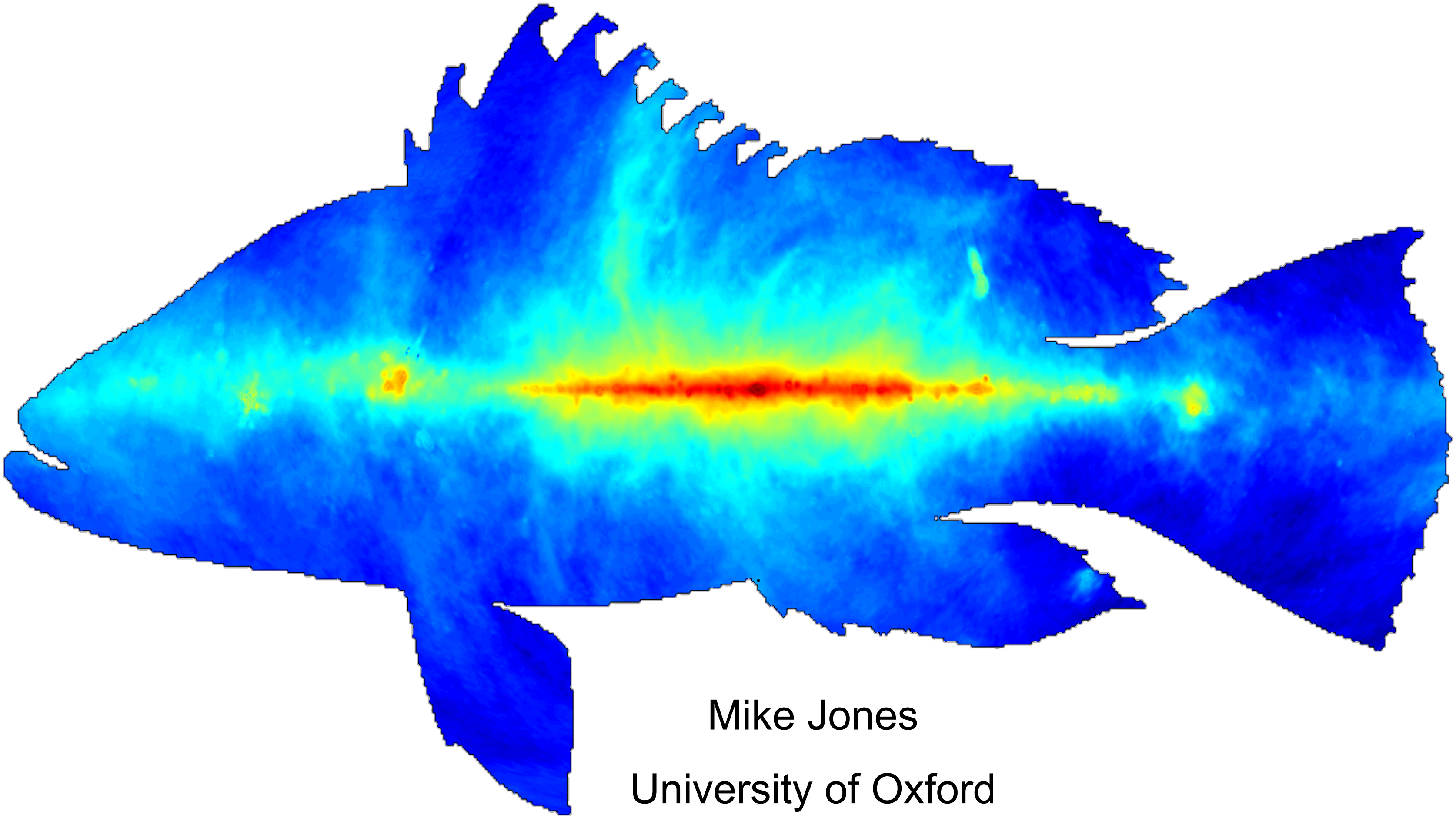
C-Band All-Sky Survey (C-BASS)



Mike Jones

University of Oxford

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

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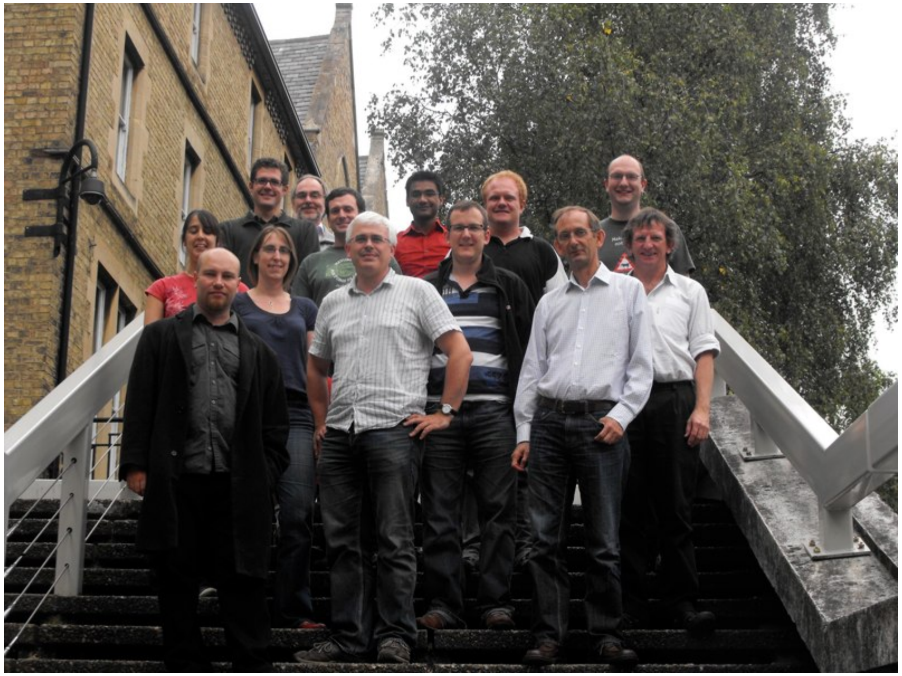
Dayton Jones, Russ Keaney, Oliver King, Stephen Muchovej, Tim Pearson, Tony Readhead, Matthew Stevenson

South Africa

Justin Jonas (Rhodes), Pieter Stronkhorst, Keith Jones (HartRAO)

KACST, Saudi Arabia

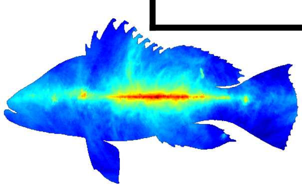
Yasser Hafez, Fahad Albaqami

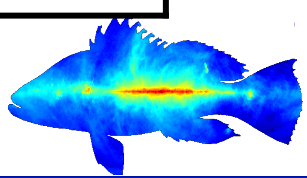


Collaboration meeting, Oxford, July 2011

C-BASS - Overview

Sky-coverage	All-sky
Angular resolution	0.73 deg (43.8 arcmin)
Sensitivity	< 0.1mK r.m.s
Stokes coverage	I, Q, U, (V)
Tsys	~20K, including sky
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 - Science Goals

Primary aims:

• To provide all-sky maps in I, Q and U at 5 GHz for the community.

• To allow more accurate subtraction of the polarized Galactic synchrotron emission from e.g. WMAP, Planck and future B-mode experiments.

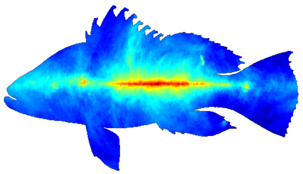
Secondary aims:

• To map the local (≤1 kpc) Galactic magnetic field and improve our understanding of the the propagation of cosmic rays through it.

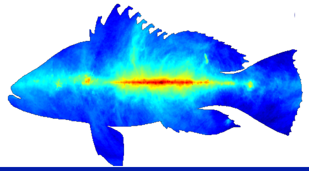
• To further study the distribution of anomalous dust.

• To improve the modeling of Galactic total intensity emission and hence allow CMB experiments to access the currently inaccessible region close to the Galactic plane.

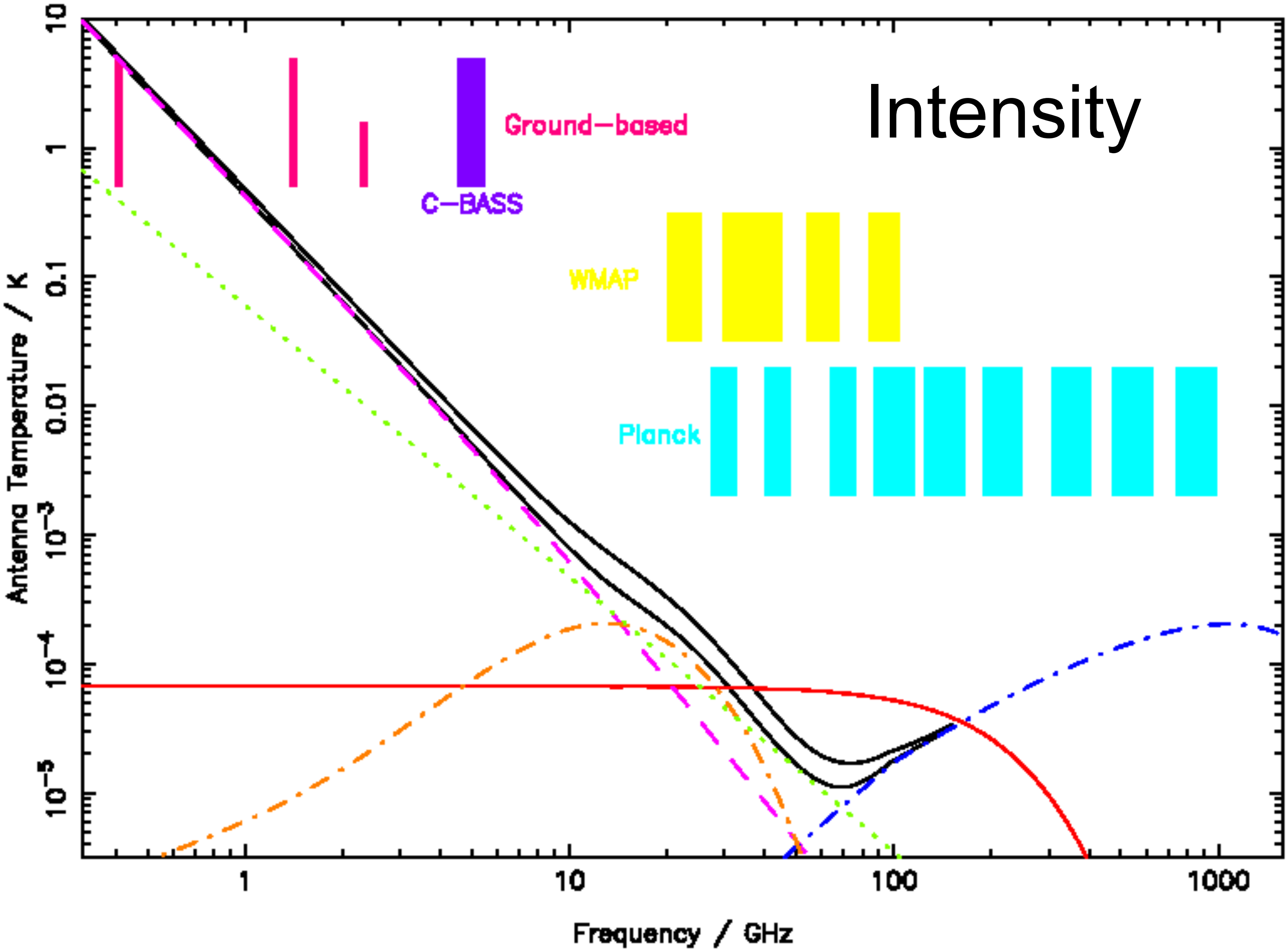
• Help our understanding of / belief in the Galactic Haze….



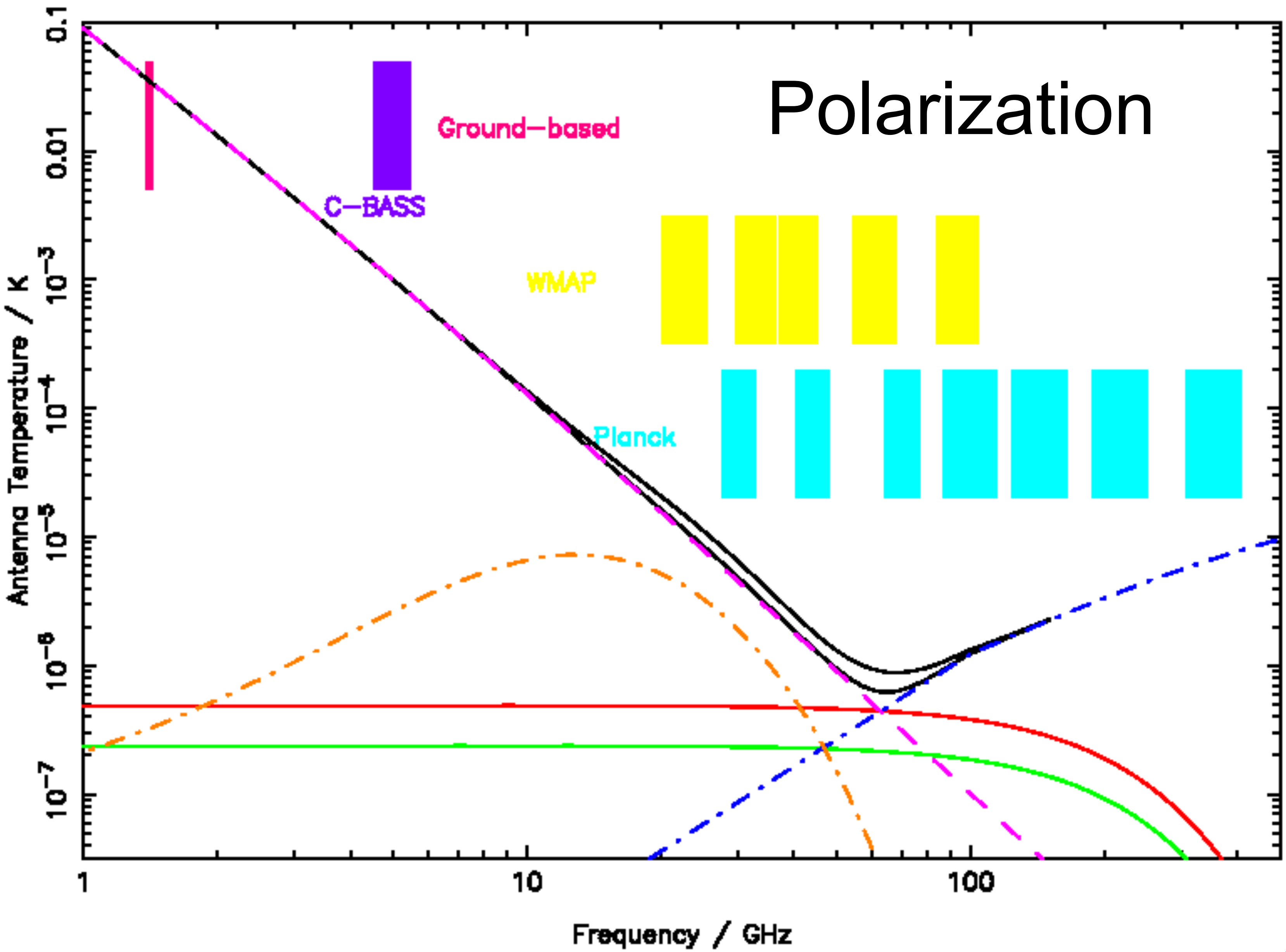
….to name but a few ….



Why a 5 GHz survey?



Why a 5 GHz survey?



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)

Impact on Planck results (1)

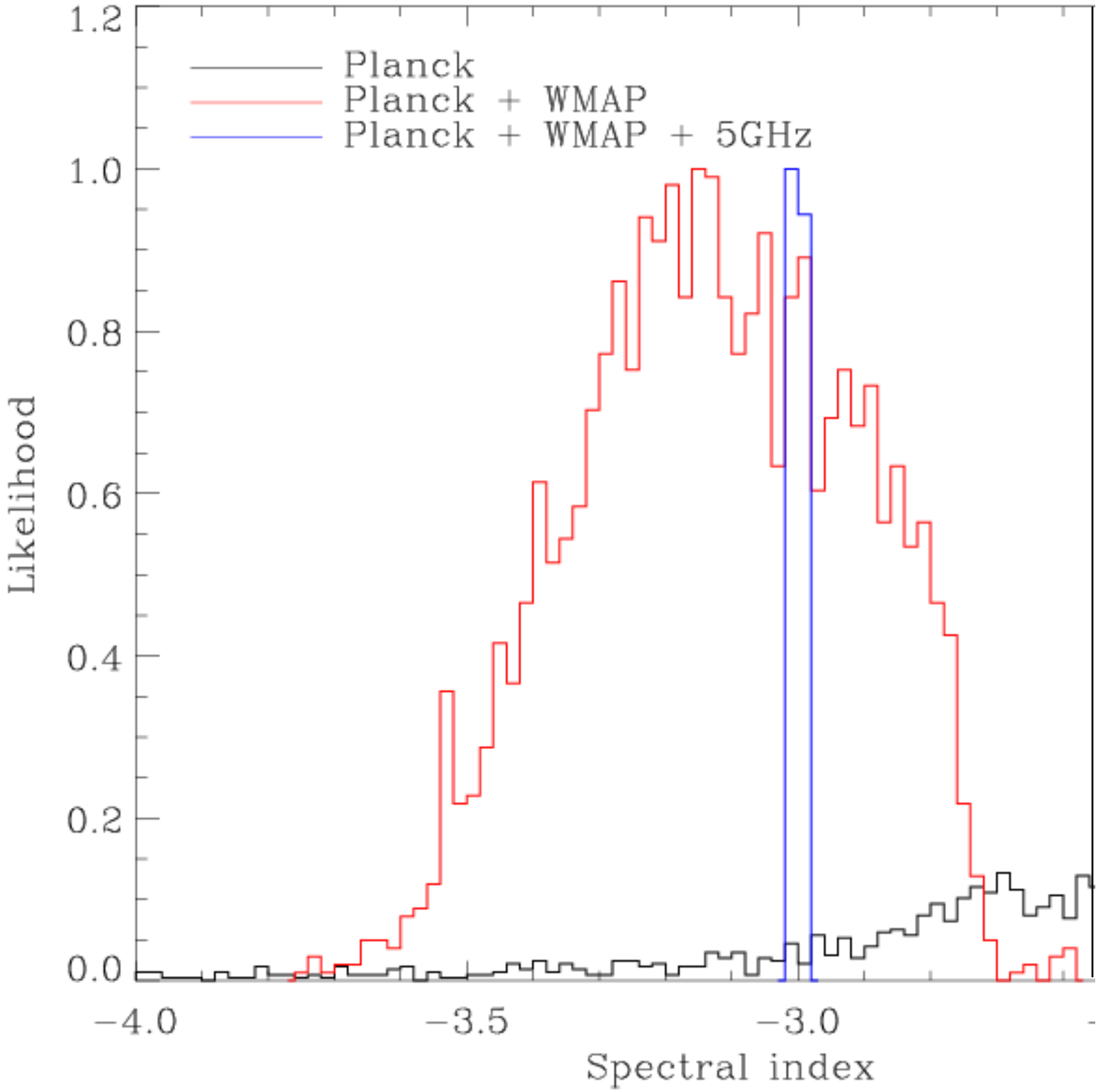
	Planck	Planck+CBASS
Stokes I		
CMB mean error (μK)	5.4	4.0
Synch amp error (μK)	1.4	0.44
Synch index error	0.29	0.03
Dust amp error (μK)	3.4	2.8
Dusts index error	0.26	0.29
Stokes Q,U		
CMB mean error (μK)	3.6	2.7
Synch amp error (μK)	0.67	0.17
Synch index error	0.29	0.03
Dust amp error (μK)	1.3	0.97
Dust index error	0.26	0.29

Typical high latitude 1 deg pixel
Mean synch amplitude 80 uK@ 23 GHz
MCMC reconstruction

25% improvement
× 3 improvement
× 10 improvement

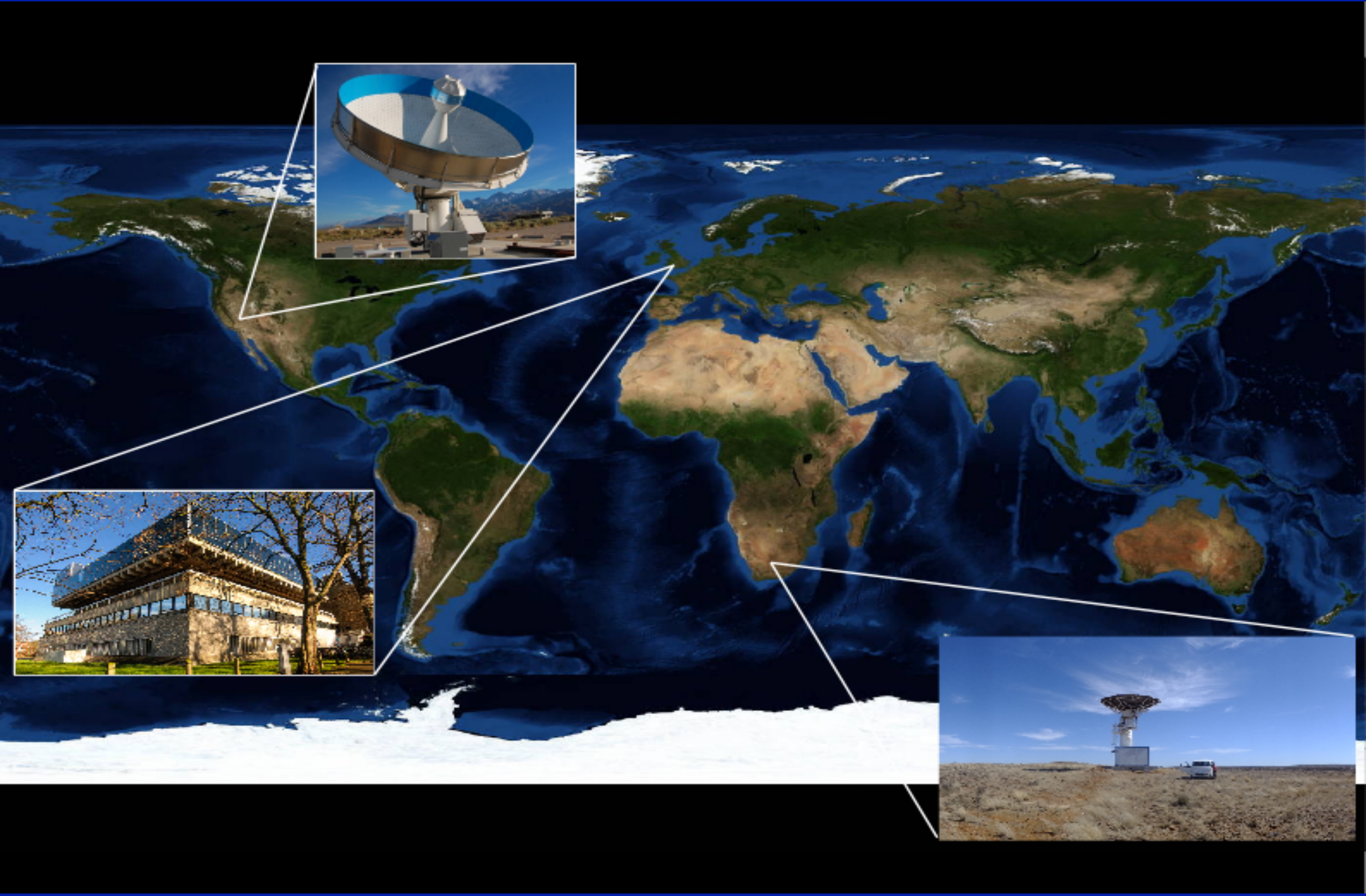
25% improvement
× 4 improvement
× 10 improvement

Impact on Planck results (2)



Constraining the synchrotron spectral index…

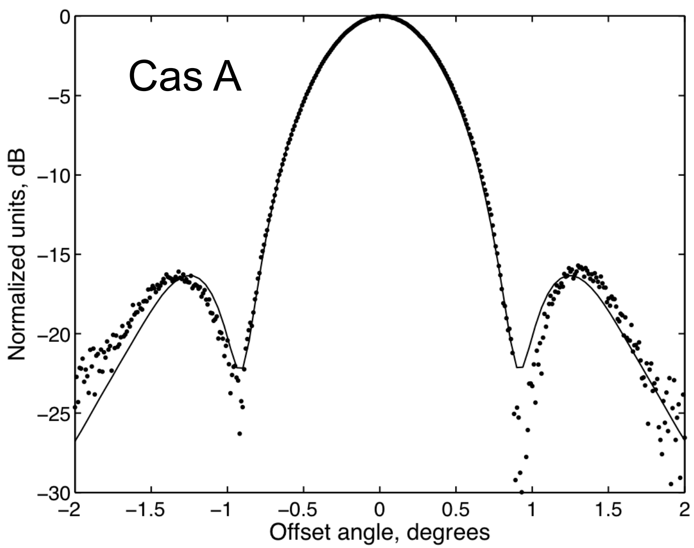
The C-BASS Survey

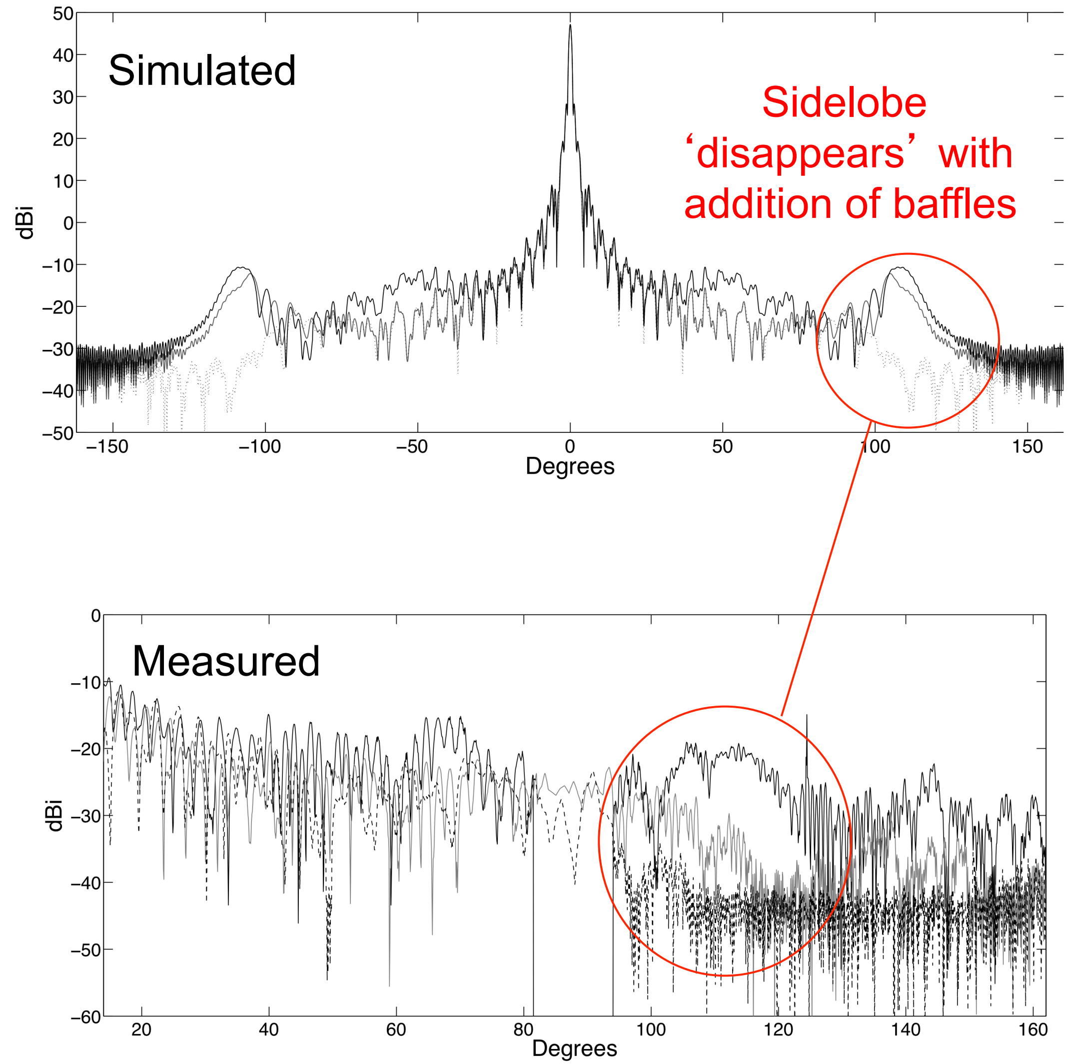


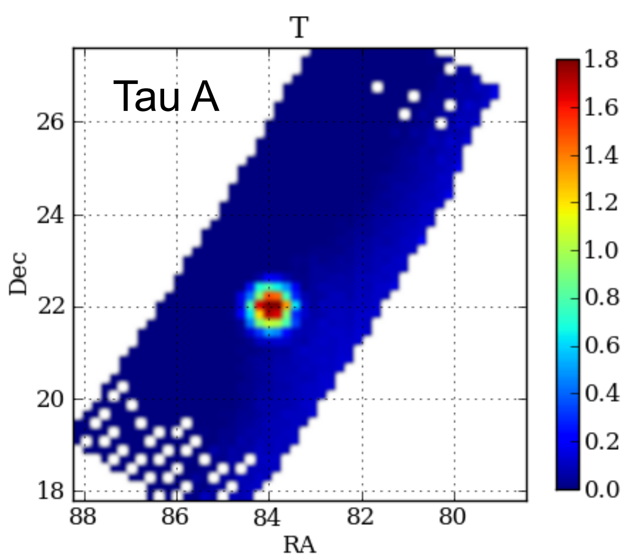
C-BASS North Telescope

- 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

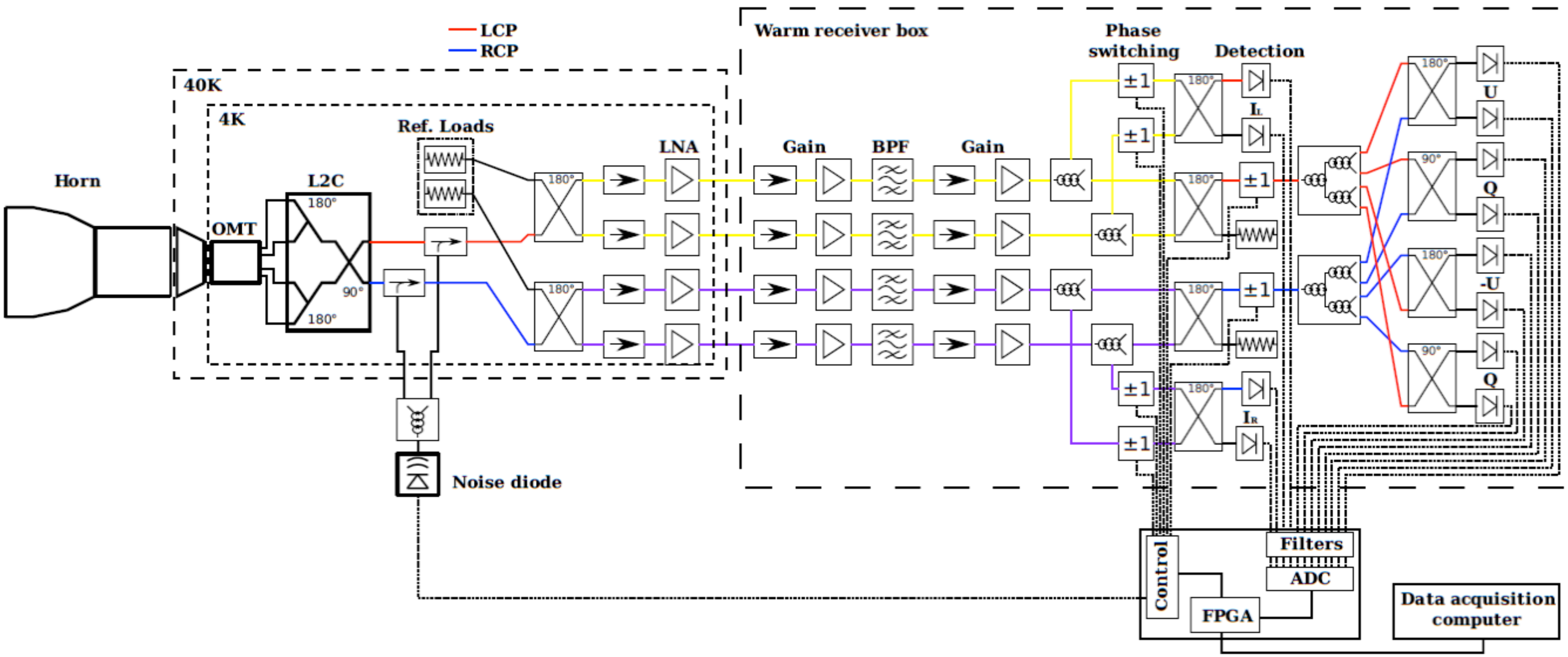






(see Holler et al. 2011, arXiv:1111.2702v2)

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

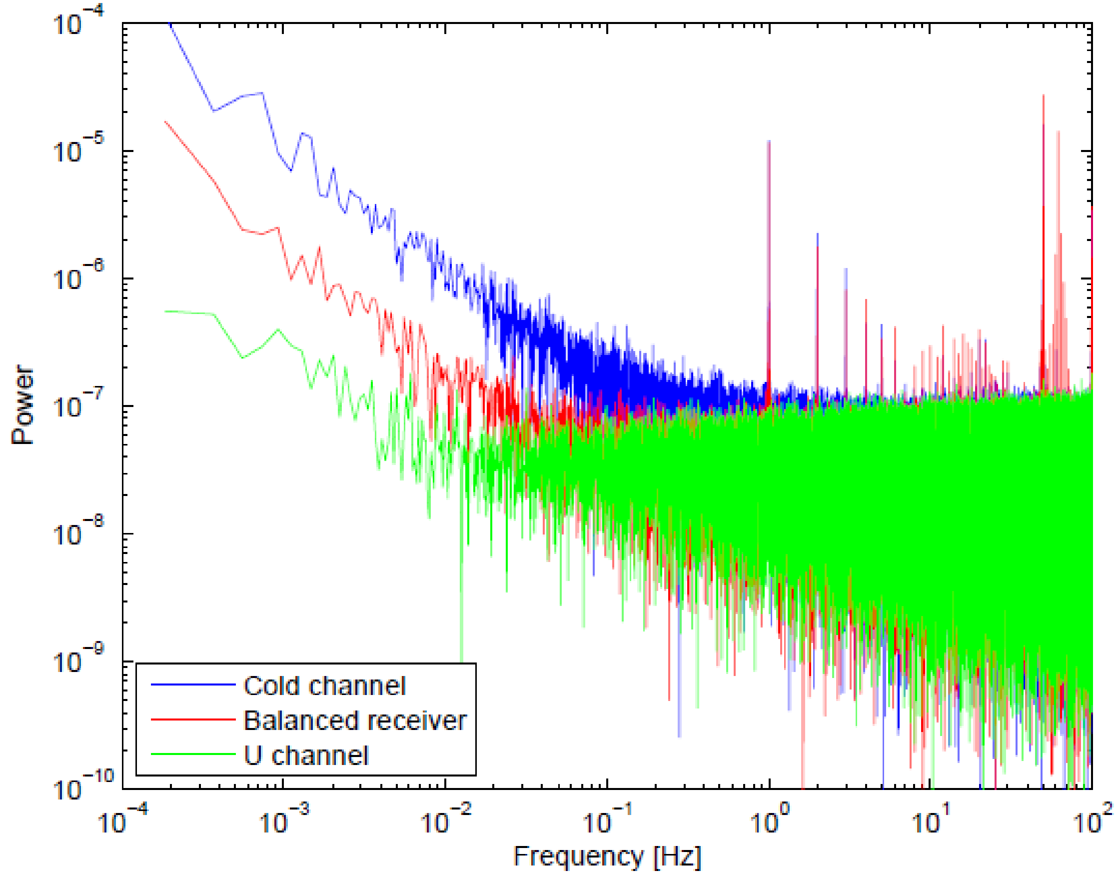
Receiver noise power spectra

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

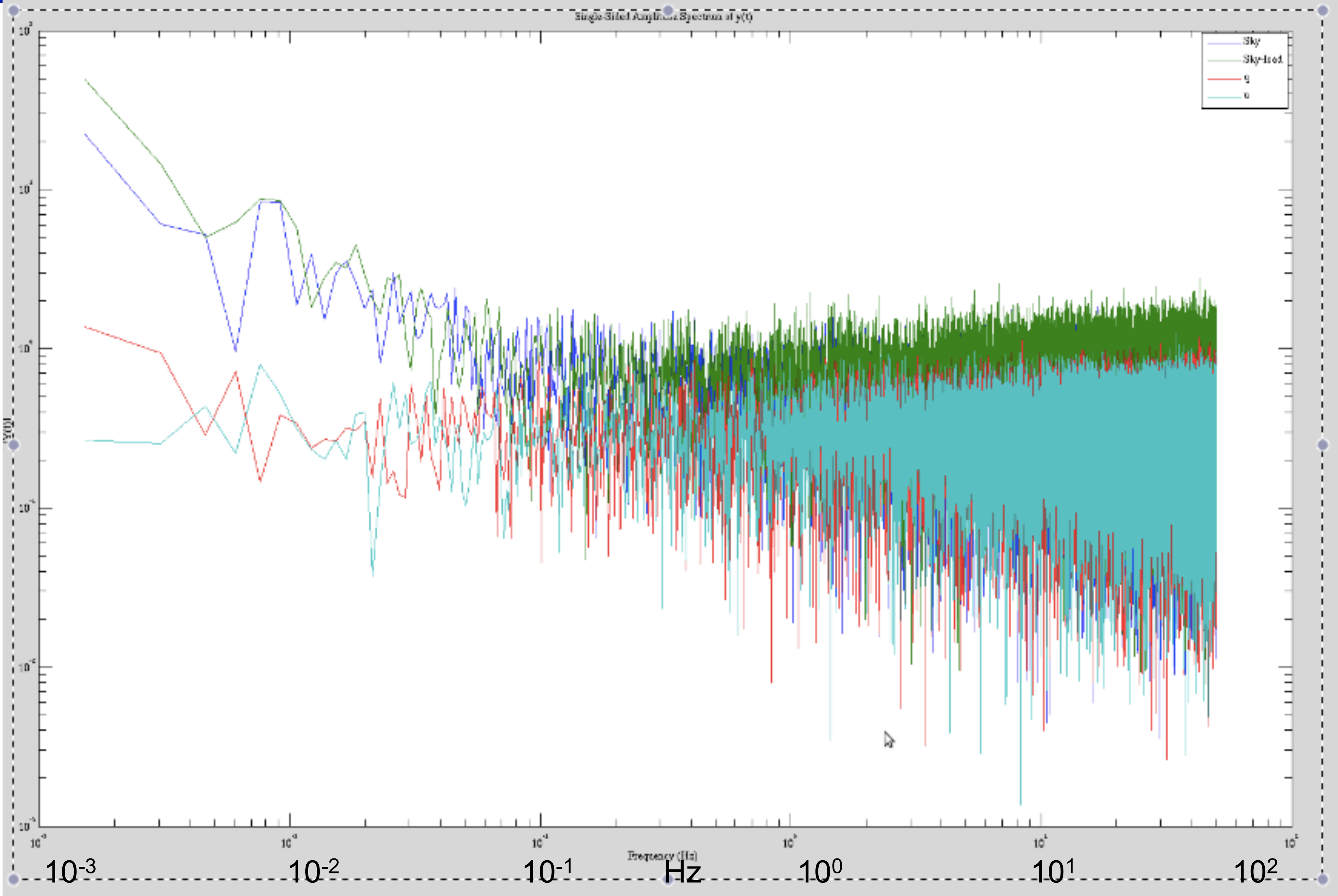
Intensity channel, balanced $f_{\text{knee}} \sim 30$ mHz

Polarization $f_{\text{knee}} \sim 10$ mHz

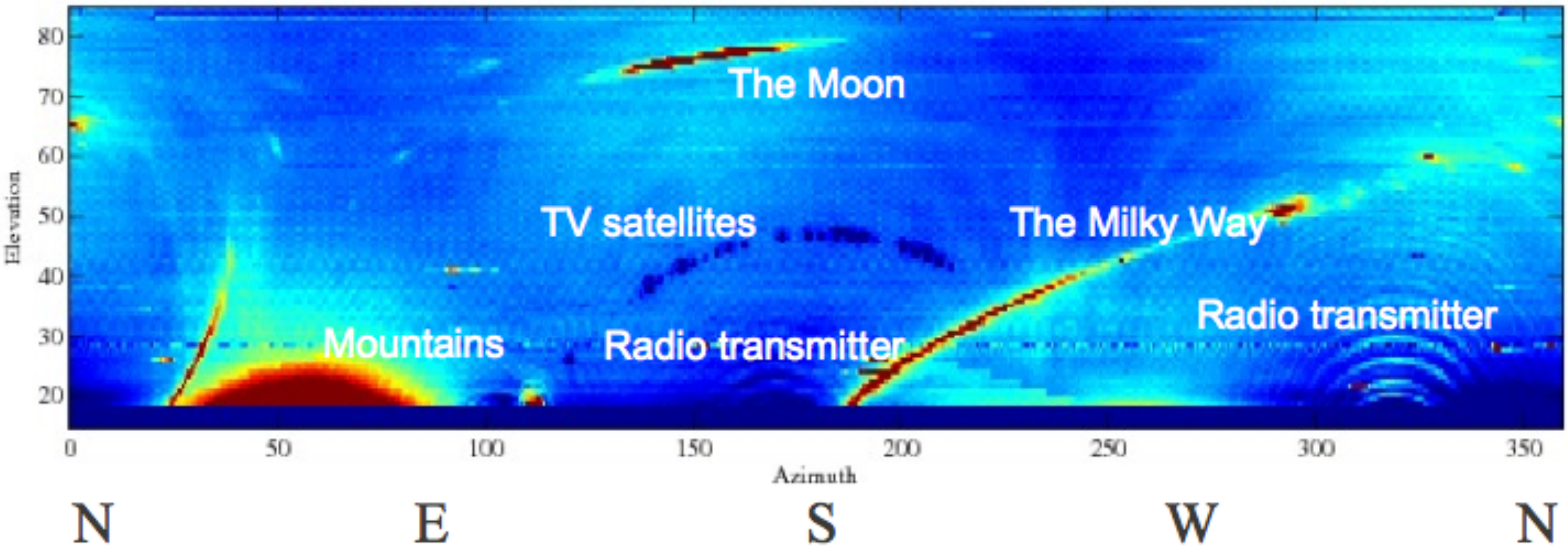
Should be minimal polarization $1/f$ receiver noise at $f_{\text{scan}} = 11$ mHz



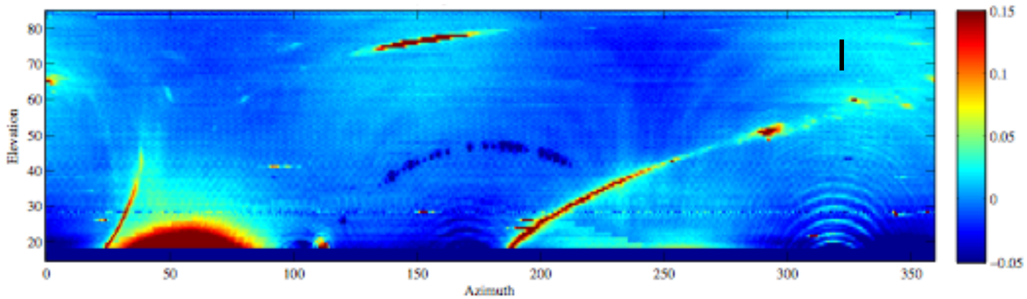
Noise power spectrum (C-BASS S)



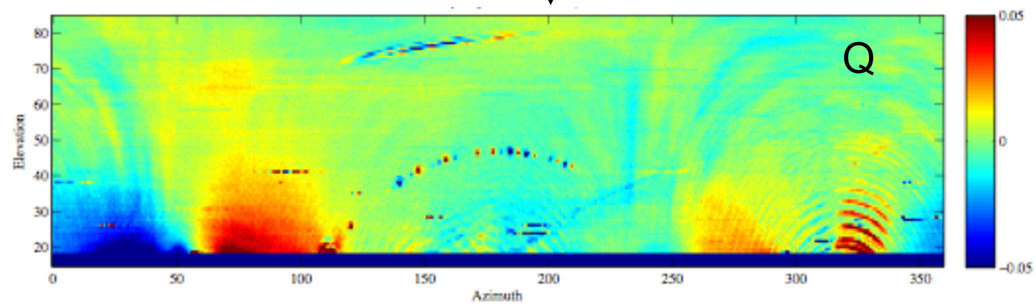
C-BASS North Site (1)

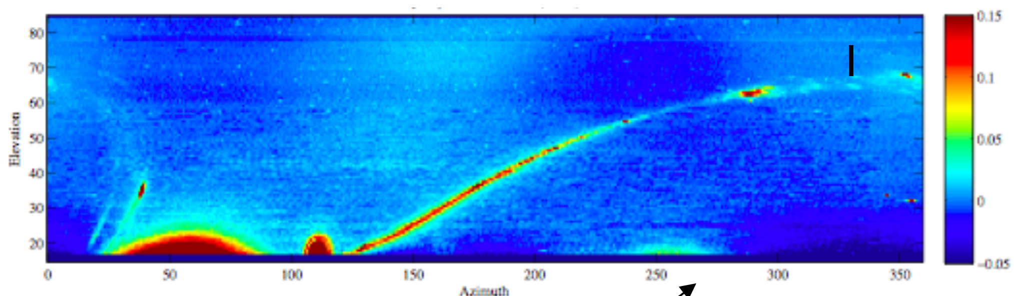


C-BASS North Site (2)

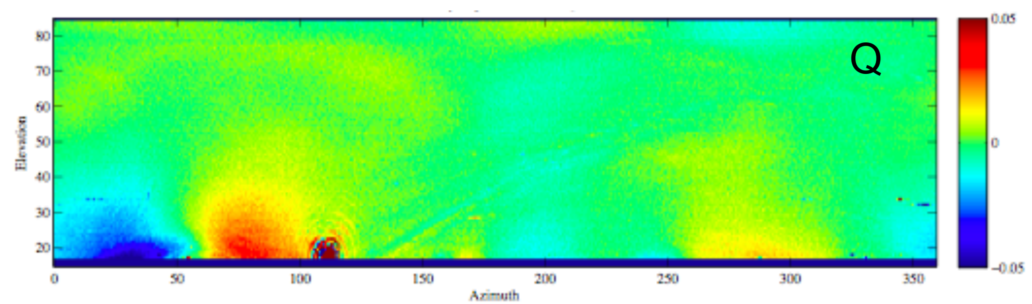


Before installation of notch filter (in-band) and second bandpass filter



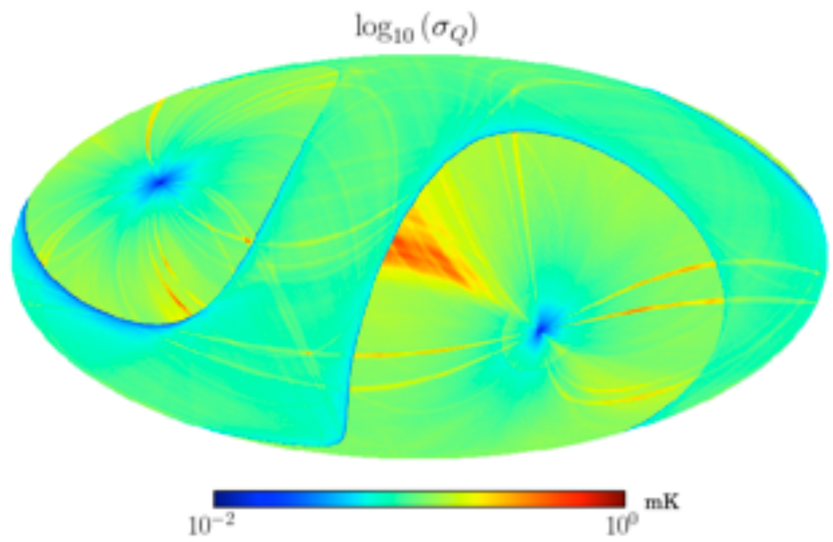


After installation of extra filters



Survey Parameters

- 360° scans at constant elevation.
- Deep NCP scans for check of systematics.
- Survey data at 2 elevations
  - Through NCP
  - Through NCP + 10 °
- Scan speed of 4 deg/s → scan in 90s
  - Need fknee < 10 mHz (√Receiver works)
- Pointing and opacity and flux calibration every 2 hours.
- Continuous gain monitoring via noise diode injection.
- Estimate of 6 months continuous observing for full hemisphere survey down to 0.1mK.

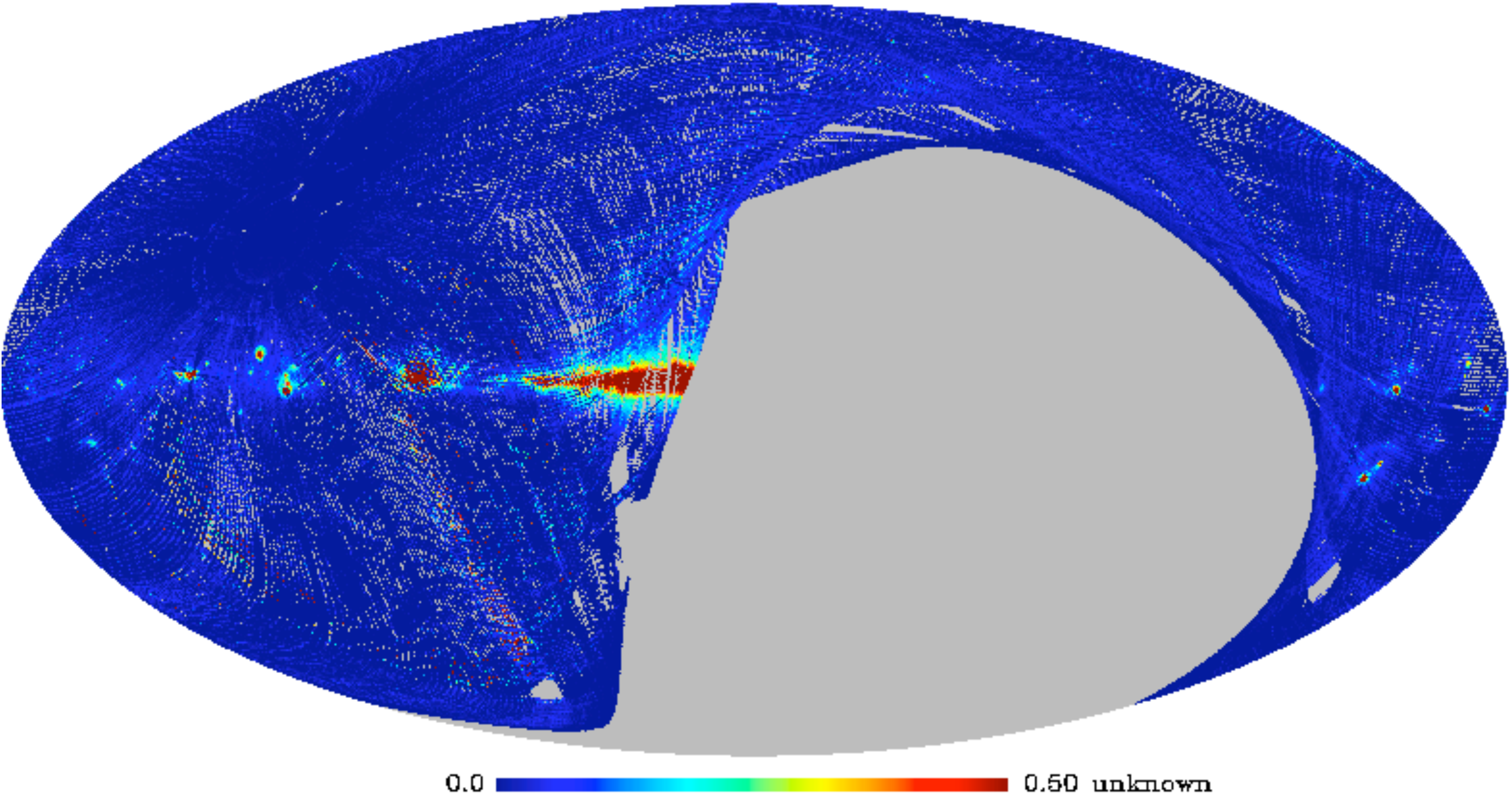


Simulation of single elevation scans through NCP and SCP.

- Daytime only for 6 months.
- Random drop-outs added.

- Very good coverage at poles and overlap region.
- NCP + 10° and SCP +10 ° fill in mid declinations.

One week...



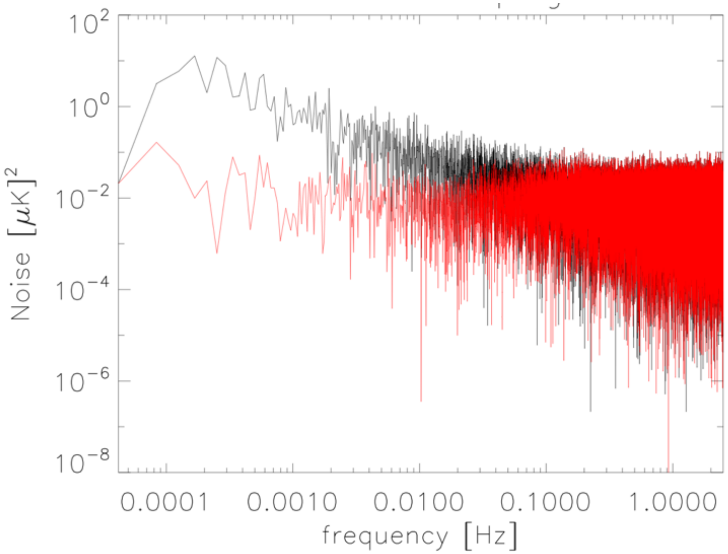
Descart Destriping Mapper

- Model timestream as sum of:

  Signal projected by pointing *P*

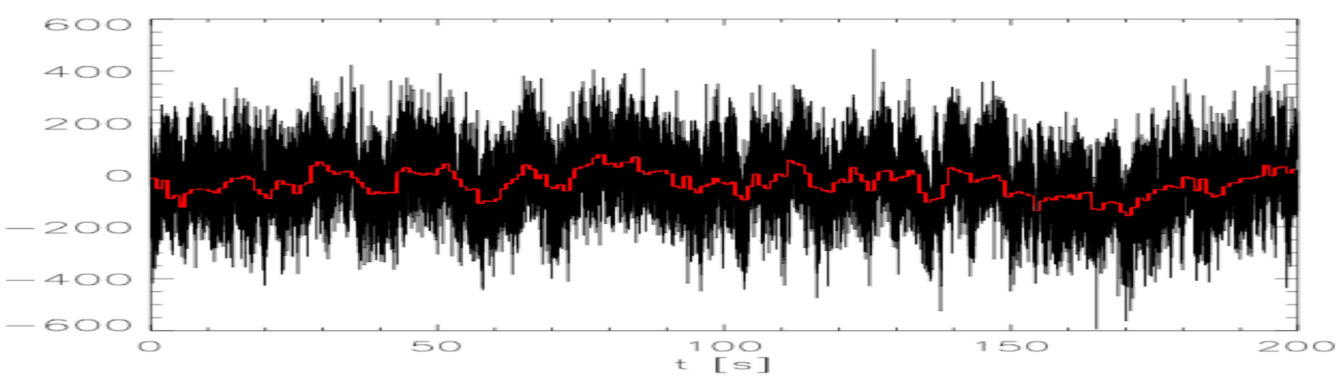
  1/f noise modeled by baseline offsets *a*

  purely white noise *w*



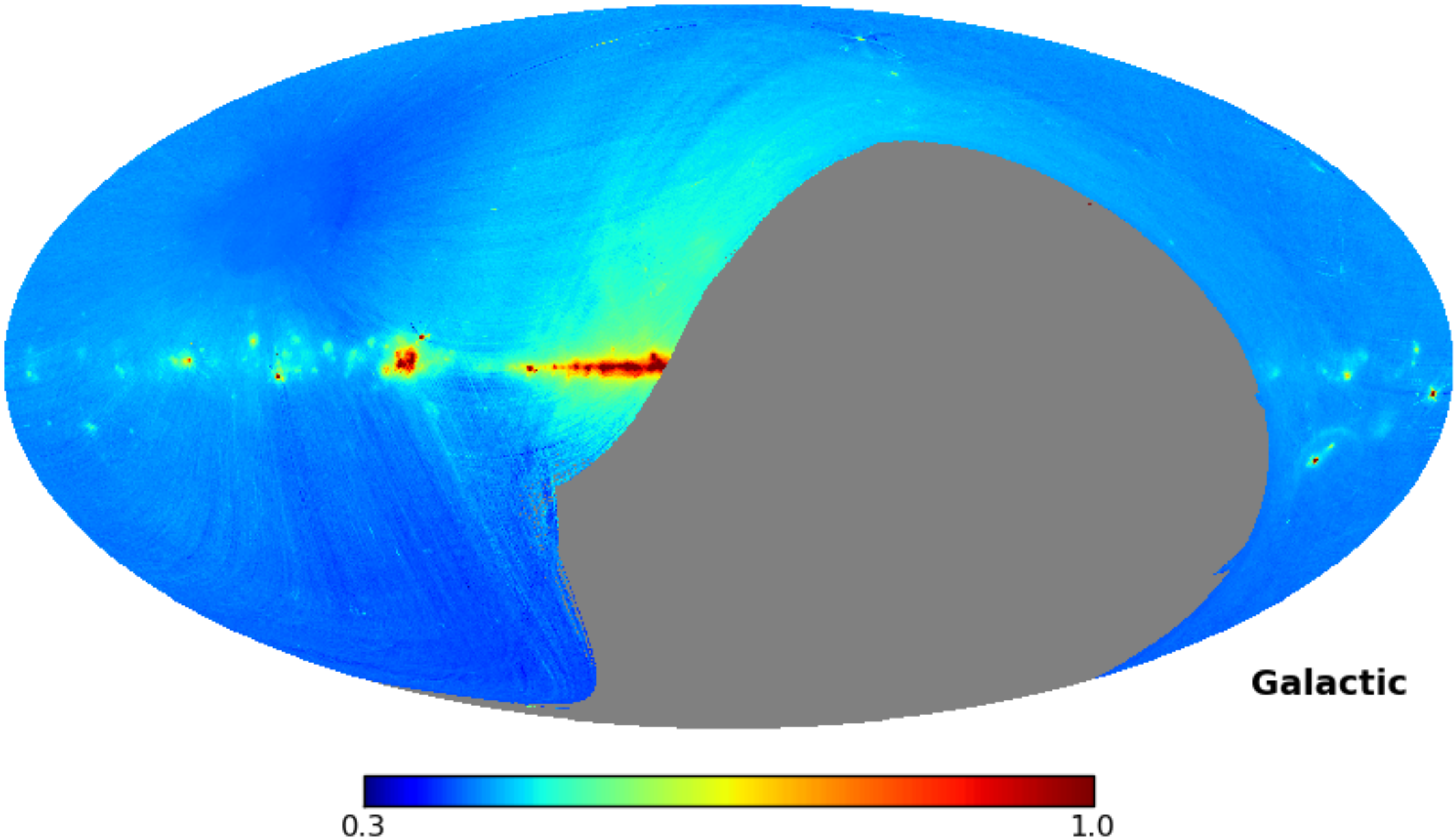
- Solve for *a* with conjugate gradient and subtract to make problem purely white noise

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

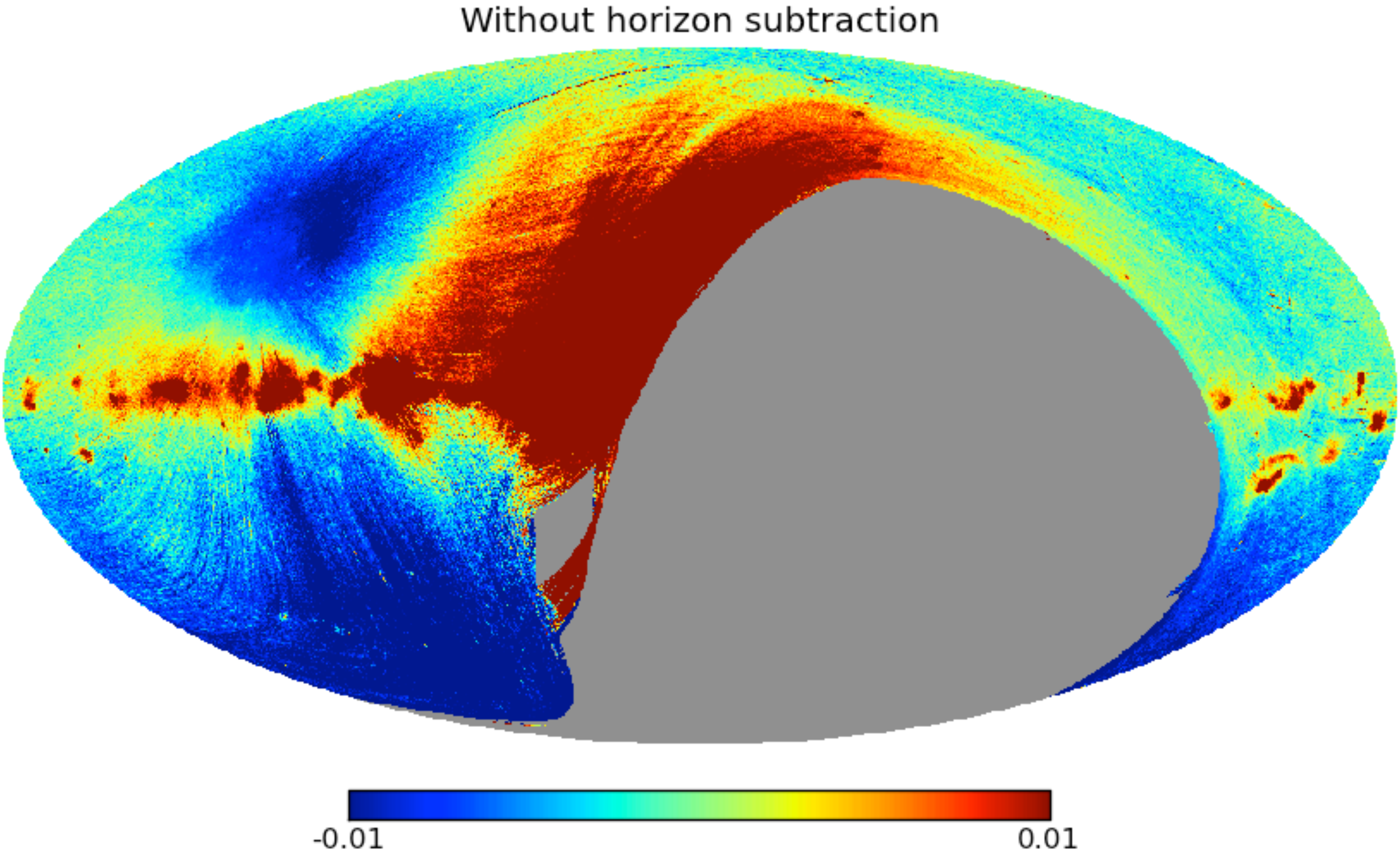


Sutton et al MNRAS 2010, 407, 1387

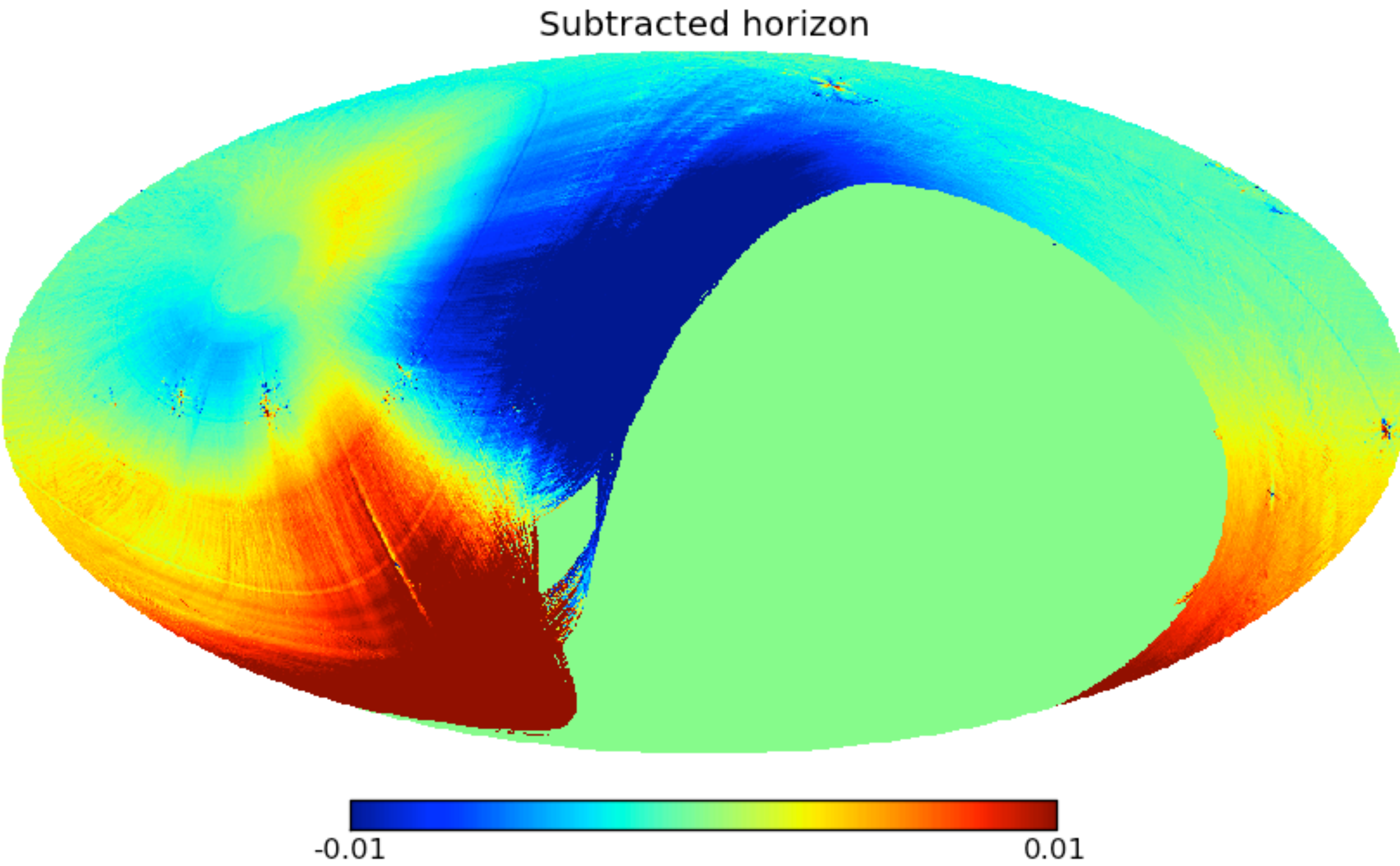
A few weeks' (pre-upgrade) data



C-BASS North: Early maps



C-BASS North: Early maps



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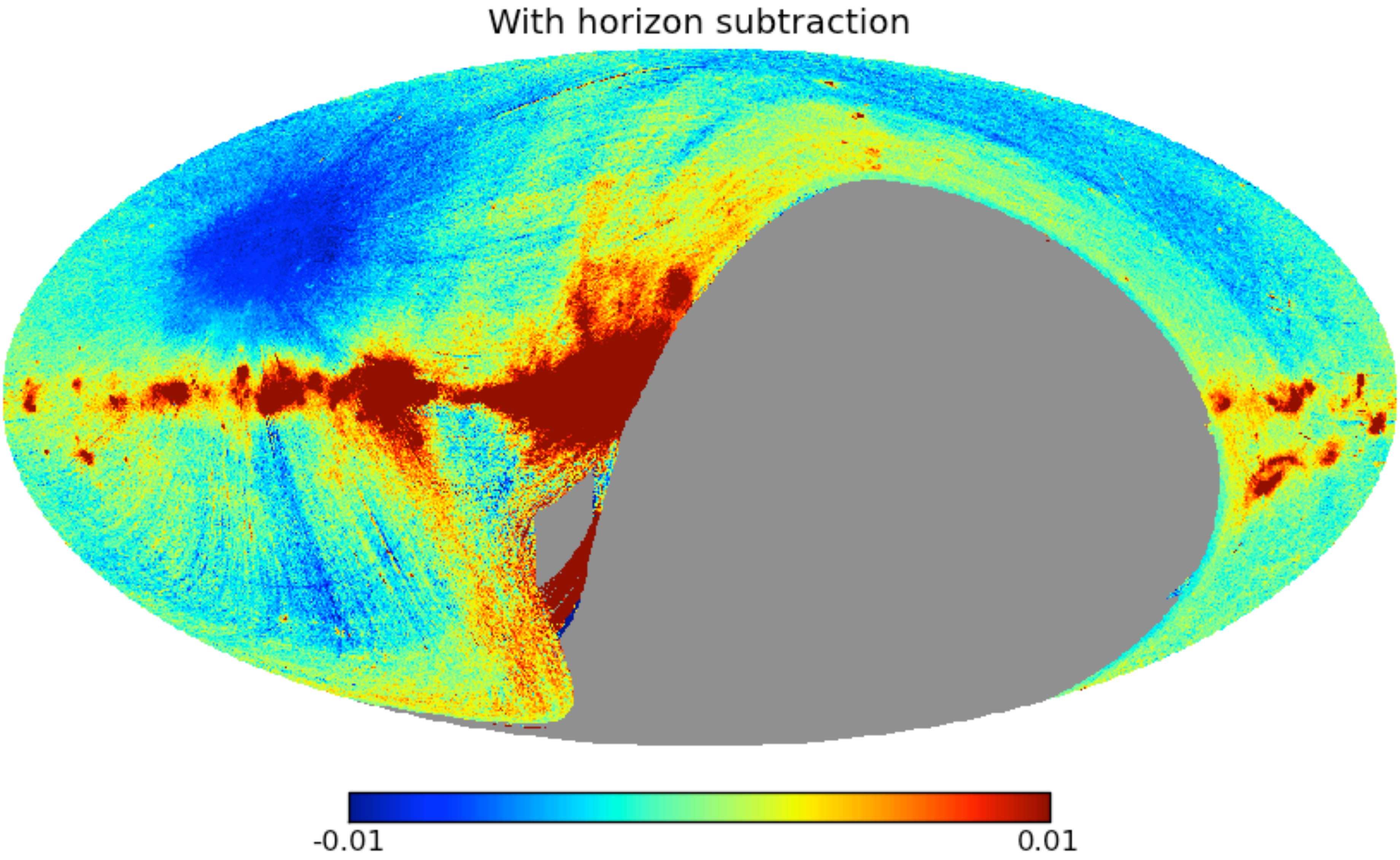
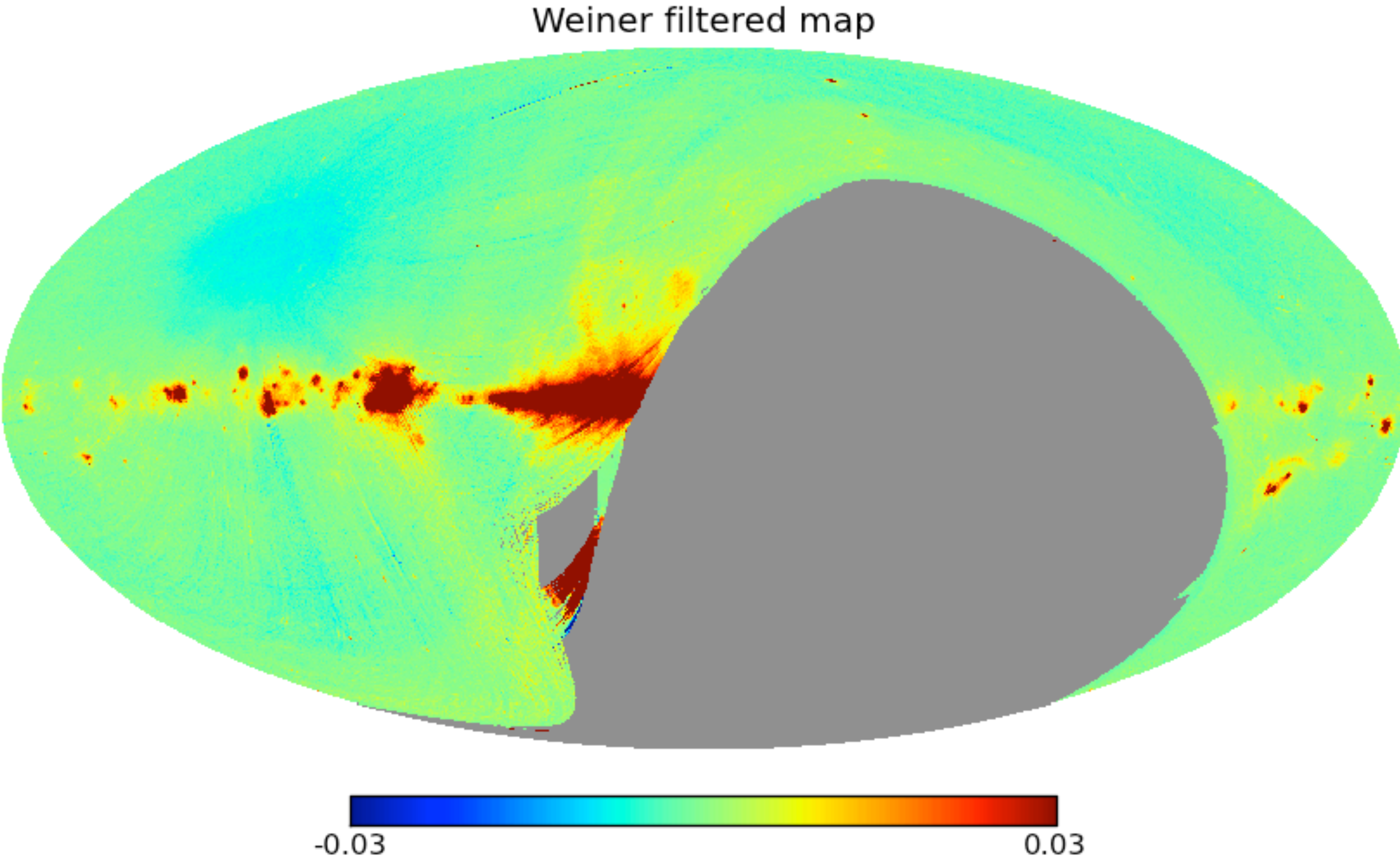
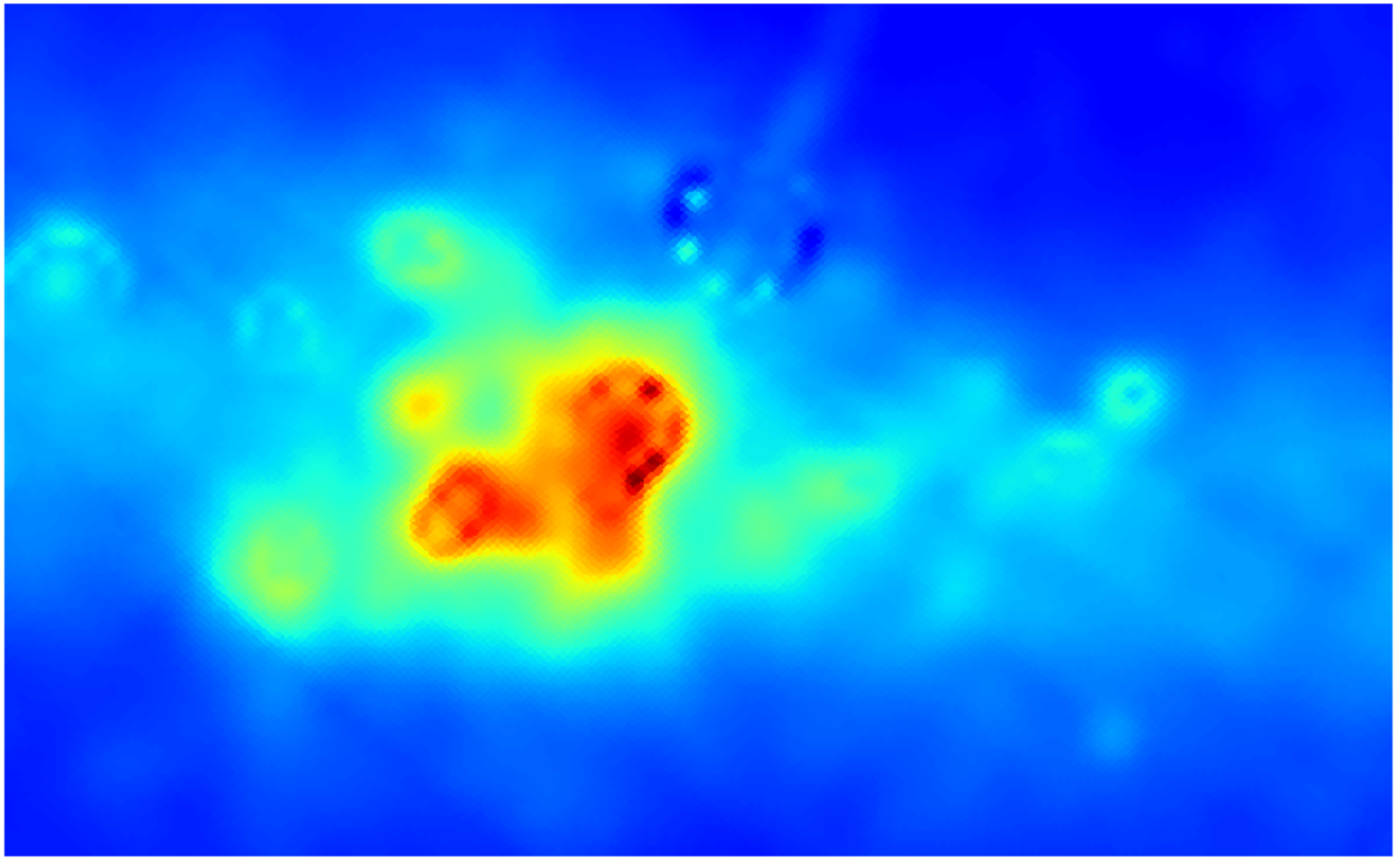


C-BASS North: Early maps

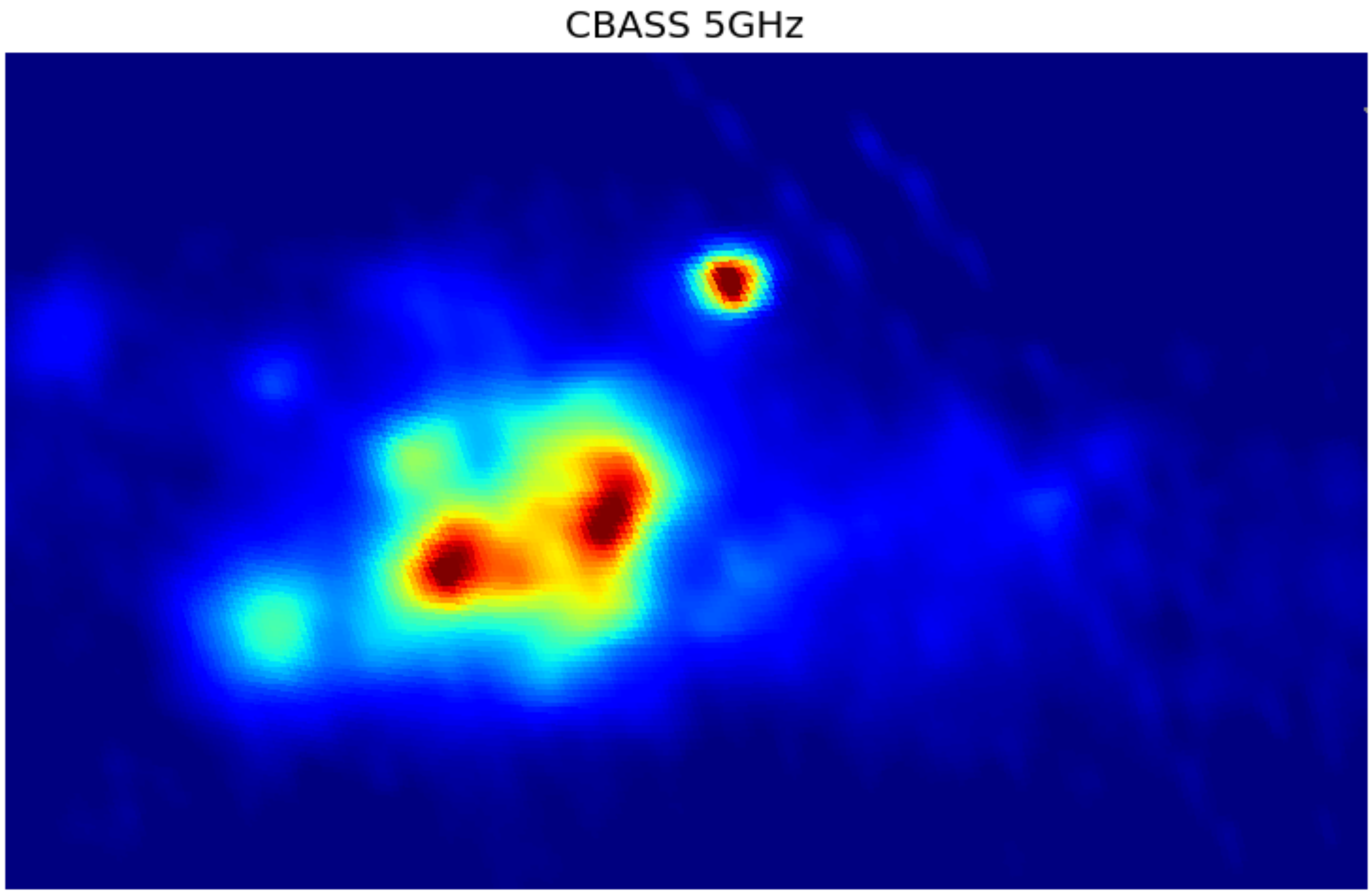


Preliminary results

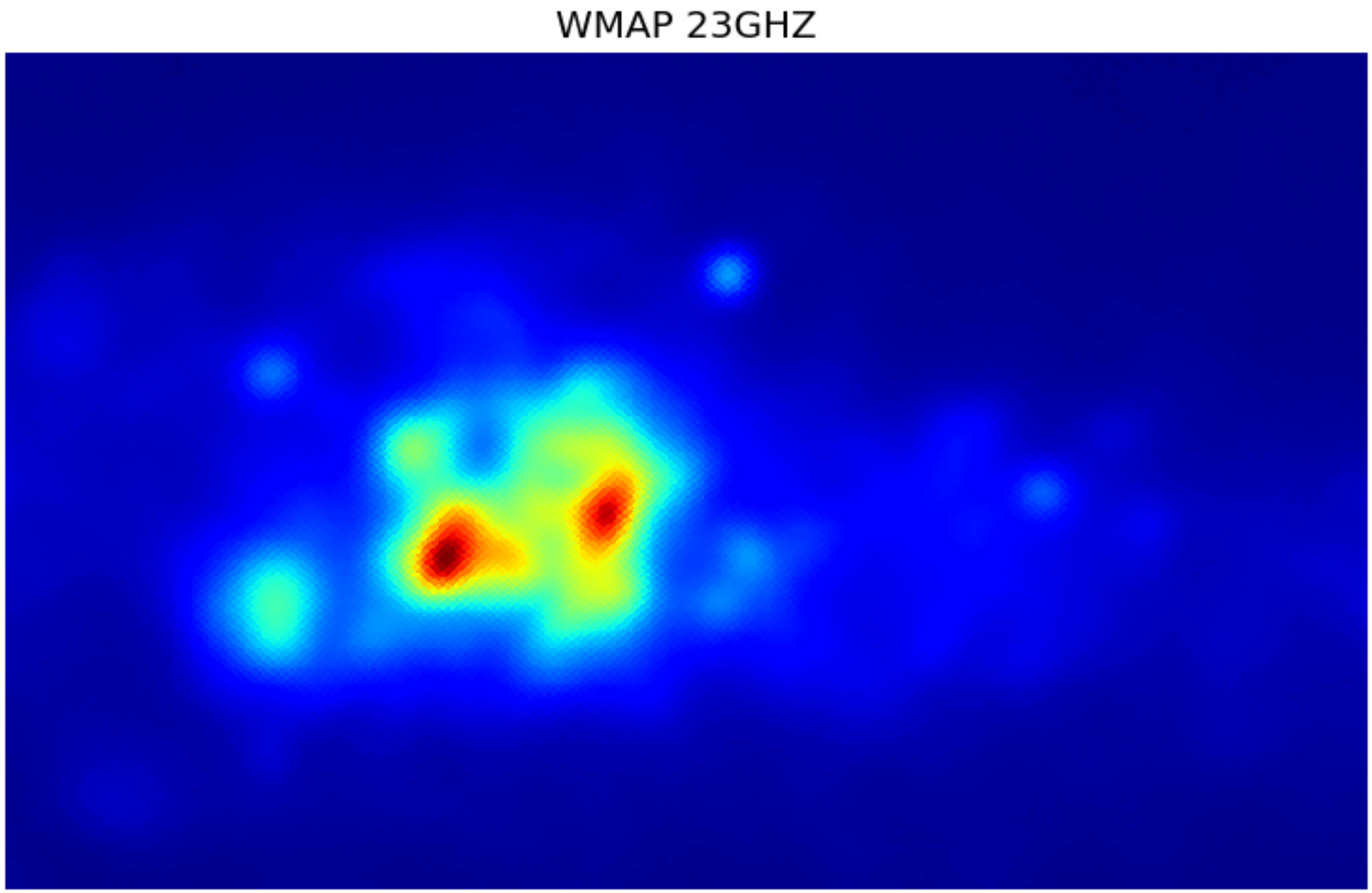
Haslam 408MHz



Preliminary results

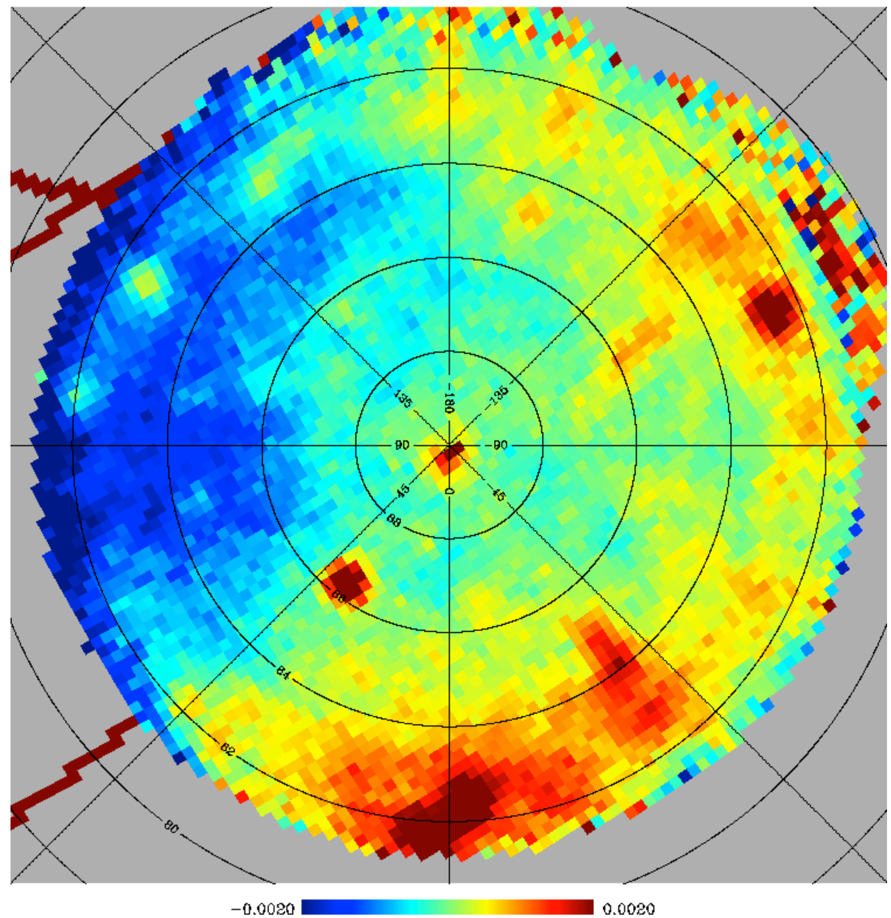


Preliminary results

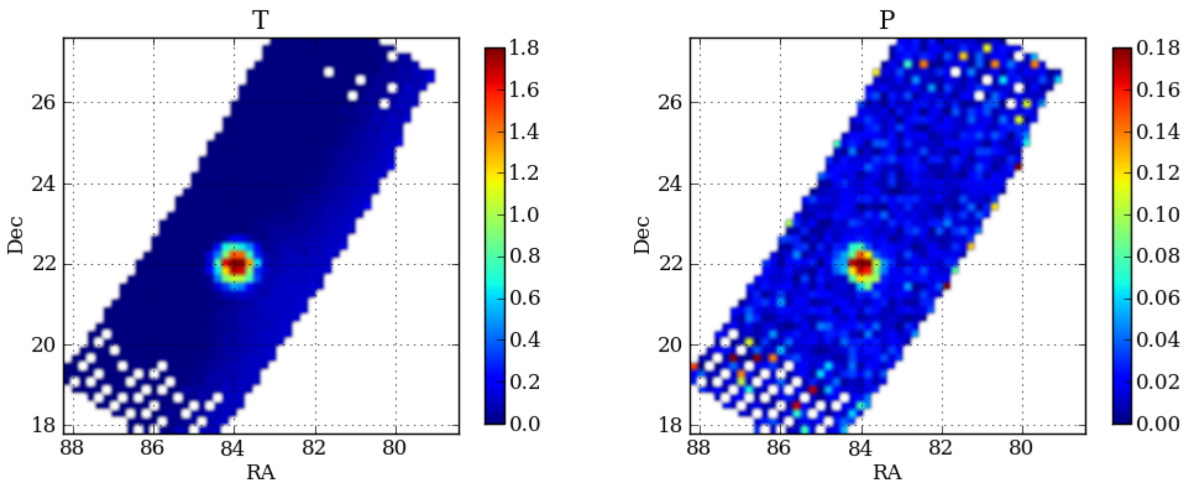


NCP data

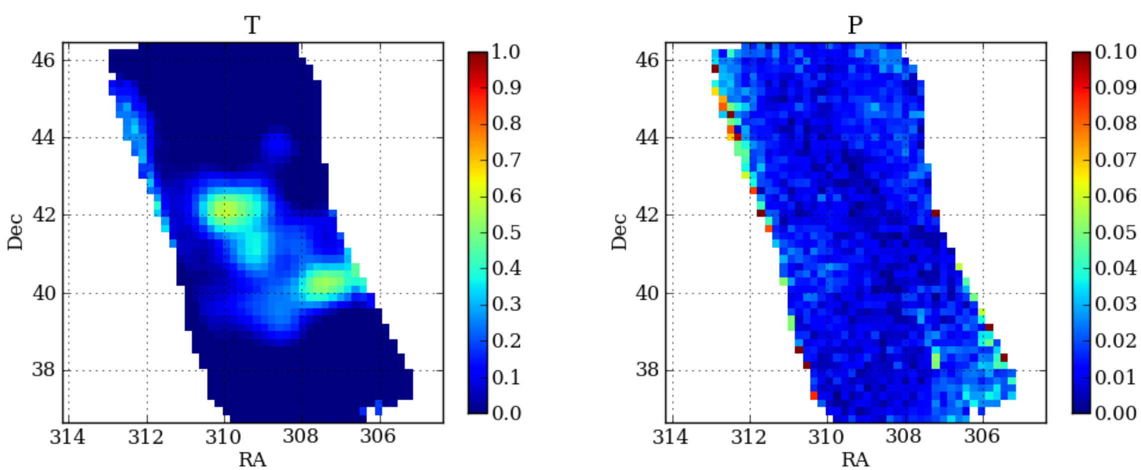
- Scan strategy naturally favours NCP
- Also use daytime data for short scans through NCP (telescope back to Sun)
- Will end up with a very deep map…



C-BASS North: Early maps



- Tau A
- Internally calibrated
- Polarization measured at expected value ~7%



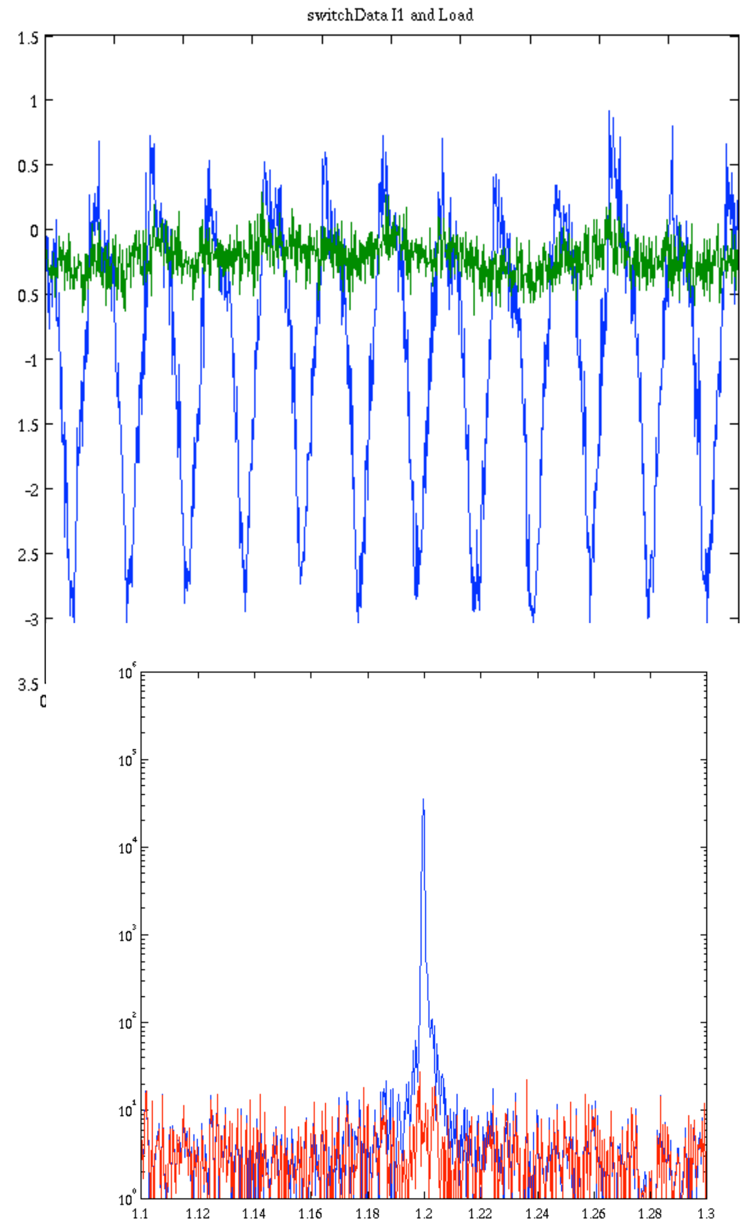
- DR21
- Internally calibrated
- No polarization detected - as expected

- Raw cross-polar leakage < -20dB

(Prediction from optics alone is < -50dB)

C-BASS N upgrades

- Sep – Nov 2012
- Replaced LNAs (eMERLIN) (T_{amp} ~12K) with Low Noise Factory (Chalmers) (T_{amp} ~3K)
- T_{sys} ~50K -> 22K
- Speed up by ~5x
- Fixed gradually worsening microphonics
- Now experts on soldering of cryogenic stainless steel cables…

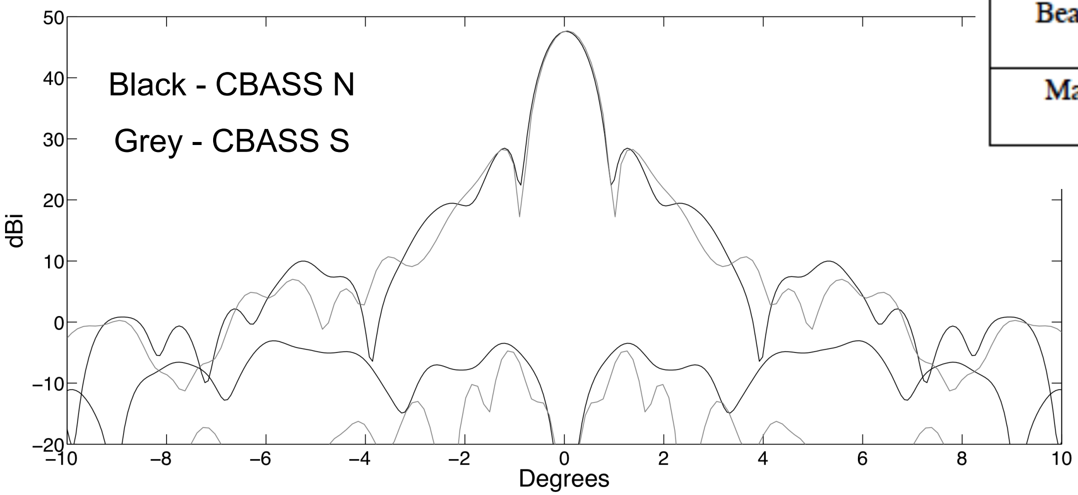


C-BASS South Telescope

- CBASS South in the Karoo desert, South Africa
- 7.6m ex-telecoms dish
- Cassegrain optics

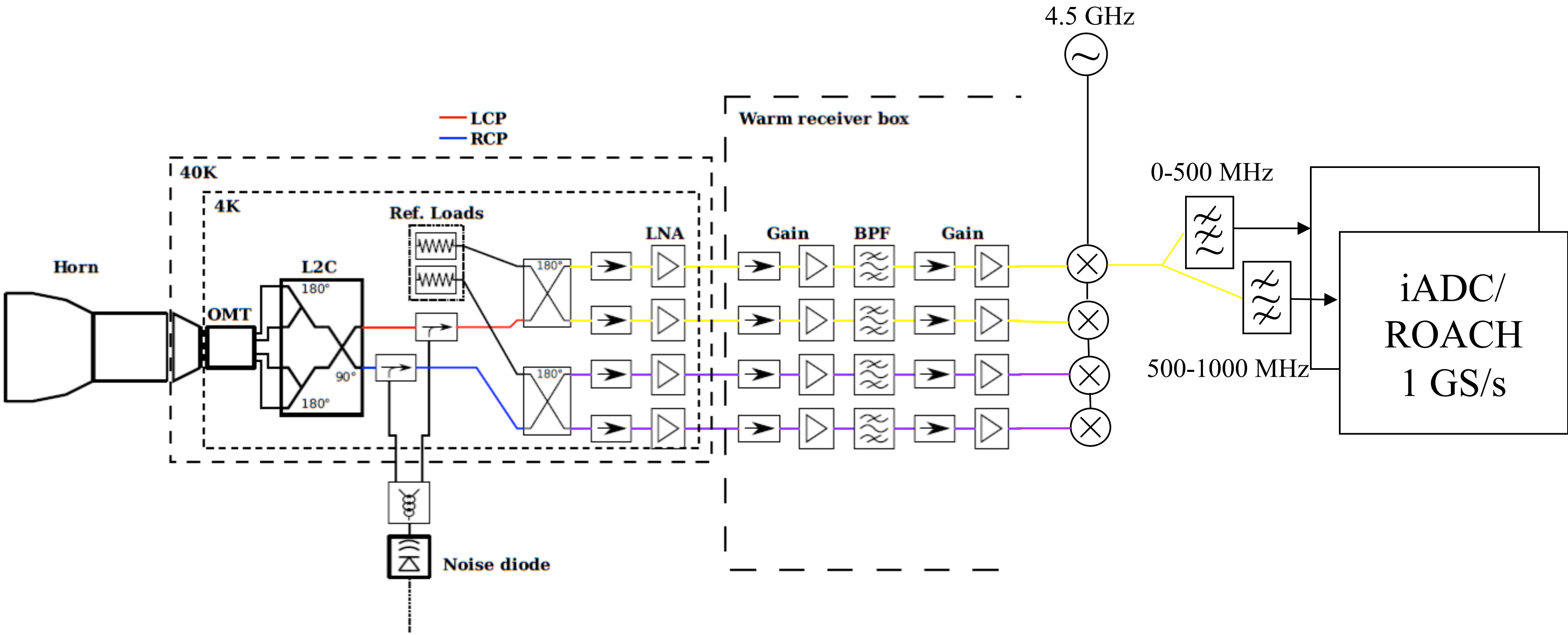
C-BASS South

Performance at 5 GHz	6.1-m antenna	7.6-m antenna
FWHM	0.73°	0.73°
Gain	47.6 dBi	47.7 dBi
First sidelobe level	−19.1 dB	−19.3 dB
Cross-polar level	−51 dB	−52 dB
Primary mirror radius	3.048 m	3.835 m
Primary illumination radius (−40 dB)	2.96 m	3.25 m
Secondary mirror radius	0.51 m	0.50 m
Antenna type	Gregorian	Cassegrain
Primary baffle depth	0.80 m	–
Secondary baffle depth	0.30 m	–
Primary baffle temp. contribution	0.7 K	–
Secondary baffle temp. contribution	0.2 K	–
Beam efficiency (power within ±5°)	91.9%	91.3%
Main beam efficiency (power within first null)	80.0%	80.0%



- Performance matched to CBASS North
- No need for baffles - dish is very under-illuminated

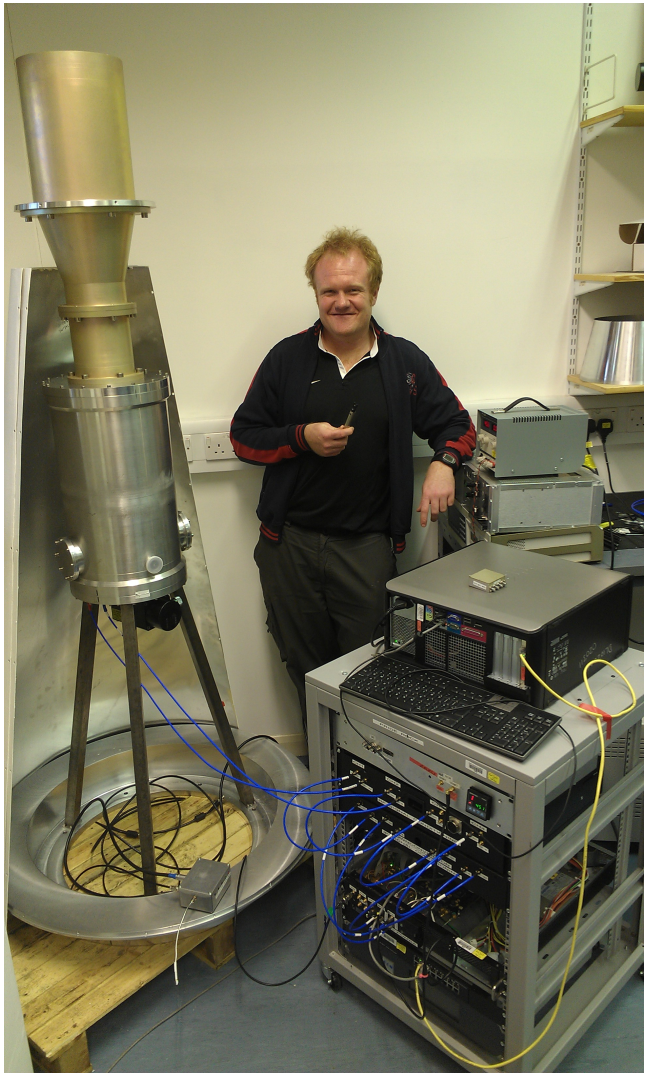
C-BASS South Receiver



- 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

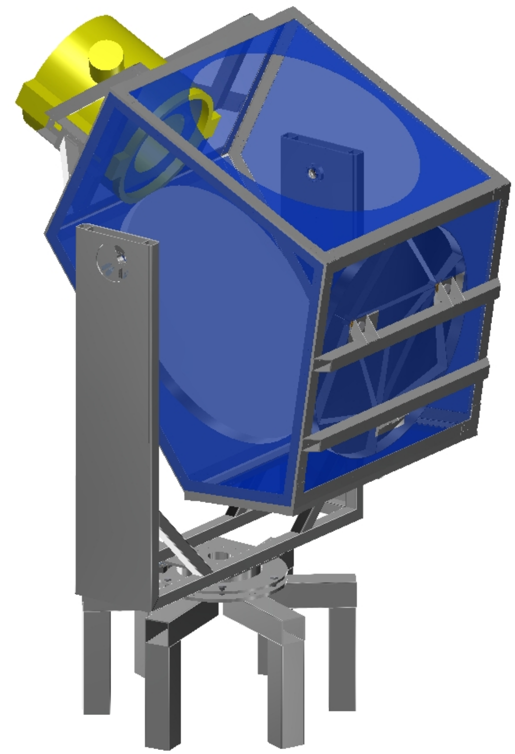
Current Status

- C-BASS North: observing…
- Continue through 2013
- C-BASS South: commissioning in Oxford
- Deploy to HartRAO in early 2013
- Commission at HartRAO
- Transfer to Karoo.



X-BASS/Ku-BASS?

- What is the next best freq for synchrotron?
- $\sqrt{(5 \times 23)} = 10.7$ GHz – optimum for measuring curvature?
- $\beta \sim 3$ so signal ~8 x fainter – need 64x more data! (beams/bandwidth/time)
- Eg 19 pixels, 3 GHz BW ($T_{sys} \sim$ 20K). Focal plane is ~500mm across
- Existing ~2m telescope – matched beam to C-BASS



Goonhilly C-band

- Goonhilly 3 – 29-m antenna, ex satcoms, SW UK
- Building C-Band receiver – interferometry (eMERLIN) and single-dish
- C-BASS clone receiver
- 9 arcmin beam with 500 μK $s^{1/2}$ NET…