MIGHTEE-H I: The $M_{\text{HI}} - M_*$ relation over the last billion years

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ABSTRACT

We measure the $M_{\text{HI}} - M_*$ relation over the last billion years down to $M_{\text{HI}} \sim 10^7 M_\odot$ using the MIGHTEE Early Science data with a Bayesian technique. This technique is applied to the H I detections, without binning the datasets, while taking account of the intrinsic scatter in the $M_{\text{HI}} - M_*$ relation. We divide the full sample of 249 galaxies into 161 spirals, 64 irregulars, 15 mergers, and 9 elliptical galaxies to measure their $M_{\text{HI}} - M_*$ relations. We fit this relation with both linear and non-linear models, and find that the non-linear model is preferred over the linear one for the full H I-selected sample with a measured transition stellar mass as $\log_{10}(M_*/M_\odot) = 9.1^{+0.8}_{-0.95}$, beyond which the measured slope flattens. This finding supports the view that the lack of H I gas is ultimately responsible for the decreasing star formation rate observed in the massive main sequence galaxies. For the spiral galaxies alone, which are biased towards those galaxies with the highest stellar masses in our sample, the slope beyond the transition mass is shallower than for the full sample, indicative of distinct gas processes ongoing for the spirals/high-mass galaxies from other types of galaxies with lower stellar masses. We also observe a moderate evolution of the $M_{\text{HI}} - M_*$ relation when splitting our samples into two redshift bins over the last billion years, which can largely be attributed to the effect of sample selection and hence highlights the potential of the full MIGHTEE survey.

Key words: galaxies: scaling relation – radio lines: galaxies – methods: statistical

1 INTRODUCTION

The relation between the mass of neutral atomic hydrogen (H I) gas and stars in galaxies reveals the connection of star forming activity to their raw fuel, but this relation is not straightforward due to complex physical processes involved in the course of galaxy evolution. A comprehensive and accurate measurement of this relation is required to illuminate their interplay, and thus to help us better understand the physics of galaxy formation and evolution.

In particular, exploring the H I and stellar mass ($M_{\text{HI}} - M_*$) relation has been one of the main means used to enlighten the processes of gas consumption and star formation. For example, both Huang et al. (2012) and Maddox et al. (2015) have found an upper limit for H I mass as a function of the stellar mass at high masses for H I-selected samples. Maddox et al. (2015) and Parkash et al. (2018) suggest that this upper limit can be explained by a stability model in which the

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large halo spin of disk galaxies can stabilize the H\textsc{i} disk and prevent it from collapsing and forming stars (Obreschkow et al. 2016), but the highest spin parameter is restrained by the amount of gas infall and tidal torque that haloes can experience during the proto-galactic growth, and therefore the gas fraction is linked to the specific angular momentum of galaxies in general (Zoldan et al. 2018; Mancera Piña et al. 2021b). As such this could also be related to the position of the galaxies with respect to the cosmic web, the filaments of which are presumably the source of the infalling gas (see e.g. Tudorache et al. 2022).

Furthermore, there have been discoveries of flattening of the star formation rate (SFR)-\textit{M} relation at high stellar masses from the local to high-z Universe (e.g. Noeske et al. 2007; Erfanianfar et al. 2015; Johnston et al. 2015; Leslie et al. 2020; Fraser-McKelvie et al. 2021). The mechanisms responsible for this flattening remain under debate (e.g. Gavazzi et al. 2015; Tacchella et al. 2018; Popesso et al. 2019; Cook et al. 2020; Feldmann 2020), and can be broadly summarised as the lack of H\textsc{i} gas versus the low conversion efficiency from H\textsc{i} to stars, through the molecular hydrogen (H$_2$) phase. A thorough investigation into the link between H\textsc{i} and the stellar mass can help to disentangle these two possible causes. Noticeably, the flattening of the SFR-\textit{M} relation towards high masses resembles the upper limit found on the $M_{\text{HI}} - \text{M}_\star$ relation.

Over the past few decades, the direct detection of emission lines from the neutral hydrogen component of galaxies has been limited to the local Universe, or massive H\textsc{i} systems, by the sensitivity of modern radio instruments, such as Parkes and Arecibo telescopes. Nonetheless, several studies have been conducted to investigate the H\textsc{i} and stellar mass ($M_{\text{HI}} - \text{M}_\star$) relation (Catinella et al. 2010; Huang et al. 2012; Maddox et al. 2015; Parkash et al. 2018), benefiting from the H\textsc{i} Parkes All-Sky (HIPASS) Survey (Barnes et al. 2001) and the Arecibo Legacy Fast ALFA (ALFALFA) survey (Giovanelli et al. 2005). All these studies indicate an increase in the H\textsc{i} mass with stellar mass, but diverge at the high mass end owing to the effect of sample selection, limited statistics, or both.

With the MeerKAT radio telescope and the future SKA, we are entering a new era of radio astronomy. The MeerKAT International GHz Tiered Extragalactic Exploration (MIGHTEE; Jarvis et al. 2016) is one of the large survey projects that is underway with MeerKAT, and will cover 20 square degrees over the four best-studied extragalactic fields observable from the southern hemisphere to $\mu$Jy sensitivity at GHz frequencies. The MIGHTEE-H\textsc{i} early science project has already allowed us to reach $M_{\text{HI}} \lesssim 10^7M_\odot$ in the local Universe, and $M_{\text{HI}} \sim 10^9M_\odot$ up to $z = 0.084$, with higher H\textsc{i}-mass galaxies observable out to the lower-frequency end of the L-band window at $z \sim 0.6$ (Maddox et al. 2021).

At high redshift, stacking approaches (e.g. Delhaize et al. 2013; Rhee et al. 2013; Healy et al. 2019; Chowdhury et al. 2020; Guo et al. 2021; Sinigaglia et al. 2022) have been developed to break the barrier of the sensitivity limitation. However, in these stacking processes, one only measures the average properties of galaxies bearing the consequence of losing information about their intrinsic scatter, which is a key parameter to describe the shape of the distribution of H\textsc{i} masses and hence the strength of the correlation between H\textsc{i} and a second galaxy property, such as the stellar mass.

In addition, only the arithmetic operations (e.g. average) of the H\textsc{i} fluxes are allowed for these stacking practices as the logarithmic operation cannot be done for negative fluxes that are influenced by the background noise, although an arithmetic average would be sufficient if we were just interested in measuring the cosmic H\textsc{i} density. In terms of scaling relations, there are notable differences in the means and standard deviations between arithmetic and logarithmic operations of H\textsc{i} masses mostly due to the different contribution of the low mass samples (Rodríguez-Puebla et al. 2020; Saintonge & Catinella 2022). For H\textsc{i}-selected samples, the logarithmic average (or median) can adequately trace the main distribution, and is preferred in the literature (Cortese et al. 2011; Huang et al. 2012; Maddox et al. 2015; Parkash et al. 2018). Therefore, it will add further complexities to a fair comparison of measured scaling relations between stacked samples and direct detections, based on different statistics. Above all, these approaches require binning the datasets in a second galaxy property, and it could be troublesome to determine the binning width when the sample size is small.

In this paper, we use a Bayesian technique for measuring the $M_{\text{HI}} - \text{M}_\star$ scaling relation consistently without binning the datasets, while taking account of their intrinsic scatter, based on our previous work (Pan et al. 2020; Pan et al. 2021). This technique employs fluxes of H\textsc{i} emission line as measurables that can naturally account for the thermal noise from the radio receiver on the linear scale, while the intrinsic scatter of galaxy properties may be better described on the logarithmic scale. This is non-trivial as the propagation of uncertainties measured from the linear to logarithmic scale must rely on an approximation which breaks down when the signal to noise ratio is low. If we instead measure the scaling relation in flux space, this issue does not exist.

With this technique, we measure the $M_{\text{HI}} - \text{M}_\star$ relation using the MIGHTEE Early Science data for the H\textsc{i}-selected galaxies. We note that this technique can be easily adjusted and applied to measure other H\textsc{i} scaling relations and the H\textsc{i} mass function directly above or below the detection threshold.

This paper is organised as follows. We describe our MIGHTEE-H\textsc{i} data in Section 2, and the Bayesian technique in Section 3. We present our main results in Section 4, and conclude in Section 5. We use the standard ΛCDM cosmology with a Hubble constant $H_0 = 67.4\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$, total matter density $\Omega_m = 0.315$ and dark energy density $\Omega \Lambda = 0.685$ (Planck Collaboration et al. 2020), and AB magnitudes throughout.

2 DATA

2.1 MIGHTEE-H\textsc{i}

MIGHTEE-H\textsc{i} is the H\textsc{i} emission project within the MIGHTEE survey, and is described in detail by Maddox et al. (2021). The MIGHTEE--H\textsc{i} Early Science data were collected between mid-2018 and mid-2019, in L-band ($900 < \nu < 1670\,\text{MHz}$), with a spectral resolution of 208 kHz over two well-studied fields: COSMOS and XMM-LoSS. The visibilities were processed with the IDIA Pipeline\footnote{https://idia-pipelines.github.io}: processMeerKAT. This pipeline does full-polarisation calibration on MeerKAT data including automated flagging. The spectral line imaging was carried out using the CASA task TCLEAN (robust=0.5), and the continuum subtraction was undertaken in both the visibilities and imaging planes using the standard CASA routines UVSUB and UVCONTSUB. The effect of direction-dependent artefacts was reduced by a per-pixel median filtering operation. The full data reduction pipeline for MIGHTEE-H\textsc{i} is described by Frank et al. (in prep). Key parameters of the processed Early Science data are listed in Table 1.


2.2 \text{H} \text{I} \text{ flux}

We employ the Cube Analysis and Rendering Tool for Astronomy (CARTA Comrie et al. 2021) for visual source finding, then we extract a cubelet centred on all detected sources. We smooth the cubelet, and clip it at a 3\sigma threshold as a mask for removing the noise, then apply the mask to the cubelet with original resolution. We then clip out by hand any remaining noise peaks and integrate the flux densities over the frequency channels to make moment-0 maps. The total flux is calculated by summing all flux densities over the spatial pixels. We obtain uncertainties on the bright and faint sources varying from 5\% to 20\% of their \text{H} \text{I} fluxes roughly (see Ponomareva et al. 2021, for full details).

The \text{H} \text{I} mass under the optically thin gas assumption can be calculated via

\[ M_{\text{HI}} = 2.356 \times 10^5 D_L^2 (1+z)^{-1} S, \]

where \( M_{\text{HI}} \) is the \text{H} \text{I} mass in solar masses, \( D_L \) is the luminosity distance in Mpc, and \( S \) is the integrated flux in Jy km s\(^{-1}\) (Meyer et al. 2017). We note that our technique works on the \text{H} \text{I} flux space directly rather than the mass space, and this equation is only needed for our technique to predict the flux \( S \) when the \text{H} \text{I} mass is modelled by the \( M_{\text{HI}} - M_\ast \) relation in Section 3.2.

2.3 Ancillary data

All MIGHTEE fields are covered by various multi-wavelength photometric and spectroscopic surveys ranging from X-ray to far-infrared bands (e.g. Cuillandre et al. 2012; Jarvis et al. 2013; Aihara et al. 2017; Aihara et al. 2019). We measure the magnitudes of the sample galaxies by extracting the flux within an elliptical aperture defined in the \( u,r,i,z,Y,J,H,K_s \)–bands. Based on independent, repeat measurements of several galaxies, the photometry is accurate to \( \pm 0.015 \) mags. We then employ the Spectral Energy Distribution (SED) fitting code LePhare (Ilbert et al. 2006) for deriving the stellar properties of the galaxies, such as stellar mass, stellar age and star formation rate, and the uncertainty on the stellar mass is conservatively assumed to be \( \pm 0.1 \) dex, due to assumptions made on galaxy metallicity, star formation history, initial mass function (IMF), etc. in the SED fitting process (Adams et al. 2021; Maddox et al. 2021). In particular, the star formation histories use Bruzual & Charlot (2003) stellar synthesis models including templates with either a constant star formation history or an exponential star formation history. For the exponential star formation history, there are a few different characteristic timescales for the exponent (\( \tau \)) ranging from \( \tau = [0.1, 0.3, 1, 2, 3, 5, 10, 15, 30] \) Gyr. For each template, there are also 57 different ages from 0.01 Gyr up to the age of the universe.

Supplemented with such a rich ancillary data set, we are in an excellent position to study \text{H} \text{I} galaxies from various perspectives, and understand the links between \text{H} \text{I} gas and other key galaxy properties such as colour, SFR, and stellar mass, in order to gain a complete picture of the diverse galaxy populations as they evolve across the cosmic time.

2.4 Morphological classification

We classify our \text{H} \text{I} detections into four samples based on their optical morphology. In total, we have a sample of 276 \text{H} \text{I} detections. By removing the objects outside the deep imaging footprint of the Hyper SuprimeCam Subaru Strategic Program (HSC-SSP Aihara et al. 2017) and the ones without a classified type, we have a total number of 249 galaxies including 161 spiral galaxies (SP), 64 irregulars (IR), 15 mergers (ME), and 9 elliptical galaxies (ET). Details of the galaxy morphology classification are described in Rajanjohnson et al. (2022). We note that many of the galaxies classified as irregular are in fact very low mass, and thus could alternatively be classified as dwarf galaxies. We do not differentiate early and late-stage mergers due to their small sample size, and label all of them as ME in our analysis.

In Figure 1, we show the colour- and SFR-stellar mass diagrams colour-coded by their morphologies on the left and right panels, respectively. We draw the upper boundary of the green valley galaxies from Schawinski et al. (2014) as the grey dashed line on the colour-stellar mass diagram, and ridge lines of the main sequence of star forming galaxies from Peng et al. (2010) and Speagle et al. (2014) as grey and blue dashed lines, respectively. These demonstrate that our \text{H} \text{I}-selected sources are mostly settled in the blue cloud and green valley, and largely distributed above the main sequence of star forming galaxies, with very few being red (or passive) galaxies. The irregular and spiral galaxies dominate at the low and high mass ends, respectively, with considerable overlapping area at the intermediate mass range. This feature motivates us to separate the \text{H} \text{I}-selected galaxies based on their morphology, and investigate the dominant sample of spirals, in addition to the \text{H} \text{I}-selected sample as a whole.

It is worth noting that the SFR-\( M_\ast \) relation predominantly follows a power law at low stellar masses, and flattens at \( M_\ast \geq 10^{10} M_\odot \) as expected for the main sequence galaxies (e.g. Lee et al. 2015; Schreiber et al. 2015; Saintonge et al. 2016; Leslie et al. 2020), even with our limited sample size from the Early Science data.

3 BAYESIAN ANALYSIS

3.1 Bayesian framework

Our technique is established on Bayes' theorem

\[ \mathcal{P}(\Theta|D, H) = \frac{\mathcal{L}(D|\Theta, H)\Pi(\Theta|H)}{\mathcal{Z}(D|H)}, \]

where \( \mathcal{P} \) is the posterior distribution of the model parameters \( \Theta \), given the available data \( D \) and a model \( H \), \( \mathcal{L} \) is the likelihood of the data \( D \) given parameter values and the model, and \( \Pi \) is the prior knowledge of our prejudices about the values of the model parameters. \( \mathcal{Z} \) is the Bayesian evidence, which can be thought of as a normalization factor and can be expressed as an integral of \( \mathcal{L} \) and \( \Pi \) over a \( n \)-dimensional parameter space \( \Theta \),

\[ \mathcal{Z}(D|H) = \int \mathcal{L}(D|\Theta, H)\Pi(\Theta|H)d^n\Theta, \]

and in addition it crucially facilitates model selection between different models when their evidences are compared quantitatively, as the evidence is the probability of the data given a model after all the free parameters are marginalized over. The difference in the log-evidence, \( \ln(\mathcal{Z}_B) - \ln(\mathcal{Z}_A) \), known as the Bayes factor, is commonly used to

Table 1. Key parameters of the MIGHTEE-\text{H} \text{I} Early Science data.

| Survey area       | \(-1.5 \text{ deg}^2 \) (COSMOS) |
|-------------------|---------------------------------|
| Integration time  | \(~3 \times 1.2 \text{ deg}^2\) (XMMLSS) |
| Velocity resolution | 44.11 km s\(^{-1}\) at \( z = 0 \) |
| Synthesized Beam  | 14.5''\( \times \)11'' (COSMOS) |
| 3\sigma \text{H} \text{I} column density sensitivity | \( 4.05 \times 10^{15} \) atoms cm\(^{-2}\) (COSMOS) |
|                   | \( 9.83 \times 10^{15} \) atoms cm\(^{-2}\) (XMMLSS) |
interpret how much better Model B is compared to A, providing a fair way of discriminating between models with different numbers of parameters. We follow the criteria in Malefahlo et al. (2021), where $\Delta \ln(Z) < 1$ is "not significant", $1 < \Delta \ln(Z) < 2.5$ is "significant", $2.5 < \Delta \ln(Z) < 5$ is "strong", and $\Delta \ln(Z) > 5$ is "decisive".

We use MULtieNest (Feroz et al. 2009; Buchner et al. 2014), an efficient and robust Bayesian inference tool for cosmology and particle physics, to sample the parameter space and explore the full posterior distribution for parameter estimation and the evidence for Bayesian model comparison.

### 3.2 $M_{\text{HI}} - M_*$ models

We fit two $M_{\text{HI}} - M_*$ models: linear and non-linear models to the data in their logarithmic space, given that both have been used previously (e.g. Maddox et al. 2015; Parkash et al. 2018). First, we model the logarithmic average of $M_{\text{HI}}$ as a linear function of $\log_{10}(M_*)$ as follows

$$\langle \log_{10}(M_{\text{HI}}) \rangle = \alpha \langle \log_{10}(M_*) \rangle - 10 + \beta,$$

where $\alpha$ and $\beta$ are the free parameters corresponding to the slope, and intercept at $M_* = 10^{10} M_\odot$. We note this single power law relation as "Model A".

For the non-linear relation, we use the double power law relation:

$$\langle \log_{10}(M_{\text{HI}}) \rangle = \log_{10} \left( \frac{M_0}{M_*^a + M_*^b} \right),$$

where $M_0, a, b$ are the free parameters to be fitted for. $M_0$ indicates the transition stellar mass, and $M_*^a$ is a value along the ordinate at $M_* = M_0$; $a$ and $b$ determine the low- and high-mass slopes of the scaling relation. We denote this double power law relation as "Model B", i.e. our non-linear model. When $a = b$, Eq. (5) is equivalent to Eq. (4).

### 3.3 Likelihood

The relationship between H I and stellar mass of galaxies cannot be fully described by a single variable function, no matter which model we use. We actually require a bivariate distribution function to capture the whole picture of the $M_{\text{HI}} - M_*$ relation. Without loss of generality, we assume the Model A or B supplemented with an intrinsic scatter $\sigma_{\text{HI}}$ is good enough to describe this relation for our relatively small sample, then the probability of having a H I mass ($M_{\text{HI}}$) at a given stellar mass ($M_*$) follows,

$$P(M_{\text{HI}}|M_*) = \frac{1}{\sqrt{2\pi} \sigma_{\text{HI}}} e^{-\frac{1}{2} \left( \frac{\langle \log_{10}(M_{\text{HI}}) \rangle - \langle \log_{10}(M_{\text{HI}}) \rangle - \sigma_{\text{HI}}}{\sigma_{\text{HI}}} \right)^2}.$$ (6)

We take the intrinsic scatter $\sigma_{\text{HI}}$ as an additional free parameter for our Models A and B. This Gaussian form of distribution function can be replaced with a more adequate form of Schechter function or any other forms if required.

With this conditional HI mass distribution, the probability of having a measured flux, $S_m$, for a single source can be expressed as

$$P(S_m|M_*) = \int dM_{\text{HI}} P(M_{\text{HI}}|M_*) P_n(S_m - S(M_{\text{HI}})),$$ (7)

where $P_n$ follows the noise distribution of Normal(0, $\sigma_n$), and $S(M_{\text{HI}})$ is given by the Eq. (1).

The likelihood of all the sources having the measured fluxes, given the model and known stellar masses, is given by

$$L \propto \prod_{\text{source}} P(S_m|M_*, \text{Model A}(\alpha, \beta, \sigma_{\text{HI}})),$$

or $|M_*, \text{Model B}(a, b, \sigma_{\text{HI}}, M_0, M_\tau))$.

By maximizing Eq. (8), we obtain the best fitting $M_{\text{HI}} - M_*$ relation with an estimate of the intrinsic scatter.

### 3.4 Priors

Priors are our background knowledge of the model parameters, and thus define the sampled parameter space. A uniform prior distribution
Table 2. Priors of the Model A and B for the H I and stellar mass relation.

| Model | Parameter | Prior Probability Distribution |
|-------|-----------|-------------------------------|
| A     | $\alpha$  | uniform $\in [2.5, 2.5]$      |
|       | $\beta$   | uniform $\in [7, 12]$         |
| B     | $\sigma_{HI}$ | uniform $\in [0, 2]$        |

Table 3. Measured parameters of the $M_{HI} - M_*$ relation with Model A

| Morphology | Parameter | $0.0<z<0.04$ | $0.04<z<0.084$ | $0.0<z<0.084$ |
|------------|-----------|---------------|----------------|---------------|
| Spirals    | $\alpha$  | $0.382^{+0.106}_{-0.091}$ | $0.208^{+0.045}_{-0.044}$ | $0.278^{+0.039}_{-0.040}$ |
|            | $\beta$   | $0.003^{+0.153}_{-0.0145}$ | $0.64^{+0.043}_{-0.046}$ | $0.9^{+0.041}_{-0.043}$ |
|            | $\sigma_{HI}$ | $0.51^{+0.07}_{-0.07}$ | $0.42^{+0.03}_{-0.02}$ | $0.44^{+0.01}_{-0.02}$ |
| N          |           | $37$           | $124$           | $161$          |
| Full Sample| $\alpha$  | $0.524^{+0.061}_{-0.059}$ | $0.273^{+0.032}_{-0.031}$ | $0.387^{+0.028}_{-0.026}$ |
|            | $\beta$   | $0.116$        | $0.67^{+0.041}_{-0.036}$ | $0.96^{+0.038}_{-0.034}$ |
|            | $\sigma_{HI}$ | $0.49^{+0.05}_{-0.04}$ | $0.4^{+0.02}_{-0.02}$ | $0.46^{+0.02}_{-0.02}$ |
| N          |           | $67$           | $182$           | $249$          |

Table 4. Measured parameters of the $M_{HI} - M_*$ relation with Model B

| Morphology | Parameter | $0.0<z<0.04$ | $0.04<z<0.084$ | $0.0<z<0.084$ |
|------------|-----------|---------------|----------------|---------------|
| Spirals    | $\alpha$  | $-0.871^{+0.264}_{-0.408}$ | $-0.232^{+0.087}_{-0.088}$ | $-0.523^{+0.115}_{-0.214}$ |
|            | $\beta$   | $0.205^{+0.555}_{-0.193}$ | $1.18^{+0.917}_{-0.197}$ | $0.032^{+0.629}_{-0.220}$ |
|            | $\sigma_{HI}$ | $0.477^{+0.076}_{-0.055}$ | $0.411^{+0.025}_{-0.026}$ | $0.44^{+0.025}_{-0.023}$ |
| log(M_0)   | $9.798^{+0.233}_{-0.228}$ | $9.951^{+0.157}_{-0.149}$ | $9.869^{+0.198}_{-0.184}$ |
| log(M_0)   | $9.02^{+0.11}_{-0.113}$ | $11.3^{+0.84}_{-0.72}$ | $9.52^{+1.26}_{-1.32}$ |
| Full Sample| $\alpha$  | $-0.75^{+0.118}_{-0.152}$ | $-0.31^{+0.081}_{-0.081}$ | $-0.67^{+0.109}_{-0.157}$ |
|            | $\beta$   | $0.226^{+0.623}_{-0.38}$ | $0.57^{+0.854}_{-0.38}$ | $0.03^{+0.329}_{-0.03}$ |
|            | $\sigma_{HI}$ | $0.47^{+0.044}_{-0.041}$ | $0.39^{+0.021}_{-0.019}$ | $0.43^{+0.025}_{-0.02}$ |
| log(M_0)   | $9.84^{+0.203}_{-0.449}$ | $10.084^{+0.157}_{-0.445}$ | $9.77^{+0.239}_{-0.415}$ |
| log(M_0)   | $9.41^{+0.79}_{-0.95}$ | $11.06^{+0.79}_{-2.14}$ | $9.15^{+0.8}_{-0.95}$ |

Table 5. Relatives between Model A and B. Note that the Model A is our reference Model for the evidence comparison.

| Morphology | Parameter | $0.0<z<0.04$ | $0.04<z<0.084$ | $0.0<z<0.084$ |
|------------|-----------|---------------|----------------|---------------|
| Spirals    | $\Delta \log (Z_B)$ | $1.94^{+0.06}_{-0.06}$ | $0.24^{+0.03}_{-0.03}$ | $1.44^{+0.04}_{-0.04}$ |
| Full Sample| $\Delta \log (Z_B)$ | $2.06^{+0.1}_{-0.1}$ | $0.85^{+0.06}_{-0.06}$ | $6.16^{+0.07}_{-0.07}$ |

provides an equal weighting of the input parameter space, and is preferred in general if this prior distribution is not known well. We assign uniform prior probability distributions to $\alpha$, $\beta$ and $\sigma_{HI}$ for our Model A. For Model B, we assign uniform distributions to $a$, $b$ and $\sigma_{HI}$, and adopt uniform logarithmic priors for $M_0$ and $M_*$. All of these priors are listed in Table 2.

4 RESULTS

In this section, we investigate the relation between HI mass and stellar mass for our HI-selected sample with the Bayesian method outlined in Section 3. First, we use the full sample to maximise the baseline in stellar mass and HI mass for fitting the relation. We then consider the morphologically classified spiral galaxies as a separate population in order to compare with previous studies. We also split the sample into two redshift bins of $0<z<0.04$ and $0.04<z<0.084$ to investigate whether there is any evidence for evolution in this relation.

4.1 $M_{HI} - M_*$ relation for H-selected galaxies

We show the HI and stellar mass distribution for the complete H-selected sample in the top panels of Figure 2. The best fitting lines for our linear Model A and non-linear Model B are shown as the blue lines on the left and right panels, respectively. The $1\sigma$ statistical scatter, predominantly due to the HI flux uncertainties and our limited sample size are denoted by blue shaded areas, while the total (statistical plus intrinsic) scatter in the HI mass distribution around the stellar mass are shown by green shaded regions.

All the measured parameters for these fits are listed in Tables 3 and 4, the relative Bayesian evidence are shown in Table 5. We find that the non-linear model is decisively preferred over the linear model for the full sample at $0<z<0.84$.

The agreement between the full MIGHTEE-HI sample and the spectroscopic ALFALFA-SDSS galaxy sample (Maddox et al. 2015) is excellent for our non-linear Model B, with most parts of the Maddox et al. (2015) relation (denoted by grey dashed line) falling within the $1\sigma$ statistical uncertainties of our data (blue shaded area). Compared to ALFALFA, the deficit at the high HI mass ($M_{HI} > 10^{10} M_\odot$) end seen in both panels suggests we detected fewer HI galaxies at these masses in the MIGHTEE-HI Early Science data. This is likely due to the limited volume surveyed thus far which precluded us from finding the rarer, high HI-mass systems in the current area, and we will require the full MIGHTEE survey, where the survey volume will reach 20 deg$^2$, to fully explore this region. Our results are in excellent agreement with the Simba simulation (Dave et al. 2019), where we include the H-selected main sequence galaxies (MS) defined as specific SFR ($sSFR$) $>10^{-1} \cdot 8.0$ Gyr$^{-1}$ (blue dashed circles). However, we do find a deviation of the HI masses between the H-selected MIGHTEE sample and the Hi-selected Simba sample without including red galaxies (red dashed circles). This deviation suggests that Simba overestimates the amount of HI gas in the massive dead red galaxies as these galaxies seem to have a moderate amount of HI gas and would have been detected by MIGHTEE-HI, thus weighting down the average HI mass at the massive end if they were present. The statistical significance of this difference is however quite low, and would need to be investigated with a larger sample.

For Model A, the excess at the low-mass end is due to the model being a poor description of the data and this excess disappears when we use a more flexible non-linear model to fit for the data (on the right panel). The low-number statistics also plays a role at the low mass end as the statistical error, indicated by the blue area, increases. The global difference between our linear Model A and binned median HI masses in Maddox et al. (2015) also suggests the limitation of a simple linear modelling, due to the complex nature of the $M_{HI} - M_*$ relation. Nonetheless, the Model A is consistent with Parkash et al. (2018) at the high-mass end but a higher detection of rate of HI galaxies at the low-mass end suggests that the Parkash et al. (2018) sample is less complete at $M_{HI} < 10^9 M_\odot$.

For Model B, we find a transition stellar mass of $\log_{10}(M_*/M_\odot) = 9.15^{+0.8}_{-0.95}$, which breaks the $M_{HI} - M_*$ relation into two regions. At the high mass end, the measured slope (indicated by the parameter $b$, is much flatter than that at the low mass end (indicated by the parameter $a$). This finding is consistent with the steeper slope of Model
Figure 2. Measured $M_{\text{HI}} - M_{\star}$ relation (top) and its posterior parameters (bottom) with the best fitting Model A (left) and B (right) at $0 < z < 0.084$ for the full H\textsc{i} selected sample from MIGHTEE-H\textsc{i}. Top row: The dots are spiral and irregular galaxies while triangles and diamonds correspond to mergers and elliptical galaxies. They are colour-coded by redshift. The blue shaded areas are the statistical uncertainties, and the green ones are the intrinsic scatters added to the statistical uncertainties. The orange line is the H\textsc{i}-selected sample from Parkash et al. (2018). The grey dashed circles are the measurements from ALFALFA (Maddox et al. 2015). The blue dashed circles are the main sequence galaxies (MS) from the Simba simulation (Dave et al. 2019) while the red ones are their full H\textsc{i} samples. The diagonal light grey dashed line is the one-to-one relation. The black line at the bottom of the top panels indicates the normalised distribution of stellar mass. Bottom row: The grey histograms are the (1 or 2 dimensional) marginal posterior probabilities. The blue curves are the cumulative distributions, and the blue dots are the median posterior parameters with 1$\sigma$ error bars.

A measured from the full H\textsc{i} sample with respect to the spiral-only galaxies which tend to be massive systems (see also Section 4.2), and is also in line with the upper envelope of H\textsc{i} mass fraction found by Maddox et al. (2015). Thus, we confirm that the H\textsc{i} gas fraction decreases as a function of stellar mass at $M_{\star} \gtrsim 10^{9} M_{\odot}$ with the MIGHTEE-H\textsc{i} Early Science data. This trend is similar to the galaxy main sequence, where the SFR-$M_{\star}$ relation is linear up to a critical mass of $\sim 3 \times 10^{10} M_{\odot}$, and then flattens out towards higher masses (e.g. Erfanianfar et al. 2015). It is also interesting to note that a similar curvature has been suggested for the baryonic specific angular momentum-baryonic mass relation with the slope change occurring occurring at $\sim 10^{9} M_{\odot}$ (e.g. Kurapati et al. 2018, 2021), albeit whether this break is real is still debated (Mancera Piña et al. 2021a,b).

We also notice that there is very little difference between the median H\textsc{i} masses in Maddox et al. (2021) and our Model B. The scatter on the median H\textsc{i} masses is very close to our measured global intrinsic scatter of $0.435^{+0.02}_{-0.02}$ dex, and the distribution of H\textsc{i} masses at a given stellar mass can be modelled adequately by a symmetric function (e.g. Gaussian function). On the other hand, we should also
Figure 3. $M_{\text{HI}}$ as a function of the SFR for the full H\textsubscript{i}-selected sample from the MIGHTEE-H\textsubscript{i} catalogue at $0 < z < 0.084$. Measurements in dots are colour-coded by their morphologies. The dashed and solid blue lines are the best fitting of Model A and B, respectively. The blue and green shaded areas correspond to the uncertainty budget. Thus, it shows that the lower turnover mass of $M_{\text{HI}}$ and the SFR of gas in galaxies is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses, although the SFR gas is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses, although the SFR gas is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses, although the SFR gas is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses, although the SFR gas is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses, although the SFR gas is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses, although the SFR gas is likely ultimately responsible for the decreasing star formation rate towards the higher stellar masses.

4.2 $M_{\text{HI}} - M_*$ relation for H\textsubscript{i}-selected spirals

In this section, we consider the population of morphologically classified spiral galaxies. In Figure 4, we show the measured $M_{\text{HI}} - M_*$ relation and the posterior parameters for the H\textsubscript{i}-selected spiral galaxies from the MIGHTEE-H\textsubscript{i} catalogue at $0 < z < 0.084$, with our best fitting Model A and B on the left and right top panels, respectively. From the best fits and Bayesian evidences listed in Tables 3, 4 and 5, we see that the data are much less in favour of the non-linear model over the linear one with $\ln(Z_{\odot}) = 1.44 \pm 0.04$, which is significant but not strong or decisive. We also find that the posterior distributions of Model B for spirals are not as well-converged as for the full sample in Figure 2.

For both models, we find a systematically higher detection of H\textsubscript{i} gas than what Parkash et al. (2018) found at $M_* \geq 10^9 M_\odot$. It is likely to be the result of different selection effects, with Parkash et al. (2018) sample being $M_*$-selected and the MIGHTEE-H\textsubscript{i} sample being H\textsubscript{i}-selected. The latter tends to be populated by higher H\textsubscript{i} mass objects at any given stellar mass. It implies that there still exists a certain amount of H\textsubscript{i}-poor spiral galaxies to be picked up by a deeper H\textsubscript{i} survey. We measure an intrinsic scatter of $0.44 \pm 0.03$ dex for both models, which is roughly consistent with the $0.4$ dex obtained in Parkash et al. (2018).

As the stellar masses for spiral galaxies are limited to $M_* \sim 10^9 M_\odot$ in Parkash et al. (2018), we compare our measurements with Maddox et al. (2015) at the low mass end, and it is clear that the disagreement increases from the intermediate to low mass end due to the inclusion of other types of galaxies in Maddox et al. (2015) and our full sample, along with the simplicity of our linear model. On the other hand, the deviation at the high mass end seems to be real, as the spirals dominate the high mass end of our H\textsubscript{i}-selected sample.

To compare with the Simba spirals, we select galaxies in Simba with fraction of kinetic energy ($\epsilon_{\text{rot}} > 0.7$ (Sales et al. 2012), and denote their median H\textsubscript{i} masses against the stellar masses as red dashed circles. We then use the same criterion of $sSFR > 10^{-1.8} \pm 0.3$ Gyr$^{-1}$ to exclude the red spiral galaxies, and show their $M_{\text{HI}} - M_*$ relation as blue dashed circles. Overall, we find good agreement between MIGHTEE-H\textsubscript{i} and Simba MS spirals for the $M_{\text{HI}} - M_*$ relation, and notice a lower detection of the average H\textsubscript{i} mass for the whole Simba spiral sample at the most massive end. This trend is similar to what we found in Section 4.1 for the full MIGHTEE-H\textsubscript{i} sample, and indicates that there are probably too many red spiral galaxies that have non-negligible amount of H\textsubscript{i} gas in Simba.

The best fitting transition stellar mass for our Model B for the spirals is $\log_{10}(M_*/M_\odot) = 9.52^{+1.26}_{-1.87}$, which is higher than the $\log_{10}(M_*/M_\odot) = 9.15^{+0.8}_{-0.95}$ for the full sample, but has much larger statistical uncertainties due to reduced number of sources. This trend roughly corresponds to the difference of the best fitting slopes with Model A between these two samples on the $M_{\text{HI}} - M_*$ relation, where the spirals have an obvious shallower slope of $0.278$ compared to the $0.387$ for the full sample, although the corresponding intrinsic scatter is similar.

The distinction of our best fitting models between spirals and the full H\textsubscript{i}-selected sample is a strong indication of very different gas processes between the spiral and lower-mass irregular galaxies, since the irregulars dominate over other types of galaxies except the spirals in our catalogue. Indeed, given the stability model for...
Figure 4. Measured $M_{\text{HI}} - M_*$ relation (top) and its posterior parameters (bottom) for spiral galaxies with the best fitting Model A (left) and B (right) at $0 < z < 0.084$ from MIGHTEE-H$^1$ catalogue. Top row: The dots are spiral galaxies colour-coded by redshift. The blue shaded areas are the statistical uncertainties, and the green ones are the intrinsic scatters added to the statistical uncertainties. The orange line is the stellar mass-selected spirals from Parkash et al. (2018). The grey dashed circles are the measurements from ALFALFA (Maddox et al. 2015). Bottom row: The grey histograms are the (1 or 2 dimensional) marginal posterior probabilities. The blue curves are the cumulative distributions, and the blue dots are the median posterior parameters with 1σ error bars.

4.3 Evolution of the $M_{\text{HI}} - M_*$ relation

In Figures 5, we show the $M_{\text{HI}} - M_*$ relation in two redshift bins to investigate whether there is any evidence for evolution in this relation out to $z \sim 0.084$, along with the best fitting parameters listed in Table 3 for Model A. We also show the redshift evolution in Figure 6 and Table 4 for our Model B. The posterior parameters of Model A and B are appended in Figures A1 and A2.

The main feature of the evolution of the $M_{\text{HI}} - M_*$ relation is the change of our model slopes (i.e. $\alpha$ of Model A) from the low- to high-z Universe in Figure 5. The slopes at $0.04 < z < 0.084$ appear to be less steep than those at $0 < z < 0.04$. This trend corresponds to the transition of non-linearity to linearity of the $M_{\text{HI}} - M_*$ relation from...
the low- to high-z bins in Figure 6. These evolutionary features can be largely attributed to the flux-limited nature of our H\textsc{i}-selected sample (i.e. Malmquist bias). As we go to higher redshifts, our sample is more biased towards the massive galaxies, and these are mostly spirals. This is clearly indicated by the normalised stellar mass distribution (black line) at the bottom of each figure.

We also observe a moderate evolution of the $M_{\text{HI}} - M_*$ relation for the spirals and the full sample when compared to Parkash et al. (2018). A plausible reason is that their results are based on the H\textsc{i} Parkes All-Sky Survey catalog (HICAT), a H\textsc{i}-survey limited to the local Universe, and hence the agreement becomes poorer towards the high redshift, where we have a good number of massive H\textsc{i} galaxies. However, due to the fact that most the dwarf irregulars in our sample are at lower redshifts, we find that Model B is only significantly preferred for the low redshift bin, where the transition stellar masses are $\log_{10}(M_*/M_\odot) = 9.02^{+1.01}_{-1.11}$ and $9.41^{+0.79}_{-0.93}$ for the spirals and full sample, respectively.

There is a tighter scatter observed for the $M_{\text{HI}} - M_*$ relation at higher redshifts, irrespective of the fitting models or galaxy types. This indicates that the $M_{\text{HI}} - M_*$ relation for massive galaxies is better constrained by the process of galaxy evolution than for the small dwarfs, while the incompleteness of low H\textsc{i} mass galaxies at high redshift could also play a part in reducing the intrinsic scatter.

We confirm that the notable difference of measured slopes between spiral and full H\textsc{i}-selected galaxies for the $M_{\text{HI}} - M_*$ relation at $0 < z < 0.84$ persists in the split redshift bins. The slopes of Model A for the full sample are 0.542 and 0.273 at $0 < z < 0.04$ and $0.04 < z < 0.084$, respectively, against 0.382 and 0.208 for the spirals. Considering that, in a narrower redshift bin, the effect of Malmquist bias is less strong, this differing slope is arguably rooted in the distinct processes of the gas regulation for spirals and other types.

The notable deviation between MIGHTEE-H\textsc{i} and Simba simulation detected at the high mass end for the full sample and for the spirals alone is also preserved in the narrower redshift bins, where our H\textsc{i}-selected sample is more complete.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{mhi_mstar_relation.pdf}
\caption{Measured $M_{\text{HI}} - M_*$ relation with Model A at $0 < z < 0.04$ (left) and $0.04 < z < 0.084$ (right) for the full H\textsc{i} selected sample (top) and spirals (bottom) from MIGHTEE-H\textsc{i} catalogue (see caption of Fig. 2 for details).}
\end{figure}
5 CONCLUSIONS

We have developed a Bayesian technique that allows us to measure the $M_{\text{HI}} - M_*$ relation above or below the detection threshold in a unified way while taking into account its intrinsic scatter without binning the datasets. We implement this technique with the MIGHTEE-HI Early Science data, and highlight our main results as:

- We measure the $M_{\text{HI}} - M_*$ relation down to $M_{\text{HI}} \sim 10^7 M_\odot$, and up to $z=0.084$ using a H I selected sample of 249 galaxies. We use a double power law model to fit our data, and find this non-linear model is preferred by the data over the linear model, with a transition stellar mass of $\log_{10}(M_*/M_\odot) = 9.15^{+0.8}_{-0.95}$, which roughly corresponds to the break in the stellar mass of $M_* \sim 10^9 M_\odot$ found by Maddox et al. (2015). Beyond this transition (or break) stellar mass, the slope of $M_{\text{HI}} - M_*$ relation flattens.
- We also examine the SFR-$M_{\text{HI}}$ relation and find that it is almost linear across the whole H I mass range, albeit with a large scatter of $\sim 0.48$ dex. Combined with the flattening feature on the $M_{\text{HI}} - M_*$ relation, this supports the hypothesis that the shortage of H I gas supply is likely ultimately responsible for the quenching of the star formation activity observed in massive main sequence galaxies.
- By separating our full sample into spirals, irregulars, mergers and ellipticals, we find the H I sample is dominated by the spirals at the high mass end, and by the irregulars at the low mass end. These two type of galaxies exhibit significantly different slopes for the $M_{\text{HI}} - M_*$ relation, and are likely to be responsible for the detected transition stellar mass from the full sample, although we cannot rule out a pure mass dependence. In addition, we find that the ellipticals show a lower fraction of H I mass than other types from the H I-selected sample, and the highest mass galaxies show a higher fraction of H I mass than predicted by hydrodynamic simulations (Davé et al. 2019), although small number statistics prohibits a strong statement about the H I characteristics of elliptical galaxies and the most massive ones.
- We observe a moderate evolution of the $M_{\text{HI}} - M_*$ relation when splitting our samples into two redshift bins over the last billion years, with shallower slopes at higher redshifts. This trend is largely due to the nature of our flux-limited catalogue with the more massive H I samples dominating at higher redshifts. We also measure a tighter scatter for the $M_{\text{HI}} - M_*$ relation at higher redshifts regardless of the fitting models or galaxy morphologies.

Taken together, our new analysis using the MIGHTEE-HI Early Science data agrees with the results presented in Maddox et al. (2015), where they also found an upper envelope in the amount of H I that a galaxy can retain is dependent on its stellar mass, and we find that this is likely to be related to the morphology of the galaxy. A direct cause of this result could be the tight link between specific angular momentum (or halo spin parameter) and the gas fraction (Obreschkow et al. 2016; Kurapati et al. 2021; Hardwick et al. 2022) for rotation-dominated galaxies. Interestingly, the transition mass that we find using our double-power law (Model B) to describe the $M_{\text{HI}} - M_*$ relation corresponds to the $M_{\text{HI}}/M_*$ ratio at which we find that the spin axis of the galaxy to flip from aligned to mis-aligned from its nearest filament, using a subset of the same data (Tudorache et al. 2022). Given that Maddox et al. (2015) suggest that at $M_* > 10^8 M_\odot$, galaxies with higher H I fractions sit in haloes with higher spin parameters which can work to stabilise H I disks, the spin parameter may in turn be related to their proximity to a filament, along which the gas flows in towards the galaxy (e.g. Codis et al. 2018). Given the limited statistics available in Tudorache et al. (2022) and this study, we cannot decisively investigate these multi-dimensional trends, however, with the full MIGHTEE survey such an analysis would be within reach.

DATA AVAILABILITY

The MIGHTEE-H I spectral cubes and source catalogue will be released as part of the first data release of the MIGHTEE survey.

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REFERENCES

Adams N. J., Bowler R. A. A., Jarvis M. J., Häußler B., Lagos C. D. P., 2021, Monthly Notices of the Royal Astronomical Society, 506, 4933–4951
Ahiria H., et al., 2017, Publications of the Astronomical Society of Japan, 70
Ahiria H., et al., 2019, PASJ, 71, 114
Barnes D. G., et al., 2001, MNRAS, 322, 486
Bruzual G., Charlot S., 2003, MNRAS, 344, 1000
Buchner J., et al., 2014, A&A, 564, A125
Figure 6. Measured $M_{\text{HI}} - M_*$ relation with Model B at $0 < z < 0.04$ (left) and $0.04 < z < 0.084$ (right) from MIGHTEE-$\text{H}_1$ catalogue for the full $\text{H}_1$ selected sample (top) and spirals (bottom) from MIGHTEE-$\text{H}_1$ catalogue (see caption of Fig. 2 for details).
0 < z < 0.04 for Full Sample

0.04 < z < 0.084 for Full Sample

0 < z < 0.04 for Spirals

0.04 < z < 0.084 for Spirals

Figure A1. Posterior parameters of $M_{\text{HI}} - M_*$ relation for Model A at $0 < z < 0.04$ (left) and $0.04 < z < 0.084$ (right) for the full HI selected sample (top) and spirals (bottom) from MIGHTEE-HI catalogue (see caption of Fig. 2 for details).
Figure A2. Posterior parameters of $M_{\text{HI}} - M_*$ relation for Model B at $0 < z < 0.04$ (left) and $0.04 < z < 0.084$ (right) for the full H I selected sample (top) and spirals (bottom) from MIGHTEE-H I catalogue (see caption of Fig. 2 for details).