Section A: Overview of the Research Project

1. Title of research project:
The cosmic HI density in the LADUMA field

2. Broad area of research:
Science

3. Academic level of research project:
Doctoral

4. Abstract
The LADUMA (Looking At the Distant Universe with the MeerKAT Array) survey will observe neutral hydrogen gas, HI, in galaxies back to when the Universe was less than one third of its current age using the MeerKAT radio telescope. While the HI content of galaxies in the local Universe has been well-studied, very little is yet known about the neutral gas content of galaxies at larger cosmic distances due to the unfeasibly long observing times required on the previous generation of radio telescopes. The cosmic neutral gas density, $\Omega_{\rm HI}$, is a parameter which describes the density of neutral hydrogen in the universe and is important to measure in order to understand its relation to star formation in galaxies over the age of the universe. $\Omega_{\rm HI}$ has been measured directly in the nearby universe through direct HI detections and stacking experiments, and at high redshifts indirectly through absorber measurements. However, it is still unclear how the low and high redshift measurements connect. The very high sensitivity and observing frequency range of MeerKAT will enable us to observe the HI in galaxies over a range of environments and look-back times to fill in the gap in measurements between low and high redshift.

Primary supervisor's details:

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Section B: Details of the Research Project

Scientific merit:
Over the past 11 billion years, the star-formation rate density has dropped by almost 2 orders of magnitude (Hopkins & Beacom 2006); galaxies today are forming stars at only a fraction of the rate that they were 11 billion years ago. Since neutral hydrogen, HI, provides the reservoir from which molecular hydrogen, and consequently, stars form, it is important to understand the evolution of the HI in order to understand this reduction in star formation rate and the evolution of galaxies over cosmic time. The cosmic neutral HI density, $\Omega_{\rm HI}$, is the parameter which describes the density of neutral hydrogen in the Universe and has been measured both directly (direct HI galaxy detections or HI stacking) at low redshifts and indirectly using absorber measurements as a proxy at higher redshifts. However, the evolution of $\Omega_{\rm HI}$ at intermediate redshifts ($0.3 < z < 1.5$) is still unclear as there are large uncertainties on the stacking and absorber measurements in that redshift range.

While a great deal is known about the stellar content of galaxies out to very high redshifts (long look-back times), due to infrared, optical and UV measurements with large ground-based and space telescopes, our current knowledge of the gas content of galaxies lags significantly behind. Due to a spin-flip transition of the electron, neutral hydrogen emits a signal at 21 cm (1420 MHz) which can be measured by radio telescopes. However, the sensitivity of previous radio telescopes has not been high enough to enable observations much further than the local universe due to the prohibitively long observing times required. MeerKAT's excellent sensitivity, wide frequency coverage, and high angular resolution will enable us to make HI measurements beyond the local universe out to redshifts of z~1.4 with the LADUMA (Looking At the Distant Universe with the MeerKAT Array) survey, one of the MeerKAT Large Survey Projects.

The goal of this project will be to use early LADUMA data (L-band and possibly also UHF-band data, dependent on available observations) to measure the cosmic HI density in different environments and as a function of redshift using the HI stacking technique. L-band data will enable measurements out to $z<0.58$ and the addition of UHF-band data will push the redshift range out to $z<1.4$, filling in the gap over the intermediate redshift range between existing direct measurements and indirect measurements of Ω_{HI}. With these measurements the aim is to better constrain the evolution of Ω_{HI} as well as to probe the consistency (or not) between direct HI and indirect absorber measurements at higher redshifts. It will also be possible, using the same methods, to estimate the average HI properties of different sub-samples of galaxies in different environments in the LADUMA field.

Feasibility:

Data availability and analysis techniques:
The project will make use of data from the first set of LADUMA 32k L-band data and possibly also UHF data (it is expected that UHF data should become available over the time of this PhD project). It is envisaged that the student will join the LADUMA pipeline team to help with processing aspects of the data.

The project will rely on the HI stacking technique whereby galaxies are identified in optical catalogues, their spectra are extracted from the HI data cubes (detections and non-detections) and are stacked based on their redshifts (measured optically). This is a very useful technique in cases where the signal-to-noise ratio is too poor to directly detect individual galaxies and the HI properties of galaxy samples can then be measured on average. The student will use the HI stacking software developed by LADUMA team members (Healy et al. 2019).

Over the past years, the LADUMA team have put together a database consisting of thousands of optical redshifts of galaxies in the LADUMA field which will be used for the HI stacking. The student will likely be involved in additional spectroscopic campaigns at higher redshifts (e.g. on SALT).

Resources and equipment:
As a LADUMA team member, the student will have access to the IDIA compute facilities where the LADUMA data will be processed and analysed. Being at UCT will enable the student to interact with IDIA researchers and technical experts who will be able to help support the computing aspects. As a student in the Department of Astronomy, the student will also have access to the usual desk and office space, internet access and library access afforded to all postgraduate students.

High level breakdown of activities:
- Contribute to creating LADUMA HI data cubes based on first tranche of L-band data (2021)
- Collaborate with other LADUMA team members investigating and identifying different galaxy environments in the LADUMA field to identify appropriate sub-samples for stacking analysis. (2021)
- Cross correlate HI detections with existing multi-wavelength photometry (2021)
- Stack sub-samples of galaxies to determine average gas fractions of galaxies and Ω_{HI} in different environments at different redshifts. (2021 – 2022)
- Repeat the steps above for UHF-band data (2022 – 2023)
- Write up thesis (2023)

Relevance to SARAO research priority areas:
This project falls squarely under the priority area: “Topics exploiting data projected to be available by 2021-22 from key radio astronomy instruments located in South Africa. […] MeerKAT is the highest priority area.”
This project will utilize data from the MeerKAT Large Survey Project, LADUMA. Some of this data (L-band) is already in hand and more is expected to be forthcoming over the next weeks/months of 2020. Therefore the data will be in hand by the time this project starts. It is expected that additional UHF-band data will be collected by 2021 as well.

Skills/experience useful to the student on this project:
Good python programming skills will be needed and experience in analyzing and working with HI data cubes will be an advantage. However, the student will learn these skills on the project if they have not yet had this experience.

Dr Sarah Blyth, February 2020