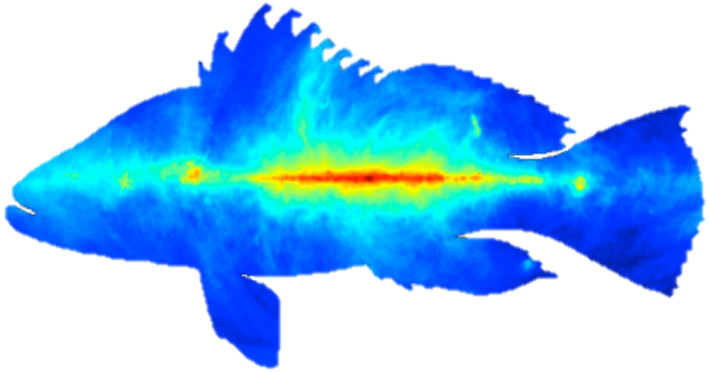
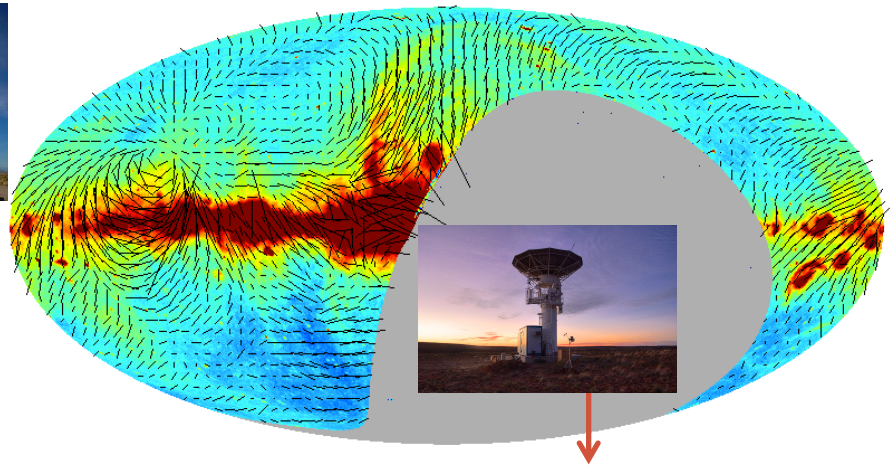


THE C-BAND ALL-SKY SURVEY

Moumita Aich, University of KwaZulu-Natal, South Africa
*for the **C-BASS** collaboration*



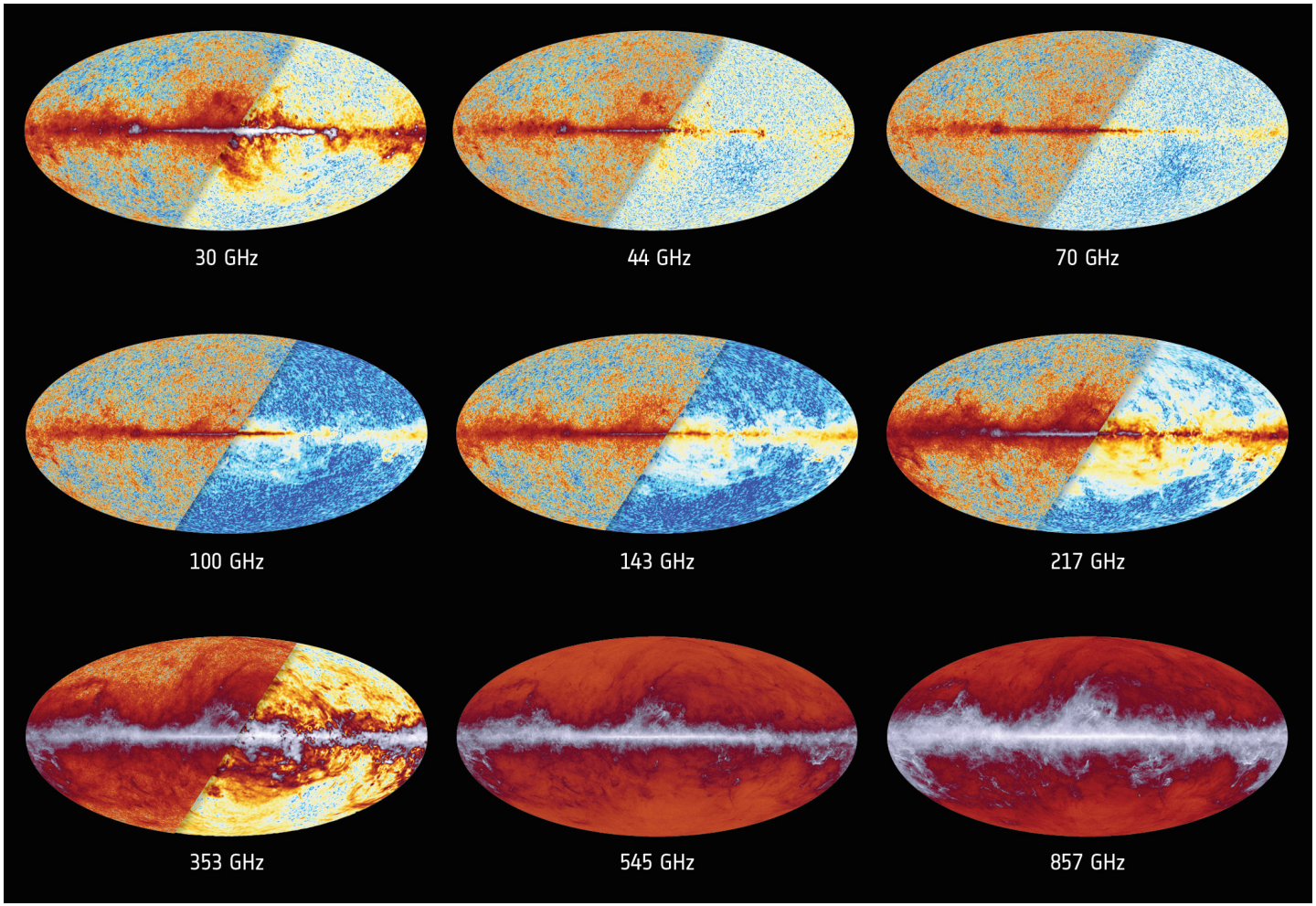
Cosmology with Large Surveys
Durban
23 November 2016

http://www.astro.caltech.edu/cbass

Figure courtesy: Mike Peel

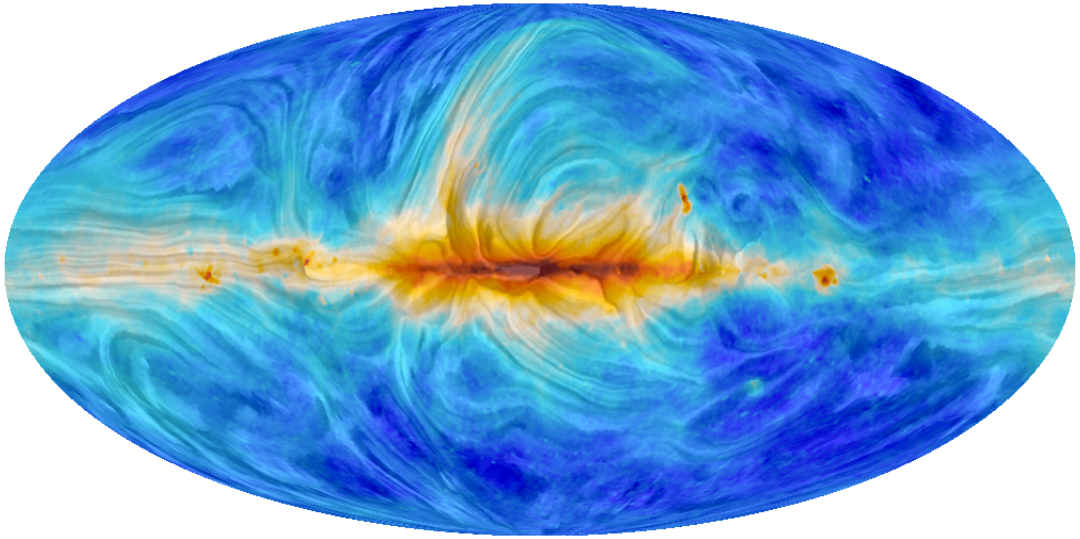
CMB temperature and polarisation

Planck Legacy Archive: ESA and the Planck Collaboration



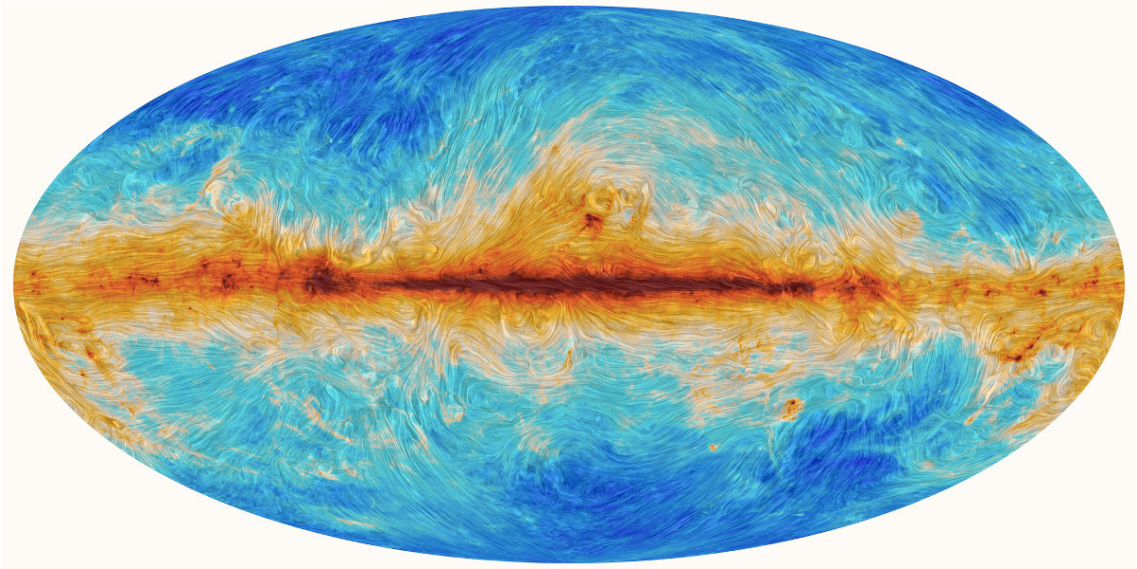
Polarised foregrounds

Planck Legacy Archive: ESA and the Planck Collaboration

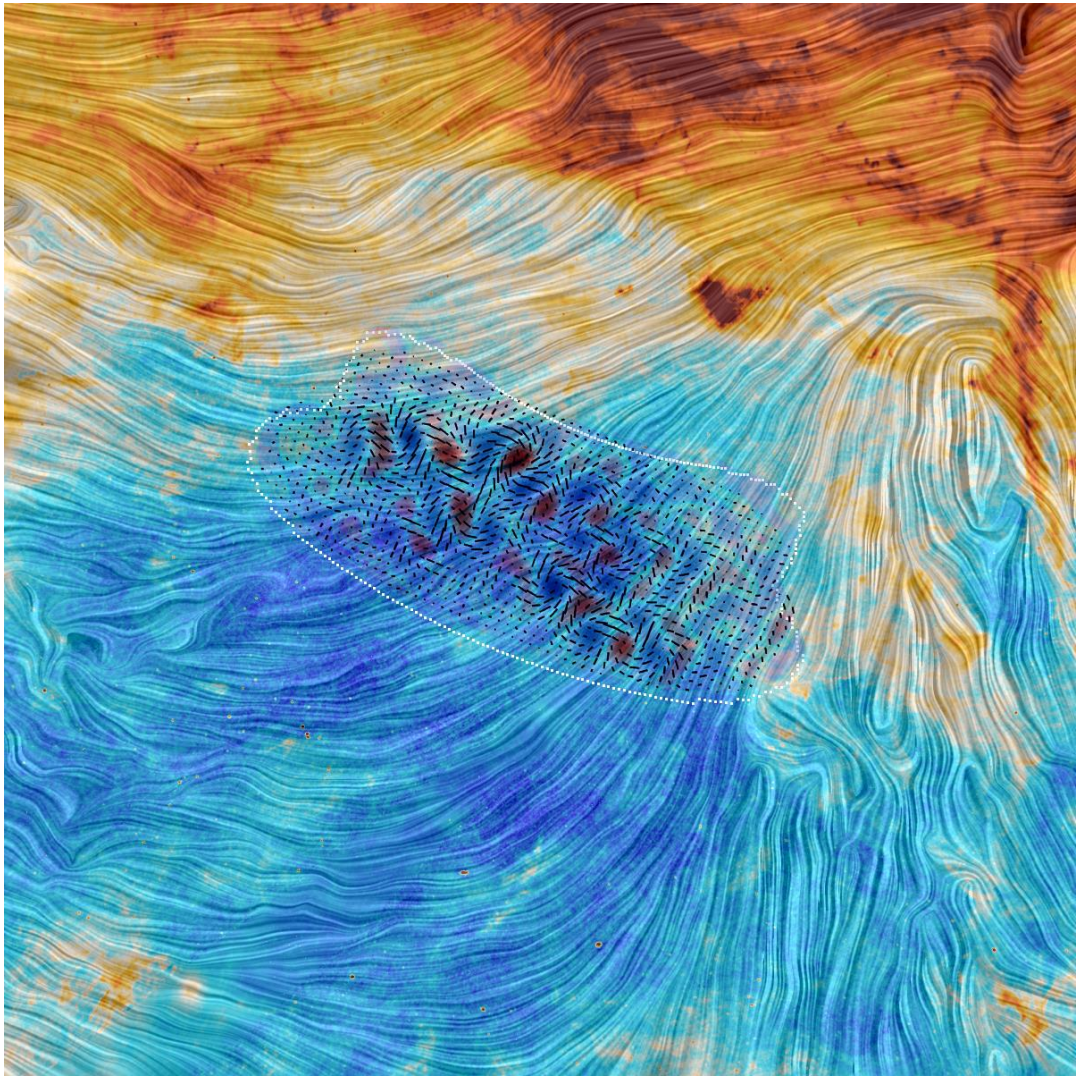


Magnetic field lines traced by synchrotron radiation at 30 GHz

Magnetic field lines traced by dust emission at 353 GHz



Field observed by BICEP+KECK

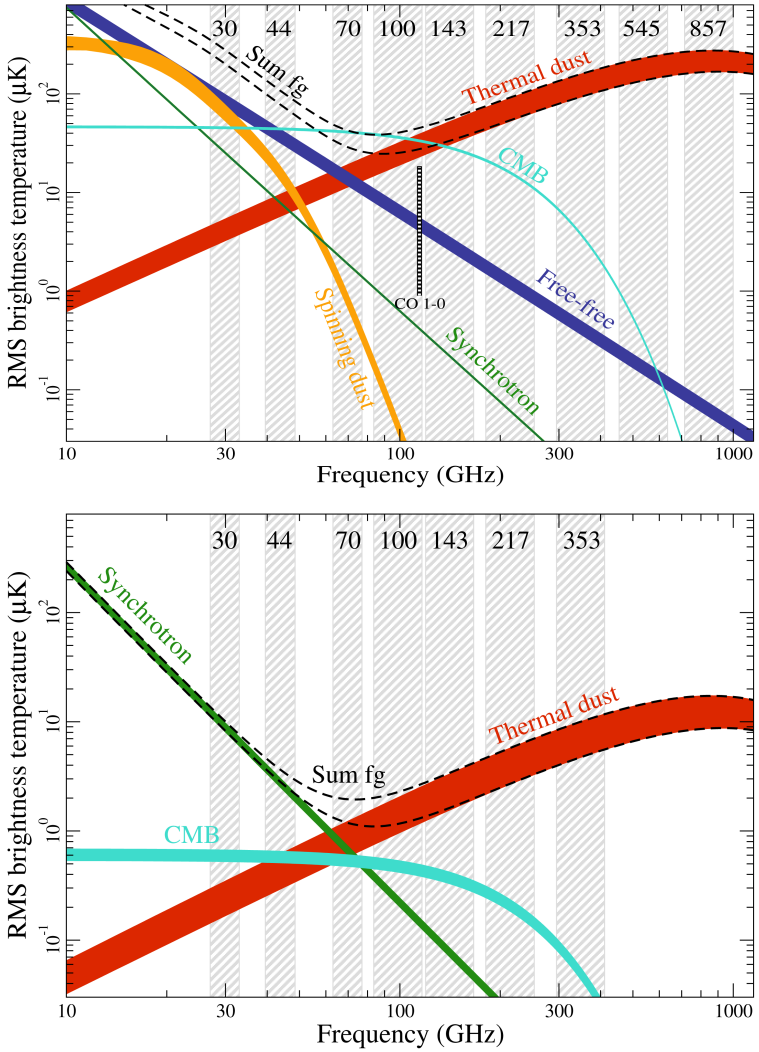


The Planck data has allowed us to characterize the power spectra of dust polarisation towards cosmological fields.

➡ The Southern hole – Even in the seemingly cleanest part of the sky this signal cannot be neglected

Figure courtesy: Jon Gudmundsson

Galactic foregrounds in Planck bands

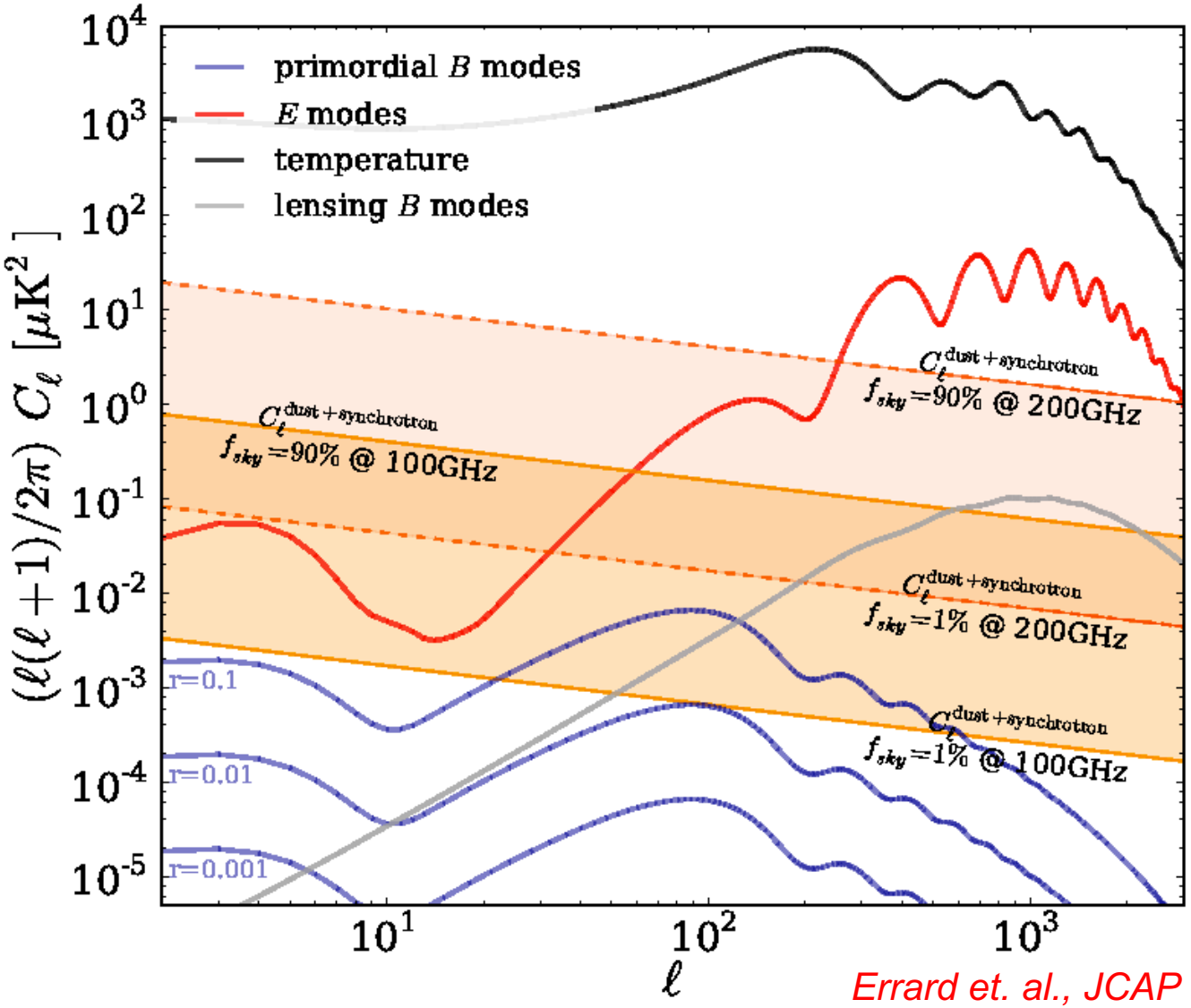


- Total intensity appear to be more complicated than polarisation!
- Foreground minimum at ~80 GHz
- Polarisation might be less complicated but requires higher precision (CMB weaker)
- Foreground minimum at ~70 GHz

Temperature and polarisation foreground spectra
Planck Collaboration, 2015, arXiv:1502.01588

Galactic foregrounds and the CMB polarisation power spectra

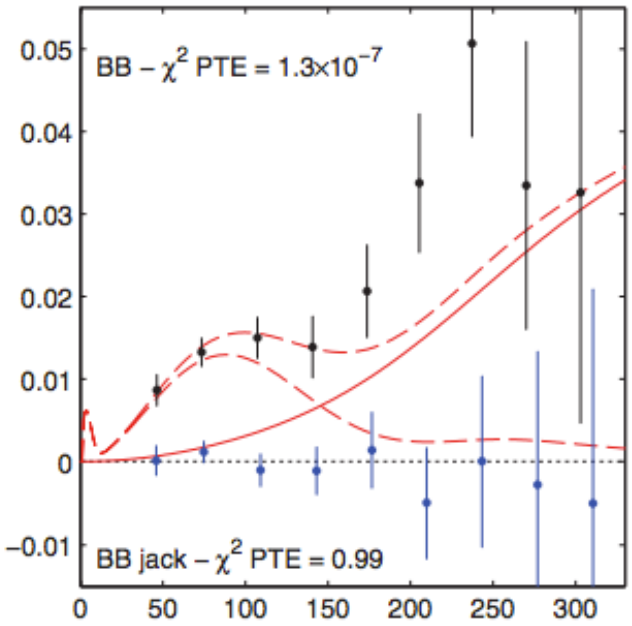
Nature probably not so kind (unless r ~ 0.1 or bigger!) – Clive Dickinson



Errard et. al., JCAP 03(2016)052

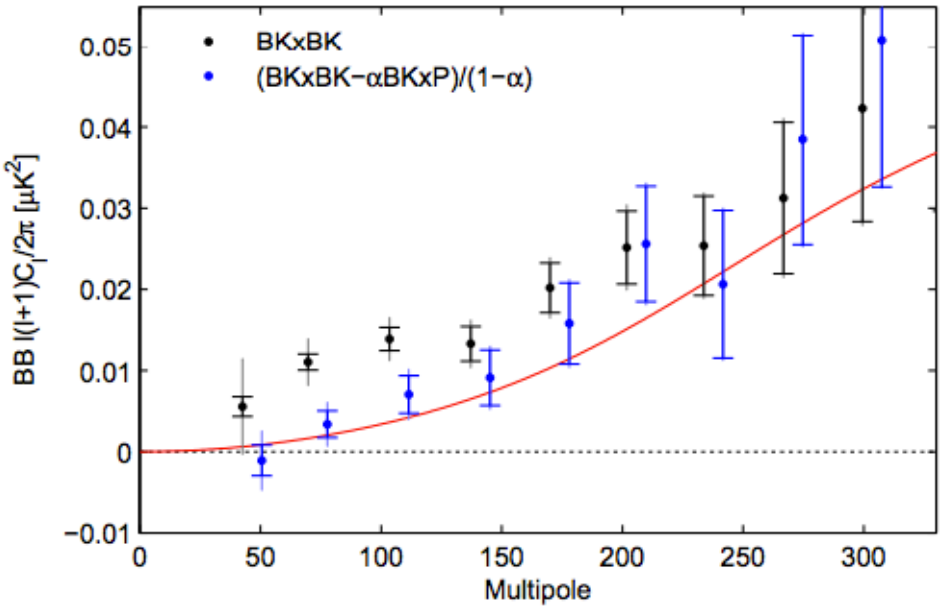
Challenges in CMB polarisation power spectrum

Curse of polarised foregrounds



BICEP B-modes

PRL 112, 241101, (2014)



Residual signal after dust subtraction
Planck and BICEP/KECK

PRL 114, 101301 (2015)

r	unsubtracted	DDM2 cross	DDM2 auto
BICEP2	$0.2^{+0.07}_{-0.05}$	$0.16^{+0.06}_{-0.05}$	$0.12^{+0.05}_{-0.04}$
BICEP2×Keck	$0.13^{+0.04}_{-0.03}$	$0.10^{+0.04}_{-0.03}$	$0.06^{+0.04}_{-0.03}$

Need for a synchrotron dedicated study

- Low frequency temperature foreground spectrum consists of free-free, synchrotron and anomalous microwave emission – degenerate in the narrow band 23-70 GHz
- Break degeneracy - extend to lower frequency
- Sky maps where low-frequency foregrounds are clearly detected in each pixel
- Ground based – for wavelengths much longer than 1 cm
- Polarised foreground components synchrotron emission and thermal dust emission are spatially correlated (WMAP 23 GHz and Planck 353 GHZ)[1,2]
- Synchrotron has same 'color' as CMB in 200-400 GHz range; the same level as BB at r=0.01

[1] *Steve K. Choi, Lyman A. Page, JCAP12(2015)020*
[2] *Planck intermediate results. XXII, A&A Volume 576, April 2015*

Low-frequency ground-based surveys

Survey	Frequency (GHz)	Angular Resolution (deg.)	Sky Coverage	Status
GEM: Galactic Emission Mapper	0.4/1.4/2.3/5/10	~0.5 (10GHz)	Full-sky	Low frequencies noisy 10 GHz on-going
S-PASS: S-band Parkes All-Sky Survey	2.3	0.1	Southern Sky	First results out Observations complete Analysis on-going
C-BASS: C-Band All-Sky Survey	5.0	0.75	Full-sky	First results out Northern obs complete Southern obs have begun
QUIJOTE: Q-U-I JOint Tenerife Experiment	11,13,17,19	~1	Northern sky	First results out Obs on-going Possibility of full-sky in future

C-Band All Sky Survey (C-BASS)

- The C-Band All Sky Survey (C-BASS) is a project to produce high signal-to-noise all sky maps at a central frequency of 5 GHz in intensity and linear polarisation (Stokes I, Q, and U)

- Primary goal: a **synchrotron template** for use in CMB foreground subtraction, **inflationary B-mode searches.**
  - Maps at this frequency are dominated by synchrotron radiation and largely uncorrupted by Faraday rotation.
  - A 'low frequency channel' for Planck and future experiments

- Secondary goals:
  - understand emission mechanisms in the diffuse interstellar medium and the magnetic fields
  - study distribution of AME, constrain models of Galactic structure
  - to help understanding of the Galactic Haze.

C-BASS members (current, active)

- **University of Oxford** - Mike Jones, Angela Taylor, Luke Jew, Jamie Leech, Christian Holler, Richard Grumitt
- **University of Manchester** - Adam Barr, Paddy Leahy, Clive Dickinson, Mike Peel, Joe Zuntz, Saarah Nakhuda
- **Caltech/JPL** - Tim Pearson, Tony Readhead, Charles Lawrence
- **South Africa SKA Project** - Charles Copley, Heiko Heilgendorff, Moumita Aich, H. Cynthia Chiang, Jon Sievers, Justin Jonas
- **KACST** - Yaser Hafez

UNIVERSITY OF OXFORD
MANCHESTER 1824 The University of Manchester
JPL Jet Propulsion Laboratory California Institute of Technology
CALIFORNIA INSTITUTE OF TECHNOLOGY 1891
SKA SKA AFRICA SQUARE KILOMETRE ARRAY
UNIVERSITY OF KWAZULU-NATAL INYUVESI YAKWAZULU-NATALI
مدينة الملك عبد العزيز للعلوم و التقنية KACST
THE ROYAL SOCIETY

C-BASS specifications

Sky coverage	All sky
Angular resolution	0.73 degree (43.8 arcmin)
Sensitivity	0.1 mK rms
Stokes coverage	I, Q & U
Frequency	4.5 - 5.5 GHz (centered at 5 GHz)

To observe the entire sky, C-BASS uses two different ground based radio telescopes.

C-BASS North vs South

	North	South
Location	Owens Valley Radio Observatory	SKA Support Base in Klerefontein
Bandwidth	4.5 – 5.5 GHz across 1 channel	4.5 – 5.5 GHz across 128 channels
Backend	Analogue	Digital
Dish Diameter	6.1 m with absorbing baffles	7.6 m under-illuminated
Optical Configuration	Gregorian	Cassegrain
Angular Resolution	0.73 degrees	0.73 degrees
Sensitivity	0.1 mK per beam	0.1 mK per beam
Start of Observations	Nov 2012	Late 2015
End of Observations	Early 2015	

Table courtesy: Heiko Heilgendorff

Observations at 5 GHz

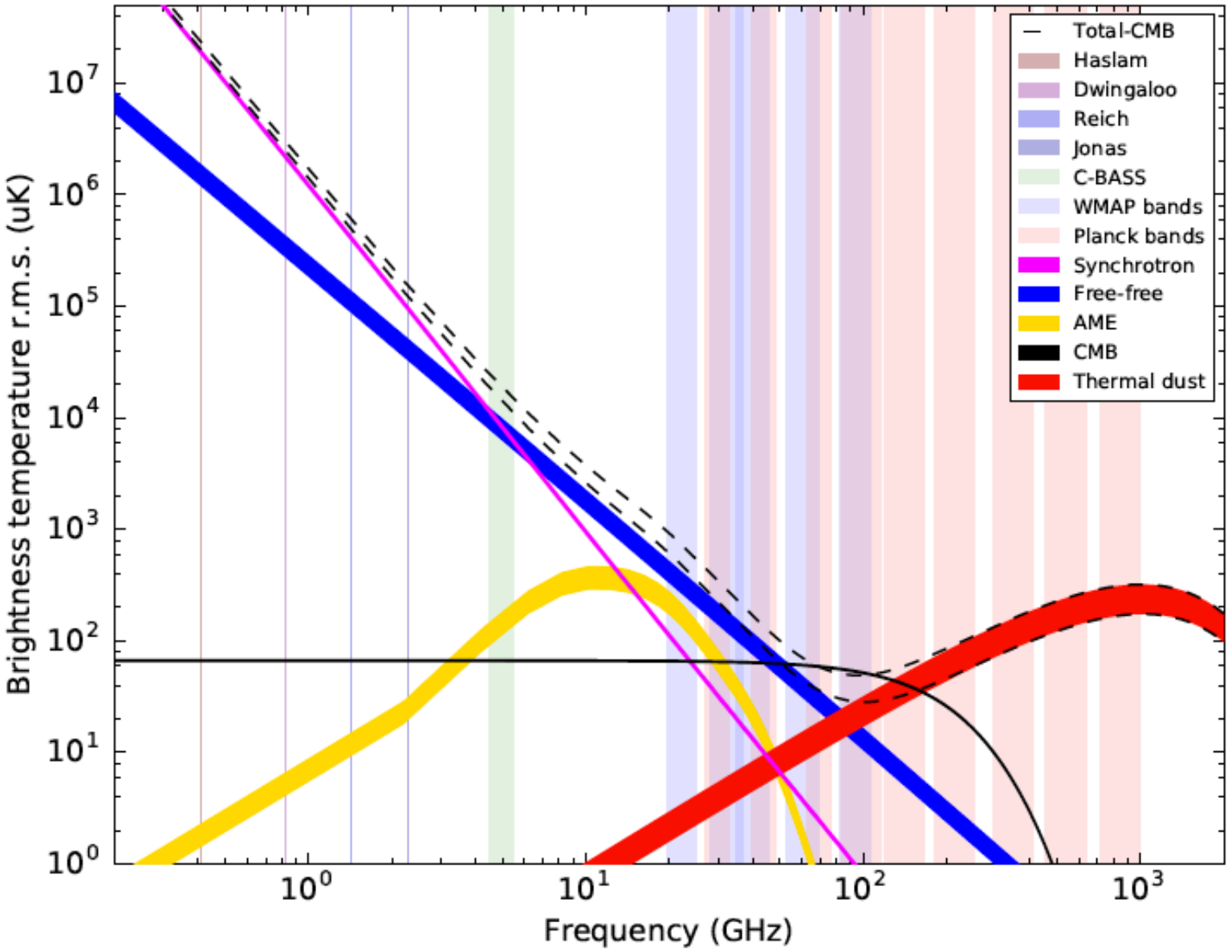
Map	Instrument	ν_0^a [GHz]
Haslam	Effelsberg/Jodrell/Parkes	0.408
K band	WMAP	22.8
30 GHz	*Planck* LFI	28.4
Ka band	WMAP	33.0
Q band	WMAP	40.6
44 GHz	*Planck* LFI	44.1
V band	WMAP	60.8
70 GHz	*Planck* LFI	70.4
W band	WMAP	93.5
100 GHz	*Planck* HFI	100
143 GHz	*Planck* HFI	143
217 GHz	*Planck* HFI	217
353 GHz	*Planck* HFI	353
545 GHz	*Planck* HFI	545
857 GHz	*Planck* HFI	857

Planck 2015 results. XXV.

* *1.420 GHz (Reich & Reich 1986)*

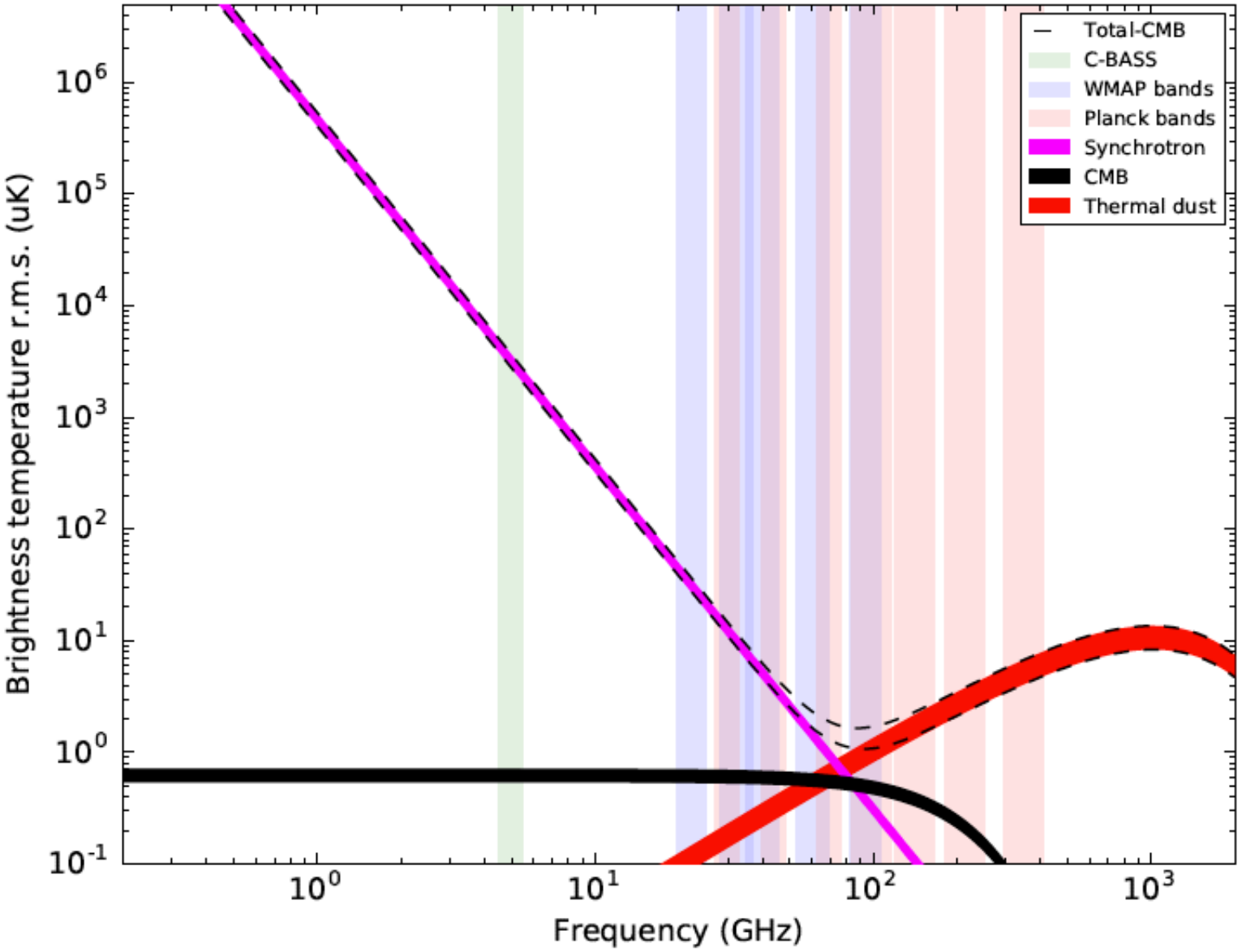
- All-sky survey centered at 5 GHz (**C-band**), with 1 GHz bandwidth.
- Free-free is unpolarised, AME has low polarisation if any (*Dickinson et al. 2011*, *Rubino-Martin et al. 2012*, QUIJOTE results - *Genova-Santos et al. 2016*) **synchrotron is up to 75%**.
- **Halfway (in log ν)** between surveys at 1.4 GHz (Stockert, Reich & Reich) and 23 GHz (WMAP)
- Low frequency to **complement WMAP, Planck**
- Not too low, so largely **uncorrupted by Faraday rotation**. This makes it the **1st synchrotron survey whose polarisation angles and fractions can be extrapolated to higher frequencies.**
- **Invaluable synchrotron template** for CMB foreground subtraction.
- Constraining **synchrotron spectral index** and its variation across the Galaxy
- Major resource for studying the interstellar medium and **magnetic field** of the Galaxy.

Observations at 5 GHz - temperature



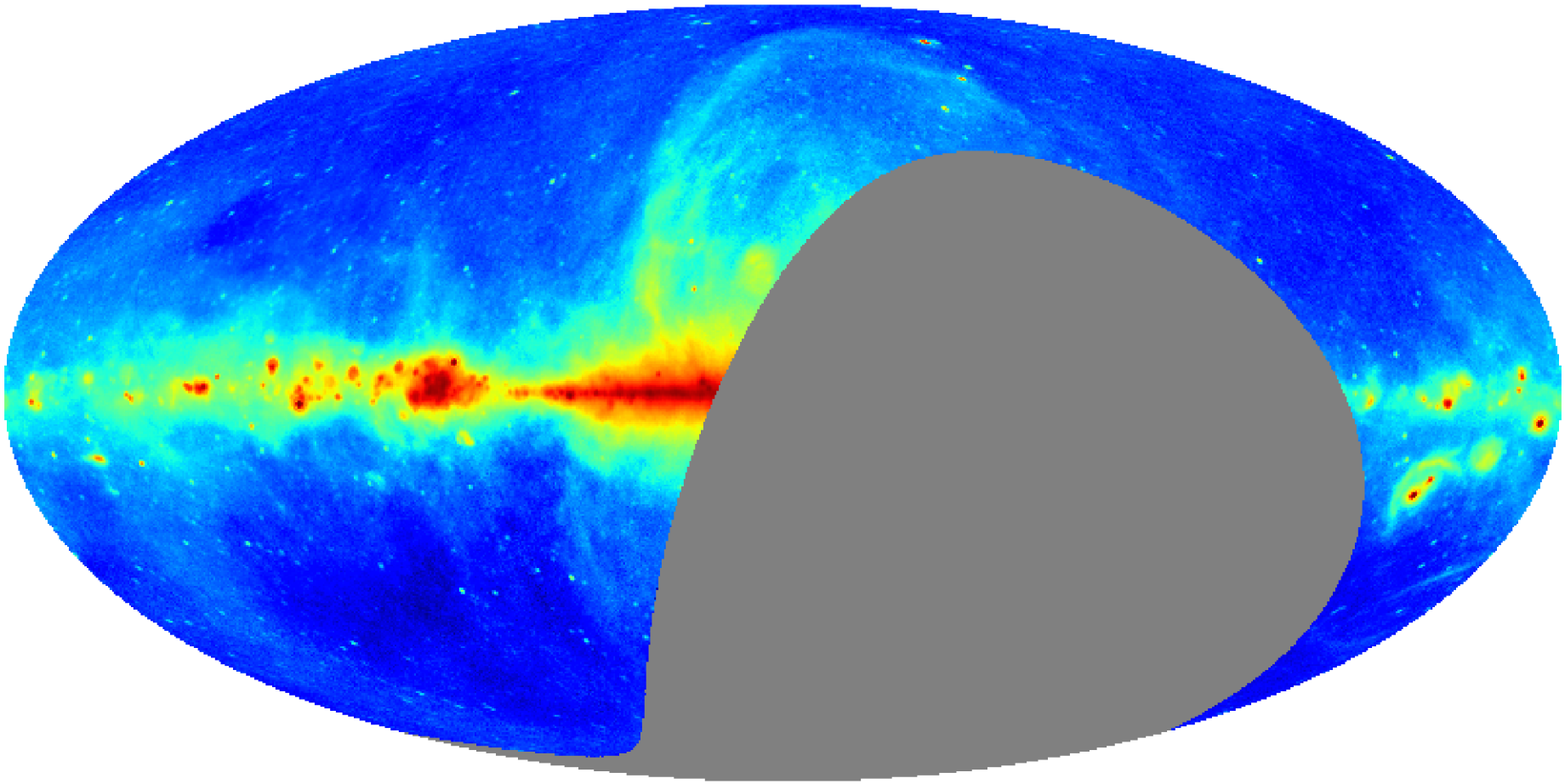
The C-Band All-Sky Survey: Design and capabilities.
Jones, M.E., et al. 2016, In preparation

Observations at 5 GHz - polarisation



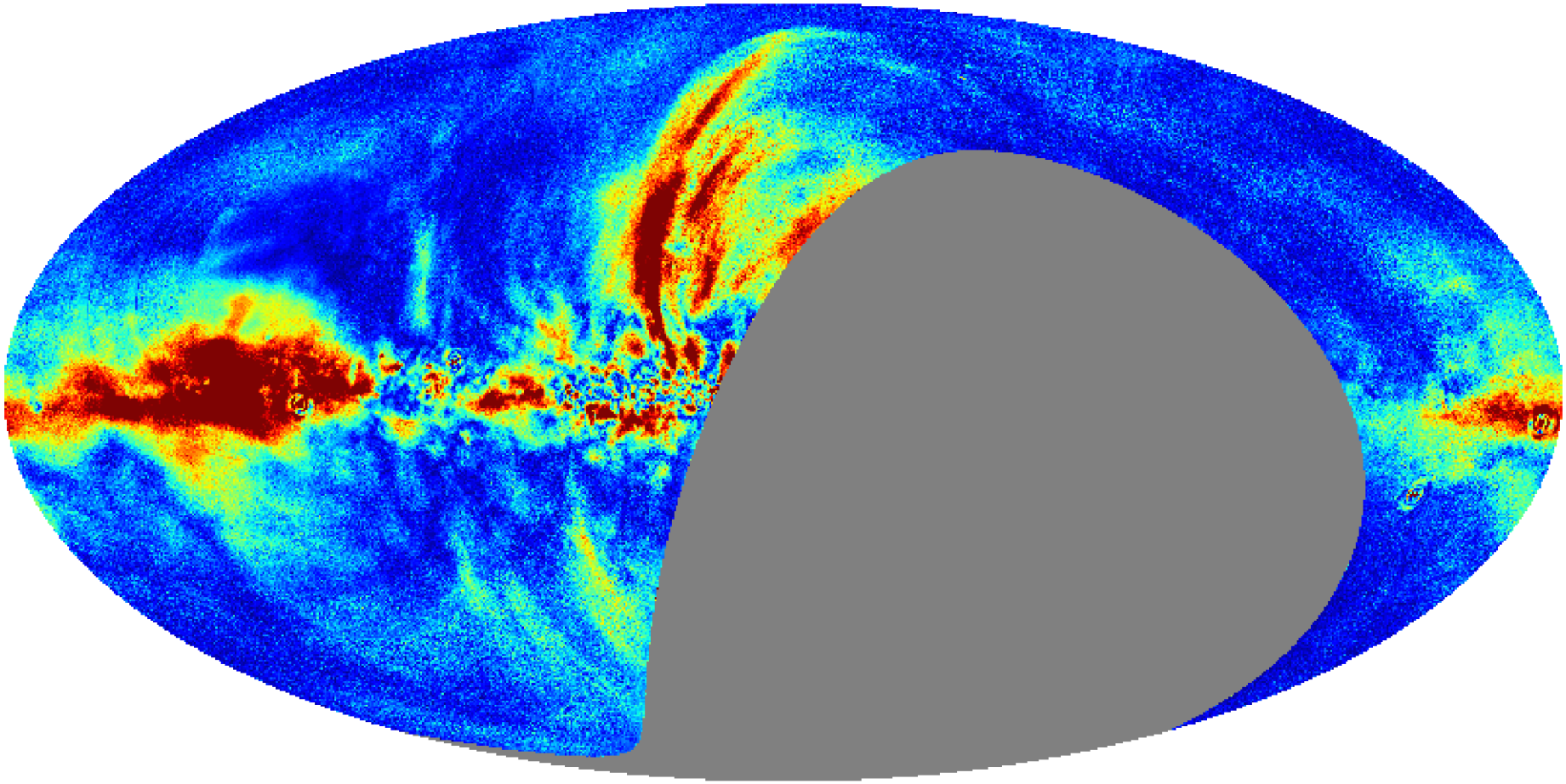
The C-Band All-Sky Survey: Design and capabilities.
Jones, M.E., et al. 2016, In preparation

Preliminary full season temperature map from C-BASS north



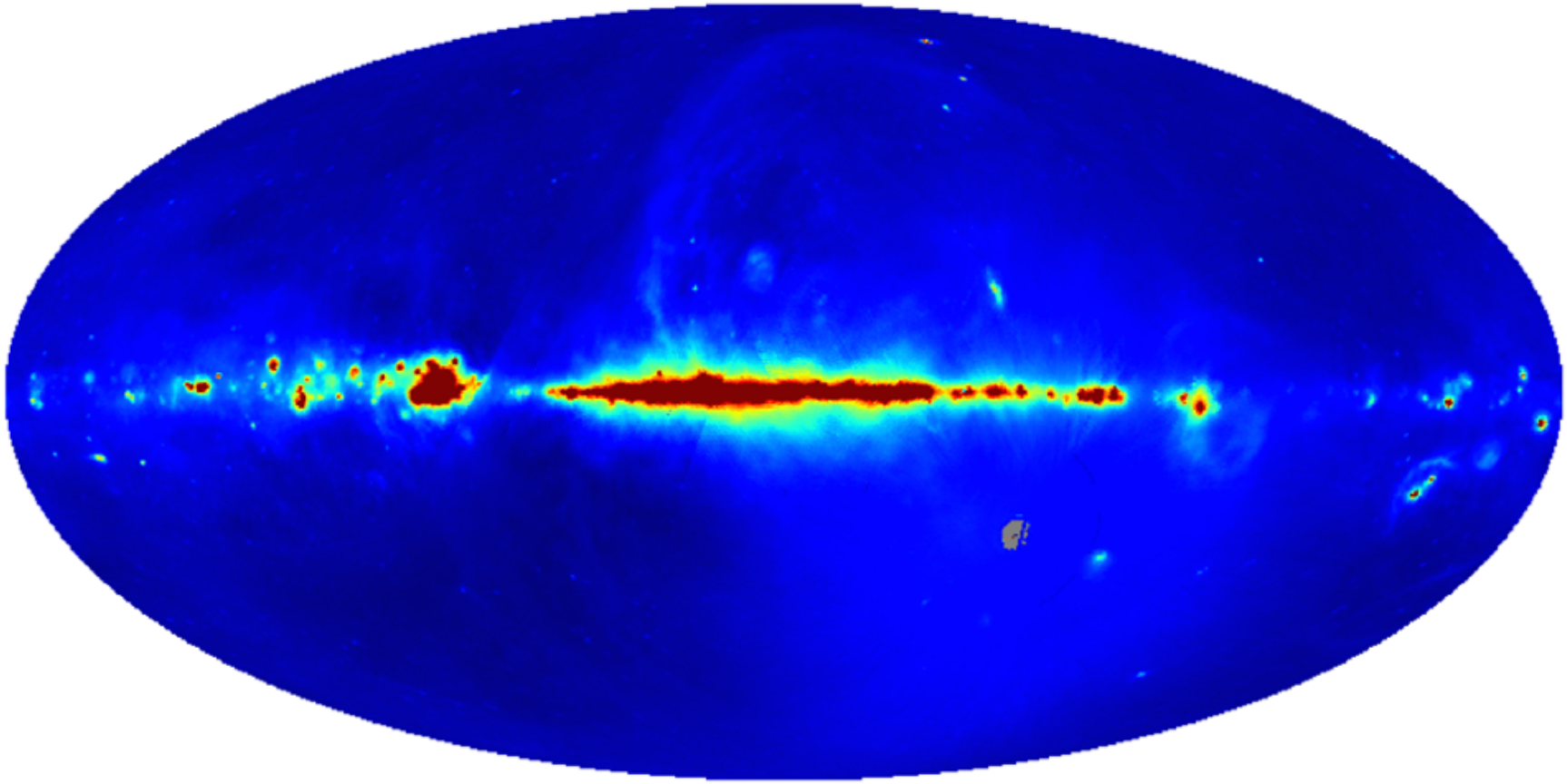
These are not the final maps as work is continuing on calibration and removal of systematic effects such as ground-spill, atmospheric 1/f noise and instrumental cross-polarisation.

Preliminary full season polarisation amplitude map from C-BASS north



These are not the final maps as work is continuing on calibration and removal of systematic effects such as ground-spill, atmospheric 1/f noise and instrumental cross-polarisation.

Preliminary all-sky intensity map from C-BASS



- Includes ~ 3 months of C-BASS south data, uncalibrated, uncleaned, lacks ground subtraction (gives rise to the background slope towards the SCP).
- Currently surveying through the SCP and will be surveying at a variety of elevations as per the north.

Figure courtesy: Angela Taylor

Impact of C-BASS

- C-BASS is on track to delivering a well quantified full sky map and fulfilling the project goals

- Characterization of the interstellar medium:
  - Constrain synchrotron spectral index across the Galaxy
  - Template of (polarised) synchrotron emission
  - Characterization of free-free emission in the Galactic plane
  - Improved understanding of anomalous microwave emission (AME)
  - Studying the galactic magnetic field

• Jones, M.E., et al. 2016. The C-Band All-Sky Survey (C-BASS): Design and capabilities. *In preparation*

• Irfan, M.O., et al. 2015. C-Band All-Sky Survey: a first look at the Galaxy. *MNRAS* **448**, 3572-3586.

• King, O. G., et al. 2014. The C-Band All-Sky Survey (C-BASS): design and implementation of the northern receiver. *MNRAS* **438**, 2426-2439.

Survey status

- The **northern** survey observations at Owens Valley, USA are **complete**
- The **southern** survey at Klerefontein, South Africa started in **late 2015**
- Data analysis pipeline is complete: working on optimization of
  - RFI detection
  - Sun contamination (data selection and subtraction)
  - Ground contamination
  - Polarisation calibration
  - Pointing corrections
- Aim to have final **northern maps** in **late 2016**
- **Southern survey** should be completed in **2018**, with full-sky maps soon thereafter

Thanks!