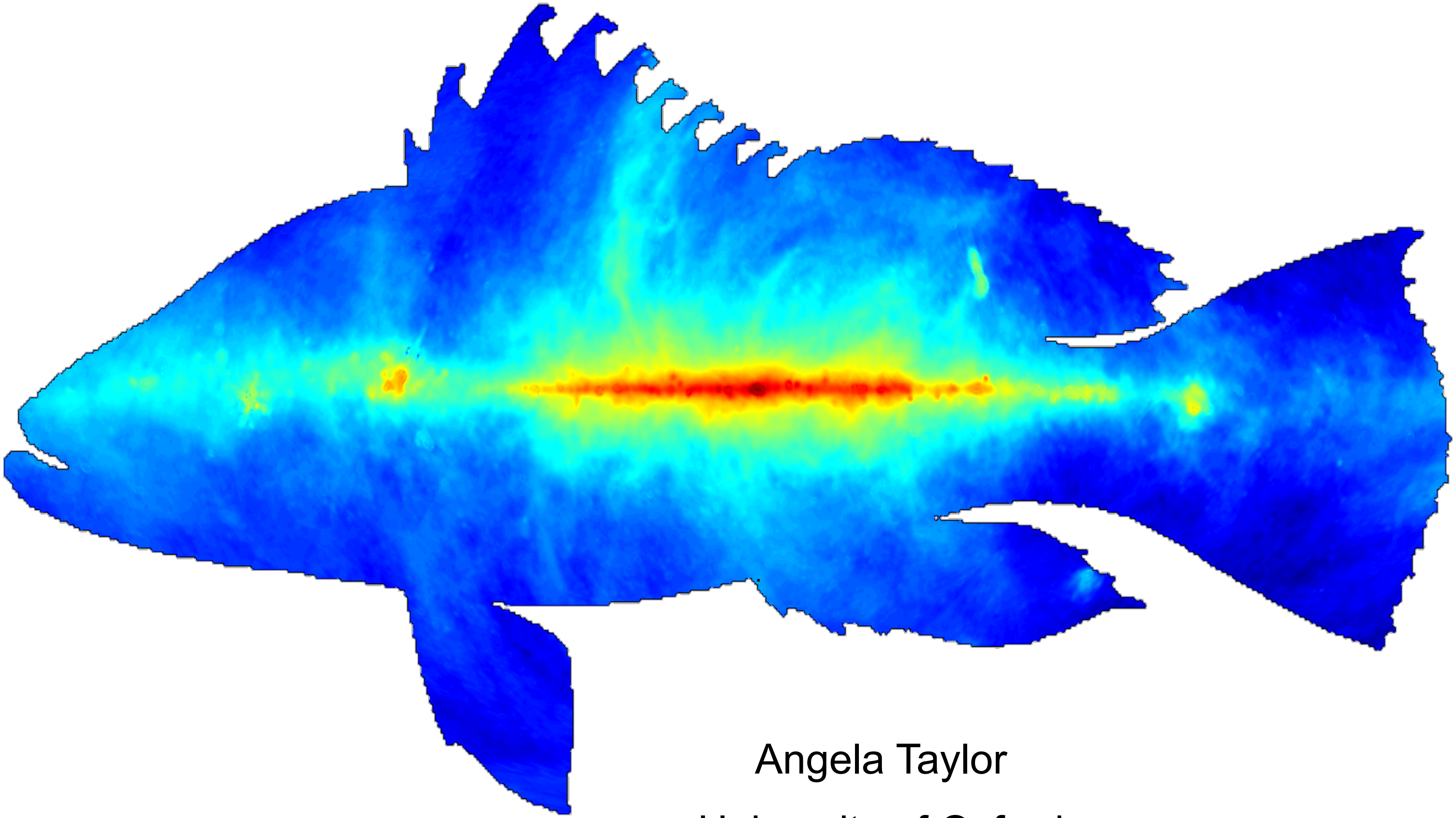
C-Band All-Sky Survey (C-BASS)



Angela Taylor

University of Oxford

4th ASI/COSMOS Workshop: Ground-based CMB experiments, Milan, March 2019.

The C-Band All-Sky Survey

University of Oxford, UK

Angela Taylor, Mike Jones, Jamie Leech, Luke Jew, Richard Grumitt, Jaz Hill-Valler, Alex Pollak, Christian Holler (Hochschule München, Germany)

University of Manchester, UK

Clive Dickinson, Paddy Leahy, Adam Barr, Stuart Harper, Roke Cepeda-Arroita, Mike Peel

Caltech, USA

Tim Pearson, Tony Readhead

South Africa

Justin Jonas (Rhodes/SKASA), Heiko Heligendorff, Moumita Aitch (UKZN), Cynthia Chiang, Jon Sievers (UKZN & McGill,Canada)

KACST, Saudi Arabia

Yasser Hafez

Moved on…

Oliver King, Matthew Stevenson, Mel Irfan, Stephen Muchovej, Joe Zuntz, Charles Copley

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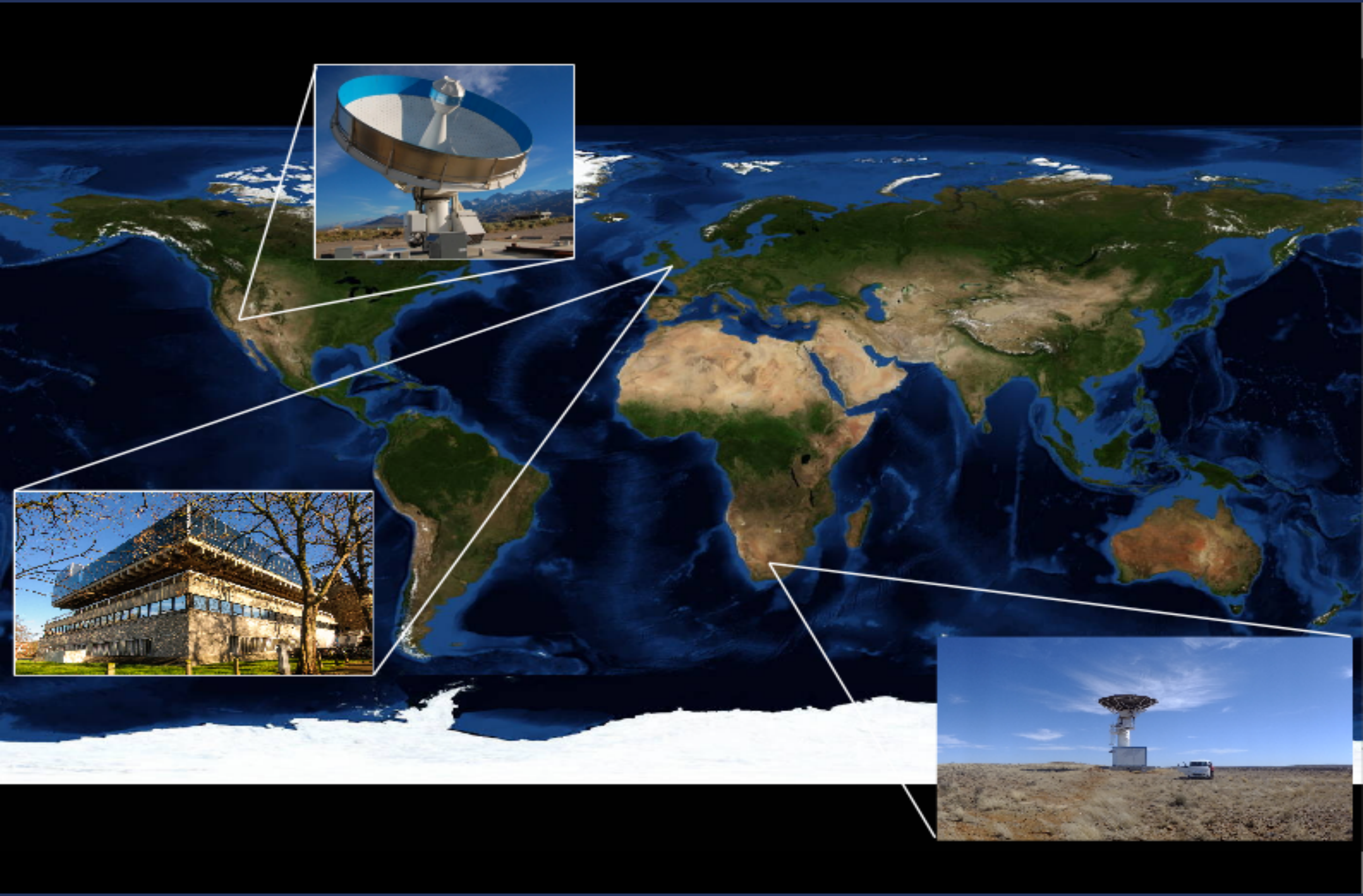
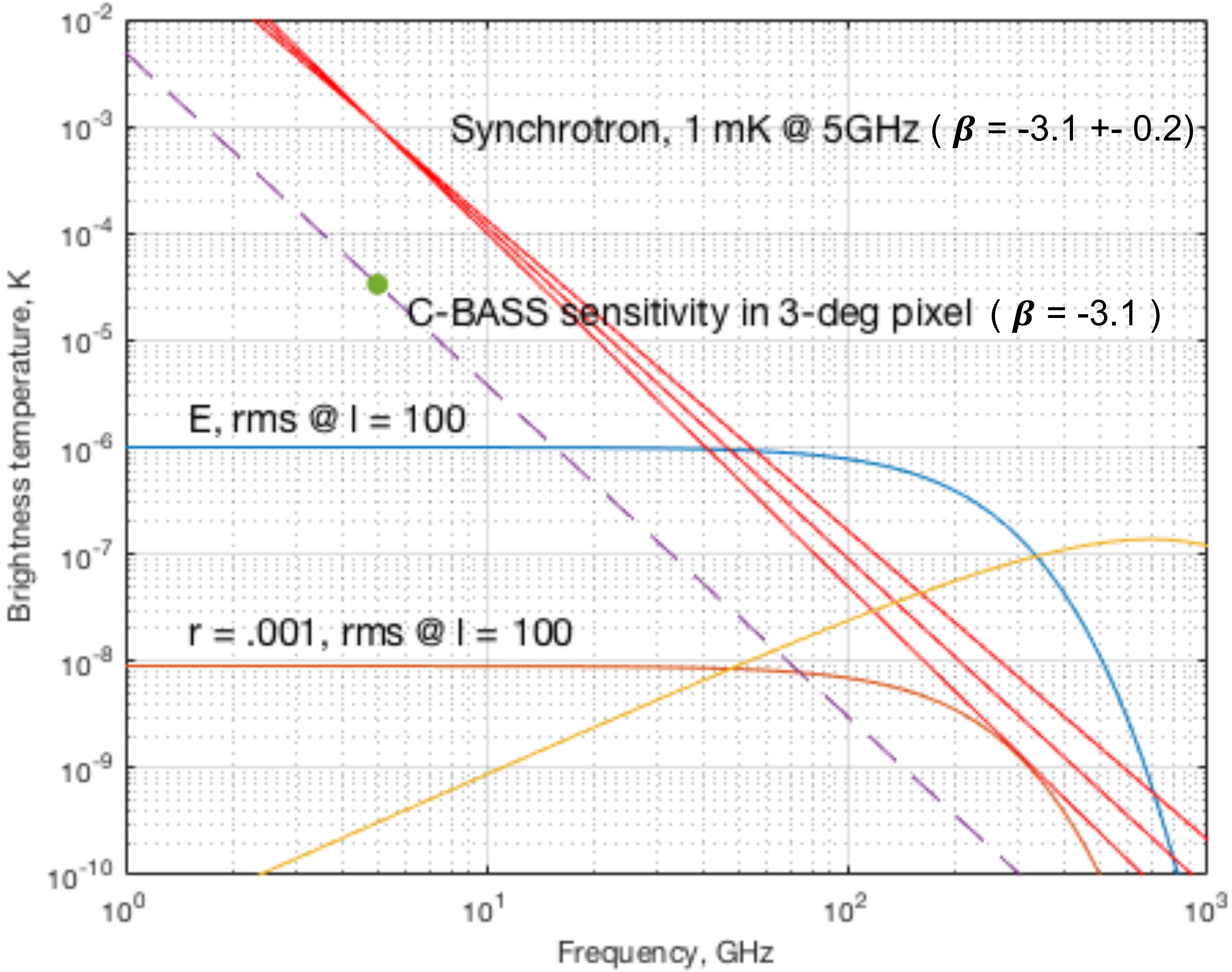
The C-BASS Survey



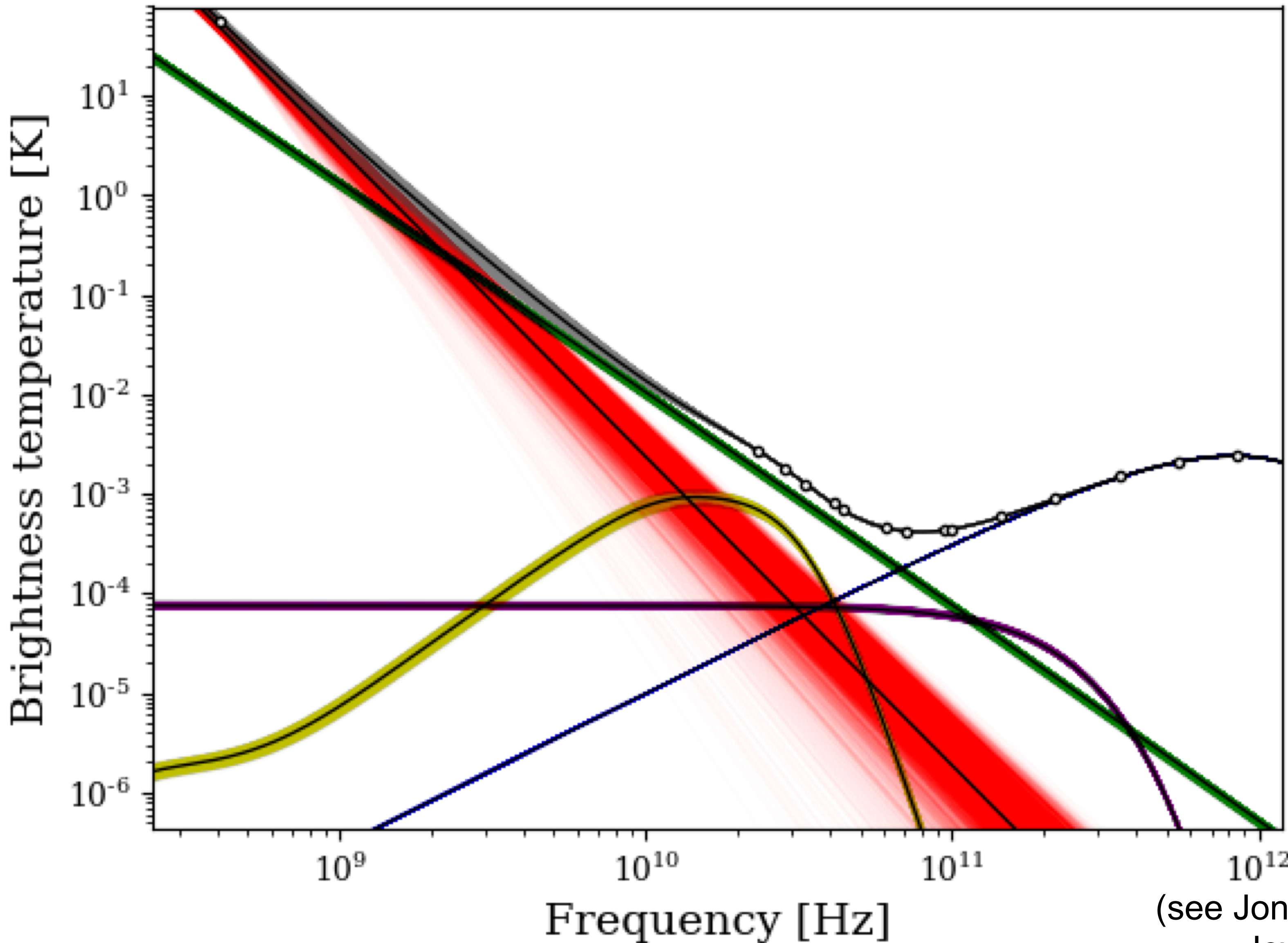
C-BASS - Overview

Sky-coverage	All-sky
Angular resolution	0.75 deg (45 arcmin)
Sensitivity	< 0.1mK r.m.s in 1 deg beam (confusion limited in I) 6000 μK-arcmin @ 5GHz == 0.75 μK-arcmin @ 100 GHz, β = -3
Stokes coverage	I, Q, U, (V)
Frequency 	1 (0.5) GHz bandwidth, centered at 5 GHz
Northern site 	OVRO, California Latitude, 37.2 deg
Southern site	MeerKAT/SKA site, Karoo, South Africa Latitude -30.7 deg

CBASS polarization sensitivity



CBASS simulations - *I*

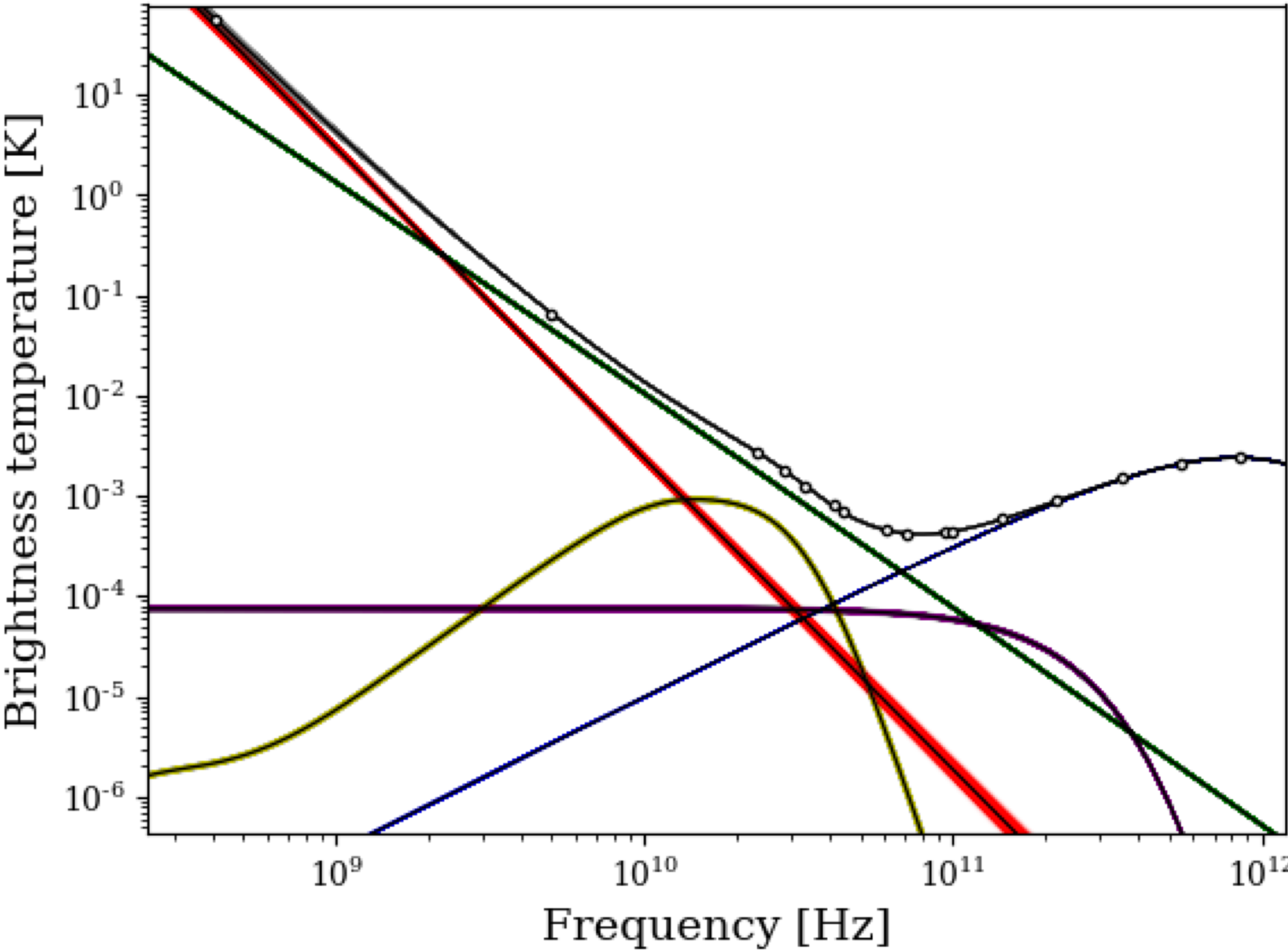


Haslam
WMAP
Planck

High-foregrounds pixel (1-deg)

(see Jones et al. 2018
Jew et al. in prep)

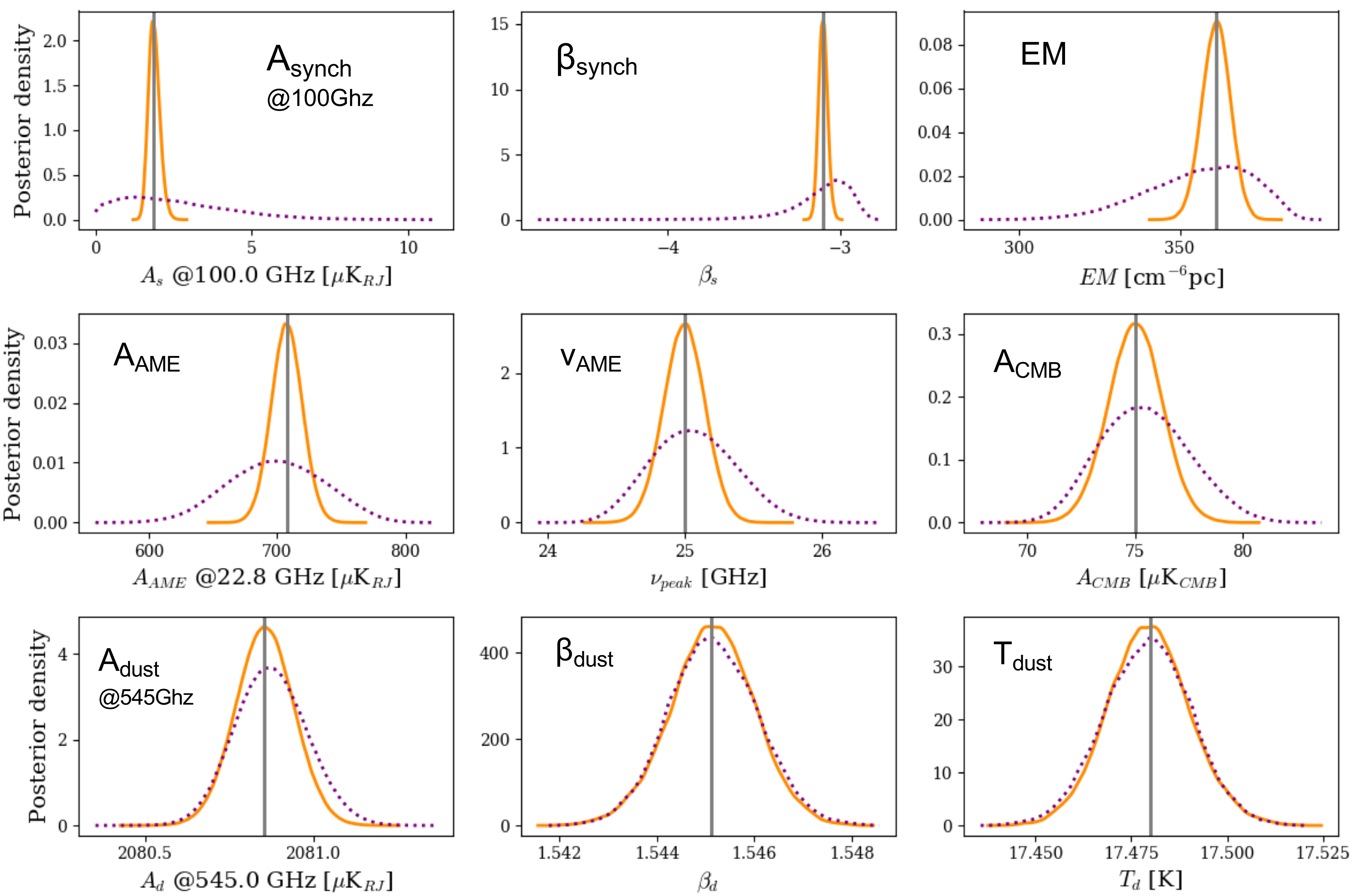
CBASS simulations - *I*



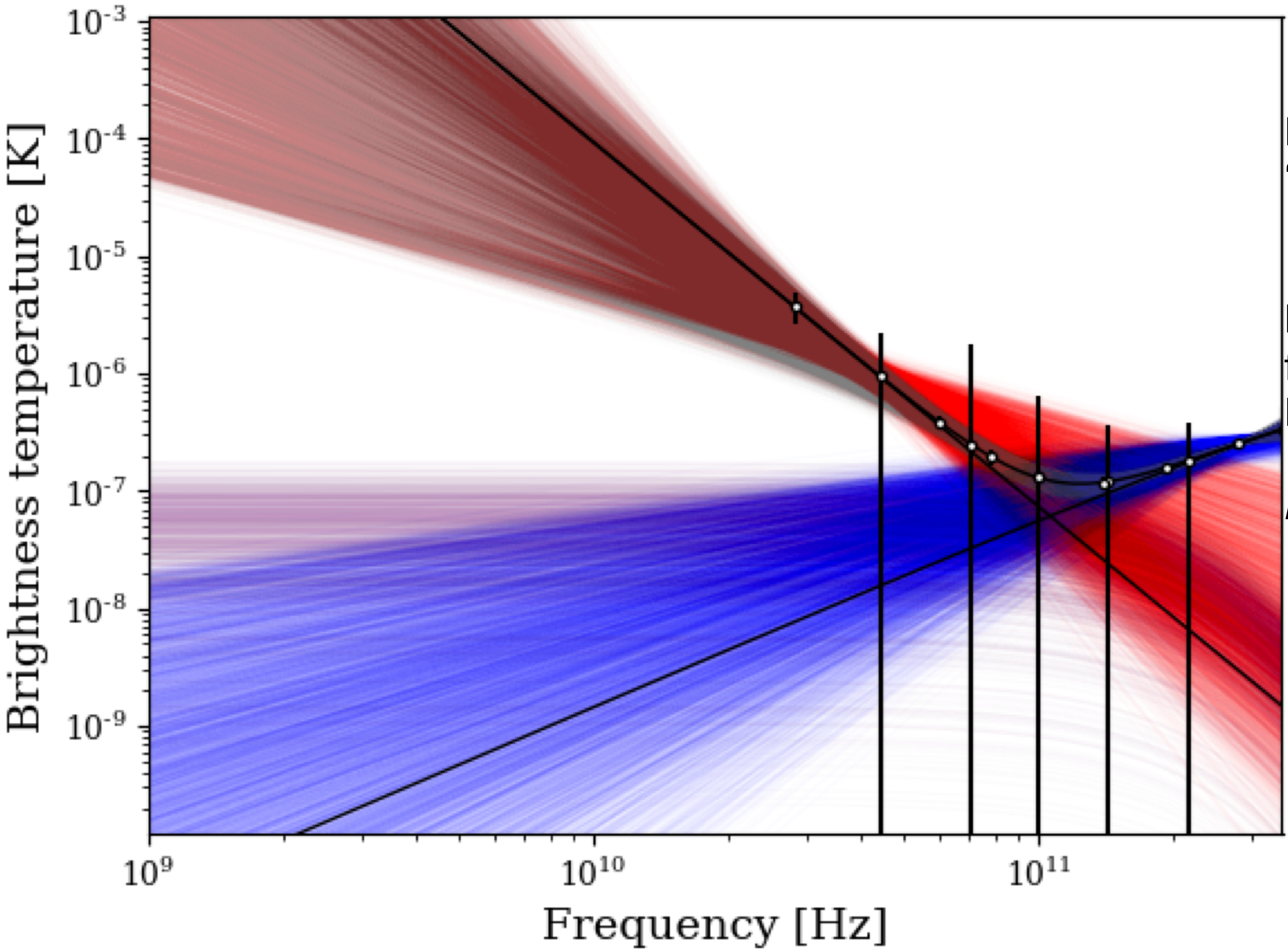
Haslam
WMAP
Planck
+ CBASS

High-foregrounds pixel (1-deg)

CBASS simulations - I



CBASS simulations - *P*

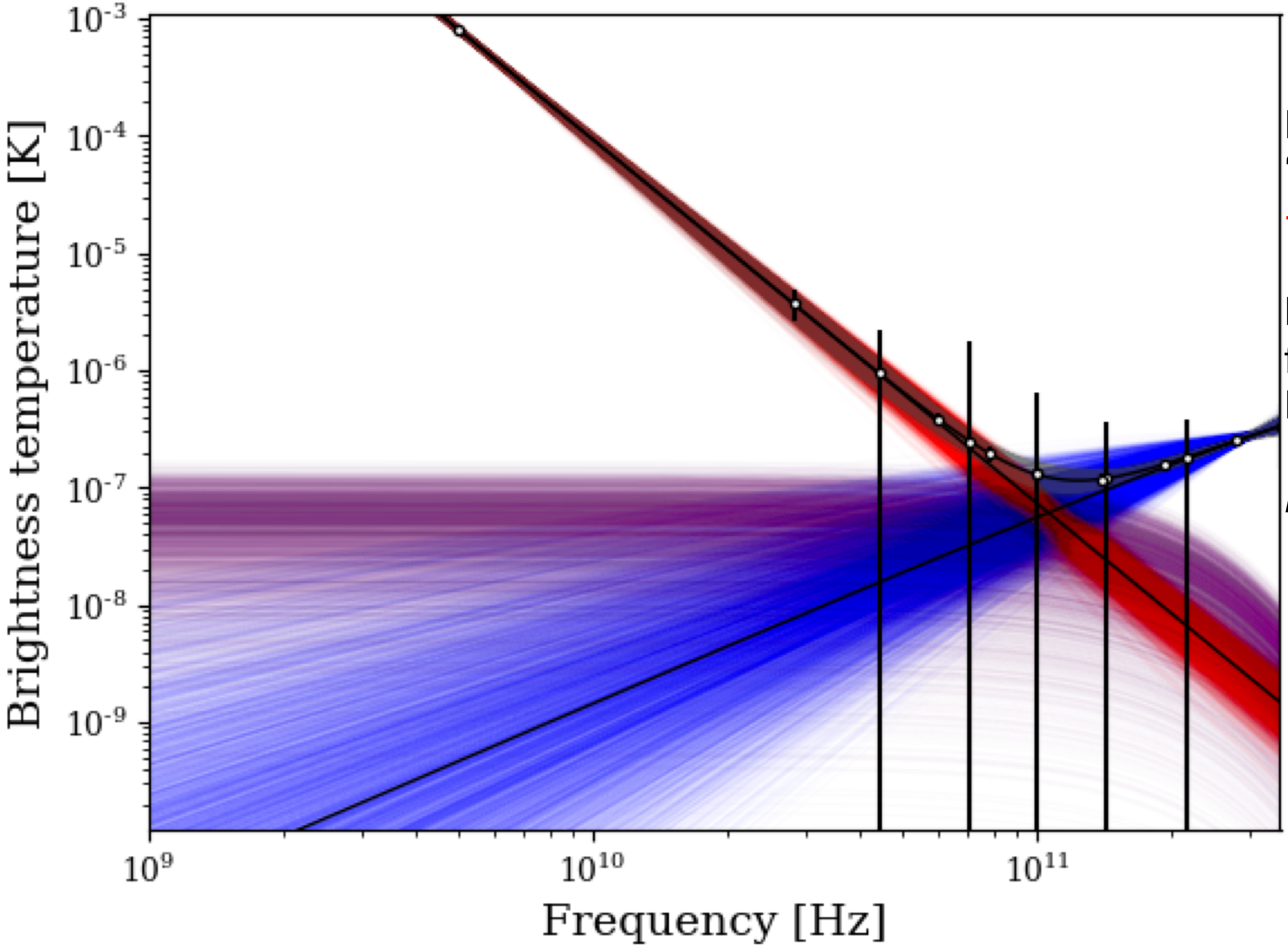


Planck
'LiteBIRD'

Low-foregrounds Pixel (3-deg)

r = 0

CBASS simulations - *P*

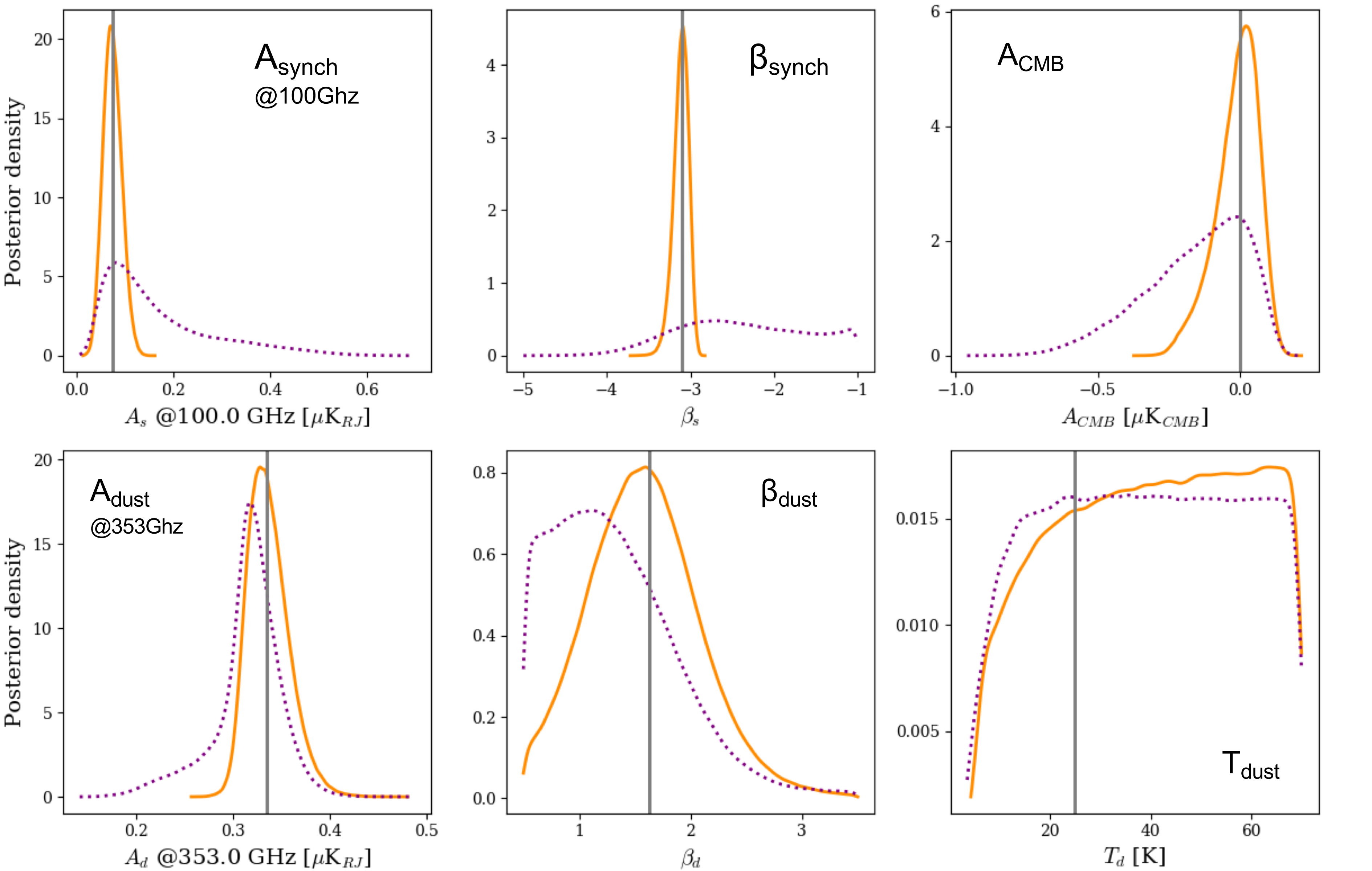


Planck
'LiteBIRD'
+CBASS

Low-foregrounds Pixel (3-deg)

r = 0

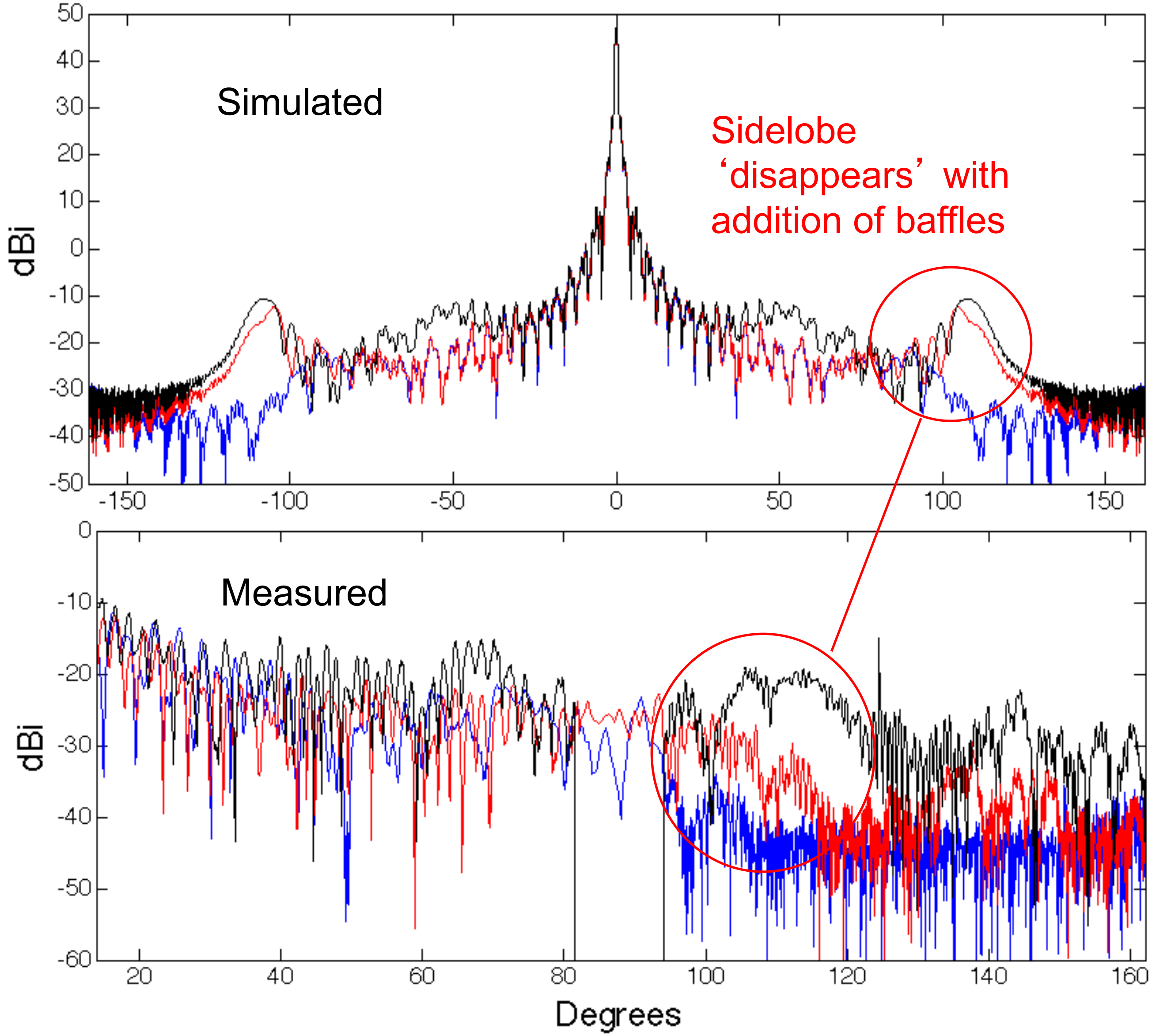
CBASS simulations - *P*



C-BASS North Telescope

- 6.1-m dish, with Gregorian optics
- Secondary supported on foam cone
- Receiver sat forward of the dish
- Very clean, circularly-symmetric optics
- Absorbing baffles to minimize spillover

C-BASS North: beam measurements

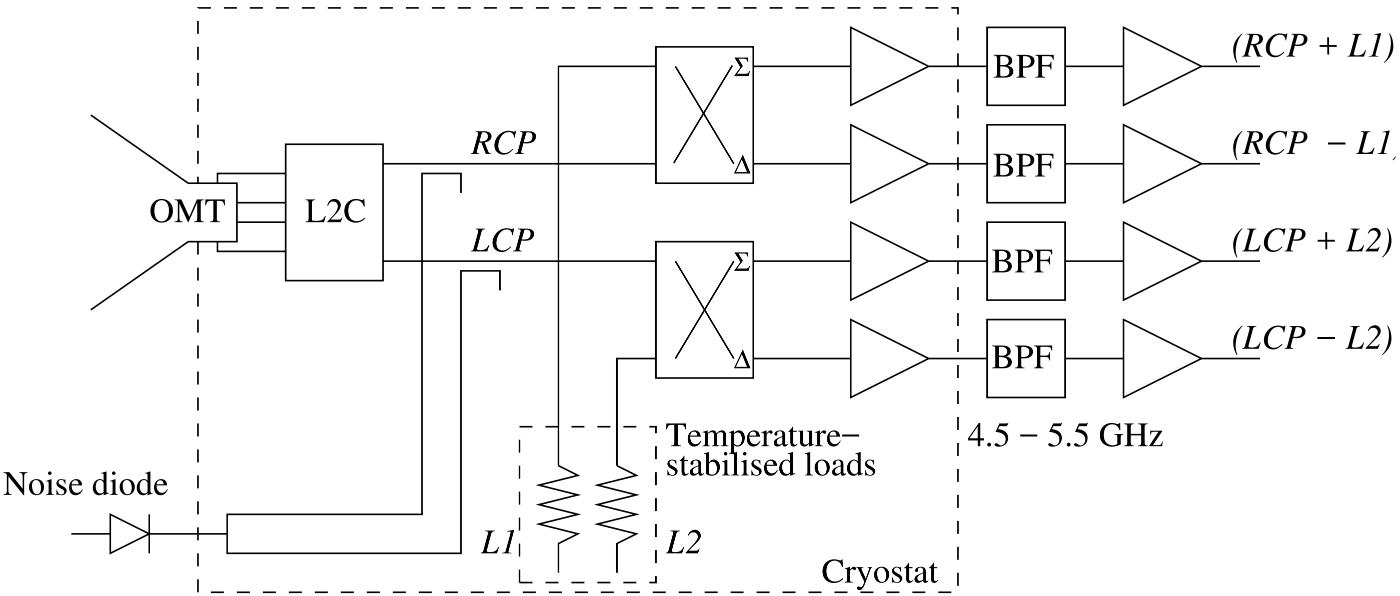


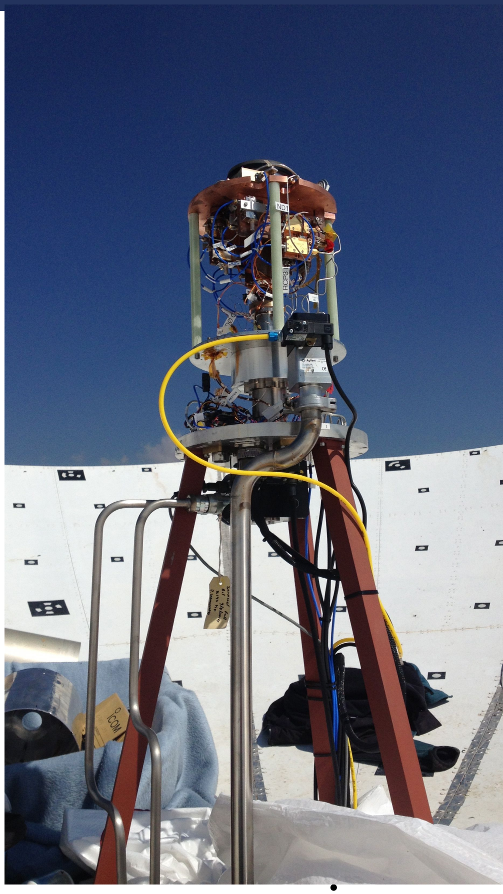
(see Holler et al. 2011, arXiv:1111.2702v2)

C-BASS South Telescope

- CBASS South at Klerefontein, Karoo desert, South Africa (SKA support site)
- 7.6m ex-telecoms dish
- Cassegrain optics
- Similar receiver to north – but frequency resolution (128 ch)

C-BASS Receiver

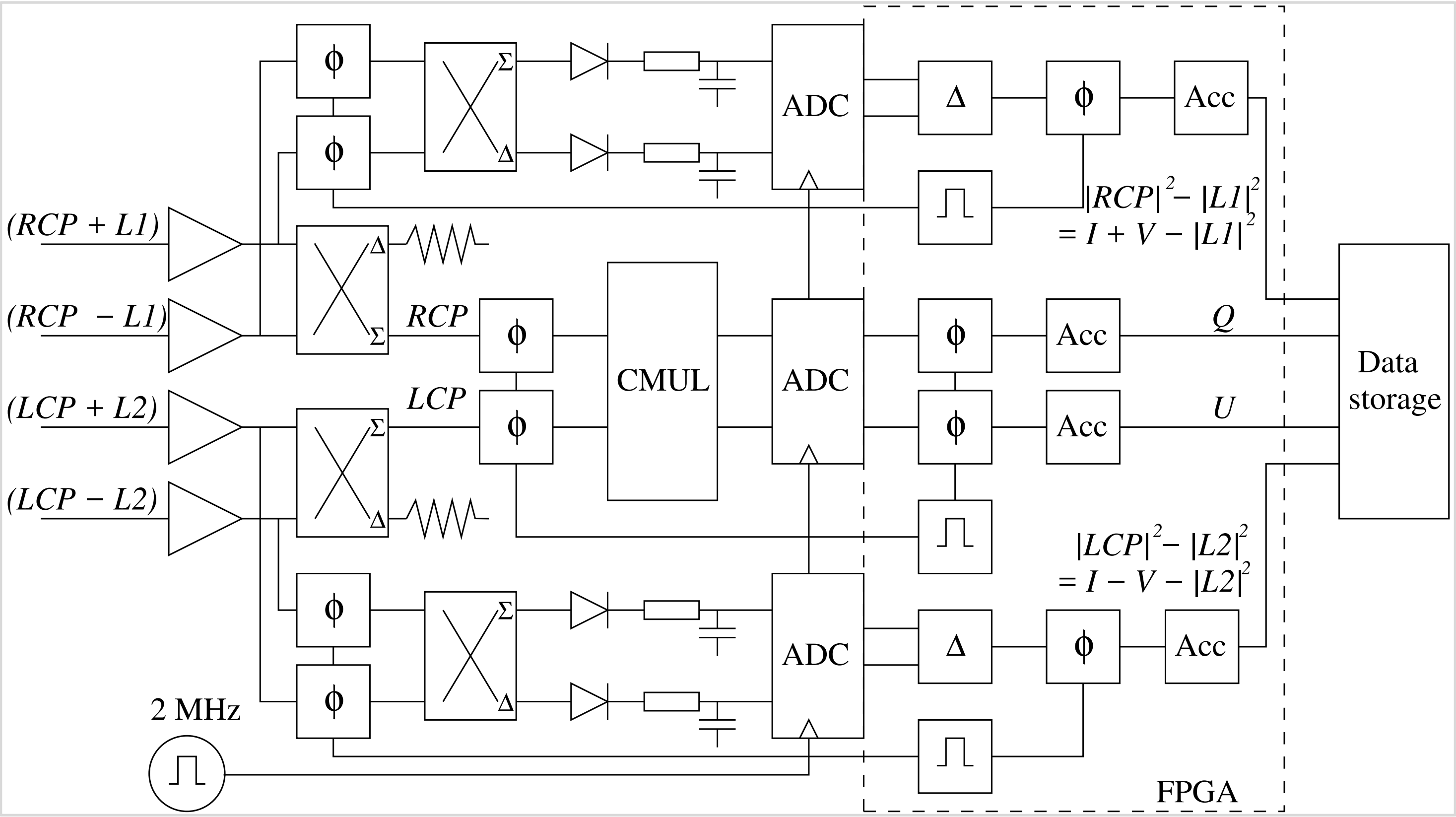




Both receivers use correlation polarimeter and continuous comparison radiometer:

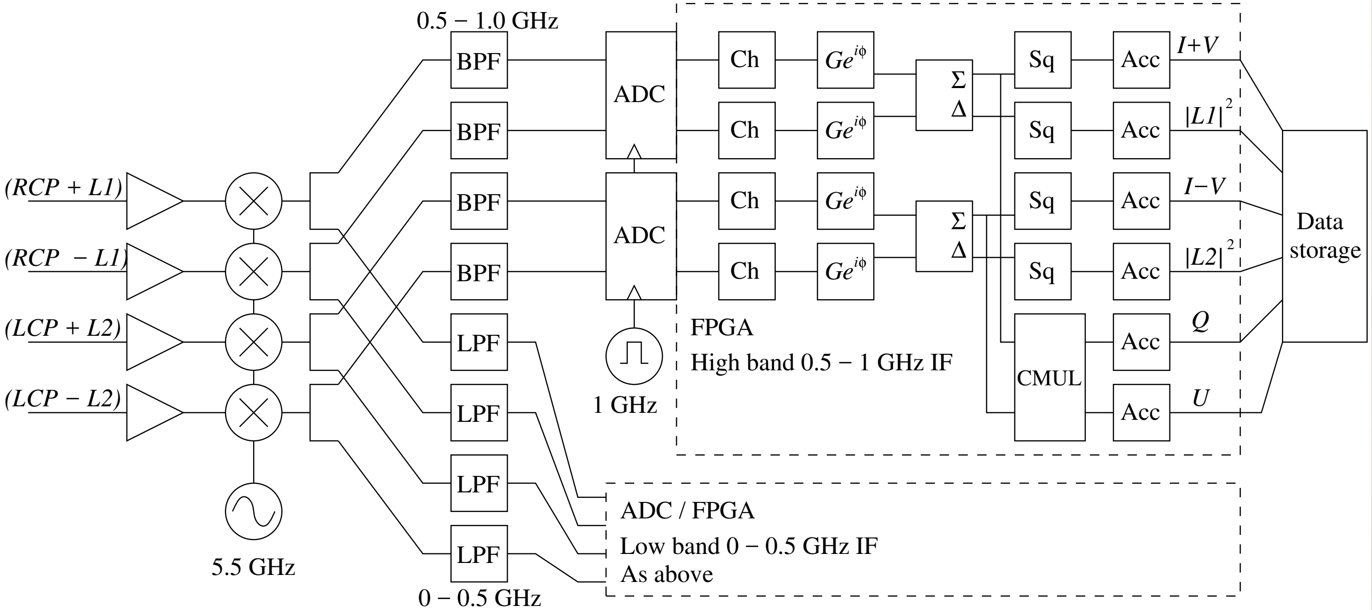
- Correlate RCP & LCP → Q, U
- Difference RCP & LCP separately against internal load → I, V

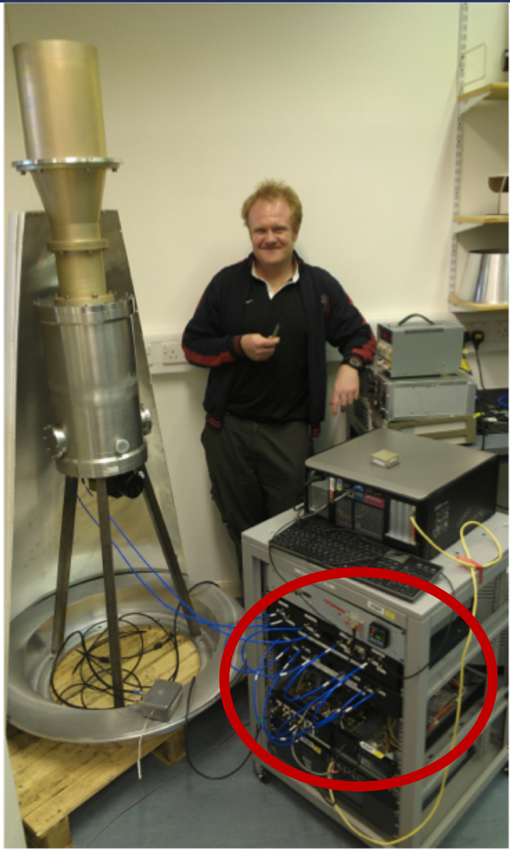
C-BASS North Receiver



- Analogue polarimeter/radiometer – all done with hybrids and diodes…
- Sky and load signals separated post-amplification, squared and differenced – gives *I* relative to loads
- RCP and LCP complex multiplied – gives $Q + iU$

C-BASS South Receiver

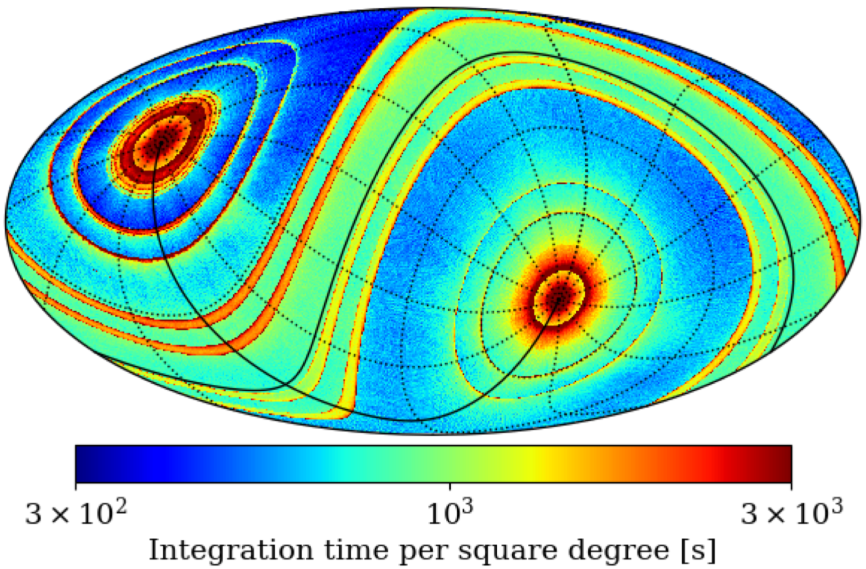




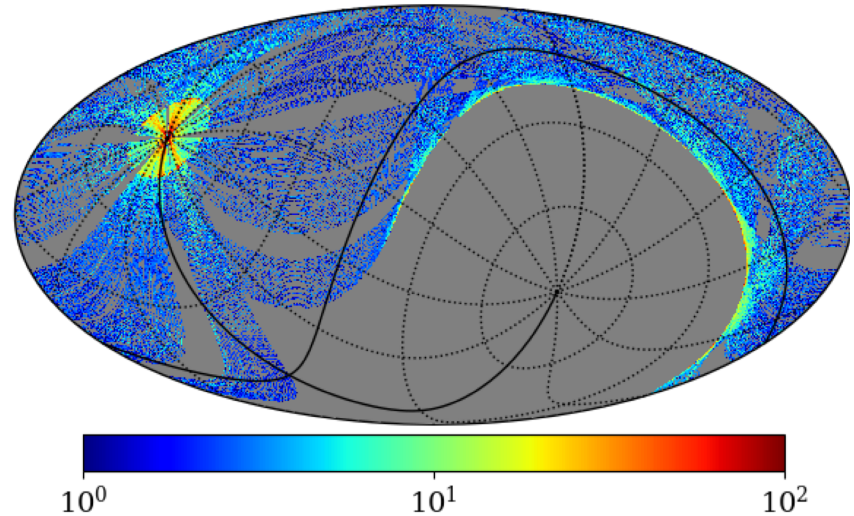
- Digital system in two bands:
- Downconversion to 0 – 0.5, 0.5 – 1 GHz
- Sample at 1 GHz, channelise to 64 channels (Δν=0.07GHz), calibrate gains
- Square and difference sky and load → *I* ; correlate RCP, LCP → *Q*, *U*

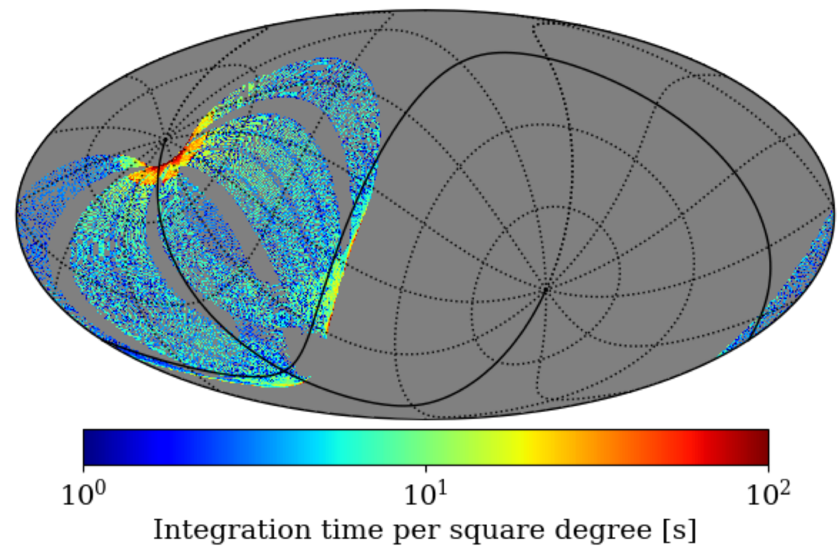
Scan Strategy

- 360 deg azimuth scans at elevation of poles + 10, 30, 40, 50
- Scan as fast as possible: ~4 deg/s
- One scan ~90 s
- Use 5 slightly different scan speeds so fixed frequency contaminants ≠ same sky modes



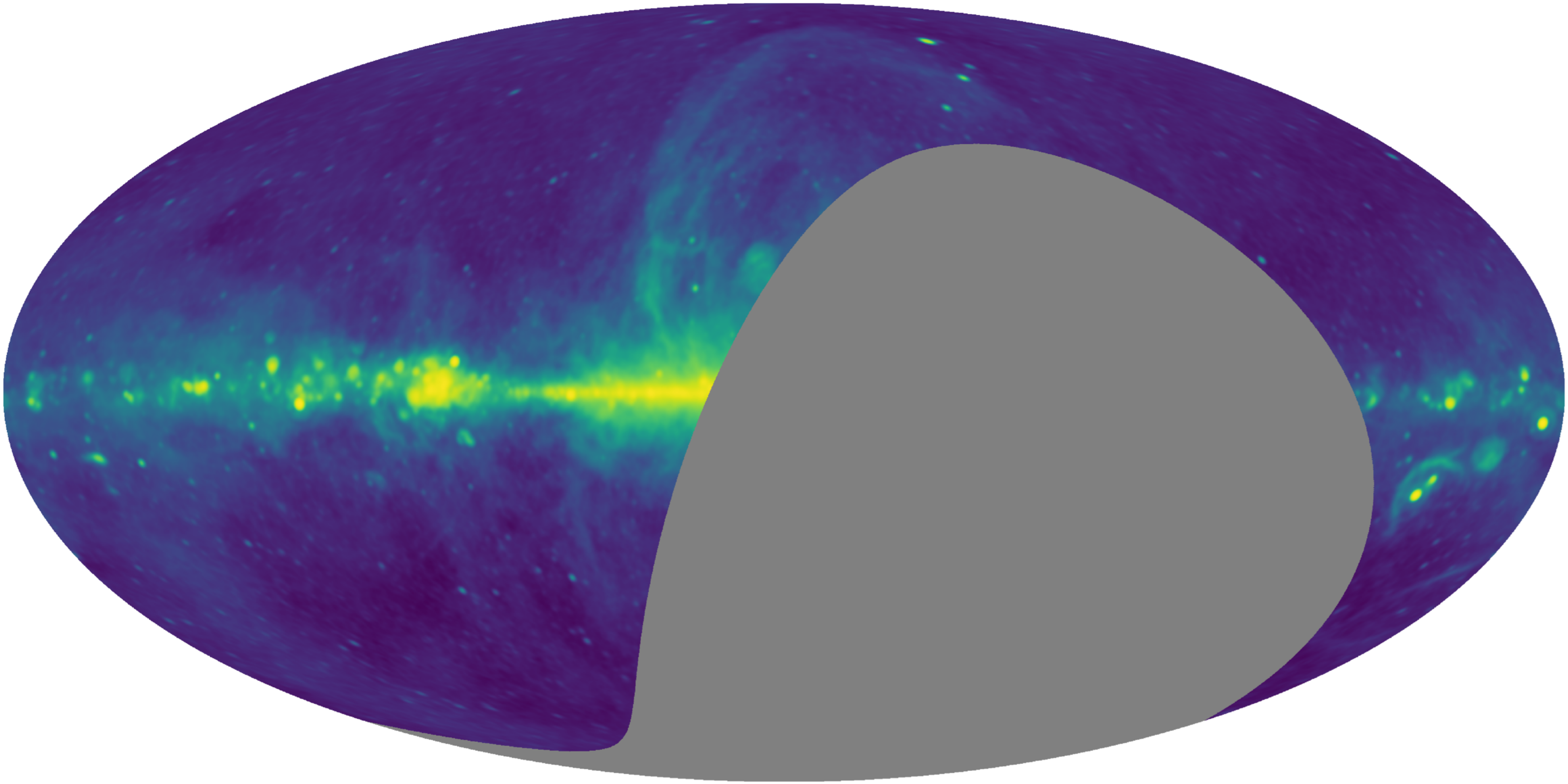
Real (North) + simulated (South) survey coverage





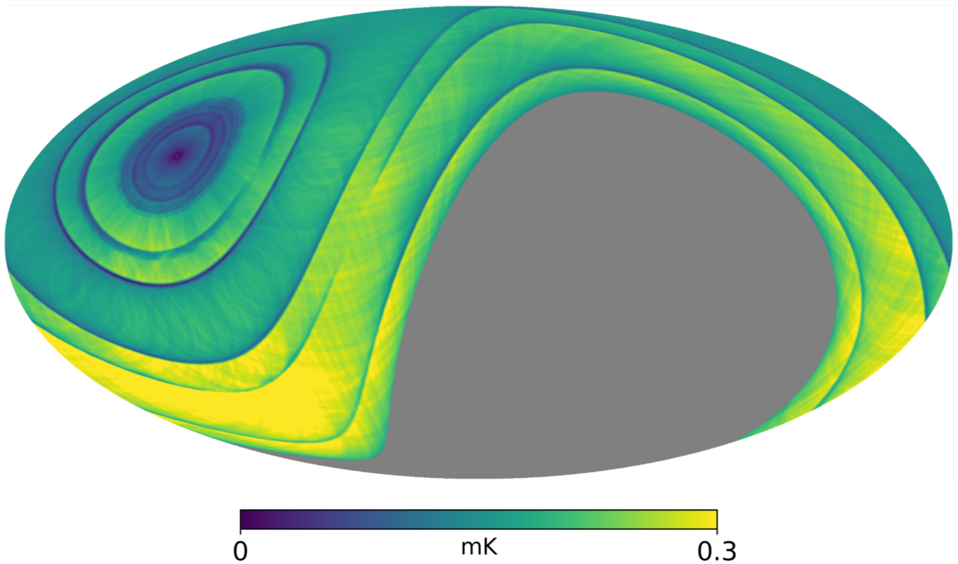
Example of scan coverage in 1 day (top) through pole (bottom) offset

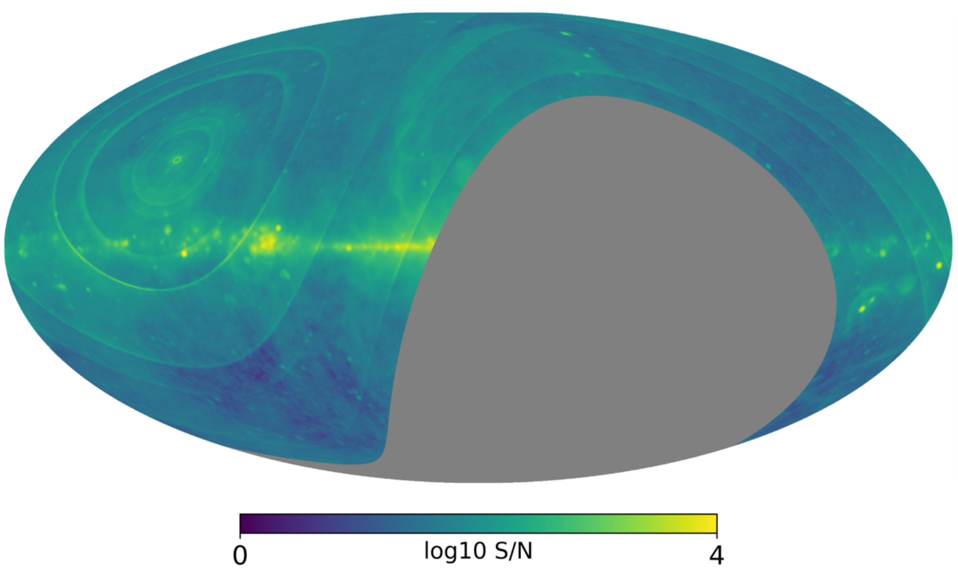
CBASS-N: *Intensity*

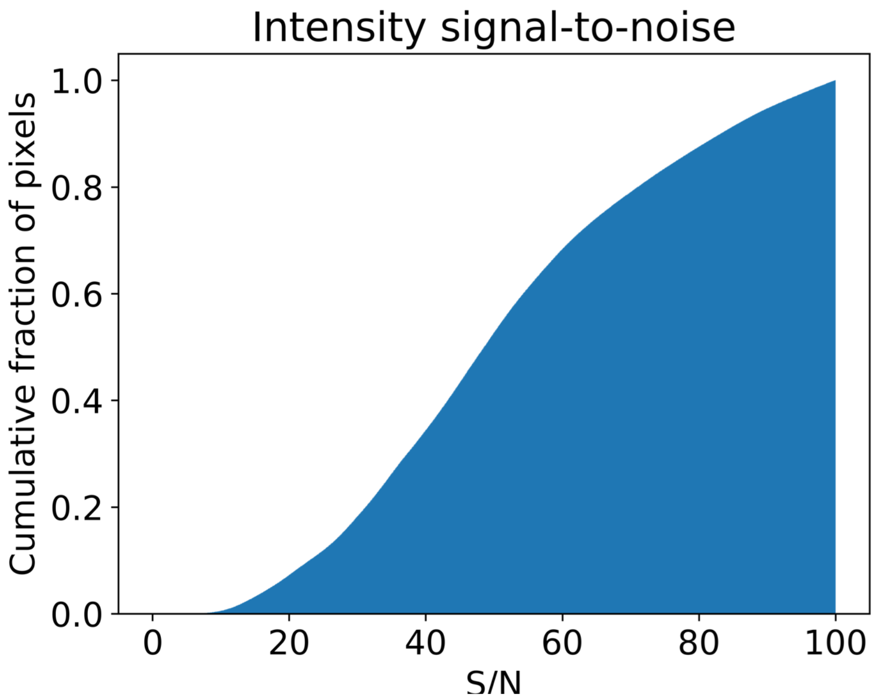


- Night-time only data.
- All elevations (37,47,67 & 77 deg elevation)
- (Highly non-linear colour scale to show ~10,000:1 dynamic range features)

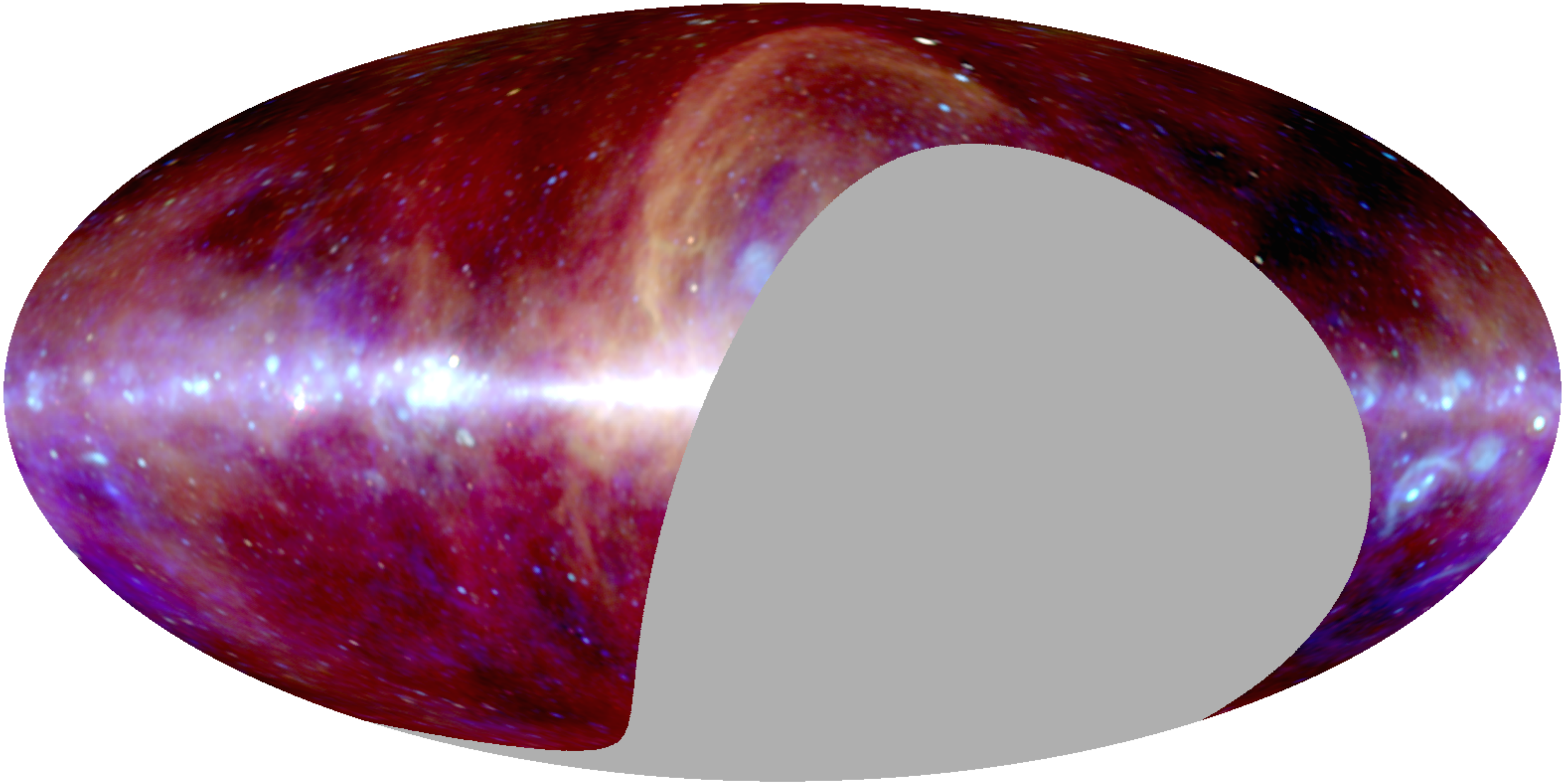
CBASS-N: Intensity Sensitivity







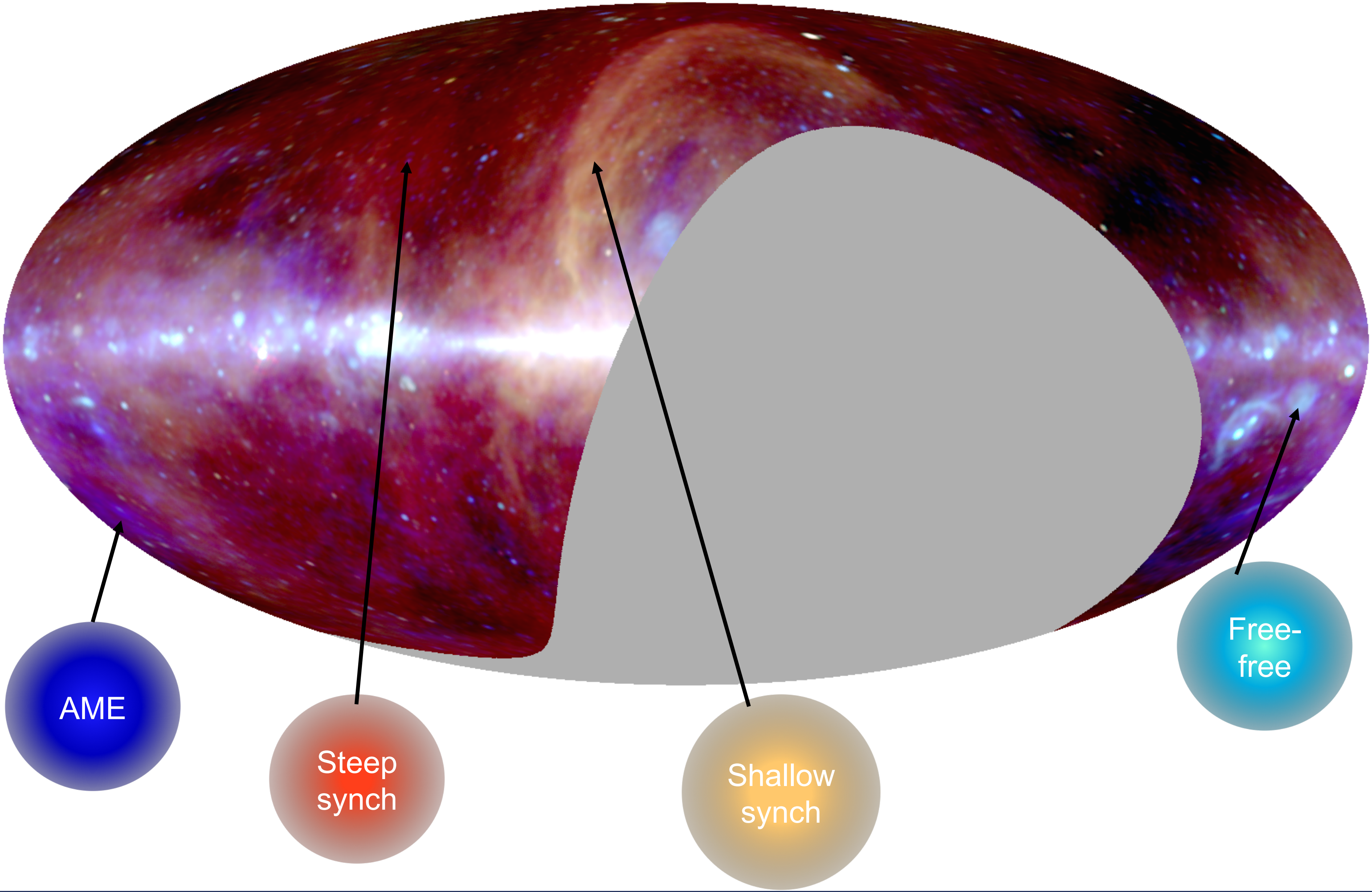
408 MHz - 5 GHz – 23 GHz



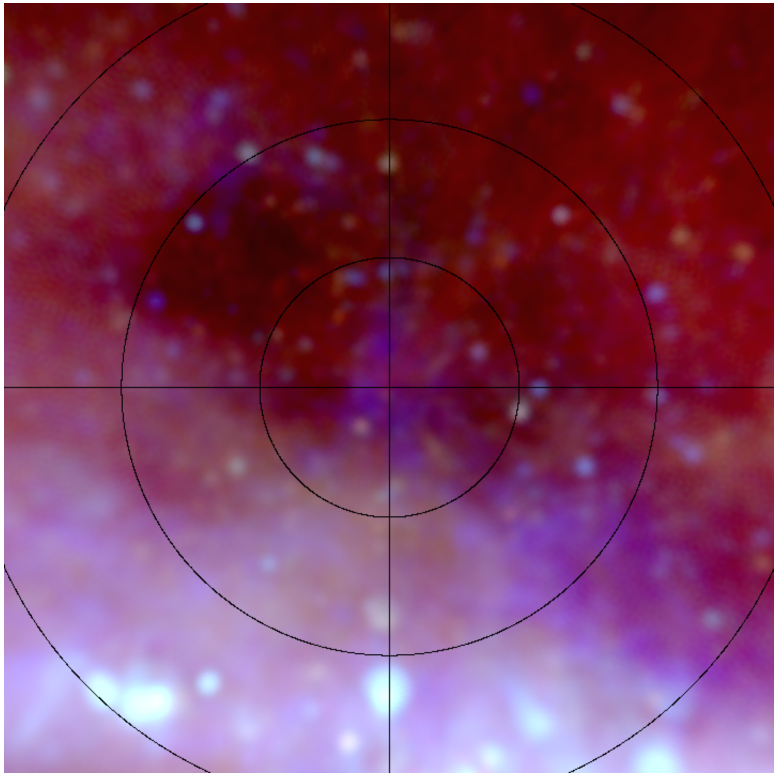
This map is a three-colour image

- RED: Haslam et al 408 MHz map
- GREEN: C-BASS I map
- BLUE: WMAP (K-CMB) band ~ high-ν diffuse emission with the CMB removed.
- Colours balanced such that temperature spectrum of index −2.7 would appear white.

408 MHz - 5 GHz – 23 GHz



TT-plots, template fitting & spectra

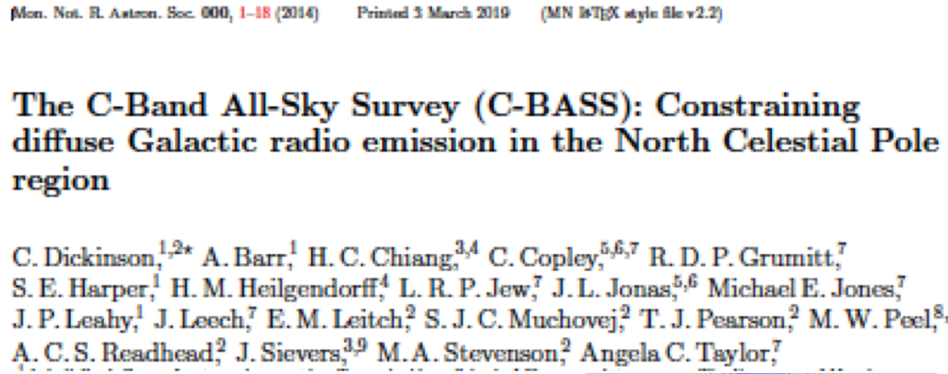


3-colour map of NCP Region

Clearly see purple AME ‘by eye’

Full template-fitting analysis in:

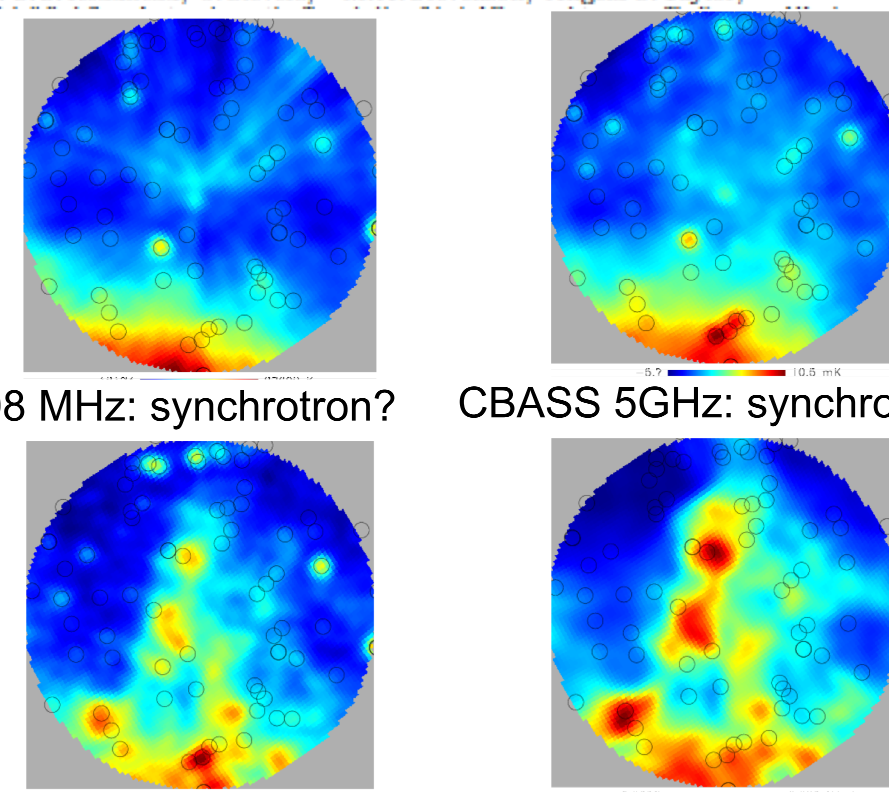
Dickinson et al., MNRAS, 2019



Mon. Not. R. Astron. Soc. 000, 1–18 (2014) Printed 3 March 2019 (MN LaTeX style file v2.2)

The C-Band All-Sky Survey (C-BASS): Constraining diffuse Galactic radio emission in the North Celestial Pole region

C. Dickinson,[1,2*] A. Barr,[1] H. C. Chiang,[3,4] C. Copley,[5,6,7] R. D. P. Grumitt,[7] S. E. Harper,[1] H. M. Heilgendorff,[4] L. R. P. Jew,[7] J. L. Jonas,[5,6] Michael E. Jones,[7] J. P. Leahy,[1] J. Leech,[7] E. M. Leitch,[2] S. J. C. Muchovej,[2] T. J. Pearson,[2] M. W. Peel,[8,1] A. C. S. Readhead,[2] J. Sievers,[3,9] M. A. Stevenson,[2] Angela C. Taylor,[7]

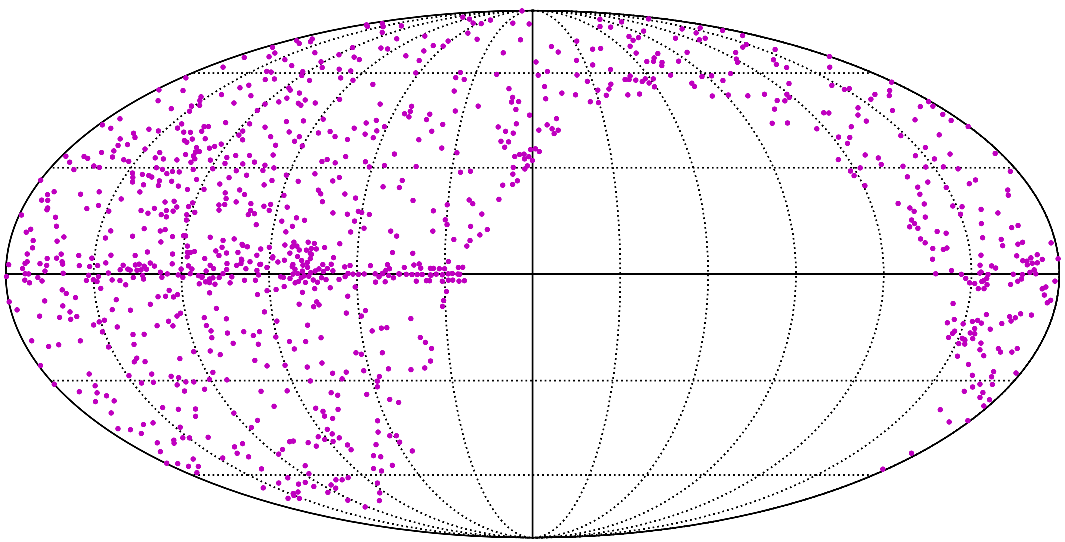


408 MHz: synchrotron? CBASS 5GHz: synchrotron?

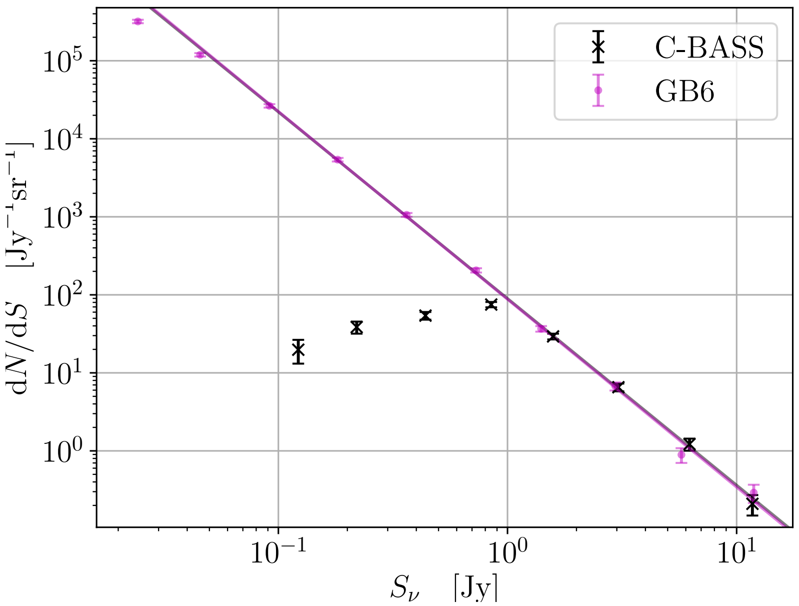
23 GHz: synchrotron + AME? IRIS 100 μm: thermal dust

Point Source Detection

- GB6 provides positions of all likely 5GHz sources in the C-BASS map.
- We have also independently detected point sources.
- Compared both catalogues.
- Provides a point source mask for C-BASS analyses
- Also a useful tool for looking at e.g. variability and polarization properties



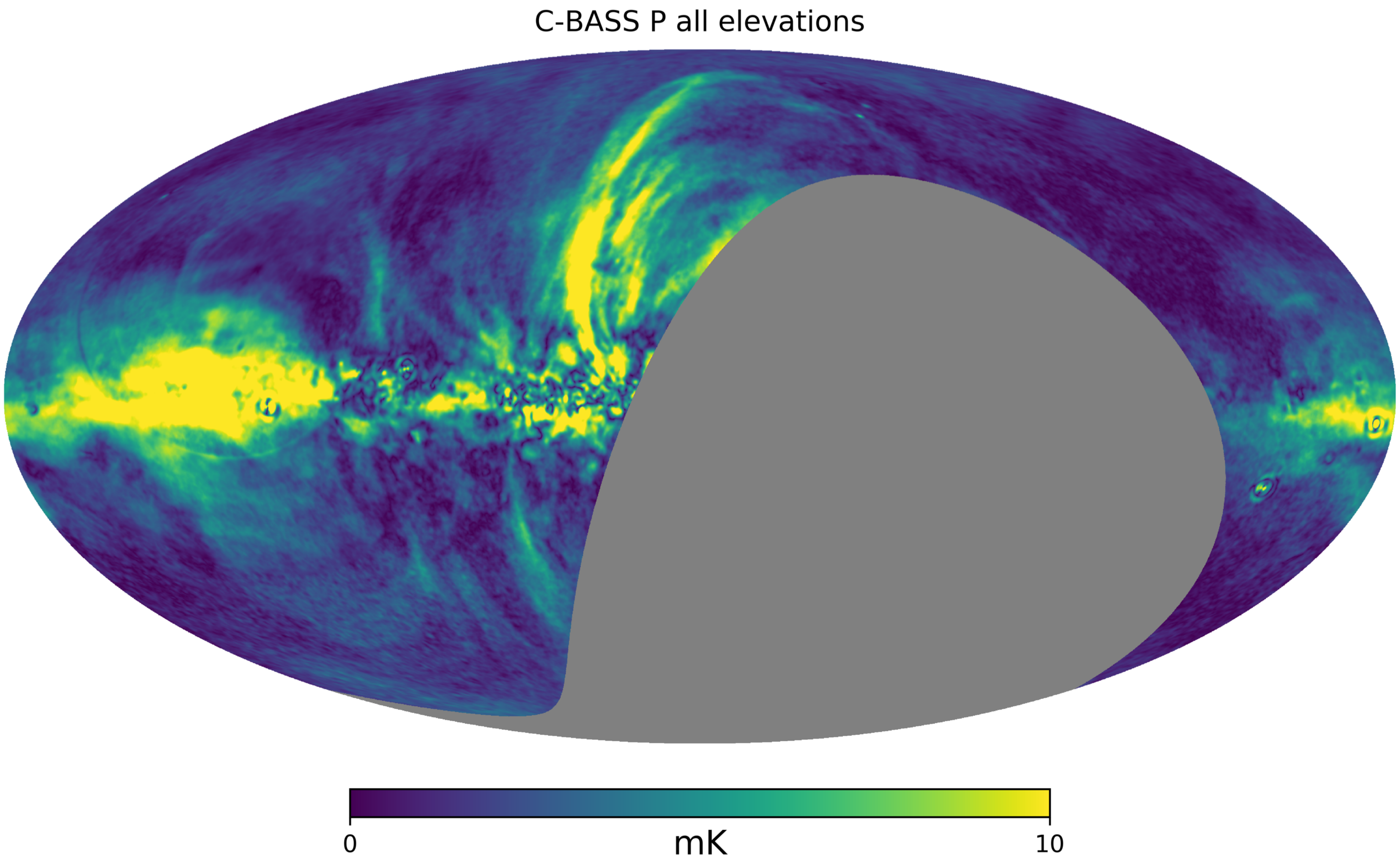
C-BASS point sources detected at > 4-sigma



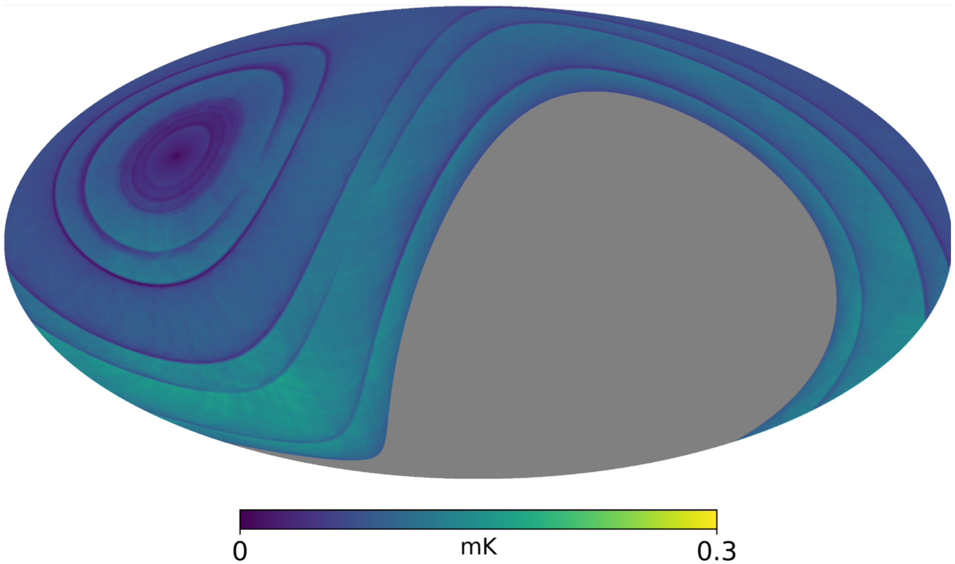
Differential Source counts

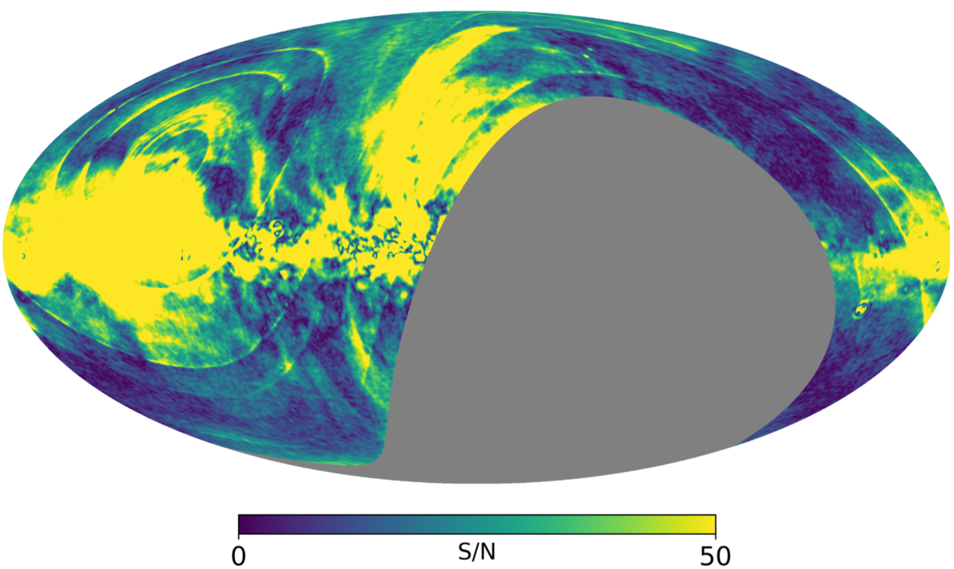
(Grumitt et. al. in prep)

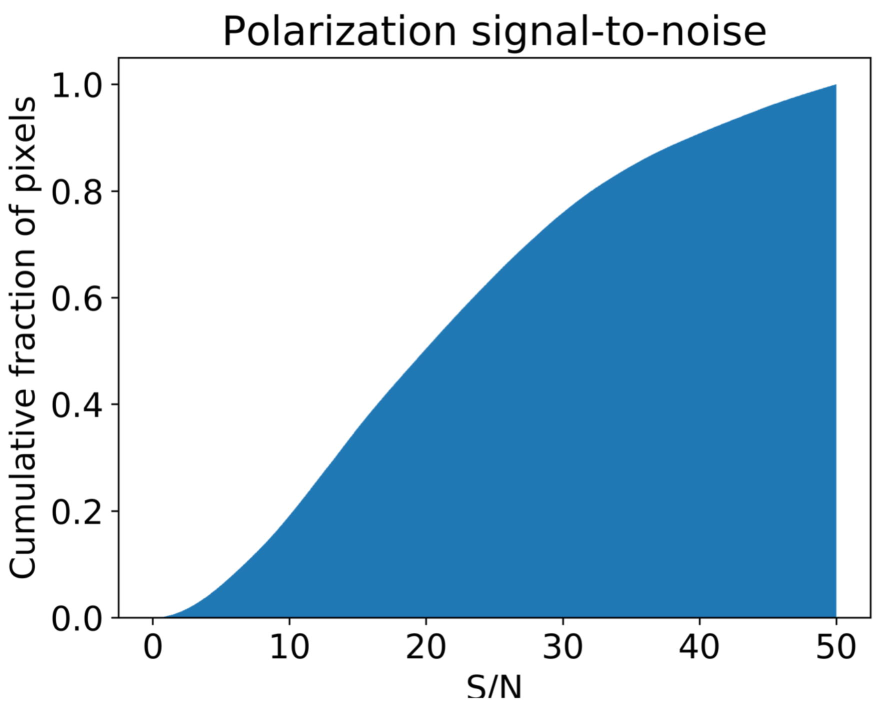
CBASS-N: *Polarized Intensity*



CBASS N – Pol Sensitivity







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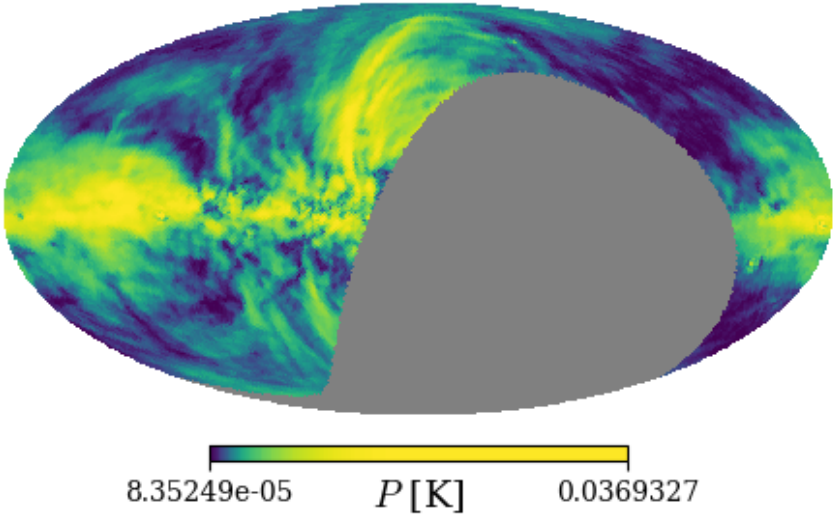
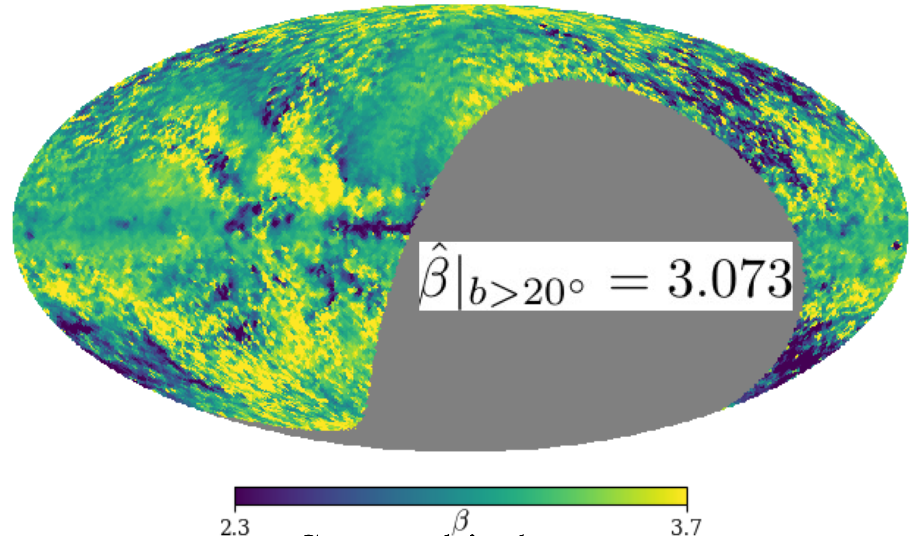
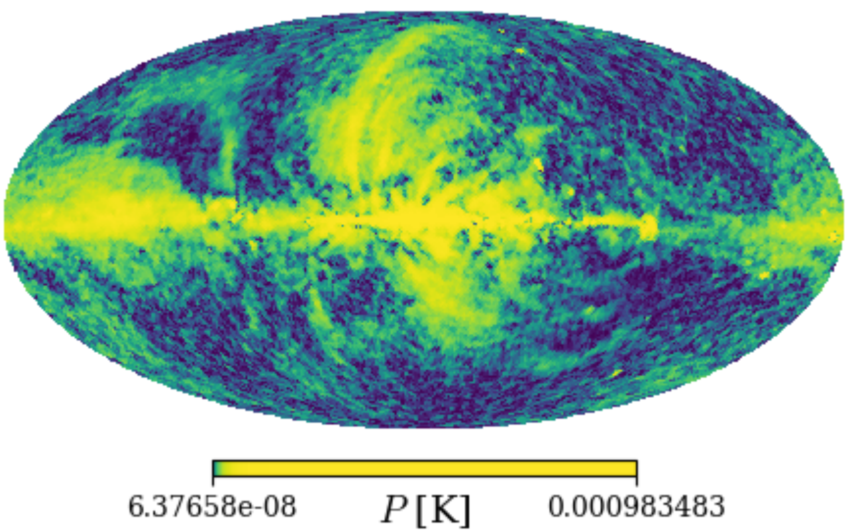
Polarized spectral indices 5 -30 GHz



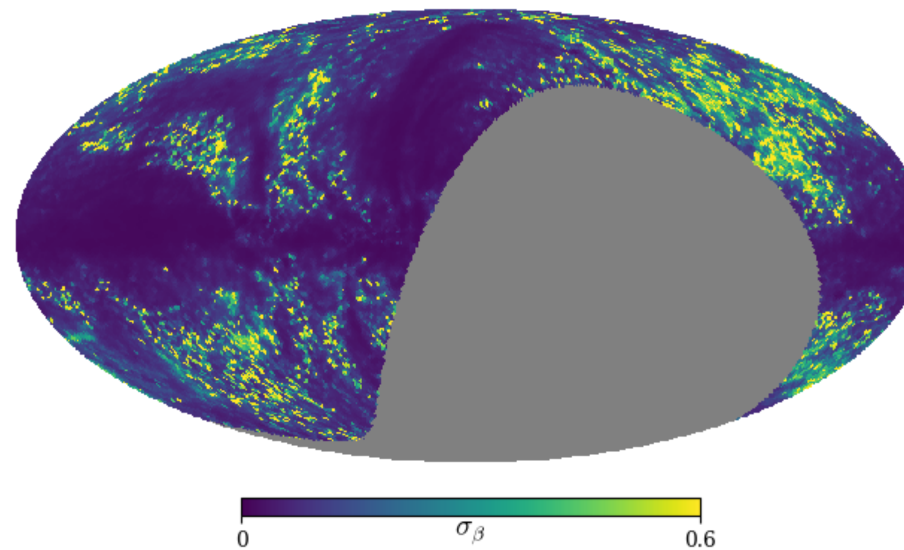
(a) C-BASS P map



Spectral index map

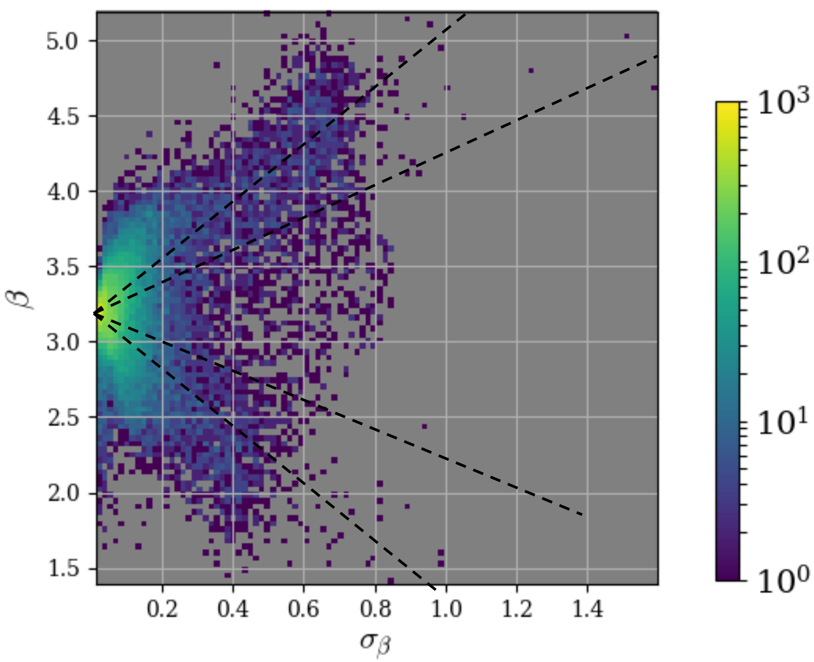


(c) *Planck* 30 GHz P map

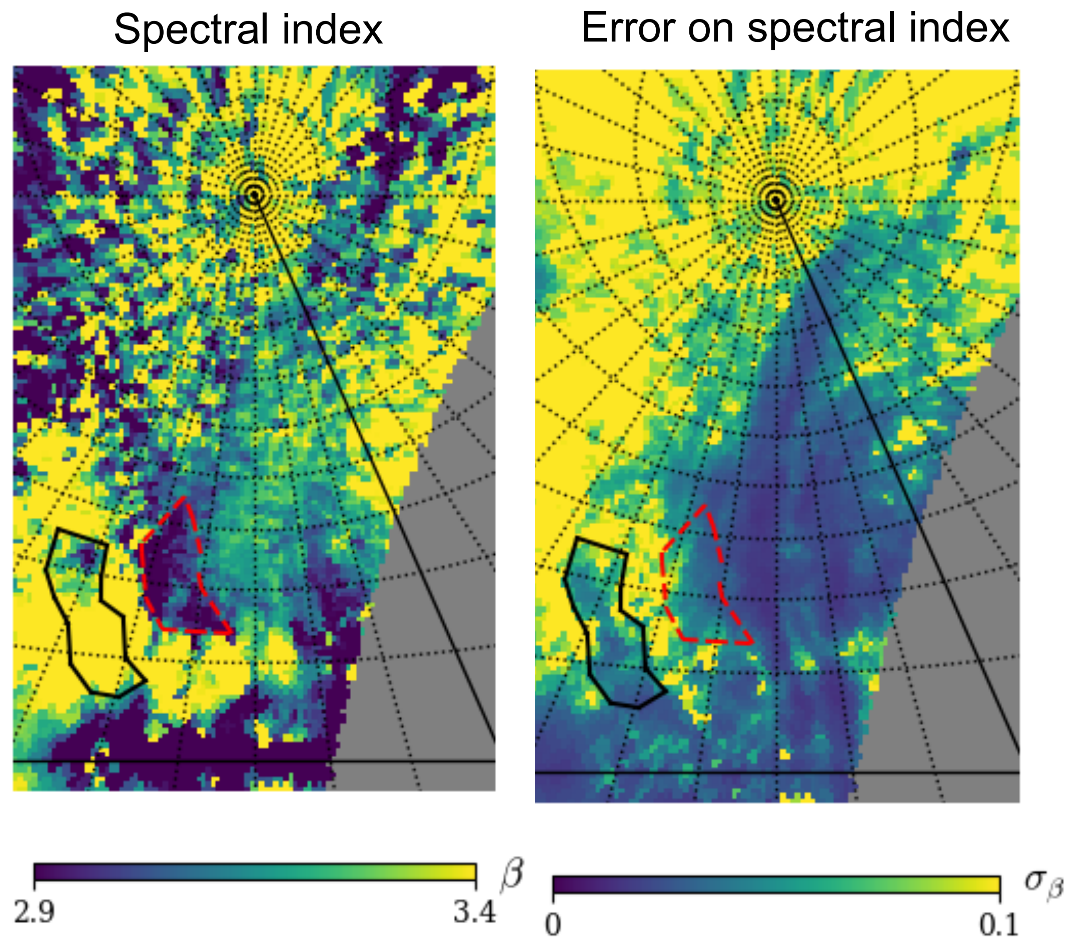


Spectral index error map

Real variations in polarized β (1)

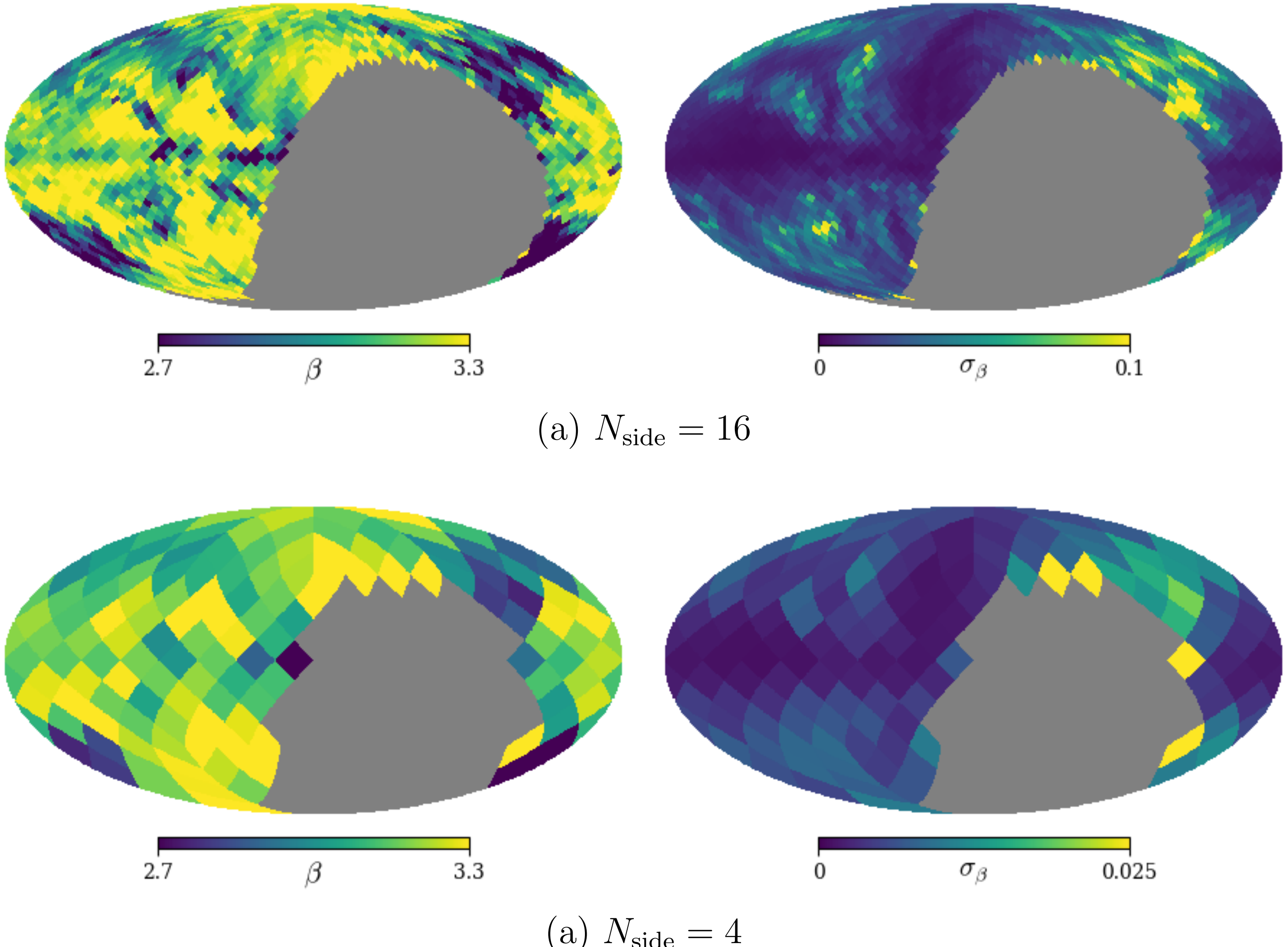


Distribution of b vs error on β
- Dashed lines indicate 1-, 2- σ deviations from mean



Adjacent regions with low s_b but very different β

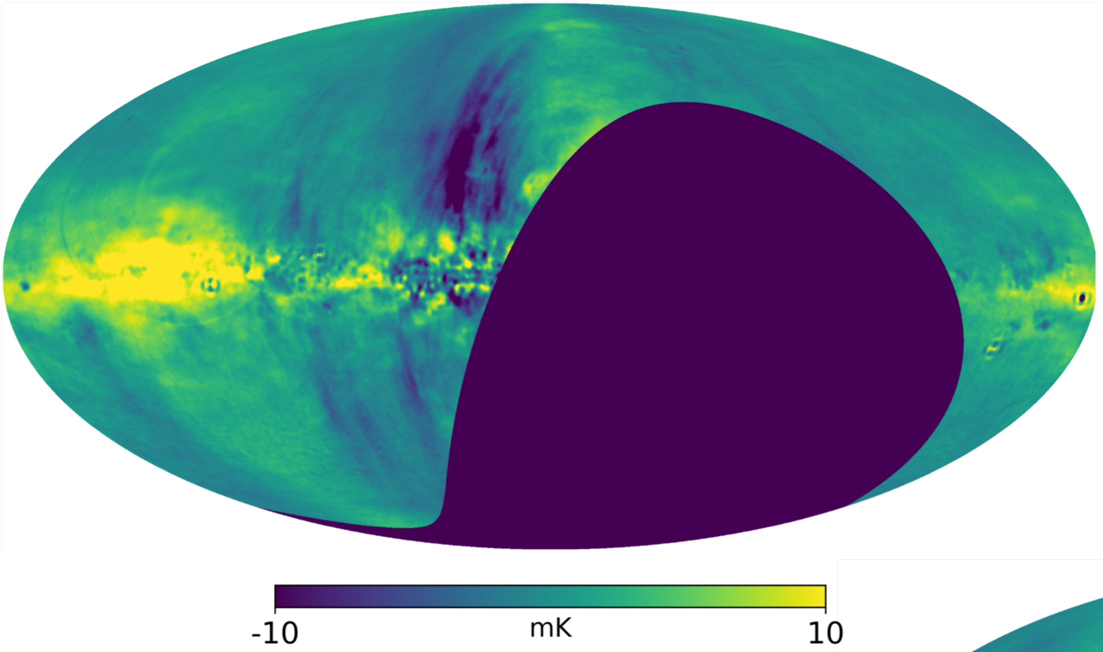
Real variations in polarized β (2)



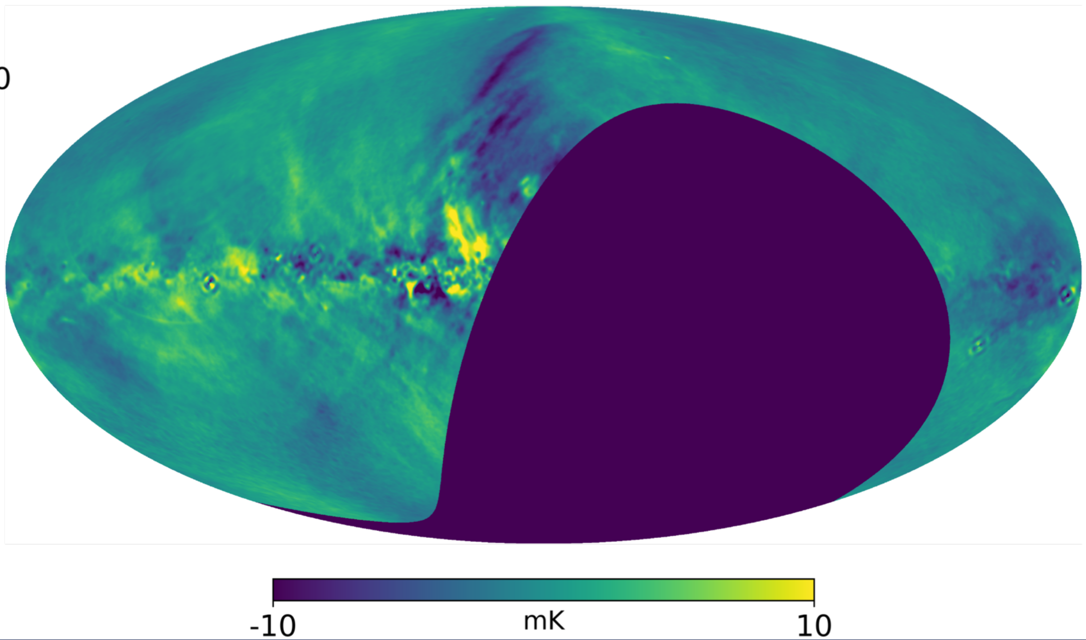
Downgraded maps of β, σ_β – variations >> σ_β on large scales

(see Luke Jew, Dphil Thesis, https://ora.ox.ac.uk/objects/uuid:31f0227a-84be-421a-ae46-eebe9f422767)

C-BASS N – Q & U Maps

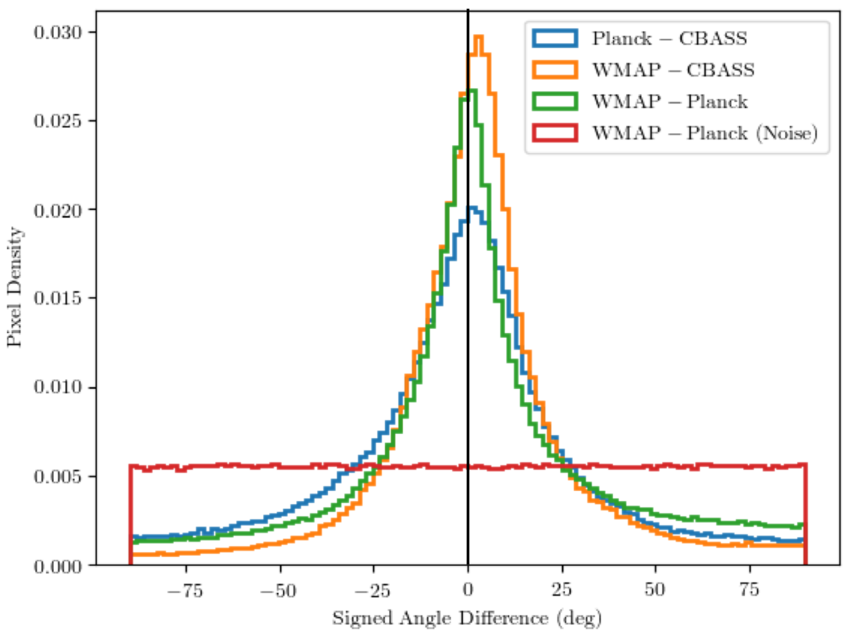


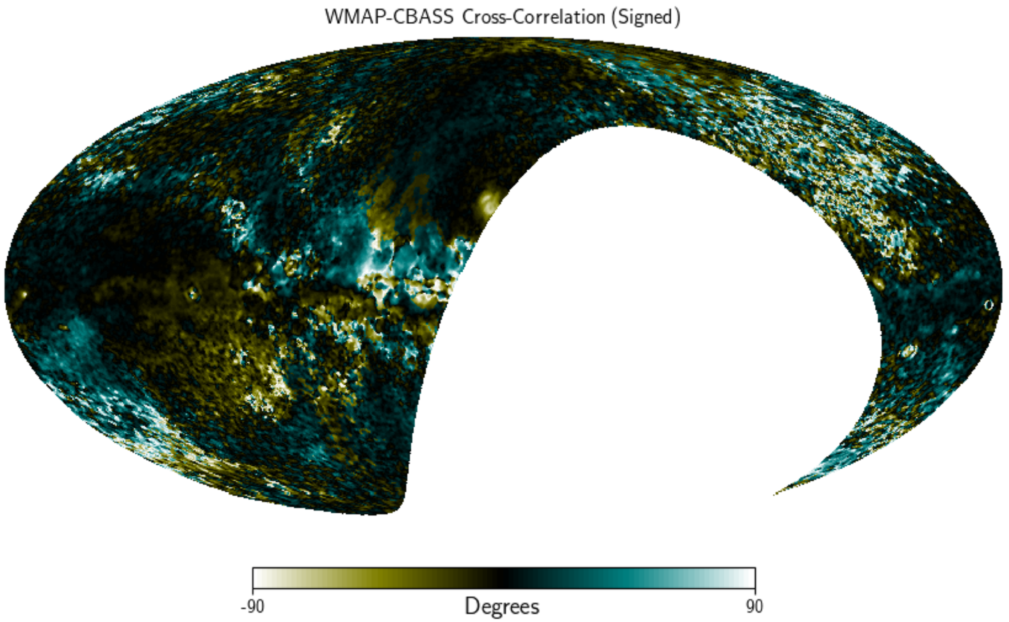
C-BASS U all elevations



CBASS N: Pol angle calibration

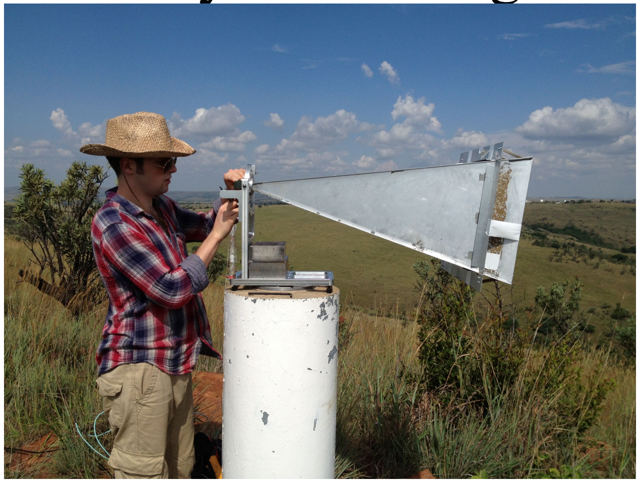
- Primary calibrator is Tau A
- We currently use WMAP measured TauA polarization angle at 30-90 GHz (-88deg, Weiland et al., 2011)
- Correct for Faraday rotation between WMAP and C-BASS (~4deg)
- Cross-check with WMAP/Planck pol. angle correlation



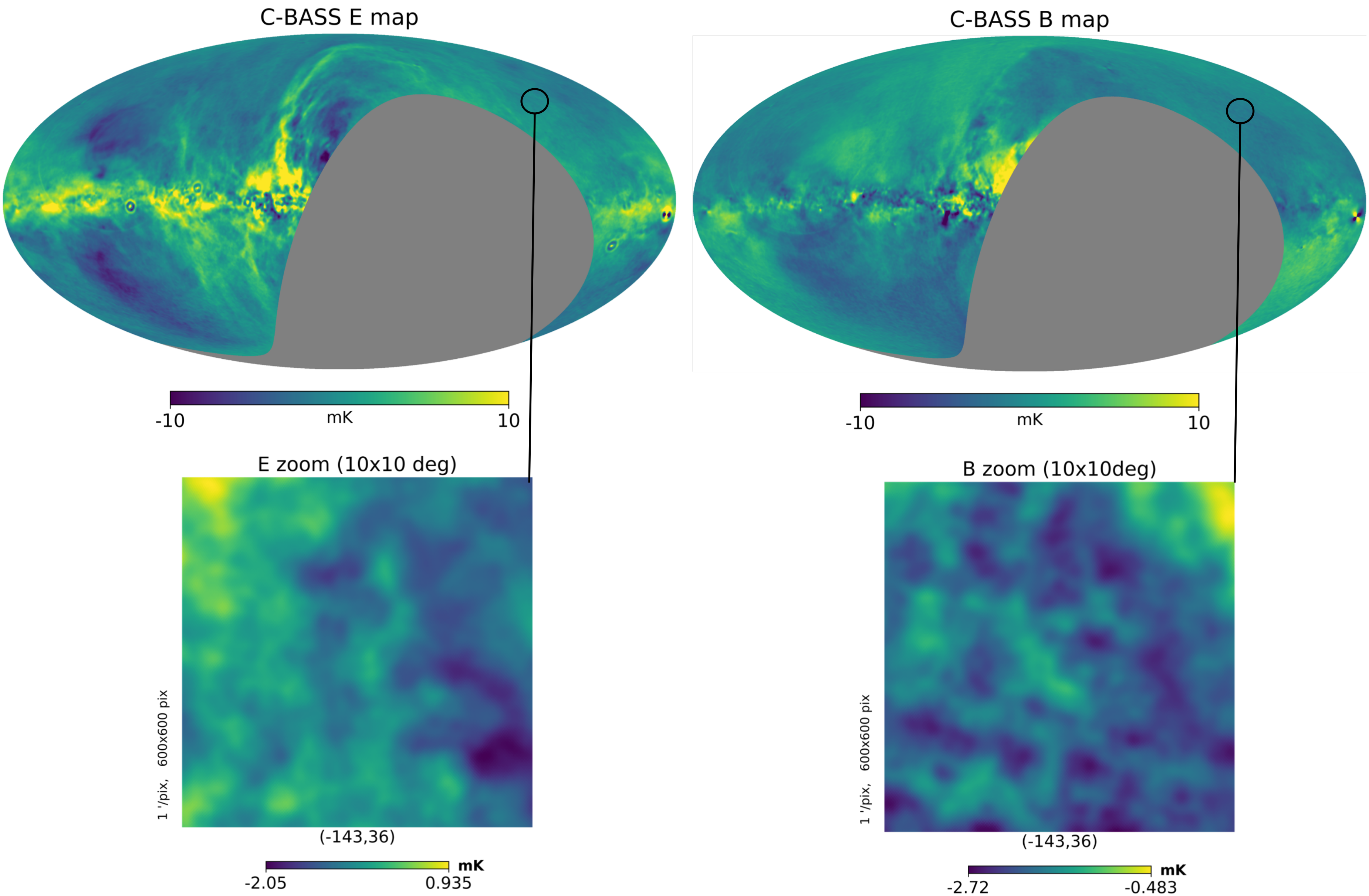


Absolute Polarization Cal

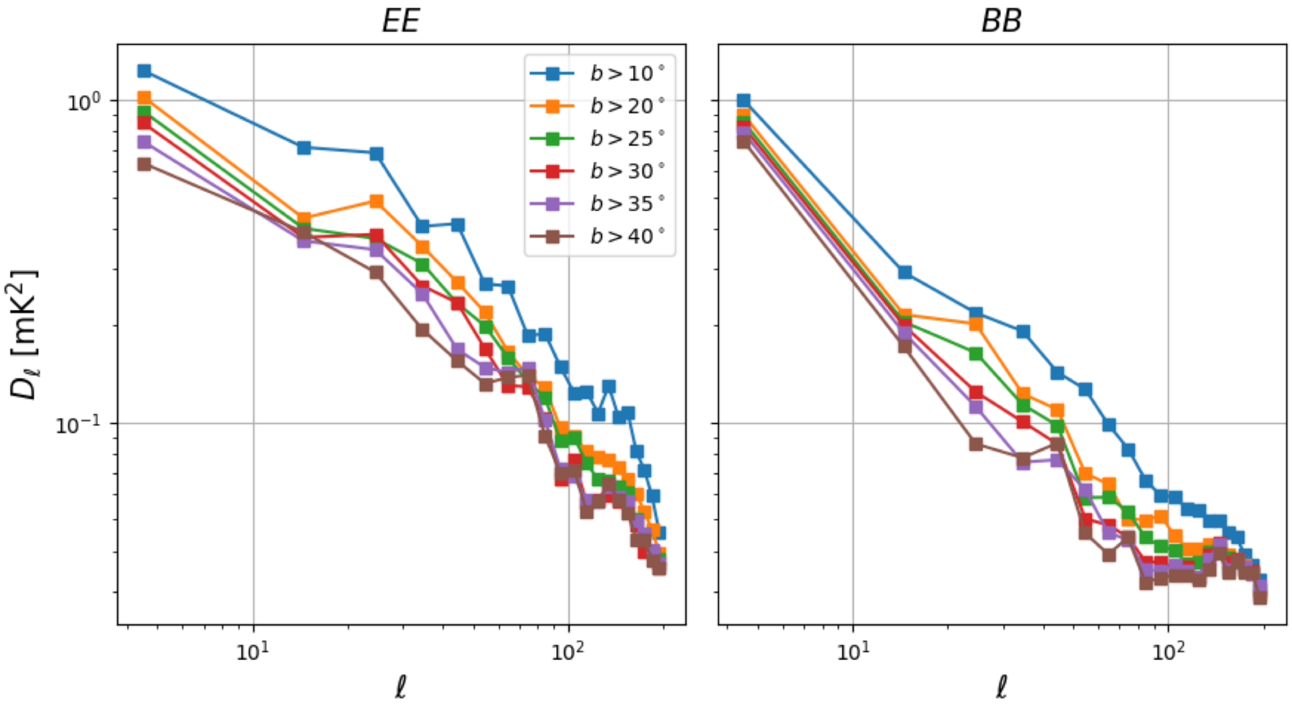
- We have (attempted!) to make an absolute polarization angle measurement of TauA using C-BASS S + ground-based transmitter.
- Still analyzing the data, but should give an accuracy of ~0.1deg.

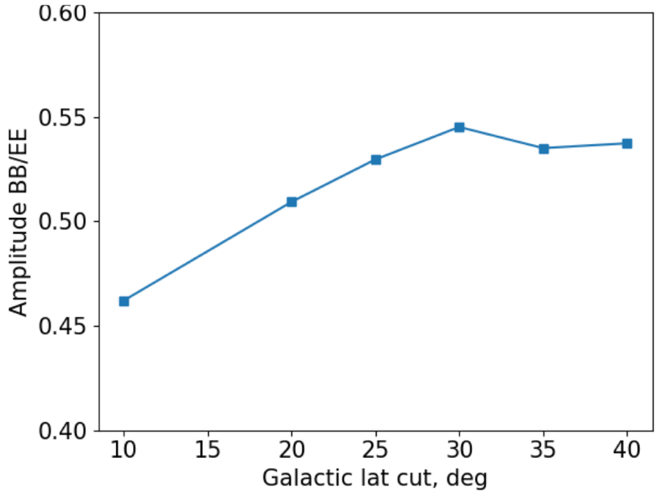


E and B Maps


C-BASS E map
-10
mK
10
C-BASS B map
-10
mK
10
E zoom (10x10 deg)
1 '/pix, 600x600 pix
(-143,36)
-2.05
0.935
mK
B zoom (10x10deg)
1 '/pix, 600x600 pix
(-143,36)
-2.72
-0.483
mK

EE & BB angular power spectra



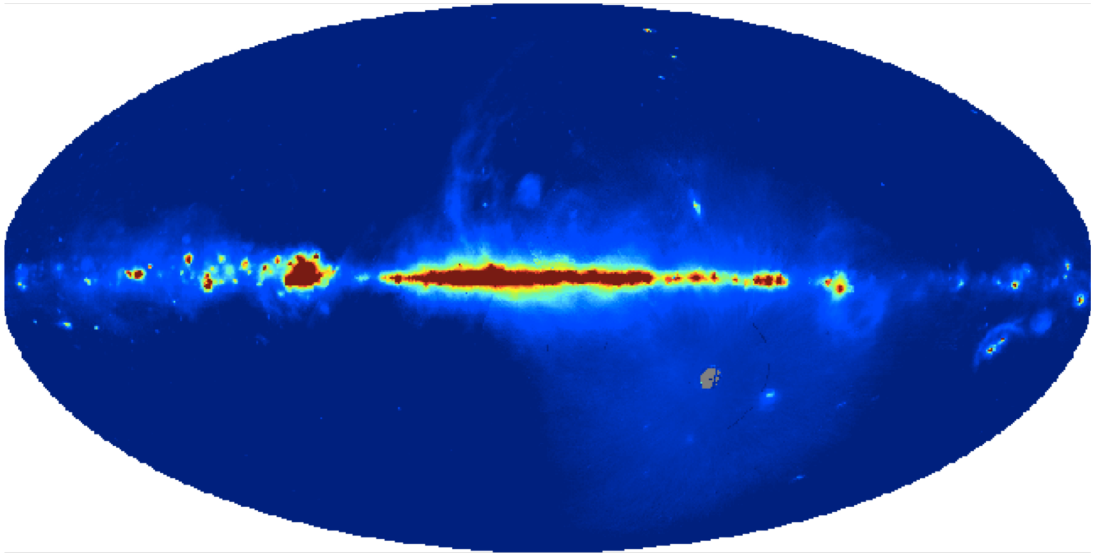


- Galactic masks: 10, 25, 30, 35, 40, 45deg
- Fit BB and EE with:
- $D_l = A\left(\frac{l}{80}\right)^{\alpha}$ → $A^{BB}/A^{EE} \sim 0.5$
- Next steps – predicting level of synch contamination for B-mode CMB …

Summary

- C-BASS-N data being analysed - first results/papers imminent…
  - Northern sky intensity map
  - Template fitting, TT, spectral index analysis, Commander analysis
  - Point source catalogue/mask
  - Polarized intensity + map spectral indices + cross-spectra
  - E & B maps/spectra and impact for CMB

- C-BASS-S continuing to observe – needs at least 12-18 months data.



C-BASS N + S

C-BASS S, Karoo Desert, South Africa

Thank you

https://cbass.web.ox.ac.uk