The HIX galaxy survey I: study of the most gas-rich galaxies from HIPASS

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ABSTRACT
We present the H\textsuperscript{\textsc{i}} eXtreme (HIX) galaxy survey targeting some of the most H\textsuperscript{\textsc{i}} rich galaxies in the Southern hemisphere. The 13 HIX galaxies have been selected to host the most massive H\textsuperscript{\textsc{i}} discs at a given stellar luminosity. We compare these galaxies to a control sample of average galaxies detected in the H\textsuperscript{\textsc{i}} Parkes All Sky Survey (HIPASS). As the control sample is matched in stellar luminosity, we find that the stellar properties of HIX galaxies are similar to the control sample. Furthermore, the specific star formation rate and optical morphology do not differ between HIX and control galaxies. We find, however, the HIX galaxies to be less efficient in forming stars. For the most H\textsuperscript{\textsc{i}} massive galaxy in our sample (ESO075-G006, log $M_{\text{HI}} [M_{\odot}] = (10.8 \pm 0.1)$), the kinematic properties are the reason for inefficient star formation and H\textsuperscript{\textsc{i}} excess. Examining the Australian Telescope Compact Array (ATCA) H\textsuperscript{\textsc{i}} imaging and Wide Field Spectrograph (WiFeS) optical spectra of ESO075-G006 reveals an undisturbed galaxy without evidence for recent major, violent accretion events. A tilted ring fitted to the H\textsuperscript{\textsc{i}} disc together with the gas-phase oxygen abundance distribution supports the scenario that gas has been constantly accreted on to ESO075-G006 but the high specific angular momentum makes ESO075-G006 very inefficient in forming stars. Thus, a massive H\textsuperscript{\textsc{i}} disc has been built up.

Key words: galaxies: individual: ESO075-G006 – galaxies: ISM – galaxies: kinematics and dynamics.

1 INTRODUCTION

Over the last two decades large, systematic surveys of the atomic hydrogen (H\textsuperscript{\textsc{i}}) content of galaxies have allowed us to study the relation between star formation, stellar and H\textsuperscript{\textsc{i}} content of galaxies. Scaling relations have shown that the H\textsuperscript{\textsc{i}} content of galaxies in the local Universe is well correlated with the galaxies' stellar content (Haynes, Giovanelli & Chincarini 1984; Catinella et al. 2010; Dénes, Kilborn & Koribalski 2014; Brown et al. 2015). For this work, outliers towards the very H\textsuperscript{\textsc{i}} rich end of such scaling relations are examined aiming to investigate why these galaxies host a more massive H\textsuperscript{\textsc{i}} disc than average. Two scenarios are considered: these galaxies are either more efficient at accreting gas from their environment, or they are less efficient at converting available gas into stars than H\textsuperscript{\textsc{i}} poor galaxies (see also Huang et al. 2014). A combination of the two scenarios is also possible.

The mechanisms through which galaxies can accrete gas and replenish their gas reservoir are broadly separated into two categories: gas-rich mergers (‘clumpy accretion’) or accretion of gas from the halo or the intergalactic medium (‘smooth accretion’).

Gas-rich mergers may include both minor and major mergers. Major mergers have been found to be a less dominant channel of gas accretion both in observational work and simulations (e.g. van de Voort et al. 2011; Wang et al. 2013 and also Sancisi et al. 2008; Sánchez Almeida et al. 2014 and references therein). A series of gas-rich minor mergers may contribute to the gas replenishment of galaxies but observations have shown that also this channel does not deliver enough gas to a galaxy to sustain star formation (Di Teodoro & Fraternali 2014).

In the local Universe, indirect evidence of cosmological gas accretion has been found: the integrated metallicity of galaxies is
lower than expected in chemical evolution models of a closed and isolated galaxy (van den Bergh 1962; Sánchez Almeida et al. 2014 and references therein). Hence, the gas content of a galaxy needs to be replenished with metal-poor gas, i.e. gas originating from the intergalactic medium. This is supported by cosmological hydrodynamical simulations by Davé et al. (2013), who among others have shown that the cycle of gas inflow, gas outflow and star formation is essential to reproduce scaling relations between two or three properties of galaxies, such as the gas content, the stellar content, the star formation activity or the metallicity. In particular the stellar mass-metallicity relation (Mannucci et al. 2010; Hughes et al. 2013) is driven by smooth, stochastic accretion: the accretion of cosmological gas triggers star formation (increase of star formation) and dilutes the interstellar medium (decrease of the gas-phase metallicity). Furthermore, Moran et al. (2012) find that massive galaxies with a higher H i content have a steeper drop in gas-phase oxygen abundance. Putting this in the context of cosmological gas accretion, it implies that the outskirts of a galaxy are diluted by metal-poor inflowing gas. It is, however, suggested that in the local Universe cosmological accretion is less efficient than at higher redshifts, as the Hydrogen Accretion in LOcalGAlaxies Survey (HALOGAS, Heald et al. 2011) survey was not able to detect the necessary amount of H i clouds to sustain star formation (Heald et al. 2011; Heald 2015).

In addition to cosmological gas accretion, the ‘Galactic Fountaining’ mechanism can facilitate the accretion of hot halo gas on to the galaxy (Oosterloo, Fraternali & Sancisi 2007; Fraternali, Sancisi & Kamphuis 2011). In this model, the supernova driven galactic fountain initially expels metal-rich gas from the galactic disc into the halo. This now extra-planar gas cools down and falls back on to the disc. As this happens hot halo gas condenses on to the expelled gas, cools and gets dragged along into the disc. Thus, the gas content of the disc increases (Marinacci et al. 2010, 2011). In H i observations the expelled, extra-planar gas can be identified by its lag in rotation velocity. An example for this process could be NGC 891 (Oosterloo et al. 2007; Fraternali et al. 2011), but also several galaxies observed in the context of the HALOGAS survey (Heald et al. 2011; Gentile et al. 2013) have shown evidence for lagging extra-planar gas. It is to be noted though that evidence for sufficient density of hot haloes is scarce (see e.g. Bogdán et al. 2015).

The alternative is that these very gas-rich galaxies are inefficient at converting their available gas into stars. Wong et al. (2016) suggest that the H i-based star formation efficiency (SFE) is in particular related to the stability of a disc. An elevated specific angular momentum can be one mechanism to stabilize a disc towards gravitational instabilities (Forbes et al. 2014; Krumholz & Burkhardt 2016) and we therefore consider it as a reason for decreased SFE. An enhanced angular momentum has two effects on the galaxy. One is keeping recently accreted gas at larger galactocentric radii and lower densities (Kim & Lee 2013; Forbes et al. 2014), where conditions are less favourable for star formation. Secondly, a high angular momentum stabilizes the gas against Jeans instabilities and subsequent star formation (Toomre 1964; Obreschkow et al. 2016). Simulations suggest that the angular momentum in a local galaxy is independent of the angular momentum of the host halo (Stevens, Croton & Mutch 2016), but is determined by the merger history and feedback (Genel et al. 2015; Lagos et al. 2017). Furthermore, the angular momentum is thought to constrain the upper envelope of the gas fraction – stellar mass plane (Maddox et al. 2015).

In this paper, we present the H i eXtreme (HIX) galaxy survey. For this survey, we are targeting galaxies that contain at least 2.5 times more H i than expected from their stellar luminosity. In order for these galaxies to accumulate that much H i we expect them to have either gone through a recent episode of elevated gas accretion (both smooth and clumpy), to be unable to form stars efficiently from their gas reservoir or a combination of these two scenarios.

The HIX and a control sample of galaxies are observed in H i with the Australian Telescope Compact Array (ATCA) and optical integral field spectra are obtained with the WiFeS spectrograph for the HIX galaxies. This combined data set plus publicly available data allow to search for evidence of gas accretion as well as inefficient star formation as a reason for the H i excess.

The term H i excess has been used in many different ways. We use the term ‘H i excess’ to describe a more massive H i content than expected from optical properties.

This article is structured as follows. In Section 2, we outline the sample selection and the survey strategy. In Section 3, we present observed and publicly available data as well as the data reduction. Section 4 compares our sample to the broader galaxy population. Section 5 focuses on the most extreme galaxy in our sample, EOSS-007-G006, and in Sections 6 and 7 we discuss our findings and conclude.

Throughout the paper we will assume a flat Λ cold dark matter cosmology with the following cosmological parameters: $H_0 = 70.0 \text{ km Mpc}^{-1} \text{s}^{-1}$, $\Omega_m = 0.3$. All velocities are used in the optical convention ($cz$).

## 2 Survey Description and Sample Selection

### 2.1 Sample Selection

The sample of HIX galaxies is selected from a parent sample of 1796 galaxies in the Southern hemisphere. This is a subset of the H i Parkes All Sky Survey (HIPASS) catalogue and the HIPASS bright galaxy catalogue (Koribalski et al. 2004; Meyer et al. 2004) including only H i detections with reliable, single optical counterparts. This sample has been compiled by Dénes et al. (2014) to obtain scaling relations between the stellar and the H i content of galaxies. Using their scaling relation between the R-band luminosity as published in HIPASS optical counterpart catalogue (HOPCAT; Doyle et al. 2005) and the HIPASS H i mass, an H i mass is predicted for each galaxy and compared to the H i mass as measured from the integrated 21 cm emission line in HIPASS.

The detailed selection criteria for the HIX sample are:

(i) an HIPASS measurement of at least 2.5 times more H i than expected from the scaling relation. Fig. 1 shows the scaling relation by Dénes et al. (2014) between the R-band absolute magnitude and the HIPASS H i mass, which was used here.

(ii) absolute K-band magnitude $M_K < -22.0 \text{ mag}$, restricting the sample to massive spiral galaxies. This is equivalent to a K-band luminosity log $L_K[L_\odot] = 42.8$ or a stellar mass of log $M_\star [M_\odot] = 9.7$.

(iii) declination $< -30 \text{ deg}$ for observability with the Australian Telescope Compact Array (ATCA).

We furthermore exclude galaxies near the galactic plane where the high density of foreground stars complicates the photometric measurements.
3 OBSERVATIONS, DATA REDUCTION AND AUXILIARY DATA

3.1 ATCA observations

In this work, we only present the ATCA observations for ESO075-G006, which is the most extreme galaxy in our sample with respect to (relative) H\textsc{i} mass and will be further discussed in Section 5. The ATCA H\textsc{i} data of the remaining HIX and control galaxies will be presented in a subsequent paper.

For the observations of ESO075-G006, the standard ATCA flux and bandpass calibrator PKS 1934-638 has also been observed as the phase calibrator, which was visited regularly during the observations. The observations were carried out between 2012 November and 2013 January. On source times are 5.6, 9.3 and 5.6 h in the 1.5D, 750C and EW367 array configurations, respectively. The Compact Array Broad-band Backend (CABB, Wilson et al. 2011) allows to observe continuum and spectral line simultaneously. The continuum band is 2048 MHz wide, has a frequency resolution of 1 MHz and is centred on 2.1 GHz. Spectral line observations cover a 8.5 MHz bandwidth with a channel width of 0.5 kHz. This is equivalent to a velocity resolution of 0.1 km s\(^{-1}\) at 1370 MHz, which is the band’s central frequency. In this paper, we only utilize the spectral line data, which will be smoothed to channel widths of 4 and 10 km s\(^{-1}\).

3.2 Radio data reduction and analysis

The data reduction of the ATCA H\textsc{i} observations is completed using standard tasks in the program package MIRIAD (Sault, Teuben & Wright 1995) and the PYTHON wrapper mirpy.\(^3\)

After removing radio frequency interference, a semi-automated pipeline conducts bandpass, flux and, phase calibration and subtracts a first order polynomial baseline for each array configuration separately. All available observations from different array configurations are then combined in the Fourier transformation. For the detailed analysis of the H\textsc{i} properties of ESO075-G006 in Section 5, two different data cubes were produced. The cube for the moment analysis has been combined by using a Briggs’ robust parameter of 0.5 and a channel width of 4 km s\(^{-1}\) to maximize sensitivity, the cube for the tilted ring fitted with a robust parameter of 0.0 and a velocity channel width of 10 km s\(^{-1}\) to maximize spatial resolution. As the longest baselines with Antenna 6 are in most cases too long to pick up signal from diffuse and extended H\textsc{i} and merely add noise to the data, all baselines with Antenna 6 are excluded. For the H\textsc{i} data of ESO075-G006, this leads to synthesized beam sizes of 52.4 arcsec by 41.2 arcsec (rob = 0.5) and 40.6 arcsec by 25.3 arcsec (rob = 0.0) and a noise level of 1.81 and 1.2 mJy beam\(^{-1}\), respectively. The lowest column density limit in the moment analysis (on rob = 0.5 data) assumes a 3 \(\sigma\) detection over a velocity width of 12 km s\(^{-1}\) and amounts to 70 mJy beam\(^{-1}\) km s\(^{-1}\) = 0.4 \(\times\) 10\(^{20}\) cm\(^{-2}\) = 0.3 M\(_{\odot}\) pc\(^{-2}\). Moment maps have been created with the MIRIAD task \textit{moment}, including a 3 \(\sigma\) clipping. Moment 1 and 2 maps are further masked to the lowest column density contour and all moment maps are regridded to the resolution of the SuperCOSMOS optical image.

The resulting ATCA data cubes are then further analysed with standard MIRIAD tasks, SAOIMAGE do9, TiltedRingFItting Code (TIRIFIC, Józsa et al. 2007) and PYTHON scripts.\(^4\)

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1 http://ned.ipac.caltech.edu/
2 http://atoa.atnf.csiro.au/
3 https://pypi.python.org/pypi/mirpy
4 https://www.python.org/
3.3 WiFeS observations

ESO075-G006 has also been observed with the Wide Field Spectrograph (WiFeS, Dopita et al. 2007) integral field unit (IFU) mounted on the Siding Spring Observatory ANU 2.3 m telescope. ESO075-G006 has been observed with three pointings towards the north-western edge, the centre and the south-eastern edge of the disc. WiFeS has been setup with $R = 3000$ gratings in both the red and blue arm in combination with the dichroic set at 560 nm. For reliable skyline subtraction, galaxy data have been taken in the nod-and-shuffle mode. Every night of observations has been completed with standard calibration images including bias, sky and dome flatfield and wire imaging for centring the slitlets as well as NeAr and CuAr arc lamp spectra for wavelength calibration. Two to three times a night a standard star for flux calibration has been observed. The observations of ESO075-G006 have been conducted in 2014 August, 2015 July and October under photometric conditions. For more details of the three pointings, see Table 2.

3.4 WIFES data reduction and analysis

Childress et al. (2014) provide the fully automated PYWIFES pipeline for WiFeS data. This pipeline includes bad pixel repair, bias and dark current subtraction, flat fielding, wavelength calibration, sky subtraction, flux calibration and data cube creation. The resulting data cubes are 70 pixels by 25 pixels (35 arcsec by 25 arcsec) in size.

PYWIFES is run on each observed galaxy data cube individually. For each pointing, data cubes are median stacked afterwards. This way small spatial offsets between observations can be taken into account. This procedure results in two data cubes for each pointing: one containing the red half of the spectrum and the other one the blue half.

One stellar population model is constructed for each pointing by median stacking the spectra of all spaxels in one pointing. The stellar population fit is conducted on both the red and blue cube together using the pPXF method and complimentary PYTHON script.
by Cappellari & Emsellem (2004). The stellar population model library is taken from Vazdekis et al. (2010).

For the measurement of the emission line strength, the data cubes of the red and blue half of the spectrum are analysed independently. Each individual data cube is Voronoi binned following Cappellari & Copin (2003) and Cappellari (2009). The Voronoi binning is constructed such that the signal-to-noise ratio in the wavelength range around the O[III] (blue) or N[II] line (red) reaches 50. The error map necessary for the binning is constructed from the variance data cube as given by the pyWIFES pipeline. The sizes of final Voronoi bins are between 1 and 200 spaxels. In each Voronoi bin, the stellar continuum model as fitted to the entire pointing is subtracted. Emission lines are fitted with Gaussians in each Voronoi bin. This results in a redshift measurement from the Hα line and line strengths that can be used to estimate the gas-phase oxygen abundance.

The Voronoi bins of the red and the blue arm are different. So each pixel is assigned the value of the entire bin, and metallicities are calculated on a pixel-by-pixel basis.

### 3.5 Public data

In addition to the observed data, publicly available data are also used:

(i) The HIPASS survey data are used to calculate the H I mass (Barnes et al. 2001; Meyer et al. 2004; Zwaan et al. 2004).

(ii) The AllWISE data release (Cutri et al. 2013) of the WISE mission (Wright et al. 2010) provides images in the four mid-infrared WISE bands: W1 (3.4 μm), W2 (4.6 μm), W3 (12 μm), W4 (22 μm). The flux of galaxies in each band is measured from images obtained from the ICORE co-adder7 (Masri & Fowler 2009) and converted into magnitudes following the prescription in the WISE data handbook.

(iii) The catalogue of extended sources in the Two Micron All Sky Survey (2MASX, Skrutskie et al. 2006) provides magnitudes in the J, H and K bands and precise coordinates of the centre of the stellar disc.

(iv) The HOPCAT (Doyle et al. 2005) provides B, R- and I-band magnitudes, optical position angles and optical semi-major to semiminor axis ratios from SuperCOSMOS (Hambly et al. 2001a,b). HOPCAT also states the Galactic extinction corrected 2MASS data for the HIPASS parent sample are retrieved from the VizieR catalogue access tool, which also took care of reliable cross-matching.

#### 3.6 Estimating galaxy properties

The H I mass is calculated from the published HIPASS integrated 21 cm emission signal by

\[ M_{\text{HI}}[\text{M}_\odot] = \frac{2.356 \times 10^5}{1+z} \times (D[\text{Mpc}])^2 \times F_{\text{HI}}[\text{Jy km s}^{-1}], \]

where \( z \) being the galaxy’s redshift, \( D \) the distance to the galaxy in Mpc and \( F_{\text{HI}} \) the integrated flux density in units of Jy km s\(^{-1}\). The error estimation closely follows the error estimation of \( F_{\text{HI}} \), as suggested by Koribalski et al. (2004):

\[ \frac{S/N}{\sqrt{\text{rms}^2 + (0.05S_{\text{peak}})^2}} \]

\[ \Delta F_{\text{HI}} = \frac{4}{S/N} \sqrt{S_{\text{peak}} F_{\text{HI}} dm}, \]

where \( S_{\text{peak}} \) is the peak intensity in the spectrum, \( \text{rms} \) the root mean square of the data cube, and \( dm \) the velocity resolution. Using Gaussian error propagation, the error of \( F_{\text{HI}} \) is then propagated and combined with the error of the distance to estimate the error of the H I mass.

All stellar masses for the HIX, control and HIPASS samples were estimated following equation 3 in Wen et al. (2013), which assumes a linear relationship between the log of the stellar mass and the log of the Galactic extinction corrected 2MASS K-band luminosity.

Baryonic masses for HIX and control samples are the sum of atomic and stellar mass. The atomic gas mass is the H I mass increased by 35 per cent to include Helium.

Star formation rates (SFRs) for the HIX, control and HIPASS samples are estimated using the GALEX NUV luminosity in combination with the WISE 3-band luminosity to account for dust obscured star formation. We use the prescription in equations 1 and 2 in Saintonge et al. (2016) assuming a Chabrier (2003) initial mass function (IMF). Where GALEX photometry is not available, the SFR prescription by Cluver et al. (2014), which is based solely on the luminosity in the W3 band, is used. Their IMF is consistent with a Chabrier (2003) IMF and the comparison of SFRs estimated with the both methods does not reveal systematic offsets. ESO075G006 is not detected in the W3 band. Its SFR does therefore not include a mid-IR component.

The gas-phase oxygen abundance is estimated with the O3N2 and N2 method using the Hα, H β, [O iii], λ5007 Å and [N ii], λ6584 Å emission lines as described by Pettini & Pagel (2004).

### 4 THE HIX SAMPLE IN CONTEXT

In this section, the HIX galaxy sample is presented and compared to the control sample, the parent sample and other H I-rich samples, where appropriate data are available.

As a first overview, Fig. 2 shows the optical images of all HIX galaxies except ESO075-G006, for which the optical image is shown

5 http://irsa.ipac.caltech.edu/applications/ICORE/

6 http://www-wfau.roc.ac.uk/sss/index.html

7 http://asd.gsfc.nasa.gov/archive/galex/FAQ/count_background.html

8 https://github.com/ericmandel/funtools
in Section 5. All HIX galaxies are spiral galaxies. One of them shows clear signs of interaction (ESO245-G010), the remaining galaxies appear quite regular.

### 4.1 H I MASS AND STELLAR MASS

The relation between gas fraction (defined as $M_{\text{H}I}/M_*$) and stellar mass is well known and used here to test the HIX selection criteria and compare the HIX galaxies to the control and parent sample as well as other samples.

Fig. 3 shows this relation. Most HIX galaxies are located above the 1σ scatter of the parent sample, while the control galaxies populate the HIPASS scatter. The two HIX galaxies that are located within the grey shaded area are ESO208-G026 and IC 4857. They have been selected to be H I-excess galaxies according to the R-band scaling relation of Dénès et al. (2014). On the gas mass fraction versus stellar mass plane, however, they lie within the scatter of the HIPASS parent sample and thus, their H I-richness on that scale is not as obvious as for the other HIX galaxies. In a future analysis of spatially resolved H I data of these galaxies, we will determine whether these two galaxies are true HIX galaxies, more ‘normal’ HIPASS galaxies or something in between.

For comparison, Fig. 3 also shows the running average of the GALEX Arecibo SDSS survey sample (GASS, data release 3, Catinella et al. 2010, 2012, 2013). Non-detections are included as upper limits. GASS is a stellar mass selected sample and as such not biased towards H I rich systems as it is the case for HIPASS.
The running average of the GASS sample is therefore lower than for the HIPASS parent sample and even our control sample appears H$\text{I}$ rich compared to GASS. This further emphasizes that the HIX galaxies are among the most H$\text{I}$ rich galaxies in the local Universe.

We further compare the HIX sample to other surveys of H$\text{I}$ rich galaxies: HighMass (Huang et al. 2014), a sample by Lemonias et al. (2014), H$\text{I}$-Monsters (Lee et al. 2014), HIGHz (Catinella & Cortese 2015) and bluedisk (Wang et al. 2013). For HighMass and Lemonias et al. (2014) sample galaxies, SFRs and stellar masses were calculated the same way as for the HIX galaxies. For the HIGHz and bluedisk galaxies, those values were taken from the respective publications. For all samples, distances and H$\text{I}$ masses were adopted from the respective publications.

HighMass and Lemonias et al. (2014) galaxies have been selected from ALFALFA (Giovanelli et al. 2005) using the log $f_{\text{HI}}$–log $M_\star$[$M_\odot$] scaling relation. Thus, both samples are also located above the 1σ scatter of HIPASS. While the Lemonias et al. (2014) sample focusses on early type, AGN hosting galaxies, HighMass galaxies are spirals. HI-Monsters are HI massive galaxies (log $M_{\text{HI}}$[$M_\odot$] > 10.3) from ALFALFA, i.e. very similar to HighMass. The HI-Monsters sample includes in addition a selection of low surface brightness (LSB) galaxies like Malin 1. HIGHz are a sample of the highest redshift HI detections of single galaxies. The bluedisk sample has been selected to be H$\text{I}$ rich for their morphology and star formation activity. Fig. 3 shows that these bluedisk galaxies lie well within the 1σ scatter of HIPASS.

In being H$\text{I}$ massive and spiral galaxies, the HighMass (and H$\text{I}$-Monsters) sample galaxies appear to be the most similar to the HIX sample.

As none of the HIX galaxies is a LSB galaxy and most of the H$\text{I}$-Monsters have larger stellar masses than the HIX galaxies, there is little overlap between these studies. Where both samples overlap, they host comparably massive H$\text{I}$ reservoirs at a given stellar mass.

Similar to the HIX survey, the HighMass survey aims to select the most HIX galaxies from an H$\text{I}$-selected survey (in this case from ALFALFA). To compare the two sample selections, we use the 2MASS stellar masses for our HIPASS parent sample. These are only available for 1475 out of 1796 galaxies. We further cut this sample down to galaxies, that (a) are located at Dec. $< -30$ deg, (b) are more massive than our stellar mass cut ($M_\star < -22$ mag) and (c) are neither in close proximity to the Galactic plane (for good photometry) nor a massive neighbouring galaxy (exclude source confusion). Applying the HighMass sample selection to this parent sample yields 22 galaxies. These 22 galaxies include all HIPASS galaxies except for the two galaxies that are also located in the HIPASS 1σ scatter in Fig. 3 (ESO208-G026, IC 4857). The remaining 11 galaxies in this ‘HIPASS-HighMass’ sample do not appear in the HIX survey because they are not outliers to the Dènes et al. (2014) scaling relation. This means, when estimating their H$\text{I}$ mass from their R-band luminosity, the estimated H$\text{I}$ mass is not 2.5 times larger than their measured H$\text{I}$ mass. Three of the HighMass like galaxies that are not in HIX have large stellar masses (log $M_\star$[$M_\odot$] $\approx 11.0$). There are, however, no differences found, when comparing the distribution of H$\text{I}$ mass and H$\text{I}$ mass fraction of the HIX like galaxies and HighMass like galaxies above our stellar mass cut.

4.2 Star formation activity

In order to further characterize the sample of HIX galaxies, we investigate their star formation activity and compare it to the control sample.

In Fig. 4, the scatter plot shows the relation between the SFE defined as SFR divided by H$\text{I}$ mass, and stellar mass for the HIX and control samples. This definition has been used before by e.g. Wong et al. (2016) and Schiminovich et al. (2010). We obtain a linear fit to the data with a Monte Carlo method. This method includes creating 1000 random samples that have the same mean and standard deviation in stellar mass and SFE as the sample, to which the line is fitted. To each of these random samples, a line is then fitted with a standard least squares fit. The final slope and interception of the fit is then mean of the results of the 1000 random samples.

The average specific SFRs of HIX (log sSFR [yr$^{-1}$] = (−10.3 ± 0.2)) and control sample (log sSFR [yr$^{-1}$] = (−10.4 ± 0.2)) are comparable, i.e. at a given stellar mass both samples form stars at a similar rate. However, as HIX galaxies are more H$\text{I}$ rich than the control sample, their SFE are systematically lower as can be seen in Fig. 4.

IC 4857 is the only HIX galaxy that forms stars at similar efficiency as the control sample. ESO123-G023 and ESO240-G011 are the least efficient control galaxies.

The model by Wong et al. (2016) is calibrated on Survey for Ionisation in Neutral Gas Galaxies (SINGG, H$\text{I}$ selected, Meurer et al. 2006) and comes in two flavours: The relative contributions by H$\text{I}$ and H$\text{II}$ are disentangled using a prescription either dependent on the stellar surface mass density (D) or the hydrostatic pressure (P). While the hydrostatic pressure model is the preferred model by Wong et al. (2016), the stellar surface mass density model better describes the SFEs of the control sample. The HIX galaxies form stars less efficiently than suggested by both models. All galaxies form stars less efficiently than the average value found by Schiminovich et al. (2010). It is to be noted though that the scatter of their data is three orders of magnitudes. The SFEs of all HIX and control galaxies are larger than $10^{-1.75}$ yr$^{-1}$. Below this SFE, Schiminovich et al. (2010) consider a galaxy passive for their H$\text{I}$ reservoir.

Linear fits to the SFEs of the HighMass and Lemonias et al. (2014) galaxies are also shown in Fig. 4. In particular, the linear fit to the HighMass galaxies is very close to that of the HIX sample further emphasizing the similarity of the two samples.
Lemonias et al. (2014) galaxies tend to be less efficient than the HIX galaxies. The HIGHZ sample is the most efficient at forming stars from their massive H\textsc{i} reservoirs.

To summarize, HIX galaxies form stars less efficiently than the control sample. As outlined in Section 1, one reason for decreased SFE can be the increased angular momentum of a galaxy. In the following section, we will discuss ESO075-G006, for which the resolved ATCA H\textsc{i} data will be analysed and the increased angular momentum hypothesis will be tested.

5 THE MOST EXTREME: ESO075-G006

ESO075-G006 hosts the most massive H\textsc{i} disc of the HIX galaxies with an H\textsc{i} mass of log $M_{\text{H\textsc{i}}}/M_\odot = (10.8 \pm 0.1)$ as measured in HIPASS. This measured H\textsc{i} mass is 2.6 times larger than expected from its HOPCAT R-band magnitude. An H\textsc{i} mass of almost $10^{11} M_\odot$ is rare. According to the H\textsc{i} mass function by Martin et al. (2010) based on ALFALFA, in a volume of 400 000 Mpc$^{-3}$ one expects to find only one galaxy to hosts an as massive H\textsc{i} disc as ESO075-G006.

In this section, the optical morphology, the H\textsc{i} properties and kinematics, the optical spectra and the local environment of ESO075-G006 will be discussed. This section aims to understand the reason for the H\textsc{i} excess in the most extreme HIX sample galaxy. Similar analysis for the remaining HIX galaxies and a comparison to the control sample will be presented in a future paper.

5.1 Optical morphology of ESO075-G006

The SuperCOSMOS $B_j$-band image of ESO075-G006 is shown in Section 5.2. ESO075-G006 hosts a bar and seems to be accompanied by a dwarf galaxy located to the north-west. In the optical, an inner ring and an outer pseudo-ring is visible as the RC3 morphological classification indicates. The inner ring is also visible in GALEX NUV images as a star-forming ring (see grey-scale image in Section 5.6, exposure time: 207 s). As both the SuperCOSMOS and GALEX NUV imaging is relatively shallow, faint spiral arms or an XUV disc cannot be excluded. There is no GALEX FUV image available. The stellar mass is calculated as log $M_*,M_\odot = 10.5$ and the ESO-LV catalogue gives a 25 mag arcsec$^{-2}$ isophotal radius of 30.2 arcsec = 21.7 kpc.

As some of the most H\textsc{i} massive galaxies known, e.g. Malin 1 (Pickering et al. 1997), are LSB galaxies, ESO075-G006 is a good candidate for a LSB galaxy. However, when using the central K-band surface brightness as indicator (Monnier Ragaigne et al. 2003), the value of 17.41 mag arcsec$^{-2}$ of ESO075-G006 is brighter than the threshold to LSB discs.

5.2 H\textsc{i} morphology and radial column density profiles

The two H\textsc{i} data cubes for ESO075-G006 have been produced as explained in Section 3. In this section, we use the robust = 0.5, $\text{dv} = 4 \text{ km s}^{-1}$ data cube to analyse the distribution of H\textsc{i} in ESO075-G006.

Fig. 5 shows the spectrum as taken from the ATCA data cube and from the HIPASS data. They agree within the noise level. The double horn is close to symmetric indicating that the approaching and receding half of the disc contain approximately the same amount of gas. The integrated flux density of ESO075-G006 measured from the ATCA data amounts to 12.8 Jy km s$^{-1}$. Using equation (1) this translates into log $M_{\text{H\textsc{i}}}/M_\odot = 10.8 \pm 0.1$, which is in agreement with the HIPASS measurement of log $M_{\text{H\textsc{i}}}/M_\odot = 10.8 \pm 0.2$ and indicates that the ATCA data cube is not missing any diffuse H\textsc{i}.

The H\textsc{i} column density contours overlaid on the optical SuperCOSMOS image are shown in Fig. 6(c). The locations of maximum column density in the H\textsc{i} disc are found to the north and south of the centre and align with the ridge of the central bar. Furthermore, they coincide with the outermost spiral arms as visible in NUV and faintly visible in the optical. The approaching and receding half appear very similar, i.e. the disc is symmetric. No obvious signs of interaction and tails are visible. In the centre of the disc, the H\textsc{i} column density drops to approximately 1 $M_\odot$ pc$^{-2}$. This is a common feature of H\textsc{i} discs and hints to molecular gas in the centre of ESO075-G006 (Bigiel & Blitz 2012). The distance between the geometrical centre of the H\textsc{i} disc and the 2MASX coordinates of the stellar disc centre is less than 10 arcsec, which is smaller than the spatial resolution element. Therefore, both coincide. In conclusion, the H\textsc{i} morphology points towards a well-settled disc.

Profiles along the semimajor axis in north-western and south-eastern direction. The two profiles along the major axis are also presented in Fig. 7(a). Within the errors of the measurements, the approaching and receding sides show the same radial column density behaviour, again pointing towards a regular H\textsc{i} disc.

The size of an H\textsc{i} disc is commonly quantified through $R_{\text{HI}}$, which is the radius at which the column density of the H\textsc{i} drops to 1 $M_\odot$ pc$^{-2}$ (Broeils & Rhee 1997 and later Wang et al. 2014, 2016) have found $R_{\text{HI}}$ to correlate remarkably well with the H\textsc{i} mass of the disc. This relation indicates that the average H\textsc{i} column density in settled H\textsc{i} discs is constant from galaxy to galaxy. For ESO075-G006 $R_{\text{HI}} = (74 \pm 4)\text{ kpc}$ is measured from the azimuthally averaged radial profile in Fig. 7(a) and corrected for beam smearing following Wang et al. (2014, 2016). The measured value is then compared to the expected $R_{\text{HI}, \text{exp}}$ that is calculated from...
5.3 H\textsc{i} KINEMATICS

In this section, we investigate the H\textsc{i} kinematics in detail searching for evidence of recent gas accretion, e.g. radial motions or vertical gradients indicating a galactic fountain.

5.3.1 2D moment analysis

Panel (b) of Fig. 6 shows the velocity field of ESO075-G006. The iso-velocity contours show the typical spider-web pattern of regularly rotating discs. Radial motions can induce S-shaped iso-velocity contours in the central parts of the galaxy. This, however, is not seen and is a first indication that radial motion are not playing a major role in the velocity field of ESO075-G006.

Fig. 6(d) shows the velocity dispersion of the H\textsc{i} disc of ESO075-G006. The low velocity dispersion in the outer parts, especially along the major axis of the disc further indicates a regularly rotating disc. The increase of the measured velocity dispersion towards the centre of the disc is due to projection effects.

5.3.2 3D kinematic analysis

To further explore the kinematic properties of ESO075-G006, a tilted ring model is fitted to the robust = 0, $dV = 10 \text{ km s}^{-1}$ H\textsc{i} cube using TIRIFIC (Jørgensen et al. 2007). For the fit seven rings, each 30 arcsec wide, are defined. In addition two half discs are defined, each centred on the major axis with an opening angle of 180 deg. This way the approaching and the receding side of the H\textsc{i} disc can be fitted independently. However, only the surface brightness is allowed to vary between the half discs, all other quantities are fitted to full rings. A variety of models were fitted to the data:

(i) a flat rotating disc.
(ii) a warped disc with purely rotational motions.
(iii) discs with lagging thick discs, i.e. Galactic Fountain mechanism.
(iv) flat and warped discs with radially constant or varying radial velocity components.
(v) rotating discs with a combination of radial velocity components and vertical velocity gradients.
All models return similar values for surface brightness, systemic and rotation velocity, inclination (range), position angle (range) and kinematic centre. The flat disc model is not able to produce a flat rotation curve at large radii but requires a sharp drop in the rotation velocity by 30 km s$^{-1}$. This model is therefore excluded. More complicated and exotic models [models (iii), (iv) and (v)] do not trace emission in channel maps and position–velocity diagrams better than a warped disc with purely rotational motions. The data are limited by sensitivity and spatial resolution. The effects investigated in models (iii), (iv) and (v) can still occur in ESO075-G006 but we are not able to detect evidence in favour of them. We apply Occam’s Razor and select the simplest model with a flat rotation curve, which is the warped disc. In the following, this model is presented and discussed.

The rotation curve is shown in Fig. 7(b). Fitting a rotation curve of the functional form:

$$v_{\text{rot}}(r) = v_{\text{flat}} \left[ 1 - \exp \left( -r / l_{\text{flat}} \right) \right]$$

(Leroy et al. 2008 and references therein) yields a rotation velocity of $v_{\text{flat}} = (201 \pm 6)$ km s$^{-1}$.

The model suggests a warp in inclination, which is dropping from 41 to 36 deg between radii of 90 and 120 arcsec. The radial variation of inclination, i.e. the warp is shown in Fig. 7(c). This is a warp at the lower end of the warp scale found e.g. in galaxies from The H$\text{I}$ in Nearby Galaxy Survey (THINGS, Walter et al. 2008; Schmidt et al. 2016). The position angle is held constant with radius and is fitted to 306 deg (see again Fig. 7c).

Furthermore, TIRIFIC finds a velocity dispersion $\sigma$ of 11.2 km s$^{-1}$ and a systemic velocity of 10 613 km s$^{-1}$. The kinematic centre of the disc is located at 21h 23$^{\text{m}}$ 29.5$^{\text{s}}$ – 69$^{\circ}$ 41′ 06″, which is the same location as the 2MASX centre of the stellar disc.

Fig. 8 shows selected channel maps of the input data and resulting model cube. The model performs especially well in the velocity range between 10521 and 10721 km s$^{-1}$. More elaborate models have not been able to decrease the residuals in channels 10 501 km s$^{-1}$.

### 5.4 Stability of ESO075-G006’s disc

Combining the results of the TIRIFIC fitted with radial profiles of H$\text{I}$ and stellar mass, a global stability parameter can be determined for ESO075-G006 following Obreschkow & Glazebrook (2014) and Obreschkow et al. (2016).

H$\text{I}$ and stellar masses are calculated in elliptical concentric annuli. Inclination and position angle for each annulus are taken from the TIRIFIC result. For high sensitivity, the H$\text{I}$ mass map is measured from a moment 0 map created from the robust = 0.5 data cube without clipping. For the stellar masses, luminosities are measured from 2MASS $K$-band images and converted to stellar masses again following equation 3 in Wen et al. (2013). Together with the TIRIFIC measurement of the rotation curve, the integrated specific baryonic angular momentum calculated by

$$J_{\text{B}} = \frac{\sum_{i} (M_{\text{H}\text{I},i} + M_{\text{*,i}}) V_{\text{rot},i} r_{i}}{\sum_{i} (M_{\text{H}\text{I},i} + M_{\text{*,i}})}$$

(M$\text{H}\text{I}$ and M$\text{*,i}$ are the H$\text{I}$ and stellar mass and $V_{\text{rot},i}$ the rotation velocity in the $i$th annulus with radius $r_{i}$). Equation (5) assumes that stars and H$\text{I}$ rotate at the same speed.

The global stability parameter is then calculated by:

$$q = \frac{J_{\text{B}} \times \sigma}{G \times M_{\text{B}}} = \frac{8922 \text{ km s}^{-1} \text{ kpc} \times 11.2 \text{ km s}^{-1}}{G \times 10^{10.22 \pm 0.1} M_{\odot}}$$

Figure 7. Radial profiles of H$\text{I}$ properties. (a) The radial H$\text{I}$ column density profile of ESO075-G006 in azimuthally averaged rings (black points and dashed line) and along the major axis from the centre going north-westerly (south-easterly) in light (dark) blue lines. The bottom grey dashed line marks the lower limit on column densities of 0.4 × 10$^{20}$ cm$^{-2}$, the top grey dashed line marks the 1 M$_{\odot}$ pc$^{-2}$ level. The vertical grey, solid line marks the measured $R_{\text{HI}}$. (b) Rotation curve from TIRIFIC, the black dashed line connects the measurements and the black solid line is a fit to the data. (c) The radial variation of the inclination (black) and the position angle (grey) as fitted by TIRIFIC.
The gravitational constant. We find $q = 0.16 \pm 0.02$. In Fig. 9, the atomic to baryonic mass fraction is shown as a function of $q$. The data point for ESO075-G006 agrees with the analytic model by Obreschkow et al. (2016). This model assumes a flat, exponential disc, where gas is converted into stars when it is not Toomre-stable (Toomre 1964) and gas is stabilized by the specific baryonic angular momentum of the disc. For ESO075-G006 this implies, that the SFE is decreased by the relatively high specific baryonic angular momentum of the disc. The galaxy is therefore able to build up and support a very massive H$_\text{i}$ disc. It is still an H$_\text{i}$-excess galaxy for its optical luminosity. For its specific baryonic angular momentum, however, it hosts a normal amount of H$_\text{i}$.

The angular momentum of the molecular gas was not included in this analysis, as no measurements are available. We argue, however, that the molecular gas does not contribute significantly to the baryonic angular momentum as most of the molecular gas will be located at small radii and the estimated molecular gas mass is smaller than both the H$_\text{i}$ and the stellar mass.

For comparison, we also show the data for THINGS galaxies (Walter et al. 2008; Obreschkow & Glazebrook 2014; Obreschkow et al. 2016), the only sample of massive galaxies for which this detailed analysis has been performed. We furthermore estimate the stability parameter for those HighMass galaxies, for which a rotation velocity and an exponential scalelength or a 25 mag arcsec$^{-2}$ isophotal radius has been published. For this estimate, the stellar specific angular momentum is calculated following equations 4

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and 6 in Obreschkow & Glazebrook (2014). The specific angular momentum of the atomic gas is assumed to be twice the stellar specific angular momentum. For the baryonic specific angular momentum, these estimates are combined using equation (5). Except for AGC 248881, the HighMass galaxies follow the model. The outlier is located in close proximity to other massive galaxies and its kinematics might therefore be altered. Encouraged by the success of this model to explain the extremely high H\textsc{i} mass of ESO075-G006 and HighMass galaxies, we will further populate this graph and test the model with the remaining HIX and control galaxies in the future.

5.5 The local environment of ESO075-G006

The data cube has been searched for dwarf galaxies and remnants thereof. A candidate for such a dwarf galaxy is the object to the north-west of the ESO075-G006. Arp & Madore (1987) have classified this galaxy together with ESO075-G006 as an interacting double.

Following the Hyper-Leda convention, the companion is identified as PGC 277784 (Paturel et al. 2003) and is classified as a non-star object in the Guide Star Catalogue (GSC, Lasker et al. 2008). The coordinates of this object are: 21h 23m 16.0" --69° 40' 25". Assuming this companion is located at the same distance as ESO075-G006, a stellar mass can be estimated from the 2MASS K-band magnitude (taken from the 2MASS point source catalogue, Cutri et al. 2003). This yields log $M/[M_\odot]$ = 9.0.

Including the stellar mass of the dwarf in the stability analysis in the previous section does not change the $q$ parameter significantly. To do so, we assumed that the dwarf would travel at the same rotation velocity as the surrounding H\textsc{i}.

No separate H\textsc{i} content is detected for PGC 277784 above the column density limit within the data cube. Assuming this dwarf to be an unresolved point source at the 3σ column density limit and to have a velocity width of 50 km s$^{-1}$, the upper limit for its H\textsc{i} mass is log $M_{HI}/[M_\odot]$ ≤ 8.7. With the estimated stellar mass, this is equivalent to log $f_{HI} = -0.5$, which is well below the 1σ scatter of the HIPASS running average in Fig. 3.

The residual data cube of the TRIFOC fit, i.e. the difference between the input data cube and the output TRIFOC model cube, does not reveal excess emission in the area of PGC 277784. Hence, there is no H\textsc{i} emission within the data cube that cannot be explained with the warped H\textsc{i} disc model. It is to be noted though that the spatial resolution is limited and could be too coarse to detect signs of the companion.

No signature of other galaxies are found within an H\textsc{i} data cube of 1 deg in side length and $V_{sys}$ ≤ 600 km s$^{-1}$.

The nearest, similarly sized neighbour of ESO075-G006 is 2MASX J21200298-6924152, which is at a larger projected distance than 1 Mpc and its recession velocity differs by 600 km s$^{-1}$. Crook et al. (2007) does not place ESO075-G006 in a group. In summary, ESO075-G006 appears as an isolated field galaxy.

5.6 Optical spectra of ESO075-G006

We observed ESO075-G006 with three different WiFeS pointings along the ridge of the bar. For each of these pointings one stellar population model has been fitted to the median stacked spectra of all spaxels in the pointing, the recession velocity has been measured from the redshift of the H\textsc{r} line and gas-phase oxygen abundances have been measured for all star-forming regions, in which the necessary lines for metallicity estimation have been detected.

![Figure 10](http://www.mpa-garching.mpg.de/SDSS/DR7/)

Using the results of the stellar population modelling, a recession velocity of the stellar disc at each pointing has been measured. Furthermore, the redshift of the H\textsc{r} line in all Voronoi bins indicates the rotation of the ionized gas component. All three components, i.e. stars, atomic and ionized gas are corotating. This indicates that the disc of ESO075-G006 has not been recently (less than one orbital time) disturbed by any major merger.

From the emission lines in the WiFeS data cubes, metallicities can be measured as explained in Section 3.6. In Fig. 10 those observed (star-forming) regions, in which the four necessary emission lines have been detected, are circled. For these region, a gas-phase oxygen abundance has been estimated.

The central metal abundance in the bar amounts to 12 + log(O/H) = 8.7. For a comparison, we take the Sloan Digital Sky Survey data release 7 (Abazajian et al. 2009) in a similar redshift range as the HIX galaxies. The stellar mass for these galaxies were taken from the MPA-JHU catalogue. From these data, we select all those galaxies that lie within 10.4 ≤ log $M/[M_\odot]$ ≤ 10.6 and estimate the metallicity the same way as for ESO075-G006 from emission lines. The average and standard deviation of all estimated metallicities is 12 + log(O/H) = 8.7 ± 0.1. Hence, the central gas-phase oxygen abundance of ESO075-G006 is average for its stellar mass.

In the four regions located on the outer spiral arms / the outer ring, the metallicity amounts to 12 + log(O/H) = 8.4 ± 0.1. Moran et al. (2012) investigated the radial profiles of gas-phase oxygen abundance using the same metallicity estimator. In the same stellar mass range as ESO075-G006, they find the metallicity in some galaxies to drop as low as in ESO075-G006 but most galaxies are more metal rich in the outskirts (see fig. 4 of Moran et al. 2012). They further find a relation between the H\textsc{i} mass fraction and the metallicity in the outskirts of a galaxy (see fig. 8 of Moran et al. 2012). For log $f_{HI}$ > 0.0, they observe the metallicity in the outskirts to drop to values around 8.3, which is similarly metal poor as the outskirts of ESO075-G006. This result, however, should be taken with caution as the relation between outer metallicity, and log $f_{HI}$ > 0.0 is only sparsely sampled in Moran et al. (2012) and no reliable measurement of $f_{HI}$ is available for ESO075-G006. Hence, the location
of outskirts in ESO075-G006 might be different than in the Moran et al. (2012) galaxies.

6 DISCUSSION

In the following, the results from Section 4 and 5 will be discussed. We will start with the discussion of ESO075-G006 then continue on to setting the HIX galaxies into context.

6.1 ESO075-G006

The aim of the detailed examination of ESO075-G006 has been to investigate the origin of the H I excess. As indicated in Section 1, we are considering H I excess due to both clumpy and smooth accretion as well as due to inefficient star formation. In our data set, we can search for evidence for any of following processes:

(i) non-circular gas motions due to inflowing gas or a lag of the thick disc as produced by a Galactic Fountain.

(ii) gas-phase metallicity gradients or inhomogeneities as gas accreted from the intergalactic medium is metal-poor. Metallicity inhomogeneities might coincide with star-forming regions, which were triggered by the accretion event (Filho et al. 2013; Ceverino et al. 2016).

(iii) lopsided H I morphologies as filaments of cold gas accretion are distributed randomly.

(iv) signs of recent mergers, which would disturb both the H I and the stellar disc.

(v) a high angular momentum or other factors that reduce the SFE (Leroy et al. 2008; Obreschkow & Glazebrook 2014).

The hypothesis that ESO075-G006 went through a recent gas-rich major merger can be dismissed, because both the morphology and the velocity field are very regular and the stellar, atomic and ionized gas components are corotating.

Furthermore, H I richness purely due to a gas-rich minor merger with the dwarf companion in the north-west is also disfavoured. We find no evidence of this dwarf hosting its own distinct gas reservoir. The upper limit for the H I mass of the dwarf is log $M_{\text{HI}}[\text{M}_\odot] \leq 8.7$, the difference between the measured and expected H I mass of ESO075-G006 is log $M_{\text{HI}}[\text{M}_\odot] \leq 10.6$. Hence, the detection upper limit in H I mass of the dwarf is two orders of magnitudes too small to explain ESO075-G006’s H I excess.

If the H I reservoir of PGC 277784 has already been incorporated into the H I disc of ESO075-G006, we can estimate the amount of H I brought in by PGC 277784 from its stellar mass and the gas mass fraction – stellar mass relation (see Fig. 3). If PGC 277784 used to be an average HIPASS galaxy, this would result in log $f_{\text{HI}} = 0.3$, which is equivalent to an H I mass of log $M_{\text{HI}}[\text{M}_\odot] = 9.3$. This is still more than an order of magnitude too small to explain the entire H I excess mass. Hence, there needs to be an additional reason for the H I excess of ESO075-G006. It is possible, however, that interaction with PGC 277784 is responsible for the small warp, as the warp occurs at similar galactocentric radii as the location of PGC 277784.

Our best-fitting TIRIFIC model does not need any radial gas motions or vertical velocity gradients to explain the velocity field of ES0075-G006. This implies that accretion or a Galactic Fountain could only operate at smaller column densities or spatial scales than can be detected in the H I data of ES0075-G006. Hence, H I excess due to a recent phase of violent cosmological accretion as well as a very active Galactic fountain cannot be confirmed. We find, however, that the gas-phase oxygen abundance drops in the outskirts of ES0075-G006. In general, metallicity gradients are attributed to accretion of pristine, cosmological gas (e.g. Moran et al. 2012). Stevens et al. (2017) find in the hydrodynamical, cosmological EAGLE simulations that hot halo gas already takes on the structure of the disc before it is accreted on the disc. If hot halo gas accretion is the dominant accretion channel in ES0075-G006, it would therefore be near impossible to detect signs of accretion in the morphology and kinematics of the galactic disc. One possible scenario might therefore be that ES0075-G006 is accreting gas but at low column densities or from the hot halo rather than through filaments.

An explanation for the massive H I disc of ES0075-G006 is provided by the global stability parameter (Obreschkow et al. 2016). Due to its high specific baryonic angular momentum, ES0075-G006 is able to stabilize the gas against star formation. A potential scenario for ES0075-G006 is that gas is constantly accreted over time. Due to the high stability of the disc, however, ES0075-G006 was not able to convert the accreted gas efficiently into stars as it is accreted and the massive H I disc built up over time. A similar scenario is suggested for HighMass galaxy UGC 12506 (Hallenbeck et al. 2014) and Malin 1 (Boissier et al. 2016).

The reason for the high specific angular momentum can only be speculated about. Possible scenarios are that either ES0075-G006 has been formed in a dark matter halo at the high-spin tail of the halo spin distribution, ES0075-G006 has accreted angular momentum e.g. through accretion from filaments that were aligned with the galaxy rotation or ES0075-G006 simply has not lost any angular momentum over time. The semi-analytic simulation Dark-SAGE (Stevens et al. 2016) suggest that the angular momentum of galaxies in the local Universe is not determined by the angular momentum of the host halo. Current hydrodynamical simulations suggest that galactic discs lose angular momentum in major mergers (Lagos et al. 2017) and galactic winds increase the angular momentum (Genel et al. 2015). As ES0075-G006 is very isolated it might have never encountered any major merger, in which it could have lost angular momentum. It might have furthermore gone through an epoch of very active star formation, which in turn will have increased galactic winds and the angular momentum of the disc.

At the current SFR and without any further gas accretion, it would take ES0075-G006 approximately 15 Gyr to return on to the Dènes et al. (2014) scaling relation. So, unless, the H I disc of ES0075-G006 gets significantly stripped, it is likely to continue be an H I excess galaxy for a very long time.

6.2 HIX galaxies in context

The HIX galaxies have been selected to have a high H I mass in comparison to their R-band luminosity. For most HIX galaxies, this also implies a high H I mass fraction at a given stellar mass.

Comparing the H I-based SFE of the HIX and control sample suggests that HIX galaxies form stars systematically less efficiently than the control sample.

The stellar mass range, the morphology and the specific SFR (sSFR) of HIX galaxies is similar to these properties of the control galaxies. This is important as Brown et al. (2015) have identified the H I mass fraction as a primary driver for sSFR as well as a residual relation with morphology and stellar mass. So, if the control and the H I rich sample match in these properties, the difference in H I content arises from other causes. Therefore, the comparison of this control to the HIX sample will enable us to investigate possible recent gas accretion events and answer the questions on where the
excess gas has come from and why the excess gas has not yet been converted into stars.

We will address these questions in subsequent papers, in which we will investigate the H\textsc{i} disc and the distribution of the gas-phase oxygen abundance of the HIX galaxies in greater detail.

7 CONCLUSIONS

In this work, we present the HIX galaxy survey targeting the most H\textsc{i} massive galaxies for their R-band luminosity. We find that these galaxies are normal star-forming spirals for their stellar mass. However, their H\textsc{i} disc is more massive than in a control sample and they are inefficient at converting this gas reservoir into stars.

The most extreme galaxy in the sample is ESO075-G006. Making use of tilted ring fits to ATCA H\textsc{i} interferometric data combined with gas-phase metallicity information from WiFeS optical IFU spectra, we find that this galaxy has not recently undergone major or violent accretion events but appears to be accreting at low levels. Its H\textsc{i} excess can, however, be attributed to a very high specific angular momentum, which prevents accreted gas from being transported to the centre of the disc and converted into stars. Comparing the current SFR of ESO075-G006 to the amount of excess gas suggests that unless ESO075-G006 loses H\textsc{i} in other processes than star formation at the current rate, it will continue be an H\textsc{i} excess galaxy for a very long time.

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