

The ultra-deep H I radial profiles of late-type galaxies from MHONGOOSE

S. Veronese^{1,2,3}, W. J. G. de Blok^{1,2,4}, E. Brinks⁵, D. Kleiner¹, S. Kurapati¹, J. Healy^{6,4}, and F. M. Maccagni⁷

¹ Netherlands Institute for Radio Astronomy (ASTRON), Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands, e-mail: veronese.astro@gmail.com

² Kapteyn Astronomical Institute, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands

³ Max Planck Institute for Radio Astronomy, Auf dem Hügel 69, 53121 Bonn, Germany

⁴ Department of Astronomy, University of Cape Town, Private Bag X3, 7701 Rondebosch, South Africa

⁵ Centre for Astrophysics Research, University of Hertfordshire, College Lane, Hatfield AL10 9AB, United Kingdom

⁶ Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, UK

⁷ INAF – Osservatorio Astronomico di Cagliari, Via della Scienza 5, 09047, Selargius, CA, Italy

Received 3 March 2026 / Accepted 16 June 2026

ABSTRACT

Galaxy discs have a finite extent, yet how and where their neutral atomic hydrogen (H I) components end is not fully understood. The existence of a break in the H I disc at column densities of $\sim 10^{19} \text{ cm}^{-2}$ has been debated since early 21-cm observations of the spiral galaxy NGC 3198. We present the H I radial profiles of 16 star-forming late-type galaxies from the MeerKAT H I Observations of Nearby Galactic Objects: Observing Southern Emitters (MHONGOOSE) survey spanning a range of H I mass from $10^7 M_{\odot}$ to $10^{10} M_{\odot}$. Via spectral stacking we probed their H I discs down to inclination-corrected column densities of a few times 10^{17} cm^{-2} at kiloparsec resolution. The H I radial profiles of high-mass ($M_{\text{HI}} > 10^9 M_{\odot}$) galaxies are characterised by an inner plateau, followed by a knee at column densities of $\sim 5 \times 10^{20} \text{ cm}^{-2}$, but no edges were unambiguously identified. The H I radial profiles of low-mass ($M_{\text{HI}} < 10^9 M_{\odot}$) galaxies show a steeper decline and no edges either. We find that the profiles are self-similar when normalised to the radius at which a mass surface density of $0.01 M_{\odot} \text{ pc}^{-2}$ is reached, in agreement with recent literature results, but we also found a possible correlation between the normalisation radius and the environment, suggesting that environment contributes to the shaping of the H I distribution in galaxies. The emerging picture is that the diverse morphology of the H I radial profiles is difficult to interpret, and future studies with a larger sample are necessary for quantifying the contribution of internal and external processes acting at different levels for different galaxies.

Key words. Galaxies: evolution - Galaxies: formation - Radio lines: galaxies - Line: identification

1. Introduction

Galaxy discs probed by stars and gas have a finite extent. It is well known that the radial surface brightness distribution of stellar discs is exponential (Freeman 1970; de Grijs & van der Kruit 1996) over a wide range of galaxy luminosities (de Blok et al. 1995; de Jong 1996; Kregel et al. 2002; Pohlen & Trujillo 2006), yet it is debated whether such discs exhibit an outer edge or a break in the surface brightness (Kregel et al. 2002; van der Kruit 2007; van der Kruit & Freeman 2011; Comerón et al. 2012; Martínez-Lombilla et al. 2019; see also the work by Minniti et al. 2011 on the stellar edge of the Milky Way). The radial column density distribution of the gaseous disc in the outskirts of galaxies is also not well understood. The first observational indication of a steep edge in the gas distribution was presented by van Gorkom (1991), who studied the neutral atomic hydrogen (H I) emission from the spiral galaxy NGC 3198. It was shown that on the NE side of the galaxy, the H I column density suddenly drops towards large radii, going from $\sim 10^{20} \text{ cm}^{-2}$ to $\sim 10^{18} \text{ cm}^{-2}$ in a few kiloparsecs. Subsequent H I observations of other galaxies down to column densities of a few times 10^{18} cm^{-2} provided more ambiguous results, with the outer parts of galaxies showing extended discs (Braun & Thilker 2004; Westmeier et al. 2005; Wolfe et al. 2013, 2016; Pisano

2014; Ianjamasimanana et al. 2018).

van Gorkom (1991) pointed out that interpreting the observed edge in NGC 3198 is non-trivial because of the strong lopsidedness of the galaxy. The steep decline could represent a physical edge, or it could be the consequence of the photoionisation of H I caused by an incident cosmic ionising background (CIB; e.g. van Gorkom 1991; Maloney 1993; Dove & Shull 1994; Weymann et al. 2001; Corbelli & Bandiera 2002; Popping et al. 2009; Haardt & Madau 2012; Madau & Haardt 2015; Bland-Hawthorn et al. 2017). Currently, there is no direct measurement of the CIB intensity but only indirect estimates (Weymann et al. 2001; Haardt & Madau 2012; Bland-Hawthorn et al. 2017). Having a precise measurement is fundamental to our understanding of galaxy evolution, as it sets the condition for the ionised-to-neutral gas ratio (Faucher-Giguère et al. 2009; Rahmati et al. 2013; Faucher-Giguère et al. 2015), which impacts the yet-to-be-understood cosmic gas accretion onto galaxies (see the reviews by Putman et al. 2012; Tumlinson et al. 2017; Péroux & Howk 2020; Faucher-Giguère & Oh 2023).

The H I radial profile, which describes the average H I distribution at given radii from the galaxy centre, can thus provide an empirical baseline to constrain the CIB intensity.

Indeed, the CIB intensity is a parameter of the photoionisation models used to describe the observed shapes. However, the morphology of the H I radial profile could also depend on other quantities, such as gas distribution and kinematics, or it could also be that the steep edge is a physical feature (i.e. it marks a decrease in the true mass density of hydrogen).

Past studies of H I radial profiles in a large sample of galaxies have mostly been limited by column densities of a few times 10^{19} cm^{-2} , that is, the column density at which the steep edge is supposed to occur. For instance, using a 3σ over 16 km s^{-1} definition for the H I column density sensitivity, the Westerbork HI Survey of Spiral and Irregular Galaxies (WHISP; van der Hulst et al. 2001) on the Westerbork Synthesis Radio Telescope (WSRT; Högbom & Brouw 1974) reached column densities of a few times 10^{19} cm^{-2} at $60''$ angular resolution, The HI Nearby Galaxies Survey (THINGS; Walter et al. 2008) on the Very Large Array (VLA; Thompson et al. 1980) reached $\sim 10^{19} \text{ cm}^{-2}$ at $30''$, and the Hydrogen Accretion in Local GALaxies (HALOGAS; Heald et al. 2011), again on the WSRT, managed to go as low as $5 \times 10^{18} \text{ cm}^{-2}$ at $30''$ (see also Maccagni & de Blok 2024 for a comprehensive description about past H I surveys and Ianjamasimanana et al. 2018 for details about previous studies of THINGS and HALOGAS H I radial profiles). None of these surveys was able to unambiguously identify edges in the gaseous discs.

Along with column density sensitivity, angular resolution is also a limiting factor in determining the presence of breaks. The work by Sardone et al. (2021) presented H I radial profiles of 18 nearby galaxies, some of which are also included in this paper, observed with the Green Bank Telescope (Jewell & Prestage 2004). They probed the gaseous disc down to column densities of $6.3 \times 10^{17} \text{ cm}^{-2}$ (3σ over 20 km s^{-1}), but galaxies were mostly unresolved at the angular resolution of $9''.1$, making it impossible to determine the existence of breaks. Similarly, the recent work by Wang et al. (2025) probed the H I radial profile of 35 nearby galaxies with the FAST (Jiang et al. 2019) telescope down to column densities of $\sim 10^{18} \text{ cm}^{-2}$ (3σ over 20 km s^{-1}). Again, the angular resolution of $3''.24$ was not sufficient to resolve galaxies with enough resolution elements to detect any break.

With the MeerKAT telescope (Jonas & MeerKAT Team 2016), we now have the observational capabilities to reach, in reasonable observing times, limiting column densities of $\sim 10^{18} \text{ cm}^{-2}$ at $30''$ and even a few times 10^{17} cm^{-2} at $60''$. Indeed, the recent MeerKAT H I Observations of Nearby Galactic Objects: Observing Southern Emitters (MHONGOOSE; de Blok et al. 2024) survey represents a major step forward in the empirical study of H I in the local Universe. MHONGOOSE provides H I observations of 30 nearby gas-rich dwarf and spiral galaxies with different stellar masses ($4.7 \leq \log M_* \leq 10.7 M_\odot$) and star formation rates ($-2.52 \leq \log \text{SFR} \leq 0.75 M_\odot \text{ yr}^{-1}$). The survey reaches column densities down to a few times 10^{17} cm^{-2} , angular resolution from $7''$ to $90''$, and a spectral resolution of 1.4 km s^{-1} in a 1.5° -wide field around each target. Hence, the MHONGOOSE sample represents the ideal dataset to improve our understanding of the H I distribution in the outskirts of galaxies. In this paper, we present the radial profiles of a subsample of MHONGOOSE galaxies and investigate the possible relationship between their properties and the morphology of their H I radial profile.

This paper is organised as follows. In Sect. 2 we present how the H I data were reduced and the MHONGOOSE subsample was selected. In Sect. 3 we describe how we derived the H I radial profiles, and in Sect. 4 we discuss the results, focusing

on identifying edges and exploring alternative mechanisms driving the shape of H I profiles. Finally, in Sect. 5 we list our conclusions and briefly provide some discussion of future prospects.

2. Data reduction and sample selection

Each of the 30 MHONGOOSE galaxies was observed for a total of 55 h spread over ten observing sessions lasting 5.5 h each. The ten observation tracks underwent the same calibration procedure through the Containerized Automated Radio Astronomy Calibration (CARACal) pipeline (Józsa et al. 2020) described in de Blok et al. (2024). CARACal provides a unified platform for standard reduction steps, including data flagging, calibration, continuum subtraction, and spectral line imaging. The H I cubes were generated via WSClean (Offringa et al. 2014; Offringa & Smirnov 2017) within the CARACal pipeline. The cleaning of H I data followed a three-step iterative strategy using the Source Finding Application (SoFIA-2; Westmeier et al. 2021) to create masks for cleaning.

Since we were looking for resolved H I in the outskirts of galaxies, we needed to have a balance between angular resolution and sensitivity. Therefore, we opted for $30''$ cubes, which were obtained by weighting the visibilities with a robust parameter of 1.5 without any tapering. These data reach an average 3σ limiting column density sensitivity of a few times 10^{18} cm^{-2} over 16 km s^{-1} . We used the intensity maps (moment 0) and the intensity-weighted mean velocity fields (moment 1) produced by SoFIA-2 within the MHONGOOSE pipeline. For an extensive description of the data reduction procedure and creation of the various maps, see de Blok et al. (2024).

As we wanted to relate any features in the outer H I profile to the intrinsic density distribution of the H I rather than other processes (such as environmental effects), we excluded MHONGOOSE galaxies that are interacting. The MHONGOOSE sample was initially selected to include only isolated galaxies; however, thanks to the deeper MeerKAT observations, we found that two targets (J1103-23 and J1254-10a) are actually close systems (Kleiner et al., in prep). We also excluded edge-on galaxies (inclination $\geq 80^\circ$; J0516-37, J1153-28, J1303-17b and J2009-61) because of our approach to determining the radial profile by averaging the column density in annuli. Finally, we did not consider galaxies with irregular kinematics based on a preliminary visual inspection of the moment 1 map and a proper kinematical model, as done in Sect. 3.2. The kinematically irregular galaxies are dwarfs ($M_{\text{HI}} < 10^{8.1} M_\odot$: J0049-20, J0320-52, J1321-31, J0429-27, J0454-53, J0135-41) and more massive galaxies (J0331-51 and J0546-52). The final sample consists of 16 out of the 30 MHONGOOSE targets, and we list in Table 1.

3. Data analysis

We derived the H I radial profile by averaging the column density in a set of rings (e.g. Maloney 1993; Ianjamasimanana et al. 2018). This approach has the advantage of maximising the signal-to-noise ratio (S/N), and hence it goes as deep as the data allow. Following the procedure described in Ianjamasimanana et al. (2018), we divided each galaxy into concentric elliptical annuli. We set the ring width along the major axis as being equivalent to the major axis of the beam to ensure that each radial point is independent (Begeman 1987; Gentile et al. 2013; Oh et al. 2015; Mancera Piña et al. 2020, 2022). The H I radial profile is then simply the average column

Table 1: Basic properties of the MHONGOOSE galaxies in our sample.

HIPASS	Name	α (J2000.0) [h m s]	δ (J2000.0) [° ' "]	D [Mpc]	$\log(M_{\text{HI}})$ [$M_{\odot}$]	i [°]	$\log(M_{\star})$ [$M_{\odot}$]	$\log(\text{SFR})$ [$M_{\odot} \text{ yr}^{-1}$]
J0008-34	ESO349-G031	00 08 13.36	-34 34 42.0	3.3	7.11	35	6.13	-2.52
J0031-22	ESO473-G024	00 31 22.51	-22 45 57.5	7.2	7.95	57	6.84	-2.22
J0052-31	NGC0289	00 52 42.36	-31 12 21.0	21.5	10.35	45	10.43	0.16
J0309-41	ESO300-G014	03 09 37.87	-41 01 49.7	10.9	8.89	59	8.90	-0.99
J0310-39	ESO300-G016	03 10 10.48	-40 00 10.5	8.0	7.80	36	7.22	-2.52
J0351-38	ESO302-G014	03 51 40.90	-38 27 08.0	16.8	8.90	28	8.19	-2.52
J0335-24	NGC1371	03 35 01.34	-24 55 59.6	22.7	9.97	46	10.63	-0.62
J0419-54	NGC1566	04 20 00.42	-54 56 16.1	17.7	10.08	37	10.68	0.61
J0445-59	NGC1672	04 45 42.50	-59 14 49.9	19.4	10.29	34	10.69	0.75
J0459-26	NGC1744	04 59 57.80	-26 01 20.0	9.3	9.54	57	9.18	-0.78
J1106-14	KKS2000-23	11 06 12.00	-14 24 25.7	13.9	8.74	70	7.51	-1.82
J1253-12	UGCA307	12 53 57.29	-12 06 21.0	11.0	8.88	60	8.05	-1.56
J1318-21	NGC5068	13 18 54.81	-21 02 20.8	5.2	9.01	28	9.36	-0.54
J1337-28	ESO444-G084	13 37 19.99	-28 02 42.0	4.6	8.02	40	6.69	-2.52
J2257-41	NGC7424	22 57 18.37	-41 04 14.1	7.9	9.60	32	9.56	-0.46
J2357-32	NGC7793	23 57 49.83	-32 35 27.7	3.6	8.96	47	9.34	-0.71

Notes. The inclination angles refer to the optical disc. For further details, see Table 1 of de Blok et al. (2024).

density within each annulus, corrected for the inclination of the ring. The calculation can be done directly on the moment 0 map or on the cube via spectral stacking to further increase the sensitivity of the data and reach larger radii. In the following, we explain how we determined the H I radial profiles of our sample. We refer the reader to Sect. A for a thorough discussion about how we tested the methodology against mock and real data and about how we quantified the main sources of uncertainties.

3.1. Spectral stacking

The H I radial profile can be retrieved directly from the moment 0 map or by spectrally stacking the cube within the rings. Spectral stacking (Zwaan 2000; Chengalur et al. 2001; Fabello et al. 2011; Delhaize et al. 2013; Kanekar et al. 2016; Healy et al. 2021; Amiri et al. 2023) consists of extracting spectra along N different lines of sight (LoSs), aligning them to a reference velocity (Khandai et al. 2011; Maddox et al. 2013; Neumann et al. 2023), and co-adding them so that the flux density in a given channel (k) of the stacked spectrum ($F_{s,k}$) is

$$F_{s,k} = \frac{\sum_{i=1}^N F_{i,k} w_i}{\sum_{i=1}^N w_i}, \quad (1)$$

where $F_{i,k}$ is the flux of the spectrum i in the channel k and w_i is a weight. We chose $w_i = \frac{1}{\sigma_i^2}$, where σ_i^2 is the noise in the i th spectrum, to give less weight to noisy spectra (e.g. Fabello et al. 2011; Kanekar et al. 2016; Ianjamasimanana et al. 2018; Healy et al. 2019, 2021; Chowdhury et al. 2022; Bera et al. 2023).

The effectiveness of spectral stacking is mainly based on two conditions: Gaussian noise and spectral alignment. The former guarantees that the noise decreases as $\sqrt{N}$, while the latter maximises the S/N of the stacked spectrum. Veronese et al. (2025b) have shown that the MHONGOOSE noise can be assumed to be Gaussian. Therefore, the first condition holds. For the spectral alignment, we used an extended velocity field obtained by combining the observed moment 1 map with an extension to larger radii. This extension was computed by assuming that the orientation of the gas disc on the sky and the rotational velocity are constant and equal to the values of the outermost annulus. Although constant rotation velocity extension is a common choice

in the literature (e.g. Ianjamasimanana et al. 2018), assuming that the geometry is also constant might be an oversimplification, as H I discs are known to warp in the outermost regions (García-Ruiz et al. 2002). We briefly discuss in Sect. A.1 how we quantified the impact of these assumptions. In Fig. 1 we show the result of the velocity field extension for the galaxy J0459-26.¹ This extended velocity field was used to spectrally align the cube. The alignment consisted of shifting each spectrum along the spectral axis so that its central channel corresponds to the value of the same LoS in the extended velocity field.

A line finder (Veronese et al. 2025b) was used to detect emission in the stacked spectra and quantify its flux. The line finder, which is based on the SoFIA-2 algorithm (Serra et al. 2015; Westmeier et al. 2021), applies an initial σ clipping and then smooths each stacked spectrum with a boxcar kernel, applying a σ clipping again after each iteration. We chose a kernel equal to 15 channels (21 km s⁻¹) and opted for a σ threshold of three. Detections within three channels (4.2 km s⁻¹) are grouped together into the same source. The resulting source is deemed reliable if it spans more than seven channels (9.8 km s⁻¹), which is the typical dispersion of the H I line (Leroy et al. 2008; Ianjamasimanana et al. 2012). We visually inspected the stacked spectra to confirm the detections of the line finder. Finally, the total flux of a line was calculated as the sum of the flux in each detected channel.

3.2. Rings parametrisation

The geometry of the rings used to extract the H I radial profiles of our MHONGOOSE galaxies was determined by performing a 3D fit on the H I cubes with the 3DFIT task of the 3D-Based Analysis of Rotating Objects via Line Observations (3D-Barolo; Di Teodoro & Fraternali 2015). This procedure consists of modelling the disc of the galaxy with a set of rings, each with its own rotation centroid (x_0, y_0), scale height (z_0), inclination, and position angles (i, φ). The latter are defined as the angle the receding major axis makes in the plane of the sky measured from north through east. The velocity of the gas

¹ The velocity field colour map look-up table used throughout this paper is from English et al. (2024).

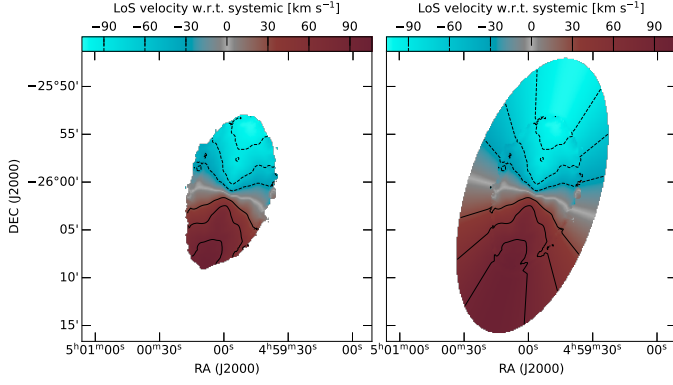


Fig. 1: Extension of the J0459-26 velocity field. The left-side panel shows the moment 1 map derived from SoFiA-2 as part of the MHONGOOSE pipeline. Dashed contours refer to the approaching side, whereas solid lines correspond to receding velocities. In the right-side panel, the extended velocity field is shown, which was used to spectrally align the cube for stacking.

Table 2: Kinematical centre, position, and inclination angle of the rings used to compute the H I radial profiles.

Galaxy	Centre (J2000) [h m s], [° ' '']	i [°]	φ [°]
J0008-34	00 08 11.66, -34 35 03.0	42 ± 1	219 ± 3
J0031-22	00 31 24.03, -22 46 18.5	45 ± 2	173 ± 8
J0052-31	00 52 43.45, -31 12 35.0	55 ± 2	130 ± 8
J0309-41	03 09 39.73, -41 02 10.7	59 ± 1	170 ± 7
J0310-39	03 10 12.31, -40 00 24.5	44 ± 1	190 ± 2
J0335-24	03 35 03.40, -24 56 27.6	46 ± 1	151 ± 8
J0351-38	03 51 40.90, -38 27 57.0	34 ± 2	135 ± 3
J0419-54	04 20 02.05, -54 56 30.1	40 ± 1	223 ± 6
J0445-59	04 45 46.15, -59 15 17.9	48 ± 2	99 ± 15
J0459-26	04 59 58.84, -26 01 34.0	62 ± 1	162 ± 3
J1106-14	11 06 13.44, -14 24 46.7	59 ± 2	238 ± 4
J1253-12	12 53 58.72, -12 06 42.0	61 ± 2	138 ± 4
J1318-21	13 18 56.31, -21 02 41.8	53 ± 12	224 ± 40
J1337-28	13 37 21.57, -28 03 03.0	47 ± 1	70 ± 2
J2257-41	22 57 20.23, -41 04 28.1	26 ± 2	226 ± 5
J2357-32	23 57 50.94, -32 35 48.7	42 ± 2	293 ± 6

Notes. The angles are the medians over all rings as determined from the tilted-ring fit, while the uncertainties are the standard deviation. Values for J0335-24 and J1318-21 were taken from Veronese et al. (2025a) and Healy et al. (2024), respectively.

along a LoS in a given ring is computed as (Begeman 1987)

$$v_{\text{los}} = v_{\text{sys}} + (v_{\text{rot}} \cos \theta + v_{\text{rad}} \sin \theta) \sin i, \quad (2)$$

where v_{sys} , v_{rad} , and v_{rot} are the systemic, radial, and rotation velocity, respectively, whereas θ is the azimuthal angle in the plane of the disc, measured with respect to the major axis position angle φ . The five geometric variables (x_0 , y_0 , z_0 , i , φ), the three kinematic parameters (v_{sys} , v_{rot} , v_{rad}), and the intrinsic velocity dispersion (σ_0) are all simultaneously fitted for each ring. We followed the strategy described in detail in Di Teodoro & Peek (2021). It consists of a two-stage fit done on the approaching and receding sides separately as well as on both sides of the galaxy simultaneously. In the first stage, the free parameters are fitted. However, a systematic issue in 3D modelling is that the derived

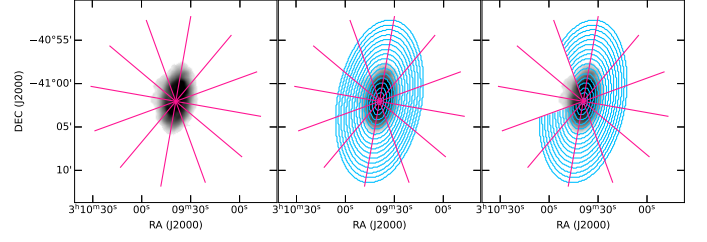


Fig. 2: Elliptical regions used to derive the H I radial profile for J0309-41. In all panels, the moment 0 map of the galaxy is overlaid with the 30° wide conical sectors (indicated with magenta lines) used to filter out the disturbances in the disc. In the central panel we overlay also the initial rings (in blue), whereas in the right-side panel we show only the parts of the annuli used to derive the clean H I radial profile.

φ and i often show the largest scatter (Di Teodoro & Fraternali 2015). Thus, a second stage regularises φ and i and repeats the fit on the remaining free parameters. We chose Bezier functions (Di Teodoro & Fraternali 2015) for this regularisation, as for most of our galaxies φ and i cannot be approximated by a constant or a simple polynomial. For galaxy J0335-24 we used the model presented in Veronese et al. (2025a), where the same method was applied, and for galaxy J1318-21 we retrieved φ and i from Healy et al. (2024).

The goodness of the fit was assessed with a visual comparison of the data and the model using diagnostic plots. These include the moment 1 residuals and the position-velocity (pv) diagram (see Figs. B.1 and B.2 for a representative example based on the galaxy J0459-26). The pv is a slice across the cube that gives the velocity of the gas as a function of a spatial coordinate, which in this case is the distance from the centre of the galaxy. Since the velocity of the gas along the LoS is given by Eq. (2), the pv along the major axis ($\theta = 0^\circ$, top-left panel of Fig. B.2) traces the rotation curve of the galaxy if the position angle is constant as a function of radius. However, along the minor axis ($\theta = 90^\circ$, bottom-left panel of Fig. B.2), non-circular motions can instead be identified via deviations from the systemic velocity. Finally, we considered the median value of the position and inclination angle of all rings to build the set used to calculate the H I radial profiles. These values are listed for each galaxy in Table 2.

3.3. Results

After having evaluated the reliability of our method to recover the H I radial profile of a galaxy (see Sect. A.2), we applied it to the 16 MHONGOOSE galaxies considered in this study. Although we selected our sample to exclude major disturbances in the disc, a few minor perturbations such as tails and streams were still present for some galaxies. To avoid such features affecting the profile, we further divided each ring into twelve 30° wide sectors, as shown in the left panel of Fig. 2 for the galaxy J0309-41. We again derived the H I radial profile but this time after excluding the sectors that show the greatest disturbances, as shown in the panel on the right side of Fig. 2. To take care of the effect of the filling factor of the rings, discussed at the end of Sect. A.2, we considered the H I radial profile derived from the moment 0 map only for rings with a filling factor $> 50\%$.

In Fig. 3 we provide the global and per-sector H I radial pro-

Table 3: Azimuthal angles, with respect to the position angle of the receding side measured in the plane of the sky, excluded from the computation of the H I radial profile.

Galaxy	θ
J0008-34	none
J0031-22	none
J0052-31	90°-360°
J0309-41	210°-300°
J0310-39	none
J0335-24	0°-150°, 270°-330°
J0351-38	120°-180°
J0419-54	0°-150°, 270°-360°
J0445-59	0°-60°, 150°-300°, 330°-360°
J0459-26	none
J1106-14	none
J1253-12	90°-120°, 180°-330°
J1318-21	30°-120°
J1337-28	none
J2257-41	none
J2357-32	none

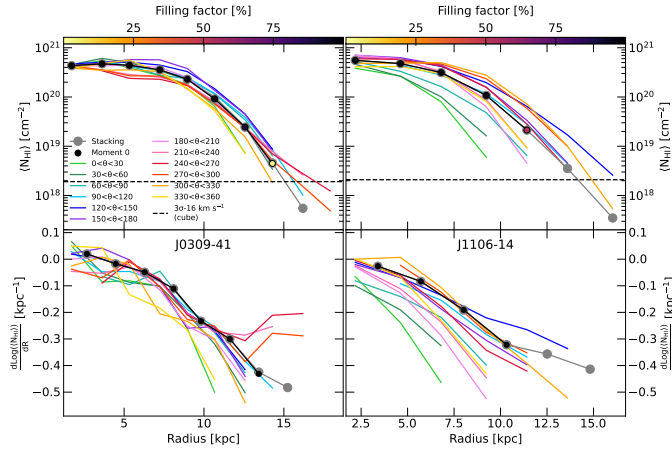


Fig. 3: H I radial profile (top row) and its slope (bottom row) for each azimuthal sector for galaxies J1106-14 (left) and J0309-41 (right). The H I radial profile derived from the entire galaxy via stacking is reported with gray points. The points colour-coded with the ring filling factor refer to the H I radial profile derived for the moment 0 map. The coloured lines are the radial profile of each azimuthal sector as recovered via stacking only (see text for further details). The dashed black line is the 3σ noise level in the cube over 16 km s^{-1} .

files² for J1106-14 and J0309-41 together with their slope, which we define as

$$\frac{\Delta \text{Log} N_{\text{HI}}}{\Delta R} = \frac{\text{Log} N_{\text{HI}}(R + \Delta R) - \text{Log} N_{\text{HI}}(R)}{\Delta R}. \quad (3)$$

The figure clearly highlights the sectors that deviate from the rest of the profiles. For example, J0309-41 has a disc disturbance that distorts the profile at azimuthal angles $210^\circ < \theta < 300^\circ$. In Table 3 we list the azimuthal sectors that were excluded for each galaxy. Deriving again the H I radial profile without such

² The global and per-sector H I radial profiles of each galaxy is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/>

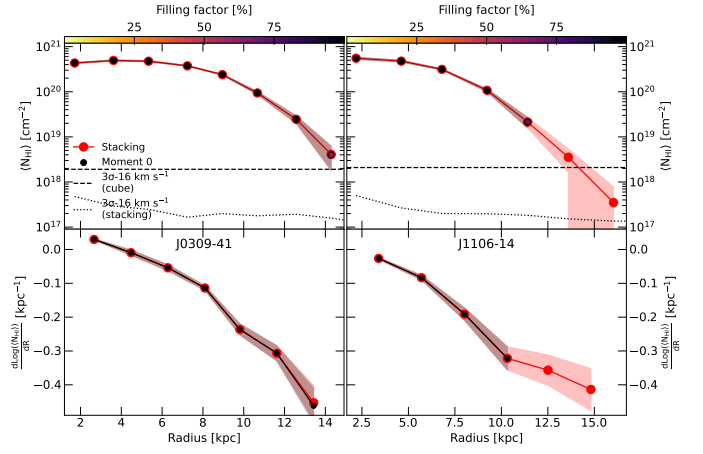


Fig. 4: H I radial profile (top row) and its slope (bottom row) for galaxies J1106-14 (left) and J0309-41 (right) after excluding disturbed sectors (only applies to J0309-41). The H I radial profile derived from stacking and from the moment 0 map is given with red and coloured points. The colour coding reflects the ring filling factor for the moment 0 map. The black and red shaded areas are the uncertainty from the moment 0 and stacking, respectively, derived from Monte Carlo simulations. The dashed black line is the 3σ noise level in the cube over 16 km s^{-1} , and the dotted black line is the noise level achieved via stacking using the same definition.

regions resulted in the curves presented in Fig. 4 for J1106-14 and J0309-41. In Fig. 5 we show this ‘clean’ H I radial profile (top panel) and its slope (bottom panel) on the same scale for all galaxies.³ Fig. 5 revealed that the profiles are rather smooth. However, there seem to be two major differences between those of low-mass ($M_{\text{HI}} \lesssim 10^9 M_\odot$) and those of high-mass galaxies: The latter are less steep, as can be appreciated by looking at the slopes. The same trend was also observed in the H I radial profiles presented by Ianjamasimanana et al. (2018) and Wang et al. (2025).

4. Discussion

4.1. The presence of disc edges

The goal of the work in this paper was to identify edges in the H I discs and relate them to a physical break or photoionisation. In the profiles presented in Fig. 5, we observed knees occurring at column densities of about $\sim 5 \times 10^{20} \text{ cm}^{-2}$, reflecting the column density threshold above which the formation of molecular hydrogen (Savage et al. 1977; Bigiel et al. 2008) and cold ($\sim 100 \text{ K}$) H I (Kanekar et al. 2011) is favourable,⁴ but we did not see any evident breaks. A majority of the slopes almost monotonically decrease in radius, as shown in the bottom panel of in Fig. 5, and the spread in their values renders any quantitative determination for the presence of breaks challenging. For example, it is not possible to identify edges at a single slope value.

If the shape of the H I radial profile is the result of the hydrogen becoming mainly ionised, then from photoionisation models we expect a break to occur at a certain critical column den-

³ The clean H I radial profile of each galaxy is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/>

⁴ Follow-up studies of the molecular radial profile may test whether the knee is really caused by the molecular-to-atomic transition.

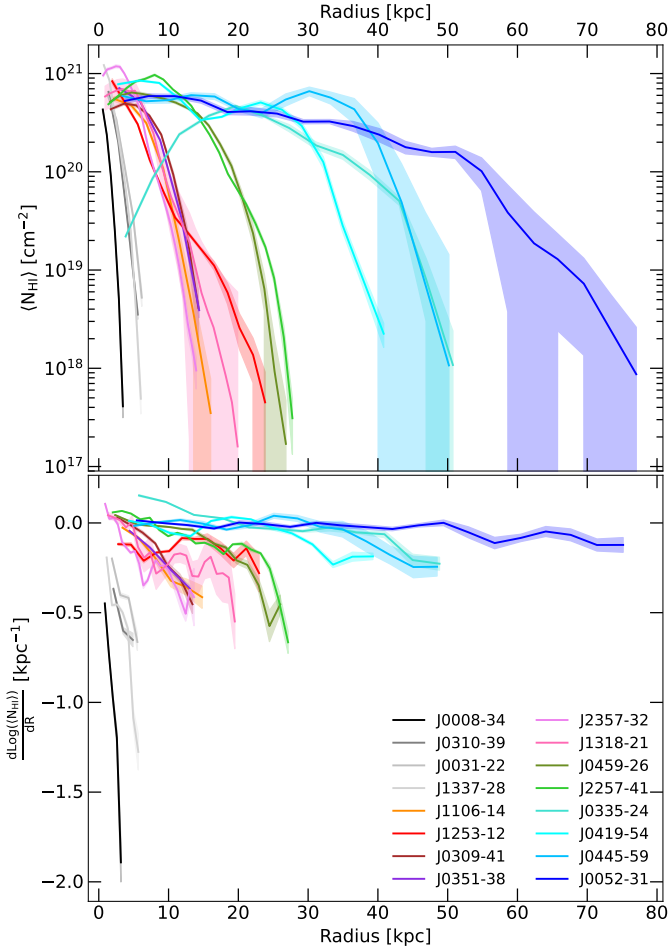


Fig. 5: Clean H I radial profiles (top panel) and their slope (bottom panel) on the same radial scale for the 16 MHONGOOSE galaxies studied in this work. The coloured shaded areas are the uncertainty derived from Monte Carlo simulations.

sity (Maloney 1993; Dove & Shull 1994; Bland-Hawthorn et al. 2017):

$$N_C = 2.6 \times 10^{19} \left(\frac{\phi_i \sigma_g v}{\Sigma_h} \right)^{\frac{1}{2}} \text{ cm}^{-2}, \quad (4)$$

where ϕ_i is the ionising background flux in units of $10^4 \text{ phot cm}^{-2} \text{ s}^{-1}$, σ_g is the vertical velocity dispersion of the gas in units of 10 km s^{-1} , v is the asymptotic rotation velocity of the disc in units of 150 km s^{-1} , and Σ_h is the mass surface density of the dark matter halo in units of $100 \text{ M}_\odot \text{ pc}^{-2}$. This critical value is expected to be $\sim 10^{19} \text{ cm}^{-2}$ if the atomic gas is warm ($T \sim 10^4 \text{ K}$) and smoothly distributed in the galactic potential.

To identify a break at the critical column density we calculated N_C for our galaxies while taking the relevant parameters from the kinematical modelling (see Table 4 for the list of values). We used the mean rotation velocity in the outer disc as an estimator for v and the mean dispersion for σ_g , which was assumed to not vary with inclination. These simplifications have a minimal impact on the derived N_C . In fact, an error of a factor of ten in v or σ_g would change N_C by only a factor of about three. For ϕ_i and Σ_h , we opted for $\phi_i = 10^4 \text{ phot cm}^{-2} \text{ s}^{-1}$ (Bland-Hawthorn et al. 2017) and a typical $\Sigma_h = 100 \text{ M}_\odot \text{ pc}^{-2}$ (Saburova & Del Popolo 2014).

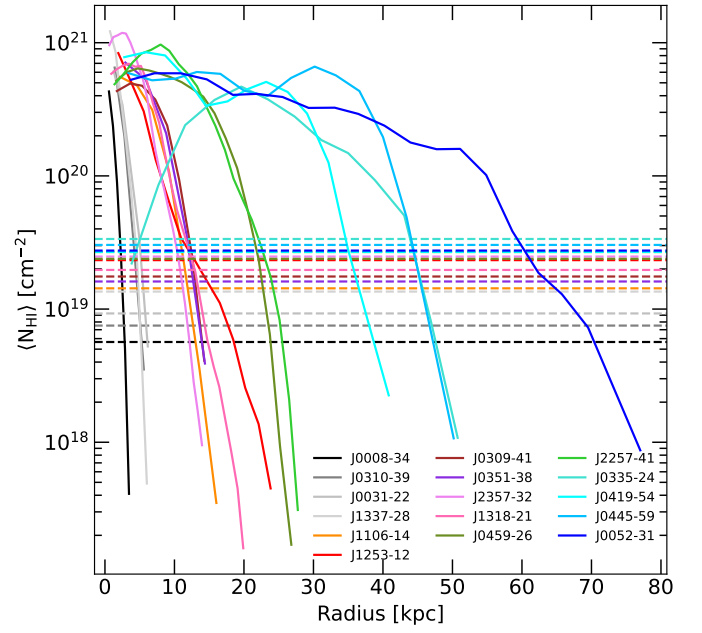


Fig. 6: H I radial profile of our galaxies and their column density at which the hydrogen should become mostly ionised. This critical value is reported, with the same colour of the galaxy, with the horizontal dashed lines. The colour-coding of the galaxies is the same as in Fig. 5. Given the crowdedness of the plot, we also refer to Table 4 for the critical column density of each galaxy.

In Fig. 6 we show the H I radial profiles of these galaxies together with their predicted critical column density. From the plot, we did not observe a correlation between N_C and the shape of the profiles nor any evidence of a break. For instance, J0052-31, J0419-54, and J2257-41 have almost the same $N_C \sim 2.7 \times 10^{19} \text{ cm}^{-2}$, but their profiles differ, with J2257-41 having a much shorter plateau in the inner part and a steeper decline. Also, J0310-39 and J0031-22 should have a break around $N_C \sim 0.9 \times 10^{19} \text{ cm}^{-2}$, but their H I distribution decreases steeply from the very centre, with no evidence of an edge at the expected N_C . The same holds for the slopes at the critical column density, ranging from -0.1 for the most massive galaxy (J0052-31) to -1.5 for the least massive galaxy (J0008-34). Consequently, we argue that in our galaxies we are not observing the break predicted by photoionisation. Nonetheless, there is also another consideration to make: the available photoionisation models have mostly been calibrated on the van Gorkom (1991) observations of NGC 3198. Therefore, it could be that these predictions are galaxy dependent.

4.2. Possible mechanisms shaping the H I radial profiles

The lack of evident edges in the H I radial profiles and the different slopes reveal that photoionisation is likely not the main driver of the radial distribution of neutral gas. Since we observed from Fig. 5 that low-mass galaxies have a shorter central plateau and a steeper decline than high-mass galaxies, our first guess is that what we see is a resolution effect. Indeed, even if galaxies have been observed at roughly the same angular resolution, their different distances and sizes imply a varying linear resolution. Therefore, it could be that the steeper slope observed for low-mass galaxies is due to the lower linear resolution with which we are sampling their radial profile. We tested this by computing

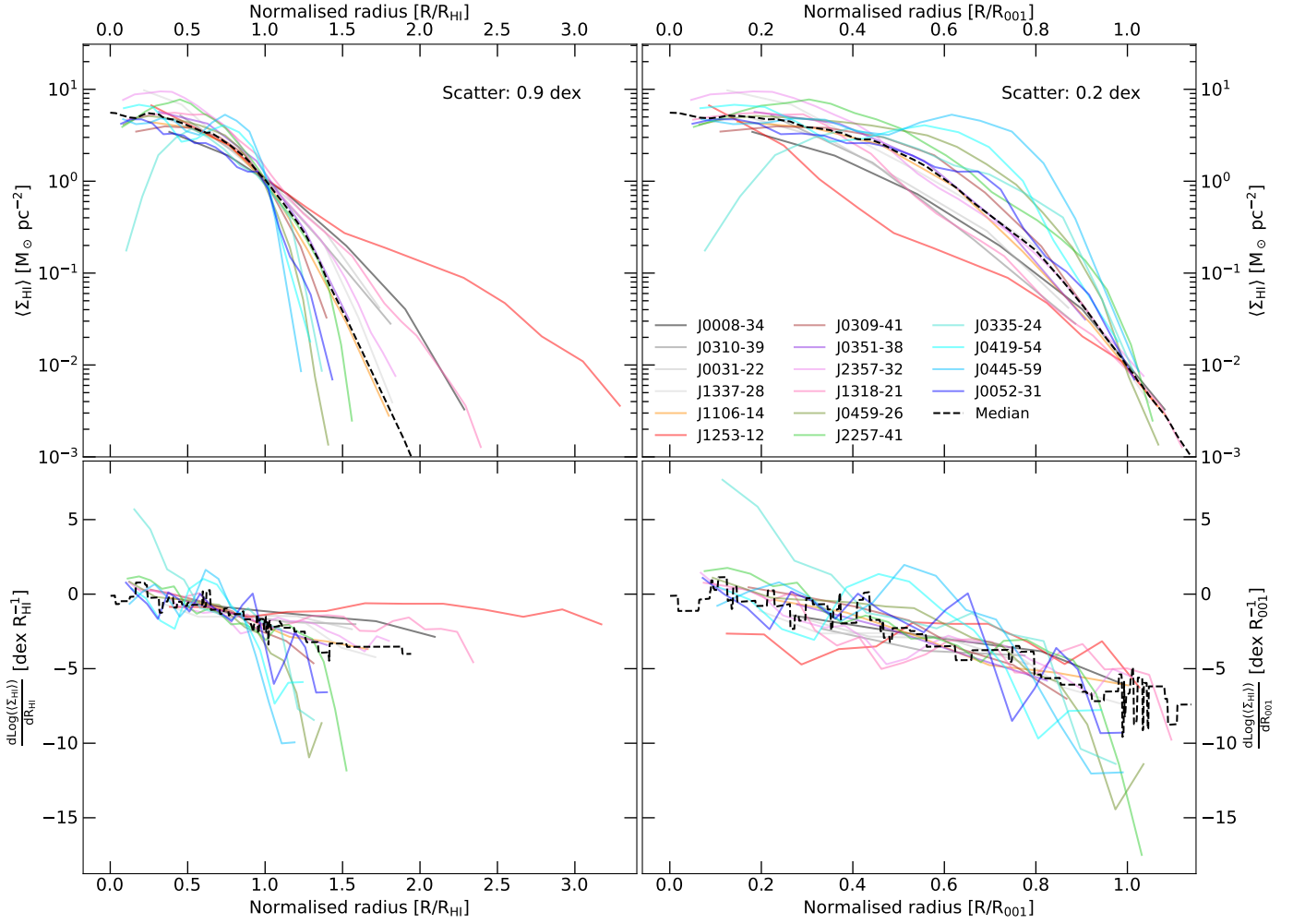


Fig. 7: H I radial profiles (top panels) and their slopes (bottom panels) when normalised to the radius at which the mass surface density reaches $1 \text{ M}_{\odot} \text{ pc}^{-2}$ (R_{HI} ; left panels) and to the radius at which the mass surface density reaches $0.01 \text{ M}_{\odot} \text{ pc}^{-2}$ (R_{001} ; right panels). The dashed curves refer to the median profile.

the ratio between the beam size (which is equivalent to the ring width) and the extent of the H I disc for each galaxy. We found that all of our galaxies are well resolved, with J0310-39 having the smallest beam-to-size ratio (0.25, i.e. four resolution elements) and J0052-31 being the most resolved (beam-to-size ratio of 0.05, equivalent to 20 resolution elements). Consequently, resolution does not play a major role in this work.

The observed trends between the slope of the H I radial profiles and the galaxy mass might be reflect the well-known H I mass-size relation (Broeils & Rhee 1997; Swaters et al. 2002; Wang et al. 2016; Rajohnson et al. 2022), which has recently been found to hold down to column densities of $\sim 10^{18} \text{ cm}^{-2}$ (Wang et al. 2025). As discussed in detail by Wang et al. (2016), one interpretation for the existence of the H I mass-size relation is that the physical processes acting on the H I, such as gas accretion (Faucher-Giguère & Oh 2023), neutral-to-molecular gas conversion (Saintonge & Catinella 2022), photoionisation (Madau & Haardt 2015), and galaxy interactions (Ellison et al. 2015), have the same impact among different galaxies (Wang et al. 2016). If this is true, then different galaxies should exhibit H I radial profiles with similar shapes and slopes when normalised to a given radius.

In Fig. 7 we show the H I radial profiles and their slopes when normalised to R_{HI} (left panels), which is the radius at which a

mass surface density of $1 \text{ M}_{\odot} \text{ pc}^{-2}$ is reached, and when normalised to R_{001} (right panels), corresponding to the radius where the mass surface density is $0.01 \text{ M}_{\odot} \text{ pc}^{-2}$. When normalising to R_{HI} , most⁵ galaxies resemble the median profile out to R_{HI} , after which they significantly diverge (scatter of ~ 0.9 dex). When normalising to R_{001} instead, the profiles align more closely with the median distribution (scatter of ~ 0.2 dex). The same effect was observed by Wang et al. (2025), although we must note that their sample does not include low-mass galaxies and care must be taken when making comparisons with their result. They interpret this behaviour as a possible hint that the physical processes acting on the low-column density H I (gravity, photoionisation, gas accretion) are common to all galaxies. In contrast, since different shapes are observed when normalising to higher Σ_{HI} thresholds, the processes affecting the denser H I distribution (mainly stellar and active galactic nucleus feedback) are different for different galaxies. Our analysis seems to support this view, but with one important caveat: It holds if environmental effects are negligible.

Among the aforementioned external processes, the environ-

⁵ The only exception is J0335-24. This galaxy hosts a low power active galactic nucleus that might be responsible for the lack of H I in the inner regions of the galaxy (Veronese et al. 2025a).

Table 4: Critical column density and parameters used in its computation.

Galaxy	v km s ⁻¹	σ_g km s ⁻¹	N_C 10 ¹⁹ cm ⁻²
J0008-34	8.5	8	0.6
J0031-22	21	9	0.9
J0052-31	158	11	2.7
J0309-41	73	9	1.8
J0310-39	13	10	0.8
J0335-24	256	10	3.4
J0351-24	50	11	1.6
J0419-54	149	11	2.7
J0445-59	154	13	3.0
J0459-26	114	11	2.4
J1106-14	57	8	1.4
J1253-12	105	11	2.3
J1318-21	86	10	2.0
J1337-28	46	9	1.3
J2257-41	160	10	2.7
J2357-32	125	11	2.5

Notes. The values for v and σ_g are from the best-fit of 3D-Barolo. $\phi_i = 10^4$ phot cm⁻² s⁻¹ and $\Sigma_h = 100$ M_⊙ pc⁻² are assumed from Bland-Hawthorn et al. (2017) and Saburova & Del Popolo (2014), respectively.

ment is of particular concern. It is known from both simulations (Nickerson et al. 2013; Nierenberg et al. 2013; Engler et al. 2021) and observations (Nierenberg et al. 2012; Sales et al. 2013; Geha et al. 2017; Mao et al. 2021, 2024) that low- and high-mass galaxies generally have different environments, with the latter having more satellites because of their deeper potential. The presence of companions might influence the distribution of gas in the host galaxy, for instance, by gravitationally disturbing its outer disc. Our sample does not include strongly interacting galaxies, and in our analysis we already excluded the most disturbed regions of the disc (see the discussion in Sect. 3.3). However, it could still be that weak gravitational interactions produce not only clear morphological disturbances but also more subtle effects, such as the shallower decline observed for the high-mass galaxies. To test this hypothesis, we performed a least squares linear fit to the slopes of the unnormalised radial profiles, as from the bottom panel of Fig. 5 it is evident how the slope values decrease approximately linearly in radius. In the top panel of Fig. 8, we show this ‘rate of decline’ for the slopes, i.e. the second derivative of the H I radial profile, as a function of the number of satellites reported in Table 7 of de Blok et al. (2024). We found that the H I radial profile of galaxies with at least one companion has a second derivative close to zero, while the profile of galaxies without satellites has a higher (in absolute value) rate of decline. Furthermore, when no satellites are present, it seems that the smaller the H I mass of the galaxy, the faster the rate of decline.

Another diagnostic of the impact of satellites on the H I radial profiles comes from checking whether there is a correlation between environment and normalisation radii. Indeed, the gravitational interaction likely does one (or more) of the following: redistributes the gas outward via tidal torques, builds extended low-density envelopes, and prevents sharp truncations. This effectively increases the normalisation radius, especially at lower column density thresholds. Therefore, we plotted three different normalisation radii as a function of the number of satellites (see

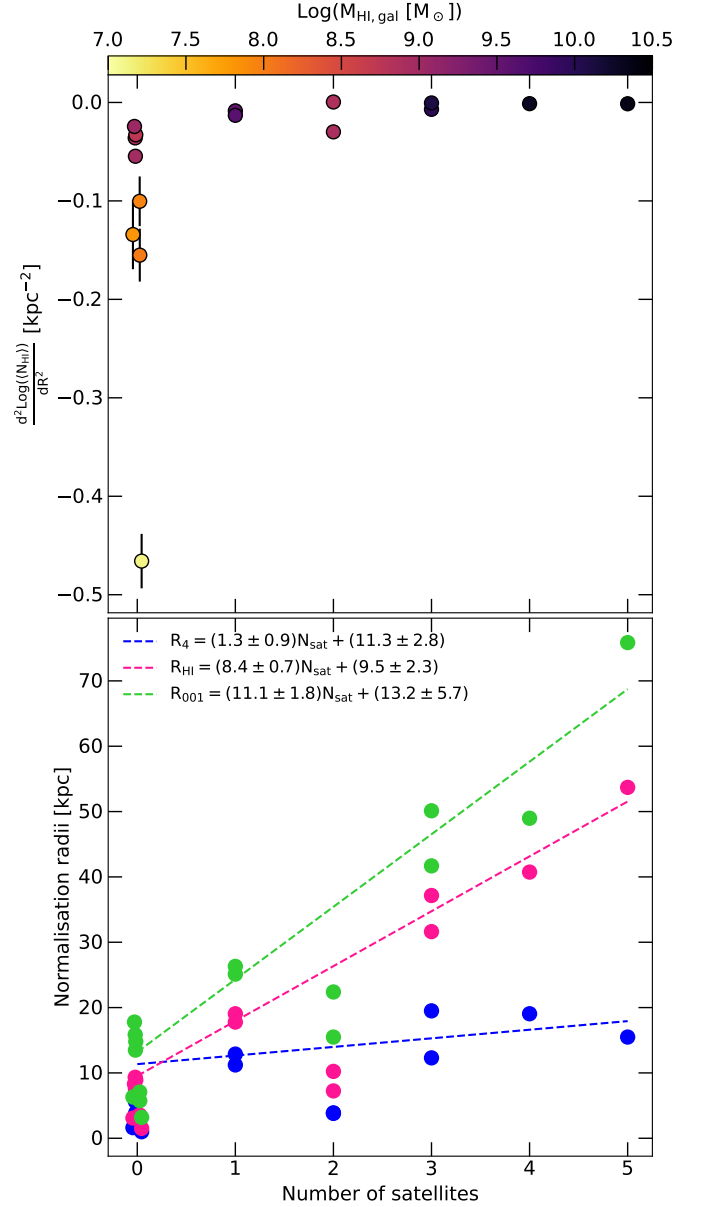


Fig. 8: Slope decline (top panel) and normalisation radii (bottom panel) as a function of the number of satellites. In the top panel each circle is a galaxy, colour-coded by its H I mass. Where not visible, uncertainties are smaller than the circle. In the bottom panel, the blue, pink, and green points refer to R_{001} , R_{HI} , and R_4 , respectively. The dashed lines, colour-coded with the normalisation radius they refer to, are linear least square fits considering at least one satellite. Slopes and intercepts are given in the top-left corner. In all panels a small horizontal offset has been applied to galaxies without satellites for better readability.

the bottom panel of Fig. 8): R_{001} , R_{HI} , and R_4 , i.e. the radius at which a mass surface density of $4 \text{ M}_{\odot} \text{ pc}^{-2}$ is reached. The latter ($N_{\text{HI}} \sim 5 \times 10^{20} \text{ cm}^{-2}$) roughly corresponds to the location of the knee in the unnormalised radial profiles (see Sect. 4.1) and traces the inner regions of the H I disc where the H I-to-H₂ transition is likely to occur (Savage et al. 1977; Bigiel et al. 2008). We did a simple least squares linear fit to galaxies with at least one companion to quantify the correlation. The outcome was that we saw a stronger linear correlation towards normalisation radii probing

lower column densities:

$$R_4 = (1.3 \pm 0.9)N_{\text{sat}} + (11.3 \pm 2.8)$$

$$R_{H\text{I}} = (8.4 \pm 0.7)N_{\text{sat}} + (9.5 \pm 2.3) \quad (5)$$

$$R_{001} = (11.1 \pm 1.8)N_{\text{sat}} + (13.2 \pm 5.7) \quad (6)$$

where N_{sat} is the number of satellites. This means that even gentle interactions impact the H I distribution. Quantifying the impact of the environment, for instance, by considering the total mass of the satellites or by including disturbed regions of the disc, as well as interacting galaxies in our sample requires a larger sample size and is outside the scope of this paper, so we leave it for future investigations.

In conclusion, we find that the radial H I distribution of non-interacting galaxies becomes more self-similar at progressively lower column density thresholds, in agreement with previous studies such as Wang et al. (2025). In addition to what was proposed in the literature, we argue that the environment must be taken into account when interpreting this self-similarity. Indeed, the presence of satellites, even if they are not causing direct gas stripping, redistributes the gas to larger radii, producing extended and shallow outer profiles. When scaled by an environmentally dependent radius, these profiles appear self-similar, but this similarity arises from the scaling itself rather than from universal underlying physics.

5. Conclusion and future prospect

We have presented the H I radial profiles of 16 MHONGOOSE galaxies. We probed, at spatial resolutions from 0.6 kpc to 4 kpc depending on galaxy distance, the gaseous disc down to column densities of a few times 10^{17} cm^{-2} , more than an order of magnitude lower than the expected column density at which the disc should become mostly ionised (Maloney 1993; Dove & Shull 1994; Bland-Hawthorn et al. 2017) and an order of magnitude lower than a previous observational analysis based on THINGS and HALOGAS observations (Ianjamasimanana et al. 2018). In the following, we list our main findings:

- i) The H I radial profiles are characterised by an inner plateau, likely associated with the transition from atomic to molecular hydrogen, followed by a knee at column densities of about $5 \times 10^{20} \text{ cm}^{-2}$. We did not observe breaks at column densities of a few times 10^{19} cm^{-2} , the point at which the hydrogen should become mostly ionised (as predicted by photoionisation models).
- ii) We find that the H I radial profiles are self-similar when normalised to the radius at which a mass surface density of $0.01 \text{ M}_{\odot} \text{ pc}^{-2}$ is reached, in agreement with recent work by Wang et al. (2025).
- iii) We also find that galaxies with at least one satellite do not show a steep decline and that the normalisation radius correlates with the number of satellites, suggesting that the environment plays a role in shaping the H I distribution in galaxies.

Our analysis was mainly limited by two observational factors: sample size and environment. In the future, insights on what drives the H I distribution in galaxies might come from a more precise quantification of the impact of the environment. A statistically significant number of low-mass galaxies, which are expected to not retain satellites, might constitute a good control sample to test against and would also offer the possibility to simultaneously confirm whether it is true that they have a steeper

profile than high-mass systems.

A thorough revision of photoionisation models may also be necessary. For instance, Eq. (4) assumes that the H I velocity dispersion outside the stellar disc is set by the gravitational potential of the dark matter halo, i.e. the volume density is dominated by dark matter. However, recent studies find that the volumetric densities of gas in these regions could be much larger (e.g. Bacchini et al. 2019), and they may significantly contribute to the gravitational force perpendicular to the disc, thus affecting the velocity dispersion and consequently the analytical form of Eq. (4). New results from the eROSITA X-ray telescope (Predehl et al. 2021) have confirmed the presence of a hot circumgalactic medium (Zhang et al. 2024a) whose X-ray luminosity correlates with the galaxy stellar mass (Zhang et al. 2024b). The pressure from the hot medium may compress the H I disc, decreasing its thickness and increasing the gas volumetric density (Wang et al. 2024; Lin et al. 2025). Hence, extending the revised photoionisation models to a larger sample of galaxies can give invaluable information for a better estimate of the CIB intensity and the ionisation state of the circumgalactic medium that would impact our understanding of galaxy formation and evolution.

Acknowledgements. We thank the anonymous referee for the constructive comments. This work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 882793 'MeerGas'). The MeerKAT telescope is operated by the South African Radio Astronomy Observatory, which is a facility of the National Research Foundation, an agency of the Department of Science and Innovation. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is funded by the National Aeronautics and Space Administration and operated by the California Institute of Technology. JH acknowledges support from the UK SKA Regional Centre (UKSRC). The UKSRC is a collaboration between the University of Cambridge, University of Edinburgh, Durham University, University of Hertfordshire, University of Manchester, University College London, and the UKRI Science and Technology Facilities Council (STFC) Scientific Computing at RAL. The UKSRC is supported by funding from the UKRI STFC.

References

- Amiri, M., Bandura, K., Chen, T., et al. 2023, *ApJ*, 947, 16
 Bacchini, C., Fraternali, F., Iorio, G., & Pezzulli, G. 2019, *A&A*, 622, A64
 Begeman, K. G. 1987, PhD thesis, -
 Bera, A., Kanekar, N., Chengalur, J. N., & Bagla, J. S. 2023, *ApJ*, 950, L18
 Bigiel, F., Leroy, A., Walter, F., et al. 2008, *AJ*, 136, 2846
 Bland-Hawthorn, J., Maloney, P. R., Stephens, A., Zovaro, A., & Popping, A. 2017, *ApJ*, 849, 51
 Braun, R. & Thilker, D. A. 2004, *A&A*, 417, 421
 Broeils, A. H. & Rhee, M. H. 1997, *A&A*, 324, 877
 Chengalur, J. N., Braun, R., & Wieringa, M. 2001, *A&A*, 372, 768
 Chowdhury, A., Kanekar, N., & Chengalur, J. N. 2022, *ApJ*, 937, 103
 Comerón, S., Elmegreen, B. G., Salo, H., et al. 2012, *ApJ*, 759, 98
 Corbelli, E. & Bandiera, R. 2002, *ApJ*, 567, 712
 de Blok, W. J. G., Healy, J., Maccagni, F. M., et al. 2024, *A&A*, 688, A109
 de Blok, W. J. G., van der Hulst, J. M., & Bothun, G. D. 1995, *MNRAS*, 274, 235
 de Grijs, R. & van der Kruit, P. C. 1996, *A&AS*, 117, 19
 de Jong, R. S. 1996, *A&A*, 313, 45
 Delhaize, J., Meyer, M. J., Staveley-Smith, L., & Boyle, B. J. 2013, *MNRAS*, 433, 1398
 Di Teodoro, E. M. & Fraternali, F. 2015, *MNRAS*, 451, 3021
 Di Teodoro, E. M. & Peek, J. E. G. 2021, *ApJ*, 923, 220
 Dove, J. B. & Shull, J. M. 1994, *ApJ*, 423, 196
 Ellison, S. L., Fertig, D., Rosenberg, J. L., et al. 2015, *MNRAS*, 448, 221
 Engler, C., Pillepich, A., Pasquali, A., et al. 2021, *MNRAS*, 507, 4211
 English, J., Richardson, M. L. A., Ferrand, G., & Deg, N. 2024, *CosmosCanvas: Useful color maps for different astrophysical properties*, *Astrophysics Source Code Library*, record ascl:2401.005
 Fabello, S., Catinella, B., Giovanelli, R., et al. 2011, *MNRAS*, 411, 993
 Faucher-Giguère, C.-A., Hopkins, P. F., Kereš, D., et al. 2015, *MNRAS*, 449, 987

- Faucher-Giguère, C.-A., Lidz, A., Zaldarriaga, M., & Hernquist, L. 2009, *ApJ*, 703, 1416
- Faucher-Giguère, C.-A. & Oh, S. P. 2023, *ARA&A*, 61, 131
- Freeman, K. C. 1970, *ApJ*, 160, 811
- García-Ruiz, I., Sancisi, R., & Kuijken, K. 2002, *A&A*, 394, 769
- Geha, M., Wechsler, R. H., Mao, Y.-Y., et al. 2017, *ApJ*, 847, 4
- Gentile, G., Józsa, G. I. G., Serra, P., et al. 2013, *A&A*, 554, A125
- Haardt, F. & Madau, P. 2012, *ApJ*, 746, 125
- Heald, G., Józsa, G., Serra, P., et al. 2011, *A&A*, 526, A118
- Healy, J., Blyth, S. L., Elson, E., et al. 2019, *MNRAS*, 487, 4901
- Healy, J., Blyth, S. L., Verheijen, M. A. W., et al. 2021, *A&A*, 650, A76
- Healy, J., de Blok, W. J. G., Maccagni, F. M., et al. 2024, *A&A*, 687, A254
- Högbom, J. A. & Brouw, W. N. 1974, *A&A*, 33, 289
- Ianjamasimanana, R., de Blok, W. J. G., Walter, F., & Heald, G. H. 2012, *AJ*, 144, 96
- Ianjamasimanana, R., Walter, F., de Blok, W. J. G., Heald, G. H., & Brinks, E. 2018, *AJ*, 155, 233
- Jewell, P. R. & Prestage, R. M. 2004, in *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, Vol. 5489, *Ground-based Telescopes*, ed. J. M. Oschmann, Jr., 312–323
- Jiang, P., Yue, Y., Gan, H., et al. 2019, *Science China Physics, Mechanics, and Astronomy*, 62, 959502
- Jonas, J. & MeerKAT Team. 2016, in *MeerKAT Science: On the Pathway to the SKA*, 1
- Józsa, G. I. G., White, S. V., Thorat, K., et al. 2020, *CARACal: Containerized Automated Radio Astronomy Calibration pipeline*, *Astrophysics Source Code Library*, record ascl:2006.014
- Kanekar, N., Braun, R., & Roy, N. 2011, *ApJ*, 737, L33
- Kanekar, N., Sethi, S., & Dwarakanath, K. S. 2016, *ApJ*, 818, L28
- Khandai, N., Sethi, S. K., Di Matteo, T., et al. 2011, *MNRAS*, 415, 2580
- Kregel, M., van der Kruit, P. C., & de Grijs, R. 2002, *MNRAS*, 334, 646
- Leroy, A. K., Walter, F., Brinks, E., et al. 2008, *AJ*, 136, 2782
- Lin, X., Wang, J., Staveley-Smith, L., et al. 2025, *ApJ*, 982, 151
- Maccagni, F. M. & de Blok, W. J. G. 2024, *arXiv e-prints*, arXiv:2407.03166
- Madau, P. & Haardt, F. 2015, *ApJ*, 813, L8
- Maddox, N., Hess, K. M., Blyth, S. L., & Jarvis, M. J. 2013, *MNRAS*, 433, 2613
- Maloney, P. 1993, *ApJ*, 414, 41
- Mancera Piña, P. E., Fraternali, F., Oman, K. A., et al. 2020, *MNRAS*, 495, 3636
- Mancera Piña, P. E., Fraternali, F., Oosterloo, T., et al. 2022, *MNRAS*, 512, 3230
- Mao, Y.-Y., Geha, M., Wechsler, R. H., et al. 2024, *ApJ*, 976, 117
- Mao, Y.-Y., Geha, M., Wechsler, R. H., et al. 2021, *ApJ*, 907, 85
- Marasco, A., de Blok, W. J. G., Maccagni, F. M., et al. 2025, *A&A*, 697, A86
- Martínez-Lombilla, C., Trujillo, I., & Knapen, J. H. 2019, *MNRAS*, 483, 664
- Minniti, D., Saito, R. K., Alonso-García, J., Lucas, P. W., & Hempel, M. 2011, *ApJ*, 733, L43
- Neumann, L., den Brok, J. S., Bigiel, F., et al. 2023, *A&A*, 675, A104
- Nickerson, S., Stinson, G., Couchman, H. M. P., Bailin, J., & Wadsley, J. 2013, *MNRAS*, 429, 452
- Nierenberg, A. M., Auger, M. W., Treu, T., et al. 2012, *ApJ*, 752, 99
- Nierenberg, A. M., Treu, T., Menci, N., Lu, Y., & Wang, W. 2013, *ApJ*, 772, 146
- Offringa, A. R., McKinley, B., Hurley-Walker, N., et al. 2014, *MNRAS*, 444, 606
- Offringa, A. R. & Smirnov, O. 2017, *MNRAS*, 471, 301
- Oh, S.-H., Hunter, D. A., Brinks, E., et al. 2015, *AJ*, 149, 180
- Péroux, C. & Howk, J. C. 2020, *ARA&A*, 58, 363
- Pisano, D. J. 2014, *AJ*, 147, 48
- Pohlen, M. & Trujillo, I. 2006, *A&A*, 454, 759
- Popping, A., Davé, R., Braun, R., & Oppenheimer, B. D. 2009, *A&A*, 504, 15
- Predehl, P., Andritschke, R., Arefiev, V., et al. 2021, *A&A*, 647, A1
- Putman, M. E., Peek, J. E. G., & Joun, M. R. 2012, *ARA&A*, 50, 491
- Rahmati, A., Pawlik, A. H., Raičević, M., & Schaye, J. 2013, *MNRAS*, 430, 2427
- Rajohnson, S. H. A., Frank, B. S., Ponomareva, A. A., et al. 2022, *MNRAS*, 512, 2697
- Saburova, A. & Del Popolo, A. 2014, *MNRAS*, 445, 3512
- Saintonge, A. & Catinella, B. 2022, *ARA&A*, 60, 319
- Sales, L. V., Wang, W., White, S. D. M., & Navarro, J. F. 2013, *MNRAS*, 428, 573
- Sardone, A., Pisano, D. J., Pingel, N. M., et al. 2021, *ApJ*, 910, 69
- Savage, B. D., Bohlin, R. C., Drake, J. F., & Budich, W. 1977, *ApJ*, 216, 291
- Serra, P., Westmeier, T., Giese, N., et al. 2015, *MNRAS*, 448, 1922
- Swaters, R. A., van Albada, T. S., van der Hulst, J. M., & Sancisi, R. 2002, *A&A*, 390, 829
- Thompson, A. R., Clark, B. G., Wade, C. M., & Napier, P. J. 1980, *ApJS*, 44, 151
- Tumlinson, J., Peebles, M. S., & Werk, J. K. 2017, *ARA&A*, 55, 389
- van der Hulst, J. M., Terlou, J. P., Begeman, K. G., Zwitter, W., & Roelfsema, P. R. 1992, in *Astronomical Society of the Pacific Conference Series*, Vol. 25, *Astronomical Data Analysis Software and Systems I*, ed. D. M. Worral, C. Biemesderfer, & J. Barnes, 131
- van der Hulst, J. M., van Albada, T. S., & Sancisi, R. 2001, in *Astronomical Society of the Pacific Conference Series*, Vol. 240, *Gas and Galaxy Evolution*, ed. J. E. Hibbard, M. Rupen, & J. H. van Gorkom, 451
- van der Kruit, P. C. 2007, *A&A*, 466, 883
- van der Kruit, P. C. & Freeman, K. C. 2011, *ARA&A*, 49, 301
- van Gorkom, J. 1991, in *Astronomical Society of the Pacific Conference Series*, Vol. 16, *Atoms, Ions and Molecules: New Results in Spectral Line Astrophysics*, ed. A. D. Haschick & P. T. P. Ho, 1
- Veronese, S., de Blok, W. J. G., Fraternali, F., et al. 2025a, *A&A*, 703, A249
- Veronese, S., de Blok, W. J. G., Healy, J., et al. 2025b, *A&A*, 693, A97
- Vogelaar, M. G. R. & Terlou, J. P. 2001, in *Astronomical Society of the Pacific Conference Series*, Vol. 238, *Astronomical Data Analysis Software and Systems X*, ed. J. Harnden, F. R., F. A. Primini, & H. E. Payne, 358
- Walter, F., Brinks, E., de Blok, W. J. G., et al. 2008, *AJ*, 136, 2563
- Wang, J., Koribalski, B. S., Serra, P., et al. 2016, *MNRAS*, 460, 2143
- Wang, J., Lin, X., Yang, D., et al. 2024, *ApJ*, 968, 48
- Wang, J., Yang, D., Lin, X., et al. 2025, *ApJ*, 980, 25
- Westmeier, T., Braun, R., & Thilker, D. 2005, *A&A*, 436, 101
- Westmeier, T., Kitaef, S., Pallot, D., et al. 2021, *MNRAS*, 506, 3962
- Weymann, R. J., Vogel, S. N., Veilleux, S., & Epps, H. W. 2001, *ApJ*, 561, 559
- Wolfe, S. A., Lockman, F. J., & Pisano, D. J. 2016, *ApJ*, 816, 81
- Wolfe, S. A., Pisano, D. J., Lockman, F. J., McGaugh, S. S., & Shaya, E. J. 2013, *Nature*, 497, 224
- Zhang, Y., Comparat, J., Ponti, G., et al. 2024a, *A&A*, 690, A267
- Zhang, Y., Comparat, J., Ponti, G., et al. 2024b, *A&A*, 690, A268
- Zwaan, M. A. 2000, PhD thesis, University of Groningen, Netherlands

Appendix A: Testing the method

A.1. Uncertainty estimation

The uncertainty associated with the radial profile includes a number of different effects, such as the angular resolution, the uncertainty on the parameters of the kinematical modelling, and assumptions on disc geometry and kinematics outside the detection mask. Quantifying the impact of each source of uncertainty is non-trivial.

A.1.1. Resolution

MHONGOOSE galaxies are well resolved, the least resolved being J0310-39 with four resolution elements. However, the finite angular resolution implies that computing the slope using Eq. 3 might be sensitive to how large ΔR is. Indeed, one would expect that the larger ΔR , the larger the deviation from the expected value of the slope, i.e. the proper derivative $d(\text{Log}N_{\text{HI}})/dR$. We estimated the impact of a finite ΔR by degrading the resolution of the profiles by a factor of 2, that is, by sampling the profiles presented in Fig. 4 every two radial points. In Fig. A.1 we compare the second derivative of the original profiles with their undersampled version. It is clear that resolution does not play a major role in our case, as the second derivatives are consistent within 1σ and their uncertainty does not change significantly when the angular resolution is degraded.

A.1.2. Tilted-ring fit

The rings used to compute the H I radial profiles were created by averaging the geometry of the disc as given by the 3D fitting described in Sect. 3.2. This effectively means that we are assuming the disc to have a uniform and constant geometry. To test the impact of this assumption, as well as the impact of the uncertainty on the inclination and position angle of the rings, we run for each galaxy 5000 Monte Carlo simulations. Each simulation consists of extracting the radial profile from the moment 0 map and via stacking by varying the inclination and position angle of the rings according to the uncertainties reported in Table 2, and accounting for regions where tails and asymmetries are visible in the moment 0 map (as discussed in Sect. 3.3). As shown in Fig. 5, the uncertainty associated with geometrical errors is relevant only for galaxies J0052-31, J0445-59 and J1318-21, meaning their disc is likely too warped to assume constant geometry. However, the conclusion about lack of an edge associated with photoionisation and about the shallower decline with respect to low-mass galaxies still holds.

A.1.3. Geometry and kinematics assumptions

For most galaxies we are tracing the radial profile out to only one beam outside the SoFiA-2 detection mask, despite the employing of spectral stacking. The lack of a significant amount of H I in the outer regions is consistent with the result presented by Veronese et al. (2025b) and Marasco et al. (2025) based on the comparison between the observed H I distribution around MHONGOOSE galaxies with the predicted distribution around Milky Way-like galaxies from cosmological simulations. Therefore, we do not expect that the velocity field extension described in Sect. 3.1 significantly affects our results, as we cannot detect H I emission in such regions even via stacking. Furthermore, Veronese et al. (2025b) discussed the difficulties in choosing the correct velocity extension given our ignorance about the kin-

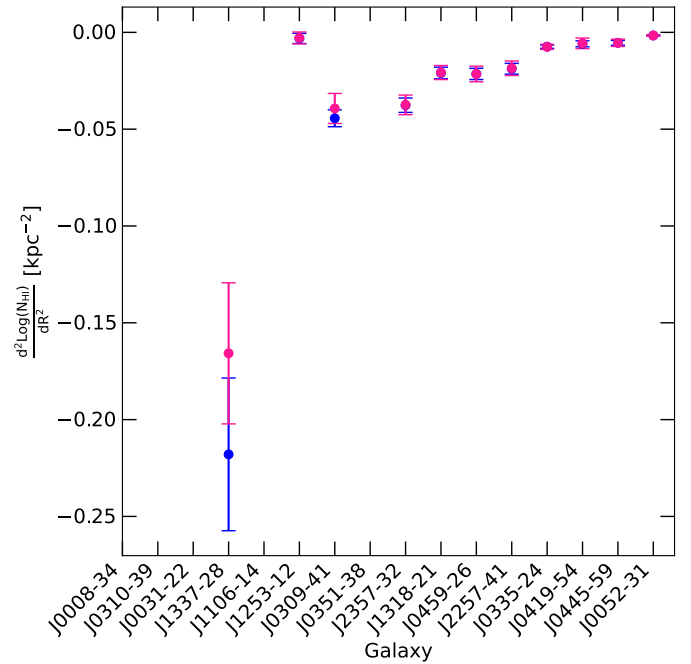


Fig. A.1: Comparison between the second derivative of the H I radial profiles at native resolution (blue) with the second derivative of the H I radial profiles undersampled by a factor of 2 (pink). No data are shown for galaxies J0008-34, J0310-39 and J0031-22 as we do not have enough points in their undersampled profile to compute the second derivative.

ematics of the gas at such large galactocentric radii. They showed that is hardly any difference between employing a constant rotation curve, as done here, or no rotation at all. Other studies have also shown that an alignment error of up to 50 km s^{-1} does not significantly impact the outcome of H I spectral stacking (Khandai et al. 2011; Maddox et al. 2013; Neumann et al. 2023). Given the low level of emission detected outside the SoFiA-2 mask, we argue that our assumption of constant disc geometry in these regions, i.e. no warp, also has little impact on our conclusions.

A.2. The effectiveness of our method

We tested the ability of our method to recover the H I radial profiles. For this we build a sample of six mock galaxies. Each model is created on a set of rings whose width along the major axis is $35''$. This value is equal to the average major axis of the synthesised beam of the MHONGOOSE observations used in this paper. Two galaxies have a maximum radius of $900''$, two of $450''$, and two of $200''$. We placed them at a distance of 10 Mpc, so as to achieve physical sizes (R_{max}) of 45 kpc, 22.5 kpc and 12 kpc. These are representative of the radial extent of the MHONGOOSE galaxies studied here. For each size, one model has an inclination of 40° and the other of 60° , i.e. spanning the range of inclinations in our MHONGOOSE subsample. We defined a rotation curve for each size. It rises linearly to a maximum velocity, which is reached at half of the maximum radius, and is flat afterwards. We chose maximum velocities of 115 km s^{-1} , 100 km s^{-1} and 80 km s^{-1} for the largest, intermediate, and smallest galaxies. Lastly, we defined a radial H I distribution approximately constant in the inner parts followed by an exponential decline.

We used the ring parameters and the rotation curve to build six mock H I cubes via the GALMOD task of 3D-Barolo, originally included in the Groningen Image Processing System (GIPSY; van der Hulst et al. 1992; Vogelaar & Terlouw 2001). We created a Gaussian noise cube and convolved it with the average beam of the MHONGOOSE observations ($35'' \times 27''$) in order to reach a noise level comparable to that of real observations (3σ limit of $2 \times 10^{18} \text{ cm}^{-2}$ over 16 km s^{-1}). This noise cube was coadded to the mock galaxies. We then produced moment 0 maps and velocity fields by running SoFiA2 with the same source finding parameters used for MHONGOOSE (de Blok et al. 2024). This leads to data products as close as possible to real MHONGOOSE observations.

We derived the observed H I profiles from the moment 0 map of each mock galaxy by computing the average column density in the rings corrected for the inclination. Blank or masked pixels are not included in the computation. We also derived the H I radial profile using the stacking procedure described in Sect. 3.1. In this case, all the LoS of the annuli were considered. We measured the total flux detected in the stacked spectrum of each ring and converted the value into the face-on column density.

Looking at the result of the test, provided in Fig. A.2, we can evaluate the implications of our approach. For all mock galaxies, above the 3σ noise limit of the cube the H I profile retrieved from the moment 0 map and from stacking are consistent with each other and with the reference profile built by GALMOD. The filling factor of the rings on the moment map, i.e. the number of LoS included in the SoFiA2 mask divided by the total number of LoS in the ring, is also $> 50\%$ in this regime. As soon as the filling factor drops below 50% we cannot trace the H I profile with the moment 0 map and have to rely on stacking.

A.3. Identify edges with our method

The aim of the work in this paper was to confirm the existence of an edge in the H I radial profile of nearby galaxies as predicted by photoionisation models. We used mock galaxies to investigate whether we can actually detect the edge given the angular resolution of the data and the approach we used. Therefore, we created another set of three mock galaxies with a sharp edge at column densities of $\sim 10^{19} \text{ cm}^{-2}$.

To create the edge, we took the H I distribution of the models with a 60° inclination and clipped it below the column density of 10^{19} cm^{-2} , i.e. all values $< 10^{19} \text{ cm}^{-2}$ were set to 0. We used GALMOD to create the mock cubes based on this input distribution and repeated the procedure to derive the H I radial profiles. In Fig. A.3 in the upper panels, we compare the smoothly declining profiles with the edged profiles, and in the lower panels we compare their slopes.

This test showed that at the angular resolution of our data ($35''$), the edge is seen as a sudden change in the slope value in the last radius detected. In particular, the slope reaches a value of ~ -0.5 (close to the expected value of -0.4 from photoionisation models) no matter the size of the galaxy.

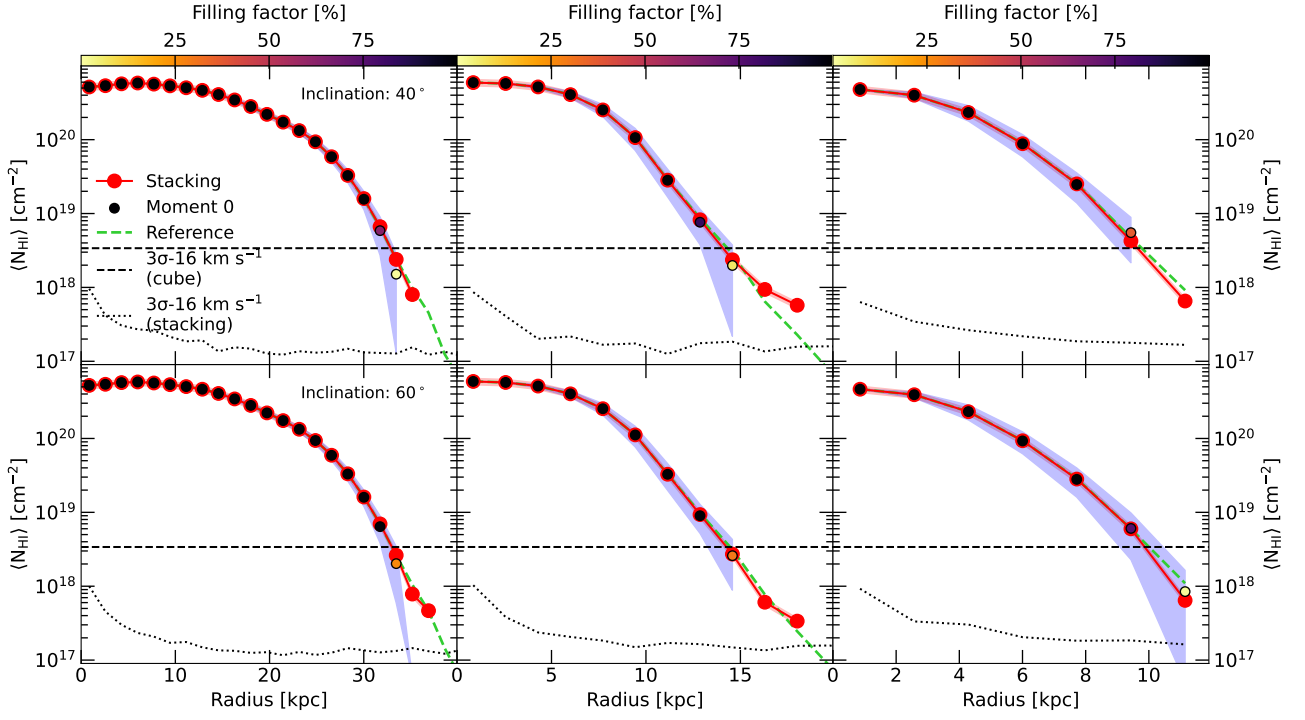


Fig. A.2: H I radial profiles of the six mock galaxies. Galaxies in the first row have inclination of 40° and in the second row of 60° . In all panels, the reference profile from GALMOD is given with a green dashed line, whereas the points, colour-coded with the filling factor of each ring, are the radial profile derived from the moment 0 map. The red points, instead, are the radial profile determined from the stacked spectra. The blue and red shaded areas are the uncertainty from the moment 0 and stacking, respectively. The former is defined as the standard deviation of the intensity values in each ring, whereas the latter as 10% of the total flux in the line, equivalent to the typical uncertainty on the calibration of the H I flux. The black dashed line is the 3σ noise level in the cube over 16 km s^{-1} . The black dotted line is noise level achieved via stacking using the same definition.

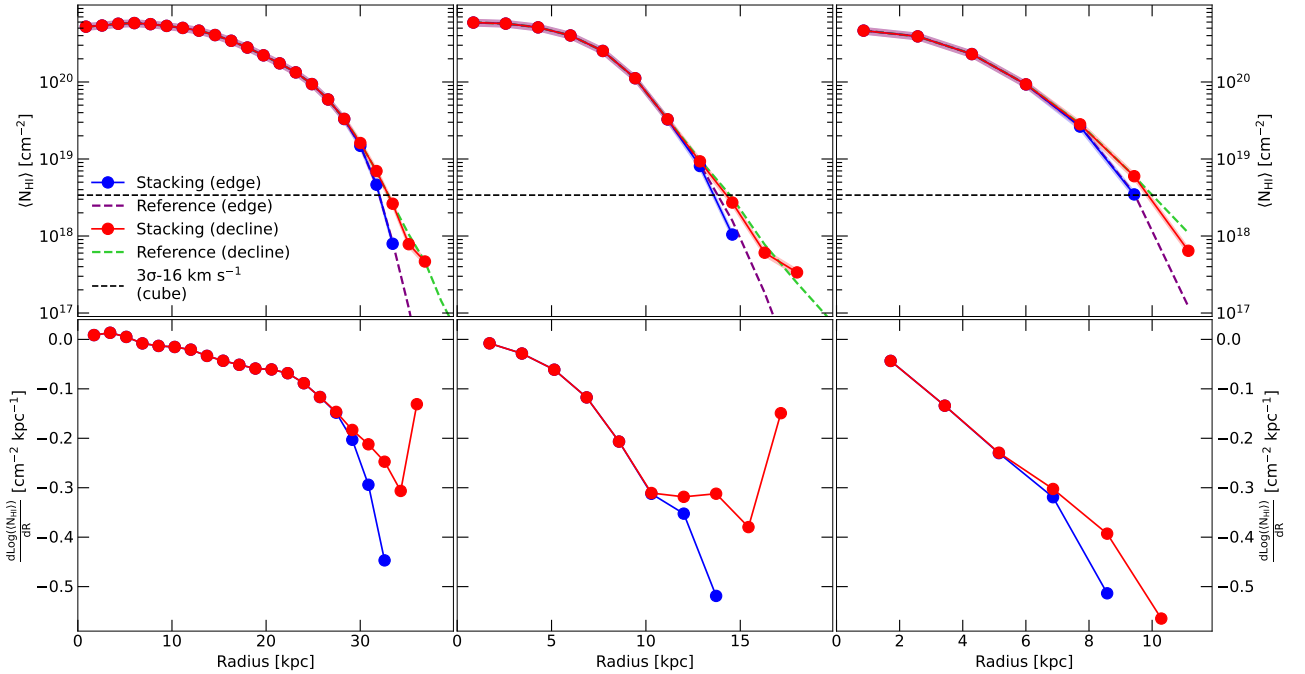


Fig. A.3: Comparison of the H I radial profiles of three mock galaxies having a smoothly declining H I distribution or a disc edge. In the top panels, the reference profile from GALMOD is given with a dashed line (green for the smoothly declining distribution and purple for the distribution with an edge), whereas the points (red for the smoothly declining distribution and blue for the distribution with an edge) are the radial profiles determined from the stacked spectra. The blue and red shaded areas are the uncertainties on the flux in the stacked spectra. In the bottom panels the slopes of the smoothly declining profile (red) and for the profile with an edge (blue) are shown. The black dashed line is the 3σ over 16 km s^{-1} noise level in the cube.

Appendix B: Ancillary plots

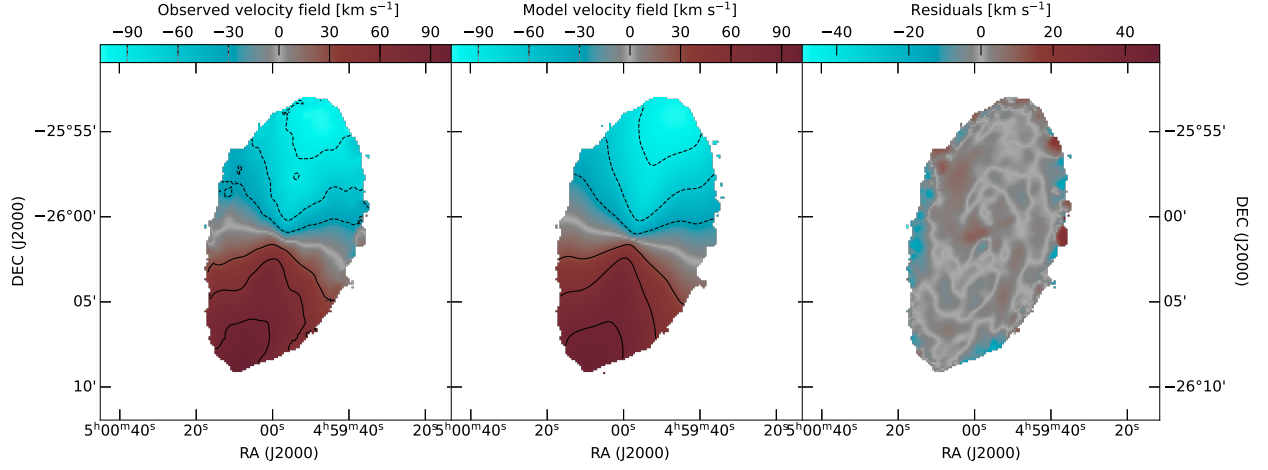


Fig. B.1: Comparison between J0459-26 observed and modelled velocity field. Left-to-right are shown the observed, modelled and residual velocity field. The model was derived from 3D-Barolo. The residuals are in terms of data–model. In the first and second panels, dashed contours refer to the approaching side, whereas solid lines correspond to receding velocities. The contour levels are given at the colorbar on top of each plot with respect to the systemic velocity of 739.9 km s^{-1} .

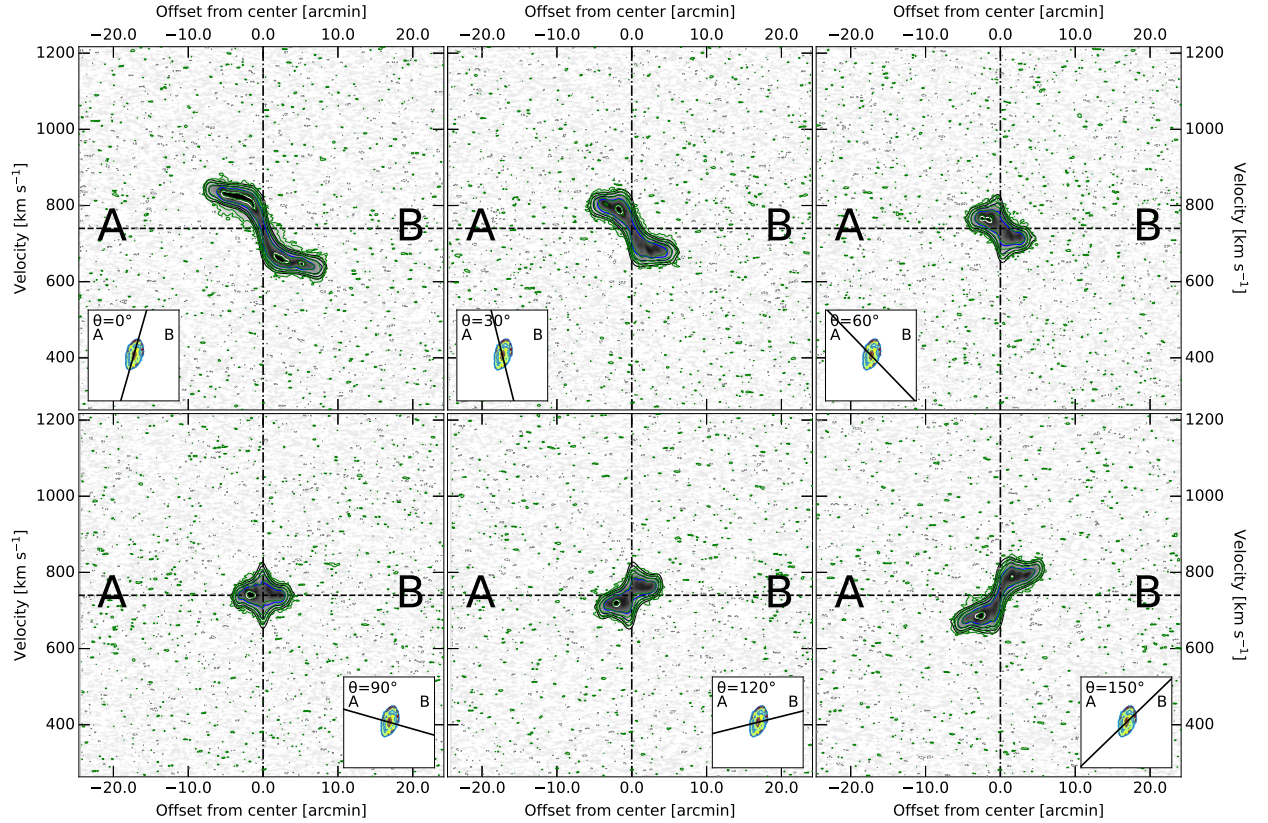


Fig. B.2: J0459-26 pv diagrams at azimuthal angles (θ) of (0, 30, 60, 90, 120, 150) degrees for the data and the best-fit model derived by 3D-Barolo. The model was determined by fitting the approaching and receding side of the galaxy simultaneously. Both the data and the model cube were Hanning-smoothed to a velocity resolution of 7 km s^{-1} . For each panel, the background grey-scale image is the beam-wide slice extracted from the data cube at a given θ . Solid contour levels are denoting the (4, 16, 64, 256, 1024) σ level. The coloured lines refer to the model, the green curves to the data. The dashed grey contour refers to the -4σ level. The dashed black horizontal line corresponds to the systemic velocity, whereas the dashed-dotted black vertical line denotes the galaxy centre. The insets show the moment 2 map and the slice along which the pv is extracted. Letters A and B provide the orientation in the main panels.

Appendix C: Comparison with THINGS

The MHONGOOSE galaxy J2357-32 (NGC 7793) is included in THINGS and its H I radial profile was also presented by Ianjamasimanana et al. (2018), thus allowing a direct comparison. The authors aimed at quantifying disc edges in nearby galaxies, and for this they used a combination of THINGS and HALOGAS data. Via stacking they probed the H I radial profile down to $\sim 10^{19} \text{ cm}^{-2}$ in 9 out of 17 galaxies, including J2357-32, and a few times 10^{18} cm^{-2} for the others. They found no evidence for the predicted sharp H I column density break and suggested that factors other than photoionisation, such as late-stage gas accretion from the cosmic web, may determine the extent of H I discs, recommending deeper observations to confirm this. MHONGOOSE provided such observations and so we compare here the NGC 7793 radial profile between THINGS and MHONGOOSE to show the improvement in column density and to look for the presence of an edge.

We used the THINGS natural-weighted data (Walter et al. 2008) including the H I cube, the primary beam corrected moment 0 map and the moment 1 map. The beam size of the data is $15.6'' \times 10.8''$, the spectral resolution is 2.6 km s^{-1} and the 3σ noise level is $2.7 \times 10^{19} \text{ cm}^{-2}$ over 16 km s^{-1} . We derived the H I radial profile following the same procedure used for the MHONGOOSE data, with the only difference that the width along the major axis of the elliptical annuli has been set equal to the THINGS beam size ($15.6''$). In Fig. C.1 we show the outcome.

The improvement in tracing the H I radial profile provided by MHONGOOSE with respect to THINGS is evident. Indeed, MHONGOOSE extends the profile radially by 25% just with the moment 0 map, and by 35% when stacking is employed. These results come from the much better sensitivity, which allow to probe the profile down to column densities at least 1 dex lower than THINGS. However, despite those improvements, we cannot identify a clear disc edge in our deeper MHONGOOSE data either.

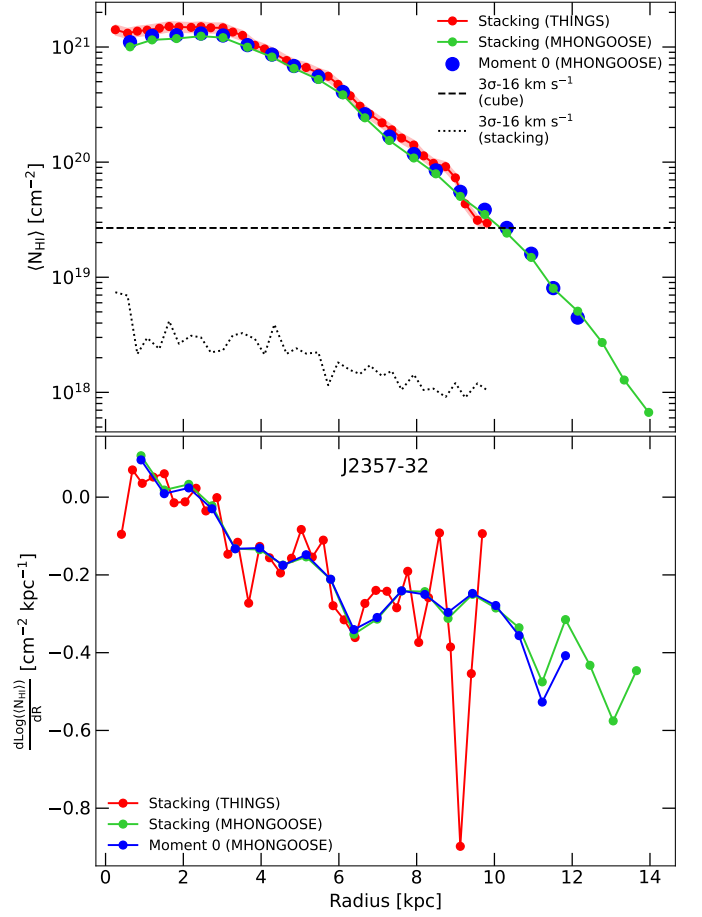


Fig. C.1: Comparison between the MHONGOOSE and THINGS H I radial profiles of the galaxy J2357-32. In the top panel is shown the H I radial profile derived from the MHONGOOSE (blue points) moment 0 map. The red and green curves are the H I radial profiles derived from stacking the THINGS and the MHONGOOSE cubes, respectively. The red shaded area denote the uncertainty on the stacking points, measured as the 10% of the line flux. This corresponds to the typical calibration error in the flux. The horizontal dashed line and the dotted curve indicate the noise level in the moment 0 map and stacked spectra of the THINGS data. In the bottom panel the radial slope of the H I profile is shown for the above datasets and methods.