Q and U Observations at Cm wavelengths and Km baselines with the ATCA (QUOCKA)

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Scientific aims

The field of cosmic magnetism is rapidly evolving. In recent years, there have been substantial new realisations in our understanding of magnetism and radio polarisation. We now appreciate that there exist deep degeneracies between source models with different combinations of synchrotron emission, magnetoionic turbulence, and Faraday rotation (Horellou & Fletcher 2014; Sun et al. 2015; Schnitzeler et al. 2015). Our ability to interpret polarised sources is dramatically improved when we obtain polarisation information over broader bandwidths (e.g., Farnes et al. 2014; Gaensler et al. 2015). The utility of the data depend crucially on the λ^2 coverage – even a modest increase in frequency coverage can result in a large improvement in the quality of the resulting Faraday depth spectra. Low frequencies are vital for "resolution" in Faraday depth space and thus in identifying distinct Faraday-rotating components along the line of sight, while high frequencies provide the critical "short spacings" that are essential to understand the inner structure of complicated ("Faraday thick") sources.

Still missing in the study of cosmic magnetism is a comprehensive classification of the complexity exhibited by polarised radio sources. Whether most sources are simple or Faraday thick remains unclear, although early efforts (e.g., Anderson et al. 2015) indicate that a substantial fraction are complex. Where does the complexity originate, and how is it connected to source morphology? Clarifying this developing picture by building an extensive library of broadband polarisation spectra, beginning to understand the internal structure of the sources, and revealing the connection to other source properties (e.g. environment, degree of activity, redshift, projected proximity to foreground sources) are the primary aims of this legacy program. Host galaxy identification and characterisation will be enabled through the availability of optical data from e.g. DES and TAIPAN, along with WISE infrared colours. Progress in the radio will be uniquely enabled by ATCA's exceptional broadband capability: by covering the $1 - 8\,\mathrm{GHz}$ range with excellent angular resolution, we will be able to isolate the core and lobe components of AGN (which are polarised at high and low frequency, respectively) as well as cover the full span of λ^2 coverage needed for reliable modeling.

The QUOCKA legacy survey targets up to ≈ 2700 brightest polarised sources below $\delta = -20°$ and will build on our currently limited knowledge of the Southern polarised sky, providing a valuable resource for commissioning efforts with the SKA and its pathfinders. In the northern sky ($\delta > -40°$) there is a large catalogue of RMs (Taylor et al. 2009), but a similar sample in the south has not yet been published. The QUOCKA catalog will enable study of large foreground objects, filling the Faraday sky and investigating the large-scale Galactic magnetic field (e.g., Oppermann et al. 2012). This project is highly complementary to ASKAP's POSSUM (Gaensler 2009) survey; by covering a much broader frequency range, QUOCKA will expand POSSUM's scientific potential. Most importantly, it will generate lasting legacy value by providing the community with a high-quality set of polarisation spectra that cover a unique and broad frequency range, informing future ASKAP/MeerKAT/SKA1 observations (all with more limited frequency coverage) through the QUOCKA library of reliable polarisation templates. Thanks to the ATCA's excellent polarisation performance, we will also measure the broadband circular polarisation properties of all sources (cf. O'Sullivan et al. 2013). This will generate the largest sample of circularly polarised sources to date, allowing robust inferences on AGN jet physics, and provide a key catalog for planned studies with the SKA (Agudo et al. 2015).

Observational Strategy

As indicated above, frequency coverage is of vital importance. We will seek to maximise the utility of the CABB correlator by observing all sources in two modes, covering two frequency bands (1-3 and 4-8 GHz). The low-frequency band will complement, and provide unique additional high-frequency coverage for, polarisation work with ASKAP including the eventual POSSUM catalog. For the high frequencies we will use the CFB 1M mode, while in the low frequency range we can incorporate zoom bands to work commensally with spectral line (absorption or emission) studies. Our team is well aware of how to deal with RFI in the low frequency band, and we do not anticipate RFI-related issues in the higher frequency bands.

We have carefully considered the optimal array configurations that will provide suitable angular resolution, matched at all frequencies. We prefer a 6-km array (6a or 6b) for the 1-3 GHz observations, which will provide higher angular resolution than ASKAP, allowing us to break additional degeneracies associated with multiple unresolved source components within the ASKAP beam and also minimise RFI. At the higher frequencies, we will make use of a 1.5-km array (1.5a or 1.5b).

The required sensitivity is, in the first stage of the survey, driven primarily by the need for high signal-to-noise (S/N) flux density measurements in several coarse channels across the full combined bandwidth. For high quality modeling, we require not only sufficient S/N in the linear polarisation products, but also to well characterise the total intensity spectrum (which can be quite complicated over such large frequency ranges). We aim for 16 MHz combined channels from the low frequency observations, and progressively wider channels in the high frequency observations. To obtain $S/N \gtrsim 5$ in each channel for the brighter NVSS polarised sources (we use $P > 8$ mJy to build a sufficiently large statistical sample below), we require ≈ 30 minutes per source delivering a broadband sensitivity of $130\,\mu\mathrm{Jy\,beam}^{-1}$. Ultimately it is this broadband sensitivity that is the key characteristic, allowing flexible tradeoff between λ^2 resolution and narrowband sensitivity. To obtain the same approximate S/N for sources with a typical spectral index of $\alpha = 0.7$ ($S \propto \nu^{-\alpha}$), we require a characteristic broadband sensitivity at the higher frequencies of $60\,\mu\mathrm{Jy\,beam}^{-1}$, again requiring 30 minutes. We rely on the ATCA's excellent on-axis polarisation performance but note that added value will be derived from weaker polarised sources located elsewhere in the field of view of each pointing.

This project is intended to build up in a staged manner to maximise leverage from existing data products, produce early high-impact results, and grow into the era of planned survey activities with ASKAP and other telescopes. In the first stage (described here), we intend to target with pointed observations a sample drawn from 2731 sources below declination $\delta < -20°$ that are either

a) sufficiently polarised in the NVSS rotation measure catalog ($P > 8\,\mathrm{mJy}$ from Taylor et al. 2009) and with sufficient flux ($I > 100\,\mathrm{mJy}$) to allow excellent characterisation of the total intensity spectrum; or

b) sufficiently bright in SUMSS ($I > 140\,\mathrm{mJy}$ from Mauch et al. 2003, equivalent to the NVSS Stokes-I threshold for $\alpha = 0.7$), and detected in polarisation at 8 GHz with AT20G (Massardi et al. 2011). We include the AT20G criterion to ensure that the sources are polarised, and to avoid a bias against sources with strong Faraday complexity that might result from selecting only sources polarised at 1.4 GHz.

We may ultimately filter this list based on characteristics such as angular size (from the SUMSS catalog) or other science-motivated considerations. In a later development, we intend to expand the sample on the basis of polarised sources identified during ASKAP-12 early science, and still later with sources from the POSSUM catalog. We note that additional polarised sources will be detected within the target fields defined by our primary sample and will form a secondary unbiased sample. The observations will span the full range of LST.

Excellent *uv* coverage will be required because most sources will be resolved, and we aim to avoid beam depolarisation and to break degeneracies. We will therefore plan to observe each source at several LST slices (7×5 min snapshots per source, spanning 12 h). Thus, we can accommodate 20 sources per 12 h track. The QUOCKA sample of up to 2731 sources will thus require up to $274 \times 12 = 3288$ hours.

Resources

The team behind this project has a wealth of collective experience using ATCA for polarisation projects, and are working at the forefront of modern radio polarimetry. We have strong ties with the POSSUM project (a strong overlap in personnel) and can therefore make use of resources of common interest, such as analysis pipelines and catalog creation routines.

We note that the observing strategy is designed to minimise the amount of time and resources required to generate science-ready data products from the observations. The targeted survey approach proposed here will allow us to make use of the ATCA's excellent on-axis polarisation performance and largely run automated pipelines to obtain polarisation spectra from the primary (on-axis) sample. We do anticipate the need for effort in setting up the automated system and defining a standard strategy for all sources.

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