out, as the volume of the blind surveys so far conducted is modest ($\lesssim 70$ deg^2 each). Therefore large, low column density galaxies, could have been missed due to detection limits. In addition, the surveys conducted so far typically have an H I mass limit of $\sim 10^8 M_\odot$, which leaves the possibility of a large population of low–mass ($M_{\rm HI} \sim 10^7$ $M_\odot$)H I clouds. To be cosmologically significant however, the numbers of such clouds would have to be ~ 100 times the number of 'normal' 10^9 $M_\odot$ galaxies.

There have been two notable serendipitous discoveries of clouds of neutral hydrogen, that have no stellar content to faint limits. These are both bound to stellar systems, and are different in their nature. The Leo ring, discovered by Schneider et al. (1983) is a ring of H I gas surrounding the M96 group, and has an H I mass of $\sim 10^9 M_\odot$. No star formation has been detected in the ring, and an analysis of the dynamics of the ring and surrounding galaxies suggests that the ring is in fact primordial (Schneider, 1989). The other intergalactic H I cloud discovered is the Virgo Cloud, H1225+01 (Giovanelli and Haynes, 1989). This system consists of two H I clumps, the larger, NE clump with an optical counterpart in the form of a faint, dwarf irregular galaxy, and a smaller SW clump, in which no optical emission has been detected to a surface brightness limit of 27.0 V mag arcsec^{-2} (Salzer et al., 1991). The total gas mass of this system is $\sim 3 \times 10^9$ $M_\odot$ at a distance of 20 Mpc (Chengalur et al., 1995). Both the Leo Ring and the Virgo Cloud may represent gas clouds that have not reached the critical density for star formation even though they are massive.

There is one population of H I clouds without optical counterparts: The High Velocity Clouds (HVCs). These clouds have velocities that can not be explained with a simple model of galactic rotation. HVCs are widespread across the sky, with a covering factor estimated to be 0.2 – 0.4 for $N_{\rm HI} > 7 \times 10^{17}$ atoms cm^{-2} (Wakker and van Woerden, 1997). The distance of these clouds is hard to determine, hence their origin is uncertain. It is likely that the population of clouds cannot be explained using just one formation scenario (Putman and Gibson, 1999). The question of the distance to HVCs was raised with Mathewson et al. (1975) suggesting that HVCs lying in the direction of the Sculptor group were associated with the group. Haynes and Roberts (1979) later determined that the clouds were not related to the group. Mirabel and Cohen (1979) surveyed the vicinity of several dwarf galaxies looking for intergalactic clouds, and found a number of HVCs which they concluded were not related to their nearby dwarf galaxies.

The determination of distances to HVCs is problematic, and all methods are indirect. One method used to estimate the distance to HVCs is to use a relationship between the cloud size and H I line-width (Haud, 1990). This is a similar method to distance measurements that have been obtained from HII regions in extragalactic galaxies (Melnick, 1978). The method assumes that the clouds are kinematically similar in nature, and produces distances that are not inconsistent with expected results. A more direct measurement of the distance to HVCs is using stellar absorption. The distance to a handful of clouds has been determined in this manner (eg: Danly et al. (1993), Keenan et al. (1995)). An upper limit to the distance of a cloud can be found in these observations if absorption is observed, however a non-detection does not necessarily mean a lower limit to the cloud, as the stellar line-of-site might pass through a low-column density region of the HVC. Some HVCs form part of the Magellanic Clouds/Galaxy interaction, and therefore their approximate distances are known (eg: Putman (2000)). Hα emission has been detected in the Magellanic Stream and a number of HVCs and using models of the escape of ionising photons from the Milky Way (Bland-Hawthorn and Maloney, 1999; Weiner and Williams, 1996), distance estimates can be obtained from the amount of ionisation present in the clouds. However, accurate models for the escape of photons from the Galaxy are needed, and it is unclear to what extent photons from other nearby galaxies might affect the ionisation of HVCs.

A new sub–population of compact HVCs (CHVCs) has been catalogued by Braun and Burton (1999), who argue these clouds are located at a typical distance of 1 Mpc. CHVCs may be infalling into the Local Group and could represent the remnants of the formation of our Local Group, rather than primordial H I clouds that have not yet formed galaxies. There is some debate about the distances which have been suggested for the CHVCs. Braun and Burton (1999) argue that the clouds must be located throughout the local group as their velocity dispersion is minimised in a reference frame consistent with the Local Standard of Rest. In addition, modelling by Blitz et al. (1999) of the formation of CHVCs in the local group from the interaction if the Milky Way and M31 is consistent with some of the CHVCs being at distances of $\sim$ 1 Mpc. If the clouds did lie at this distance, they would have a typical mass of $\lesssim 10^7 M_\odot$.

Evidence against a Local Group origin of CHVCs comes from Zwaan and Briggs (2000), who found no intergalactic clouds in a blind H I survey using the Arecibo telescope. Zwaan and Briggs (2000) detected 66 H I galaxies, and calculate they should have found up to 200 clouds with the properties of the CHVCs described by Braun and Burton (1999), down to the sensitivity limit of their survey. And from observations of HCO absorption, Combes and Charmandaris (2000) claim that the clouds cannot be at a distance greater than 20 kpc from the Milky Way from their cloud size–line width relationship, assuming the clouds are virialised. Although Braun and Burton (1999) and Blitz et al. (1999) propose a convincing argument for the origin of CHVCs, none of the proposed models are fully consistent with the data.

During the routine cataloguing of galaxies in the SCC region, a nearby H I cloud was discovered. The cloud, HIPASS J1712-64, does not have an optical counterpart to faint limits. The H I structure of the cloud in the HIPASS data was consistent with a nearby, semi–resolved dwarf galaxy, and it was only when cross-checks with optical catalogues were made that it was discovered this object appeared to have no optical counterpart. The follow-up observations of this cloud are now described, and the physical parameters, including H I characteristics and optical limits are derived. A further six H I clouds were catalogued in the SCC region, with properties not inconsistent with them being CHVCs. This Chapter concludes with a discussion about the nature, distance and origin of these H I clouds.

6.2 Observations

HIPASS J1712-64 was discovered by eye in the full sensitivity HIPASS cube H039. A peak image of this cube can be seen in Figure 6.1, with HIPASS J1712-64 identified. As can be seen by this figure, HIPASS J1712-64 is as bright as the nearby galaxies, and has a peak flux of ~ 150 mJy beam^{-1} in the HIPASS data, which gives it a peak signal to noise ratio of ~ 12. This source was noted as being unusual when a NED search failed to show a corresponding catalogued optical detection, and inspections of Digital Sky Survey images showed a crowded star field without any obvious extragalactic optical counterpart. A follow-up observation of 1.8h duration was made using the same Multibeam system at the Parkes Telescope, with a $3^{\circ} \times 4^{\circ}$ field centered on the original detection position. This follow-up observation was made to independantly test that the detection was real. HIPASS J1712-64 was easily detected in this data, even though the RMS of the follow-up cube was much higher than the original (~ 19 mJy beam^{-1} cf. ~ 13 mJy beam^{-1}).

6.2.1 H I Observations

Due to the large beam size and coarse velocity resolution of the HIPASS data, H I synthesis observations were made at the ATCA, and narrow-band observations were made at the Parkes Telescope. Table 6.1 lists the details of the observations.

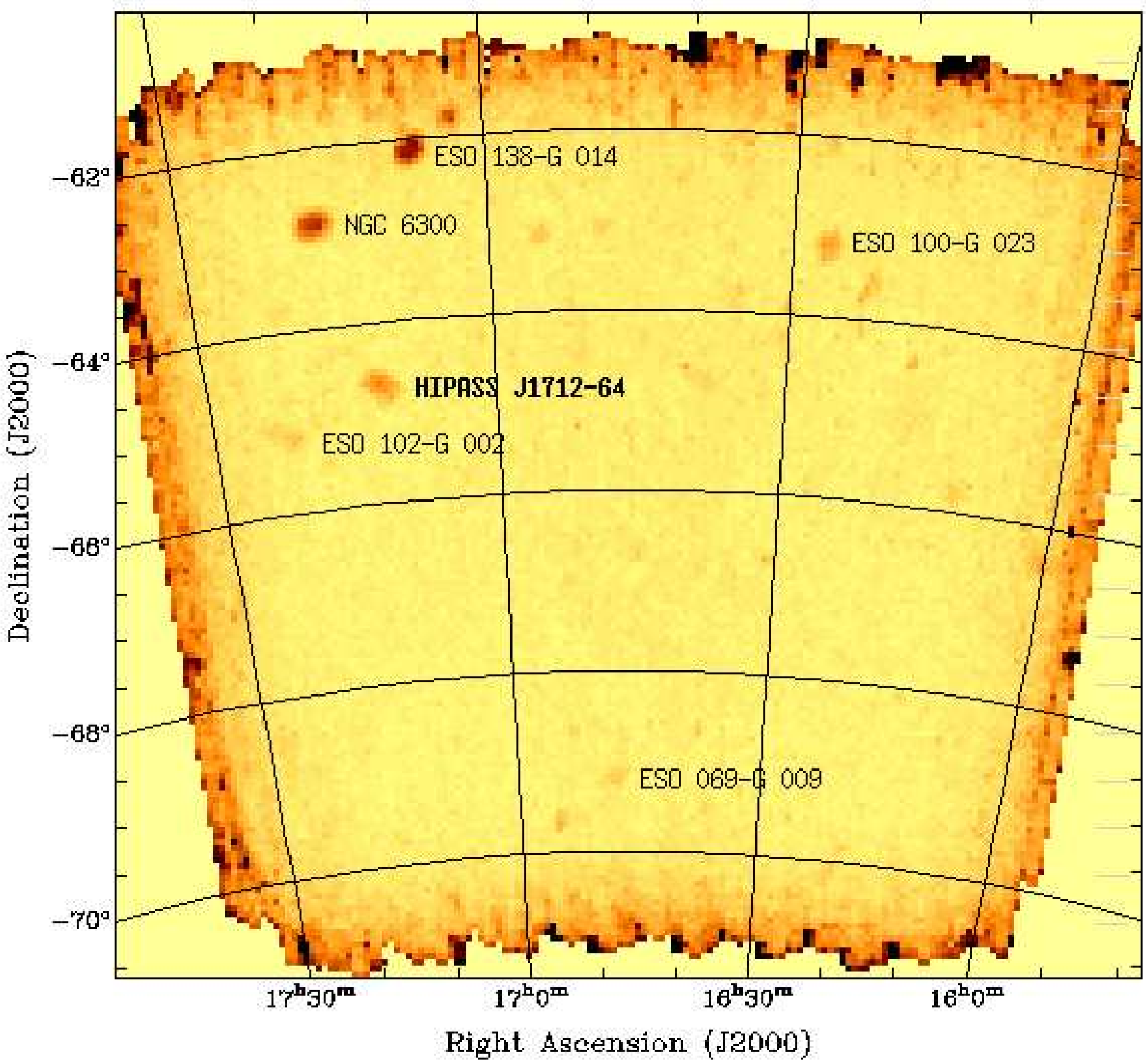


Figure 6.1: Peak image of cube H039 in the velocity range 300km s^{-1} to 3000km s^{-1}. HIPASS J1712-64 is shown with other galaxies of different velocities in the cube.

The first follow-up observations took place on 1999 June 30 at the ATCA, using the 375m array. Approximately 10 hours of data were taken, using an 8MHz bandpass with 512 channels, which gave a channel spacing in the final cube of 3.3 km s^{-1} and a FWHM resolution, before Hanning smoothing, of 4.0 km s^{-1}. The primary flux calibrator PKS 1934-638 was observed twice during the observing run, and a secondary calibrator, PKS 1814-637, was observed every 30 minutes for 4 minutes. The data were reduced using the MIRIAD data reduction package. The data were flagged and calibrated in amplitude and phase, and band-pass corrected. Several bright continuum sources were removed from the data set by fitting spectral base-lines to the line-free channels. Natural weighting was used to form the data into a cube which increased the signal-to-noise of the cube, at the expense of an increase in beam size. The data were CLEANed until the absolute maximum residual in each plane fell below 10 mJy. The data were then RESTORed, and the beam size for the cube was $2\farcm0 \times 1\farcm9$. HIPASS J1712-64 was easily detected in this ATCA data.

A second set of H I synthesis observations was made on the 1999 November 15, using the 210m array at the ATCA. Approximately 10 hours of data were taken, using the same primary and secondary calibrators as the previous ATCA observations. A 4MHz bandpass with 1024 channels was used to increase the velocity resolution of these observations. The resulting velocity channel separation was 0.82 km s^{-1} before Hanning smoothing. Due to technical difficulties, only 4 antennas were available for the majority of the observations, and inspection of the data during reduction showed severe interference in about 2.5 hours of observations. It was necessary to edit this data out, which resulted in uneven coverage of the U-V plane and a more elongated beam than the 375m array observations. Similar data reduction techniques as previously were used, with the data being CLEANed until the absolute maximum residual in each plane fell below 20 mJy. The higher cleaning limit was placed on the data due to the poorer quality compared to the 375m array observations. The data were then RESTORed, with a resulting beam size for the cube of $3\farcm6 \times 2\farcm6$. A spatially integrated spectrum of this data with the 375m data and original HIPASS data can be seen in Figure 6.2.

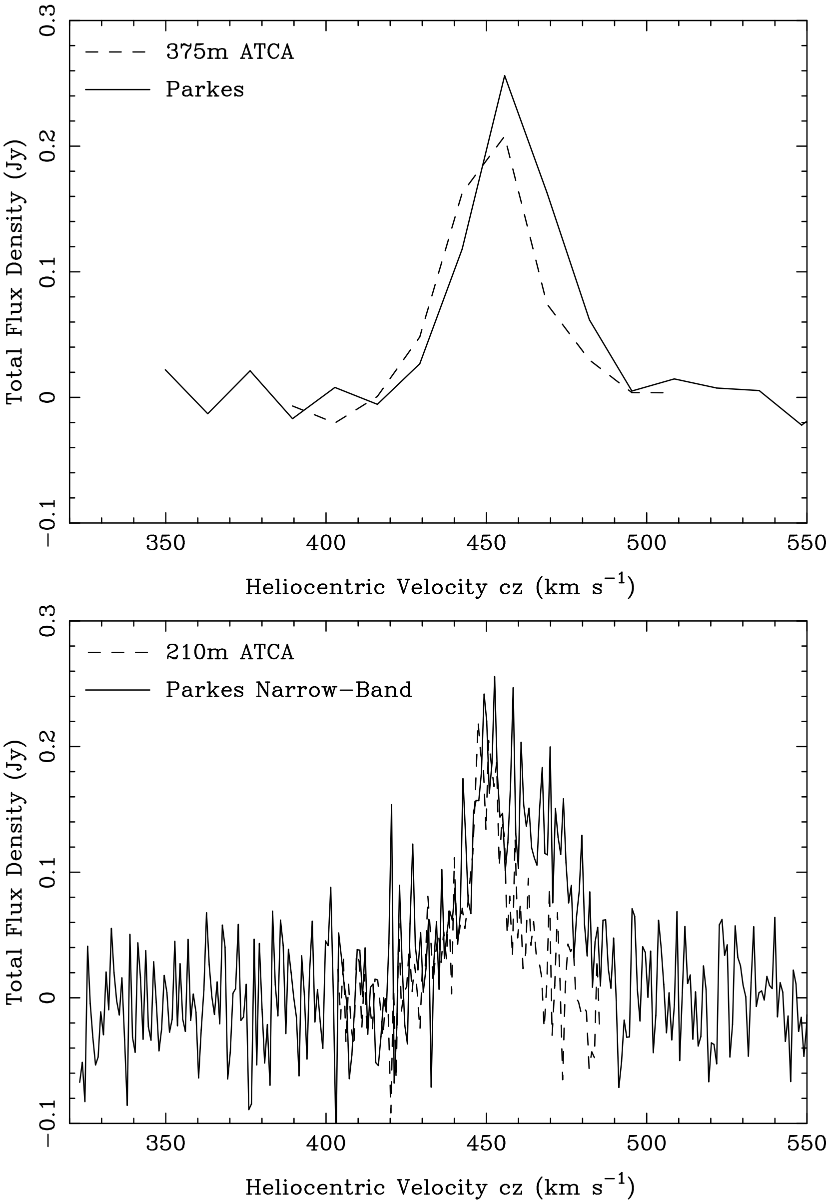


Figure 6.2: Spatially Integrated Spectrum of HIPASS J1712-64, showing low velocity resolution Parkes and 375m ATCA data [Top], and high resolution Parkes Narrow-Band and 210m ATCA data [Bottom]. The interferometric observations miss some of the H I flux at higher velocities, indicating extended H I.

Narrow band observations were made at the Parkes Telescope using the Multibeam receiver in narrow-band mode. The velocity resolution of this data is the same as the 210m array data, ie: 0.82 km s^{-1}. The RMS of the narrow-band cube is 32 mJy $beam^{-1}$ per channel, which is higher than the original cube. However, as the velocity resolution is much higher than the original observations, if the data was smoothed to 13.2 km s^{-1} the noise would be about half that in the original cube. HIPASS J1712-64 has a large flux, so it is still possible to detect the cloud in the narrow-band data. The spatially integrated spectra from the Parkes narrow-band data is shown in Figure 6.2. Combining the 210m array data and the narrow band data produced a detailed velocity field for J1712-64. Channel maps for this data set are shown in Figure 6.3. This high velocity resolution data shows very little rotation in either of the components of HIPASS J1712-64.

The data from the ATCA observations was smoothed to the velocity resolution of the original HIPASS data, and then combined using the MIRIAD task IMMERGE. The resulting combined column density map can be seen in Figure 6.4.

Table 6.1: H I Observations of J1712-64

Observational Configuration	Integration Time	Velocity Resolution	RMS (Jy/beam)	Beam Size	Date(s)
HIPASS	500 s	18 km s^{-1}	0.013	$15'$	1997-1999
Multibeam Follow-up	1.8h	18 km s^{-1}	0.019	$15'$	1999 June 2
ATCA (375m)	$\sim$10 h	3.2 km s^{-1}	0.003	$2\overset{'}{.}0\times1\overset{'}{.}9$	1999 June 30
Multibeam Narrow-Band	24h	0.82 km s^{-1}	0.032	$15\overset{'}{.}4$	1999 November 3
ATCA (210m)	$\sim$7.5 h	0.82 km s^{-1}	0.005	$3\overset{'}{.}6\times2\overset{'}{.}6$	1999 November 16

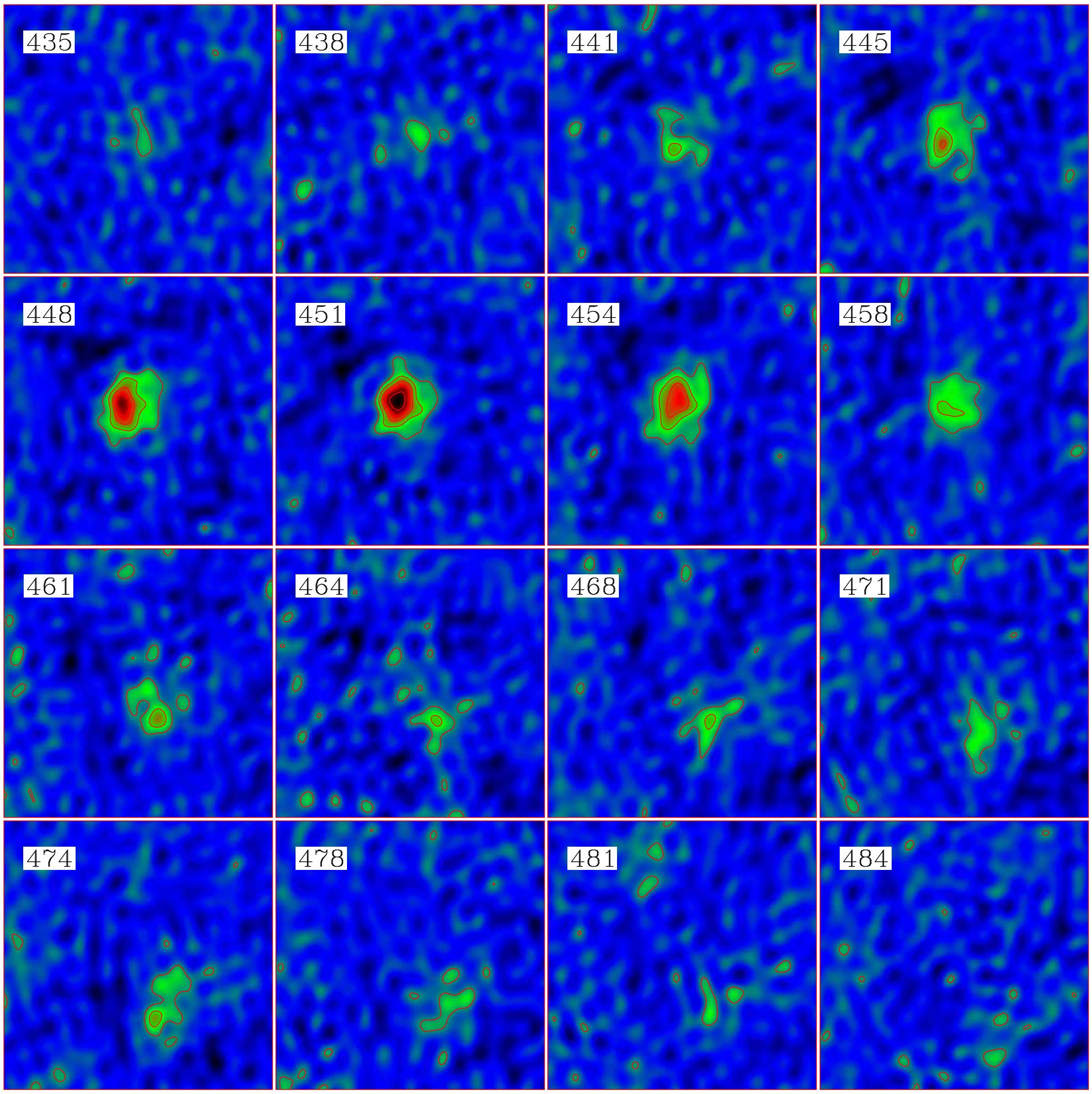


Figure 6.3: Channel maps for HIPASS J1712-64 produced from a combination of 210m ATCA data and multibeam narrow-band data.

6.2.2 Optical Observations

Optical observations were made at the MSSSO 40 inch Telescope in I-Band on 1999 April 15, and in B and R-Band on the 1999 May 4, at the Chile CTIO 1m Telescope (see Table 6.2). The data were reduced using the IRAF data reduction package, and the B and R-Band images were calibrated using photometric observations of Landolt Standard field 104 (Landolt, 1983). The optical point source magnitude limits for the calibrated images are B $\sim$ 19.8 and R$\sim$ 19.2.

Observing Band	Telescope	Integration Time	Date
B	CTIO 40 inch	3600s	4 May 1999
R	CTIO 40 inch	1800s	4 May 1999
I	MSSSO 40 inch	3000s	15 April 1999

Table 6.2: Optical Observations of J1712-64

6.3 H I Structure

The H I column density map (Fig. 6.4) shows that HIPASS J1712-64 has two components. A main component (hereafter the NE component), and a smaller, possibly infalling cloud (hereafter the SW component), are joined by a bridge of neutral hydrogen gas. The NE component is centered at R.A. $17^{\mathrm{h}}12^{\mathrm{m}}35$s, Declination $-64^{\circ}38'12''$(J2000), and emission from the component can be seen between velocity channels 450–464 km s^{-1} in the 210m ATCA data. The peak flux of the NE component from the combined image is 151 mJy, and it has a ΔV_{50} of 14 km s^{-1}. (see Table 6.3).

The SW component is much smaller than the NE component. It is centered at R.A. $17^{\mathrm{h}}11^{\mathrm{m}}35$s, Declination $-64^{\circ}45'11''$(J2000). The systemic velocity of this component is 464 km s^{-1}, and emission is seen from velocity channels 454–474 in the 210m ATCA data. Looking at the velocity contours of HIPASS J1712-64 it can be seen that there is a very small velocity gradient accross the NE component of less than 6 km s^{-1}, and a slightly larger, although still small velocity gradient perpendicular to the major axis of HIPASS J1712-64 in the SW component. The SW component has just one quarter of the integrated flux of the NE component.

The overall structure appears to be that of two separate, but interacting components, which is similar to, although smaller than, the Virgo Cloud (Giovanelli and Haynes, 1989).

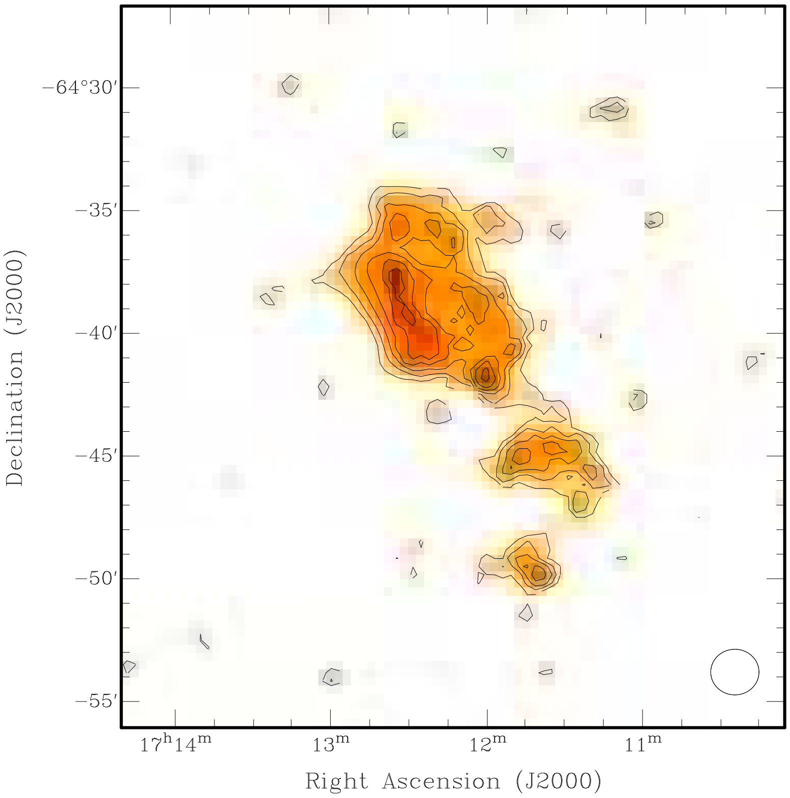


Figure 6.4: H I column density map all data combined. The column density levels are from 8.8 $\times$ 10^{18} cm^{-2} to 2.9 $\times$ 10^{19} cm^{-2}. The beam is shown in the bottom right hand corner (118 $\times$111 arcsec). Two main components can be seen to the cloud, along with a smaller clump in the South.

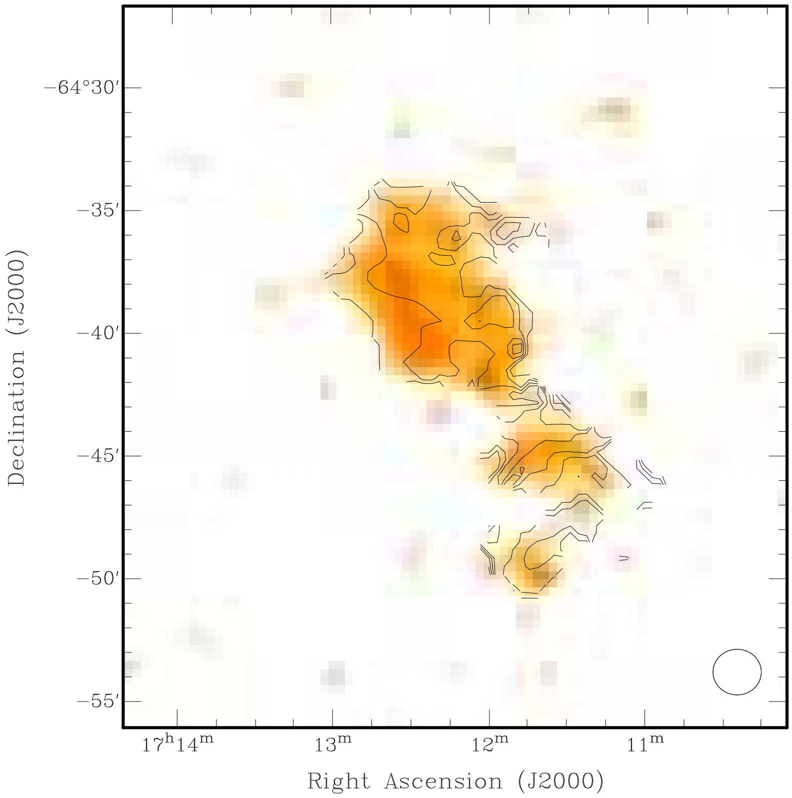


Figure 6.5: Velocity countours of HIPASS J1712-64 from the high resolution ATCA and multi-beam data, overlaid on a flux integrated image from the combined data. The contours for the NE component go from 440 km s^{-1} to 450 km s^{-1}, and for the bridge and SW component from 450 km s^{-1} to 476 km s^{-1}, in steps of 4 km s^{-1}.

Table 6.3: Measured H I Parameters for J1712-64. Values were measured from the ATCA/Parkes combined H I data cube unless indicated.

	N.E. Component	**S.W. Component**	**Overall**
Position:			
R.A.	$17^{h}12^{m}35^{s}$	$17^{h}11^{m}35^{s}$	…
Declination	–64°38′12″	-64°45′11″	…
l	326°.65	326°.48	…
b	-14°.63	-14°.61	…
Heliocentric Velocity†	451 km s^{-1}	464 km s^{-1}	…
50% Velocity Width†	14 km s^{-1}	21 km s^{-1}	…
20% Velocity Width†	18 km s^{-1}	31 km s^{-1}	…
Velocity Dispersion, σ†	4 km s^{-1}	…	…
Peak column density	3.5×10^{19} cm^{-2}	2.8×10^{19} cm^{-2}	…
Total flux density	4.7 Jy km s^{-1}	1.3 Jy km s^{-1}	7.0 Jy km s^{-1}
Size	11′.4 × 8′.2	4′.9 × 4′.1	15′.9 × 8′.2
Position Angle	32°	125°	32°

†Values derived from combined 210m data and Multibeam narrow-band data.

6.4 Optical limits

HIPASS J1712-64 is close to the Galactic plane, at $(l, b) = (326.6^{o}, –14.6^{o})$, so the foreground extinction needed to be determined at this position. The extinction in the region was estimated using three different methods. Firstly, the extinction based on dust temperature determined from the COBE/DIRBE and IRAS/ISSA maps (Schlegel et al., 1998) is $E(B-V) = 0.11$ mag. Using the Burstein and Heiles (1982) extinction map suggests a similar value for the extinction in the region: $E(B-V)$=0.09. Finally, the local H I column density from the HIPASS data (which was reprocessed to avoid any spatial filtering[1]) is 484 K km s^{-1}, which corresponds to $N_{\rm HI}= 8.8 \times 10^{20}$ atoms cm^{-2}. Following the conversion formula of Burstein and Heiles (1978), this implies $E(B-V) = 0.12$ mag. So although the stellar density in the region is quite high, there is no evidence for large optical extinction in the direction of HIPASS J1712-64.

[1]Data reprocessing and temperature estimate made by Lister Staveley-Smith

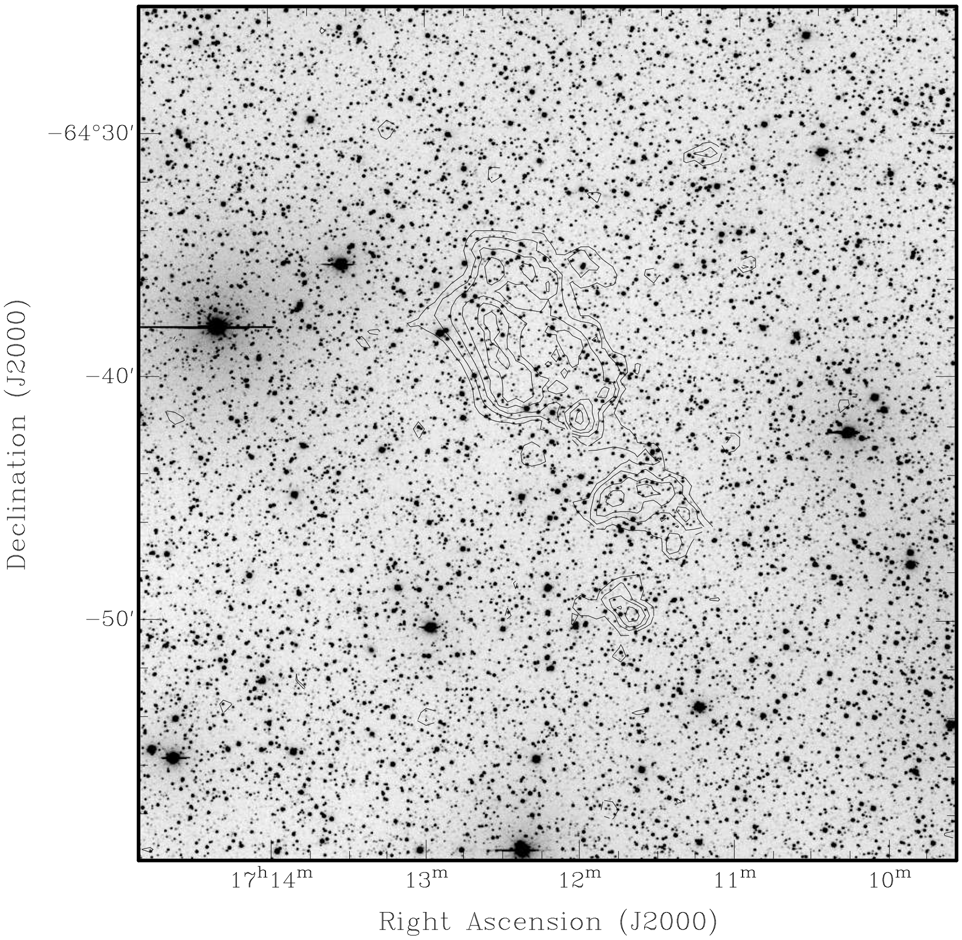


Figure 6.6: Optical BR image with H I contours of HIPASS J1712-64 overlaid.

A search for an optical counterpart using blue and red film copies of the UK Schmidt Telescope (UKST)/ESO southern sky survey revealed no optical counterpart. Subsequently, two deep original plates were obtained from the UKST plate archive and subjected to a photographic enhancement technique (Malin, 1978) that is capable of revealing extended features over 5 mag fainter than the night sky (Malin and Hadley, 1997). At the site of the UKST (Siding Spring) this is typically $\mu(B) = 22$ mag arcsec^{-2}.

Only two suitable plates were available, and an image was made by combining photographically-enhanced derivatives from them. The plates used were J1659 (IIIa-J/GG 395, 395–530 nm) and OR15092 (IIIa-F/RG 590, 590-690 nm). The plates were of excellent quality, however in both cases the object centre was close to the vignetting region towards the edge of the UKST focal plane.

The IIIa-J passband is the most sensitive to extended stellar light (assuming a solar spectrum) and would reveal extended features at least as faint as 27.5 mag arcsec^{-2}. The derivative from the red-sensitive plate achieves a detection limit of about $\sim$ 26.8 mag arcsec^{-2} because of the brighter night sky in the red. Nothing unusual is seen on deep derivatives from either plate, or on the combined image. However, it should be mentioned that large, featureless low surface brightness objects are particularly difficult to detect in crowded fields. The surface brightness limit can be used to estimate the H I mass–to–light ratio (M_{HI}/L_B) for HIPASS J1712-64. Firstly, a limit on the total flux for the cloud is determined using a 'top–hat' of radius r arcseconds, with a surface brightness of $\mu_B > 27$ mag arcsec^{-2}, allowing for extinction. In this case,

$$m_B > \mu_b - 2.5\log(\pi r^2). \tag{6.1}$$

The possible size of any optical counterpart is uncertain. For an optical counterpart of 1 arcminute in diameter lying just underneath our detection limit, this leads to a B magnitude of $m_B > 18.4$. Using the distance modulus[2], the calculated absolute magnitude is $M_B > -8.8$ mag. This gives us a large H I mass–to–light ratio of $M_{HI}/L_B > 24\,M_\odot/L_\odot$ (see Table 6.4). However, for an optical counterpart of 5 arcminutes in diameter lying just beneath the detection limit, a much lower H I mass–to–light ratio is found: $M_{HI}/L_B = 2\,M_\odot/L_\odot$. Thus the limit on the H I mass–to–light ratio for this cloud depends on the assumed optical diameter.

Other HIPASS detections in the same region of sky as J1712-64 have been optically identified using the Digitised Sky Survey. J1712-64 lies within the boundary of two $8^o \times 8^o$ standard HIPASS cubes. Excluding J1712-64, a visual search for galaxies in the two cubes found 19 galaxies in each cube, with three in common, ie a total of 35 galaxies. Optical counterparts can be seen for all but one of these galaxies. The missing detection is a small H I detection near a bright star so an optical counterpart cannot be ruled out. It is concluded that there is nothing unusual about the extinction in the region nearby HIPASS J1712-64.

[2] $M - m = 5\log(D(\mathrm{pc})/10)$

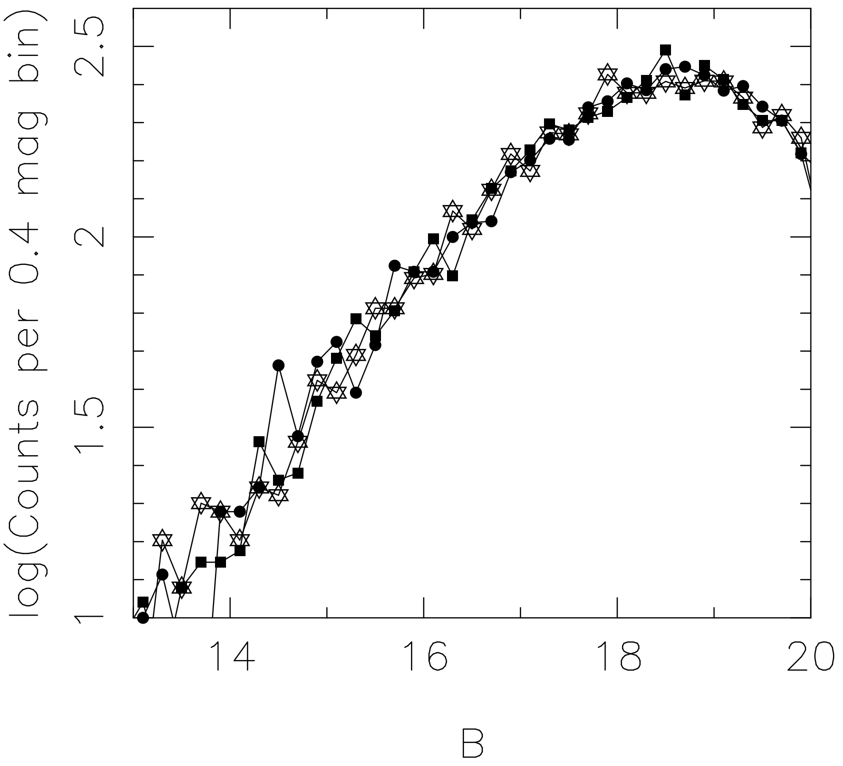


Figure 6.7: Number counts of stars in the central region of the B-band image and two surrounding regions. The star symbols show star number counts in the region where we would expect to see an excess of stars. No systematic exess is seen.

An optical counterpart could be overlooked if the galaxy lies close to the Milky Way, and is resolved into stars. One method of detecting a resolved galaxy in a crowded field of stars is to look for a separate stellar population by studying the magnitudes of the stars in the field and nearby comparison fields. This method was successfully used to detect the Sagittarius Dwarf Galaxy (Ibata et al., 1995). The method was applied to the HIPASS J1712-64 B–band CCD image. This image covers an area of about 1 deg^2, which is substantially larger than the H I detection. Fig. 6.7 shows a histogram of stellar magnitudes for a $20'$ field covering the extent of the H I detection, and other nearby fields of the same size. These fields are statistically equivalent, thus there is no evidence for a resolved galaxy in the direction of the H I detection.

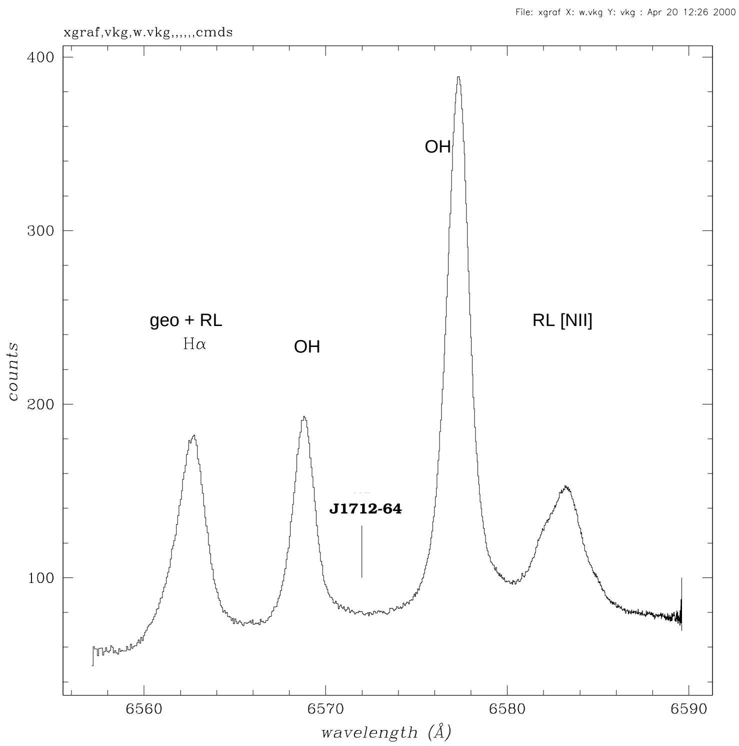


Figure 6.8: H-α spectrum of HIPASS J1712-64. No detection is seen above a limit of 30 mR. The other lines marked are caused by emission from the Galaxy.

A 30 minute observation of HIPASS J1712-64 was made using the Taurus Tunable Filter (TTF) on the Anglo-Australian Telescope (AAT) by J. Bland-Hawthorn. The spectrum is shown in Figure 6.8[3]. HIPASS J1712-64 is undetected in H-α to a limit of 30 mR. The lines present in the spectrum are caused mostly by emission in the outer regions of our Galaxy. This non–detection compares to the detection of Hα in the Magellanic Stream by Weiner and Williams (1996). They detected clouds of Hα surface brightness between 0.2 and 0.37 R, which is much brighter than the limit obtained for HIPASS J1712-64 from the AAT. The non-detection may lead to the calculation of a lower limit of the distance to HIPASS J1712-64 using models of ionising photons from the Galaxy (Bland-Hawthorn and Maloney, 1999).

[3]Spectrum provided by M. Putman & J. Bland-Hawthorn

6.5 The Nature of HIPASS J1712-64

Due to the low systemic velocity of HIPASS J1712-64, it is likely that its peculiar and Hubble expansion velocities are comparable. We can apply velocity corrections for the Solar and Galactic motion and then use the Hubble flow to predict the distance to the cloud. However, this method does not take into account any local graviatational influence so it is not clear whether the Hubble flow is relevant for an object with such a low heliocentric velocity. As we have no other distance estimator for this object (and no optical detection), we will firstly derive the distance to J1712-64 using the Hubble Flow, with the caveat that the error might be quite large. We then discuss the chacteristics of HIPASS J1712-64 if it is in fact situated much closer to our Galaxy, and the likelihood of it being an HVC or Magellanic debris.

6.5.1 An Extragalactic Object?

There is a possibility that HIPASS J1712-64 is a member or an outlier of the Local Group. The systemic velocity of Local Group members is plotted in Figure 6.9[4]. It can be seen that J1712-64 is removed from the other members of the Local Group, therefore implying that it is not in fact a member of the Local Group.

Assuming HIPASS J1712-64 is not a member of the Local Group, the velocity with respect to the Local Group can be determined using $V_{\rm LG} = V_{\rm sys} - 79\cos l\cos b + 296\sin l\cos b - 36\sin b$ $= 240$km s^{-1} (Yahil et al., 1977). An alternate correction of $300\sin l\cos b$ gives $V_{\rm LG} = 291$ km s^{-1} (IAU convention). Finally, the POTENT program (Bertschinger et al., 1990) gives a velocity of $V_{\rm LG} = 172$ km s^{-1}. Using a Hubble constant of 75 km s^{-1} Mpc^{-}1, these values give a distance range of 2.3 Mpc from the POTENT determination, to 3.8 Mpc for the IAU convention determination. For subsequent calculations, the 'middle' distance will be used, 3.2 Mpc determined using the Yahil et al. (1977) equation, adopting an error of $\pm$1Mpc.

The velocities within J1712-64 are very low. The velocity separation of the NE and SW components is only 12 km s^{-1} and the velocity dispersions within each component are small. For the NE component, the mean velocity dispersion from the ATCA data is $\sigma \sim 4$ km s^{-1}, and possible slightly more for the SW component.

If the velocity difference between the NE and SW components is indicative of the rotation of a bound, binary system, the minimum system mass is $1.5 \times 10^8 M_\odot$ (Faber and Gallagher,

[4]Figure produced by Lister Staveley-Smith

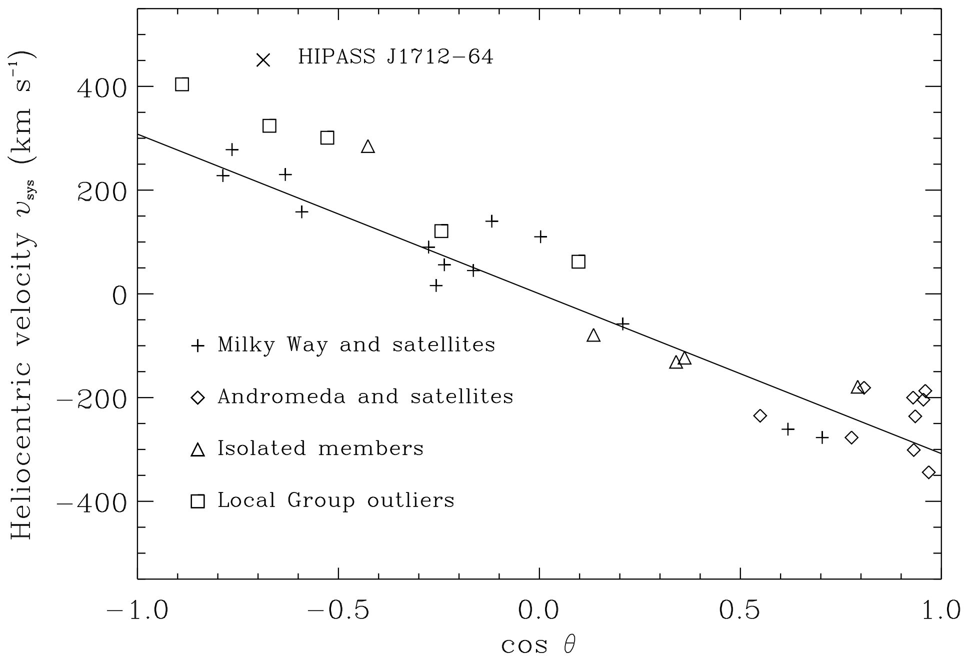


Figure 6.9: Local Group members and outliers

1979), an order of magnitude above the H I mass. The 'virial' distance, at which the total mass is 1.3 times the H I mass (to account for He), is implausibly distant (> 20 Mpc) implying that the system contains substantial dark matter, or else is not bound. The orbital period of the two components corresponding to the minimum total mass is $\sim$ 4 Gyr.

The NE component can be modelled as a pressure-supported sphere of gas of total enclosed mass

$$M_T = \frac{\alpha\sigma^2 r}{G} \tag{6.2}$$

where σ is the line-of-sight velocity dispersion ($\sim$ 4 km s^{-1}), r is the radius ($\sim$ 4 kpc) and $\alpha \sim 1 - 3$ depending on the mass distribution. For an isothermal sphere, $\alpha \approx 2$, which gives $M_T(NE) = 3.0 \times 10^7\ M_\odot$, which is only $\sim$ 1.8 times higher than the H I mass for this component.

The critical column density above which local axisymmetric instabilities can occur in a uniformly rotating gaseous disk is given by the Toomre stability criterion:

$$\Sigma_c = \frac{2v_s\Omega}{\pi G} \tag{6.3}$$

where v_s is the sound speed and Ω is the angular frequency (Binney and Tremaine, 1987). Kennicutt (1989) has shown that similar relations for differentially rotating stellar disks approximately predict the column density above which star formation occurs in spiral galaxies. If we use $\Omega = v/r$ with $v \approx \sigma \approx v_s$ and $r = 4$ kpc for the NE component, then we obtain $\Sigma_c \approx 8 \times 10^{19}$ atoms cm^{-2}. This is more than a factor of two above the peak measured column density of just 2.9×10^{19} atoms cm^{-2}, and is consistent with the absence of visible star-formation.

Table 6.4: Derived H I Parameters for J1712-64

	N.E. Component	**S.W. Component**	**Overall**
Systemic Velocity	451 km s^{-1}	464 km s^{-1}	...
Local Group Velocity[a]	332 km s^{-1}	344 km s^{-1}	...
Distance[b]	...	...	3.2 Mpc
H I **Mass**	1.1 $\times 10^7 M_\odot$	3 $\times 10^6 M_\odot$	1.7 $\times 10^7 M_\odot$
Peak Column Density	2.9 $\times 10^{19}$cm^{-2}	1.2 $\times 10^{19}$cm^{-2}	...
Linear Size (kpc)	11 $\times$ 8 kpc	5 $\times$ 4 kpc	15 $\times$ 8 kpc
Dynamical Mass, M_T	$\sim 3 \times 10^7 M_\odot$	...	$> 1.5 \times 10^8 M_\odot$
Blue Luminosity, L_B[c]	...	...	$< 7 \times 10^5 L_\odot$
M_{HI}/L_B[c]	...	...	$> 24 M_\odot/L_\odot$

[a] Using the formula of Yahil et al. (1977)
[b] Assuming an identical distance for the NE and SW components, and using d = V_{LG}/H_0
[c] Assuming an optical diameter of 1 arcmin

6.5.2 A High-Velocity Cloud?

An alternative explanation for the classification of HIPASS J1712-64 is that it is an unusual high-velocity cloud (HVC) lying at the edge of our own Galaxy. However, there are two good reasons to exclude the possibility of J1712-64 being a normal HVC. The first is its velocity, which is 40 km s^{-1} higher than any currently catalogued HVC (e.g. those around the Large Magellanic Cloud, Putman (2000)). The second is the structure of HIPASS J1712-64. The majority of HVCs have a core-halo morphology with only 10–50% of the total flux able to be recovered by interferometry (Wakker and van Woerden, 1997). However, the ATCA observations were able to recover 80% of the total flux of HIPASS J1712-64.

It is possible the HIPASS J1712-64 is an extreme version of CHVC. Six examples of CHVCs were studied in detail by Braun and Burton (2000). These objects exhibited narrow line-widths and also show apparent velocity gradients. However, similar to general HVCs, these objects displayed a core-halo morphology, which is not seen in HIPASS J1712-64. The velocity gradient of HIPASS J1712-64 lies along the major axis of the main cloud, and this characteristic is also seen in the Braun and Burton (2000) high-resolution data. If HIPASS J1712-64 lies at a distance of 1 Mpc, as suggested by Braun and Burton (1999) for CHVCs, then the total mass for the system is ~ 10 times less than the extragalactic scenario: $M_{\rm HI} = 1.6 \times 10^6\ M_\odot$.

The most likely scenario is that HIPASS J1712-64 originated from gravitational scattering off the Magellanic Clouds/Galaxy system. J1712-64 lies in a 2400 deg^2 region around the South Celestial Cap (Putman et al., 1998), where many of the HVCs appear to have originated from the interaction of the Magellanic Clouds with the Milky Way. However, HIPASS J1712-64 does not lie close to the Clouds (it is 46$^{\rm o}$ from the LMC), and the Leading Arm, which includes a number of known HVCs from Wakker and van Woerden (1991) (see Figure 3 of Putman et al. (1998)), is $\sim 20^{\rm o}$ away. Koribalski (2000) detected a large H I cloud at a slightly lower velocity of ~ 400 km s^{-1}, only a few degrees away from HIPASS J1712-64. This may provide further evidence that these H I clouds are related to the Magellanic Clouds and the Leading Arm. If HIPASS J1712-64 was formed in this manner, then a velocity separation of ~ 300 km s^{-1} and a spatial separation from the LMC of ~ 60 kpc (or ~ 80 kpc from the Galaxy) would be consistent with an ejection event coinciding with the last LMC/SMC encounter which probably occurred $\sim 2 \times 10^8$ yr ago (Gardiner and Noguchi, 1996)[5].

6.6 Distribution of H I Clouds and Galaxies

HIPASS J1712-64 was the first (and brightest) of the 7 H I clouds found in the SCC region. None of them have visible optical counterparts, and they lie in the velocity range $318 < V_{cloud} < 460$ km s^{-1}. Table 6.5 gives the H I parameters of these H I clouds. Five of the clouds (apart from J1712-64) have been observed with the ATCA, but were not detected. We therefore conclude that they are low column density objects.

The relationship of these clouds with the Magellanic Clouds is not clear. Figure 6.10 shows a velocity integrated map of the clouds, and other galaxies detected in HIPASS, within a

[5] Calculation performed by Lister Staveley-Smith

velocity range of 320 to 500 km s^{-1}. The clouds are indicated by a name starting with J. For orientation, the Magellanic Clouds are to the top right of the Figure, and the plane of the Galaxy runs across the bottom of the Figure. The majority of the clouds can be seen to the right, and they seem to align with the supergalactic plane. In addition to the clouds found in the SCC region, two clouds were found just outside this region. The largest of the clouds, J1718-59 lies just outside of the SCC region, and was discovered by Koribalski (2000). The proximity of this cloud with HIPASS J1712-64 leads to the conclusion that the two are related, and may be high–velocity tidal gas from the Magellanic Clouds/Galaxy interaction. J1616-55 also lies outside of the SCC region, and was discovered in the ZOA survey observations (Staveley-Smith et al., 1998).

An alternative explanation for the clouds is that they are an extragalactic phenomenon, and we are seeing the remnants of structure formation along the supergalactic plane. If the clouds are extragalactic, their combined H I mass is small and will not dominate the calculation of the cosmological H I mass density.

Name	R.A. (J2000)	Dec. (J2000)	Vel (km s^{-1})	ΔV_{20} (km s^{-1})	ΔV_{50} (km s^{-1})	S_{peak} (Jy)	S_{int} (Jy km s^{-1})
HIPASSJ1614–72	16:14:22	–72:15:55	383	35	21	0.155	2.4
HIPASSJ1712–64	17:12:05	–64:41:28	457	69	44	0.194	9.47
HIPASSJ1858–67	18:58:25	–67:22:57	433	82	42	0.079	4.43
HIPASSJ1901–67	19:01:19	–67:27:00	424	119	49	0.043	1.64
HIPASSJ1913–67	19:13:00	–67:05:49	425	71	44	0.092	5.34
HIPASSJ1931–68	19:31:32	–68:03:30	372	82	41	0.074	3.93
HIPASSJ2118–82	21:18:02	–82:32:45	318	57	36	0.113	5.00

Table 6.5: H I Clouds with no optical counterparts found in the SCC region.

6.7 Discussion

Although there have been many previous searches for extragalactic H I in optically blank fields, there has been little success, implying that massive H I "protogalaxies" are rare at this epoch. However, the limit on low-mass H I clouds is not as strict, and it is possible that similar objects to HIPASS J1712-64 exist in abundance in the local universe. Indeed, a number of such clouds were found in SCC region. Some limits to the number of low–mass clouds in the local universe were set by Banks et al. (1999), who found 10 new group members in the 600 deg^2 HIPASS survey of the Centaurus A group. The sensitivity limit for this survey was $\sim 10^7\, M_\odot$, so it is possible that a population of clouds with even lower H I mass exist. Deeper observations such as Disney et al. (1999) may reveal more low–mass, $M_{\rm HI} \lesssim 10^7\ M_\odot$ H I detections in this region.

From a study of the Lyα forest lines and a VLA H I study, Shull et al. (1999) suggest that, at z=0, there may exist clouds, or sheets, of ionised gas $\sim$ 1 Mpc in extent, that contain $\sim$ 30 times more baryons than the neutral gas confined to known galaxies. The clouds found in the SCC region may be visible manifestations of these large primordial clouds. So while the H I gas in these clouds is low, there may be sufficient baryons in the region available to form a galaxy if they were able to cool. The possibility that the dynamical mass of HIPASS J1712-64 is $\sim$ 10 times greater than the H I mass, suggests there may be dark matter of some sort associated with the system.

Isolated H I clouds can be used to set stringent limits on the local metagalactic background radiation. Deep narrow–band CCD images of the Hα line in H I 1225 + 01 and the Leo ring place limits of $\mathrm{J_0} < 3 - 8 \times 10^{-23} \mathrm{ergs\,s^{-1}\,cm^{-1}\,sr^{-2}\,Hz^{-1}}$ for quasar-like light (Donahue et al., 1995). Hα observations of J1712-64 returned a null result, so it is possible that a limit may be placed on the distance the cloud is from the Galaxy, and a longer integration time may help to place stronger limits on the local metagalactic background radiation.

The distribution and velocity of the clouds found in the SCC region will have to be investigated further to determine their nature and origin. It is likely that they represent high velocity H I clouds created during the Magellanic Clouds/Galaxy interaction, however the possibility that the clouds represent high–density peaks of much lower density sheets of gas cannot be ruled out. As the mean dispersion of the NE component of HIPASS J1712-64 appears to be low (σ = 4 km s^{-1}), the upper limit to the kinetic temperature is T < 2000 K. This may mean that cool gas is present in the cloud, which might be detected in absorption from a bright quasar. A search for bright quasars nearby HIPASS J1712-64 found PKS 1708-648 19$'\!.$4 from the centre of the cloud. No unambiguous evidence for absorption was detected in the spectrum of this quasar, however the quasar is situated well past the last measurable contour of HIPASS J1712-64. Observations of optical quasars behind the H I clouds may help to elucidate their nature, by providing their metallicities.

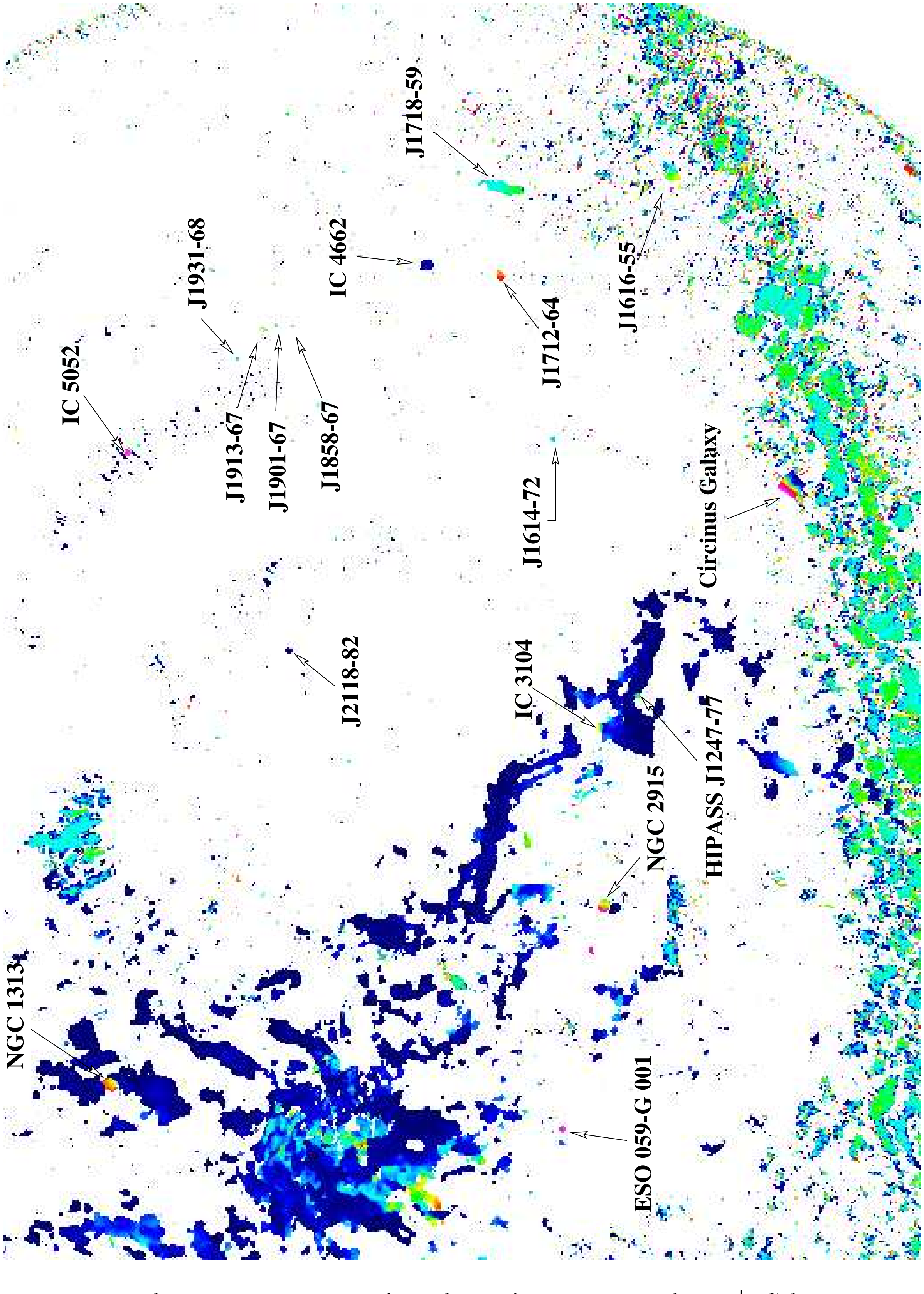


Figure 6.10: Velocity integrated map of H I clouds, from 320 to 500 km s^{-1}. Colour indicates velocity: Blue to pink indicates increasing velocity.

Chapter 7

New Detections from the SCC Sample

7.1 Introduction

Optically, the sky has been well catalogued for galaxies, and is complete for galaxies which are optically high in surface brightness, and have large diameters. Blind H I surveys such as HIPASS enable compact high surface brightness (HSB) galaxies and more diffuse low surface brightness (LSB) galaxies to be discovered. One hundred and forty galaxies without previous optical identification were found in the SCC sample. Most of the galaxies catalogued for the first time in the SCC region were either optically compact, or LSB galaxies, or lay behind the plane of the Galaxy where the obscuration was too high for them to be seen in the optical.

The HSB galaxies in this sample were easily visible on the DSS I images, and they had a compact stellar–like core. The LSB galaxies were much fainter, and several were not visible in the DSS I images. The optical emission in these galaxies was more diffuse, than the HSB galaxies. Eighteen of the new HIPASS detections were detected at the Australia Telescope Compact Array. Table 7.1 gives the observing parameters for these galaxies.

Table 7.2 gives properties of the new galaxies discovered in the SCC region that have been subsequently observed with the ATCA. The systemic velocity of the galaxies was measured by taking the mid-point of the 20% velocity width, then applying the IAU Local Group correction (see Equation 2.1) [Column 2]. The 50% velocity width was found using the MIRIAD task MBSPECT [Column 3]. The distance was calculated assuming Euclidean geometry, and using H_0 of 75 km s^{-1} Mpc^{-1} [Column 4]. The H I diameter [Column 5] was measured as the major axis of the H I from the lowest plotted contour. The contours were typically 3σ, and the few that were not are marked as such in the Table. The Low and High column densities

(N_{HI}) are the values of the lowest and highest contours plotted for each galaxy [Column 6 & 7]. The H I mass is calculated using the determined distance in Mpc, and Equation 1.3 [Column 8].

Optical images from DSS I are shown for all galaxies, and where no optical counterpart is seen on these images, the DSS II image is also presented.

SOURCE	R. A. (J2000)	DEC. (J2000)	Beam Size (arcsec)	ARRAY
HIPASS J0039-76	00 39 08	-76 20 12	55 × 48	750m
HIPASS J0116-63	01 16 48	-63 30 01	77 × 40	750m
HIPASS J0305-69	03 05 24	-68 56 31	85 × 39	750m
HIPASS J0511-72	05 11 34	-72 18 21	131 × 87	375m
HIPASS J0554-71	05 54 42	-71 55 50	119 × 92	375m
HIPASS J0751-62	07 51 33	-62 19 59	176 × 68	375m/750m
HIPASS J0908-64	09 08 21	-64 42 10	57 × 48	750m
HIPASS J1005-73	10 05 03	-73 51 15	80 × 56	750m
HIPASS J1150-69	11 51 35	-69 48 26	85 × 39	750m
HIPASS J1242-77	12 42 06	-77 55 19	71 × 53	750m
HIPASS J1247-77	12 47 35	-77 34 53	71 × 53	750m
HIPASS J1339-72	13 39 23	-72 54 54	63 × 61	750m
HIPASS J1407-75	14 07 28	-75 53 24	63 × 61	750m
HIPASS J1456-72	14 56 42	-72 33 10	78 × 39	750m
HIPASS J1650-62	16 49 49	-62 33 05	72 × 35	750m
HIPASS J1705-68	17 05 55	-68 57 33	79 × 43	750m
HIPASS J1816-67	18 15 45	-67 01 36	62 × 45	750m
HIPASS J2039-63	20 39 01	-63 46 15	81 × 45	750m

Table 7.1: Observational parameters of ATCA follow-up for new galaxies

HSB Galaxies

Name	V_{LG}^{a} (km	ΔV_{50} s^{-1})	Distance^{b} (Mpc)	H I Diam.^{c} (kpc)	Low N_{HI} (cm^{-2})	Peak N_{HI} (cm^{-2})	$M_{\rm HI}$ ($M_{\odot}$)
HIPASS J0039–76	1560	56	20.8	21	1×10^{19}	8.3×10^{20}	6.4×10^{8}
HIPASS J0116–63	2130	119	28.4	8	5×10^{19}	2.1×10^{20}	7.4×10^{8}
HIPASS J0305–69	1156	117	15.4	8	7×10^{19}	2.3×10^{20}	6.4×10^{8}
HIPASS J0554–71	1227	58	16.4	7	3×10^{19}	6.0×10^{19}	1.6×10^{8}
HIPASS J0751–62†	5947	56	79.3	23	2×10^{19}	7.3×10^{19}	3.1×10^{9}
HIPASS J0908–64	1562	39	20.8	12	1×10^{20}	3.2×10^{20}	1.1×10^{9}
HIPASS J1407–75	2590	108	34.5	30	9×10^{19}	4.2×10^{20}	1.9×10^{9}
HIPASS J1706–68‡	7860	288	104.8	71	6×10^{19}	2.6×10^{20}	1.6×10^{10}
HIPASS J1816–67	3199	183	42.7	25	6×10^{19}	3.8×10^{20}	2.6×10^{9}
HIPASS J2039–63‡	1539	52	20.5	12	3×10^{19}	1.5×10^{20}	3.6×10^{8}

LSB Galaxies: Low Mass

Name	V_{LG}^{a} (km	ΔV_{50} s^{-1})	Distance^{b} (Mpc)	H I Diam.^{c} (kpc)	Low N_{HI} (cm^{-2})	Peak N_{HI} (cm^{-2})	$M_{\rm HI}$ ($M_{\odot}$)
HIPASS J0511–72	1289	72	17.2	10	2×10^{19}	2.6×10^{20}	3.2×10^{8}
HIPASS J1005–73	979	42	13.1	8	2×10^{19}	4.2×10^{20}	5.0×10^{8}
HIPASS J1242–77	2433	64	32.4	23	4×10^{19}	3.5×10^{20}	6.2×10^{8}
HIPASS J1247–77	167	29	2.2	1.5	3×10^{19}	5.5×10^{20}	4.7×10^{6}

LSB Galaxies: High Mass

Name	V_{LG}^{a} (km	ΔV_{50} s^{-1})	Distance^{b} (Mpc)	H I Diam.^{c} (kpc)	Low N_{HI} (cm^{-2})	Peak N_{HI} (cm^{-2})	$M_{\rm HI}$ ($M_{\odot}$)
HIPASS J1338–72	3017	136	40.2	23	7×10^{19}	2.1×10^{20}	1.5×10^{9}
HIPASS J1456–72	2925	121	39.0	34	4×10^{19}	2.5×10^{20}	1.5×10^{9}
HIPASS J1151–69‡	6704	26	89.4	52	7×10^{19}	1.7×10^{20}	1.9×10^{10}
HIPASS J1650–62‡	4125	89	55.0	24	4×10^{19}	1.3×10^{20}	9.2×10^{9}

[a] Using: $V_{LG} = V_{sys} + 300 \sin l \cos b$
[b] $D = V_{LG}/H_0$
[c] Assuming Euclidean geometry, and using lowest column density contour
† Lowest contour is 2σ
‡ Lowest contour is 2.5σ

Table 7.2: New Galaxies from the SCC Region. The Local Group velocity (V_{LG}), ΔV_{50} and N_{HI} are derived from the ATCA data, and $M_{\rm HI}$ is derived from the HiPASS data. See Table 2.1 for other H I parameters.

7.2 HSB Galaxies

A number of new HSB galaxies were found in the SCC region. These galaxies are optically compact and have a large range of H I masses. The H I disks typically extend well past the observed stellar emission.

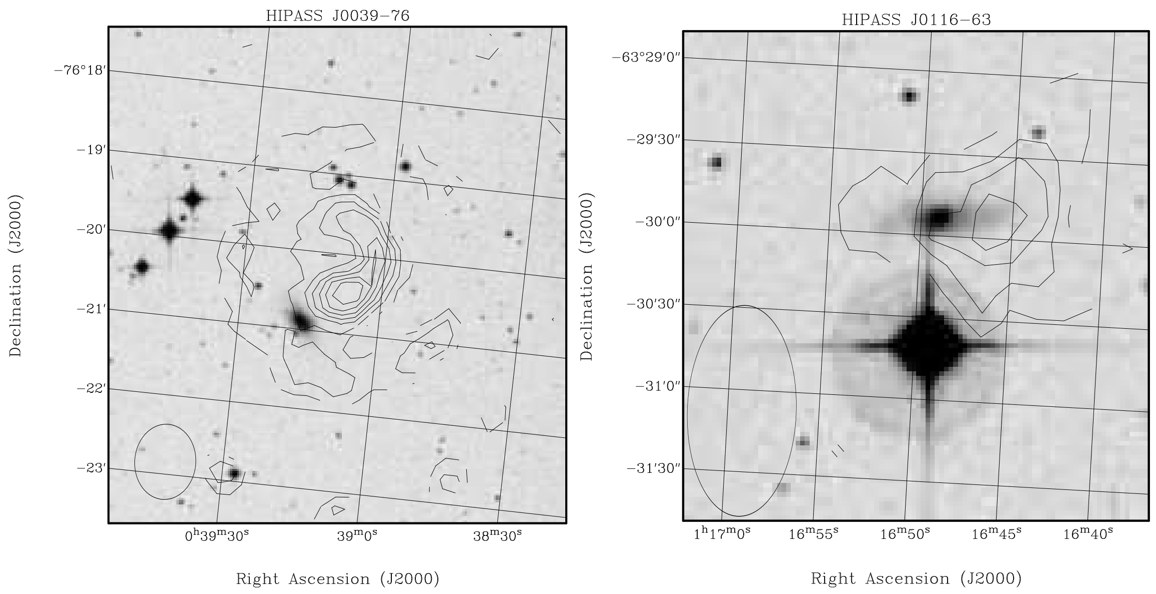


Figure 7.1: HIPASS J0039–76 & HIPASS J0116–63 overlaid on DSS I images.

HIPASS J0039–76

HIPASS J0039–76 has a very compact, HSB optical counterpart, and a larger disk of H I that is offset to the optical emission by about one beam size. The peak column density at the centre of the H I emission is quite high: 8.3×10^{20}, yet no star emission is seen at this position. The contours of the H I disk are not regular, which may indicate an interaction in the past. The linear size of the H I emission is 20.8 kpc at a distance of 20.8 Mpc.

HIPASS J0116–63

A compact, HSB core is seen to this galaxy, with a fainter disk also visible. The H I mass is not high ($8.8 \times 10^8 M_\odot$), and the optical emission is slightly offset to the peak H I contour, by less than a beamwidth. The peak column density for the galaxy is 2.1×10^{20} cm^{-2}, and the galaxy has a distance of 28.4 Mpc. The size of the H I disk is comparable to that of the optical, and is 8 kpc in diameter.

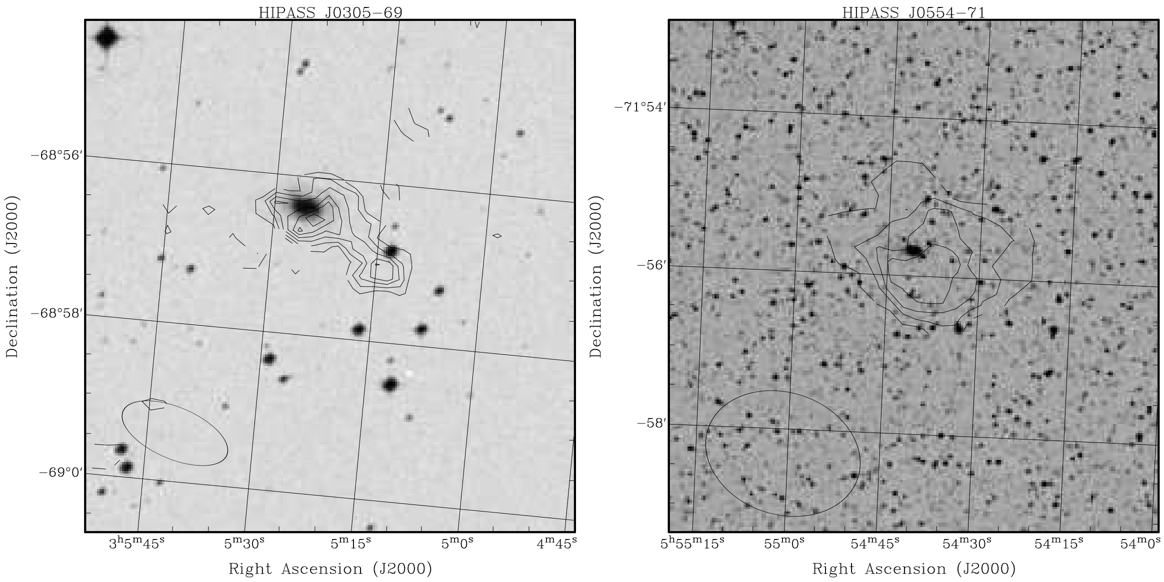


Figure 7.2: HIPASS J0305–69 & HIPASS J0554–71 overlaid on DSS I images.

HIPASS J0305–69

The optical counterpart to HIPASS J0305–69 is bright, and the H I emission is not a regular disk around the optical emission. There is a second peak of emission, apparently joined by a bridge of H I. The second region of H I emission shows no visible optical counterpart, although there is a stellar–like object just offset from the smaller clump which may in fact be a compact galaxy. Both of the emission regions lie at the same systemic velocity, 1156 km s^{-1}. The peak H I column density in the larger clump is 2.3×10^{20} cm^{-2}, and in the smaller clump it is about half of that. The system has a total H I mass of 6.4 $\times10^8$ $M_\odot$. Only 20% of the H I emission detected with HIPASS was detected with the ATCA follow-up observations, so there appears to be a large amount of extended H I in the system.

HIPASS J0554–71

HIPASS J0554–71 was observed with the 375m array, and is quite compact, as all of the single dish H I flux is recovered in the synthesis observations. This may mean the H I is unresolved in this data. The H I mass of this galaxy is $M_{\rm HI} = 1.6 \times 10^8 M_\odot$, and its Local Group velocity is 1227 km s^{-1}. HIPASS J0554–71 has a very compact optical counterpart that is easily visible in the DSS I image, lying near the centre of the H I emission.

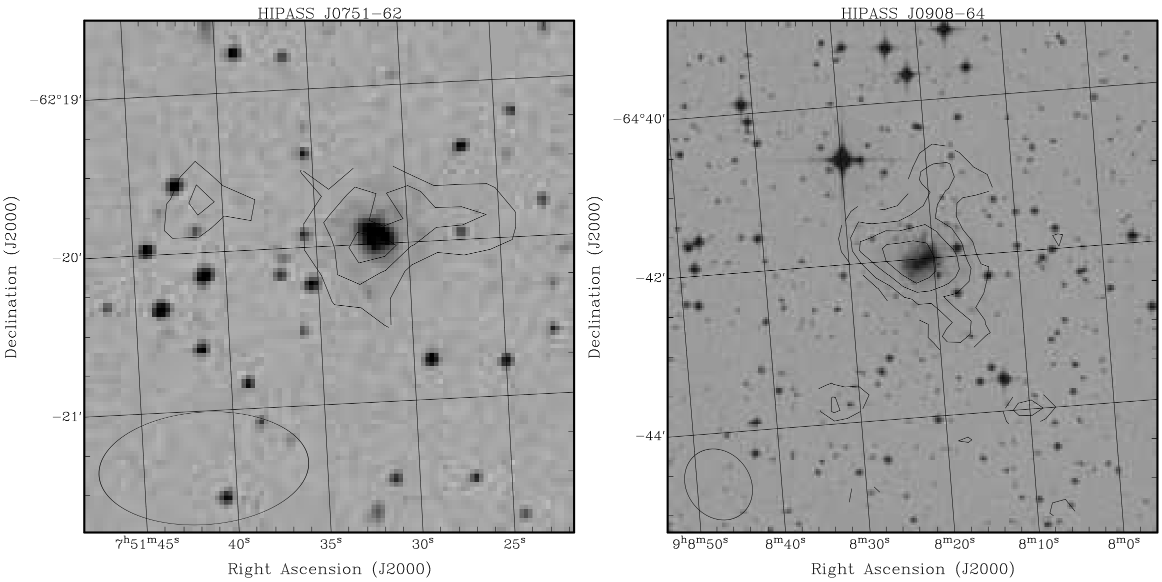


Figure 7.3: HIPASS J0751–62 & HIPASS J0908–64 overlaid on DSS I images.

HIPASS J0751–62

This galaxy lies at a Local Group velocity of 5947 km s^{-1}, and has a fairly low peak column density of 7.3×10^{19} cm^{-2}. The highest column density region in the H I emission lies directly over the optical galaxy. Approximately 65% of the H I emission was detected in the ATCA observations. There is a small H I detection near the main galaxy.

HIPASS J0908–64

The optical emission for HIPASS J0908–64 lies within the highest density contour plotted, which is 3.2×10^{20} cm^{-2}. The H I disk is about three times that of the optical diameter, and less than one third of the H I gas was detected in the ATCA observations, which leaves scope for a more extended disk. The velocity width for this galaxy is small, with a ΔV_{50} of just 39 km s^{-1}, but the H I mass is not low ($M_{\rm HI}$= 1.1×10^9 $M_{\odot}$). This galaxy appears to be seen face–on.

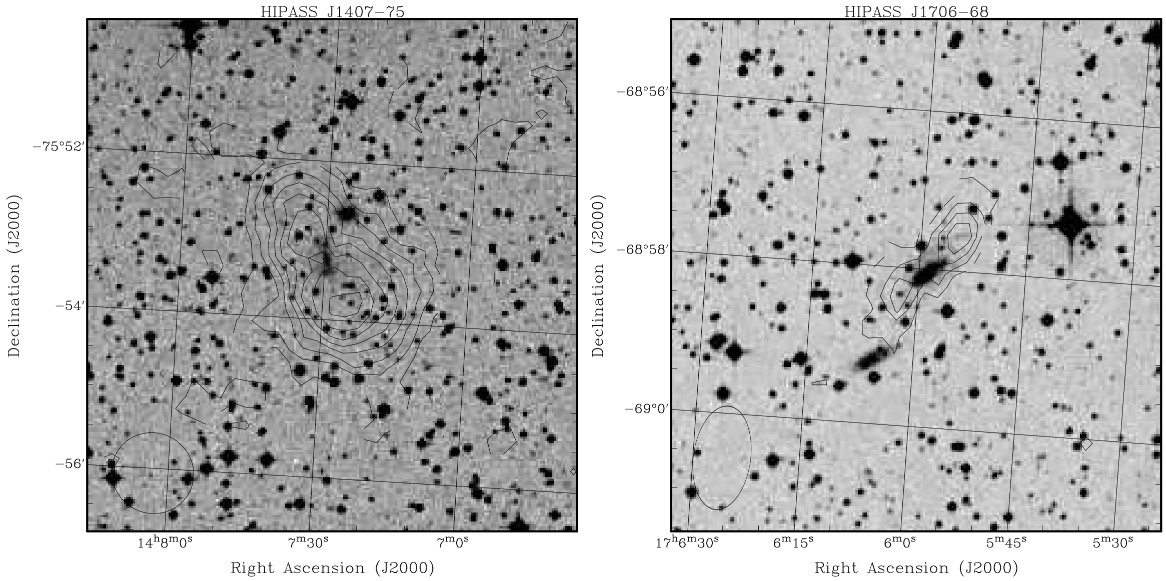


Figure 7.4: HIPASS J1407–75 & HIPASS J1706–68 overlaid on DSS I images.

HIPASS J1407–75

HIPASS J1407–75 has two optical galaxies near the centre of the H I emission, and it is uncertain whether the two are related. One is an LSB galaxy, and the other a more compact HSB galaxy. The H I emission comprises of two cores of emission, but neither lies directly over the two optical counterparts. The velocity distribution of the H I emission around the two galaxies shows a smoothly rotating disk with no evidence of disturbance. The H I mass for this system is $M_{\rm HI} = 1.9\times10^9\,M_\odot$, and the system lies at a Local Group velocity of 2590 km $\;{\rm s}^{-1}$.

HIPASS J1706–68

This H I detection has two optical galaxies nearby. The H I emission surrounds the brighter of the two optical galaxies. The H I mass for the system is large: $1.6\times10^{10}\,M_\odot$. Only 17% of the H I emission was detected with the ATCA (750m), so it is possible the second optical galaxy lies in a more extended, lower column density H I disk. The peak column density for the H I is 2.6×10^{20} cm^{-2}, and the H I emission lies at a Local Group velocity of 7860 km $\;{\rm s}^{-1}$. The size of the H I disk is 71 kpc at a distance of 104.8 Mpc. This galaxy appears to be seen edge–on, and the two highest column density regions of emission are at different velocities, separated by $\sim 200\,{\rm km\;\;s^{-1}}$.

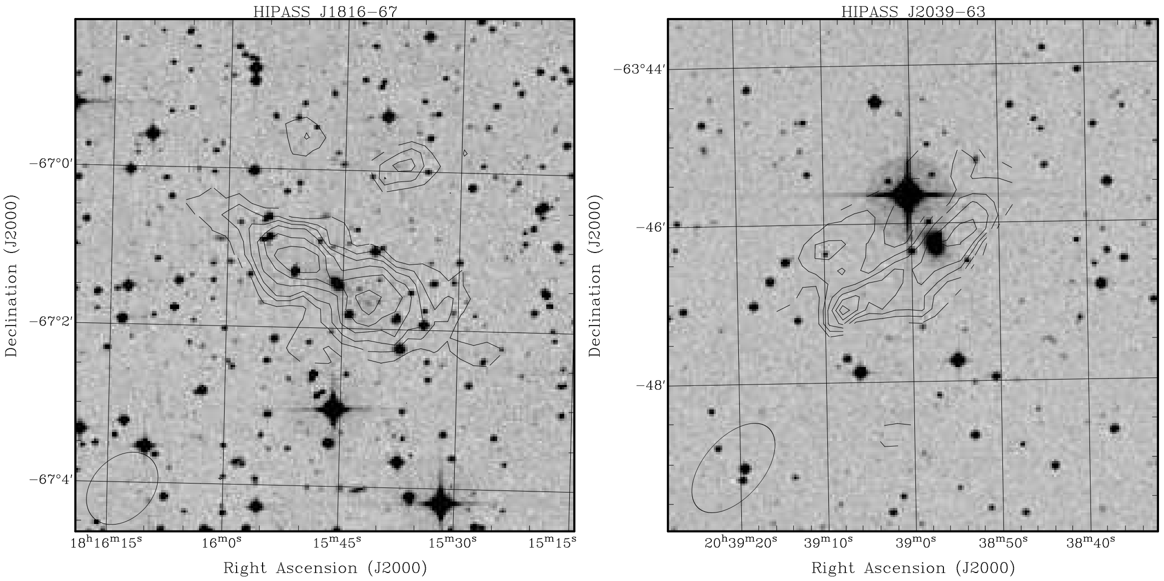


Figure 7.5: HIPASS J1816–67 & HIPASS J2039–63 overlaid on DSS I images.

HIPASS J1816–67

The optical emission associated with HIPASS J1816–67 is very compact, and lies between two concentrations of H I. The H I mass for the system is $2.6\times10^{9}\ M_{\odot}$, and the Local Group velocity of the galaxy is 3199 km s^{-1}. The major axis of the H I emission is $\sim$ 31 kpc, at a distance of 42.7 Mpc. This is more than 10 times larger than the visible optical extent of $\sim$ 2.3 kpc. The velocity structure of this galaxy indicates it is edge–on.

HIPASS J2039–63

There is a compact optical counterpart associated with HIPASS J2039–63 which lies between the two peaks of the H I emission. The H I emission is more extended than the optical extent of the galaxy. The H I mass of the galaxy is $M_{\rm HI} = 3.6 \times 10^{8} M_{\odot}$, and the Local Group velocity is 1539 km s^{-1}. HIPASS J2039–63 is a dwarf galaxy, with a linear extent of 16 kpc in H I and an optical extent of 2 kpc. This galaxy has measured optical magnitudes (see Table 2.2), with a R magnitude of 15.89, and a B magnitude of 14.75. This translates to an M_{HI}/L_B of $\approx 1\ M_{\odot}/L_{\odot}$.

7.3 LSB Galaxies: Low Mass

Four new low–mass LSB galaxies were observed at the ATCA. The number of new low–mass galaxies found in the sample does not represent a large "missing mass" of galaxies, but they are individually interesting to determine the characteristics of star formation.

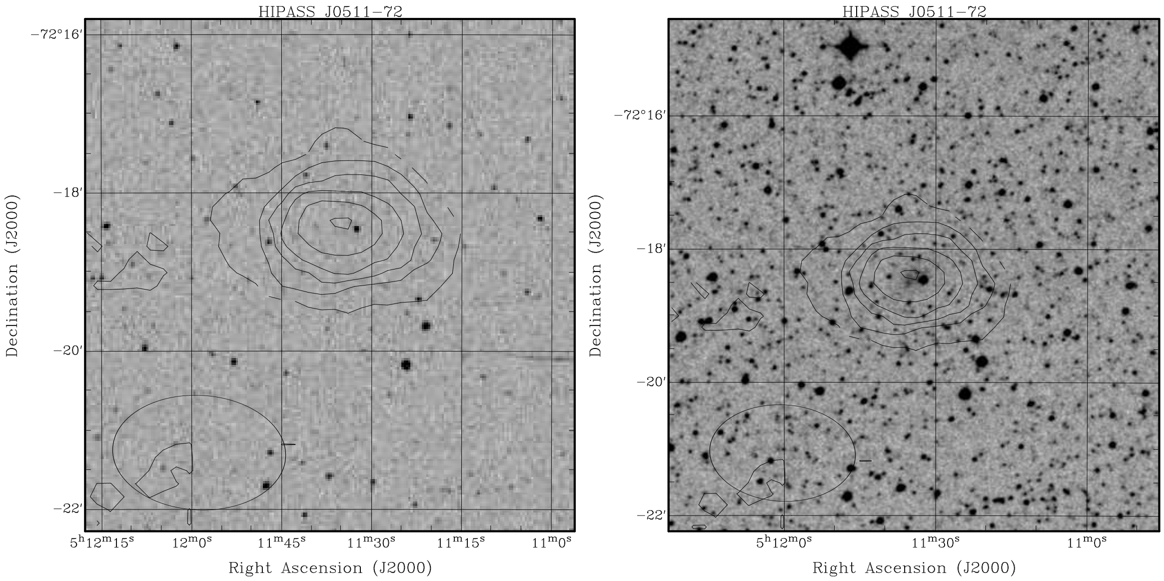
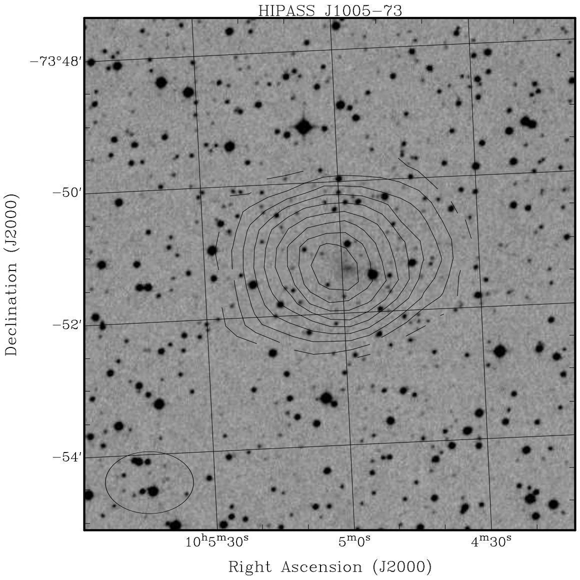


Figure 7.6: HIPASS J0511–72 overlaid on DSS I [Left] and DSS II [Right] images.

HIPASS J0511–72

This galaxy was observed with the 375m array as no obvious optical counterpart could be seen on the DSS I image. A very faint optical counterpart can be seen in the redder DSS II image. This galaxy lies behind the Large Magellanic Cloud, so optical light from the companion may be obscured. The Local Group velocity of the galaxy is 1289 km s^{-1}, and its 50% velocity width determined from the ATCA data is 72 km s^{-1}. The H I distribution around the optical counterpart seems to be Gaussian, but is likely to be unresolved as 100% of the H I flux was recovered in the 375m ATCA synthesis observations. The H I mass for this galaxy is $M_{\rm HI} = 3.2 \times 10^8 M_\odot$. The peak column density for the galaxy is $2.6{\times}10^{20}$ $\rm cm^{-2}$. The size of the H I is $\lesssim 9.5$ kpc, at a distance of 17.2 Mpc.



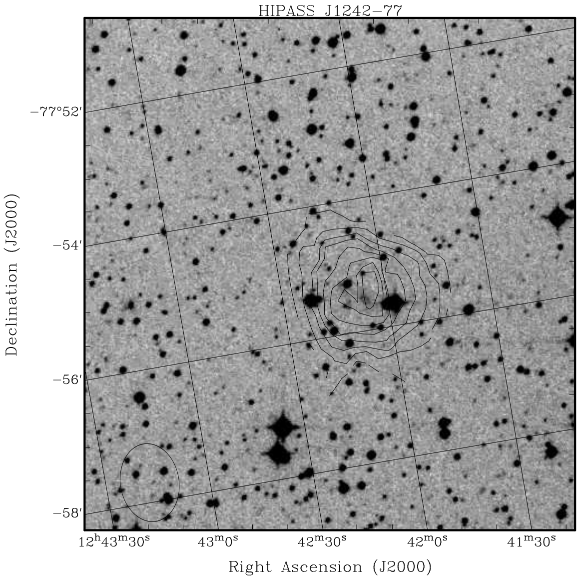


Figure 7.7: HIPASS J1005–73 & HIPASS J1242–77 overlaid on DSS I images.

HIPASS J1005–73

HIPASS J1005–73 is barely visible on the DSS I image, and has quite a large disk of H I surrounding it. The disk does not seem to be disturbed at all, and the maximum column density contour of $4.2{\times}10^{20}$ cm^{-2} includes the optical emission. The H I mass of this LSB dwarf is 5.0×10^8 $M_{\odot}$, and it lies at a Local Group velocity of 979 km s^{-1}. Approximately half of the HIPASS flux was recovered in the ATCA (750m) observations. The size of the H I disk is $\sim$ 8 kpc at a distance of 13.1 Mpc. For comparison, the optical companion is $\sim$ 2 kpc in diameter.

HIPASS J1242–77

In the centre of the H I emission of HIPASS J1242–77 lies a very low surface brightness dwarf galaxy. The contours that contain the optical galaxy are $3.5{\times}10^{20}$ cm^{-2}, similar to the other LSB galaxies investigated so far. The galaxy lies at a Local Group velocity of 2433 km s^{-1}, and has an H I mass of 6.2×10^8 $M_{\odot}$. All of the H I flux from the single dish data was recovered in the ATCA (750m) data. The optical extent of this dwarf is slightly higher than the previous two LSBs, with a diameter of $\sim$ 4.5 kpc. The H I extent is $\sim$ 15 kpc, at a distance of 32.4 Mpc.

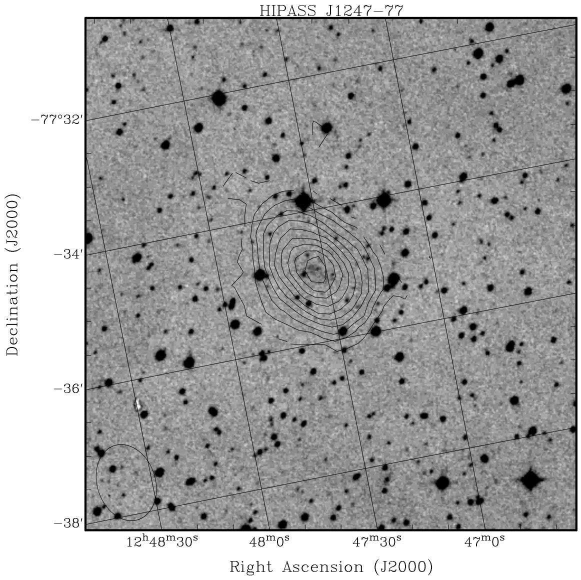


Figure 7.8: HIPASS J1247–77 overlaid on DSS I image.

HIPASS J1247–77

This LSB galaxy is just barely visible on both the DSS I and DSS II images. The optical emission is contained within the highest contour on the H I map, which represents a column density of 5.9 $\times 10^{20}$ cm^{-2}. HIPASS J1247–77 lies near the Leading Arm of the Magellanic Cloud emission, and is distinguished from the Leading Arm clouds due to its compact nature and small optical counterpart. The galaxy lies at a velocity of just 404 km s^{-1}, and is $\sim$ 2 degrees away from the dwarf galaxy, IC 3104 which lies at a velocity of 430 km s^{-1}. The Local Group velocity of this galaxy is 167 km s^{-1}, and the H I mass of this object assuming a distance of 2.2 Mpc is just $M_{\rm HI} = 4.7 \times 10^6 M_\odot$. However, the distance estimate we have chosen may not be valid due to gravitational influences. The synthesis observations recover $\sim$ 80% of the total flux for the object. The 20% velocity width of the galaxy is 49 km s^{-1}. Like the other low–mass LSBs, the disk seems Gaussian and undisturbed, and the optical counterpart lies in the highest column density region. The size of the optical companion is just 210 pc, and the extent of the H I emission is 1.3 kpc.

7.4 LSB Galaxies: High Mass

Four LSB galaxies of higher mass were observed at the ATCA. The first two have a modest H I mass of $\sim 10^9\, M_\odot$, while the last two are quite large, with H I masses of $\sim 10^{10}$. Unlike the low–mass LSBs, the H I disks of the larger mass galaxies are more disturbed, and only a fraction of the H I flux is recovered in the follow–up observations.

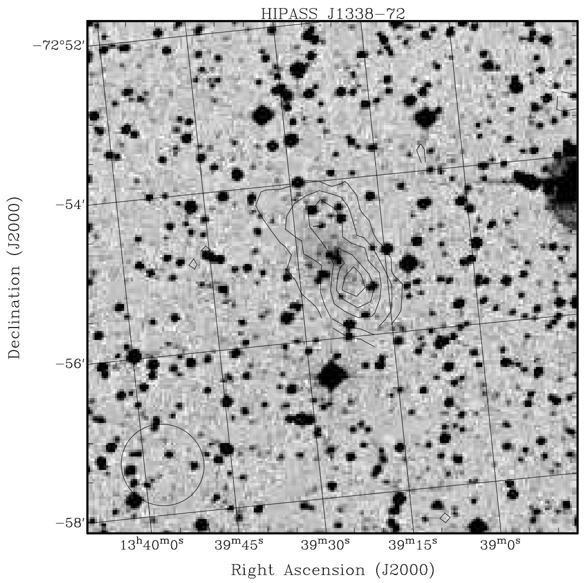


Figure 7.9: HIPASS J1338–72 overlaid on DSS I image.

HIPASS J1338–72

HIPASS J1338–72 lies in a region of high stellar density, however an optical galaxy is visible. The optical emission lies between two higher column density regions in the H I emission. The peak column density for this galaxy is 2.1×10^{20} cm^{-2}, and it lies at a velocity of 3254 km s^{-1}. The H I mass is $1.5 \times 10^9 M_\odot$, and the major axis of the H I emission extends 23 kpc at a distance of 40.2 Mpc.

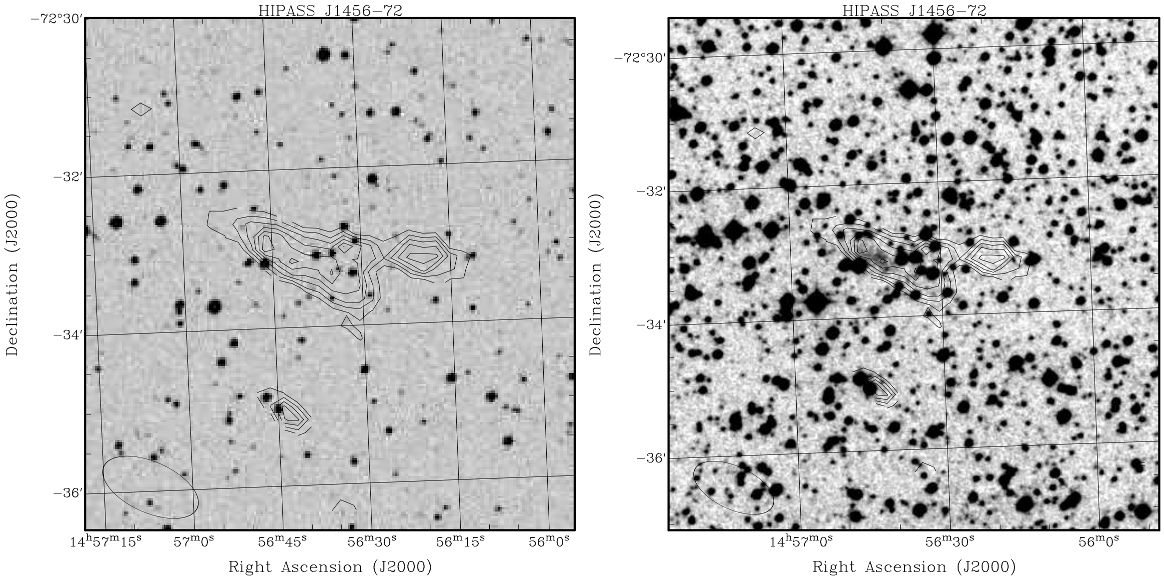


Figure 7.10: HIPASS J1456–72 overlaid on DSS I [Left] and DSS II [Right] images.

HIPASS J1456–72

HIPASS J1456–72 lies in a crowded star field (as can be seen in the DSS II image), and no optical counterpart can be seen in the DSS I image. The H I emission has a large concentration joined with a smaller clump, and there appears to be a small companion to the south of the larger galaxy, although no optical counterpart can be seen for this small emission region. The H I mass for the system is $M_{\rm HI} = 1.5 \times 10^9\, M_{\odot}$, and the galaxy lies at a velocity of 2925 km $\,\mathrm{s}^{-1}$. The extent of the H I is $\sim$ 34 kpc, at a distance of 39 Mpc.

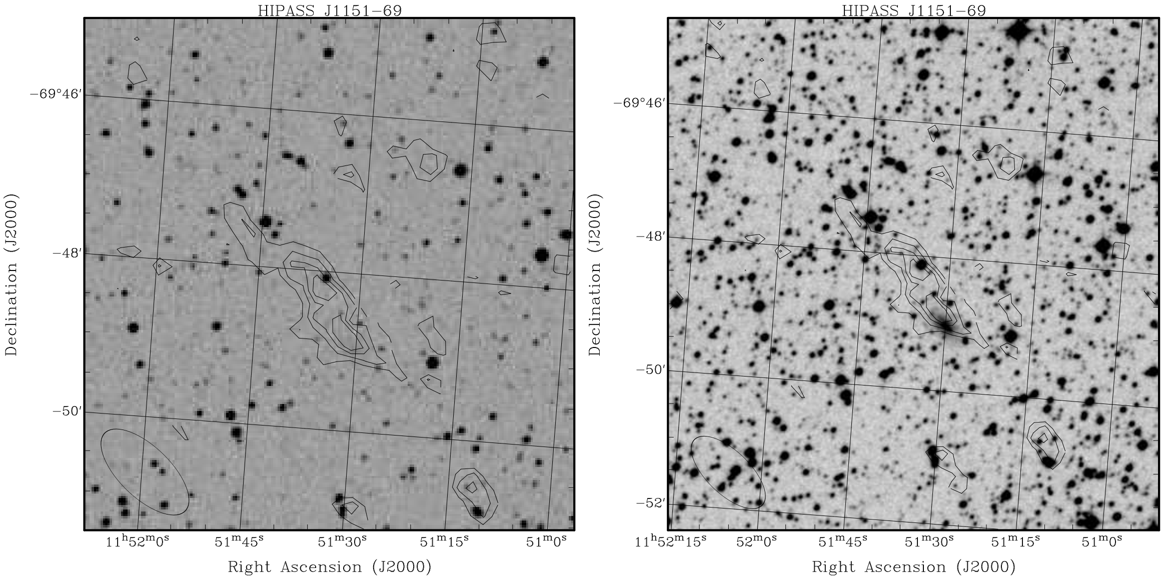


Figure 7.11: HIPASS J1151–69 overlaid on DSS I [Left] and DSS II [Right] images.

HIPASS J1150–69

This galaxy is not visible in the DSS I image, but is seen as a faint smudge in DSS II. The optical counterpart is not in the centre of the H I emission, but lies on the lowest two contours of the map. The H I mass of this galaxy is quite large, $M_{\rm HI} = 1.9 \times 10^{10} M_{\odot}$, but only 6 % of the H I flux is recovered in the synthesis observations compared to the single beam observations. The Local Group velocity of the galaxy is 6704 km s^{-1}, and it has a 50% velocity width of 26 km s^{-1} from the ATCA data. The 50% velocity width from the HIPASS data is 306 km s^{-1} so only a small fraction of the emission is being detected in the ATCA observations. The diameter of the H I is 52 kpc, and this is a lower limit to the actual extent of the disk as such little H I flux was recovered in the higher resolution observations.

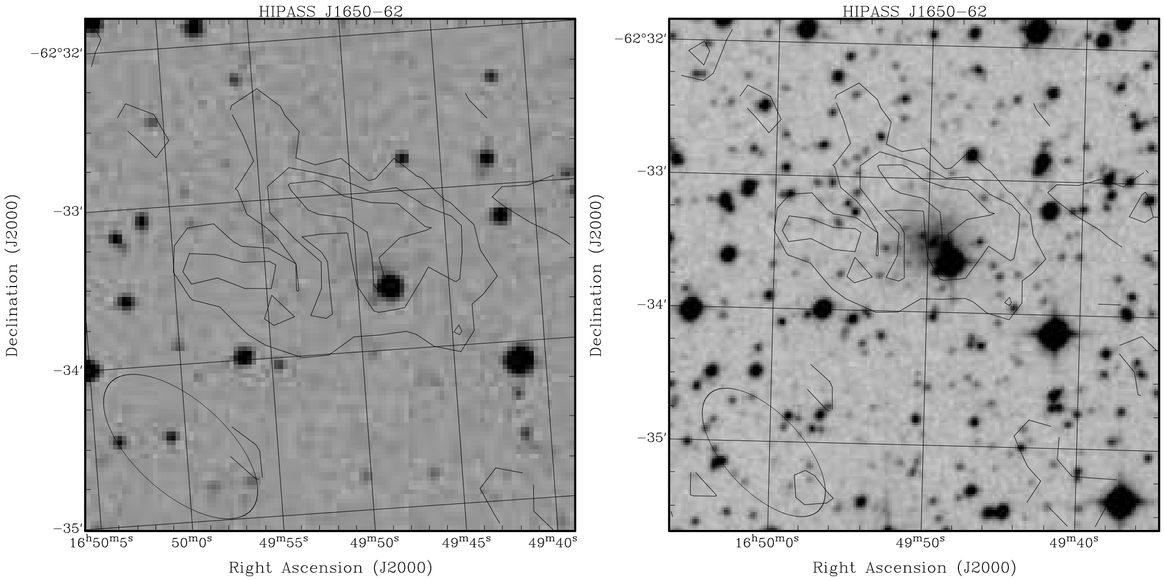


Figure 7.12: HIPASS J1650–62 overlaid on DSS I [Left] and DSS II [Right] images.

HIPASS J1650–62

This galaxy lies as a velocity of 4286 km s^{-1}, and has an H I mass of $9.2 \times 10^9 M_\odot$. No optical counterpart is seen at all in the DSS I image, while an amorphous optical companion is visible o the DSS II image. Only 20% of the single dish flux is recovered with the 750m ATCA observations, indicating an extended lower column density disk of gas. The observed H I emission is only a couple of times the extent of the optical emission, and has a diameter of $\sim$ 24 kpc at a distance of 55 Mpc.

7.5 Combined Properties

Even though this is a small sample of galaxies, there are similarities and differences between the low surface brightness galaxies of low and high–mass and the high surface brightness galaxies. Most of the observed galaxies have H I emission that extends well beyond the optical emission region, in some cases up to 10 times the optical extent (eg: J1816-67). All of the low–mass HSB counterparts are offset from the highest column density region in the H I disk, and with the high–mass HSB galaxies, the optical counterpart is situated between two high column density H I regions in 3 out of 5 cases, and the velocity structure in these galaxies indicates an edge–on disk of H I. The other two HSB companions lie in the centre of the H I emission. In contrast, all of the low–mass LSB optical counterparts lie directly in the centre of undisturbed H I disks, and all of the high—mass LSB have optical counterparts that are offset to the H I.

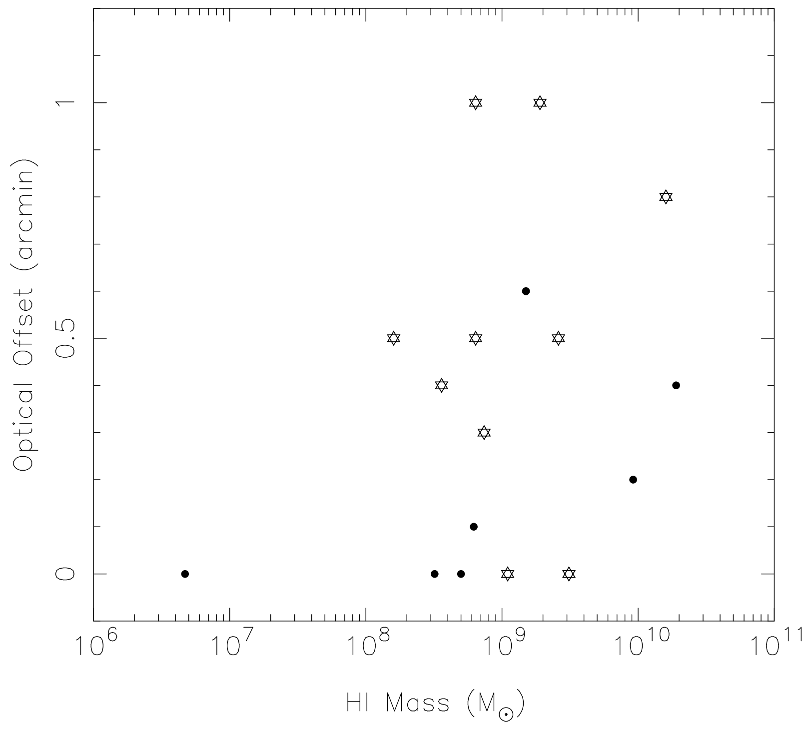


Figure 7.13: Optical offset from H I centre. The filled circles indicate LSB galaxies and the stars show HSB galaxies. The offsets were measured visually, and took the centre of the highest column density contour of the H I emission and the centre of the optical counterpart.

Figure 7.13 shows the offset of the optical companion versus the H I mass of the galaxy. The offset was measured visually, from the centre of the optical emission to the centre of the highest column density H I contour. In this figure, the stars show HSB galaxies and the filled circles show LSB galaxies. The mean offset for the LSB galaxies is 0.2 arcmins, while for the HSB galaxies this is 0.5 arcmins. An optical counterpart offset from the H I emission may indicate an interaction has taken place in a galaxy. In this sample, more HSB counterparts were offset than the LSB galaxies. It is possible that the star formation in the HSB galaxies has been triggered by an interaction, and the offset optical position to the H I is a remnant of this. The LSB dwarf galaxies in the sample showed no evidence of previous interactions. Without such a stimulant to promote their star formation it is possible that these galaxies have quiescently formed stars. Observations of the stellar population of these dwarf galaxies would be useful in determining their age, and star formation history, and thereby determine if this is in fact the first phase of star formation these galaxies have experienced.

The H I surface densities of the HSB and LSB galaxies range from $\rho_{HI} \sim 0.5\,M_{\odot}\mathrm{pc}^{-2}$ to $\rho_{HI} \sim 3.5\,M_{\odot}\mathrm{pc}^{-2}$. Figure 7.14 shows ρ_{HI} plotted against the linear H I extent of the galaxies. No systematic difference is seen between the HSB and LSB samples. Also plotted is the relationship found by Broeils and van Woerden (1994), who find a H I surface density of 3 $M_{\odot}\mathrm{pc}^{-2}$ for their sample of spiral galaxies. This surface density is consistent with our data, including both LSB and HSB galaxies.

In contrast de Blok et al. (1996) found that for a sample of LSB galaxies and HSB galaxies, the LSB galaxies systematically had a lower H I surface brightness. van der Hulst et al. (1993) determined that the average surface densities in their LSB galaxy sample were two times less than HSB galaxies. In the galaxies in our sample, the surface density of the galaxies varies across the galaxy, and it may be the peak surface density rather than the average H I surface density that governs star formation. van Zee et al. (1997) find the H I surface densities of LSB dwarfs to be the same as that of the HSB dwarfs in their sample. They suggest the star formation is governed by local gas densities, with the star formation occurring at the the position of highest column density. This is consistent with the LSB dwarf galaxies in our sample, where the only visible star formation occurs at the highest H I column density.

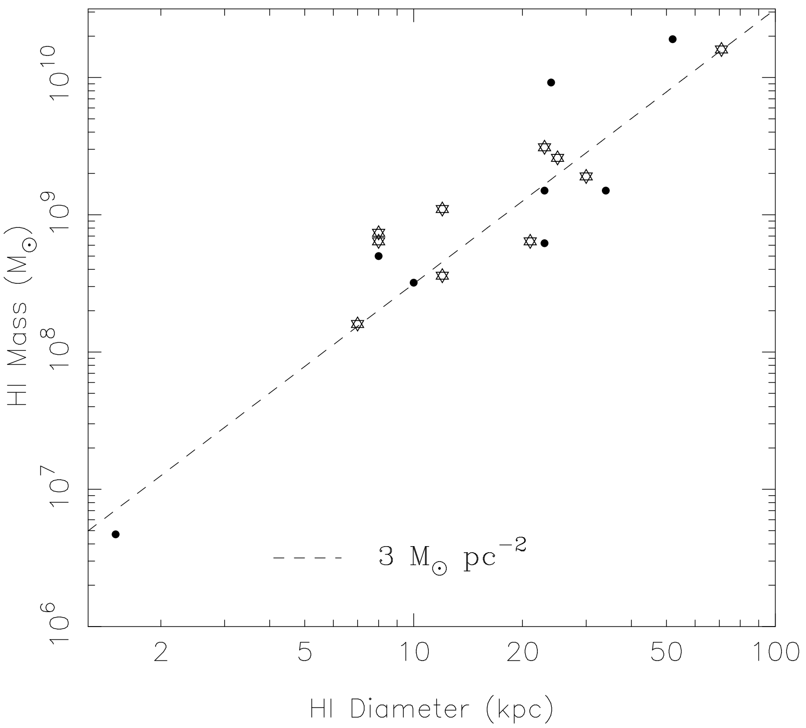


Figure 7.14: H I mass vs H I extent. The filled circles indicate LSB galaxies and the stars show HSB galaxies. The dashed line shows a surface density of 3 $M_\odot$ pc^{-2}, as found by Broeils and van Woerden (1994). No difference in H I surface density is seen between the LSB and HSB galaxies.

Chapter 8

Conclusions

This thesis has presented the first results from the South Celestial Cap (SCC) region of the 21-cm HIPASS survey. An H I catalogue produced from this region contains 533 galaxies, which is twice as large as any other blind H I catalogue produced so far, yet represents just 11% of the HIPASS survey region. Compared to all optically catalogued galaxies in the SCC region, the HIPASS sample contained far more late–type spiral and dwarf galaxies than the optical sample. The large–scale structure of galaxies detected by their H I emission in this region is similar to the structure observed optically, and there is strong evidence of clustering. The H I galaxies were not found to fill the voids, and optical clusters such as Pavo II were not detected in the SCC sample, possibly because of H I deficiency in their central regions. Thus neither very high nor very low density regions are abundant in H I–rich galaxies.

The automated galaxy finder, MultiFind, was developed to search through the three dimensional HIPASS dataset. An automatic galaxy finder is necessary with a large data–set such as HIPASS to ensure any catalogue produced is uniform and has quantifiable limits. MultiFind was tested with simulations and was successful in detecting galaxies to a peak flux limit of 60 mJy. The finder searched through 23 HIPASS cubes in the SCC region to a flux limit of 60 mJy. At this flux limit, $\sim$ 94% of the galaxies catalogued previously 'by eye' were recovered, and no additional galaxies to the visual catalogue were found by MultiFind. This galaxy finder represents a 'first pass' at the problem of detecting galaxies automatically in HIPASS data. The finding process was automated, but the output candidate galaxy lists had to be checked visually, and each galaxy was parameterised individually. MultiFind ran into problems near the Galactic plane due to the large number of continuum sources seen in the HIPASS data. More sophisticated rejection techniques are needed to overcome this problem.

MultiFind has now been successfully run over the whole of the HIPASS data region, excluding the Galactic plane, to a flux level of 90 mJy by Baerbel Koribalski. The resulting catalogue contains the brightest 1000 galaxies in neutral hydrogen in the Southern sky. MultiFind is currently being used to help create a catalogue of galaxies down to a flux limit of 50 mJy. With more simulations on the detection efficiency of MultiFind, the final catalogue should be one in which the selection effects and completeness can be well quantified.

The visual catalogue produced from the SCC region was used to calculate an H I mass function (HIMF). To determine how thorough the cataloguing of this region was, two additional people checked a large portion of the data, finding a small percentage of new galaxies which were subsequently added to the catalogue. Then MultiFind was tested on ~50% of the region and turned up no new galaxies. The HIMF for this region showed a larger number of low–mass H I galaxies than most previous H I surveys. However, the number of dwarf galaxies found was not enough to dominate the H I mass density. A Schechter function was fit to the $\sum 1/V_{max}$ HIMF, with parameters $\alpha = 1.52$, log $M_{\rm HI}{}^* = 10.1$, and $\theta^* = 3.2 \times 10^{-3}$. The accuracy of the $\sum 1/V_{max}$ method, and the maximum likelihood method for calculation the shape of the HIMF was tested with simulations. It was found that the $\sum 1/V_{max}$ method accurately reflected the input data set, while the maximum likelihood method tended to return a faint–end slope that was shallower than the input. The HIMF was calculated using two density-independent methods, to determine the effect of galaxy clustering on the output. The faint–end slope was slightly shallower in these calculations, but with no significant difference.

The HIMF for different optical types of galaxies was investigated. The HIMF for spirals was fit well by a Gaussian with log $M_{\rm HI}{}^* = 8.95$, and log $\sigma = 0.74$. The HIMF for late–type galaxies was well–fit by a steep power–law, with slope $\alpha = 2.15$. No fit was made for early–type galaxies due to poor number statistics. In the full sample HIMF a persistent 'dip' was seen in the H I density at a mass of $M_{\rm HI} \sim 10^8\ M_\odot$. This might be explained as the intersection between the H I distribution of galaxies of different optical type.

The total H I mass density, ρ_{HI}, for the local universe was found to be $\rho_{HI} = 6.7 \times 10^7\, h_{75}\, M_\odot$ Mpc^{-3}. This translated to a cosmological H I mass density of $\Omega_{HI} = 4.1 \pm 0.4 \times 10^{-4} h_{75}^{-1}$. These values are higher than previous determinations from both blind H I surveys and H I surveys based on optical catalogues.

A new class of high velocity H I clouds was discovered in the SCC region, and the origin and therefore the distance of these clouds is unclear. The majority lie along the supergalactic plane, which may indicate they are visible manifestations of large sheets of low column density gas. However, the clouds lie at a similar velocity to parts of the Magellanic Stream, so an origin from the Galaxy/Magellanic Clouds interaction is possible. One cloud, HIPASS J1712-64, was observed in the optical B and R-bands, and with high–resolution H I synthesis imaging at the Australia Telescope Compact Array. No optical counterpart to this cloud was seen to faint limits, and for an optical counterpart one arcmin in diameter, the H I mass–to–light ratio is $M_{\rm HI}/L_B > 24 M_\odot/L_\odot$. No H$\alpha$ emission was detected in a spectrum centered on the cloud. A lower limit to the Hα flux obtained from this observation may lead to the calculation of a lower distance to HIPASS J1712-64 using models of the ionising flux from the Galaxy.

The search for more H I clouds similar to those found in the SCC region will help in interpreting their origin. N–body simulations of the Magellanic Clouds/Galaxy interaction could determine if it would be possible to produce H I clouds at the positions seen in the SCC region. For the clouds that have already been discovered, the determination of their metallicities via absorption spectra of bright quasars would aid in the formation scenario of the clouds. If they are found to be metal–rich, then it would be more likely that they are of Magellanic origin.

The H I properties of a sub–sample of newly detected galaxies in the SCC region were investigated using high–resolution H I data from the Australia Telescope Compact Array. The Low Surface Brightness galaxies in the sample lay in H I distributions that showed little evidence of interaction, while the High Surface Brightness galaxies lay in H I disks that were often irregular, and offset from the position of the optical companion. Surprisingly, there was no difference seen in the average H I surface density of the HSB and LSB galaxies in the sample. High resolution H I observations of a greater sub–set of the HIPASS galaxies is needed to determine the differences in the H I surface density of galaxies of different optical type.

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