

C-Band All-Sky Survey

Radio Synchrotron Background, Barolo 2022

Stuart Harper, University of Manchester, 15 June 2022

C-BASS Collaboration



Angela Taylor Mike Jones Jamie Leech **Richard Grummit**

Caltech

Tim Pearson Tony Readhead



Justin Jonas Sizwe Seranyane



The University of Manchester

Clive Dickinson Paddy Leahy Stuart Harper



Jon Sievers H. Cynthia Chiang Moumita Aich



Mike Peel



Moved on...

Adam Barr, Roke Cepeda-Arroita, Oliver King, Matthew Stevenson, Mel Irfan, Stephen Muchovej, Joe Zuntz, Charles Copley, Luke Jew, Jaz Hill-Valler, Heiko Heligendorff















Overview

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





	1	1	ľ	ĩ	1
5	5	1	1	1	1
1	8	1	•	ľ	1
	1		•		1
			,		į.
			į,		1
	ĩ.		Ĩ		ų,
	0		1	1	1
			•		
~	÷	-	v	1	-
	2				1
2		1		2	1
			1		
	-		•	4	1
	-			1	1
					1
	÷				×
			1		
	-	7	7	7	7
	-	1		5	3
	-	5	1	÷	3
	1		1		J
			•		į,
					J
	1			1	1
	1		í		
	5		Ĩ	1	1
	1		1		
	a.		k		Ļ
	ĩ		í	f	1
5	1	5	ĩ	1	1
	1		ſ		1
	1		•	i.	1
			•		ł
	×.			í,	J
1	2	1	į	1	1
				2	
			1	1	1
					_
2	2	2		2	1
		5	1	÷	3
			•		4
					4
					4
			í	į,	1
1	1	1	ĵ	ĩ	1
-	1		1		J
		-		1	1
			,		
			,		
	-				1
2	1	1	ſ	į.	
	1	1	1	í	į,
	٠				ġ
	1				ł
	į.		į,		ų,
	5		Ĩ		1
	٠		1	1	1
	2		•		J
	1	1		1	1
			į		
	1		j		
	÷		ŝ	1	4
2	5	1	f	ŝ	1
5	÷	5		ĩ	1
	×.		į,		ł
			Ĩ		ġ
	2		1		į.
	1		•		1
	1	.*		*	1
	1		į,	•	1
			ĵ		
			-		
			1	i.	4
-	I.	1	1	į.	1
	ĩ	1	1	ĩ	1
	1		Ĩ		
			1		ł
1	1		•		į.
١.	1	-	1		1
1000	1	1	1	-	1
N			ļ	1	١
١			ľ	*	1
	Υ.				1
Ì	Ç,		*		. 8
1	١		,		
	1	5	i		



Galactic Projection Hit Maps



Real North + Simulated South coverage

Stuart Harper University of Manchester

C-BASS **Calibration and Beam**

- Tau A is primary absolute brightness scale calibrator
- Measured on sky using bright point sources & compared with simulated **GRASP** map
- •Symmetric optics allows for very accurate calibration of brightness scale
- •Holler et al, 2013 for more information on the beam



Stuart Harper University of Manchester

	u	k	at	e	K	1	t		B	a	I	n			-
	Ż	1	1	1	Ż	1	1	1	ž	1	1	1	2	1	1
	8	3	2	ŝ	2	0	2	ŝ	2	0	2	ŝ	2	ē	ſ
	j	1	j	1	j	•	1	1	j	•	1	1	j	1	-
						•				•		•		ł	-
			÷	1	÷	1	ç	1	ç	1		ł	ç		-
	ł	1	1	1	ł	ŝ	1	1	ž	ŝ	1	ŝ	ž	1	-
	g	ŝ	ŝ	8	ŝ	ŝ	ŝ	8	ŝ	ŝ	ŝ	8	ŝ	è	-
	3	1	ł	ł	2	ł	ł	ł	2	ł	ł	į	ž	1	ľ
	•	•	•	1	•	•	•	1	•	•	•	•	•	ł	-
				1				1						ì	_
															-
		,													ļ
	3	3	1	1	1	•	1	1	1	•	1		ź		ľ
															ļ
		;		1		•	•	1		•	•	;		;	-
	1	1	1	1	ŕ		1	1	Ċ		•	1	Ċ	1	-
	-		1	1	1		1		-			-	1	2	2
				1		_	1	-	~	-	1	1			
	1		-	-	1	1					1	Ĩ	Î		
•		1							*	1			•		Ĩ
	0	1	1	2	0	1	6	2	ŝ	1	1	1	ŝ	2	1



- Noise diode injected in R/L so appears in 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/QU
- •QU mixing < 10%
- \cdot I -> Q/U leakage < 1%







- RFI Largely sporadic, notch filter remove worst contamination from the band.
- Ground pick-up Modelled using daily templates and subtracted. < 1% remaining contamination.
- 1.2 Hz Oscillations Microphonics signal that maps to ~1 degree scales. Suppressed to < 1%.
- Residual 1/f noise Suppressed to a few per cent or better at scales > 10 degrees.



















Jack-knife tests: Quantify large-scale systematics — Validate quality of data Large-scale systematics less than 1% on scales > 20 degrees.









 Ground pick-up — Modelled using daily templates.

< 1% remaining contamination in $m=0 \mod at scales > 10 \deg$.







- that maps to ~1 degree scales.
- Suppressed to < 1%.



Stuart Harper University of Manchester









Before notch filters

After notch filters









C-BASS Maps of Galactic Synchrotron Emission

-BASS











Calibration errors



Weiland et al. 2022 (arXiv:2203.11445)

Comparison of intensity data with sync+ff model 1.4 GHz 2.3 GHz





Fan Region IIIs







Polarisation vectors overlaid

using LIC







Polarisation vectors overlaid using LIC **Fan Region**









C-BASS







WMAP K-band





C-BASS III Fan Region IIIs







C-BASS III Fan Region IIIs







C-BASS III Fan Region IIIs







arXiv: 2202.10411

	$\left< \beta \right>_{\rm regions}$	β _{all}
$0.408 - 4.76{ m GHz}$	$-3.04^{-2.92}_{-3.16}\pm0.02$	-3.02 ± 0.02
$0.408-22.8\mathrm{GHz}$	$-3.04^{-2.98}_{-3.14}\pm0.01$	-3.02 ± 0.01
$0.408-28.4\mathrm{GHz}$	$-3.04^{-2.98}_{-3.17}\pm0.01$	-3.01 ± 0.01
0.408-33 GHz	$-3.04^{-2.98}_{-3.18}\pm0.01$	-3.06 ± 0.01
$4.76 - 0.408 \mathrm{GHz}$	$-2.93^{-2.90}_{-3.16}\pm0.04$	-3.01 ± 0.04
4.76-22.8 GHz	$-3.10^{-2.99}_{-3.32}\pm\!0.02$	-2.92 ± 0.02
4.76-28.4 GHz	$-3.11^{-3.02}_{-3.29}\pm0.02$	-2.91 ± 0.02
4.76-33 GHz	$-3.09^{-2.98}_{-3.29}\pm0.02$	-3.01 ± 0.02



Template Fitting of Diffuse Galactic Microwave Emission in the Northern Sky









Median = -3.12





Spectral index



University of Manchester

Spectral index error







- Initial release papers on commissioning and data reduction release expected later in the year.
- Current on-going work with the C-BASS data:
 - Study of polarisation map structures (see also Paddy's talk!).
 - Polarisation spectral index maps per pixel and template fitting.
 - Spectral template fitting of magnetic dust emission polarisation models.
 - Updated measurements of the AME in M31.
 - Assessment of level of foreground subtraction needed for future CMB missions.





- Northern data pipeline/mapping complete.
- Excellent calibration (~1%).
- Very low large-scale systematics.
- First set of Northern data papers by the end of the year.
- Public data release shortly after papers, but keen to work directly with other groups with complementary data/analysis tools!
- Southern survey suspended due to Covid 1-2 years of data taking expected in South.

Stuart Harper University of Manchester

4	The C-BASS	-
House Collab	noration Science Instrumentation Cellery Publications - External Links Jobs	
H / ACKAN		
	The C-Sand All-Sky Survey (C-SASS), template - tong of Office Galactic Microwave Emission in the Northern Sky S.E.Raper C.Dixdmont A. Ban, & DixedaAmstu, R.D. F. Granic, H.M. Helgerbort, J. Nec, J. Ljonac, V.B., pres. J. P. Leity, J. Leech T. J. Feators N.W. Pell A.C.S. Raich and and A. C. Tayow Menthy Notices of the Royal Astronomical Science, Accepted 2022 April 25	
	Detection of Spectral Variations of Anomalous Microwava Emission with QU JD IE and C-8455 R. Cepeta-Andrica, S. Harpen, C. Oxbinons, A. Rabifo-Martin, R. F. Ginosa-Santos, Angela C. Taylor, T., Pearson et al Sectory Andrica Diseases and Sectory and Sectory, John asyung	
	The C-Jand Alk-Sky Survey (C-JASS): Total Intenarby point-source detection over the northern sky R. O. P. Grandz, Angels C. Taylor, Lake Jew, Michael G. Janes, C. Olddrean, A. Barr, H. C. Chaing, F. Gepede-Arts or, S. C. Harper, K. V. Helgerdonff, J. Janes, J. P. Leah _W J. Loost, T. J. Courses, M. M. Cod, K. C. S. Courbend, J. Sonro Monthly Not do: of the Toyle Astronomical Society, Volume 405, Issue 2, pp. 341-1955	
	The C Band All Sty Survey (C BASS): Simulated surametric fifting insingle pixels in total intensity and polarization Luke any Angels C Taylor, Michael E Jener, A. Sarr, H. C. C Hang, C. Biddinson, R. D. F. Ghandt, S. E. Haper, H. V. Halgendorft, J. Hill-Valler (J. Jonar, J. P. Leshy, J. Leshy, J	
	The C Band All Sky Survey (C BASS), Bigital leackend for the northern survey M.A. Sieverson, T. J. Parson, Michael B Jones, C.J. Copley, C. Biolinezh, L.J. John, O. S. Shy, S., J.C. Madiavej, and Argela C Taylor Monthly Mitches of the Knyal Mitche model contex (20 carys: 15)	
0000	The Clear di Allowy Survey (CleASS), Constraining offuse trajectoradio emission in the North Celestial Polenegion C. Stekhon, A. Berc, H. C. Chaing, C. Copley, R. D. P. Chanda, S. C. Harper, H. M. Halgendorff, L. R. P., ew. J. L. Jonat, Micheel S. Jonak, P. Ledry, J. Lech, S. M. Lebri, S. J. C. Macheng, T. J. Harver, M. K. S. Washerd, J. Severa M. A. Stewards, Angeles C. Leyron J. Harver, M. Freed, A. C. S. Washerd, J. Severa M. A. Stewards, Angeles C. Leyron arXiv:1110.114811 (acrosph.62)	
	The Clister d'AlkSky Survey (Morion d 2013 conference paper) Angela C.T.glor (Sr. dw. C6455 collaborations Source C.C.B.S.C.(Sr.S. Jonator)	
	The Crister d All-Sky Survey (CISASS), Design and caseb Titles Michael E.(Sheel Angele C. Tayler Mountie Alds C.). Consy, 4. Optical Chang R., Cavie C. Dichinson, R. D. P. Granita, Visan Hales, Hello M. Helgenderff, C.M. Heller, M. C. Infor- Line II. P. (Sky), (Mex., participal Transform), Fourier R. V. Heller, S. (F. Mannaeg, L.). Paraset, V. W. (Vellis, C. C. Hendhead, Jonathan S. Wert, M. S. Meerrank, 2000 Monthly Net con of the Toyal Astronomical Society, Volume 45, base 5, p.3824-3542	
	C Band WI Sky Sarvey, a first look at the Galaxy M D. Han, C Dikmon, R D. Barks, E Copley, R J. Cash, P. G. Famelra, C M. Holler, J. J. Jenas, Michael B. Jones, O. G. King, J. P. Baelys, Levis, J. M. Leitch, S., C. Michael, T. J. Parrozy, M.W. Pee, A. C.S. Reachead, M. A. Sevenach, C. Subor, Anglia C Taylor, J. Zanta Monthly Notices of the Tayle Category Intel Society, 448, 3572-3586 (Varch 2015)	
.	Astronomical receiver model inglusing scattering matrices C. G. King Methol E. Jones, C. Scolwy, S. J. Davis, J. P. Jaaly, J. Leect. S., C. Machovej, T. J. Feanor, Angela C. Taylor Sconney with the of the Knyal Astronomical Society, 2017, 172 Autor (January et the	3
A Martine State	The C Band All Sky Survey (C BASS): Design and implementation of the northern receiver C G King Mothel E Jones, E., Blackheit, C. Codwy RJ, Davis, C Dick non-C M, Hoher, V. Culifan, J. J. John, J. P. Leavy, J. Leavy, J. Leavy, J. C. Vuchevel, T. J. Penner, N. A. Stavenson, Argels 1. Dytor Use by Notices of the Royal Astronomical Booky, 108, 5126-3409 (Varch 2014)	1
	A Circularly Symmetric Antonno Dos gn With High Palarization Parity and Low Saillower Holler, C. R., Taylor, A. C., Jones, Y. E., Ong D. S., Nuclevel, S. J. C. Sovenson, Y. A., Wite, R. J., Coster, C. J., Davis, R. J., Paeson, T. J., Beachaec, A. C. S. Rev. Diseaschool an Antonna and Encogenities (1970) 1970	3
	The Criser di Alk-Sky Survey: Instrument design, status, and first-look date Dierris Reg, Eterstropie, Kir, Kwei, Koran Dawi, Lie-Doomoo, Weera Hales, Unister Hore, Jaya Joo, Cit, Jeroni, Jone, Martael - Jose, Ji Kator, exv, Stephen J. S Surmey, Incomp. Person, Korony I. S. Headberg, Marthewa Investor, Auges J. Tejlor Dillinees, Som Encom, and Fachifured Detectors and Instrumentation for Accordingly Edited by Helland. Pages St. Bruithine, Jonal, Proceedings of the SF E. Vourie 7711, pp. 2020 (2020) (2020) (2020)	A STATE
	Compact broadbandig Linear of the model transid area between Fix Jong, C.D., weine, S., Wilson, H. E. Electronica Letters, 40(20), pp. 1146-1140 (October 2007)	1

Papers and theses already published See: https://cbass.web.ox.ac.uk

0