Section A: Overview of the Research Project Proposal

1. Title: **Wide-band polarimetric imaging and polarization selfcal with MeerKAT and VLA**
2. Broad field of research: **Science**
3. Academic level of research project: **Doctoral**
4. Abstract: MeerKAT is providing a rich trove of polarization information with every observation. A lot of this remains under-exploited due to the intricacies of polarization calibration, as well as the need to correct for the wide-field polarimetric leakage response of the primary beam. The technique of self-calibration has been around since the 1980s, but has not been adapted to the polarization problem despite some initial work by Hamaker in the context of the measurement equation. Recent results with MeerKAT demonstrate both the feasibility and the urgent need for pol self-cal, particularly in the context of wide-field imaging. This project aims to develop this technique, and to demonstrate its application on a number of science targets.
5. Primary supervisor: **Prof Oleg Smirnov,** o.smirnov@ru.ac.za, Rhodes University

Section B: Research Project Proposal

Scientific merit: Since its demonstration by Cornwell & Wilkinson in the 1980s, the technique of self-calibration (also known as second-generation calibration, or 2GC), in which a model of the sky and a model of the instrumental gains are improved in alternate iterations, has become a mainstay of interferometric data processing, unlocking the sensitivity of modern radio interferometers, and allowing dynamic ranges of 10^5-10^6 to be reached. Self-cal ignores polarisation information, and polarimetric imaging is still generally stuck in the "first-generation" approach of transferring solutions from known reference calibrators. There have been good reasons for this: polarized signals are weak, and thus rarely require high dynamic ranges, and a formulation of pol-self-cal is mathematically tricky due to the various degeneracies inherent in polarimetric measurements. Pol-self-cal was thus both difficult and unnecessary.

Both of these aspects are now changing. MeerKAT's extreme sensitivity has increased the dynamic range of polarization images and therefore sets more stringent requirements on calibration; the Southern sky is relatively poorer in good polarization calibrators; MeerKAT can detect polarization across a wide field of view and therefore polarization DDEs (off-axis leakage) needs to be accounted for this to be exploited; finally, recent work (Hugo, Smirnov, Perley) shows that polarization effects, in particular absolute leakage, can be a DR limitation even in unpolarized images. At the same time, recent developments in techniques and tools (Cotton,

Smirnov, Kenyon, Tasse et al, Offringa, Pratley, etc.) are making a formulation of polarisation self-cal tractable.

This project aims to develop a working version of a wide-field pol-self-cal technique, based on the expertise and tools (CubiCal, DDFacet) accumulated within the RATT group. A number of MeerKAT datasets from the first open time call are waiting for polarization to be exploited, so the project will have immediate rich scientific spin-offs. We also have data from the JVLA available via our collaboration with Rick Perley, in particular, deep polarimetric observations of 3C273, if improved via pol-self-cal techniques, will have a high scientific impact.

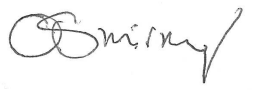
Feasibility: the *theoretical* background for pol-self-cal has long been laid (Hamaker 2006, Smirnov 2011). A number of *practical* recent advances in data reduction (Cotton, Kenyon, Hugo, Tasse et al.) provides most of the building blocks. Full-pol models for MeerKAT's primary beams are available (de Villiers 2022) At a minimum, this project can simply collect the blocks into a coherent whole, and this can be straightforwardly achieved in the first year. Application of the technique to real data, on the other hand, should provide a lot of scope for exploration and improvement.

Validation data is readily available: a number of MeerKAT open time projects within RATT are prime for polarimetric exploitation. JVLA data on 3C273 is also available.

Link to SARAO research priority areas for 2023: Any and all MeerKAT imaging observations will yield more science via better polarimetry.

Any particular qualifications, academic abilities, skills and/or experience that a student should have in order to successfully deliver on the objectives of the research proposed: Good coding skills and a good maths background. Familiarity with radio interferometry and observational radio astronomy would be a big advantage but it is not strictly required.

Supervisor



Oleg Smirnov 22 February 2023