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Hydrogen tails, plumes, clouds and filaments

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Abstract. Here I present a brief review of interacting galaxy systems with extended low surface brightness (LSB) hydrogen tails and similar structures. Typically found in merging pairs, galaxy groups and clusters, H I features in galaxy surroundings can span many hundreds of kpc, tracing gravitational interactions between galaxies and ram pressure forces moving through the intra-group/cluster medium. Upcoming large H I surveys, e.g., with the wide-field (FOV = 30 square degrees) Phased Array Feeds on the Australian SKA Pathfinder (ASKAP), will provide a census of LSB structures in the Local Universe. By recording and comparing the properties (length, shape, H I mass, etc.) of these observed structures and their associated galaxies, we can – using numerical simulations – try to establish their origin and evolutionary path.

Keywords. galaxies, neutral hydrogen (H I), radio telescopes, galaxy interactions, tidal tails

1. Introduction

The evolution and transformation of a galaxy is strongly influenced by its environment, where it is exposed to varying degrees of tidal interactions, ram pressure stripping, collisions, and ionising radiation. Here I present a preliminary review of extended H I features found in the outskirts of galaxies and typically observed in galaxy groups and clusters. By gathering information on peculiar extensions, such as tidal tails and plumes, bridges towards companions, cloud complexes and other debris, we can quantify the amount of gas found outside galaxies, investigate the responsible removal mechanisms, and determine the age of the encounter. Given the wide range of H I morphologies and kinematics, all seen in projection at one snapshot in time, this is not an easy task. Large-scale simulations of increasingly complex galaxy evolution scenarios are helpful to explore the parameter space.

The comprehensive H I Rogues Gallery, created by Hibbard et al. (2001a), contains one of the largest collections of H I maps and classifications of peculiar galaxies. When published it listed 181 systems (individual galaxies, pairs, compact groups, etc.) with a total of 400+ galaxies. Only a few were added to the "living Gallery" in the following years, while further growing the collection and enhancing the visualisation of its content would be of great interest. In Koribalski (2004) I highlight a few more spiral galaxy systems with H I bridges, plumes and cloud complexes. H I structures around early-type galaxies are examined by Oosterloo et al. (2007) who identify several tails and rings as well as large disks and offset clouds.

A catalog of long H I streams (>100 kpc; 42 objects), many including the host/associated galaxies, is presented by Taylor et al. (2016) who discuss the origin of H I clouds (<20 kpc; 51 objects). While this list includes many prominent H I features, some of which are also mentioned here, it is dominated by gas-rich galaxy pairs and mergers (e.g., NGC 6872/IC 4970 studied by Horellou & Koribalski 2007). Detached H I clouds/streams, often without stellar counterparts, are typically found in wide-field H I surveys (e.g., Ryder et al. 2001, Scott et al. 2012) carried out with single dish telescopes. We are now commencing an era of wide-field interferometric H I surveys with recent results from ASKAP and MeerKat, including the discovery of tidal tails, presented by Lee-Waddell et al. (2019) and Serra et al. (2019), respectively.

While most talks at this wonderful conference focussed on stellar LSB features, it is worth highlighting the importance of detailed H I mapping (incl. its kinematics) in complementing our understanding of galaxy transformations and evolution. As optical imaging is capable of detecting ever fainter LSB structures, we will be able to better analyse the stellar content of H I tidal tails and pinpoints pockets of new star formation as well as, in some cases, the formation of tidal dwarf galaxies (TDGs). Interferometric H I imaging can sometimes help to distinguish Galactic cirrus from extragalactic features seen in deep optical images. As the number of detected stellar streams is growing rapidly, thanks to new instrumentation as well as dedicated deep optical imaging of galaxies (e.g., Martínez-Delgado et al. 2008), complimentary deep H I observations are needed.

2. Overview

In Table 1 I list some of the largest H I structures detected near galaxies in the Local Universe, arranged by their approximate size. This is a preliminary collection (40 galaxy systems) — additions by readers are very welcome — with only a limited set of relevant properties. A more comprehensive review by the author is in preparation. Given the diversity of H I structures observed outside galaxies (tidal tails, rings, plumes, cloud complexes, ...), any size/length measurements are approximate and do not take into account projection effects. The listed H I mass is that measured within the given size of the structure, which for rings and cloud complexes corresponds to their diameter and for filaments, bridges and tidal tails to their length. We typically use the same structure designation as given in the cited publications. In some case, the structure size includes the associated galaxies, where separation of the various components is not easily done.

One of the largest H I structures known in the Local Universe is the Magellanic Stream, which together with the Leading Arm spans ∼200 degrees on the sky, tracing the interactions between the Milky Way and the Magellanic Clouds. Assuming a distance of 55 kpc, the Magellanic Stream has a length of at least 180 kpc and an H I mass of 2.7×10^8 $M_\odot$ (Brüns et al. 2005), approximately half that of the whole Magellanic System. Westmeier & Koribalski (2008) discover further wide-spread H I debris in the vicinity of the stream.

The most spectacular H I cloud so far identified in the H I Parkes All-Sky Survey is HIPASS J0731–69 (Ryder et al. 2001) with an H I mass of $\sim 10^9$ $M_\odot$ and located ∼200 kpc north-east of the spiral galaxy NGC 2442; Ryder & Koribalski (2004) show it to consist of numerous clumps along a partial loop. Furthermore, Oosterloo et al. (2004) disovered four large H I clouds scattered along a ∼500 kpc arc surrounding the elliptical galaxy NGC 1490. H I rings of diameter ∼200 kpc have been detected around the E/S0 galaxies M 105 (the 'Leo Ring', Schneider et al. 1989, Stierwalt et al. 2009), NGC 5291 (Malphrus et al. 1997) and NGC 1533 (Ryan-Weber et al. 2004). Their formation mechanism is explored in numerical simulations by Bekki et al. (2005a,b) who, inspired by the discovery of HIPASS J0731–69 (Ryder et al. 2001) find tidal H I structures resembling rings, tails and plumes of sizes up to 500 kpc.

H I plumes of size 100 to 200 kpc are found near NGC 4388 (Oosterloo & van Gorkom 2005) and NGC 4254 (M 99; Kent et al. 2007) in the Virgo cluster, east of NGC 3628 in

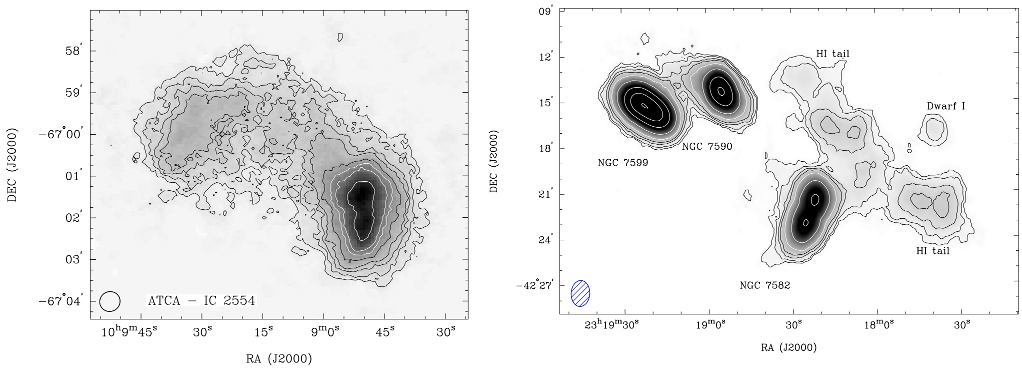

Figure 1. ATCA H I intensity maps of the IC 2554 galaxy system (HIPASS J1008–67; left) and the NGC 7582 triplet (HIPASS J2318–42; right). The prominent H I plume east of IC 2554 has an H I mass of close to 10^9 $M_\odot$ (Koribalski, Gordon & Jones 2003), while the broad tidal tails north of NGC 7582 contain nearly 2×10^9 $M_\odot$ (Koribalski 1996).

the Leo Triplet (Rots 1978, Stierwalt et al. 2009) as well as west of NGC 3263 (English et al. 2010). Extended H I tidal tails (length 50 to 100 kpc) are generally associated with merging galaxy pairs, e.g., Arp 85 (M 51; Rots et al. 1990), Arp 143 (Appelton et al. 1987), Arp 215 (Smith 1994), Arp 244, better known as 'The Antennae' or NGC 4038/9 (Gordon et al. 2001, Hibbard et al. 2001b), and Arp 270 (Clemens et al. 1999). A ∼100 kpc long tidal arm is detected in the spiral galaxy M 83 (Koribalski et al. 2018), likely formed by accretion of a dwarf irregular galaxy. Two of the longest H I tidal tails known so far (length 160 and 250 kpc) are both associated with galaxy groups in the outskirts of Abell 1367 (Scott et al. 2012).

For comparison, the largest known galaxy H I disks are of similar size, e.g., Malin 1 (Pickering et al. 1997), HIPASS J0836–43 (Donley et al. 2006) and NGC 765 (Portas et al. 2010). Their H I diameters (>100 kpc) are in fact as expected from their H I mass based on the H I size-mass relation (Wang et al. 2016).

2.1. *HI streams and debris*

• **HCG 16/NGC 848**. — Verdes-Montenegro et al. (2001) find extended H I emission (stretching ∼320 kpc from NW to SE) in HCG 16 (Arp 318; HIPASS J0209–10) and surroundings, enveloping the gas-rich group members NGC 833/5, NGC 838/9 and NGC 848. They estimate a total group mass of at least 2.6×10^{10} $M_\odot$ and estimate that ∼50% of the gas is now dispersed in tidal features, including a narrow H I bridge from NGC 833/5 to NGC 848.

• **HCG 44/NGC 3162**. — Serra et al. (2013) find H I debris scattered throughout HCG 44 (HIPASS J1017+21) and its environment, some of it forming a stream of at least 200 kpc length. An even larger H I bridge of length ∼450 kpc is detected in improved HIPASS data of the area (see Fig. 2), extending between HCG 44 and the asymmtric spiral galaxy NGC 3162 (HIPASS J1013+22). We measure an H I mass of at least 4×10^8 $M_\odot$. See Leisman et al. (2016) for an in-depth study of the Leo Group using Arecibo H I

Table 1. Preliminary list of the largest known H I structures in the Local Universe.

Galaxy System	**H I structure**	**H I Size** [kpc]	**H I mass** [10^9 M$_\odot$]	Distance [Mpc]	References
NGC 3226/7 (Arp 94)	lobes/tails	730	1.5	25	here
”	inner tails	170	0.8	25	Mun95
NGC 4532/DDO 137	clumpy tail	500	0.5	16.7	Koo08
NGC 1490	clouds/arc	500	8	75	Oos04
HCG 44/NGC 3162	stream/bridge	450	0.4	25	Ser13
HCG 16/NGC 848	bridge/envelope	320	13	52.9	Ver01
FGC 1287 triplet	tidal tail	250	5.7	92	Sco12
NGC 4254 (M 99)	tidal tail	250	0.8	16.7	Ken07
IC 1459	cloud complex	250	1	29	Sap18
NGC 2442/2434	partial ring	200	1	15.5	Ryd01
NGC 2444/5 (Arp 143)	tidal tail	200	0.5	53	App87
M 105/NGC 3384	Leo ring	200	1	10	Sch89
NGC 3690/IC 694 (Arp 299)	narrow tail	180	3.3	48	HY99
Local Group	Mag. Stream	180	0.3	0.05	Brü05
NGC 3263	Vela cloud	175	4	38	Eng10
NGC 5291	partial ring	170	50	58	Mal97
NGC 7252 (Arp 226)	NW tidal tail	160	2.1	63.2	Hib94
”	E tidal tail	83	1.5	”	”
RSCG 42 group	tidal tail	160	9.3	92	Sco12
HCG 92 (Arp 319)	tidal tail/arc	125	6.5	85	Wil02
Cartwheel Galaxy	plume/bridge	110	3	124	Hig96
NGC 4388 (M 86)	complex tail	110	0.3	16.7	OG05
M 81 group	tidal bridges	100	0.7	3.6	Yun94
NGC 2146	streams + debris	100	4.6	12.2	Tar01
HI 1225+01	bridge/tail	100	2	20	Che95
NGC 6215/6221	bridge	100	0.3	18	KD04
NGC 3256	tidal tails	100	5	38	Eng03
NGC 7582	tidal tails	100	2	20	Kor96
M 51 (Arp 85)	tidal tail	90	0.5	9.6	Rot90
NGC 4038/9 (Arp 244)	southern tail	90	2.5	19.2	Gor01
”	northern tail	30	0.2	”	”
NGC 4111	plume	72	0.1	15	VZ01
Leo Triplet (Arp 317)	tidal tail	70	0.5	6.7	Rot78
NGC 1316 (Fornax A)	tidal tails	70	0.7	20	Ser19
CGCG097–087	tidal tail	70		92	Sco12
NGC 3395/6 (Arp 270)	tidal tail	63	0.5	21.7	Cle99
NGC 4424	narrow tail	60	0.04	15.2	Sor17
HCG 31	southern tail	56	6.4	54.3	Ver05
”	NW tail	50	4.0	”	”
”	NE tail	35	0.3	”	”
NGC 2782	plume	54	1.4	34	Smi94
NGC 3310 (Arp 217)	southern tail	51	0.27	13	KS01
”	northern tail	23	0.23	”	”
NGC 4694	tail/bridge	50	0.9	17	Duc07
NGC 4026	plume/filament	38	0.2	17.1	VZ01
IC 2554	tidal plume	30	0.7	16	KGJ03

multibeam data.

• **NGC 2146**. — Taramopulos et al. (2001) detect extended H I streams to the north and south of the peculiar spiral NGC 2146, possibly formed by a tidal interaction with an unseen H I-rich LSB companion ∼800 Myr ago. They derive an H I mass of 6.2×10^9 M$_\odot$ for the system, half of which resides in the southern stream. The northern stream and the galaxy contain approximately one quarter of the mass each.

• **IC 1459**. — Saponara et al. (2018), using the Australia Telescope Compact Array (ATCA), detect a large H I cloud complex near the elliptical galaxy IC 1459 (HIPASS J2257–36) as well as further H I debris in the wider surroundings. The total extent of these tidal debris, extending from the north-east of the spiral galaxy NGC 7418A (HIPASS J2256–36a) to the north-east of IC 1459 is at least ~250 kpc ($M_{HI} \sim 10^9$ $M_\odot$).
The IC 1459 galaxy group was our first WALLABY science target for H I observations with an early array of only six PAF-equipped ASKAP antennas. Serra et al. (2015b) report the detection of 11 spiral galaxies and three H I clouds, two near the edge-on galaxy IC 5270 (HIPASS J2258–35) and one near the spiral galaxy NGC 7418 (HIPASS J2256–37). At the time we were only observing with nine of the 36 ASKAP beams (each with FWHM ~1 degr). Comparison of ASKAP and HIPASS data showed that the two ASKAP discovered compact clouds (H I mass $\sim 10^9$ $M_\odot$ each) are embedded within a larger H I plume containing an additional $\sim 10^9$ $M_\odot$ of diffuse H I emission. While the low angular resolution of HIPASS can make it difficult to identify H I tails, streams or plumes very close to H I-rich galaxies, an offset between the optical and the H I distributions is a promising signature.

• **NGC 3263**. — English et al. (2010), also using the ATCA, find a large H I cloud complex ("the Vela Cloud") with a mass of $3 - 5 \times 10^9$ $M_\odot$ and size of 100 kpc × 175 kpc. The cloud resides south of the merging galaxy NGC 3256 (HIPASS 1027–43), studied in detail by English et al. (2003), and west of the tidally disturbed galaxy NGC 3263 (HIPASS J1029–44b).

2.2. *HI rings and partial rings*

• **NGC 1490**. — Oosterloo et al. (2004) report the discovery of several large H I clouds along a ~500 kpc long arc around the elliptical galaxy NGC 1490. The total H I mass of the clouds, as determined from Parkes and ATCA data, is $\sim 8 \times 10^9$ $M_\odot$. Deep optical images reveal a very low surface brightness optical counterpart in the core of the largest H I cloud, suggesting one of the highest known H I gas to light ratios. Oosterloo et al. favour a tidal origin for this arc-shaped cloud ensemble (HIPASS J0352–66), possibly similar to that of the Leo Ring (see Bekki et al. 2005a,b).

• **NGC 2434 group**. — Ryder et al. (2001) discovered one of the most massive starless (= "dark") H I clouds, named HIPASS J0731–69 (see also Koribalski et al. 2004). It has an H I mass of nearly 10^9 $M_\odot$ and is located in the NGC 2434 galaxy group, roughly between the one-armed spiral NGC 2442 (HIPASS J0736–69) and the galaxy pair NGC 2397/2397B (HIPASS J0721–69). Its closest neighbour is the gas-poor elliptical galaxy NGC 2434, located 23′ (~100 kpc) south-east of HIPASS J0731–69. Closer inspection of the HIPASS data cube reveals H I emission along a partial ring, spanning about 40′ × 20′ (ie. 200 kpc × 100 kpc), connecting to NGC 2442. No stellar counterparts have been detected towards any part of this extended H I structure. Only partial GALEX coverage is available for this area and does not reveal any associated ultra-violet emission. See Bekki et al. (2005a,b) for possible formation scenarios.

• **NGC 5291**. — Malphrus et al. (1997) discover a 170 kpc (N-S) × 100 kpc (E-W) diameter, partical H I ring associated with the peculiar early-type galaxy NGC 5291 and its companion, the Seashell galaxy. Bournaud et al. (2007), using numerical simulations, suggest the H I feature was created by a head-on collision with a massive elliptical galaxy

∼360 Myr ago. The NGC 5291 system is also detected in HIPASS (Koribalski et al. 2004) and catalogued as HIPASS J1347–30.

2.3. *Two HI tails*

• **NGC 3226/7 (Arp 94)**. — The merging galaxy system NGC 3226/7 appears to have two sets of tidal tails, possibly one old and one young pair, offset by ∼45 degr on the sky (see Fig. 2). Discovered in HIPASS data, while investigating the nearby HCG 44/NGC 3162 system (Serra et al. 2013), these giant H I tails/lobes span ∼100′ (ie. 730 kpc for a distance of 25 Mpc). The whole system contains at least 1.5×10^9 . $M_\odot$, at least half of which resides in the north-eastern lobe. The latter was first discovered in northern HIPASS (Wong et al. 2006) and catalogued as HIPASS J1025+20. The giant H I lobes are likely quite old (>1.5 Gyr) and probably falling back towards the merger core as shown in disk-disk merger simulations by Di Matteo et al. (2005). The inner H I tidal tails, discovered by Mundell et al. (1995), span only ∼20′ (oriented north to south) and are likely relatively young, recently formed and still fast moving. Deep optical images of this area reveal a very faint stellar counterpart to the northern H I tail (e.g., Appleton et al. 2014; Duc et al. 2015). Similarly deep images are not yet available for the outer H I tails/lobes; neither DSS nor SDSS images show any likely optical counterparts.

• **NGC 7252 (Arp 226)**. — Hibbard et al. (1994) detect two extended, countermoving H I tidal tails in the "Atoms-for-Peace" galaxy NGC 7252 with a combined length ∼243 kpc, while no H I is found in the central stellar body. While the stars and H I emission in the eastern (E) tail have similar extent, the H I emission in the north-western (NW) tail extends ∼50% further than the stars. This is one of many signatures of the original spiral galaxy progenitors whose major merger resulted in an elliptical galaxy remnant, notable for its stellar shells and loops (see also Hibbard & Mihos 1995).

• **NGC 7582**. — Koribalski (1996) find extended H I tails associated with the starburst spiral galaxy NGC 7582, which is a member of the Grus Quartet. The two tails, probably stripped from NGC 7582's outer disk by tidal interactions, span ∼18′ (105 kpc). Their kinematical signature suggests a connection to the southern (approaching) side of NGC 7582. Together the two tidal tails have an H I mass of nearly 2×10^9 $M_\odot$, which is approximately 15% of the total H I mass detected in the Grus Quartet. The latter consists of four large spiral galaxies: a triplet consisting of NGC 7582, NGC 7590, NGC7599 (HIPASS J2318–42; see Fig. 1) and the face-on starburst galaxy NGC 7552 (HIPASS J2316–42) to the west (not shown here). H I is also detected in a dwarf irregular companion galaxy (marked Dwarf 1) and located just north of NGC 7582.

2.4. *One-sided HI tails and plumes*

• **NGC 2782**. — Smith (1994) finds a 54 kpc long H I plume on the western side of the peculiar spiral galaxy NGC 2782, opposite to its eastern stellar tail. Using kinematic modelling she demonstrates that an off-center head-on collision between two galaxies of mass ratio ∼4:1 about 200 Myr ago can reproduce the observed system. In such a scenario, the smaller companion becomes the eastern extension and the long western plume consists of gas pulled out from the larger galaxy. Smith (1994) derives an H I mass of 1.4×10^9 $M_\odot$ for the western plume, which is ∼40% of the system's total H I mass. Knierman et al. (2013) find young star clusters forming within both tidal tails and compare their formation with those in the tidal arms/tails of other mergers, e.g. NGC 6872/IC 4970 (Horellou & Koribalski 2007) and NGC 3256 (English et al. 2003). Related to this is the study of tidal dwarf galaxy formation by Lelli et al. (2016) in the

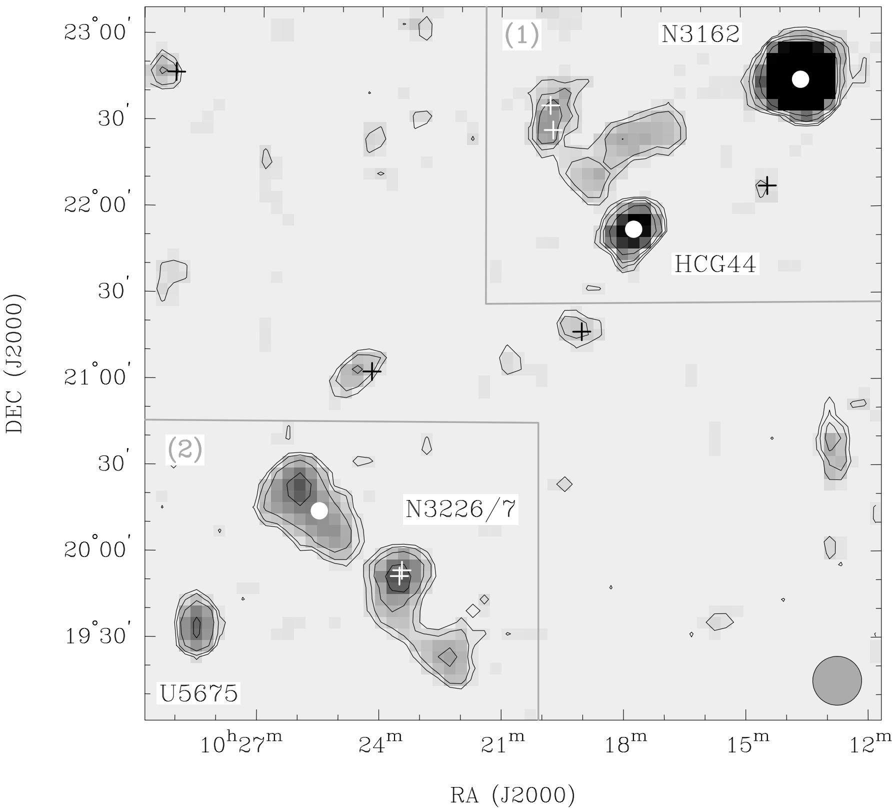

Figure 2. HIPASS intensity map of (1) the long H I stream reaching from HCG 44 (HIPASS J1017+21) towards the peculiar spiral galaxy NGC 3162 (HIPASS J1013+22) and (2) the giant bipolar lobes associated with the merging galaxy pair NGC 3226/7 (Arp 94). The full NE-SW extent of the giant H I lobes is $\sim$100′ (ie., 730 kpc); its southern component (HIPASS J1025+20) was first detected by Wong et al. (2006). Hints of the 450 kpc-long H I stream between HCG 44 and NGC3162 were first detected by Serra et al. (2013). — The HIPASS contours are 0.5, 1, 2 and 4 Jy/beam km/s. Here I use a convolved Parkes beam of 17′, displayed in the bottom right corner.

NGC 4694, NGC 5291 and NGC 7252 systems.

• **NGC 3690/IC 694 (Arp 299)**. — Hibbard & Yun (1999) find a 180 kpc long northern H I tail/plume in Arp 299, likely formed via a merger of two spiral galaxies $\sim$750 Myr ago. While this tidal tail is barely visible in the optical, it is accompanied by a remarkable LSB stellar tail, $\sim$20 kpc offset, with very little H I emission.

• **IC 2554**. — Koribalski, Gordon & Jones (2003) detect a large H I cloud between the peculiar galaxy IC 2554 and the elliptical galaxy NGC 3136B. The cloud is connected to the northern (approaching) end of IC 2554 and forms an arc-shaped plume to the east (see Fig. 1). The IC 2554 system (HIPASS J1008–67) contains a total H I mass of 2×10^9 M$_\odot$, a third of which resides in the cloud. The role of NGC 3136B, situated just east of the 30 kpc sized H I cloud and undetected in H I, remains unclear as its systemic velocity is $\sim$500 km/s higher than that of IC 2554, suggesting it is not a likely interaction partner. Alternately, IC 2554 may be a merger remnant.

3. Summary and Outlook

The large number and diversity of H I structures observed near galaxies within groups and clusters suggests that such features are common. A review of currently known H I structures, many without detected stellar counterparts, is timely in view of upcoming large-scale H I surveys, e.g. WALLABY ($\delta < +30°$; $z < 0.26$; resolution $\sim 30''$ and 4 km/s) on ASKAP (Koribalski 2012), which will detect a wealth of such extended LSB H I structures. It will assist in our preparations for the exploration and analysis of very large 3D data volumes, e.g., searching for large H I structures using our modular Source Finding Application (SoFiA; Serra et al. 2015a) as well as new AI/ML algorithms (e.g., Gheller et al. 2018). We also like to be able to recognise and classify peculiar objects from the shape of their integrated H I spectra alone, as most will remain spatially poorly resolved. Simulated deep H I images, like those of Arp 299 at redshifts $z = 0.1$ to 0.6 (Hibbard 2000), will help to assess the detectability of H I tails and other features at large distances.

The MeerKat H I survey of the Fornax cluster (led by Paolo Serra) will have excellent angular and velocity resolution as well as sensitivity to shed new light on the outskirts of galaxy disks impacted by ram pressure and tidal forces. It will also deliver a large number of "dark" H I clouds such as the debris recently found in the vicinity of NGC 1316 (Fornax A) by Serra et al. (2019). Some of these H I clouds are also detected in the improved HIPASS data cubes. In the Local Universe, the combination of single-dish and interferometric data will likely deliver the most reliable H I measurements. Where initially only the densest H I clumps are detected and detectable with an interferometer, single dish telescopes can also detect the diffuse H I emission, often spread over much larger scales. Notable are the three H I sources in the vicinity of Cen A (Koribalski et al. 2018; their Fig. 14), whose nature and origin requires further investigation.

Recent ASKAP 21-cm observations of the Eridanus galaxy group/cluster with the full array of PAF-equipped telescopes (36× 12-m antennas, 36 beams) are delivering a large number of new galaxy detections and hopefully also some new H I clouds, streams and tidal tails.

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Discussion

Sarah Pearson: Deep optical images of the galaxy M 51 show faint stellar extensions, e.g. to the north and north-west — see talk by Chris Mihos — very different to the location of its 90-kpc long H I tail. How do you explain this ?

Such differences are important signatures of the disk composition and size of the progenitor galaxies as well as the physical processes involved in their interaction/merger. Furthermore, it is likely that multiple merging events took place, resulting in a rich set of loops, shells and tidal tails. Prominent offsets between H I and stellar features are also observed in, e.g., Arp 299 (Hibbard & Yun 1999) and NGC 2782 (Smith 1994).

Noah Brosch: What can you say about the gas kinematics of the tidal features you showed during your talk ?

Analysing the H I kinematics of tidal tails, plumes, streams, etc. is essential to understanding the galaxy interactions by which they formed. The velocity field often reveals the 3D shape of these features as well as their continuity or lack thereof. In particular, the observed kinematic signatures allow to distinguish between different simulations that may have resultied in similar morphologies. In most cases, medium to high velocity resolution (∼4–20 km/s) H I observations are available for the listed galaxy systems. WALLABY – the ASKAP H I All Sky Survey – has a resolution of $\sim 30''$ and 4 km/s (Koribalski 2012; Lee-Waddell et al. 2019).

Ignacio Trujillo: Deep optical images of the LSB galaxy Malin 1 show a very narrow stellar feature towards the north-east, reaching just beyond the spiral pattern; is any H I emission detected in that region ?

The known H I disk of Malin 1 (see Pickering et al. 1997) does not extend to the tip of this LSB feature, neither is any peculiar H I emission detected in that direction.

John Beckman: Are the ASKAP Phased Array Feeds cooled ? What is the T_{sys} ?

All 36 ASKAP PAFs are passively cooled using solid-state thermo-electric Peltier modules. The effective system temperature (T_{sys}/η) is ∼70–75 K across the central part of the band (1.0 – 1.4 GHz) and somewhat higher near the edges of the full band (0.7 – 1.8 GHz). A bandwidth of ∼300 MHz is available for each observation, divided into ∼17 000 channels, resulting in 4 km/s velocity resolution. The ASKAP data rate is huge and, at least initially, it will not be possible to keep all spectral line visibilities.

Samuel Boisssier: What can you say about associated GALEX ultraviolet emission ?

During my studies of the outer H I disks of nearby galaxies I have found GALEX FUV and NUV imaging of great value, allowing the detection of star forming regions often well beyond those visible in optical sky surveys. The XUV-disks of spiral galaxies are typically accompanied by 2X-H I disks, where dense H I clumps in the galaxy outskirts are nearly always detected in GALEX FUV emission. The same appears to be the case for H I tail tidal, which often shown GALEX emission associated with the densest H I clumps.