High Resolution analysis of the South Pole Atmosphere for BICEP/Keck CMB observations

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FROM PLANCK TO THE FUTURE OF CMB
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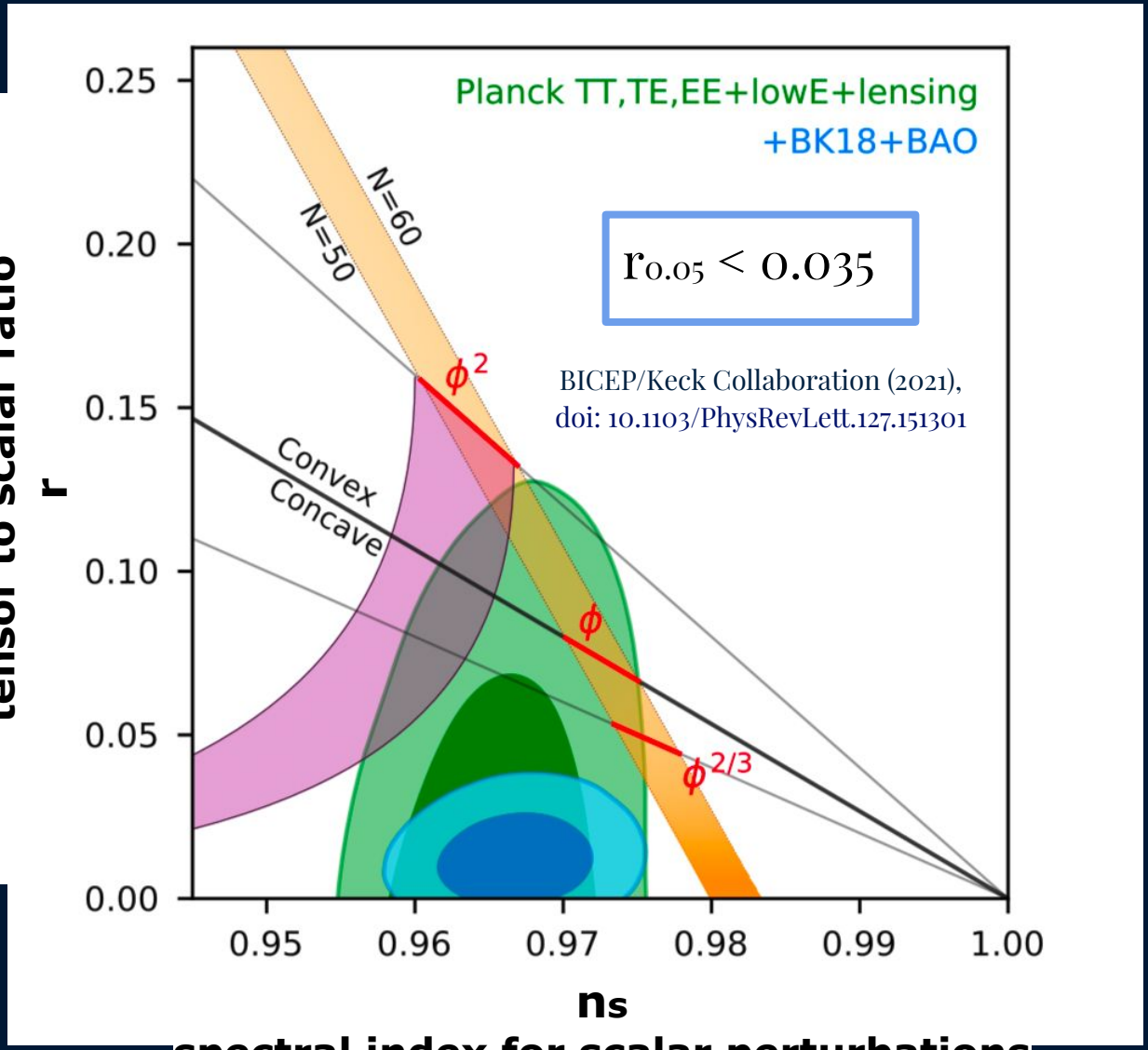
Constraining Inflation with the BICEP/Keck (BK) program

This work is part of the Bicep-Keck program to search for B-modes



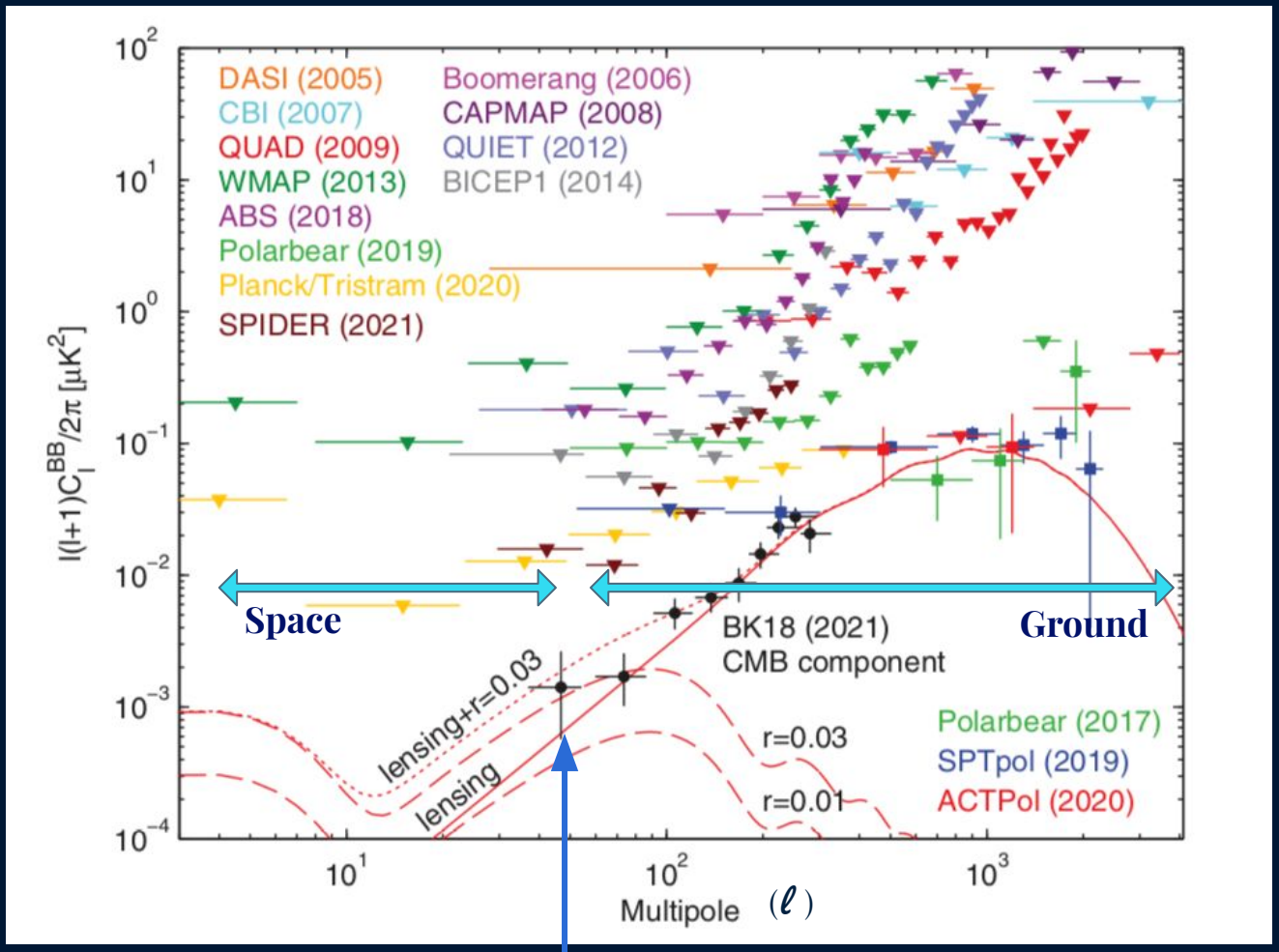
The BK data set the most stringent constraints on inflation up to date

These constraints already challenge the initially most appealing models of inflation.

Next generation of receivers (Bicep Array) will be even more sensitive, and it's expected to start observing the sky full capacity in less than 2 years!

Constraining Inflation with the BICEP/Keck (BK) program

Understanding atmospheric emission will let CMB experiments explore larger angular scales



Lowest ℓ data point (ℓ = 35)

Atmospheric emission limits the angular scales BK can measure reliably

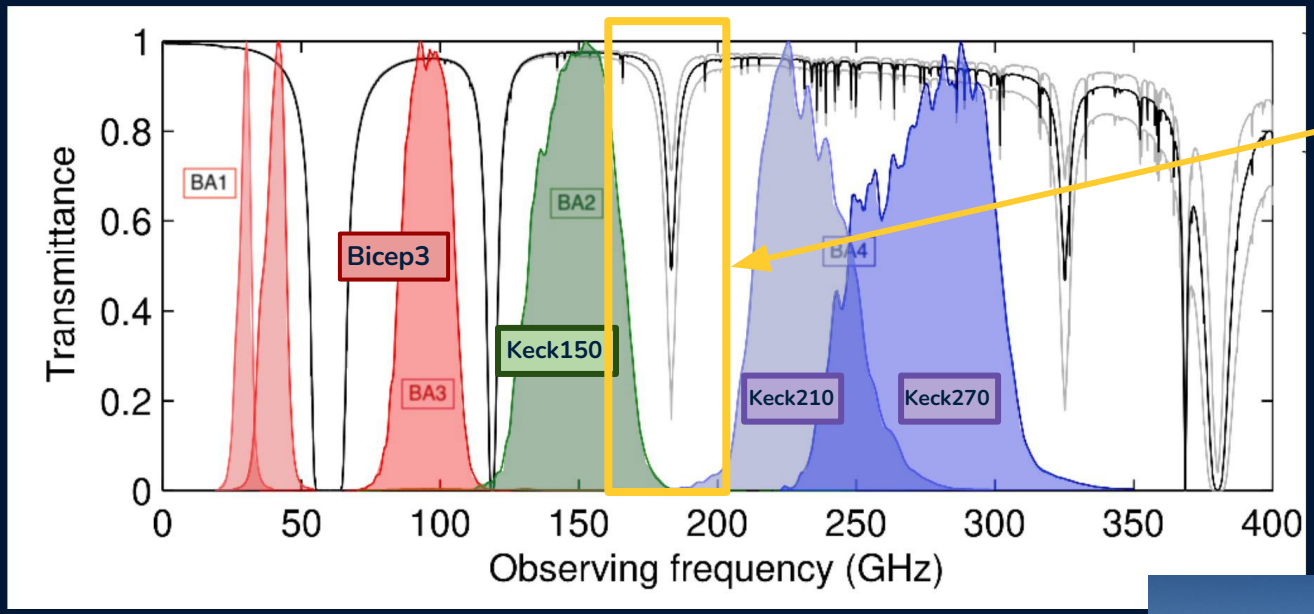
For BK the observable range in ℓ is not limited by the angular size of the map but by the filter we apply to clean maps from atmospheric noise

Pushing down the limit in ℓ means:

- Getting access to a region with minimum contamination from gravitational lensing
- Mapping a multipole range that has never been mapped before

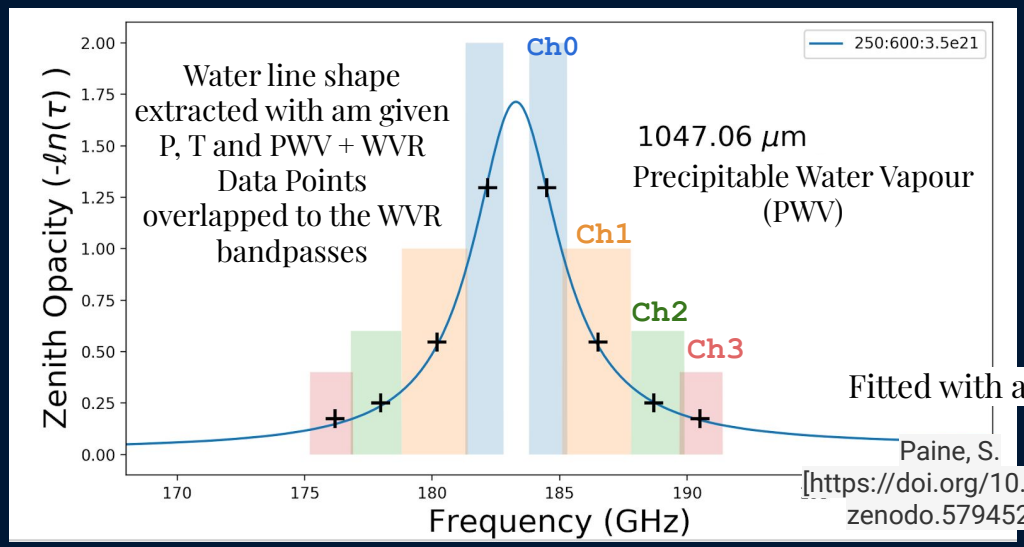
We have deployed a Water Vapour Radiometer (WVR) next to BK

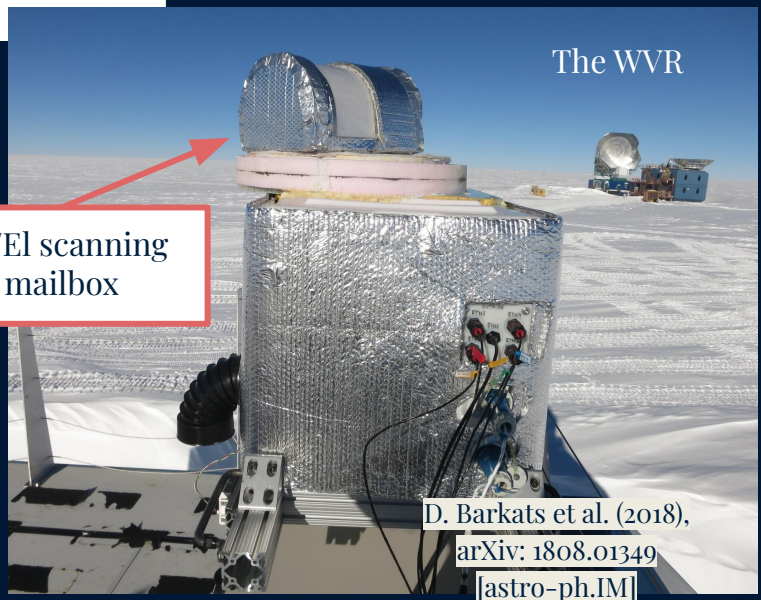
Spectrum of atmospheric transmission at the South Pole, extracted with am, with the measured bandpasses for Bicep/Keck Receivers



Target:
183.3GHz Water Line

The WVR performs Az scans at El=55deg (the center of BK maps) + once per hour it stops and acquires one Sky Dip

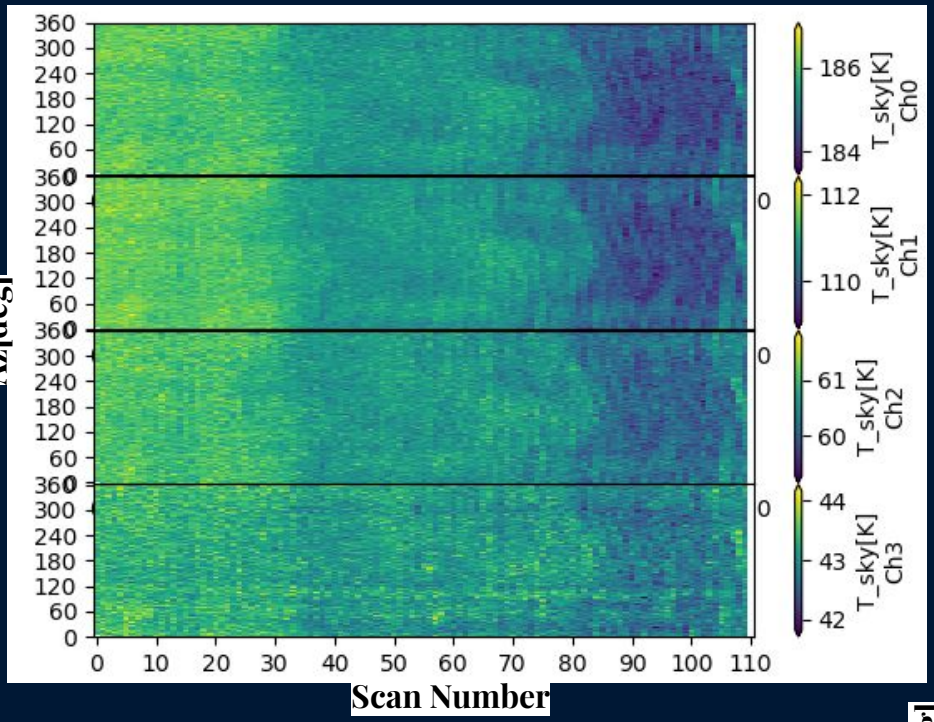




D. Barkats et al. (2018), arXiv: 1808.01349 [astro-ph.IM]

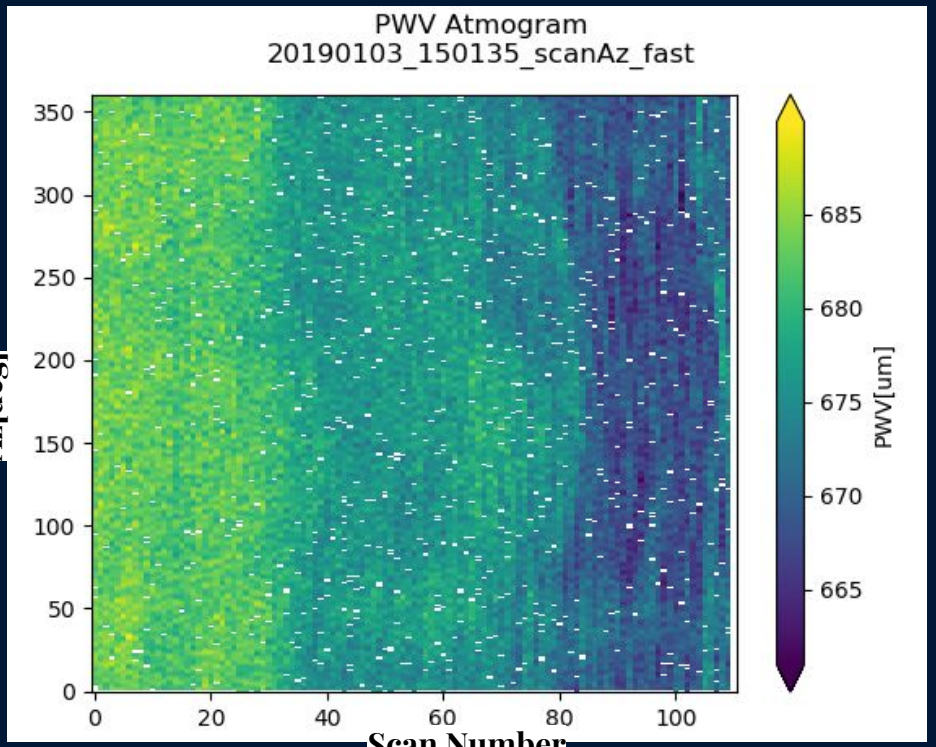
From Radiometric Temperatures to Precipitable Water Vapour (PWV)

Map of Tsky as measured by the WVR in its 4 frequency channels



~ 50 min of data

Map of the PWV in the South Pole Atmosphere extracted from WVR radiometric temperatures. This dataset includes 110 Az scans

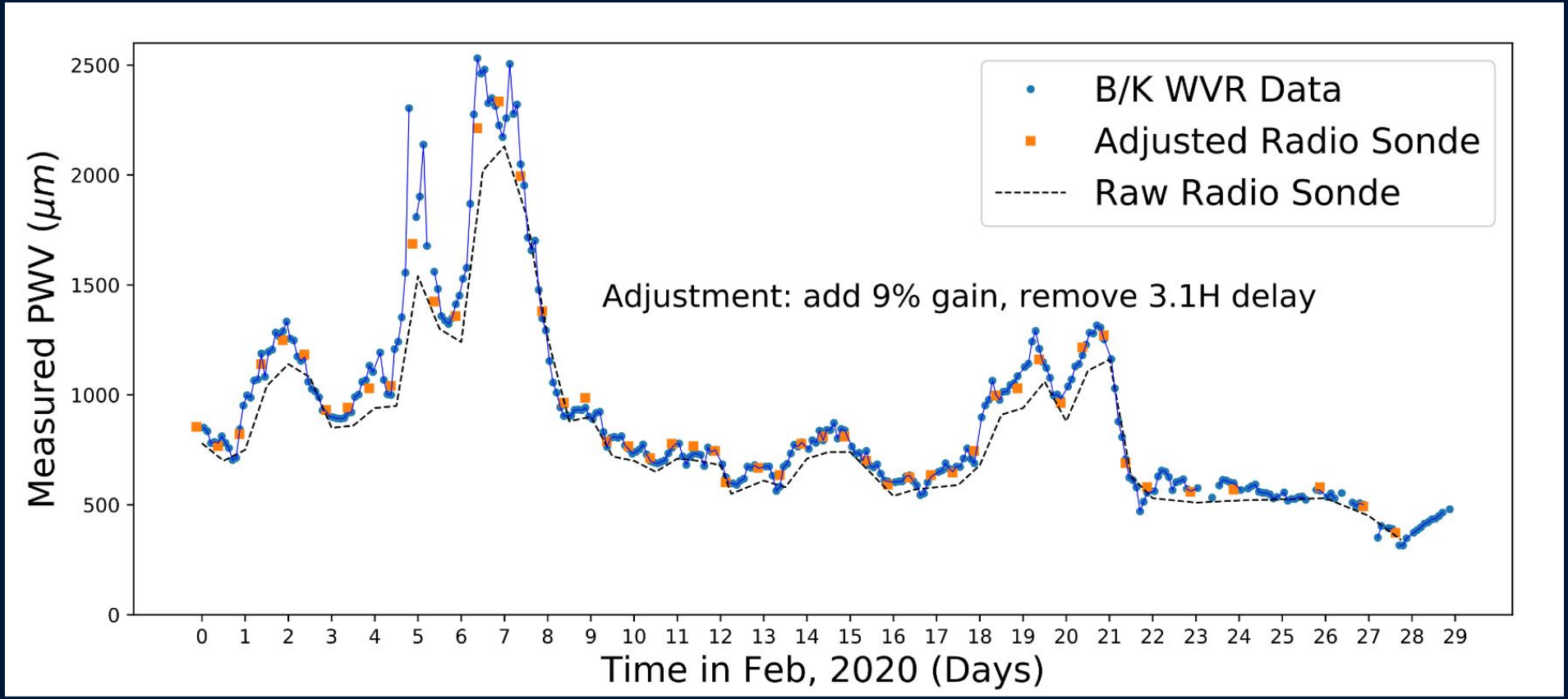


4 Tsky ⇨ PWV

For each spatial point we convert the 4 temperatures into a single precipitable water vapour (PWV) value fitting our data with the spectral shape of the line

Instrument Performance

Comparison between the WVR and radiosonde PWV data for one month of data, after correcting for the ~3h delay and after adding a 9% gain to the Radiosonde data

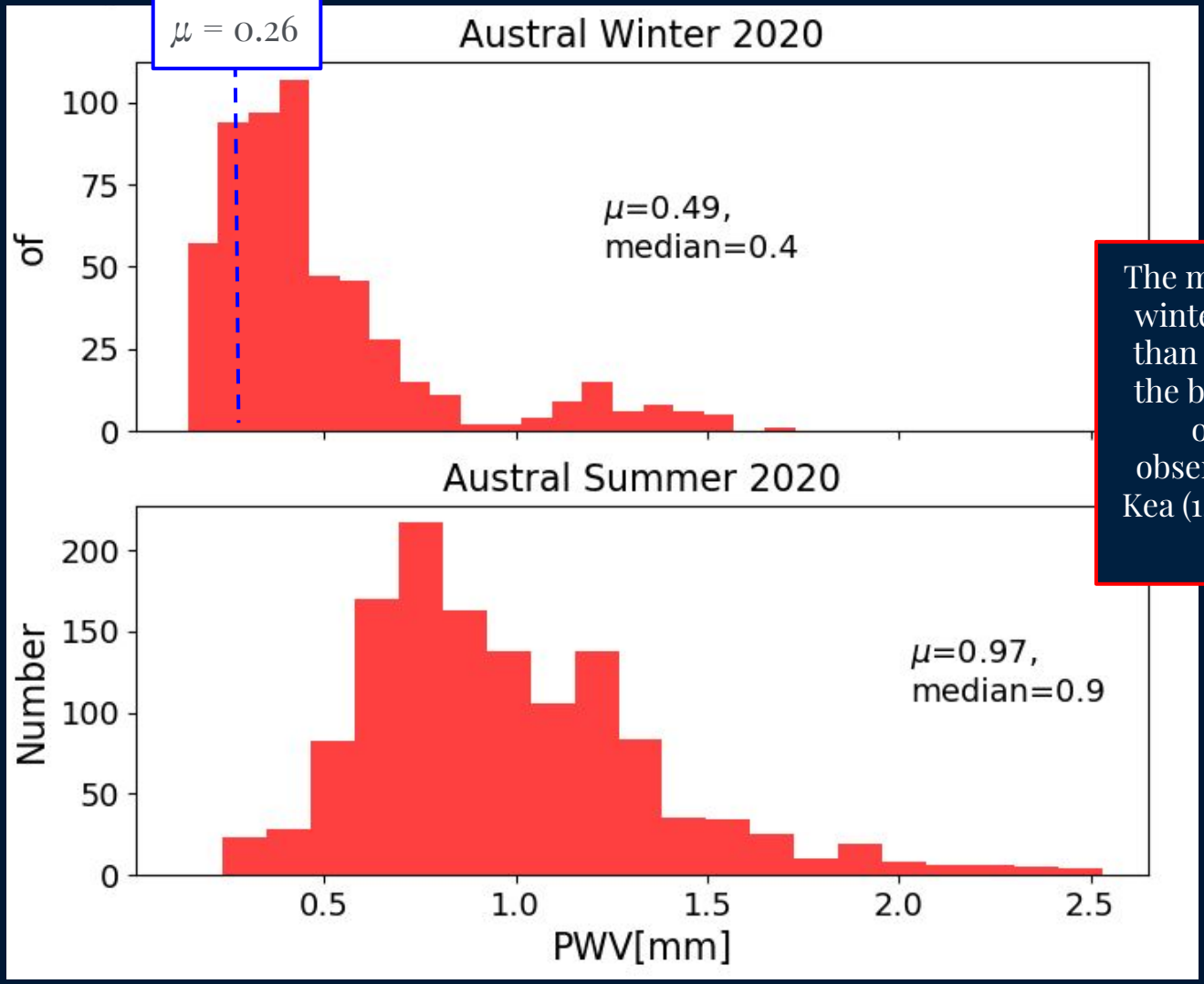


Very good agreement between the two datasets !

The South Pole Atmosphere - PWV

[R. S. Bussman et al. (2005), doi:10.1086/427935]

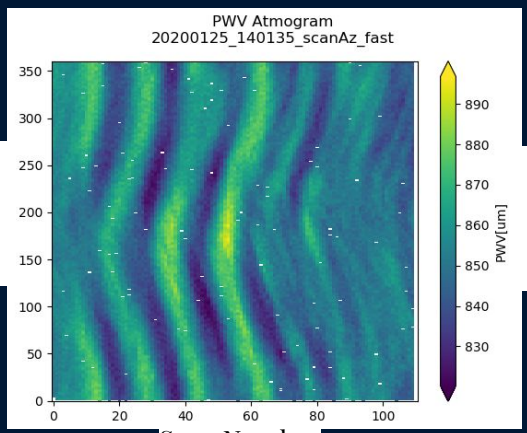
Tropospheric PWV from WVR data

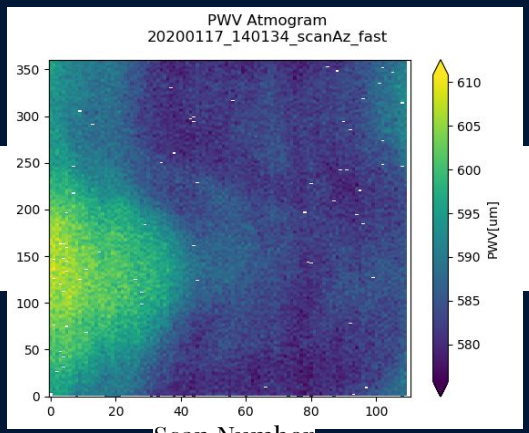


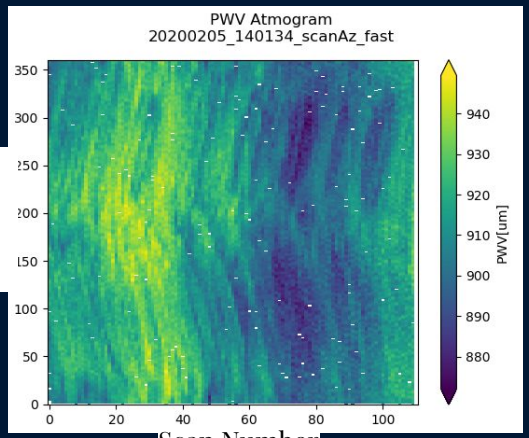
The mean value for the austral winter 2020 (0.49 mm) is less than half of the PWV mean in the best six months for other optimal sites for mm observations, such as Mauna Kea (1.65 mm) and the Atacama desert (1.00 mm).

The South Pole Atmosphere - Wind

PWV Atmograms for different days



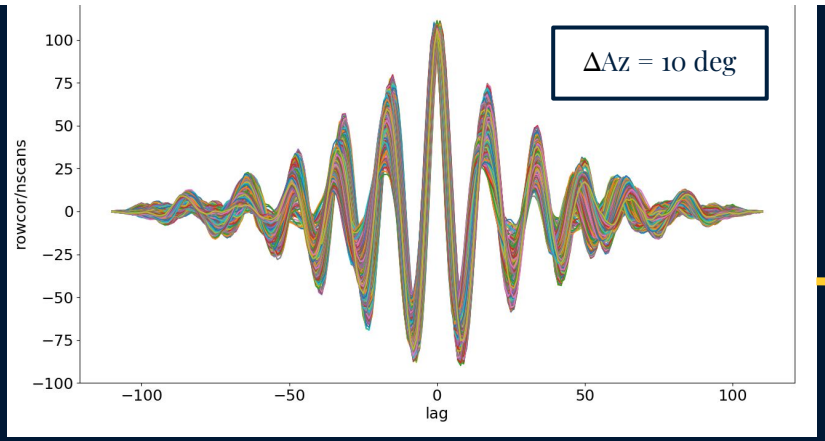




If the atmospheric slab containing PWV structures moves like a rigid object, two timestreams at different Az will contain the same signal, just with some delay which depends on the wind speed

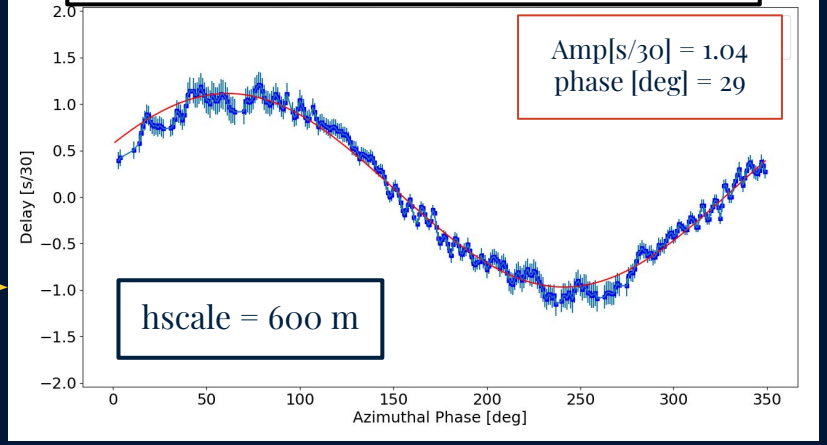
The wind speed can be extracted from the amplitude ($A=Delay_{max}$) of this sin function

Correlation function for all timestream pairs at Az - Az+ΔAz



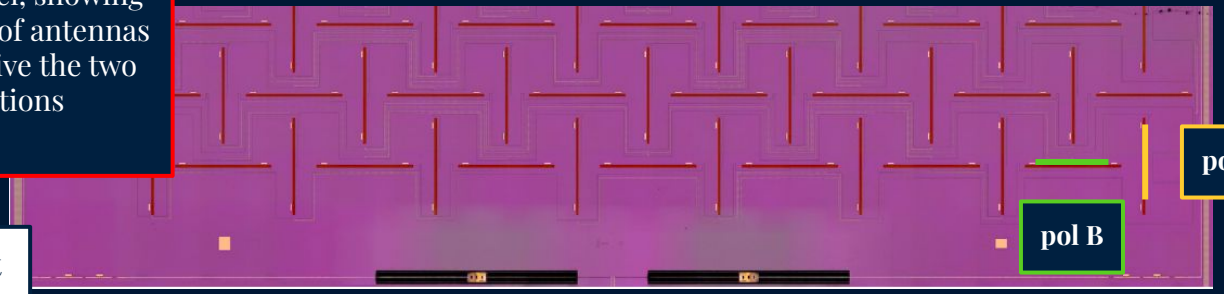
Position of the peak as a function of Az

$$w_s = h_{scale} \cdot \tan(el_{wvr}) \cdot \sin(\Delta Az)/Delay_{max}$$

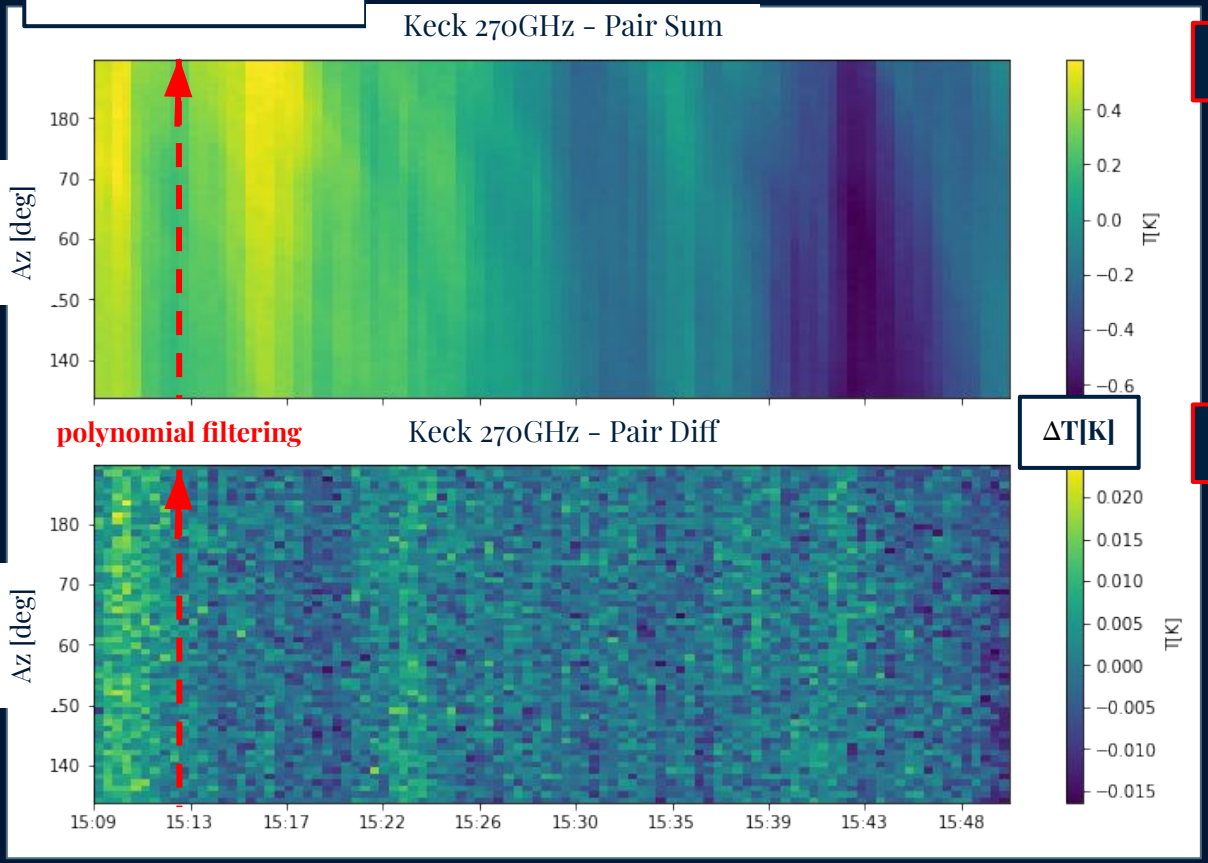


Atmospheric Signal in BK Maps

The edge of a BA pixel, showing the two orientations of antennas that separately receive the two linear polarizations



~ 50 min of scans at constant Elevation



Pair Sum = **A** + **B**

Total Power

Pair diff = **A** - **B**

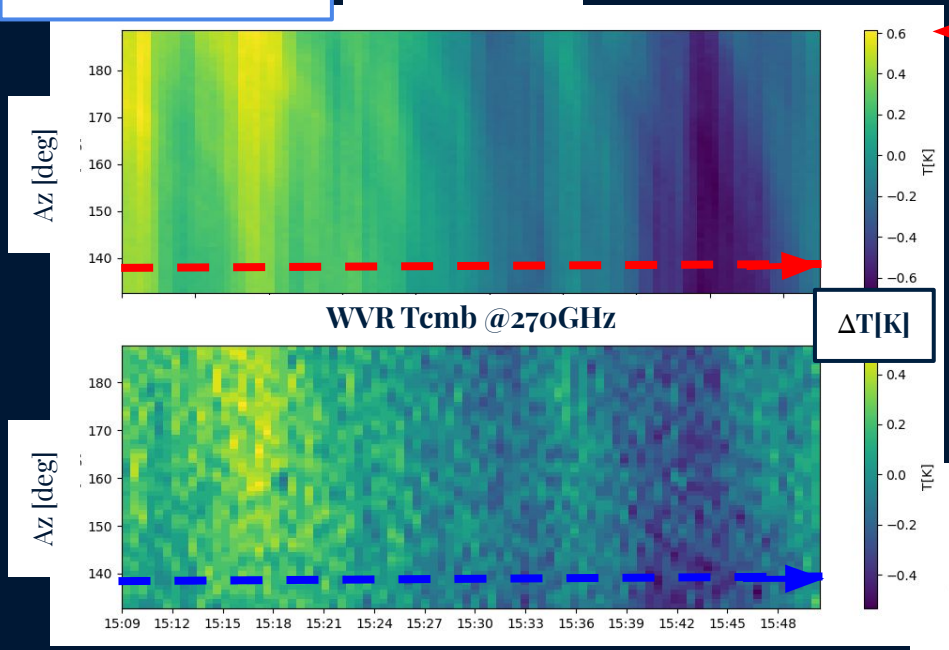
Polarized signal

Atmospheric signal is removed from BK data with a 3rd order polynomial filtering to each half scan

Cleaning atmospheric Signal in BK Maps using WVR maps

~ 50 min of scans at constant Elevation

Keck 270GHz Pair Sum

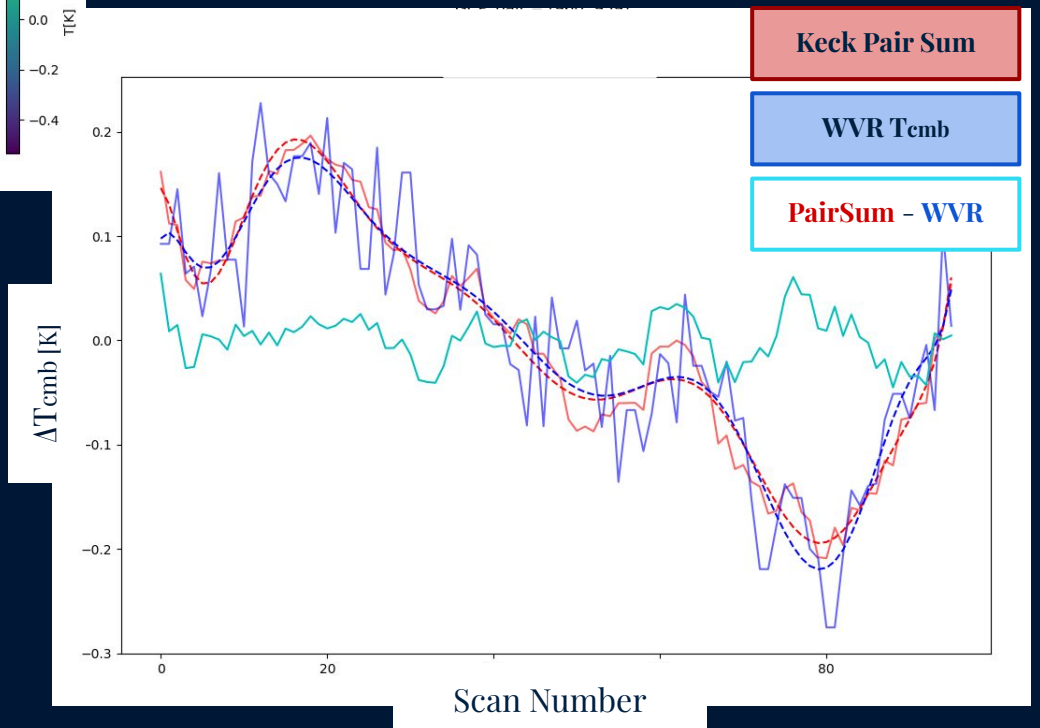


Keck270 Pair Sum map compared to WVR PWV Atmogram converted into expected Tcmb

What if we filter in the orthogonal direction and using no CMB information but just WVR data?

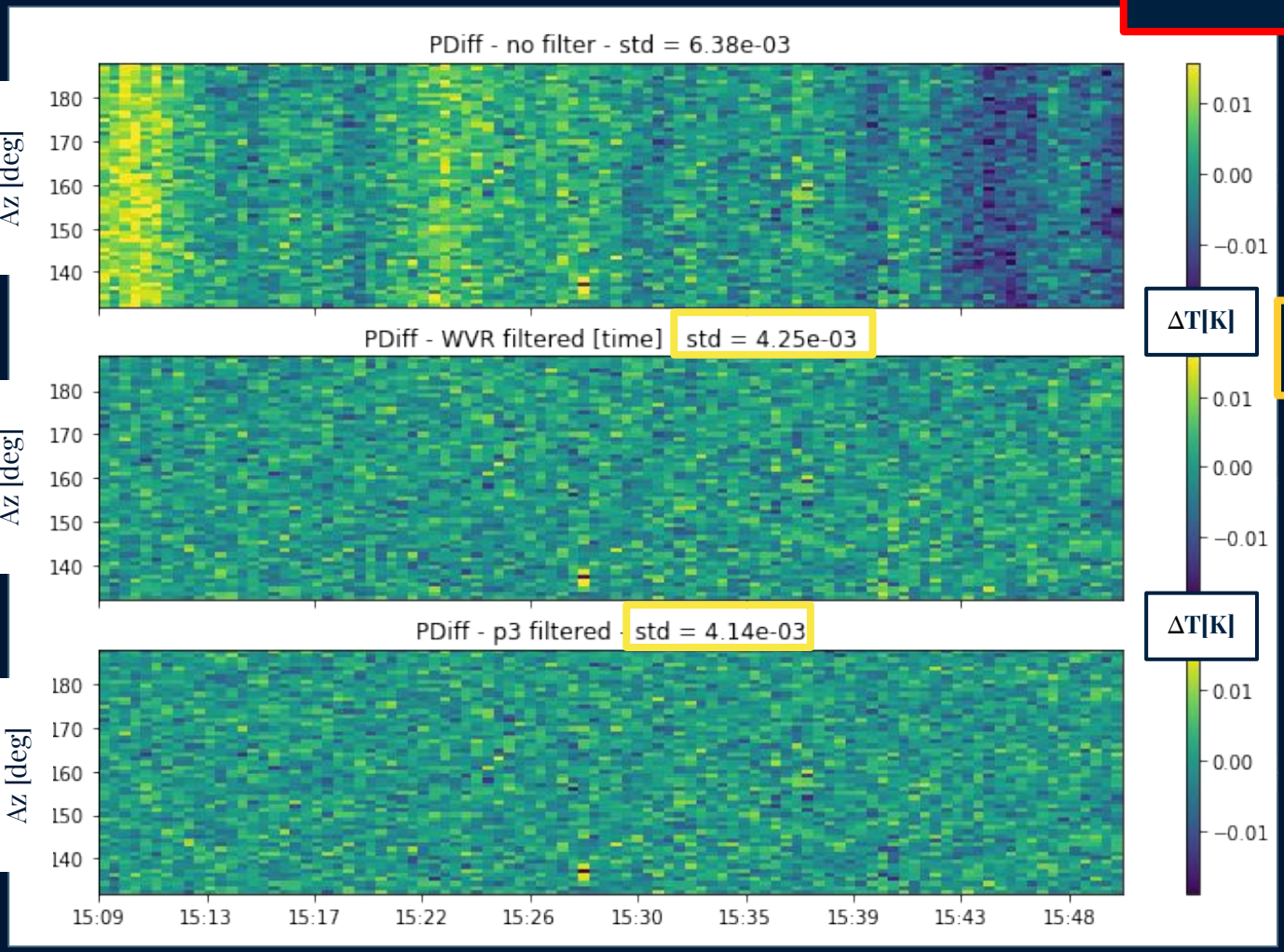
New filtering method

1. Fit to a 12th order polynomial both WVR and BK timestreams
1. Extract a scale factor (α) through a linfit of the two polynomial model
3. Filter Az per Az: $BK_{clean} = BK - \alpha \cdot WVR_{p12model}$



Results from the two methods in comparison

Keck 210GHz



Work in progress

The achieved rms is comparable

But using just WVR data and no CMB data in creating a model for the atmosphere to clean BK maps, we don't get rid of all the large angular scale structures

Conclusions

- We have deployed a Water Vapour Radiometer (WVR) at the South Pole. This scans the sky continuously in Az at an elevation that matches the center of BK maps.
- WVR data can be used, alone, to characterize the South Pole atmosphere, and extract PWV seasonal averages, PWV fluctuations timescales and fluctuations scale heights.
- WVR maps in PWV can be converted into T_{cmb} maps in the frequency band of interest and used to clean CMB maps from atmospheric noise.
- Using this filtering method the achieved rms is comparable with the rms achieved using the standard 3rd order polynomial filtering.
- Applying this new method, instead of the standard polynomial filtering, could allow us to recover large angular scales structures and push down the limit on ℓ in the CMB power spectrum.

Ph Credits: Mark Halpern