Constraining polarized synchrotron emission with QUIET and FOCUS

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Astrophysics from the radio to the sub-millimetre
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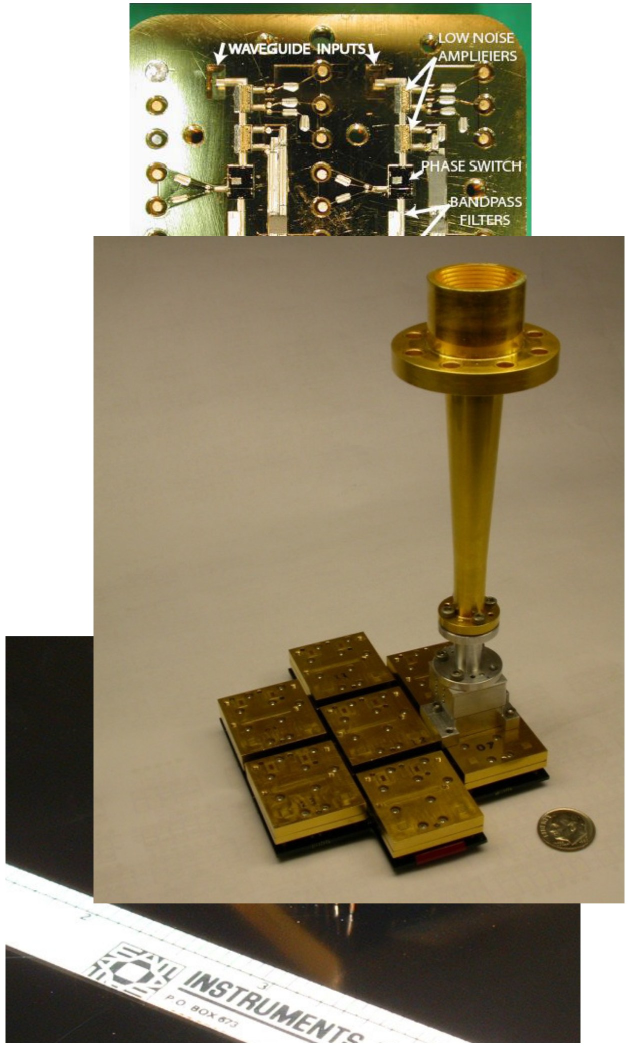
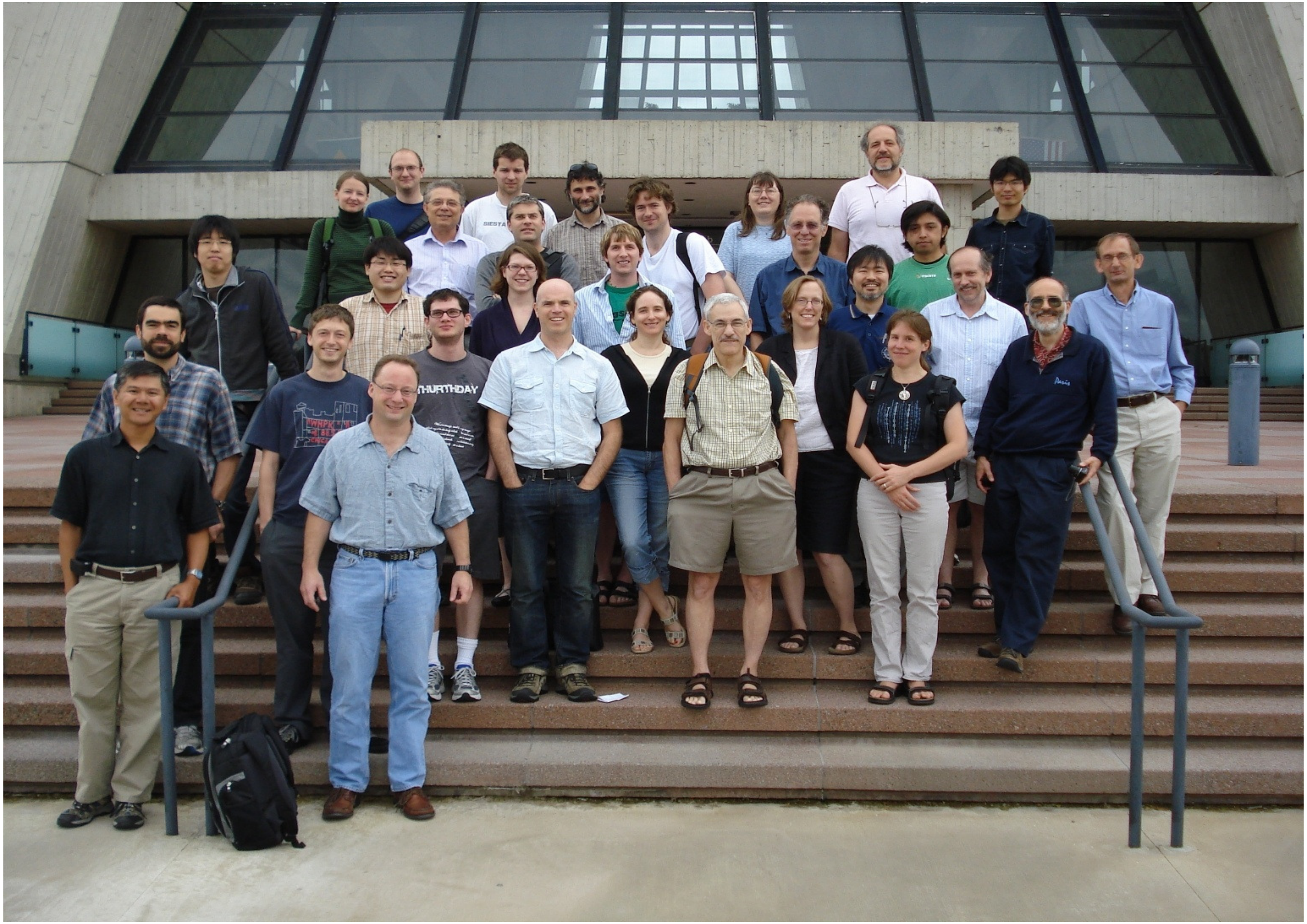
QUIET (Q/U Imaging ExperimenT)

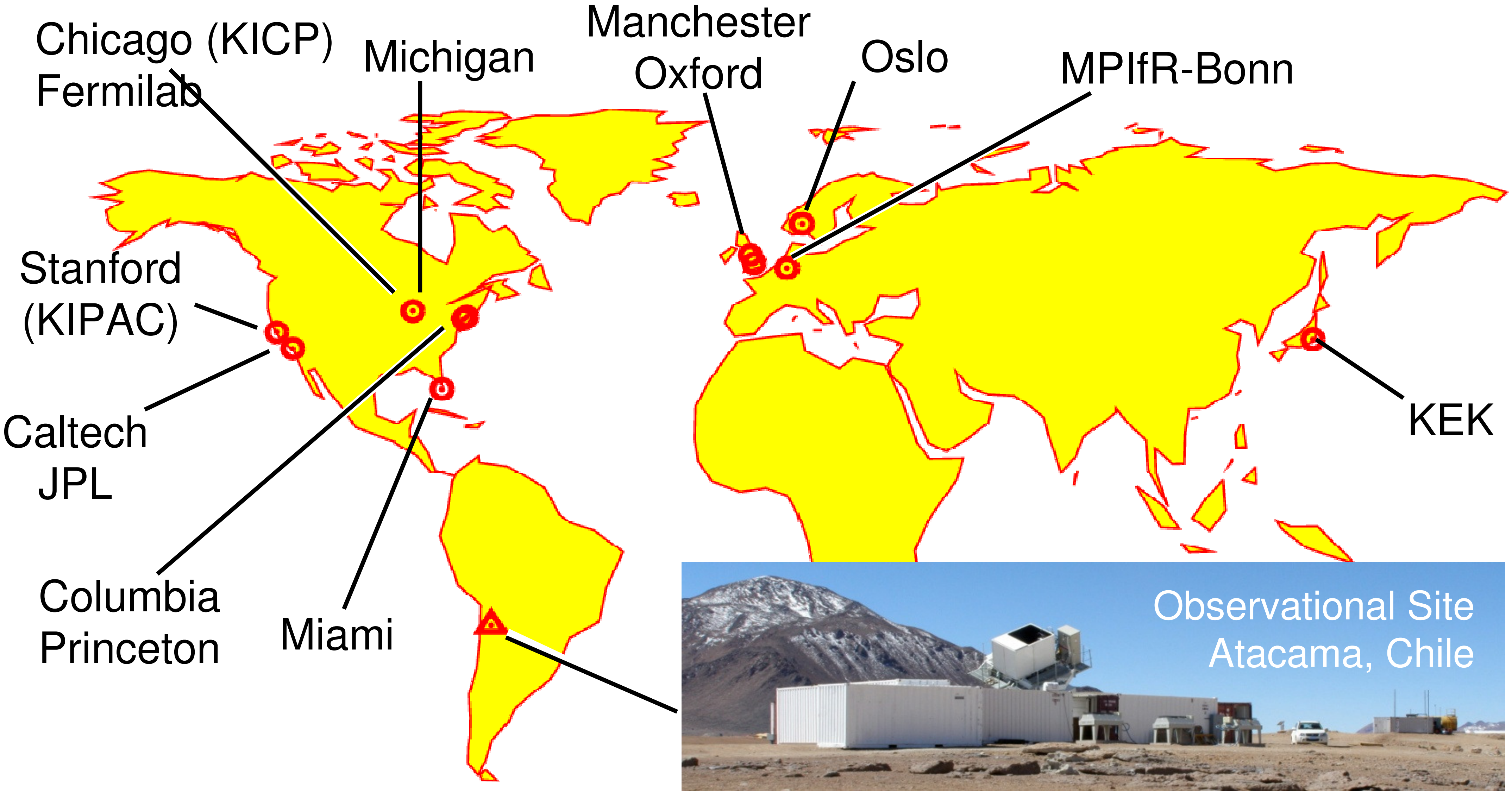
- QUIET is a ground-based B-mode experiment for measuring CMB polarisation
- Only current B-mode radiometer experiment
  - Different, and possibly better, systematics
  - Unique *radiometer on a chip* technology
  - Input to case studies for the next generation satellite
- Phase I (Pilot)
  - 19 Q-band detectors (43 GHz) Aug 08 - May 09
  - 91 W-band detectors (95 GHz) Jun 09 – Dec 10
- QUIET2 (If funded)
  - ~500 detectors in 3 bands (30, 37 and 95 GHz)
  - Measure the E- and B-mode spectra between l = 25 and 2500
  - detection of lensing at more than 20σ
  - constraining the tensor-to-scalar ratio *r* down to 0.01
- FOCUS (if funded)
  - Redeploy QUIET Q-band reciever
  - Use as foreground monitor for other experiments



QUIET collaboration



QUIET collaboration

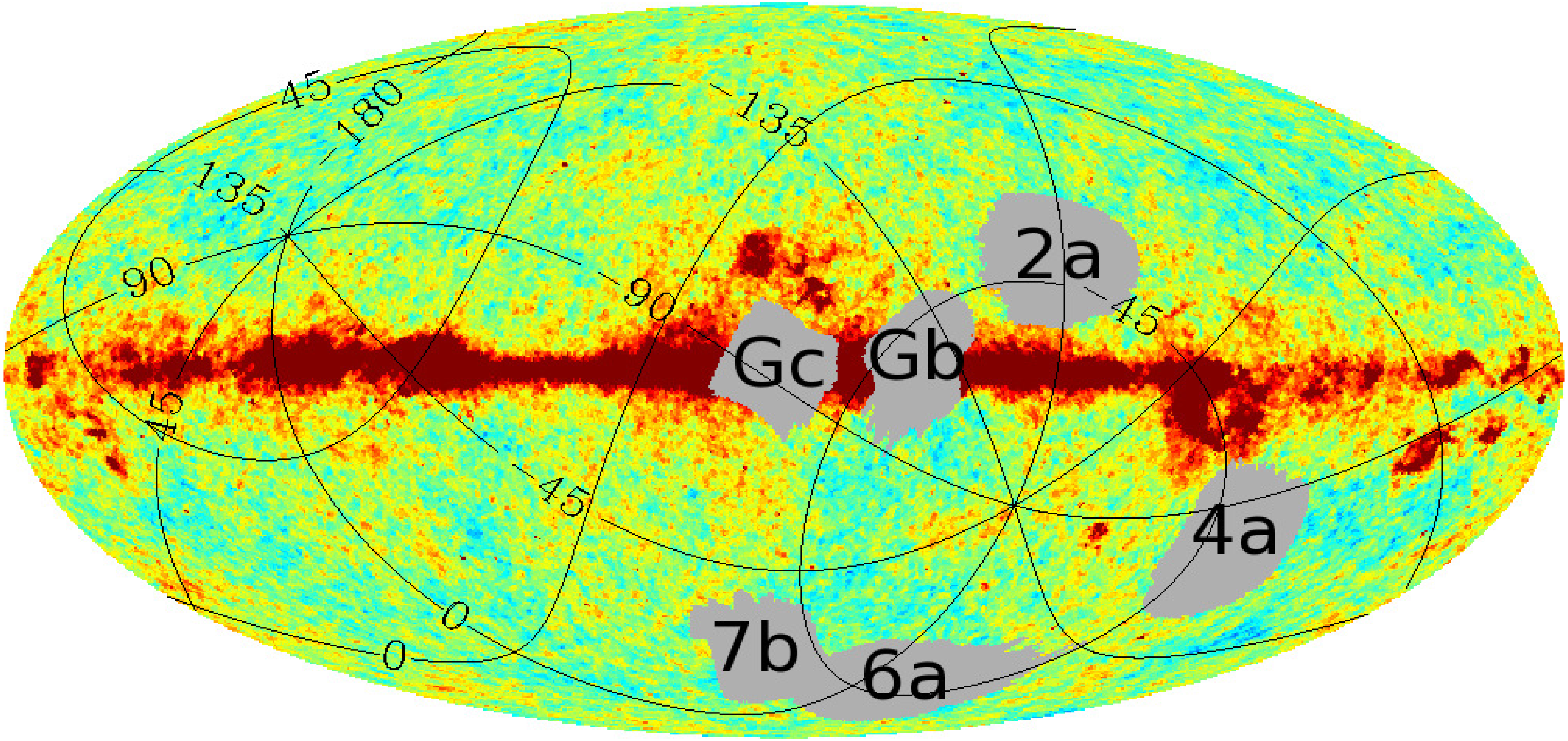


5 countries, 14 institutes, ~40 people

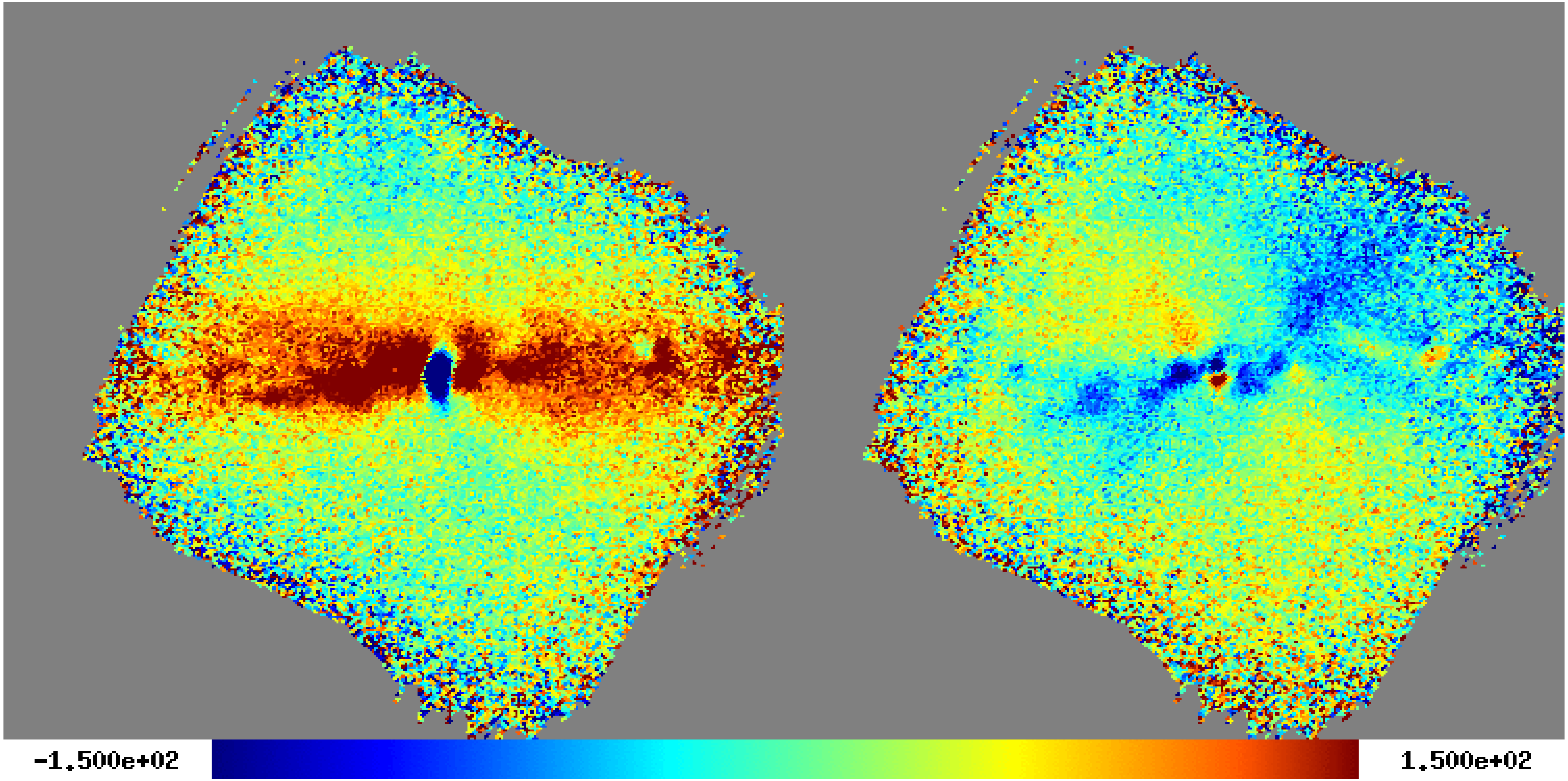
The site

- Located at 5080 m above sea level at the Chajnantor platau in the Atacama desert in Chile
- One of the driest places on earth
  - South pole has 40% lower PWV, but lower temperature results in comparable transmission
  - More of the sky is available than on south pole, and the same patch of sky can be observed from different angles. Good for systematics control
  - Accessible year round, day and night

QUIET Patches



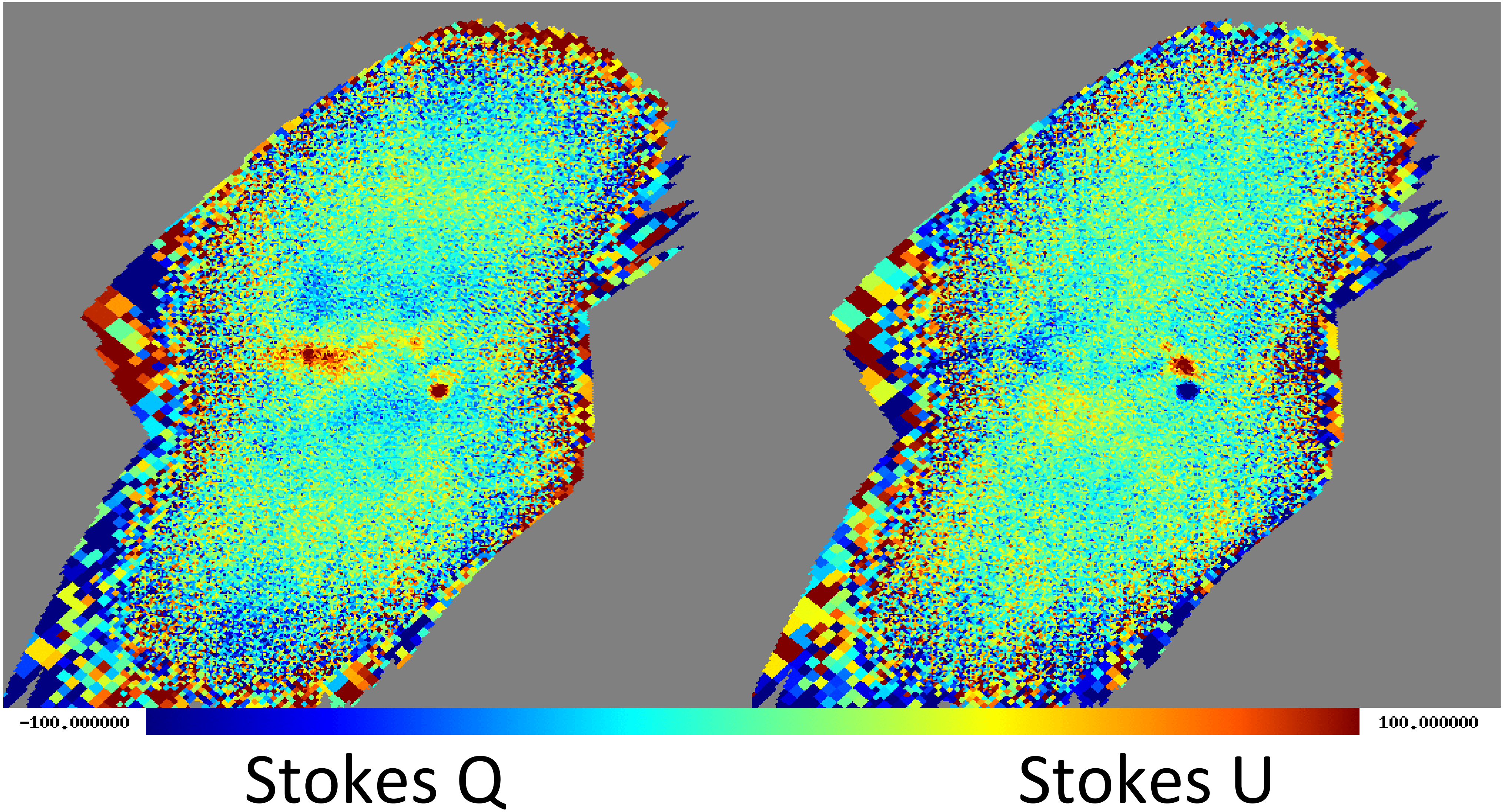
QUIET vs WMAP – galactic center



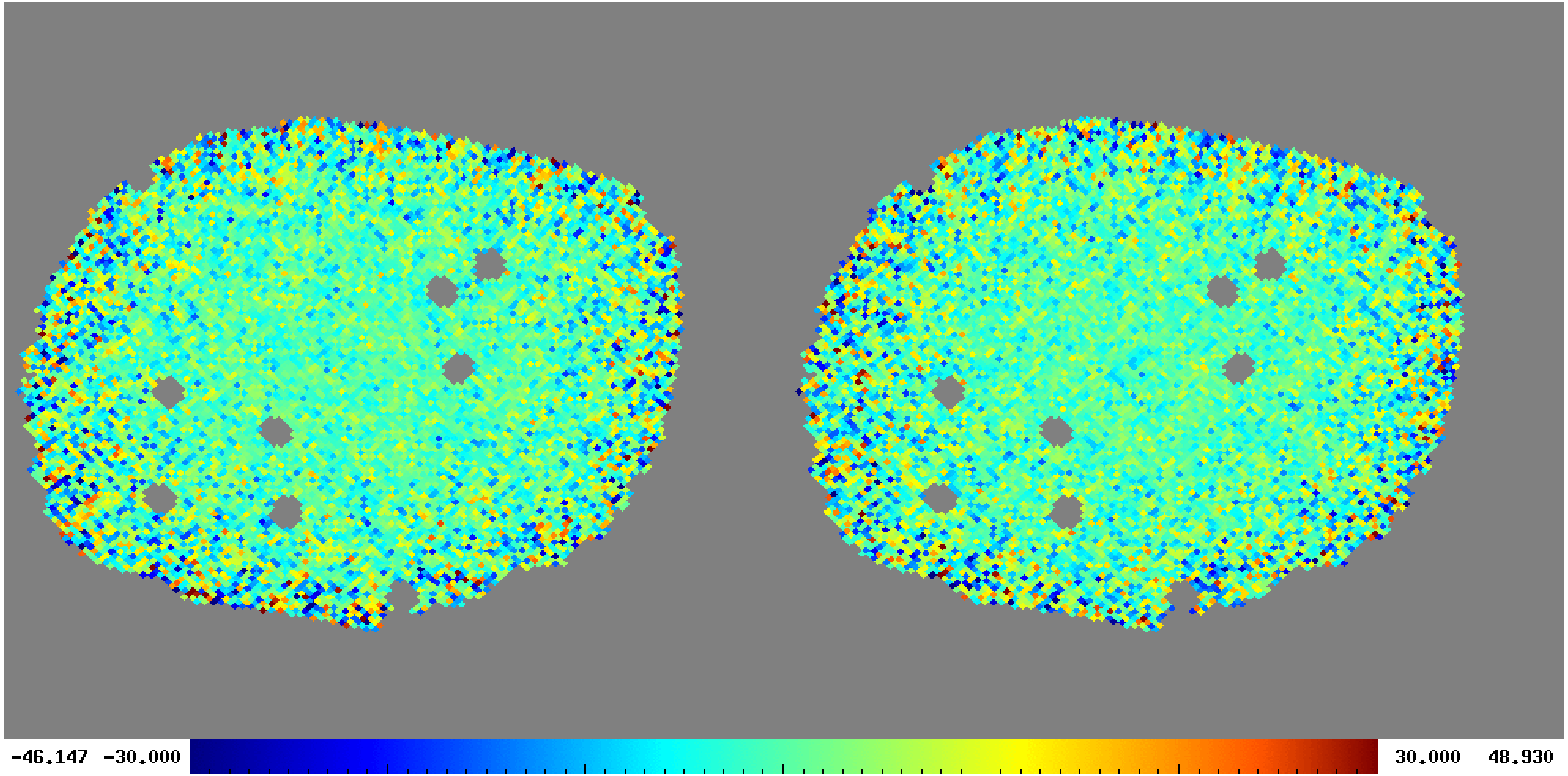
Stokes Q

Stokes U

QUIET vs WMAP – galactic plane

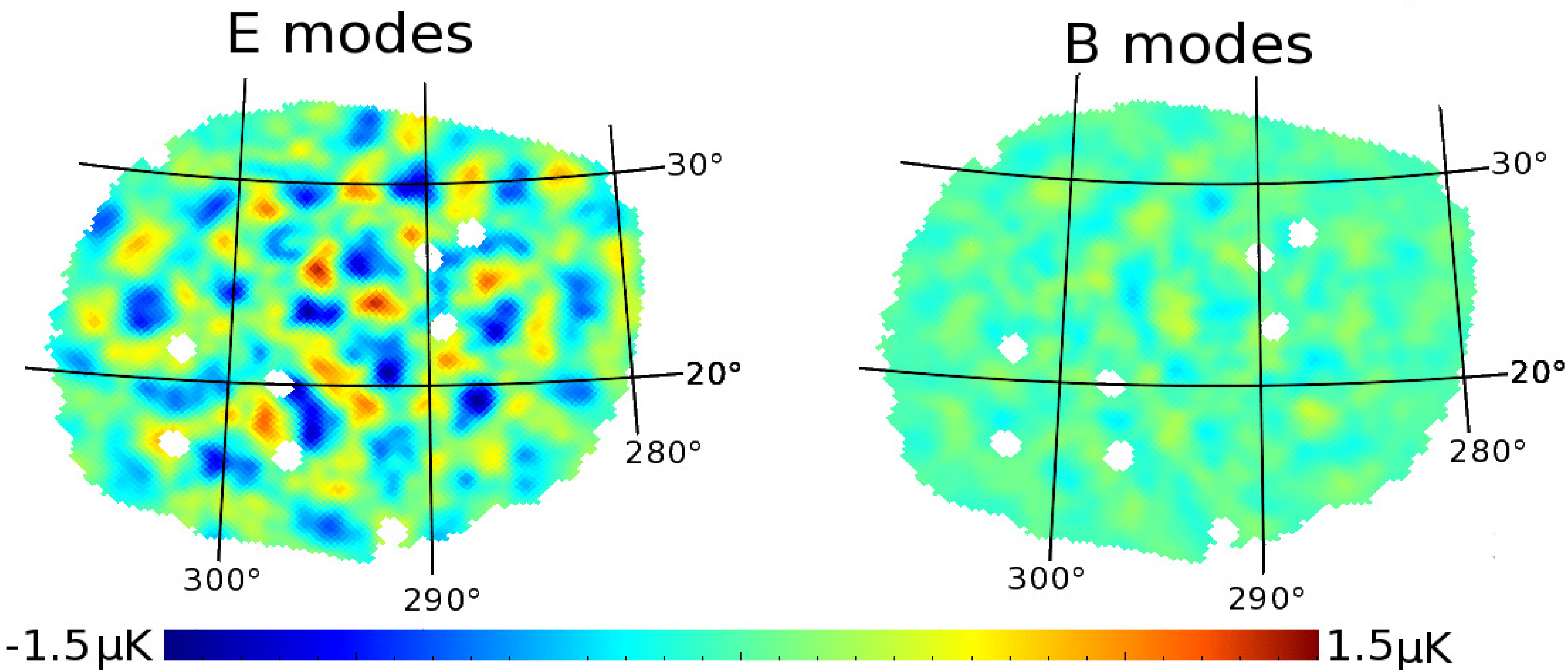


QUIET vs WMAP – CMB patch

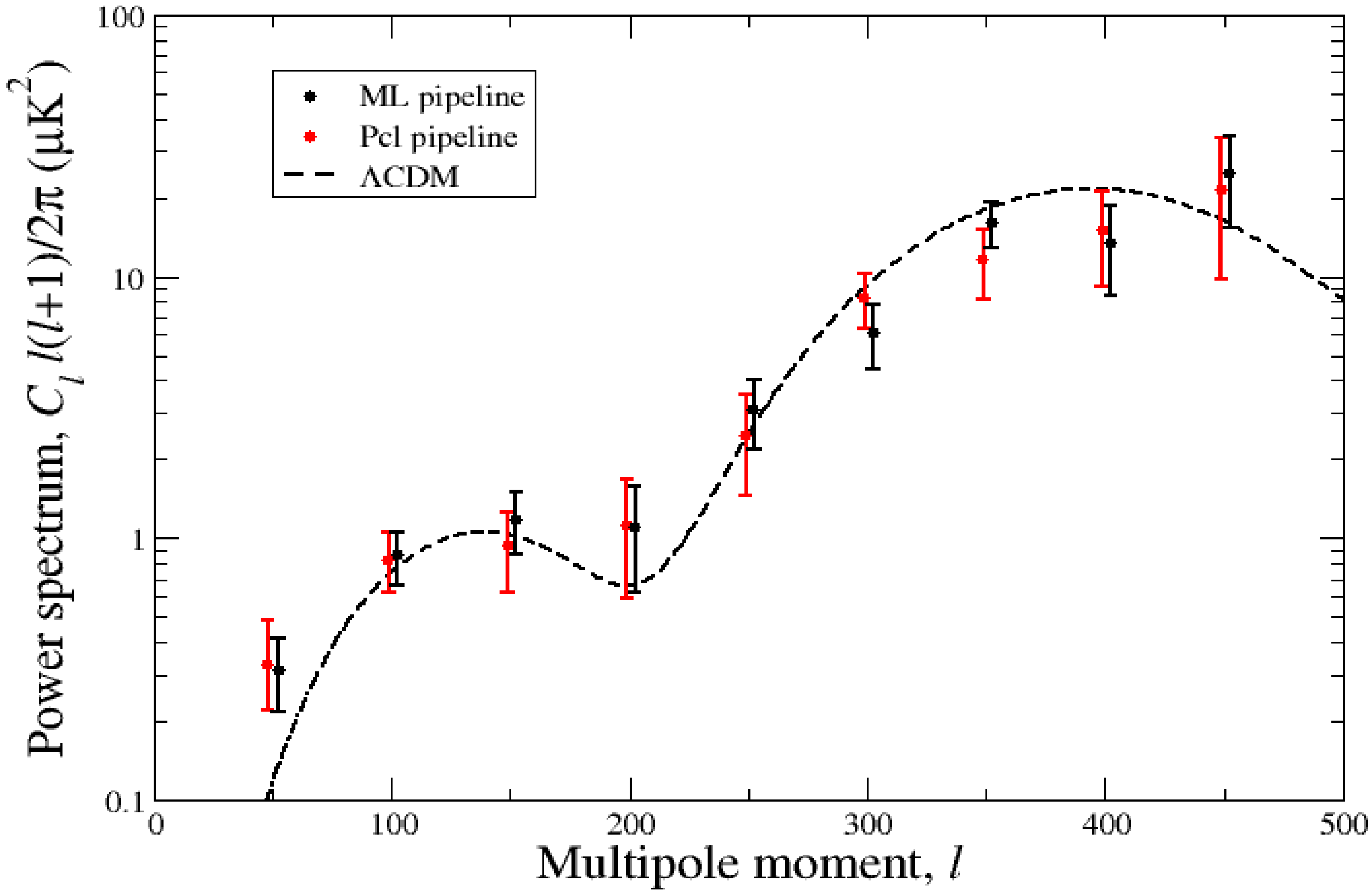


Stokes Q Stokes U

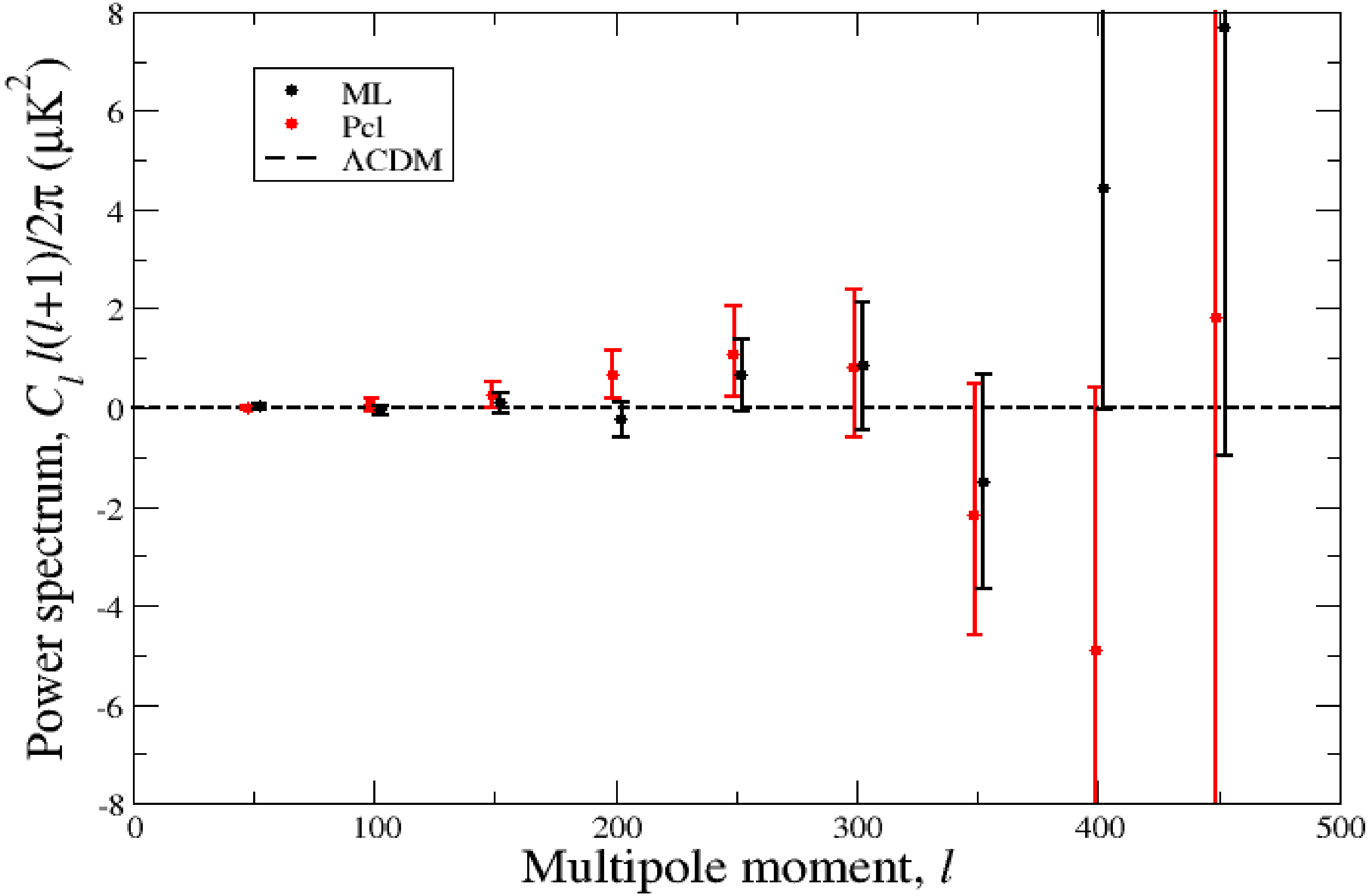
Decomposition into E and B modes



The EE power spectrum



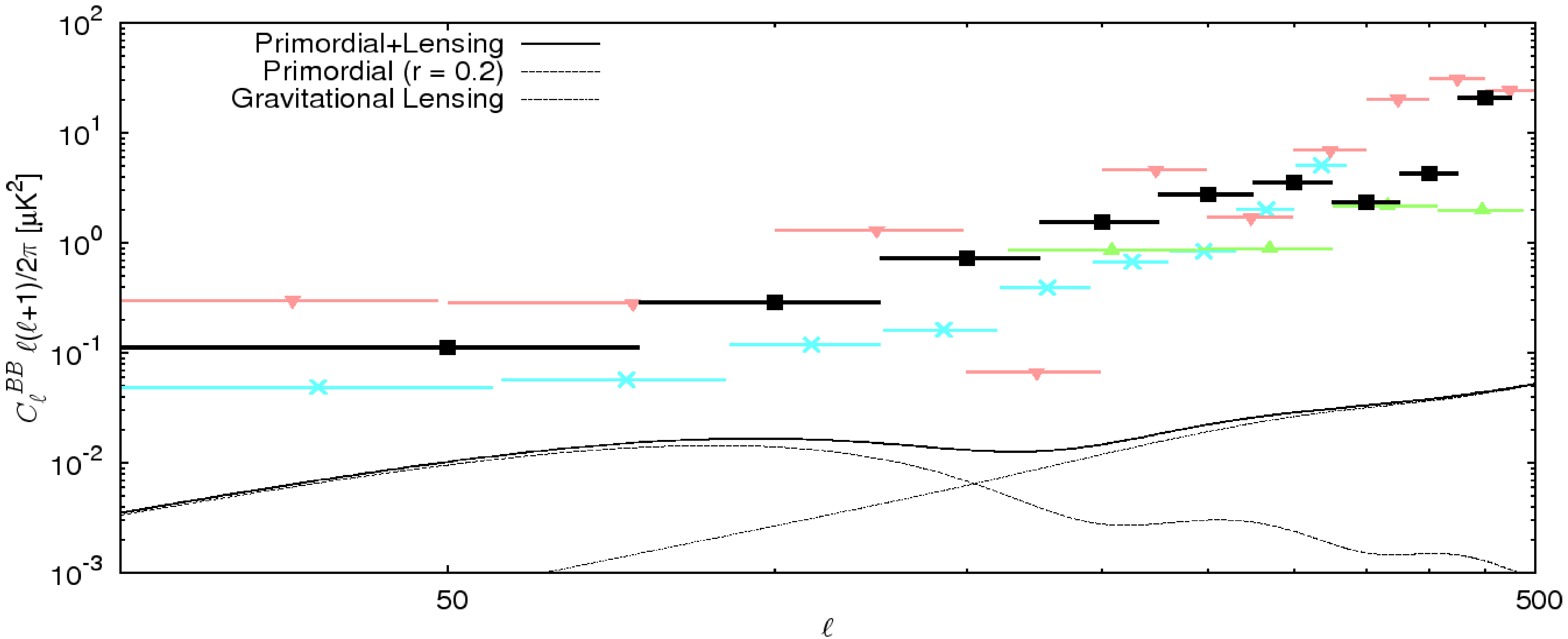
The BB power spectrum



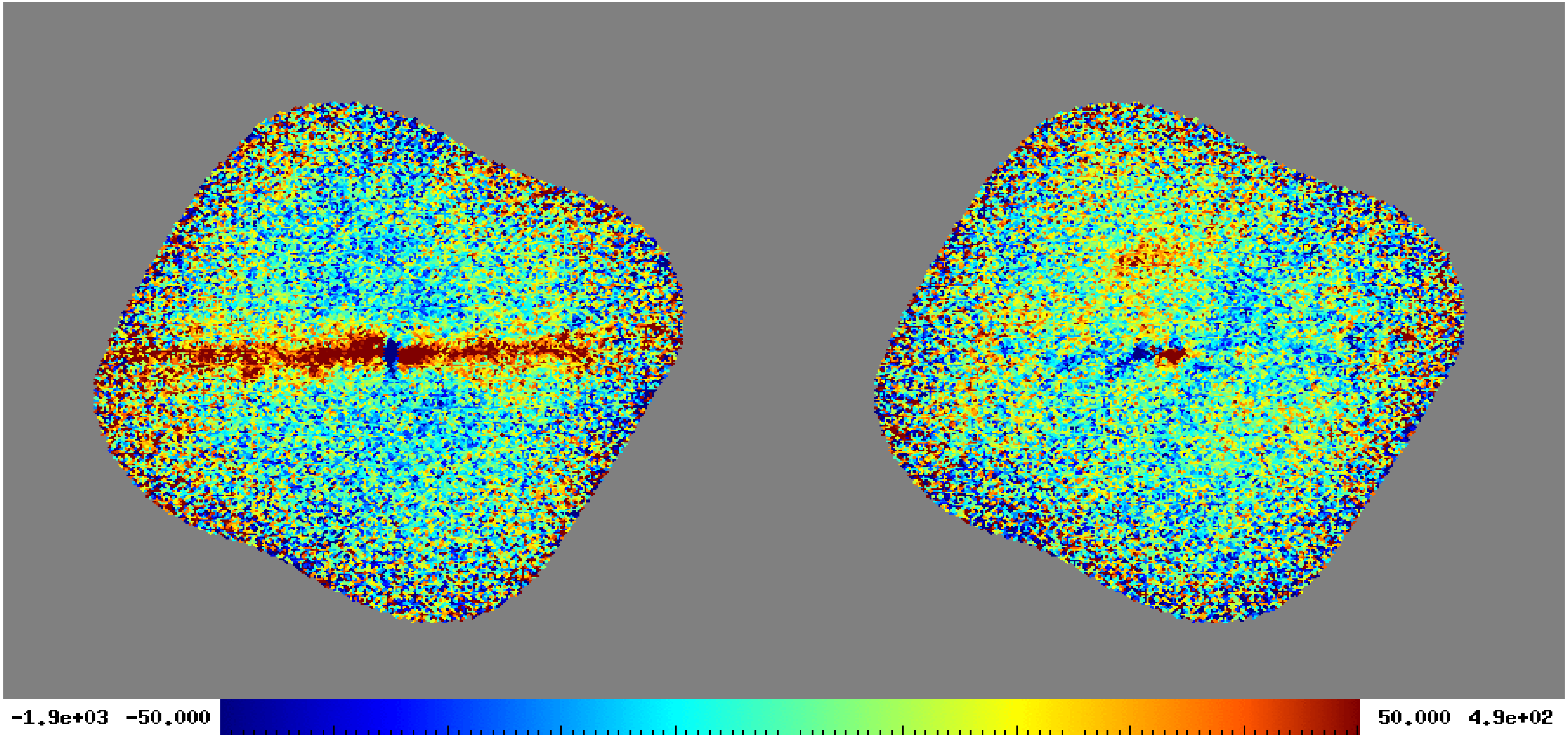
Tensor-to-scalar ratio r

- ML: r = 0.52+0.97−0.81.
- PCL: r=0.35+1.06-0.87 (r < 2.2 at 95% confidence)

(BICEP: r < 0.72 at 95% confidence)



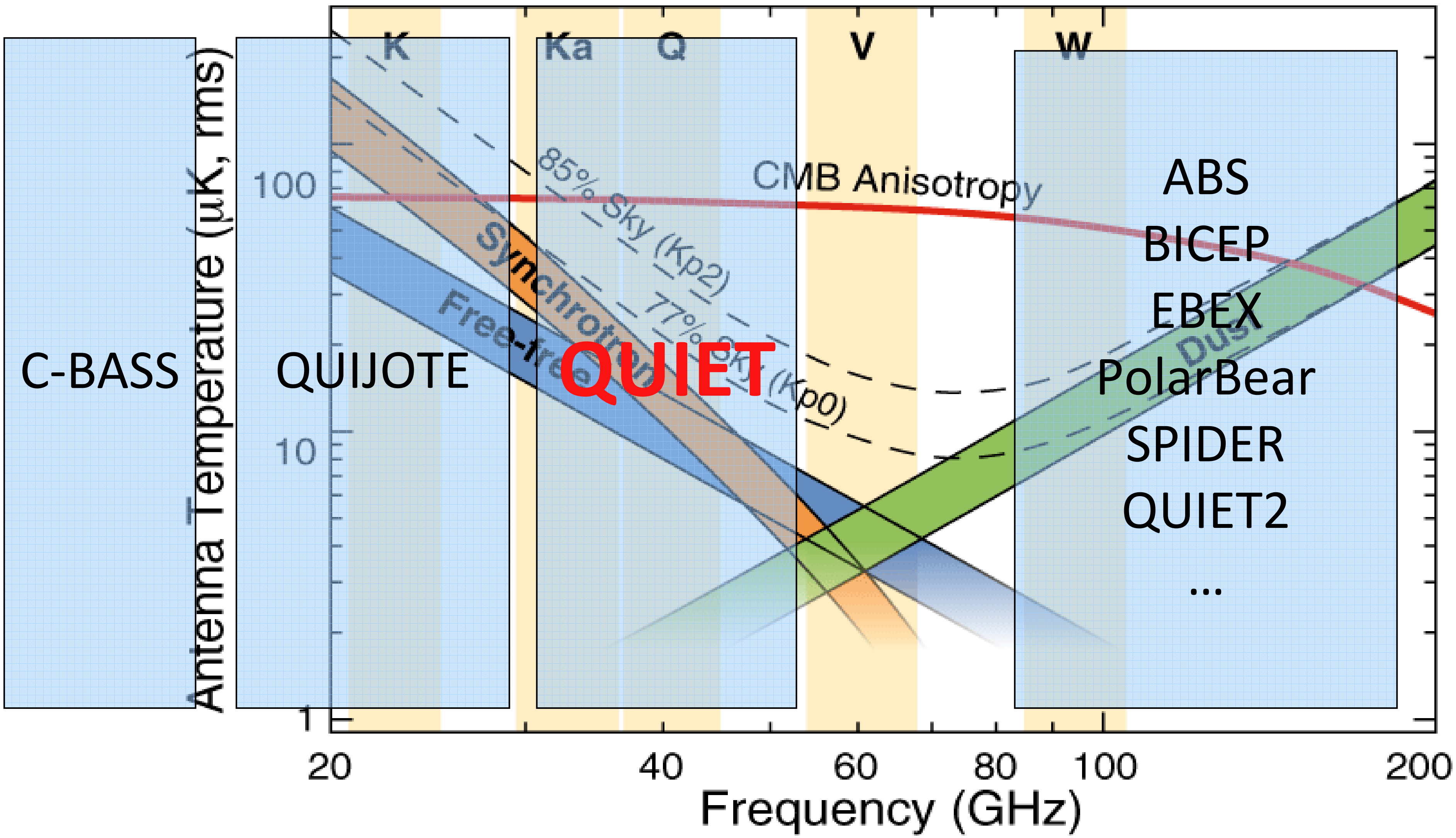
W-band galactic center



Stokes Q

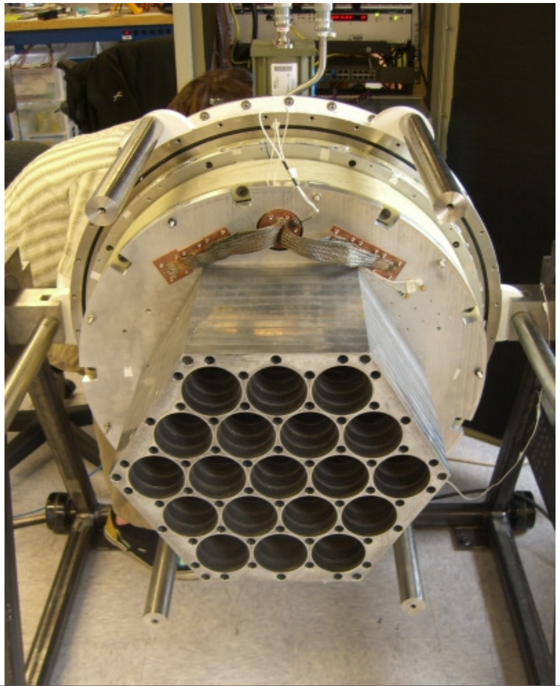
Stokes U

Another look at the frequency spectrum

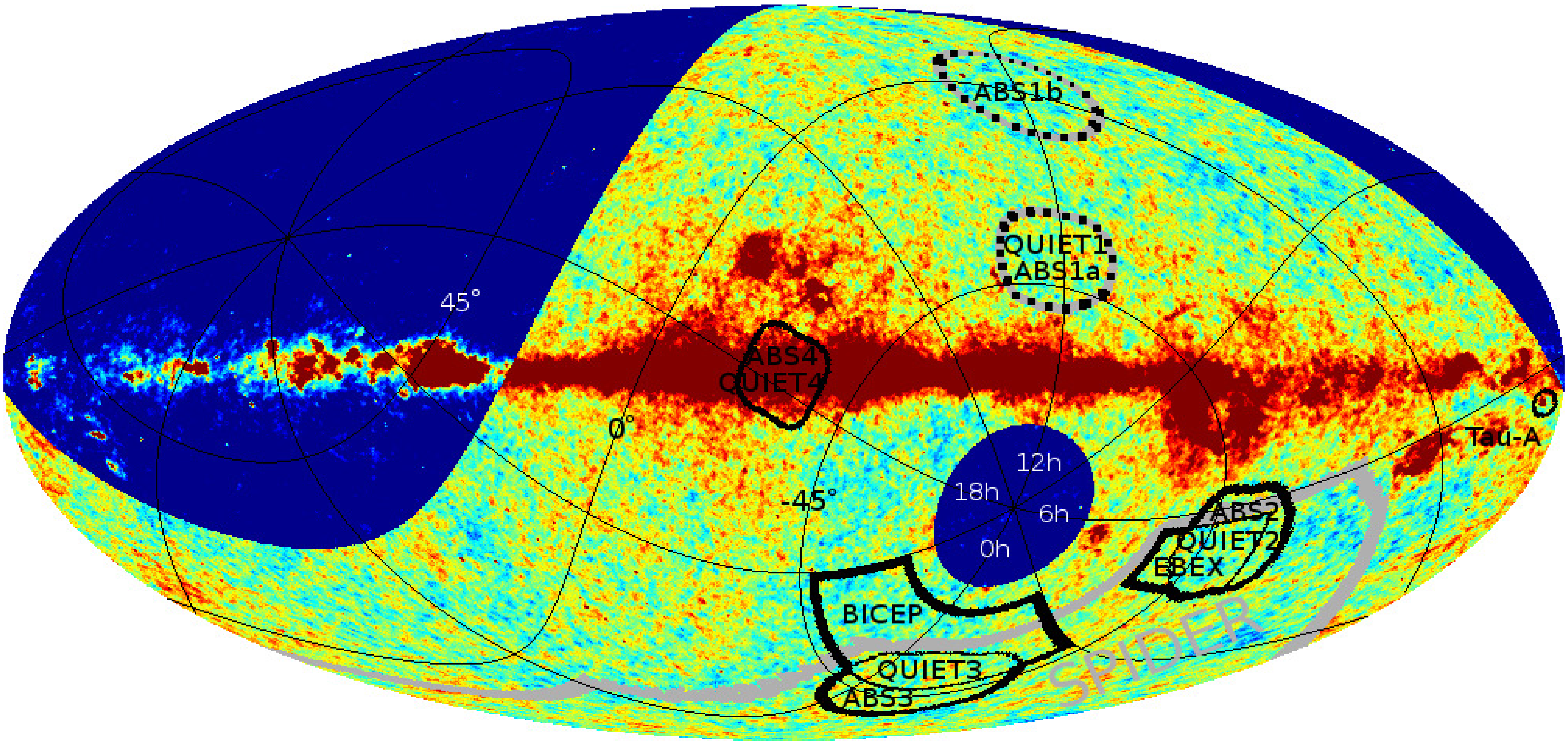


FOCUS – a fast synchrotron mapper

- **FOCUS – a dedicated foreground experiment aiming to map synchrotron for other CMB experiments**
- Redeploy QUIET Q-band reciever
  - The QUIET receiver is by far the world's most sensitive CMB instrument at Q-band
  - Current array sensitivity is 69 μK√s
- Redeploy at ACT site
  - Share infrastructure; cost efficient
- Collaboration consists of Columbia (A. Miller PI), Princeton, Oslo, Miami and Michigan
- Initially a two-year observation phase
- Will observe the same fields as ABS, BICEP/KECK, EBEX and (parts of) SPIDER
  - Explicit agreements already arranged
  - All high-frequency experiments will need to demonstrate that a possible B-mode detection is not due to synchrotron emission



FOCUS fields



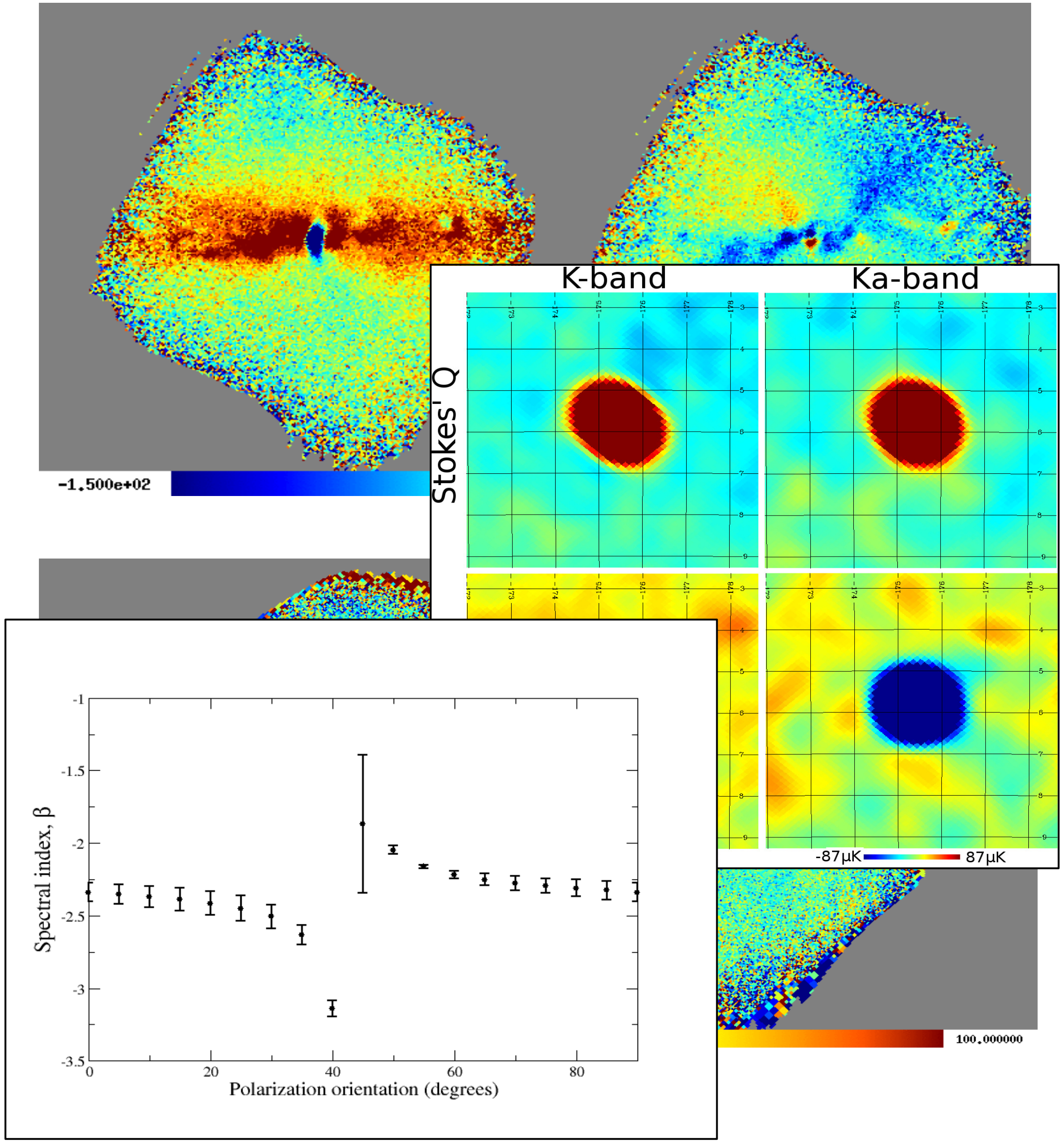
FOCUS at a glance

Frequency	43 GHz
Bandwidth	9 GHz
Module sensitivity	190-270 μK√s
Array sensitivity	55 μK√s
Beam size	27'.3
Sky coverage	2470 deg^2
Map sensitivity	0.55-1 $\mu K/deg^2$

- Map sensitivity of 0.55 $\mu K/deg^2$ at 43 GHz corresponds to a synchrotron uncertainty of 0.07 $\mu K/deg^2$ at 90 GHz and 0.02 $\mu K/deg^2$ at 150 GHz

QUIET/FOCUS as a calibrator for Planck?

- Pros:
  - High signal-to-noise
  - Low systematics
  - Large sky coverage
  - Many distinct features in the map
  - Minimal frequency extrapolation
    - QUIET 43 GHz vs. Planck 44 GHz
- Cons:
  - Scales >~ 5° not well constrained
  - Fast Planck map making code for small patches must be written
- What about the WMAP K-band?
  - Strongly asymmetric beam
  - Long frequency extrapolation
    - What is the spectral index?



THE EFFECT OF ASYMMETRIC BEAMS ON POLARIZED SPECTRAL INDICES

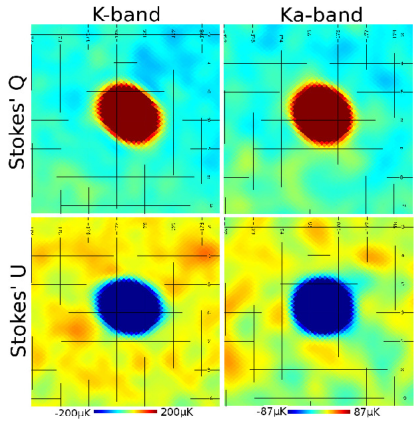
INGUNN KATHRINE WEHUS (OXFORD), UNNI FUSKELAND (OSLO) AND HANS KRISTIAN ERIKSEN (OSLO)

PROBLEM

Estimation of foreground spectral indices with multifrequency CMB data often requires that all maps have a common angular resolution. In such analyses, the data are therefore smoothed to a common resolution. For the WMAP data, the most typical resolution is 1° FWHM, which is slightly larger than the angular resolution of the WMAP K-band (23 GHz) channel. However, asymmetric beams may affect the derived indices even after such smoothing.

We quantify this effect directly by analyzing the strongest polarized point source in the WMAP data, Tau A, and measure its spectral index as a function of polarization orientation (e.g., Stokes' Q vs U, and all linear combinations between them).

VISUAL INSPECTION OF TAU A



First, we simply plot a zoom-in of Tau A in both K- and Ka-band in the two Stokes' parameters after smoothing to 1° FWHM. The coordinate system is rotated by 22.5° relative to the intrinsic polarization direction of Tau A, to maximize signal-to-noise in both components. Note:

1. All four images show evidence of a strongly asymmetric beam.
2. The structures are different between K- and Ka-band, and between Q and U.

ESTIMATING SPECTRAL INDICES

We assume that the data follow a power-law, ν^β, in antenna temperature units. Given observations at two different frequencies, ν_1 and ν_2, the spectral index may then be found as

$$\beta = \frac{\log[d_{\nu_1}(p)/d_{\nu_2}(p)]}{\log[\nu_1/\nu_2]}$$

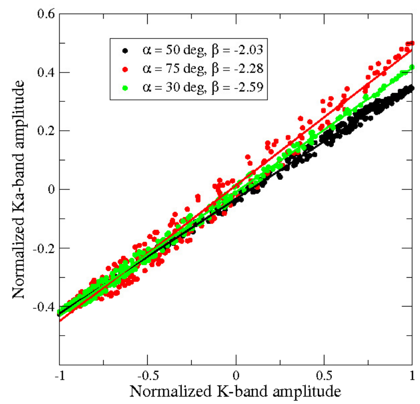
Taking into account noise and possible constant offsets in either frequency, it is in practice more robust to fit a straight line, $y = ax + b$, to d_1 as a function of d_2, and let $\beta = \log a/\log(\nu_1/\nu_2)$.

We estimate β as a function of rotation angle, α, using data on the form

$$Q'(\alpha) = Q\cos 2\alpha + U \sin 2\alpha;$$

since Tau A is a point source with known constant polarization angle, this function should be independent of α.

The figure below shows the resulting TT plots for three different values of α for Tau A: Note that the best-fit slopes are visibly different for all three cases.



THE FULL PAPER

The full paper is available on the preprint archive, http://arxiv.org/pdf/1201.6348v1

MEASURED PROPERTIES OF TAU A

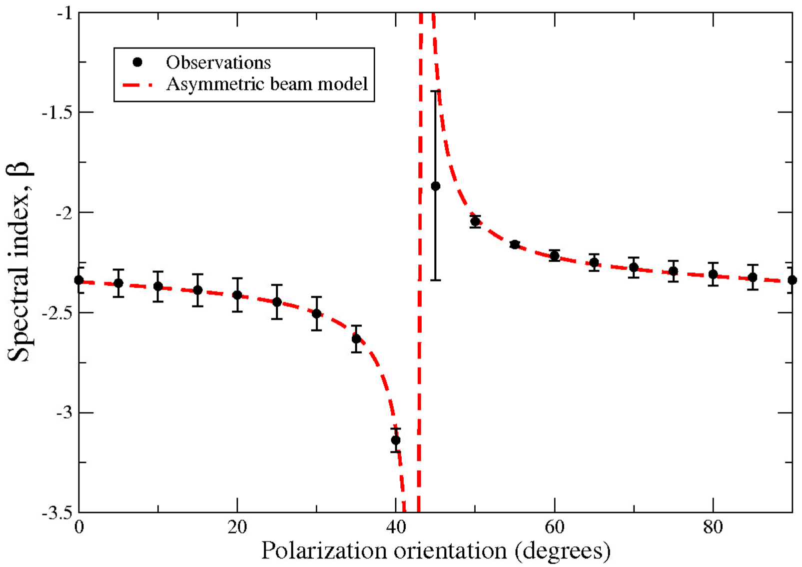
In addition to β, we also measure the apparent morphology (FWHM, ellipticity and orientation) and polarization properties of Tau A. We use these values to construct a model for the observations, defined by an elliptical Gaussian in the two frequency channels.

Property	K-band	Ka-band
FWHM (degrees)	0.985 ± 0.001	0.992 ± 0.001
Ellipticity	0.142 ± 0.001	0.079 ± 0.001
Orientation (degrees)	54.0 ± 0.3	57.8 ± 1.5
Polarization fraction	6.17 ± 0.01	6.48 ± 0.04
Polarization orientation	88.43 ± 0.03	87.6 ± 0.1

THE SPECTRAL INDEX OF TAU A AS OBSERVED BY WMAP

Black points: Spectral index of Tau A as a function of rotation angle, α, with 3σ uncertainties.

Red line: Spectral index from a perfect noiseless simulation with the same asymmetric beam properties as Tau A.



CONCLUSIONS

Using Tau A as a high signal-to-noise showcase, we have demonstrated that intrinsic beam asymmetries in the low-frequency WMAP channels leads to significant errors in the derived foreground spectral index at 1° angular scales. For Tau A the errors are as large as $\Delta\beta \sim 1$. Similar results have been found for three other bright polarized sources (Virgo A, 3C273 and Fornax A). Given the physical origin of the effect, it should also apply to diffuse foregrounds.

Therefore, when using the WMAP data for foreground studies, one should either consider only scales significantly larger than 1°, or take into account the full asymmetric beam structure.

We believe that this test should prove useful as a systematic diagnostic for Planck and other experiments as well. For further details of the analysis, we refer the interested reader to Wehus, Fuskeland & Eriksen (2012).

Summary

- CMB polarisation is a future main source of cosmological data
  - Detecting primordial gravitational waves will teach us about inflation
- QUIET is among the most sensitive CMB B-mode experiments in the world:
  - Unique radiometer technology
  - Q-band receiver is world leading in published array sensitivity at 69 uK sqrt(s)
  - Excellent location
- Q-band results show that everything is working
  - Power spectra consistent with LCDM
  - Current constraint on tensor-to-scalar ratio is $r = 0.35 \pm 1.0$
- W-band results being finalized now
  - Papers on instrumentation, analysis, galactic foregrounds and point sources to come
- FOCUS will play a critical role as a foreground monitor for high-frequency experiments
  - ABS, EBEX, BICEP/KECK and SPIDER
- QUIET/FOCUS data may potentially be useful for Planck polarization calibration
  - Very high signal to noise and low systematics