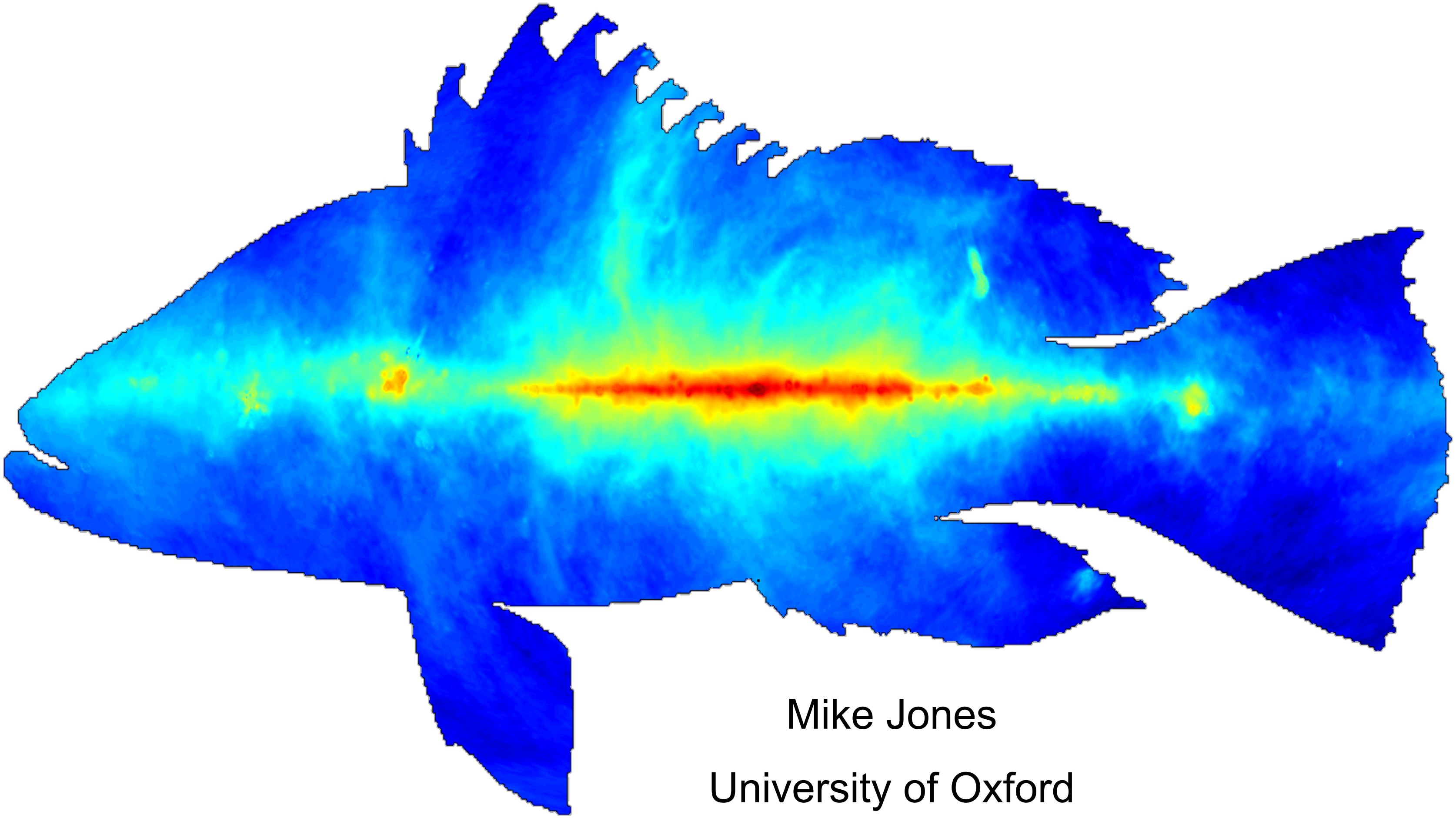
C-Band All-Sky Survey (C-BASS)



Mike Jones

University of Oxford

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

University of Oxford, UK

Angela Taylor, Mike Jones, Jamie Leech,,
Luke Jew, Richard Grummit, Jaz Hill-Valler,
Alex Pollak

Hochschule München, Germany

Christian Holler

University of Manchester, UK

Clive Dickinson, Paddy Leahy, Mike Peel,
Adam Barr

Caltech, USA

Tim Pearson, Tony Readhead,

South Africa

Justin Jonas (Rhodes/SKASA), Cynthia
Chiang, Heiko Heligendorff, Moumita Aitch
(UKZN)

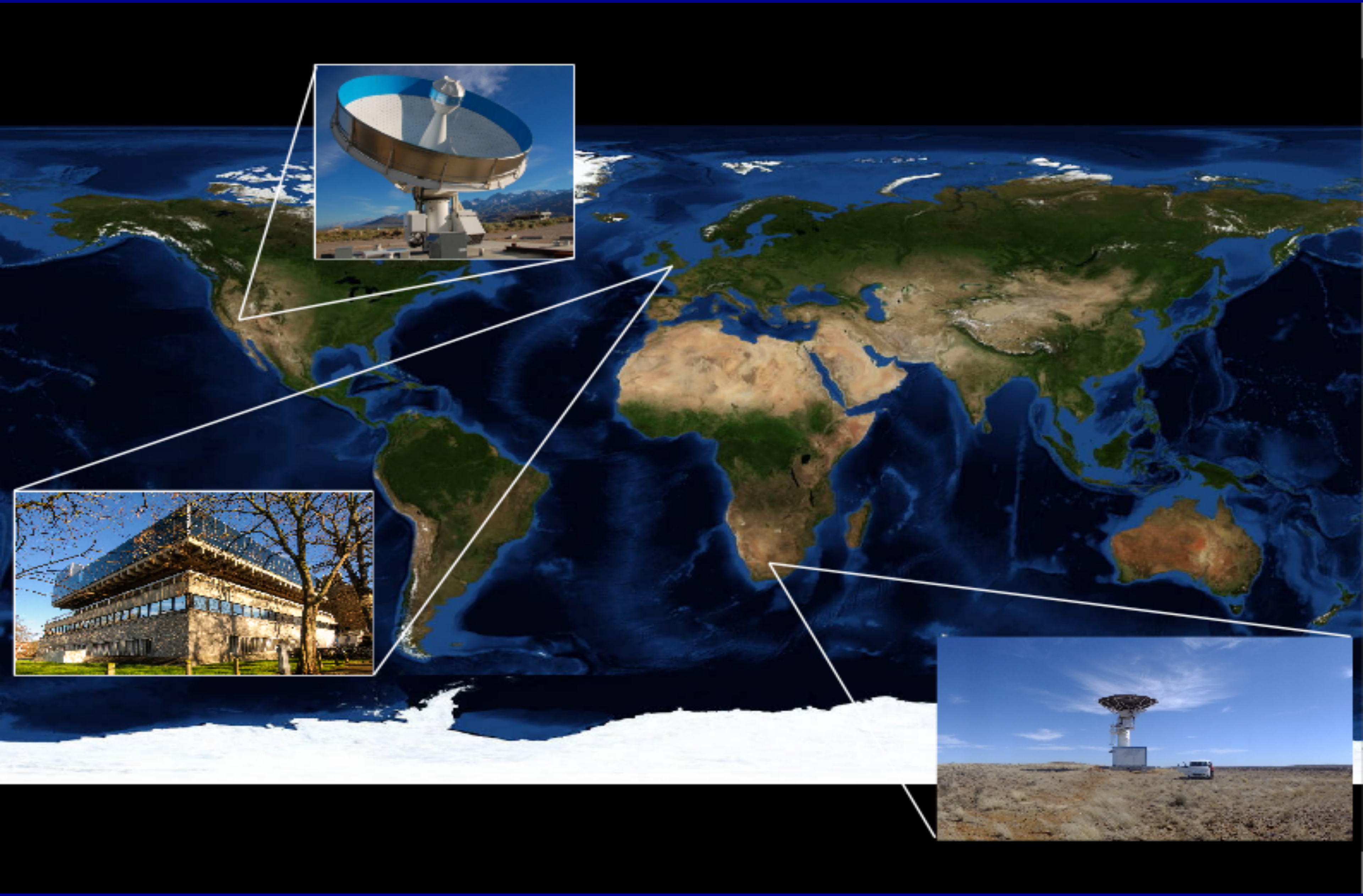
KACST, Saudi Arabia

Yasser Hafez

Moved on…

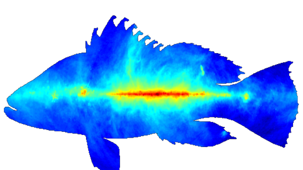
Oliver King, Matthew Stevenson, Mel Irfan,
Stephen Muchovej, Joe Zuntz, Charles
Copley

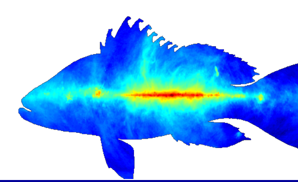
The C-BASS Survey



C-BASS - Overview

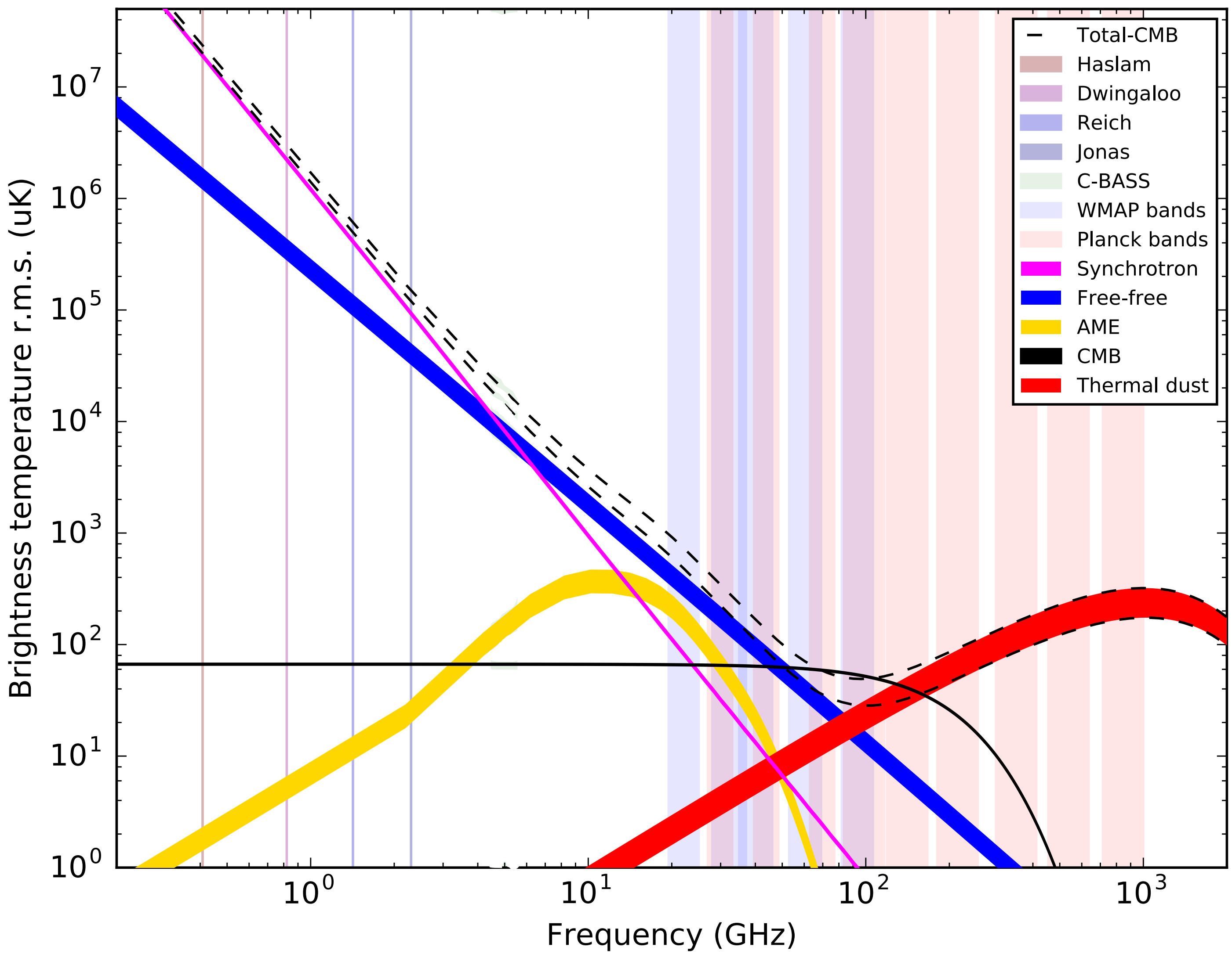
Sky-coverage	All-sky
Angular resolution	0.75 deg (45 arcmin)
Sensitivity	< 0.1mK r.m.s (confusion limited in I)
Stokes coverage	I, Q, U, (V)
Frequency	1 (0.7) GHz bandwidth, centered at 5 GHz
Northern site 	OVRO, California Latitude, 37.2 deg
Southern site 	MeerKAT site, Karoo, South Africa Latitude -30.7 deg





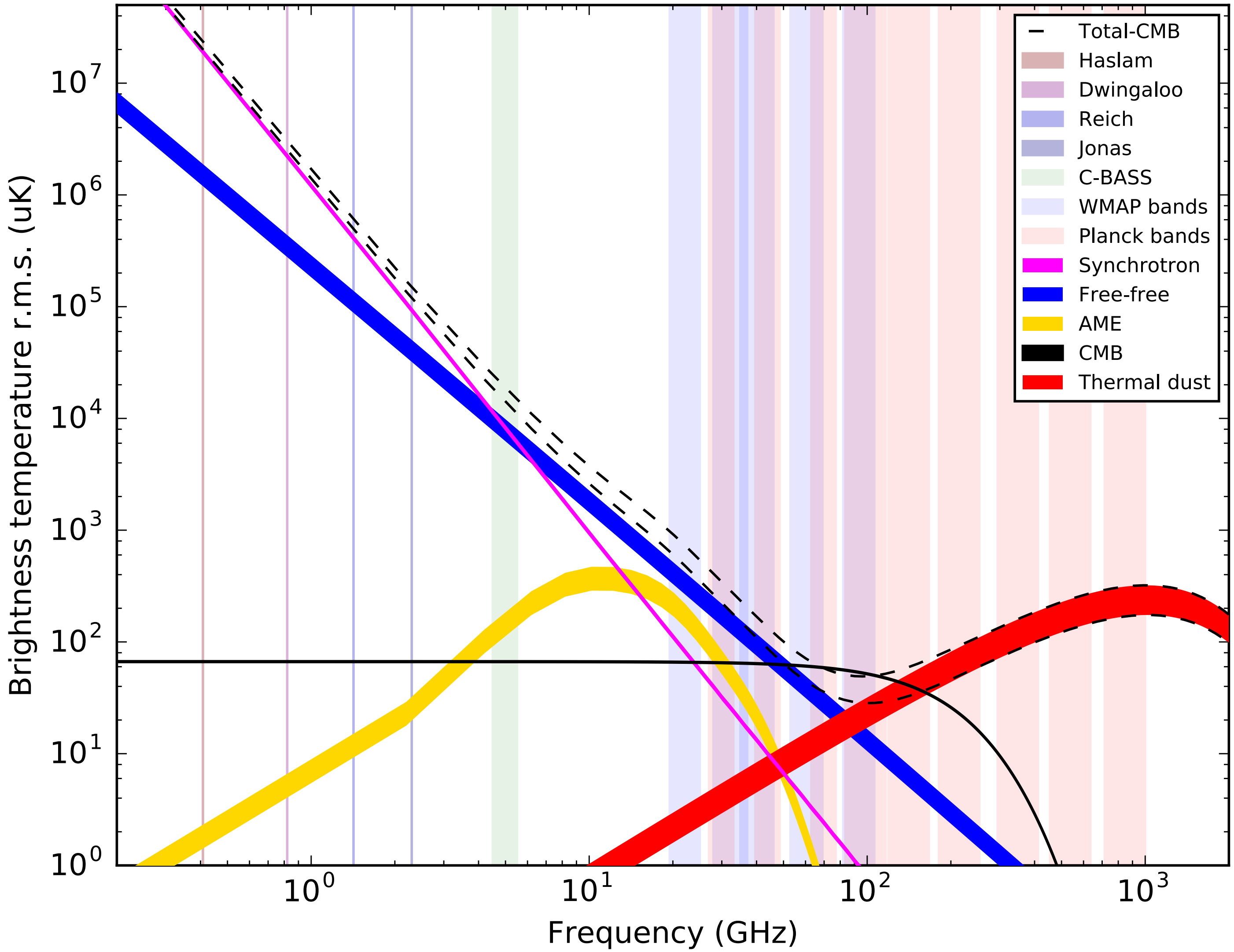
Why a 5 GHz survey?

Intensity



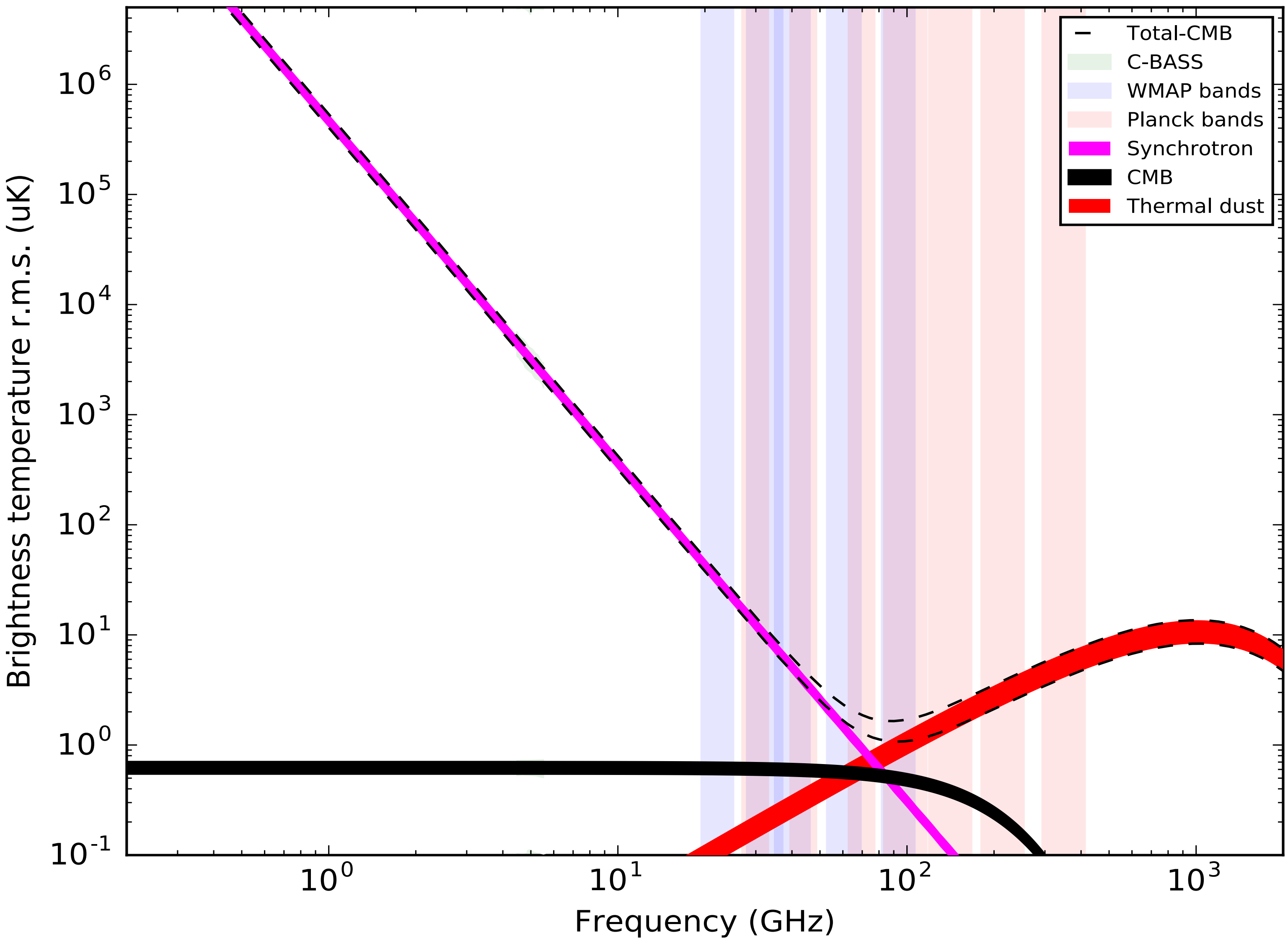
Why a 5 GHz survey?

Intensity



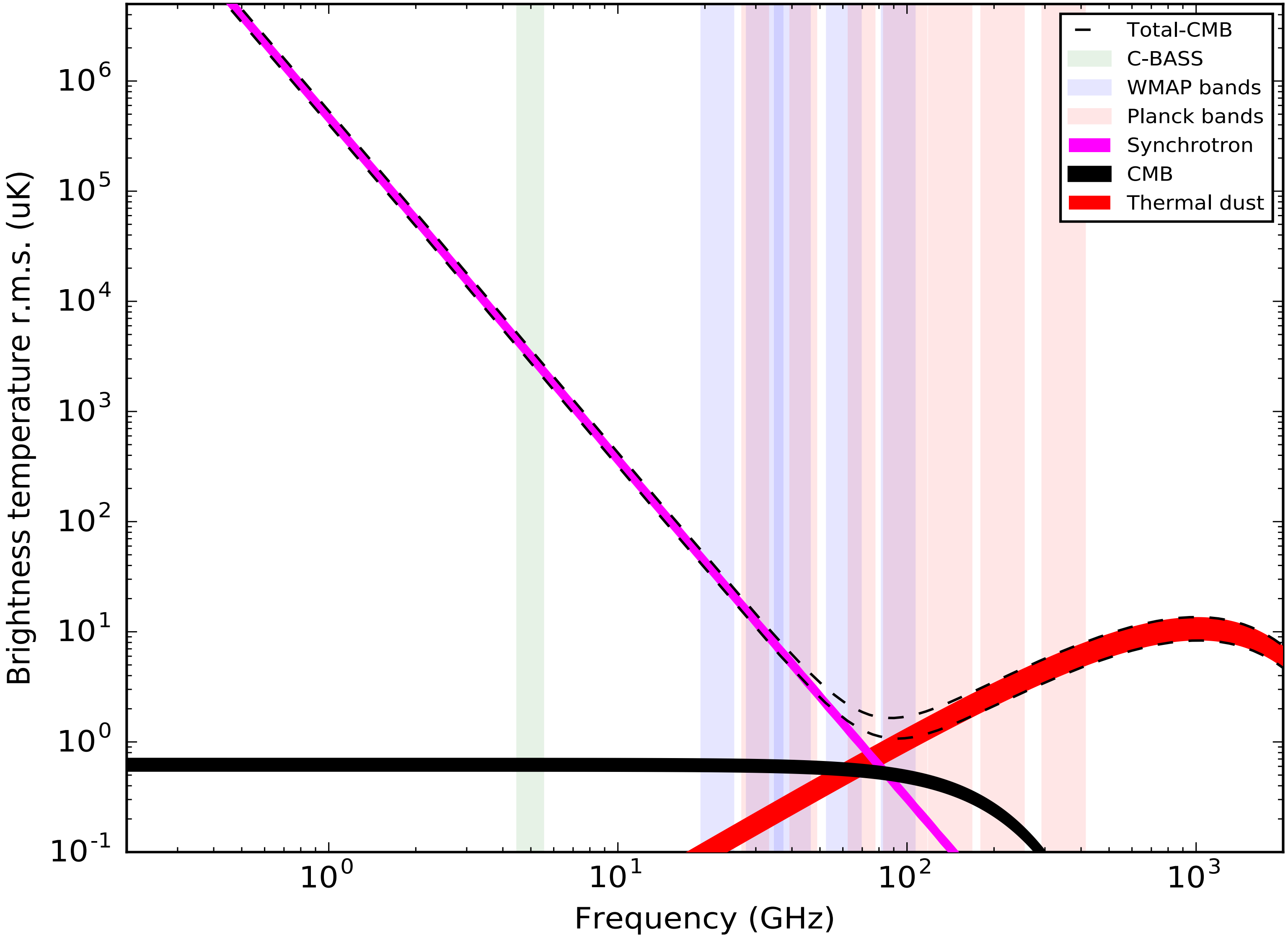
Why a 5 GHz survey?

Polarization

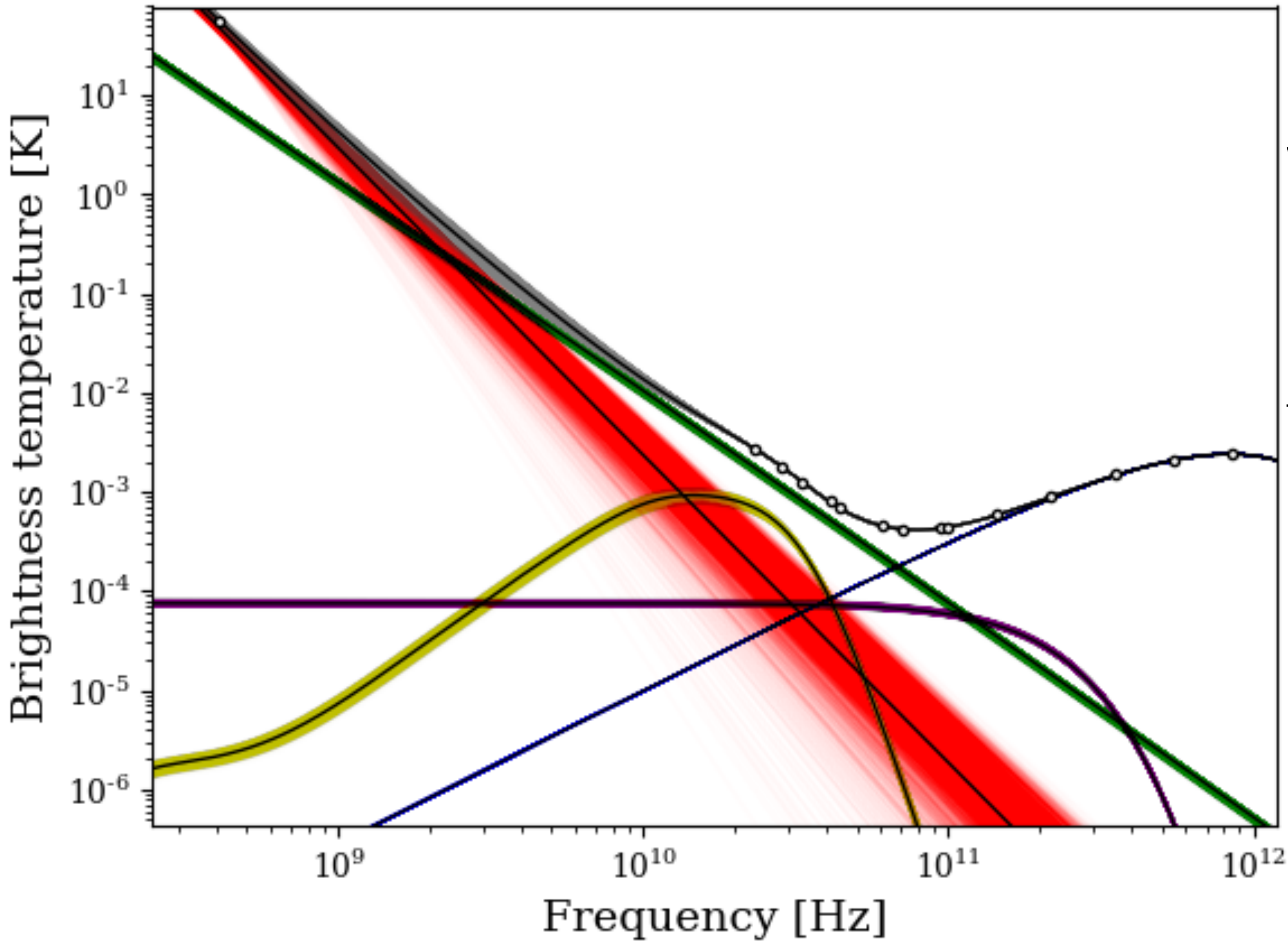


Why a 5 GHz survey?

Polarization



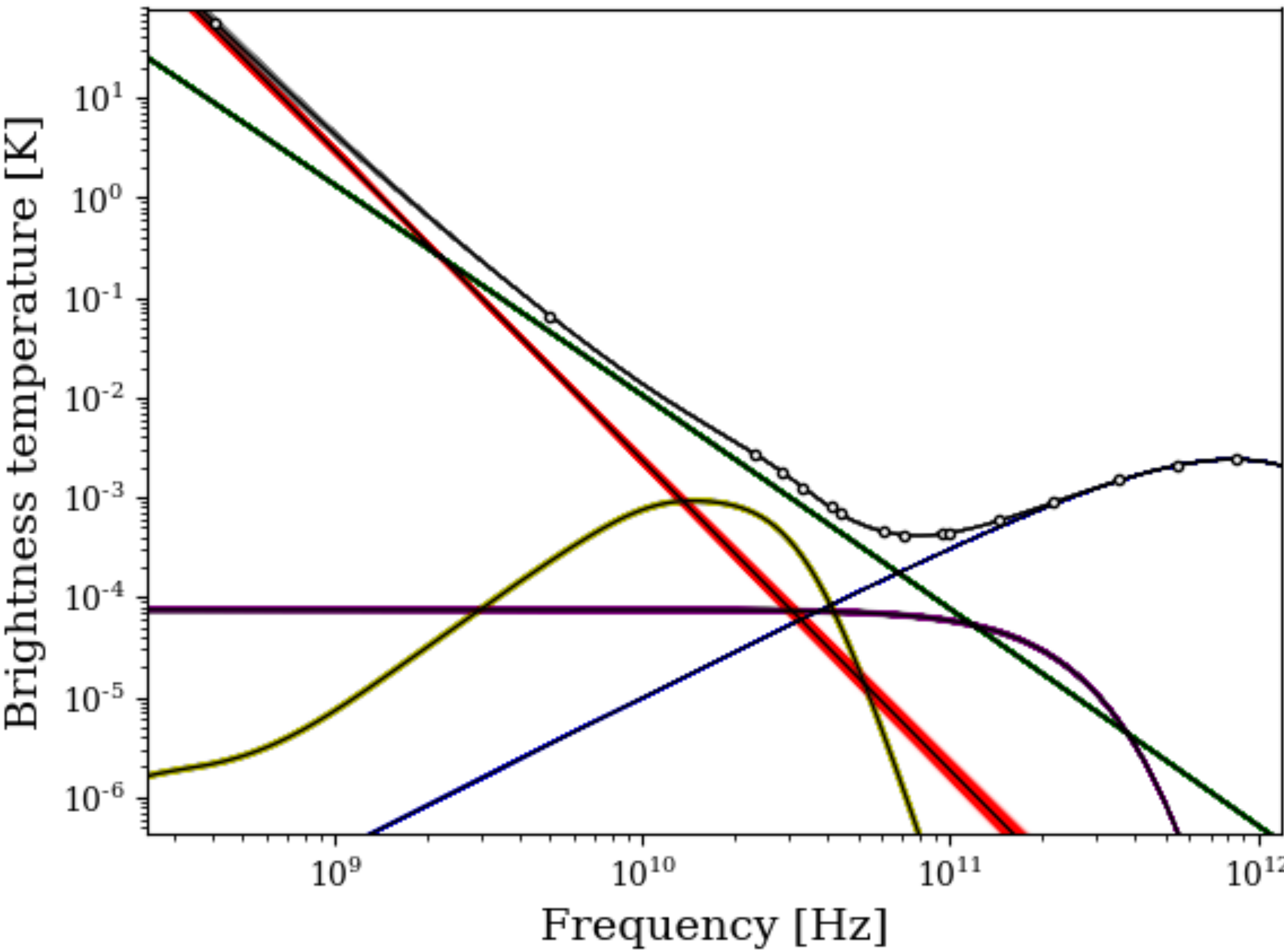
CBASS simulations - *I*



Haslam
WMAP
Planck

High-foregrounds pixel (1-deg)

CBASS simulations - *I*

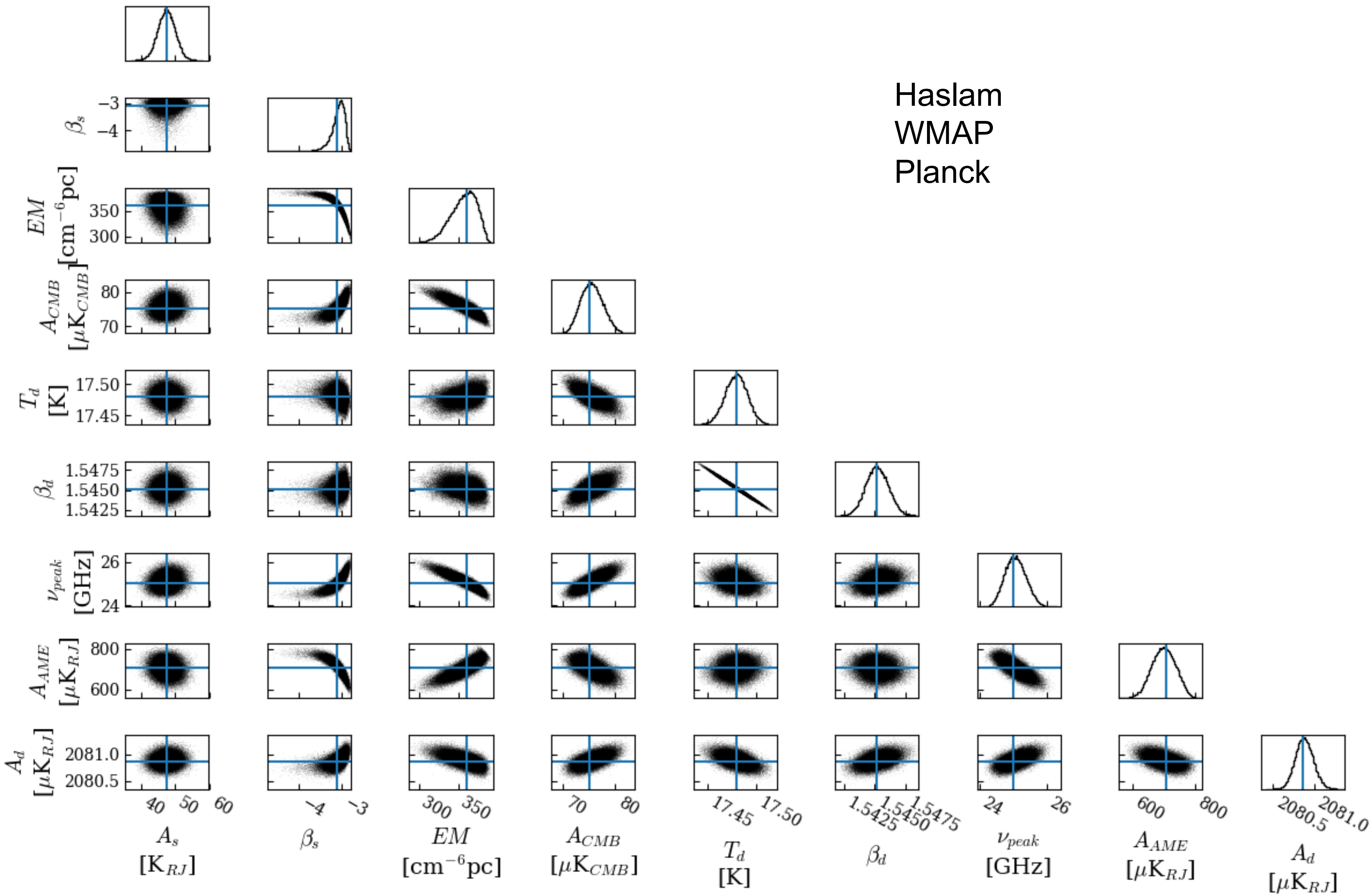


Haslam
WMAP
Planck
+ CBASS

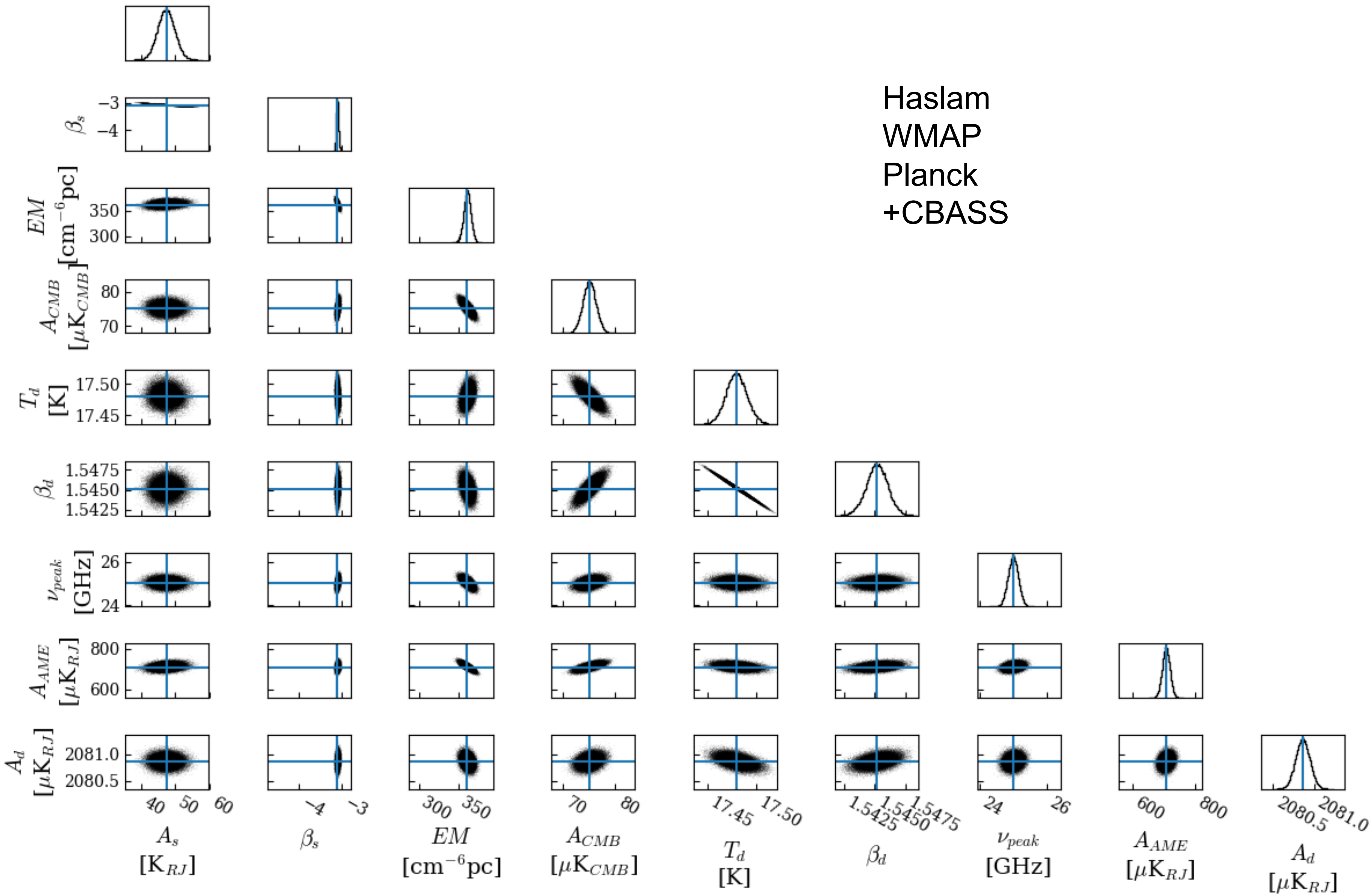
High-foregrounds pixel (1-deg)

CBASS simulations - I

Haslam
WMAP
Planck

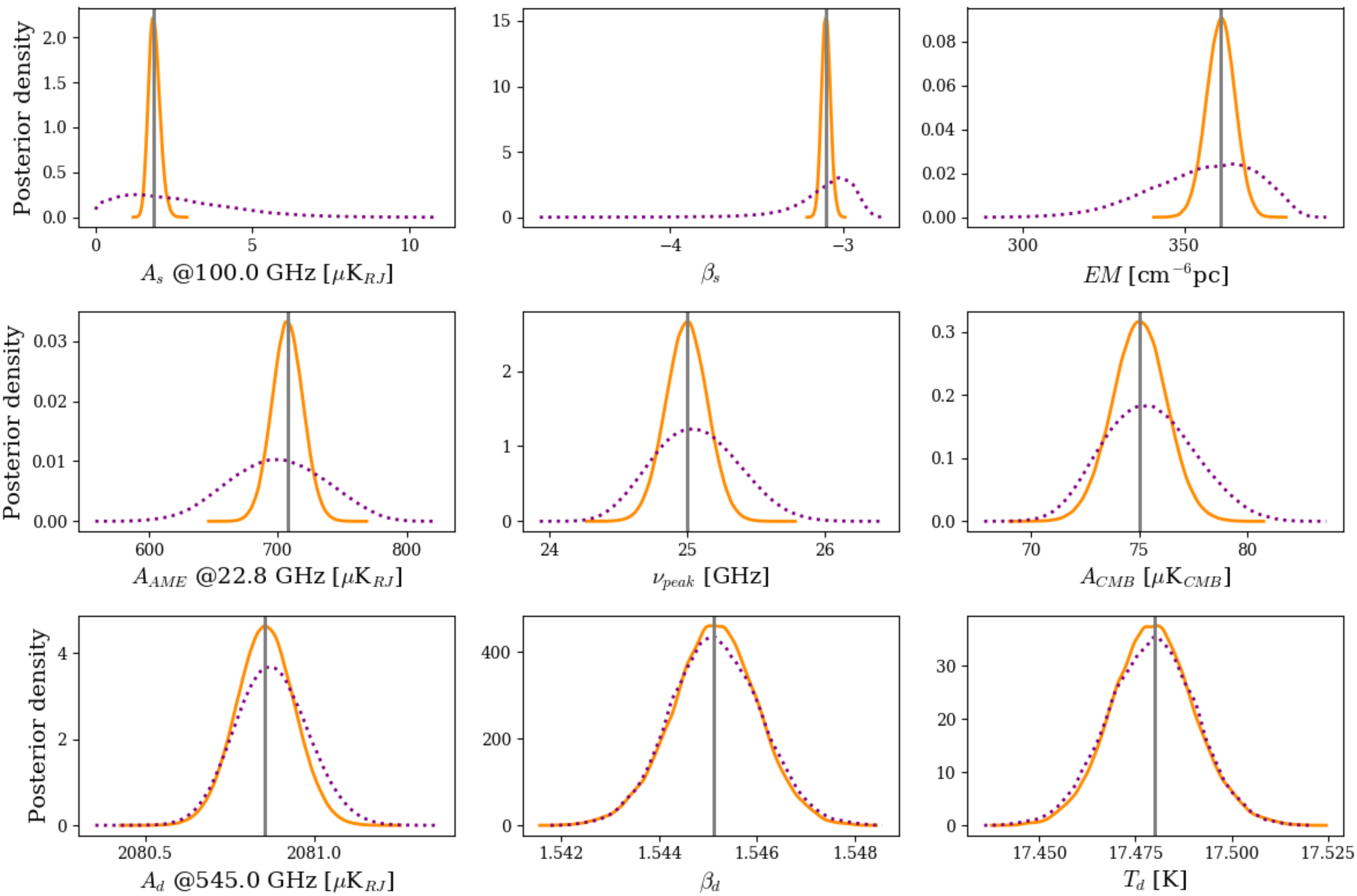


CBASS simulations - I

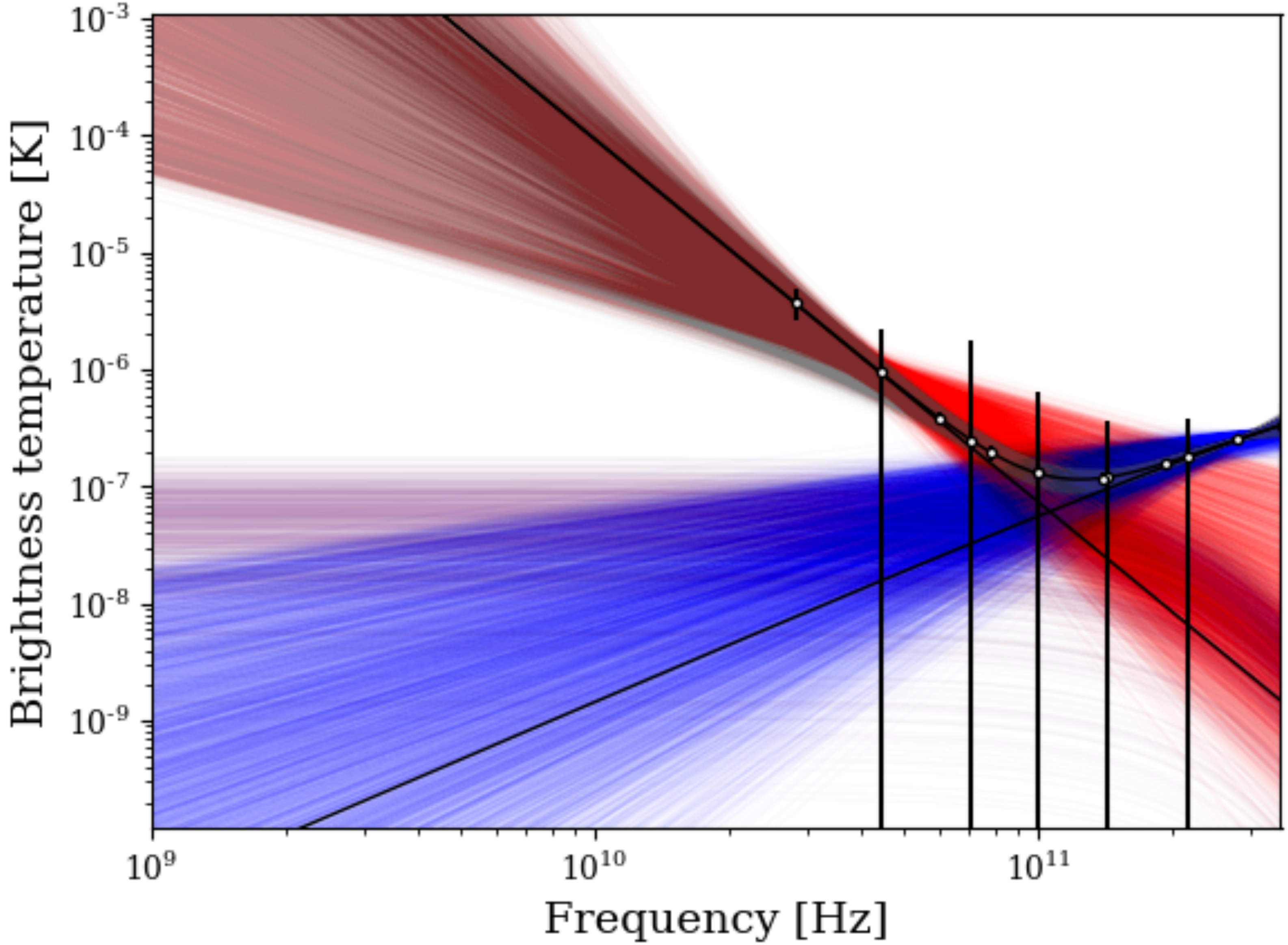


Haslam
WMAP
Planck
+CBASS

CBASS simulations - I



CBASS simulations - *P*

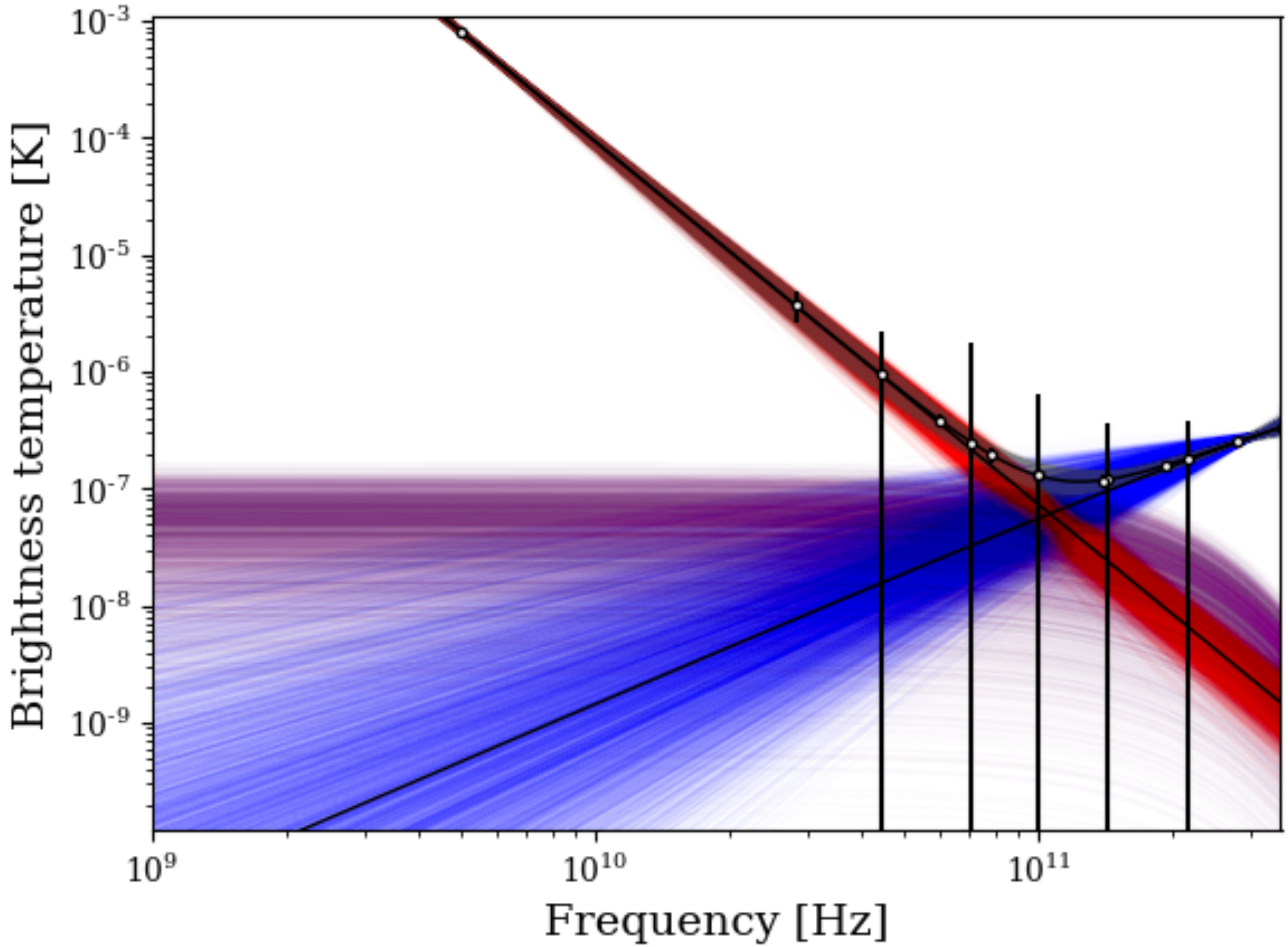


Planck
'LiteBIRD'

Low-foregrounds Pixel (3-deg)

$r = 0$

CBASS simulations - *P*

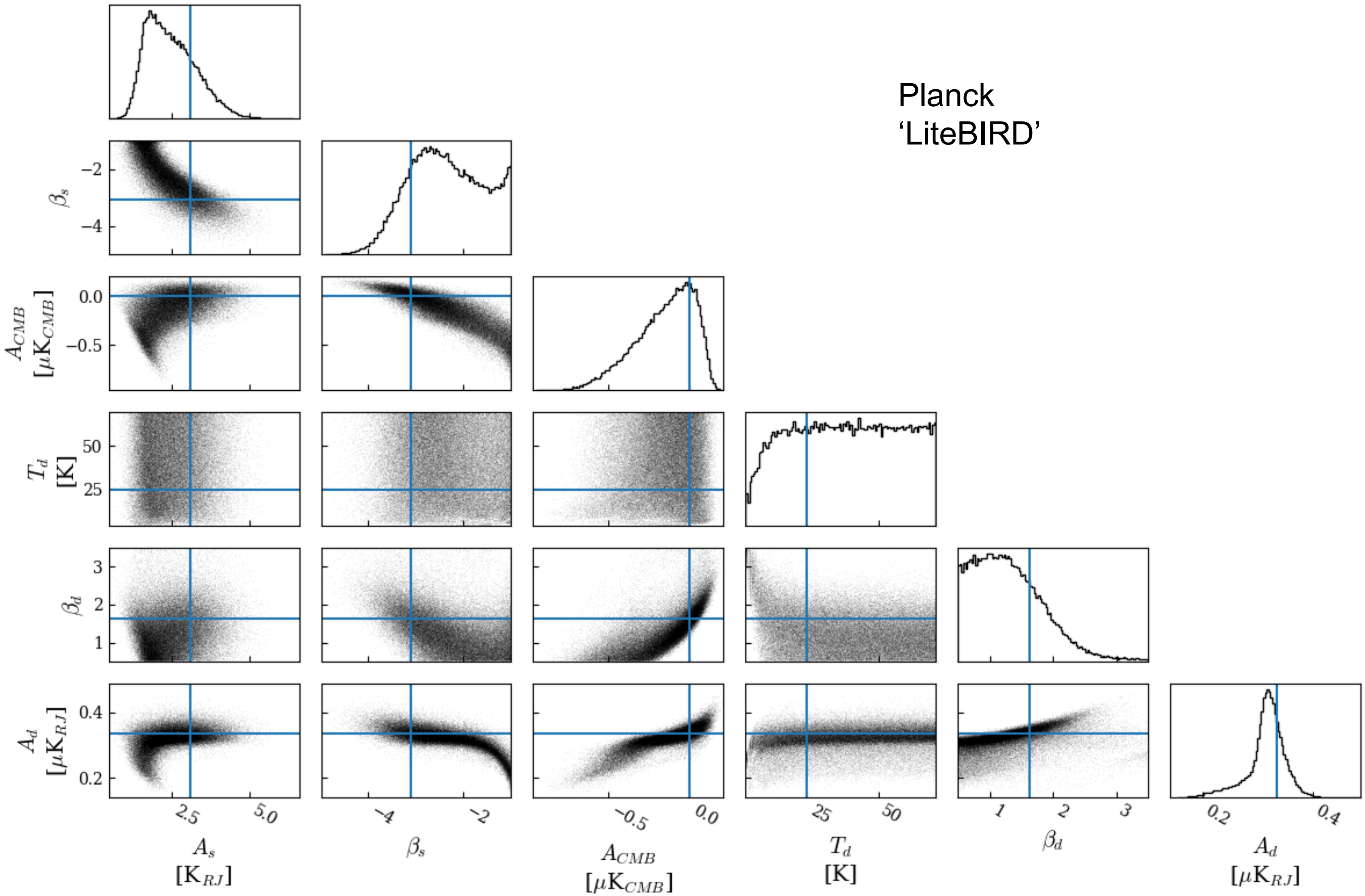


Planck
'LiteBIRD'
+CBASS

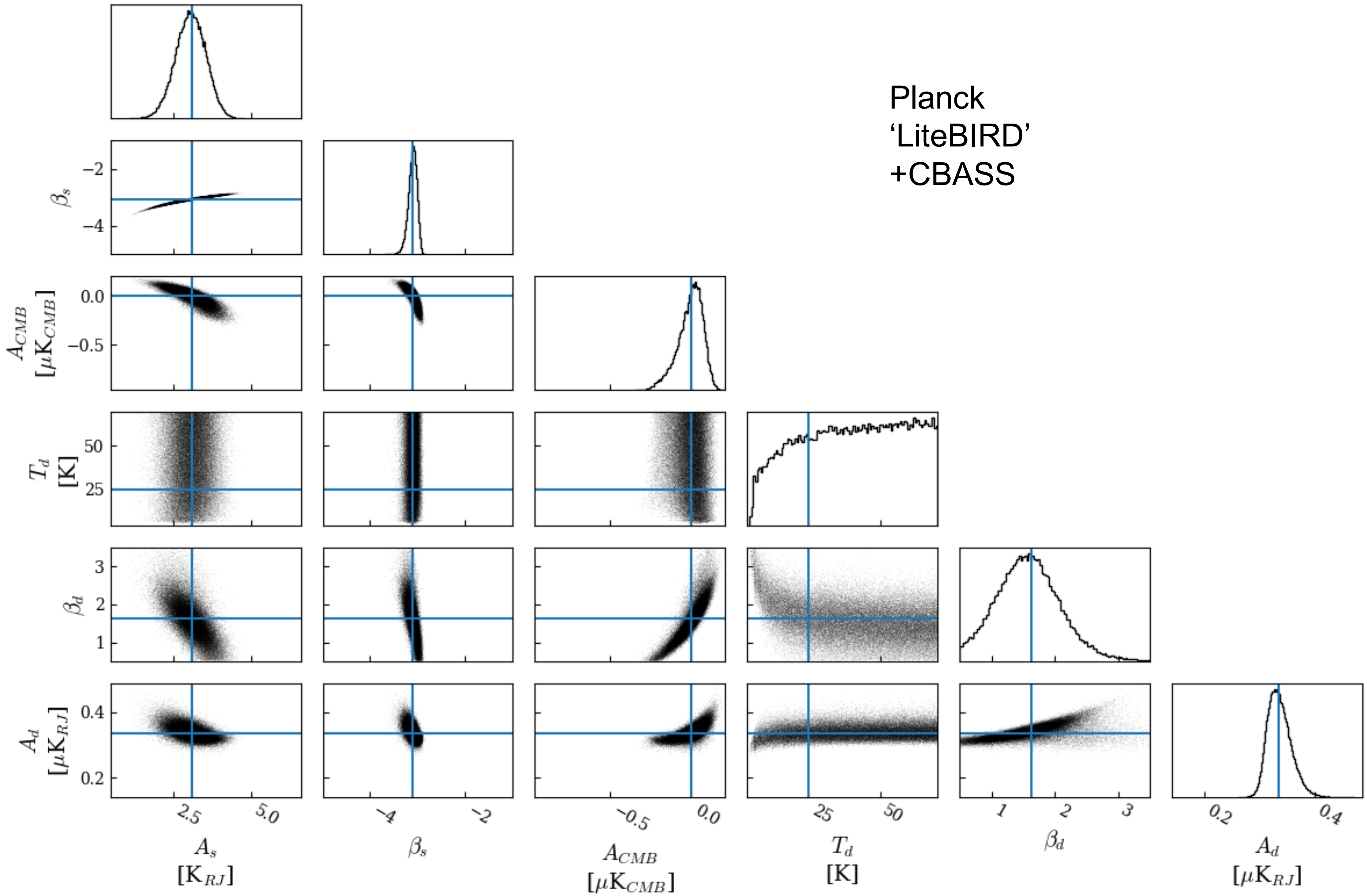
Low-foregrounds Pixel (3-deg)

$r = 0$

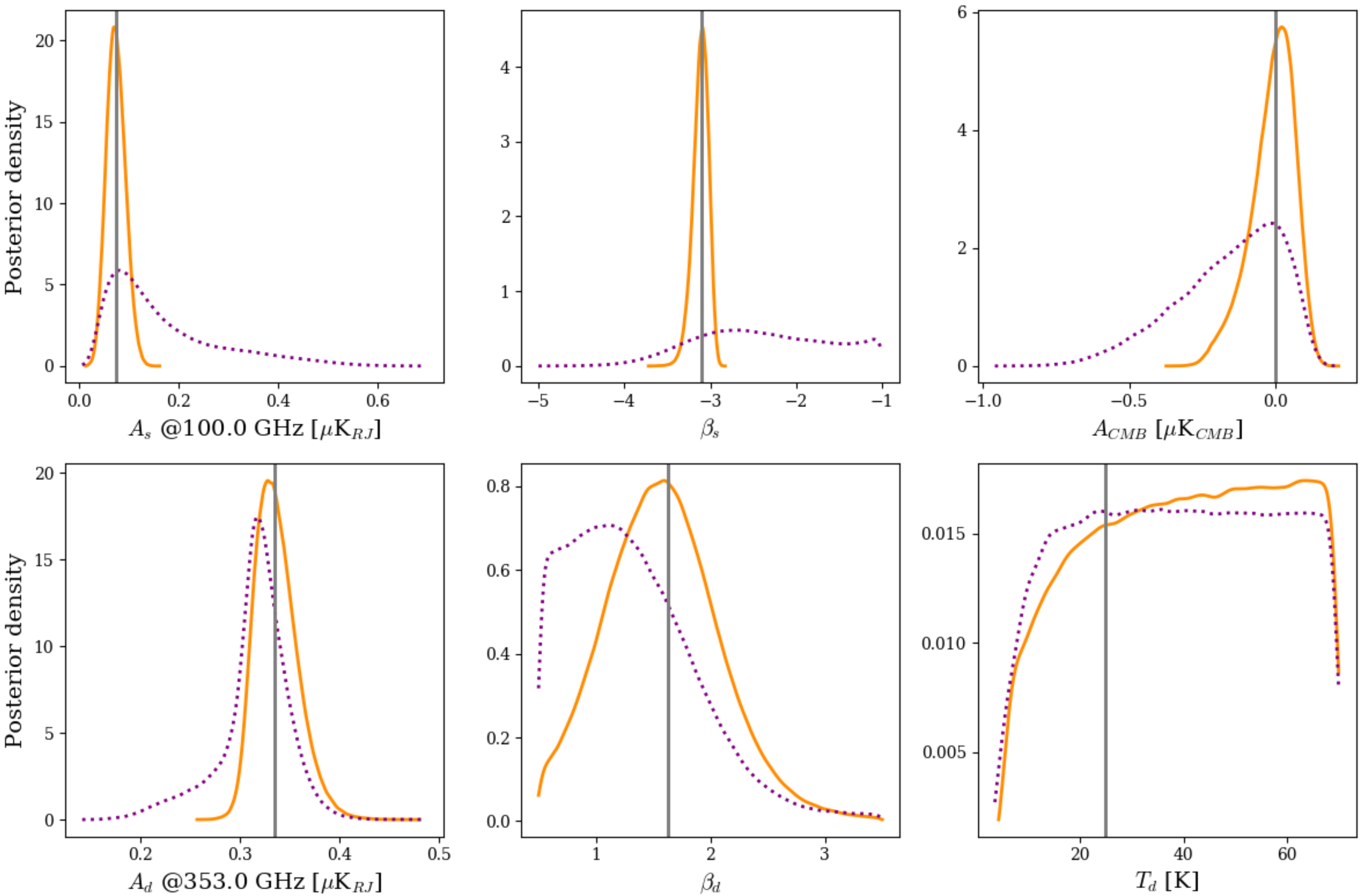
CBASS simulations - *P*



CBASS simulations - *P*



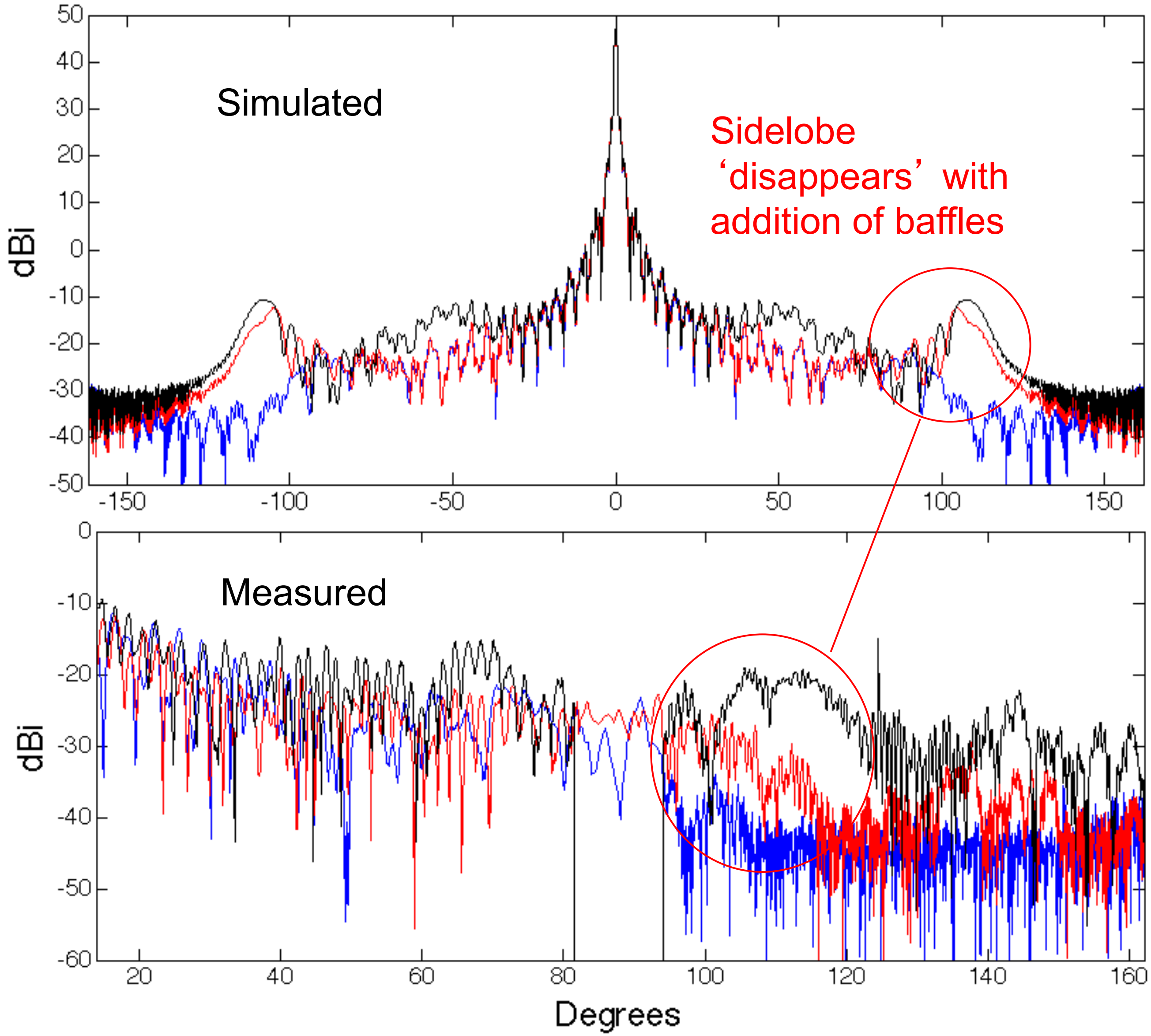
CBASS simulations - *P*



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

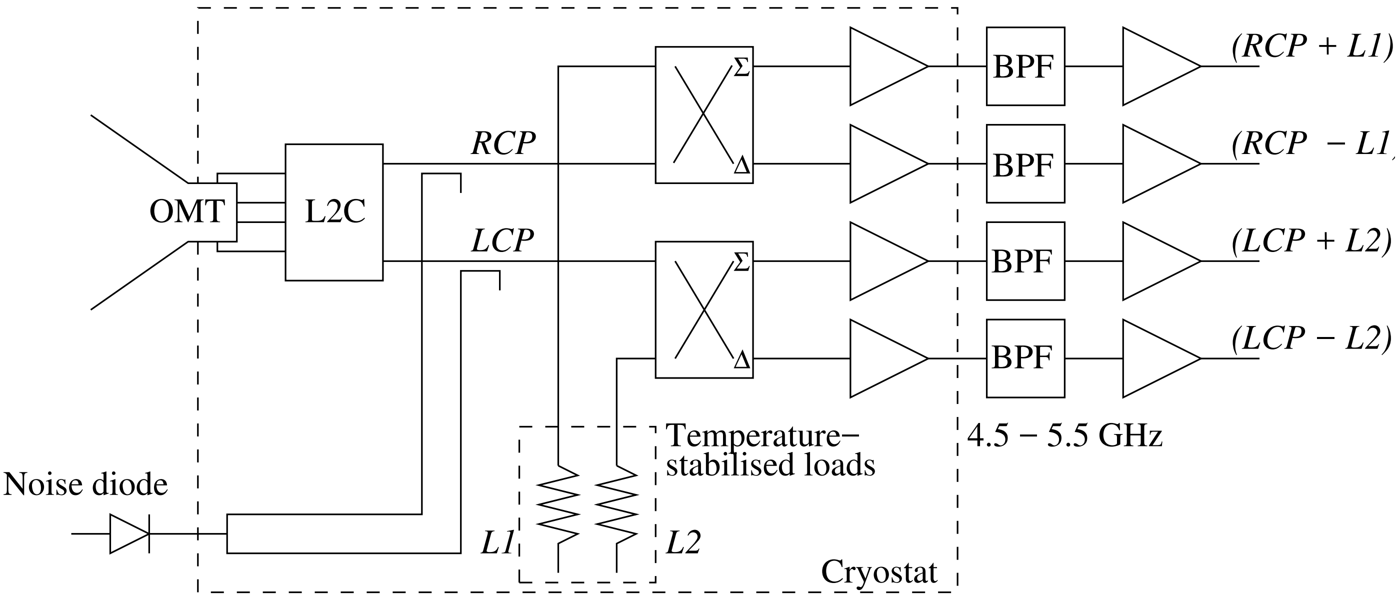


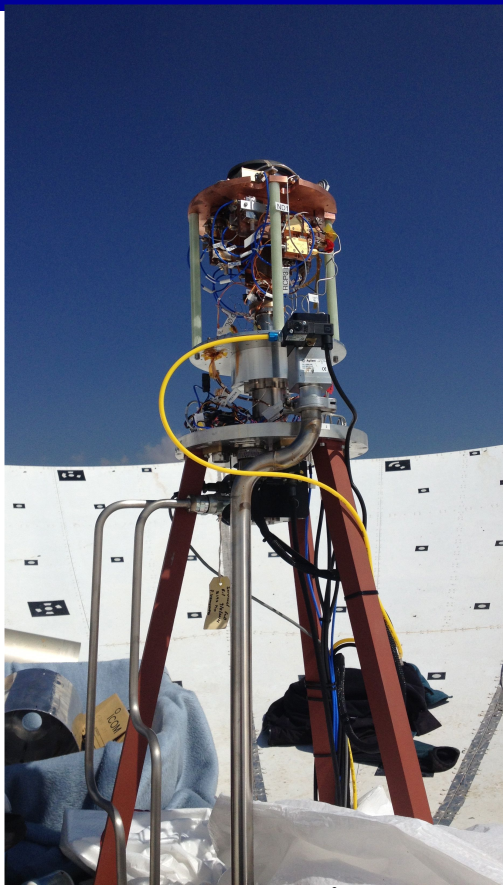
e Holler et al. 2011, arXiv:1111.2702v2)

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

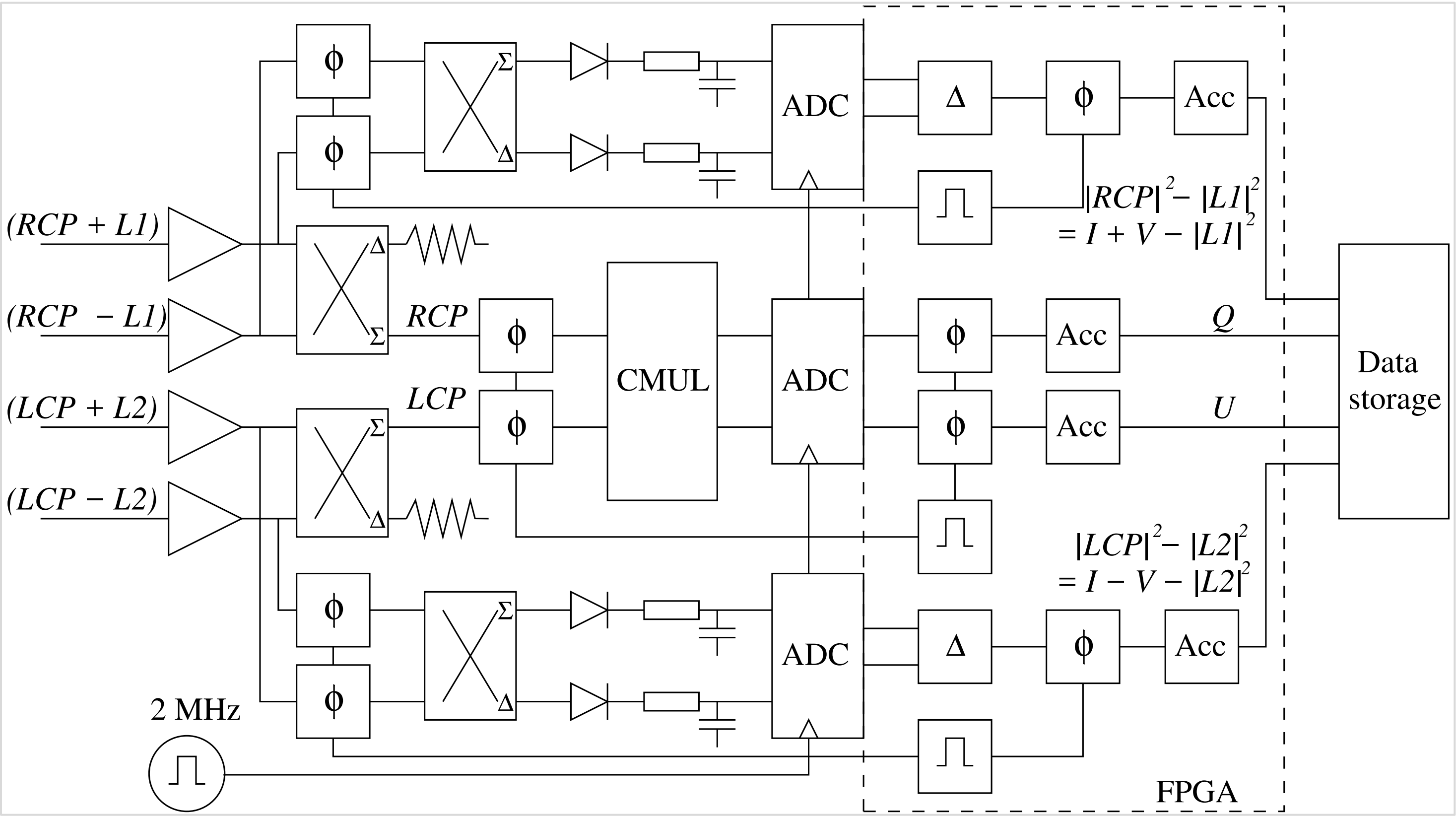




Both receivers use correlation polarimeter and continuous comparison radiometer:

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

C-BASS North Receiver

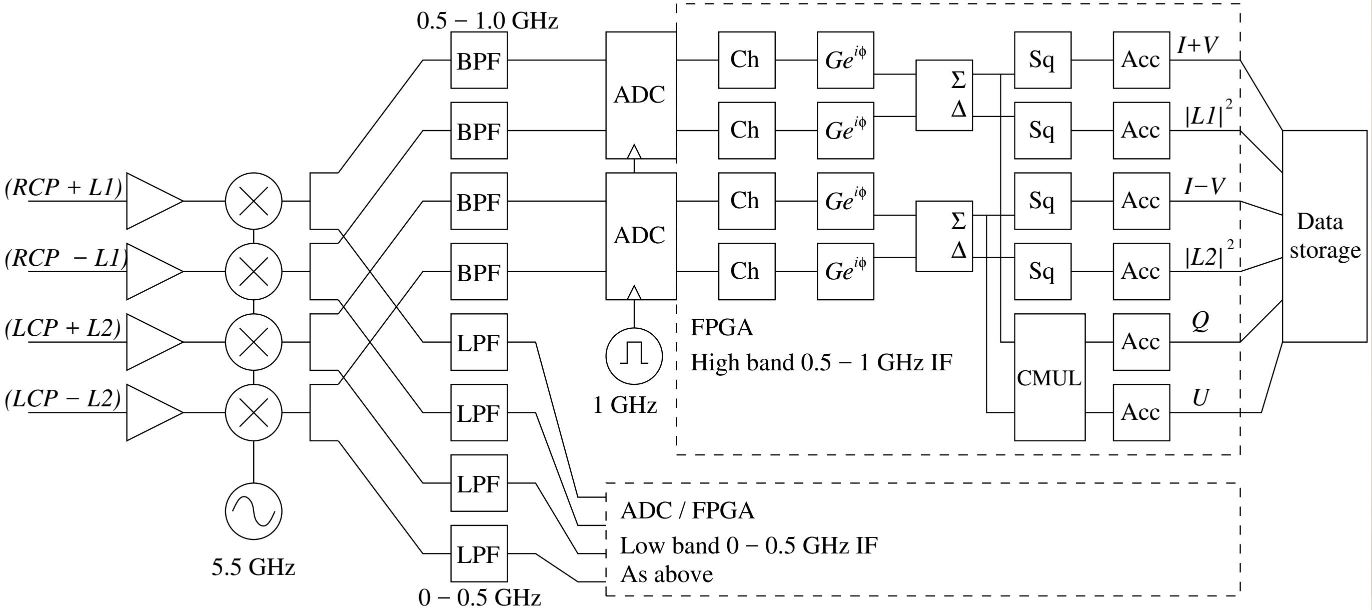


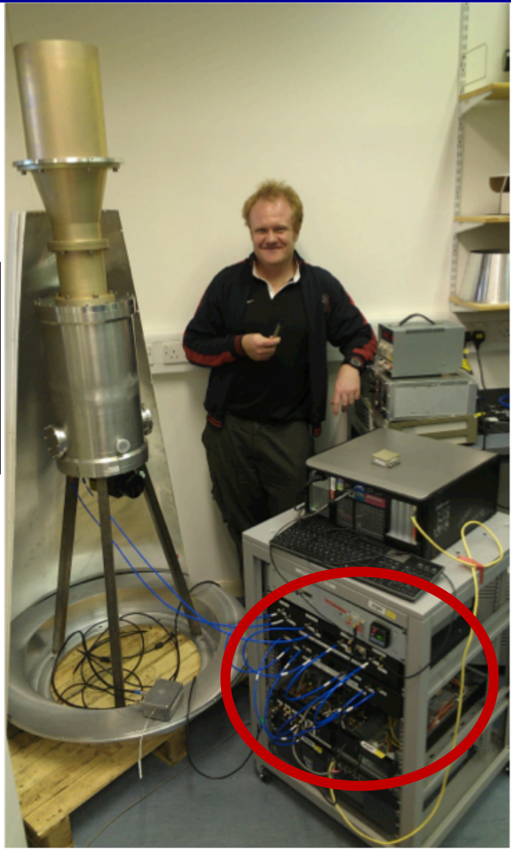
Analogue polarimeter/radiometer – all done with hybrids and diodes…

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:

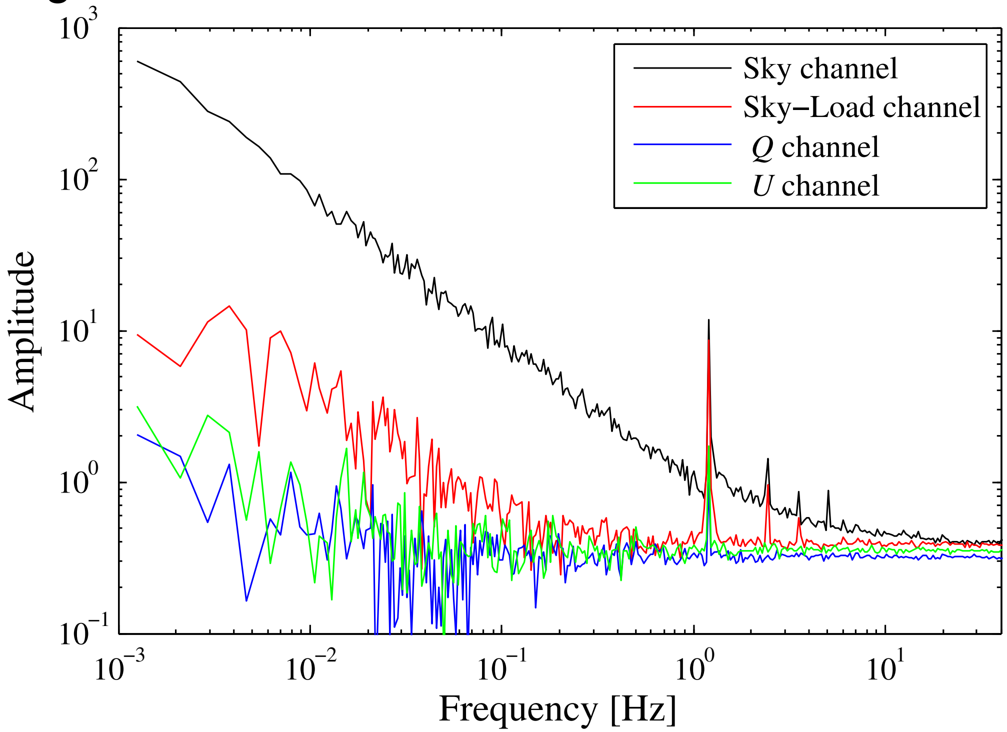
Downconversion to 0 – 0.5, 0.5 – 1 GHz

Sample at 1 GHz, channelise to 64 channels each, calibrate gains

Square and difference sky and load → I ; correlate RCP, LCP → Q, U

Receiver noise power spectra

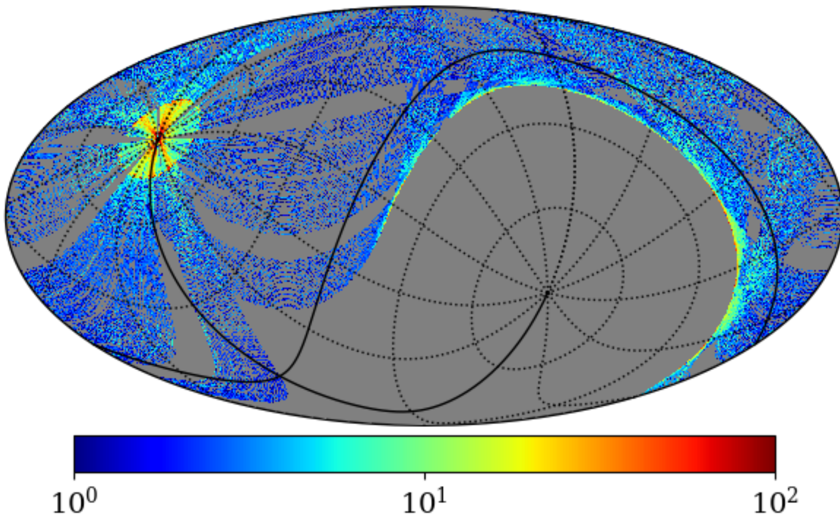
Continuous-comparison radiometer rejects 1/f noise by comparing the sky signal to a stabilized load signal.

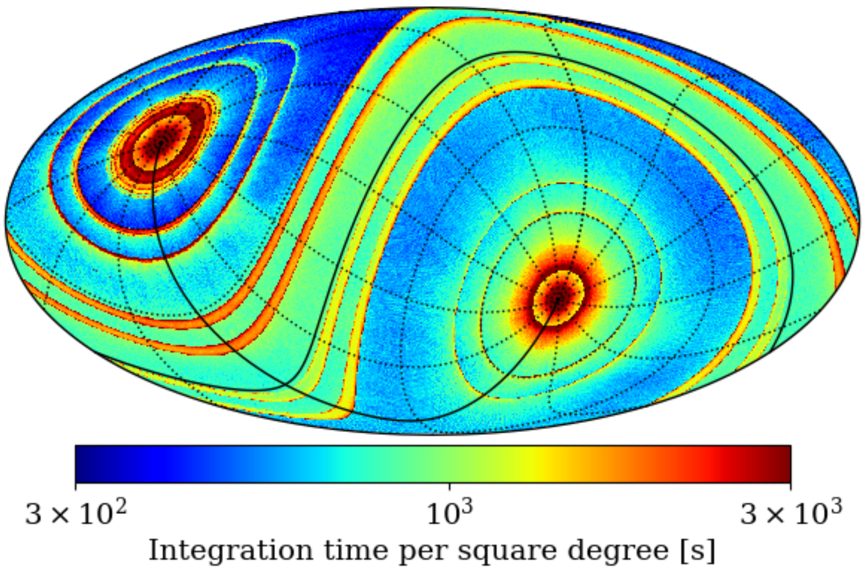


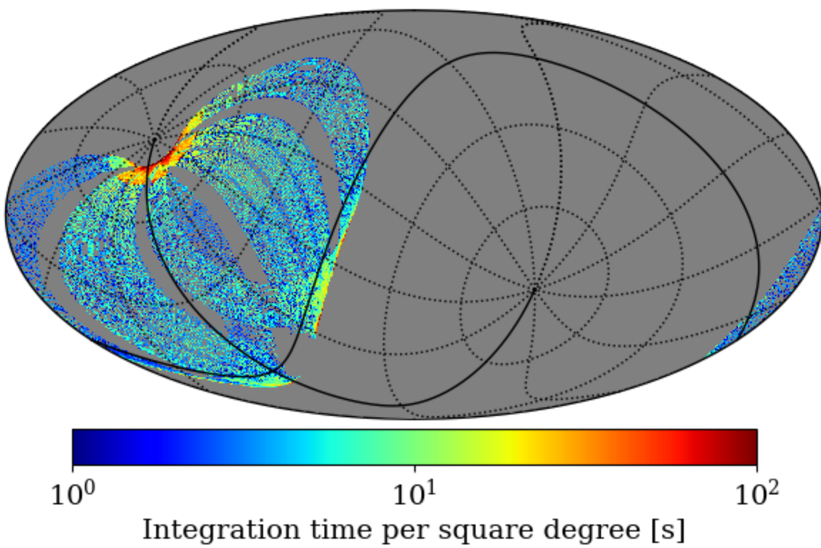
- 1/f in single I channel is reduced by a factor of ~20 relative to raw sky signal
  - knee frequency moved from ~ 4Hz to 0.2Hz
- Q and U have knee-frequencies < 10mHz
- The receiver is stable over full azimuth scans (90s) – can extract data over full-sky

Scan Strategy

- 360 deg azimuth scans at elevation of poles + 10, 20, 30…
- Scan as fast as possible: ~4 deg/s
- One scan ~90 s
- Use 5 slightly different scan speeds so fixed frequency ≠ same sky modes

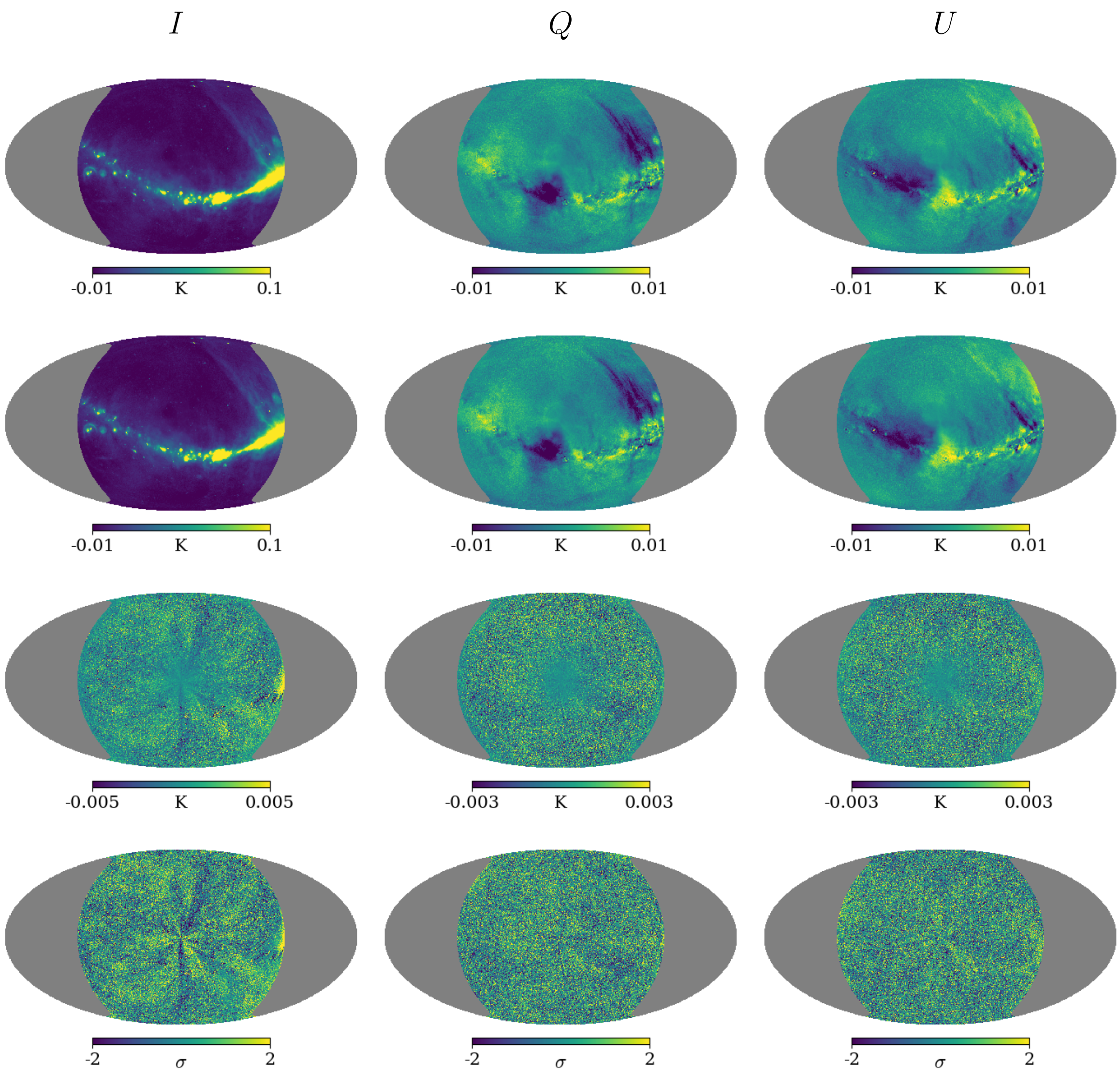




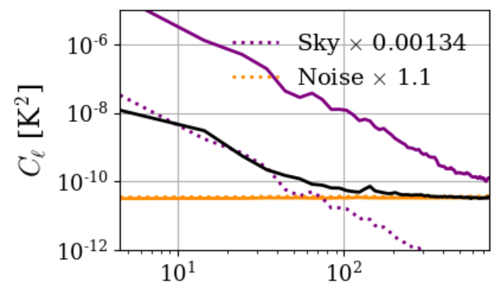


CBASS-N data: Null tests

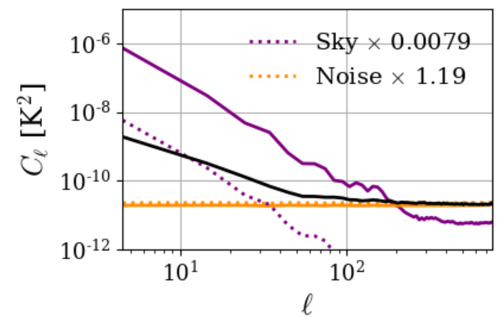
Initial data set – elevation 37 only (through NCP) – about 35% of N data



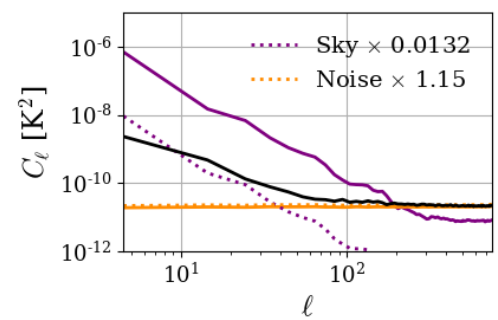
I



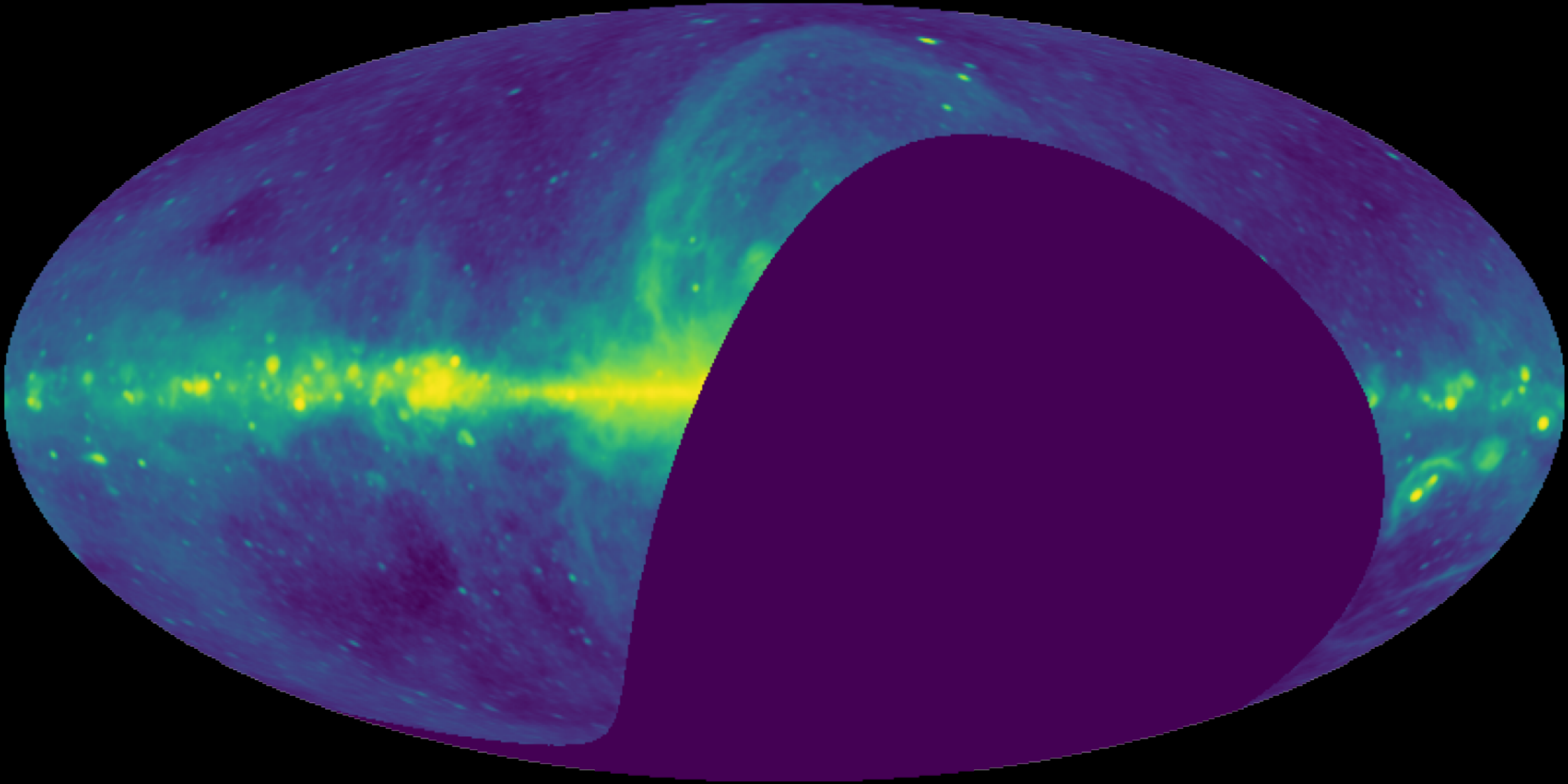
Q



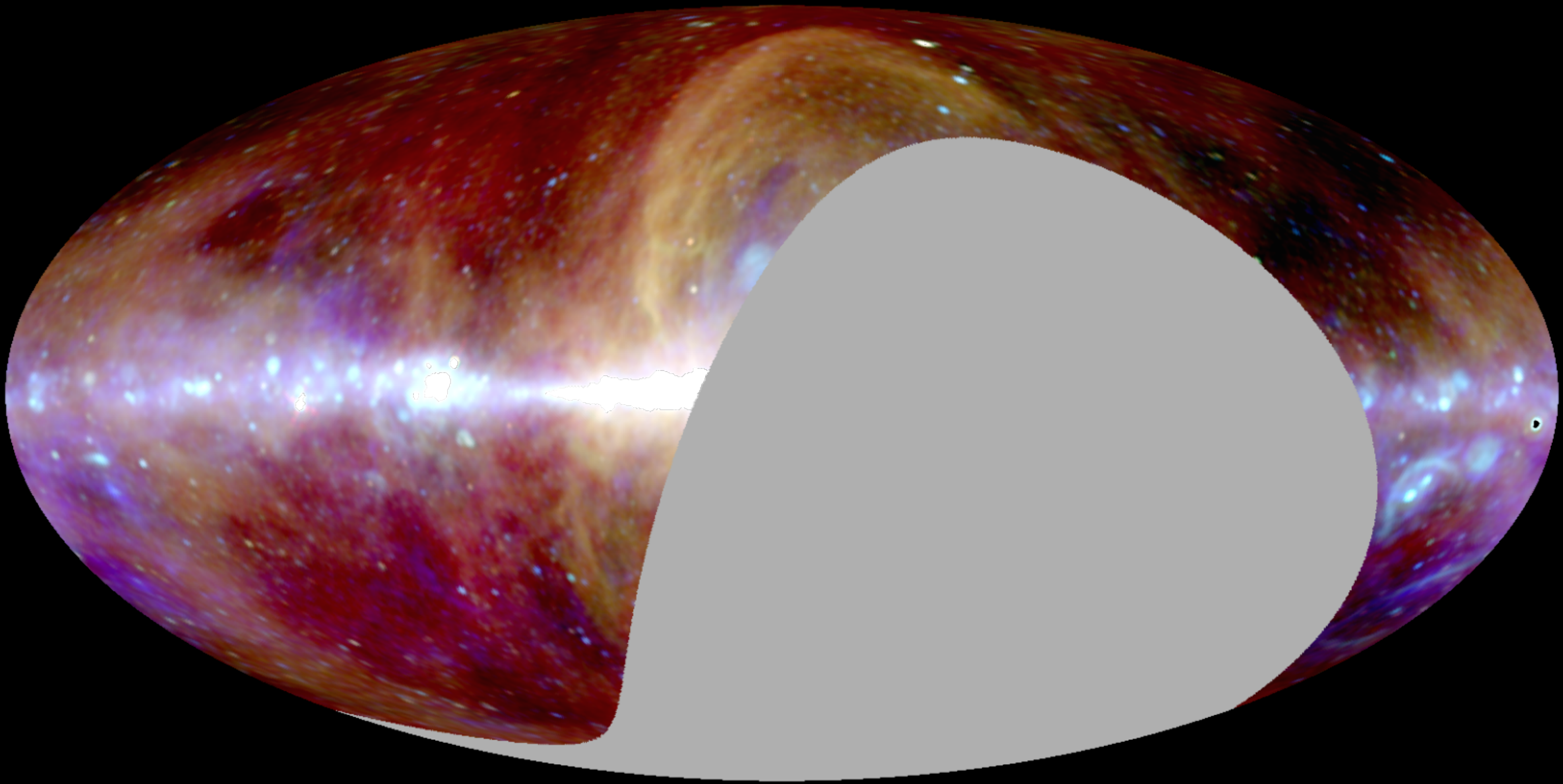
U



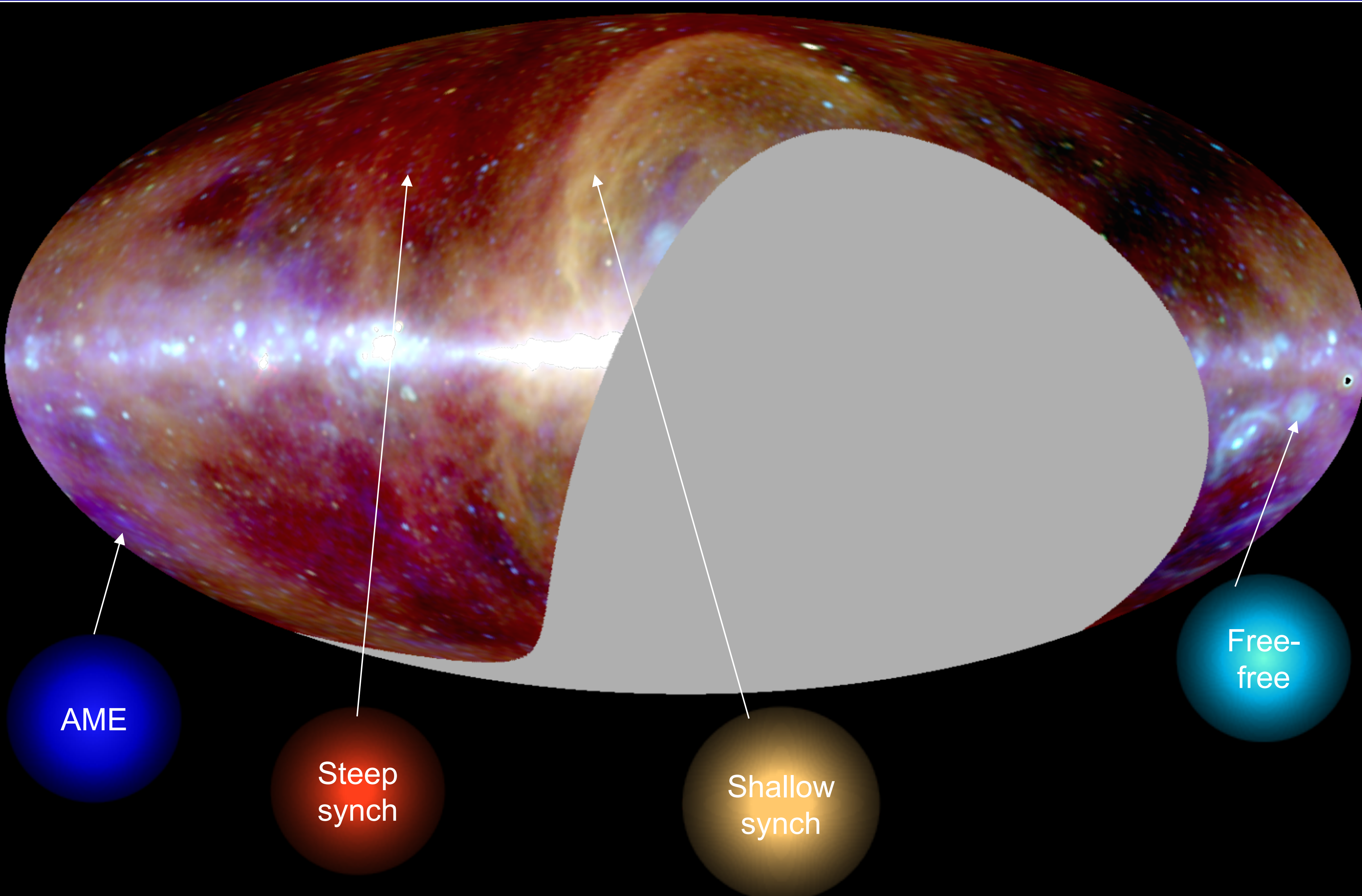
CBASS-N I



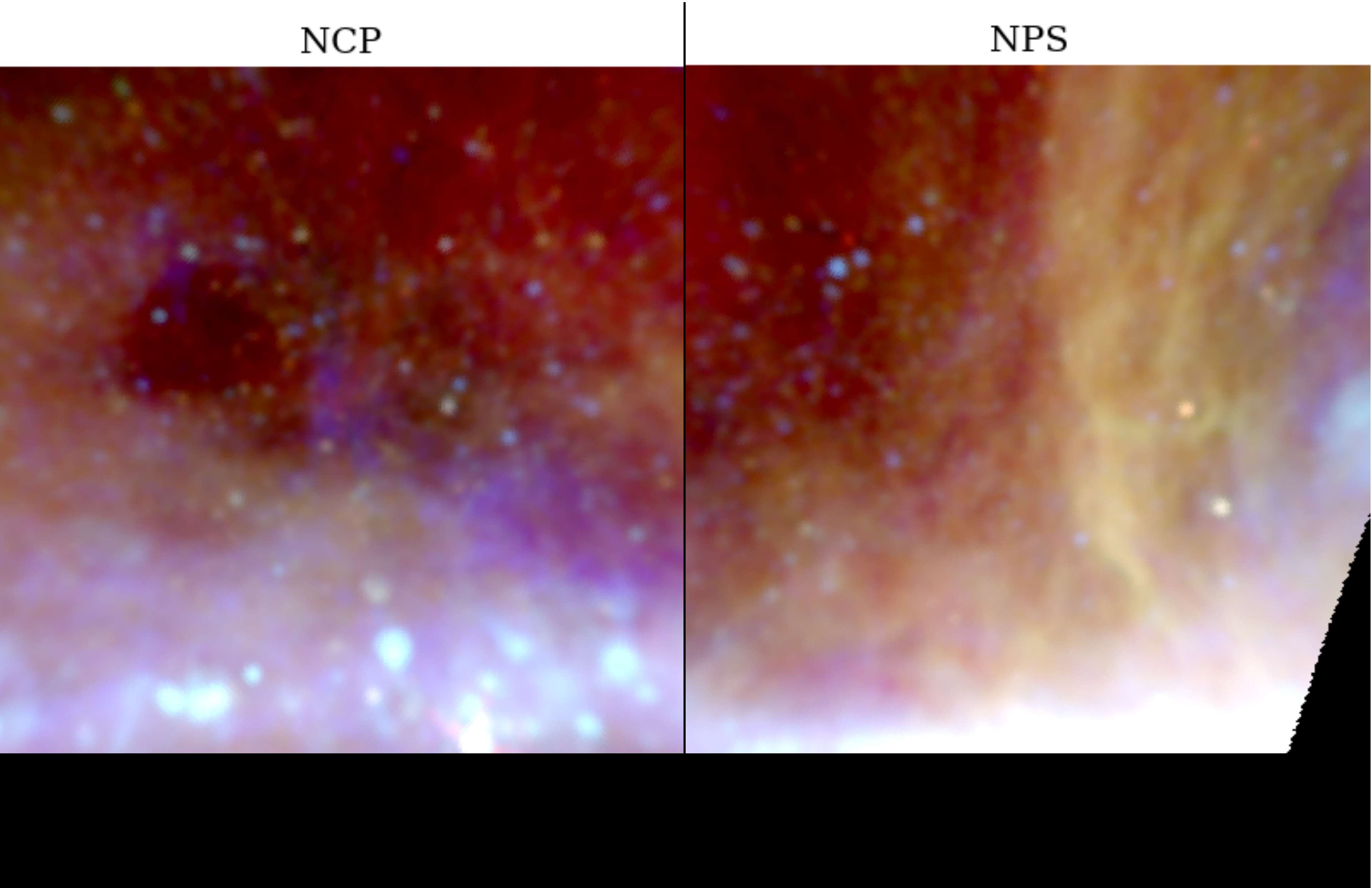
408 MHz - 5 GHz – 23 GHz



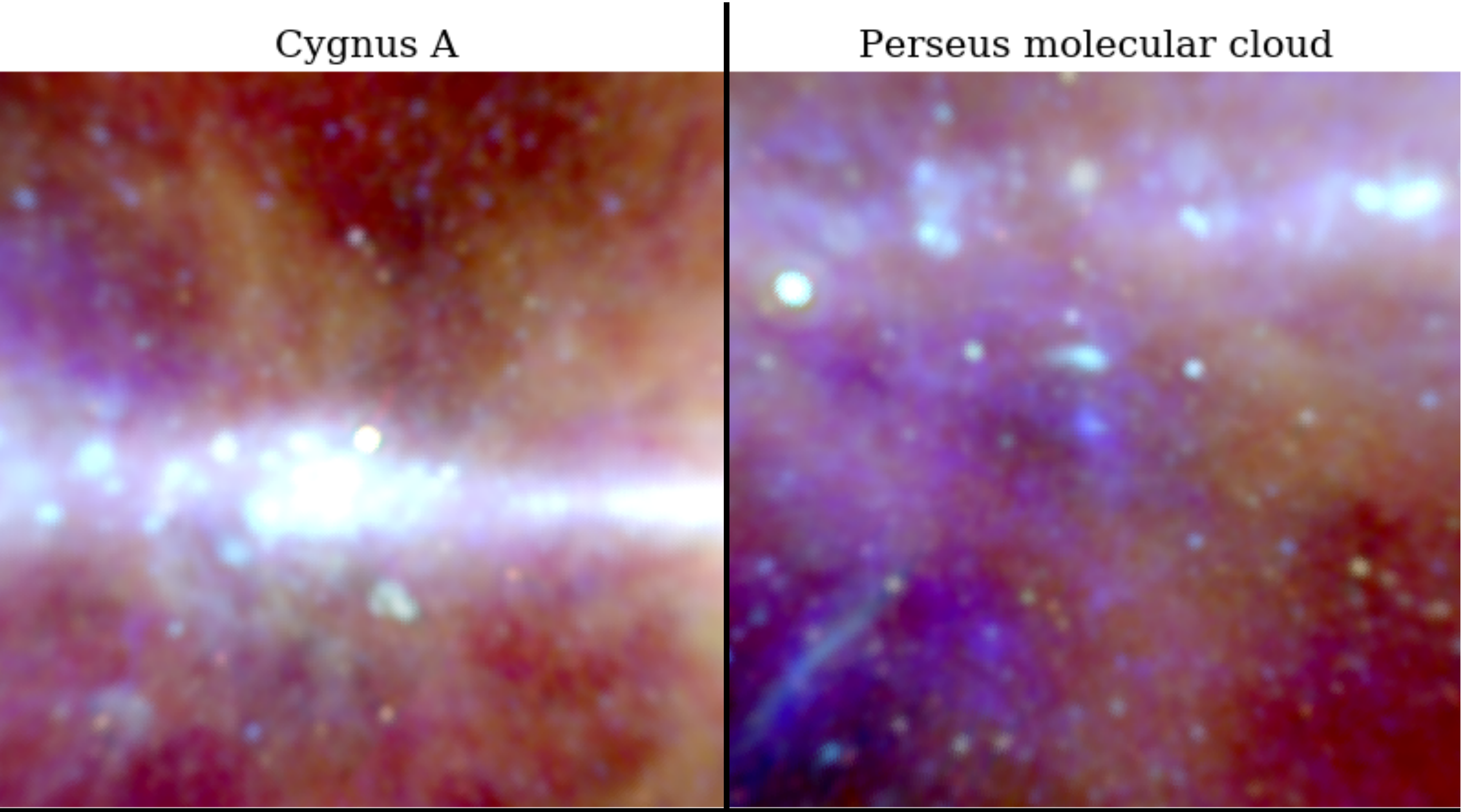
408 MHz - 5 GHz – 23 GHz



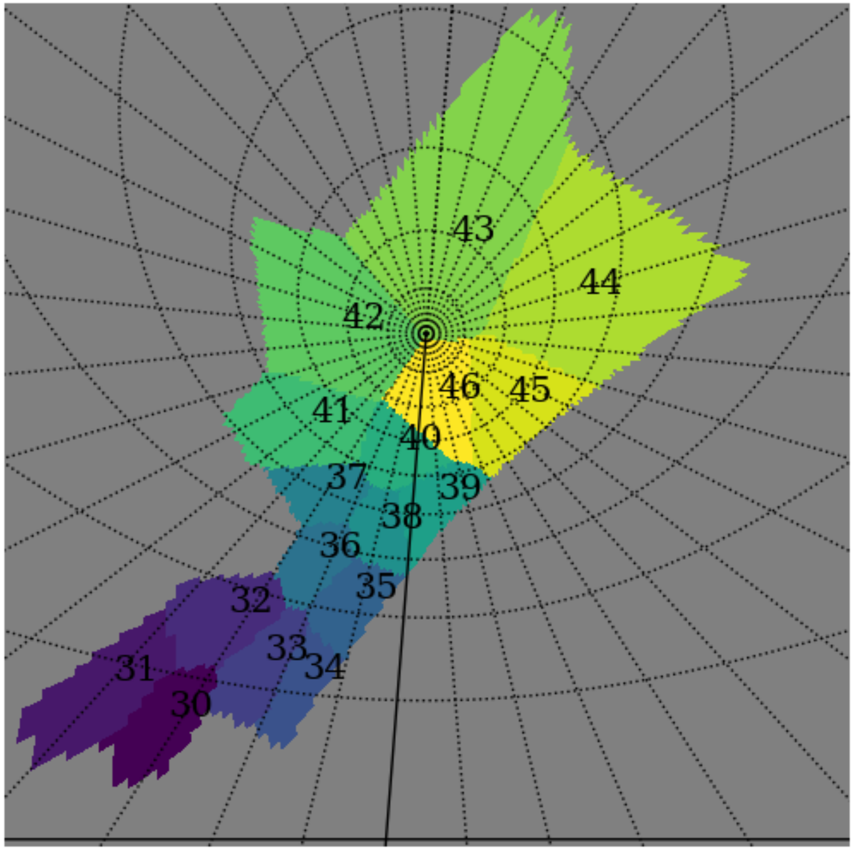
3-colour zoom-ins

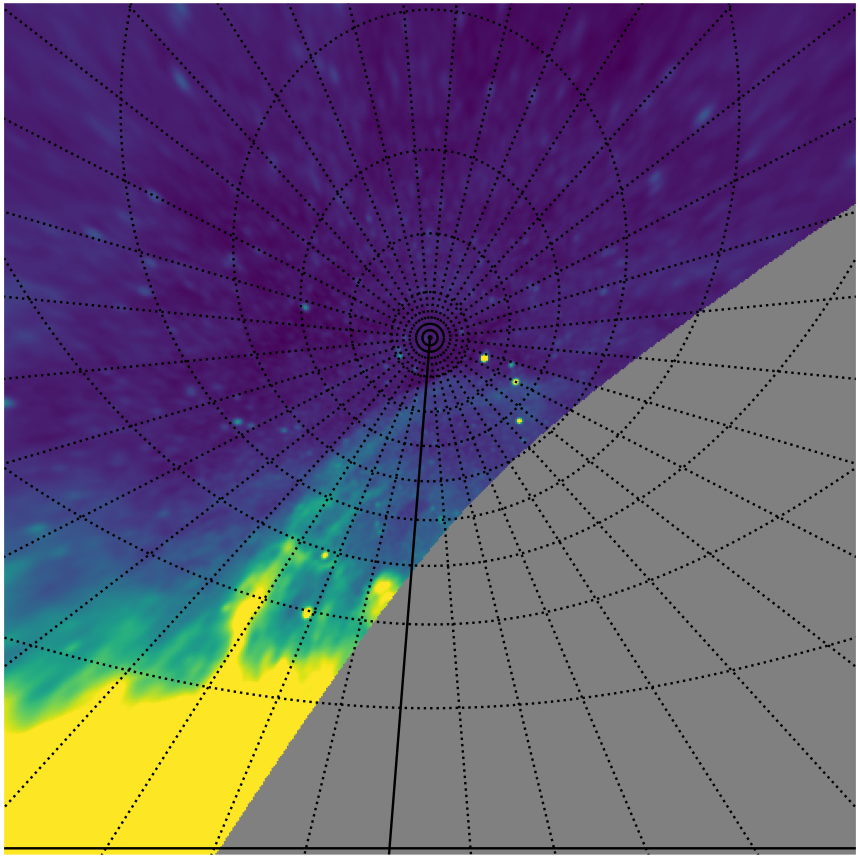


3-colour zoom-ins

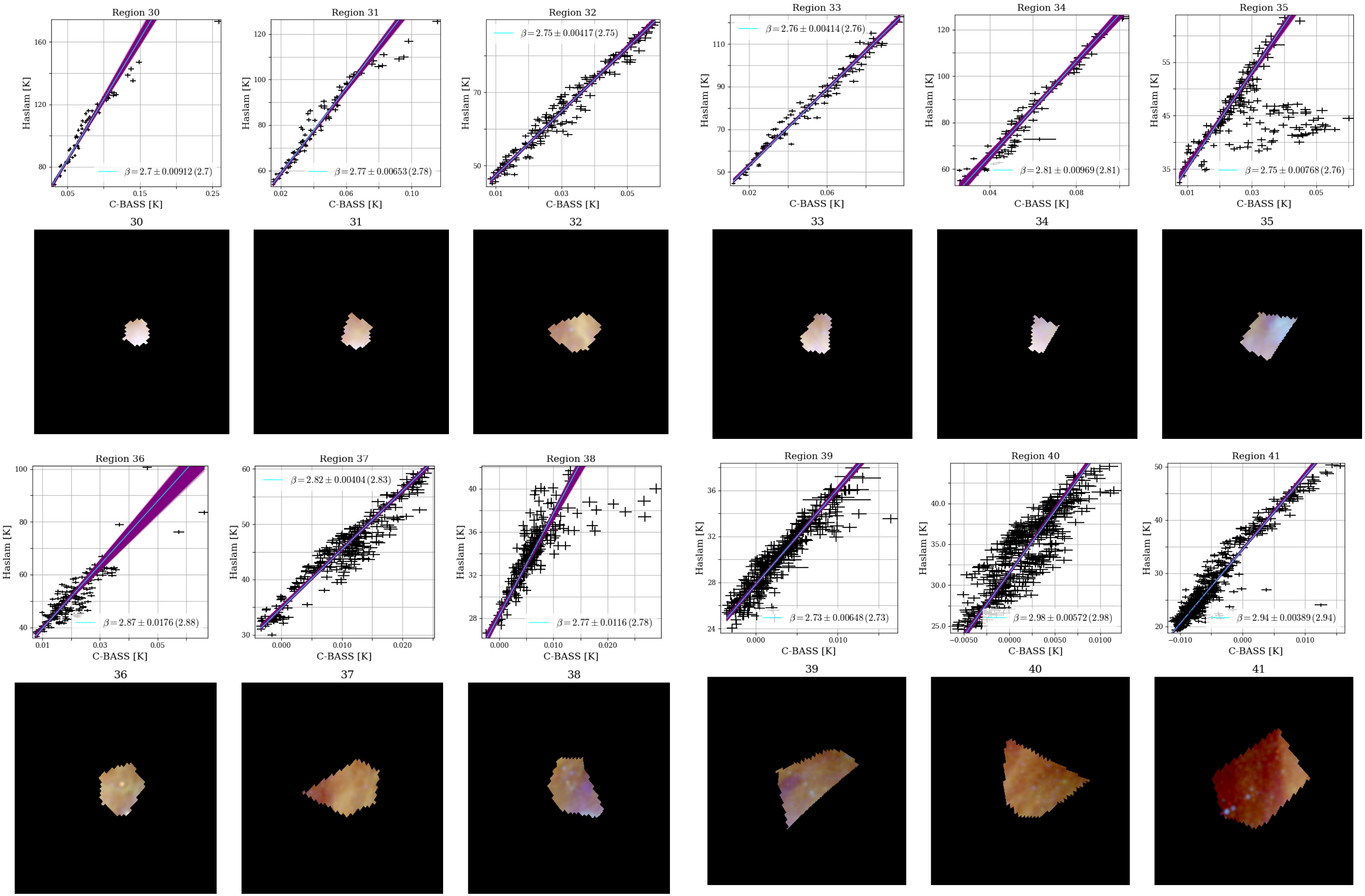


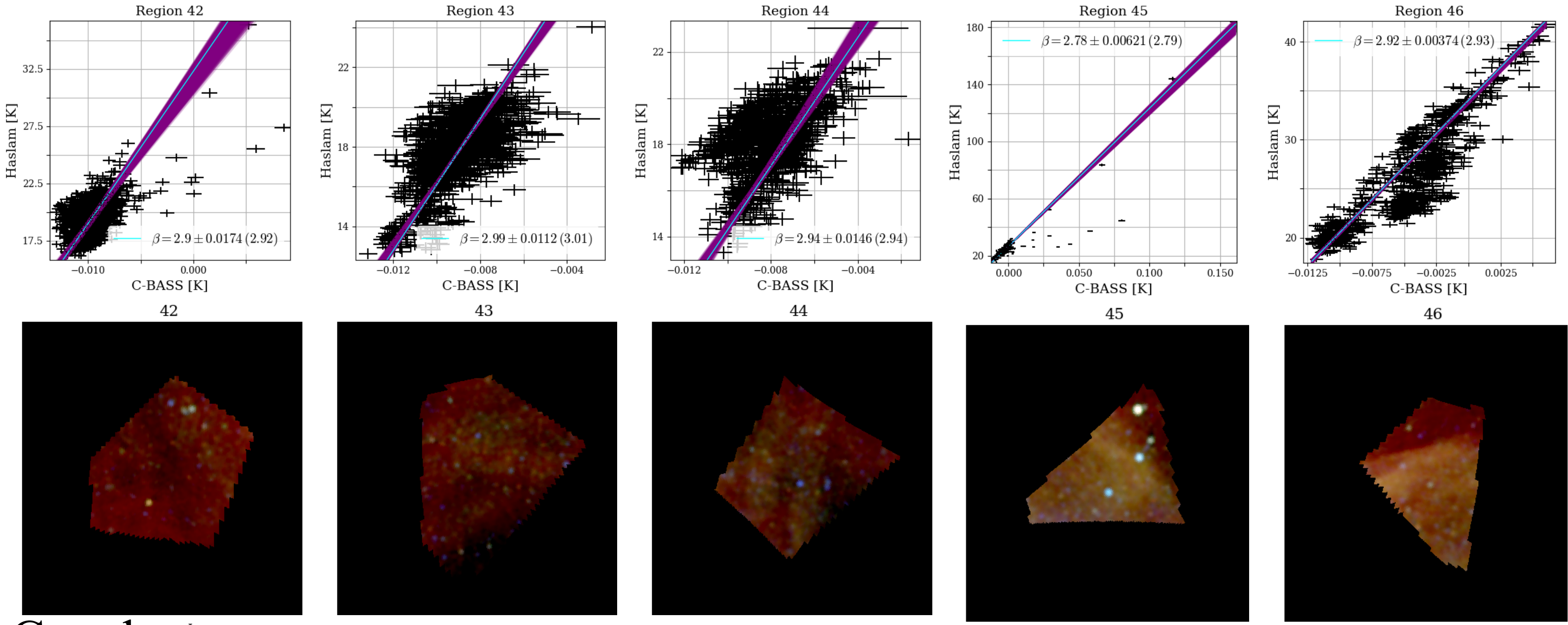
First look at the spectral index – *TT* plots





- *TT* plots Haslam – C-BASS
- Fit for a single power law plus outliers (ignored in fit for β)
- Work our way up the North Polar Spur
- β generally gets steeper but lots of complication…


Region 30
$\beta = 2.7 \pm 0.00912\,(2.7)$
Region 31
$\beta = 2.77 \pm 0.00653\,(2.78)$
Region 32
$\beta = 2.75 \pm 0.00417\,(2.75)$
Region 33
$\beta = 2.76 \pm 0.00414\,(2.76)$
Region 34
$\beta = 2.81 \pm 0.00969\,(2.81)$
Region 35
$\beta = 2.75 \pm 0.00768\,(2.76)$
Haslam [K]
C-BASS [K]
30
31
32
33
34
35
Region 36
$\beta = 2.87 \pm 0.0176\,(2.88)$
Region 37
$\beta = 2.82 \pm 0.00404\,(2.83)$
Region 38
$\beta = 2.77 \pm 0.0116\,(2.78)$
Region 39
$\beta = 2.73 \pm 0.00648\,(2.73)$
Region 40
$\beta = 2.98 \pm 0.00572\,(2.98)$
Region 41
$\beta = 2.94 \pm 0.00389\,(2.94)$
36
37
38
39
40
41



Conclusions:

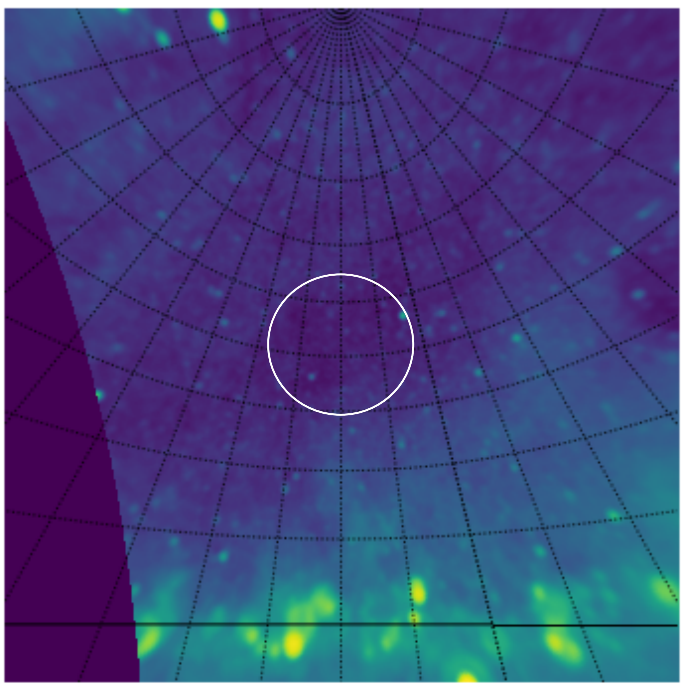
- Intensity spectral index seems to steepen with increasing Galactic latitude
- But it's complicated and multiple components are mixed up on quite small scales
- Need to do a proper pixel-by-pixel analysis - *Commander*

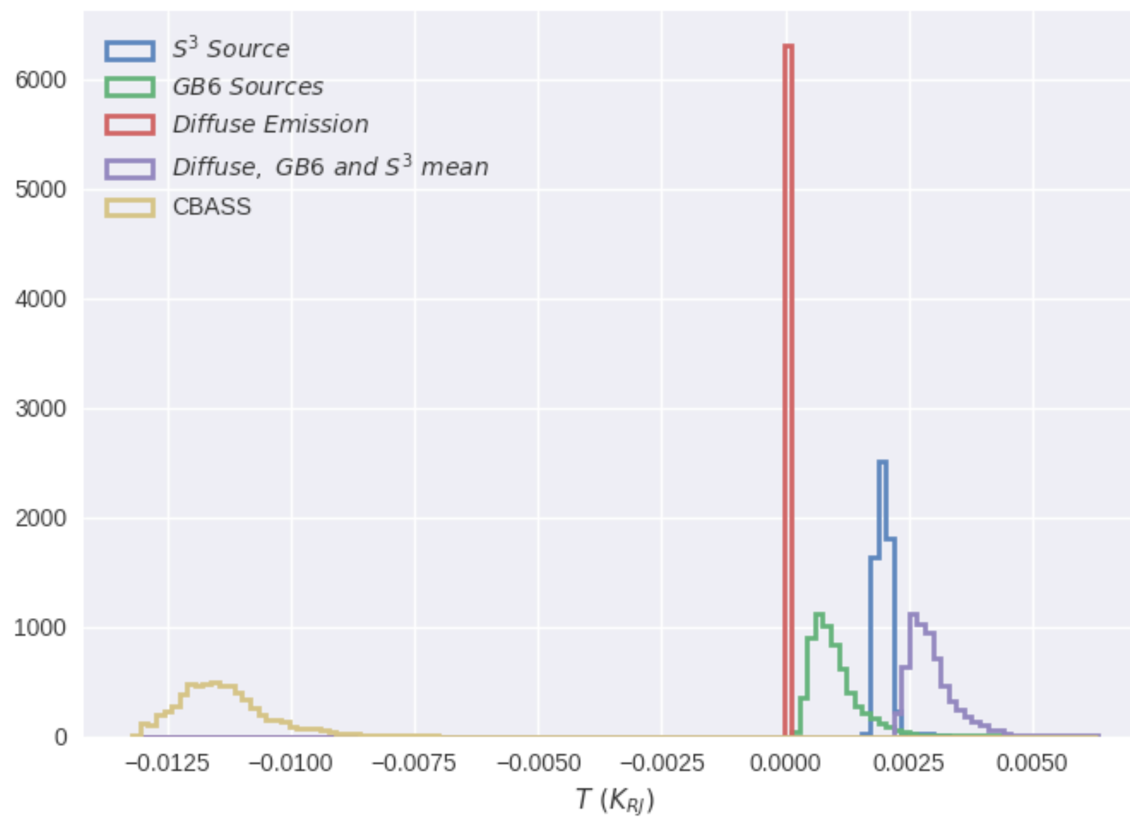
Zero level from source counts (work in progress)

Need zero level of I map for component fitting (zero level of raw map is arbitrary)

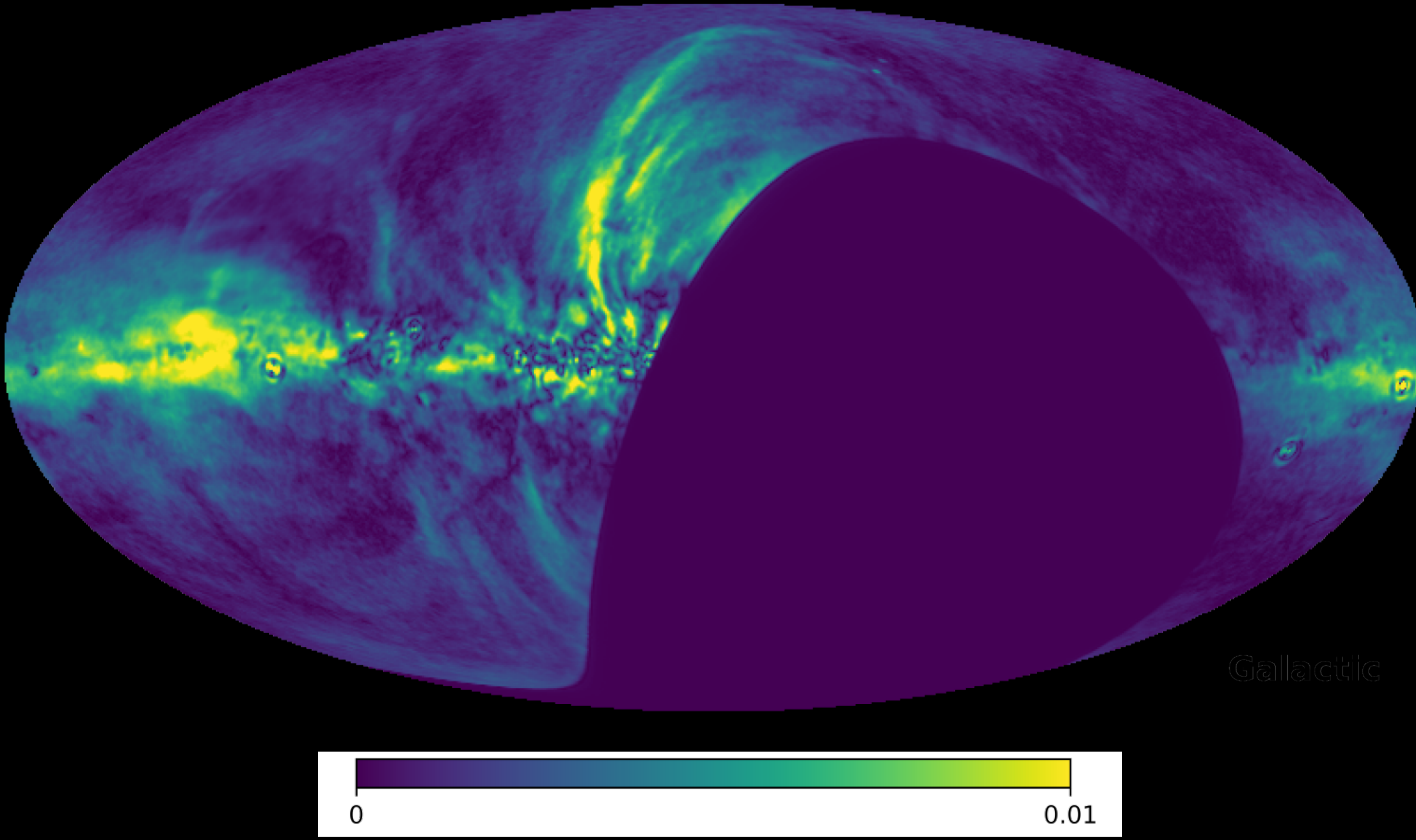
- Select quiet patches of sky
- Calculate pixel distribution due to discrete sources (GB6) and confused sources (S^3 model)
- Fit CBASS pixels plus offset

Seems to be consistent at least at ~1 mK level - TBC

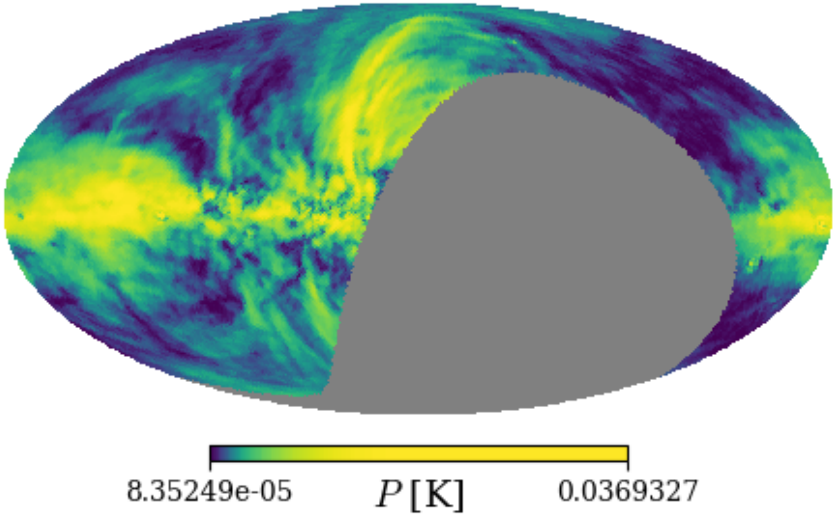




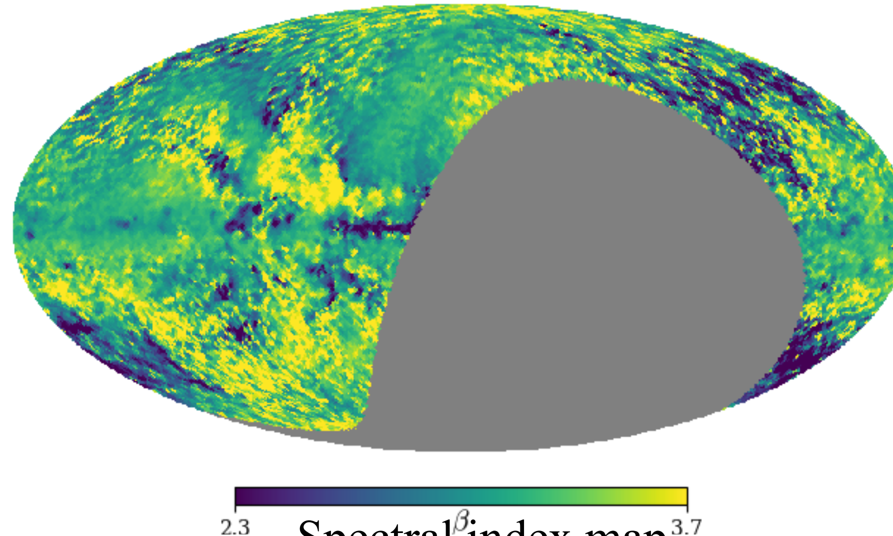
CBASS-N *P*



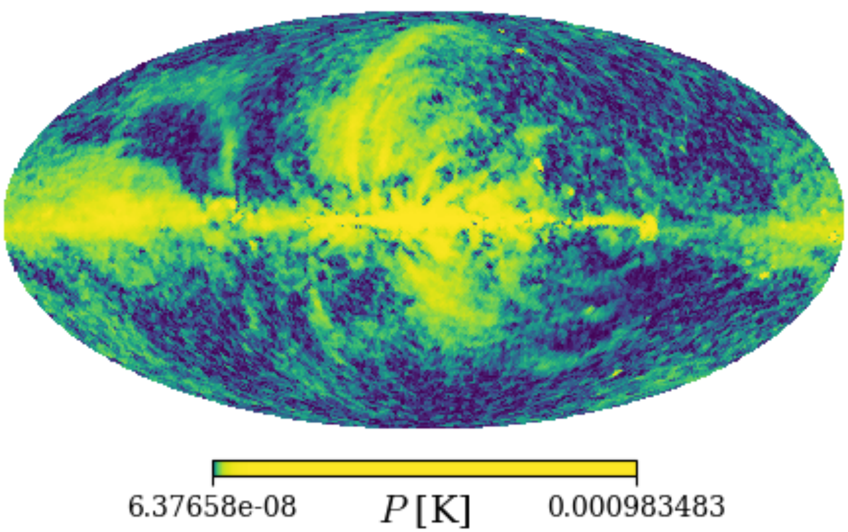
Polarized spectral indices 5 - 30 GHz



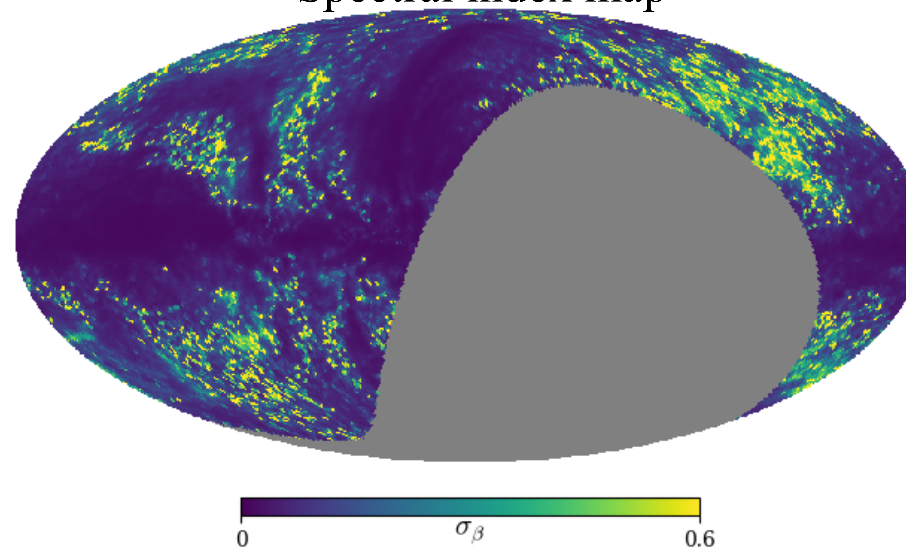
(a) C-BASS P map



Spectral index map

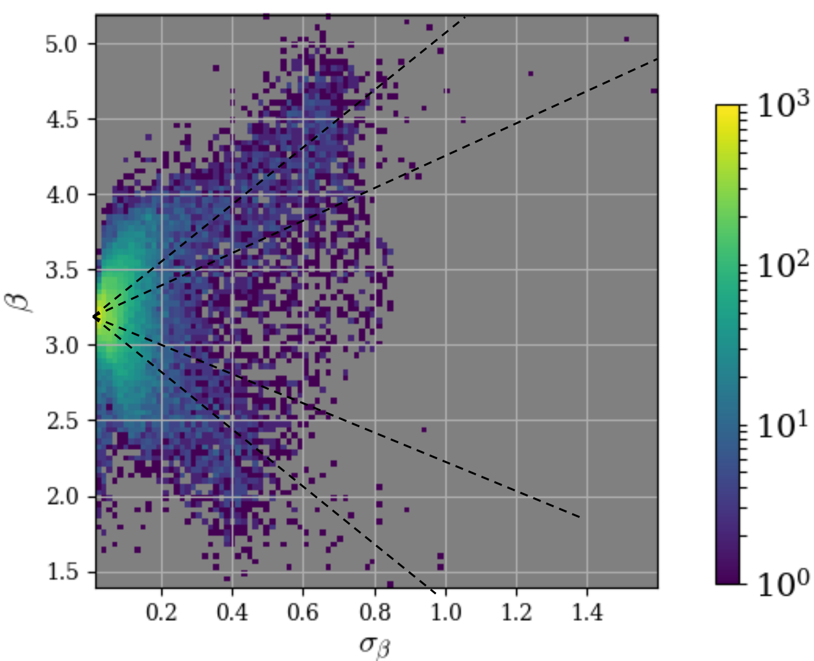


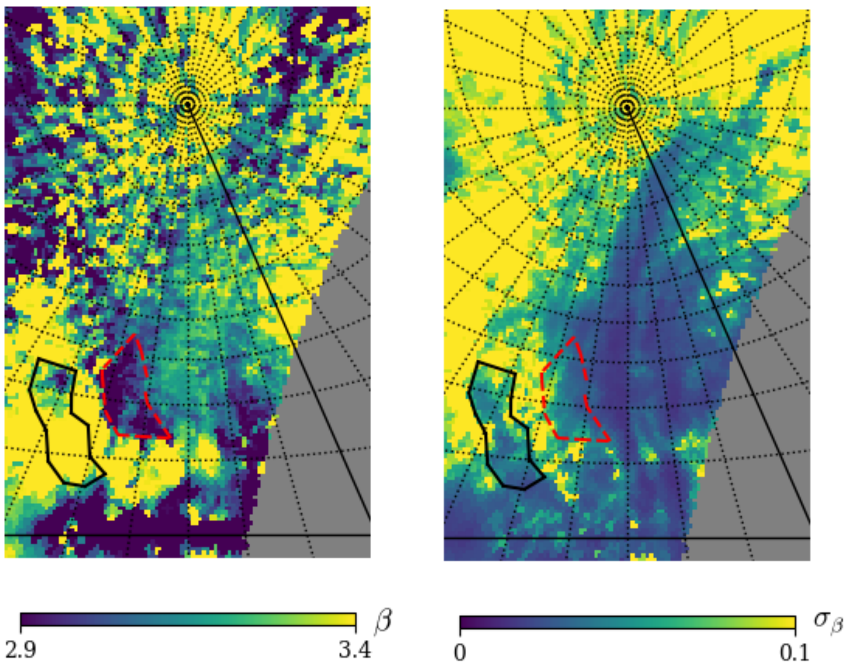
(c) *Planck* 30 GHz P map



Spectral index error map

Real variations in polarized β (1)

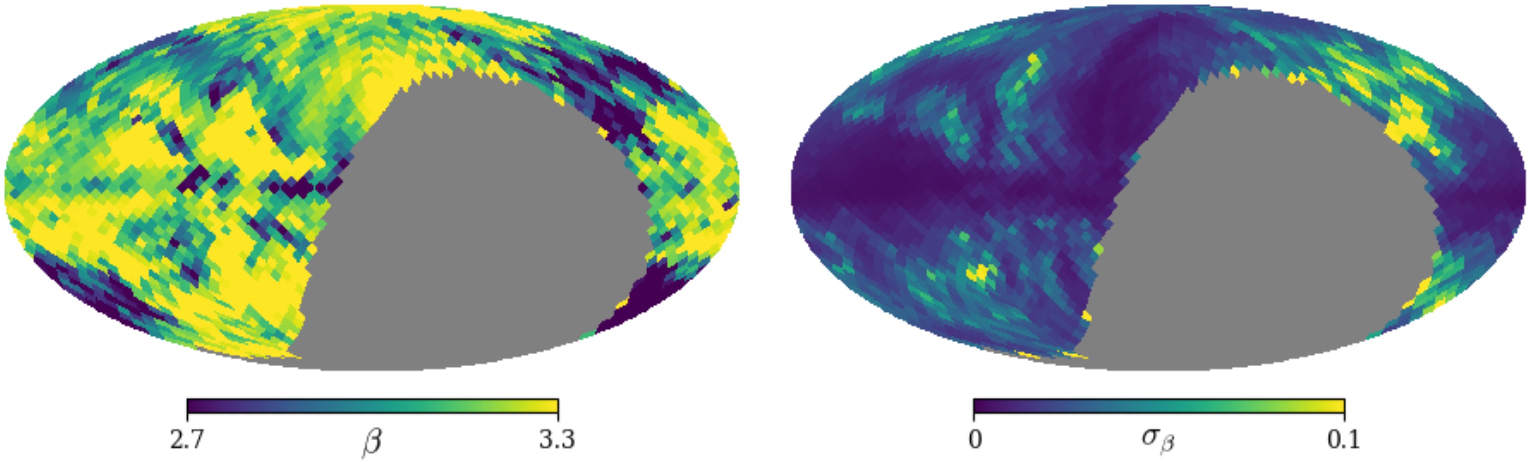




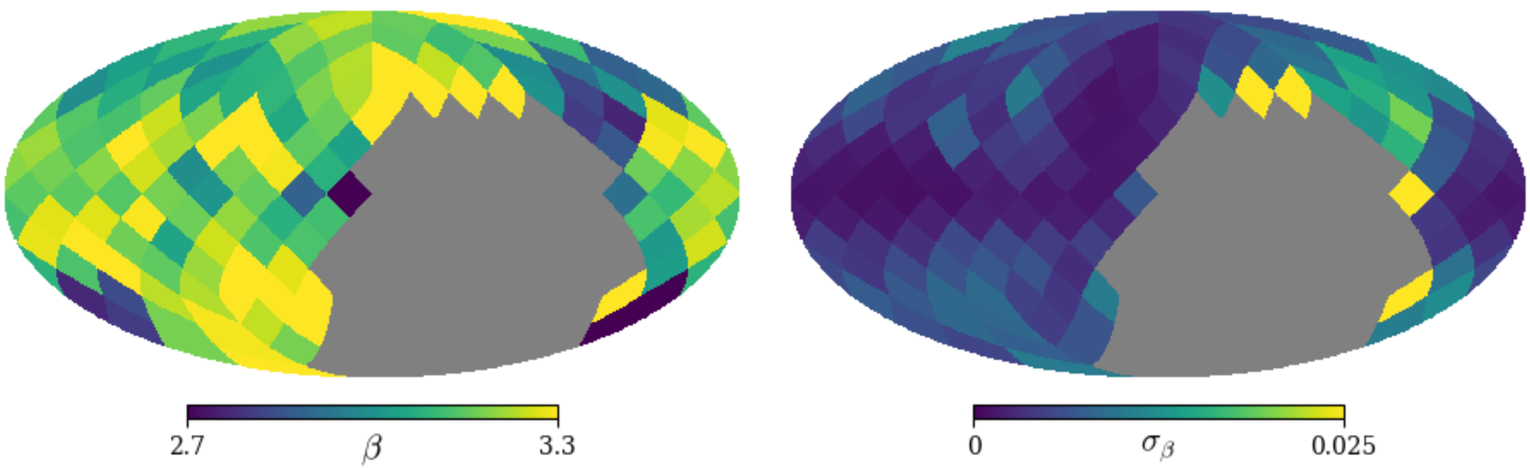
Distribution of β vs error on β
- Dashed lines indicate 1-, 2-σ deviations from mean

Adjacent regions with low σ_β but very different β

Real variations in polarized β (2)



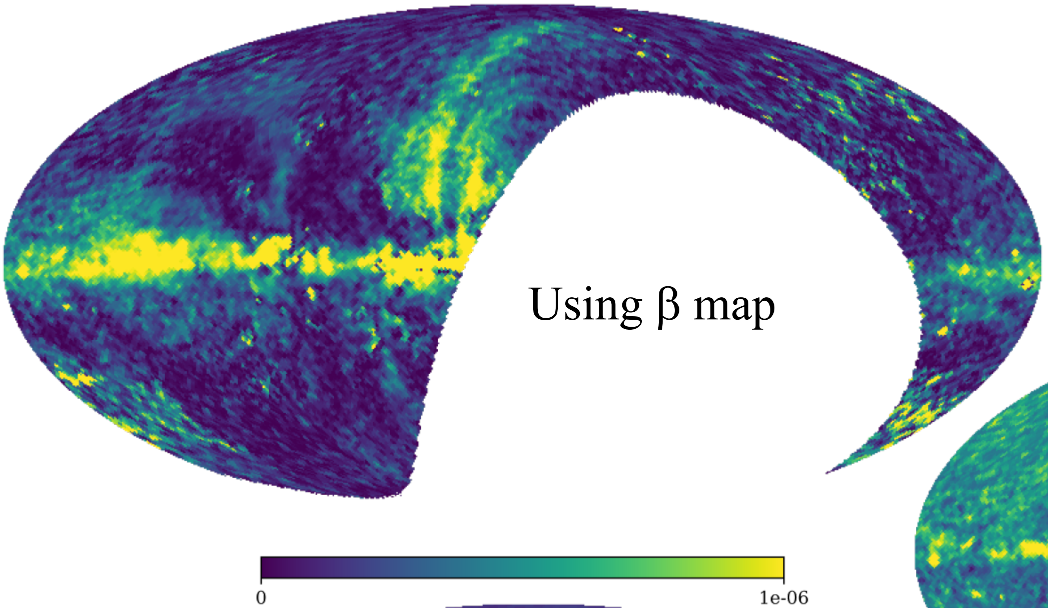
(a) $N_{\rm side} = 16$

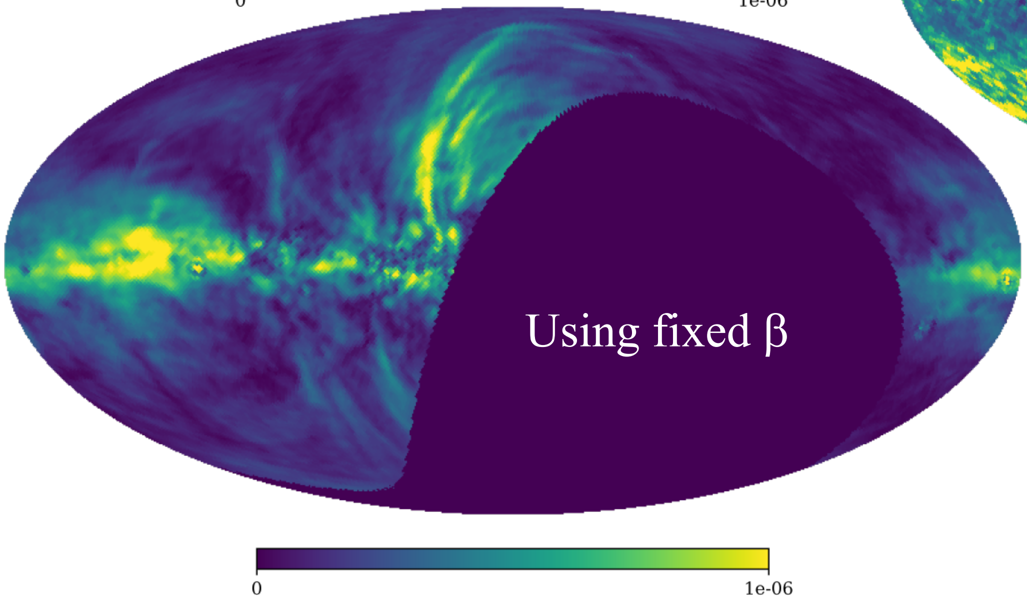


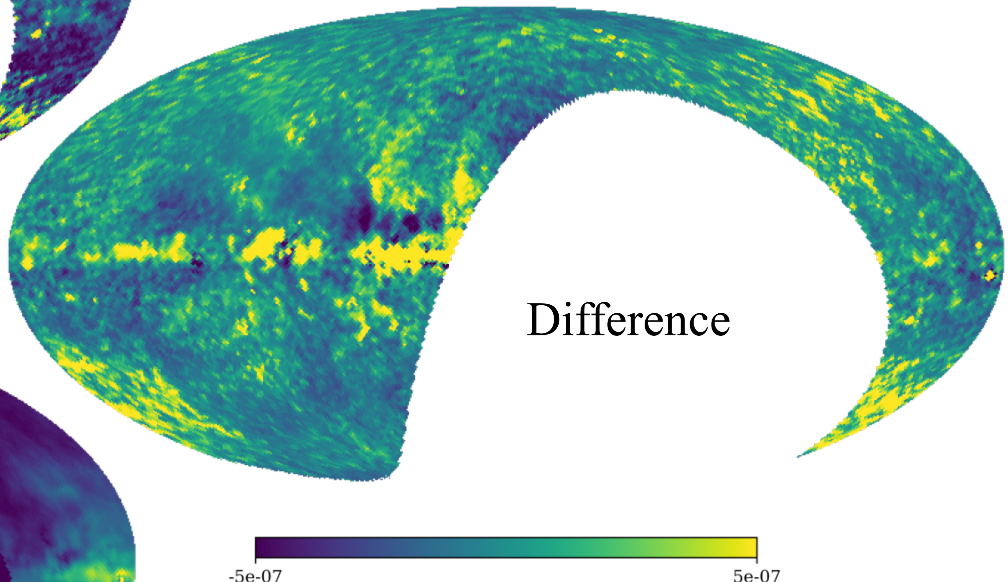
(a) $N_{\rm side} = 4$

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

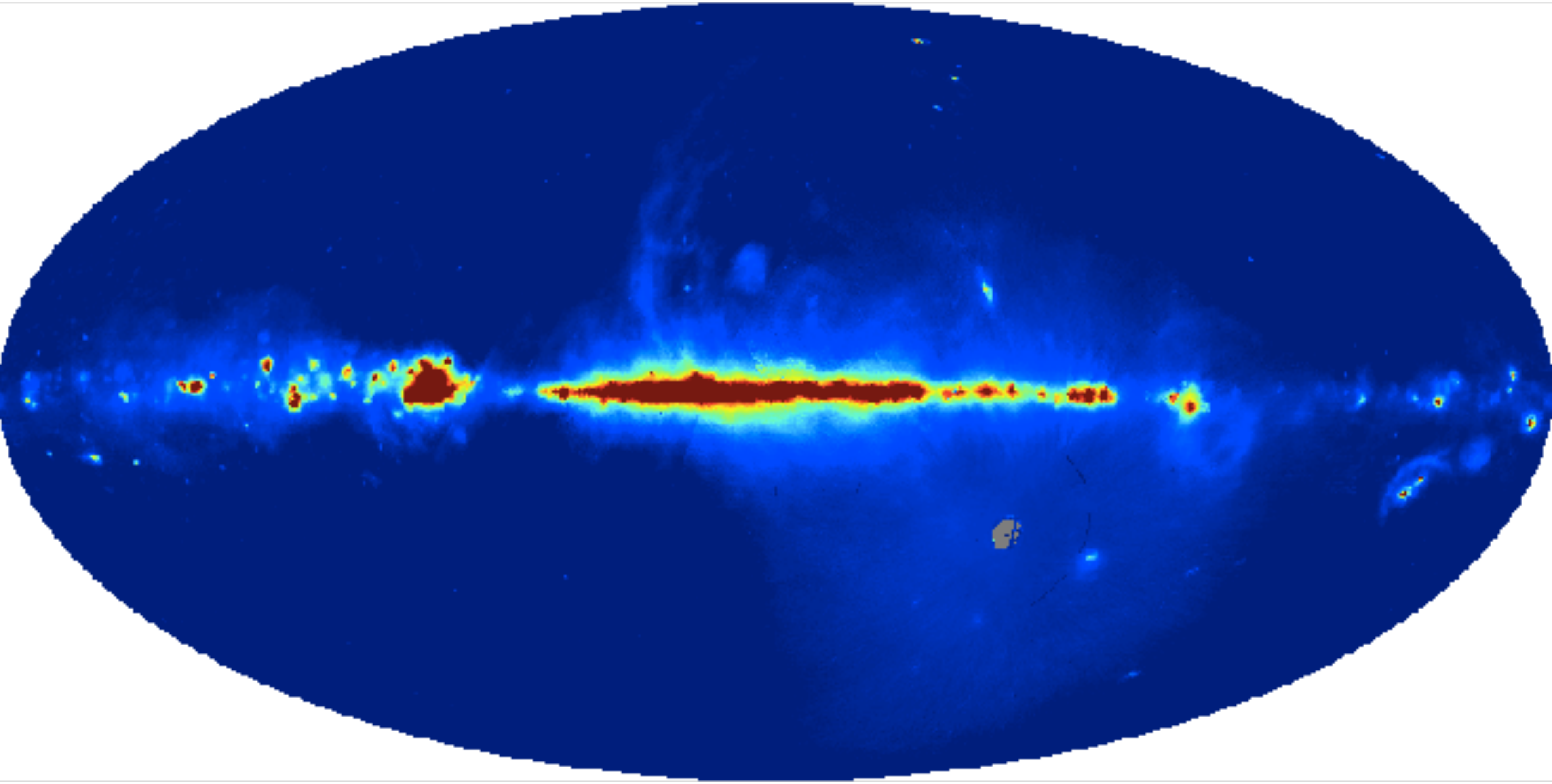
P maps extrapolated to 100 GHz







CBASS-All-Sky (first go!)



CBASS - status

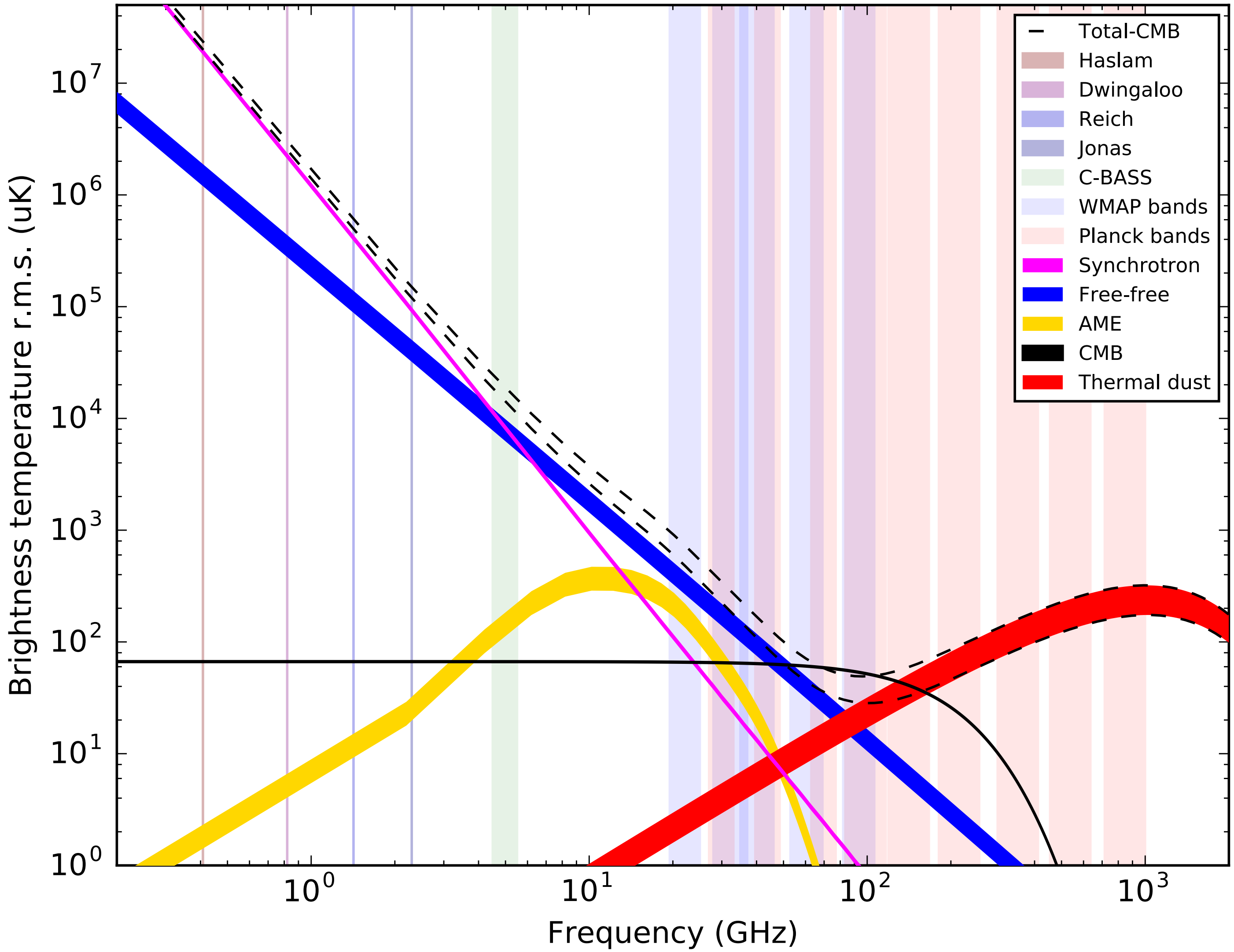
- Reducing Northern data now – observations finished
- First set of data papers based on el=37 data only in next few months
- No public data release yet, but keen to work with other groups with complementary data/analysis tools.
- Southern survey happening now – 1-2 yrs data taking expected in south
- Full data release once surveys completed and combine.

Next-BASS

- Still not enough measurements to constrain all likely foreground components
  - .408 – 5 – 23 – 30: 4 measurements, vs
  - Synch with curvature/self-absorbtion (5-6 params) – free-free (2) – AME with multiple components (3-4?): 10-12 params
- Ideally fill in complete frequency space between C-BASS and satellite frequencies: 6 – 30 GHz or higher.
- Sensitivity at least equivalent to CMB experiments at ~100 GHz: 1 μK-arcmin x frequency lever-arm
- Resolution at least as good as C-BASS: ~6 m telescope
- High frequency resolution for RFI/line emission removal

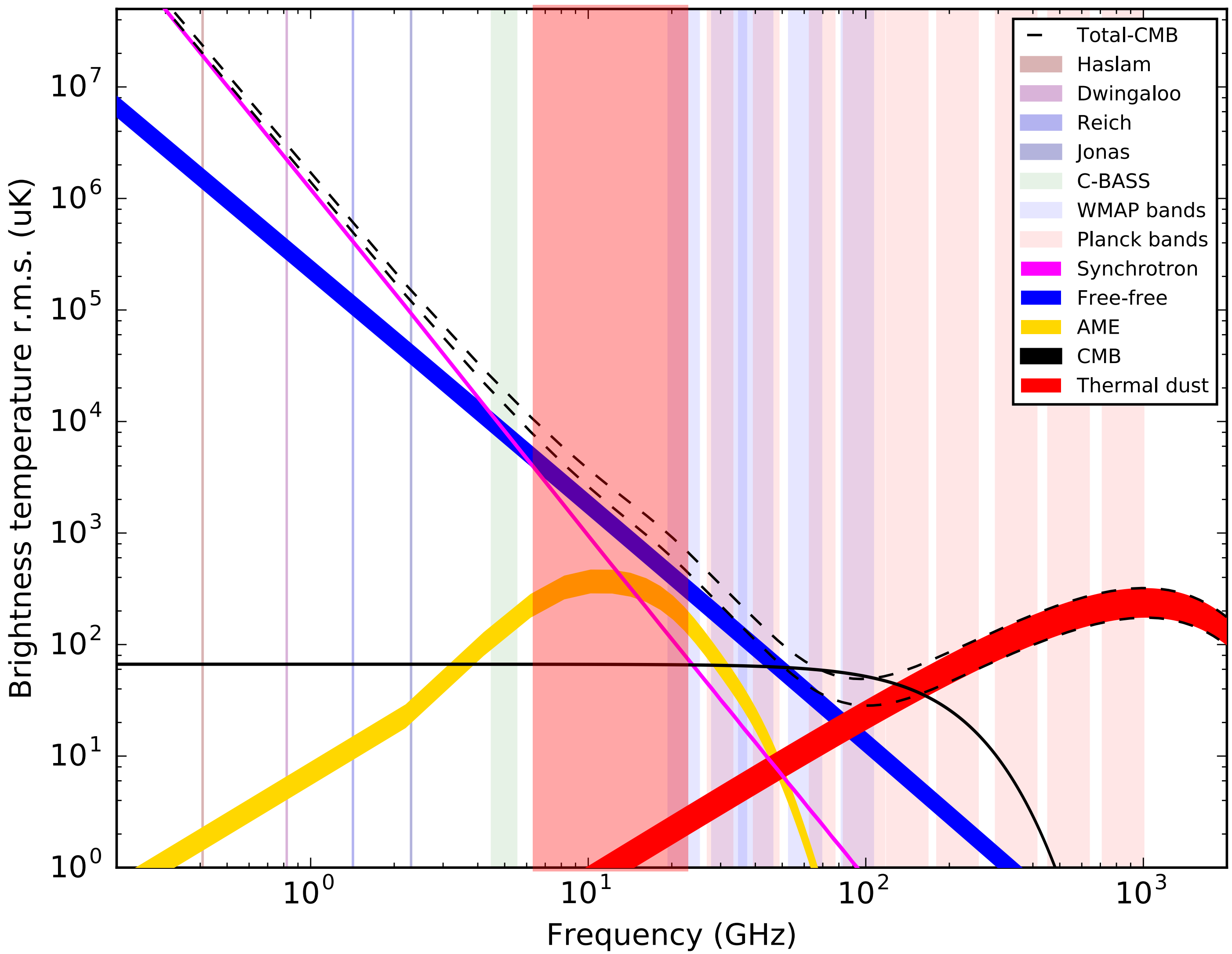
Why NextBASS?

Intensity



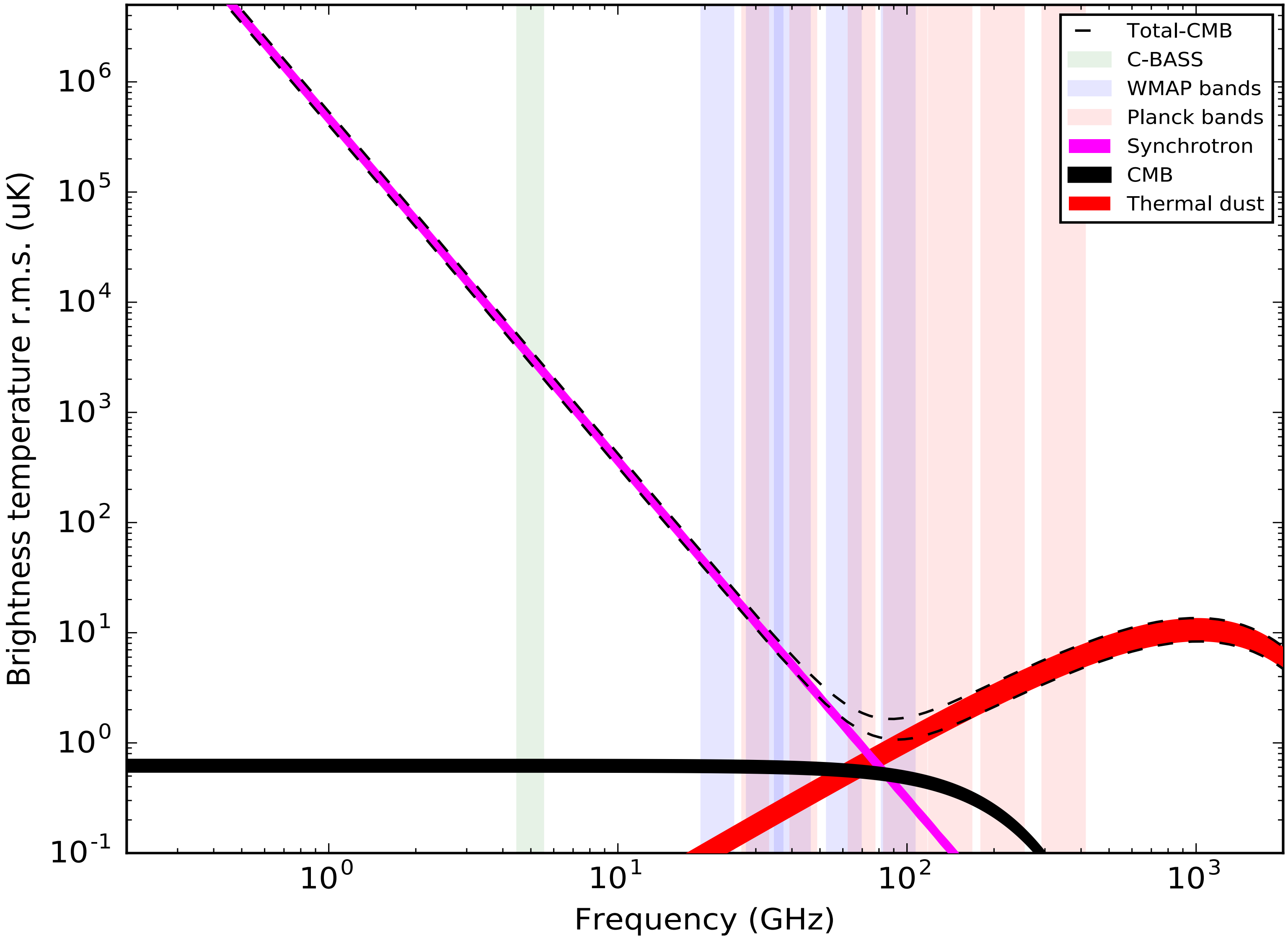
Why NextBASS?

Intensity



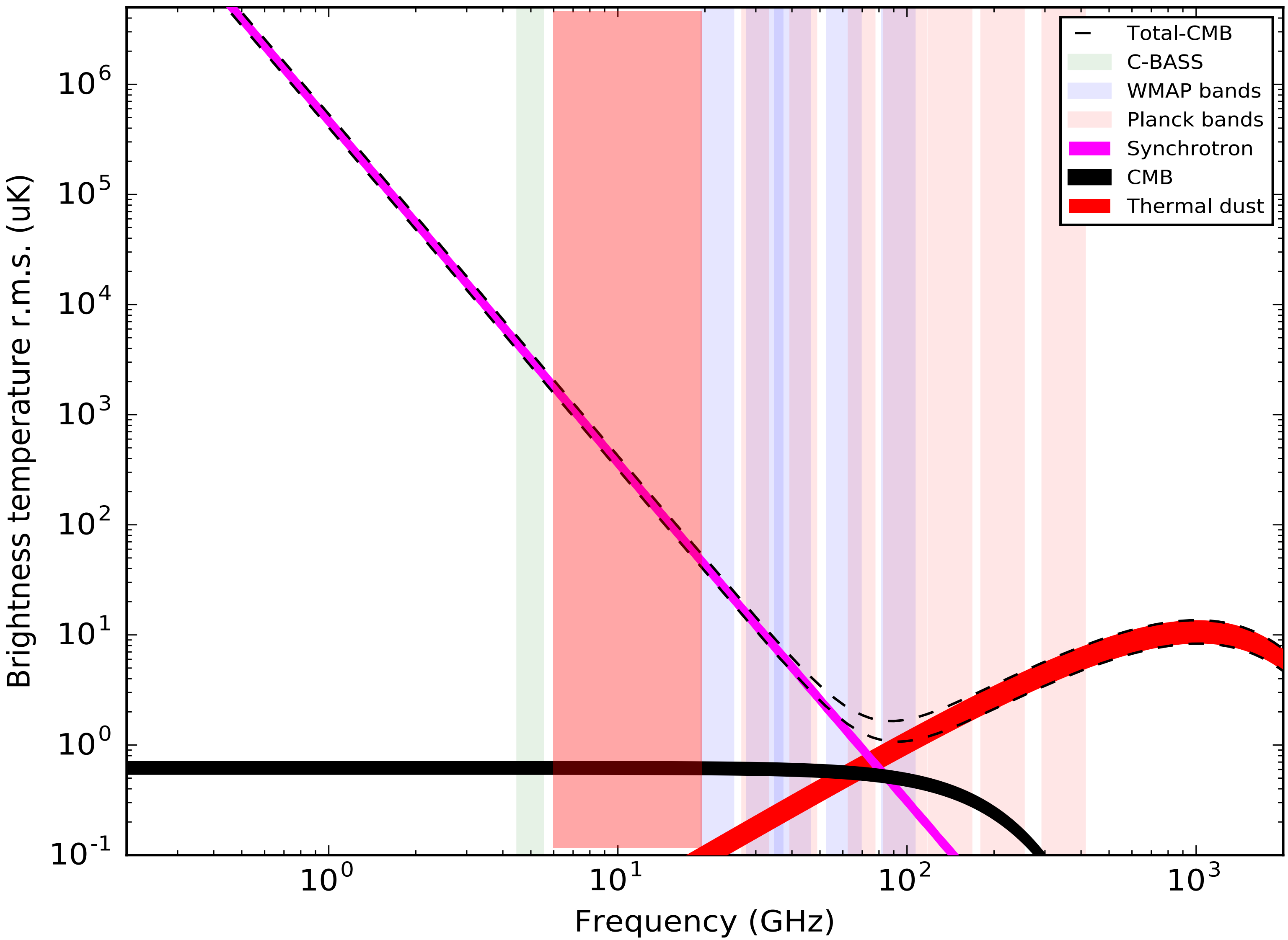
Why NextBASS?

Polarization



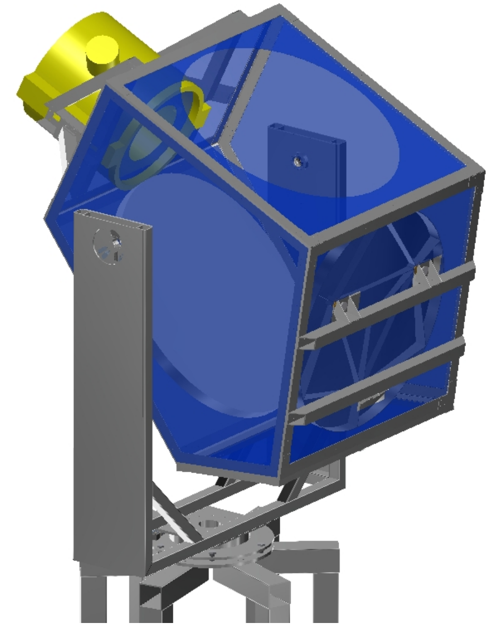
Why NextBASS?

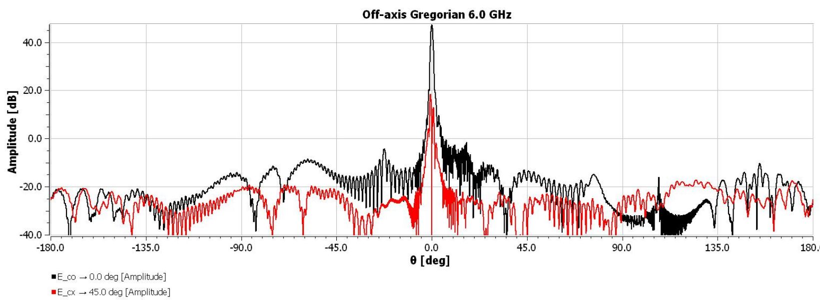
Polarization



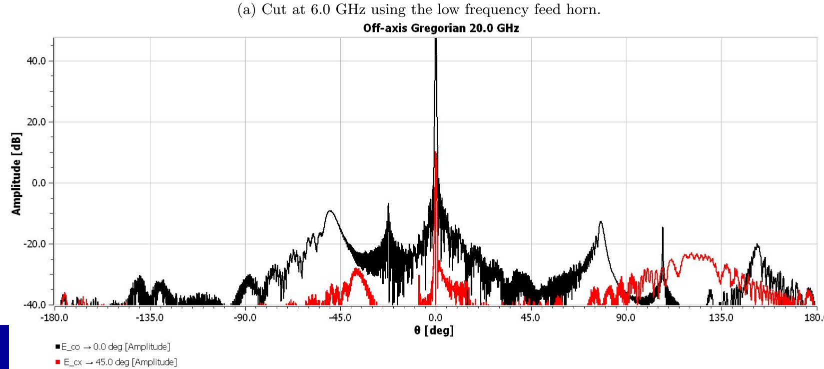
Next-BASS?

- 6-m aperture Compact Range antenna (aka Crossed Dragone)
  - Large focal plane
  - Easy to completely shield
- C-BASS-style radiometer/polarimeter for stability
- Two feed types
  - 7 – 15 GHz
  - 15 – 30 GHz
- Digital backend based on SKA designs

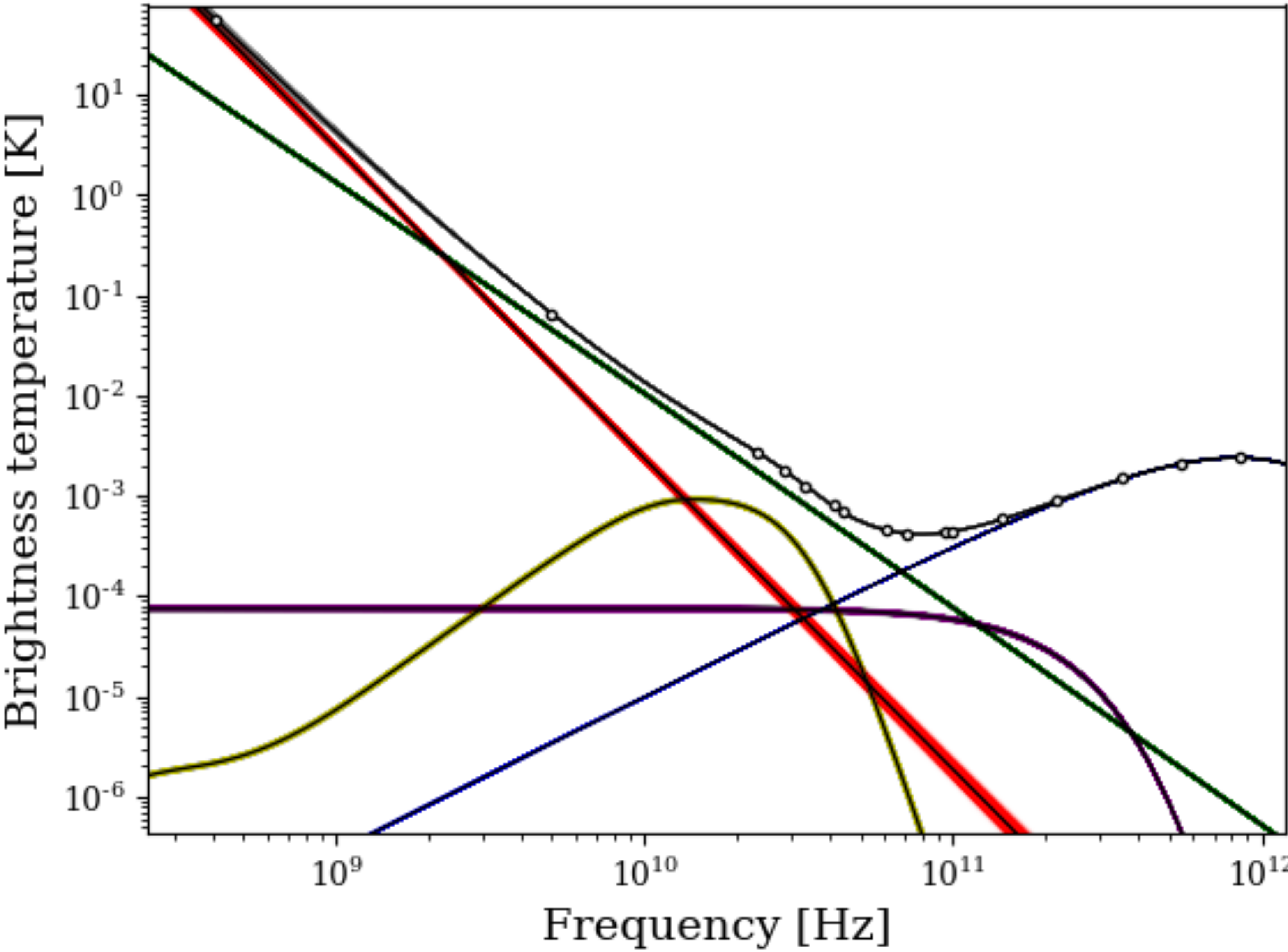




(a) Cut at 6.0 GHz using the low frequency feed horn.



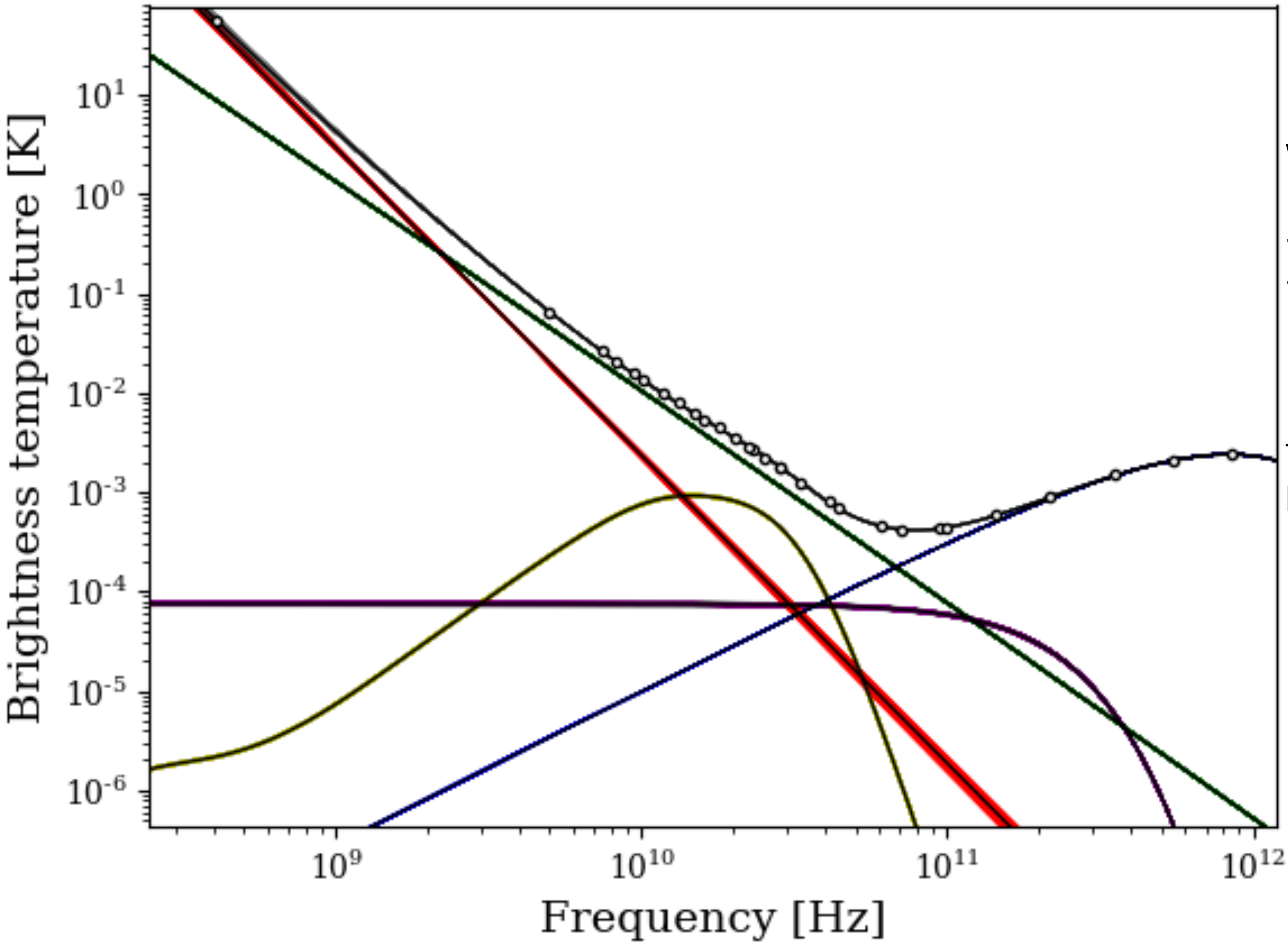
CBASS simulations - *I*



Haslam
WMAP
Planck
+ CBASS

High-foregrounds pixel (1-deg)

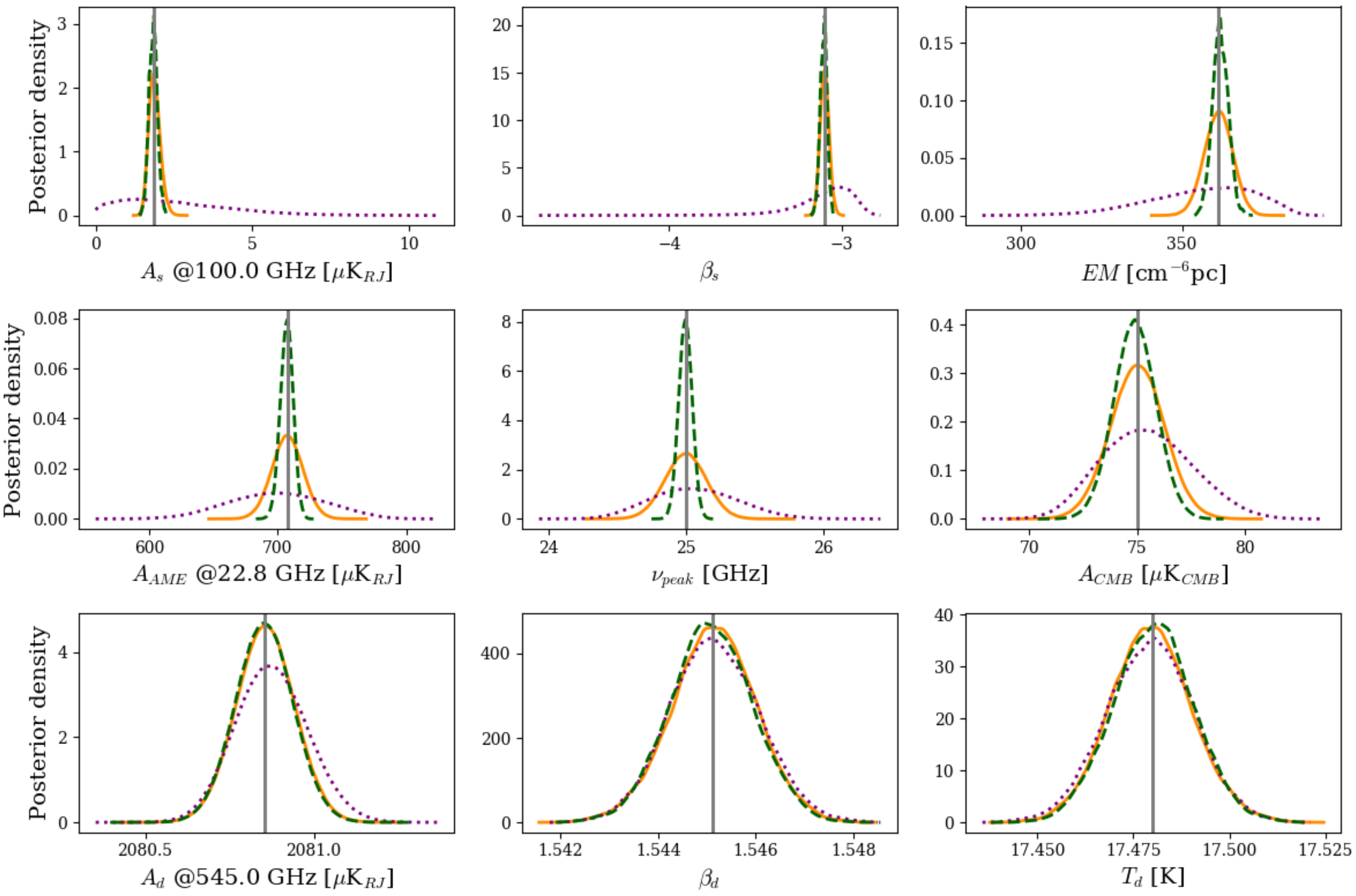
NextBASS+ – intensity



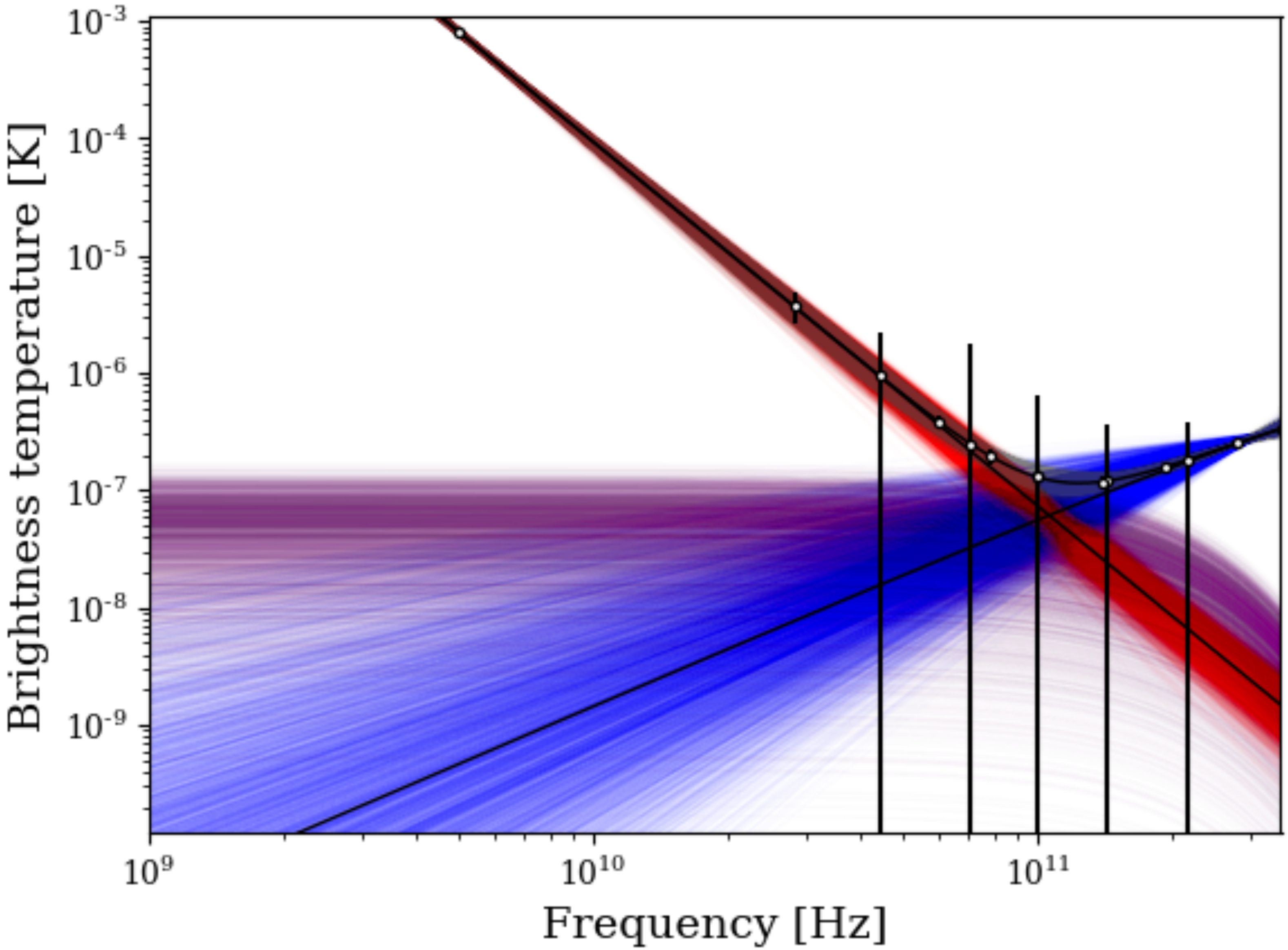
Haslam
WMAP
Planck
+ CBASS
+ NextBASS

High-foregrounds pixel (1-deg)

NextBASS+ – intensity



CBASS simulations - *P*

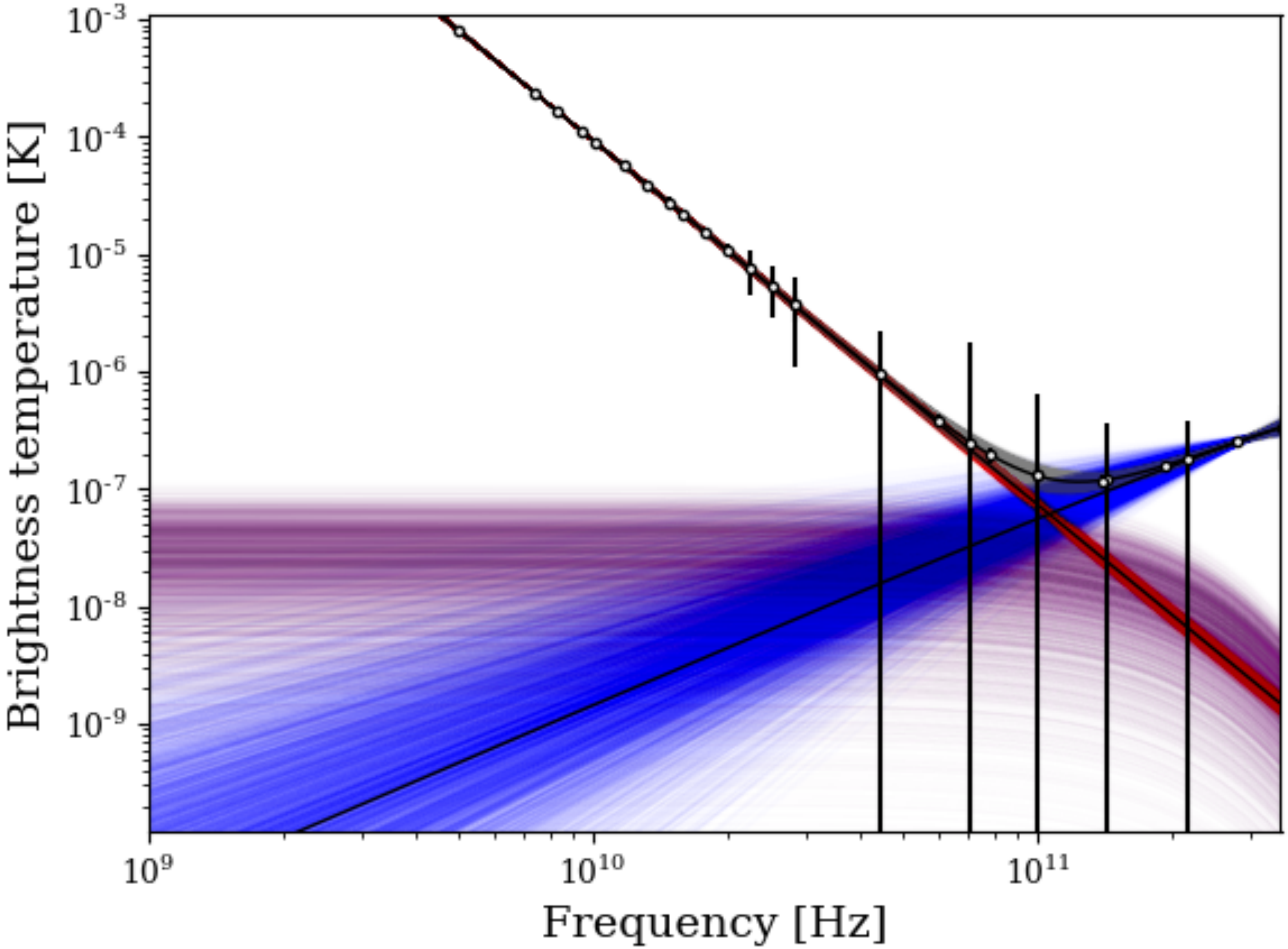


Planck
'LiteBIRD'
+CBASS

Low-foregrounds Pixel (3-deg)

r = 0

NextBASS+ – polarization

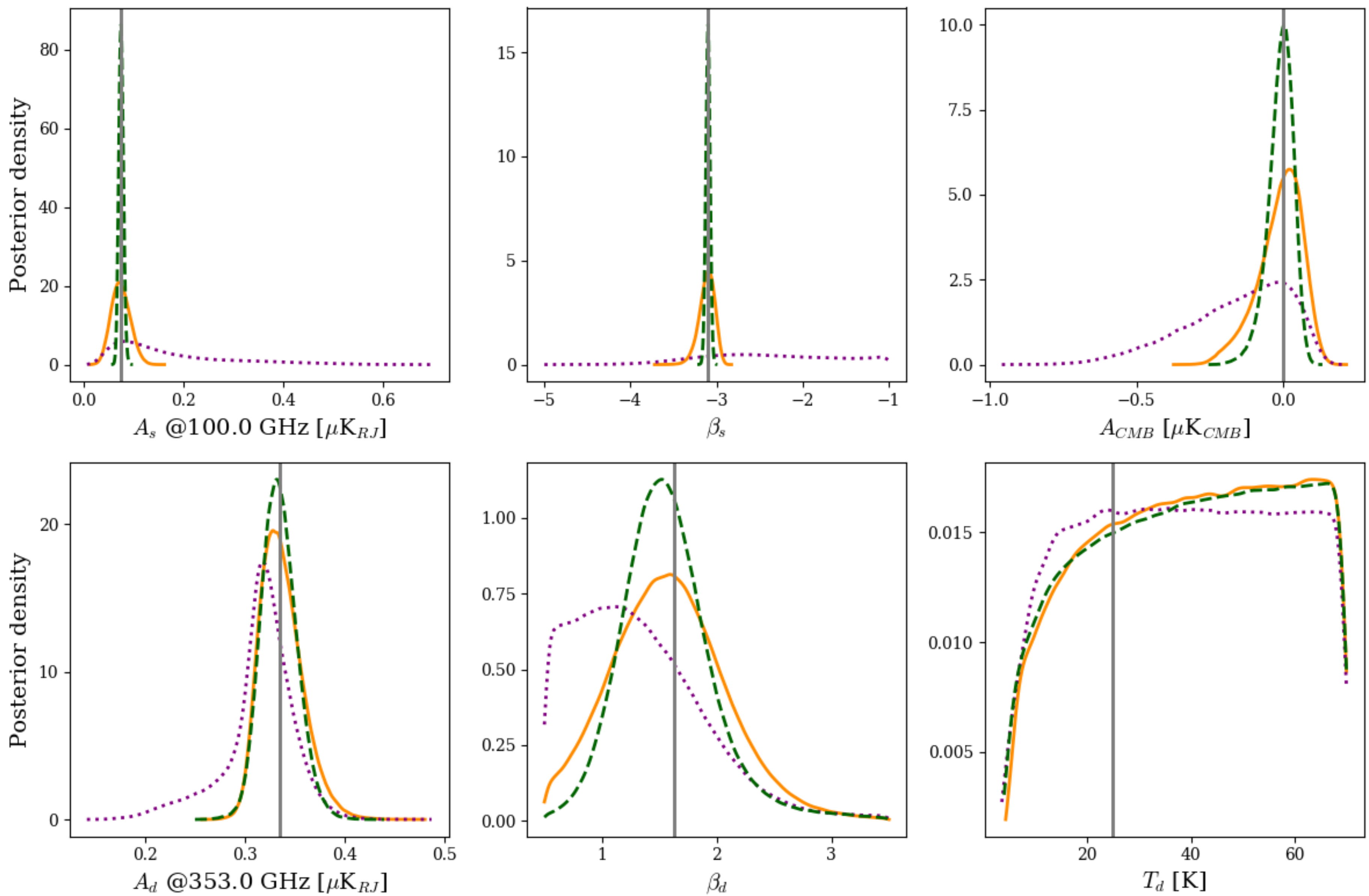


Planck
'LiteBIRD'
+CBASS
+NextBASS

Low-foregrounds Pixel (3-deg)

$r = 0$

NextBASS+ – polarization



NextBASS status

- Doing design work on optics, feeds, OMTs, digital receivers…
- Extending simulations to more realistic models/modelling errors
- Proposal with European Research Council (last chance before Brexit…)
- With more limited funding can use ex-Clover 2-m telescope – better than nothing!