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INTERGALACTIC STELLAR DISTRIBUTIONS IN THE INTERACTING M81/M82 GALAXY GROUP

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ABSTRACT

Previous H I observations of the M81/M82/NGC 3077 galaxy group clearly show a widespread H I distribution within this galaxy group. While the gas is vulnerable to tidal disruption from a galaxy encounter, are there also stars embedded in this H I distribution? Our deep, 1 deg^2 exposures of the M81/M82 group in 10 optical bands using the Beijing-Arizona-Taipei-Connecticut (BATC) filter set clearly reveal widespread stellar distributions that coincide with the atomic hydrogen clouds—considered to be the relics of the merging process of the galaxies—splayed over the region. The spectral energy distributions of the stellar groups to the east and west of M81 (including the "Arp Loop") are similar to that measured at the southeast edge of the optical disk of M82. This similarity in stellar radiation, combined with the observed peculiar rotational velocity of M82, suggests that the diffuse stellar population in the intergalactic space around M81 is possibly a relic of the tidally disrupted disk of M82 during the last close encounter. Alternately, the stars could have formed in situ in the H I as it was drawn out of the galaxies. Recent measurements of distances to and radial velocities of M81 (3.63 Mpc and 48 km s^{-1}, respectively) and M82 (3.9 Mpc and 296 km s^{-1}) lend further support to the notion of a close passage between these two galaxies several hundred million years ago.

Subject headings: galaxies: individual (M81, M82) — intergalactic medium

Online material: color figure

1. INTRODUCTION

The presence of widespread H I distributed within the M81/M82/NGC 3077 group has been known for nearly 30 years (Cottrell 1977; van der Hulst 1979; Appleton et al. 1981). At least 25% of the H I in this group lies between the galaxies (Appleton et al. 1981). Recent high angular resolution Very Large Array (VLA) observations of H I in this group have been made by Yun et al. (1994). The intergalactic H I gas is thought to be matter from a close tidal encounter among the galaxies in this group. The encounter has been estimated to have taken place some 200–300 Myr ago, on the basis of the radio observations of an H I tail in NGC 3077 pointing toward M81 (Cottrell 1977).

Previous optical observations revealed stellar concentrations suspected to be dwarf galaxies, including Holmberg IX, Arp Loop, and BK3N (Makarova et al. 2002), at or near the H I peaks around the member galaxies. These observations include those of Bremnes et al. (1998), who imaged individual dwarf galaxies within the M81 field with small fields of view, and those of Karachentsev et al. (2002), who used the *Hubble Space Telescope* (*HST*) to find that part of the Arp Loop near M81 resolved into stars. Generally, the intergalactic material is thought to be predominantly H I in nature, forming a common hydrogen envelope in which the member galaxies are embedded (Yun et al. 1994). However, very few continuum observations have been made of the entire field of this galaxy group at optical wavelengths. A handful of early images with photographic plates have suggested very faint continuum emission, indicative of a stellar component associated with the H I gas (Getov & Georgiev 1988; Efremov et al. 1986). Owing to the very low surface brightness (27 mag arcsec^{-2} in *B*) of the diffuse emission between M81 and M82, the existence of widespread stellar continuum radiation in the M81 group system has never been fully explored. Even the most recent observations of a new H I cloud in the M81 group led to no identification of any optical counterparts (Walter et al. 2005).

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2. OBSERVATION AND DATA REDUCTION

We have obtained deep exposures of a major fraction of the M81 group using the multicolor wide-field Beijing-Arizona-Taipei-Connecticut (BATC) survey system (Fan et al. 1996; Zhou et al. 2001). The BATC observing system employs a 15 intermediate-band filter system across the whole optical spectrum accessible from the ground with filter bandwidths ranging from 25 to 35 nm and avoids the strong night-sky emission lines (Yan et al. 2000). The field of view of the Xinglong Observatory, China, 60/90 cm f/3 Schmidt telescope is $58' \times 58'$. Our observations include all of M82, almost all of M81, and half of the "north tidal bridge" (Yun et al. 1994) from NGC 3077 toward M82, but not NGC 3077 itself.

Our observations cover a wavelength range of 455–848 nm using the 10 reddest of our filters, with a total exposure time of 71 hr from 1995 to 2002. The CCD images are centered at R.A. = $09^h55^m35^s.25$, decl. = $69°21'50''.9$ (J2000). The dome flat-field images were taken by using a diffuser plate in front of the correcting plate of the Schmidt telescope. This provides satisfactory flat fields for our use (Zhou et al. 2004). For flux calibration, the Oke-Gunn primary flux standard stars were observed during photometric nights. These data trace stellar components associated with the H I emission. We also took images in the hydrogen Hα and Hβ lines (32 hr) to mark the excited nebulosity. These image frames were processed in the usual BATC manner (Zhou et al. 2004). An image made from combining the best seven continuum filter observations is shown in Figure 1. The image is overlaid with the H I contour

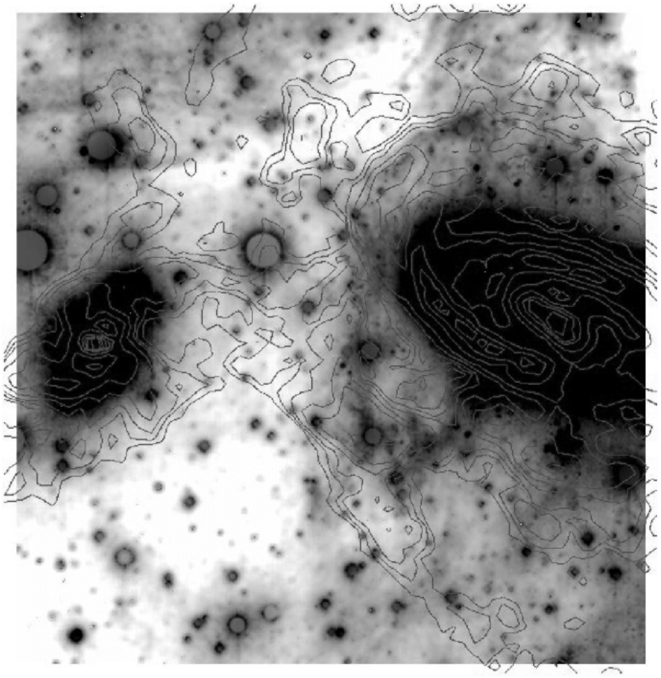

Fig. 1.—Image made from combining the data from the seven continuum filters with best observational quality, totaling 50 hr observation of the M81 group. We show this image with a high stretch, to emphasize the intergalactic continuum emission we find. The H I map from Yun et al. (1994) overlays this optical image, showing coexistence of the stellar and the H I components in the M81/M82 group.

map from Yun et al. (1994), showing the coexistence of the stellar and the gaseous components in the field of this interacting system.

As the M81 system fills the entire field of view, in order not to introduce artifacts into our image, we fit and subtract only a low-order, two-dimensional (row: 2, column: 1) polynomial surface from the background. All stars and background galaxies are masked and substituted by the average values of the surrounding pixels. The masked images are then smoothed to reduce the background noise. Although the flux level in the combined image may not be accurate near the lower limit, the

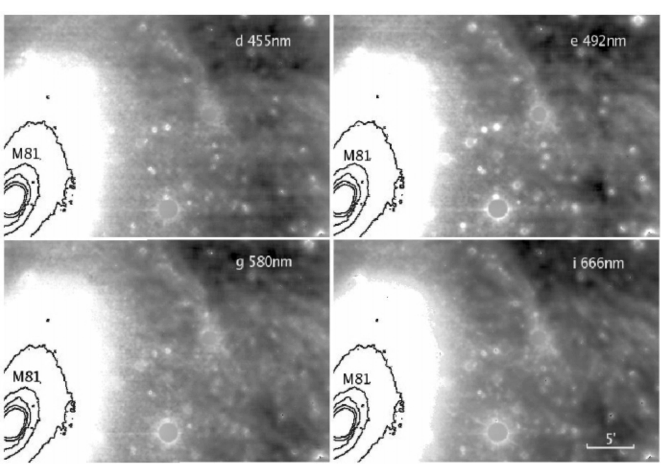

Fig. 2.—Subimages of the southwest region of the field in the 455, 492, 580, and 666 nm bands. The 25 mag isophote of M81 is indicated in each subimage. The same structure observed in these combined images, as in Fig. 1, in each of these four continuum bands confirms the existence of stellar distributions outside of M81 in the M81/M82 group.

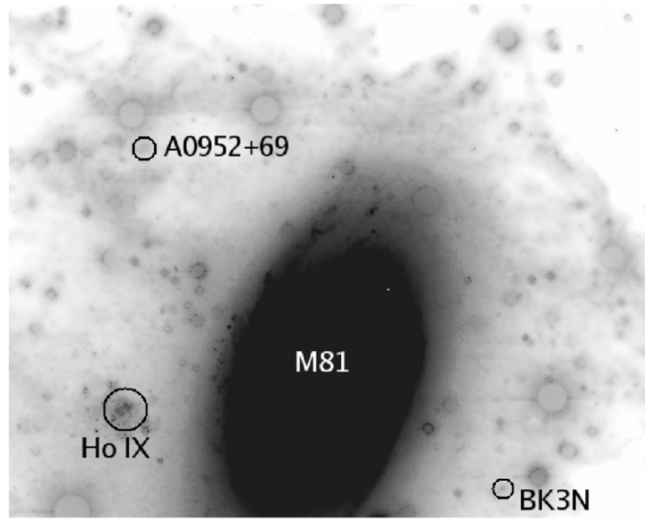

Fig. 3.—The 666 nm band subimage of the Arp Loop and the vicinity of M81. The three identified dwarf irregular galaxies, A0952+69, Ho IX, and BK3N, are circled and labeled in the image. A smooth and circular stellar structure begins to be visible optically immediately outside of M81's disk and extends in the northeast direction until it reaches its farthest point where the H I gas of concentration II is located. It then curves back extending westward almost horizontally in our images, until it merges into another ringlike structure protruding northward from the tip of M81.

small-scale structure of the diffuse stellar emission is preserved in this manner for subsequent analysis. Widespread stellar distribution is clearly detected across the field in all 10 continuum filter bands. Figure 2 shows the southwest corner (the west side of M81) of the image in four separate filters. The position of

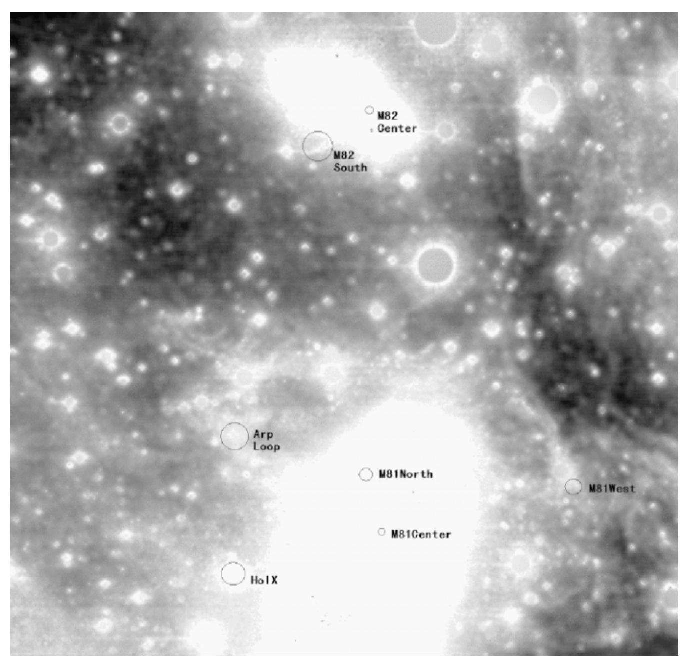

Fig. 4.—Deep composite image made from the 492, 526, and 666 nm filters. M81 is to the right, M82 to the left. Diffuse stellar emission is clearly visible throughout the image, with enhancements around major member galaxies. Threading structure can be seen reaching out from both the east and west sides of M81 behind foreground structures (Arp Loop and the optical spiral arm). Some of the filaments seem to connect to the filaments west of M82. The seven locations where the SEDs are measured (cf. Fig. 5) are circled and labeled. [*See the electronic edition of the Journal for a color version of this figure*.]

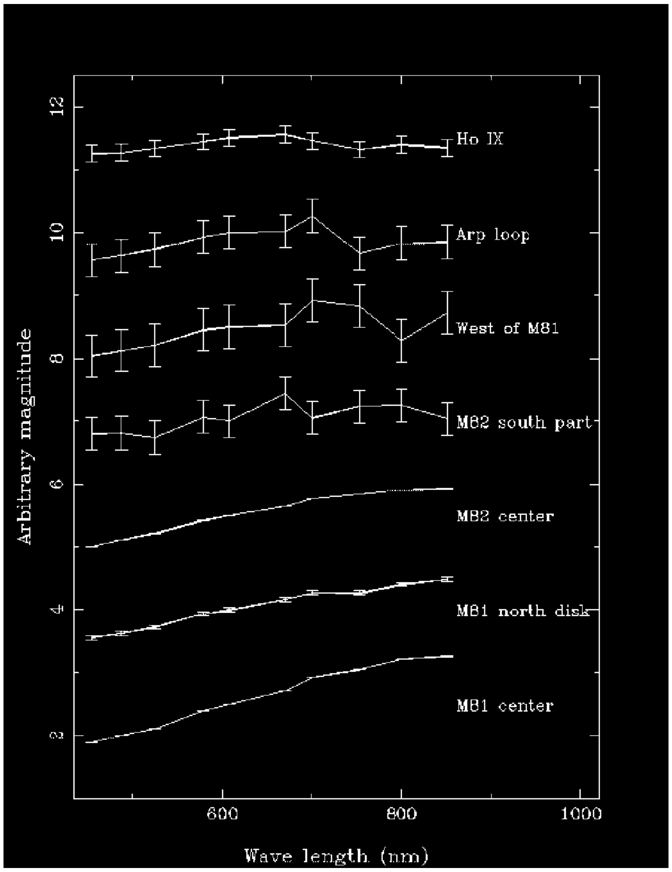

FIG. 5.—The 10-color SEDs measured at seven locations throughout the image of the M81 group. The colors at the east and west sides of M81 are strikingly similar to the SED color measured at the southeast edge of M82, suggesting either that the diffuse materials are stars stripped off from the galaxies in the previous close encounter or that star formation occurred quickly after the encounter in the stripped H I gas.

M81 itself is indicated by a sketch of the galaxy, with the outermost isophote at the 25 mag arcsec^{-2} level.

3. DISCUSSION

Bremnes et al. (1998) have suggested that diffuse emission in the M81 field could be due to Galactic cirrus. As such, then it is relevant if the diffuse emission we see is connected to the galaxies in a straightforward manner indicative of a tidal origin.

Arp first noticed a looplike structure around the northern tip of M81 (Arp 1965). In the VLA observations (Yun et al. 1994) (see the contours in Fig. 1), the Arp Loop (referred to as "Concentration II") in Yun et al. appears to be a set of patchy H I clouds peaking at about 20′ northeast of the nucleus of M81. Karachentsev et al. (2002) have used *HST* to resolve this feature into stars. Optical observations subsequently reveal a concentration of stars suspected to be a dwarf galaxy named A0952+6914. Our observation thus provides a digital description of this structure at optical continuum wavelengths. Figure 3 presents the observations of the Arp Loop in the 666 nm band.

In addition to the Arp Loop, the H I observation shows that another structure reaching out from the northern tip of M81 looks just like an ordinary spiral arm (Yun et al. 1994), while in our optical data it stands clearly outside the galactic optical disk. We suggest that it is a tidal tail induced by the encounter. This is the first time a low surface brightness stellar counterpart of this H I tidal feature is detected. The overall structure around the northern tip of M81 thus actually contains "two loops." Figure 4 presents the composite image co-added from the 492, 527 and 666 nm filters. Diffuse stellar light is present almost all over the image, with enhancements in the vicinity of M81 and M82. Detailed examination of Figure 4 reveals that the stellar distribution has threads reaching out from both the east and west sides of M81, behind the foreground structures (the Arp Loop and the optical "spiral arm"). A few of these filaments seem to permeate northward and connect to the filaments west of M82.

To further investigate the nature of the stellar population, we estimate the spectral energy distributions at seven locations (identified in Fig. 4) on the dwarf galaxies and on and off the galactic disks (Fig. 5). The color of the known dwarf galaxy, Holmberg IX, is relatively blue owing to its ongoing star formation. However, the spectral energy distributions of the Arp Loop and the west side of M81 are strikingly similar to that measured at the edge of the optical disk of M82. This is in contrast to what Bremnes et al. (1998) found, but their observations did not cover the wide field of view that ours do.

Note that M82 has been suspected to have a truncated disk, as suggested by its peculiar, declining rotational curve (Sofue 1992). Some of the stars we see around M81 originally might well have belonged to M82 but were stripped off during the last encounter. M82, being smaller in mass, now is left with just its center regions. Alternately, the stars could have formed in the H I gas as it was stripped from the galaxies (and was presumably of higher density than it is now).

The radial velocities relative to the cosmic background radiation are 48 km s^{-1} for M81 and 296 km s^{-1} for M82 (de Vaucouleurs et al. 1991). Freedman et al. (1994) and Sakai & Madore (1999) derive distances of 3.63 and 3.9 Mpc for M81 and M82, respectively. The line-of-sight separation of ~0.27 Mpc today suggests a close encounter about 300 Myr to 1 Gyr ago. This timescale coincides with the epoch of enhanced star formation activities in M82 (van Driel et al. 1998). One possibility for the origin of these stars is that M81 and M82 passed by each other some 500 Myr–1 Gyr ago and, during this close encounter, the disk of M82 was seriously disrupted, leaving behind just its center regions. The relics of the disk (both stellar and gaseous components) are splayed all over the intergalactic space, which is what we see in our optical continuum observations. The other possibility is that the stars we see formed in the H I gas when it was of higher density than it is now.

4. CONCLUSION

In summary, our observations indicate that stars are widespread in the intergalactic regions of the M81/M82/NGC 3077 galaxy group. Their connection to the galaxies indicates a tidal origin for these stars, not an origin due to Galactic cirrus. The stellar distribution coincides with, and is at least as spread out as, the hydrogen gas that connects the interacting galaxies. We propose that the two major member galaxies in this group, M81 and M82, passed by each other not long ago and that the disk of M82 was disrupted to become the diffuse emission seen today in the H I, as well as in the stellar continuum observations. Details of the observations presented here will be given elsewhere.

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REFERENCES

Appleton, P. N., Davies, R. D., & Stephenson, R. J. 1981, MNRAS, 195, 327
Arp, H. 1965, Science, 148, 363
Bremnes, T., Bingelli, B., & Progniel, P. 1998, A&AS, 129, 313
Cottrell, A. G. A. 1977, MNRAS, 178, 577
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Jr., Buta, R. J., Paturel, G., & Fouqué, P. 1991, Third Reference Catalogue of Bright Galaxies (New York: Springer)
Efremov, Y. N., Karachentsev, I. D., & Karachentseva, V. E. 1986, Soviet Astron. Lett., 12, 181
Fan, X.-H., et al. 1996, AJ, 112, 628
Freedman, W. L., et al. 1994, ApJ, 427, 628
Getov, R. G., & Georgiev, T. B. 1988, Soviet Astron. Lett., 14, 345
Karachentsev, I. D., et al. 2002, A&A, 383, 125
Makarova, L. N., et al. 2002, A&A, 396, 473
Sakai, S., & Madore, B. F. 1999, ApJ, 526, 599
Sofue, Y. 1992, PASJ, 44, L231
van der Hulst, J. M. 1979, A&A, 75, 97
van Driel, W., Kraan-Korteweg, R. C., Binggeli, B., & Huchtmeier, W. K. 1998, A&AS, 127, 397
Walter, F., Skillman, E. D., & Brinks, E. 2005, ApJ, 627, L105
Yan, H.-J., et al. 2000, PASP, 112, 691
Yun, M. S., Ho, P. T. P., & Lo, K. Y. 1994, Nature, 372, 530
Zhou, X., Jiang, Z.-J., Xue, S.-J., Wu, H., Ma, J., & Chen, J.-S. 2001, Chinese J. Astron. Astrophys. 1, 372
Zhou, X., et al. 2004, AJ, 127, 3642