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



From Planck to the future of CMB, Ferrara, May 23-27 2022



The C-Band All-Sky Survey

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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
2	

OXFORD CBASS polarization sensitivity



C-BASS unique features

- Only all-sky experiment at (or near) 5 GHz:
 - High enough v that Faraday rotation < few degrees at highlatitude
 - Low enough $\boldsymbol{\nu}$ that synchrotron is very bright
 - Below main emission from AME, so predominantly synchrotron
- Well-characterized beam (simulated and measured) so accurate temperature scale (cf e.g Haslam)
- Intensity and polarization measured and cross-calibrated simultaneously
- Differences from LFI:

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- Radiometer operates on R and L not X and Y, so Q, U obtained directly, not by differencing
- Both phase switches operated so 4-state switching gives better suppression of systematics



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



OXFORD C-BASS North: beam measurements



OXFORD 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 channels)





C-BASS Receiver





Both receivers use correlation polarimeter and continuous comparison radiometer:

- Correlate RCP & LCP \rightarrow Q, U
- Difference RCP & LCP separately against internal load $\rightarrow I, V$

See: King et al MNRAS 438 2426 (2014)



C-BASS North Receiver





- Analogue polarimeter/radiometer all done with hybrids and diodes...
- Sky and load signals separated post-amplification, squared and differenced
 - gives / relative to loads
- RCP and LCP complex multiplied gives Q + iU
- Redundancy in multiplier gives two copies of Q, U should be identical

OXFORD Receiver noise power spectra



- 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



C-BASS N Survey

- Data taken from 2012-2015
- 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







Calibration

- Noise diode injected in to R, L so appears simultaneously in I, Q
- *Q,U* amplitude scale thus tied to *I* scale
- Measure apparent *I*, *Q*, *U* using long,
 ~12h raster scans of Tau A
- Derive matrix linking observed *i,q,u* to true *I,Q,U*
- *QU* mixing at < 10%
- $I \rightarrow Q, U$ leakage < 1%
- Polarization angle and Faraday correction taken from Weiland et al 2011





Beam



OXFORD Main systematics/challenges

- RFI mostly sporadic (airborne), some fixed
- Ground pick-up fundamentally degenerate with m=0 in celestial coordinates i.e. declination rings
- Microphonic 1.2 Hz signal from coldhead
- Data are signal-dominated in *I* so need a sky model to subtract before RFI excision, ground and 1.2 Hz removal → iterative processing
- Residual 1/f dealt with in mapper not TOD



RFI: C-BASS North Site (1)







RFI: C-BASS North Site (2)





Ground pickup

Temperature (K)

- Ground signal ~0.1 K in I
- Iteratively generate ground templates
- Use successive maps to remove sky before creating templates
- Minimizes filtering of sky signal
- Extensive simulations!
- Ground Residuals < 1%









1.2 Hz microphonics

- Due to vibrations from coldhead.
- Locked to mains frequency nominal 60 Hz but drifts within limits controlled by power utility
- Waveform evolves alongside frequency/phase drifts
- Large enough to require removal before any other TOD processing
- Process:
 - Subtract current best map from TOD
 - Locate peak of power spectrum near 1.2
 Hz in block of 120s of TOD
 - Fold on exact frequency
 - Subtract template from TOD
 - Check S/N of 1.2 Hz peak (peak/white noise)
 - Repeat if over threshold & for 2.4Hz
 - Extensive simulations again!





CBASS-N: *Intensity*



OXFORD CBASS-N: Polarized Intensity



Signal-to-noise of > 5 for 80% of the sky in polarisation.



CBASS-N: Sensitivity





CBASS-N: Polarization



Polarized intensity + line integral convolution B-field angles



Polarization angles





CBASS Data Quality

Jack-knife tests:

- Quantify residual large-scale systematics
- Validate quality of intensity and polarisation calibration
- Large-scale systematics less than 1% of expected signal at scales < 20deg





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Polarized Spectral Index

• C-BASS, WMAP K, Ka, Planck 30

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- Fit single straight spectral index per pixel
- Rician likelihood to deal with noise bias
- Jeffreys prior for Rician distribution to prevent runaway posteriors at low S/N



Example fits with decreasing signal-to-noise at the higher (non-CBASS frequency)



Spectral index



OXFORD 5-22-27-32 GHz spectral index error



OXFORD 5-22-27-32 GHz spectral index

Spectral index

Spectral index error



FORD Spectral index distribution

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OXFORD Implication for CMB @ 100GHz

Polarized intensity prediction at 100 GHz (mean)



OXFORD Implication for CMB @ 100GHz

Polarized intensity prediction at 100 GHz (low)



OXFORD Implication for CMB @ 100GHz

Polarized intensity prediction at 100 GHz (high)





CBASS - status

- Northern data pipeline/mapping complete.
- Excellent calibration (~1%)
- Very low large-scale systematics
- First set of North data papers by end of year.
- Public data release shortly after papers, but still keen to work directly with other groups with complementary data/analysis tools
- Southern survey suspended due to Covid – 1-2 yrs data taking expected in south
- Full data release once surveys completed and combine – maps, beams, source catalogue/source subtracted maps (not TOD).

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Thank you!



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