

Free–Floating HI Clouds in the M 81 Group

Elias Brinks¹, Fabian Walter² and Evan D. Skillman³

¹Centre for Astrophysics Research, University of Hertfordshire, College Lane,
Hatfield AL10 9AB, United Kingdom
email: E.Brinks@herts.ac.uk

²Max–Planck–Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
email: walter@mpia.de

³Dept. of Astronomy, Univ. of Minnesota, 116 Church St. SE, Minneapolis, MN 55455, USA
email: skillman@astro.umn.edu

Abstract. Recent VLA observations pointed at dwarf spheroidal (dSph) galaxies in the M 81 group reveal a hitherto hidden population of extremely low mass ($\sim 10^5 M_{\odot}$) HI clouds *with no obvious optical counterparts*. We have searched 10 fields in the M81 group totalling 2.2 square degree, both targeting known dwarf spheroidal galaxies and blank fields around the central triplet. Our observations show that the new population of low–mass HI clouds appears to be confined to a region toward the south–east of the central triplet (at distances of ~ 100 kpc from M 81). Possible explanations for these free–floating HI clouds are that they are related to the dSphs found to the South–East of M 81, that they belong to the galaxies of the M 81 triplet (equivalent to HVCs), that they are of primordial nature and provide fresh, unenriched material falling into the M 81 group, or that they are tidal debris from the 3–body interaction involving M 81–M 82–NGC 3077. Based on circumstantial evidence, we currently favour the latter explanation.

Keywords. galaxies: individual (M81), galaxies: interactions, intergalactic medium, radio lines: galaxies

1. Introduction

The nearby M 81 group has been the subject of several surveys in the 21–cm line of atomic hydrogen (HI). These surveys can be divided into two broad categories: targeted and blind. Appleton *et al.* (1981) using the 76–m Lowell telescope and later Yun *et al.* (1994; see also Yun *et al.* 2000) mapped the large–scale HI distribution in the group, tracing the complex tidal tails and bridges resulting from the 3–body interaction between M 81, M 82, and NGC 3077. Other targeted surveys, extending beyond the area covered by the triplet, have been those by Huchtmeier & Skillman (1998) and Huchtmeier *et al.* (2000) to determine the HI content of optically selected objects such as dwarf galaxies. Motivations for blind surveys have varied from i) searches for High Velocity Clouds (HVC) and Compact HVC analogues and ii) deep surveys to push down the HI luminosity function, to iii) searching for “Dark Galaxies”, i.e., dark matter haloes which have not as yet turned (part of) their gas content into stars. The first blind survey which included the M 81 group was that of Lo & Sargent (1979). Recently, Boyce *et al.* (2001) have repeated this at improved resolution and sensitivity as part of HIJASS, the HI Jodrell All–Sky Survey.

Boyce *et al.* (2001) detected four known dIrr galaxies close to M 81. They also detected an HI cloud apparently devoid of stars, HIJASS J1021+6842. If anything else, this shows that blind HI surveys can still surprise and reveal objects which have been overlooked in one of the best studied and most surveyed nearby groups. Walter *et al.* (2005) present

Table 1. Summary of targets for the VLA D-array observations

name	type	RA (2000.0)			DEC (2000.0)			m _B mag	detection
		h	m	s	°	'	"		
KDG 61	sph	09	57	03.1	+68	35	31	15.2	y
FM 1	sph	09	45	10.0	+68	45	54	17.5	n
BK 5 N	sph	10	04	41.1	+68	15	22	17.4	y
KDG 64	sph	10	07	01.9	+67	49	39	15.5	y
KK 77	sph	09	50	10.5	+67	30	24	16.3	n
HIJASS	?	10	21	00.0	+68	42	00	?	y
DDO 71	sph	10	05	06.4	+66	33	32	15.9	n
DDO 78	sph	10	26	27.4	+67	39	16	15.8	n
BK 6 N	sph	10	34	29.8	+66	00	30	16.9	n
KKH 57	sph	10	00	15.9	+63	11	06	17.9	y

VLA follow-up observations of HIJASS J1021+6842; Karachentsev & Kaisin (2007) report the possible detection of an optical counterpart in the form of faint H α emission which, if confirmed, would imply that although it would be one of the most extreme low surface brightness systems, HIJASS J1021+6842 wouldn't be a "Dark Galaxy".

In what follows we will report on a project which started out with the intention to study the HI content of previously catalogued dSph galaxies in the M81 group. Deep observations were proposed to detect HI *in* these systems and *outside* the optical bodies in order to derive how much gas is associated with the galaxies themselves and how much is found in their immediate neighbourhood. We were interested in the latter to set constraints on the mechanisms that might be at work to remove gas from low-mass dwarfs. In the course of the project, however, we detected HI well beyond several of our targets, prompting us to change from targeted observations to blind survey mode.

2. Observations and Results

The observations reported here were made with the NRAO† Very Large Array (VLA) over an extended period. Originally 9 dSph galaxies, plus HIJASS J1021+6842 were observed in VLA D-array in February 2003 (see Table 1). In addition to mapping the source detected by Boyce *et al.* (2001), HI was detected in the fields of BK5N, KKH 57, KDG 61, and KDG 64. Follow-up C-array observations were obtained on these targets in April 2004. The resulting HI surface brightness maps of the combined C plus D-array observations are shown in Fig. 1. The maps were made using natural weighting for best sensitivity. They have an angular resolution of 35'' which, at the assumed distance of the M81 group of 3.63 Mpc (Freedman *et al.* 2001), corresponds to 0.6 kpc. The rms noise is typically 0.6 mJy beam⁻¹ or 0.3 K at a velocity resolution of 5.2 km s⁻¹. These single channel noise levels can be used to calculate a column density detection threshold. Assuming a signal to be genuine if it is detected at the 3 σ level across 3 channels, we find a minimum detectable column density of 2.5×10^{19} cm⁻². Using the same criterion we arrive at a minimum detectable HI mass for an HI cloud filling the beam, at the distance of the M81 group, of $9 \times 10^4 M_{\odot}$.

The results of our observations can be summarised as follows:

KKH 57 We find a clear detection coinciding with the optical counterpart. The HI signal is only four channels wide at a systemic velocity of 203 km s⁻¹; spatially the HI

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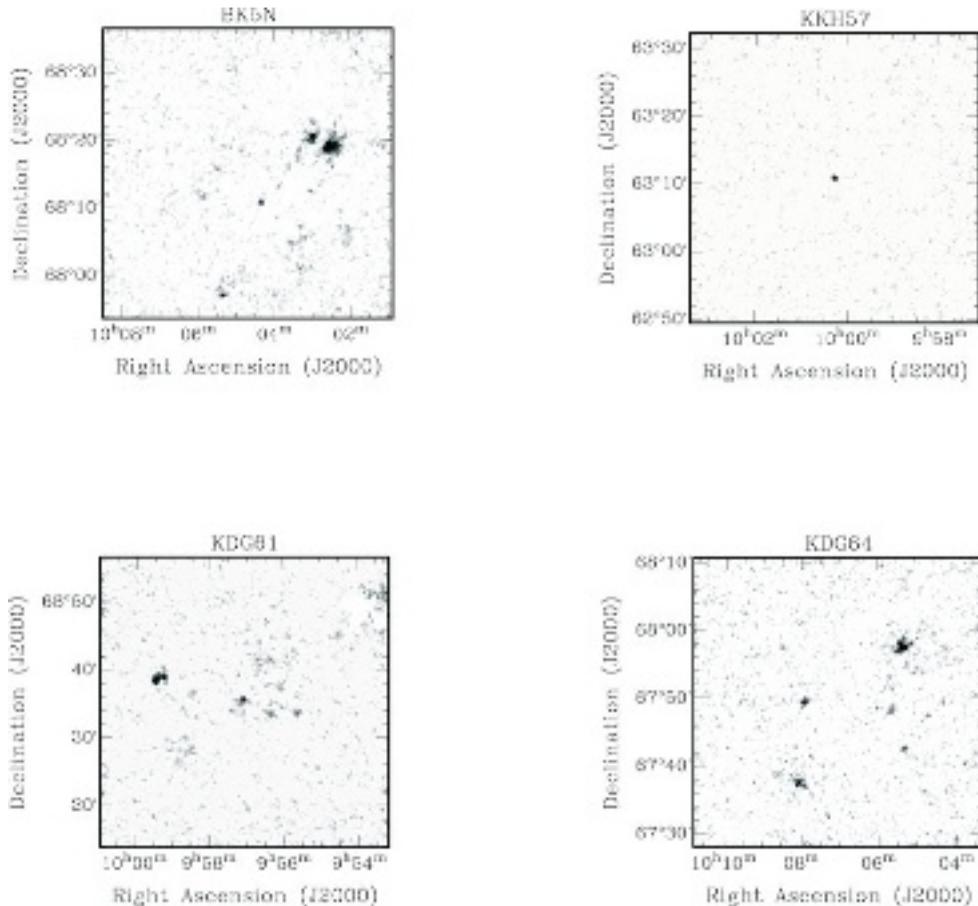


Figure 1. HI surface brightness maps of the four fields where HI emission was detected, BK5N, KKH 57, KDG 61, and KDG 64. KKH 57 is the only field where we detected HI associated with the target dSph; in the other three fields, free-floating HI is found whereas the target galaxies remain undetected down to a level of $9 \times 10^4 M_{\odot}$ (based on a 3σ detection threshold over 3 channels).

is unresolved. The low M_{HI}/L suggests this is a transition galaxy, i.e., an object which combines properties of a dSph, such as a low luminosity and prominent old stellar population, with those of a dIrr, e.g., the presence of HI (see Mateo 1998, for a more detailed treatise and Skillman *et al.* 2003, for examples). No other clouds are detected in this field.

KDG 61 Boyce *et al.* (2001) claim that this is a clear case of a transition galaxy. Their beam, however, is $12'$ large and they are limited by confusion due to HI coming from the triplet. KDG 61 lies close to M 81 and, even with our much higher resolution data, it is not trivial to separate emission from KDG 61 or other field objects from M 81 emission. We seem to find several HI clouds which are neither related to the SE tidal arm nor to KDG 61 itself, at velocities ranging from -45 to -15 km s^{-1} .

BK5N Several HI clouds are detected with velocities from -130 to -75 km s^{-1} , well offset from the optical counterpart (for which no optical radial velocity has been published).

KDG 64 = UGC 5442 The optical galaxy lies at $-18 \pm 14 \text{ km s}^{-1}$ (Simien & Prugniel 2002). We find HI emission offset in position and velocity, with HI detected at velocities

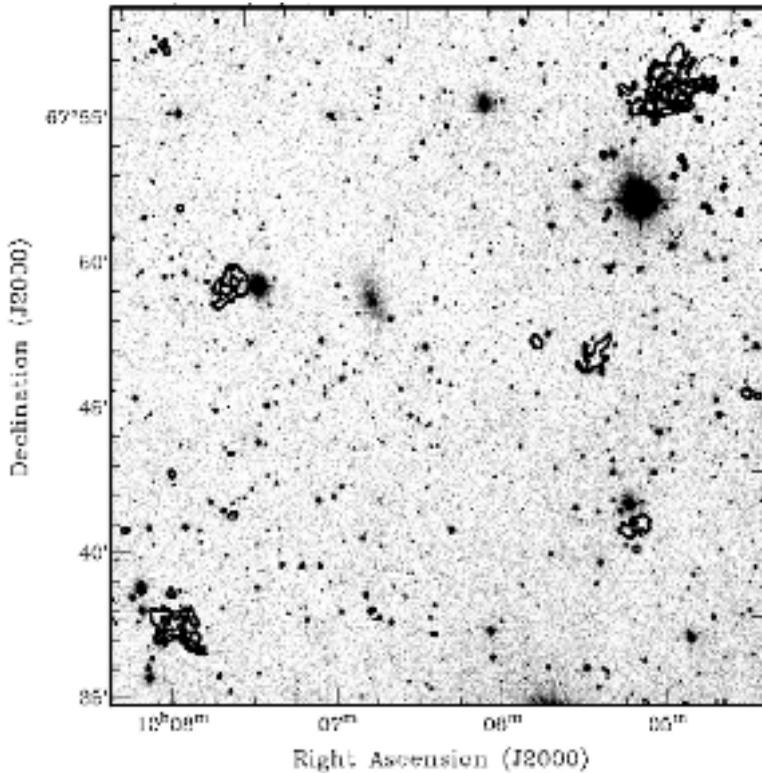


Figure 2. Optical image based on the *Digitized Sky Survey (DSS)* covering the field imaged in HI with the VLA centred on KDG 64. The contours indicate the locations of half a dozen free-floating HI clouds. Note that no HI is associated with KDG 64.

ranging from -120 to -70 km s^{-1} . This is illustrated in Fig. 2 which shows the location of the HI clouds with respect to the optical galaxy.

In summary, except for KKH 57, none of the dSph targets were detected, confirming that most of them are devoid of HI. However quite surprisingly, HI was detected in several of the fields centred on a number of our targets but not obviously associated with them, neither in position nor in velocity. This then, of course, begs the question if these clouds are somehow associated with the dSph galaxies, or if they are semi-randomly distributed within the M81 group. In order to investigate this, follow-up “blind” HI observations, of a further six fields were obtained with the VLA in D-configuration (observations taken in June, July, and August 2004). HI was found in only one of these fields, bordering BK5N and KDG 64 to the East.

In total, about a dozen barely resolved HI clouds were detected. They seem to predominantly occupy a region to the South-East of the triplet, extending as far away as ~ 100 kpc. Their radial velocities are in the range -130 to -70 km s^{-1} . Velocity dispersions are ~ 8 km s^{-1} . HI masses are of order $10^5 M_{\odot}$. Figure 2 shows a DSS image of the field mapped around KDG 64 with some of the HI clouds indicated with contours. No optical counterparts are visible on the DSS. The M81 group has been surveyed several times in the optical down to levels considerably fainter than the DSS. In fact, it is one of the best studied nearby groups (e.g., Froebrich & Meusinger, 2000). We can therefore be confident that these objects have very little starlight associated with them.

3. Discussion

So what are they and what is their origin? There are several possibilities. They could be:

- (a) primordial material which is infalling towards the M81 triplet;
- (b) High Velocity Cloud (HVC) analogues belonging to M81;
- (c) material originally part of BK5N and KDG 64 which has been expelled;
- (d) or tidal debris scattered into the SE quadrant.

Taking each of these possibilities in turn, the first explanation, infall of primordial material, is rather *ad hoc*. Without a determination of the metallicity of the gas in these HI clouds, it will be difficult to rule out this hypothesis. However, if primordial material were still to be around at column and space densities found here, it should have been detected in other nearby groups as well. No similar objects have been seen in deep HI observations, reaching comparable HI detection limits (Pisano *et al.* 2004, 2007).

If they represent analogues to HVCs, one would expect their velocity centroid to coincide with that of their host galaxy, M81. Also, their distribution would be expected to be more isotropic rather than that found here. No clouds were found in any of the other targeted observations nor in the blind pointings which together covered areas in and around the triplet. The third option, that they represent material that has been expelled from BK5N and KDG 64 is also hard to defend. Not only do the clouds seem uncorrelated spatially with both dwarfs, but in the one case where we have velocity information for the dwarf, the velocities of the clouds are offset substantially.

This leaves us with the last option, the clouds being tidal debris. Inspection of the HI observations by Appleton *et al.* (1981) shows that the HI clouds fall along the extension of their “feature VII”, but beyond the area covered by either their survey or the VLA mosaic by Yun *et al.* (1994). Feature VII is prominent in the velocity range from -130 to -100 km s^{-1} , in broad agreement with the clouds found near BK5N and KDG 64. The VLA map by Yun *et al.* resolves feature VII, showing seemingly a spur branching off from the tidal bridge connecting NGC 3077 with M81, which points roughly in the direction of the dwarf spheroidals. This is illustrated in Fig. 3 which shows Yun’s HI surface brightness map as contours overlaid on an optical image. The numerical simulation published by Yun (1997) shows material from M81 being dragged out by the passage of NGC 3077 and spread out towards the South–East. It therefore seems likely that the HI clouds found there are, in fact, tidal debris. They could be the neutral density peaks of a more dilute sheet of gas which is mostly ionised by the extragalactic radiation field, as a result of the column density being in general close to the value below which HI will become fully ionised. Peak column densities fall well below the canonical $\sim 10^{21} \text{ cm}^{-2}$ threshold for star formation, explaining the lack of an optical counterpart.

4. Conclusions

In a search for HI in and around the lowest–mass dwarf spheroidal (dSph) galaxies in the M81 group, we have discovered an unexpected population of HI clouds with masses of order $10^5 M_{\odot}$. Our observations of HIJASS J1021+6842 which were taken during the same observing runs were published separately (Walter *et al.* 2005). So far, about a dozen clouds have been detected within a region to the South–East of the triplet (in the vicinity of the dSphs KDG 64 and BK5N); there were no detections toward regions around other dSph galaxies in the same group and in five more “blind” pointings.

From a technical perspective, our observations go much deeper than any previous blind surveys done with single dish telescopes in the M81 group (Lo & Sargent 1979;

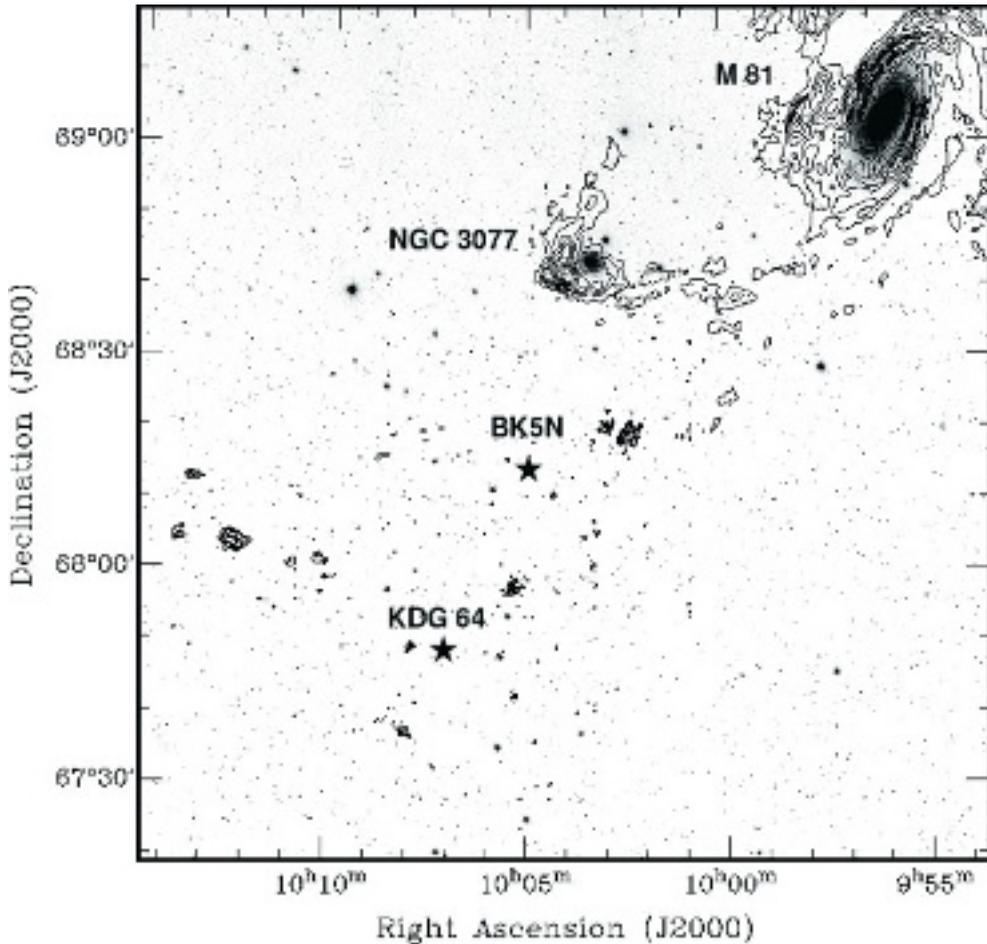


Figure 3. Optical image taken from the DSS of a $2^{\circ} \times 2^{\circ}$ field to the South-East of M81. Overlaid are contours of the HI distribution as measured by Yun *et al.* (1994), showing the tidal tail connecting M81 with NGC 3077, and a “spur” pointing to the South-East. In addition we plot as contours the HI clouds detected in the VLA observations reported here that are seen in the direction of BK5N and KDG 64, plus the HI clouds encountered in VLA D-array observations in one of the “blind” pointings located due East of the two dwarf galaxies. The approximate locations of BK5N and KDG 64 are indicated with stars.

Boyce *et al.* 2001). The barely resolved clouds detected with the $35''$ VLA beam fall below the detection limit of single dish telescopes as a result of beam dilution. Our VLA data are also more sensitive by an order of magnitude than similar such surveys done in the Centaurus and Sculptor groups with the ATCA (de Blok *et al.* 2002; see also the discussion of the null result with Arecibo by Zwaan & Briggs 2000).

The HI clouds detected here don't seem to have any optical counterparts. Circumstantial evidence argues in favour of these clouds being debris from the tidal interaction of the galaxies making up the M81 triplet, notably the passage of NGC 3077 sweeping in a prograde fashion around the South of M81. In order to better understand these enigmatic clouds further observations (extending the area around BK5N and KDG 64 covered thus far) are being analysed.

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