Section A: Overview of the Research Project Proposal

1. Academic level of research project:	Masters
2. Broad field of research:	Astronomy/Astrophysics
3. Title of the research project:	Strong gravitational lensing of neutral hydrogen with galaxy clusters: a deep search with MeerKAT-64 data

4. Research project abstract/summary (max 250 words)

The MeerKAT LADUMA and MIGHTEE-HI surveys are set to revolutionize our understanding of neutral hydrogen (HI) emission in galaxies out to intermediate redshifts ($z \sim 1.45$), 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. MeerKAT stands poised to play a leading role in exploring the new frontier offered by lensed HI observations, which will enable direct detections out to $z_{HI} \sim 1.45$, limited only by the instrument's frequency range, not its sensitivity. This project will exploit that advantage and search for lensed HI in the volume behind seven clusters observed with MeerKAT-64 (with the data already calibrated). In addition, the project will build on the techniques developed by our HI lensing collaboration, opening the opportunity for high-impact, rapid-turnaround MeerKAT science results. The insight gained from this project will also direct contribute towards an ambitious lensed HI survey proposal that we argue will play a legacy role well into the SKA era through the more complete view of the HI history of the Universe that it provides.

Section B: Supervisor(s) Details

1. Primary supervisor's details

a. Prof Roger Deane
b. University of Pretoria
c. roger.deane@up.ac.za / 078 582 2308
d. Supervision of postgraduate students: **please see CV where details are listed as requested**

Section C: Full Research Project Proposal

Overview:

Strong gravitational lensing provides the deepest views of the Universe through its magnification of the solid angle of distant galaxies combined with the conservation of surface

brightness. It enables studies of high-redshift galaxies only possible with next-generation facilities without the lensing phenomenon. To date, HI has only been detected directly at low redshifts, limited by the sensitivity and frequency range of current radio telescopes. MeerKAT and SKA1-MID will dramatically change this picture, pushing out to redshifts of z~1 for the several thousand hour surveys proposed.

Despite the detection of high-redshift HI being a key objective, what had not been considered in the MeerKAT science case when designing these surveys was the ability to detect gravitationally lensed HI emission in high-redshift galaxies. The instantaneous bandwidth and sensitivity of MeerKAT will yield the potential to produce high-impact, rapid-turnaround early science. In our MNRAS Letter (Deane, Obreschkow & Heywood, 2015), 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. In our recently submitted paper, we report the first marginal detection of lensed HI with the GMRT, which will be the HI emission distance record if confirmed (Blecher et al., submitted). 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.

This project will provide the prospective student with amongst of the deepest cm-wave radio observations of southern and equatorial galaxy clusters ever made. These data are calibrated by the legendary Bill Cotton (NRAO) and so the student will be in the extremely fortunate position of having expertly calibrated MeerKAT-64 data in hand. The focus will therefore be on imaging these data and searching the resultant cube for lensed HI detections. The student will benefit from the multi-wavelength, Bayesian framework developed in Blecher et al. and use this to rank marginal detections for followup as well as perform a ranking-based HI stacking experiment. Since the data are calibrated and techniques largely developed, the student will be spend the vast majority of the MSc on the analysis of world-class data of a pioneering nature. Any detections will immediately result in high-impact publications.

The experience gained from this project, in combination with the simulation software framework developed by our group, will inform the strategic design decisions on optimal cluster lens HI surveys with both MeerKAT and SKA1-mid.

Research work structure:

Year 1:

This year will focus on the acquisition of the relevant expertise in gravitational lensing, interferometric (specifically spectral-line) imaging, and 3D source finding expertise. The student will also become well-versed with the Bayesian framework to robustly interpret marginal and non-detections developed in Blecher et al. (submitted).

Year 2:

This year will focus on the imaging and analysis scripts developed in year 1 on all the relevant MeerKAT-64 observed clusters (calibrated data are in hand). Based on the results of this, the student will contribute towards an optimal design strategy for future MeerKAT, and SKA1-MID lensed HI cluster lensing observations and publish any detections.

Links to SARAO priority areas:

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 revolutionize our view of the HI history of the Universe, which is a key goal of MeerKAT through many of its LSPs.

Beneficial skills/qualifications/background:

While no skills are needed as a pre-requisite for this project, some programming (particularly python) experience and/or radio interferometry would provide an advantage to the student.

Data and equipment availability:

The University of Pretoria is extremely well equipped to perform the imaging and source finding required for this project, by virtue of its membership to the Inter-University Institute for Data-Intensive Astronomy (IDIA).

Section D: Signatures

Roger Deane, 31 August 2018