Section A: Overview of the Research Project Proposal

1. Academic level:	PhD
2. Broad field of research:	Astronomy/Astrophysics
3. Title of the research project:	MeerKAT Galaxy Cluster Lens: Strong lensing magnification models and Ω_{HI} constraints in a survey of galaxy clusters
4. 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 to (a) derive lens models of the few dozen clusters observed with MeerKAT in science-commissioning time using what ancillary data are available (optical, infrared, X-ray); and (b) make predictions on the HI cosmic density (Ω_{HI}) constraints that will be possible under a range of detection scenarios (stacked and direct) with this exquisite MeerKAT cluster survey. Since (a) and (b) are strongly related, they are best performed together by someone with a strong theoretical background and a desire to develop their observational expertise. The insight gained from this project may play a legacy role well into the SKA era through the more complete view of the HI history of the Universe that it will very likely provide.

The context of these objectives is that our understanding of the cosmic evolution of neutral hydrogen is currently limited by the inability to detect it in emission in galaxies beyond relatively low redshifts (z~0.2). The MeerKAT LADUMA and MIGHTEE-HI surveys are set to revolutionize our understanding of neutral hydrogen (HI) emission in galaxies out to intermediate redshifts ($z \sim 1$), but mostly using statistical techniques between $0.6 < z < 1.45$. However, as was demonstrated in the early 1990s with molecular line observations, utilizing the natural amplification afforded by strong gravitational lensing can dramatically increase the effective sensitivity of a given telescope. A MeerKAT survey of a few dozen clusters, data for which is expected to be a available to a subset of the South African community by the start of this PhD project, will be a game-changing repository to perform deep searches for highly-magnified HI emission in the distant Universe. In our previous and upcoming publications we have shown the opportunity that lies in this approach (Deane, Obreschkow & Heywood, 2015; Blecher et al., 2019; Blecher et al., in prep.). In these papers, we demonstrate that SKA precursors have the potential to make the highest redshift HI detections to date within a small fraction of the total duration of the deep HI surveys, provided the appropriate targeted lensed surveys are designed. Based on our simulation results (Blecher et al., in prep.), clusters are the optimal route to that. Our group, including Profs Ian Heywood (Oxford) and Danail Obreschkow (ICRAR, UWA) is now well established with the relevant observational, lens modeling, and theoretical HI expertise, enabling it to making pioneering contributions to this new field. The student can therefore expect to gain holistic postgraduate training in this area and will benefit significantly from the recent observational and lens modeling successes of senior PhD student Tariq Blecher; as well as the calibration, imaging, and source-finding expertise of MSc student Shilpa Ranchod. This PhD project

therefore has its own unique key objectives, while fitting directly within a now experienced and growing lensed HI team. The project will build on the techniques developed by our HI lensing collaboration, opening the opportunity for high-impact results.

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.*

Lens modelling of galaxy clusters 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).

Senior PhD student Tariq Blecher has a wealth of experience in lens modelling for a small subset of the clusters to be made available by SARAO. While not all of these will have similarly extensive multi-wavelength coverage to perform extensive lensing analyses, macro-magnification models will be limiting objectives in the case of sparse data. In addition, the sensitivity of our inferences based on macro lens modelling assumptions is something we already have much of the machinery in place to carry out (through Blecher's PhD work). So feasibility risks are largely mitigated by work already carried out by the lensed HI group, the prospective student for this project would just need to scale this up to several dozen clusters.

All required data is assumed to be in hand, pending final confirmation from SARAO.

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 topics with MeerKAT, playing a critical part in the analysis of and inference from a number of MeerKAT galaxy cluster observations. This project can be considered as an ultra-deep tier in the HI surveys to be performed with MeerKAT, with the deep (LADUMA) and medium (MIGHTEE-HI) approved Large Survey Projects. This tiered structure will revolutionise our view of the HI history of the Universe, which is a key goal of MeerKAT through many of its LSPs.

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 theoretical background in physics and mathematics will significantly assist the potential student. Programming experience, particularly in Python, will also be highly beneficial. A physical understanding of galaxy clusters will be useful.