Section A: Overview of the Research Project Proposal

1. Academic level: PhD

2. Broad field of research: Astronomy/Astrophysics

3. Title of research project: Goal-orientated stacking to enhance MeerKAT statistical analyses and VLBI multi-source self-calibration

4. Primary Supervisor: Prof Roger P. Deane

5. Institution: University of Pretoria

Section B: Research Project Proposal

1. **Scientific merit:** *describe the objectives of the research project, placing them in the context of the current key questions and understanding of the field.*

The key objectives of this project are two-fold, firstly, to perform a suite of visibility stacking experiments on realistic synthetic data generated from the TRECS SKA simulations (Bonaldi et al. 2019). This allows us to test where this approach is more effective than the traditional image-plane stacking approach. Parameters to vary will be the CLEAN depth, stacking depth, bandwidth used, maximum distance from phase centre, etc. There will be a particular focus on the ability to recover the median angular diameter of the stacked sources, a notoriously poorly constrained parameter from image-plane stacking. The second primary objective is to use the visibility stacking algorithm in a VLBI-context, for a dual-purpose role in both source characterisation and improved calibration. This will use co-supervisor Jack Radcliffe's Multi-Source Self-Calibration (MSSC) algorithm (Radcliffe et al. 2016) in combination with a University of Pretoria developed "goal-orientated" stacking algorithm, which seeks to select input objects that maximise the median flux. While the two objectives may seem disparate at first sight, the extent of the scientific and technical overlap makes for a powerful synergy.

The context of this is driven by both the desire to push below the noise threshold to understand the faint radio source population; and the need to perform self-calibration on wide-field VLBI observations in order to improve the signal-to-noise (SNR). Historically, this was not always possible due to the much lower sky density of VLBI sources when compared to the arcsec-scale sky. By taking this visibility stacking approach to MeerKAT data and wide-field VLBI data, we maximise our ability to measure sizes in the visibility plane. This permits us to measure accurate brightness temperatures in VLBI data, and for us to isolate faint real sources below nominal thermal noise threshold in MeerKAT data.

The science drivers of both of the above stems from the overwhelming evidence that supermassive black holes play a critical role in the evolution of their host galaxies. For massive galaxies, the stellar assembly appears to be regulated by the energy output associated with accretion onto a nuclear black hole. An important research area within galaxy evolution is therefore to characterize the accretion history of the Universe. A powerful method in doing so is to perform wide-field surveys using the technique of VLBI, which combines the signals from radio antennas separated by ~10,000 km to give milliarcsecond resolutions. This is an essential complement to the wide-area surveys to be performed with the arc-second resolution next-generation radio interferometers such as MeerKAT and the Square Kilometre Array (SKA) in the Karoo. Wide-field VLBI surveys will not only enable the separation of actively accreting black holes and star formation emission components; but also enable the discovery of exotic objects such as binary supermassive black holes and strong gravitational lenses. At the same time, we wish to see to what extent the statistical brightness temperature measurement can be used as a potential discrimination for high SNR detections.

A key ingredient is a so-called “goal-orientated” stacking algorithm, which maximises the statistical flux density from an input catalogue of candidate “true” sources below the nominal noise threshold. The co-addition of sub-sets of visibilities centred on different astrophysical objects with certain features then serves as an input to a new process (i.e. the self-calibration loop) which in turn creates a new feature (the percentage improved image noise rms). While focused on VLBI multi-source self-calibration (MSSC) in this case, such a technique would have many more use cases in other areas of astronomy.

***2. Feasibility:** outline the methods that will be used to achieve the objectives. Provide details on the availability of required data / access to required equipment / availability of research facilities and other resources required. Include any relevant expected intermediate milestones and associated timeframes towards attaining the overall objectives of the project.*

Visibility-plane stacking is a computationally expensive process, however, the University of Pretoria is extremely well equipped to perform this, by virtue of its membership to the Inter-University Institute for Data-Intensive Astronomy (IDIA), which has a already produced a singularity container with the appropriate software available along a large cloud computing architecture that is large enough to implement these algorithms.

The goal-orientated stacking algorithms has two working variants which were written by two students at the University of Pretoria. All that is a required from a feasibility perspective is to link with these algorithms in a loop with UP/SARAO postdoc Dr Jack Radcliffe’s multi-source self-calibration algorithm (MSSC), hence Jack’s role as co-supervisor on this project. All required MeerKAT and VLBI data is already in hand.

*3. **Link the proposed project to one or more of the SARAO research priority areas for 2020** (refer to Section 4 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).*

This project relates directly to Science with MeerKAT, playing a critical part in the statistical analysis any deep MeerKAT observations of an extragalactic field, including the approved Large Survey Projects (i.e. both continuum and spectral line stacking). The second objective links directly to VLBI science. Finally, it links to interferometric data processing and calibration, for obvious reasons.

4. If relevant, describe 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.

A strong computational background is a key requirement. This project requires someone with radio interferometric expertise through simulations, calibration, and imaging. However, one of the primary drivers is enhanced scientific exploitation of MeerKAT datasets, so the prospective students must have a keen sense of, and appreciation for the scientific goals.