Overview of the research proposal

1. **Academic level:** M.Sc. (masters)
2. **Broad field of research:** Astronomy/astrophysics
3. **Title of research project:** The ubiquity of warps in HI discs in the local Universe and across cosmic time
4. **Research project abstract:**

MeerKAT will allow us to routinely detect the HI content of galaxies at redshifts $z \gtrsim 0.2$. Traditionally, this has always been a very difficult feat to achieve. However, as sensitive as MeerKAT will be, its ability to spatially resolve the HI content of galaxies will be limited. With 75% of the antennas being distributed within a 1-km-diameter core, MeerKAT will have a spatial resolution of approximately 15 arcsec. Even the most HI-massive galaxies ($\sim 10^{10.5}$ $M_\odot$) will have apparent HI diameters smaller than 15 arcsec when located at redshifts $\gtrsim 0.25$. A significant fraction of HI detections will therefore yield only a measure of the HI spectrum (i.e., global profile) of a galaxy.

The HI spectrum of a galaxy is, in fact, a global measure of *both* the kinematics and the distribution of its HI content. As such, it contains a wealth of information about the galaxy. The main aim of the proposed M.Sc. project is to develop, test, and implement statistical and computational methods that will quantify the links between the shapes of HI spectra and the intrinsic distribution of HI within galaxy discs. Specifically, the HI spectra will be used to infer the presence of a possible warp in the HI disk of a galaxy. Warps in HI discs are thought to be as a result of merger or interaction activity. The project will therefore serve as a study of the interaction/merger activity of galaxies over a cosmologically significant redshift range that extends beyond the local Universe. If this goal is achieved or at least proven achievable in principle, it opens up the exciting possibility of using MeerKAT image sets to study the intrinsic HI properties of thousands of galaxies in a statistically meaningful manner.

To date, there are only a few hundred galaxies (limited to the nearby Universe) that have had their HI disc structure studied in detail. Finding new ways to leverage the information contained in the HI spectra of galaxies will significantly promote our understanding of the processes that drive the creation of warps in galaxy discs, and hence the galaxy formation and evolution histories.

Supervisor details

1. Primary supervisor's details:

a. **Title and full name:** Dr Edward Elson
b. **Name of university:** University of the Western Cape
c. **Email address:** drelson.e.c@gmail.com
d. **Supervision of postgraduate students:**

Masters students:

Name of student	Nationality	Date started degree	Date completed/ will complete	Title of research project	Co-supervisor
Unarine Tshiwawa	SA	July 2017	Dec 2018	A study of the angular momentum content of early-type galaxies	Prof. Roy Maartens
Modisha Tladi	SA	July 2018	Dec 2019	Mock MeerKAT observations of gas in galaxies	Prof. Roy Maartens

2. Co-supervisor's details:

There will be no co-supervisor for the proposed project.

Full research project proposal

Scientific merit

A quantitative study of the processes that drive galaxy formation and evolution is a huge ongoing challenge in modern astrophysics - arguably constituting one of the biggest unsolved problems. The HI content of a galaxy is a sensitive probe of its formation history and ongoing evolution. Specifically, the interaction/merger rate of galaxies as a function of cosmic time is an important quantity to measure and compare to the predictions of simulations of structure formation. A sensitive probe of recent interaction/merger activity of a galaxy is the presence of a warp in its HI disc.

In order to use HI observations to study the distribution and kinematics of the neutral gas in a galaxy disc, the galaxy must be spatially and spectrally *resolved*. MeerKAT, despite being a highly sensitive instrument, will not spatially resolve the HI content for a substantial fraction of galaxies that it directly detects. The well-known HI mass-size relation can be used to show that even the most HI-massive galaxies (~ $10^{10.5}$ $M_{\odot}$) have an intrinsic maximum HI diameter of approximately 100 kpc. A galaxy of this intrinsic (physical) size has an angular size smaller than 15 arcsec when located at redshifts higher than ≈ 0.25.

Hence, if the aim is to use MeerKAT HI imaging to study the structure of galaxy discs (specifically the ubiquity of warps within them) beyond the local Universe; new and novel methods of doing so using only HI spectra will need to be developed, tested, and implemented. This is the goal of the proposed M.Sc. project.

Feasibility

The project will be handled in two parts: 1) simulations, and 2) analysis of real HI galaxy spectra.

The simulations component will involve generating hundreds (more likely thousands) of model HI galaxy spectra based on different combinations of the important parameters used to describe the distribution and kinematics of HI in galaxy discs. The student will use the GALMOD task within the GIPSY software package to generate a large library of 3-dimensional galaxy models. The models will be parameterised by at least the following important parameters: central concentration of HI within the disc of a galaxy, maximum circular rotation speed of the HI, turnover radius of the knee of a galaxy's rotation curve, HI disc thickness, disc inclination (variable with radius), and disc position angle (also variable with radius). These parameters can be used to uniquely specify the radial distribution of HI mass within a galaxy and also its rotation curve. The HI mass profile and rotation curve are then used to create the full 3-dimensional (axis-symmetric) model of the galaxy. Having generated a 3-dimensional model of a galaxy, the total amount of flux within each channel can be represented as a function of channel number (or corresponding radial velocity) in order to generate an HI spectrum for the galaxy. In this manner, the student will generate a suite of HI spectra - the detailed shapes of which will be linked to the known intrinsic parameters used to create the corresponding 3-dimensional galaxy models. By studying the ways in which the *full* range of important galaxy parameters affect the shapes of HI spectra, we should be able to isolate the effects caused specifically by the presence of a warp within the HI disc. The most likely result will be that a warped HI disc yields an asymmetric HI spectrum. However, the much more subtle effects of a warped disc on the shape of an HI spectrum will be studied. A systematic study of this nature has not been carried out before. It alone will constitute a very interesting an relevant scientific study.

Once the links between the shapes of HI spectra and the warp properties of HI discs have been determined and quantified, the newly acquired knowledge can be applied to real data in order to quantify the prevalence of warps in HI galaxy discs. The ultimate aim of this project (or perhaps a PhD extension of it) will be to study the prevalence of warps in galaxies as a function of cosmic time (i.e., out to high redshifts using MeerKAT data). However, a perfect nearby-Universe data set for this study is the recently-released catalogue of ~ 31 500 HI line sources from the full ALFALFA survey. The ALFALFA survey was carried out with the Arecibo telescope - the data therefore have a spatial resolution of $\approx$ 3.5 arcmin. As such, most of the HI sources (which are galaxies) are spatially unresolved. The ALFALFA data therefore serve as a local Universe analogue of the sort of data MeerKAT will produce for high redshifts. The ALFALFA data are publicly available. The student will develop his/her own Python code to model the shapes of all ALFALFA HI spectra and then interpret the models in the context of the known effects of warped HI disc geometries on the shapes of HI spectra. Using this approach to search for signs of warped HI discs in the spectra of ALFALFA galaxies will allow, for the first time, for the ubiquity and properties of HI warps in galaxies to be studied over a huge range of galaxy environments in the local Universe. Again, this is something that has not been done before.

If successful methods of identifying the presence of warps in galaxy discs can be properly demonstrated for the ALFALFA data, an attempt will be made to do the same for any available LADUMA data. However, the ALFALFA data will serve as the primary data set for the project. This is to ensure that the project is *not* be based solely on a new MeerKAT data set that may require extensive quality checking before being "science ready".

As mentioned above, the ALFALFA data are publicly availably - the student will therefore have no problem obtaining them. The process of using GIPSY to produce many 3-dimensional galaxy models is not computationally intensive - the student should be able to carry out the modelling on his/her personal computer (a moderately powerful laptop or desktop). Modelling all of the ALFALFA spectra might be computationally intensive. However, at UWC we have access to some powerful machines that can be used to carry out this component of the project. If the student requires any extra storage devices (i.e., hard drives), we will make them available.

Links of project to SARAO research priority areas

The proposed project is directly linked to the SKA priority area of "science topics that involve the exploitation of MeerKAT data projected to be available by 2018-2019". This is because the ALFALFA HI spectra of local Universe galaxies will be - in terms of their typical structure and characteristics - the same as the HI spectra generated from MeerKAT observations of much higher redshift galaxies. All of the methods generated and applied to the ALFALFA data sets will be directly applicable to MeerKAT data. If MeerKAT data become available to the student during the project, he/she will be strongly encouraged to make an attempt at analysing the data in order to search for the presence of warped galaxy discs. If such a task proves to be beyond the scope of the M.Sc. (mainly due to time constraints), it may be naturally extended to a PhD.

LADUMA will be the MeerKAT survey that directly probes the HI content of galaxies out to z ~ 0.5. The very large majority of LADUMA-detected galaxies will yield only HI spectra. Using the knowledge gained from the proposed project to glean further insights into the more detailed properties of galaxies from their HI spectra will surely greatly boost the scientific impact of LADUMA data. The same will surely be true for data froM MIGHTEE, although MIGHTEE will not probe high redshifts. However, the MIGHTEE data will be highly complementary in the sense that they will probe a large range of galaxy environments.

Qualifications, academic abilities, skills/experience required by the student

In order to successfully manage the various above-mentioned components of the project, the student will need to have some experience working with real data. Most important will be a good computational/programming skill set. The student will be expected to write all of their own Python code to handle the various components of the project. The project lends itself to the implementation of various machine learning methods. Any such experience a student may have will surely be beneficial. Most importantly, the student should be self-motivated and prepared to work diligently, thoroughly, and enthusiastically.

Primary supervisor: Dr. E. Elson

10 July 2018, Cape Town.