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An Extragalactic H I Cloud with No Optical Counterpart?

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ABSTRACT

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We report the discovery, from the H I Parkes All-Sky Survey (HIPASS), of an isolated cloud of neutral hydrogen which we believe to be extragalactic. The H I mass of the cloud (HIPASS J1712-64) is very low, $1.7 \times 10^7 \mathcal{M}_{\odot}$, using an estimated distance of ~ 3.2 Mpc. Most significantly, we have found no optical companion to this object to very faint limits ($\mu(B) \sim 27$ mag arcsec^{-2}). HIPASS J1712-64 appears to be a binary system similar to, but much less massive than, HI 1225+01 (the Virgo H I Cloud) and has a size of at least 15 kpc. The mean velocity dispersion, measured with the Australia Telescope Compact Array (ATCA), is only 4 km s^{-1} for the main component and because of the weak or non-existent star-formation, possibly reflects the thermal linewidth ($T < 2000$ K) rather than bulk motion or turbulence. The peak column density for HIPASS J1712-64, from the combined Parkes and ATCA data, is only 3.5×10^{19} cm^{-2}, which is estimated to be a factor of two below the critical threshold for star formation. Apart from its significantly higher velocity, the properties of HIPASS J1712-64 are similar to the recently recognised class of Compact High Velocity Clouds. We therefore consider the evidence for a Local Group or Galactic origin, although a more plausible alternative is that HIPASS J1712-64 was ejected from the interacting Magellanic Cloud/Galaxy system at perigalacticon $\sim 2 \times 10^8$ yr ago.

Subject headings: galaxies: formation, irregular, individual (HIPASS J1712-64) – radio lines: galaxies

1. INTRODUCTION

Until recently, there has been no extensive survey of the extragalactic sky in neutral hydrogen (H I). The mass distribution in the Universe has therefore been traced by galaxy surveys in other wavebands, particularly in the optical, but also in the infrared using the IRAS satellite. Because of the limited nature of existing H I surveys, it is unclear whether there is a significant local population of H I-rich objects not seen in optical and infrared surveys (away from the Galactic Plane). In particular, the existence of H I clouds without optical counterparts, or 'H I protogalaxies' might significantly add to the local H I mass density of the Universe. Recent observations by Zwaan et al. (1997) and Schneider, Spitzak & Rosenberg (1998) arrive at somewhat differing conclusions regarding the low H I-mass galaxy population, leading to some uncertainty in the contribution of these objects to the HI mass in the local Universe.

Limits to the presence of a population of H I-rich clouds and 'protogalaxies' have been set by a number of 'blind' or semi-'blind' H I surveys conducted in a range of environments: clusters (Barnes et al. 1997; Dickey 1997), groups (Kraan-Korteweg et al. 1999; Banks et al. 1999; Fisher & Tully 1981a), voids (Krumm & Brosch 1984), and in the general field (Henning 1995; Sorar 1994; Spitzak & Schneider 1998; Shostak 1977). In addition, there have been numerous observations in off-source calibration regions for galaxies which have been optically-selected. For example, Fisher

& Tully (1981b) serendipitously detected a couple of dozen galaxies in the calibration scans from their survey, all with optical counterparts.

A number of H I clouds without optical counterparts have been found. However, many appear to be closely associated with massive galaxies (Williams & Van Gorkom 1988; Giovanelli et al. 1995) and perhaps the product of tidal interactions (Hibbard & van Gorkom 1996). A number of potential H I protogalaxies have later been classified as High Velocity Clouds (Mathewson et al. 1975), and argument continues over the extragalactic nature of a specific class of Compact High Velocity Clouds (Braun & Burton 1999; Zwaan et al. 2000). One of the larger blind H I surveys to date (Spitzak & Schneider 1998) detected 75 galaxies in 55 deg^2 of sky. One detection was found not to have any obvious optical counterpart, though a bright star just near the peak of the H I emission may obscure a low surface brightness optical companion.

The closest and best examples of H I clouds without prominent counterparts are the Virgo Cloud HI 1225+01 (Giovanelli & Haynes 1989), and the Leo ring (Schneider et al. 1983). Both of these H I clouds were later found to be associated with optical galaxies. HI 1225+01 was found serendipitously during routine calibration observations. It comprises two regions of H I emission: the largest has a Magellanic-type dwarf irregular galaxy at the position of the highest H I column density, while the smaller, possibly infalling cloud shows no optical emission to a faint limiting magnitude (Chengalur et al. 1995). The larger component has a total dynamical mass of $\sim 1.0 \times 10^{10}\, d_{20}\mathcal{M}_{\odot}$, and a gas mass of $\sim 3 \times 10^9\, d_{20}^2\mathcal{M}_{\odot}$ where d_{20} is the distance in units of 20 Mpc. The heliocentric velocity of the cloud is 1275 km s^{-1} and the extent of the H I emission is about $\sim 200\, d_{20}$kpc. The Leo ring is an intergalactic cloud found during H I observations of the Leo group of galaxies. It comprises a large ring of H I emission surrounding NGC 3384 and M105, with an H I mass of $\sim 10^9\mathcal{M}_{\odot}$. The velocity structure suggests that it is probably not a tidal tail from the nearby galaxies, but a primordial gas cloud which has not started forming stars (Schneider 1989). The cloud is gravitationally bound to the optical galaxies in the group. Both of these objects have been used in Hα studies to determine limits on the local ionising background (Donahue et al. 1995), finding limits which suggest that quasar light, not galactic light, dominates the local ionizing background at low redshift.

The H I Parkes[15] All Sky Survey (HIPASS) has been underway since 1997 and, when complete, will be the largest blind H I survey to date, surveying a volume at least two orders of magnitude larger than any previous survey. In early HIPASS observations of 600 deg^2 in the Centaurus region, Banks et al. (1999) found 10 new members of the nearby Centaurus A group. However, all of these have optical companions, although 5 are faint and were previously uncatalogued. Other early observations include the south celestial cap (Putman et al. 1998; Kilborn, Webster & Staveley-Smith 1999). During routine inspection of this data, a resolved H I detection, HIPASS J1712-64, was selected for follow-up observations as it showed no catalogued galaxy in the vicinity and no

[15]The Parkes telescope is part of the Australia Telescope which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

optical counterpart on the Digitised Sky Survey. It also had a low systemic velocity (though well-separated from Galactic gas and High Velocity Clouds) and a significant angular size.

The observations of HIPASS J1712-64 are discussed in § 2; the H I structure, dynamics and optical limits are discussed in § 3. Alternative High Velocity Cloud and Local Group hypotheses are discussed in § 4, the nature of HIPASS J1712-64 is discussed in § 5, and the results are summarised in § 6. Throughout we assume a Hubble constant of 75 km $s^{-1}Mpc^{-1}$.

2. OBSERVATIONS AND DATA REDUCTION

2.1. HIPASS

HIPASS is a blind H I survey of the sky $\delta < 2°$. The survey uses the Parkes 64 m telescope which is equipped with a 13-beam receiver (Staveley-Smith et al. 1996). The observations began in February 1997, and will be finished by the start of 2000. A northern extension is being contemplated from Parkes, and parts of a complementary northern survey are currently being conducted at Jodrell Bank Observatory's Lovell Telescope. The velocity range covered is -1200 to 12700 km s^{-1}. Observations are taken by scanning the multibeam receiver in declination strips of length $\sim 8°$. Each declination scan is separated by $35'$ in R.A., and each area of sky is scanned five times, resulting in a final scan separation of $7'$. The final integration time is approximately 460 s $beam^{-1}$. The mean telescope FWHM beam is $14\farcm3$, although the gridding process increases this to $\sim 15\farcm5$ (Barnes et al. 2000).

Bandpass calibration, spectral smoothing and Doppler correction of the data are applied in real time at the telescope (Barnes et al. 1998). Once all data are collected, the spectra are gridded into data cubes which have an rms noise level of ~ 13 mJy $beam^{-1}$. The channel spacing in the final cubes is 13.2 km s^{-1}, the FWHM resolution is 18.0 km s^{-1} and the pixel size is $4' \times 4'$.

2.2. H I Observations

HIPASS J1712-64 was discovered during a routine visual inspection of data cubes. The detection is very significant: it has a peak flux of ~ 150 mJy $beam^{-1}$, corresponding to a signal-to-noise ratio of about 12. It is also significantly resolved in the beam of the Parkes telescope, extending over at least two beamwidths. On 1999 June 2, a further 2.5 hour observation was made at the Parkes telescope, using the multibeam receiver, to confirm the detection. The observation was of a $3° \times 4°$ field centered on the original detection. This observation also resulted in a clear positive detection. The rms noise in the follow-up observation is 19 mJy $beam^{-1}$. The combined, and spatially integrated, Parkes spectrum is shown in Fig. 1. The total flux density peaks at 250 mJy at a heliocentric velocity of ~ 455 km s^{-1}.

Higher resolution observations in the H I line were made at the Australia Telescope Compact Array (ATCA) on 1999 June 30. Approximately 12 hours of data was obtained using the 375 m array, and the pointing center for the observations was R.A. $17^h12^m13^s$, Decl. $-64^d39^m12^s$ (J2000). The secondary calibrator PKS 1814-637 was observed every 30 minutes for 4 minutes, to calibrate the amplitude and phase of the visibility data. The primary flux scale was set using the primary calibrator PKS 1934-638. The bandwidth of 8 MHz was divided into 512 channels, resulting in a channel spacing of 3.3 km s^{-1} and a FWHM resolution, before any smoothing, of 4.0 km s^{-1}.

The data were reduced using the MIRIAD reduction package. The data were edited, calibrated in amplitude and phase and bandpass-corrected. Several bright continuum sources were then removed by fitting spectral baselines to the line-free channels in the visibility domain. Natural weighting was used to form the data cube, which was CLEANed until the absolute maximum residual in each plane fell below 10 mJy. The final FWHM beam is $2\farcm0 \times 1\farcm9$, and the rms noise is 3.7 mJy beam^{-1}. No correction for the primary beam pattern was applied.

J1712-64 was again detected in the ATCA data. The spatially integrated spectrum (smoothed to the same velocity resolution) is overlaid on the Parkes/HIPASS data in Fig. 1. All except ~ 20 % of the Parkes flux density (mainly at higher velocities) is recovered. This implies that some diffuse or low-level emission is being missed by the ATCA. The ATCA channel images (Hanning-smoothed to 6.6 km s^{-1} resolution) are shown in Fig. 2.

A combined cube of the Parkes and ATCA data set was made by spectrally smoothing the ATCA data to match the HIPASS data, then spatially resampling the HIPASS data to match the ATCA data. The data were then combined using the MIRIAD task IMMERGE. It was assumed that both the ATCA and HIPASS flux density scales were accurate to a few per cent. The final column density image, with contours overlaid is shown in Fig. 3. The ATCA velocity field, derived from the GIPSY task MOMENTS, is shown in Fig. 4 overlaid on the column density image.

2.3. Optical Observations

A search for an optical counterpart using blue and red film copies of the UKST/ESO southern sky survey revealed no optical counterpart. Subsequently, two deep original plates were obtained from the UK Schmidt Telescope (UKST) plate archive and subjected to a photographic enhancement technique (Malin 1978) which is capable of revealing extended features over 5 mag fainter than the night sky (Malin & Hadley 1997). At the site of the UKST (Siding Spring) this is typically $\mu(B) = 22.5$ mag arcsec^{-2}.

Only two suitable plates were available, and an image was made by combining photographically enhanced derivatives from both of them: J1659 (IIIa-J/GG 395, 395–530 nm) and OR15092 (IIIa-F/RG 590, 590-690 nm). Both were plates of excellent quality but 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. For an optical companion of $1'$ in diameter and lying just beneath our optical limit, these limits suggest an absolute magnitude $M_B > -8.8$ mag, and an H I mass-to-light ratio $M_{HI}/L_B > 24$ (Table 2) .

The source was also imaged in the optical I-band at the ANU 40-inch telescope at Siding Springs Observatory on 1999 April 15. It was also imaged in the B and R-bands by the CTIO 40-inch telescope on 1999 May 4. The data were reduced using the IRAF[16] package and calibration for the B and R-band images used photometric observations of the Landolt Standard field 104 (Landolt 1983). The optical point source magnitude limits are $B \sim 19.8$ and $R \sim 19.2$ from the CCD observations. None of the images show any evidence of extended optical emission near the location of the H I detection. Fig. 5 shows the H I contours of HIPASS J1712-64 overlayed on the combined B and R-band CCD images, showing a dense starfield but no extended objects.

3. PHYSICAL PARAMETERS

3.1. H I Structure

HIPASS J1712-64 is well-resolved in each of the velocity channels with significant emission (see Fig. 2). The object appears to have two major components. The prominent one (hereafter the NE component) is centered at R.A. $17^{\rm h}12^{\rm m}35^{\rm s}$, Decl. $-64°38'12''$ (J2000) and has a velocity spread from 438 to 464 km s^{-1} in the ATCA data. The systemic velocity is 451 km s^{-1} and the velocity width is $W_{50} = 11$ km s^{-1} (Table 1). The velocities appear to increase from southeast to northwest across this component, but the difference is only a few km s^{-1} at the most (Fig. 4). The other component (hereafter the SW component) is centered at R.A. $17^{\rm h}11^{\rm m}35^{\rm s}$, Decl. $-64°45'11''$ (J2000) and has a velocity spread from 451 to 477 km s^{-1}. The systemic velocity is 464 km s^{-1} and the velocity width is $W_{50} = 20$ km s^{-1} (Table 1). Any gradient across this component is again only a few km s^{-1} (Fig. 4).

A bridge of emission appears to join the NE and SW components in a manner reminiscent of the Virgo Cloud HI 1225+01 (Chengalur et al. 1995). Velocities appear to increase smoothly from the NE to the SW components. The overall H I structure appears to be that of two separate, but interacting components.

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[16]IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

3.2. Optical Limits

The source is located close to the Galactic plane at $(l,b) = (326\overset{\circ}{.}6, -14\overset{\circ}{.}6)$, and therefore extinction may be important. We have estimated this using three methods. The local H I column density from the HIPASS data (reprocessed to avoid any spatial filtering) is 484 K km s^{-1}, which corresponds to $N_{\rm HI} = 8.8\times10^{20}$ atoms cm^{-2}. Following the conversion formula of Burstein & Heiles (1978), this implies $E(B-V) = 0.12$ mag. The extinction determined from the COBE/DIRBE and IRAS/ISSA maps based on dust temperature is essentially identical: $E(B-V) = 0.11$ mag (Schlegel et al. 1998). Finally, the Burstein & Heiles (1982) extinction maps suggest a similar value $E(B-V) = 0.09$ mag. Taking the mean value, $E(B-V) = 0.11$, this implies a blue-light absorption of $A_B = 4.0E(B-V) = 0.44$ mag. Thus although the stellar density in the optical images is quite high (see Fig. 5), there is no evidence for large optical extinction in the direction of the H I detection.

An optical counterpart could be overlooked if the J1712-64 is very close to the Milky Way and resolved into stars. One method of detecting a resolved galaxy in a crowded field of stars is to search a colour-colour plot of the stars in a field, to look for a separate stellar population. This method was used to detect the Sagittarius dwarf galaxy (Ibata, Gilmore & Irwin 1995). We applied this method to the B and R-band CCD images. These images cover an area of about 1 deg^2, which is substantially larger than the H I detection. Fig 6 shows a histogram of stellar magnitudes for a $20'$ field centred on 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.

3.3. Distance and Mass

The systemic velocity of the H I detection is $v_{\rm sys} = 451$ km s^{-1} (NE component). The velocity with respect to the Local Group can be determined using $v_{\rm LG} = v_{\rm sys} - 79\cos l\cos b + 296\sin l\cos b - 36\sin b$ (Yahil, Tammann & Sandage 1977). This gives $v_{\rm LG} = 239$ km s^{-1} which, if we assume HIPASS J1712-64 to be extragalactic and $H_\circ = 75$ km s^{-1} Mpc^{-1}, corresponds to a distance of 3.2 Mpc (see Table 2). This would place HIPASS J1712-64 at some distance beyond the Local Group. This distance is subject to considerable uncertainty. Alternate Local Group velocities range from $v_{\rm LG} = 291$ km s^{-1} (using $300\sin\ell\cos b$) to $v_{\rm LG} = 172$ km s^{-1} (POTENT, Bertschinger (1990)), giving distances of 3.9 Mpc and 2.3 Mpc, respectively. Without the aid of optical distance measures, subsequent calculations involving the distance to J1712-64 will therefore be based on the value of 3.2 (±1) Mpc. At this distance, the projected separation of the NW and SW components is ~ 9 kpc, the overall H I size is ~ 15 kpc and the H I mass is $\sim 1.7\times10^7\mathcal{M}_\odot$. For a substantially smaller distance, say 100 kpc (see § 4), the separation, size and mass are ~ 300 pc, ~ 500 pc and $\sim 1.7\times10^4\mathcal{M}_\odot$, respectively.

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} (see Table 1), possibly slightly more for the SW component, although the S/N ratio is too low for a reliable estimate.

If the velocity difference between the NE and SW components is indicative of the rotation of a bound, binary system at 3.2 Mpc, the minimum system mass is $1.5 \times 10^8 \mathcal{M}_\odot$ (Faber & Gallagher 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 ($\sim 9 M_{\rm HI}$, which would be a reasonable value for disk galaxies), or else is not bound. The orbital period of the two components corresponding to the minimum total mass is ~ 4 (d/3.2 Mpc) Gyr.

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

$$M_T = \frac{\alpha \sigma^2 r}{G} \tag{1}$$

where σ is the line-of-sight velocity dispersion (~ 4 km s^{-1}), r is the radius (~ 4 kpc) and $\alpha \sim 1-3$ depending on the mass distribution. For an isothermal sphere, $\alpha \approx 2$, which gives $M_T(\mathrm{NE}) = 3.0 \times 10^7 \mathcal{M}_\odot$, which is only ~ 1.8 times higher than the H I mass for this component. Again, for a distance of 100 kpc, the mass drops to $M_T(\mathrm{NE}) = 10^6 \mathcal{M}_\odot$, but this is now ~ 60 times greater than the H I mass if in hydrostatic equilibrium.

3.4. Stability

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

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

where v_s is the sound speed and Ω is 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 of J1712-64 (assuming it to be extragalactic), then we obtain $\Sigma_c \approx 8 \times 10^{19}$ atoms cm^{-2}. This is a factor of two above the peak measured column density of just 3.5×10^{19} atoms cm^{-2} (Fig 3), consistent with the absence of visible star-formation.

4. ALTERNATIVES

4.1. A Local Group Galaxy?

Nearby, faint galaxies which are resolved into stars can be especially hard to spot even far from the crowding in the Galactic Plane (e.g. Sextans – Irwin et al. (1990)). In § 3.2 we have shown that there is no evidence in color-magnitude diagrams for this. In addition, the Local Group velocity, $v_{\rm LG} = 239$ km s^{-1} is well beyond the ± 60 km s^{-1} which appears to encompass most known Local Group members (Grebel 1997; van den Bergh 1999). This is demonstrated in Fig. 7, where J1712-64 has the highest heliocentric and Local Group velocity of all the probable and possible Local Group members plotted. It has also has a higher velocity than the class of 'Local Group outliers' which have distances of $1 \sim 2$ Mpc and are regarded by Grebel (1997) as only potential members.

In addition, the irregular galaxy IC 4662 lies $3\overset{\circ}{.}7$ on the sky from HIPASS J1712-64, has a velocity of $v_{\rm sys} = 302 \pm 1$ km s^{-1}, almost 150 km s^{-1} lower, yet is not classified as belonging to the Local Group (van den Bergh 1999). Therefore, from its velocity, there is no evidence for J1712-64 being a galaxy lying within the Local Group.

4.2. A High Velocity Cloud?

The most likely 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. HVCs are H I objects which do not fit into a simple model of Galactic rotation and do not have optical counterparts (Wakker & van Woerden 1997; Braun & Burton 1999). They 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 & van Woerden 1997). There are two good reason 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 – Morras et al. (2000)). The second is J1712-64's HI structure. Most HVCs have a core-halo morphology with only 10–50% of the total flux able to be recovered by interferometry (Wakker & van Woerden 1997). As shown in Fig. 1, however, the ATCA observations were able to recover 80% of the total flux. It may, however, be an extreme version of the compact HVCs studied in detail by Braun & Burton (2000). These objects exhibit narrow linewidths and also show apparent velocity gradients.

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. It is possible that a compact HVC similar to J1712-64 could have originated from gravitational scattering off the three-body Magellanic Clouds/Galaxy system. However, HIPASS J1712-64 does not lie close to the Clouds (it is 46° from the LMC), and the Leading Arm, which includes HVCs 334 and 352 of Wakker & van Woerden (1991) (see Figure 3 of Putman et al. (1998)), is $\sim 20°$ away. 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 & Noguchi 1996). An examination of the spatial and velocity distribution of future objects, similar to HIPASS J1712-64, will ultimately demonstrate their relationship, if any, with the Magellanic System.

5. DISCUSSION

Although there have been many previous searches for extragalactic H I in optically blank fields (Fisher & Tully 1981a; Briggs 1990; Barnes et al. 1997; Schneider, Spitzak & Rosenberg 1998), there has been little success, implying that massive H I 'protogalaxies' are rare at the present epoch. However, HIPASS J1712-64 has a very low H I mass, $1.7 \times 10^7\ \mathcal{M}_\odot$, implying that similar objects may exist in abundance and may have escaped previous detection through lack of sensitivity. Some limits exist from the Cen A HIPASS results of Banks et al. (1999), who find 10 new group members, all with corresponding optical counterparts, in the 600 deg^2 they surveyed around the Cen A group. However, their sensitivity limit is $\sim 10^7\ \mathcal{M}_\odot$ so it is possible that slightly deeper observations (Disney et al. 1999) may reveal more such objects. The HIPASS observations of the south celestial cap, Decl. $< -62°$ (Kilborn, Webster & Staveley-Smith 1999), comprise 2400 deg^2 of sky, but contains only a few other candidate 'protogalaxies', which are awaiting follow-up CCD data. However, HIPASS J1712-64 is the most significant detection in terms of flux density and angular size. Nevertheless, for there to exist large numbers of similar objects would require them to have H I masses $< 10^7\ \mathcal{M}_\odot$.

Interestingly, a system with a similar velocity and H I morphology, ZOA J1616-55, was found in a search for galaxies in the Zone of Avoidance (ZOA) near $\ell = 325°$ (Staveley-Smith et al. 1998). This system has a similar distance and H I column density to HIPASS J1712-64 but a higher H I mass ($9 \times 10^7\ \mathcal{M}_\odot$) and diameter (86 kpc). Although lying in the ZOA, the estimated blue absorption is only $A_B = 2.7$ mag, so the lack of an optical or IR counterpart led Staveley-Smith et al. (1998) to conclude it was a galaxy pair of low optical surface brightness. J1712-64 is only 11° (projected separation 600 kpc) from J1616-55 and 19° (projected separation 1.1 Mpc) from the massive Circinus galaxy. Possibly, all three are part of a loose southern extension to the Cen A group. In the HVC hypothesis, the alternative is that Circinus is unrelated and both J1712-64 and J1616-55 have a Magellanic origin.

From a study of the Lyα forest lines and a VLA H I study, Shull, Penton & Stocke (1999) suggest that, at $z = 0$, there may exist clouds, or sheets, of ionized gas ~ 1 Mpc in extent which contain ~ 30 times more baryons than the neutral gas confined to known galaxies. Objects such as J1712-64 may be the most easily visible manifestations of these large primordial clouds. So, although the neutral gas content in J1712-64 is hardly enough to make a star cluster, let alone a galaxy, there may be significantly more baryons in the region available to form a galaxy if they were able to cool. The possibility that the dynamical mass of the J1712-64 system is ~ 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 HI 1225+01 and the Leo ring place limits of $J_0 < 3 - 8 \times 10^{-23}$ ergs s^{-1} cm^{-2} sr^{-1} Hz^{-1} for quasar-like light (Donahue et al. 1995). Hα observations of J1712-64 may also help provide strong constraints on this background. Such observations would also be useful in providing a lower limit to the distance to J1712-64 in light of the observation that many nearby HVCs have faint but detectable Hα emission probably resulting from the Galactic ionization field (Bland-Hawthorn & Maloney 1999).

The mean velocity dispersion of the NE component of J1712-64 appears to be low, $\sigma = 4$ km s^{-1} (Table 1). This gives an upper limit to the kinetic temperature of $T < 2000$ K. The existence of cool gas would be interesting as this requires that there are densities high enough to allow cooling and may therefore indicate that star-formation is about to commence. In order to search for cool gas, we examined the ATCA H I spectrum of PKS 1708-648 which is $19\farcm4$ from the center of the J1712-64. However, we were unable to detect any unambiguous evidence for absorption. This is probably not significant as the continuum source is well beyond the last measured contour of HIPASS J1712-64.

6. SUMMARY

An isolated H I cloud, HIPASS J1712-64, has been found during the course of the HIPASS survey. It appears to be a nearby extragalactic cloud lying beyond the outer fringes of the Local Group at a distance of ~ 3.2 Mpc, though an alternative explanation is that of an HVC with unique properties. Optical limits imply a surface brightness, corrected for obscuration of $\mu(B) > 27$ mag arcsec^{-2} and an H I mass-to-light ratio $M_{HI}/L_B > 24\mathcal{M}_{\odot}/L_{\odot}$ for a putative optical counterpart of diameter $1'$. The system appears to have two components, separated by 9 kpc, with a bridge of gas between them. The mean velocity dispersion of the NE component is low, ~ 4 km s^{-1} implying that HIPASS J1712-64 contains cool gas ($T < 2000$ K). However, it appears to be dynamically stable against star-formation.

Although the H I mass is low, $\sim 1.7 \times 10^7$ $\mathcal{M}_{\odot}$ (for a distance of 3.2 Mpc), the velocity differences within the system suggest that there may be an extended dark matter halo if the system is bound. Is HIPASS J1712-64 important from a cosmological point of view? This depends on whether similar objects exist in great numbers, whether they represent the cool, high-density baryonic peaks of low-amplitude overdensities, whether such objects are the building blocks of galaxy and star cluster formation, whether they are simply the left-overs of these processes, and whether they are indeed extragalactic. Future HIPASS observations will cast some light on the frequency of their occurrence, and their distribution on the sky.

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REFERENCES

Banks, G. D., et al. 1999, ApJ, 524, 612

Barnes, D. G., Staveley-Smith, L., Walsh, W., and Webster, R. L. 1997, MNRAS, 288, 307

Barnes, D. G, Staveley-Smith, L., Ye, T., and Oosterloo, T. 1998, in Astronomical Data Analysis Software and Systems VII, ASP Conference Series 145, eds Albrecht, R., Hook, R. N., and Bushouse, H. A. (San Francisco: ASP) p.89

Barnes, D. G. et al. 2000, in preparation

Bertschinger, E., Dekel, A., Faber, S. M., Dressler, A. and Burstein, D. 1990, ApJ, 364, 370

Binney, J., and Tremaine, S. 1987, Galactic Dynamics (Princeton University Press) p.310

Bland-Hawthorn, J. and Maloney, P. R. 1999, ApJ, 510, 33

Braun, R., and Burton, W. B. 1999, A&A, 341, 437

Braun, R., and Burton, W. B. 2000, A&A, 354, 853

Briggs, F. H. 1990, AJ, 100, 999

Burstein, D., and Heiles, C. 1978, ApJ, 225, 40

Burstein, D., and Heiles, C. 1982, AJ, 87, 1165

Chengular, J. N., Giovanelli, R., and Haynes, M. P. 1995, AJ, 109, 2415

Dickey, J. M. 1997, AJ, 113, 1939

Disney, M. J., Boyce, P. J., Banks, G. D., Minchin, R. F., and Wright, A. E. 1999, PASA, 16, 66

Donahue, M., Aldering, G., and Stocke, J. T. 1995, ApJ, 450, L45

Faber, S. M., and Gallagher, J. 1979, ARA&A, 17, 135

Fisher, J. R., and Tully, R. B. 1981a, ApJ, 243, L23

Fisher, J. R., and Tully, R. B. 1981b, ApJS, 47, 139

Gardiner, L. T., and Noguchi, M. 1996, MNRAS, 278, 191

Giovanelli, R., and Haynes, M. P. 1989, ApJ, 346, L5

Giovanelli, R., Scodeggio, M., Solanes, J. M., Haynes, M. P., Arce, H., Sakai, S. 1995, AJ, 109, 2415

Grebel, E. K. 1997, Rev. Mod. Astr., 10, 29

Henning, P. A. 1995, ApJ, 450, 578

Hibbard, J. E., and van Gorkom, J. H. 1996, AJ, 111, 655

Ibata R. A., Gilmore, G. and Irwin, M. J. 1995, MNRAS, 277, 781

Irwin, M. J., Bunclark, P. S., Bridgeland, M. T., and McMahon, R. G. 1990, MNRAS, 244, 16P

Kennicutt, R. C. 1989, ApJ, 344, 685

Kilborn, V., Webster, R. L., and Staveley-Smith, L. 1999, PASA, 16, 8

Kraan-Korteweg, R. C., van Driel, W., Briggs, F., Bingelli, B., and Mostefaoui, T. I. 1999, A&A, 135, 255

Krumm, N., and Brosch, N., AJ, 89, 146

Landolt, A. U. 1983, AJ, 88, 439

Malin, D. F. 1978, Nature, 276, 591

Malin, D., and Hadley, B. 1997, in The Nature of Elliptical Galaxies, 2nd Stromlo Symposium, ASP Conference Series 116, eds Arnaboldi, M., Da Costa, G. S., and Saha, P. (San Francisco: ASP) p.460

Mathewson, D. S., Cleary, M. N., and Murray, J. D. 1975, ApJ, 195, L97

Morras, R., Bajaja, E., Arnal, E. M., and Pöppel, W. G. L. 2000, A&ASuppl., 142, 25

Putman, M. E. et al. 1998, Nature, 394, 752

Schlegel, D. J., Finkbeiner, D. P., and Davis, M. 1988, ApJ, 500, 525

Schneider, S. E., Helou, G., Salpeter, E. E., and Terzian, Y. 1983, ApJ, 273, L1

Schneider, S.E. 1989, ApJ, 343, 94

Schneider, S. E., Spitzak, J. G., and Rosenberg, J. L. 1998, ApJ, 507, L9

Shostak, G. S. 1977, A&A, 54, 919

Shull, J. M., Penton, S. V., and Stocke, J. T. 1999, Publ. Astr. Soc. Australia, 16, 95

Sorar, E. 1994, Ph.D. Thesis, University of Pittsburgh

Spitzak, J.G. and Schneider, S.E. 1998, ApJS, 119, 159

Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., and Linke, R. A. 1992, ApJS, 79, 77

Staveley-Smith L., Wilson, W. E., Bird, T. S., Disney, M. J., Ekers, R. D., Freeman, K. C., Haynes, R. F., Sinclair, M. W., Vaile, R. A., Webster, R. L., Wright, A. E. 1996, PASA, 13, 243

Staveley-Smith L., Juraszek, S., Koribalski, B. S., Ekers, R. D., Green, A. J., Haynes, R. F., Henning, P. A., Kesteven, M. J., Kraan-Korteweg, R. C., Price, R. M., and Sadler, E. M. 1998, AJ, 116, 2717

Taylor, C. L., Brinks, E., Grashius, R. M., and Skillman, E.D. 1996, ApJS, 102, 189

van den Bergh, S. 1999, A&ARv, 9, 273

Wakker B. P., and van Woerden, H. 1991, A&A, 250, 509

Wakker B. P., and van Woerden, H. 1997, ARA&A, 35, 271

Williams B. A., and Van Gorkom J. H. 1988, AJ, 95, 352

Yahil, A., Tammann, G. A., and Sandage, A. 1977, ApJ, 217, 903

Zwaan, M. A., Briggs, F. H., Sprayberry, D., and Sorar, E. 1997, ApJ, 490, 173

Zwaan, M. A., and Briggs, F. H., 2000, ApJ, 530, L61

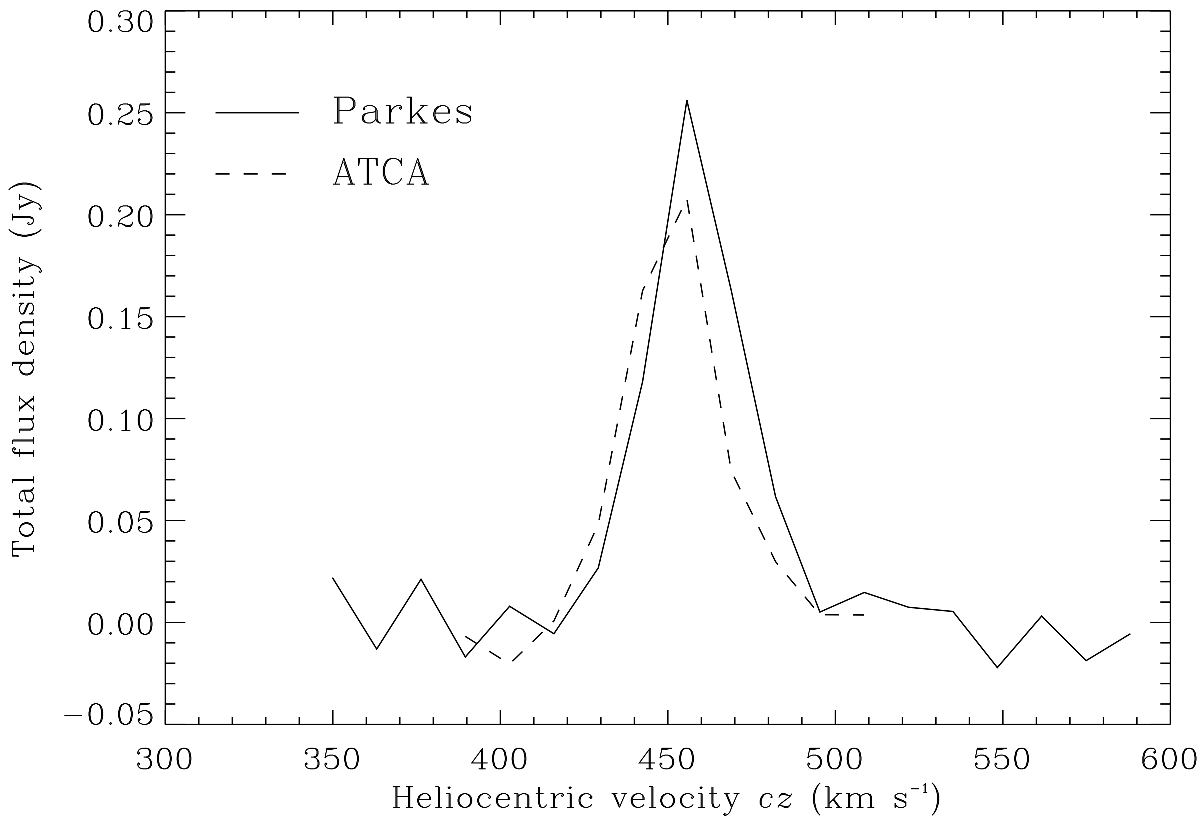

Fig. 1.— Spatially integrated H I spectra of HIPASS J1712-64 from the Parkes/HIPASS data (solid line) and the ATCA (dashed line). The ATCA appears to recover $\sim 80\%$ of the total flux density. Both spectra are derived by spatially integrating over a box centred on the mid-point of J1712-64. The size of the box was $44'$ and $16'$ for the Parkes and the ATCA data respectively. The ATCA data has been smoothed to the spectral resolution of the Parkes data. No clipping of the data points was used.

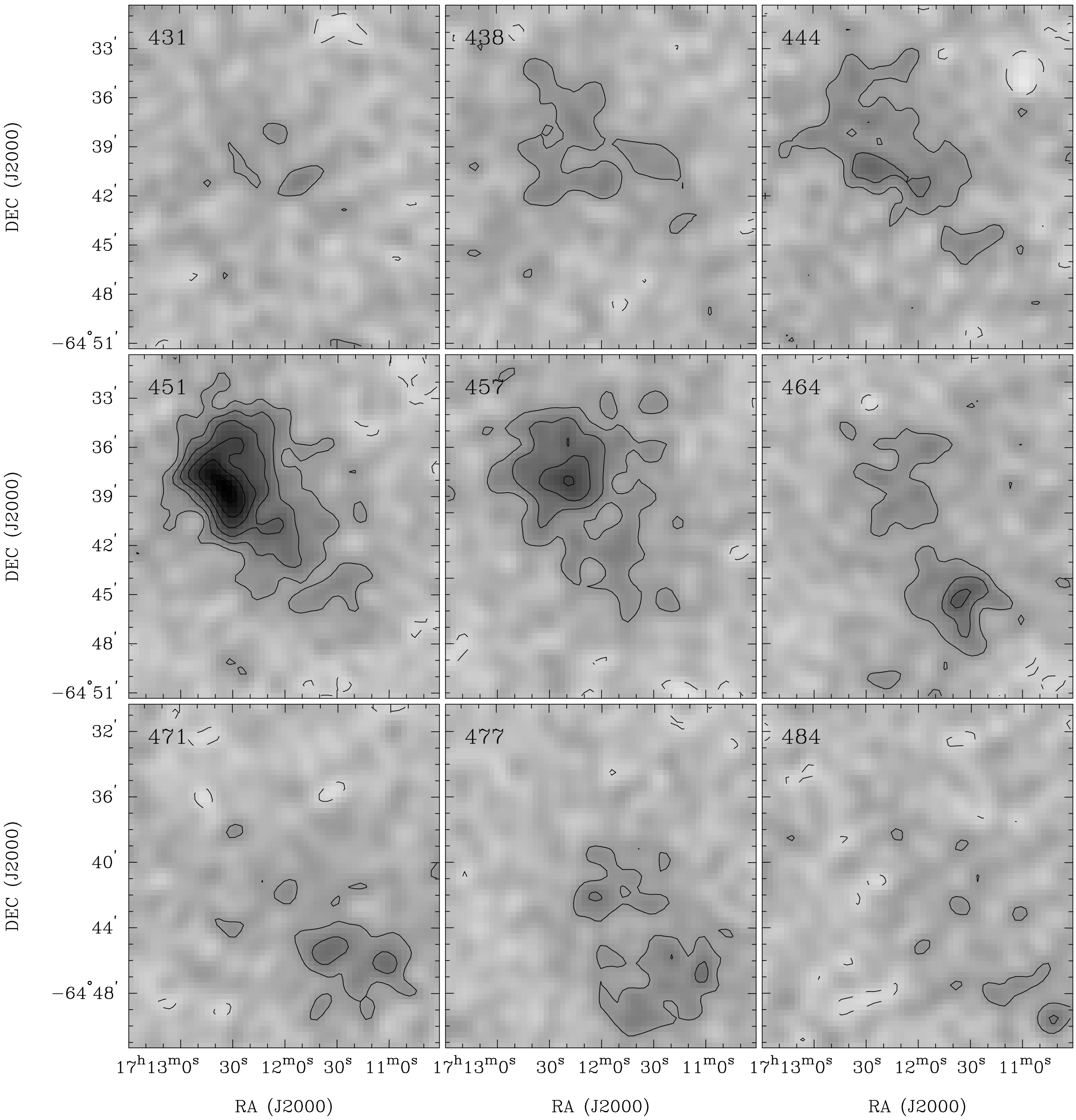

Fig. 2.— H I channels maps for HIPASS J1712-64 from the Hanning-smoothed ATCA data. The mean heliocentric velocity is given in the top left hand corner of each map. The separation of plotted channels is 6.6 km s^{-1}. The contours plotted are −5, 5, 10, 15, 20, 25 and 30 mJy per beam.

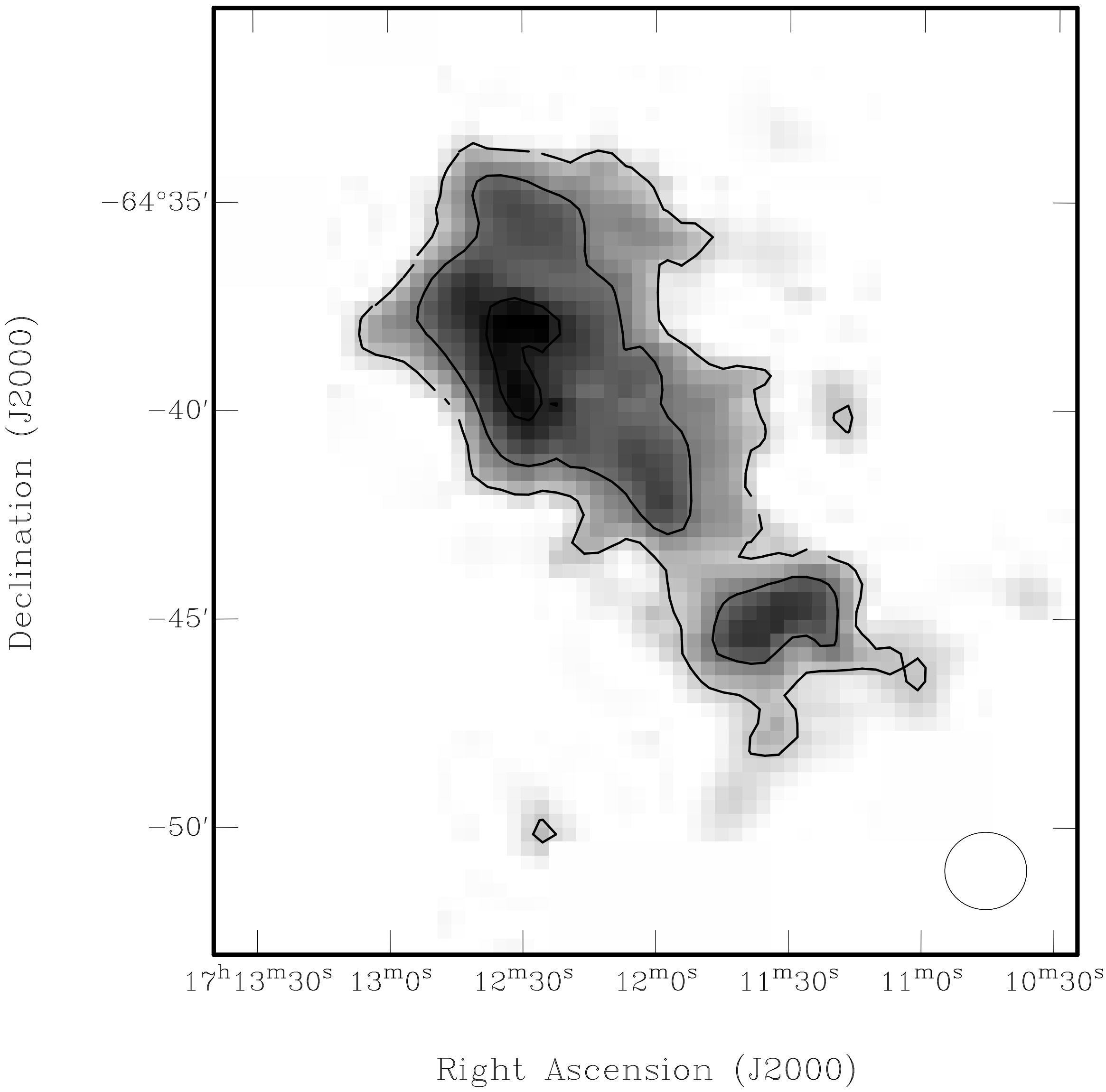

Fig. 3.— H I column density map of HIPASS J1712-64 from the combined ATCA/Parkes dataset. The contours represent increments of 1×10^{19} atoms cm^{-2} to a maximum value of 3.5×10^{19} atoms cm^{-2}. The grey scale is a linear representation of the column density. The FWHM of the final beam shown in the lower right hand corner is $2\farcm0 \times 1\farcm9$.

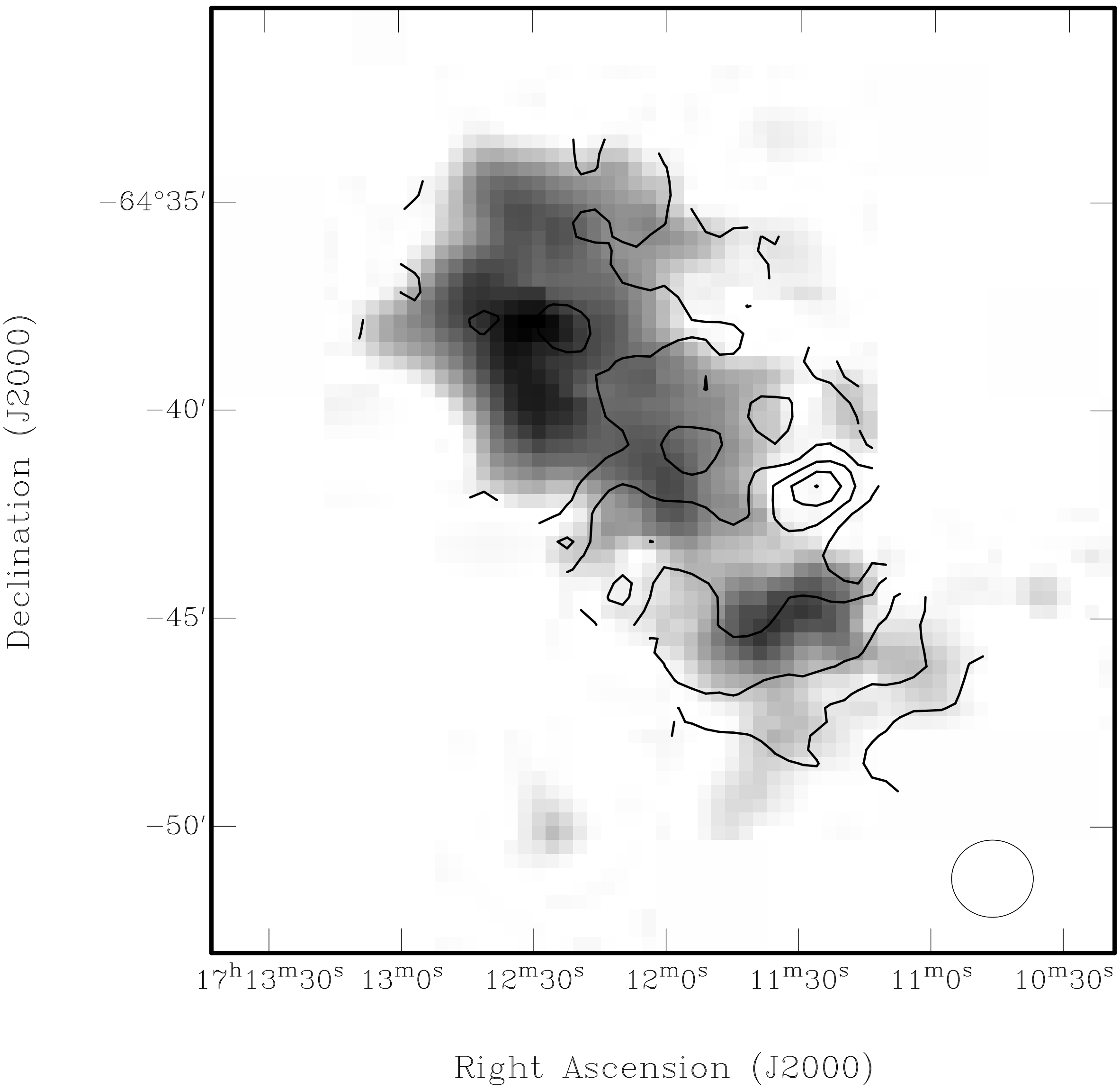

Fig. 4.— H I velocity field of HIPASS J1712-64 from the ATCA data, superimposed on the column density image (from the combined ATCA and Parkes data). The contours are at intervals of 5 km s^{-1} and range from 450 km s^{-1} in the northeast to 475 km s^{-1} in the southwest. The FWHM of the final beam shown in the lower right hand corner is $2\farcm0 \times 1\farcm9$.

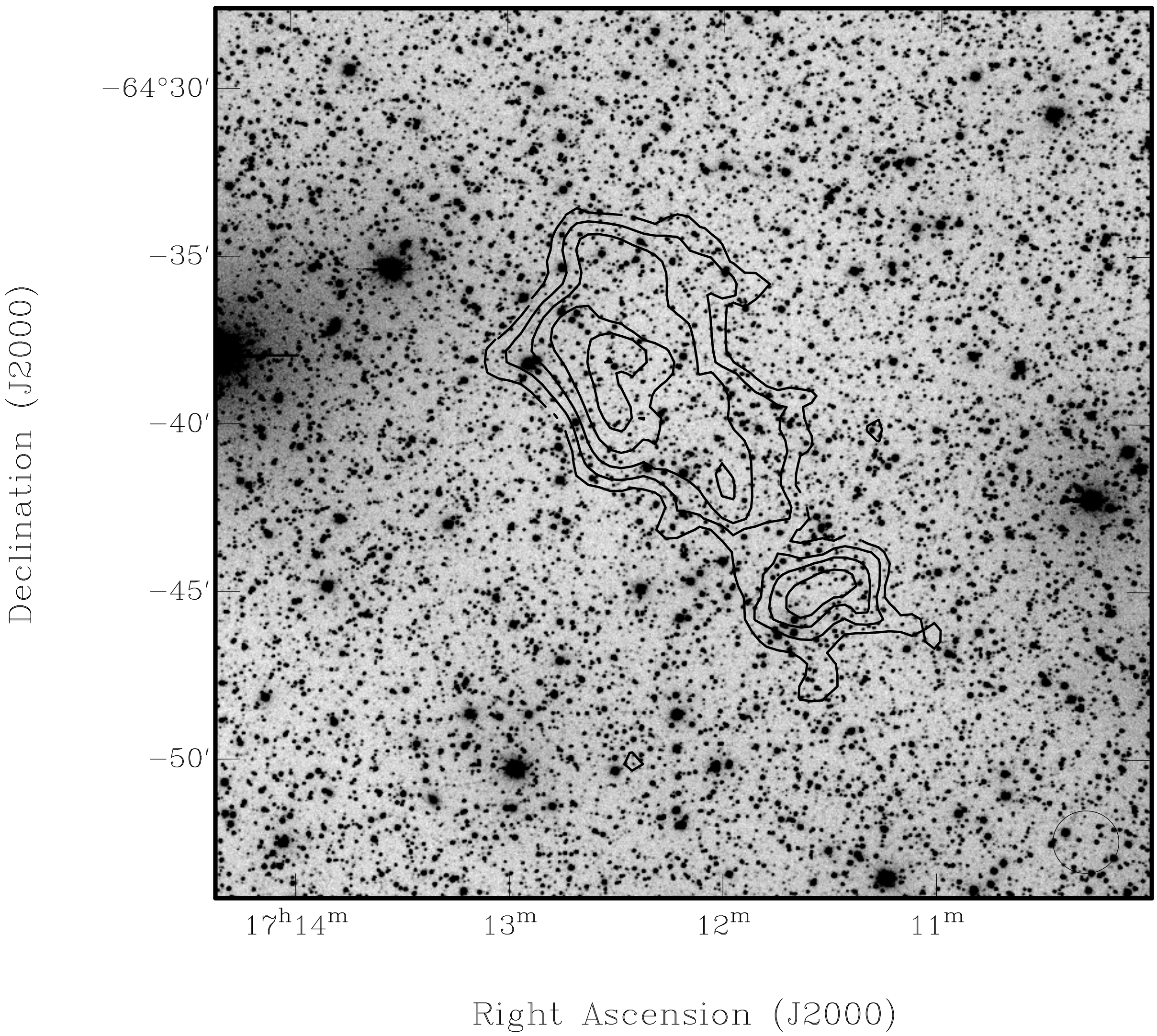

Fig. 5.— Combined B and R-band CCD optical images for HIPASS J1712-64, with Parkes+ATCA H I contours superimposed.

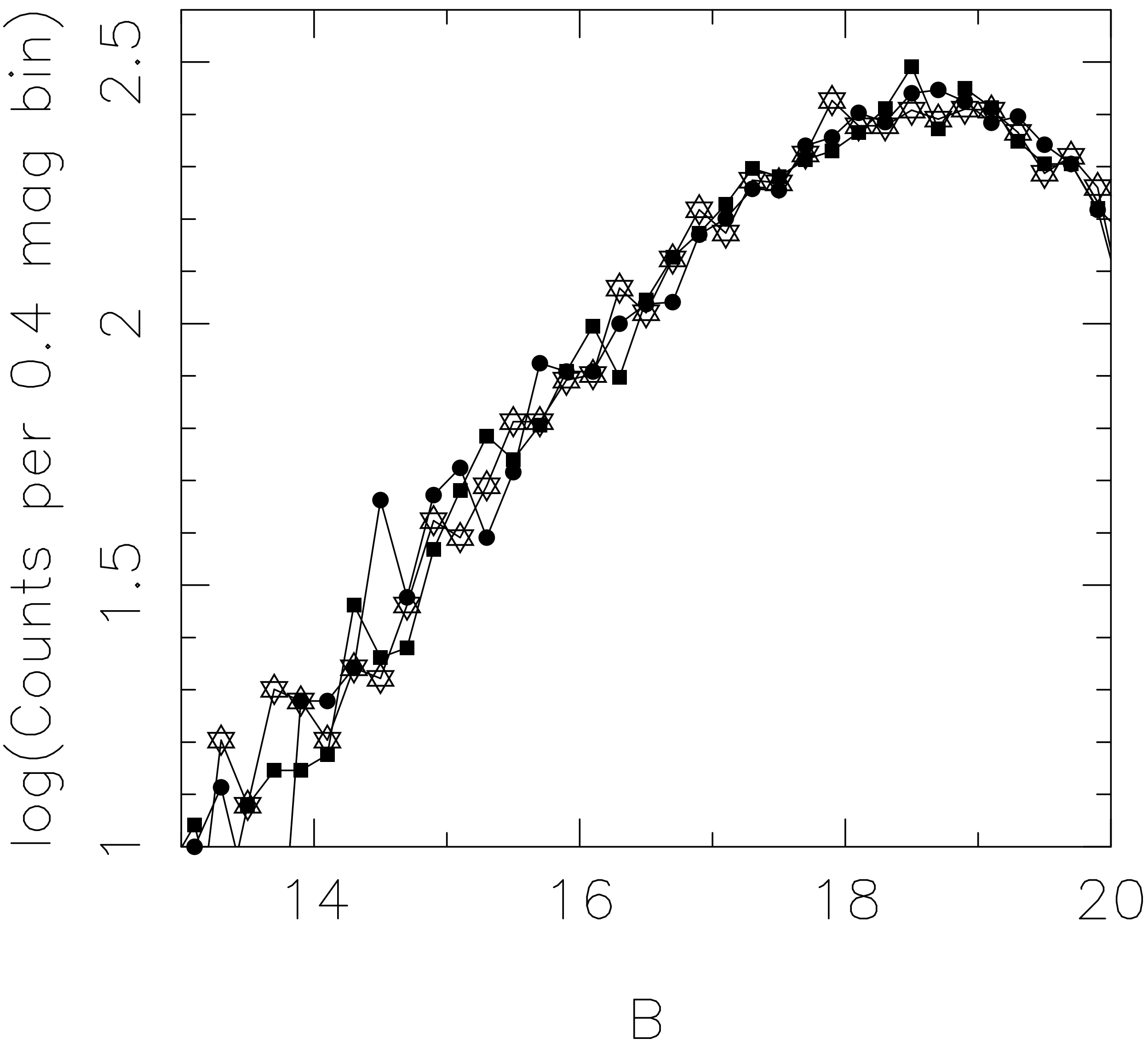

Fig. 6.— Number counts of stars in the central region of the B-band image, and two surrounding regions. The star symbols show star number counts the region where we would expect to see an excess of stars. No systematic excess is seen.

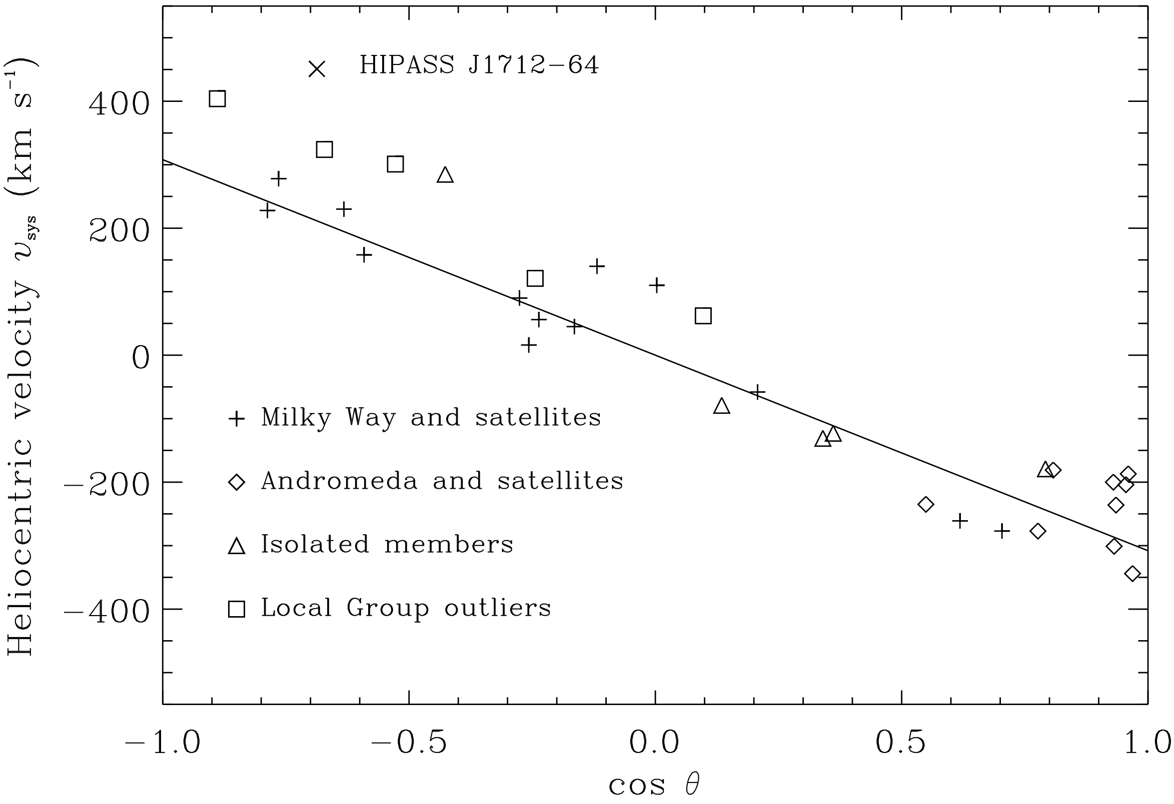

Fig. 7.— Velocities of Local Group members and outliers plotted against the cosine of the angle θ from the apex of solar motion relative to the Local Group barycenter (Yahil, Tammann & Sandage 1977). HIPASS J1712-64 has the highest heliocentric and Local Group velocity, placing it beyond the Local Group outliers, which are themselves only considered to be distant potential members (Grebel 1997).

Table 1. Measured H I Parameters for HIPASS J1712-64 and its components

	NE Component	SW Component	J1712-64
ATCA + Parkes			
RA (J2000)	$17^{\rm h}12^{\rm m}35^{\rm s}$	$17^{\rm h}11^{\rm m}35^{\rm s}$	
Dec (J2000)	$-64^\circ38'12''$	$-64^\circ45'11''$	
ℓ	$326\overset{\circ}{.}65$	$326\overset{\circ}{.}48$	
b	$-14\overset{\circ}{.}63$	$-14\overset{\circ}{.}61$	
Size	$11\overset{\prime}{.}4 \times 8\overset{\prime}{.}2$	$4\overset{\prime}{.}9 \times 4\overset{\prime}{.}1$	$15\overset{\prime}{.}9 \times 8\overset{\prime}{.}2$
PA	32°	125°	32°
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}
ATCA			
Heliocentric velocity, $v_{\rm sys}$	451 km s^{-1}	464 km s^{-1}	
50% velocity width, W_{50}	11 km s^{-1}	20 km s^{-1}	
Velocity dispersion, σ	4 km s^{-1}		

Table 2. Derived Parameters for HIPASS J1712-64 and its components

	NE Component	SW Component	J1712-64
Heliocentric velocity, $v_{\rm sys}$	451 km s^{-1}	464 km s^{-1}	
Dynamical LSR velocity, $v_{\rm lsr}$	449 km s^{-1}	462 km s^{-1}	
Galactocentric velocity,[a] $v_{\rm gsr}$	332 km s^{-1}	344 km s^{-1}	
Local Group velocity,[b] $v_{\rm LG}$	239 km s^{-1}	251 km s^{-1}	
Distance[c]	3.2 Mpc	3.2 Mpc	3.2 Mpc
Spatial size	11 kpc $\times$ 8 kpc	5 kpc $\times$ 4 kpc	15 kpc $\times$ 8 kpc
H I Mass, M_{HI}	1.1×10^7 $\mathcal{M}_\odot$	3×10^6 $\mathcal{M}_\odot$	1.7×10^7 $\mathcal{M}_\odot$
Dynamical mass,[d] M_T	$\sim 3 \times 10^7$ $\mathcal{M}_\odot$		$> 1.5 \times 10^8$ $\mathcal{M}_\odot$
Blue Luminosity, L_B			$< 7 \times 10^5 L_\odot$
M_{HI}/L_B			> 24 $\mathcal{M}_\odot/L_\odot$

[a] $v_{\rm gsr} = v_{\rm lsr} + 220 \sin \ell \cos b$.

[b] Using the formula of Yahil, Tammann & Sandage (1977).

[c] Assuming an identical distance for the NE and SW components and using $d = v_{\rm LG}/H_\circ$ with $H_\circ = 75$ km s^{-1} Mpc^{-1}.

[d] See text.