

A BLIND H I SURVEY OF THE M81 GROUP

P. J. BOYCE,¹ R. F. MINCHIN,² V. A. KILBORN,³ M. J. DISNEY,² R. H. LANG,² C. A. JORDAN,³
 M. GROSSI,² A. G. LYNE,³ R. J. COHEN,³ I. M. MORISON,³ AND S. PHILLIPPS¹

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ABSTRACT

Results are presented of the first blind H I survey of the M81 Group of galaxies. The data were taken as part of the H I Jodrell All-Sky Survey (HIJASS). The survey reveals several new aspects to the complex morphology of the H I distribution in the group. All four of the known dwarf irregular (dIrr) galaxies close to M81 can be unambiguously seen in the HIJASS data. Each forms part of the complex tidal structure in the area. We suggest that at least three of these galaxies may have formed recently from the tidal debris in which they are embedded. The structure connecting M81 to NGC 2976 is revealed as a single tidal bridge of mass $\approx 2.1 \times 10^8 M_\odot$ and projected spatial extent ≈ 80 kpc. Two “spurs” of H I projecting from the M81 complex to lower declinations are traced over a considerably larger spatial and velocity extent than by previous surveys. The dwarf elliptical (dE) galaxies BK5N and Kar 64 lie at the spatial extremity of one of these features and appear to be associated with it. We suggest that these may be the remnants of dIrr’s that have been stripped of gas and transmuted into dE’s by close gravitational encounters with NGC 3077. The nucleated dE galaxy Kar 61 is unambiguously detected in H I for the first time and has an H I mass of $\sim 10^8 M_\odot$, further confirming it as a dE/dIrr transitional object. HIJASS has revealed one new possible group member, HIJASS J1021+6842. This object contains $\approx 2 \times 10^7 M_\odot$ of H I and lies $\approx 105'$ from IC 2574. It has no optical counterpart on the Digital Sky Survey.

Subject headings: galaxies: clusters: individual (M81) — galaxies: dwarf — galaxies: evolution — galaxies: interactions — surveys

1. INTRODUCTION

The M81 Group of galaxies is one of the nearest groups to our own. Hence, a detailed study of the group may have an impact on many key areas of astronomy, such as structure formation, galaxy evolution, star formation, and dark matter. The present catalog of group members is the result of several optical surveys (e.g., Karachentseva, Karachentsev, & Borngen 1985; Karachentseva & Karachentsev 1998; Karachentsev, Karachentsev, & Huchtmeier 2001). The group contains one large spiral galaxy (M81), two peculiar galaxies (M82 and NGC 3077), two small spiral galaxies (NGC 2976 and IC 2574), and a large number of dwarfs. The core galaxies of the group are strongly interacting: there is a large, dynamically complex H I cloud embedding M81, M82, NGC 3077, and NGC 2976 (Appleton, Davies, & Stephenson 1981; Yun, Ho, & Lo 1994).

Several pointed H I surveys have been undertaken to search for H I in M81 Group candidate dwarf galaxies (Huchtmeier & Skillman 1998; van Driel et al. 1998; Huchtmeier et al. 2000). There are about 23 dwarf members or candidate members (12 dIrr’s, nine dE’s, two blue compact dwarfs [BCDs]). H I has been unambiguously detected from nine of the dIrr’s and from one BCD. Measured velocities for M81 Group objects lie in the range from -140 to 350 km s^{-1} . Dwarf galaxies are difficult to detect unambiguously in H I within the H I complex around M81. Elsewhere, H I from group members may be masked by the strong Galactic H I emission.

In this Letter, we present results from the first blind H I survey of the M81 Group. The data for this were taken as part of the H I Jodrell All-Sky Survey (HIJASS), which is described in

§ 2. In § 3, we present the observational results for the M81 Group of galaxies. In § 4, we discuss the results and present our conclusions. A distance to the M81 Group of $D = 3.63 \text{ Mpc}$ (Freedman et al. 1994) is assumed throughout this Letter.

2. OBSERVATIONS AND DATA REDUCTION

HIJASS is the northern counterpart to the H I Parkes All-Sky Survey (HIPASS; Staveley-Smith et al. 1996) that, when complete, will have surveyed the whole sky up to $\delta = 25^\circ$. HIJASS will survey the northern sky above this declination to similar sensitivity. HIJASS is being undertaken using the Multibeam 4 beam receiver mounted on the 76 m Lovell telescope (beam FWHM $\approx 12.0'$) at Jodrell Bank. A 64 MHz bandpass with 1024 channels is used, although local interference restricts the useful velocity range to about -1000 to $10,000 \text{ km s}^{-1}$. The survey is conducted by scanning the receiver in declination strips of $\approx 8^\circ$. Each declination strip is separated by $10'$, but each area of sky is scanned 8 times, resulting in a final scan separation of $1.25'$. Bandpass correction and calibration are applied using the same software as HIPASS (Barnes et al. 2001). The spectra are gridded into three-dimensional $8^\circ \times 8^\circ$ data cubes (α, δ, V_\odot) that have an rms noise level of $\approx 16 \text{ mJy beam}^{-1}$. The FWHM velocity resolution is 18.0 km s^{-1} , and the spatial pixel size is $4' \times 4'$.

To survey the M81 Group, we searched the HIJASS data between $V_\odot = \pm 500 \text{ km s}^{-1}$ in the regions $8^h < \alpha < 11^h$, $70^\circ < \delta < 78^\circ$ and $9^h 03^m < \alpha < 10^h 36^m$, $62^\circ < \delta < 70^\circ$. This area ($\approx 180 \text{ deg}^2$) includes the whole of the H I complex around M81 and most of the outer area of the group. The HIJASS data were Hanning-smoothed by three channels. This reduces the velocity resolution to 26 km s^{-1} but improves the rms noise to $\approx 11 \text{ mJy beam}^{-1}$. The relatively high spatial resolution and full spatial sampling of HIJASS make it more effective at revealing dwarf galaxies within the H I complex around M81 than previous pointed surveys. HIJASS is more sensitive to low column density gas than aperture synthesis surveys.

¹ Astrophysics Group, Department of Physics, University of Bristol, Tyndall Avenue, Bristol, BS8 1TL, England, UK; peter.boyce@bristol.ac.uk.

² Department of Physics and Astronomy, University of Wales, Cardiff, 5 The Parade, Cardiff, Glamorgan, CF24 3YB, Wales, UK.

³ University of Manchester, Jodrell Bank Observatory, Lower Withington, Macclesfield, Cheshire, SK11 9DL, England, UK.

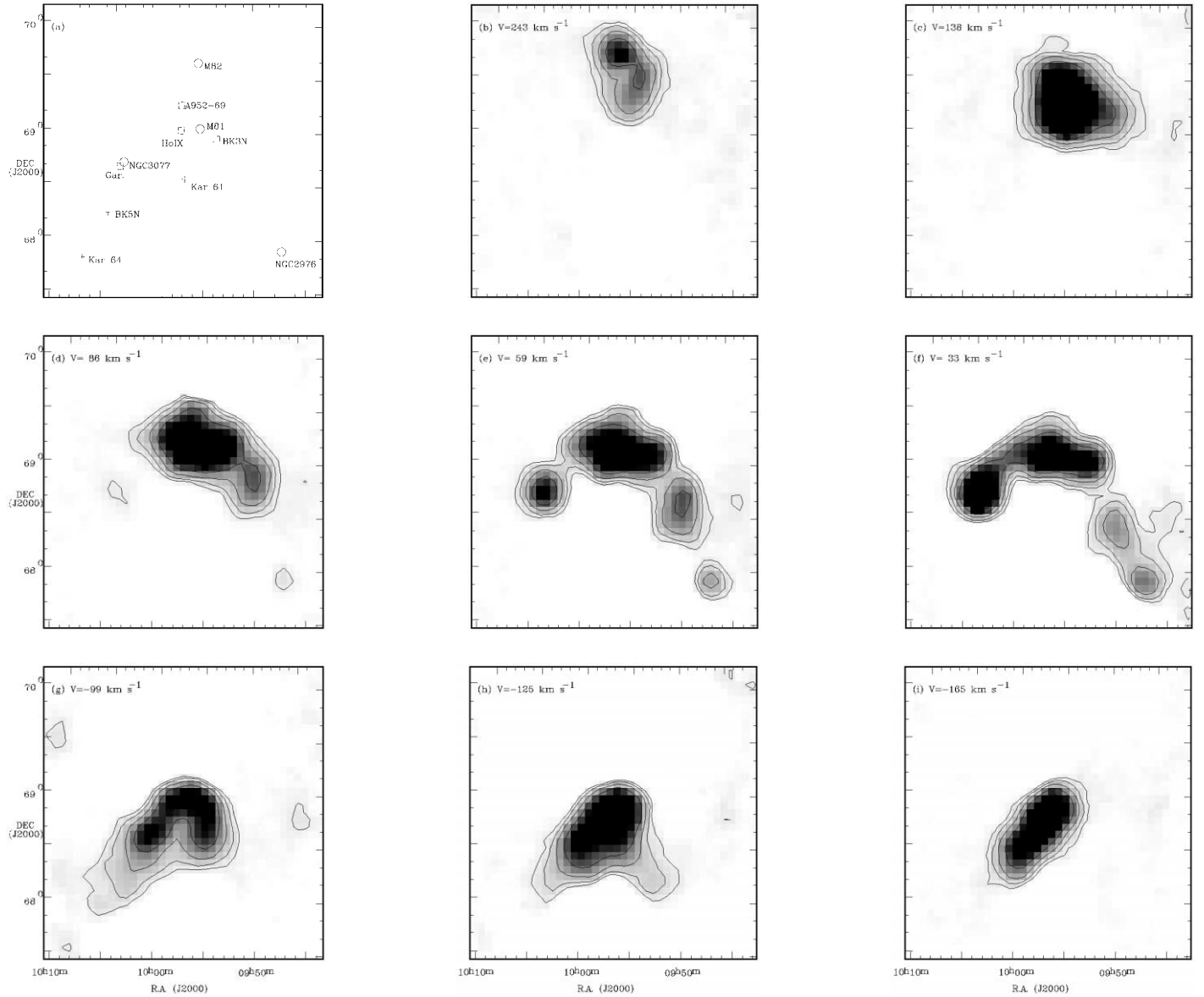


FIG. 1.—Right ascension–declination plots at selected velocity channels from Hanning-smoothed HIJASS data of the area around the M81 H I complex. The contours are set at 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, and 3.2 mJy beam⁻¹. (a) Positions of known galaxies in area (circles denote giant galaxies, squares show dIrr's, crosses show dE's), (b) $V_{\odot} = 243$, (c) 138, (d) 86, (e) 59, (f) 33, (g) -99, (h) -125, and (i) -165 km s⁻¹.

3. RESULTS

Figure 1 is a set of right ascension–declination plots of the H I emission from the H I complex around M81 at eight selected velocities. Figure 2 is a set of velocity–declination plots at four selected right ascensions.

The tidal bridge of gas between M81 and M82 (see, e.g., Appleton et al. 1981 and Yun et al. 1994) can be clearly seen in the HIJASS data, for example, in Figure 1b at $\alpha \approx 9^{\text{h}}54^{\text{m}}$, $\delta \approx 69^{\circ}30'$ at $V_{\odot} = 243$ km s⁻¹ and in Figure 2c stretching from $\delta \approx 69^{\circ}45'$, $V_{\odot} \approx 250$ km s⁻¹ to $\delta \approx 69^{\circ}00'$, $V_{\odot} \approx 0$ km s⁻¹. Within Figure 2c can also be clearly seen the dIrr galaxies Holmberg IX (at $\delta \approx 69^{\circ}03'$, $V_{\odot} \approx 50$ km s⁻¹) and A952+69 (at $\delta \approx 69^{\circ}15'$, $V_{\odot} \approx 100$ km s⁻¹). A952+69 has not been unambiguously discerned in single-dish surveys (see van Driel et al. 1998), although both objects are seen in the VLA data of Yun et al. (1994), who labeled them “concentration I” (Holmberg IX) and “concentration II” (A952+69). The HIJASS data (Fig. 2c) show them to form part of the tidal bridge between M81 and

M82. We suggest that both galaxies may have recently condensed from the tidal debris between M81 and M82. Morphologically, such “tidal dwarf galaxies” are very similar to classical dIrr's (Weilbacher et al. 2000).

A bridge of gas apparently connecting NGC 3077 and M81 can be clearly seen at $\alpha \approx 10^{\text{h}}00^{\text{m}}$, $\delta \approx 68^{\circ}50'$, $V_{\odot} = 33$ km s⁻¹ (Fig. 1f). Yun et al. (1994) dubbed this the “north tidal bridge” and considered it to result from a tidal interaction between M82 and NGC 3077. The gas around NGC 3077 is actually centered a few arcminutes west of the galaxy and is ≈ 55 km s⁻¹ higher in velocity. The dIrr galaxy Garland lies approximately at the center of the gas. Van Driel et al. (1998) suggested that Garland may be at an intermediate stage in the conversion of a tidal tail into a dwarf galaxy.

Figure 1 reveals a bridge of gas stretching from M81 at $\alpha \approx 09^{\text{h}}52^{\text{m}}$, $\delta \approx 69^{\circ}00'$, $V_{\odot} = 138$ km s⁻¹ (Fig. 1c) to NGC 2976 at $\alpha \approx 9^{\text{h}}48^{\text{m}}$, $\delta \approx 67^{\circ}50'$, $V_{\odot} = 33$ km s⁻¹ (Fig. 1f). Appleton et al. (1981) considered this to consist of three linked

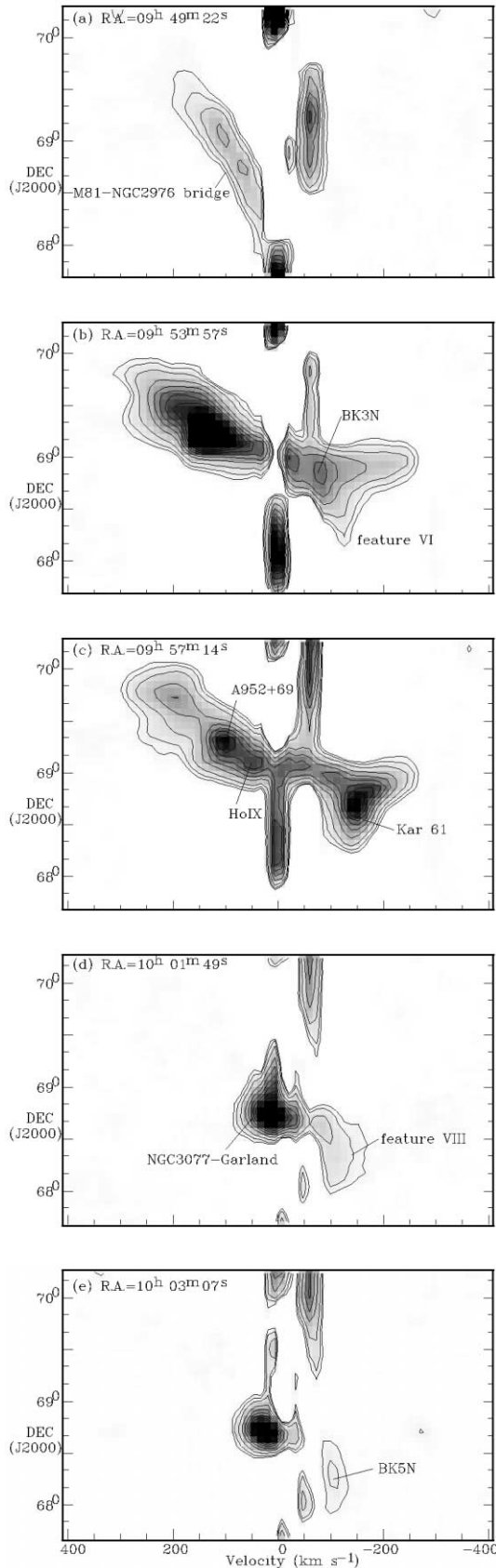


FIG. 2.—Velocity-declination plots at selected right ascensions from Hanning-smoothed HIJASS data of the area around the M81 H I complex. The contours are set at 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6 mJy beam⁻¹. (a) R.A. = 09^h49^m22^s, (b) 09^h53^m57^s, (c) 09^h57^m14^s, (d) 10^h01^m49^s, and (e) 10^h03^m07^s.

features. However, the HIJASS data show that it forms a single tidal bridge between the galaxies (see Fig. 2a at R.A. = 09^h49^m22^s). The bridge has an H I mass of $\approx 2.1 \times 10^8 M_\odot$ and a projected spatial extent of ≈ 80 kpc.

The spur of H I emission labeled “feature VIII” by Appleton et al. (1981) can be traced over a much larger spatial and velocity range in the HIJASS data. Its full spatial extent can be seen in Figure 1g ($V_\odot \approx -99$ km s⁻¹), where it extends from close to NGC 3077 out to $\alpha \approx 10^h05^m$, $\delta \approx 67^\circ45'$, a projected spatial size of ≈ 75 kpc. The spur has an H I mass of $\approx 3.1 \times 10^8 M_\odot$. The spur is strikingly seen in Figure 2d (at R.A. = 10^h01^m49^s), stretching from $\delta \approx 68^\circ35'$, $V_\odot \approx 0$ km s⁻¹ to $\delta \approx 67^\circ50'$, $V_\odot \approx -100$ km s⁻¹. The apparent association of the high-declination end of the spur with NGC 3077–Garland is clear from this. The lower declination part of the spur continues to be seen in Figure 2e (at R.A. = 10^h03^m07^s). The peak in the emission at $\delta \approx 68^\circ15'$, $V_\odot \approx -100$ km s⁻¹ occurs at the optical position of the dE galaxy BK5N. There is the suggestion of a second peak in the H I emission at $\delta \approx 67^\circ54'$, $V_\odot \approx -100$ km s⁻¹. This peak can be seen out to R.A. $\approx 10^h05^m$, very close to the optical position of the nucleated dE galaxy Kar 64. We suggest that the spur may result from tidal interaction between NGC 3077 and BK5N and/or between NGC 3077 and Kar 64.

Kar 61, the closest dE to M81 itself, can be strikingly seen in Figure 2c (at R.A. = 09^h57^m14^s) at $\delta \approx 68^\circ40'$, $V_\odot \approx -140$ km s⁻¹. While previous H I maps had shown emission at the position of this galaxy, it had not been clear whether this emission resulted from Kar 61 or from M81 (see van Driel et al. 1998). Johnson et al. (1997) found a bright H II region knot situated northeast of the galaxy center from which they measured a radial velocity of -135 ± 30 km s⁻¹. The correspondence of this velocity with that of the H I peak confirms that the H I is associated with this object. We estimate that $\sim 10^8 M_\odot$ of H I is associated with Kar 61. On the basis of *Hubble Space Telescope* imaging, Karachentsev et al. (2000) suggested that Kar 61 may be a dE/dIrr transition type. The presence of a large amount of H I supports this idea.

The spur of H I emission labeled “feature VI” by Appleton et al. (1981) is traced over a larger spatial and velocity extent in the HIJASS data. It can be clearly seen in Figure 1h at $\alpha \approx 9^h51^m$, $\delta \approx 68^\circ0'$ at $V_\odot \approx -125$ km s⁻¹ (Fig. 1h) and in Figure 2b (at R.A. = 09^h53^m57^s) stretching out to $\delta \approx 68^\circ15'$, $V_\odot \approx -125$ km s⁻¹. This spur has a projected spatial extent of ≈ 50 kpc and an H I mass of $\approx 6.5 \times 10^7 M_\odot$. The dIrr galaxy BK3N appears to lie at end of this spur closest to M81. This object is best seen in Figure 2b at $\delta \approx 68^\circ50'$, $V_\odot \approx -60$ km s⁻¹. This is the first unambiguous H I detection of this object; previous surveys were unable to disentangle its emission from that of M81 (see van Driel et al. 1998). We estimate that $\approx 1.8 \times 10^7 M_\odot$ of H I is associated with the galaxy. BK3N’s position at the top of the H I spur suggests that it may be a “tidal dwarf galaxy,” condensing from the tidal debris of the spur. Alternatively, BK3N may be a preexisting dIrr galaxy undergoing an interaction with M81.

An additional five optically identified dIrr group members (Holmberg II, Kar 52, UGC 4483, Holmberg I, and Kar 73) are within our survey area, but they are outside the M81 H I complex. All of these had been previously detected in H I. The HIJASS confirms these detections. The BCD galaxy UGC 5423, which had also been previously detected in H I, is also detected by HIJASS. The other BCD (DDO 82) in our survey area is not detected by HIJASS. We do not detect any of the dE galaxies that lie within our survey area but outside the M81

H I complex (i.e., Kar 74, DDO 71, BK6N, F8D1, KK77, FM1, and KKH 57).

An extensive search of the HIJASS data for previously unidentified M81 Group members revealed only one strong candidate, HIJASS J1021+6842. Figure 3 is a right ascension–declination plot at $V_{\odot} = 46 \text{ km s}^{-1}$ showing this object. It lies $\approx 105'$ from IC 2574 (with a projected separation of $\approx 112 \text{ kpc}$), and there is marginal evidence for a connection to this galaxy. Its FWHM velocity is $\approx 50 \text{ km s}^{-1}$, and its H I mass is $\approx 3 \times 10^7 M_{\odot}$, if it is a member of the M81 Group. No optical counterpart can be seen on the second-generation red Digital Sky Survey. It may be a very low surface brightness dIrr companion to IC 2574. We may be seeing the last remnants of a tidal encounter between IC 2574 and one of the galaxies around M81.

4. DISCUSSION AND CONCLUSIONS

The M81 Group shows a clear morphology–density relation: dE’s are found in and around the dense core close to M81, while dIrr’s are spread over a much larger area. Dwarf galaxies in the Local Group exhibit a similar relation (Greber 2001). *N*-body simulations (Mayer et al. 2001) suggest that a close tidal interaction of a dIrr galaxy with a giant galaxy can induce severe mass-loss and nonaxisymmetric instabilities in the disk of the dIrr galaxy, turning it into an object that matches the observed properties of a dE galaxy. The implication is that dIrr’s close to the Milky Way or M31 have been transformed in this way into the dE’s now observed. Those dIrr’s further away from the giants have not yet undergone a close tidal encounter and remain recognizable as dIrr’s. The HIJASS data provide some evidence that a similar scenario may explain the morphological segregation of the dwarf galaxies in the M81 Group.

The dE’s BK5N and Kar 64 appear to be associated with a tidal spur of H I mass $\approx 3.1 \times 10^8 M_{\odot}$, stretching from NGC 3077 out a projected distance of $\approx 75 \text{ kpc}$. We suggest that BK5N and Kar 64 may be former dIrr’s that have been stripped of their gas by tidal encounters with NGC 3077.

Kar 61, the only dE galaxy closer to M81 than BK5N, has $\sim 10^8 M_{\odot}$ of H I associated with it, shows signs of recent star formation, and has been described as a dE/dIrr transition object. We suggest that Kar 61 is involved in a tidal interaction with M81 but is at a much earlier stage of tidal stripping than BK5N or Kar 64. We did not detect any of the dE’s that lie further

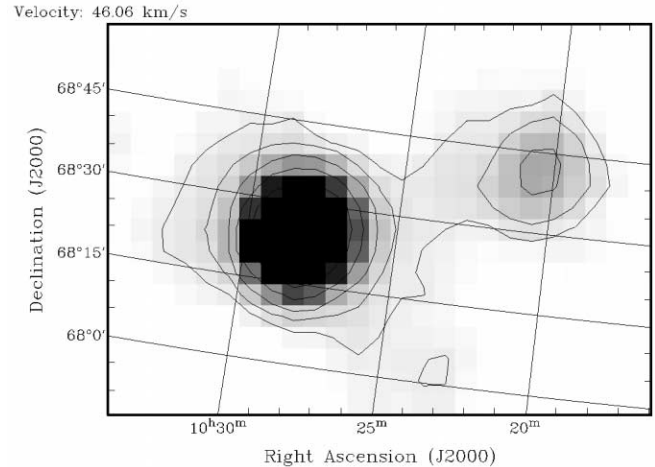


FIG. 3.—Right ascension–declination plot at $V_{\odot} = 46 \text{ km s}^{-1}$ showing the H I associated with IC 2574 (left) and the newly discovered object HIJASS J1021+6840. The contours are set at 0.05, 0.1, 0.2, 0.4, 0.8, 1.6, and $3.2 \text{ mJy beam}^{-1}$.

from M81 than Kar 61, BK5N, and Kar 64. These dE’s may already have had all of their H I stripped by previous tidal encounters.

How have the four known dIrr’s within the M81 H I complex survived if other dIrr’s have been tidally stripped and transmuted into dE’s? At least three of these (Holmberg IX, A952+69, and Garland) may actually be tidal dwarf galaxies. The fourth, BK3N, may also be a tidal dwarf galaxy, or it may be a dIrr currently being tidally stripped. The newly discovered object HIJASS J1021+6842 may be a further example of a tidal dwarf galaxy in formation, in this case one in which star formation has not yet begun.

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