



Resolved HI and Environmental Dynamics

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Spatially resolved, deep H I observations from SKA precursors and pathfinders such as MeerKAT, FAST, and ASKAP have demonstrated their ability to reveal the complex interactions between galaxies and their environments. These include, but are not limited to, recent observations of the Virgo cluster showing that the hydrodynamical effects of ram pressure stripping can operate effectively at unexpectedly large cluster-centric distances. In the Fornax cluster, the discovery of long H I tails with mixed tidal-ram-pressure origins indicates the interplay between gravitational and hydrodynamical mechanisms. Similar H I features in nearby filaments and galaxy groups, where ram pressure is expected to be weak, highlight the influence of hydrodynamical processes even in low-density environments. Multi-resolution studies have further revealed signs of cold gas accretion and H I replenishment driven by tidal interactions. While highly informative, these studies remain limited to small, specific regions of the sky. With SKA-mid AA4, it will become possible to carry out deep, spatially resolved H I imaging over hundreds of square degrees, covering environments from isolated galaxies to filaments. By reaching column-density sensitivities between 1.0×10^{18} and $\sim 1.0 \times 10^{19} \text{ cm}^{-2}$ at physical resolutions of ~ 10 and $\sim 1 - 2$ kpc, respectively, and by enabling sensitive, contiguous observations of wide areas within short integrations, SKA-mid AA4 will allow the construction of large, statistically representative samples of galaxies and detailed studies of environmental mechanisms operating across the full range of these less-studied environments at resolved scales.

1 Introduction

A well-established trend observed in studies of galaxy evolution is that the number of passive, early-type galaxies increases with rising galaxy density, while the fraction of actively star-forming, late-type galaxies decreases (e.g., Dressler, 1980). The neutral atomic hydrogen (H I) provides a fundamental probe into this transformation. As the dominant component of the cold interstellar medium (ISM) and the primary reservoir from which molecular gas and new stars form, H I is essential for sustaining ongoing star formation. Any changes in its content or spatial distribution can have a profound influence on the evolutionary pathway of galaxies, making H I an especially sensitive tracer of the physical processes that regulate galaxy evolution across environments. The exact physical mechanisms responsible for these transformations remain incompletely understood, but are broadly thought to originate from interactions between galaxies and their surroundings. Many of these mechanisms can affect the star formation activity of galaxies by disrupting or removing their gas, ultimately changing them from active star-forming to passive quenched systems.

One such process is starvation, whereby the cooling and accretion of the gas from the circumgalactic medium (CGM) onto the disc is prevented, leading to a slow consumption of the cold gas and decline of the star formation rate (Larson et al., 1980). More intense galaxy-environment interactions directly disturb or remove the cold interstellar medium (ISM) within the disc. These include gravitational interactions such as galaxy-galaxy collisions, ranging from low-velocity encounters, which may lead to mergers, to high-velocity flybys, which can disturb both the stellar component and the ISM, thereby removing or consuming the available fuel for new star-formation, (e.g. Toomre and Toomre, 1972; Farouki and Shapiro, 1981; Moore et al., 1996, 1998).

In other cases, the ISM of galaxies interacts with the intergalactic medium (IGM) embedded in the cosmic web. Such interactions can displace or even completely remove the ISM through ram pressure (Gunn and Gott, 1972) and/or viscous stripping (Nulsen, 1982), and thermal evaporation (Cowie and Songaila, 1977). These mechanisms can have complex short-term effects on the star-formation activity of galaxies, such as temporary enhancements through compression of the ISM (Bekki and Couch, 2003) or chaotic cold accretion (CCA) driven by increased gas turbulence (Gaspari et al., 2013). Ultimately, however, these interactions remove or exhaust the gas supply necessary for ongoing star formation, leading to quenching (see Cortese et al., 2021; Boselli et al., 2022 for full reviews).

The relative roles and characteristic timescales of these mechanisms are reasonably well-constrained for low-redshift clusters and their immediate surroundings. However, most galaxies in the local Universe reside outside clusters, in lower-density regions such as filaments and groups, which are known to feed galaxies and into clusters along the cosmic web (Cautun et al., 2014). In these environments, the picture is significantly less well-established: hydrodynamical effects are expected to be weaker, while gravitational encounters may play a more prominent role due to lower galaxy velocities and the reduced density of the IGM (e.g. Das et al., 2023). Observational information, however, remains limited. For instance, several studies suggest that a galaxy's distance from the filament spine correlates with its gas content, star-formation activity, and stellar mass. Galaxies located closer to filament spines tend to have higher average stellar masses (Kraljic et al., 2018) and to experience interactions more frequently (Santiago-Bautista et al., 2020), which can accelerate the

quenching of star formation (Laigle et al., 2018). However, conflicting results have been reported. For example, Kuutma et al. (2017) did not find evidence for increasing stellar mass towards filament spines, although they observed higher early-type fractions and lower star-formation rates closer to filaments. Recent work has also questioned whether filaments themselves exert a strong direct influence on galaxy evolution. Using large statistical samples and carefully constructed control populations, Zakharova et al. (2023) argued that the majority of the observed trends in gas content, morphology, and star-formation activity near filament spines are driven primarily by the prevalence of galaxy groups embedded within filaments rather than by the filaments themselves. In this view, filaments serve mainly as conduits funnelling galaxies into group environments, where most environmentally driven gas removal and transformation occur. Furthermore, earlier studies based on unresolved HI data from large-area surveys such as HIPASS (Barnes et al., 2001) and ALFALFA (Giovanelli et al., 2005) have reported that galaxies located in proximity to filament spines often exhibit reduced HI content (Crone Odekon et al., 2018; Hoosain et al., 2024). However, the limited sample sizes in these works have led to conflicting results regarding the stellar mass regime over which this trend holds. Notably, Kleiner et al. (2017) observed an opposite behaviour; an excess of HI in the most massive galaxies. Because these surveys provide only integrated HI measurements, they lack the spatial resolution necessary to examine how environmental mechanisms shape the internal distribution and kinematics of the ISM.

1.1 Resolved HI - A powerful tracer of mechanisms operating in the cosmic web

The use of sensitive and resolved HI imaging has proven to be a powerful tool to study the environmental interactions governing galaxy evolution. HI extends out to large galaxy radii at the interface between galaxies and their environment, making it one of the first components to respond to external mechanisms. In these outer regions of galaxies, the gravitational bond with the host galaxy is relatively weak and the gas is more diffuse, making the HI gas susceptible to perturbations and enabling environmental processes to leave distinct imprints on the diffuse HI disc. Moreover, the long dynamical timescales in these outskirts (on the order of ~ 1 Gyr) allow HI to retain signatures of past interactions over long periods. Studying these extended HI features in galaxies' outskirts requires a combination of resolution and sensitivity.

HI imaging maps from the SKA L-band precursors and pathfinders, JVLA, MeerKAT, FAST, ASKAP and others, has proven invaluable for revealing the complexity of galaxy-environmental interactions. An increasingly large population of galaxies is now being identified with unusual morphologies, including jellyfish galaxies, tidal tails and bridges, extreme warps, polar rings and more. While it is well established that these features arise from galaxy-environment interactions, the specific mechanisms driving their formation can vary considerably. Thus, studying galaxies with unusual morphologies can help identify and quantify the environmental processes at play.

Jellyfish galaxies exhibiting one-sided HI tail are thought to result from the aforementioned ram-pressure stripping as galaxies move through dense environments (see example in the left panel of Fig. 1). Strong ram pressure can remove HI gas and produce highly asymmetric morphologies (e.g., Boselli and Gavazzi, 2006; Fumagalli et al., 2014; McPartland et al., 2016), while compression of the interstellar medium may form knots of young stars in the stripped tails (e.g., Yoshida et al., 2008; Poggianti et al., 2019) while also triggering enhanced star formation (Vulcani et al., 2018;

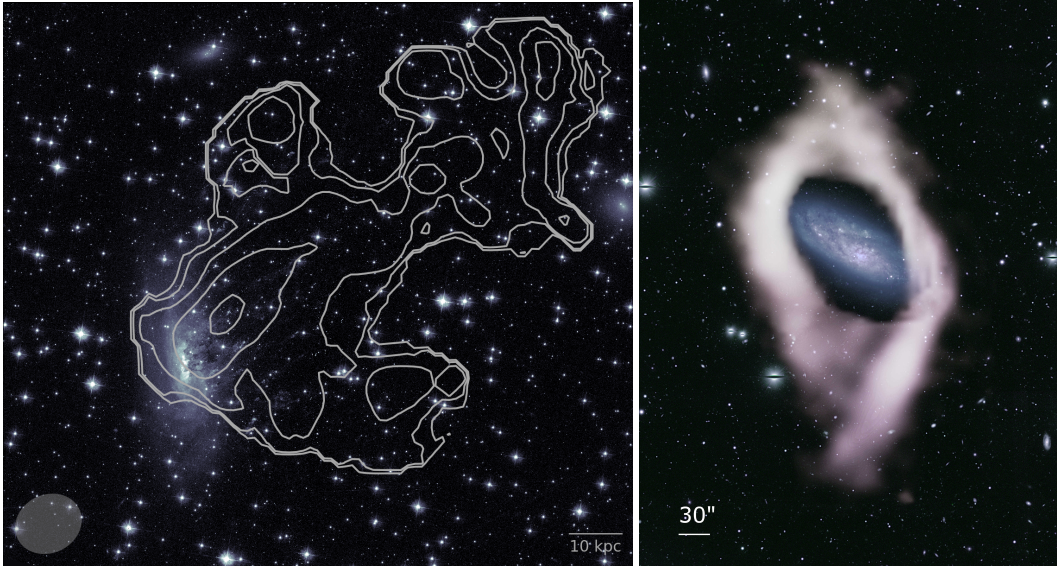


Figure 1: Examples of unusual H I morphologies reported in recent studies. *Left panel;* the H I spatial distribution of the jellyfish galaxy ESO137-001 is shown overlaid on the optical map and the HST WFC3 image. The H I contours drawn at column densities of $N_{\text{HI}} = 2.3, 4.6, 9.2, 18.4 \times 10^{19} \text{ atoms cm}^{-2}$, clearly traces the characteristic jellyfish morphology previously observed in the optical and at other wavelengths (Ramatsoku et al., 2025). *Right panel;* the anomalous H I component of the polar ring galaxy NGC 4632, illustrating that this gas is clearly oriented differently from the stellar disc. The gas in the main disc has been removed to highlight the polar structure (Deg et al., 2023a). Images are reproduced with permission.

Ramatsoku et al., 2019). Although initially identified in massive clusters (Yagi et al., 2007; Chung et al., 2007, 2009; Poggianti et al., 2016), recent observations have revealed jellyfish-like morphologies in lower-mass groups and even filaments, showing that they can occur across a wide range of environments (e.g., Roberts et al., 2021).

Even more complex morphologies have been reported in recent observations of the Virgo cluster, which revealed an extended H I tail in a galaxy located about 3° (approximately 0.86 Mpc) from the cluster centre, similar to those seen in systems undergoing hydrodynamical interactions with the intracluster medium (ICM) in cluster cores (Boselli et al., 2023). In the low-mass Fornax cluster, the discovery of long H I tails with a mixed tidal-then-ram-pressure (e.g., Serra et al., 2023; Serra et al., 2024) origin suggests a complex balance between these mechanisms. Similar H I features have also been observed in deep H I images of the galaxy groups in the MeerChoir survey and filaments like those found in the Virgo III filament located ~ 5 Mpc to the south-east of the Virgo cluster core (Finn et al., 2025). Moreover, a recent study Staveley-Smith et al. (2025) reported on the tidal bridge detected by WALLABY, which also exhibits a significantly longer tidal tail. Although this system lies outside the virial radius of the Virgo cluster, simulations indicate that the envelope of hot gas has shaped the tidal tail, and the ongoing interaction with the cluster has prevented a rapid merger (Westmeier et al., 2022; Murugesan et al., 2024).

Polar ring galaxies are another striking phenomenon, where a host galaxy contains material orbiting at $\sim 90^\circ$ to the main body, an example of which is shown in the right panel of Fig., 1. Typically,

these have been found in the optical (see, for example, Sandage 1961; Schechter and Gunn 1978; Whitmore et al. 1990; Moiseev et al. 2011), however, many have also been detected in H I (van Gorkom et al., 1987; Brook et al., 2008; Džudžar et al., 2021). With the advent of resolved, sensitive surveys on SKA pathfinders, more polar ring galaxies are being detected in H I (Deg et al., 2023a; Healy et al., 2024). For example in Deg et al. (2023a) galaxies with multiple H I components in the first WALLABY pilot data release (Westmeier et al., 2022) were reported. The anomalous gas in those systems is consistent with being polar. And Healy et al. (2024) posited that a polar structure may explain the anomalous gas revealed by the MHONGOOSE survey. In another study Stanonik et al. (2009), a H I polar-ring was detected in a wall between two voids with an H I mass comparable to the stellar mass and hints of a warp, indicating slow and recent gas accretion. The blue, UV-bright central disk detected in this and an underdense environment supports cold-flow accretion as a viable formation mechanism (Stanonik et al., 2009). Deg et al. (2023a) went further and estimated a possible incidence rate for polar ring galaxies of 1 – 3%, which is an order of magnitude larger than the previously estimated optical rate of 0.1% (Reshetnikov et al., 2011).

An alternate explanation for these systems is that they are ‘extreme’ warps. In such systems, the material may not be orbiting at 90° and is connected to the main body of the galaxy. Regardless of the precise classification, both polar ring galaxies and extreme warps must be formed by interaction events. These types of interactions include mergers, fly-by passages that deposit material on the host galaxy, accretion from the cosmic web, and more. Building up a statistical sample of well-resolved polar rings and extreme warps will constrain the precise origin mechanism, help to distinguish between the differing classes, and explore how the stability of these features affects their host galaxies.

Through these resolved and sensitive H I studies, a complex picture of the interplay between gravitational and hydrodynamical interactions is starting to emerge but they focus on small specific regions. The picture is made more complex by the recent result of tidal interactions possibly triggering the accretion of cold gas in a few individual objects (Wang et al., 2023) showing that detailed observations of larger samples are critical. These systems also provide excellent testbeds for studies for how pre-processing modifies systems as they fall into denser environments (Fujita, 2004).

Clarifying the formation pathways of these unusual morphologies is therefore essential for constraining the physical processes that drive environmental interactions and for understanding their role in galaxy evolution. Such investigations demand the high resolution, sensitivity, and survey speed which can be achieved with the SKA-mid-AA4, which will make it possible to build statistically significant samples of galaxies with resolved H I morphologies across diverse environments.

This has been a major challenge for existing and planned surveys, as none of them simultaneously meet all the observational requirements. The currently ongoing and previous H I imaging surveys lack the necessary combination of sensitivity, spatial resolution, and sky coverage required to encompass the full range of environments and to resolve the detailed structure of galaxy discs and their outskirts.

A few representative examples are shown in Fig. 2 to illustrate this limitation. Surveys that cover

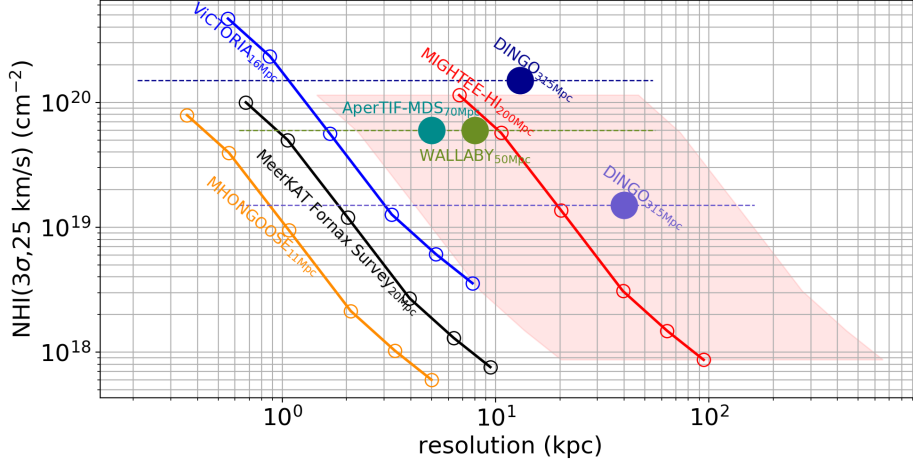


Figure 2: Comparison of the typical HI column-density sensitivities achieved by existing HI imaging surveys as a function of physical resolution, evaluated at the representative redshift or at the redshift of the main large-scale structure targeted. These redshifts are indicated with text annotations next to each line. For the large-area surveys we also show the sensitivity and physical resolution across their redshift range, e.g., red shaded area for MIGHTEE and dotted lines for WALLABY and DINGO (see also [Maccagni and de Blok 2024](#) for additional examples). LADUMA and CHILES are not shown due to their too-high redshifts.

large volumes, such as LADUMA ([Blyth et al., 2016](#)), CHILES ([Fernández et al., 2013](#)), and MIGHTEE-HI ([Maddox et al., 2021](#)), lack the sensitivity required to trace the extended HI features of galaxies at the physical resolution of a few kpc, making them unsuitable for studying environmental processes at resolved scales. Low-redshift surveys such as WALLABY ([Westmeier et al., 2022](#)), DINGO ([Meyer, 2009](#)), Apertif medium and shallow surveys ([Adams et al., 2022](#)) will detect thousands of galaxies in HI and offer large sample sizes, enabling the study of global HI properties in different environments, but lack sufficient sensitivity and physical resolution. Other surveys, including the MeerKAT Fornax Survey (MFS; [Serra et al. 2023](#)), VICTORIA ([Boselli et al., 2023](#)), and MHONGOOSE ([de Blok et al., 2024](#)), achieve excellent sensitivity and provide the few-kpc resolution necessary to investigate instabilities in galaxy discs and extended HI. However, the first two focus only on specific environments, Fornax and Virgo clusters, and therefore do not sample the full range of environments, while the latter targets individual, very nearby galaxies and consequently does not cover other large-scale structures.

2 Physical processes across environments

Combining resolved HI maps with stellar data from optical imaging will reveal the aforementioned characteristic morphological signatures as a function of environment. A key challenge faced in large, untargetted surveys, is identifying targets of interest. A tool that may potentially help are statistical measures of morphology ([Conselice et al., 2000](#); [Conselice, 2003](#); [Lotz et al., 2004](#)). These so-called ‘morphometrics’ have been widely used in optical studies ([Conselice, 2003](#); [Lotz et al., 2004](#); [Pearson et al., 2019](#); [Bellhouse et al., 2022](#); [Zhao et al., 2022](#); [Sazonova et al., 2024](#)). In HI studies, the parameter most commonly used in older studies is the profile asymmetry ([Peterson and Shostak, 1974](#); [Espada et al., 2011](#); [Bok et al., 2019](#); [Deg et al., 2020](#); [Reynolds](#)

et al., 2020). However, Holwerda et al. (2011); Giese et al. (2016) and Holwerda et al. (2025) used the full suite of morphometrics to study THINGS galaxies (Walter et al., 2008), WHISP galaxies, and WALLABY pilot observations respectively. Recently, Deg et al. (2023b) developed a 3D asymmetry morphological statistic for use with H I observations that appears to be applicable at lower radii than comparable 2D asymmetry morphometrics. Perron-Cormier et al. (2025) used this statistic on both simulations and WALLABY observations. Not only did the 3D statistic reliably detect galaxies with disturbed and unusual morphologies, it was possible to do a first comparison of simulated morphologies to observations on a statistical basis. This result highlights the dual promises of morphometrics; they can indeed find the unusual morphologies, and can be used as a test for cosmological simulations and constrain galaxy formation. Moreover, it is possible to use the population of disturbed galaxies as a proxy to measure the merger rate across a variety of environments which is an analysis that will become routine with the sensitivity and speed of the SKA.

2.1 Quantifying the effects of environment on galaxy kinematics

Early large-sample studies such as WHISP (Swaters et al., 2002) and higher-resolution mapping efforts such as THINGS (Walter et al., 2008) and LITTLE THINGS (Hunter et al., 2012) revealed a variety of non-axisymmetric features and warped velocity fields; however, the relatively small and heterogeneous nature of these samples make it hard to draw statistical conclusions. Consequently, it remains unclear whether disturbed kinematics are exceptional or rather an intrinsic property of gas discs once a broad range of masses and environments is probed. Further ambiguity arises from internal drivers of non-circular motions. Observational and numerical studies indicate that stellar feedback can drive turbulence within the neutral interstellar medium, leading to broader H I line profiles (e.g., Iorio et al., 2017). Using the aforementioned 3D asymmetry morphological statistic, it is demonstrated that part of the observed kinematic complexity may be intrinsic, rather than exclusively caused by tidal interactions or environmental influences. At the same time, cosmological hydrodynamical simulations from the NIHAO and FIRE projects emphasise a large diversity of H I kinematic morphologies at fixed halo mass (e.g. Wang et al., 2015; Hopkins et al., 2020), further complicating observational interpretation. Untargetted H I surveys of galaxies across diverse environments at kpc-resolution and high spectral fidelity will provide a statistically robust and spatially resolved view of the frequency and nature of disturbed H I kinematics, helping to determine whether such features are the rule or the exception, and to what extent stellar feedback contributes to them.

2.2 Gas contents across different environments

Although most galaxies reside in groups, these environments remain less well studied than clusters. Groups range from loose associations to compact systems, with the latter showing accelerated evolution driven by rapid gas removal. Hickson Compact Groups (HCGs; Hickson, 1982), consisting of four to ten galaxies in dense configurations, display a wide variety of H I and optical morphologies (Huchtmeier et al., 1997; Verdes-Montenegro et al., 2001) and therefore serve as excellent laboratories for studying environmental interactions. An evolutionary sequence of the HCGs, based on their H I morphologies, was proposed over two decades ago (Verdes-Montenegro et al., 2001) and was refined by Jones et al. (e.g., 2023). In this scheme, groups are assigned an H I phase according

to how much of the detected HI remains directly associated with the galaxies versus being found in extended intra-group features (tails, bridges, diffuse structures). In phase 1, galaxies keep most of their detected HI within the disc. In phase 2, between 25% and 75% of the detected HI is found in extended features, and phase 3 systems are either HI-undetected or have more than 75% of their detected HI in extended structures (Verdes-Montenegro et al., 2001; Jones et al., 2023). Recent efforts conducted with VLA and MeerKAT established a broad picture of the large-scale neutral gas distribution in HCGs beyond any previous observational results (Jones et al., 2023; Ianjamasimanana et al., 2025; Sorgho et al., 2025). Consistent with the aforementioned evolutionary model, this picture tentatively shows that late-phase (phase 3) HCGs are significantly distinct from their immediate environments, behaving as separate entities located in regions that otherwise have different gas contents. However, when observed in the early or intermediate stages of their life, HCGs do not show systematic differences with respect to their environments in terms of gas content (Sorgho et al., 2025). SKA1-Mid AA4 will be able to test this picture decisively by mapping HI in and around HCGs with uniform sensitivity and resolution across statistically meaningful samples. With a ~ 6 h L-band track, previous MeerKAT observations (Ianjamasimanana et al., 2025; Sorgho et al., 2025) failed to detect diffuse HI emission in late-phase HCGs that were apparent in single dish observations (Borthakur et al., 2010). Over similar integration times, the SKA’s AA4 array will be able to reach column-density limits of the order of 10^{18} cm^{-2} over $\sim 20 \text{ km s}^{-1}$, about 3 times more sensitive than MeerKAT. This will allow us to detect (or place stringent limits on) the diffuse intra-group reservoirs that govern the HI budget of the late-phase HCGs. The MeerKAT observations by Ianjamasimanana et al. (2025); Sorgho et al. (2025) revealed intricate HI tidal tails in intermediate-phase HCGs that were previously missed by the VLA (see Figure 3). SKA AA4 will be able to trace the full extent of HI in these HCGs, allowing us to reassess their HI content and deficiency parameters.

At the opposite end of the spectrum, isolated galaxies represent a benchmark for estimating the impact of the environment on the HI content of galaxies. Over decades, effort was put into defining a nurture-free sample of galaxies, AMIGA (Analysis of the interstellar Medium in Isolated GALaxies Verdes-Montenegro et al., 2005), on which environmental effects are minimal. Thanks to their high degree of isolation, AMIGA-like galaxies are ideal targets for the search for signs of cold gas accretion. This process of gas replenishment in present-day galaxies is predicted to consist of filaments of cool gas entering a galaxy’s halo to feed its disc (Kereš et al., 2005). Over the past several years, several studies have been undertaken to detect direct evidence of gas accretion in nearby galaxies. The HALOGAS survey, which mapped the HI distribution in 22 galaxies (down to $\sim 10^{19} \text{ cm}^{-2}$) with the WSRT, identified several HI clouds and streams in the vicinity of the sample galaxies whose origin could be attributed to accretion processes (Heald et al., 2011; Heald, 2015; ?). More recently, the MHONGOOSE project provided deep, high-resolution HI data of 30 nearby, gas-rich spiral and dwarf galaxies observed with MeerKAT (de Blok et al., 2024). Although conclusive evidences of gas accretion have yet to be found, ongoing efforts are promising. Leveraging the resolution and sensitivity capabilities of SKA-Mid AA4 to focus the search on extremely isolated galaxies, such as those of AMIGA, will provide irrefutable proof or constraints on cold gas accretion in the local universe.

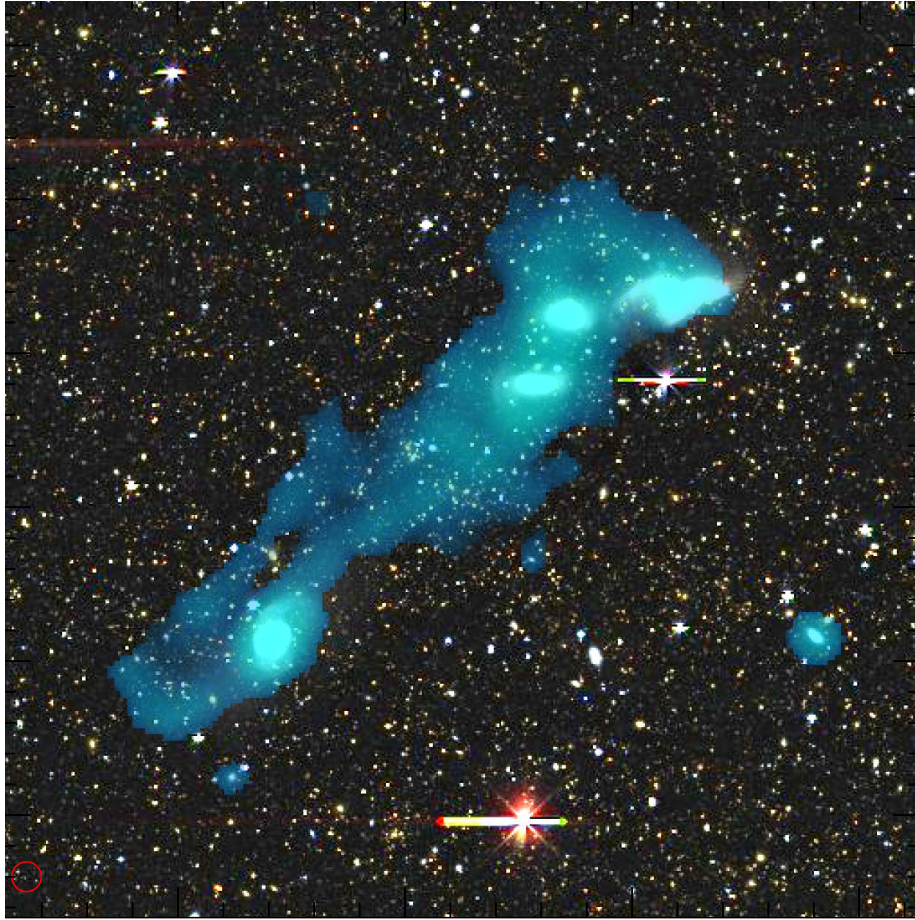


Figure 3: The HI distribution of HCG 16 as seen by MeerKAT (Ianjamasimanana et al., 2025; Sorgho et al., 2025). The blue hue represents the HI emission from the group at a threshold column density of $3.5 \times 10^{18} \text{ cm}^{-2}$. The synthesised beam of $58''$ ($\sim 14 \text{ kpc}$) is shown at the bottom-left corner in red. The background image shows DECaLS optical data to highlight the core members. Images reproduced with permission from the authors.

3 SKA-mid and resolved H I-environment dynamics

Over the past decades, observations with SKA precursors (Serra et al., 2024; de Blok et al., 2024; Healy et al., 2024; de Gasperin et al., 2025) together with cosmological simulations (Popping et al., 2009; Göller et al., 2023) have demonstrated that column-density sensitivities of at least $\sim 10^{19} \text{ atoms cm}^{-2}$ are required to detect key signatures of environmental processes in the diffuse HI phase of the intergalactic medium. For nearby systems surveyed at kpc-scale resolution (e.g. MFS, MHONGOOSE, VICTORIA), diffuse HI tails and star-forming clumps are routinely detected at $\sim 10^{19} \text{ atoms cm}^{-2}$ at $1 - 2 \text{ kpc}$ resolution and $\sim 10^{18} \text{ atoms cm}^{-2}$ at $\sim 10 \text{ kpc}$ over integration times of $10 - 50 \text{ hours}$ (Serra et al., 2023; de Blok et al., 2024; Boselli et al., 2023). These results strongly motivate an AA4-SKA-mid survey designed to blindly image a large contiguous sky area of some hundreds deg^2 comprising voids, groups, and filaments, enabling a statistically significant galaxy sample with similar sensitivities and physical resolutions.

According to the SKA-Mid sensitivity calculator (March 2026, version 2.4.1), within Band 2 (0.95 – 1.76 GHz) of AA4, and assuming all antennas are available, the desired column density sensitivity can be achieved with a rms noise level of $\text{rms} \approx 112 \mu\text{Jy beam}^{-1}$ per 26.9 kHz-wide channel. Assuming a Briggs weighting of $r = 0$ and a synthesised beam with a FWHM of $10'' \times 10''$, this sensitivity corresponds to an integration time of approximately 7 hours over a spectral resolution of 5.7 km s^{-1} .

With these parameters, we expect column density sensitivities of approximately $\sim 4 \times 10^{19} \text{ cm}^{-2}$ at 3σ assuming a linewidth of 25 km s^{-1} . To achieve the desired physical resolution, observations should target galaxies at distances of roughly 40 Mpc, which is the optimal range for achieving a spatial resolution of $\sim 1\text{--}2 \text{ kpc}$. To encompass all necessary environments a mosaic covering about $200\text{--}250 \text{ deg}^2$ would be required. Achieving this sensitivity requires an effective observing time of ~ 13 hours per square degree, for a total of approximately 2600 hours. This estimate incorporates the primary beam response and the net sensitivity gain from a Nyquist sampled mosaic, ensuring uniform depth across the survey area and enabling the detection of diffuse H I at kpc-scale physical resolutions in a wide range of environments. This would enable studies such as those of the MeerKAT Fornax or the VICTORIA survey (Serra et al., 2023; Kleiner et al., 2023), to be at scale.

For comparison, achieving the same sensitivity and physical resolution with current facilities such as MeerKAT would require approximately 60 hours per square degree for a 200 deg^2 survey. SKA-Mid AA4 therefore, increases the survey speed by a factor of about five. This improvement will make surveys that are currently prohibitively time-consuming routinely achievable programmes.

4 Conclusions

Resolved H I observations from SKA precursors have revealed a wide range of complex morphologies, including jellyfish tails, tidal bridges, warps, polar structures, and disturbed kinematics that trace the interplay between gravitational and hydrodynamical processes across different environments. These studies have demonstrated that well-known environmental processes operate far beyond the cluster regime where they are traditionally studied, extending into groups and filaments where their interplay is considerably more complex. However, existing observations remain confined to small, targeted regions. By targeting fields in the nearby Universe (within roughly 40 Mpc), kpc-scale physical resolutions can be achieved at column-density sensitivities of the order of approximately $4 \times 10^{19} \text{ cm}^{-2}$ at $1\text{--}2 \text{ kpc}$ and $2 \times 10^{18} \text{ cm}^{-2}$ at 10 kpc . These sensitivities are comparable to those obtained by current deep H I surveys, but SKA-Mid AA4 can deliver them across far larger areas due to its survey speed. It will be possible to cover a homogeneous region of approximately 200 deg^2 that includes less-studied environments, such as isolated galaxies, groups, and filaments, providing a large and statistically significant sample needed to quantify how environmental processes operate across the full range of these environments. By reducing the observing time per square degree by a factor of five relative to current pathfinders like MeerKAT, SKA-Mid AA4 makes such a survey feasible for the first time. This capability will enable the systematic identification of tidal debris, extended tails, warps, and polar structures, allowing robust measurements and the identification of gas removal processes across various environments, as well as a direct statistical comparison with cosmological simulations. It is also anticipated that one of the most

advanced wide-field optical facilities, the Vera C. Rubin Observatory, will place strong constraints on stellar structure and recent star-formation activity. In synergy with high-sensitivity H I imaging, which directly traces gas removal and accretion, this combination will provide a comprehensive and physically connected view of the environmental processes shaping galaxy evolution.

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