

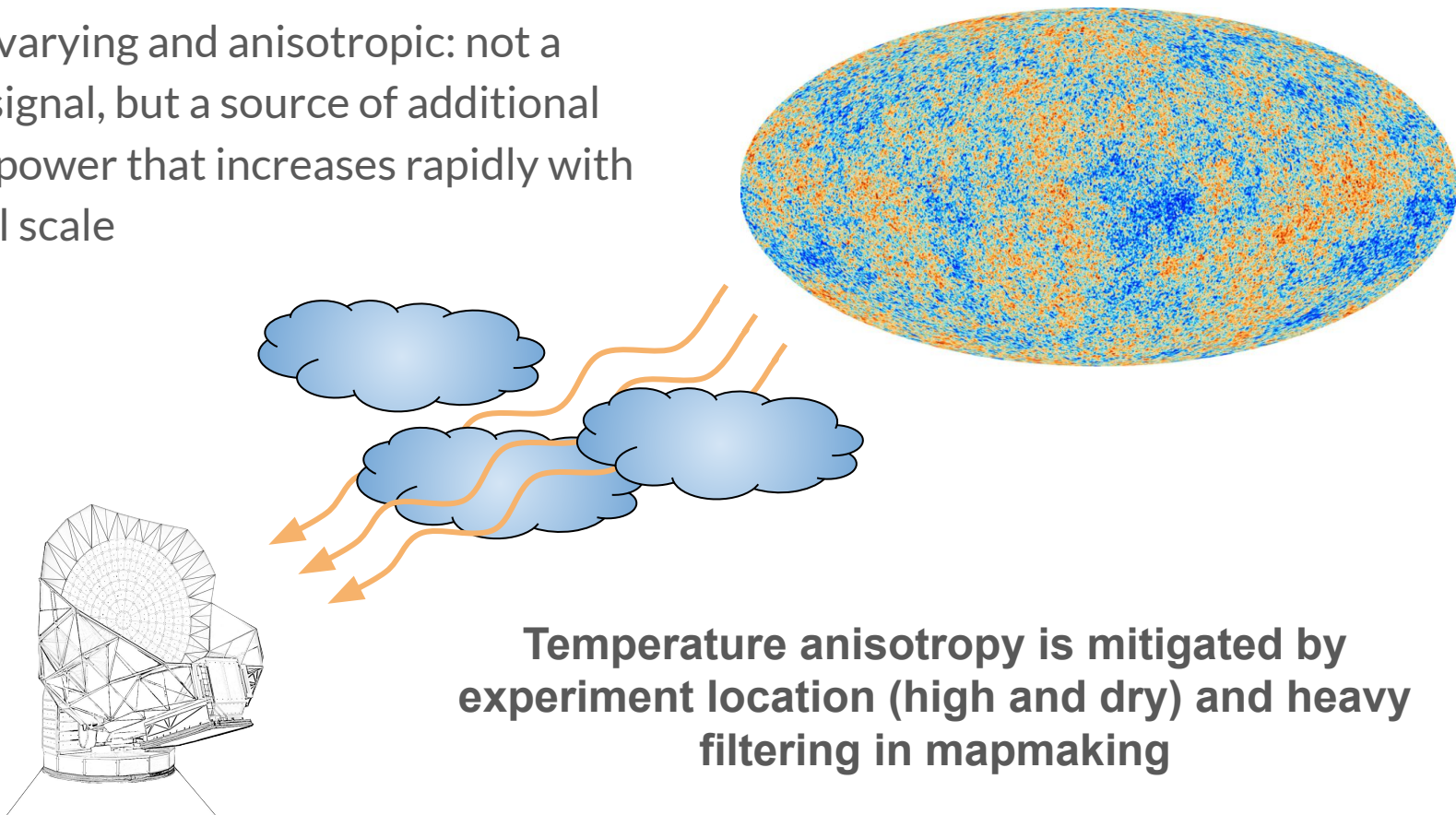
Temperature and Polarization Anisotropy of the Atmosphere

CMB-S4 Meeting 2024

Anna Coerver, Jessica Zebrowski, Satoru Takakura, Bill Holzapfel

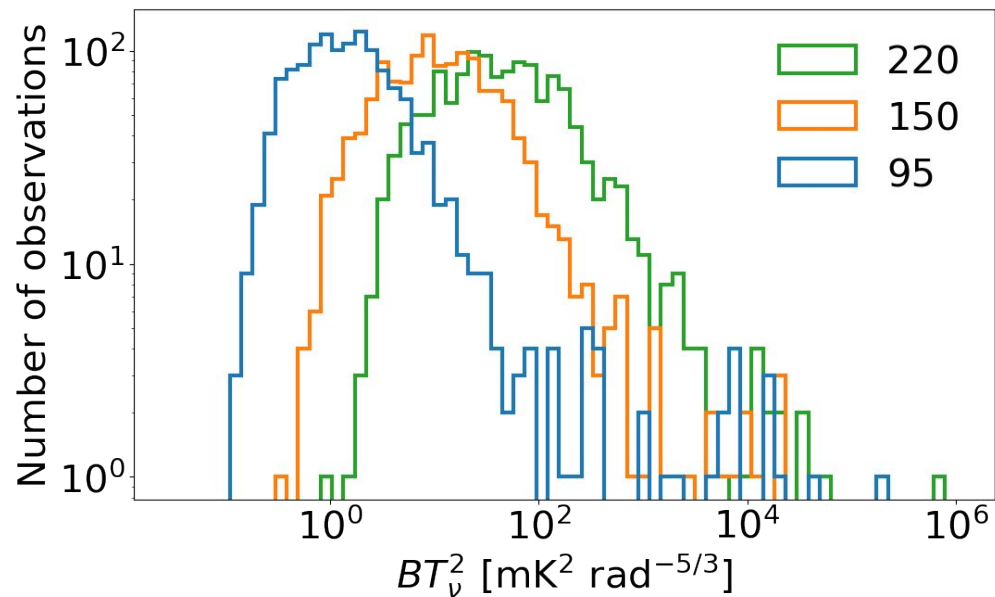
Atmospheric Temperature Anisotropy

- Time-varying and anisotropic: not a fixed signal, but a source of additional noise power that increases rapidly with spatial scale



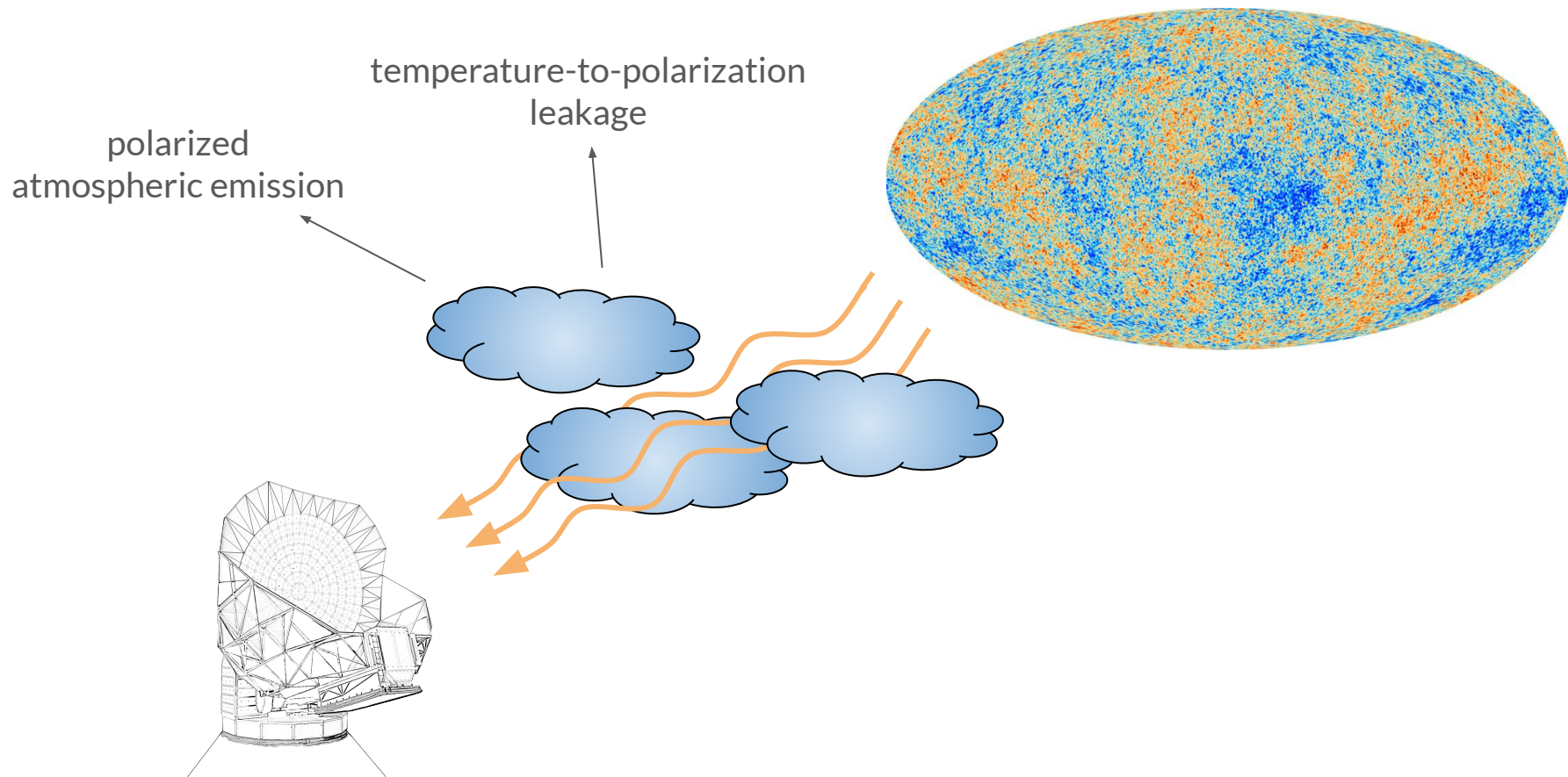
Chile and South Pole atmospheres differ

Temperature amplitude distribution at the South Pole

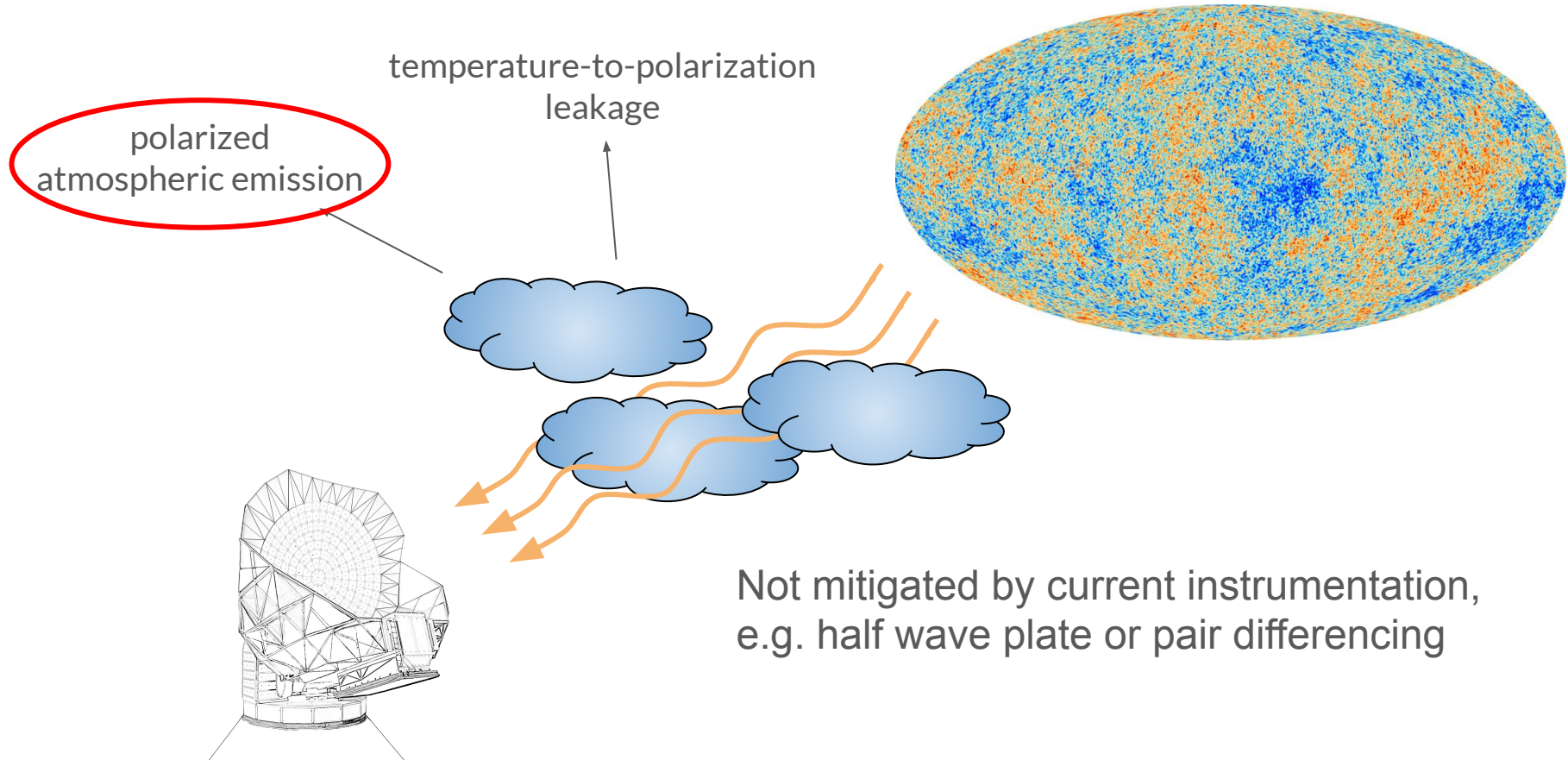


Median temperature anisotropy power at the South Pole is $\sim 100\times$ lower than in Chile

Atmospheric Polarization Anisotropy



Why is the atmosphere a problem?



Atmosphere in CMB experiments

- 2000-2015: Extensive studies on temperature atmospheric noise at both Chile and Pole (*Bussman 2005, Lay and Halverson 2000, Errard 2015, etc*)
- 2019: Polarized atmospheric noise detected by POLARBEAR in Chile ([Takakura 2019](#))
 - “Bursts” of horizontally polarized signal detected
- 2023: Polarized atmospheric noise detected by CLASS in Chile ([Li 2023](#))
- 2024: Polarized atmospheric noise detected by SPT at the South Pole ([Coerver 2024](#))

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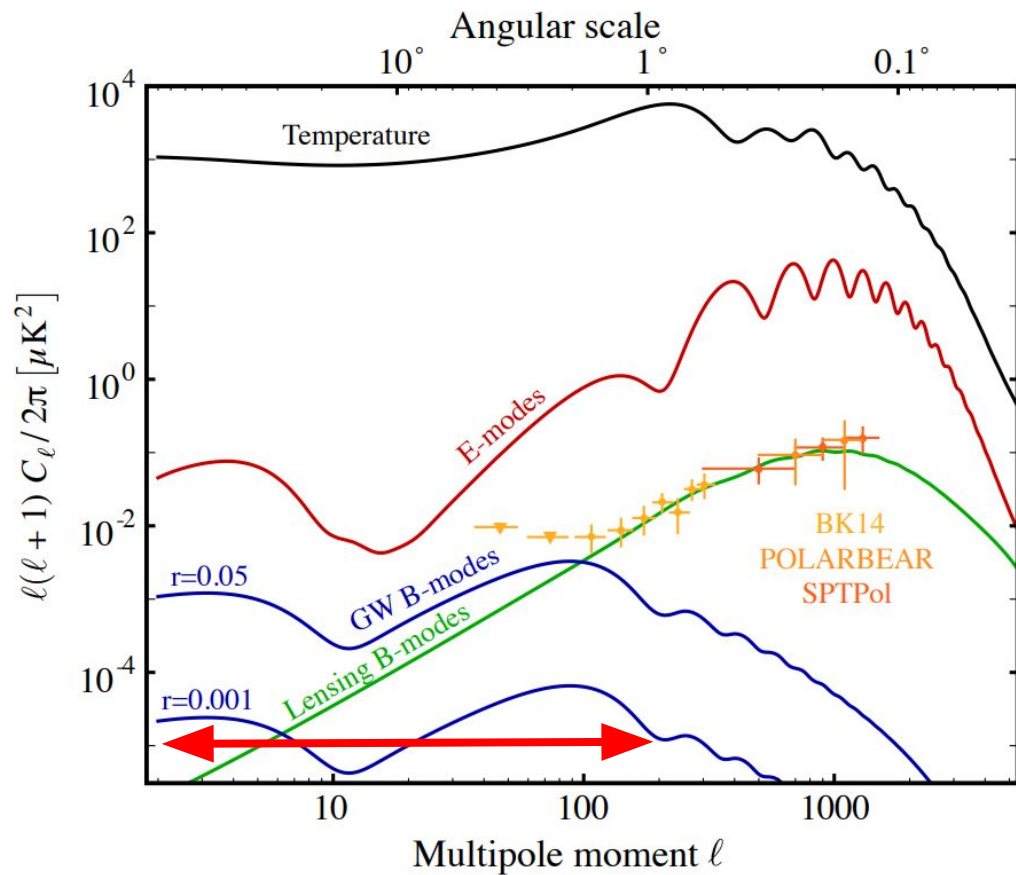
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Polarized atmosphere is a recent area of research that warrants further study

Polarized atmosphere as a contaminating signal

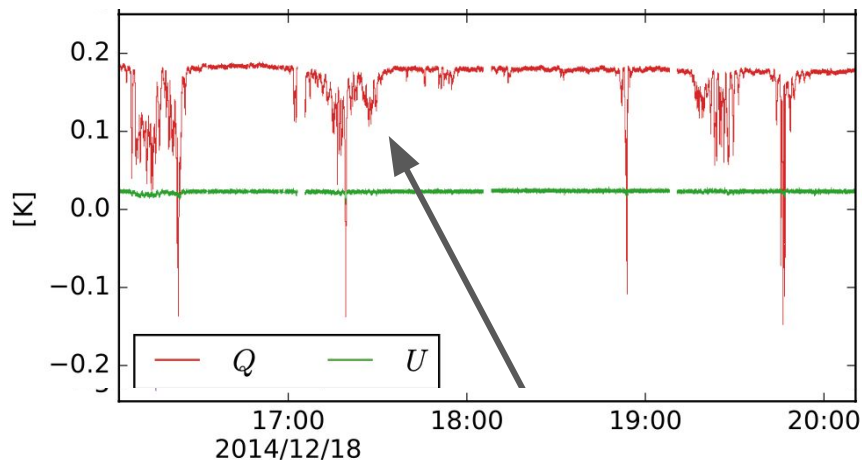


peaks at large
angular scales \rightarrow
**potential problem
for GW B-modes**

Polarized Atmosphere at Chile and Pole

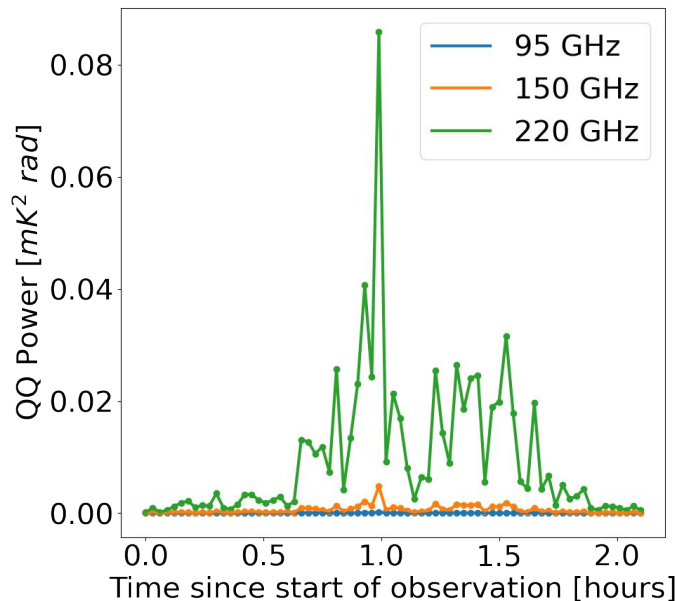
- Detected by POLARBEAR and CLASS in Chile, and now SPT at the South Pole
- Bursts of horizontal (Stokes -Q) polarized radiation

POLARBEAR



Q-only bursts \gg
CMB polarization power

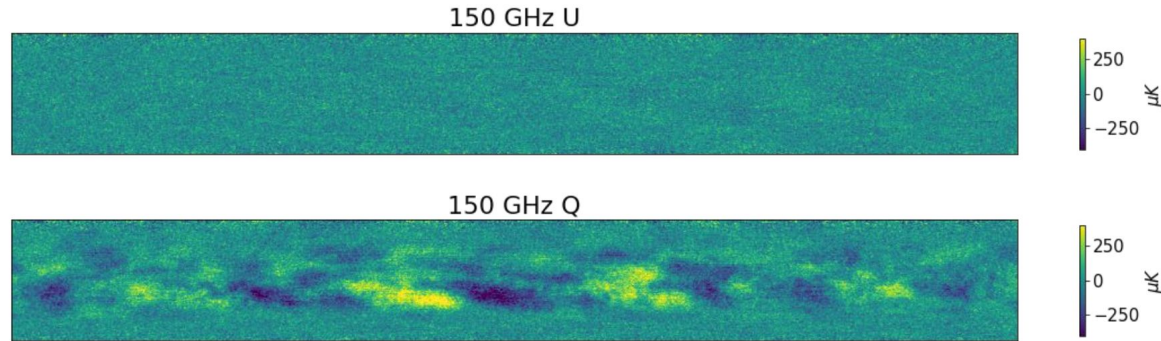
SPT-3G



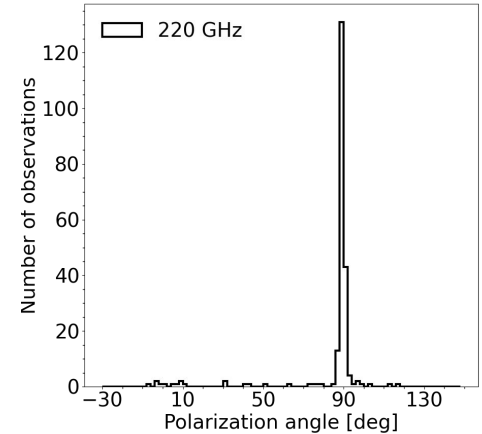
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SPT-3G



*Fig: Maps of 150 GHz Q vs U for an observation with elevated Q noise
(dimensions: 66 x 8 deg)*



For the South Pole site, we have characterized:

- Frequency scaling
- Spatial scaling
- Elevation scaling
- Amplitude distribution down to the noise floor

And confirmed that these measurements align with theory.

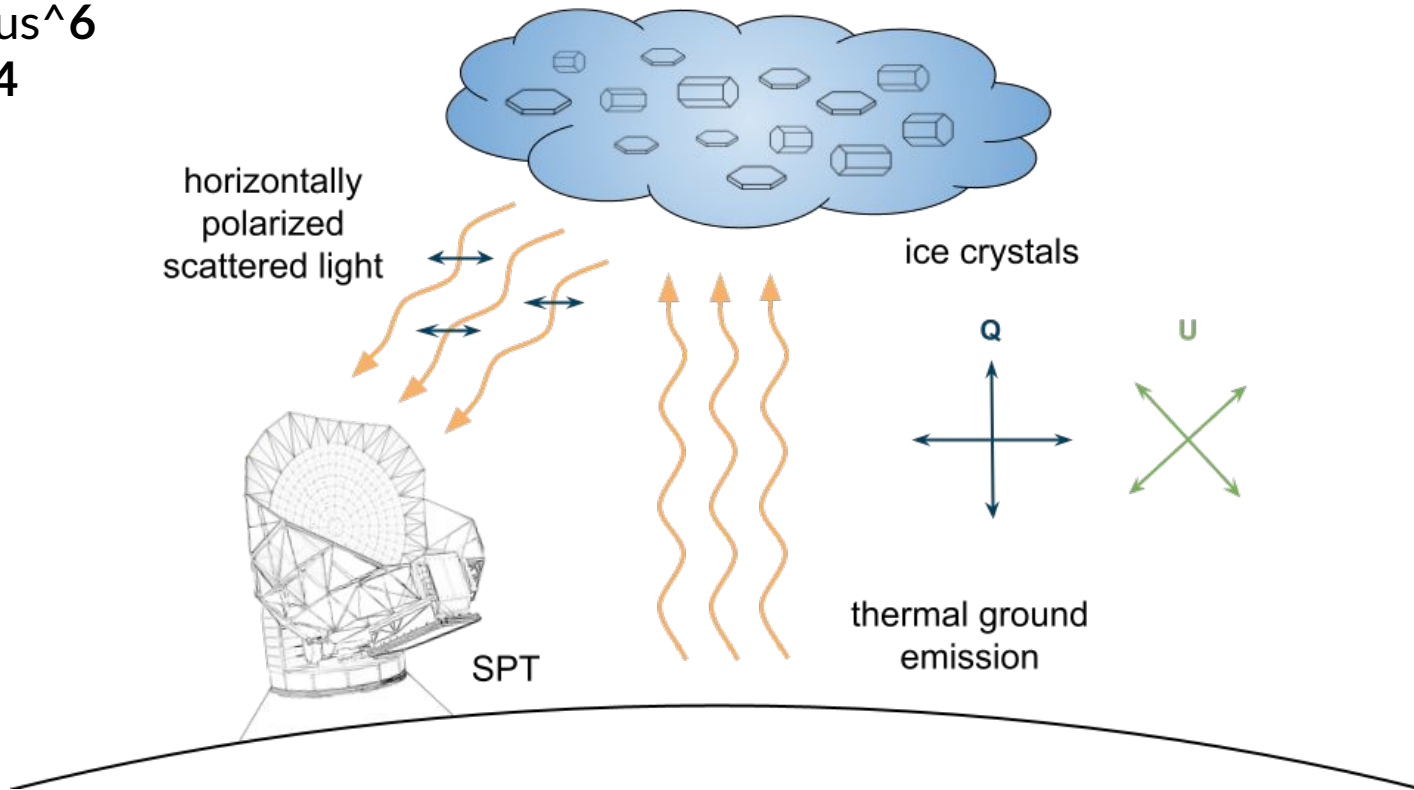
Theoretical Background

What is the physical mechanism of polarization from clouds?

Scattering

Particle radius⁶

Frequency⁴



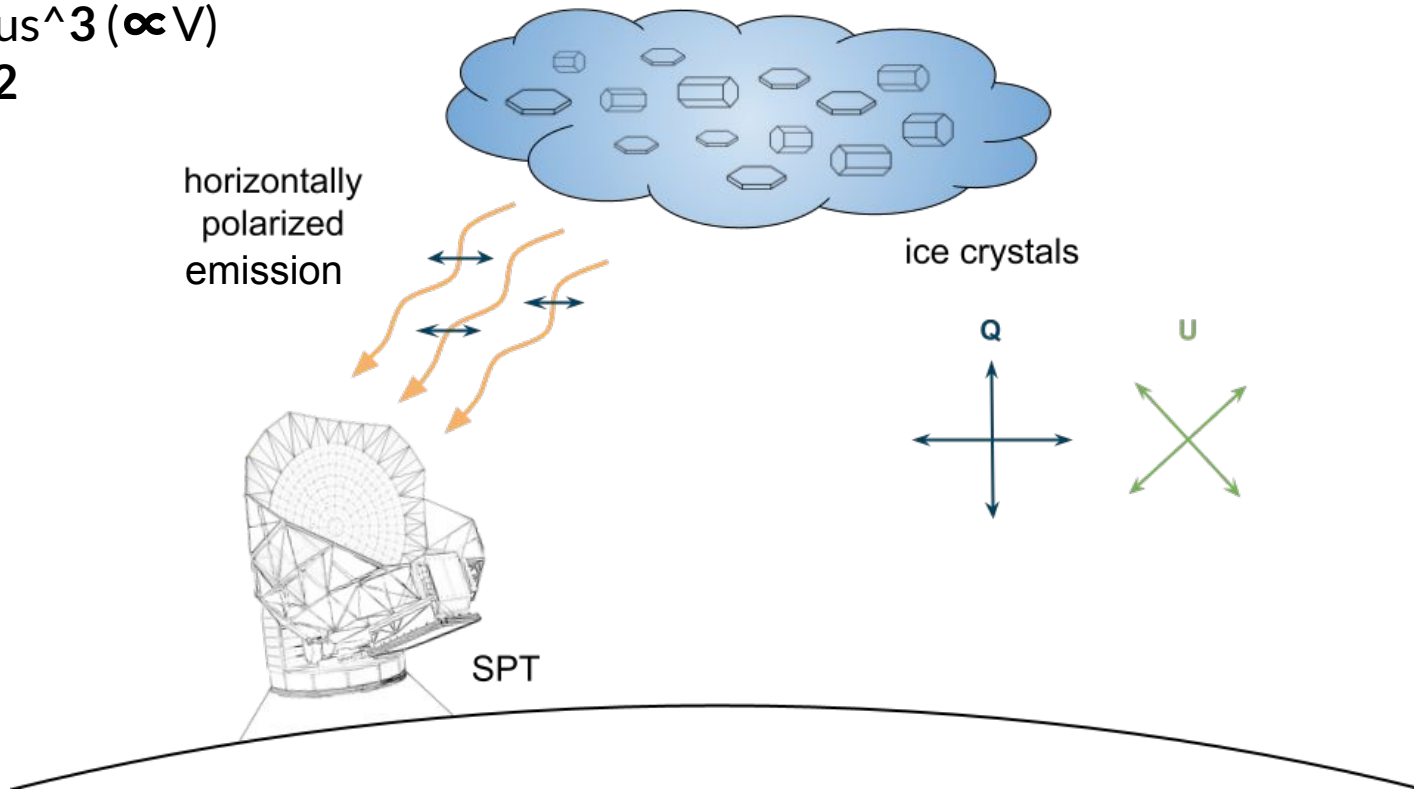
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Emission

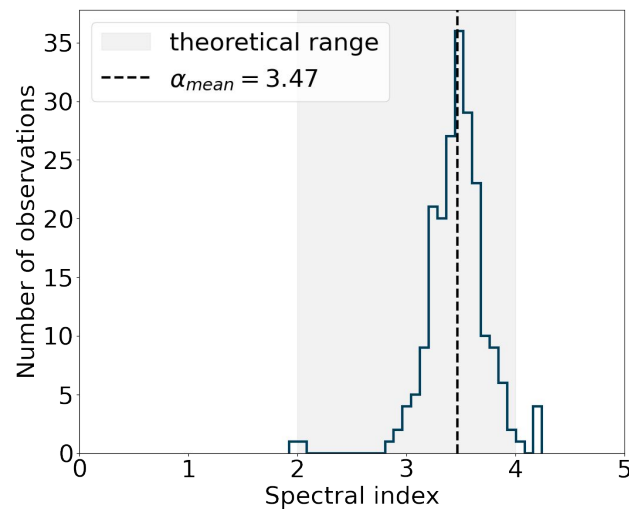
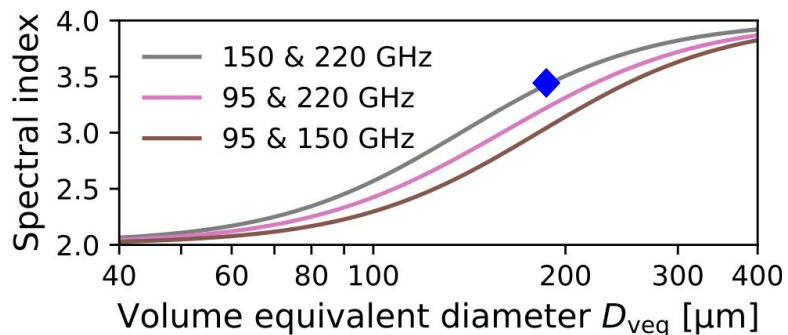
Particle radius³ ($\propto V$)

Frequency²



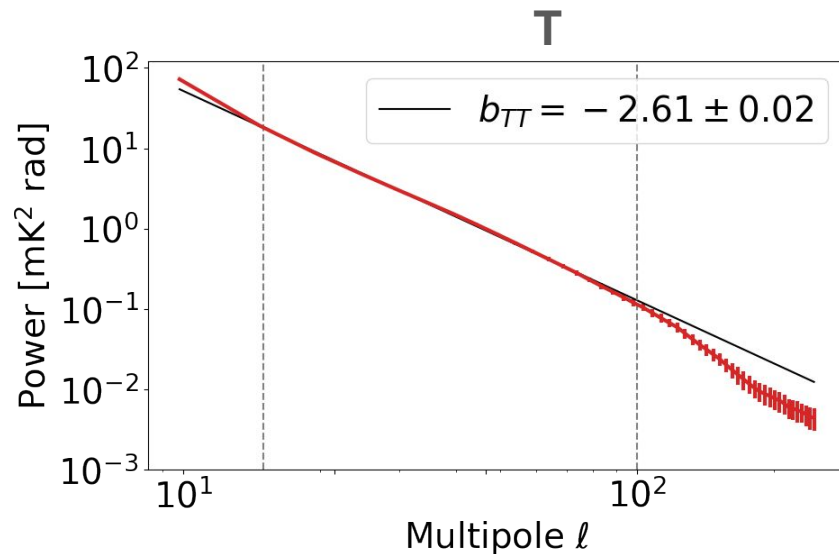
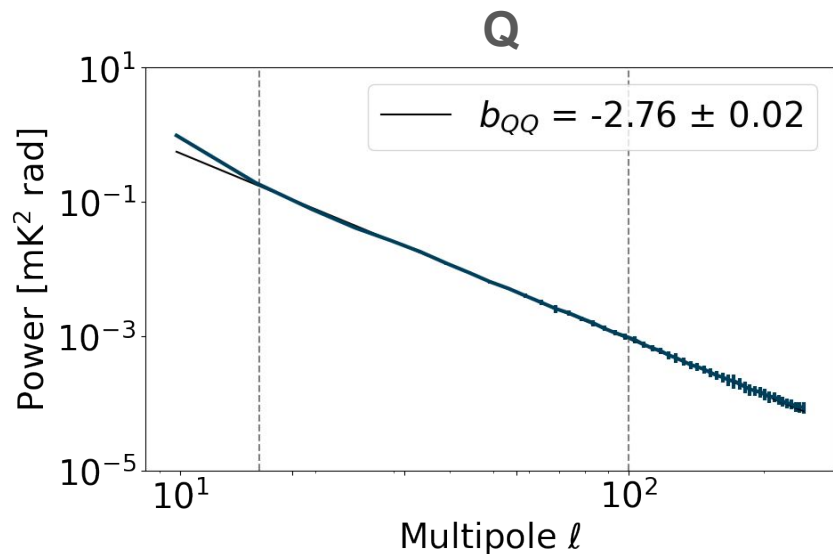
State of polarized atmosphere knowledge: frequency scaling

- Frequency scaling with SPT-3G
 - Scaling index $\alpha = 3.47$
 - Aligns with a combination of **Rayleigh scattering** ($\alpha = 4$) of thermal radiation from the ground and **thermal emission** ($\alpha = 2$) by ice crystals in the atmosphere
- CLASS measured a different scaling in the case of extreme atmosphere



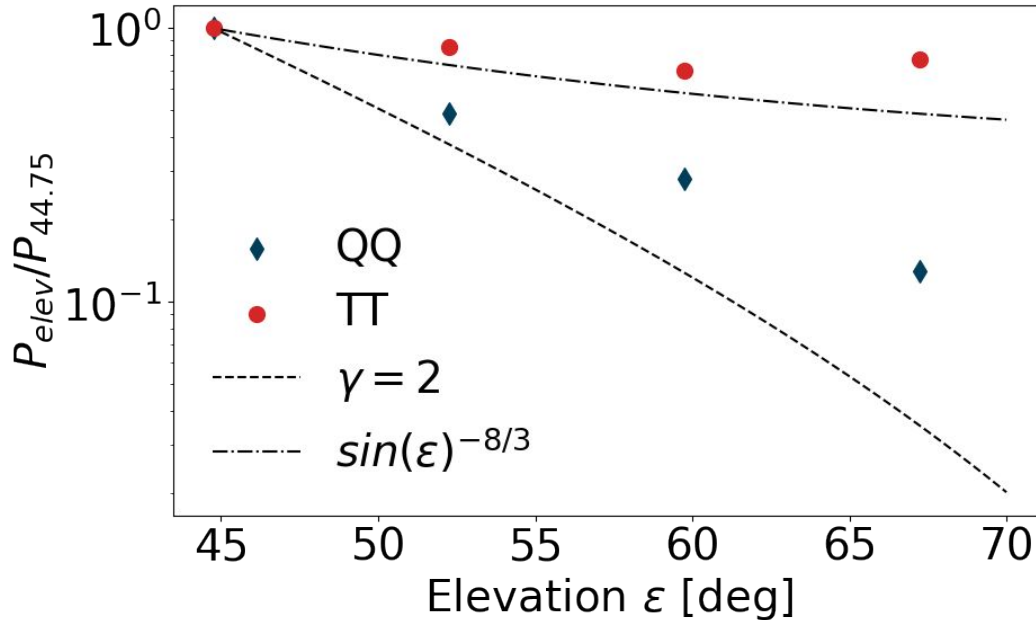
State of polarized atmosphere knowledge: spatial scaling

- Scaling index of Q and T roughly consistent with Kolmogorov turbulence index of -2.67
- Large power on large angular scales \rightarrow problem for GW B-modes



State of polarized atmosphere knowledge: elevation scaling

- Elevation scaling: signal peaks at low elevation
- Polarized signal drops more steeply than temperature signal

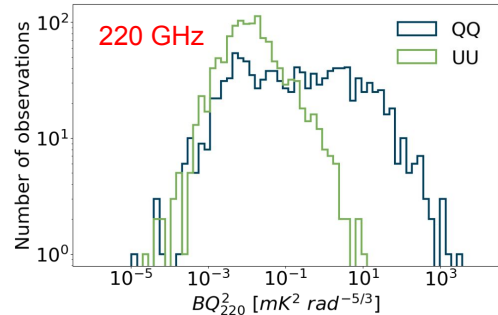
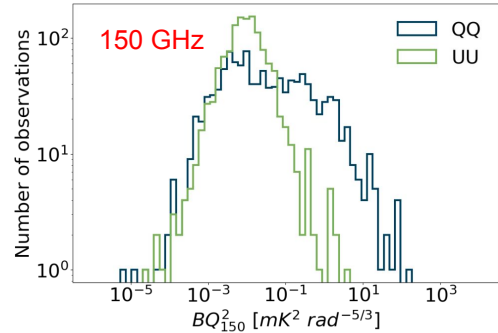
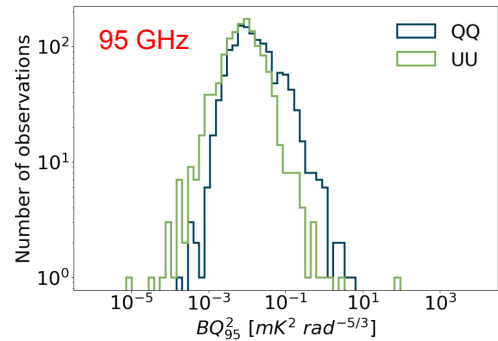
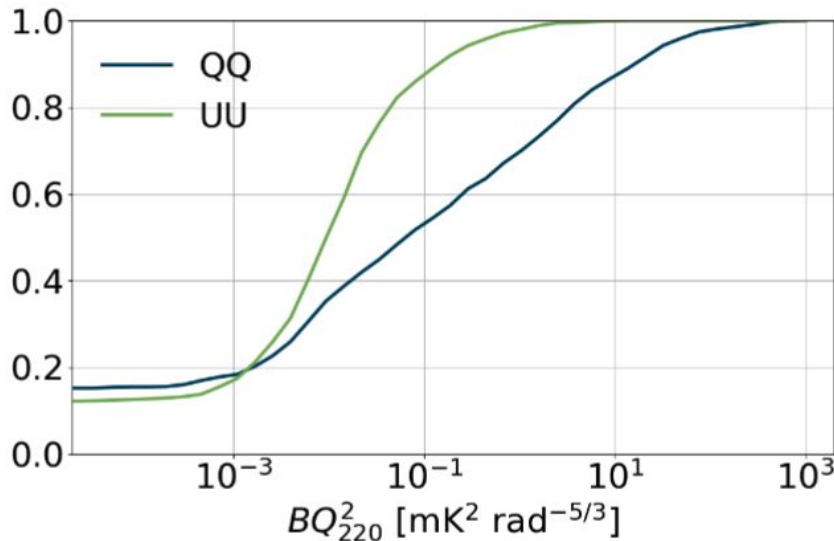


Amplitude distribution at the South Pole

- Strong frequency dependence means that detection is rare at 95 GHz and most common for 220 GHz
- Amplitude distribution can be scaled for any elevation, observing band, and angular scale

220 GHz Cumulative Distribution Function

Distribution for lowest elevation range



The questions for CMB-S4 in Chile...

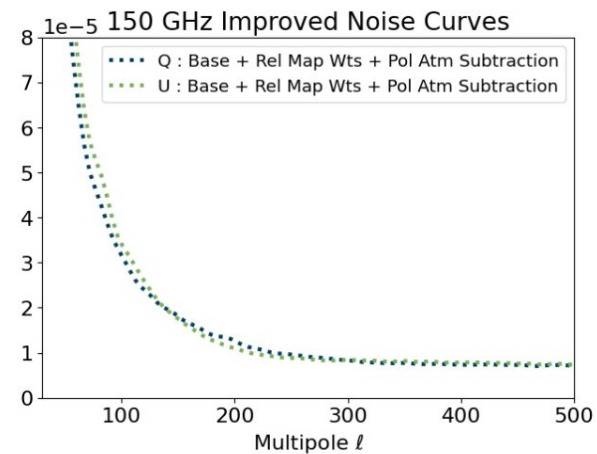
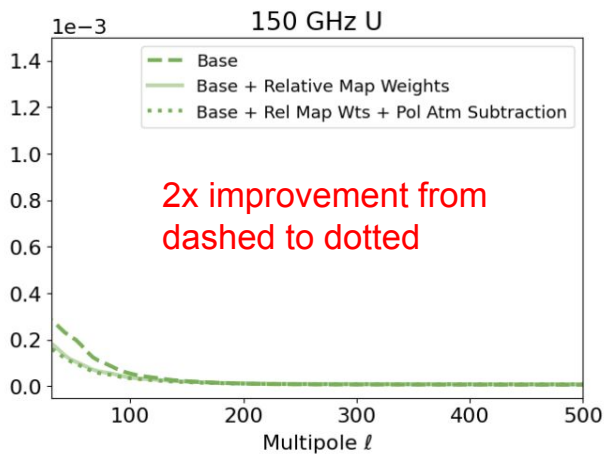
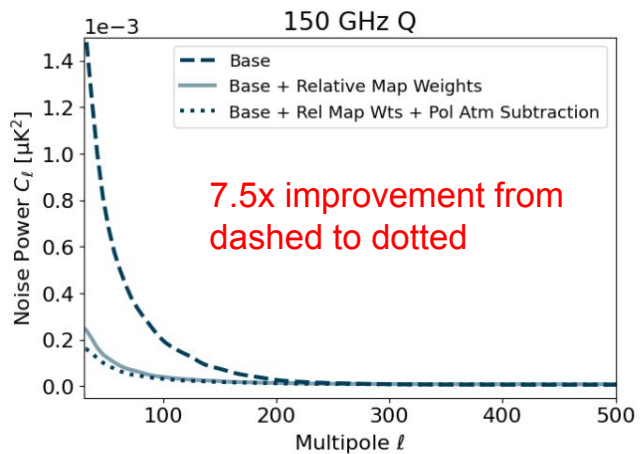
How does the signal impact map noise?

How effective are mitigation strategies?

We don't know!

Mitigation

- Polarized atmospheric effects are well-mitigated in SPT-3G data through downweighting contaminated data
- This relies on the signal being **intermittent and infrequent**
 - Shows up in **~20%** of SPT-3G maps, small penalty in data volume after mitigation methods



In conclusion

What we know about polarized atmosphere:

- Time-varying
- Horizontally polarized
- Steep frequency scaling
- Signal increases with angular scale
- Signal decreases with elevation
- Amplitude distribution at South Pole shows it is rarely a problem

→ can model the impact of polarized atmosphere for any experiment configuration at the South Pole (see our [posted paper](#))

Important to understand:

- Frequency scaling in Chile
- **Amplitude distribution in Chile**

We encourage groups with CMB data from Chile to quantify the polarized atmosphere so that the impact on CMB-S4 can be accurately modeled!