Section A: Overview of the Research Project Proposal

1. Academic level of research project
Doctoral (PhD)

2. Broad field of research
Astronomy

3. Title of research project
HI in galaxies in different environments in the LADUMA field

4. Research project abstract/summary (max 250 words)
The LADUMA (Looking At the Distant Universe with the MeerKAT Array) survey will observe the neutral hydrogen, HI, content of galaxies over a look-back time of more than two-thirds the age of the universe and will be the deepest survey of HI in galaxies until the SKA comes online. The aim of the survey is to study the galaxy evolution by investigating the HI content in galaxies over cosmic time in different environments. In this project, the student will define an environmental catalogue (field/group/cluster) for galaxies in the LADUMA survey volume using existing multi-wavelength photometry and spectroscopic redshifts. Using the first tranche of LADUMA L-band MeerKAT data they will then investigate the HI content of galaxies in different environments using HI spectral stacking techniques.

Section B: Supervisor Details

1. Primary supervisor's details
a. Title and full name
Dr Sarah Blyth

b. Name of South African or SKA Partner Country university at which the primary supervisor is a permanent academic staff member
University of Cape Town

c. Email address and/or contact telephone number
sarblyth@ast.uct.ac.za

d. Supervision of postgraduate students – please provide the details of all the previous and current postgraduate students supervised.

i. Doctoral Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Julia Healy	SA	Jan 2017	Dec 2020	Using HI Stacking to	Marc Verheijen

				determine the cosmic neutral gas density at intermediate redshift	(University of Groningen)
Tshiamiso Makwela	SA	Jan 2018	Dec 2020	The impact of visualisation of 3D astronomy objects in school learning	Saalih Allie (UCT), Dale Skippers (UCT)
Gerald Balekaki	Ugandan	Jan 2016	Jun 2019	A robust online RFI database for SKA	Michelle Kuttel (UCT), Anja Shroeder (SAAO)
Narges Hatamkhani	Iranian	Aug 2016	Dec 2019	Unveiling of the newly discovered Vela Supercluster	Renee Kraan-Korteweg (UCT)
Jamie Bok	SA	Jun 2015 (upgraded from MSc)	Dec 2019	Probing the role of HI content and environment on the galaxy main sequence	Tom Jarrett (UCT), Rosalind Skelton (SAAO)
Tom Mutabazi	Ugandan	Jul 2012	Jul 2015	The distance to the Norma cluster and its relation to the Great Attractor	Patrick Woudt (UCT)

ii. Masters Students

Name of student	**Nationality**	**Date started Masters Degree (Month and Year)**	**Date completed / will complete Masters Degree (Month and Year)**	**Title of Research Project / Thesis**	**Co-Supervisor (if relevant)**
Nazir Makda	SA	Aug 2017	Dec 2018	Ultra-diffuse galaxies in Stripe 82 Clusters	Rosalind Skelton (SAAO)
Nadine Hank	SA	Feb 2018	Dec 2019	Exploring HI asymmetries in galaxy mergers with simulations	Nathan Deg (UCT)
Julia Healy	SA	Jan 2015	Jun 2017	Using HI Stacking to study galaxy properties in the nearby Universe	Ed Elson (UCT)
Christopher Schollar	SA	Jan 2012	Jun 2015	RFI Monitoring for the MeerKAT Radio Telescope	Michelle Kuttel (UCT), Anja Schroeder (SAAO)
Scott Badenhorst	SA	Jan 2011	Jun 2015	Acceleration of the noise suppression component of the DUCHAMP source-finder	Michelle Kuttel (UCT)

Riona Ramraj	SA	Jun 2012	Jun 2014	Exploring star-formation in dwarf galaxies at z~1	David Gilbank (SAAO)
Zara Randria-manakoto	Madagascan	Jun 2009	Dec 2010	Super star clusters and star formation in interacting galaxies	Petri Vaisanen (SAAO)

1. Co-supervisor's details

a. Title and full name
Dr Rosalind Skelton

b. Name of the university/institute at which the co- supervisor is a permanent academic/research staff member
South African Astronomical Observatory (SAAO)

c. Email address and/or contact telephone number
ros@saao.ac.za, 0214609355

d. Supervision of postgraduate students – please provide the details of all the previous and current postgraduate students supervised.

i. Doctoral Students

Name of student	Nationality	Date started Doctoral Degree (Month and Year)	Date completed / will complete Doctoral Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Jamie Bok	South African	July 2016	Dec 2019	Probing the role of HI content and environment on the galaxy main sequence	Sarah Blyth, Tom Jarrett

ii. Masters Students

Name of student	Nationality	Date started Masters Degree (Month and Year)	Date completed / will complete Masters Degree (Month and Year)	Title of Research Project / Thesis	Co-Supervisor (if relevant)
Nazir Makda	South African	Feb 2017	Dec 2018	Ultra diffuse galaxies in Stripe 82 clusters	Sarah Blyth

Section C: Full 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.

One of the biggest current puzzles in galaxy evolution is to understand why the two populations of galaxies in the local Universe, star forming and quiescent galaxies, are so distinct (Strateva et al. 2001, Baldry et al. 2004). Although they are not sites of new star formation, the total mass in quiescent galaxies has grown dramatically over cosmic history, approximately doubling since a redshift of 1 (approximately 8 billion years in lookback time, e.g. Bell et al. 2004, Faber et al. 2007) and increasing by a factor of 10 since z=2.5 (e.g. Tomczak et al. 2013). This suggests that star forming galaxies transition into the quiescent galaxy population over time by quenching their star formation. It is still not clear what sets the efficiency of star formation and what causes galaxies to quench, although there are strong correlations between galaxy mass, morphology, central density, environment and star formation rate that offer tantalizing clues (e.g. Whitaker et al. 2017, Peng et al. 2014).

The LADUMA survey with MeerKAT will observe a single pointing on the sky, encompassing the Extended Chandra Deep Field South, for 3300 hours to observe the neutral hydrogen, HI, in galaxies back to when the Universe was less than one third of its current age (z~1.4). The aim of the survey is to study galaxy evolution over cosmic time by investigating the HI content of galaxies as a function of redshift (look-back time) and environment (clusters, groups, field). In order to understand the physical processes involved in galaxy evolution, and the so-called 'baryon-cycle' of gas inflows and outflows from galaxies, it is vital to determine the contribution from the neutral atomic hydrogen gas, the reservoir from which molecular gas, and eventually stars, form.

The aim of the PhD project proposed here will be to measure the environmental density of galaxies in the LADUMA field by identifying galaxy groups, clusters, and large-scale structures. This will enable the further investigation of the HI properties of galaxies (inferred from the LADUMA MeerKAT data) as a function of environment. The properties of galaxies in dense environments will be compared to those in the field in order to probe the physical processes driving evolution in the different environments. Our multiwavelength ancillary data in the field will enable comparison across a range of galaxy properties including for example, colour and stellar mass.

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.

The project is structured so that the initial stages will make use of photometric and spectroscopic data that are already in hand, and newly acquired MeerKAT L-band data in the LADUMA field

will be used in the later stages. This will ensure that the project can proceed promptly using the optical/infrared data, while the radio data are still being taken and calibrated in the first year.

Data availability and analysis techniques
A large volume of multiwavelength photometric data are already available in the LADUMA field from optical to infrared wavelengths across many different bands, e.g., the MUSYC catalogue (Cardamone et al., 2010) with UBVRIzJHK photometry over the central region. Over the past few years, the LADUMA team has collected ~8000 spectroscopic redshifts in addition to ~4000 publicly available redshifts of galaxies in the LADUMA field. In the first part of the project, the student will analyse the spectroscopic completeness across the area of the Extended Chandra Deep Field South as a function of redshift and investigate potential environmental measures. Estimates of galaxy density such as n-th nearest neighbour, derived from optically-selected catalogues, will be compared to the results of friends-of-friends group-finders. The properties of galaxies across a range of environments, ranging from close pairs of galaxies to rich groups, could then be explored.

In the second part of the project, once an environmental catalogue has been produced, the student will make use of the first tranche of LADUMA L-band data (due to start coming off the MeerKAT telescope end-2018 - early 2019) to investigate the gas properties of galaxies identified in different environments. In order to do this, both direct detections, as well as HI stacking techniques will be used. HI stacking involves co-adding the HI spectra of galaxies whose optical redshifts are known, but which may or may not be detected directly in HI in order to estimate their average HI content. This is a very useful technique in cases where the signal-to-noise ratio is too poor to reliably detect individual galaxies, and the properties of galaxy samples can then be measured on average. Stacking software has already been developed by the LADUMA team in advance of these types of analyses and will be available to be used by the student for this project in addition to our existing optical redshift catalogue.

Facilities
As a UCT student working on a LADUMA-related project with one of the Principal Investigators of the survey (Dr Sarah Blyth), the student will have access to IDIA cloud computing resources to work with their data. They will also have access to a desk and the usual internet and library access afforded to all postgraduate students at UCT. In addition, through Dr Ros Skelton's co-supervision, they will have access to SAAO resources as well. With Dr Skelton's experience as a SALT astronomer, the student will be well-supported to undertake any additional spectroscopic observations with SALT.

High-level breakdown of activities:
- Determine different environmental regions in the LADUMA field using established techniques such as friends-of-friends algorithms or other group/cluster-finding algorithms and existing multi-wavelength data (2019)
- Identify appropriate sub-samples of galaxies, in the LADUMA footprint, to be stacked and prepare for possible SALT follow-up spectroscopy on interesting regions/sources (2019 - 2020)
- Tweak and run HI source-finding algorithms (e.g. SoFiA) on the LADUMA L-band data to search for direct detections. Cross-correlate HI detections with existing multi-wavelength data (2020 - 2021)

- Stack identified sub-samples to determine the dependence of gas-fraction on stellar mass, galaxy colour, etc. as a function of environment and redshift. (2020 - 2021)
- Write up thesis (2021)

3. Link the proposed project to at least one SARAO research priority areas (refer to Annexure 1 of the Application Guide), and explain in some detail how the proposed research will contribute to the priority area(s).

The proposed project links to the SARAO research priority:
6. Science topics that involve the exploitation of MeerKAT data projected to be available by 2019 - 2020. (Multiwavelength projects that are directly linked to approved MeerKAT Large Survey Projects will be considered.)

A key aim of the LADUMA survey is to study galaxy evolution in different environments. To do this, we need to develop an environment catalog (i.e. group/cluster/field catalogue) for the galaxies in our survey volume, since a catalogue does not yet exist for this across the full LADUMA field of view, particularly at higher redshift. In this project, the student will develop such a catalogue which can then be used by the entire LADUMA team for various different analyses. This project is therefore linked directly to one of the MeerKAT Large Surveys and it will make use of both existing ancillary multi-wavelength data as well as the first tranche of LADUMA L-band data which is due to start coming off the telescope by the end of 2018, early 2019.

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.
Good python programming skills will be needed and particularly reading in and working with large catalogues of data would be an advantage. Experience with HI data analysis and optical spectroscopy will be an advantage, but the student will learn these skills during the project if they have not already had this experience.

Section D: Signatures

1. Signature of the primary supervisor, with date

_____ 31 August 2018

Dr. Sarah Blyth Date

2. If relevant, signature of the co-supervisor/research supervisor, with date

_____ 31 August 2018

Dr. Rosalind Skelton Date