Section A: Overview of the Research Project Proposal

1. Title of the research project: High redshift neutral hydrogen in the MeerKAT Cluster Legacy Survey

2. Broad field of research: Science

3. Academic level: PhD

4. Abstract of research project: 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 ~ 0.8 for the most massive HI galaxies). 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 in principle enable direct detections out to z_{HI} ~ 1.45. This project will exploit that advantage and search for lensed HI in the volume behind deep observations of ~100 galaxy clusters observed with MeerKAT as part of the Cluster Legacy Survey. In addition, the project will build on the tools and techniques developed by our HI lensing collaboration to constrain the cosmic HI density *within* these rich cluster environments between $0 < z < 0.4$ using direct detections and statistical methods, and search for correlations with cluster X-ray luminosity, viral mass, redshift, cluster dynamics, etc. This project will therefore be a comprehensive study of HI in a large sample of unique, rich cosmological environments, using deep observations with the most sensitive radio telescope in its class. In addition, the insight gained from this project will also directly contribute towards an ambitious lensed HI survey design with MeerKAT, MeerKAT+ and SKA1-mid which will provide more complete views of the HI history of the Universe.

5. Primary Supervisor Details: Prof Roger P. Deane

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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.*

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. We have recently reported what could be the first marginal detection of lensed HI with the GMRT, which would be the HI emission distance record if confirmed (Blecher et al., 2019). 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 PhD students Tariq Blecher and Charissa Button, as well as MSc student Shilpa Ranchod.

This project will provide the prospective student with amongst of the deepest cm-wave radio observations of southern and equatorial galaxy clusters ever made. The focus will therefore be on calibrating and imaging these data and searching the resultant cubes for lensed HI detections. The student will benefit from the multi-wavelength, Bayesian framework developed in Blecher et al. (2019), source finding techniques by Ranchod et al. (in prep.), and use this to rank marginal detections for followup as well as perform HI stacking experiments. The student will be spend the vast majority of the PhD on the analysis of world-class data of a pioneering nature, learning to use cutting-edge calibration and imaging algorithms along the

way. Any detections will immediately result in high-impact publications, in addition to the primary statistical objectives of this PhD.

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

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.*

All required data is in hand and due to be released to the MeerKAT Legacy Cluster Survey team in the coming months. The supervisor and members of the lensed HI team have already processed some of these data themselves with success. All processing is likely to be performed on the IDA Cloud.

3. Link the proposed project to one or more of the SARAO research priority areas for 2021 *(refer to Section 5 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).*

This project can be considered as an ultra-deep tier (as well as a “rich environment 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.

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.

Experience in interferometric calibration and imaging will be beneficial but not essential. A strong physics and/or programming background will help.