Atmospheric effects for gorund-based CMB observations

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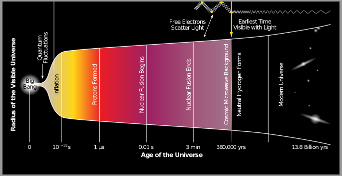
Introduce myself

- Study the Cosmic Microwave Background Radiation in intensity and polarization
  - LSPE/STRIP: Ground-Based telescope - Tenerife - late 2021
  - QUBIC: Ground-based telescope - Alto Chorrillo (Chile) - 2021/2022
  - LiteBIRD: Space satellite - L2 - in the 2020s decay
- PhD research project: atmospheric effects on CMB ground-based observations
  - Simulation of the atmospheric effects on the observed data
  - Impact on comological information
  - Elaborate mitigation techniques (software and hardware)

The CMB radiation

- Photons decoupled by matter 380.000 yeas after the big bang



- Intensity and polarization fluctuations of the order of $\Delta T/T \sim 10^{-4}$ and $\Delta T/T \sim 10^{-6}$, respectively
- The cosmological information is coded in the angular power spectum (two point correlation function on the sphere)

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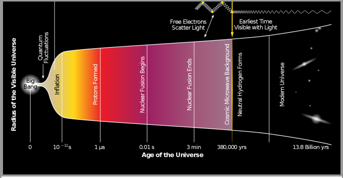

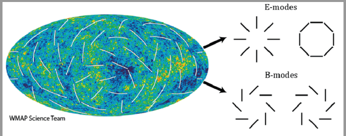

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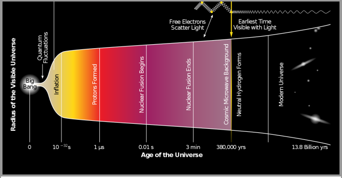

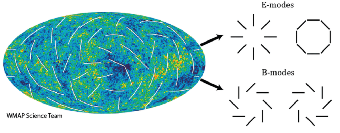

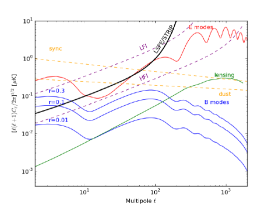

The atmosphere's role in the CMB observation

Atmospheric load in the microwave band

- Due to absorption / emission processes
  - Water vapor
  - Oxygen molecules
- The oxygen is well mixed in the atmosphere
- The water vapor presents highly variable concentrations

Assessment of the scientific impact

We have to create a model of the atmosphere and simulate its observation. We can start from the atmospheric dispersive proprieties

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The atmosphere as a dispersive medium

- Dispersive medium: $\varepsilon(\omega) = \varepsilon(\omega)_R + i\,\varepsilon(\omega)_I$
- The contribute to complex permittivity are due mostly to the water vapor and the oxygen molecules that are dissolved in the atmosphere
- $\varepsilon(\omega)_R = \sqrt{n}$, and $\varepsilon(\omega)_I = \lambda\alpha/4\pi$
- The real and imaginary parts of $\varepsilon(\omega)$ are linked by the Kramers-Krönig relations.
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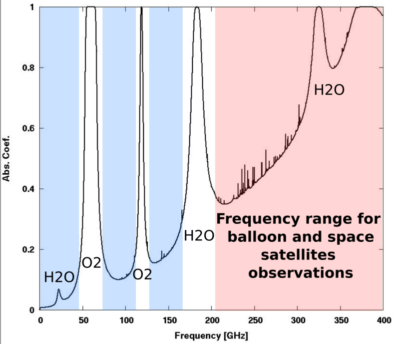

Fluctuations in the absorption coefficient

- Atmospheric brightness temperature is related to α: $T_B = \int_0^R \alpha(r) T_p(r) e^{-\tau'} \, dr$
- $e^{-\tau} \sim 1$, τ fluctuations are small compared to α
- Antenna temperature: $T_A = \frac{1}{\lambda^2} \int_V A(\hat{r}_s, \vec{r}) \alpha(\vec{r}) T_p(\vec{r}) \frac{dV}{r^2}$

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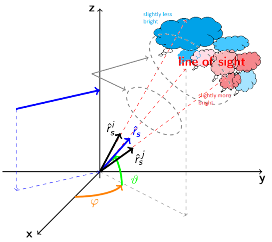

Atmosphere structures

The correlation term $\langle \alpha(r), \alpha(r') \rangle = \chi_1(|\vec{r} - \vec{r}'|) \chi_2(z, z')$.

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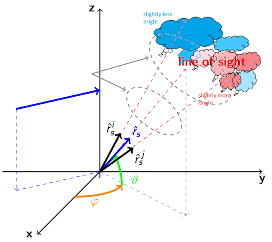

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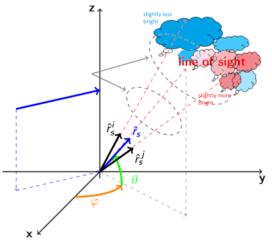

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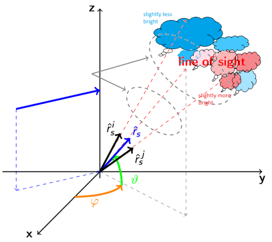

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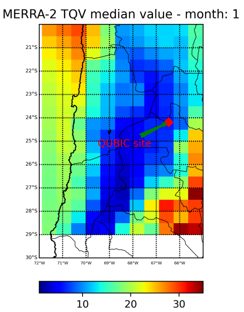
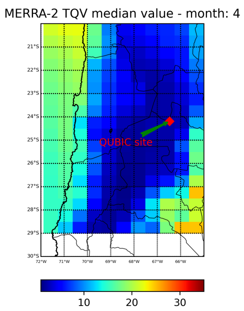
Atmospheric characterization - Alto Chorrillo

- MERRA2 reanalysis
  - TQV, TQL, TQI, HR
  - TS, PS

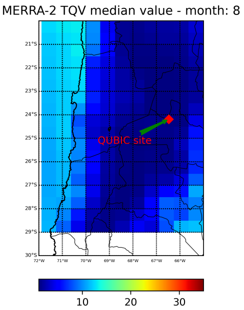
Graphical representation of the TQV distribution above the Atacama desert



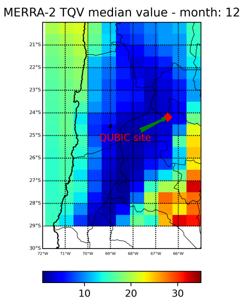
January



April



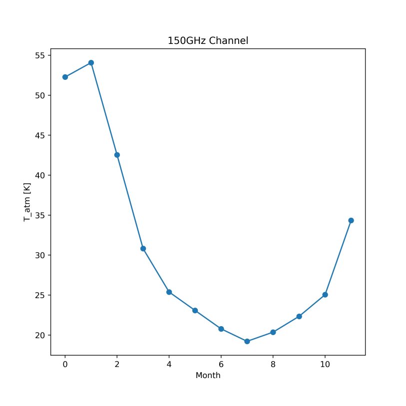
August

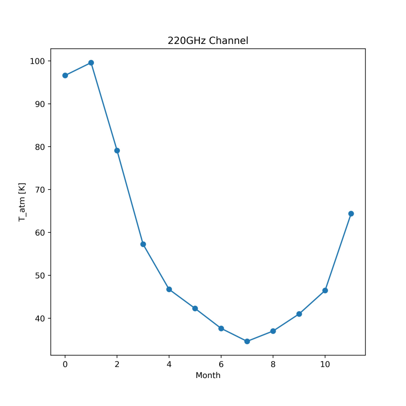


December

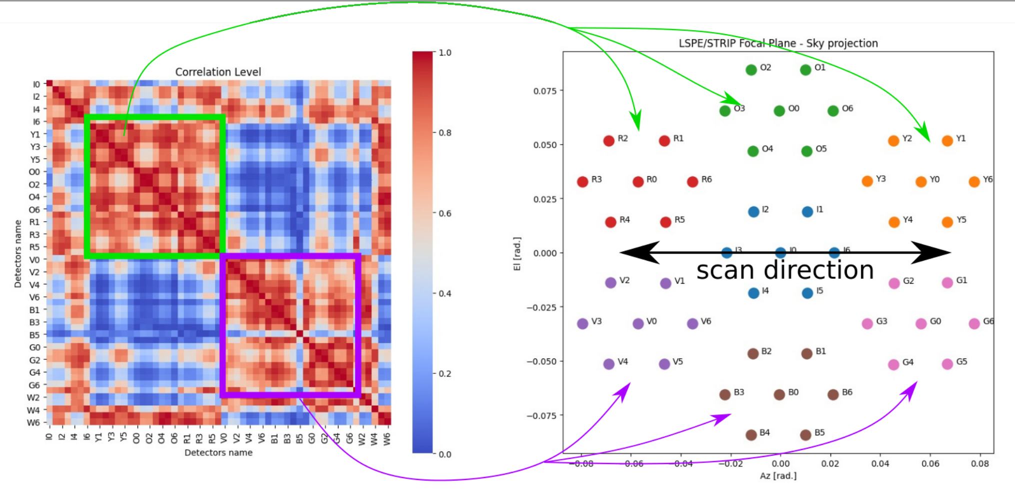
Atmosphere brightness temperature

The atmospheric emission follows a seasonal pattern





Spurious correlations between the detectors



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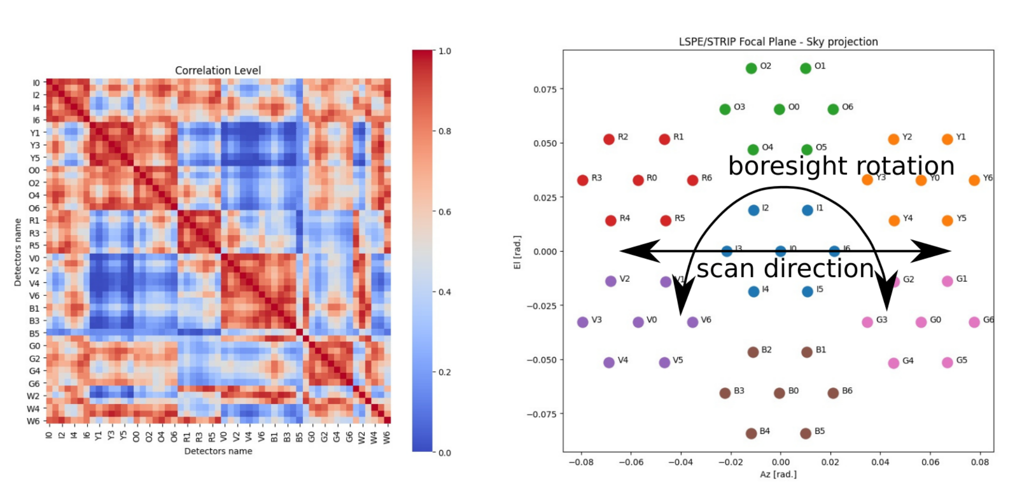
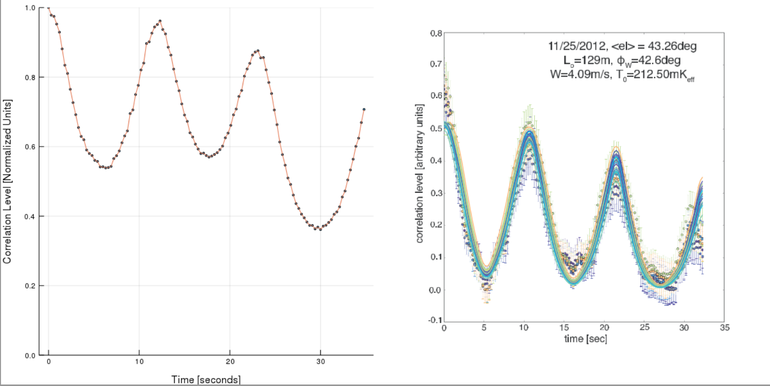


Time evolution of the single detectors autocorrelation functions

Low wind speed



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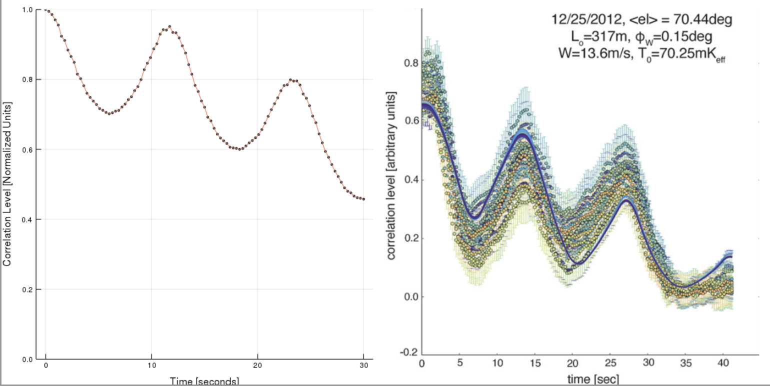
Medium wind speed



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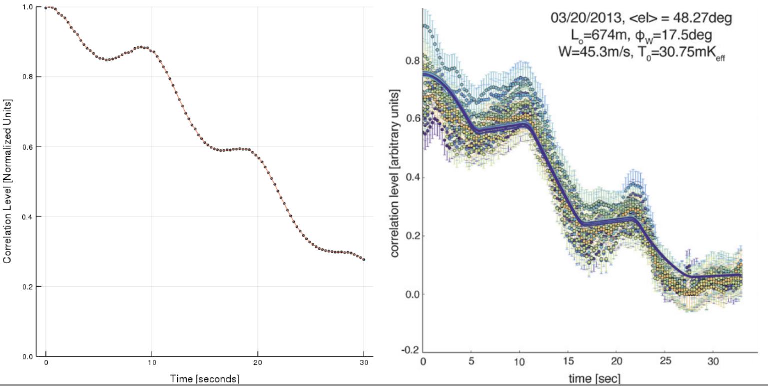
Medium wind speed along transverse direction



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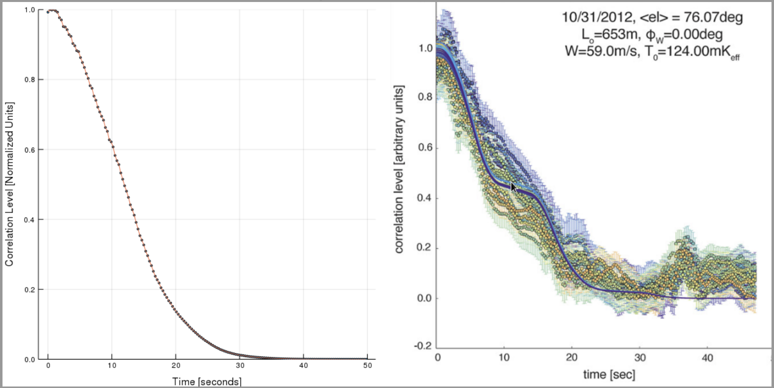
High wind speed



Conclusion

- Atmospheric effects
  - Increase white noise
  - introduce 1/f spurious noise
- Simulations play a key role in order to
  - Assess the atmosphere impact on data
  - Recognize the typical pattern in the correlation and autorrelation functions
  - Get rid of using filtering template matching tecniques in sinergy with sensible scanning strategy

Thank you for watching!

If you have any question, please contact me at: `stefano.mandelli@unimi.it`
All the plots and simulations were performed using the atmospheric framework CAL that I have developed: `https://github.com/cmbgroundbased/cal`