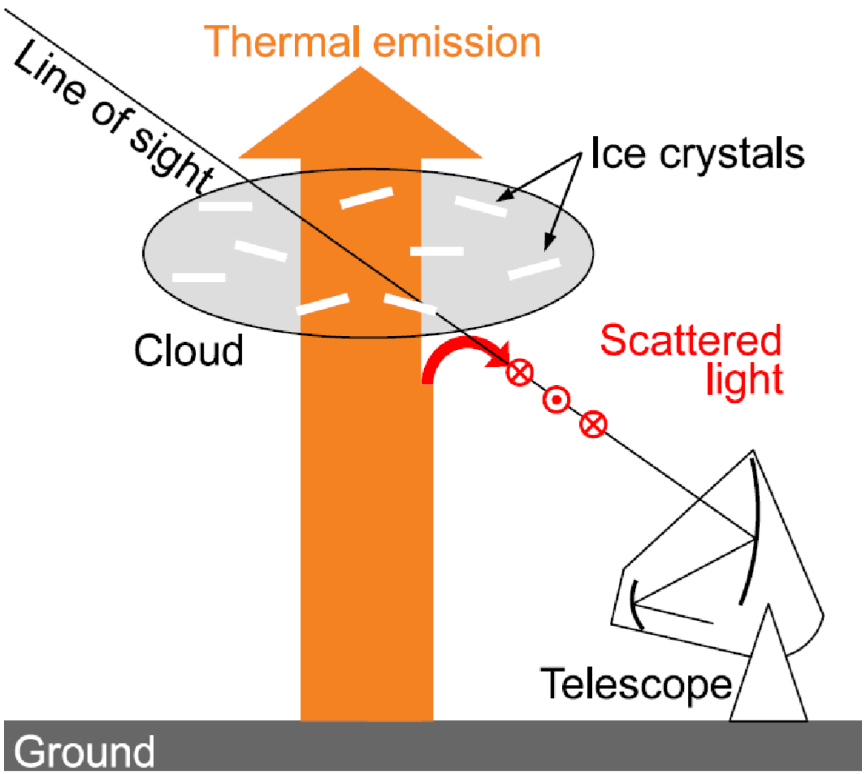
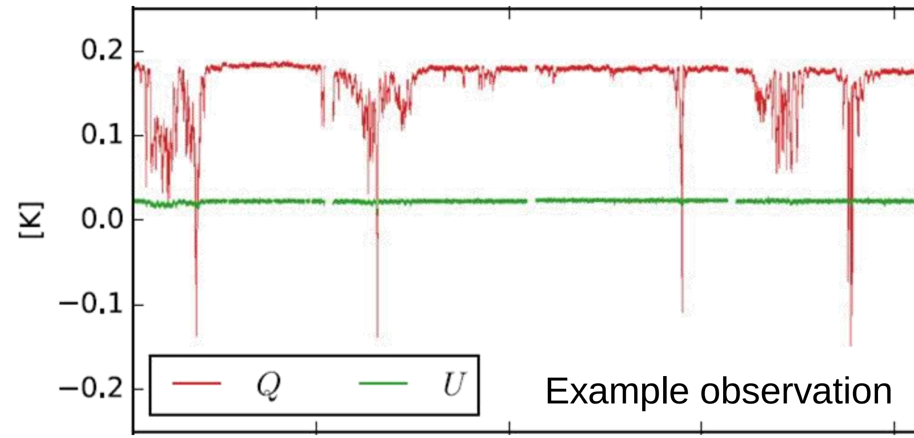
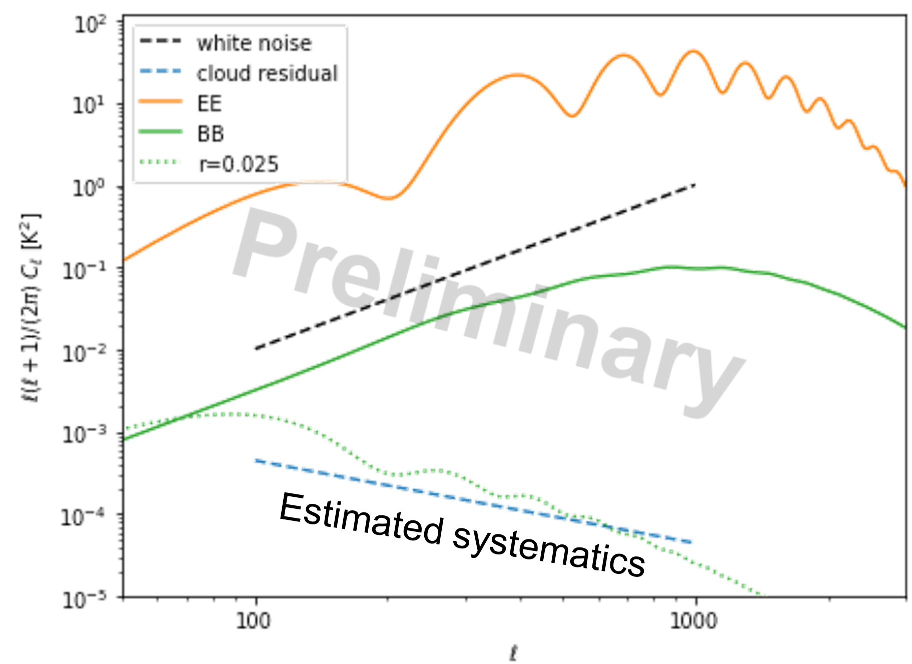
Impacts of ice clouds in POLARBEAR

Satoru Takakura
Kavli IPMU

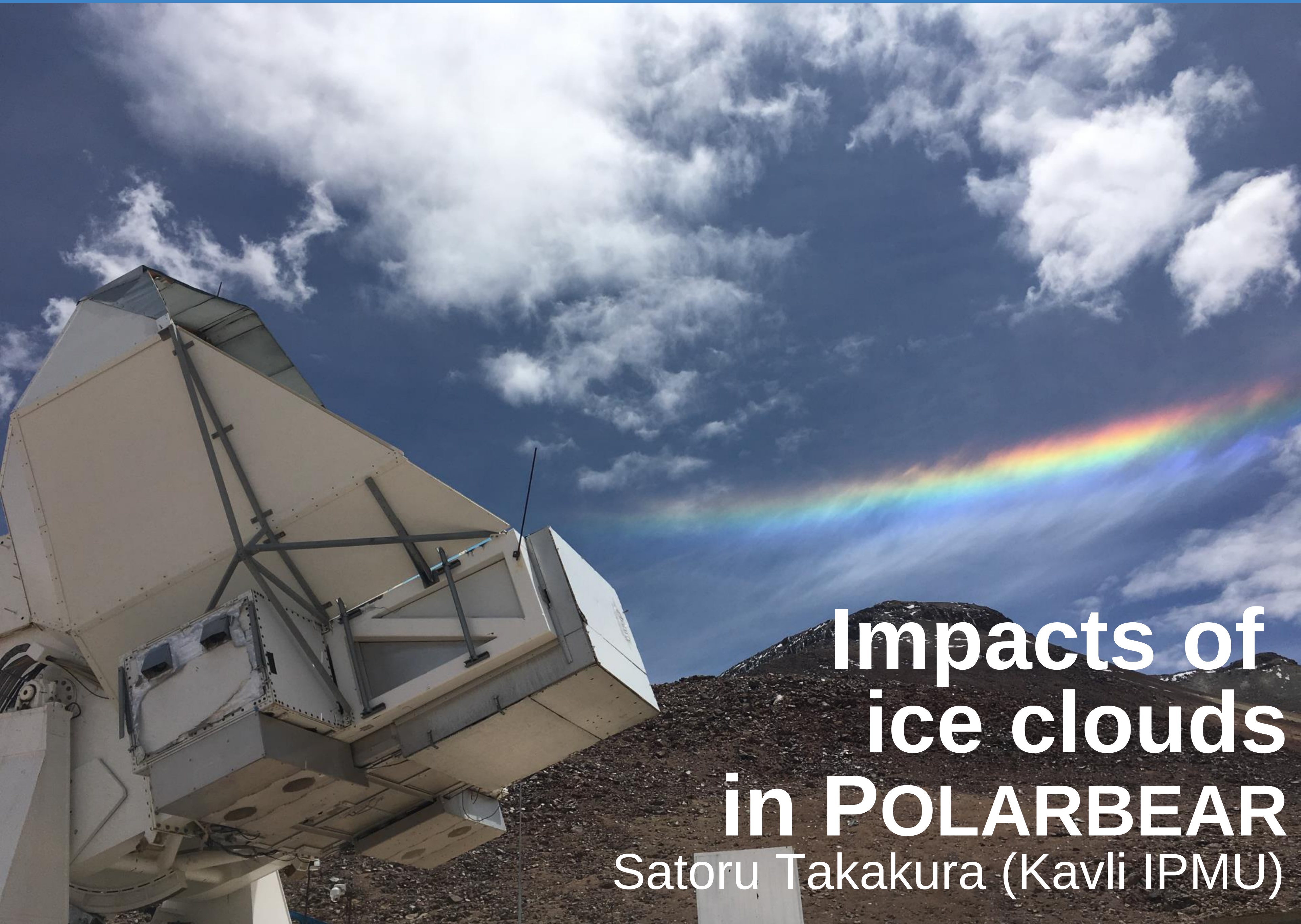
- Clouds are polarized.







S. Takakura et al 2019 ApJ 870 102 [arXiv:1809.06556]



Impacts of ice clouds in POLARBEAR

Satoru Takakura (Kavli IPMU)

Outline

- Introduction
- Polarization from clouds
- Polarized bursts in POLARBEAR data
- Estimation of systematics
- Discussion

CMB observation from ground

CMB

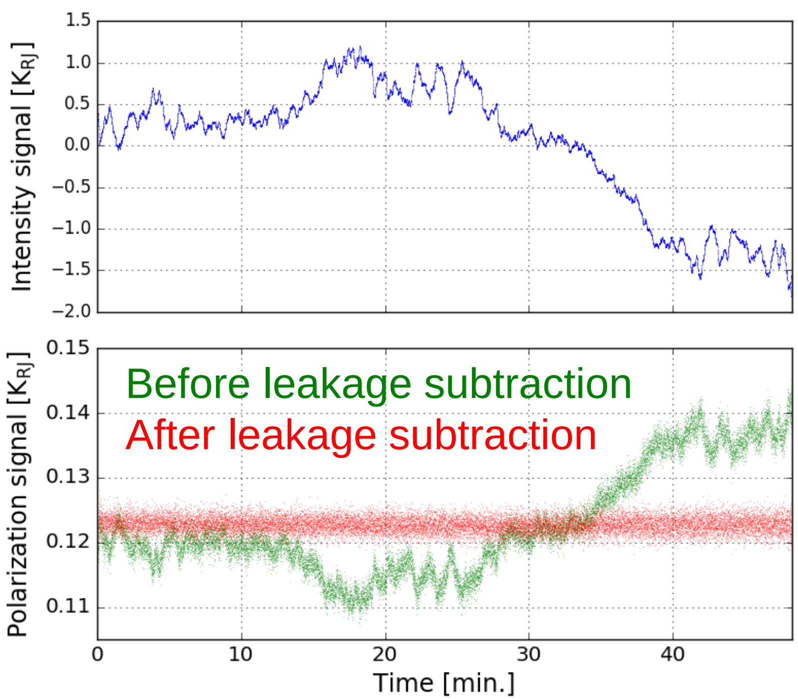
Atmospheric turbulence
causes higher noise
at larger angular scales.

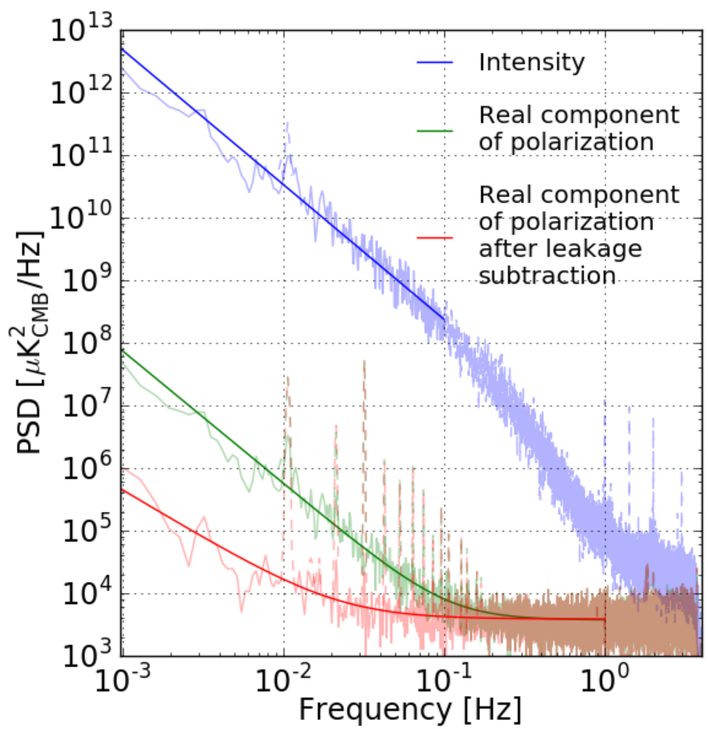
If atmosphere is not polarized

We can separate polarization component by

- Differencing orthogonal detector pair
- Polarization modulation

Atmosphere does not affect polarization measurements.

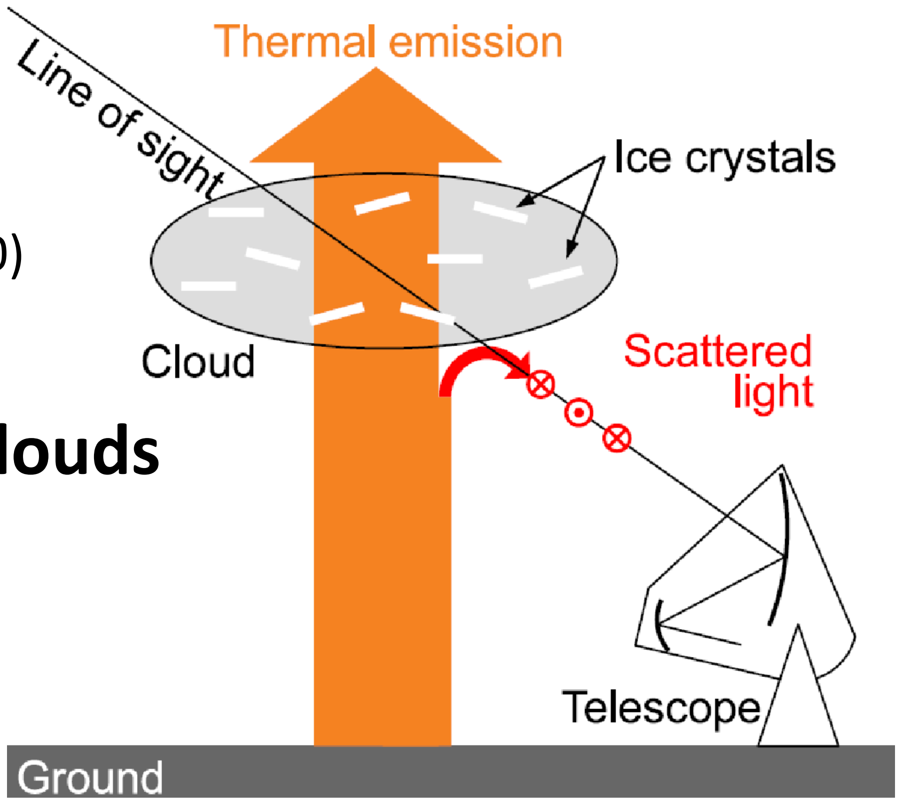




Is atmosphere polarized?

Zeeman splitting of oxygen

- Keating et al. (1998), Hanany & Rosenkranz (2003)
- Polarization signal
  - Linear: ~ 1 nK
  - Circular: ~ 100 μK
    - Measured by CLASS (2020)



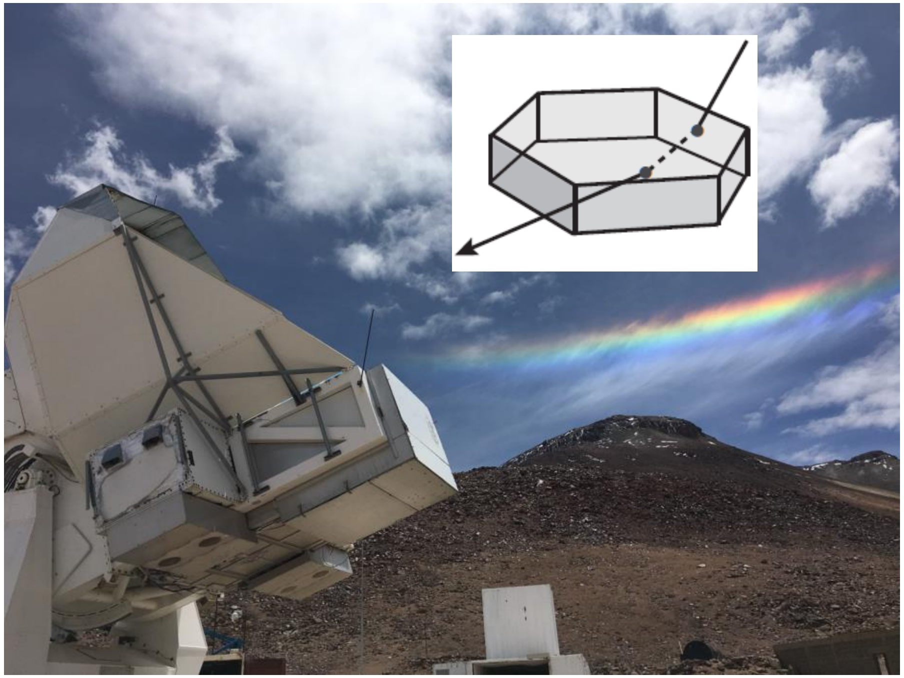
Scattering by ice crystal clouds

- Pietranera et al. (2007)
- Polarization signal
  - Linear: ~ 1 mK

Ice crystals in clouds

- Particle size: $D_e \cong$ 20–100 µm
- Number density: $n \cong 10^4$–10^5 m^{-3}
- Thickness of clouds: $\Delta h \cong 10^3$ m
- Total mass per unit area: $IWP \cong$1–10 g m^{-2}
- Shape
  - Column
  - Plate
  - Polycrystalline

PWV 1mm = 10 g m^{-2}



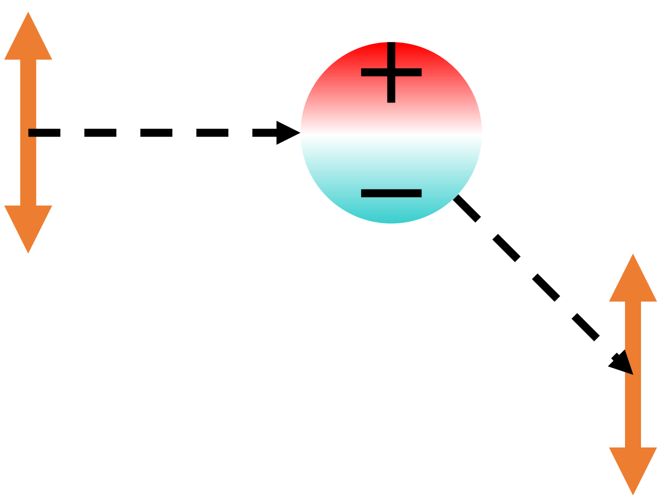
Circumhorizontal arc by horizontally aligned plate-shape crystals

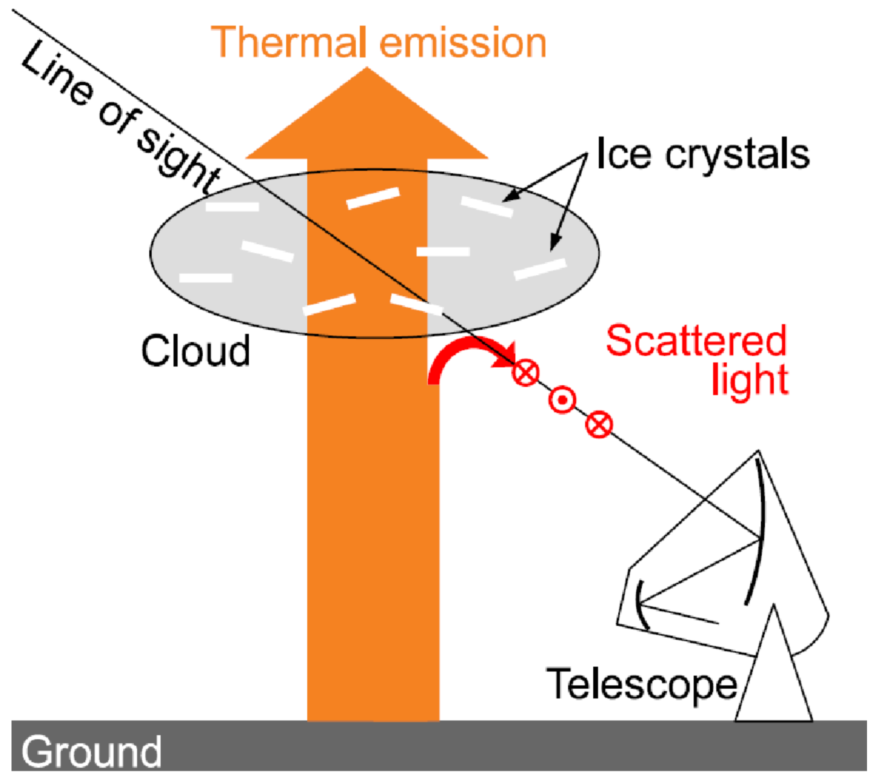
by Grant Teply

Scattering by cloud particles

Rayleigh Scattering

- Cross section ∝ (particle size)$^{\mathbf{6}}$ (frequency)$^{\mathbf{4}}$
- Optical depth: $\tau \sim 10^{-9}$–10^{-4} @150GHz





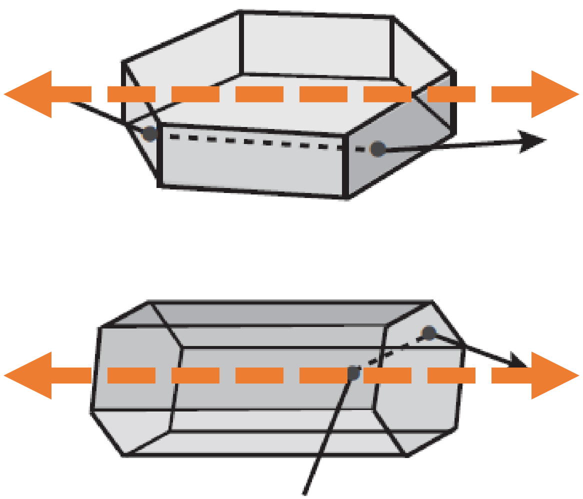
Polarization

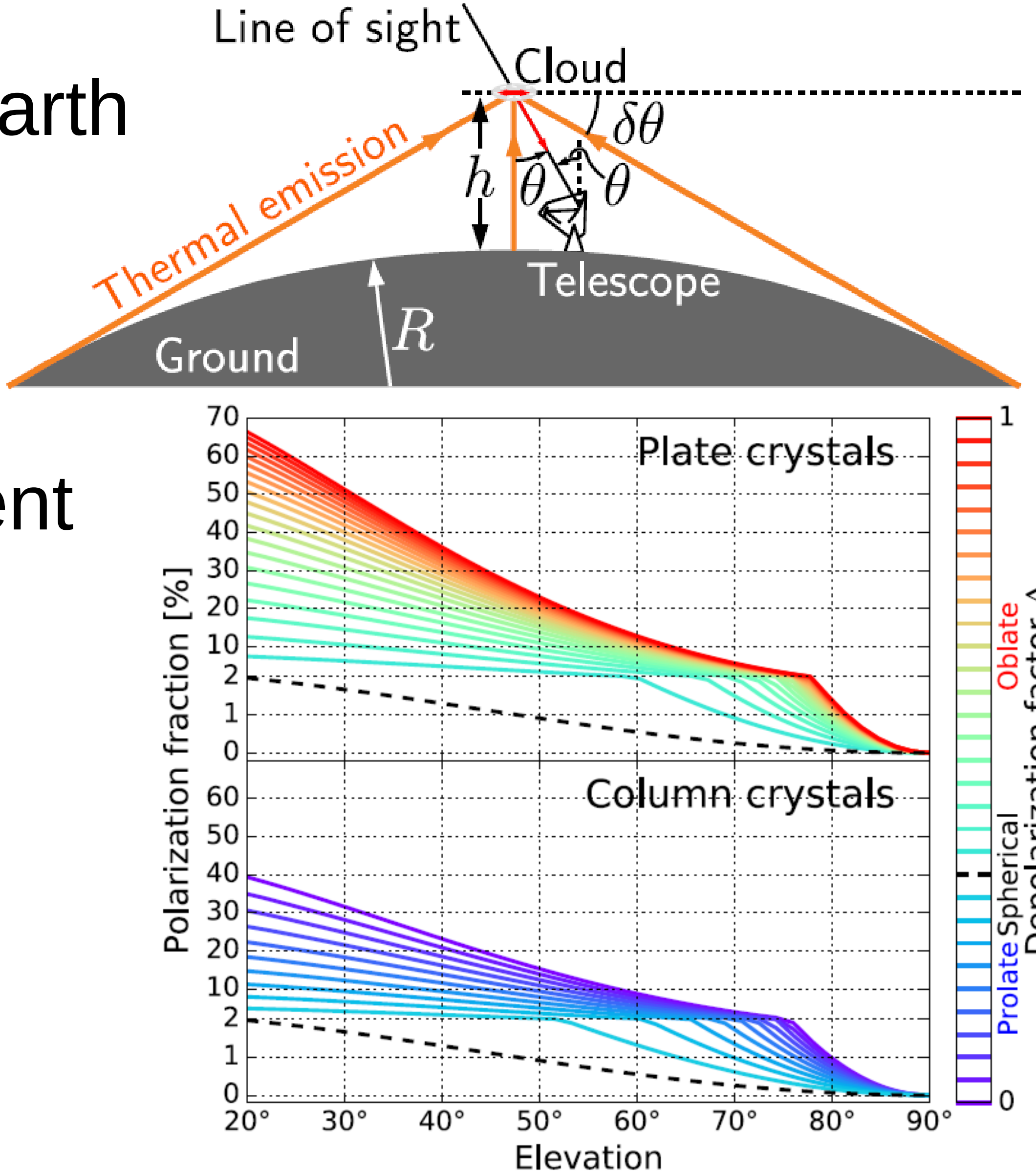
- Curvature of the Earth

  Polarization fraction

  $$\approx \frac{3}{4}\sqrt{\frac{h}{2R}}\,\sin^2\theta$$

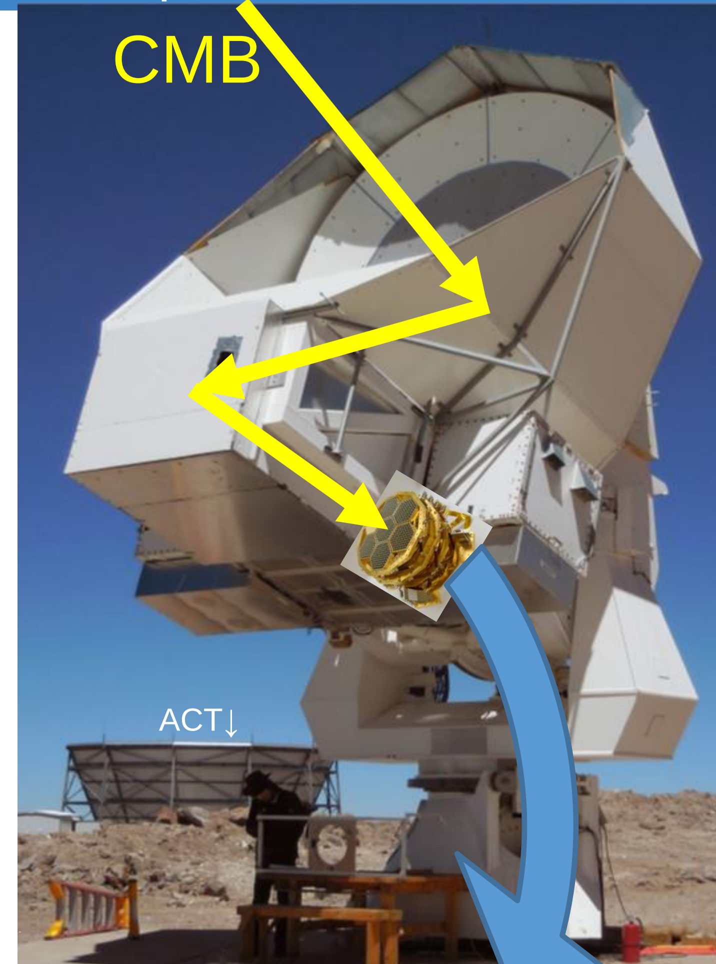
- Horizontal alignment

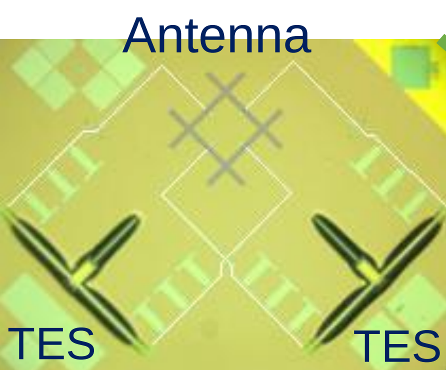


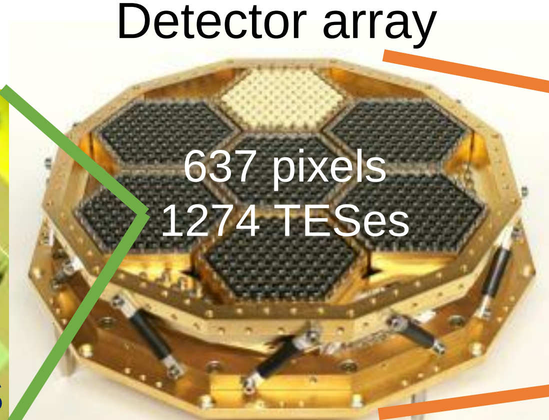


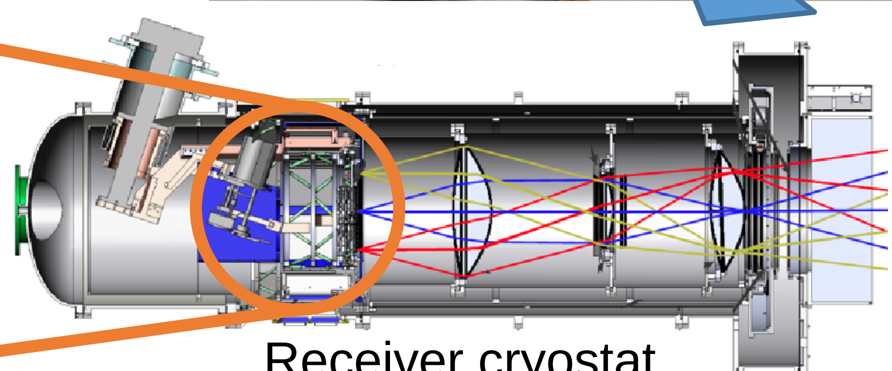
POLARBEAR

- Atacama desert in Chile (5,200 m)
- Primary mirror 2.5 m
- Frequency band 150 GHz (2mm)
- Beam resolution 3.5 arcmin.
- Low temperature receiver system
- 1,274 TES bolometers at 250mK
- Instantaneous sensitivity 23μK√s



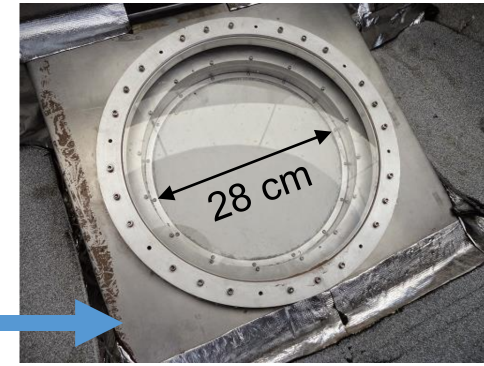


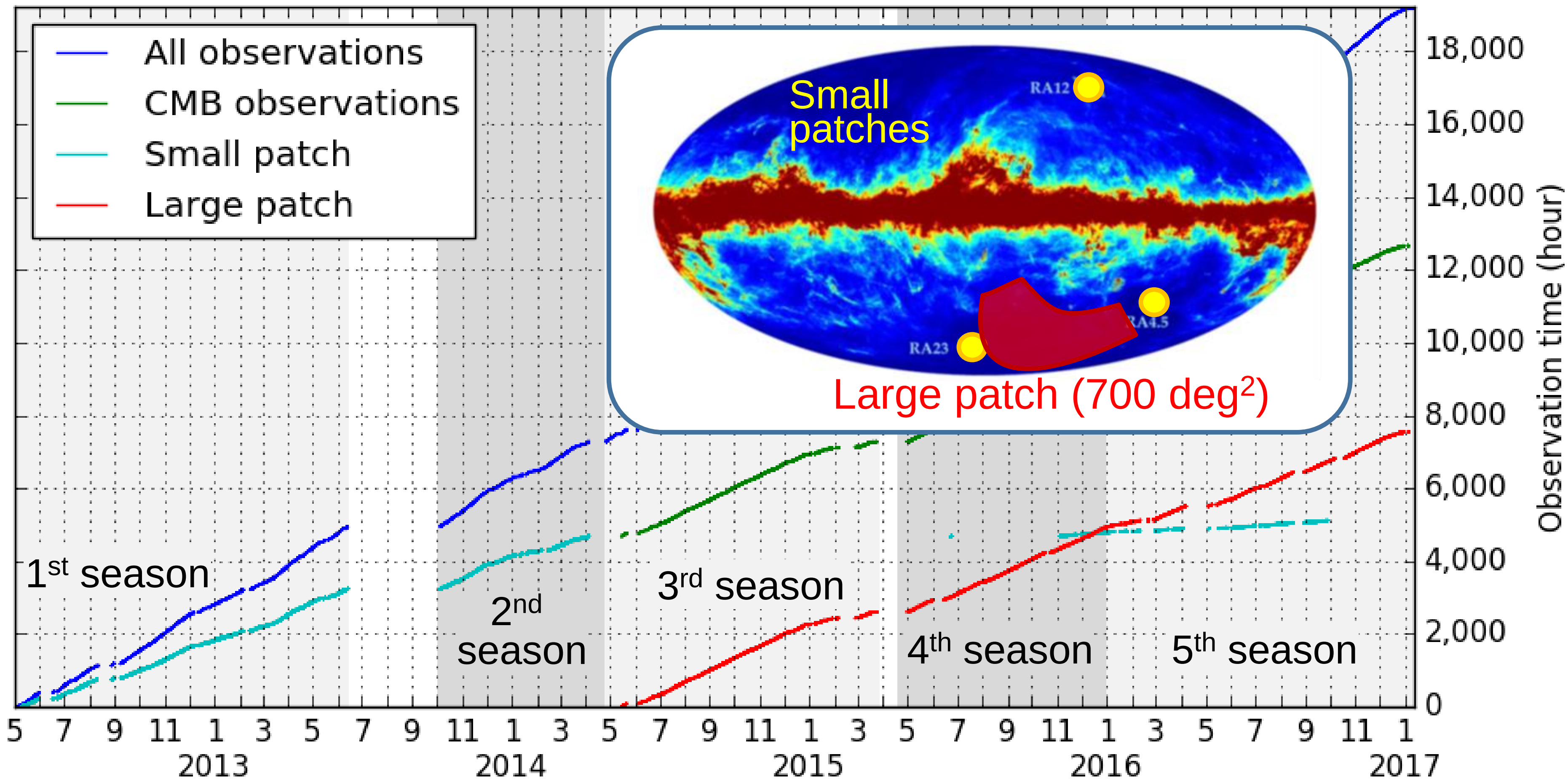




Observation history

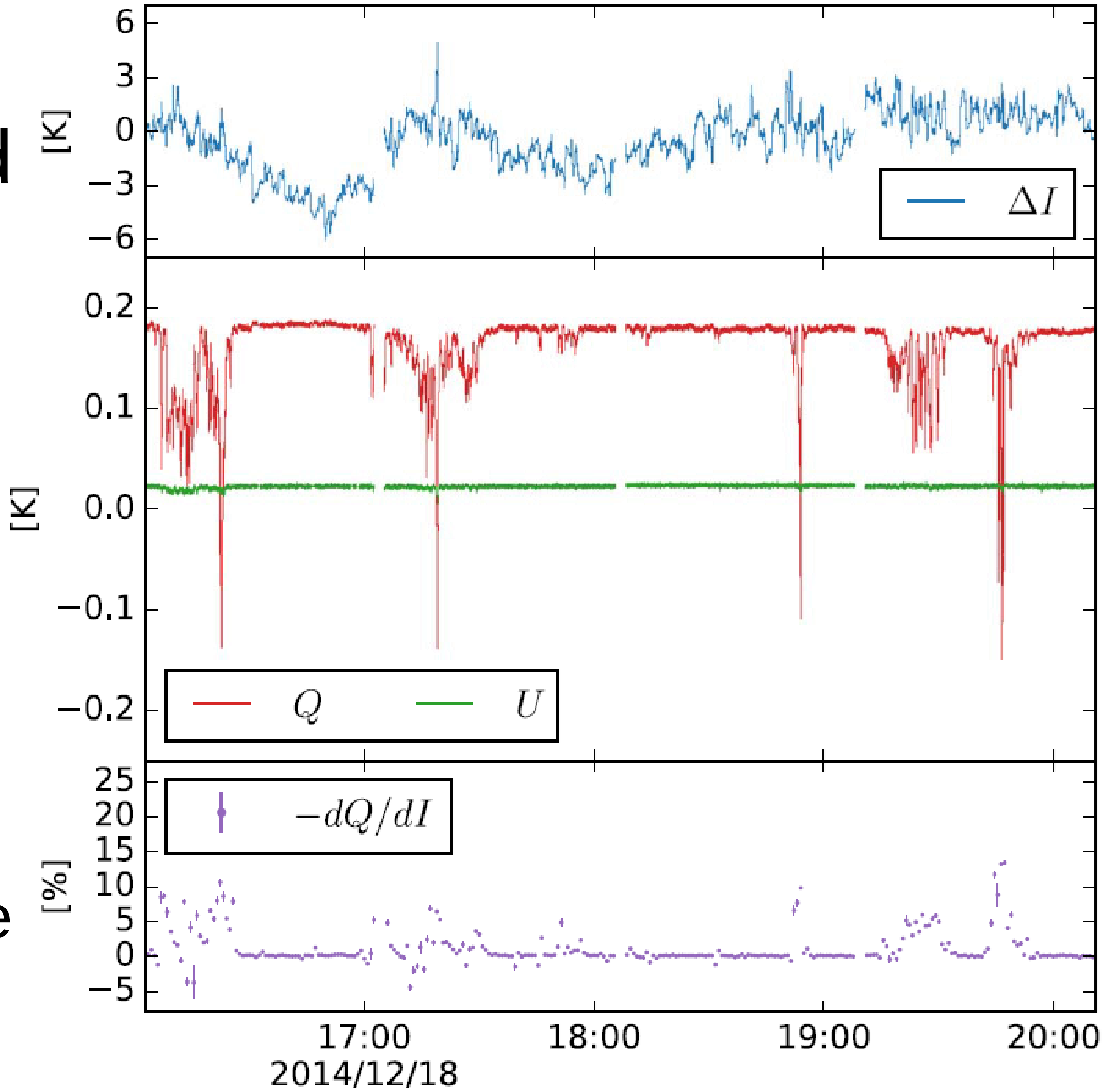
- Since 2014, we started large patch observation with a rotating HWP.





Example of polarized bursts

We occasionally find horizontally polarized bursts during cloudy observations.



We confirmed coincidence using 3 years of data.

Impacts on CMB measurements?

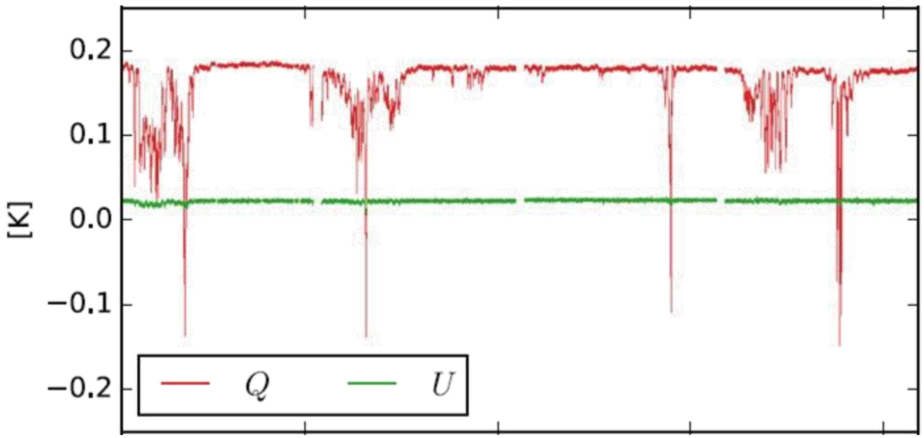
- Data selection, observation efficiency
- Systematic error due to residuals
- (Polarization angle calibration)

Polarized burst detection

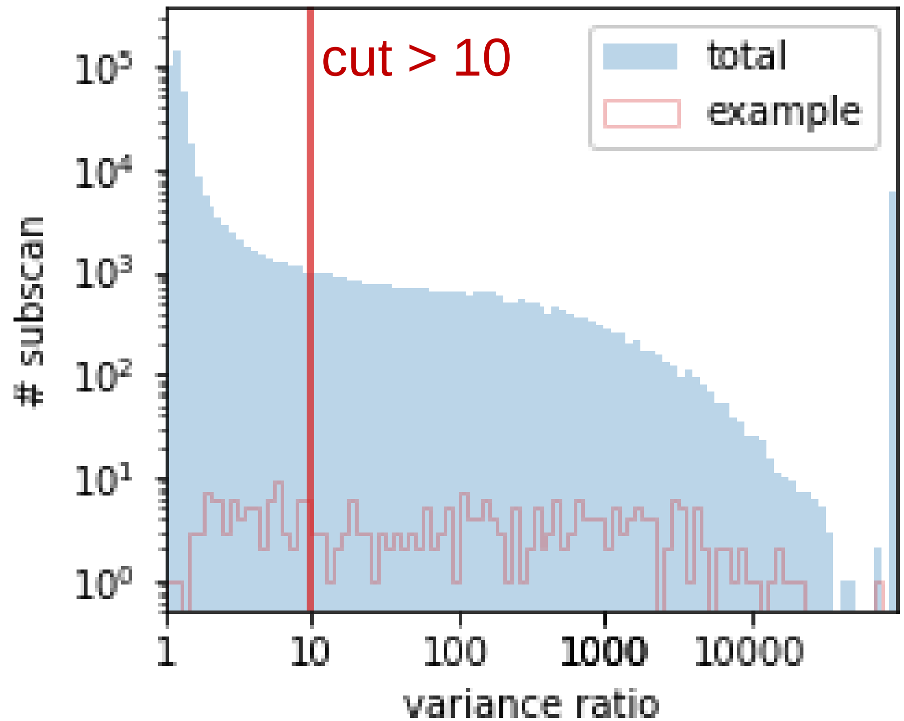
- Variance ratio between Q&U timestreams
  - Q: detector noise + cloud polarization
  - U: detector noise

Variance ratio - 1
= (Cloud SNR)^2

* Other noises (I→P leakage, ground signal) are filtered before.

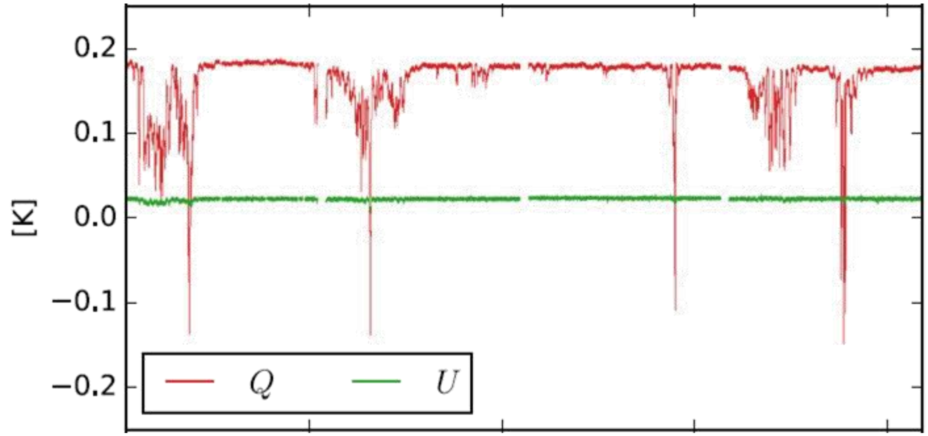


In POLARBEAR analysis
we drop ~10% of data.

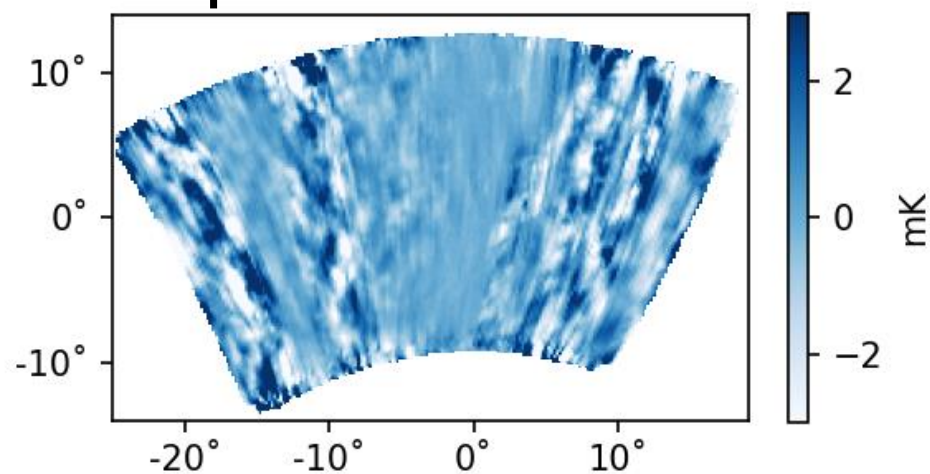


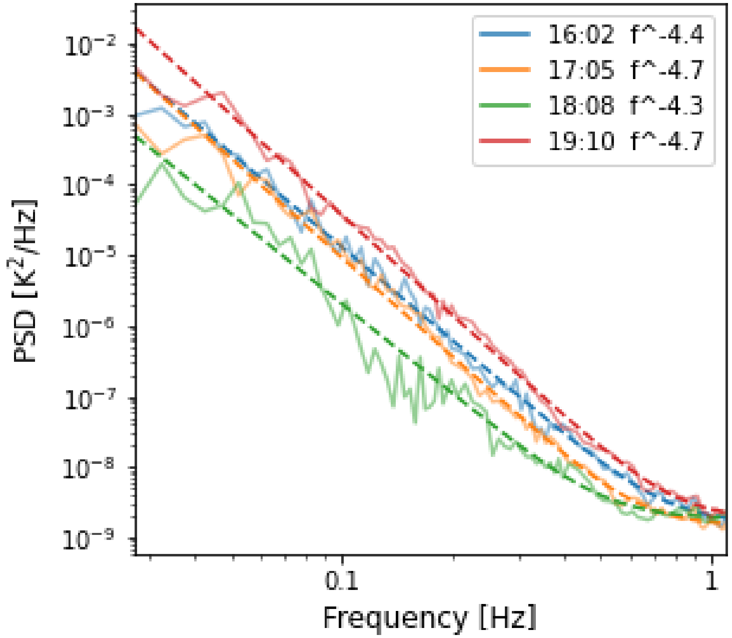
Noise spectrum

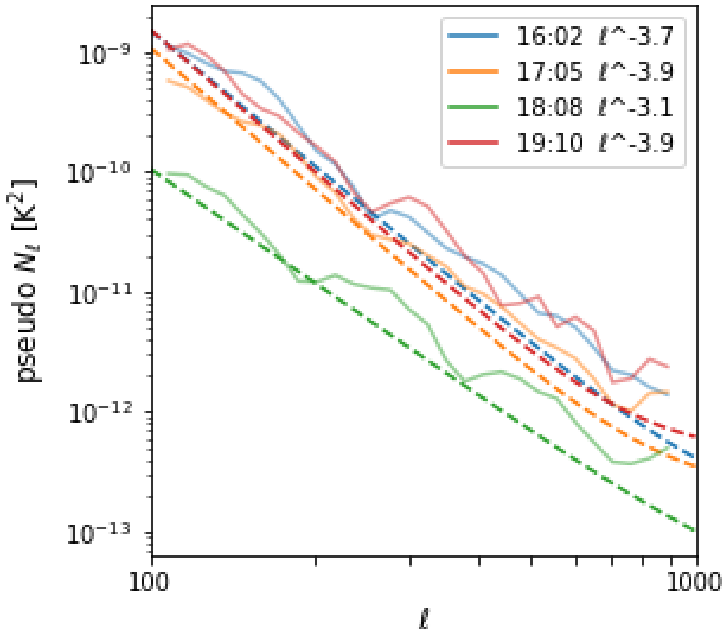
- Time domain



- Map domain



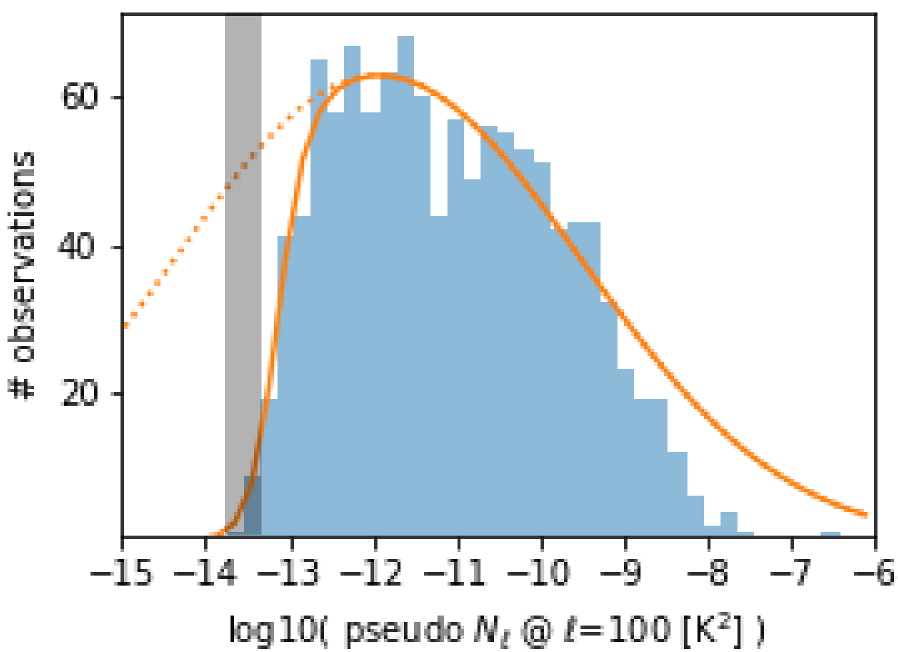




Modeling cloud probability

- Histogram of N_ℓ from observations with bursts
  - We model the histogram as log-normal distribution with cut-off due to threshold of data selection.

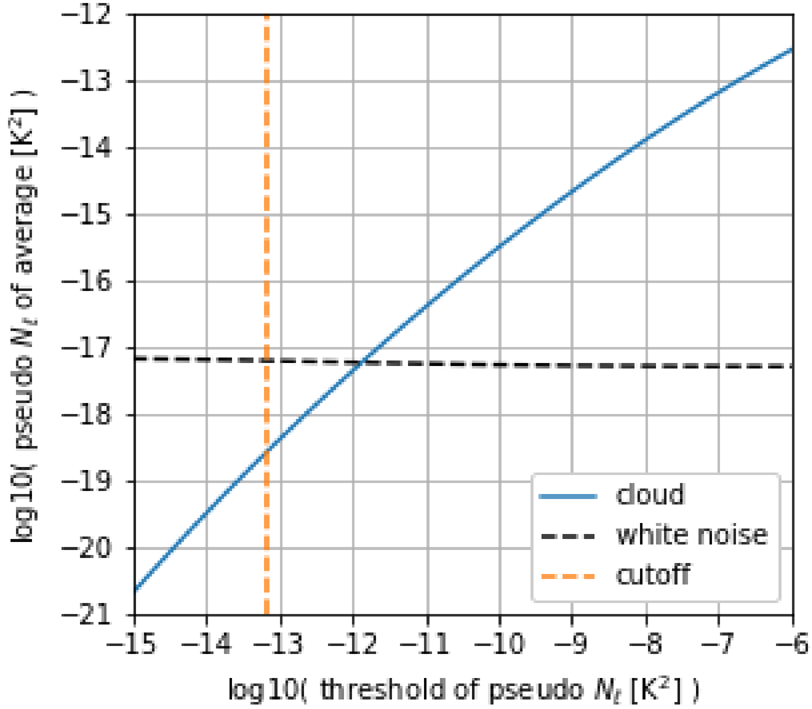
White noise

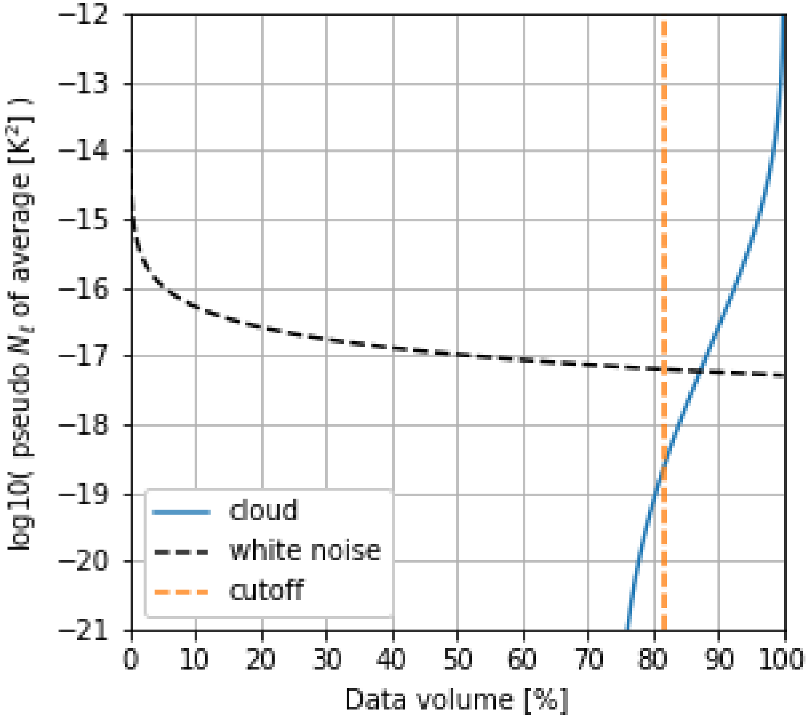


	# Obs	
Total	~7200	100%
Burst detected	~1300	18%
Fit integral	~1900	26%
Residual?	~600	8%
No cloud?	~5300	74%

Estimation of averaging effect

- Suppose averaging all data below threshold.



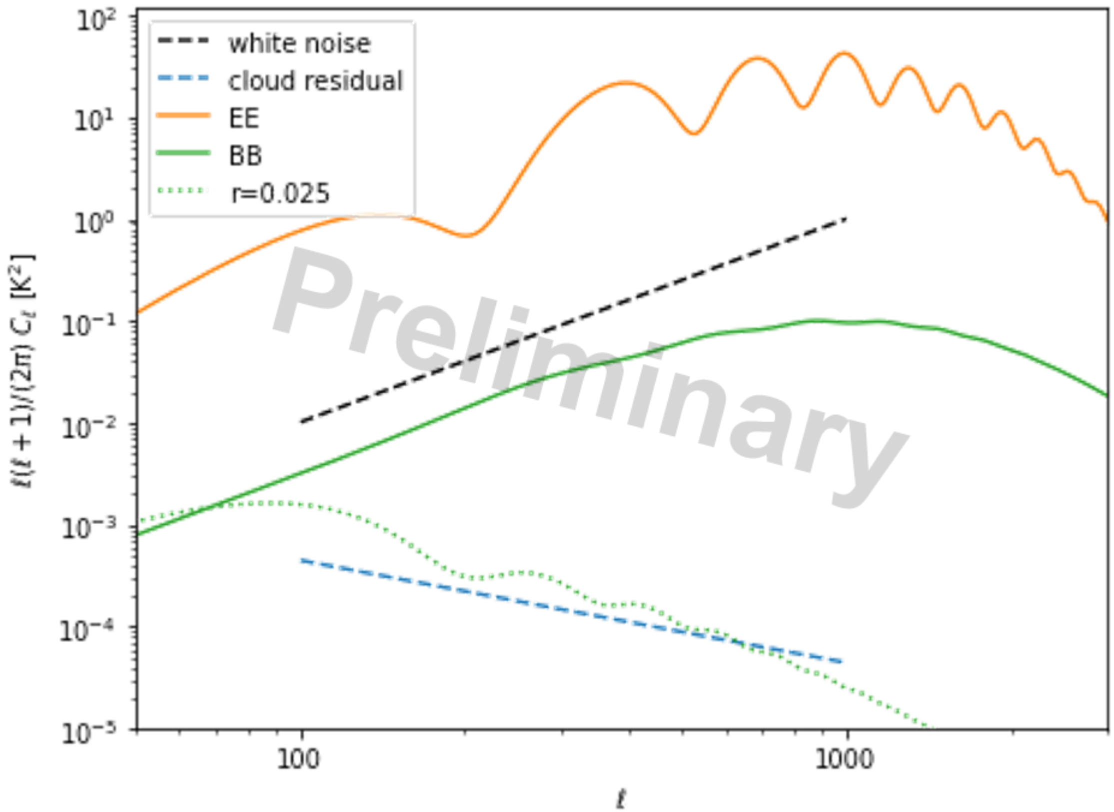


More data we include

- White noise → decrease
- Cloud residuals → increase

Systematics on CMB spectra

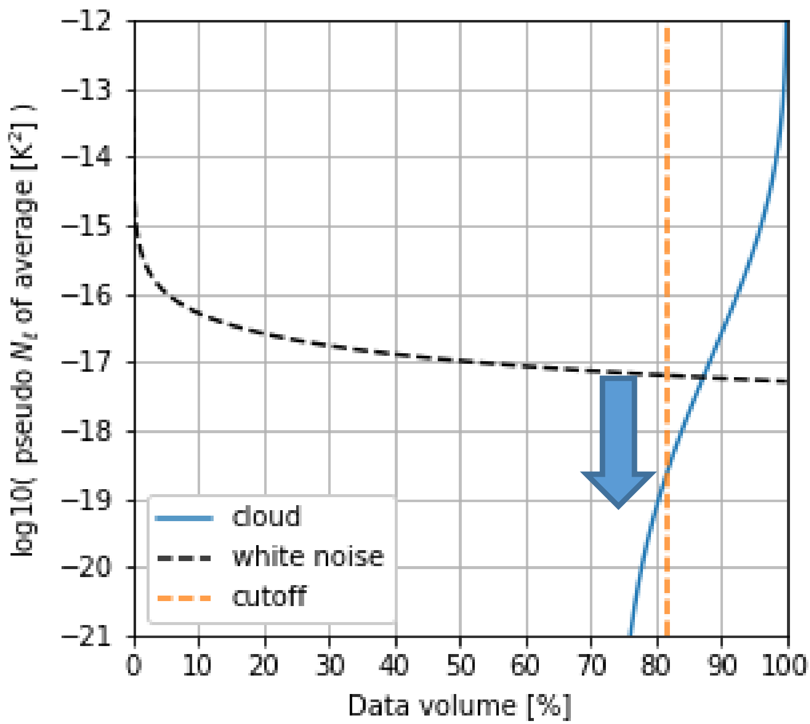
- Assuming spectral index of ℓ^{-3}



Systematics of residual clouds is small enough for POLARBEAR.

Scaling for future experiments

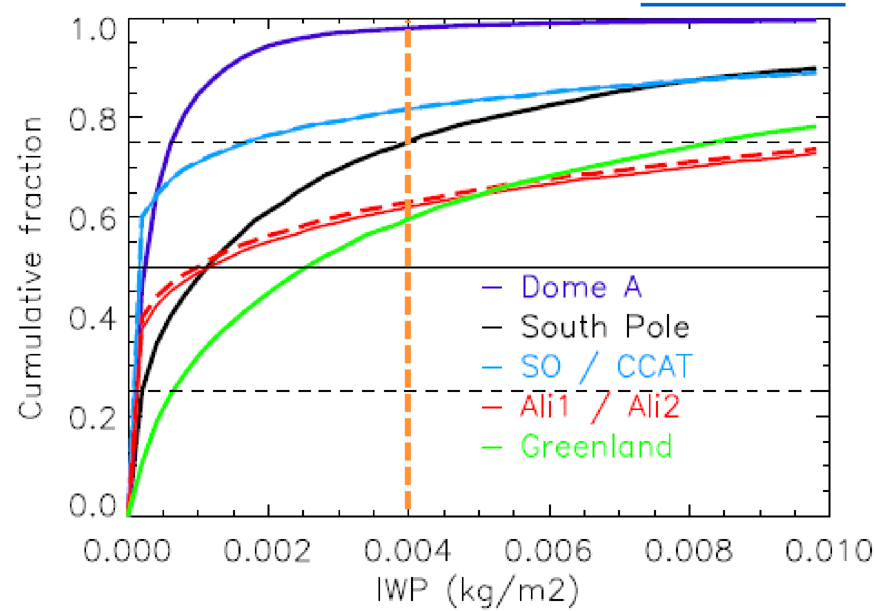
- Sensitivity
  - Need to tighten threshold.
    - How? Detector or external monitor?
    - Efficiency loss won't be so large.



- Observation band
  $\propto$(frequency)^4
- Scan strategy
  Patch size, Elevation
- Site

Median with burst
in POLARBEAR

Kuo 2017



Summary

- Clouds are polarized due to Rayleigh scattering.
- Using POLARBEAR data, we confirmed coincidence of polarized bursts and clouds.
- Cloud signal is well modeled as 1/f noise with spectral index of ~4 in PSD and ~3 in N_ℓ.
- We modeled probability of clouds and estimated systematics due to residuals.
- We drop ~10% of data due to polarized bursts.
- With current detection method, systematics is smaller than statistical sensitivity.