The MIGHTEE-HI HI Mass and Velocity Functions

PhD Project, 2022-2024

February 24, 2021

Overview

- **Project Title**
  The HI Mass and Velocity Functions for MIGHTEE-HI.
- **Broad Area of Research**
  Science.
- **Academic Level of Research Project**
  Doctoral.
- **Supervisor Details**
  - *Primary Supervisor*
    Prof Russ Taylor
    SKA Chair, UCT/UWC.
    PI of the MIGHTEE Survey.
  - *Research Supervisor*
    Dr. Bradley Frank
    Associate Director for Astronomy Computing (IDIA), SARAO/IDIA/UCT.
    Co-Chair of the MIGHTEE-HI Working Group.

Abstract

The HIMF and VF are highly complementary views of galaxy evolution. The HIMF provides a measure of the neutral hydrogen density in the nearby universe, which is an important way to constrain cosmological and galaxy formation models. The VF is a probe of the distribution of dark matter subhaloes and places a similar constraint on the cosmological models. This project focuses on measuring both the HIMF and the VF using detections

from MIGHTEE-HI – the emission line component of the MIGHTEE MeerKAT International GigaHertz Tiered Extragalactic Exploration survey.

Project Details

This project focuses on measuring the HI mass (HIMF) and velocity functions (VF) using observations from the MIGHTEE survey. MIGHTEE-HI is the HI emission project of the MeerKAT International GigaHertz Tiered Extragalactic Exploration survey (MIGHTEE; Jarvis et al. (2017); Maddox et al. (2020)) Survey. As such, this project has a very strong alignment with the "Science" focus area for postgraduate research, i.e., aims to use data from a MeerKAT Large Survey Project (LSP) to study two interesting and complementary probes of galaxy evolution.

MIGHTEE-HI will achieve excellent sensitivity ($100\,\mu\mathrm{Jy\,beam^{-1}}$ at $5.5\,\mathrm{km\,s^{-1}}$ resolution) for spectral line studies. The full survey will thus be sensitive to galaxies with a HI mass of $\mathrm{M_{HI}} \sim 10^8\,\mathrm{M_\odot}$ for galaxies closer than $z \sim 0.08$ and $\mathrm{M_{HI}} > 5 \times 10^9\,\mathrm{M_\odot}$ at $z > 0.2$. We thus expect to detect ~ 1750 galaxies in the complete survey volume, at a range of redshifts and HI masses, over the main survey area of $20\,\mathrm{sq.\,deg}$. The science goals of MIGHTEE-HI include (and aren't limited to) the measurement of the HIMF , the study of kinematics of spatially resolved HI in nearby galaxies, the Tully-Fisher relation, scaling relations and HI in galaxy evolution simulations.

The HIMF and VF are highly complementary views of galaxy evolution. The HIMF provides a measure of the neutral hydrogen density in the nearby universe, which is an important measurement to constrain cosmological and galaxy formation models. The VF is a probe of the distribution of dark matter subhaloes and places a similar constraint on the cosmological models. Both measurements utilise a very similar toolbox, i.e., they involve the construction of a probability density (per co-moving volume) of galaxies as a function of HI mass, line-width and, potentially, the rotational velocity.

There are several methods that are used to construct these functions – for example, the $1/V_{\mathrm{eff}}$ (Papastergis et al., 2011) and the stepwise maximum likelihood techniques (Zwaan et al., 2003) can be used to compute the number density of detections for the HIMF and the VF. Therefore, combining the measurement of HIMF and the VF in one project will ultimately produce consistent measurements within a consistent framework.

Current Progress and the MIGHTEE-HI WG

During 2019/2020, MIGHTEE-HI has used MeerKAT 4k observations to do early science. There are several science results that will be published on the basis of this, which includes the measurement of the detected VF using the early science data. This work was done by Wanga Mulaudzi, an MSc student at UCT under the supervision of Dr. Frank. Wanga has successfully computed the early science VF, using a novel statistical technique to estimate

the velocity width from low spectral resolution data. Wanga is close to completing her dissertation, and will publish the results by the middle of 2021.

In addition, the MIGHTEE-HI working group (WG) has a robust workflow to do source finding and the measurement of HI masses. Our HI masses have been compared successfully with single dish surveys (ALFALFA and HIPASS) and interferometric data (CHILES). The MIGHTEE-HI WG has a variety of tools at their disposal, which includes Jupyter Notebooks, recipes and scripts and the relevant in-group expertise to provide technical/scientific assistance where necessary. The research advisor of this project (Dr. Frank) has developed and prototyped many of these tools, and will thus be able to provide direct supervision/assistance to the student.

As such, the student will inherit a mature set of tools and techniques that will allow rapid progress for their analysis. The student will benefit from joining an international and diverse group of young and established researchers. MIGHTEE-HI and MIGHTEE have made significant survey and science progress since the start of early science projects, and the student will thus benefit enormously by joining a productive survey team.

Feasibility & Rough Timelines

The project involves contributing to source finding, extracting spectra/moment-zero maps and calculating HI masses and line-widths using the MIGHTEE full resolution data.

In terms of data, full resolution observations for MIGHTEE have already started (end of 2020). The MIGHTEE-WG aims to focus on high spectral line imaging during March/April 2021, with the aim of producing science quality cubes by May/June 2021. The tools required to analyse the image data products already exist and have been revised by the senior members of the team.

The analysis of MIGHTEE-HI data is done on IDIA[1]. The primary supervisor is the Director of IDIA, and the research supervisor is the Associate Director for Astronomy Computing. Therefore, the student will receive excellent access to computing resources and the best supervision possible for the technical analysis of MIGHTEE data products.

Most of the analysis for the previously mentioned early science VF measurement was completed within a year (2020). Therefore, it is reasonable to expect that the full analysis necessary for the HIMF and the VF will be done within the first 2-years of study, including the necessary literature review – since most of the tools will be available for the student immediately upon starting the project. This allows the student to complete any final analysis required to compare the results with previous results, and to compare this with the relevant cosmological simulations.

The aim is to submit either two papers, or a single combined paper, in the 3rd year of study – coinciding with the completion and submission of the student's PhD dissertation for examination.

[1] https://idia.ac.za

Skills Required

The ideal candidate would have the following attributes:

- Masters in Physics/Astronomy.
- Above-average skills with scientific computing.
- Experience with Linux, Python and Jupyter.
- Experience with statistical techniques or mathematical modelling.

References

M. J. Jarvis, A. R. Taylor, I. Agudo, J. R. Allison, R. P. Deane, B. Frank, N. Gupta, I. Heywood, N. Maddox, K. McAlpine, M. G. Santos, A. M. M. Scaife, M. Vaccari, J. T. L. Zwart, E. Adams, D. J. Bacon, A. J. Baker, B. A. Bassett, P. N. Best, R. Beswick, S. Blyth, M. L. Brown, M. Bruggen, M. Cluver, S. Colafranceso, G. Cotter, C. Cress, R. Davé, C. Ferrari, M. J. Hardcastle, C. Hale, I. Harrison, P. W. Hatfield, H. R. Klockner, S. Kolwa, E. Malefahlo, T. Marubini, T. Mauch, K. Moodley, R. Morganti, R. Norris, J. A. Peters, I. Prandoni, M. Prescott, S. Oliver, N. Oozeer, H. J. A. Rottgering, N. Seymour, C. Simpson, O. Smirnov, D. J. B. Smith, K. Spekkens, J. Stil, C. Tasse, K. van der Heyden, I. H. Whittam, and W. L. WIlliams. The MeerKAT International GHz Tiered Extragalactic Exploration (MIGHTEE) Survey. *arXiv.org*, Sept. 2017.

N. Maddox, B. S. Frank, A. A. Ponomareva, M. J. Jarvis, E. A. K. Adams, R. Davé, T. A. Oosterloo, M. G. Santos, S. L. Blyth, M. Glowacki, R. C. Kraan-Korteweg, W. Mulaudzi, B. Namumba, I. Prandoni, S. H. A. Rajohnson, K. Spekkens, N. J. Adams, R. A. A. Bowler, J. D. Collier, I. Heywood, S. Sekhar, and A. R. Taylor. MIGHTEE-HI: The HI emission project of the MeerKAT MIGHTEE survey. *arXiv.org*, Nov. 2020.

E. Papastergis, A. M. Martin, R. Giovanelli, and M. P. Haynes. The Velocity Width Function of Galaxies from the 40Shedding Light on the Cold Dark Matter Overabundance Problem. *The Astrophysical Journal*, 739(1):38, Sept. 2011.

M. A. Zwaan, L. Staveley-Smith, B. S. Koribalski, P. A. Henning, V. A. Kilborn, S. D. Ryder, D. G. Barnes, R. Bhathal, P. J. Boyce, W. J. G. de Blok, M. J. Disney, M. J. Drinkwater, R. D. Ekers, K. C. Freeman, B. K. Gibson, A. J. Green, R. F. Haynes, H. Jerjen, S. Juraszek, M. J. Kesteven, P. M. Knezek, R. C. Kraan-Korteweg, S. Mader, M. Marquarding, M. Meyer, R. F. Minchin, J. R. Mould, J. O'Brien, T. Oosterloo, R. M. Price, M. E. Putman, E. Ryan-Weber, E. M. Sadler, A. Schroeder, I. M. Stewart, F. Stootman, B. Warren, M. Waugh, R. L. Webster, and A. E. Wright. The 1000 Brightest HIPASS Galaxies: HI Mass Function and Omega$_H I$. *arXiv.org*, $(6) : 2842 - -2858, Feb.2003$.