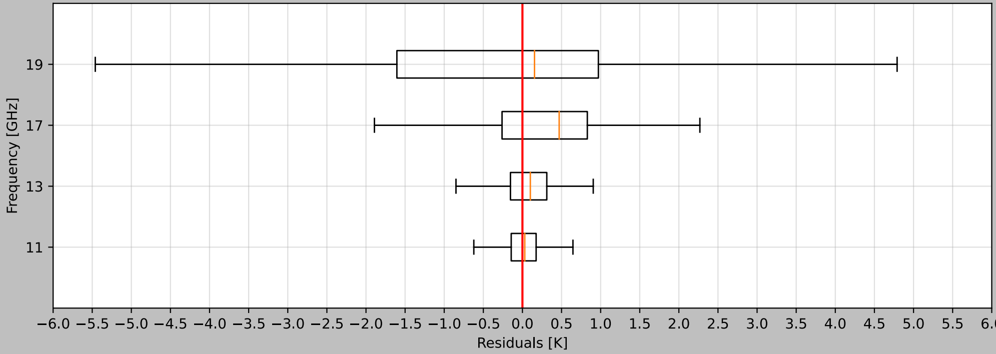
Comparison with the data



[2] doi.org/10.5281/zenodo.4597960

Simulations and data compatibility level

(Observed - Simulated) residuals



The boxplots are compatible to zero within 1σ

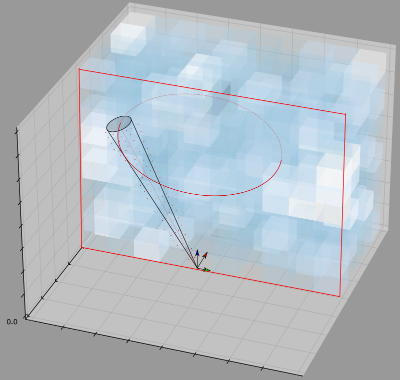
The Atmospheric Statistical Picture

Atmospheric correlations

The atmospheric correlations

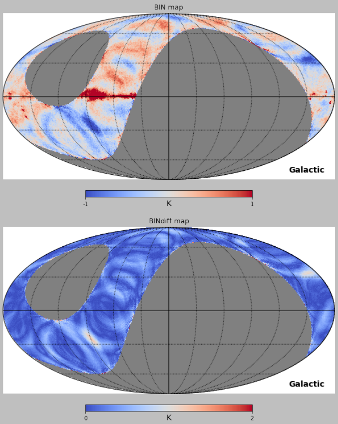
Kolmogorov Power Specturm

- The atm emission: is due by O_2 and H_2O
- The O_2 molecules are well mixed in the atmosphere
- The H_2O create turbulent structures (described by Kolmogorov)
- The features of this noise are difficult to characterized
  - The atmospheric conditions show different levels of fluctuations in time
  - These fluctuations are "convolved" with telescope scanning strategy

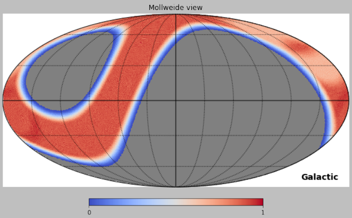


Binned maps

January



Hit map



The scan velocity is modulated as a function of the AZ angle

- **Hit homogeneously distributed**
- **Increase the number of cross-links**

Mitigation Techniques

Mitigation Techniques

- Let's start from the well know MM equation $P^t N^{-2} P m = P^t N^{-2} d$
- In the case of instrumental noise a good representation of the noise covariance matrix N^{-2} is represented by the noise model $n = \sigma^2 [1 + f_{knee}/f]^\alpha$, where the CX corr. are considered very small / negligible
- This is not true for atmospheric noise. The CX corr between detectors is dominant.

Noise model

We can complete the noise model with the atmospheric correlations

- $n(f) = \sigma^2 [1 + f_{knee}/f]^\alpha + N(w) \exp\left[-\frac{f^2}{2 * c(w)}\right]$

where $N(w)$ and $c(w)$ depend on the weather parameters w, in particular PWV, T_s, P_s. The $c(w)$ parameter depends on $1/L_0$. The parameters $N(w)$ and $c(w)$ are updated every hour.

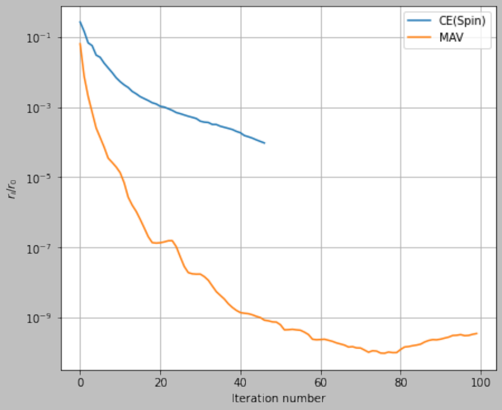
Mitigation Technique

To improve the atmospheric mitigation we can modify...

- Scanning strategy
  - CES at different speed $v(Az)$
  - Elevation modulation

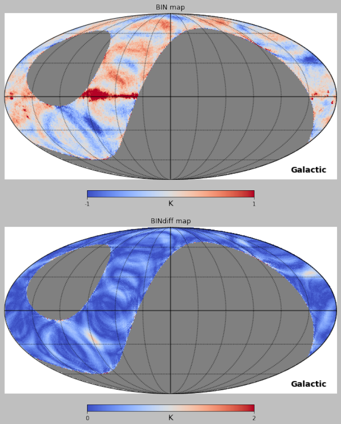
In this way, the hits on the map are more uniform ditributed. The increasing of the cross-links number improve the convergence speed-up of the conjugate gradient algorithm

Residuals

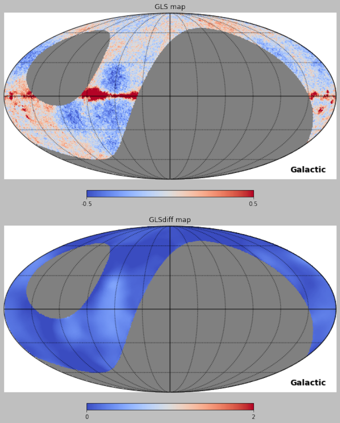


Denoised results

January - binned map



Denoised map



Conclusion and future persepectives

- Complete the mapmaker algorithm
  - Now the code is slow, in particular the part fast fourier transform part.
  - Now, it is written in Rust, but has to be converted in Julia (the language of the Strip simulation framework (by Maurizio Tomasi))
  -
- Create the polarization maps (Q and U)
  - Use the $I->Q$ and $I->U$ data to create polarization maps with atmospheric effects
  -
- Create the polarization map of the whole experiment duty cycle (1 year of observations)
  - Improve the efficiency of the mapmaker working on the speed-up of the fft part

Thank you for this great experience!