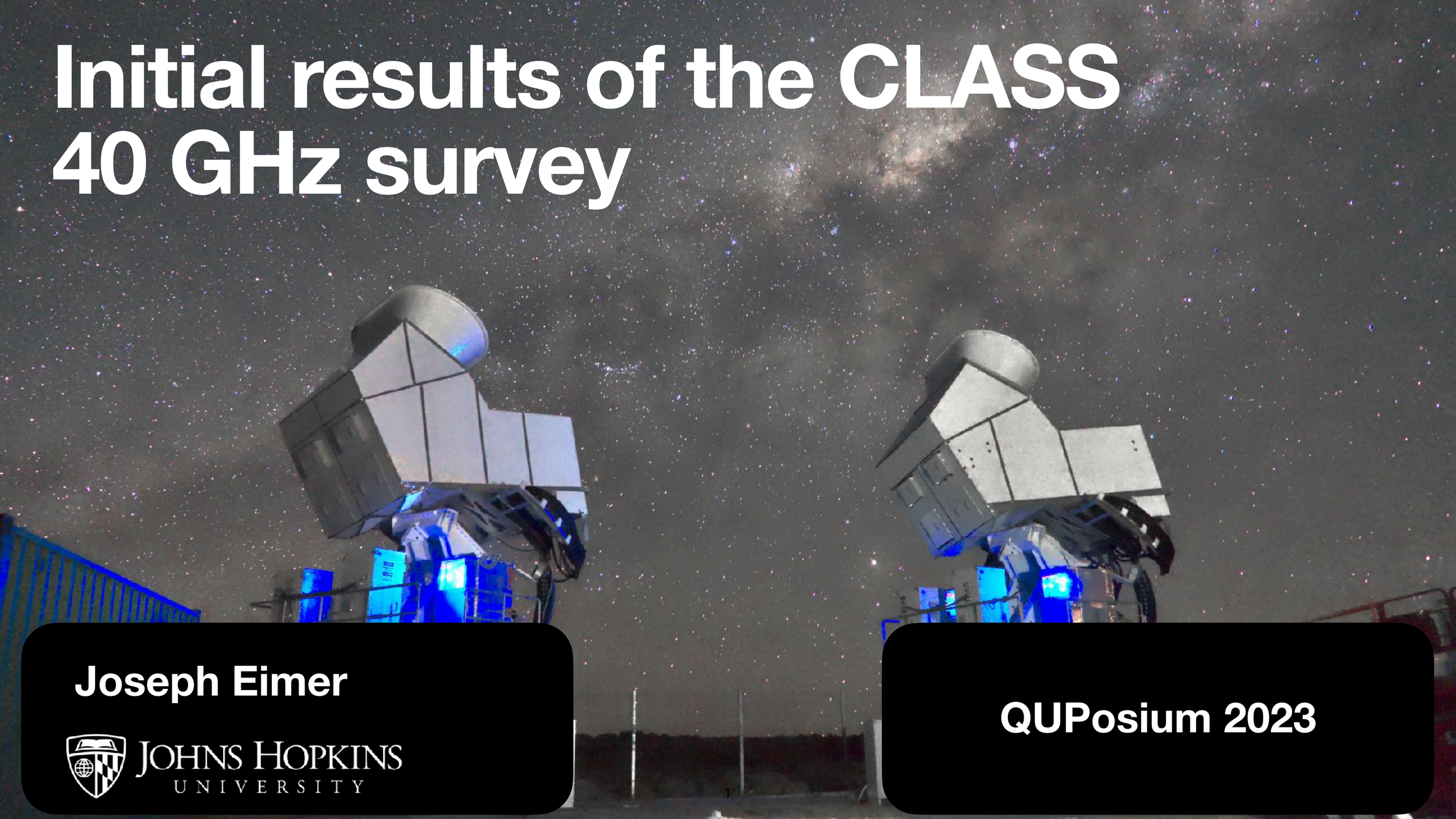
Initial results of the CLASS 40 GHz survey



Joseph Eimer

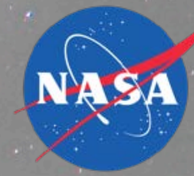
JOHNS HOPKINS UNIVERSITY

QUPosium 2023

Initial results of the CLASS 40 GHz survey

Li, Eimer, Osumi, et al. ApJ 2023: 2305.01045

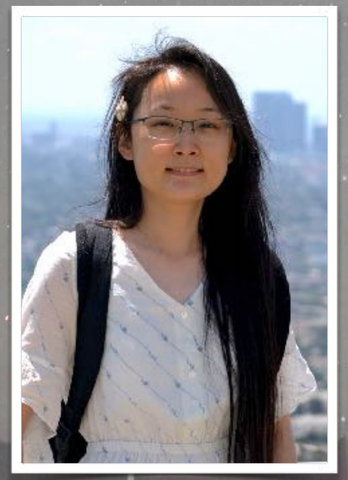
Eimer, Li, Brewer, Shi, et al.: 2309.00675



JOHNS HOPKINS UNIVERSITY

CONICYT
COMISIÓN NACIONAL DE INVESTIGACIÓN CIENTÍFICA Y TECNOLÓGICA

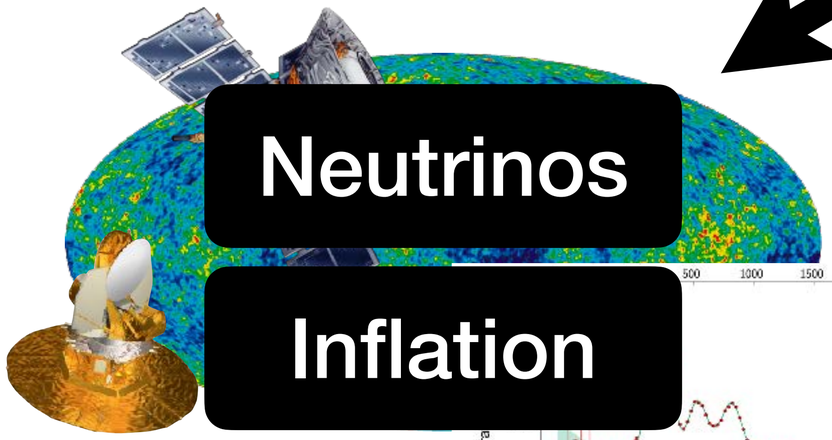
Initial results of the CLASS 40 GHz survey



Yunyang Li

Rui Shi

Overview

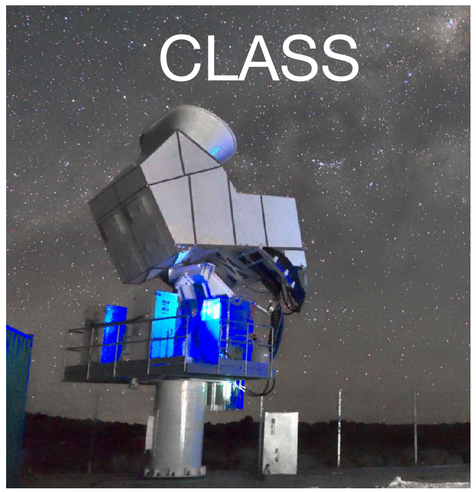


Neutrinos

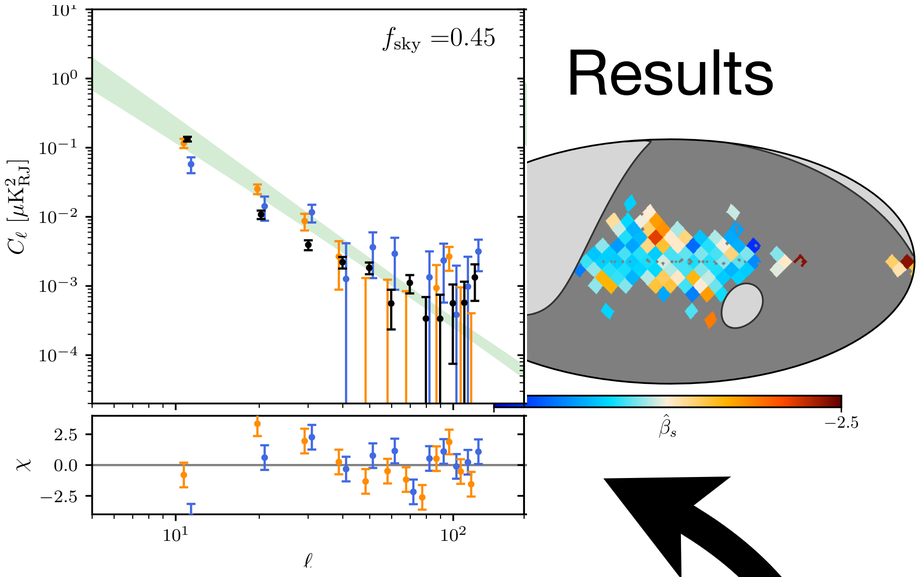
Inflation

Science

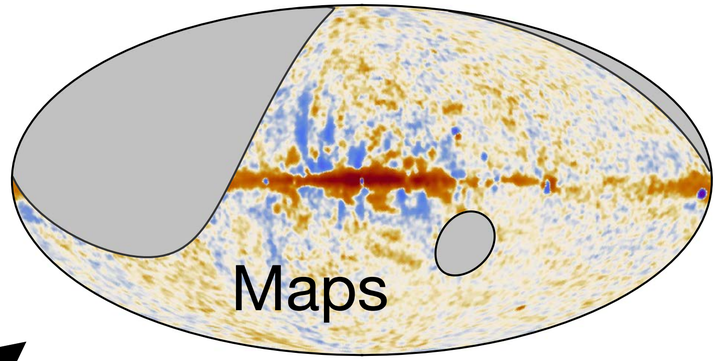
Challenges



Data



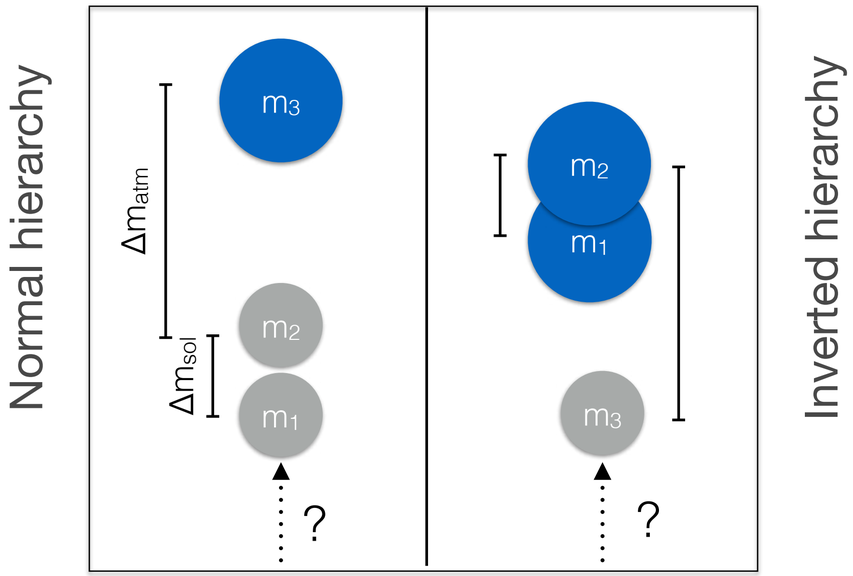
Results



Maps

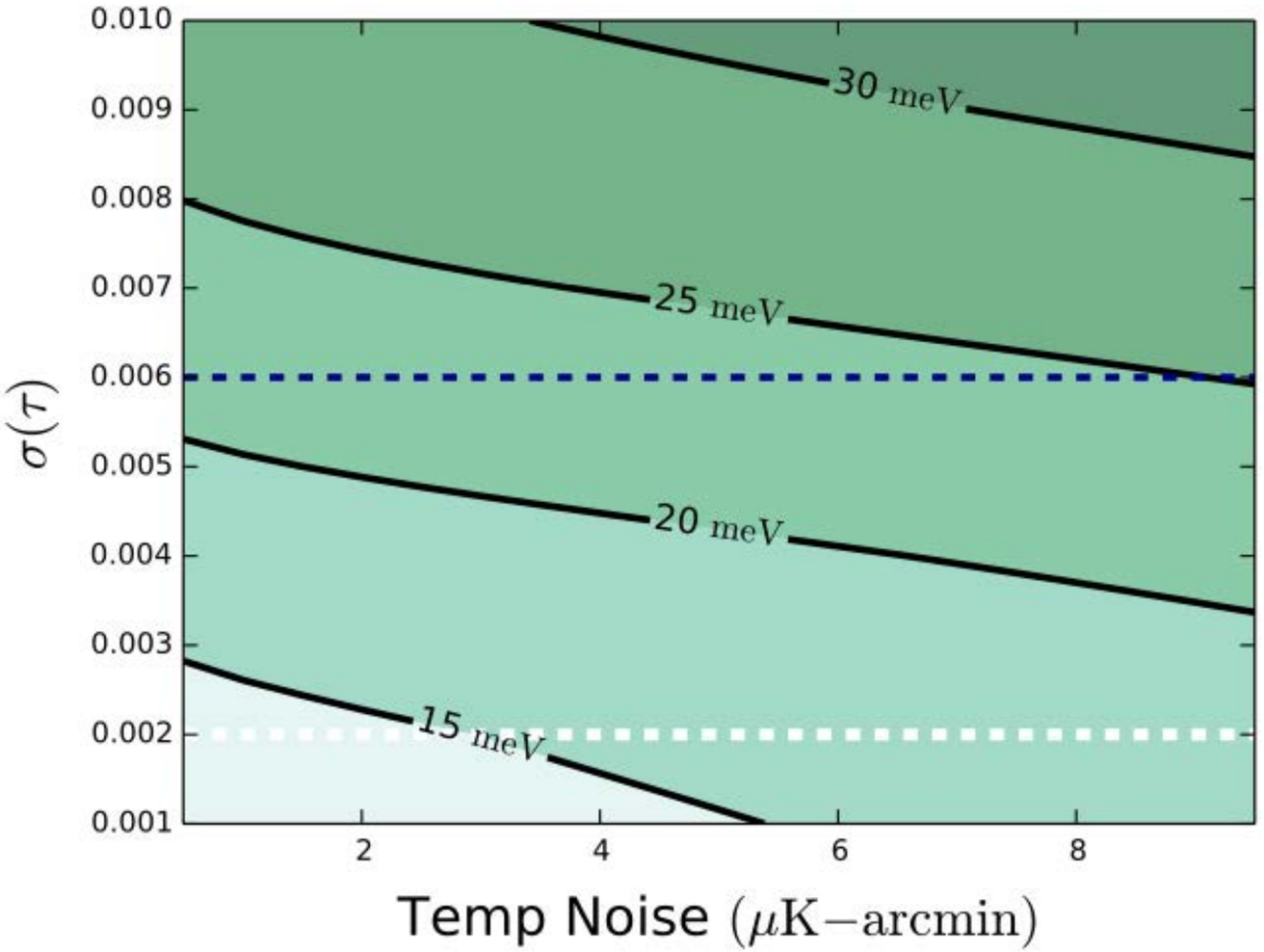
Figures: ESA, NASA, M. Petroff, Eimer et al. 2309.00675

Neutrino mass



- Next generation CMB measurements will measure the sum of the neutrino masses through their impact on CMB lensing.
- **Those measurements will be limited by the least-well measured ΛCDM parameter - the optical depth to reionization, τ.**

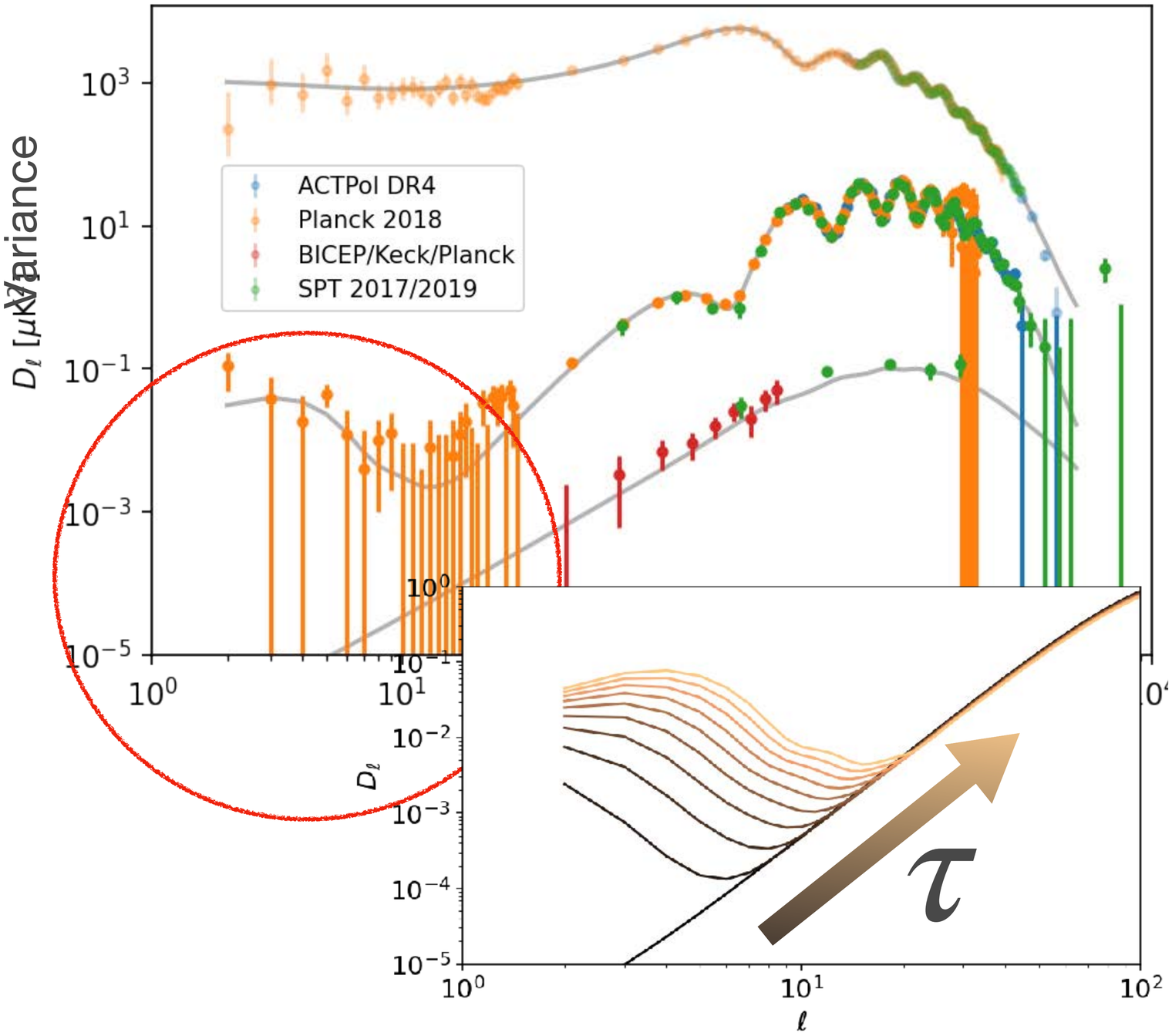
$\sigma\left(\sum m_\nu\right)$ Ref: CMB S4 - science book



Neutrino mass

- Measuring τ is done by measuring the large-scale E-modes.
- This measurement is essential for enabling measurements of the sum of neutrino mass through CMB lensing.

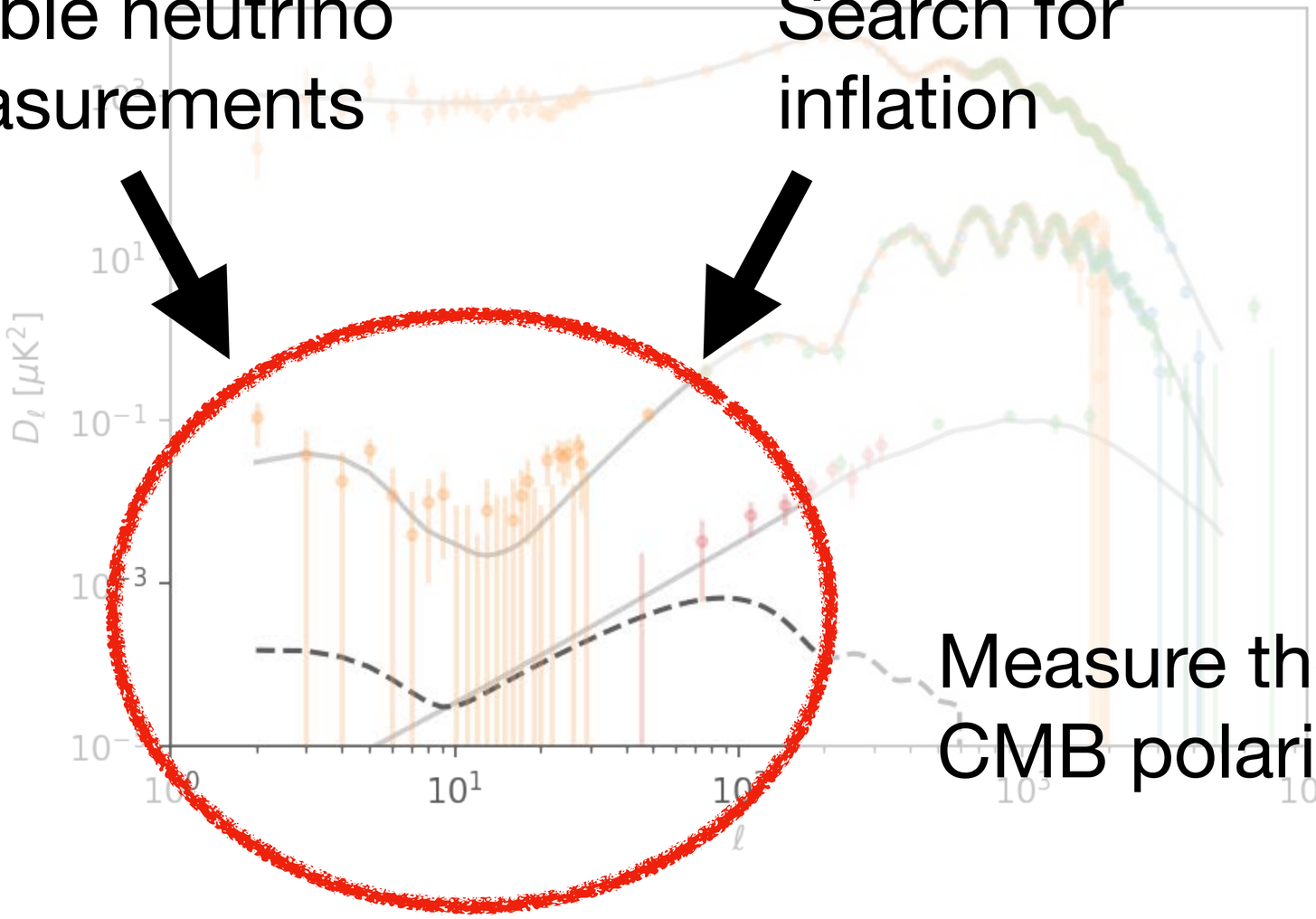
Data from: NASA LAMBDA



CLASS Objective:

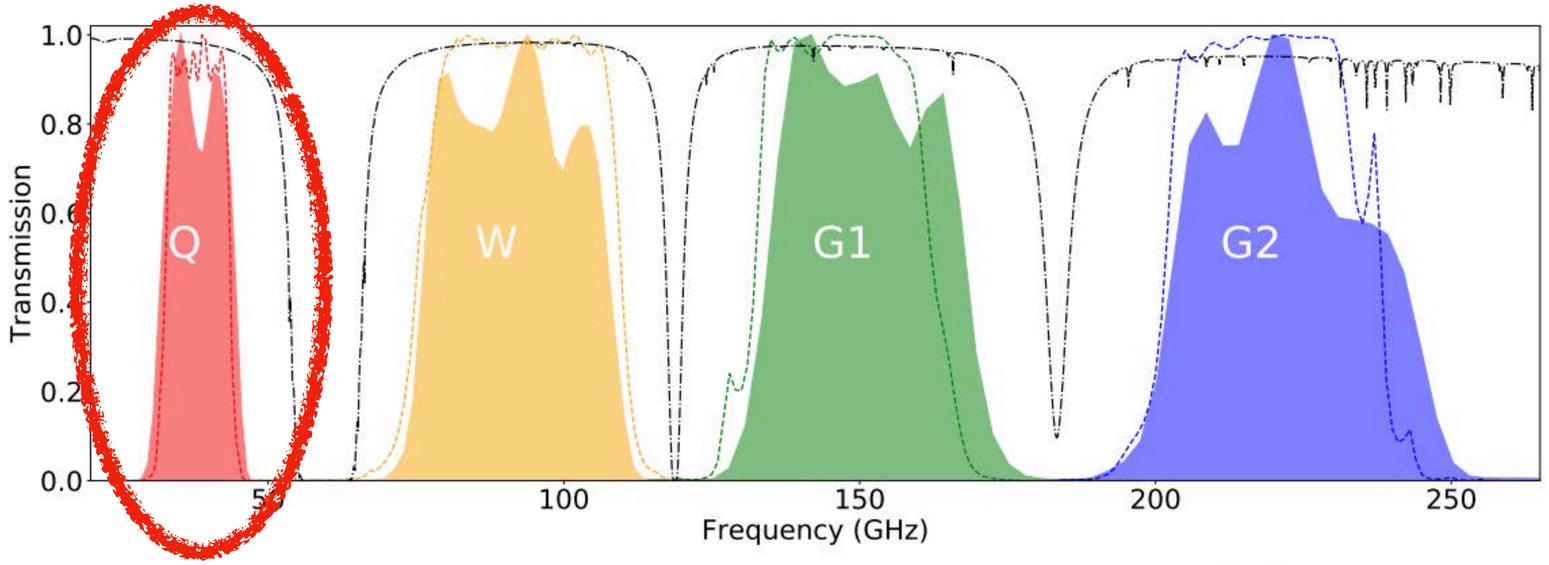
Enable neutrino measurements

Search for inflation

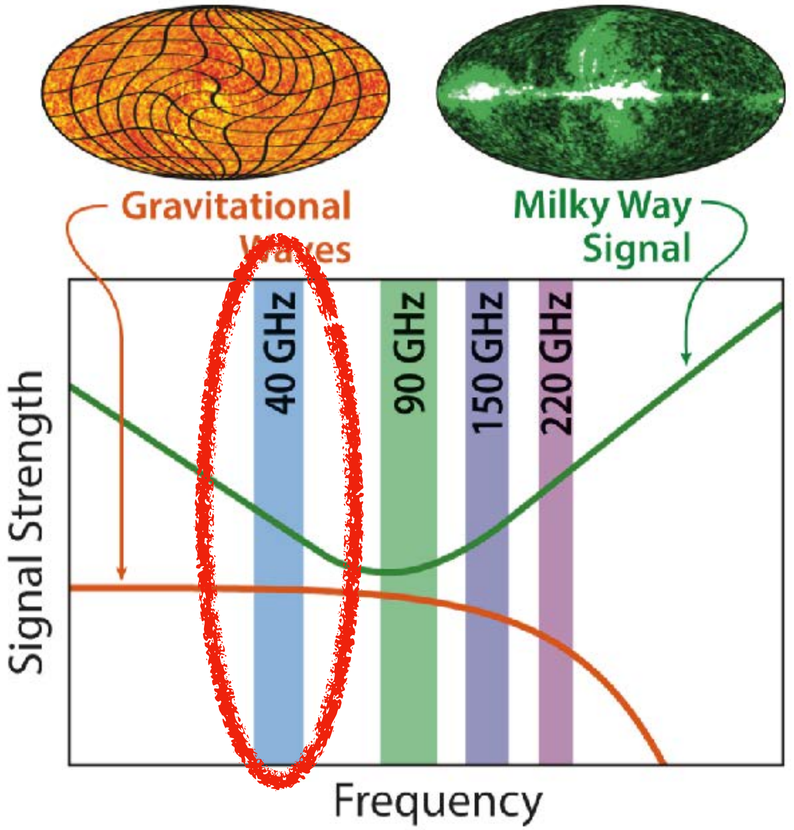


Measure the large-scale CMB polarization

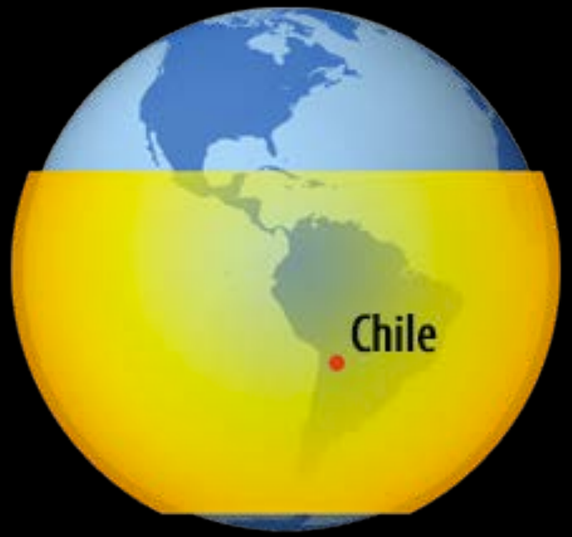
Challenges



- Large scale.
  - Front-end polarization modulation
  - Interlinked scan strategy.
- Must be distinguished from foreground components.
  - Within atmospheric transmission windows
  - Use frequencies near foreground minimum



CLASS site



Elevation: 5200 m

Survey: > 70% sky

Storage

Laboratory

Machine Shop

Control Room

Storage

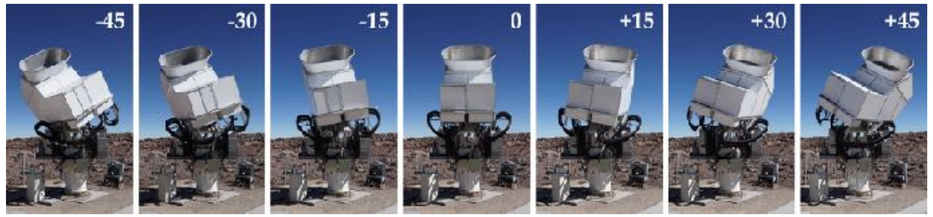
High Bay

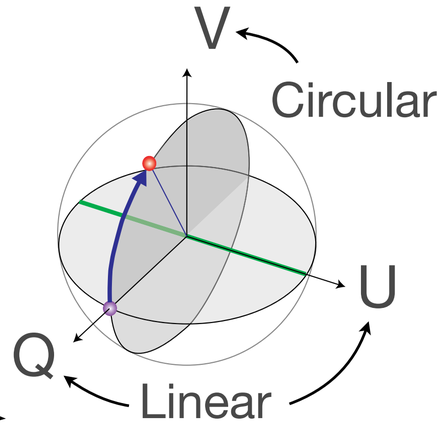
Generators

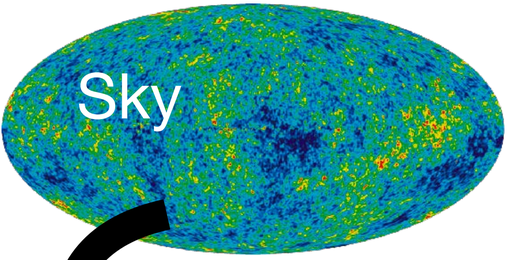
Fuel Tank

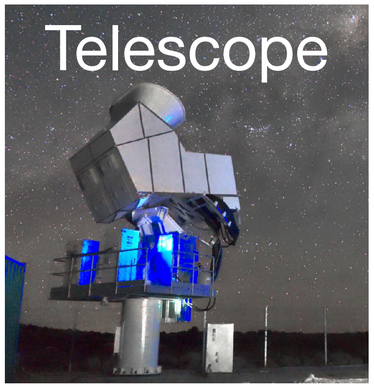
CLASS measurement

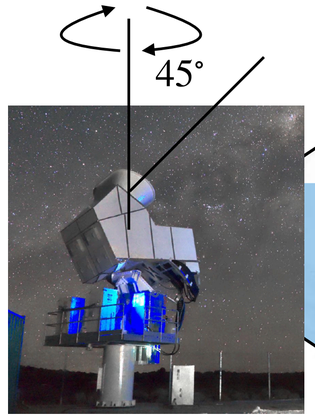
Switch boresight

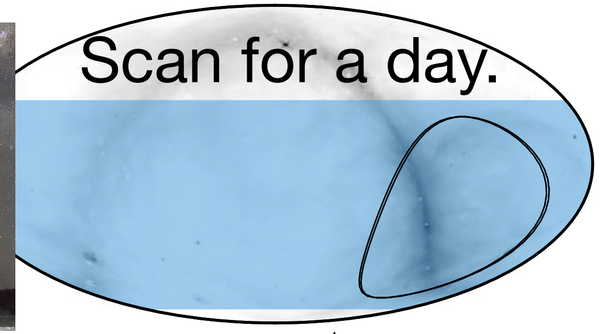


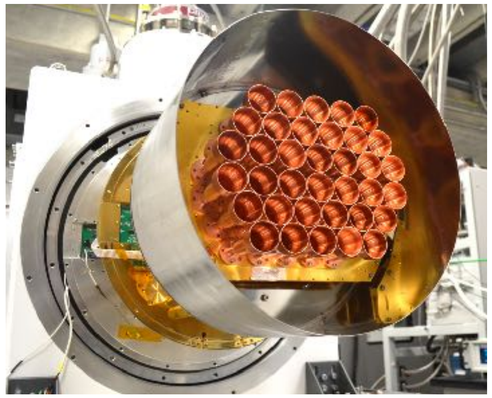


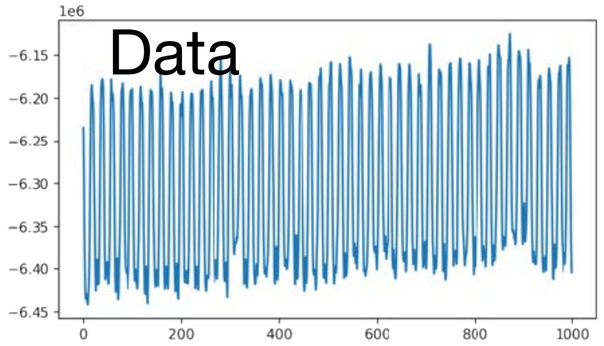






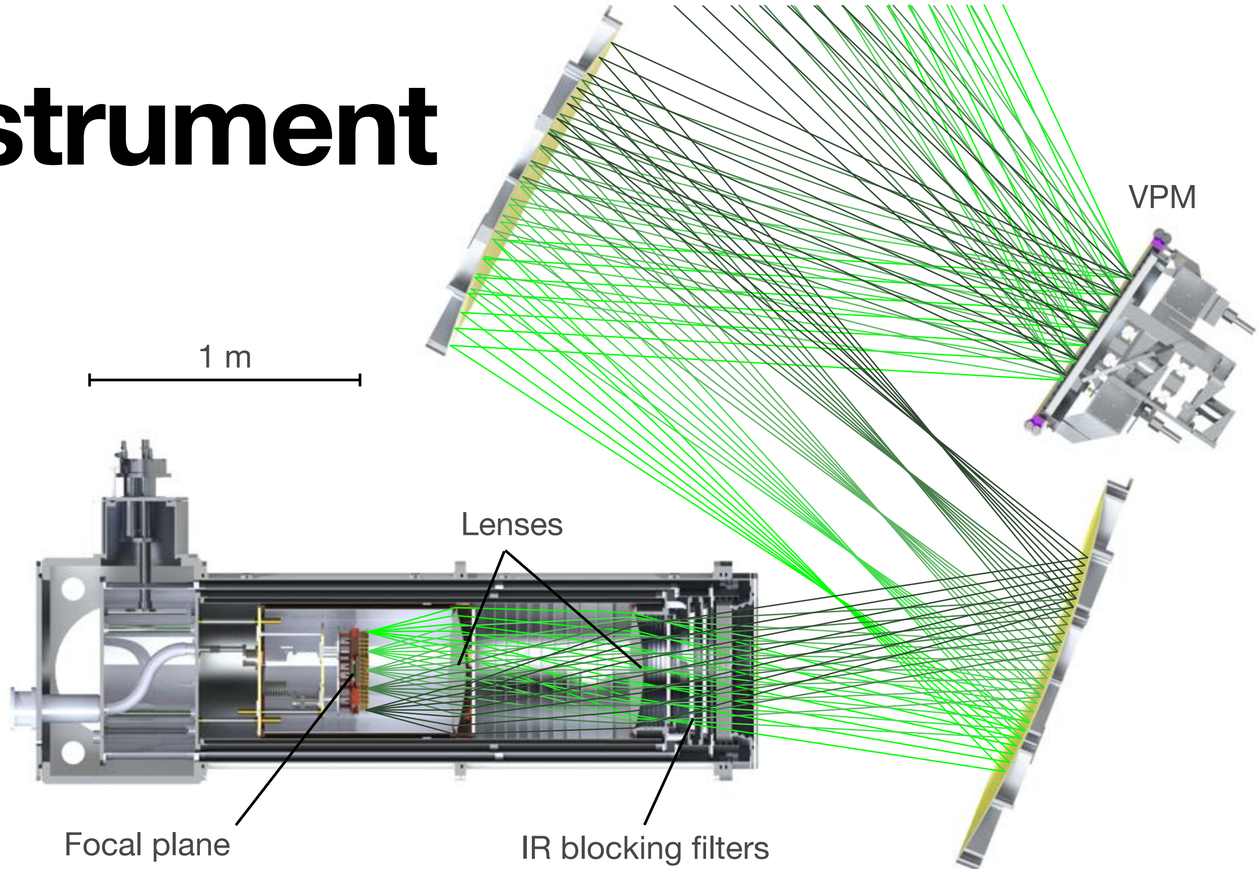






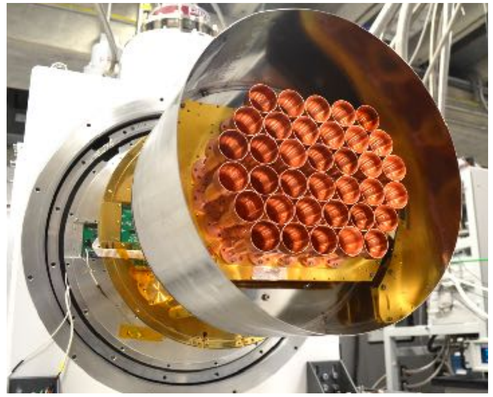
Figures: NASA, CLASS, Chuss et al. AO: 1206.2284. Datta et al. 2308.13309

CLASS instrument

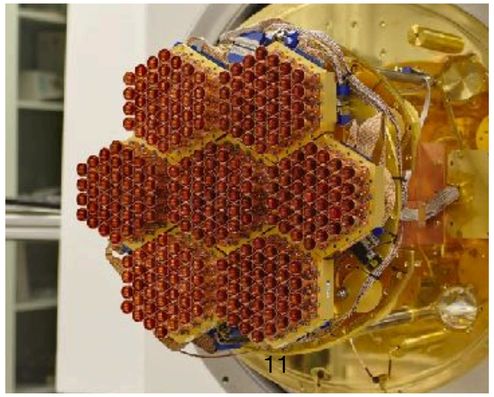


Variable-delay
Polarization
Modulator
(**VPM**)

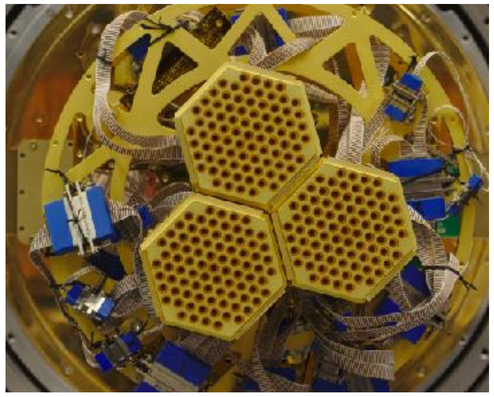
40 GHz



90 GHz

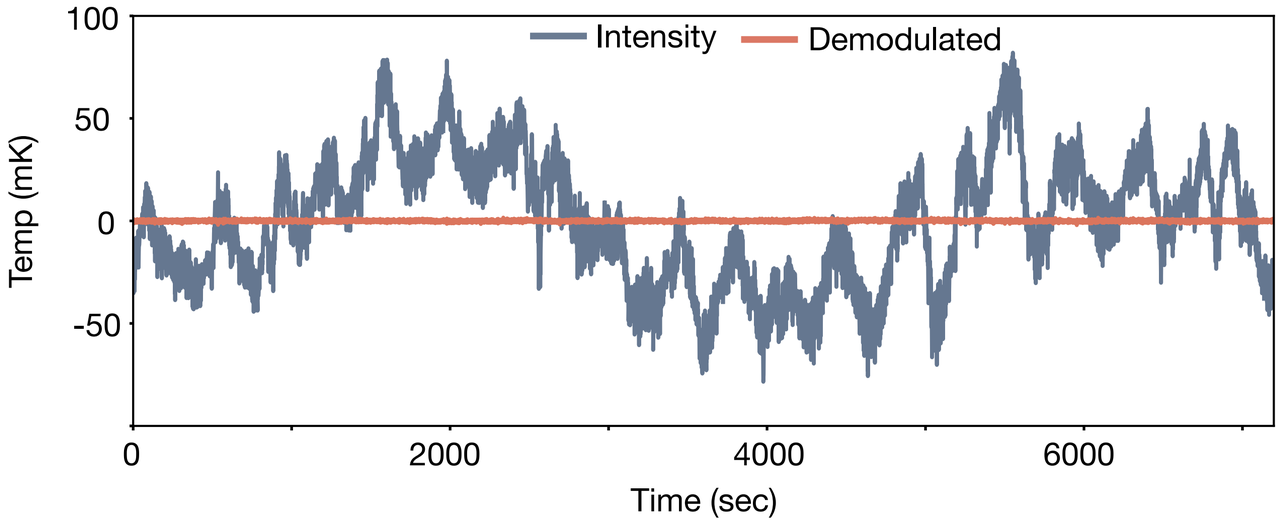


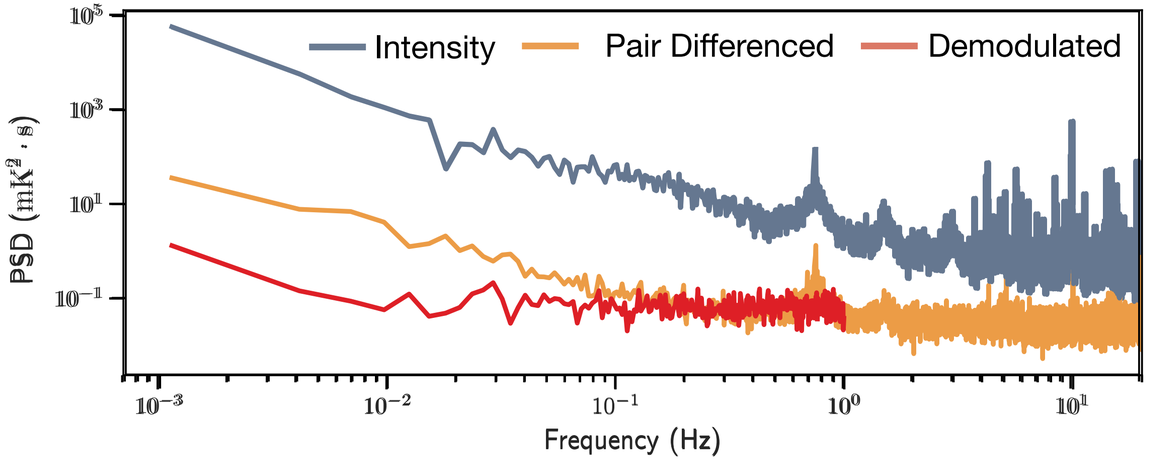
150/220 GHz

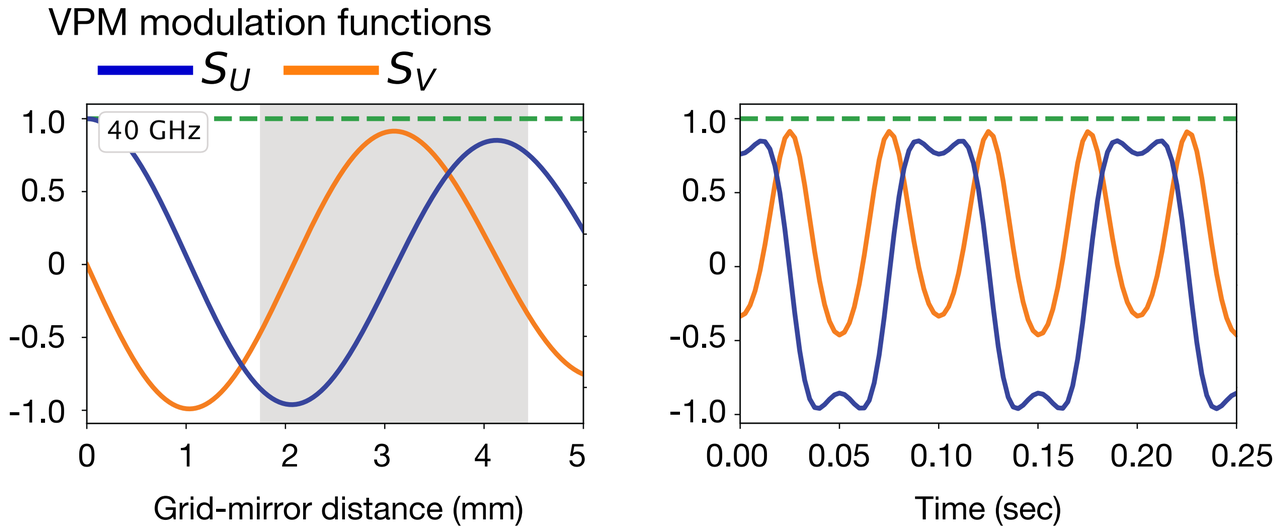


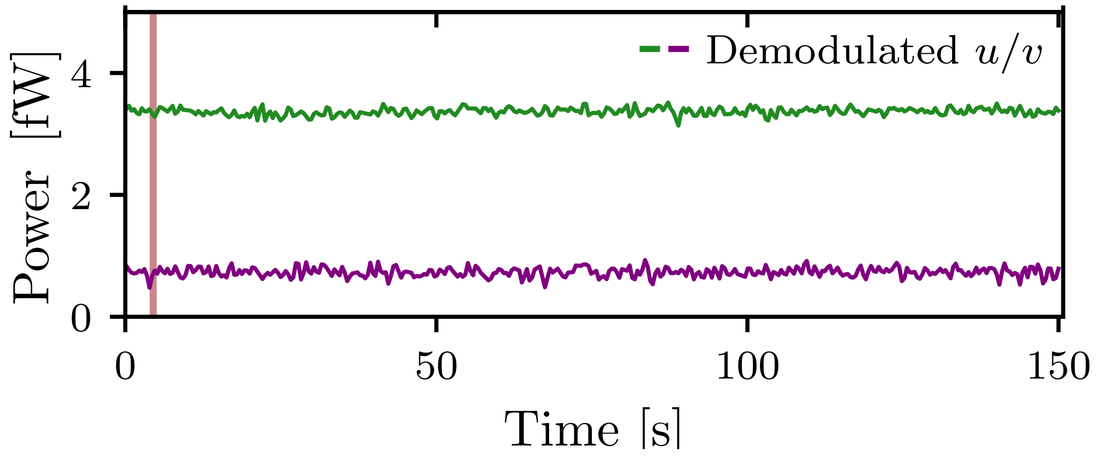
CLASS data

Harrington et al. ApJ 2021: 2101.00034







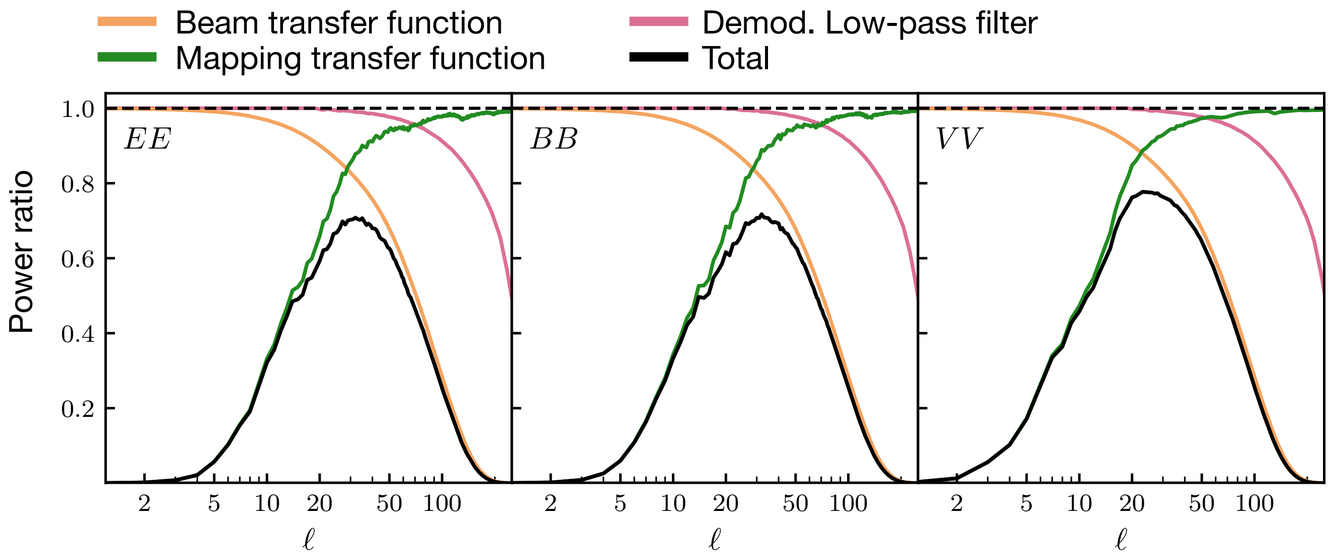


Li et al. ApJ 2023: 2305.01045

Cleary et al. in prep

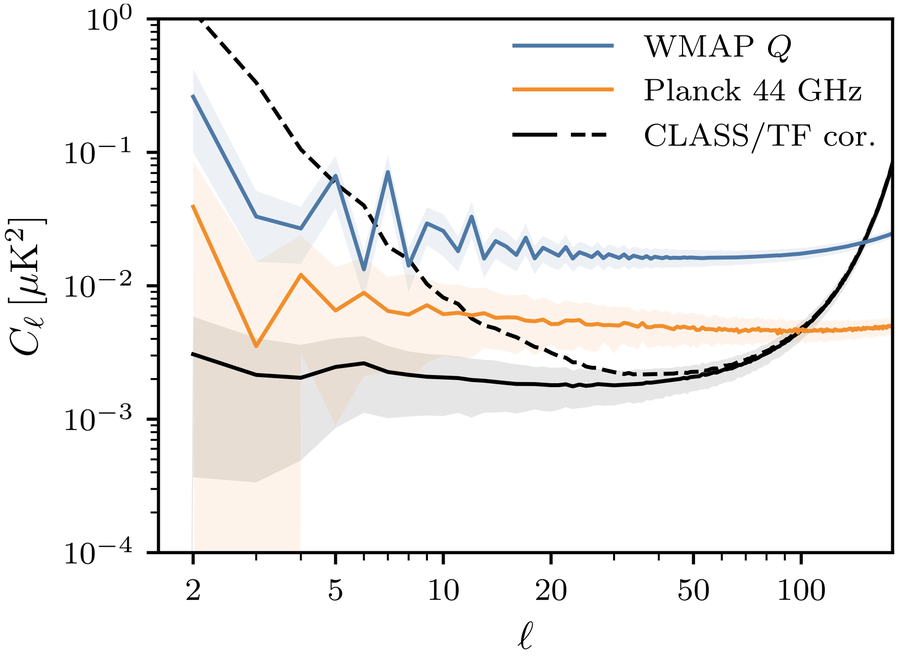
Filtering

- Residual effects
  - Az-motor servo
  - Wind-induced signals
  - Webcam RFI
  - Residual Az-synchronous signals
- Subtract templates on 3-5 hour timescales

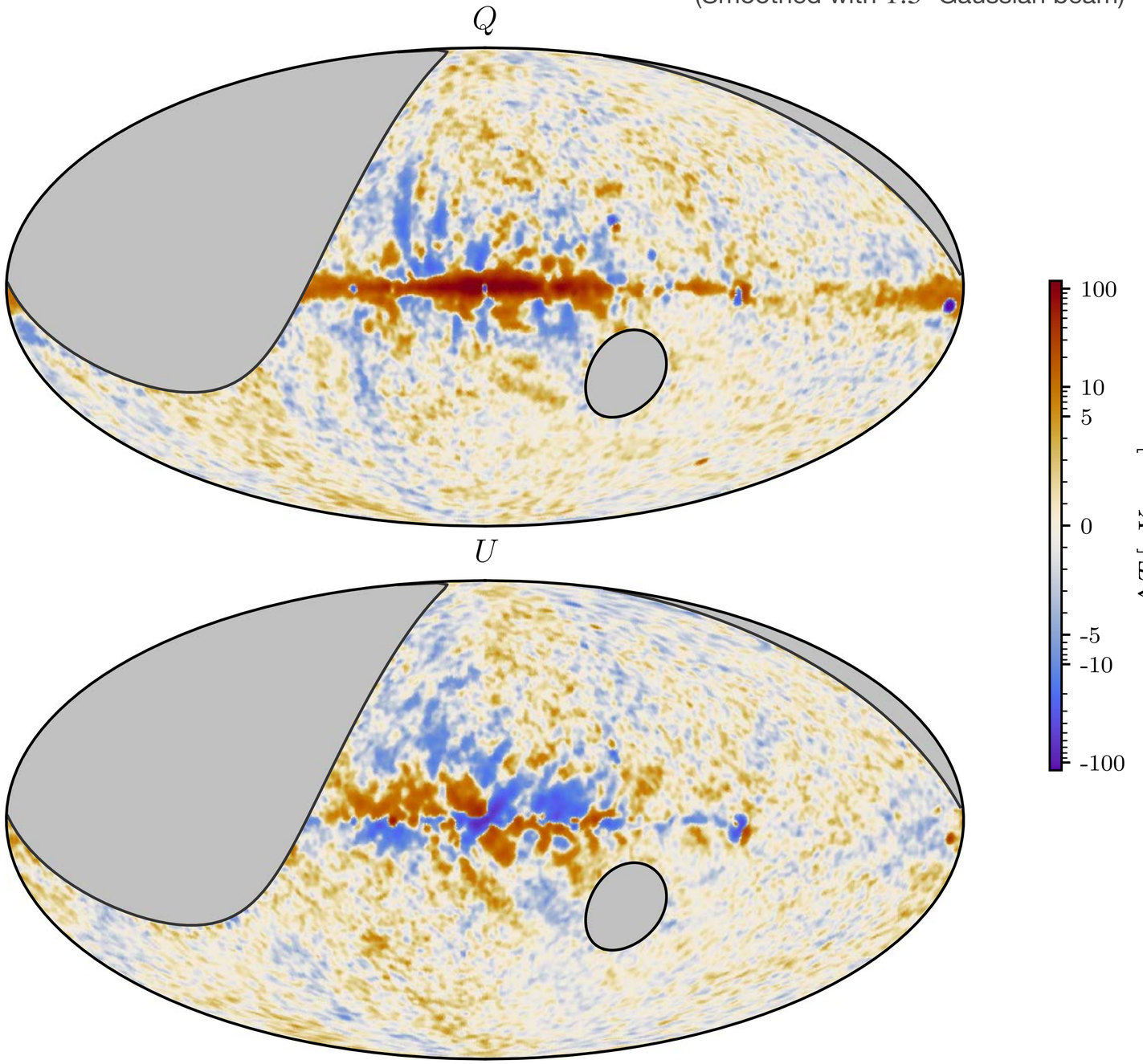


CLASS maps

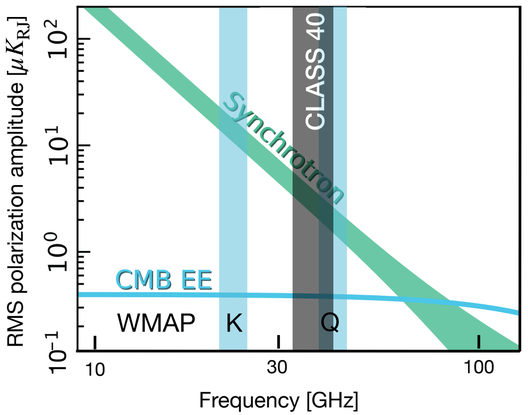
- ~75% of the sky
- Dominated by synchrotron emission
- Significant improvement over satellite measurements in the critical $10 < \ell < 100$ range.



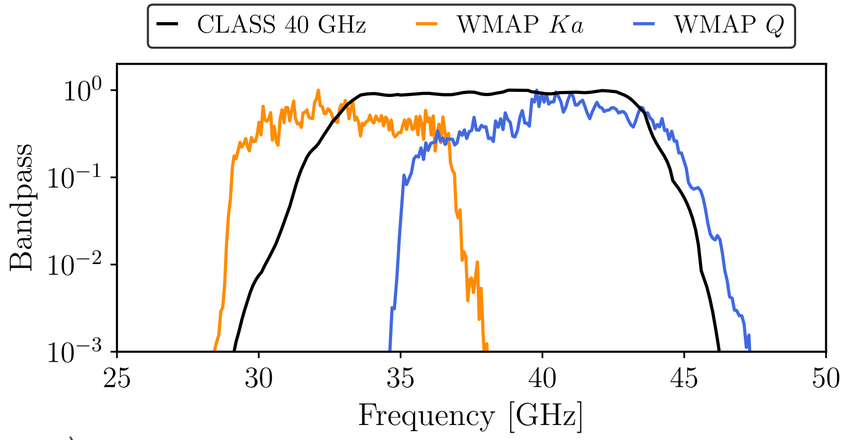
(Smoothed with 1.5° Gaussian beam)



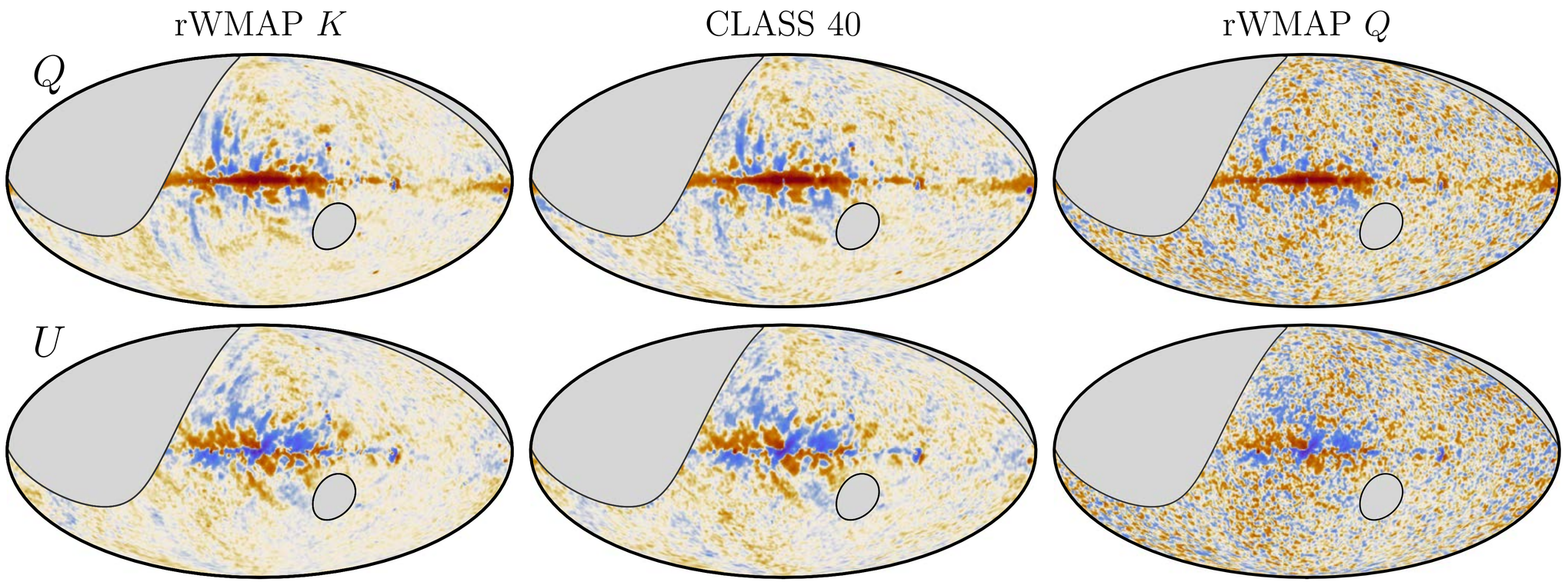
Compare to previous measurements



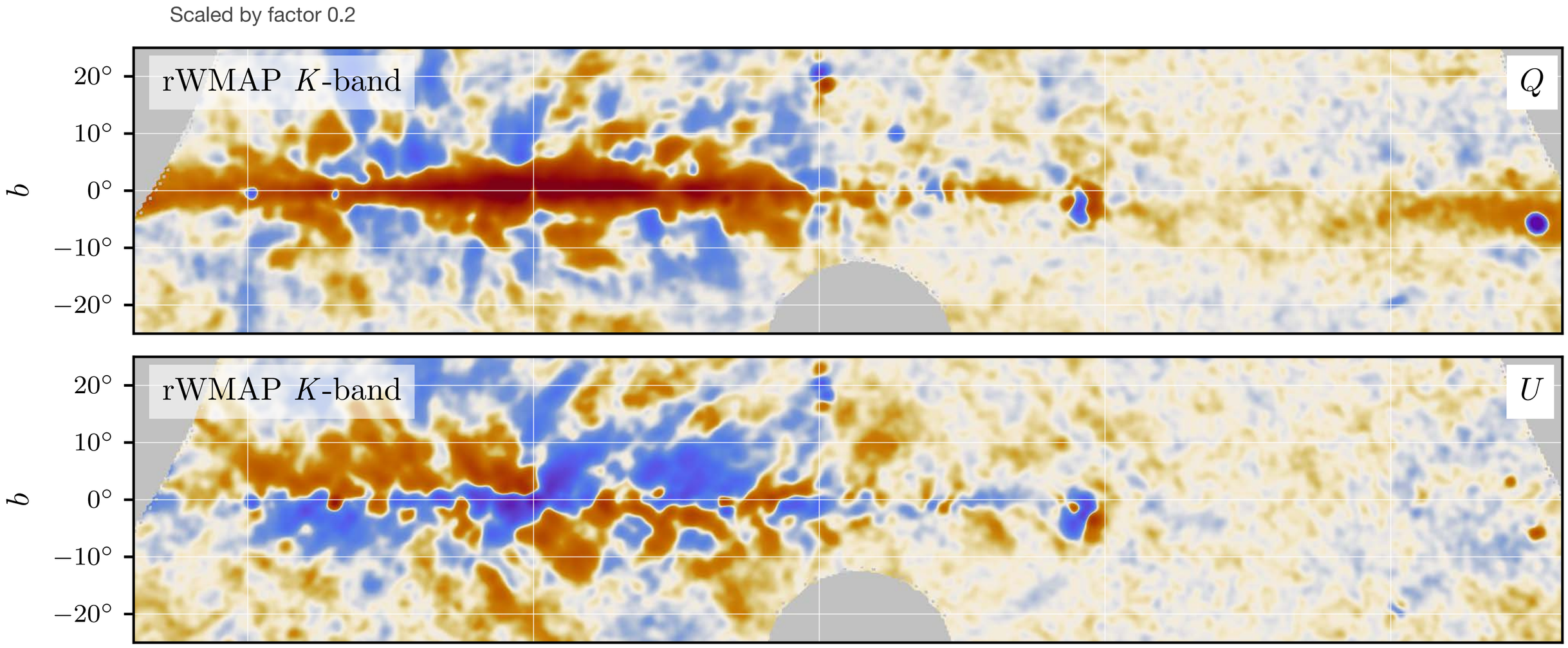
Scaled by 0.2



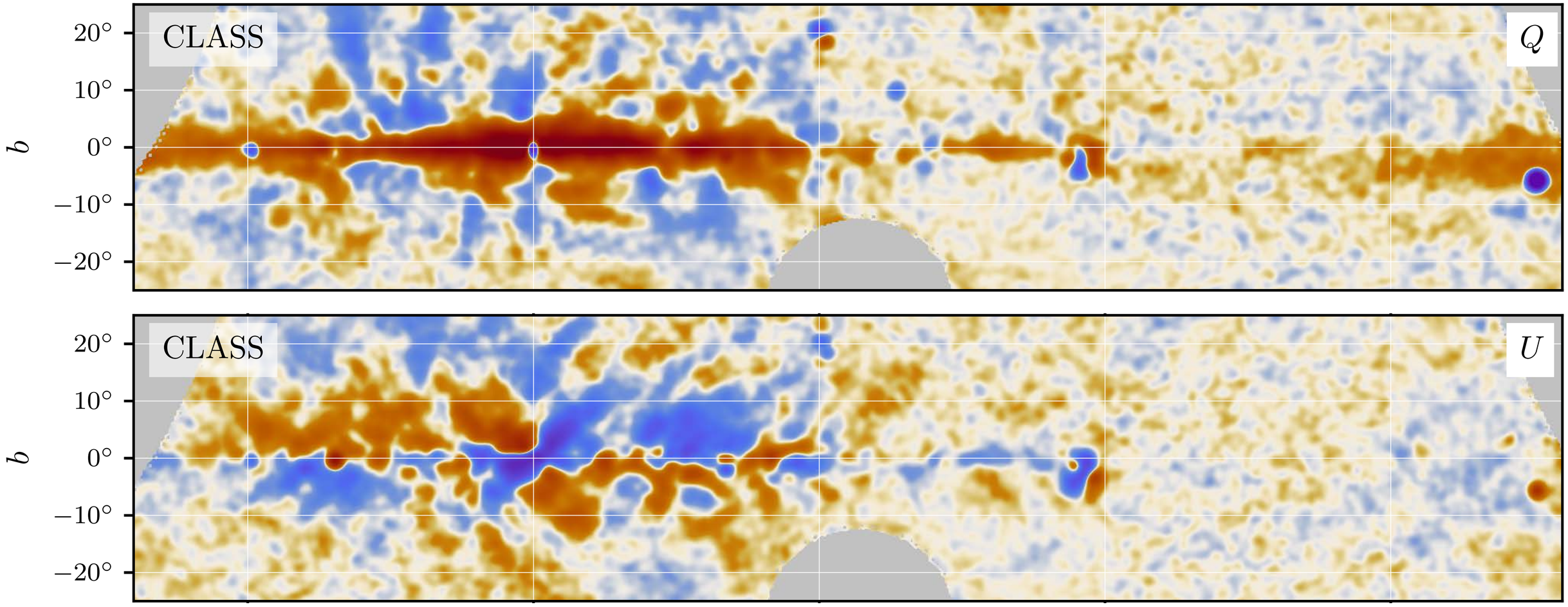
(Smoothed with 1.5° Gaussian beam)



re-observed WMAP K-band

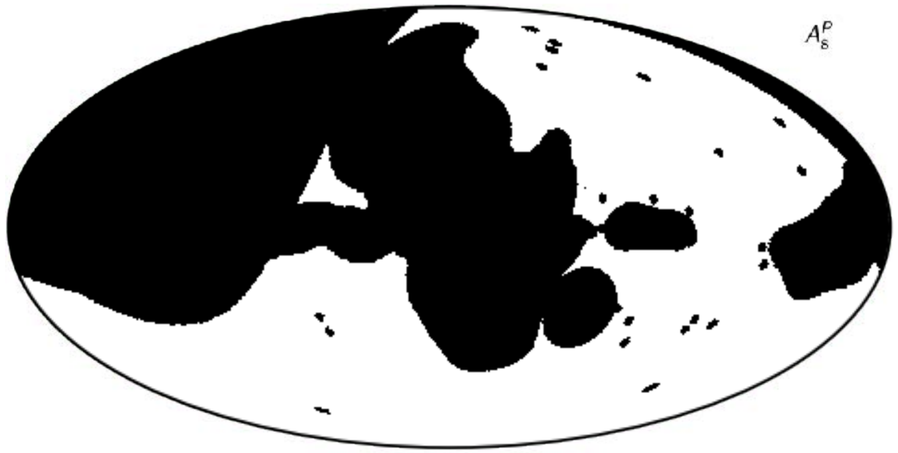


CLASS 40-GHz

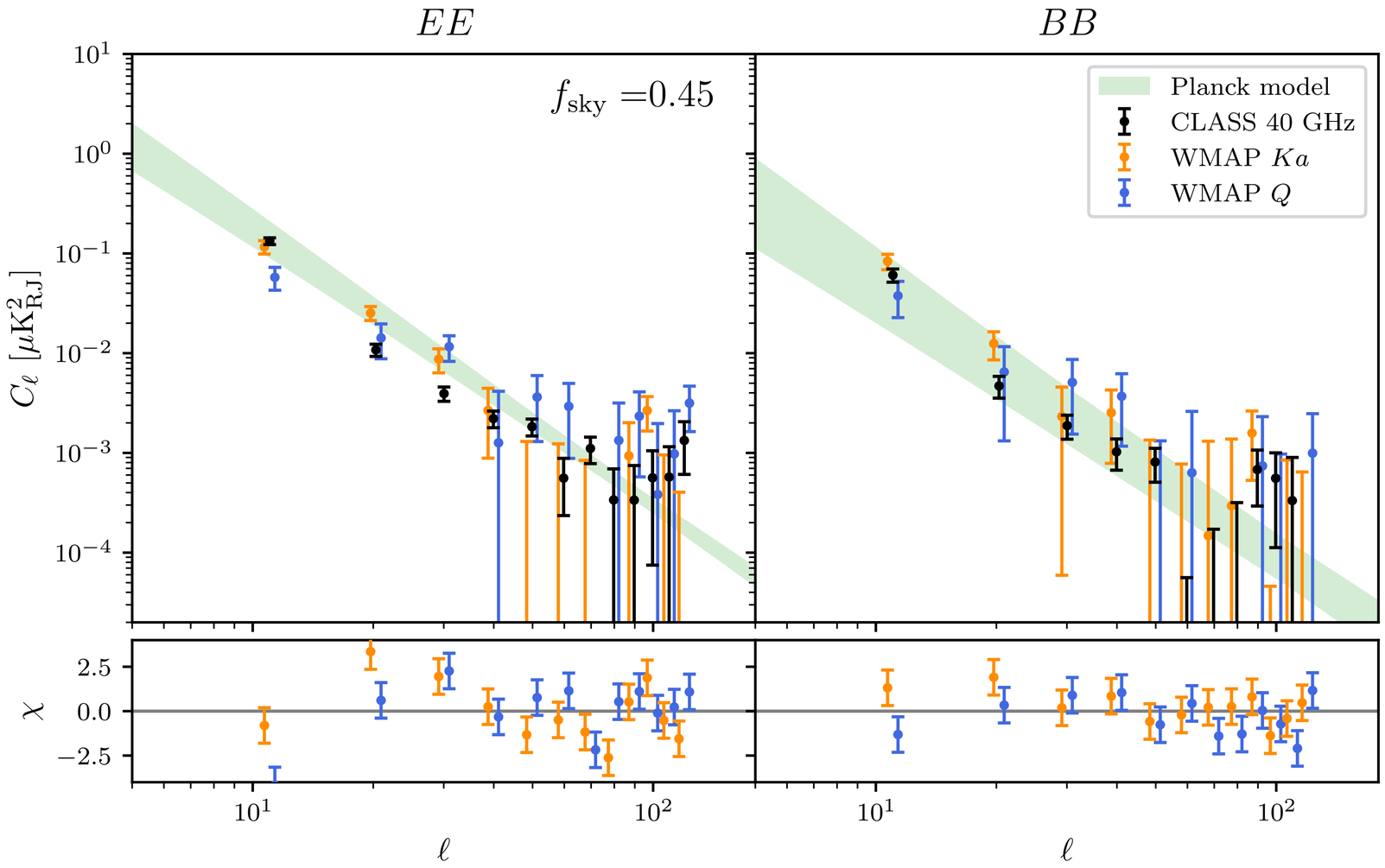


(Smoothed with 1.5° Gaussian beam)

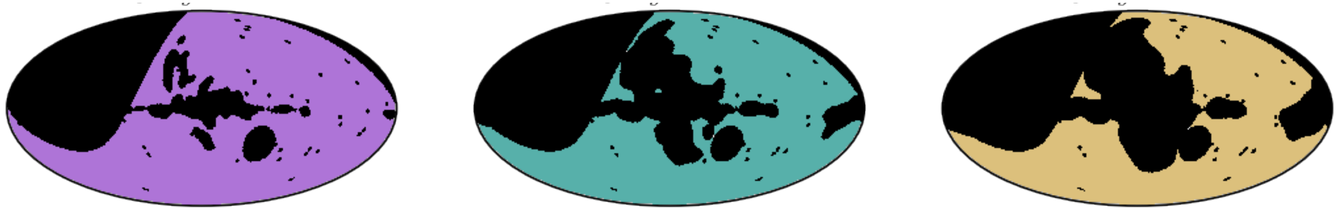
Synchrotron angular power spectrum



- Power spectrum evaluated with the brightest regions masked.
- CMB contribution has been subtracted.
- Generally consistent picture with WMAP - now with higher precision.



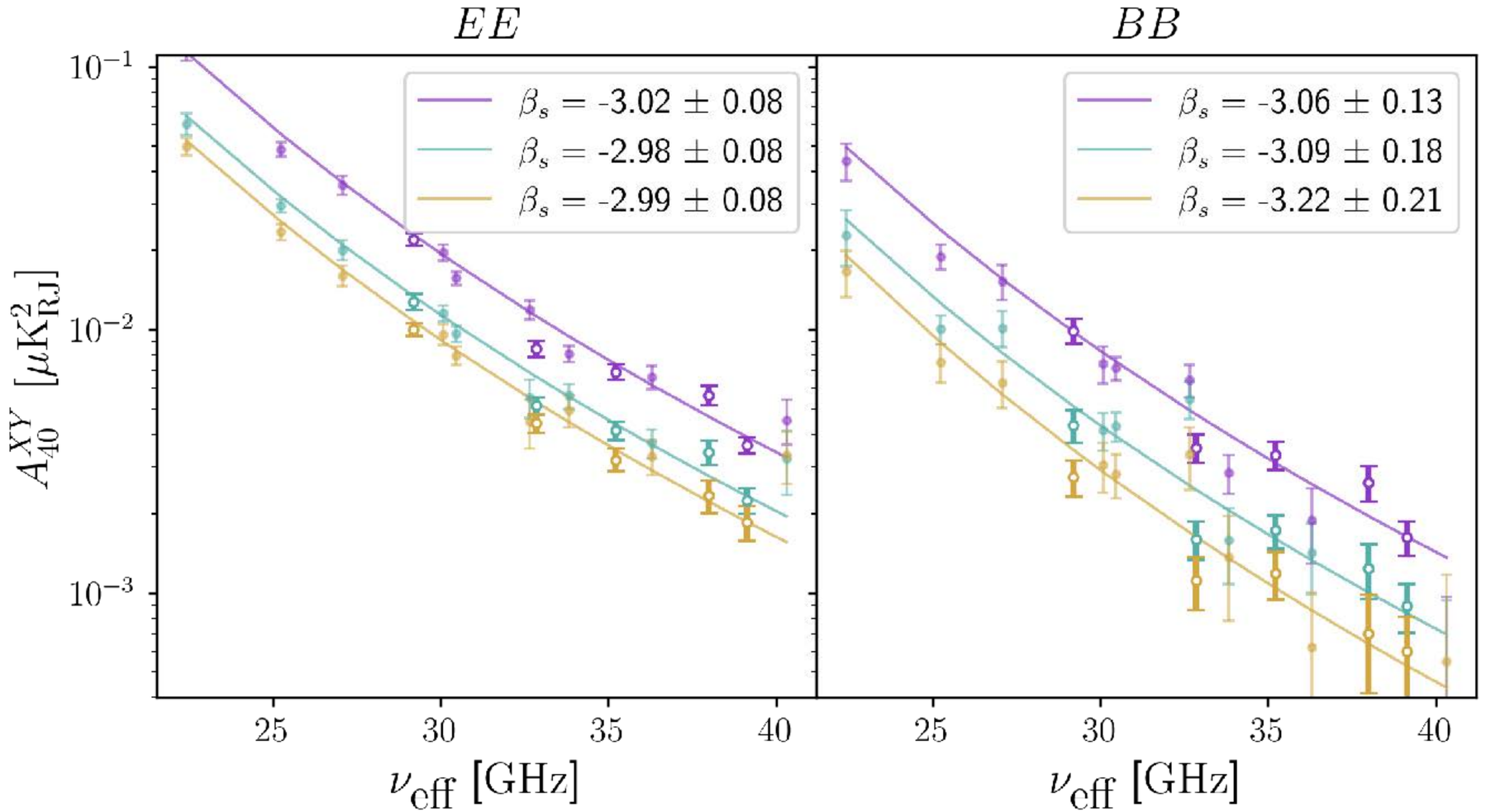
Synchrotron SED



- Combine with other cross-spectra dominated by synchrotron.

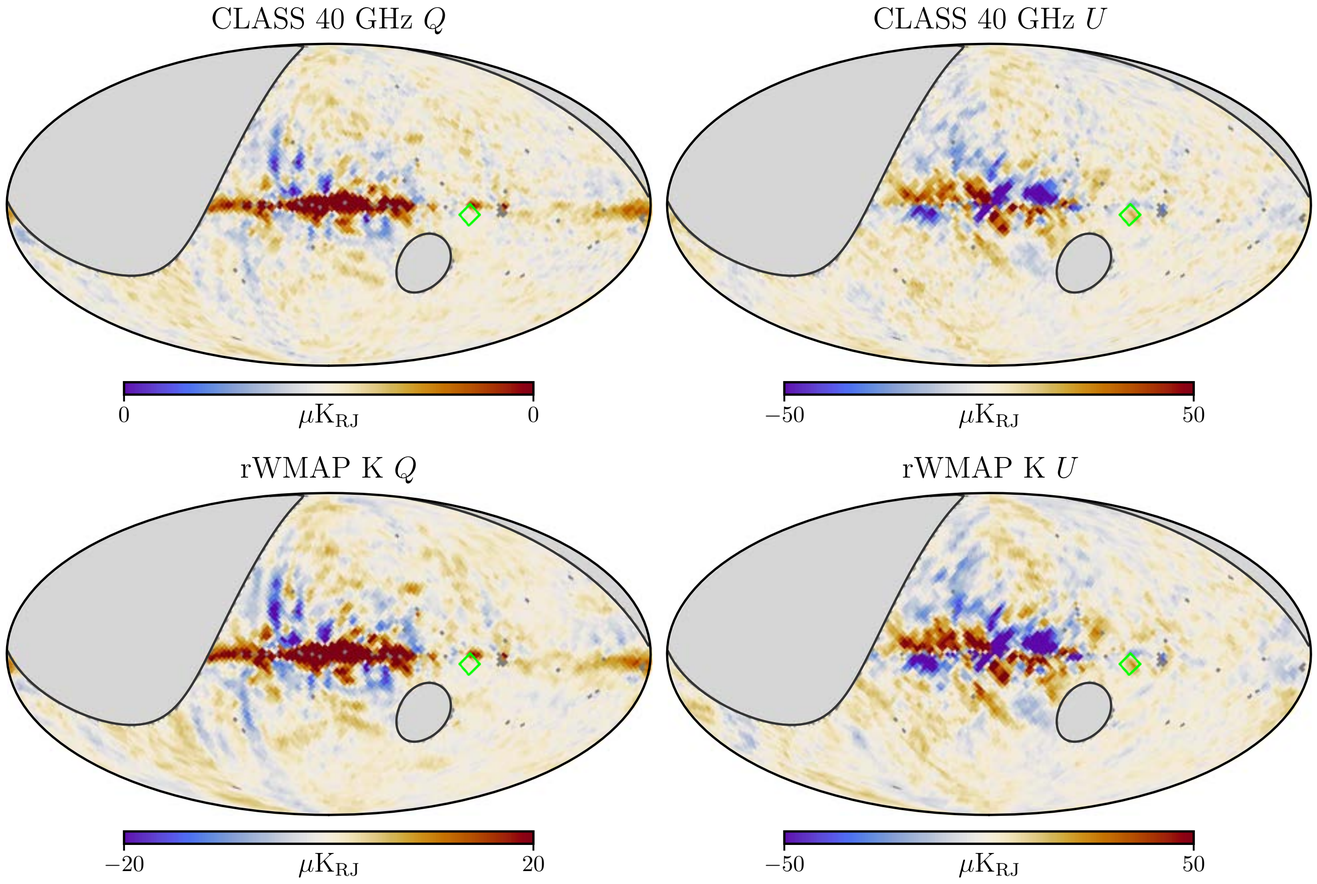
Band	Frequency [GHz]
WMAP K	22.4
Planck 30	28.4
WMAP Ka	32.7
CLASS	38.0
WMAP Q	40.3

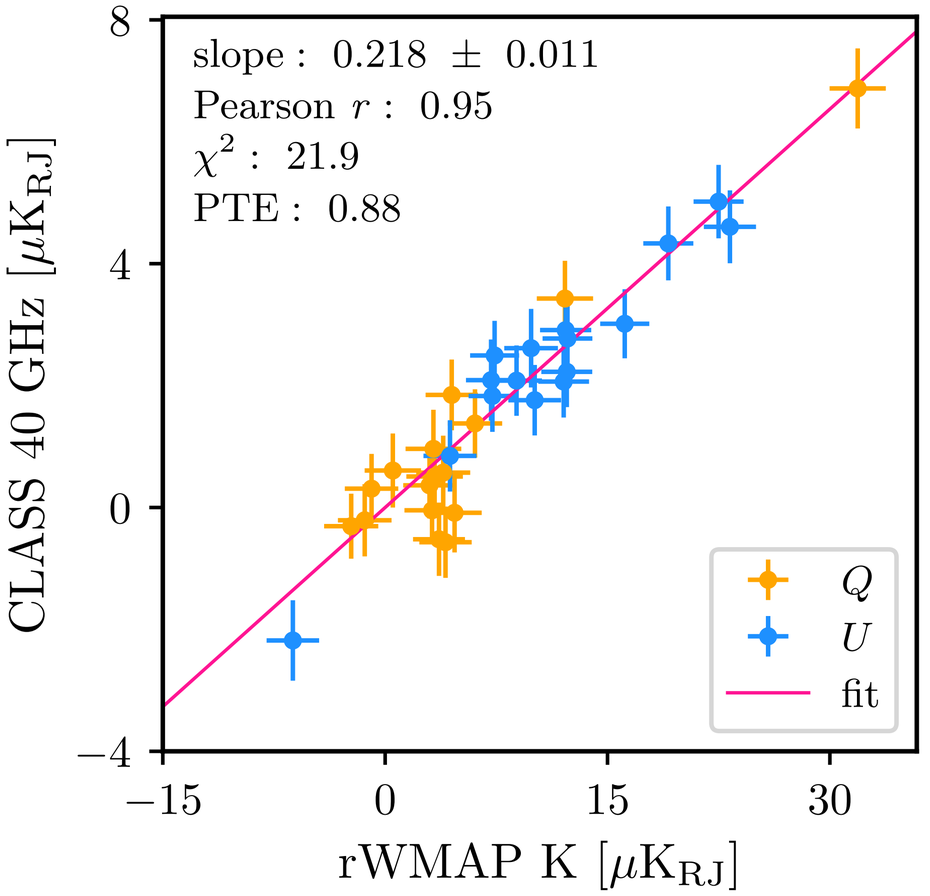
$$\mathrm{SED} \propto \left(\frac{\nu}{\nu_0}\right)^{\beta_s}$$



Synchrotron SED

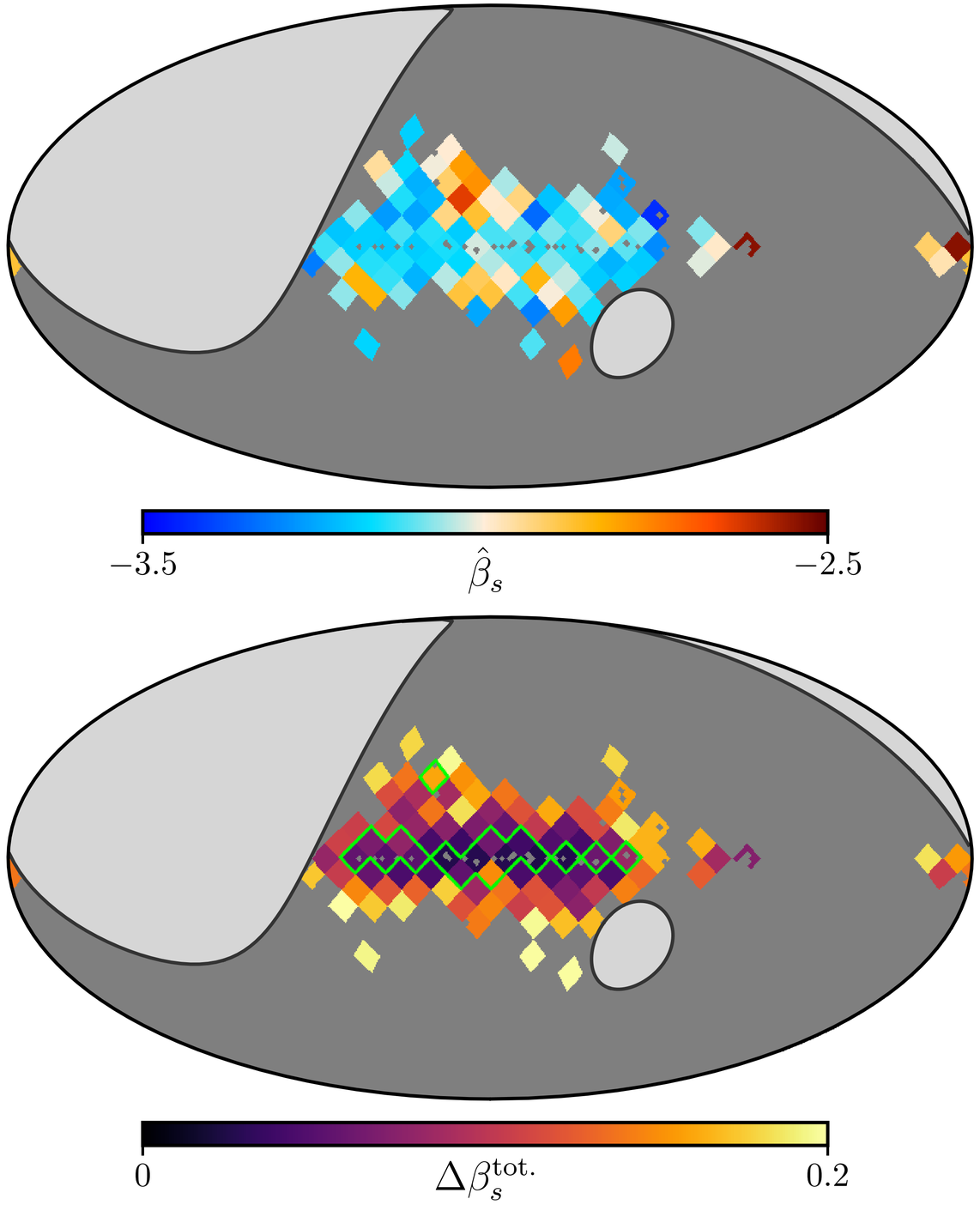
- Angular power spectra do not capture spatial variation in the SED.





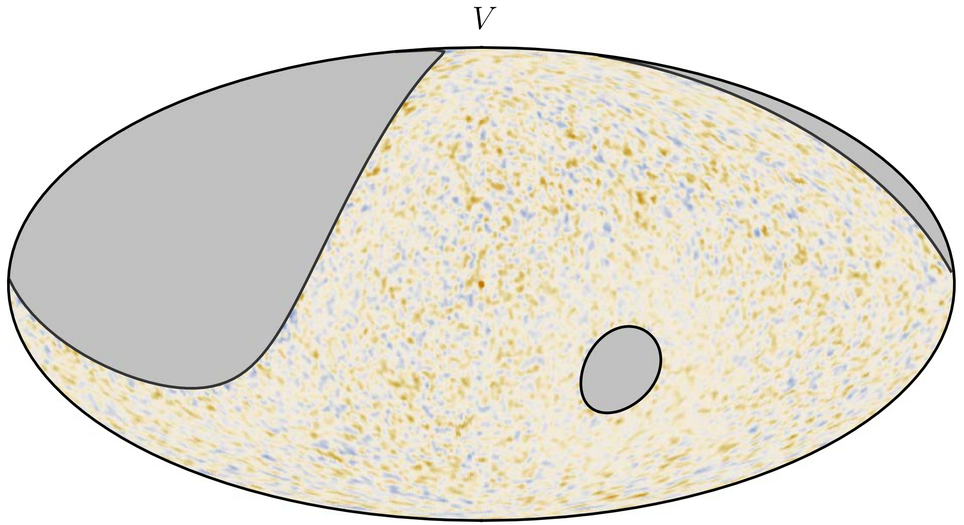
Synchrotron SED

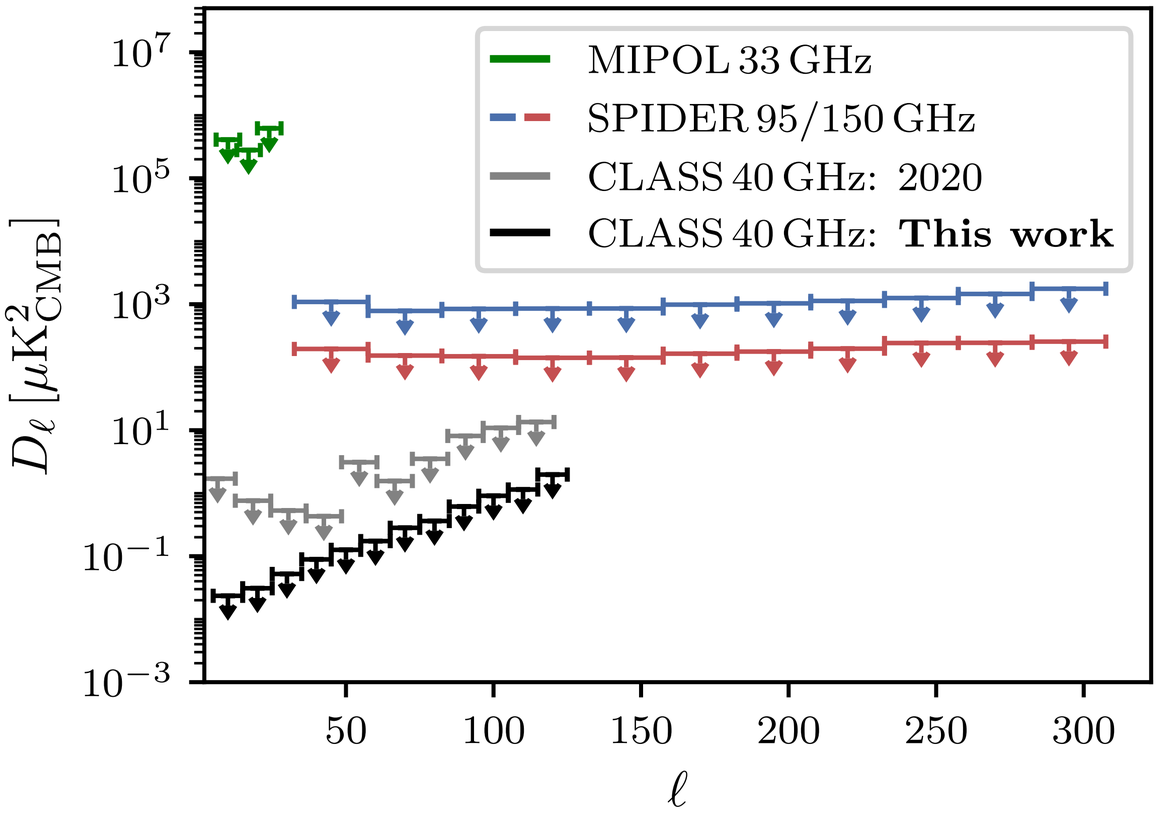
- Angular power spectra do not capture spatial variation in the SED.
- Understanding these variations are critical for component separation.
- We have expanded the region in which this method can be applied.



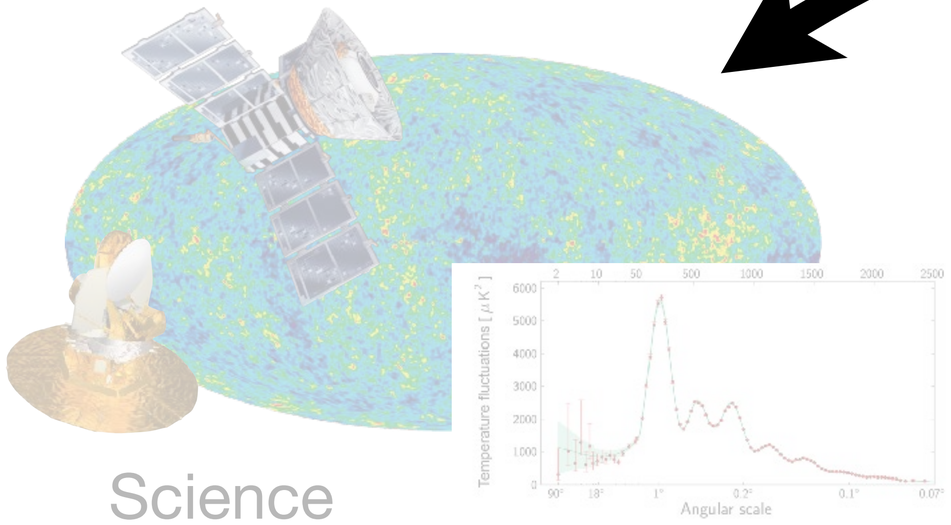
Circular polarization

- CLASS measures Stokes V.
- Generally predicted to be 0, but this should be checked.
- CLASS V-map is consistent with noise
- Improvements beyond previous CLASS result from increased data volume and improved mapping.





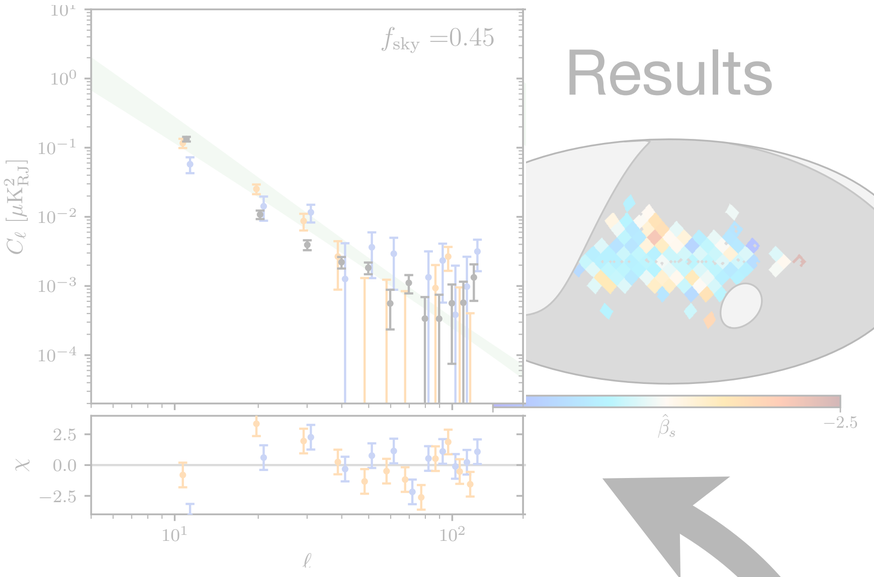
Path forward?



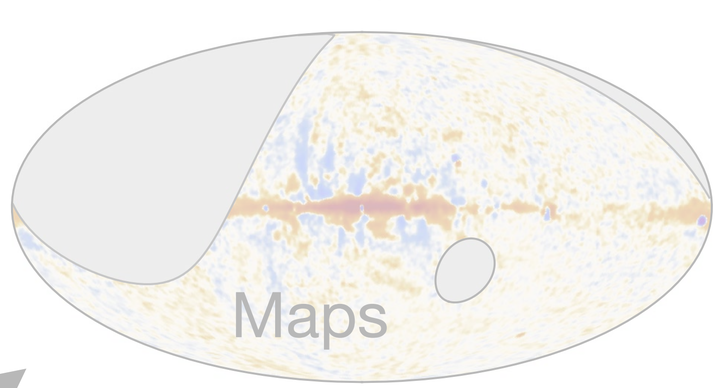
Science

Challenges

Data

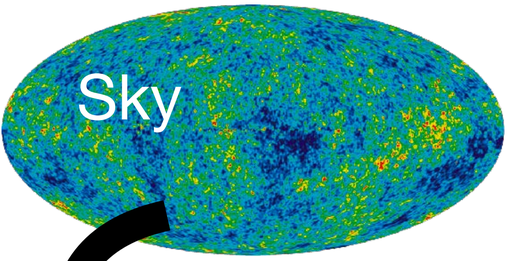


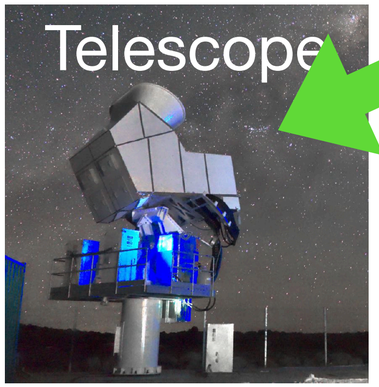
Results

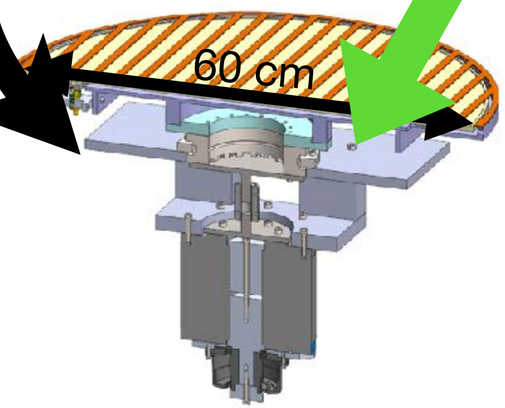


Figures: ESA, NASA, M. Petroff, Eimer et al. 2309.00675

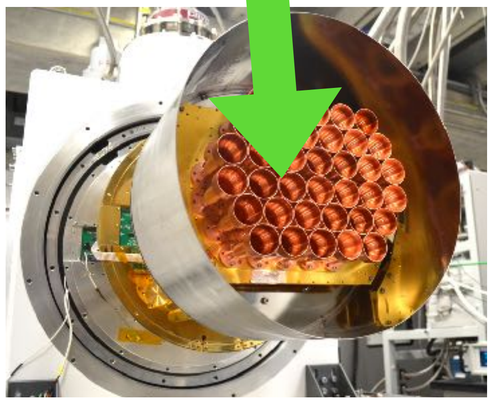
Path forward

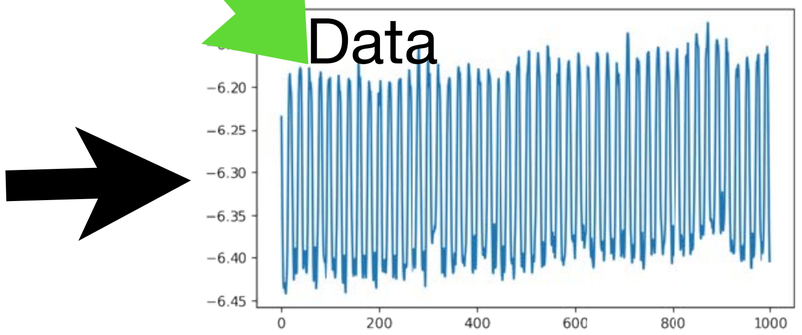


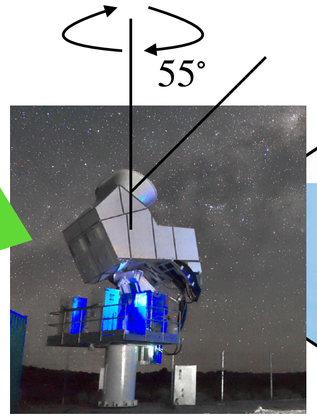


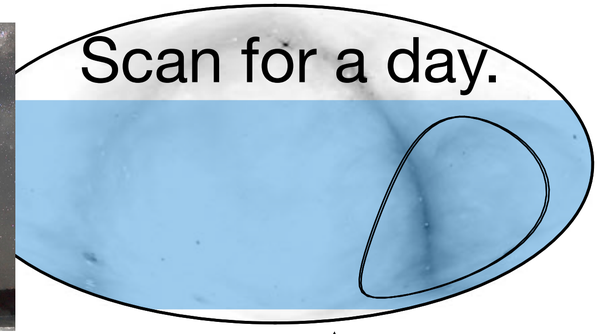


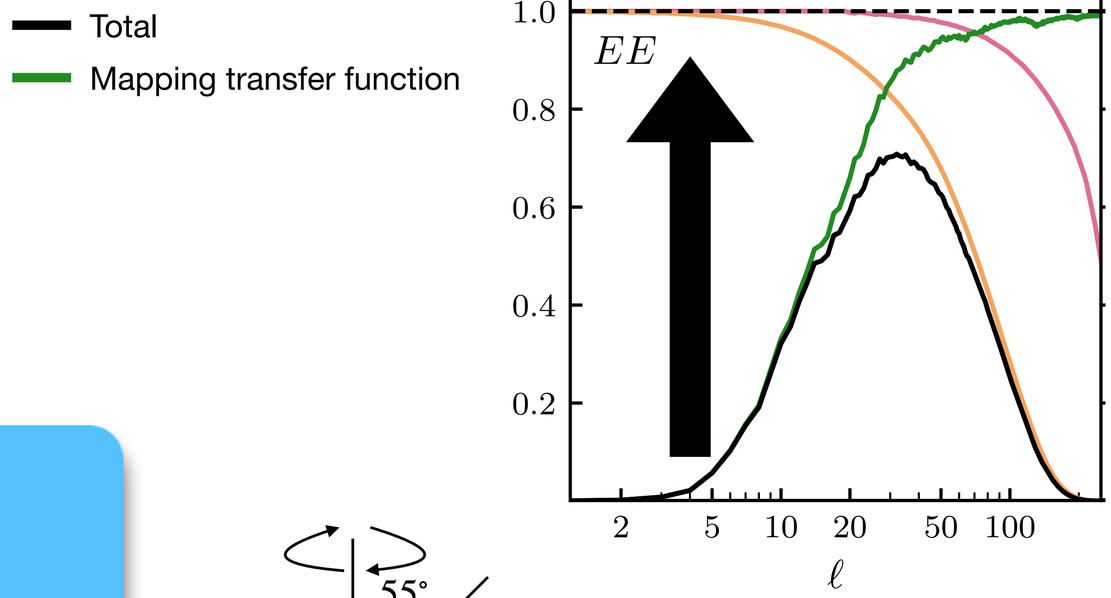
Combined approach to improve on the current performance.







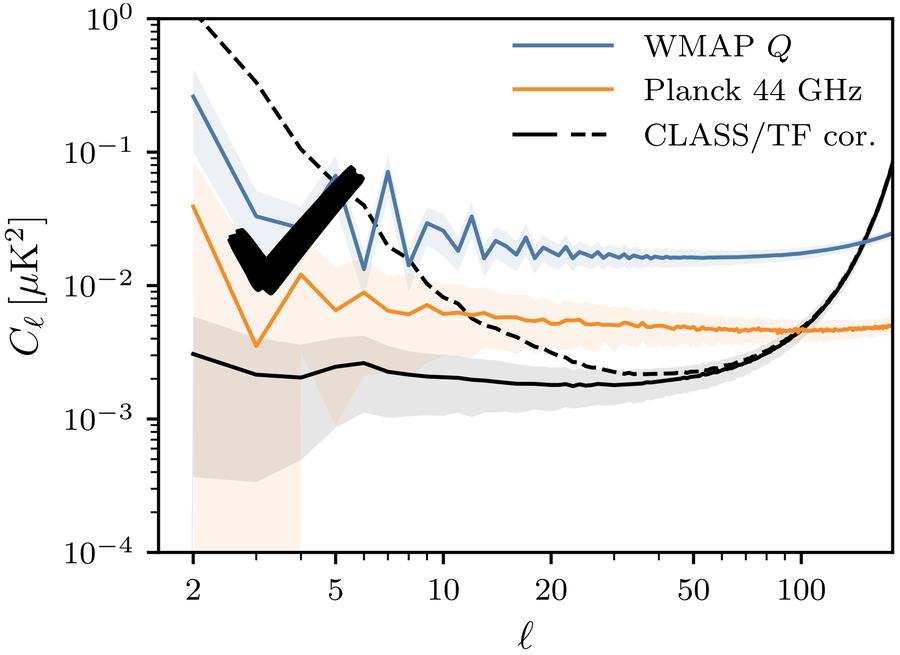


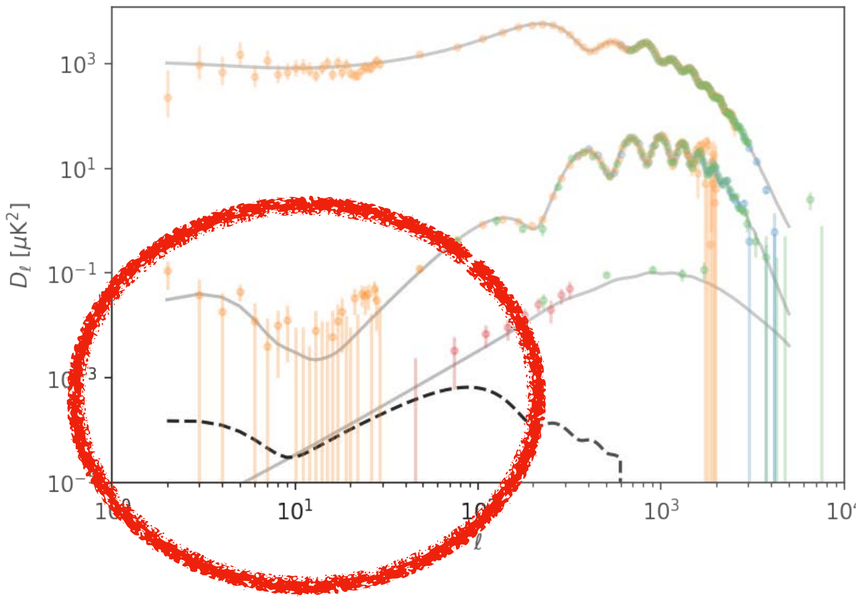


Figures: NASA, CLASS, Chuss et al. AO: Li et al. ApJ 1206.2284. Datta et al. 2308.13309

Outlook

- The CLASS 40 GHz survey has broken new ground in large-scale ground-based CMB science.
- Clear path to further improve the low-ℓ performance - working toward fully unlocking the largest scales from the ground.
- The analysis of the other frequencies is well underway.
- Improved sensitivity from instrument upgrades will allow us to further understand what limits ground-based large-scale measurements.
- Ultimately these lessons learned could motivate an expansion of the CLASS array or convincing methodology for next-generation measurements to adopt a large-angular-scale program.





Thank you