

# Cosmology Large Angular Scale Surveyor (CLASS)

Overview

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**JOHNS HOPKINS**  
UNIVERSITY

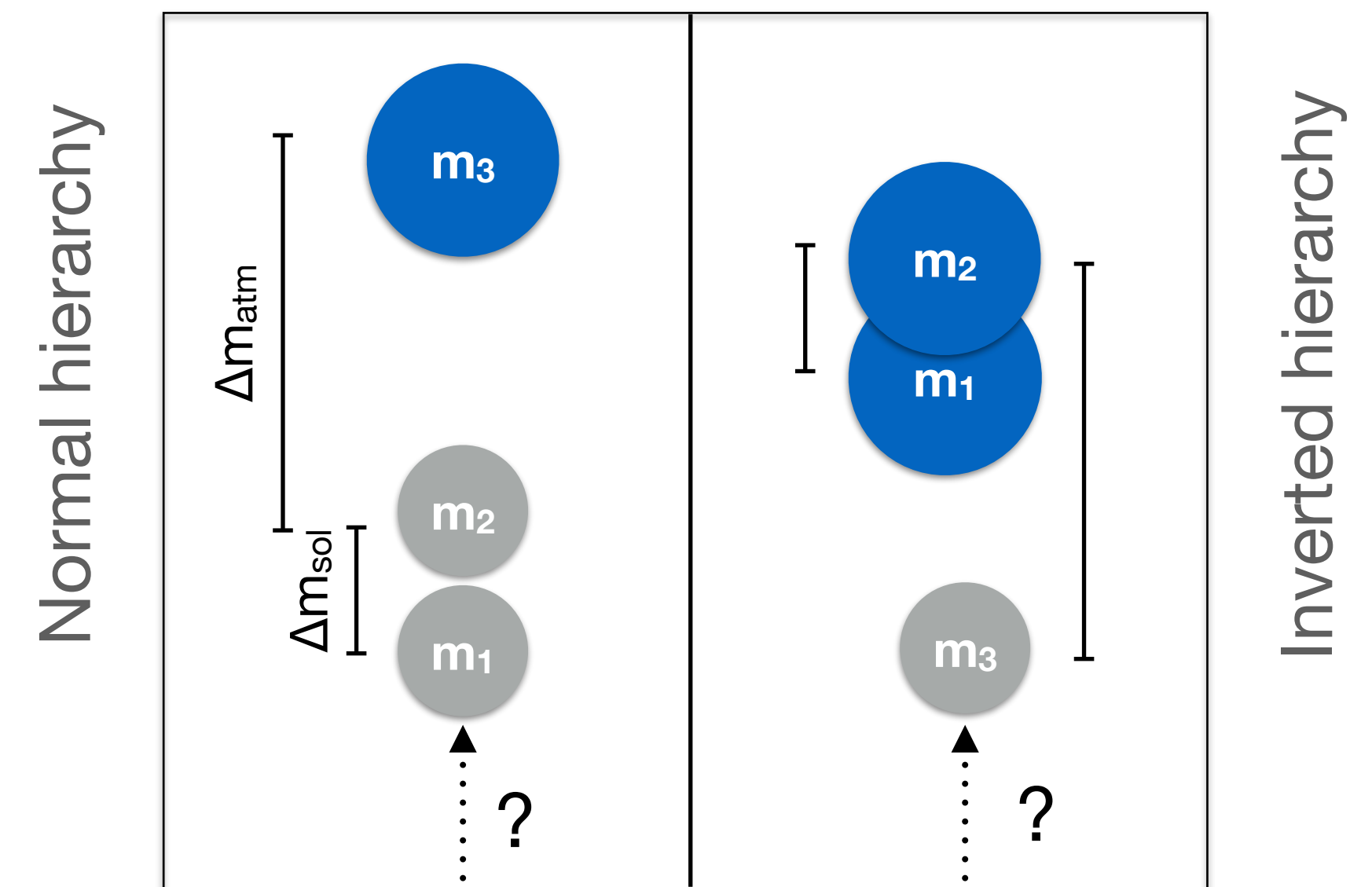
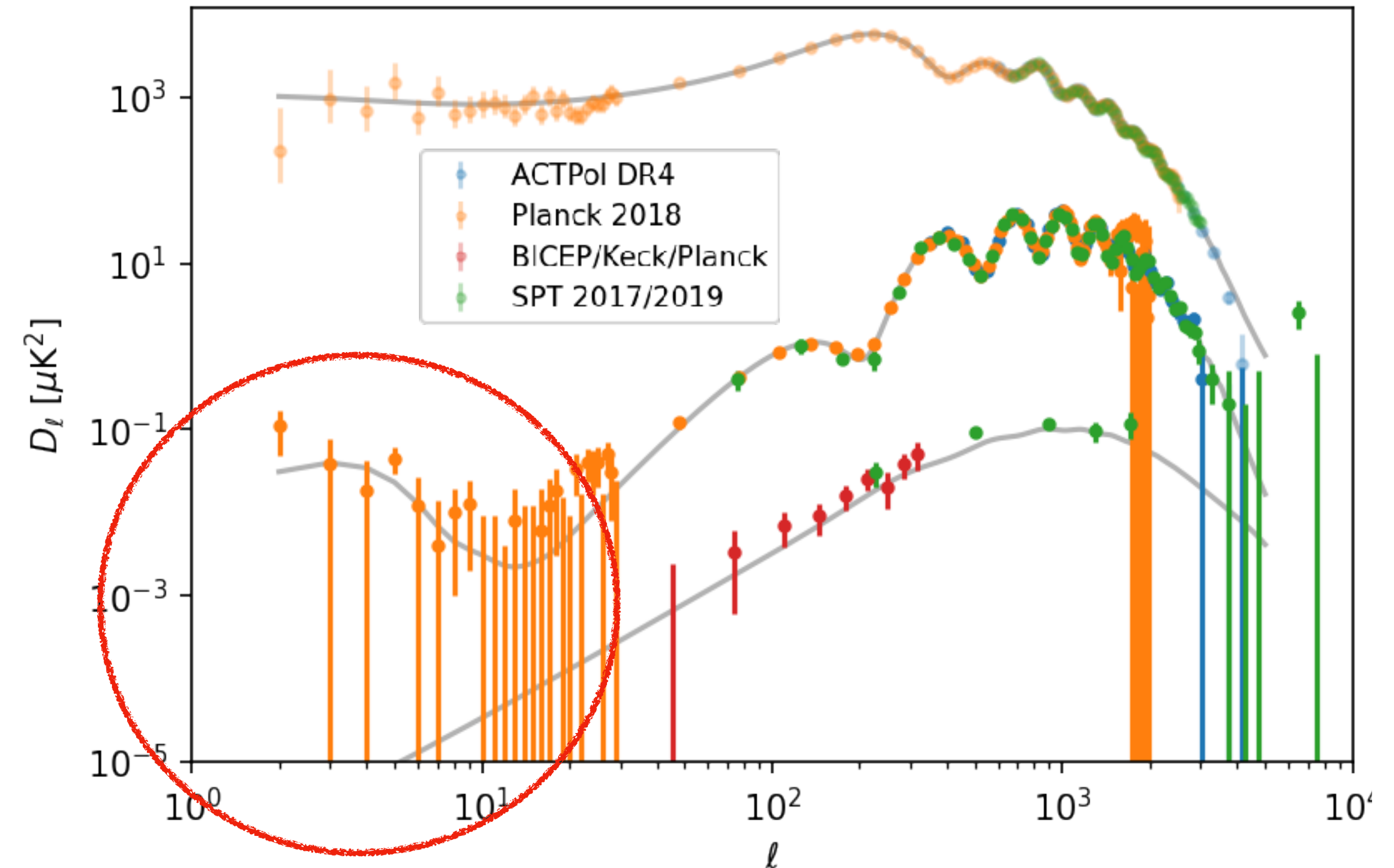
-CMB S4-  
Summer Collaboration  
meeting 2024

# CLASS Team

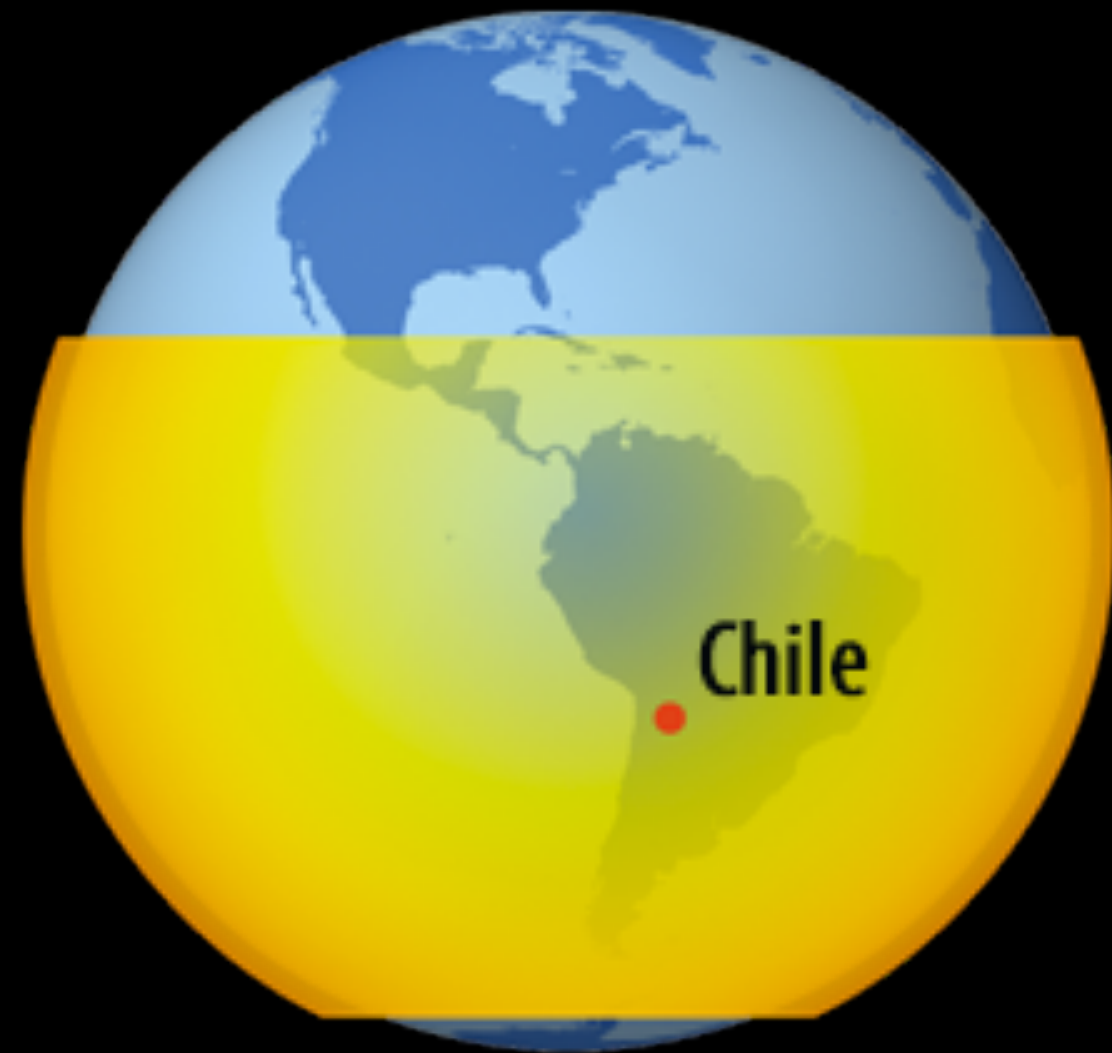


# CLASS Goals

- Measure CMB polarization at scales  $\ell < 20$  *from the ground*.
- **Improve** measurement of  $\tau$ .
- **Enable** measurement of the sum of neutrino masses.
- **Understand foregrounds** at large angular scales.
- **Discover tools/techniques** to access BB-inflation signal from the ground.

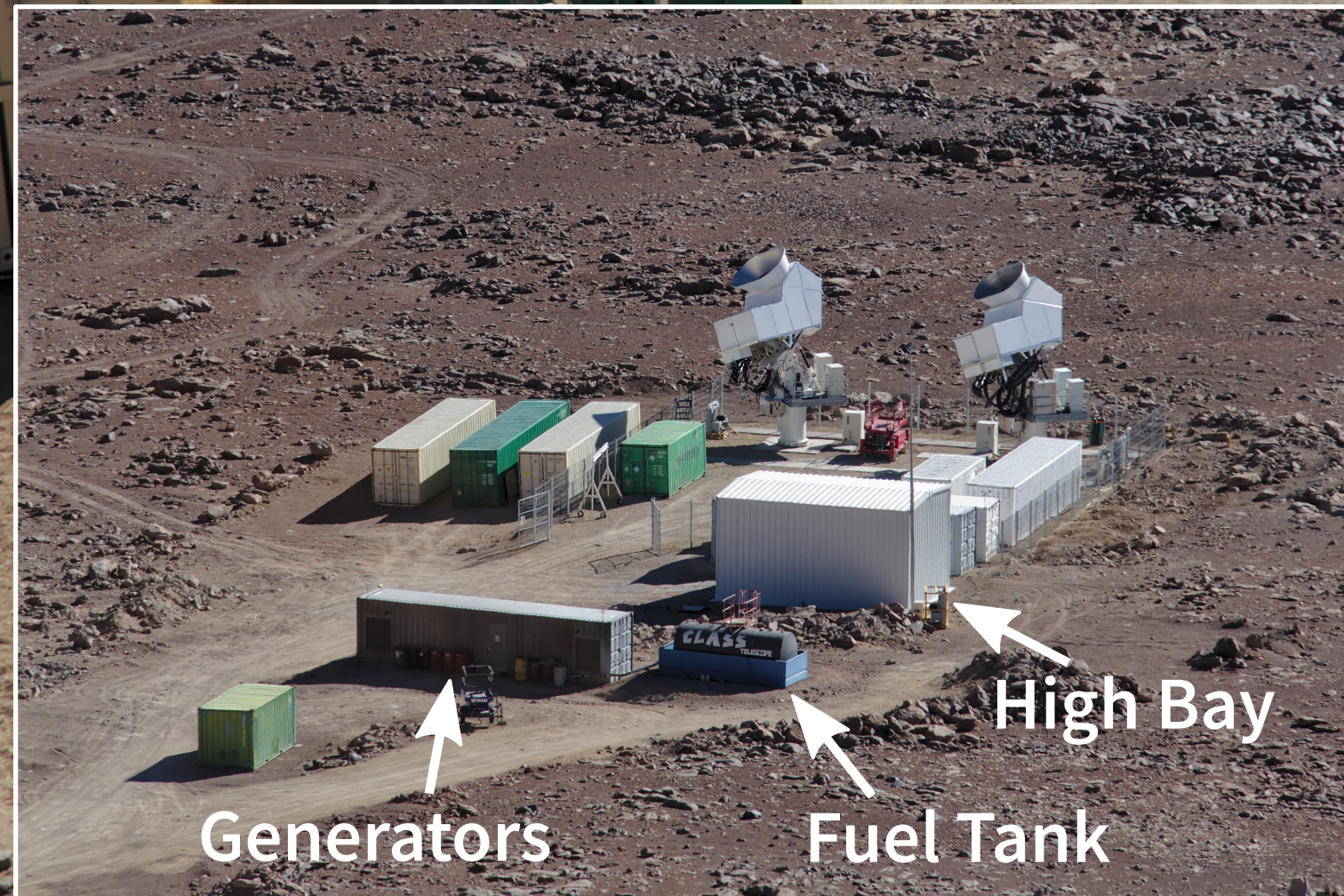
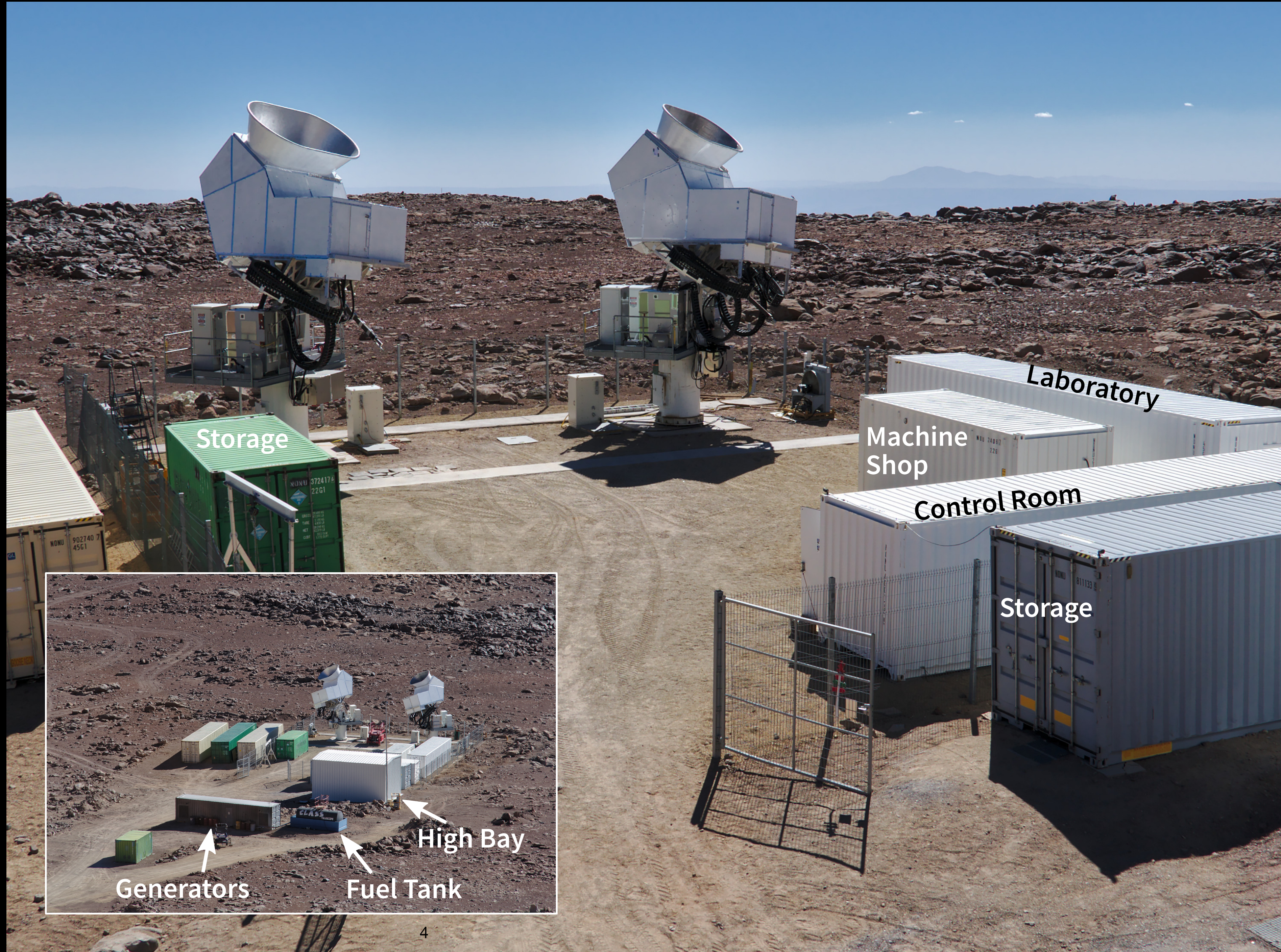


# CLASS site

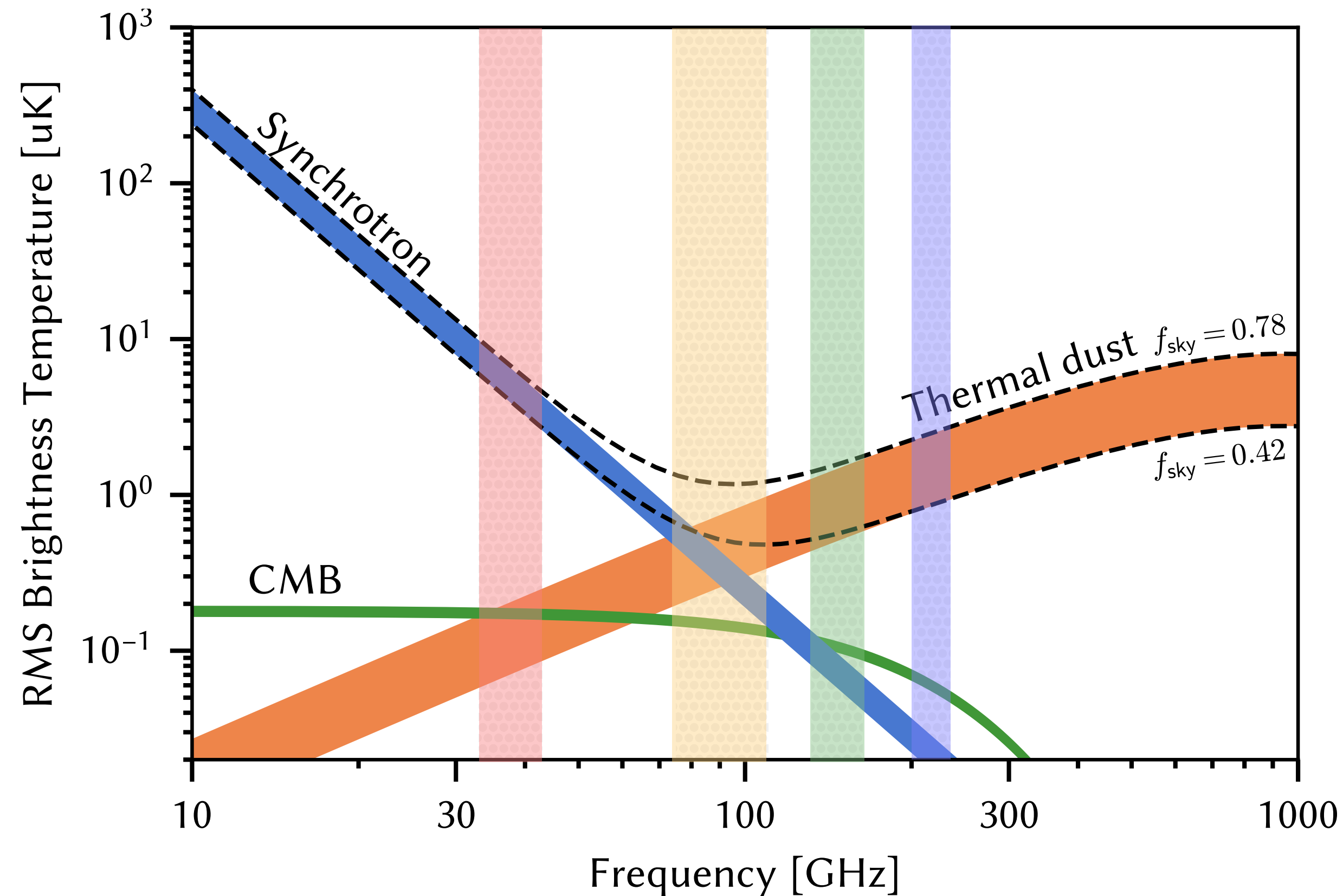
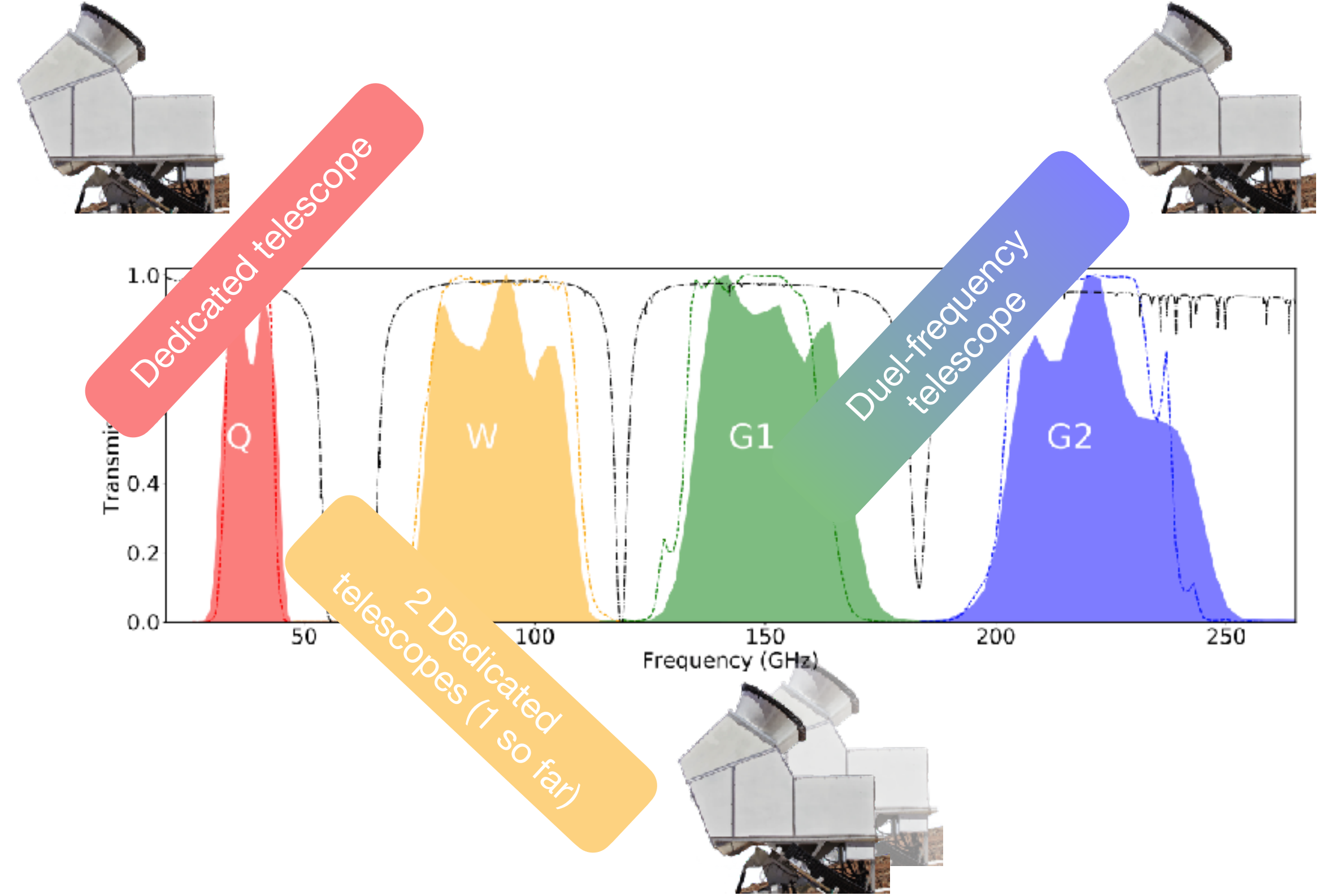
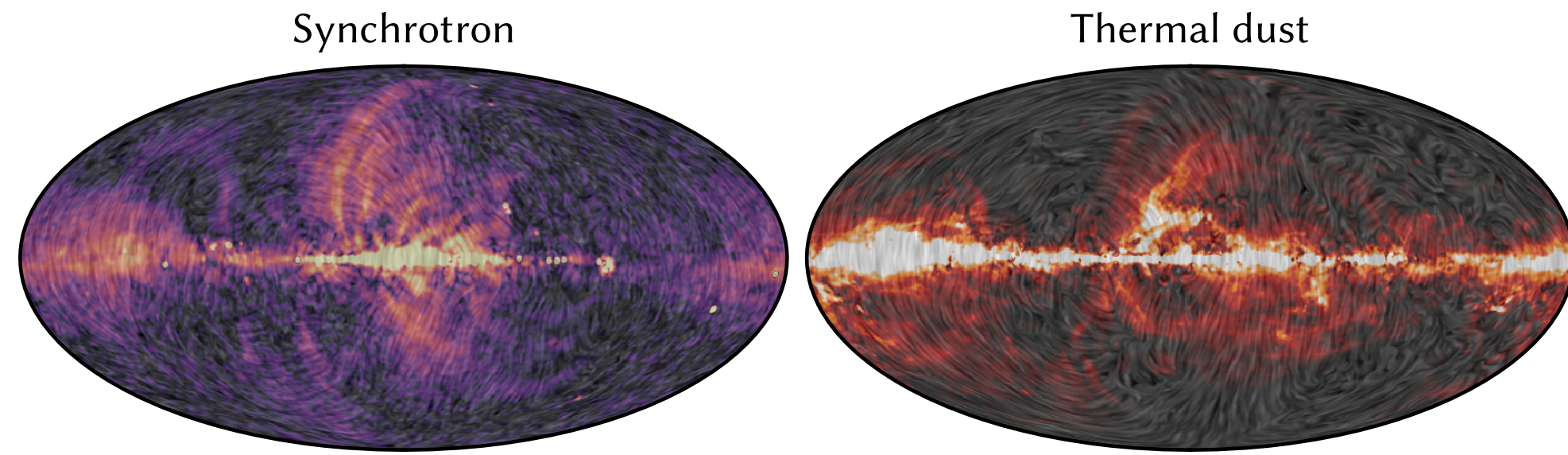


Chile

Elevation: 5200 m  
Survey: > 70% sky



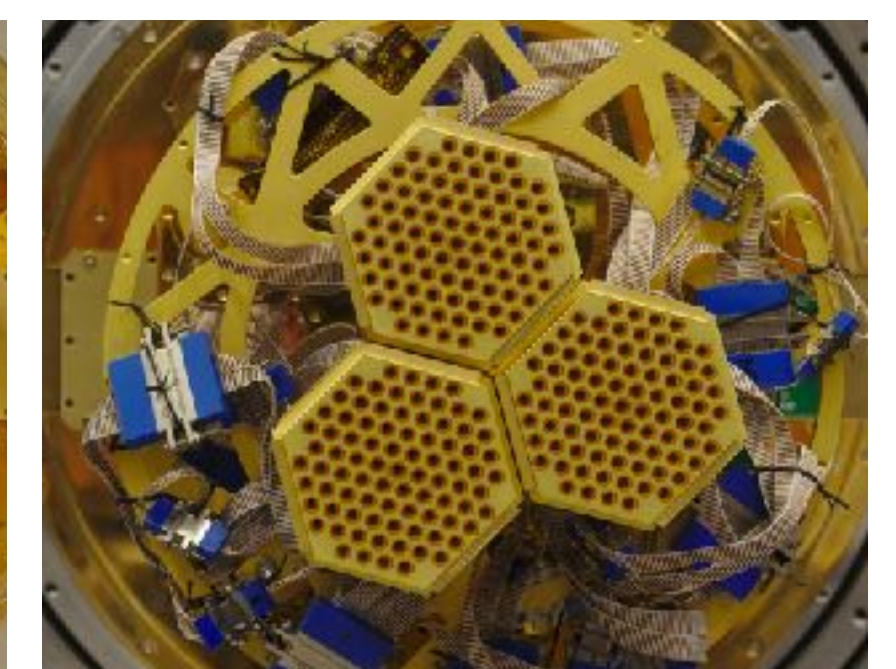
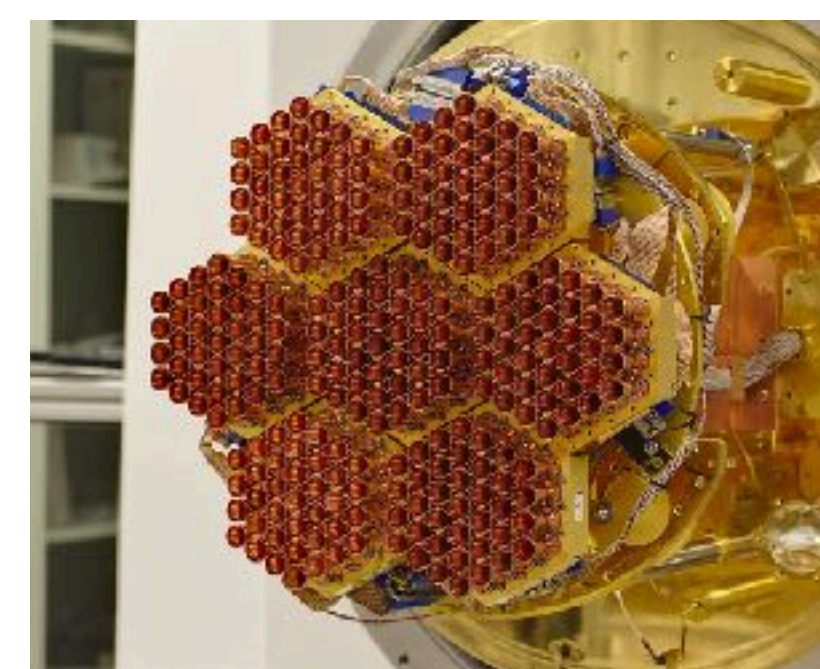
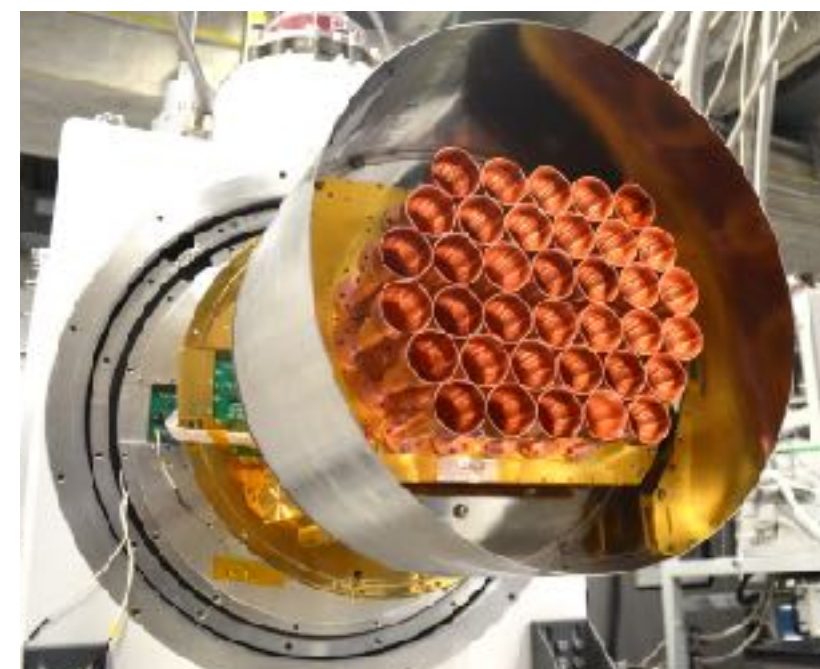
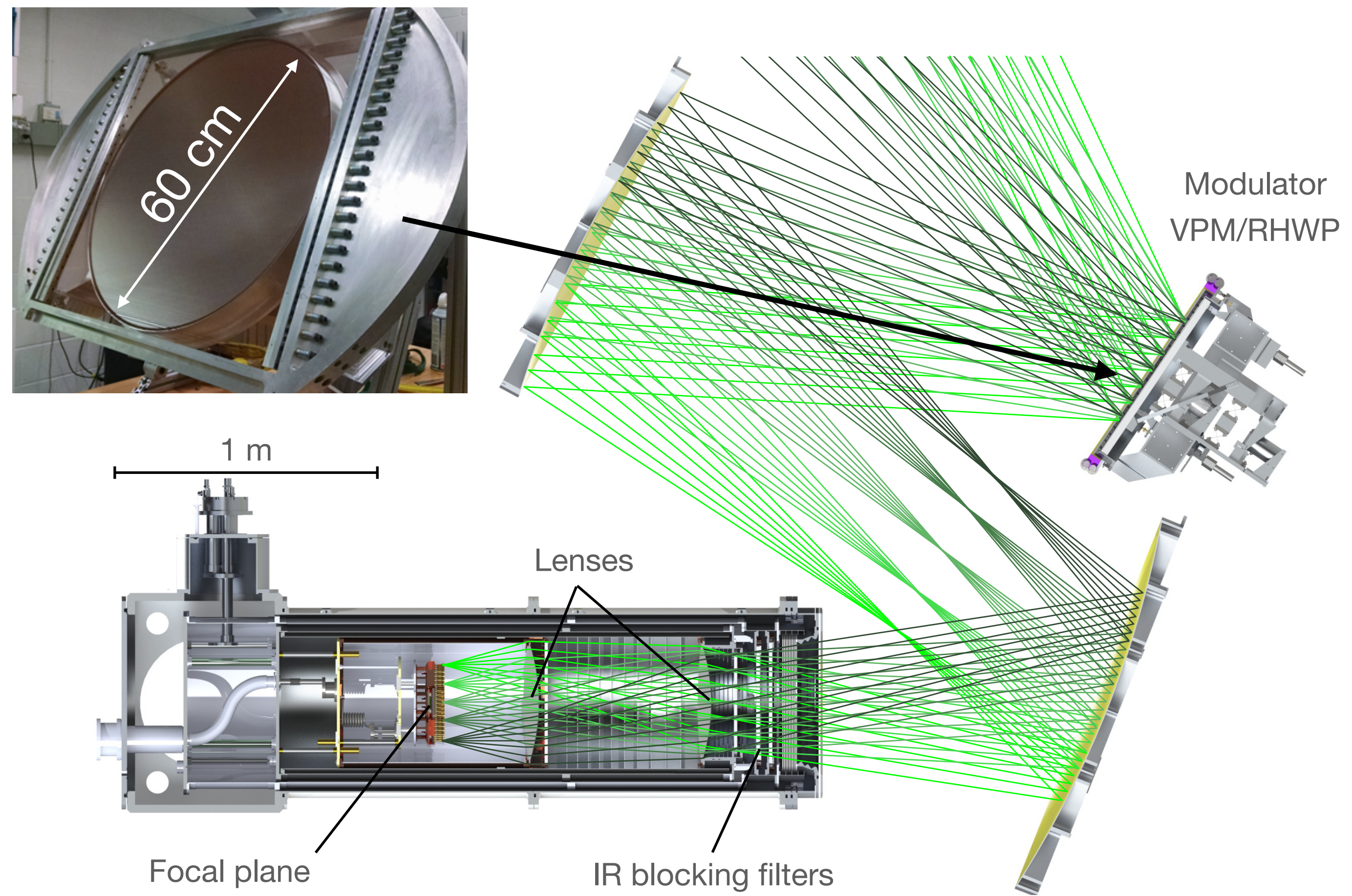
# CLASS frequencies



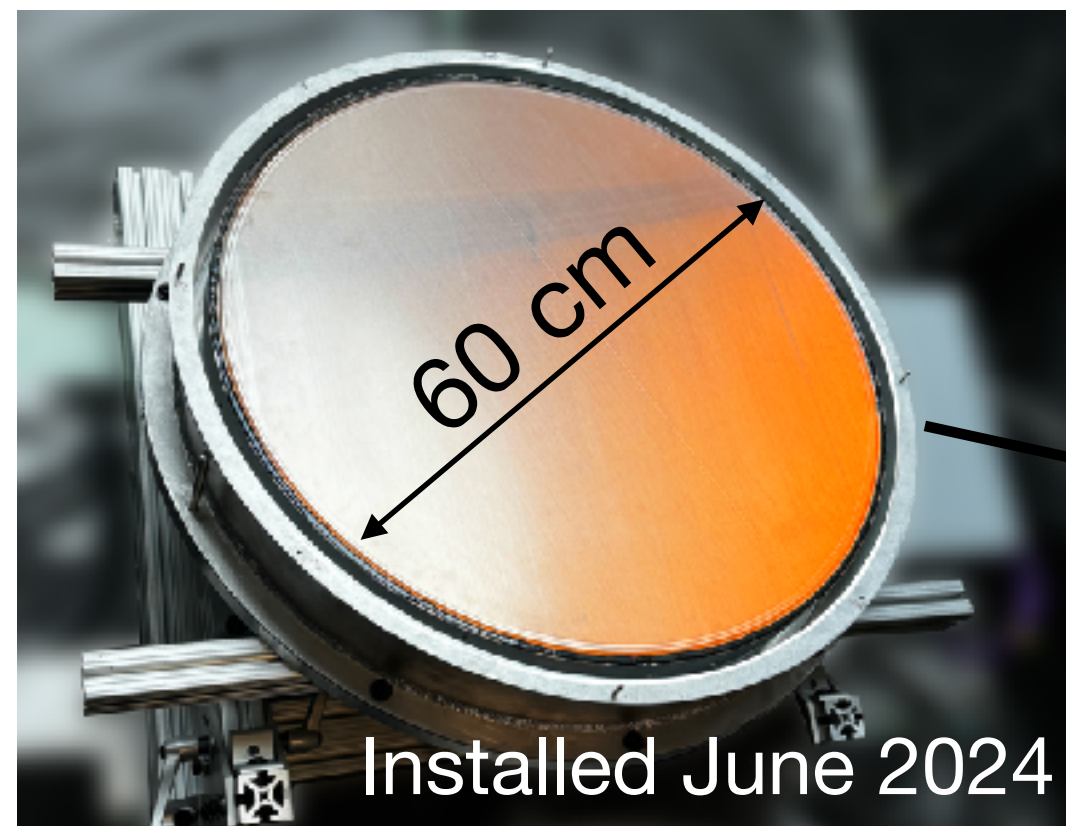
- Multi-frequency, multi-telescope observations span foreground minimum.
- Critical to characterize foregrounds at the scale you plan to measure the CMB.

# CLASS telescopes

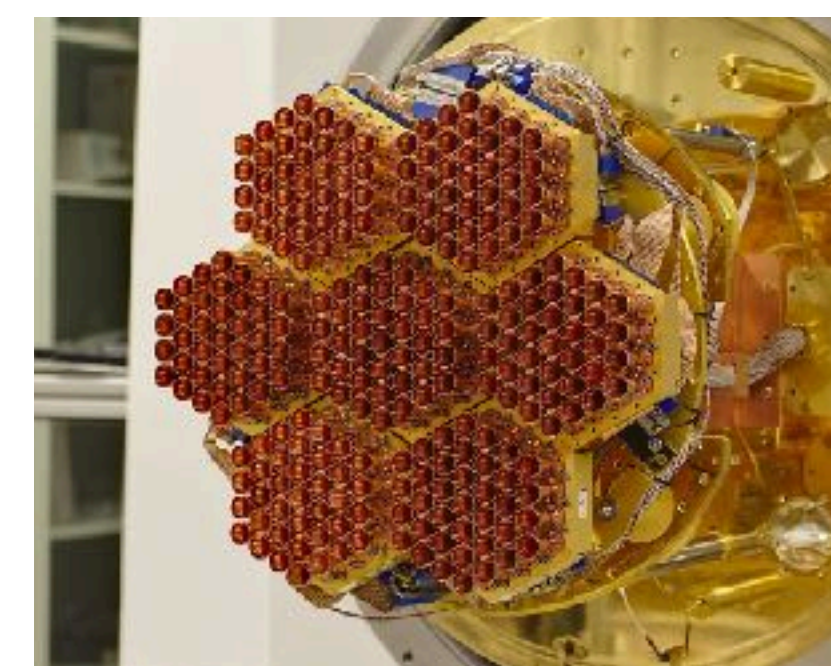
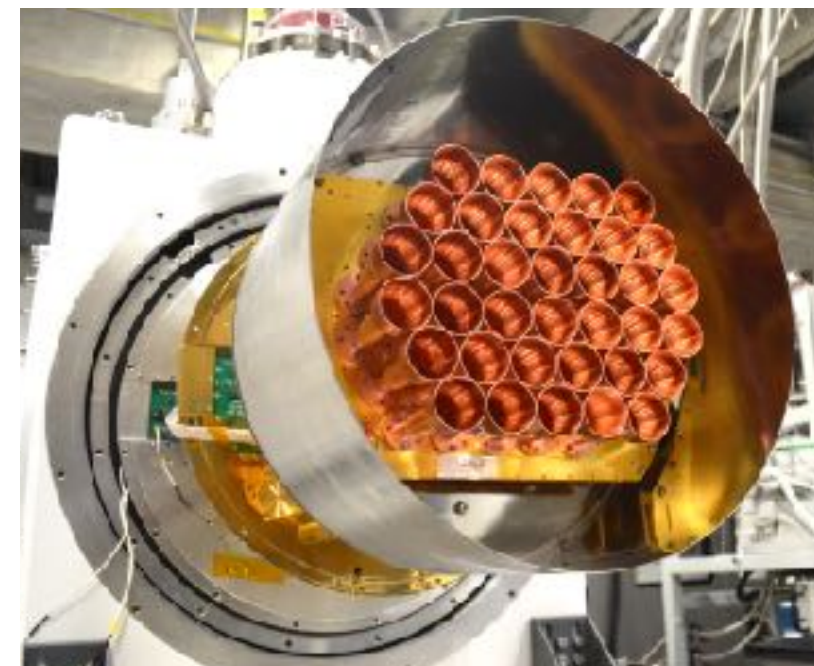
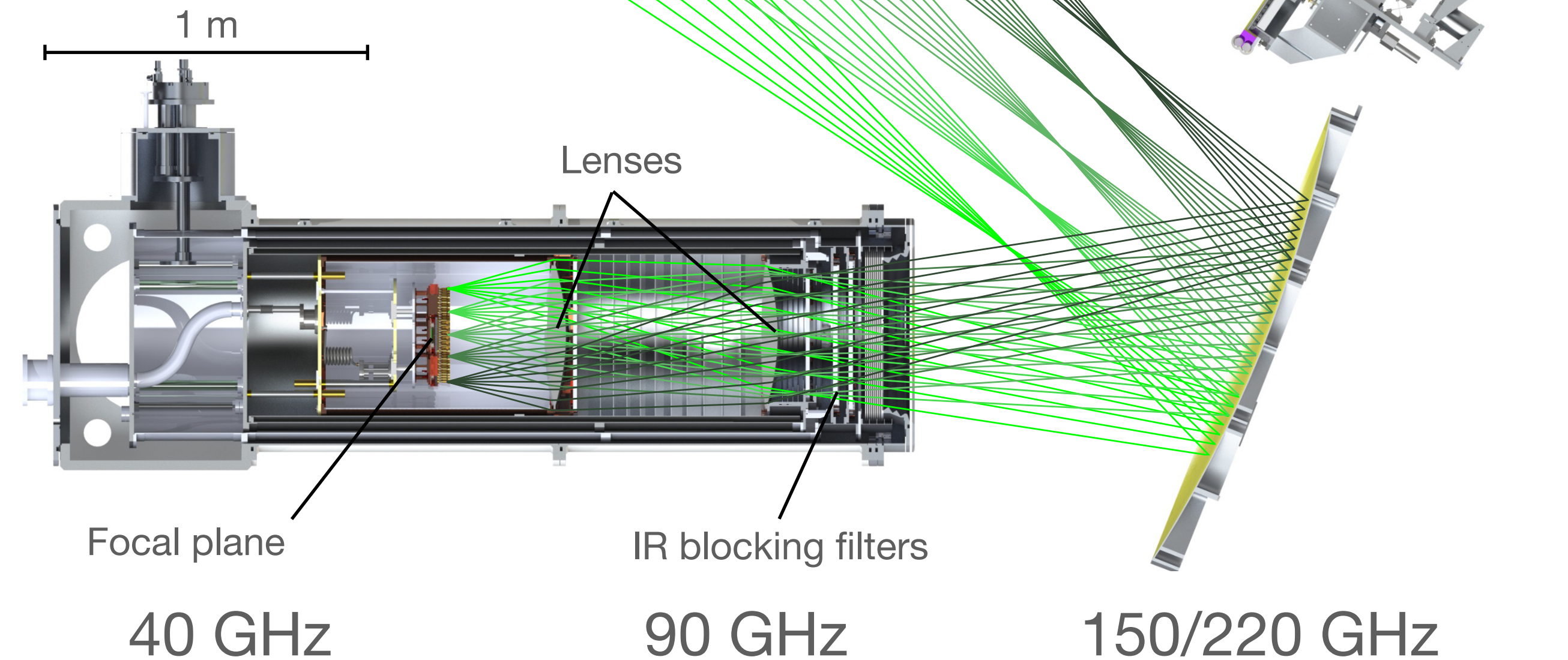
- **Front-end and fast** (10 Hz) polarization modulation.
- Common telescope catadioptric architecture for all telescopes:
  - Lenses, coatings, focal-planes, and filtering are optimized for each band.
- Continuously cooled ( $< 50$  mK), smooth-wall coupled, TES array.



# CLASS telescopes



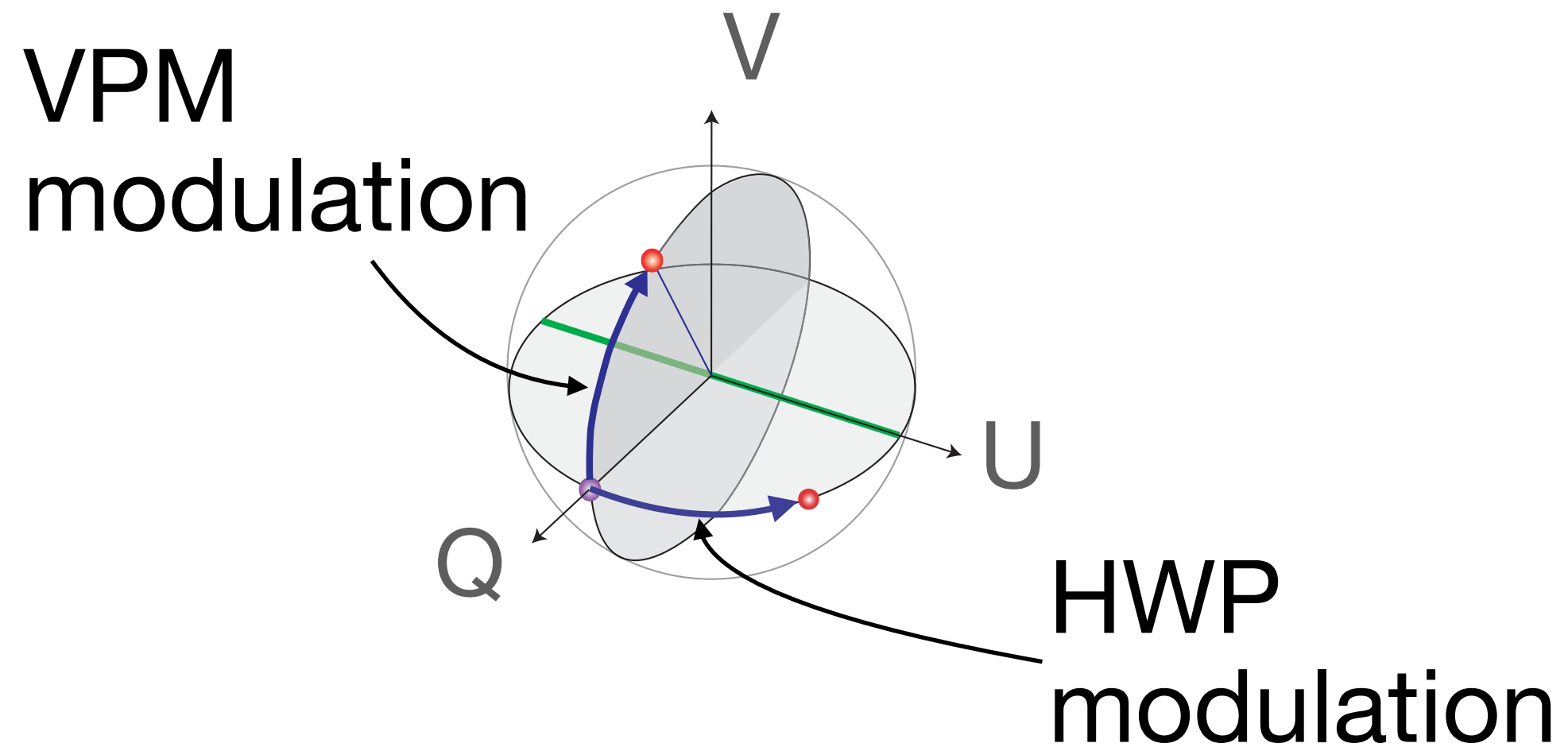
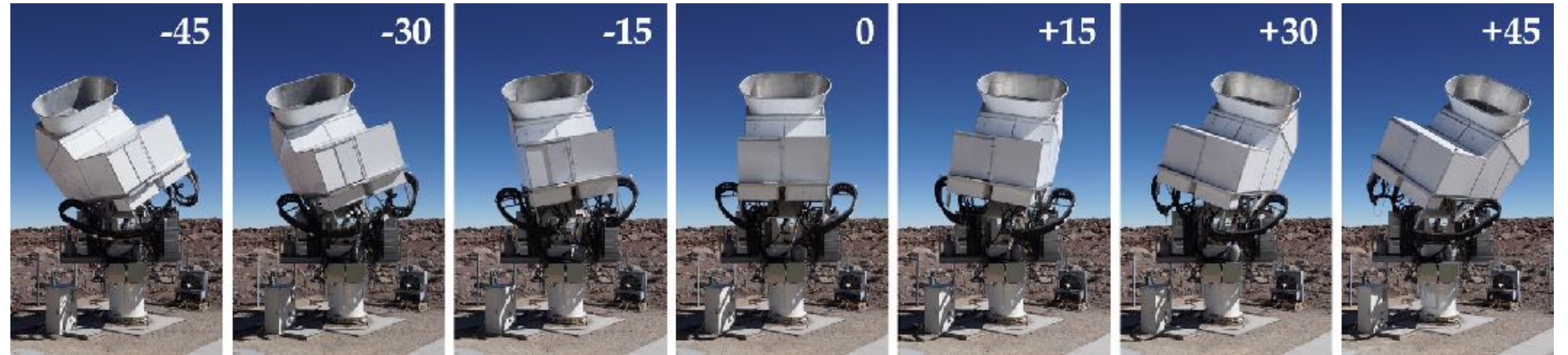
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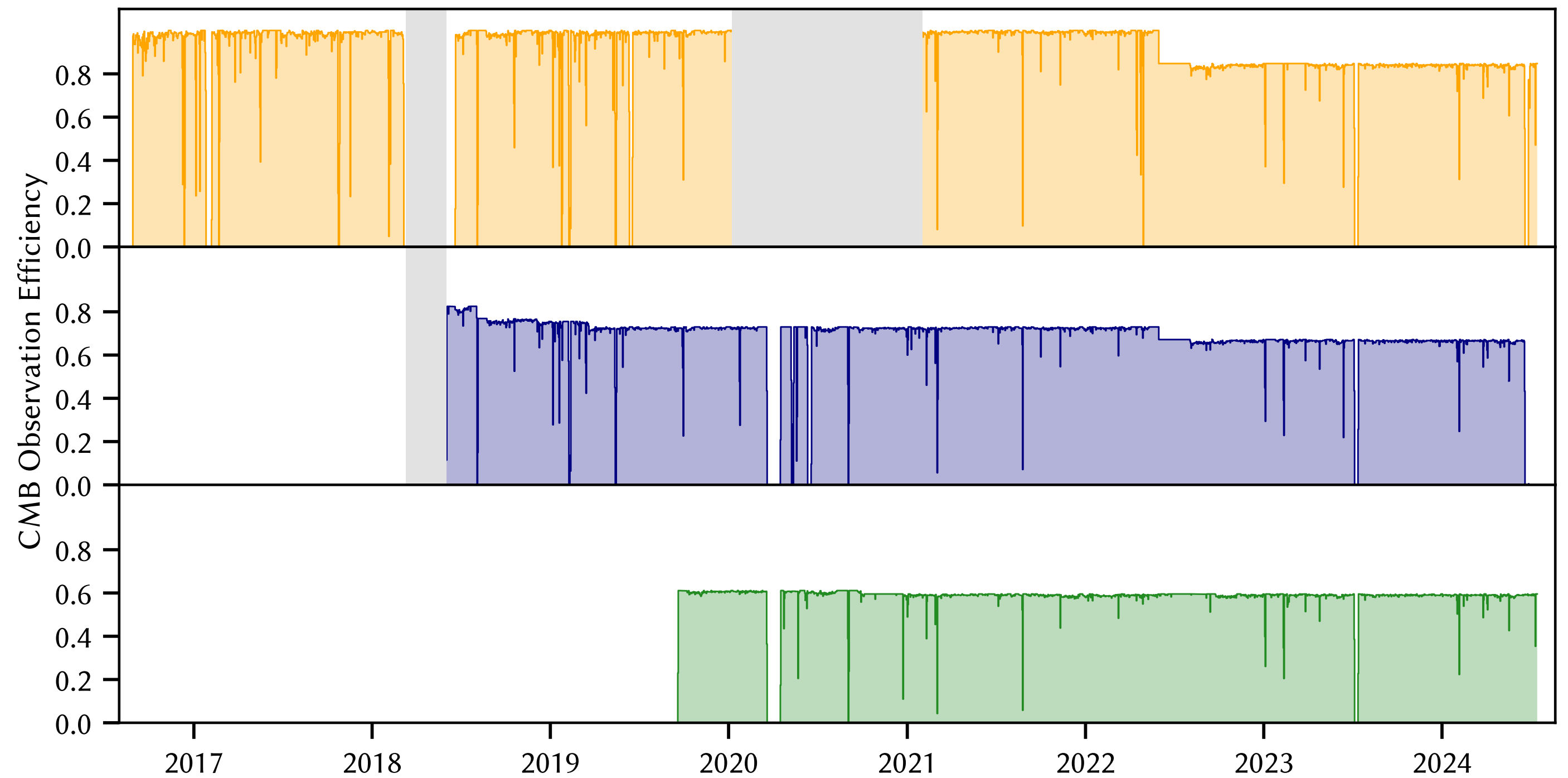
# CLASS survey



Single boresight per day



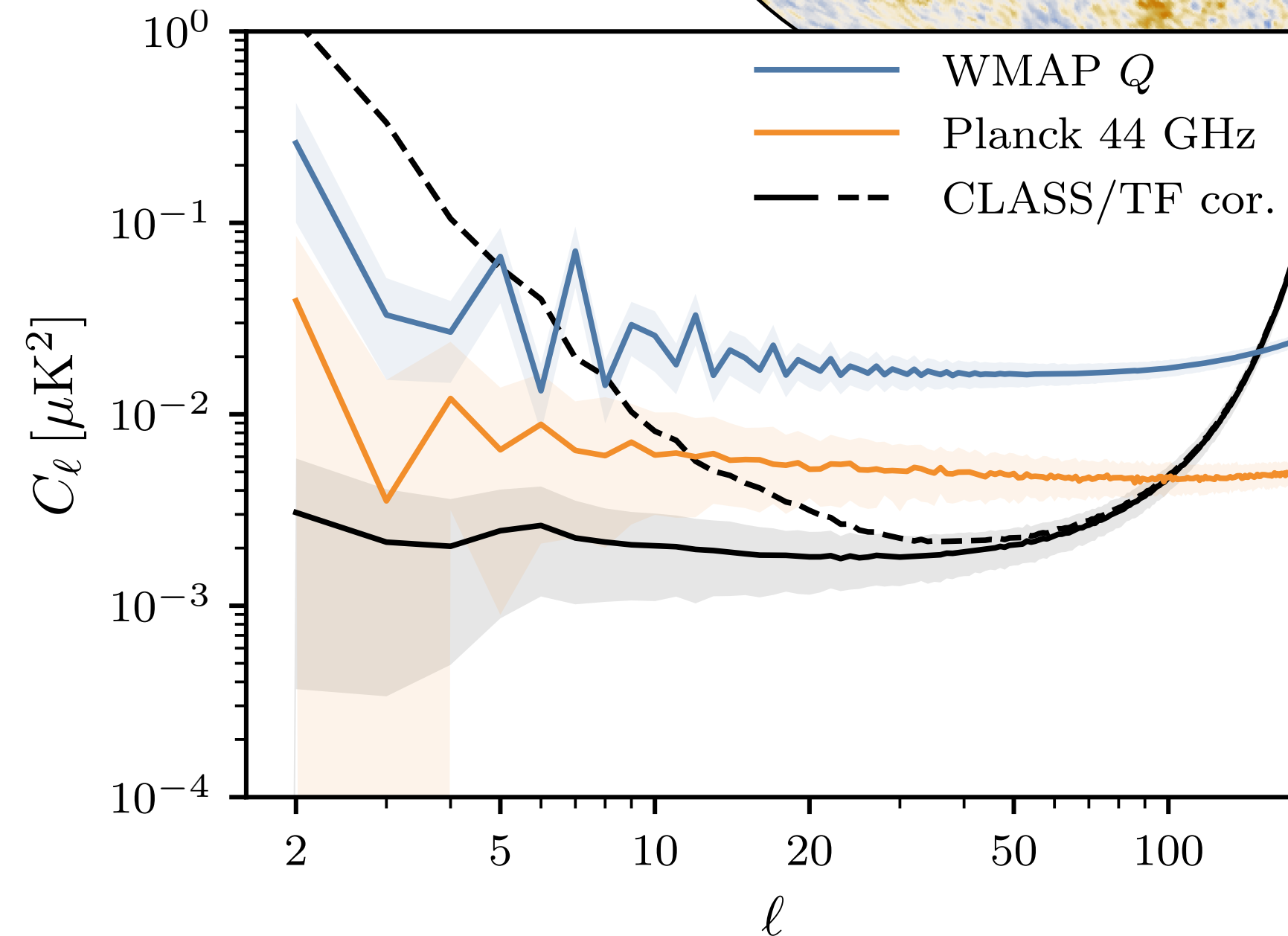
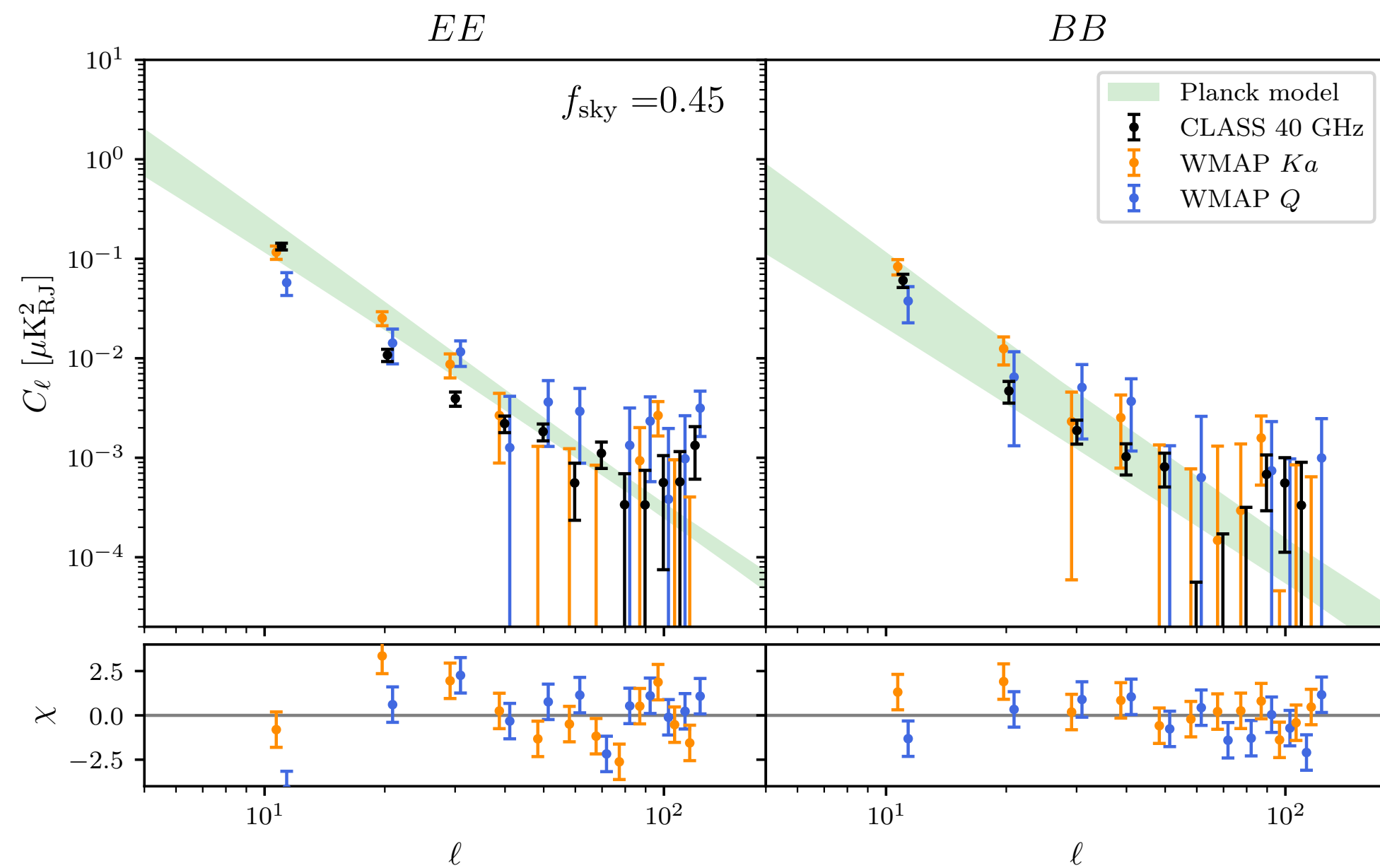
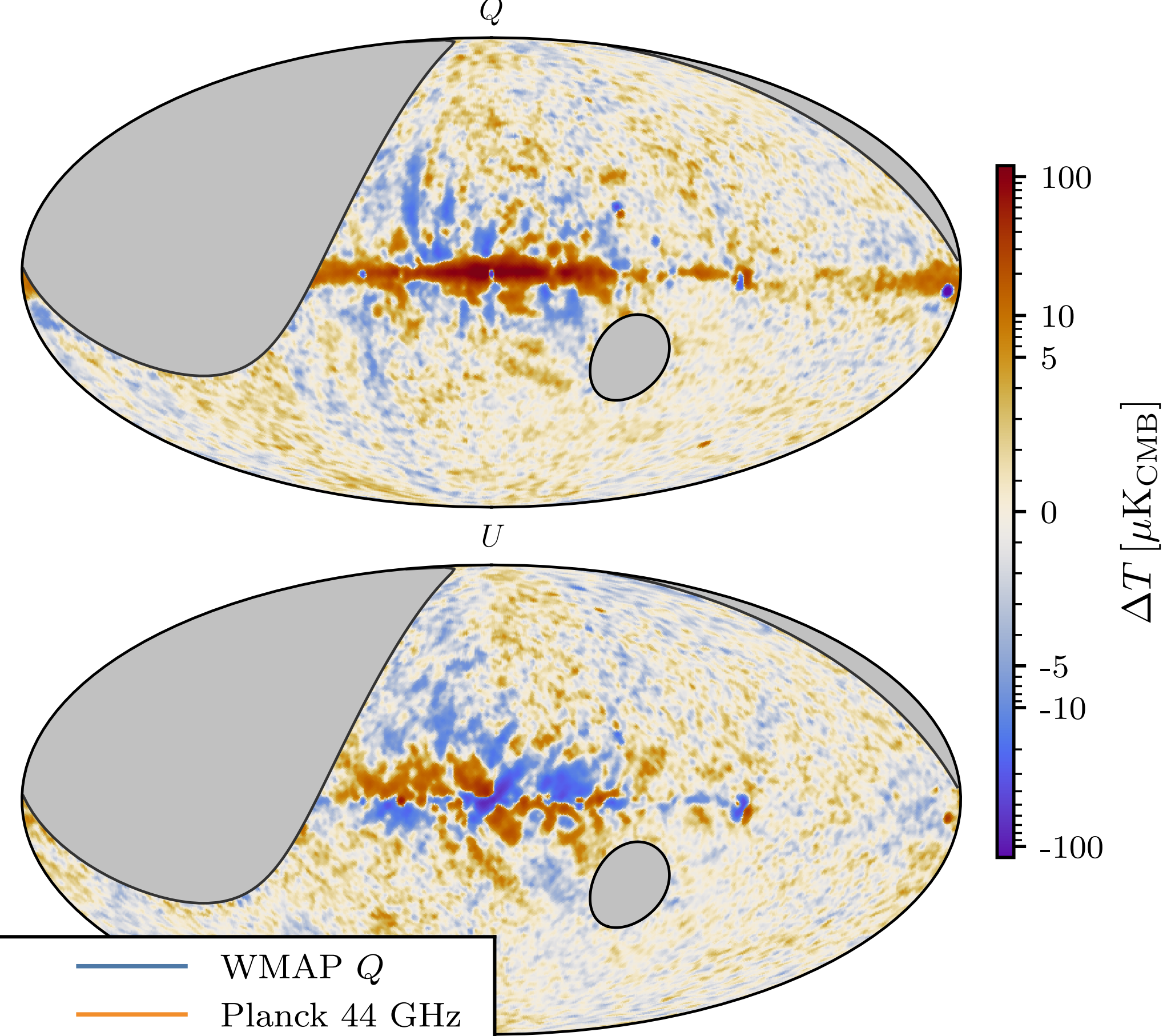
Q/W/G





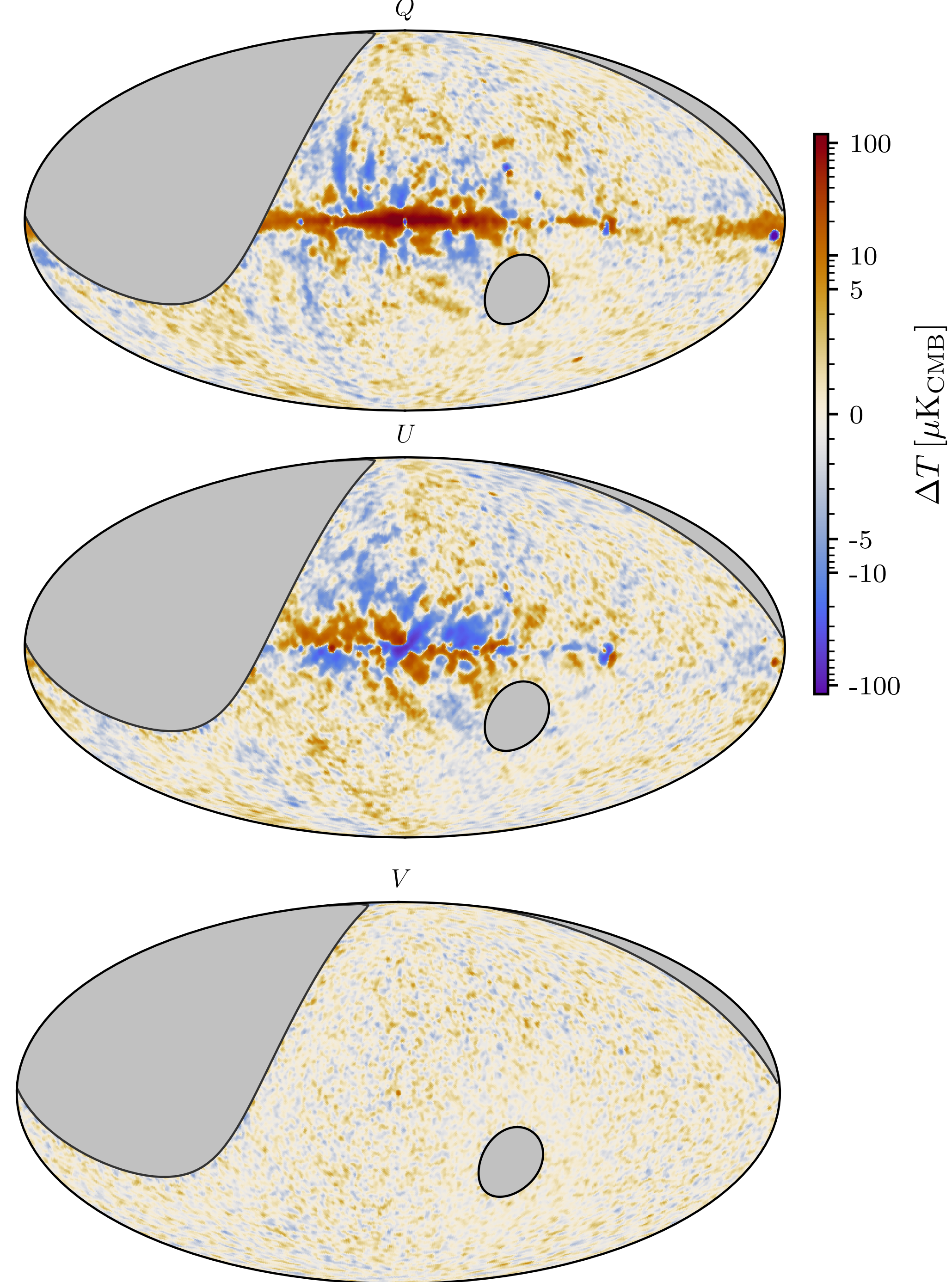
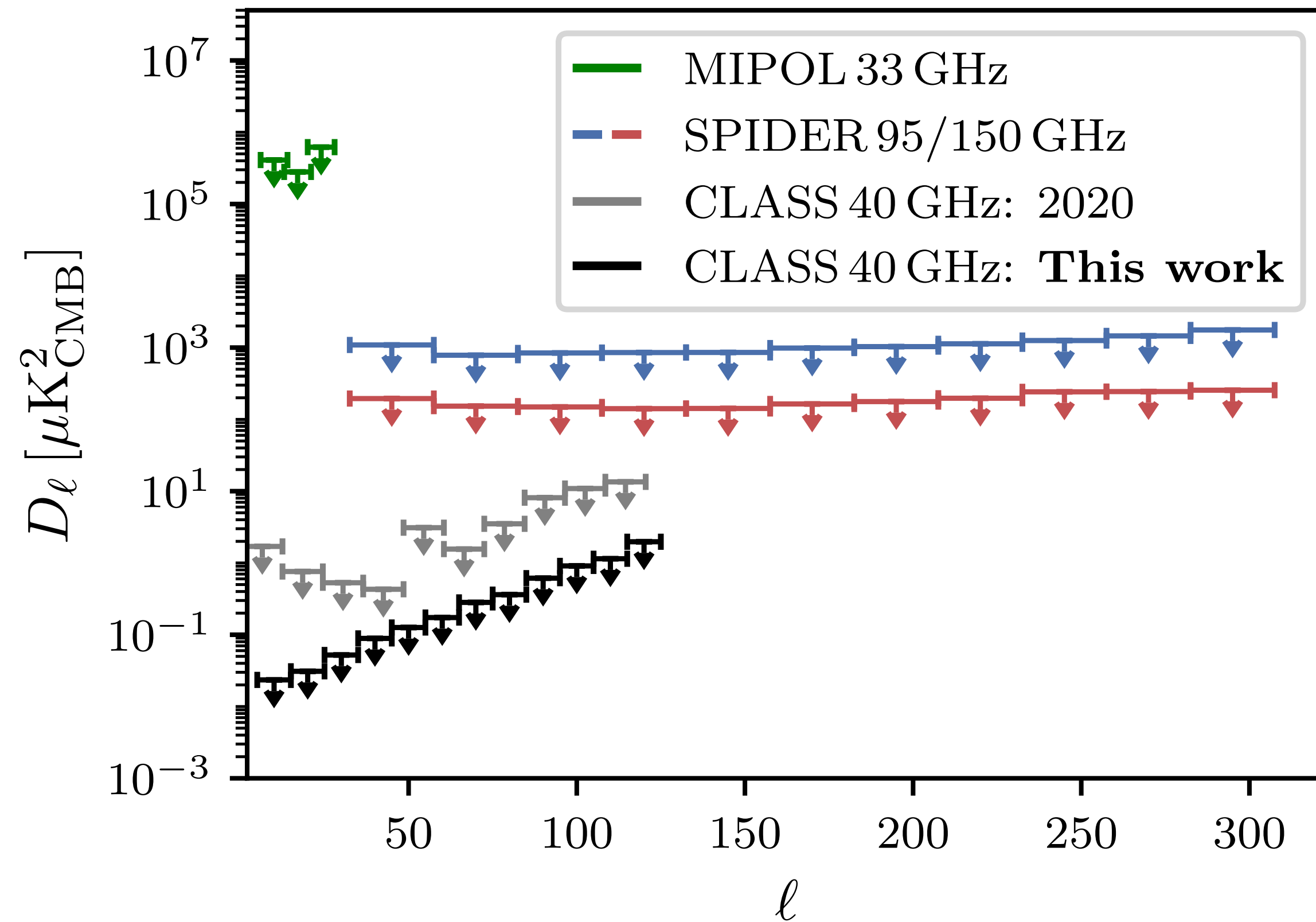
# CLASS Science Highlights

- 40 GHz results
- Characterize synchrotron foreground
- Significant improvement over satellite measurements in the critical  $10 < \ell < 100$  range.



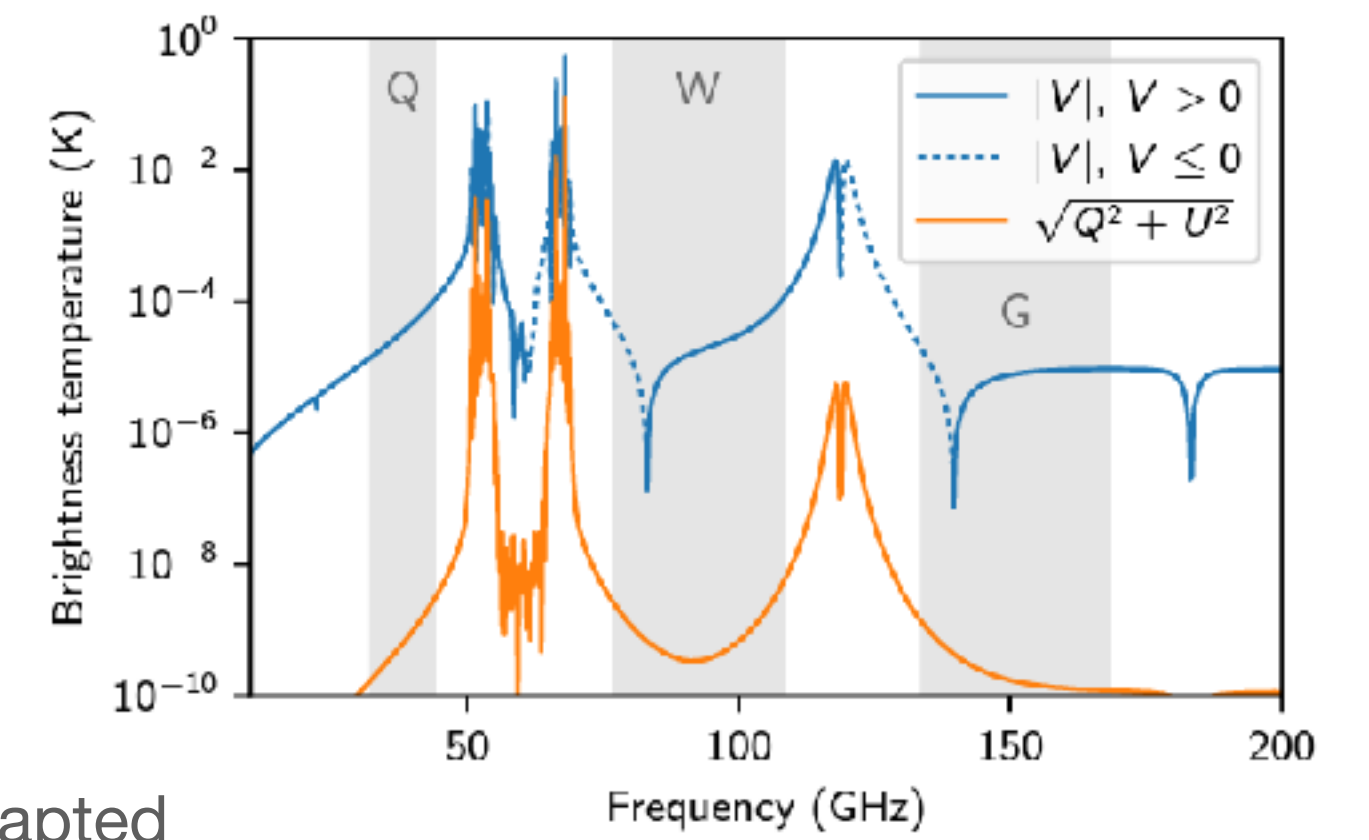
# CLASS Science Highlights

- 40 GHz results
  - Improved upper limit on circular polarization background.

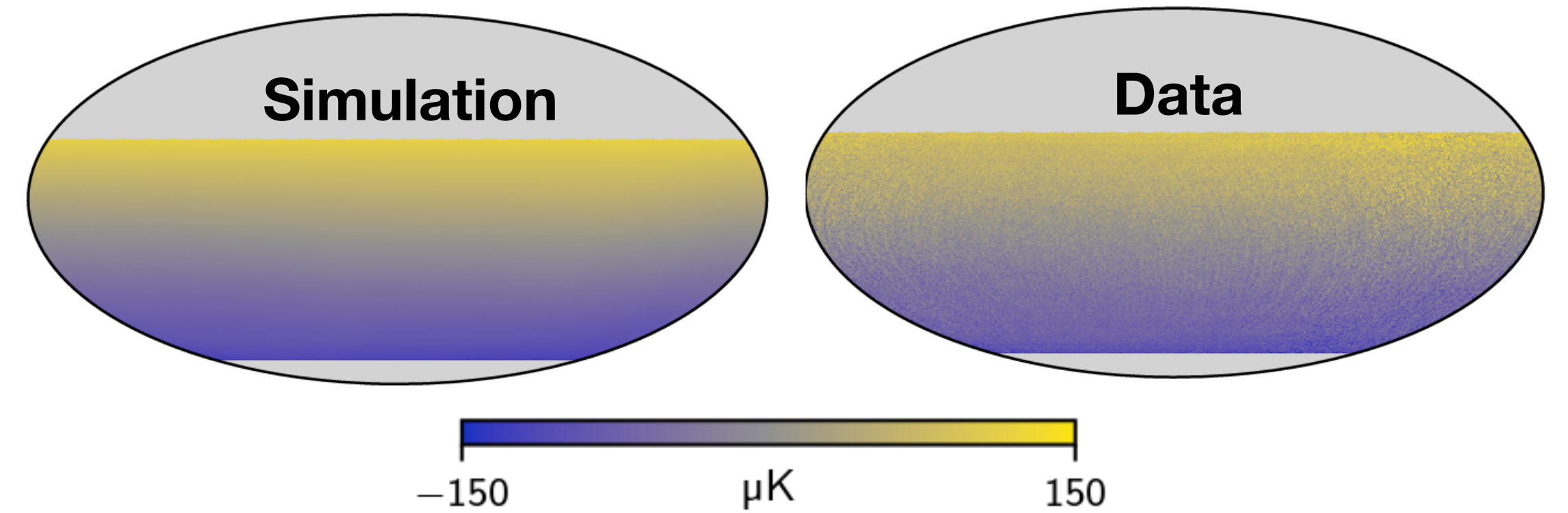


# CLASS Science Highlights

- Atmosphere effects:
  - First detection of atmospheric circular polarization.
  - Multi-frequency study of linear polarization from clouds.

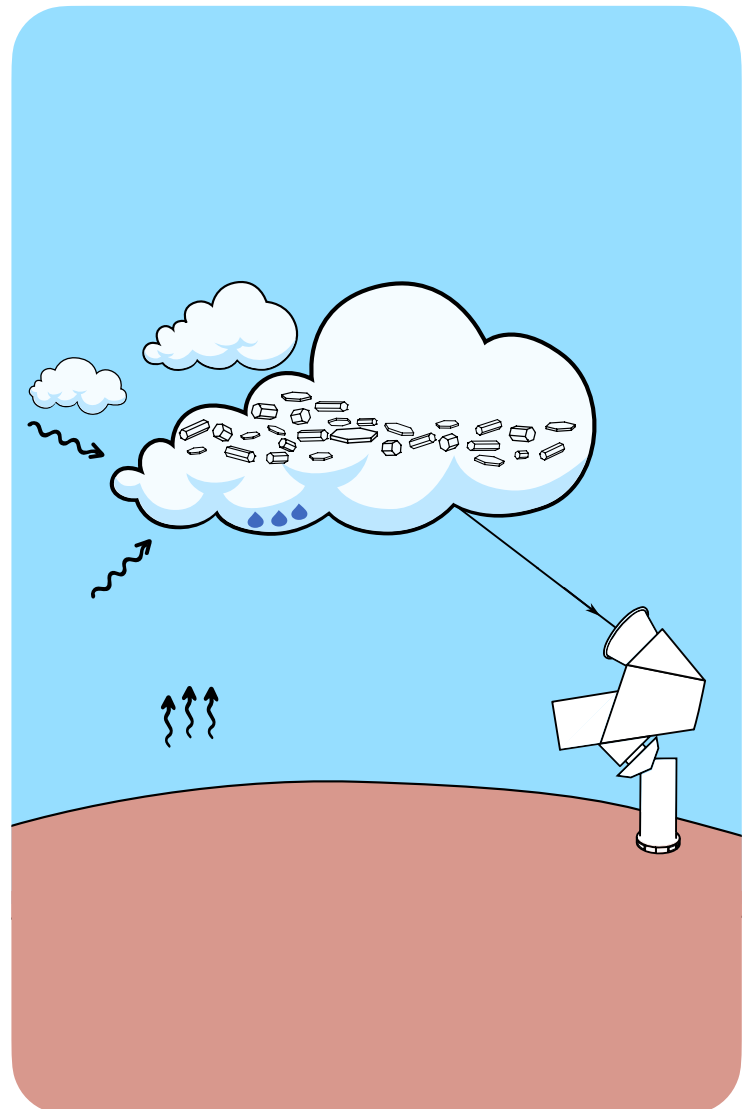


Petroff+(2020) Adapted

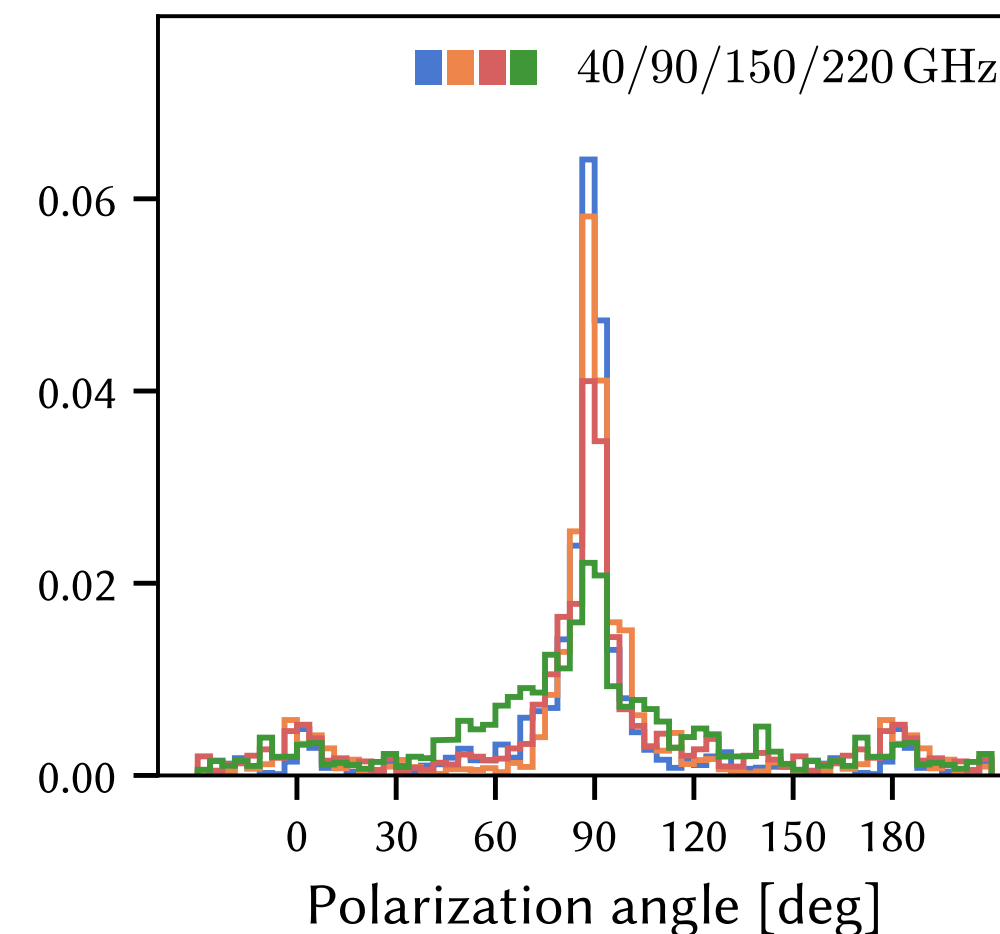


Li+(2023b) Adapted

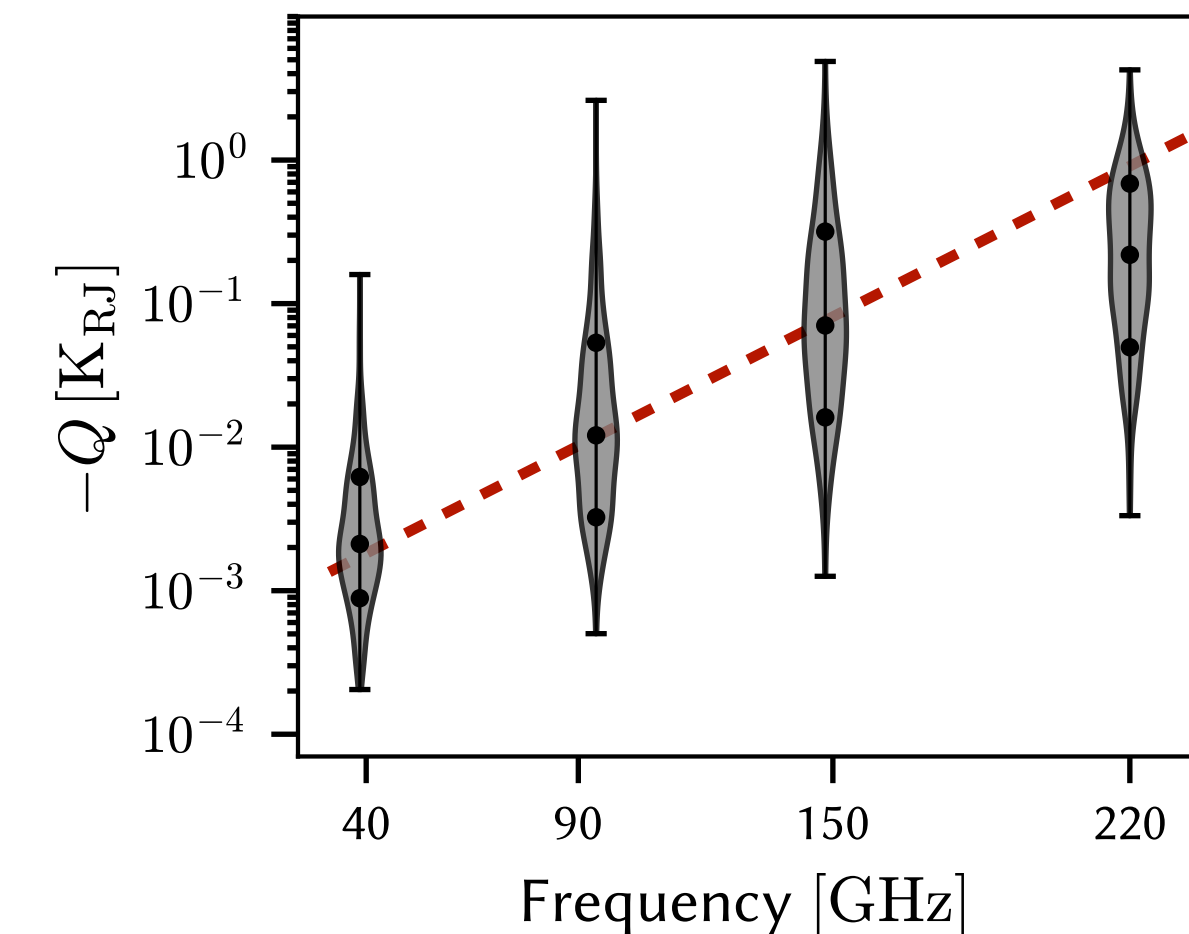
Optical confirmation



Polarization angle



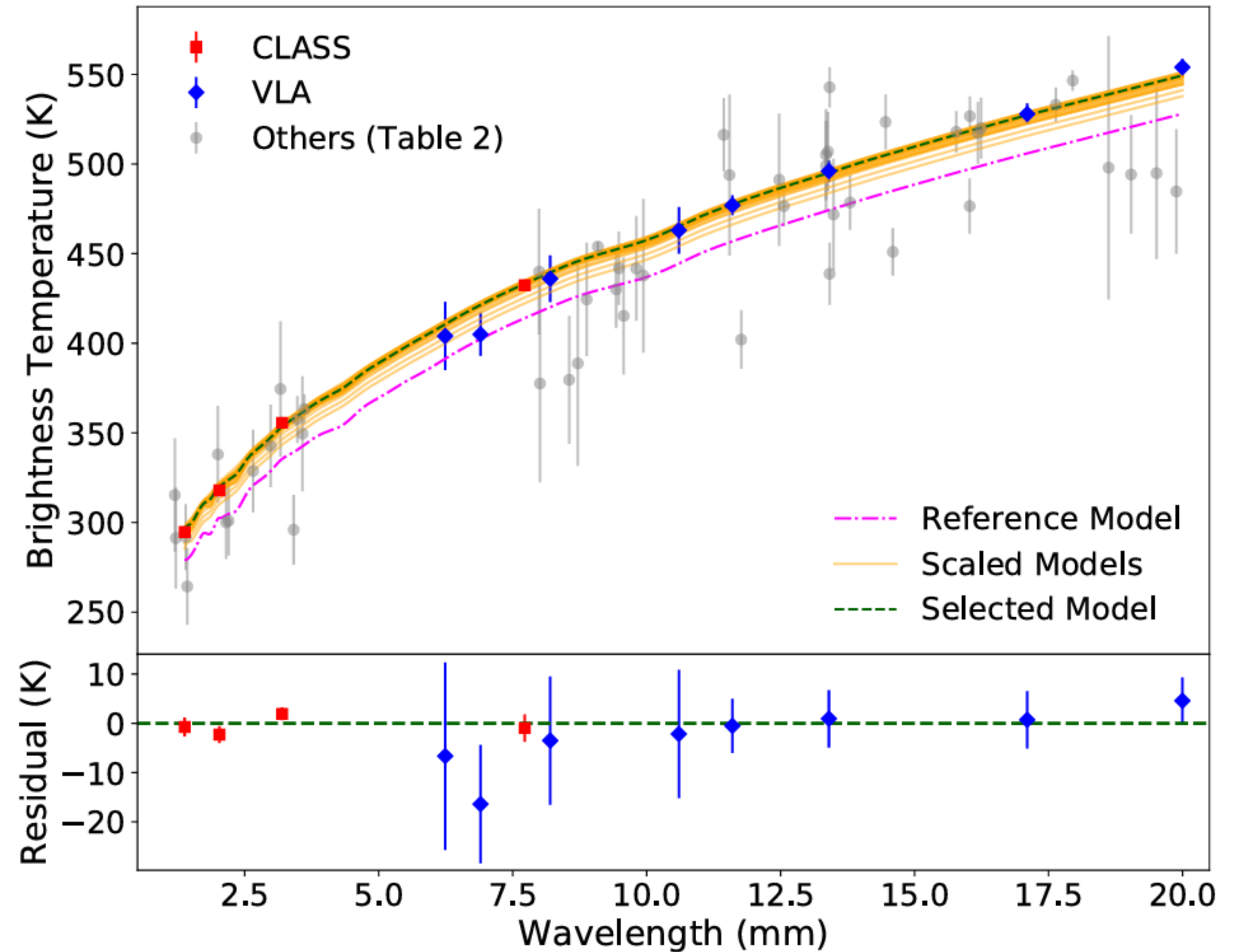
Spectrum



# CLASS Science Highlights

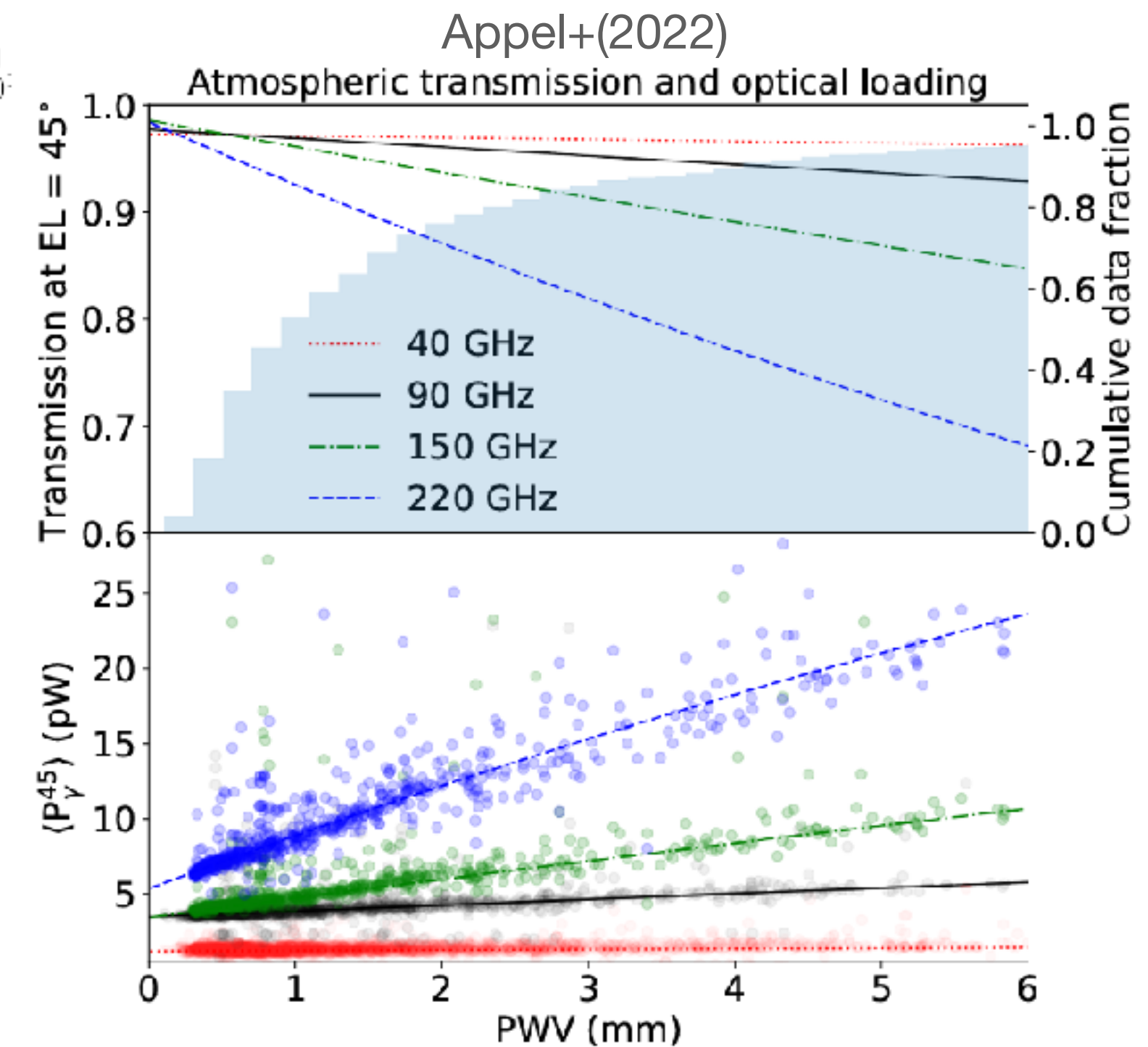
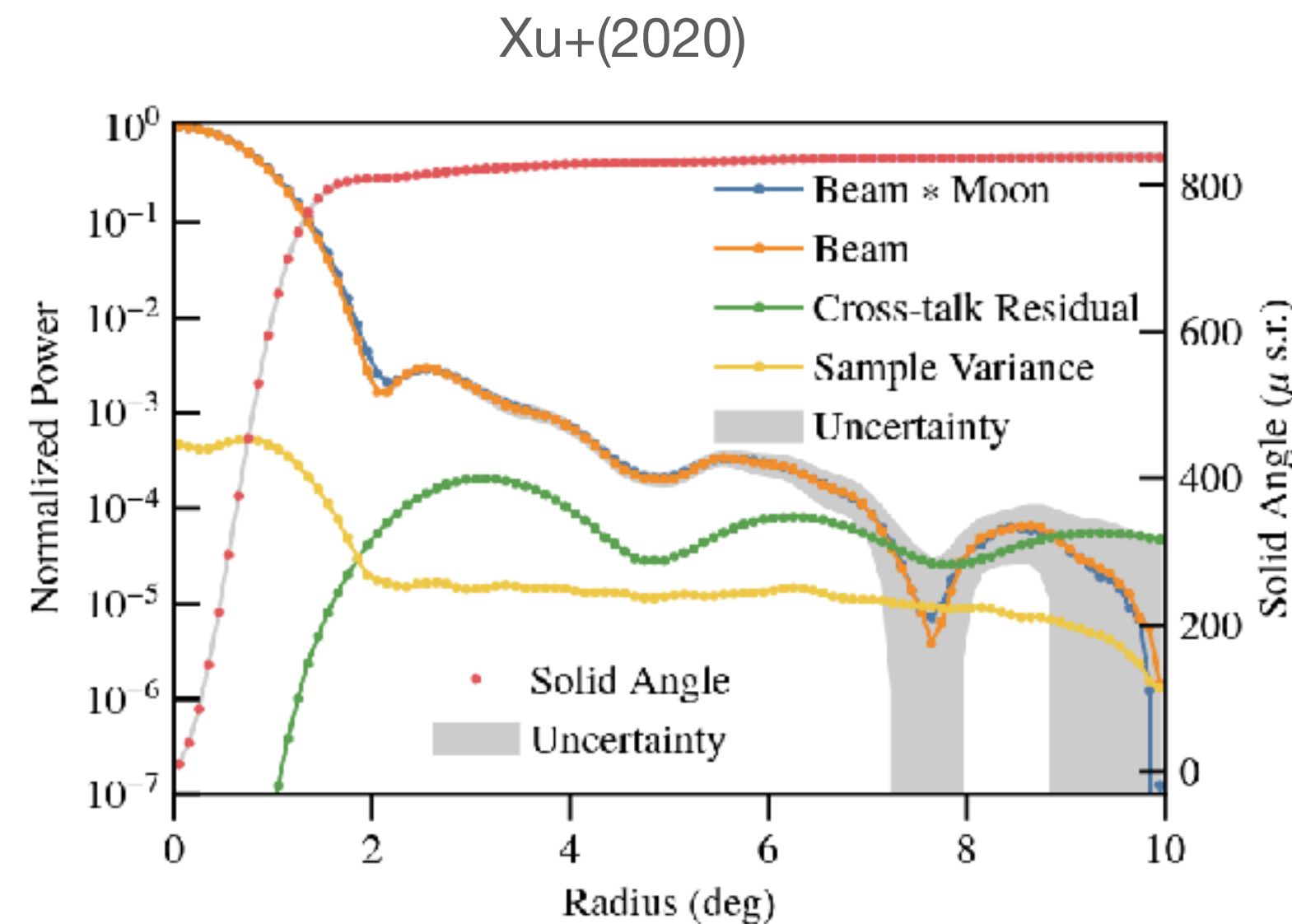
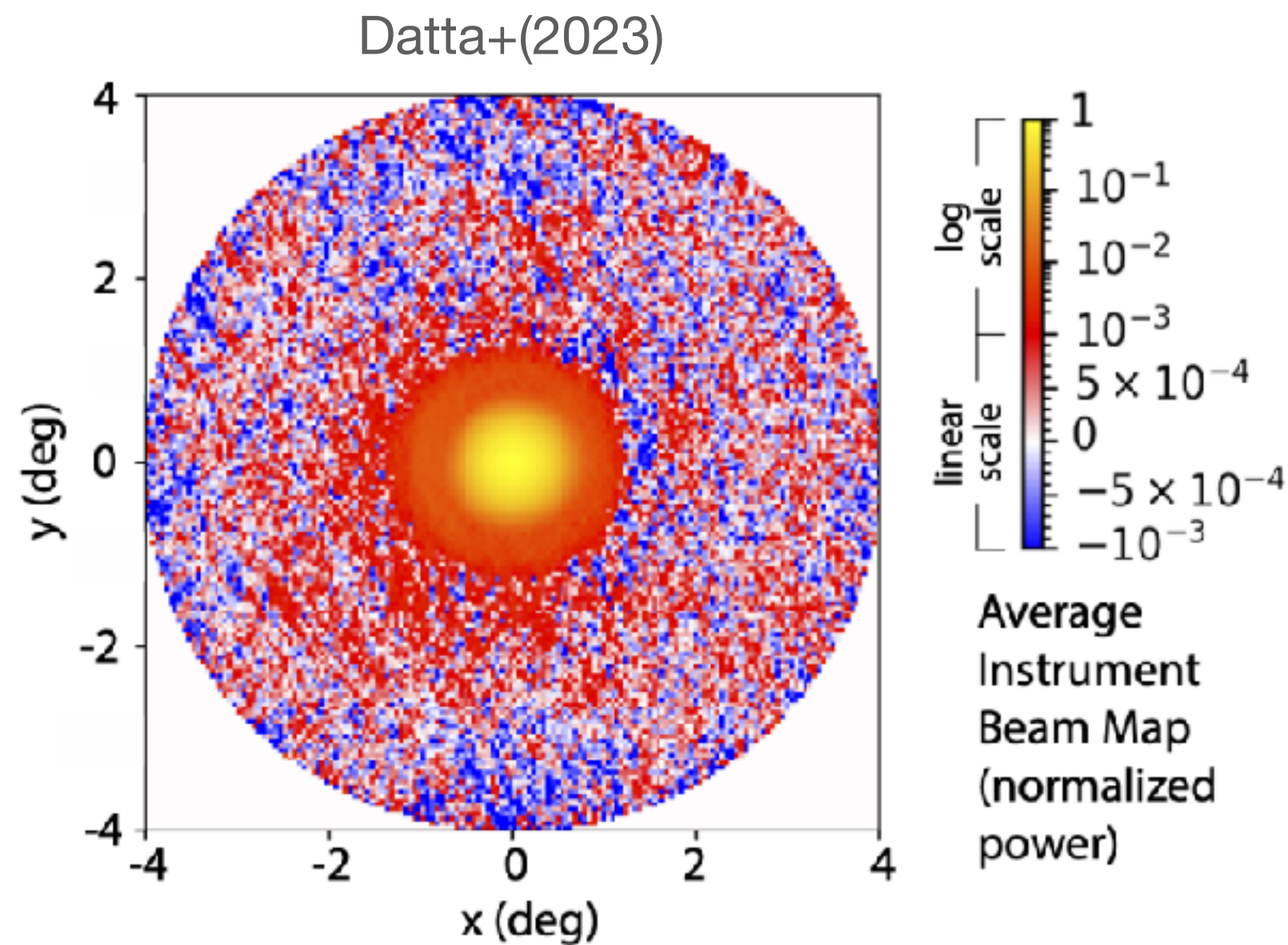
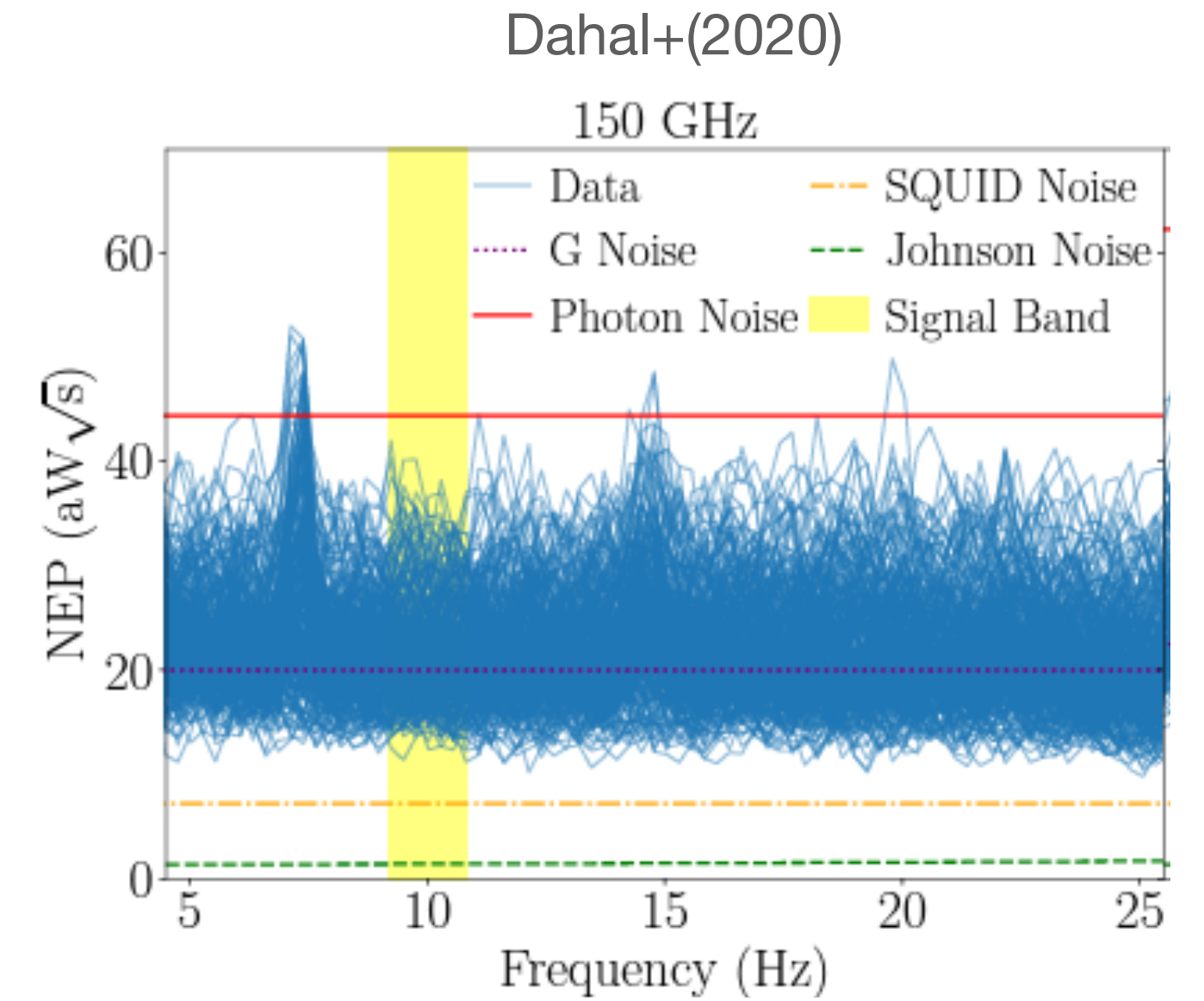
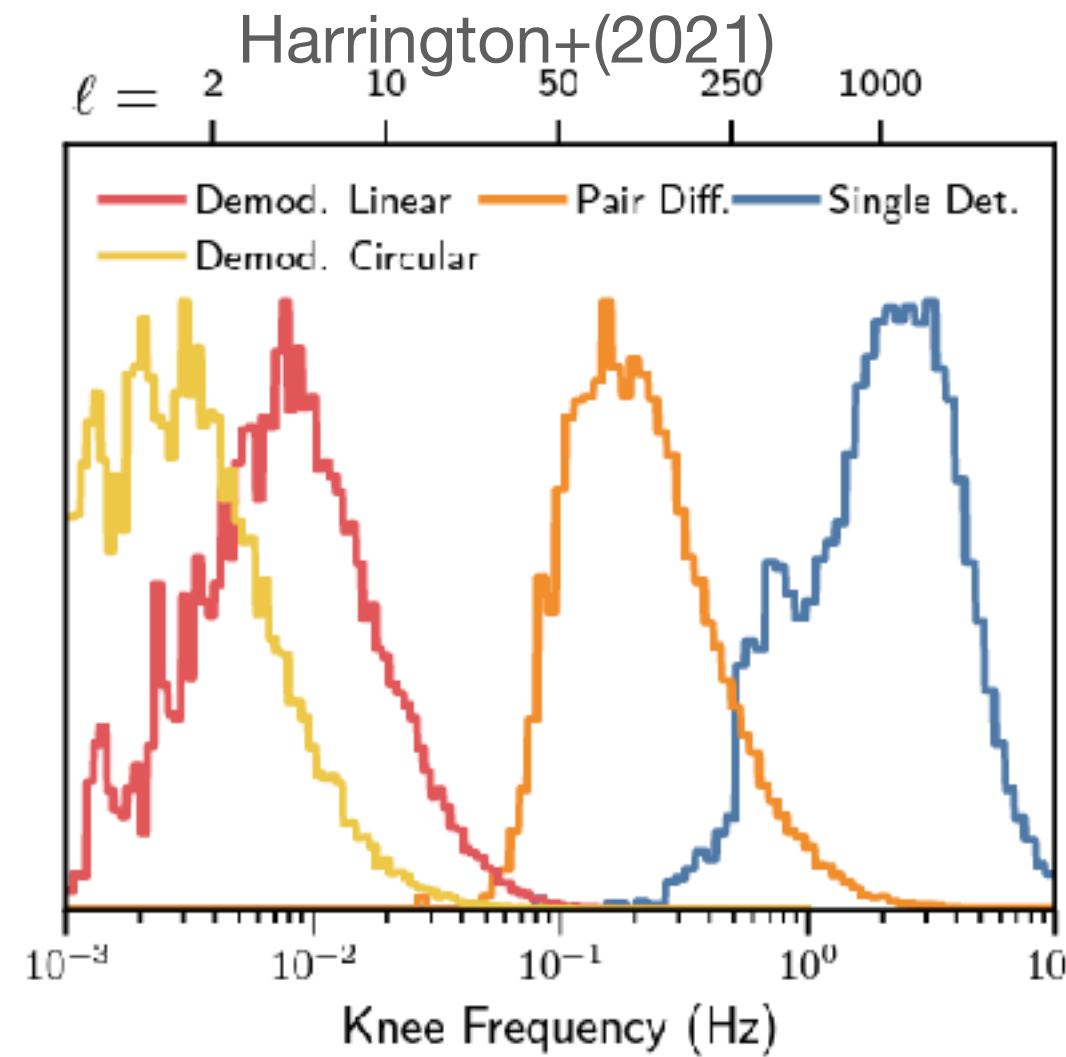
Dahal+(2021, 2023) Adapted

- Multi-frequency Venusian atmosphere study
- Rule out many atmospheric models.



# CLASS Science Highlights

- High precision instrument characterization.
  - e.g. optics, detectors, receivers, modulators, etc.
  - [sites.krieger.jhu.edu/class/publications](https://sites.krieger.jhu.edu/class/publications)



# Future Reach

- CLASS is an ideal platform for continuing to understand the limits of large angular scale CMB polarization surveys from the ground.
- CLASS will contrast modulation technology for ground-based signal stabilization. We installed a reflective HWP this past June.
- CLASS will produce maps at 40, 90, 150, 220 GHz data in Stokes Q/U/V.
- For CMB S4:
  - Improve constraint on optical depth to reionization.
  - Improve knowledge of foregrounds: especially at large ( $\ell < 20$ ) angular scales.
  - Potential demonstration for direction for S4 science—complementary to other surveys.

# Lessons learned

- Modulation is a *tremendously successful tool* for achieving the stability required for large angular scale observations.
- Residual polarized signals (T->P leakage, instrument effects, atmospheric polarization, polarized ground pickup, etc.) can survive demodulation.
- The process to identify/mitigate these residual signals is difficult to anticipate and understand. It is an advantage of the ground-based platform to have the opportunity to improve of these effects.
- There is room for significant improvement to our current measurements—no ultimate limit to the angular scale measurable from the ground has yet been found.
- More details will be covered in the VPM stability talk by Yunyang Li.

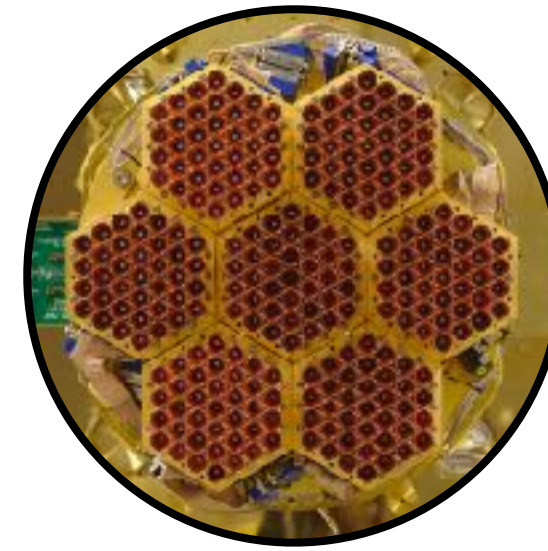
# Lessons learned



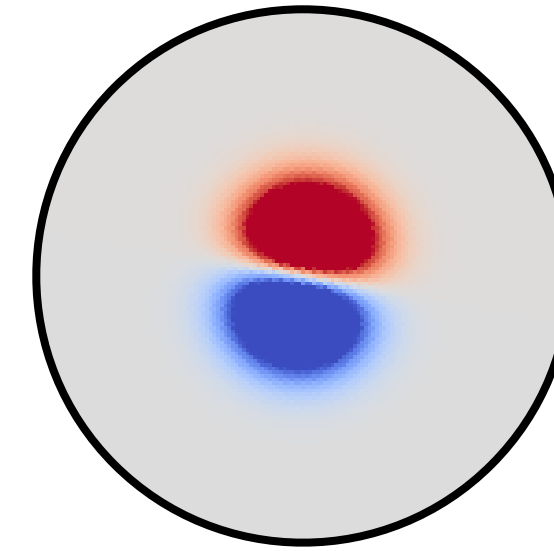
VPM modeling



Wind signal



Internal reflections



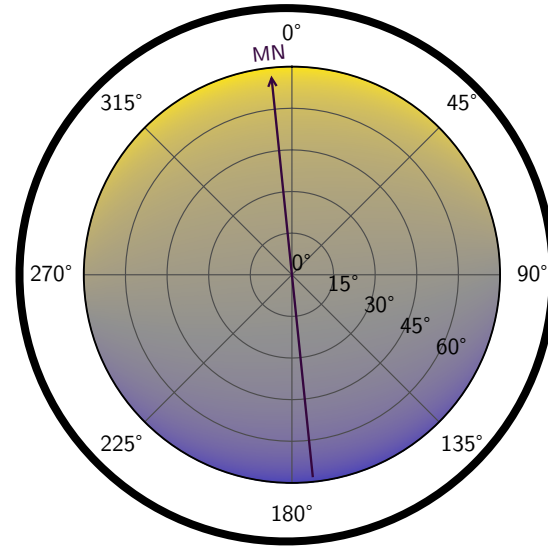
Polarization leakage



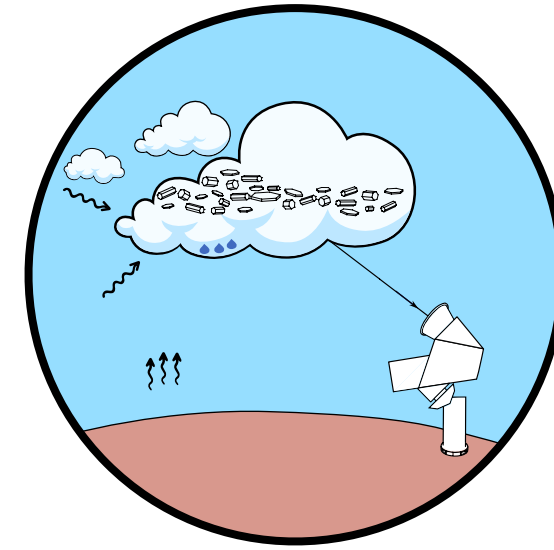
Ground pickup



Radio frequency interference



Atmospheric circular polarization



Cloud polarization

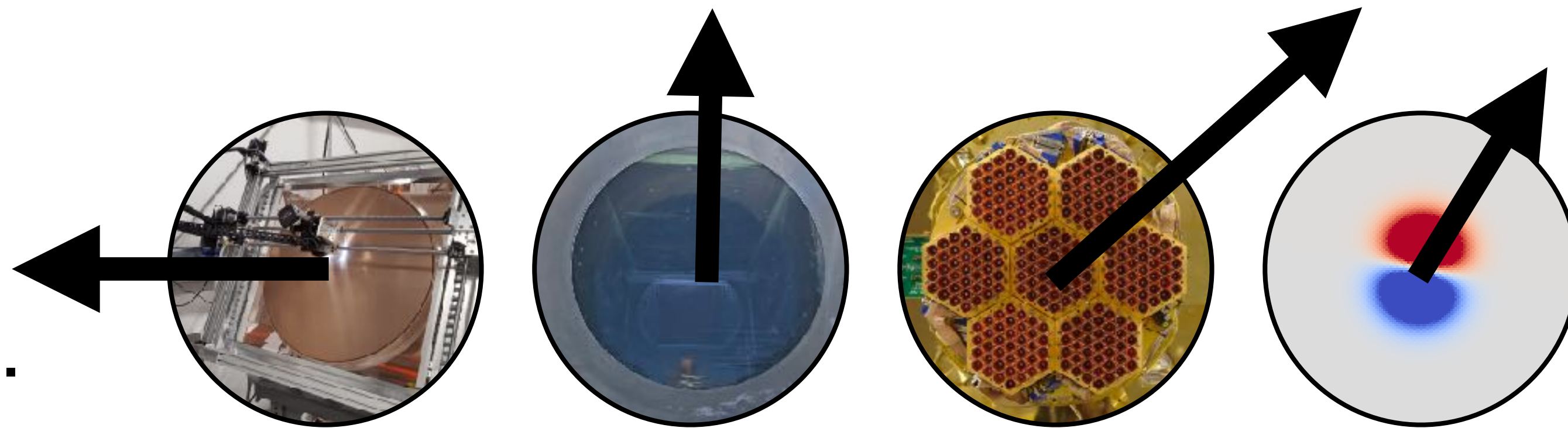


# Lessons learned

Remove source of systematic signal

Simulations show impact is currently negligible.

Modeling and pipeline enhancements.

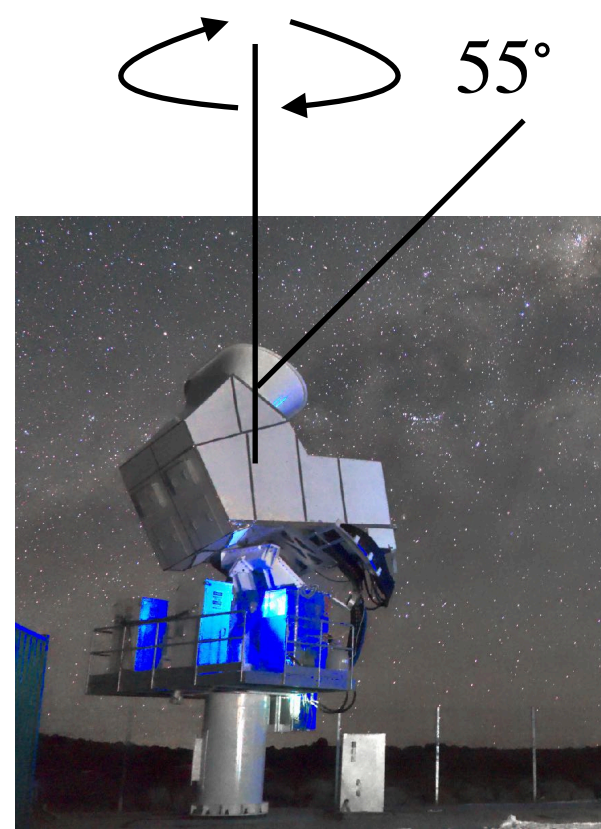


VPM modeling

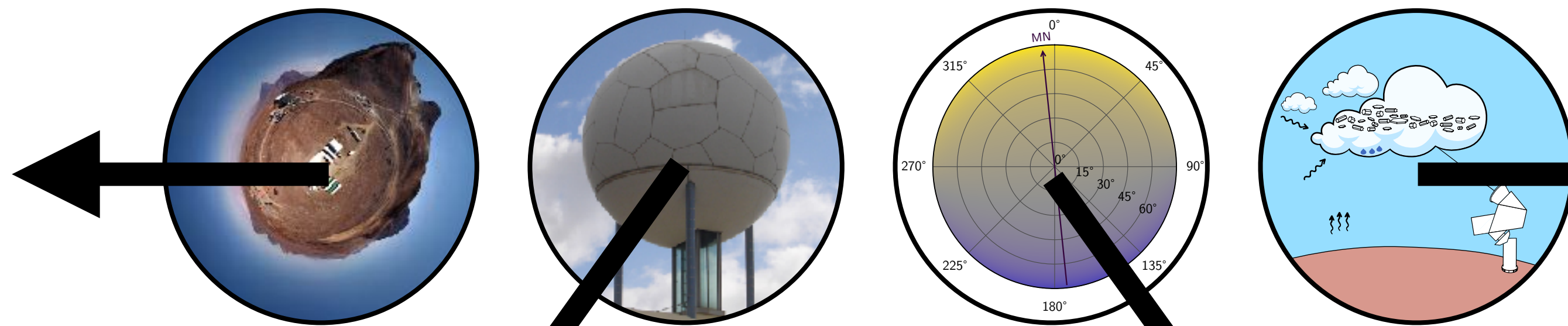
Wind signal

Internal reflections

Polarization leakage



High elevation scan analysis is ongoing.



Ground pickup

Radio frequency interference

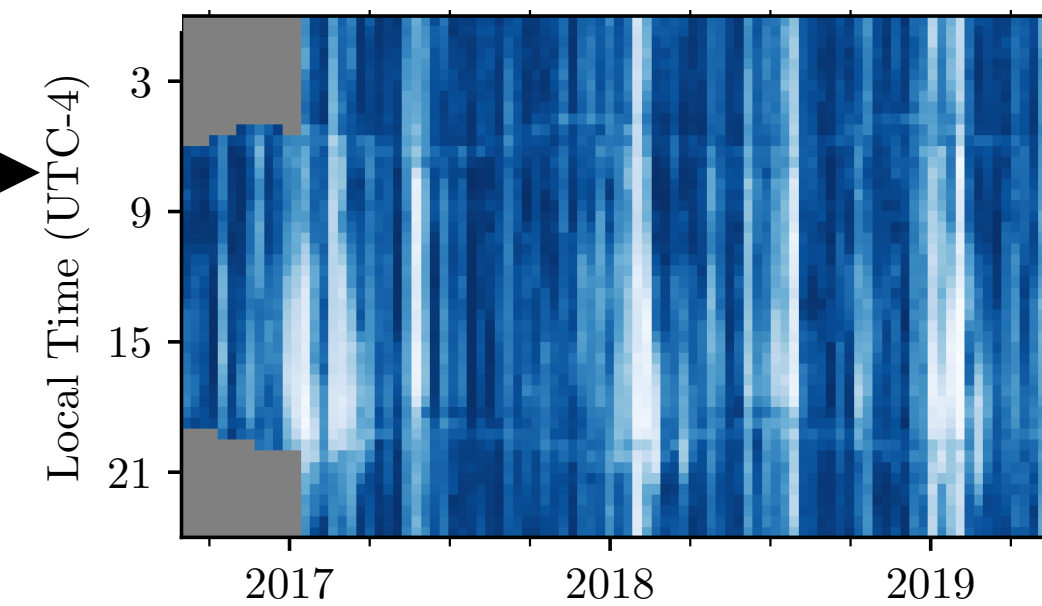
Atmospheric circular polarization

Cloud polarization

RF filter on receiver and data selection.

Found to be stable.

Improved data selection



Thank you

