PhD research proposal

# Statistical study of HI gas reservoirs of galaxies and environmental effects with WALLABY

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Supervisors: A/Prof. Barbara Catinella and Dr. Tobias Westmeier

## Abstract

Neutral atomic hydrogen plays an important role in galaxy evolution as a major component of cold gas reservoirs of galaxies that fuel star formation and is an excellent tracer of environmental effects. Global cold gas scaling relations have provided valuable insights into how the cold gas content depends on galactic properties as well as the environment. Nonetheless, the problem is that most HI data are spatially unresolved and global cold gas relations are mixing components observed at different spatial scales (i.e., the HI disk typically extends well beyond the stellar disc, where star formation takes place). Therefore the lack of spatial information for large samples of galaxies has limited our understanding of the underlying physics of how cold gas and star formation in galaxies are regulated. The ongoing Widefield ASKAP L-band Legacy All-sky Blind Survey (WALLABY) will be a breakthrough by providing a statistical number of spatially resolved HI data. In this thesis, we will use HI data from WALLABY to improve cold gas scaling relations and study environmental effects on galaxy evolution. As most WALLABY HI detections are marginally resolved, we will focus on measuring the HI content within the stellar disc to improve upon global cold gas scaling relations. We will study the environmental dependence of the ratio of HI content within/outside the stellar disc of cluster and group galaxies. Lastly, with more WALLABY data becoming available we will be able to further extend our study to investigate the effects of cosmic filaments on HI properties, and determine whether observed trends claimed in the literature (based on global HI data) are driven by the filaments or by the groups/clusters therein.

# 1 Research project

## 1.1 Background

### 1.1.1 Observations of neutral atomic hydrogen

Neutral atomic hydrogen (HI) plays an important role in galaxy evolution as a key component of the cold interstellar medium. HI is not only the most common element in the universe but also the dominant phase in cold gas reservoirs that fuel star formation in galaxies. In addition, its extended disc makes it a sensitive indicator of environmental effects on galaxies.

There have been many surveys to detect extragalactic HI emission to understand galaxy evolution. There are two main types: HI blind surveys and HI targeted surveys. The HI blind surveys are often conducted by single-dish telescopes. Their key strengths are a wide field of view and high sensitivity, which allows them to detect faint emission, and therefore be a useful tool to do all-sky surveys. There are two major extragalactic HI blind surveys; HIPASS and ALFALFA. The HI Parkes All-Sky Survey (HIPASS; Staveley-Smith et al., 1996; Barnes et al., 2001) was the all-sky survey conducted using the Parkes Radio Telescope in Australia. It provided a catalog of more than 5000 extragalactic HI sources in the southern sky. The Arecibo Legacy Fast ALFA Survey (ALFALFA; Giovanelli et al., 2005) was a HI survey conducted in the northern hemisphere, providing a comprehensive catalog of more than 30,000 extragalactic HI sources. These HI blind surveys have been a powerful way to study large-scale structures in the local universe and the properties of the HI gas in various environments, but their lack of spatial resolution, i.e., beam size of $15.5'$ and $3.'5$, respectively, prevents resolving structures within galaxies.

Interferometers, which are composed of multiple antennas working together as an array, provide significantly higher spatial resolution than single-dish telescopes. There have been many HI-targeted surveys using interferometers to observe detailed structures of galaxies. For example, the Very Large Array HI Imaging of the Virgo Cluster (VIVA; Chung et al., 2009) observed 53 late-type gas-rich galaxies in the Virgo cluster using the Very Large Array (VLA) radio telescope. Their $\sim$1kpc-scale spatially resolved HI images showed vivid gas-stripping features of galaxies in the cluster environment. The HI Nearby Galaxy Survey (THINGS; Walter et al., 2008) was a targeted survey using VLA to observe 34 nearby spiral galaxies to study the detailed properties of HI gas and their kinematics. However, it is important to note that they also have their own limitations, such as a narrow field of view, long observation times, and complexity in data processing and calibration.

The development of state-of-art new radio telescopes such as the Australian Square Kilometre Array Pathfinder (ASKAP; Hotan et al., 2021) is expected to be a breakthrough by combining the relatively large field of view of 30 $deg^2$ and spatial resolution of 30 arcsec. There are two extragalactic HI emission line surveys of ASKAP: WALLABY and DINGO. The Widefield ASKAP L-band Legacy All-sky Blind Survey (WALLABY; Koribalski et al., 2020) is a wide-field all-sky blind survey that is expected to detect $\sim$210,000 HI sources in the southern sky within z=0.1 with a spatial resolution of $30''$. While WALLABY observes wide fields in the local universe, Deep Investigation of Neutral Gas Origins (DINGO; Meyer, 2009) conducts a deeper HI survey - redshift out to 0.4 - focusing on smaller regions. These big HI surveys are expected to provide valuable HI data to study galaxy evolution over a wider range of redshifts.

### 1.1.2 Cold gas scaling relations

The interplay between a galaxy's cold gas content and its star formation is well known as the so-called gas-star formation cycle (see Figure 1). In the gas-star formation cycle, the collapse of cold atomic gas clouds leads to the formation of denser regions known as molecular clouds that provide the environment for stars to form. Within molecular clouds, stars can be formed in regions of high density and pressure. Throughout their lifetimes, stars can release gas and other particles into their surroundings through processes like stellar winds and supernova explosions. The ejected gas cools down and mixes with the surrounding interstellar medium. This cooled gas can then re-enter the cycle, becoming part of new gas clouds and fueling future generations of stars. The cycle's efficiency depends on various factors, including the availability of gas, the rate of star formation, and external processes like environmental effects. A balance between gas inflow, star formation, and gas ejection determines the overall evolution of a galaxy. When this balance is maintained, the gas-star formation cycle continues, contributing to the growth and evolution of galaxies over time. The gas-star formation cycle is a fundamental process that shapes the galaxy properties.

The cold gas scaling relations are the relations between cold gas content and other galaxy properties such as stellar mass, stellar surface density, colour, and star formation rate (e.g. Catinella et al., 2010; Saintonge et al., 2011; Janowiecki et al., 2020; Saintonge et al., 2017). Many of these studies have been carried out using global cold gas properties such as total gas mass and total gas-to-stellar mass ratio (the so-called total gas fraction) using HI as a primary component of cold gas. The eXtended GALEX Arecibo SDSS Survey (xGASS; Catinella et al., 2018) is a stellar-mass selected HI survey of $\sim$1200 galaxies in the local Universe that combined HI observations from the Arecibo radio telescope with the Sloan Digital Sky Survey (SDSS; York et al., 2000) and Galaxy Evolution Explorer (GALEX; Martin et al., 2005) ultraviolet data. In

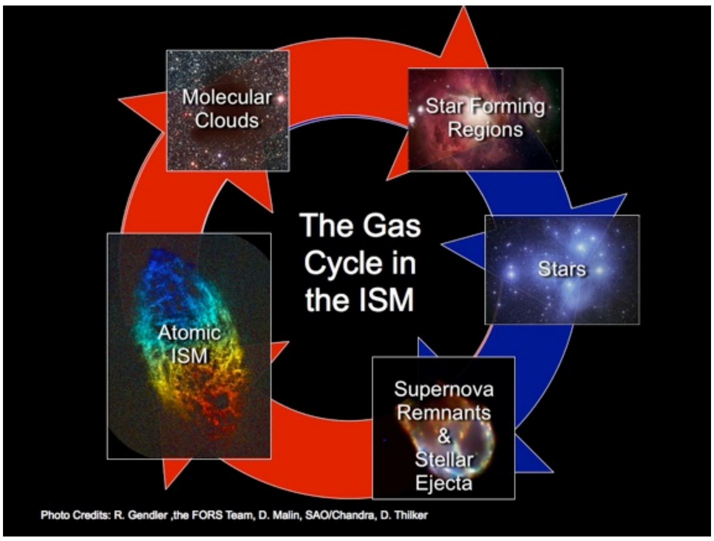



Figure 1: Gas-star formation cycle (credit: R. Gendler, the FORS Team, D. Malin, SAO/Chandra. D. Thilker).

particular, Arecibo observations provided global HI masses for the detections and upper limits for non-detections. Figure 2 presents one of their main results. They found anti-correlation between gas fraction and stellar mass-related quantities such as stellar mass and stellar surface density. Physically, it can be interpreted that massive galaxies tend to have lower gas fractions, which are likely to be early-type and bulge-dominated galaxies, but caution is needed since the same quantity - stellar mass - is used in both axes. On the other hand, the correlation between gas fraction and star formation-related quantities such as specific star formation rate and NUV-r are more significant, which indicates that active star-forming galaxies tend to have a higher gas fraction. The correlation is even stronger for the latter since the quantity is more related to the star formation in the outer disc (Bigiel et al., 2010a; Bigiel et al., 2010b). The slope changes when log sSFR[$yr^{-1}$] $\sim -11$ and NUV-r $\sim$ 4 mag, but this change could be attributed to the lack of enough samples at the low star-forming ends. These results of global cold gas scaling relations give us insights into how galaxies manage their gas content.

The environment in which galaxies are living is a secondary yet important factor influencing their properties. There are several studies that attempted to study environmental effects on global cold gas scaling relations (e.g., see review by Cortese et al., 2021, and references therein). Interestingly, they found similar trends in satellite galaxies in clusters and groups, such as anti-correlation between gas fraction and stellar mass, which underscores the importance of internal processes. The distinct difference is that galaxies residing in more massive halos systematically show lower cold gas fractions. This phenomenon is a result of gas removal processes in high-density regions such as ram pressure stripping (Gunn and Gott, 1972), which will be further discussed in Section. 1.1.3. However, the problem is that this global gas fraction is from the

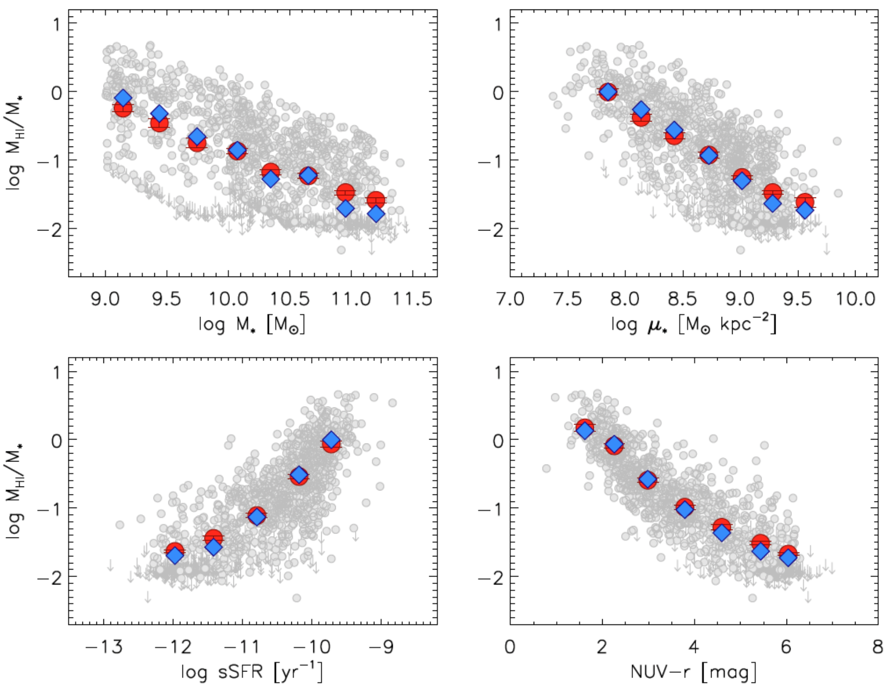



Figure 2: Global cold gas scaling relations of xGASS galaxies (Catinella et al., 2018), which show the HI mass fraction as a function of stellar mass (left-top), stellar surface density (right-top), specific star formation rate (left-bottom), and NUV-r colour (right-bottom). Large red circles and blue diamonds denote the weighted averages and weighted medians of the logarithms of gas fractions, respectively. Small grey circles are from individual HI detections, and downward arrows are from non-detections.

spatially unresolved HI data. Since the typical HI disc in galaxies is more radially extended compared to the stellar disc, the global gas scaling relations are actually comparing quantities obtained from different regions within the galaxy. Indeed, star formation happens mostly in the stellar disc, and star formation is expected to be much less efficient in the outer parts of the extended HI disc. Additionally, galaxies in high-density regions might have an HI disc which is disturbed and truncated even within stellar disc, but these global properties fail to account for that effect. Therefore, we need resolved HI data for a more detailed understanding of the underlying physics.

Unlike global scaling relations, spatially resolved scaling relations provide a deeper understanding of the internal processes within galaxies by examining properties on smaller spatial scales. A classical example is the correlation between the surface density of cold gas and the surface density of star formation rate of galaxies known as the Kennicutt-Schmidt law (Schmidt, 1959; Kennicutt, 1989). Targeted surveys such as THINGS and VIVA mapped the HI gas, which enables conducting spatially resolved scaling relations, but only for small samples of very nearby galaxies (e.g. Ellison et al., 2021; Abdurro'uf et al., 2022; Baker et al., 2022; Watts et al., 2023). As an intermediate step of spatially resolved cold gas scaling relations, Wang et al. (2020) suggested a method that estimates the HI mass within the stellar disc from global HI data. It involves creating an HI surface density profile model, using the HI size-mass relationship and the median HI profile derived from spatially resolved HI data. By applying this technique to a subset of 447 late-type galaxies from xGASS, they found similar correlations between gas fraction and other galaxy properties but with a different slope and reduced scatter. However, their results were drawn from estimated quantities from unresolved xGASS data and the viability of their approach could be confirmed with resolved HI data from WALLABY.

### 1.1.3 Environmental effects on galaxy evolution

In our current understanding of cosmology, the universe is not fully homogeneous but rather has web-like structures that provide unique environments in which galaxies are born and grow. The structures within the cosmic web are often classified into nodes, filaments, and voids based on the local density, although the local density is not a perfect way to categorise large-scale structures (Libeskind et al., 2018). Galaxies acquire gas from the surrounding cosmic web, which plays a crucial role in fueling star formation and sustaining galaxy growth.

For decades, studies of environmental effects have largely focused on high-density regions such as cluster and group environments. Over the past decades, studies have found decreased cold gas content based on single-dish HI surveys (e.g. Giovanelli and Haynes, 1985; Solanes et al., 2001), and related to that, decreased star formation rate in cluster galaxies (e.g. Lewis et al., 2002; Gómez et al., 2003; Boselli and Gavazzi, 2006). In recent years, spatially resolved HI observations using interferometers have revealed more striking features like shrunken HI discs even within the stellar disc, disturbed and asymmetric HI discs, and extended HI tails beyond the gas disc (e.g. Cayatte et al., 1990; Kenney et al., 2004; Chung et al., 2007). Many processes are proposed to account for these distinctive features shown in cluster galaxies such as ram pressure stripping (Gunn and Gott, 1972), which is a gas removal process affecting infalling galaxies due to the pressure exerted by the hot intracluster medium on the cold gas disc, tidal forces (Bekki, 1999; Mihos, 2004), and the high-speed motions within the cluster (Moore et al., 1996). Although similar processes seem to be working in group environments, gravitational interactions are likely to be more effective in groups than clusters because of the lower relative velocities between their member galaxies and the lower intergalactic medium densities, and how effectively gas can be affected in lower-density environments is still not clear (Cortese et al., 2021, and references therein). Furthermore, there is an increasing number of reports that galaxies may undergo environmental effects even before falling into the high-density regions (e.g. Fujita, 2004). There is still much left to uncover beyond what we know about large systems.

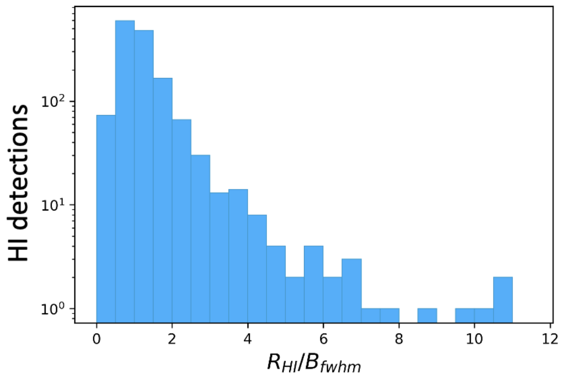
The influence of large-scale filaments on galaxy evolution is even more poorly understood. Filaments serve as pathways along which gas flow, connecting galaxies and galaxy clusters/groups, and voids. The inflow of intergalactic gas through filaments brings in new cold gas, which can replenish the gas reservoirs within galaxies and spin up gas content within galaxies (Peebles, 1969). This process is expected to be imprinted in their gas properties such as gas contents and angular momentum, and star formation activities. Simulations have provided supporting evidence for gas accretion through the cosmic web and its role in shaping galaxy properties (e.g. Codis et al., 2012; Dubois et al., 2014). However, despite these theoretical expectations and simulations, there are only a few observational studies available (Kleiner et al., 2017; Crone Odekon et al., 2018; Blue Bird et al., 2020), and their findings are somewhat controversial. For instance, Crone Odekon et al. (2018) reported a decrease in HI content near the spine of filaments based on data from the ALFALFA survey, while Kleiner et al. (2017) found opposing trends for massive galaxies using the HIPASS survey. These conflicting results could be from the limited resolution of single-dish data or a small number of resolved HI data. Thus the understanding of how gas properties are affected by the larger-scale environment remains unknown territory. To shed more light on this matter, a comprehensive spatially resolved HI data spanning diverse environments would be invaluable. It would enable us to quantitatively measure the impact of environmental processes and gain deeper insights into how different mechanisms influence the gas content of galaxies as a function of local densities.

## 1.2 WALLABY

We use the Wide-field ASKAP L-band Legacy All-sky Blind Survey (WALLABY; Koribalski et al., 2020) to conduct three projects described in section 2. WALLABY aims to map the distribution and properties of HI in galaxies across a significant portion of the southern sky. The survey is conducted using the Australian Square Kilometre Array Pathfinder (ASKAP; Hotan et al., 2021) which is a radio interferometer located in Western Australia. WALLABY is one of its key survey projects. It is expected to detect HI in ∼210,000 galaxies from $\sim 1.4\pi$ sr of the sky out to redshift z ∼ 0.1. It has a spatial and spectral resolution of $30''$ and 4 km $s^{-1}$, respectively, and its sensitivity corresponds to 1.6 mJy per beam and spectral channel. Its unprecedentedly large number of (marginally) spatially resolved HI data will allow us to improve studies that have been done with global HI properties and do statistical studies of environmental effects identifying HI-rich galaxies in different environments.

WALLABY conducted two pilot surveys before the full survey to test their observing strategy and construct data reduction pipelines and source-finding algorithms in interesting science fields (Westmeier et al., 2022; Deg et al., 2022). Currently, they released catalogs and data products publically or via internal team releases. The first pilot survey targeted the Hydra cluster, NGC 4636 group, and Norma cluster fields, and the second pilot survey targeted NGC

4808, NGC 5044, and Vela fields. Their products include a source catalog in each available field including kinematic information, each source's data cube and corresponding mask cube, and moment maps. Figure 3 shows the distribution of HI and optical radius relative to the full-width half maximum of the WALLABY beam ($B_{\rm fwhm} \sim 30''$) of 1531 HI detections in part of the WALLABY pilot survey fields (Hydra cluster, NGC 4636, NGC 4808, and NGC 5044). The HI and optical radii used in this proposal are based on preliminary results from T. Reynolds. The optical radii are measured from the Panoramic Survey Telescope and Rapid Response System (PanSTARRS; Chambers et al., 2016) images following the method described in Reynolds et al. (2023). For the purposes of our study, however, all relevant quantities will be re-measured by our team. As we conduct our study using WALLABY galaxies, we need to be mindful that a substantial number of WALLABY galaxies have HI and optical radii smaller than three and two beams, respectively, indicating that they are marginally resolved.



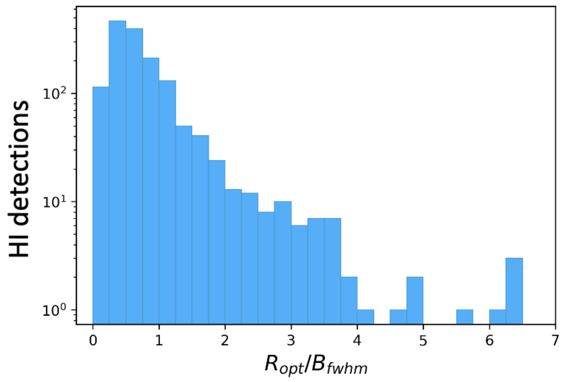




Figure 3: The number of WALLABY HI detections as a function of HI radius (left) and optical radius (right) normalized by the full-width half maximum of the WALLABY beam, where $R_{\rm HI}$ is the radius where $\Sigma_{\rm HI} = 1 M_\odot$ pc$^{-2}$,$R_{\rm opt}$ is the radius where $\Sigma_{\rm r-band} = 25$ mag arcsec$^{-2}$, and $B_{\rm fwhm} \sim 30''$.

## 2 Aims

Due to the lack of a large number of spatially resolved HI data, studies so far have been focused on studying global HI properties or well-resolved HI properties of nearby late-type galaxies. With WALLABY, we will study the regime of intermediate spatial resolution for large samples of galaxies.

Our goal is to use WALLABY data for statistical analysis of HI properties in galaxies and their dependence on the environment. We will study the effects of both internal and external processes on gas and galaxy properties. Our main focus will be on cold gas scaling relations using HI within the stellar disc by comparing the HI content to other galaxy properties and seeing how these correlations vary in group/cluster environments. Finally, as additional WALLABY data becomes accessible, we will expand our investigation to the impact of cosmic filaments on HI properties. The main projects of my PhD research are as follows:

1. We will study how the HI content within the stellar disc relates to galaxy properties by investigating cold gas scaling relations within the stellar disc using WALLABY data. This

project is inspired by the method suggested in Wang et al. (2020) to estimate HI mass within the stellar disc of spatially unresolved HI. We will validate this approach using WALLABY data, and extend it to a larger galaxy sample.

2. We will study whether the ratio of HI mass within the stellar disc to HI mass outside the stellar disc gives different outcomes for galaxies in cluster and/or group environments compared to those in the field. To classify the environments of WALLABY HI detections, we plan to use established cluster and group catalogs (e.g. Tully, 2015).

3. We will extend our analysis of environments to larger scales such as filaments. We plan to investigate the impact of large-scale environments by investigating whether HI properties such as HI content depend on the distance of the galaxy from the nearest filament spine. This involves the qualified classification of large-scale structures - especially groups and filaments. We plan to first classify galaxies using optical and spectroscopic data and then study the effects of large-scale environments on WALLABY HI detections.

The findings from my PhD research will offer valuable insights into how gas properties relate to galaxy properties and galaxies' environments.

# 3 Current status

## 3.1 Understanding WALLABY catalog and data

As a first step, I familiarised myself with the WALLABY catalogs and datacubes. I calculated moment maps from the cube. Moment 0, 1, and 2 map corresponds to intensity, intensity-weighted velocity, and intensity-weighted velocity dispersion, respectively. I extracted HI surface density profiles from the intensity maps through a series of steps and I used PYTHON packages for some steps as follows:

1. Define centre, position angle, and inclination angle ($i$)
   (a) Create 2-dimensional Gaussian
      - astropy.modelling.models.Gaussian2D
   (b) Fit the Gaussian using the Levenberg-Marquardt algorithm
      - astropy.modelling.fitting.LevMarLSQFitter
2. Fit ellipses using the parameters obtained from 1
   (a) Define ellipses
      - photutils.aperture.EllipticalAnnulus
   (b) Extract average flux within elliptical annulii
      - photutils.aperture.aperture_photometry

3. Convert the extracted flux densities to surface densities

$$\frac{\Sigma_{\rm HI}}{\rm M_{\odot}pc^{-2}} = (8.01\times10^{-21})(2.33\times10^{20})(1+z)^4\left(\frac{F}{\rm JyHz}\right)\left(\frac{ab}{\rm arcsec^2}\right)^{-1}$$

4. Correct the surface density profile for inclination

$$\Sigma_{\rm HI,corr} = \Sigma_{\rm HI}\cos i$$

I also inspected the HI maps and optical data (from the PanSTARRS survey) of WALLABY HI detections in one of the pilot fields to be able to flag cases where there is no optical counterpart or there are multiple optical counterparts, or there are issues on the HI data (e.g., source shredding).

## 3.2 Sample selection

As mentioned in Section 1.2, most WALLABY galaxies are marginally resolved having HI and optical radii smaller than three beams. When the beam is small enough compared to the galaxy size and the galaxy is well resolved, we can gain a reliable HI surface density profile. The HI mass within the stellar disc can then be estimated by integrating the mass enclosed within the optical radius. However, in cases where the galaxy is not well resolved, i.e., blurred and spread HI image, we get flattened HI surface density profiles. Consequently, the estimated HI mass obtained with a large beam size must be different from that obtained with a small beam size.

**Beam smearing effects on HI mass within stellar disc**

We checked the impact of beam smearing on the HI mass within the stellar disc by making a model. First, we created a two-dimensional HI image by using the median HI profile obtained from resolved HI data (Wang et al., 2020) (see Figure 4 black line). Second, we convolved this image with a Gaussian function of the beam. Increasing the beam size makes the convolved image more spread-out and broadened. Third, we extracted the HI surface density profile from each of those convolved images. Figure 4 presents the median HI profiles and their beam-convolved profiles. With increasing beam size, the convolved profiles show a more flattened shape.

Figure 5 shows how well HI mass within the stellar disc can be measured ($M_{\rm HI,c}/M_{\rm HI}(R<R_{\rm opt})$) at the given optical radius and the beam size normalized by the HI radius obtained from the beam-convolved profile ($R_{\rm opt}/R_{\rm HI,c}$ and $B_{\rm fwhm}/R_{\rm HI,c}$, respectively). When the beam is small, the mass can be well estimated regardless of the size of the stellar disc. However, when the beam is large, the mass is underestimated, until the optical radius is large enough to cover the large beam. The distribution of WALLABY galaxies is overlaid on the figure. The galaxies span a wide range in this space. A majority of WALLABY galaxies are located in the region where $R_{\rm opt}/R_{\rm HI,c}<1$, which indicates that their HI disc is larger than the stellar disc. Galaxies falling in the region of $R_{\rm opt}/R_{\rm HI,c}>1$ may have small HI disc because of environmental effects. It is important to note that it may be dangerous to blindly select samples or correct their mass using a certain value of $M_{\rm HI,c}/M_{\rm HI}(R<R_{\rm opt})$ since this result in Figure 5 is based on a simple model.

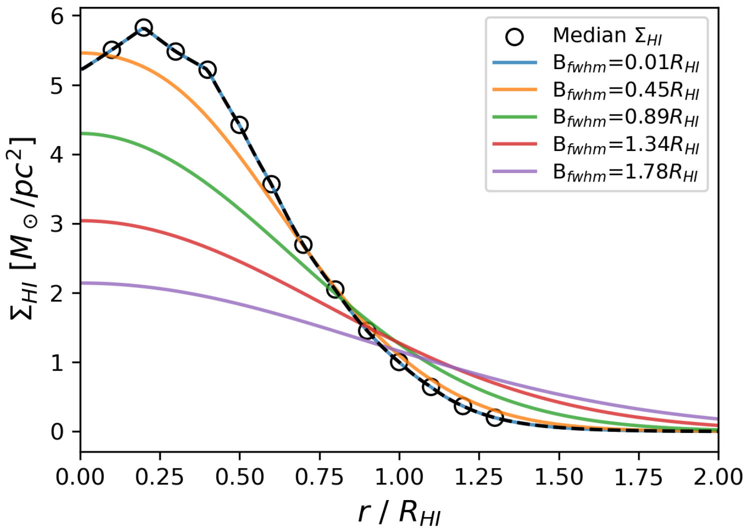



Figure 4: Median HI profile (black line and dots; Wang et al., 2020) and HI surface density profiles extracted from each beam-convolved image.

Figure 6, which essentially presents the same result as Figure 5 but in a different parameter space, provides a better insight for sample selection. What it describes is similar to Figure 5. Mass measurement is well achieved for any optical radius when the beam is small, but the mass is underestimated in the case of a large beam until the optical size is large enough to cover the large beam. An optical radius relative to the beam size ($R_{\rm opt}/B_{\rm fwhm}$) of less than 0.5 indicates that the beam is larger than the stellar disc. In this range, measuring the HI mass within the stellar disc is not meaningful. We decided to exclude samples in this range. As a result, 583 galaxies were excluded, and 928 galaxies remained for further analysis. As this is sufficient to quantify gas scaling relations, this confirms the feasibility of the first project, and any additional sample selection will depend on the level of accuracy we intend to achieve in this project.

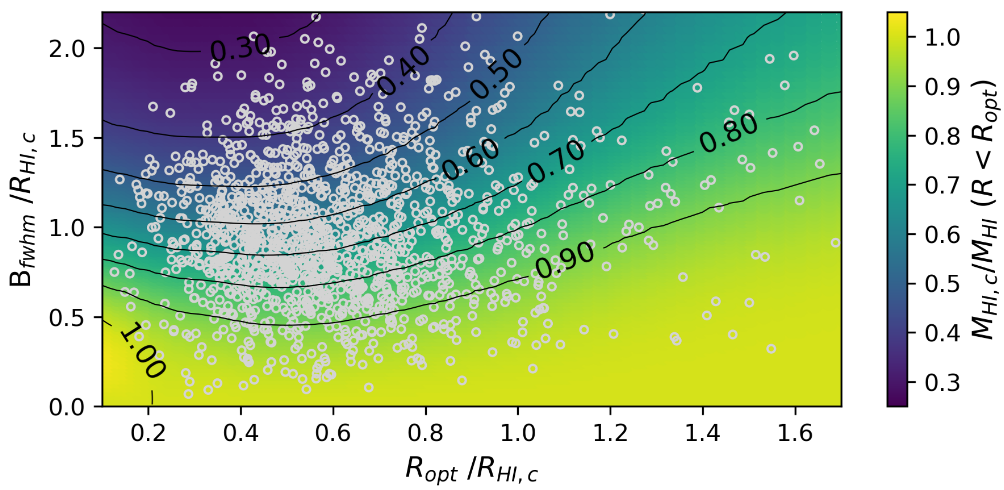



Figure 5: Ratio of HI mass within stellar disc from the beam-convolved profile to that from the median HI profile as a function of the optical radius relative to HI radius and the beam size relative to HI radius, where the HI radius is where the beam-convolved HI surface density is $1 M_\odot$ pc$^{-2}$. The light-grey circles mark the location of WALLABY galaxies in this parameter space.

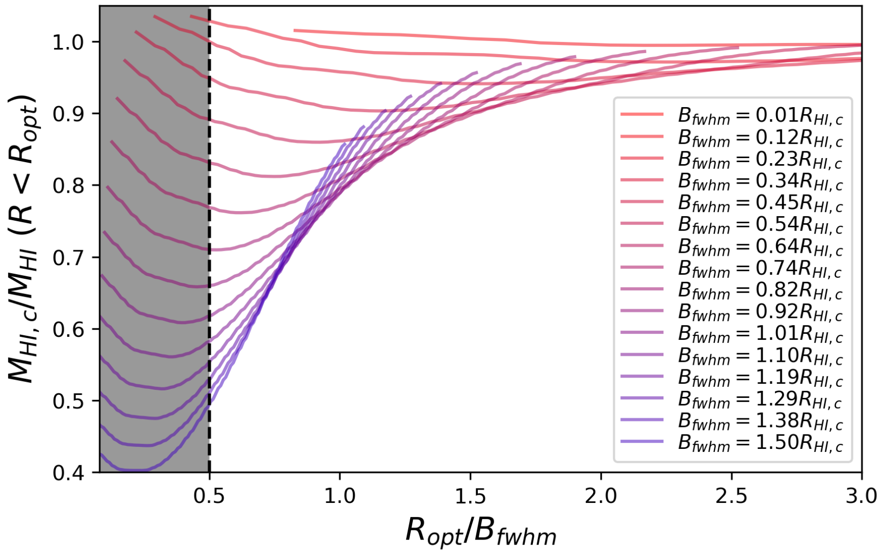



Figure 6: Ratio of HI mass within stellar disc from the beam-convolved profile to that from the median HI profile as a function of the optical radius relative to the beam. Each line is color-coded by the size of the beam. The shaded area ($R_{\rm opt}/B_{\rm fwhm}$ <0.5) marks the region where the size of the stellar disc is smaller than the beam.

# 4 Research project details & Training

## 4.1 Confidential/Sensitive information

This project does not involve the collection of confidential or sensitive information.

## 4.2 Intellectual property

This project will use WALLABY survey data. A/Prof Barbara Catinella is a co-principal investigator and Dr Tobias Westmeier is a project manager of WALLABY. The WALLABY full survey is ongoing and it started observation on May 2023. Two pilot survey data are already internally or publicly released, to which I have access.

## 4.3 Fieldwork information

This research will be conducted at ICRAR/UWA. If international/domestic travel is required, I will inform the GRS and follow the recommended guidelines.

## 4.4 Facilities

I have access to the facilities and equipment required for this research: a laptop computer is provided by UWA.

### 4.5 Skill audit

The skills required for this PhD project are listed in Table 1 with the corresponding current and desired proficiency levels.

| **Research Skill** | **Current Rating** | **Evidence** | **Desired Rating** | **Plan** |
|---|---|---|---|---|
| Identifying and accessing relevant literature | Competent | Masters thesis and one published research paper. | Proficient | I will read relevant papers on a regular basis and extend them to identify sources |
| Use of information technology skills relevant for research | Competent | Master's thesis required experience with PYTHON, and in the first 6 months of my PhD I have been using radio data. | Proficient | I will develop my coding skills of Python and learn how to use necessary research programs |
| Understanding and application of relevant data collection and analysis method | Competent | Master's thesis involved using radio data analysis. | Proficient | I will read relevant materials and consult with my supervisors to understand data and investigate proper analysis methods |
| Familiar with the principles and conventions of academic writing | Basic | Master's thesis, journal paper, and Scientific Writing unit undertaken at UWA | Proficient | I will read relevant papers, write constantly, and revise writing with feedback from my supervisors and coworkers |
| Ability to constructively defend research outcomes at seminars and conferences | Basic | Master's theses seminars and presentations, and recent poster presentation at ASTRO 3D and workshop. | Proficient | I will constantly learn and practice the ability by attending and presenting my research outcomes at seminars and conferences |

Table 1: Outline of skills required for this PhD project with the corresponding current and desired competence.

### 4.6 Research project communication

In August 2023, I presented an overview of my PhD plan to a scientific panel at ICRAR/UWA. They will provide feedback and comments about the project, and will assess the progress of my research on a yearly basis (in the late-February of 2024 - 2026). In addition, I present my progress more than once a month during weakly group meetings run by my principle supervisor. The results from my PhD will be published as journal papers, with each one focusing on each one of the following PhD projects:

- Paper 1: Studying cold gas scaling relations within stellar disc with WALLABY.

- Paper 2: Studying the ratio of HI mass within the stellar disc to HI mass outside the stellar disc in different environments with WALLABY.
- Paper 3: Studying the effect of cosmic filaments on HI properties with WALLABY.

### 4.7 Approvals

There are no required approvals for this PhD project.

### 4.8 Data management

The data required for this project will be mainly stored in the WALLABY database in which I have an account. Most of my data will be stored on the laptop computer provided to me by the University.

### 4.9 Research project and training plan

Figure 7 displays a Gantt chart indicating the planned research training plan and the research project plan. The latter specifies the estimated time for each chapter and thesis.

### 4.10 Confirmation of candidature

The tasks required to be completed for the Confirmation of Candidature are as follows:

- GRS Online Induction: completed on 10 Mar 2023.
- GRS Welcome: completed on 17 Mar 2023.
- Academic Conduct and Research Integrity (ACRI9000): completed on 10 Jun 2023.
- Research proposal: due 19 Aug 2023.
- Research proposal seminar: completed on 16 Aug 2023.
- Coursework to a total of 6 points: Scientific writing to complete in Aug 2023 (ICRAR/UWA requirement).
- Annual progress report: Due 20 Feb 2024.
- Annual progress seminar: To complete in February 2024.

Working hours: The working hours for this PhD are Monday to Friday 8:00 - 16:00.

## 5 Budget

The costs of this PhD will be covered by the GRS, the EMS faculty and ICRAR. I am part of the ASA and ASTRO 3D, which provide funds for international travel and travel assistance to attend Schools and conferences. Table 2 shows a detailed description of the projected expenses.

| Item description | Estimated cost | Funds available | Funding Source |
|---|---|---|---|
| Laptop computer | \$2095.58 | \$2095.58 | EMS |
| Additional IT supplies | \$379 | \$379 | ICRAR |
| Travel (domestic and international) | \$7500 | \$4500<br>\$1500 (subject to approval)<br>\$1500<br>(subject to approval) | GRS<br>ICRAR<br>ASA<br>ASTRO 3D |
| **Total** | \$9974.58 | \$9974.58 | - |

Table 2: Outline of the budget for this PhD.

# 6 Supervision

Principle and Coordinating Supervisor [60%]: A/Prof. Barbara Catinella.

Co-supervisor [40%]: Dr. Tobias Westmeier.

A/Prof Catinella, Dr Westmeier and I meet on a weekly basis. A/Prof Catinella provides guidance in the studying of gas properties and environmental effects on galaxy evolution and is the co-principal investigator of WALLABY. Dr. Westmeier is the project manager of WALLABY and is an expert in HI science including galaxy evolution in different environments.

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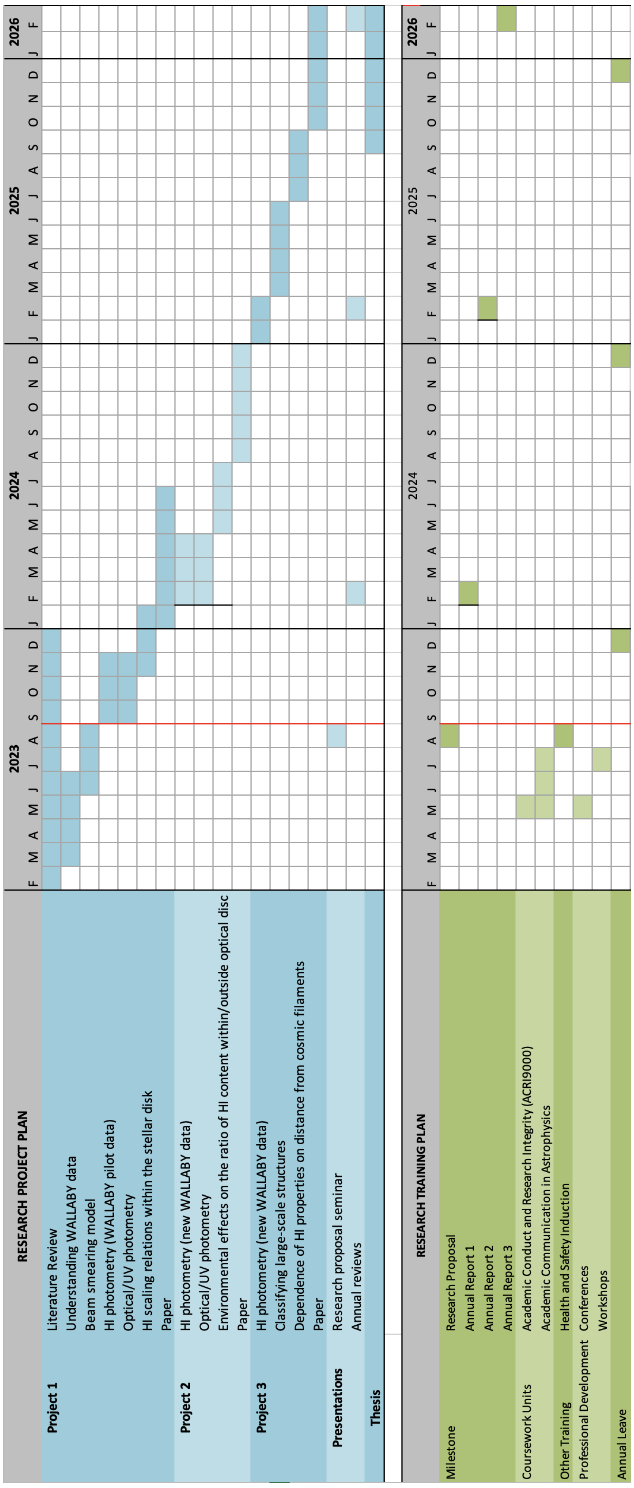


Figure 7: Timeline research plan.