

# H I debris in the IC 1459 galaxy group<sup>★</sup>

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## ABSTRACT

We present H I synthesis imaging of the giant elliptical galaxy IC 1459 and its surroundings with the Australia Telescope Compact Array (ATCA). Our search for extended H I emission revealed a large complex of H I clouds near IC 1459, likely the debris from tidal interactions with neighbouring galaxies. The total H I mass ( $\sim 10^9 M_{\odot}$ ) in the detected clouds spans 250 kpc from the north-east of the gas-rich spiral NGC 7418A to the south-east of IC 1459. The extent and mass of the H I debris, which shows rather irregular morphology and kinematics, are similar to those in other nearby groups. Together with H I clouds recently detected near two other IC 1459 group members, namely IC 5270 and NGC 7418, using Phased-Array Feeds (PAFs) on the Australian Square Kilometer Array Pathfinder (ASKAP), the detected debris make up a significant fraction of the group's intergalactic medium.

**Key words:** galaxies: groups: individual: IC 1459 — galaxies: interactions — radio lines: galaxies

## 1 INTRODUCTION

Gravitational interactions between galaxies and their environment play an important and on-going role in galaxy evolution, affecting their local and global properties such as gas content, kinematics and star formation rate. Physical processes like gas accretion, tidal effects and ram pressure stripping shape the outskirts of galaxy discs, most noticeably their H I extent and morphology (Westmeier et al. 2011). Furthermore, the kinematics of the H I gas associated with galaxies and/or tidal debris can highlight the past orbits of their interactions. Though galaxy transformations can happen in lower density environments (Cappellari et al. 2011), they occur more often in dense groups and clusters. Substantial H I debris are typically detected near massive, often early-type galaxies (Schneider 1989; Ryder et al. 2001; Bekki et al. 2005a,b; Chung et al. 2009; English et al. 2010; Struve et al. 2010). In particular, we highlight the ATLAS-3D H I results for a large sample of nearby early-type galaxies, which show a 40% H I detection rate for the non-cluster targets

(Serra et al. 2012). While most of the detections consist of H I discs or rings, H I debris in form of filaments and clouds are typical in rich groups.

The high density of galaxies in clusters together with their high velocity dispersion typically lead to significant gas stripping, particularly from the outer discs of gas-rich spirals, resulting in mainly H I-deficient galaxies near the cluster centre (Chung et al. 2007, 2009). The observed H I filaments in, for example, Virgo and Ursa Major (Oosterloo & van Gorkom 2005; Boselli & Gavazzi 2006; Verheijen & Zwaan 2001; Wolfinger et al. 2013) hint at the disruptive processes under way, while providing fuel for the formation of new dwarf galaxies from the tidal debris (Duc et al. 2004; Lee-Waddell et al. 2016).

The galaxy group environment is less dense, and interactions occur at much lower speeds than in clusters, allowing us to study tidal interactions, ram pressure stripping, minor mergers and gas accretion. Many detailed H I studies, ranging from galaxies in close pairs (e.g., Gordon et al. 2001; Koribalski & Dickey 2004; Koribalski & López-Sánchez 2009; Sengupta et al. 2015), compact groups (Gordon et al. 2003; Koribalski et al. 2003; Serra et al. 2012), Hickson compact groups (Hickson 1982; Verdes-Montenegro et al. 2001), loose groups (Kilborn et al. 2009; Pisano et al. 2011) and clusters (Chung et al. 2009) have been carried out. The stripped gas may be found as tidal tails, filaments, and plumes near

★ The radio data presented here were obtained with the Australia Telescope Compact Array (ATCA) -through the Australia Telescope Online Archive- and the 64-m Parkes telescope, which are funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

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**Table 1.** Optical properties of IC 1459 group members in the observed area.

Galaxy name	type	centre position $\alpha, \delta$ (J2000)	$v_{\text{opt}}$ [km s <sup>-1</sup> ]	$m_{\text{B}}$ [mag]	$D_{\text{B25}}$ [arcmin]	$i$ [deg]	$PA$ [deg]	offset from IC 1459 [arcmin]
IC 5269B	SBcd	22:56:36.5, -36:14:57	1659	13.2	4.1	78	96	14.5
IC 5269A	SBm	22:55:55.7, -36:20:52	2870	13.9	1.3	41	35	16.5
IC 1459	E3	22:57:11.5, -36:27:44	1691	11.0	4.9	42	47	—
dE1	dE0/Im	22:57:07.6, -36:37:15	—	15.5	0.04	—	—	9.5
dE2	dE0,N	22:57:10.6, -36:40:09	1838	17.3	0.32	—	—	12.4
IC 5264	Sab	22:56:52.6, -36:33:15	2043	13.7	2.5	77	82	6.5
NGC 7418A	SAd	22:56:41.8, -36:46:21	2102	13.8	1.8	56	83	19.5

Notes: Cols. (2–8) give the galaxy type, its centre position [<sup>h,m,s</sup>, ° ′ ″], centre velocity ( $v_{\text{opt}}$ ), blue magnitude ( $m_{\text{B}}$ ), diameter ( $D_{\text{B25}}$ ) measured at the 25th blue magnitude and the corresponding disc inclination ( $i$ ) and position angle ( $PA$ ). — References: ESO LV Lauberts & Valentijn (1989), de Vaucouleurs et al. (1991), da Costa et al. (1991), and Vader & Chaboyer (1994).

**Table 2.** ATCA H I observations of the IC 1459 galaxy group.

ATCA configuration	H214	375	750A	6A
Project	C1154	C530	C1027	C689
Date	04-03-05	19-09-96 23-09-97	08-01-02	03-02-98 08-02-98 09-02-98
Time on-source [min.]	87	396 651	554.3	163.5 40 80
Primary calibrator	PKS 1934–638 (14.95 Jy)			
Phase calibrator	0008–421	0008–421	2259–375	2259–375
Centre frequency [MHz]	1412	1412	1413	1413
Bandwidth [MHz]	8	16	8	8
No. of channels	512	512	1024	512
Channel width [km s <sup>-1</sup> ]	3.3	6.6	1.6	3.3
Velocity resolution [km s <sup>-1</sup> ]	4	8	2	4

**Table 3.** HIPASS properties of IC 1459 group members in the observed area.

Galaxy name	HIPASS name	$v_{\text{sys}}$ [km s <sup>-1</sup> ]	$w_{50}$ [km s <sup>-1</sup> ]	$w_{20}$ [km s <sup>-1</sup> ]	$F_{\text{HI}}$ [Jy km s <sup>-1</sup> ]	Reference	offset from optical position
IC 5269B	HIPASS J2256–36b	1667 ± 4	226	242	21.5 ± 3.3	(1)	1'5
IC 1459 debris	HIPASS J2257–36*	1802 ± 12	80	111	3.0	(2)	3'5
IC 5269A	HIPASS J2255–36	2872 ± 8	124	147	6.0	(2)	1'3
IC 5264	—	~1950	—	~300	—	here	—
NGC 7418A	HIPASS J2256–36a	2115 ± 5	173	209	23.5 ± 3.3	(1)	1'0

Notes: Cols. (3–6) give the H I systemic velocity ( $v_{\text{sys}}$ ), 50% and 20% velocity width ( $w_{50}$ ,  $w_{20}$ ) and integrated H I flux density ( $F_{\text{HI}}$ ). — \* HIPASS J2257–36 encompasses some of the H I debris detected near IC 1459. — References: (1) Koribalski et al. (2004) (HIPASS BGC); (2) Meyer et al. (2004) (HICAT).

the interacting galaxies, e.g. in the Abell 1367 cluster (Scott et al. 2010) and nearby groups (e.g., Higdon 1996; Koribalski et al. 2003; Koribalski & Dickey 2004; English et al. 2010). These extended H I structures can be difficult to detect, requiring high sensitivity single-dish observations to measure the low-surface brightness emission and long interferometric observations with emphasis on short baselines such as not to resolve out the diffuse H I emission.

The IC 1459 loose galaxy group provides a particularly interesting environment to study the displacement of neutral hydrogen (H I) due to tidal interactions and ram pressure stripping, since IC 1459 is a giant elliptical galaxy sur-

rounded by at least 15 neighbours (Walsh et al. 1990; Kilborn et al. 2009). This group was recently observed by Serra et al. (2015) using the first six PAF-equipped antennas of the Australian Square Kilometre Array Pathfinder<sup>1</sup> (Hotan et al. 2014, ASKAP). The wide-field ASKAP H I data, initially obtained with nine ~1 deg PAF beams, resulted in the detection of 11 galaxies and three H I clouds, two in the

<sup>1</sup> The wide field-of-view (30 sq degrees) delivered by the ASKAP Phased-Array Feeds (PAFs) with all 36 beams is particularly suitable to study the H I emission in nearby galaxy groups and clusters.

proximity of the edge-on spiral galaxy IC 5270 and one close to the spiral galaxy NGC 7418 (Serra et al. 2015). Here we explore the area around IC 1459 using single-beam Australia Telescope Compact Array (ATCA) archival H I data.

### 1.1 The IC 1459 galaxy group

IC 1459 is an early-type galaxy located in the centre of a loose group at an approximate distance of 29 Mpc (Blakeslee et al. 2001; Tonry et al. 2001); here we adopt this distance for the whole group (see also Serra et al. 2015). The IC 1459 galaxy group contains ten bright galaxies, mostly of late-type morphology, (Brough et al. 2006; Kilborn et al. 2009), which form part of the larger-scale Grus cluster (Aaronson et al. 1981; Huchra & Geller 1982). In addition, two dwarf elliptical galaxies (here denoted dE1 and dE2) have been catalogued by Vader & Chaboyer (1994) as group members, both located south-east of IC 5264. While the nucleated dwarf dE2 is clearly visible in second-generation Digitized Sky Survey (DSS2) images, its low-surface brightness neighbour dE1 is hard to see. Table 1 summarises the optical properties of IC 1459 group members in our study while Table 2 lists the H I properties from the H I Parkes All Sky Survey (Koribalski et al. 2004, HIPASS).

Deep optical images of the IC 1459 group by Malin (1985) and Forbes et al. (1995) reveal very faint outer arms, plumes and shells in the outskirts of IC 1459’s stellar body, indicative of accretion and merger activity. The faintest shells appear to encompass the neighbouring spiral galaxy IC 5264. The average distance of the largest shell from the centre of IC 1459 is 3’.8. Forbes et al. (1995) find the shells, which are oriented along the major axis of the galaxy, to have red colours similar to the main galaxy.

A low-sensitivity VLA H I map of IC 1459 and its surroundings is presented by Walsh et al. (1990), who detect three group members (IC 5269B, NGC 7418A and IC 5264) and give an upper limit of 3 Jy km s<sup>-1</sup> for the H I flux in the close vicinity of IC 1459 (ie.  $M_{\text{HI}} < 6 \times 10^8 M_{\odot}$ ). Their H I channel maps show hints of H I debris east of IC 5264 at  $\sim 1800$  km s<sup>-1</sup>. A preliminary ATCA H I map of the same area is shown by Oosterloo et al. (1999) who clearly detect extended debris around IC 1459 and briefly discuss their irregular morphology, suggesting that H I stripping from the gas-rich group members through interactions with IC 1459 is their likely origin.

ROSAT X-ray observations by Osmond & Ponman (2004) reveal very low-level extended emission near IC 1459 and a total luminosity for the group of  $L_X(r_{500}) = 41.51$  erg s<sup>-1</sup>. Kilborn et al. (2009) conducted Parkes H I observations for 16 galaxy groups and compare their H I and X-ray properties. For the IC 1459 group they derive a total H I mass at least of  $2.5 \times 10^{10} M_{\odot}$ . Based on IC 1459’s dynamically inferred black hole mass of  $3 - 12 \times 10^8 M_{\odot}$ , Verdoes Kleijn et al. (2000) estimate a total galaxy mass of  $\sim 3 \times 10^{11} M_{\odot}$  (all quoted mass estimates are adjusted to our adopted distance). Using dynamic modelling of the HST data they measure a systemic velocity of  $v_{\text{sys}} = 1783 \pm 10$  km s<sup>-1</sup>, of the ionised gas in IC 1459,  $\sim 90$  km s<sup>-1</sup> higher than IC 1459’s optical velocity of  $1691 \pm 18$  km s<sup>-1</sup> (de Vaucouleurs et al. 1991). A narrow (35 km s<sup>-1</sup>) <sup>12</sup>CO(1–0) line emission towards IC 1459 at  $v_{\text{sys}} = 1782$  km s<sup>-1</sup> was detected by Bettini

et al. (2001). They give a molecular mass limit of  $2 \times 10^7 M_{\odot}$  and suggest the emission originates from a giant molecular association, possibly a merger residual.

The IC 1459 galaxy itself has a number of peculiar features, hinting at disturbances due to interactions and/or merging: twisted isophotes first noticed by Williams & Schwarzschild (1979) and Franx et al. (1989), a fast counter-rotating stellar core (Franx & Illingworth 1988), faint stellar shells (Malin 1985) and a large H + N [III] emission-line disc showing a weak spiral structure (Goudfrooij et al. 1990). Furthermore, IC 1459 hosts a bright radio source, PKS 2254–367, characterised by two symmetric radio jets, whose activity may have been triggered by the same events that gave the galaxy its peculiar morphology and kinematics. The jets extend to only 8 pc, well within the galaxy core, indicating the AGN is very young (Tingay & Edwards 2015).

In this paper, we present ATCA H I data that allow us to study the diffuse H I emission between IC 1459 and its nearest neighbours. In Section 2 we describe the ATCA observations and data reduction, followed by our results in Section 3 and a discussion in Section 4. A summary and an outlook are given in Section 5.

## 2 OBSERVATIONS & DATA REDUCTION

H I line and 20 cm continuum observations of IC 1459 were obtained with the Australia Telescope Compact Array (ATCA) in the H214, 375, 750A, and 6A configurations between September 1996 and March 2005. The data were downloaded from the Australia Telescope Online Archive<sup>2</sup> (ATOA). The observing parameters are summarised in Table 2; the total time spent on the target field was 32.8 hours.

Data reduction and analysis were performed with the MIRIAD software package (Sault et al. 1995) using standard procedures. In addition, we extensively used KVIS, part of the KARMA package (Gooch 1996), for the visualisation of our data cubes and multi-wavelength images. We calibrated each data set separately, using PKS 1934–638 as primary flux and bandpass calibrator except for the 375 configuration, where PKS 2259–375 was used for the bandpass calibration. The latter data set is somewhat affected by solar interference.

PKS 2259–375 and PKS 0008–421 served as the phase calibrators. Using a flux density of 14.95 Jy for PKS 1934–638, we obtained 2.6 Jy for PKS 2259–375 and 4.3 Jy for PKS 0008–421. Continuum subtraction was made using UVLIN; when required options `sun` and `twofit` were used to subtract continuum emission from the Sun and radio sources in our field. With a bandwidth of at least 8 MHz (see Table 2), we were able to select line-free channel on either side of the detected H I emission within the IC 1459 galaxy group. The H I spectral line data were Fourier-transformed using ‘natural’ and ‘robust’ weighting. The longest baselines to the distant antenna six (CA06) were excluded when making the low-resolution H I cubes to enhance sensitivity for diffuse, extended H I emission. As the four data sets have three different pointing centres, marked in Fig. 1, a mosaic image

<sup>2</sup> <http://atoa.atnf.csiro.au/>

**Table 4.** ATCA H I properties of individual clouds near IC 1459.

H I clouds	centre position $\alpha, \delta$ (J2000)	velocity range [km s <sup>-1</sup> ]	$F_{\text{HI}}$ [Jy km s <sup>-1</sup> ]		$M_{\text{HI}}$ [10 <sup>8</sup> M <sub>⊙</sub> ]		nearest galaxy
C1	22:57:44, -36:33:13	1780 – 1844	0.81 ± 0.16	0.55 ± 0.02	1.61	1.09	IC 5264
C2	22:57:42, -36:38:08	1752 – 1792	0.35 ± 0.10	0.18 ± 0.02	0.70	0.35	NGC 7418A
C3	22:57:27, -36:37:13	1776 – 1800	0.18 ± 0.05	—	0.36	—	NGC 7418A
C4	22:57:17, -36:34:09	1744 – 1808	0.83 ± 0.10	0.15 ± 0.01	1.66	0.29	IC 5264
C5	22:57:13, -36:30:10	1759 – 1828	0.43 ± 0.10	0.14 ± 0.02	0.85	0.27	IC 1459
C6	22:57:04, -36:33:35	1480 – 1512	0.22 ± 0.05	—	0.5	—	IC 5264
C7	22:56:54, -36:42:09	1680 – 1736	0.7 ± 0.1	—	1.5	—	NGC 7418A

Notes: Cols. (2–6) give the centre position [<sup>h,m,s</sup>, °'"], H I velocity range, and two values for the H I flux density ( $F_{\text{HI}}$ ) and H I mass ( $M_{\text{HI}}$ ) of the identified H I clouds, as obtained from the low- and high-resolution maps, respectively (see Section 2).

was produced, then CLEANed and restored. The synthesised beam in the low-resolution H I maps is  $152'' \times 107''$ , and we measure an r.m.s. noise of  $\sim 1.7$  mJy beam<sup>-1</sup> per 8 km s<sup>-1</sup> channel in the centre of the field. The  $5\sigma$   $N_{\text{HI}}$  and  $M_{\text{HI}}$  limits over three channels are  $\sim 6 \times 10^{17}$  cm<sup>-2</sup> and  $\sim 4 \times 10^7$  M<sub>⊙</sub>. The synthesised beam in the high-resolution H I maps is  $30'' \times 30''$ . The corresponding r.m.s. noise, the  $5\sigma$   $N_{\text{HI}}$  and  $M_{\text{HI}}$  limits over three channels of the high resolution cube, used to identify high-density H I clumps, are  $\sim 0.8$  mJy beam<sup>-1</sup> per 8 km s<sup>-1</sup>,  $\sim 5 \times 10^{18}$  cm<sup>-2</sup> and  $\sim 0.2 \times 10^7$  M<sub>⊙</sub>.

### 3 RESULTS

The ATCA H I distribution within the IC 1459 galaxy group for the observed region and velocity range is shown in Fig. 1. We detect H I emission in four spiral galaxies; these are (from north to south) IC 5269B, IC 5269A, IC 5264 and NGC 7418A. Their published optical and HIPASS (Koribalski et al. 2004) properties are listed in Tables 1 & 3, respectively. We also find a complex of H I clouds near the elliptical galaxy IC 1459 as well as individual H I clouds north-east of NGC 7418A and east of IC 5264. Even though the IC 1459 group contains a diffuse hot/warm intra-group medium and probably ram pressure stripping played a role, we found relevant evidence pointing at tidal interactions between group members. The cloud properties, as measured from the presented ATCA H I data, are summarised in Table 4. These H I clouds are in addition to those discovered in ASKAP H I data of the IC 1459 galaxy group by Serra et al. (2015) near the spiral galaxies IC 5270 and NGC 7418, both of which lie outside the area observed here. The lowest contour in Fig. 1 corresponds to an H I column density of  $N_{\text{HI}} = 1.7 \times 10^{19}$  cm<sup>-2</sup> (assuming the H I gas fills the beam).

#### 3.1 H I debris near IC 1459

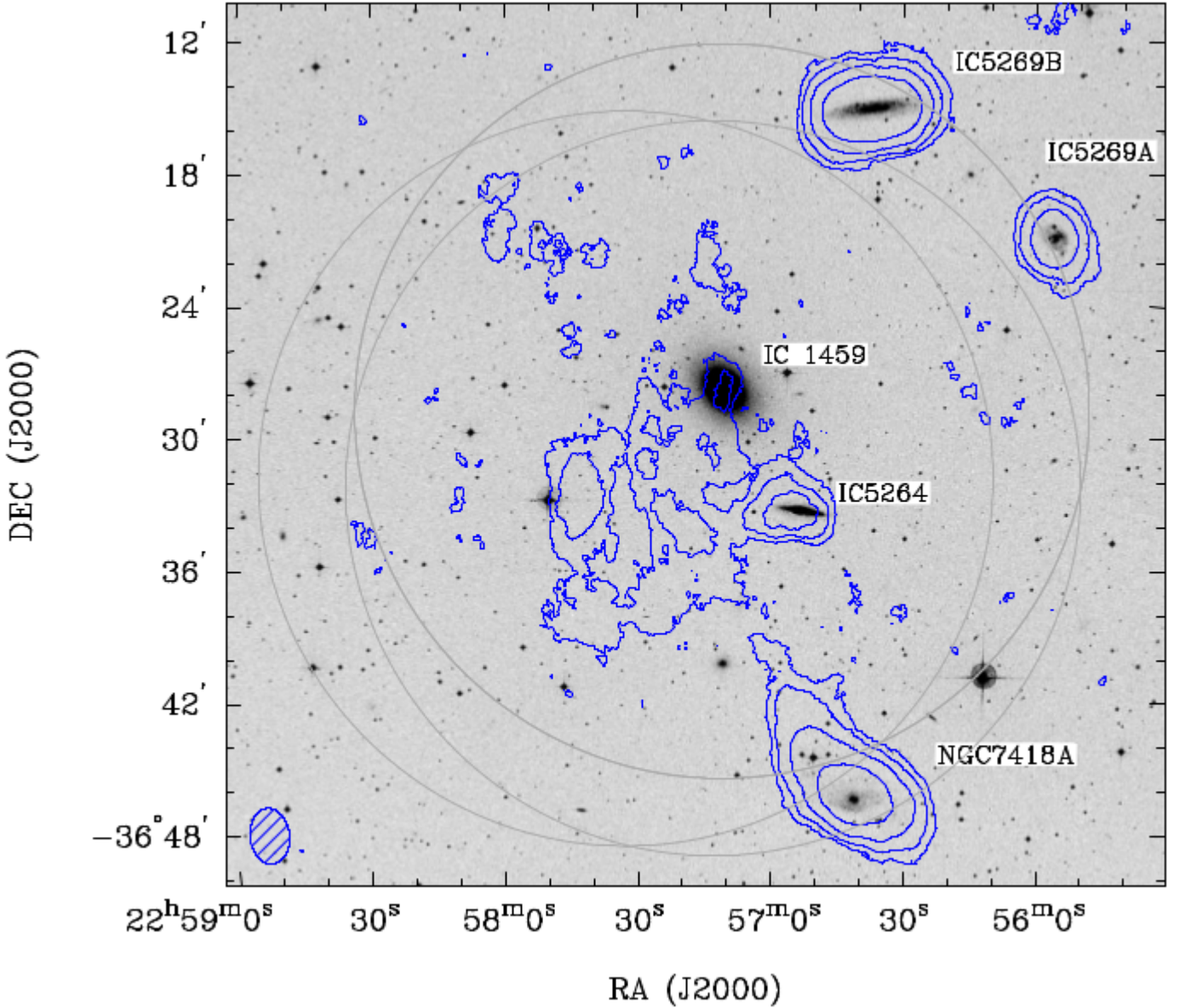
The H I debris in the surroundings of IC 1459 are widespread (see Fig. 1) and difficult to fully map with an interferometer due to their low surface brightness and extended nature. In Fig. 2 we focus on the brightest H I cloud complex, located south-east of IC 1459 and IC 5264, spanning a narrow velocity range from  $\sim 1760$  to  $1850$  km s<sup>-1</sup>. ATCA H I channel maps of these H I clouds, smoothed to 16 km s<sup>-1</sup> resolution, are shown in Fig. 3. The

H I debris complex shown in Fig. 2 spans  $\sim 10'$  (or 85 kpc at the assumed distance of 29 Mpc). The mean H I velocity field of the debris shows a weak velocity gradient, generally decreasing from north to south. The mean H I velocity dispersion is low, compared to that found in galaxies, and consistent with a cloud complex. The full extent of the H I debris shown in Fig. 1 appears to be at least  $\sim 3$  times larger than the cloud complex, spanning over  $\sim 250$  kpc from the eastern tip of NGC 7418A to the H I clouds north-east of IC 1459.

The H I debris near IC 1459 were first detected by Oosterloo et al. (1999) with the ATCA and later independently discovered in HIPASS, catalogued as HIPASS J2257–36 (Meyer et al. 2004). The HIPASS properties are given in Table 3. We note that the fitted HIPASS position,  $\alpha, \delta$ (J2000) =  $22^{\text{h}} 57^{\text{m}} 12.6^{\text{s}}$ ,  $-36^{\circ} 31' 14''$ , is  $\sim 3.5'$  offset from the optical centre of IC 1459 to the south-east and  $4.4'$  from IC 5264 to the east, in agreement with the H I debris complex identified here (see Fig. 2). The centre velocity of HIPASS J2257–36 ( $1802 \pm 12$  km s<sup>-1</sup>) and its velocity widths (see Table 3) also match those obtained here. Using our ATCA data we measure  $F_{\text{HI}} = 2.6$  Jy km s<sup>-1</sup> for the H I debris complex shown in Fig. 2, in agreement with HIPASS, and derive an H I mass of  $5.2 \times 10^8$  M<sub>⊙</sub>. For IC 5264, located just west of the H I debris complex, we measure  $F_{\text{HI}} = 0.5 \pm 0.2$  Jy km s<sup>-1</sup>.

We identified five H I clouds (C1 – C5) within the H I debris complex shown in Fig. 2; their ATCA H I properties are given in Table 4. No optical or GALEX counterparts associated with these clouds are detected in currently available survey data. Our high-resolution ( $30''$ ) ATCA H I maps (not shown here) reveal the densest clumps within these clouds. Four of the five H I clouds show compact clumps with H I masses of  $0.1$ – $1.1 \times 10^8$  M<sub>⊙</sub>. Two additional H I clouds, C6 and C7, can be disentangled from their nearest galaxies due to their distinct radial velocities,  $\sim 1480$  km s<sup>-1</sup> and  $1704$  km s<sup>-1</sup>, respectively.

The detected H I debris near IC 1459 together with H I clouds near IC 5270 ( $\sim 2100$  km s<sup>-1</sup>) and NGC 7418 ( $\sim 1450$  km s<sup>-1</sup>), as identified by Serra et al. (2015), make up a significant fraction of the groups' cold interstellar medium. The total amount of H I mass contained in clouds ( $7.2 \times 10^8$  M<sub>⊙</sub>) is almost 6 times the H I content of IC 5264



**Figure 1.** ATCA H I distribution of the IC 1459 group in the velocity range from 1200 to 2950  $\text{km s}^{-1}$ , overlaid onto a DSS2 *B*-band image. Large amounts of H I debris are detected around the giant elliptical galaxy IC 1459 as well as H I emission in four galaxies (all known group members are labelled). The contour levels are 0.25, 0.5, 1, and 2  $\text{Jy beam}^{-1} \text{ km s}^{-1}$ . The synthesised beam ( $152'' \times 107''$ ) is displayed in the bottom left corner; faint grey circles mark the three different locations of the ATCA primary beam. This image is not primary beam corrected.

( $1.2 \times 10^8 M_{\odot}$ ). According to [Dénes et al. \(2014\)](#) scaling relations, IC 5264 is an H I deficient galaxy. The scenario resembles the first stages of a process that yields to galaxies following the morphology-density relation and becoming H I deficient.

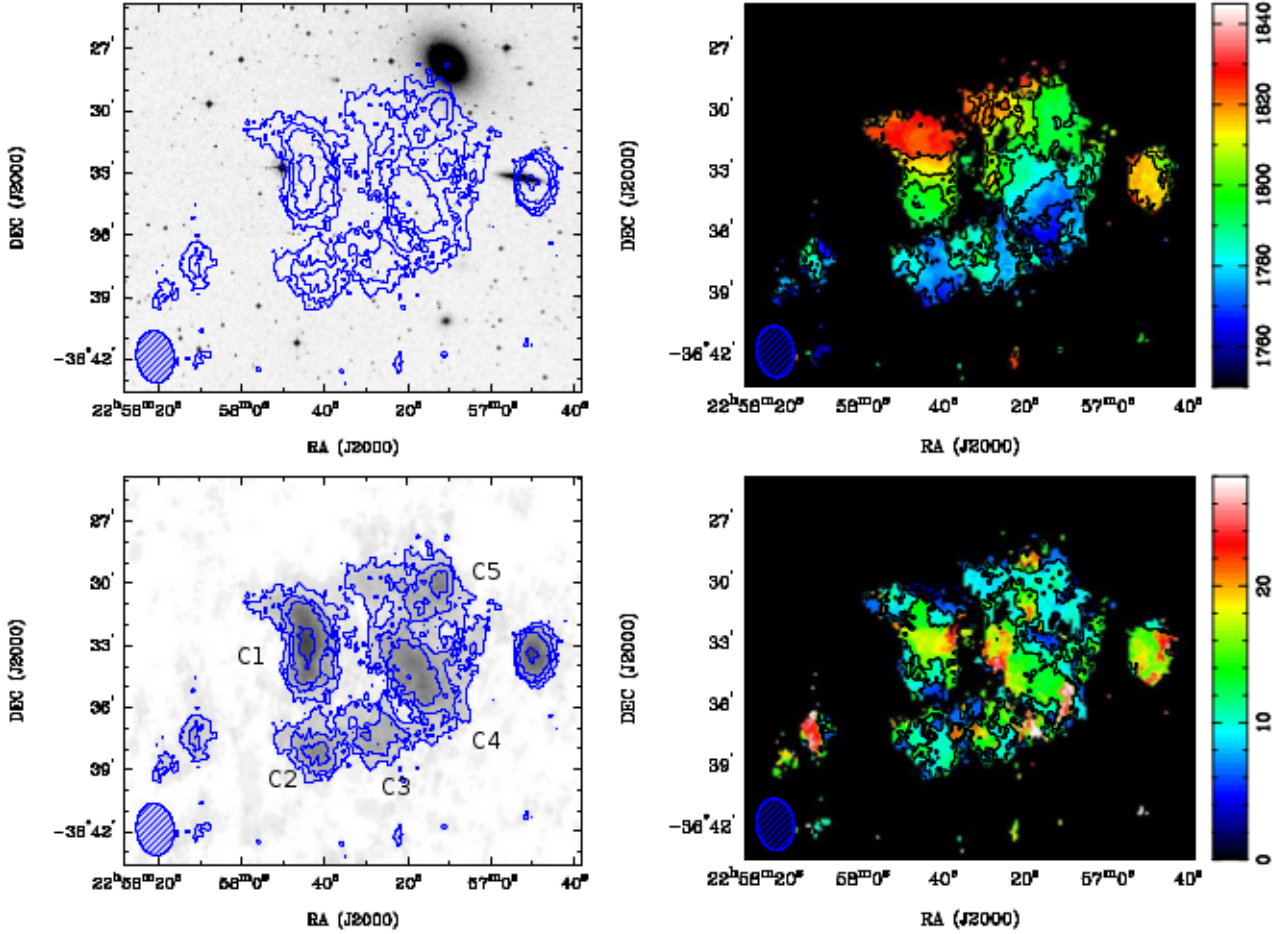
Searching for H I absorption against the bright radio continuum source PKS 2254–367 ( $\sim 1.1 \text{ Jy}$  at 21-cm) at the centre of the elliptical galaxy IC 1459 we find a weak line (2.5 sigma level) at  $\sim 1714 \text{ km s}^{-1}$  with a velocity width of  $\sim 30 \text{ km s}^{-1}$ . The closest H I clump to IC 1459 within the debris complex appears to be C5 (labelled in Fig. 2), most prominent at velocities of  $1780\text{--}1800 \text{ km s}^{-1}$  (see Fig. 3). The

CO(1–0) emission detected at  $1782 \text{ km s}^{-1}$  by [Bettoni et al. \(2001\)](#) also falls into this range.

### 3.2 H I in IC 1459 group members

The ATCA H I properties of the four spirals near IC 1459, as obtained from our low angular resolution H I data cubes (after primary beam correction), are summarised in Table 5. Due to the location of three galaxies near the 50% sensitivity of the ATCA primary beam (see Fig. 1), the quoted H I fluxes are somewhat uncertain.

The H I structure and velocity fields of IC 5269A and



**Figure 2.** ATCA H I moment maps of tidal debris south-east of the giant elliptical galaxy IC 1459 in the velocity range from 1750 to 1840  $\text{km s}^{-1}$ . Some H I emission associated with the small edge-on galaxy IC 5264 is also visible in this velocity range. (**Top Left:**) H I distribution (contours) overlaid onto the DSS2 *B*-band image; the contour levels are 0.7, 1.4, 2.1 and  $3.5 \times 10^{19} \text{ cm}^{-2}$ . (**Bottom Left:**) H I distribution (same contours); (**Top Right:**) Mean H I velocity field; the contour levels range from 1760 to 1820  $\text{km s}^{-1}$  in steps of 10  $\text{km s}^{-1}$ . (**Bottom Right:**) Mean H I velocity dispersion; the contour levels are 4, 8, and 12  $\text{km s}^{-1}$ . The synthesised beam ( $151''.9 \times 108''.7$ ) is shown in the bottom left corner of each panel.

**Table 5.** ATCA H I properties of the detected IC 1459 group members.

Galaxy	velocity range [ $\text{km s}^{-1}$ ]	$F_{\text{HI}}$ [ $\text{Jy km s}^{-1}$ ]	$M_{\text{HI}}$ [ $10^8 M_{\odot}$ ]
IC 5269B	1550 – 1780	$18 \pm 2.0$	40
IC 5269A	2770 – 2920	$1.6 \pm 0.4$	3.5
IC 5264	1800 – 2150	$0.5 \pm 0.2$	1.2
NGC 7418A	2000 – 2200	$14 \pm 1.3$	31

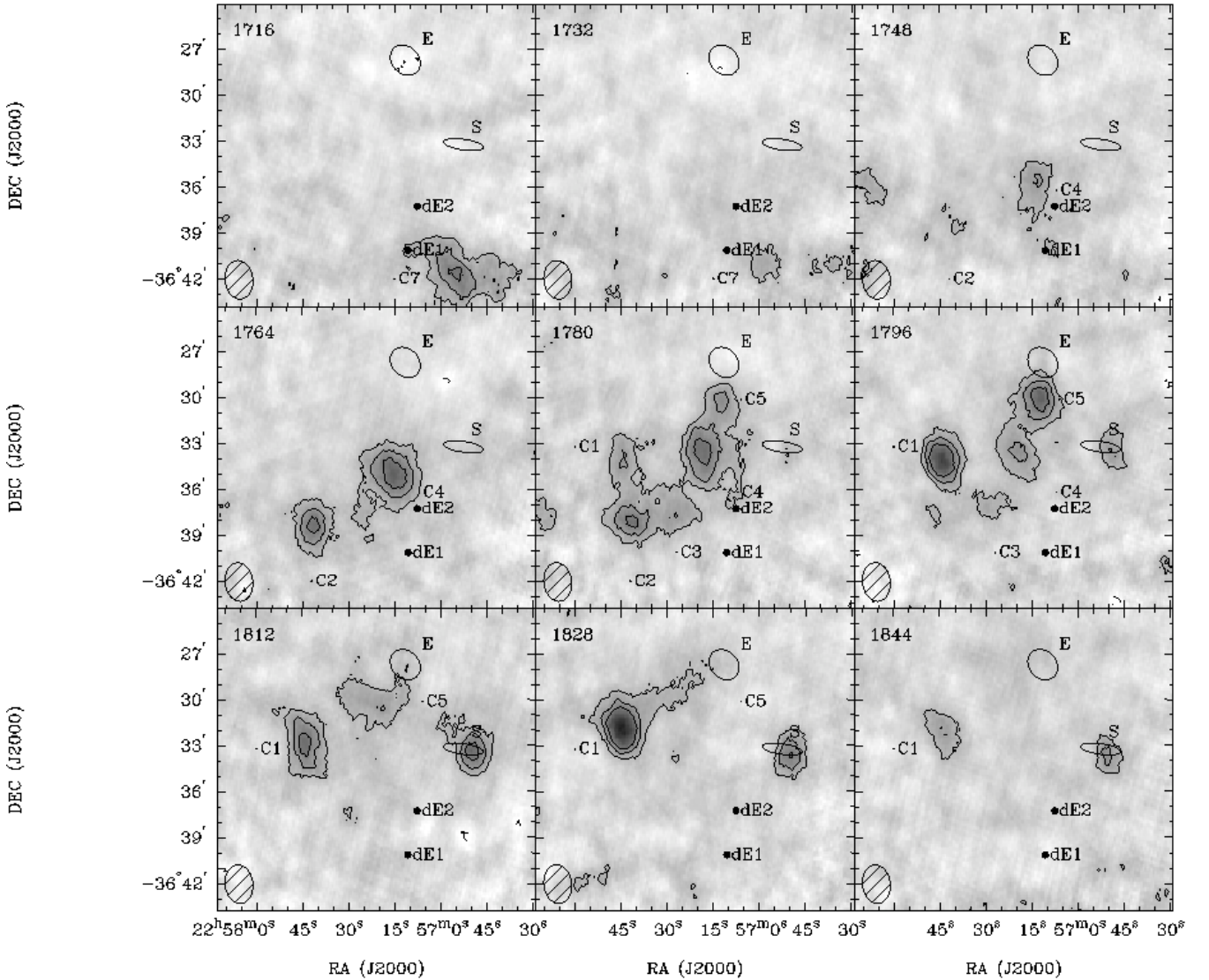
IC 5269B, both located north-west of IC 1459, appear regular and symmetric, while NGC 7418A and IC 5264 show mildly distorted H I distributions (see Fig. 4). High-resolution ASKAP H I maps of the galaxies, which are discussed below, are also shown by Serra et al. (2015).

- IC 5269B (HIPASS J2256–36b) is a late-type spiral galaxy located  $14''.5$  north-west of IC 1459 and has a sim-

ilar system velocity. Sengupta et al. (2007) and Serra et al. (2015) show high-resolution GMRT and ASKAP H I maps of IC 5269B, respectively, indicating a symmetric and regularly rotating disc. We measure  $F_{\text{HI}}$  of at least 18  $\text{Jy km s}^{-1}$ , somewhat less than detected by ASKAP and Parkes (Serra et al. 2015), and derive  $M_{\text{HI}} = 4 \times 10^9 M_{\odot}$ .

- IC 5269A (HIPASS J2255–36) is a Magellanic barred spiral galaxy located  $16''.5$  north-west of IC 1459. Its nearly face-on stellar disc appears very irregular (Buat et al. 2007), while the H I data indicate a regularly rotating disc. This galaxy is in the field of view, but unlikely a member of the group. Its systemic velocity of  $2845 \text{ km s}^{-1}$  is more than  $1000 \text{ km s}^{-1}$  higher than that of IC 1459. We derive  $M_{\text{HI}} = 3.5 \times 10^8 M_{\odot}$ .

- IC 5264 ( $v_{\text{opt}} = 2048 \text{ km s}^{-1}$ ) is a small edge-on spiral galaxy, located only  $6''.5$  south-west of IC 1459 ( $v_{\text{opt}} = 1692 \text{ km s}^{-1}$ ) and just west of the H I debris complex ( $v_{\text{HI}} \sim 1800 \text{ km s}^{-1}$ ). A partial dust lane gives it a slightly peculiar appearance in optical images (Forbes et al. 1995).



**Figure 3.** ATCA H I channel maps of the cloud complex around IC 1459. The channel velocity is shown in the top left corner (in  $\text{km s}^{-1}$ ) and the synthesised beam in the bottom left corner of each panel. The positions of the galaxies IC 1459 (E) and IC 5264 (S) as well as dE1, dE2 and the clouds are marked. The contour levels are 5.1, 8.5, and  $11.9 \text{ mJy beam}^{-1}$ .

IC 5264’s optical velocity is  $\sim 350 \text{ km s}^{-1}$  higher than that of IC 1459, either suggesting a larger distance and/or significant peculiar motions. The ATCA  $pv$ -diagram (Fig. 5) shows IC 5264’s H I emission to cover a velocity range from  $\sim 1800$  to  $2150 \text{ km s}^{-1}$ ; the observed gradient is a clear indicator of galaxy rotation. The blue-shifted H I emission of IC 5264 on its western side (see Fig. 4) falls within the velocity range of the extended H I debris complex to the east. We estimate its H I mass as  $1.2 \times 10^8 M_{\odot}$ . We also identified an H I cloud in the direction of IC 5264, at a very different radial velocity (C6 at  $v_{\text{sys}} \sim 1500 \text{ km s}^{-1}$ ).

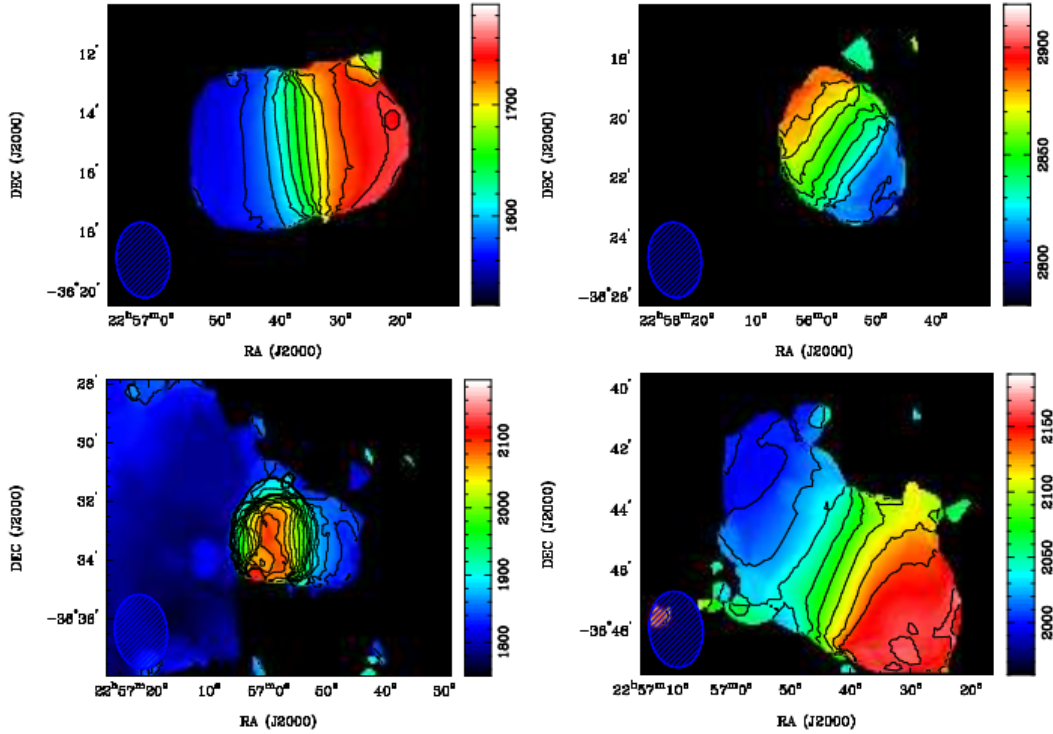
- NGC 7418A (HIPASS J2256–36a) is a late-type spiral galaxy, which lies  $19.5'$  south of IC 1459. GALEX images show an extended ultraviolet (XUV) disc and Thilker et al. (2007) note its two armed feathery-looking spiral pattern of UV-bright clumps. NGC 7418A’s ATCA H I distribution extends a factor three beyond the XUV disc and reveals a tail oriented north-east, towards the main H I debris complex

(Figs. 1 & 4). We measure  $F_{\text{HI}} = 14 \text{ Jy km s}^{-1}$ , corresponding to  $M_{\text{HI}} = 3.1 \times 10^9 M_{\odot}$ . Furthermore, we find an H I cloud (C7,  $\sim 1700 \text{ km s}^{-1}$ ) just east of NGC 7418A, offset from the systemic velocity, with an H I mass of  $1.5 \times 10^8 M_{\odot}$ .

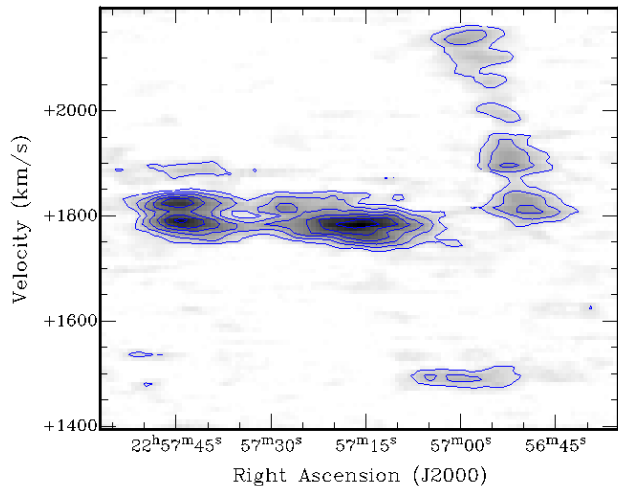
## 4 DISCUSSION

Here we discuss the inner region of the IC 1459 loose group where H I debris extending over  $\sim 250 \text{ kpc}$  with a total H I mass of  $\sim 10^9 M_{\odot}$  have been detected with the ATCA. The presence of this unsettled gas strongly indicates interactions between the group members within the group potential.

H I debris of such irregular morphology have been observed in numerous galaxy systems. For example, a  $\sim 300 \text{ kpc}$  long H I tail consisting of numerous clouds was detected near the Hickson compact group 44 (Serra et al. 2013) with an H I mass of at least  $5 \times 10^8 M_{\odot}$ . A huge H I debris com-



**Figure 4.** Low-resolution ATCA H I velocity fields of the four spirals in the vicinity of the giant elliptical galaxy IC 1459. (**Top Left:**) IC 5269B ( $1550 - 1770 \text{ km s}^{-1}$ ,  $20 \text{ km s}^{-1}$ ). (**Top Right:**) IC 5269A ( $2810 - 2880 \text{ km s}^{-1}$ ,  $10 \text{ km s}^{-1}$ ). (**Bottom Left:**) IC 5264 ( $1840 - 2100 \text{ km s}^{-1}$ ,  $20 \text{ km s}^{-1}$ ). (**Bottom Right:**) NGC 7418A ( $2000 - 2160 \text{ km s}^{-1}$ ,  $20 \text{ km s}^{-1}$ ). Contour level ranges and step sizes are given in brackets. The synthesised beam ( $151''.9 \times 108''.7$ ) is shown in the bottom left corner of each panel. These maps are not primary-beam corrected.



**Figure 5.** ATCA H I position-velocity ( $pv$ ) diagram of the area near IC 1459 shown in Figure 2. It includes the H I cloud complex ( $1750 - 1840 \text{ km s}^{-1}$ ), the galaxy IC 5264 ( $\sim 1800 - 2150 \text{ km s}^{-1}$ ), and the H I cloud C6 ( $\sim 1500 \text{ km s}^{-1}$ ). We applied 3-point Hanning smoothing to the velocities. The contour levels are 3, 6 and 10  $\text{mJy beam}^{-1}$ .

plex, known as the “Vela Cloud”, with at least  $3 \times 10^9 M_{\odot}$  was identified by English et al. (2010) near NGC 3263 in the NGC 3256 group. Extended H I filaments/debris are also ob-

served in the Ursa Major cluster (Serra et al. 2012) near the lenticular galaxies NGC 4026 and NGC 4011.

Hydrodynamical simulations by Bekki et al. (2005a) demonstrate that the group tidal field can be responsible for stripping of H I from the outer disc of gas-rich galaxies, while having little effect on their stellar discs. This scenario was explored in detail to explain the origin of the massive H I cloud (HIPASS J0731–69) discovered near NGC 2442 by Ryder et al. (2001). Gas stripping is found to be most efficient at the pericenter of the orbit on first approach. In our case, it is possible that the galaxy IC 5264 was stripped of its outer H I disc during infall to IC 1459. Using the scaling relations by Dénes et al. (2014) we find IC 5264 to be H I-deficient, which supports this scenario. Furthermore, the ASKAP H I maps presented by Serra et al. (2015) show the H I gas in IC 5264 to be offset from its stellar disc towards the south-east. Tidal interactions between NGC 7418A and IC 1459 are also likely, supported by the north-eastern H I tail of NGC 7418A, which links to the H I debris complex near IC 1459. Their projected separation of  $19''.5$  corresponds to 165 kpc at the adopted group distance of 29 Mpc. The difference in their systemic velocities ( $\sim 400 \text{ km s}^{-1}$ ) is likely due to peculiar motions within the group. The existence of intragroup X-ray emission as well as the peculiar features of IC 1459 (e.g., stellar shells and a counter-rotating ring) further support the suggested interaction scenario.

The detection of an H I absorption line at  $\sim 1714 \text{ km s}^{-1}$  towards PKS 2254–367 implies the presence of cold hydrogen clumps in front of IC 1459, likely part of the debris complex



detected in H I emission. This is further supported by the detection of CO(1–0) emission at  $1782 \text{ km s}^{-1}$  towards IC 1459 by [Bettoni et al. \(2001\)](#).

Furthermore, we note that IC 5269B and IC 1459, which are separated by  $14'.5$  (122 kpc), are the only two large galaxies in the group with systemic velocities in the velocity range of the H I debris. No signs of tidal interaction are visible in IC 5269B. The H I clouds detected near IC 5270 and NGC 7418 ([Serra et al. 2015](#)), both members of the IC 1459 group but outside the area studied here, highlight the complexity of the on-going gas stripping processes on small and large scales.

## 5 SUMMARY & OUTLOOK

Using Australia Telescope Compact Array 21-cm imaging we find a large H I debris complex near the elliptical galaxy IC 1459. The detected H I clouds span  $\sim 250$  kpc and have a total H I mass of  $\sim 10^9 M_{\odot}$ . Most of the H I debris are found to the east of the small edge-on spiral IC 5264.

Based on simulations by [Bekki et al. \(2005a\)](#) we suggest that the IC 1459 group tidal field is responsible for stripping of H I from the outer disc of IC 5264, which is notably H I-deficient, and NGC 7418A during their first infall to the group. Enhanced star formation on NGC 5264's western side, evident in GALEX UV images, may have been caused by the tidal interactions. No signs of star formation activity are detected in any of the identified H I density enhancements. Deep imaging of the molecular gas distribution within the H I debris complex would allow us to pin-point likely locations of star formation.

The 21-cm spectral line of neutral hydrogen is an excellent tracer of galaxy interactions, providing spatial as well as kinematic information of the H I gas in and between galaxies. It also allows us to derive both the H I and total mass distributions of galaxies and groups, pin-point the locations of likely star formation in the galaxy outskirts and tidal dwarf galaxies in the densest H I debris. Although the phenomena related to galaxy interactions in groups and clusters are expected to be relatively common (e.g., [Verdes-Montenegro et al. 2001](#); [Bekki et al. 2005a,b](#); [Chung et al. 2009](#); [English et al. 2010](#); [Serra et al. 2012](#); [Wolfinger et al. 2013](#); [Serra et al. 2015](#)) the need for high sensitivity to extended structures as well as suitable velocity and angular resolution make them difficult to detect and study in detail. Future H I observations with SKA Pathfinders such as ASKAP, Apertif and MeerKat (see [Koribalski 2015](#)) will allow deep H I imaging of many galaxy groups and clusters near and far. Building on the first wide-field H I results from ASKAP ([Serra et al. 2015](#)), we expect the discovery of many H I filaments, plumes, and clouds near interacting galaxies, providing new and valuable information on the evolution of galaxy groups.

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