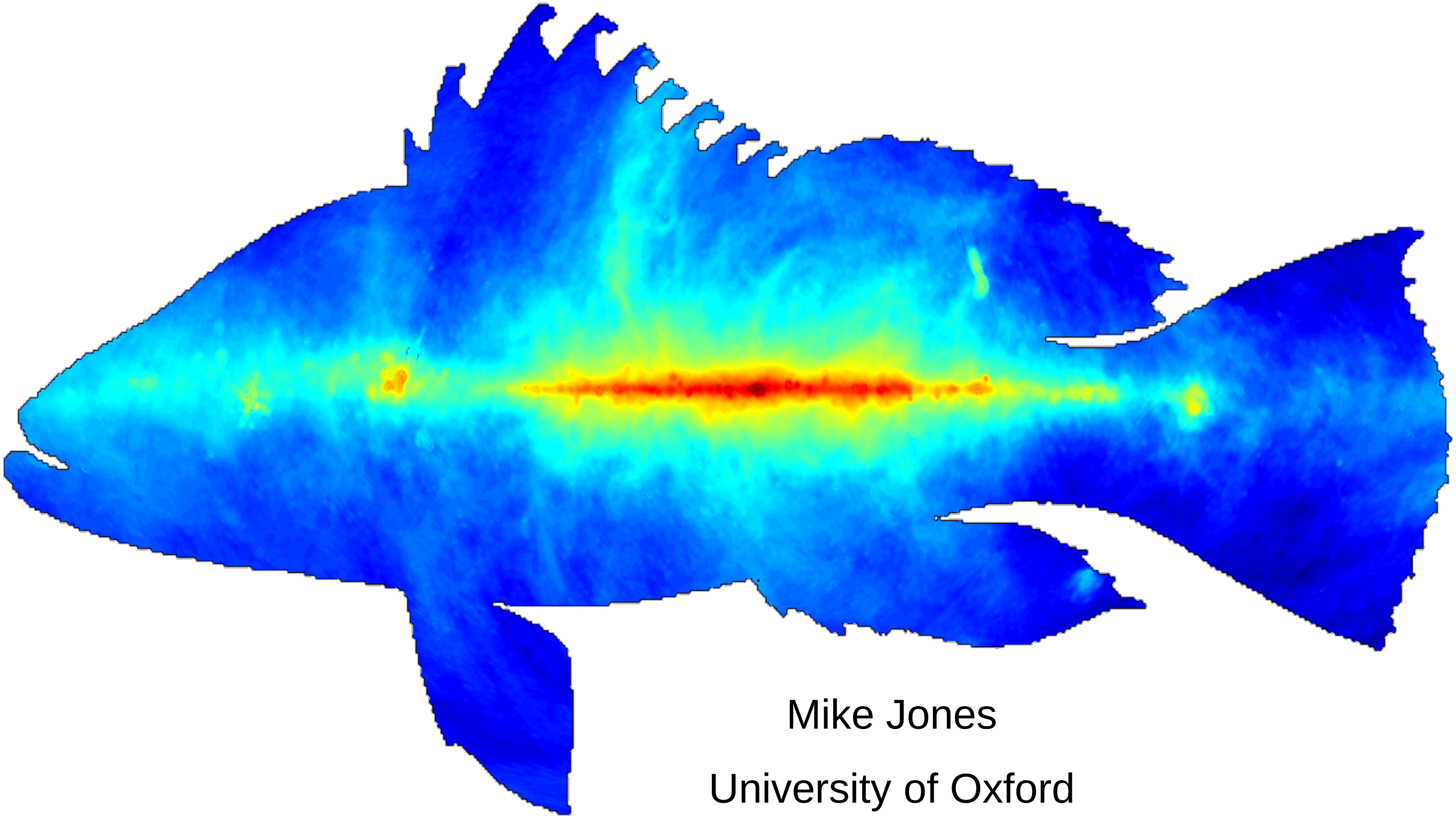
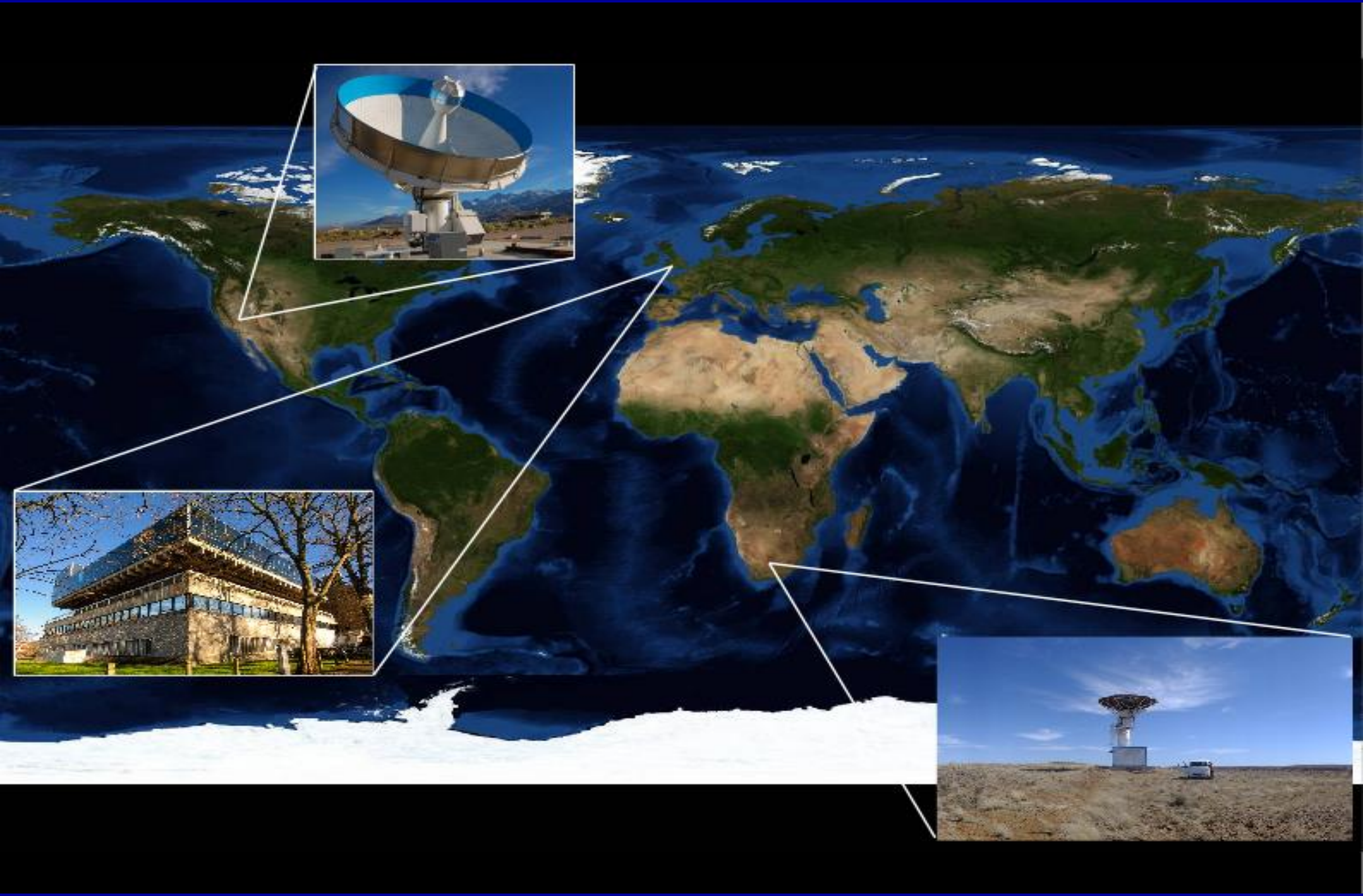
C-Band All-Sky Survey (C-BASS)



Mike Jones

University of Oxford

The C-BASS Survey



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

University of Oxford, UK

Mike Jones, Jamie Leech, Angela Taylor, Luke Jew, Jaz Hill-Valler

Hochschule München, Germany

Christian Holler

University of Manchester, UK

Richard Davis, Clive Dickinson, Joe Zuntz, Paddy Leahy, Mike Peel, Adam Barr

Caltech, USA

Tim Pearson, Tony Readhead,

South Africa

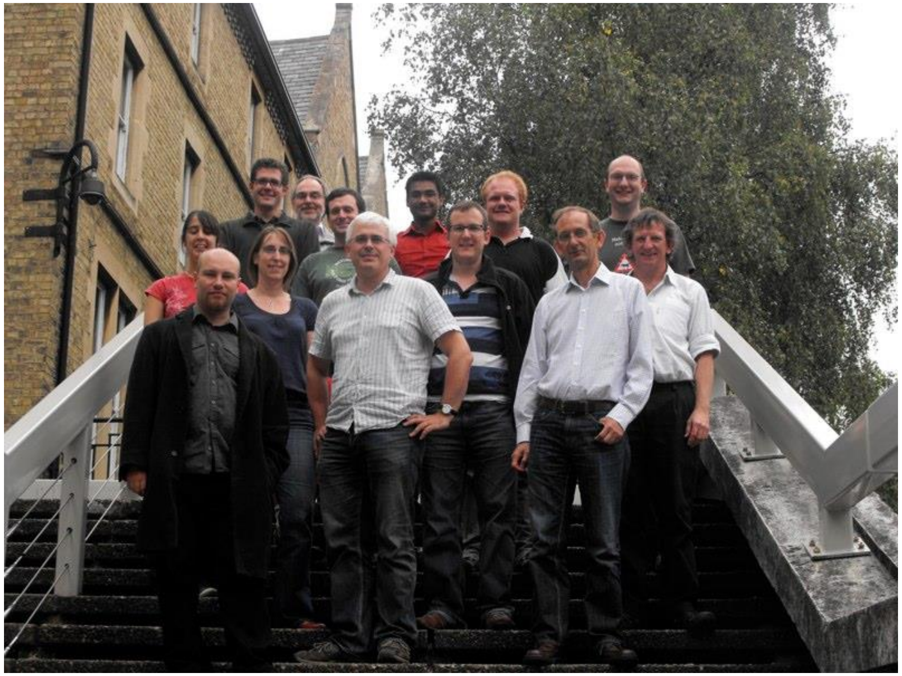
Justin Jonas (Rhodes/SKASA), Charles Copley (SKASA), Cynthia Chiang, Heiko Heligendorff, Moumita Aitch (UKZN)

KACST, Saudi Arabia

Yasser Hafez

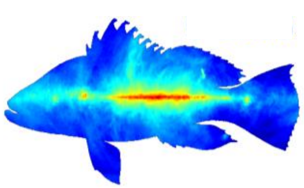
Moved on…

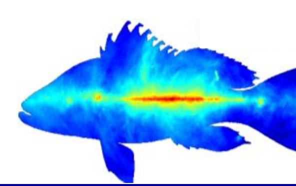
Oliver King, Matthew Stevenson, Mel Irfan, Stephen Muchovej



C-BASS - Overview

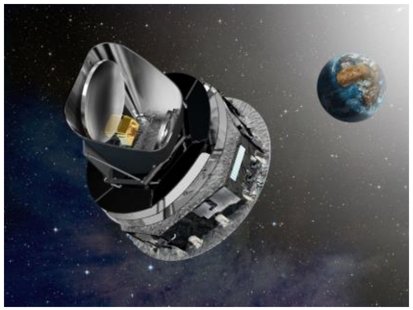
Sky-coverage	All-sky
Angular resolution	0.73 deg (43.8 arcmin)
Sensitivity	< 0.1mK r.m.s (confusion limited in I)
Stokes coverage	I, Q, U, (V)
Frequency	1 (0.7) GHz bandwidth, centered at 5 GHz
Northern site 	OVRO, California Latitude, 37.2 deg
Southern site 	MeerKAT site, Karoo, South Africa Latitude -30.7 deg

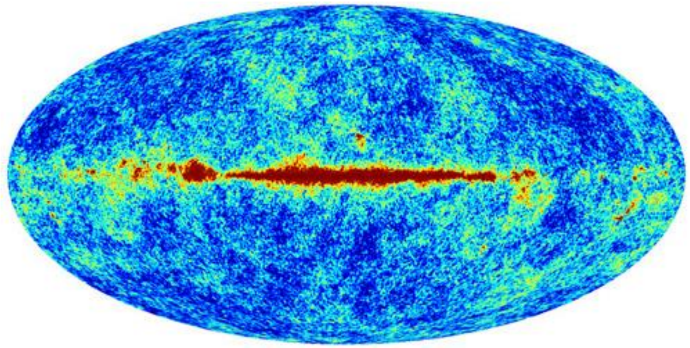




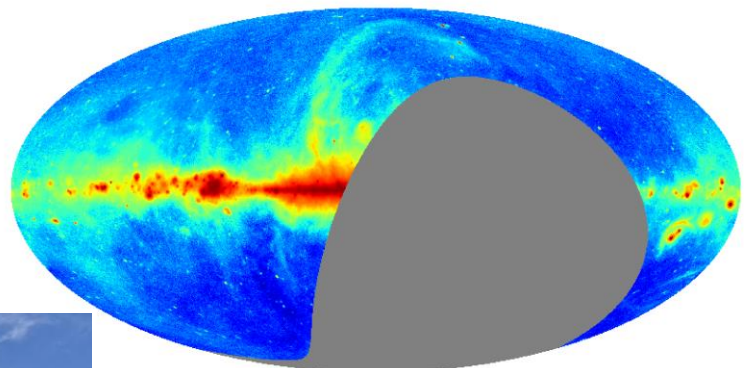
C-BASS

Main Aim: understanding the physics of the very early Universe





Planck high-frequency mission to map the cosmic microwave background (CMB), 30-800 GHz



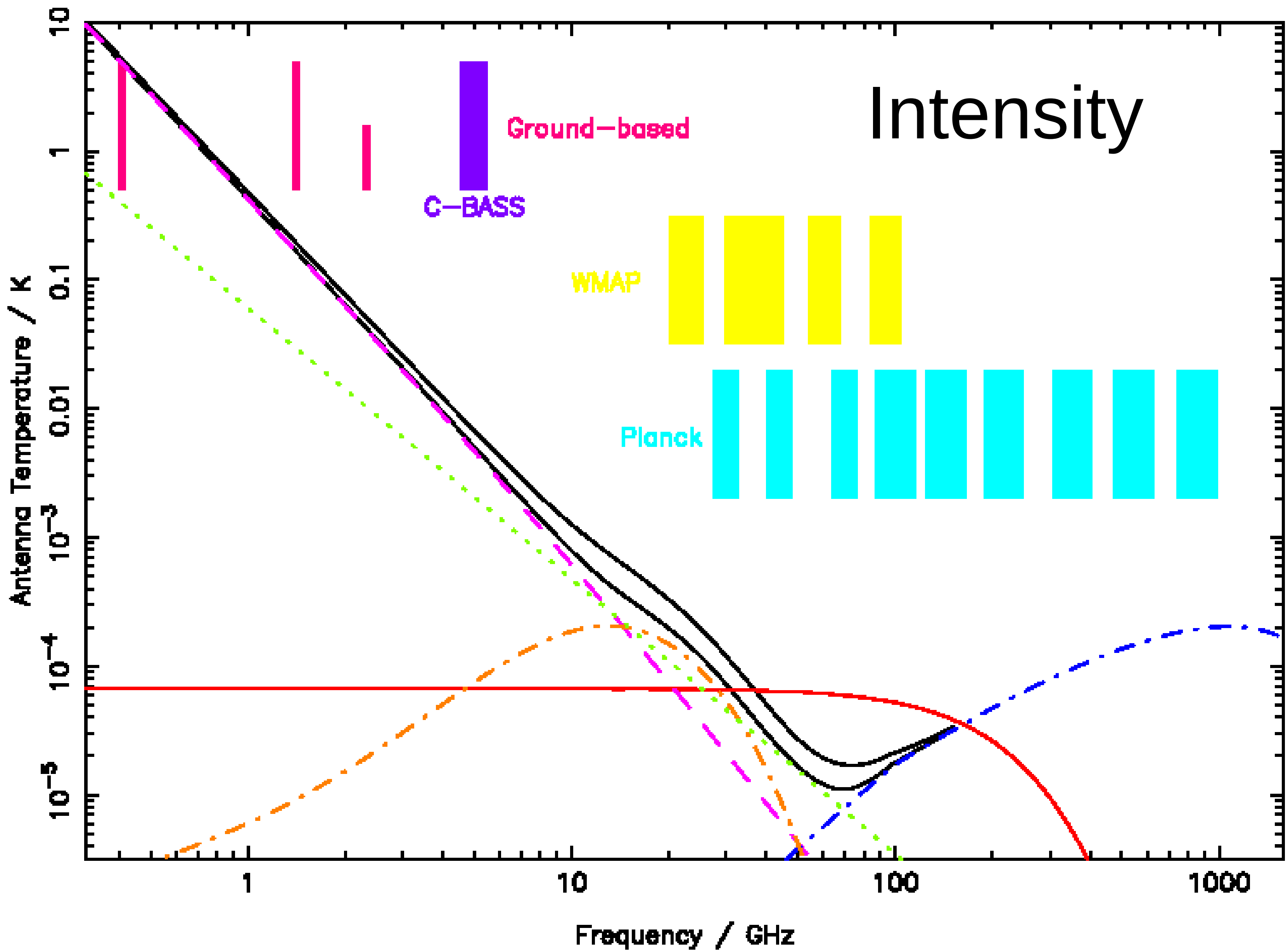
CBASS provides essential low frequency data, 5 GHz

- CMB polarization encodes fundamental physics of the beginning of the Universe.
- Planck CMB maps contaminated by Galactic emission.
- C-BASS enables cleaning of Galaxy from Cosmic Microwave Background (CMB) maps.
- Combine both data sets to get clean maps of the CMB polarization.

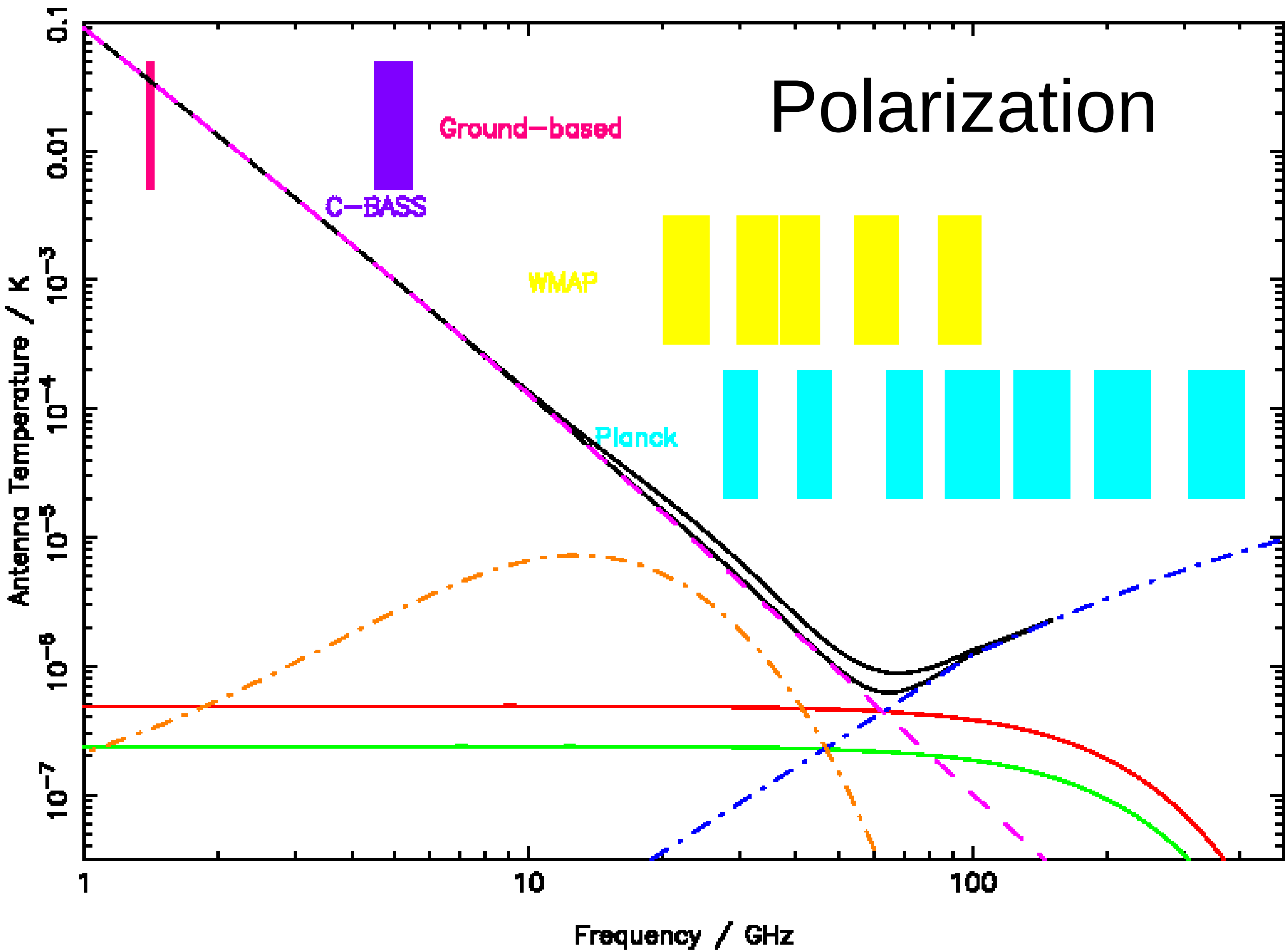
5 GHz because…

- Halfway (in log ν) between surveys at 1.4 GHz (Stockert, Reich & Reich) and 23 GHz (WMAP).
- Expected high-latitude Faraday rotation a few degrees, c.f. ~30° at 2.3 GHz.
- Below main emission from anomalous dust, so predominantly synchrotron.
- Signal still strong enough (few mK) to measure in a reasonable time (< 1 year) with a single receiver.
- 'Planck 5 GHz channel' (© R Davis)

Why a 5 GHz survey?



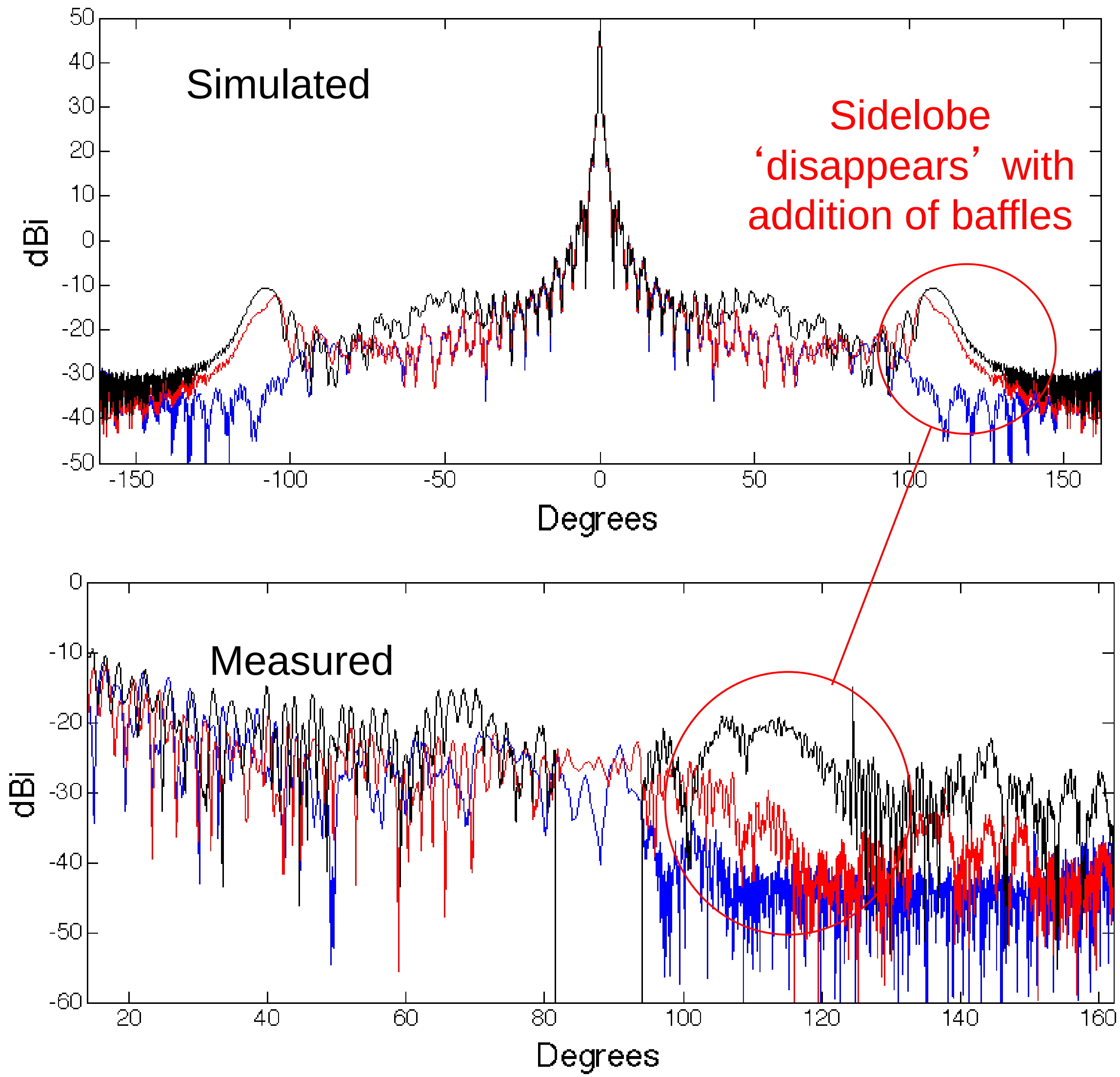
Why a 5 GHz survey?



C-BASS North Telescope

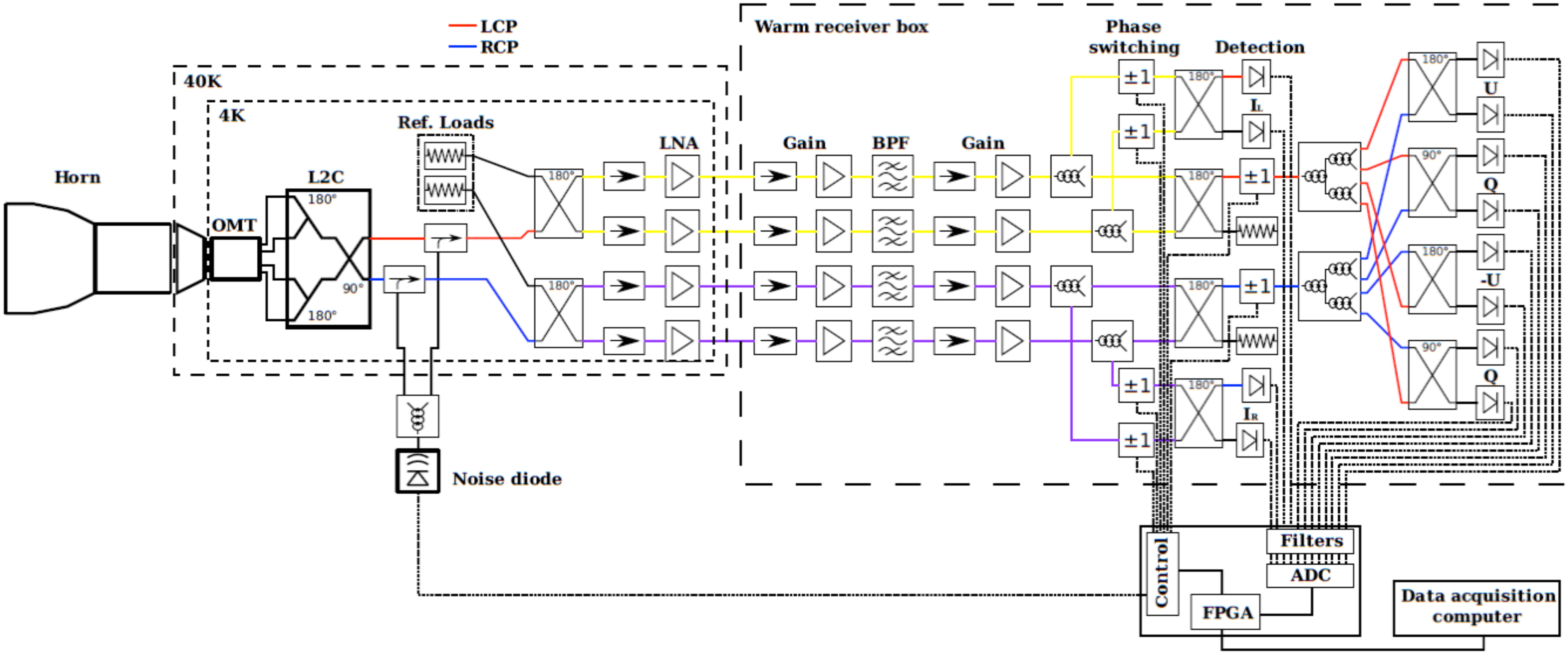
- 6.1-m dish, with Gregorian optics
- Secondary supported on foam cone
- Receiver sat forward of the dish
- Very clean, circularly-symmetric optics
- Absorbing baffles to minimize spillover

C-BASS North: beam measurements



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

C-BASS North Receiver



- Analogue correlation polarimeter
- Correlate RCP & LCP → Q, U
- Continuous comparison/pseudo-correlation radiometer
- Difference RCP & LCP separately against internal load → I, V

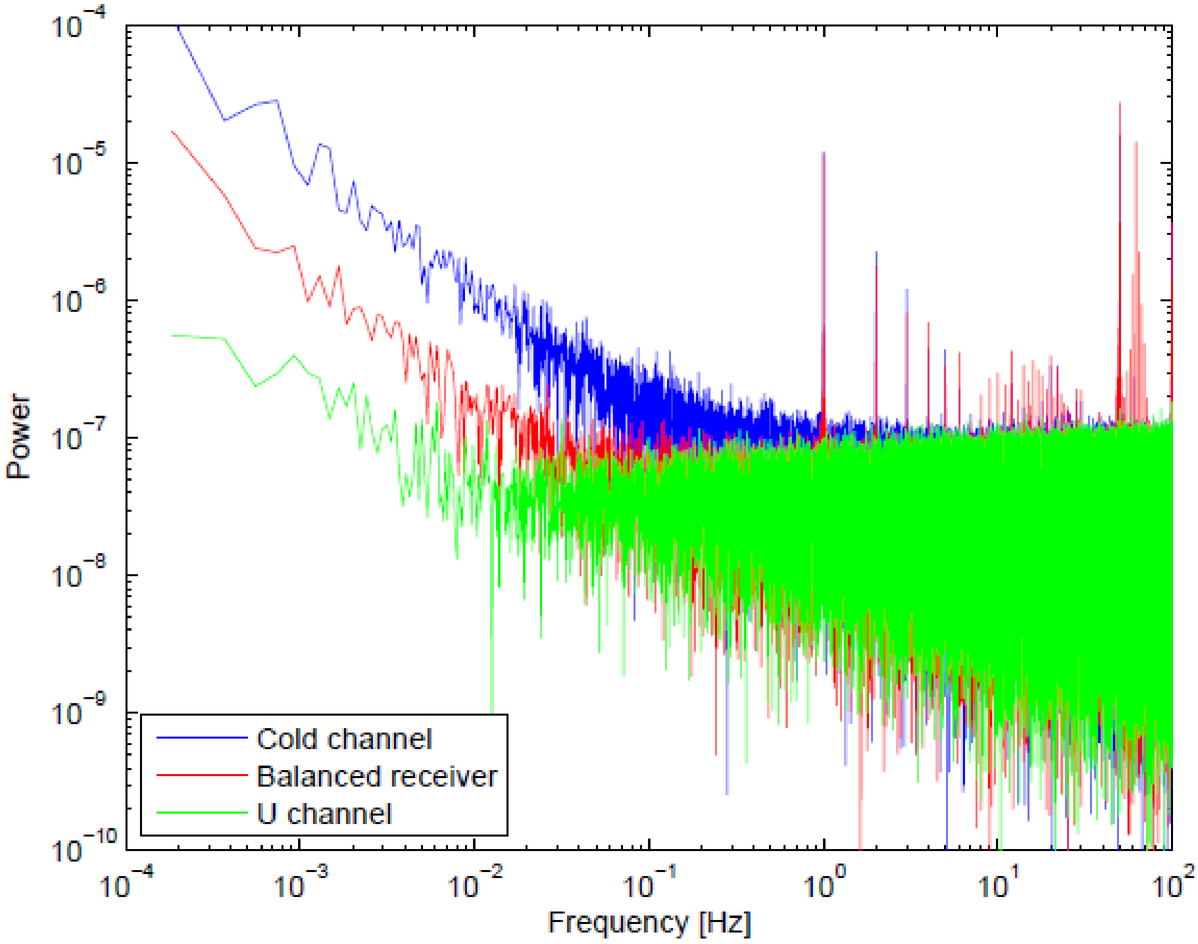
Receiver noise power spectra

C-band LNAs intrinsic f_{knee} ~1 Hz:

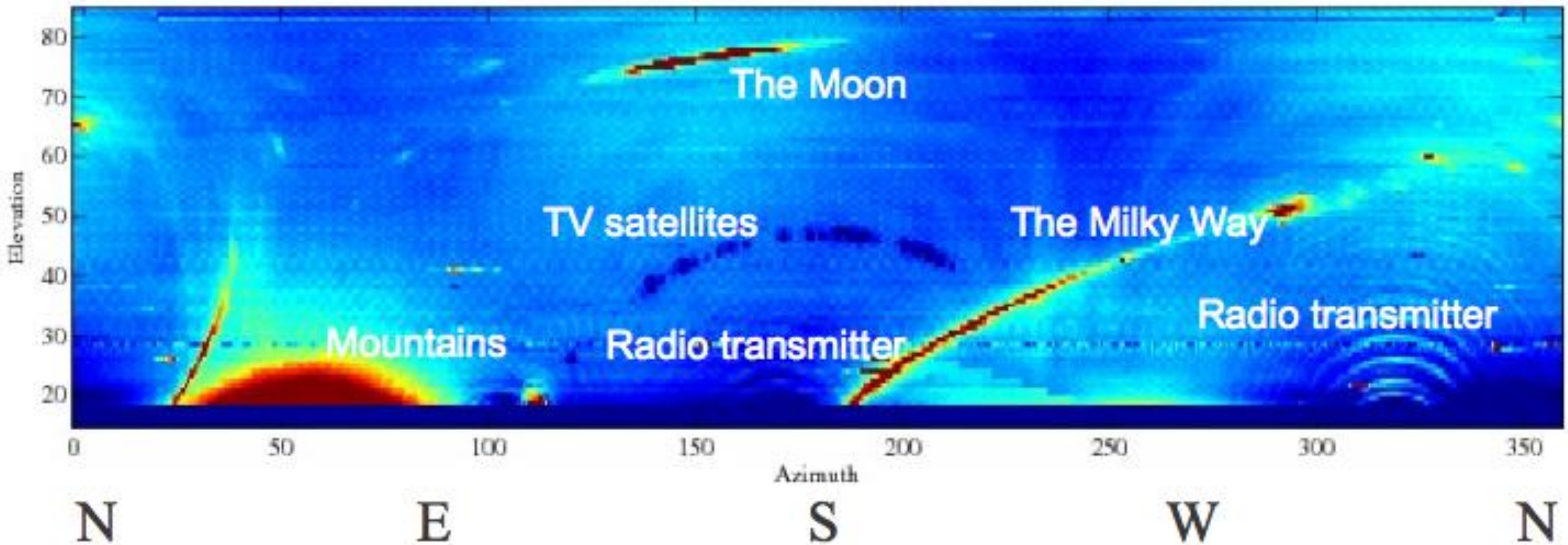
Intensity channel, balanced f_{knee} ~ 30 mHz

Polarization f_{knee} ~ 10 mHz

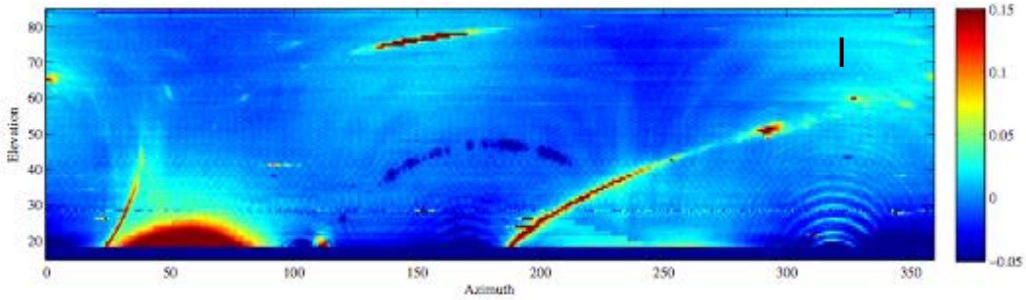
No polarization 1/f receiver noise at f_{scan} = 11 mHz



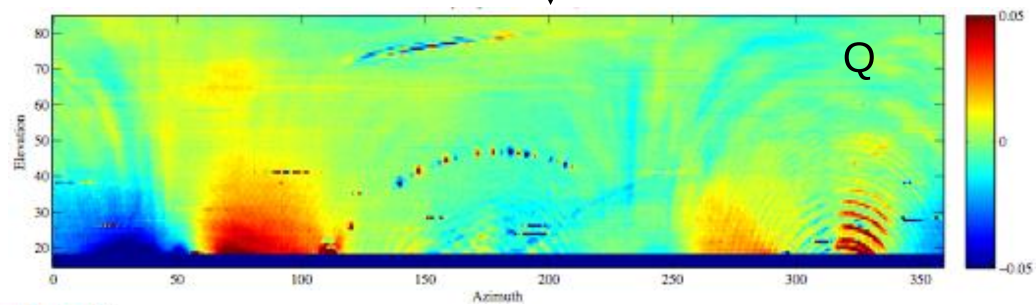
C-BASS North Site (1)

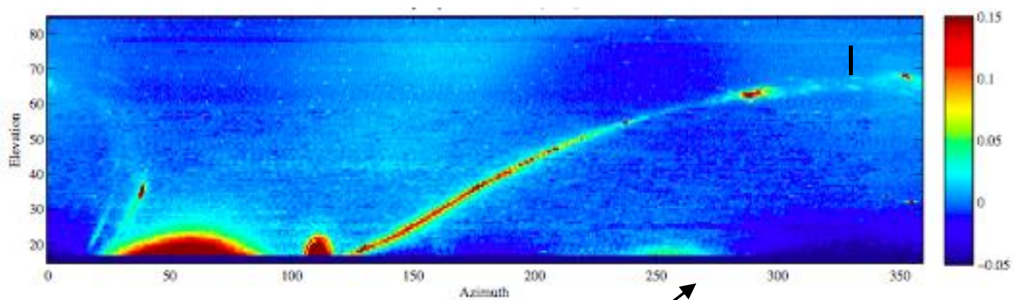


C-BASS North Site (2)

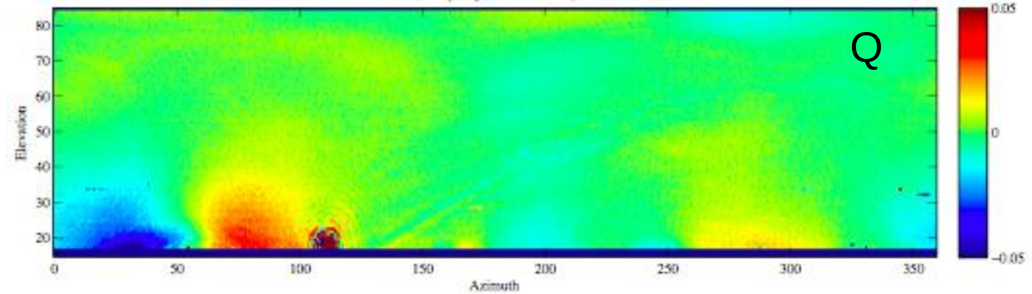


Before installation of notch filter (in-band) and second bandpass filter





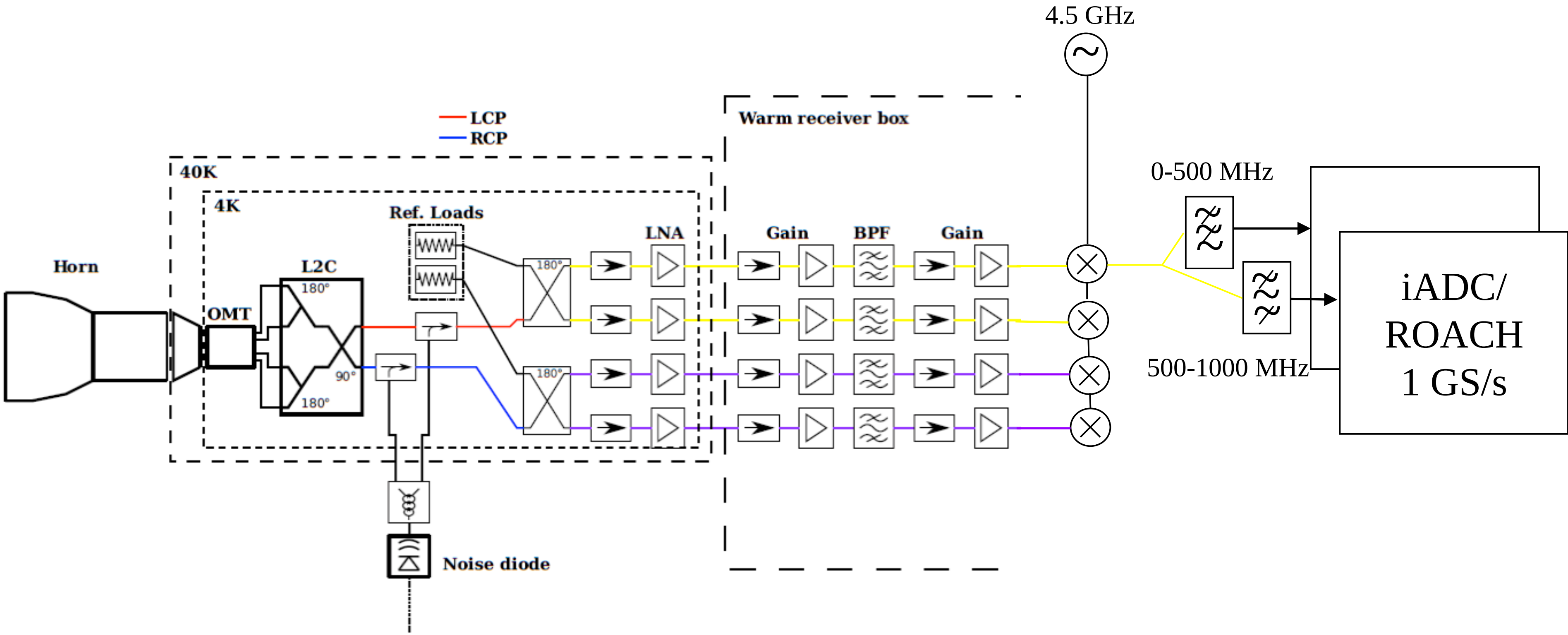
After installation of extra filters



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)

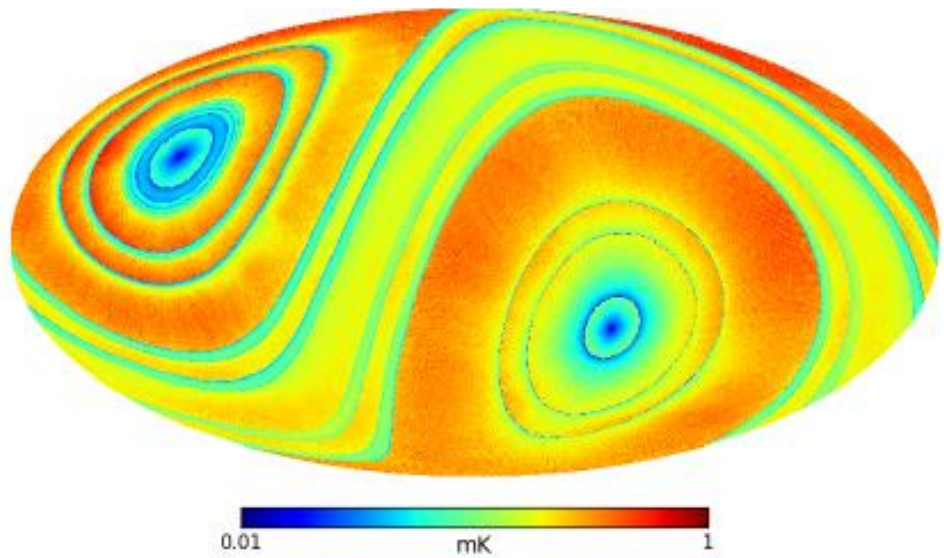
C-BASS South Receiver



- Digital correlation polarimeter – two down-converted channels of 500 MHz sampled in 1st and 2nd Nyquist zones
- 2 x ROACH FPGA board each with 4 x 1 GS/s ADC inputs
- 64-channel spectrometer per ROACH -- 128 channels in total, Δv=0.7GHz

Survey Parameters

- 360° scans at constant elevation.
- Deep NCP scans for check of systematics.
- Survey data at several elevations
  - Through NCP
  - Through NCP + 10, 20, 30… °
- Scan speed of 4 deg/s → scan in 90s
  - Need fknee < 11 mHz
- Pointing and opacity and flux calibration every 2 hours.
- Continuous gain monitoring via noise diode injection.

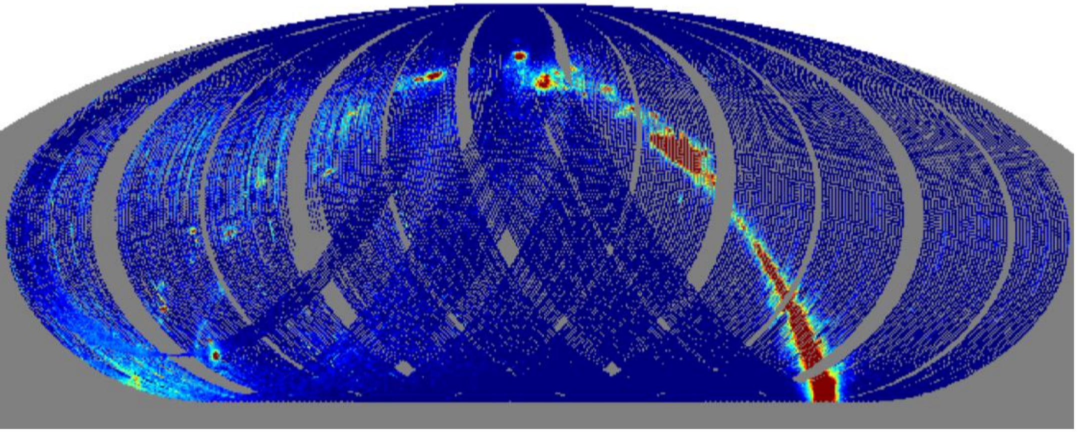


<u>Simulation of elevation scans through NCP and SCP.</u>

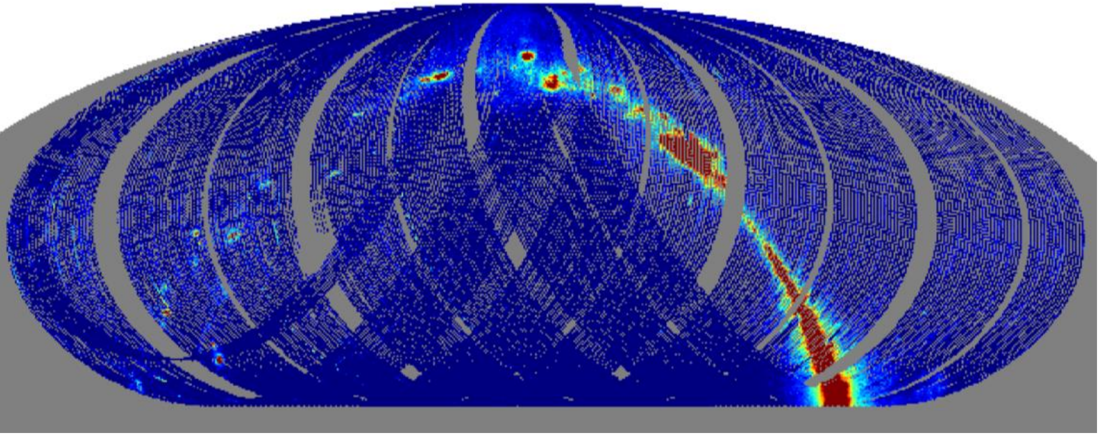
- Daytime only for 24 months.
- Random drop-outs added.

- Very good coverage at poles and overlap region.
-

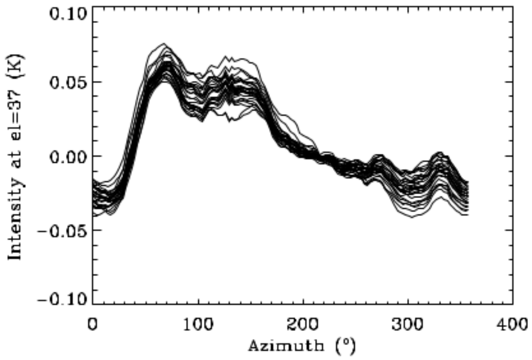
Removal of ground pick-up

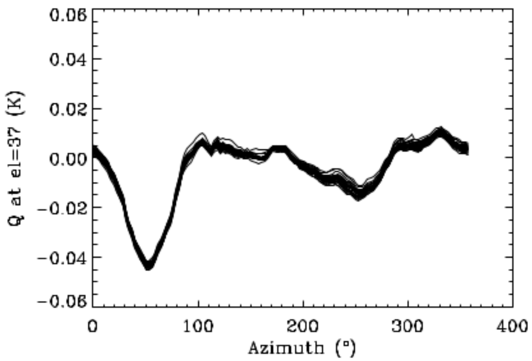


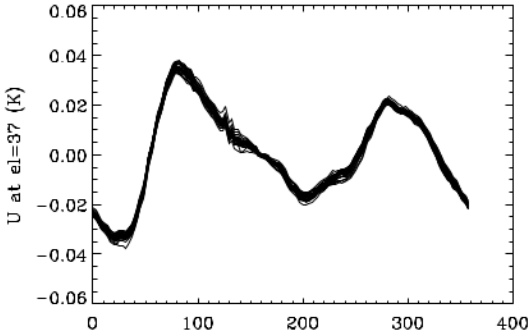
1 day map without ground subtraction



1 day map after ground subtraction







30 days of ground templates

Descart Destriping Mapper

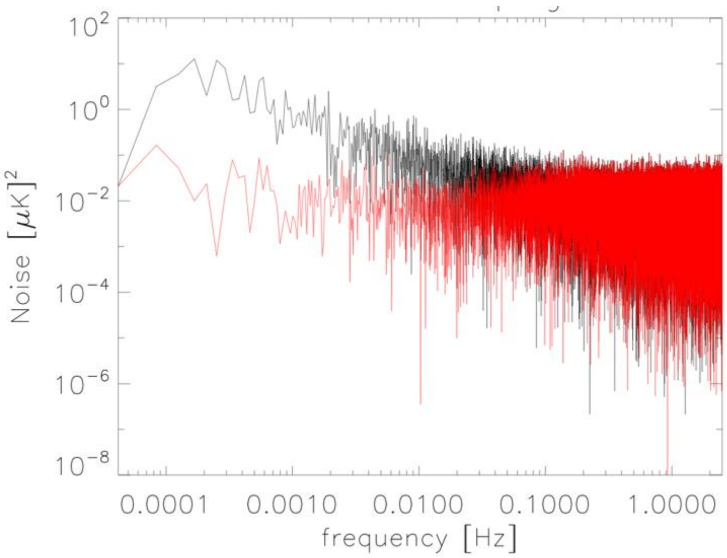
- Model timestream as sum of:

  Signal projected by pointing *P*

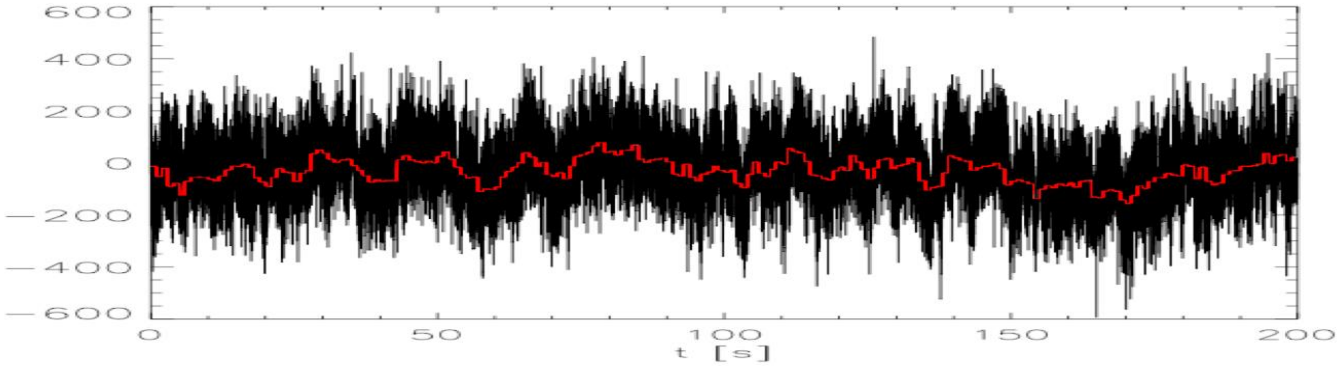
  1/f noise modeled by baseline offsets *a*

  purely white noise *w*

- Solve for *a* with conjugate gradient and subtract to make problem purely white noise



$$d_t = P_{tp} s_p + F_{ti} a_i + w_t$$



Sutton et al MNRAS 2010, 407, 1387

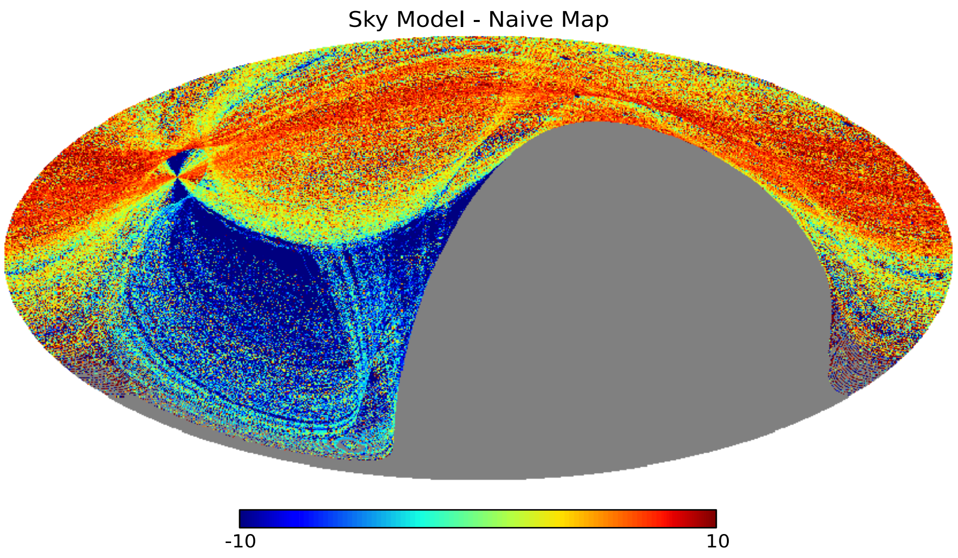
Descart Destriping Mapper

Sutton et al MNRAS 2010, 407, 1387

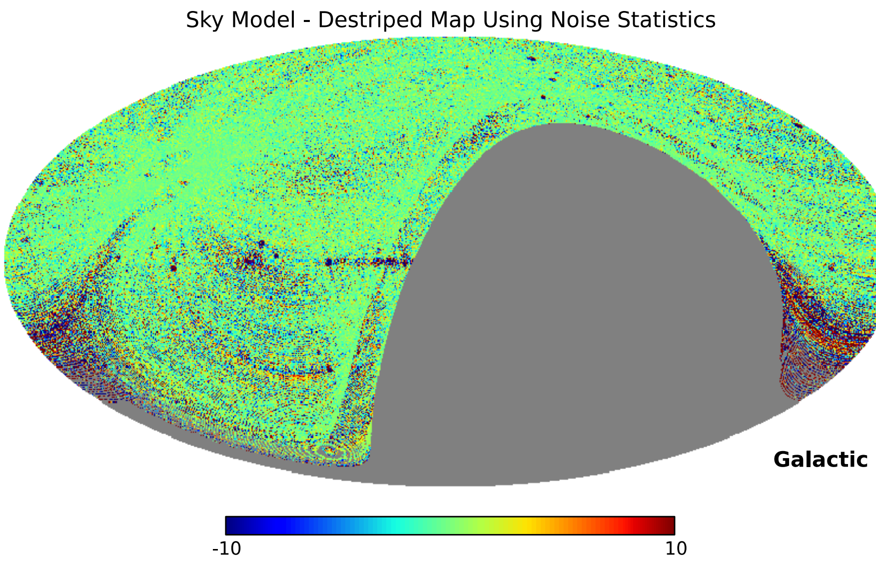
- Optimized parallel de-striping code
- Performs a maximum-likelihood fit to the correlated noise in the timestream:

Data = Signal + uncorrelated white noise + offsets

- Solves for the offsets and subtracts.

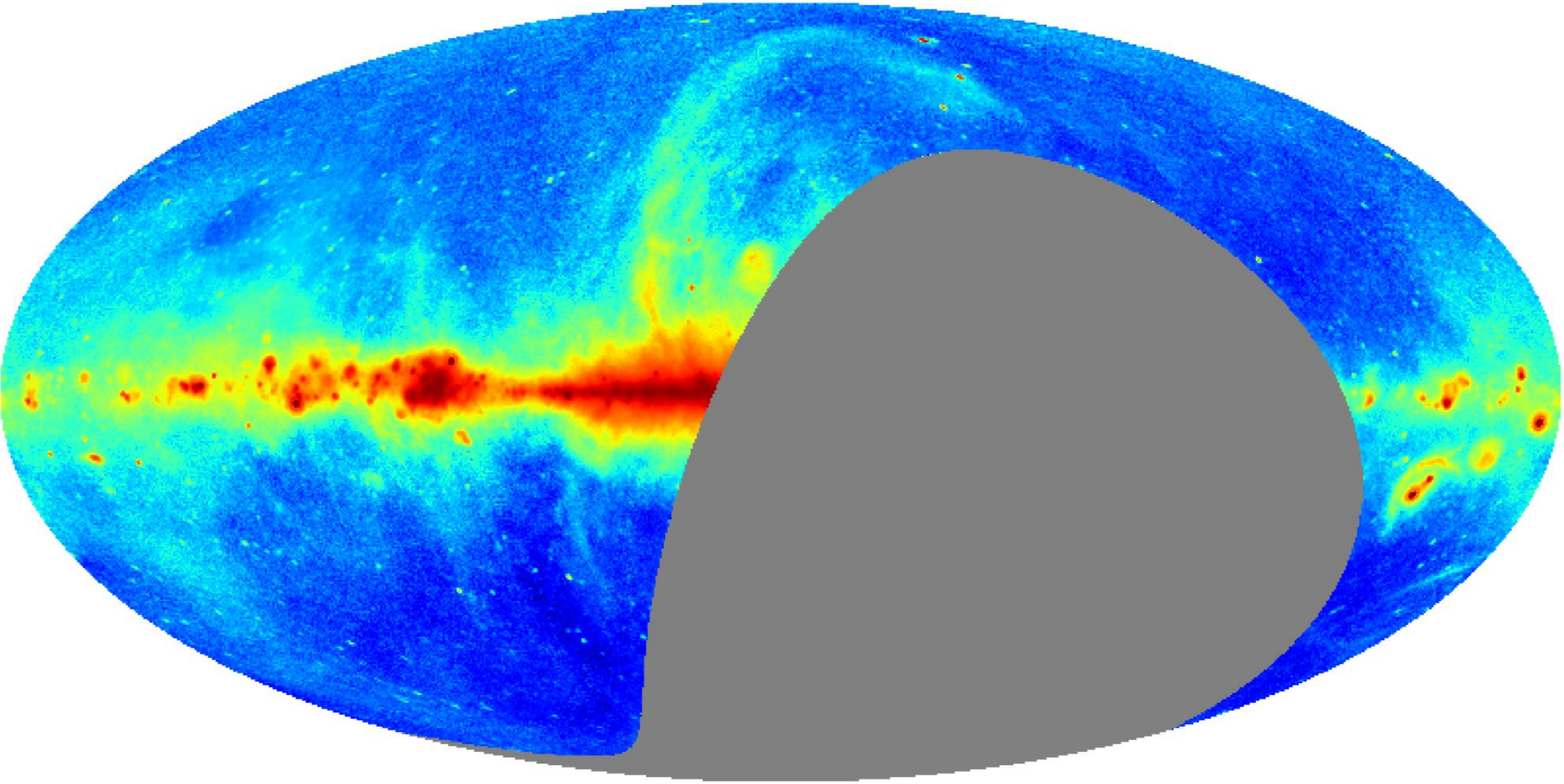


Residuals for naïve (simply binned) map

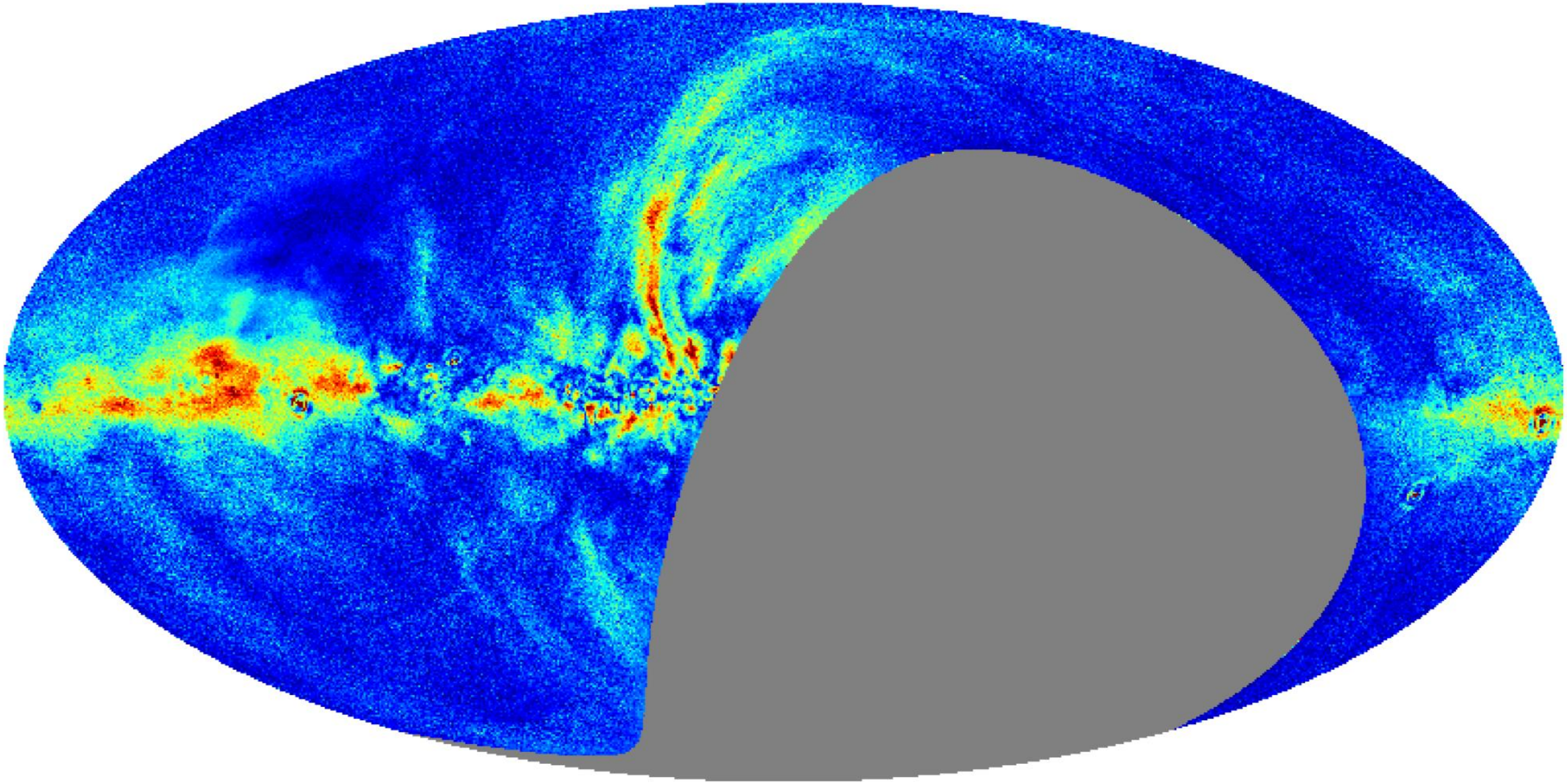


Residuals for destriped map

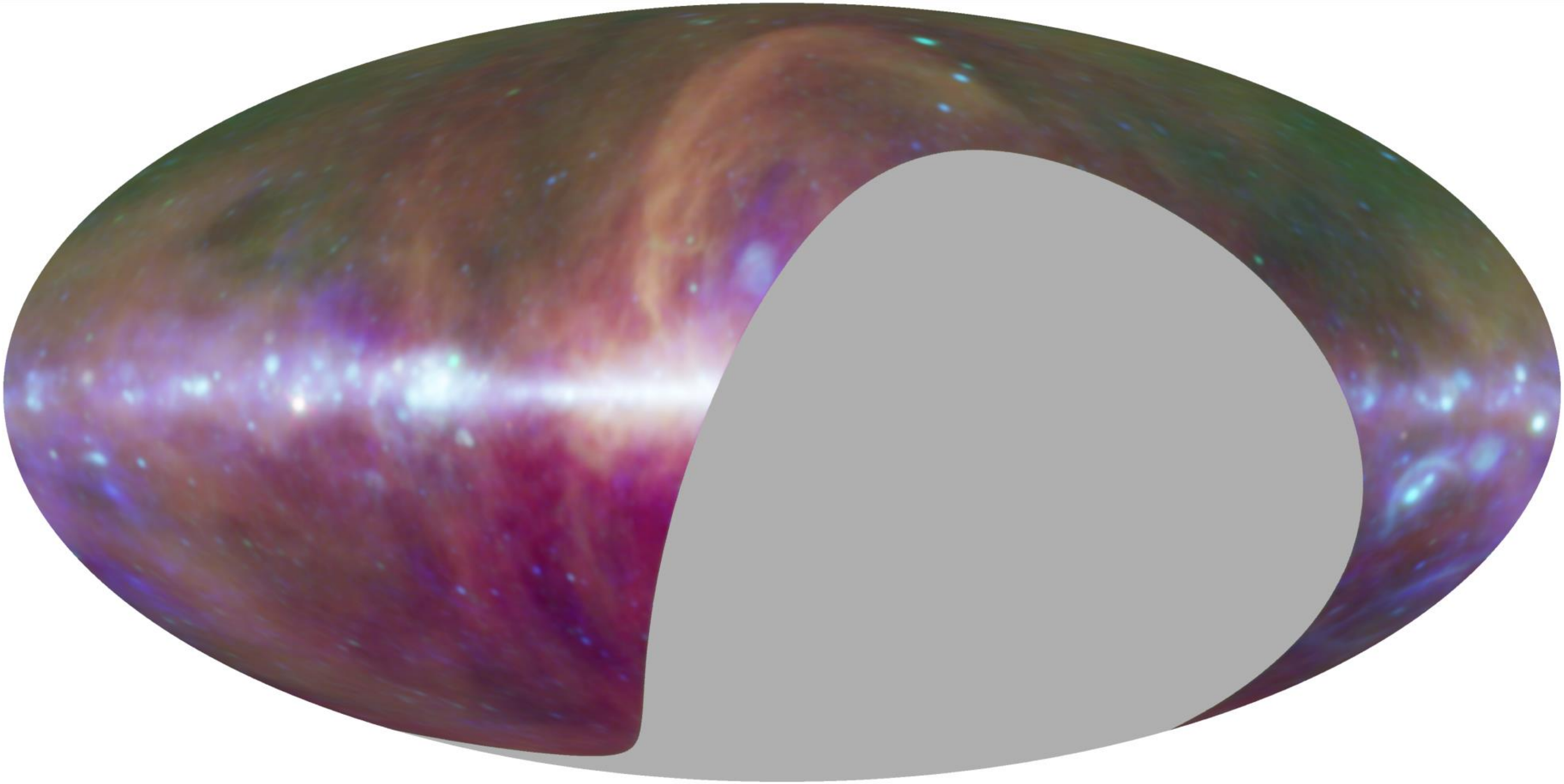
CBASS-N *I*



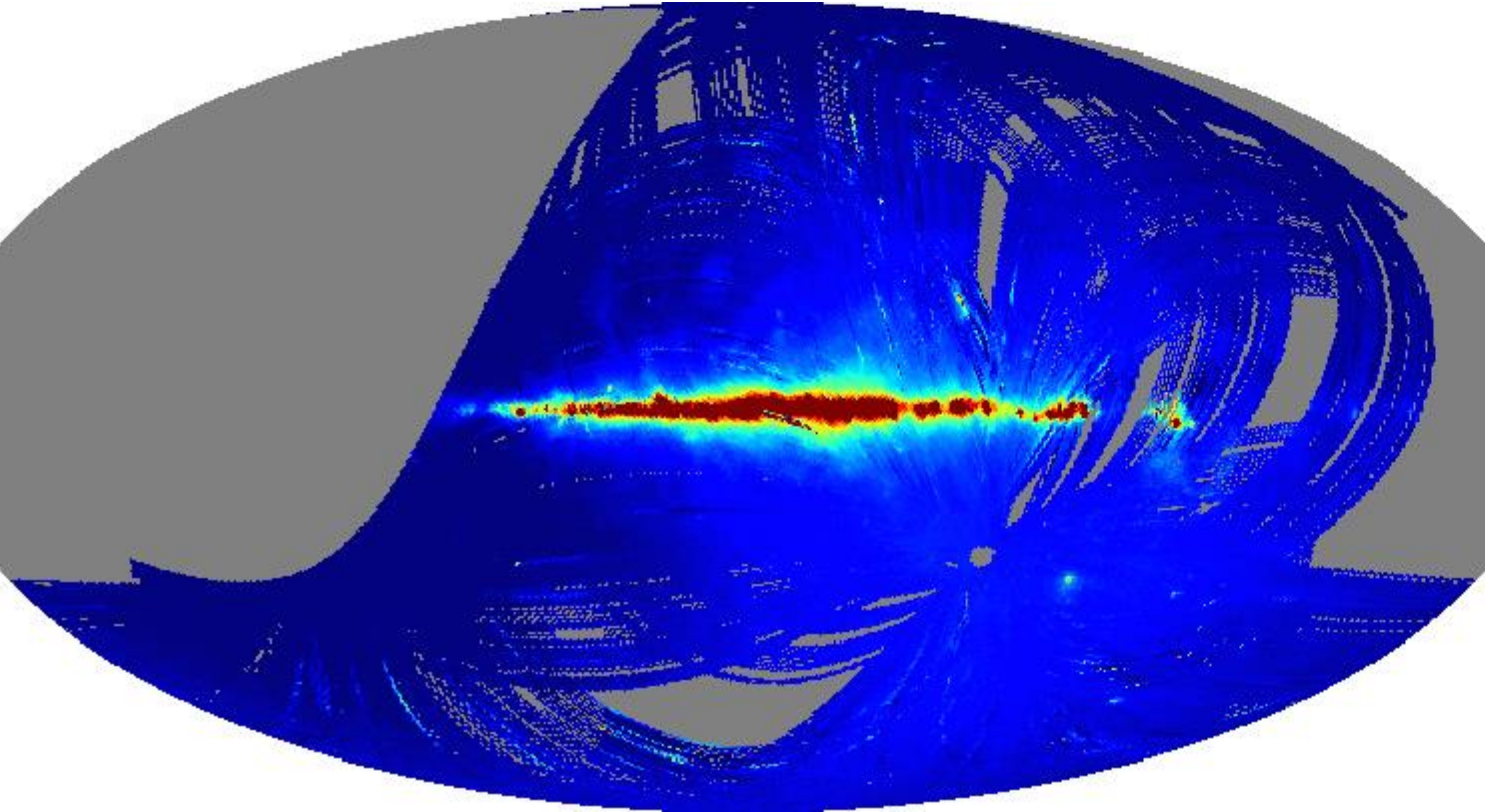
CBASS-N *P*



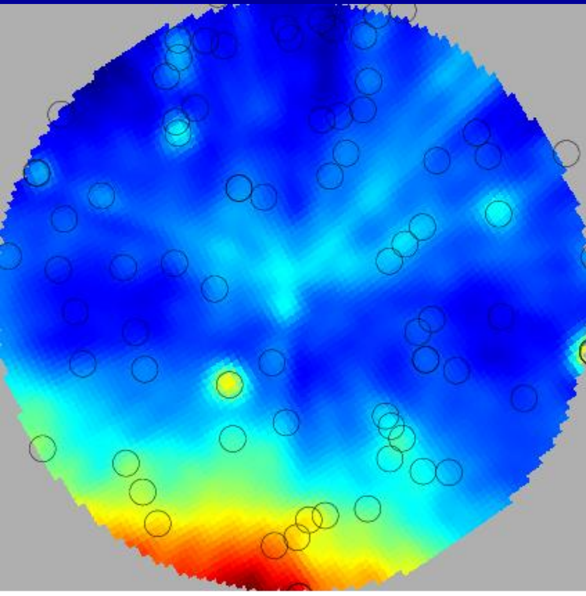
408 MHz - 5 GHz – 23 GHz



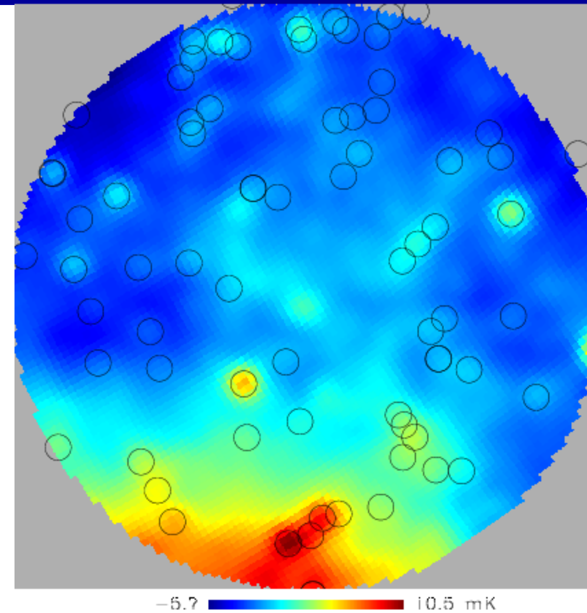
CBASS-S I (very early data!)



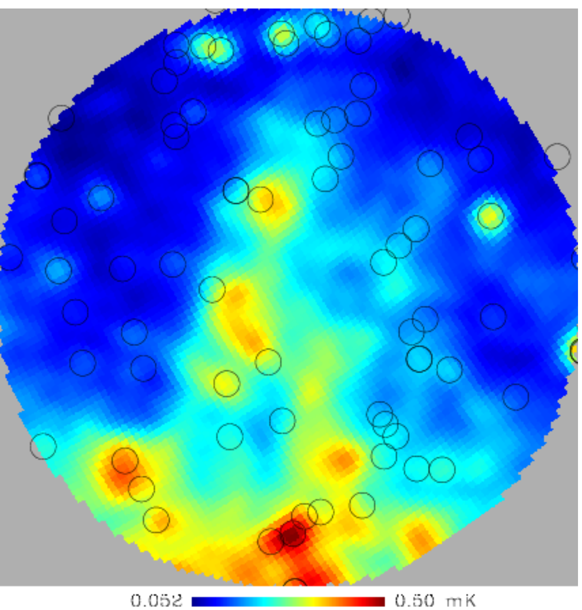
NCP - components



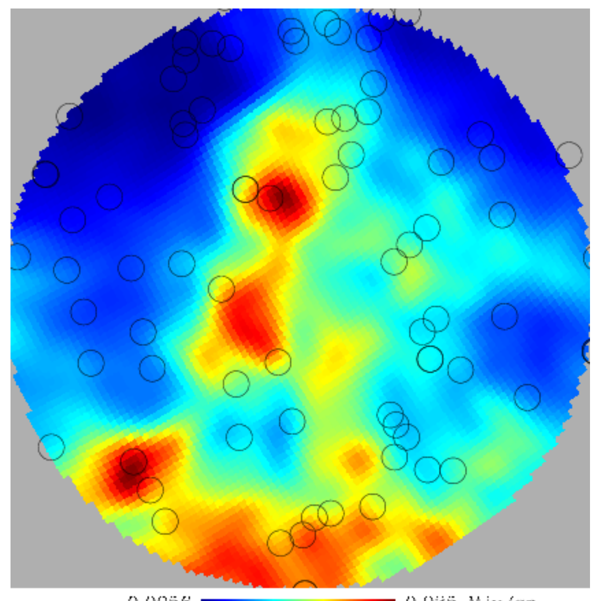
408 MHz – synchrotron?



CBASS 5 GHz - synchrotron



WMAP 23 GHz – synchrotron + AME



IRIS 100 μm – thermal dust

CBASS - data

- Reducing Northern data now – observations finished
- Staged publications -> data release
- Southern survey starting ~now.
- 2 yrs data taking expected in south
- Full data release once surveys completed and combined…
- …and project team has published a few papers!

Expected improvements in component fitting

Fitting for components from Haslam + WMAP + Planck (+CBASS):

Parameter	Without C-BASS	With C-BASS	True Value	Units
synch_beta	-3.369 ± 0.559	-3.268 ± 0.357	(-3.1)	
synch_amp	16.64 ± 2.94	16.03 ± 2.43	(16.58)	[K]
ff_EM	139.9 ± 42.8	154.0 ± 6.4	(152.0)	
ff_Te		– 7000 –		
sd1_amp	81.07 ± 30.48	87.73 ± 10.64	(85.52)	[uK]
sd1_fPeak	16.10 ± 14.46	13.14 ± 1.77	(13.46)	[GHz]
dust_amp	231.8 ± 12.66	230.7 ± 11.6	(232.2)	[uK]
dust_beta	1.587 ± 0.087	1.577 ± 0.078	(1.591)	
cmb_amp	75.45 ± 5.60	74.09 ± 3.42	(75.00)	[uK]

Synch beta error down 35%
Synch amp error down 20%
FF amp error down by factor 6.7
AME amp error down by factor 3
AME peak freq error down by factor 8
CMB amp error down by 40%

Results vary a lot over the sky with different amplitudes of various components

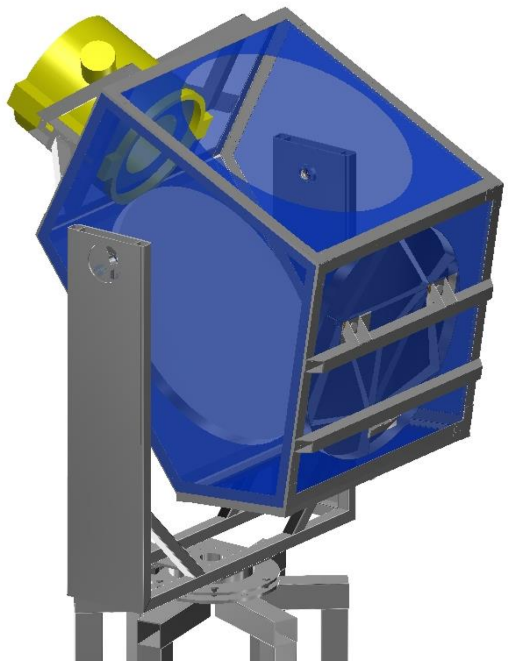
Real analysis (COMMANDER) under way now…

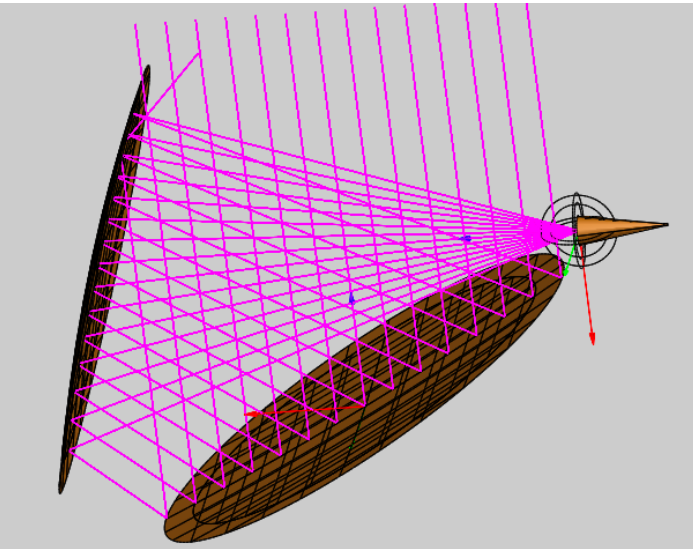
Next-BASS?

- 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 – 25 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

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
  - 6 – 12 GHz
  - 12 – 24 GHz
- Digital backend based on SKA designs





Next-BASS?

- C-BASS equivalent sensitivity at 100 GHz = 0.05 μK-arcmin with $\beta = 3$
- Minimum number of feeds to achieve 1 μK-arcmin: (assuming 20% bandwidth)
- Eg 1 – 3 feeds 6-12 GHz
- ~30 feeds 12-24 GHz
- Running detailed sims to see where the constraining power really lies