Wide-bandwidth Observations of Many sources with the Broadband Australia Telescope (WOMBAT) Survey

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SCIENTIFIC AIMS

We have entered a new era of radio astronomy due to the unprecedented spectral coverage provided by the Compact Array Broadband Backend (CABB; Wilson et al., 2011). Prior to the development of the CABB, spectra of radio galaxies and active galactic nuclei (AGNe) were often not well enough sampled to discern between competing physical models. A broadband survey that observes a large number of radio galaxies and AGN contemporaneously between 4 and 40 GHz, in total intensity and polarisation, will provide an unparalleled database of spectra. We will use this broadband spectral database to investigate the environments of radio sources, improve cosmological models by characterising source contamination, and understand complex Faraday structures.

A broadband survey of thousands of sources will be able to resolve the long-standing debate of whether radio sources display curvature in the optically-thin part of their spectra, or are best described by a non-thermal power-law (e.g. Klamer et al., 2006). The assumption that the electron distribution of particles in the relativistic plasma of these sources follows a simple power-law can lead to orders of magnitude inaccuracies in the estimates of the magnetic field strength and energy stored in the synchrotron-emitting lobes of radio sources. Accurate estimates of these physical parameters are vital in predicting the evolution of the radio galaxies and the extent in which radio lobes are contaminants of primordial cosmic microwave background anisotropies (Bonavera et al., 2011; Duffy & Blundell, 2012).

A similar debate about identifying the dominant absorption mechanism responsible for the spectral turnover in Gigahertz-Peaked Spectrum (GPS) sources (e.g. O'Dea, 1998; Tingay et al., 2015) could also be resolved by a broadband survey. As shown by Callingham et al. (2015), even with the advances in low radio frequency observations, having broadband spectral coverage at gigahertz frequencies is necessary to disentangle whether free-free absorption or synchrotron self-absorption are present in a source. Expanding this study to hundreds of GPS sources will conclusively differentiate which of these sources are the young precursors to giant radio galaxies.

A broadband radio survey also produces a unique dataset to be correlated with gamma-ray and neutrino observatories, providing comprehensive information about the physical processes operating in high energy objects and a unique avenue for elucidating the nature of unidentified gamma-ray sources. Previous studies with the ATCA and the MWA show the potential of this synergy (Mahony et al., 2010; Giroletti et al., 2016), but were limited by the lack of broadband spectral coverage. Furthermore, we predict that the proposed survey will detect $\sim$6 extreme scattering events (Bannister et al., 2016), generate a dataset that will be valuable to the next generation surveys to be conducted with ASKAP, MeerKAT and the JVLA, and identify polarised sources in the Southern Hemisphere that can be used to comprehensively test different models of magneto-ionic structure.

A broadband survey as proposed here represents a focus on using frequency space to provide a unique view of the radio sky. This new broadband perspective will correct inconsistencies in our understanding of high energy astrophysics and help produce the next generation of surveys.

TECHNICAL DETAILS

Number of objects: 6000 point sources.
LST range: Unconstrained.
Frequencies: 4.5 - 6.5 GHz and 8 - 10 GHz (4 cm band), 17 - 19 GHz and 20 - 22 GHz (15 mm band), 32 - 34

and 37 - 39 GHz (7 mm band). We also require 1.1 - 3.1 GHz (16 cm band) observations for $\sim$300 GPS sources in our target sample.
CABB Mode: 1 MHz continuum-mode (CFB 1M mode), using 2×2048 MHz instantaneous bandwidth.
Array Configuration: Our science goals are relatively insensitive to array configuration since we will be targeting unresolved sources and will not be imaging. We desire hybrid arrays (H214, H169, H75) to maximise uv-coverage for snapshot observations, especially when observing in the 15 mm or 7 mm bands. To minimise the impact of confusion when observing at 16 cm, 6 km baseline configurations (6A, 6B, 6C and 6D) would be required.
Observing strategy: We will complete two 60 second scans per source for each observing band. We require contemporaneous observations in all bands, so sources that are observed in one band need to be observed in the next band the following night. For the 16 cm observations of the $\sim$300 GPS sources in our sample, an additional $\sim$4 scans of each source will be performed to remove any confusing sources.
Required sensitivity: In the 4 cm band, a 60 s scan gives 0.5 mJy/beam RMS in a 64 MHz channel. Hence, a source with a flux density of at least 15 mJy will provide a channel signal-to-noise ratio (SNR) of 30. A broadband sensitivity of $\sim$2 mJy will be obtained for the requested target sources, assuming an average spectral index of $\alpha \sim -0.7$ ($S \propto \nu^{\alpha}$). This will also achieve a broadband SNR of $\sim$30. Such a high SNR is necessary for complicated model differentiation. Provided the source has a Stokes-I flux density of $\sim$50 mJy at 9 GHz, we will also have adequate SNR in Q and U to achieve our polarisation science goals.
Target Selection: Bright, unresolved sources will be selected from three partially overlapping large flux-limited samples:

- $\sim$2000 MWA sources brighter than 4 Jy at 150 MHz (Hurley-Walker et al., in prep.).
- $\sim$2000 NVSS/SUMSS sources brighter than 500 mJy at 1.4 GHz (Condon et al., 1998; Mauch et al., 2003).
- $\sim$2000 AT20G sources brighter than 120 mJy at 20 GHz (Murphy et al., 2010).

The selection criteria ensures that our target sample will be populated by a diverse range of AGN environments. The target sources will have a declination less than 0° to maximise snapshot uv-coverage and to match similar sky coverage as the surveys to be completed by MeerKAT, ASKAP, and the JVLA. This target list will be supplemented with a small number of other well-defined samples (e.g. O'Dea 1998). It is necessary to have close to 6000 sources to reach the required population statistics for different radio sources, and to provide a comprehensive dataset to achieve such science goals as characterising the radio source contribution to the cosmological microwave background power spectrum. Note that the ATCA calibrator database does have $\sim$900 sources covered over the frequency range requested for this survey. However, the observations at different frequencies used to form the ATCA calibrator database were not contemporaneous or calibrated for polarisation studies.
Total time requested, and time per semester: A total time of 2000 hours is requested. We ask for 350 hours per semester as this will ensure the survey is complete by the time the ASKAP, JVLA, and MeerKAT surveys are beginning, allowing this survey to be useful to the teams producing those surveys.
Resources, team members and skills: The proposed team has extensive experience of using snapshot observations with the ATCA and the JVLA to perform broadband studies of radio sources via spectral modelling. We additionally have the forefront experts to ensure polarisation calibration and interpretation is performed correctly. Our team has close connections to the survey teams of ASKAP, MeerKAT, and the MWA, ensuring what we would produce in this survey will be useful to those groups. Additionally, some members are part of the KM3NeT and Fermi teams, ensuring we can pursue our science goals of correlating neutrino emission with time-dependent AGN spectra and understanding unclassified gamma-ray sources. We also have members part of the Taipan all-sky spectroscopic survey team, providing an avenue to easily get redshift information for interesting sources. Finally, we are an equal mix of young postdoctoral researchers with permanent faculty members. This is important because it means our team has comprehensive knowledge of how to perform radio surveys but also the drive and time to dedicate to producing this survey.

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