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OPTICAL AND NEAR-INFRARED IMAGING OF THE IRAS 1-JY SAMPLE OF ULTRALUMINOUS INFRARED GALAXIES

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ABSTRACT

Optical (R) and near-infrared (K') images of the IRAS 1-Jy sample of 118 ultraluminous infrared galaxies have been studied. All but one object in the 1-Jy sample show signs of strong tidal interaction/merger. Most of them harbor a single disturbed nucleus and are therefore in the later stages of a merger event. Single-nucleus ULIGs show a broad distribution in host magnitudes with significant overlap with those of quasars. The same statement applies to $R - K'$ colors in ULIG and quasar hosts. An analysis of the surface brightness profiles of the host galaxies in single-nucleus sources reveals that about 35% of the R and K' surface brightness profiles are well fit by an elliptical-like $R^{1/4}$-law, while only 2% are well fit by an exponential disk. Another 38% of the single-nucleus systems are fit equally well with an exponential or de Vaucouleurs profile. Elliptical-like hosts are most common among merger remnants with Seyfert 1 nuclei (83%) and Seyfert 2 optical characteristics (69%). The mean effective radius of these ULIGs is 4.80 ± 1.37 kpc at R and 3.48 ± 1.39 kpc at K'. These values are in excellent agreement with recent quasar measurements obtained at H with *HST*. The hosts of elliptical-like 1-Jy systems follow with some scatter the same $\mu_e - r_e$ relation, giving credence to the idea that some of these objects may eventually become elliptical galaxies if they get rid of their excess gas or transform this gas into stars.

Key words : galaxies: active – galaxies: interactions – galaxies: Seyfert – galaxies: starburst – infrared: galaxies

I. INTRODUCTION

Ultraluminous infrared galaxies (ULIGs; log $[L_{\rm IR}/L_\odot]$ ≥ 12 by definition; $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 0$) are an important class of extragalactic objects that appear to be powered by a mixture of starburst and AGN activity, both of which are fueled by an enormous supply of molecular gas that has been funneled into the nuclear region during the merger of gas-rich spirals. Local ultraluminous infrared galaxies (ULIGs; log $[L_{\rm IR}/L_\odot]$ ≥ 12; $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 0$) represent some of the best laboratories to study in detail the violent aftermaths of galaxy collisions and their possible connection with quasars and normal (inactive) elliptical galaxies. Recent deep surveys with the Infrared Space Observatory (*ISO*) and sub-mm ground-based facilities have revealed several distant ($z \approx 0.5 - 4.0$) infrared-luminous galaxies which appear to share many of the properties of local ULIGs (*ISO* : Kawara et al. 1998; Puget et al. 1999; Matsuhara et al. 2000; Efstathiou et al. 2000; Serjeant et al. 2001; Sanders et al. 2002, in prep.; *SCUBA* : Smail, Ivison, & Blain 1997; Hughes et al. 1998; Blain et al. 1999; Eales et al. 1999; Barger, Cowie, & Sanders 1999).

To properly address the issue of the origin and evolution of ULIGs, two crucial questions need to be answered: (1) What is the dominant energy source in ULIGs: Starbursts or active galactic nuclei (AGNs) or mixture of both of them? (2) Is the dominant energy source a function of the interaction/merger phase in these systems? Considerable progress has been made in recent years in answering the first of these questions. Ground-based optical and near-infrared spectroscopic survey of the 1-Jy sample has shown that at least 25 – 30% of ULIGs show genuine signs of AGN activity (Kim, Veilleux, & Sanders 1998; Veilleux, Kim, & Sanders 1999a; Veilleux, Sanders, & Kim 1997, 1999b; see also Goldader et al. 1995; Murphy et al. 2001b). This fraction increases to 35 – 50% among the objects with log $[L_{\rm IR}/L_\odot] \geq 12.3$. Comparisons of the dereddened emission-line luminosities of the BLRs detected at optical or near-infrared wavelengths in the ULIGs of the 1-Jy sample with those of optical quasars indicate that the AGN/quasar in ULIGs is the main source of energy in at least 15 – 25% of all ULIGs in the 1-Jy sample. This fraction is closer to 30 – 50% among ULIGs with $L_{\rm IR} > 10^{12.3}$ $L_\odot$.

In this paper we try to focuss on answering the second question from the analysis of optical and near-infrared images. In §2, we briefly describe observations and data reduction, in §3, global and nuclear properties, in §4, morphological evidence for tidal interactions, in §5, host galaxy properties. The details

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of these studies are presented in two separate papers (Kim, Veilleux, & Sanders (2002) - Paper I; Veilleux, Kim, & Sanders (2002) - Paper II).

II. OBSERVATIONS AND DATA REDUCTION

(a) Optical Imaging

Optical images for all 118 ULIGs were obtained at the Cassegrain focus of the University of Hawaii (UH) 2.2m telescope with the Kron-Cousins R filter (6400 Å). These CCD images were bias-subtracted and flat-fielded using normalized dome flat. Bad columns were removed by interpolation using nearby pixel values, and cosmic-rays were removed with the COSMIC package in IRAF. Except for one object, all objects were observed under photometric conditions and have been calibrated with the Landolt standard stars (Landolt 1983, 1992).

(b) Near-Infrared Imaging

All of the near-infrared images were obtained under photometric conditions with either the NICMOS3 or QUIRC near-infrared array camera at the Cassegrain focus of the UH 2.2m telescope using a K' filter. Dome flats were obtained at the beginning and end of each night. Flat-fielded images were registered and coadded after shifting in fractional pixel units with respect to the object center. Hot pixels were properly treated in this procedure and final coadded images were calibrated from observations of infrared standard stars (Elias et. al. 1982).

III. GLOBAL AND NUCLEAR PROPERTIES

Global and nuclear (4-kpc diameter) aperture photometry was performed for each galaxy in the sample. The absolute magnitudes range from −20.1 to −26.4 at R (mean = −21.9 ± 0.9, median = −21.83) and from −23.7 to −29.3 at K' (mean = −25.3 ± 1.1, median = −25.2). Using $M_R = -21.2$ and $M_{K'} = -24.1$ for an L^* galaxy with $H_0 = 75$ km s^{-1} Mpc^{-1} (see discussion at the end of §1 in Paper II), these magnitudes are equivalent to $\sim$ 0.4 − 120 (0.7 − 120) L^* at R (K'), with means and medians around 2 (3) L^*. The ULIGs in the 1-Jy sample are on average less luminous at R than the quasars in the sample of Dunlop et al. (2002; see also Taylor et al. 1996; McLure et al. 1999), although there is considerable overlap between the two samples. We find that 1-Jy ULIGs are a better match in terms of total K' luminosities to the set of "low-luminosity" quasars of McLeod & Rieke (1994a; $-23.2 \leq M_B \leq -22.1$ mag. for our adopted H_0) than the "high-luminosity quasars" of McLeod & Rieke (1994b) and McLeod & McLeod (2001) with $M_B \leq -23.2$ mag.

The $R - K'$ and $(R - K')_4$ (nucleus) colors are significantly redder than normal galaxies [median $R - K'$ and $(R - K')_4 = 3.25$ and 4.27 mag., respectively, versus 2.62 ± 0.34 mag. for normal galaxies; see §3.3 in Paper I). These colors are also redder than those of the PG QSOs ($R - K' = 2.7$ mag. on average if redshifted to $z \approx 0.1$ to match the average redshift of the 1-Jy ULIGs; Surace 2002, private communication). The red ULIGs with integrated $R - K' \gtrsim 4$ mag. or nuclear $(R - K')_4 \gtrsim 5$ mag. that can be considered extremely red objects (EROs; Elston, Rieke, & Rieke 1988) have a tendency to host Seyfert nuclei and have warm *IRAS* 25 μm/60 μm colors.

If we define the "compactness" of a galaxy as the ratio of nuclear (4-kpc diameter) to total luminosities, then the R (K') compactness ranges from 0.03 (0.10) to 0.53 (0.91) with a mean value of 0.14±0.09 (0.36±0.17) (1 σ). The ULIGs in our sample are therefore significantly more compact at K' than at R, possibly a consequence of the lower extinction and stronger warm-dust emission at longer wavelengths.

IV. MORPHOLOGICAL EVIDENCE FOR GALAXY INTERACTIONS

(a) Frequency of Multiple Mergers

As shown in Figure 1 of Paper I, we find nearly 100% of the objects in 1-Jy sample show signs of a strong tidal interaction/merger in the form of distorted or double nuclei, tidal tails, bridges, and overlapping disks. Nearly all of these objects are involved in the interaction/merger of two and only five systems out of 118 ($\lesssim$ 5%) are comprised of more than two interacting systems. In all five cases, triplets appear to be involved although the physical connection between the various components of the triplets have not all been confirmed. The fraction (number) of multiple (> 2) nuclei, double/pair mergers, and single-nucleus merger remnants in the 1-Jy sample is 4% (5), 39% (46), and 56% (66), respectively. A recent *HST* H-band imaging study of ULIGs by Bushouse et al. (2002; see also Colina et al. 2001) find similar result. Out of 27 ULIGs, Bushouse et al. find only one candidate for multiple merger.

(b) Projected Nuclear Separations

We find that more than 70% of the objects in the 1-Jy sample have nuclear separations of less than 5.0 kpc, but 7% of the objects have separations in excess of 20 kpc. These widely separated pairs may be difficult to explain in the standard ULIGs scenario, where the main activity is triggered in the late phase of the galaxy merger (e.g., Mihos & Hernquist 1996), unless the ULIG phase was triggered by an earlier merger event which is not evident at the present epoch.

We also find a significant tendency for the Seyfert 1 galaxies and, to a lesser extent, the Seyfert 2 galaxies to have small nuclear separations. In contrast, starburst-dominated galaxies show a broad range of nuclear separation. Single-nucleus sources and close pairs

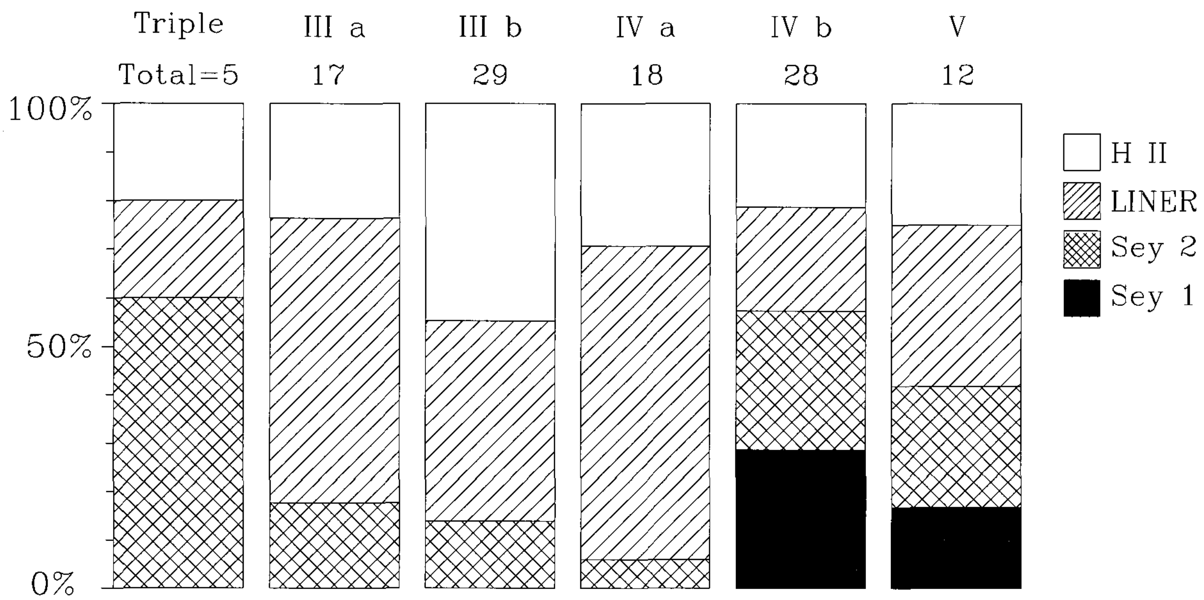

Fig. 1.— Interaction classes for the objects in the 1-Jy sample as a function of spectral type.

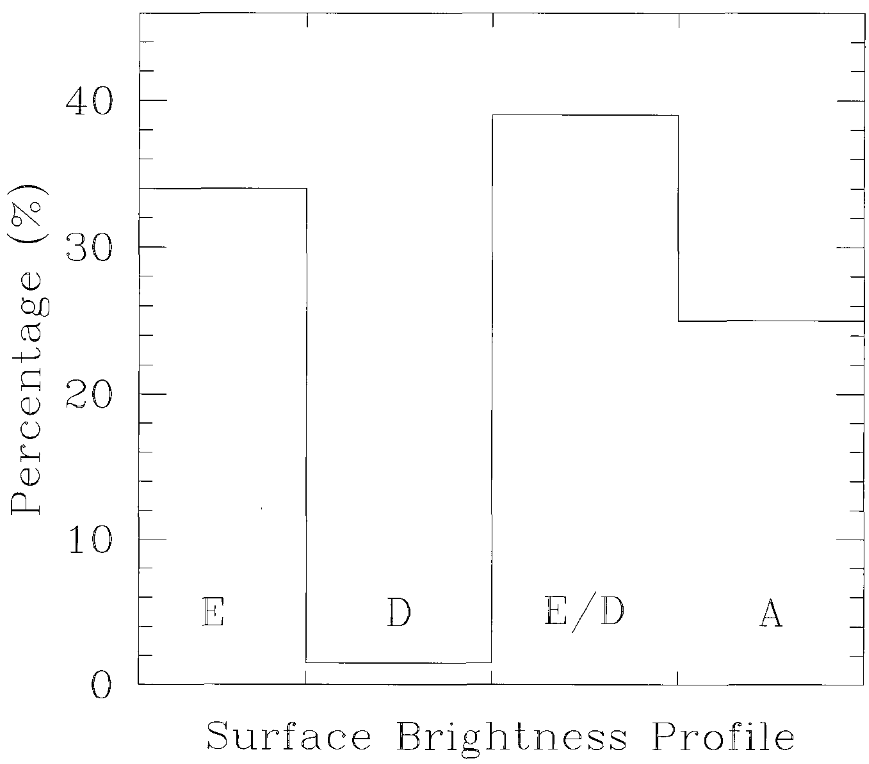

Fig. 2.— Fraction of single-nucleus 1-Jy ULIGs with disk-like (D), elliptical-like (E), elliptical/disk-like (E/D) and ambiguous (A) radial profiles.

are found to be more common in the highest infrared luminosity bin (83% of the sources with log $[L_{\rm IR}/L_\odot]$ $\geq$ 12.5 have $NS \leq 2.5$ kpc versus 58% at log $[L_{\rm IR}/L_\odot]$ < 12.24). This trend appears to extend to lower infrared luminosities: In a recent study of 56 galaxies with log $[L_{\rm IR}/L_\odot]$ = 11.10 – 11.99, Ishida (2002) finds that only about a third of these objects are advanced mergers with a single nucleus.

(c) Lengths of Tidal Tails

Numerical simulations suggest that a strong resonance between the orbital and rotational motions of stars and gas produces strong tidal tails in prograde disks (e.g., Toomre & Toomre 1972; Mihos & Hernquist 1996). In an attempt to further constrain the phase of the interaction in 1-Jy ULIGs, we have measured the total projected lengths of the tidal tails from our R-band images (the K' images are less sensitive to these faint features, so they were not used for this analysis). The measurements were done along each tail down to a constant R surface brightness of 24 magnitudes per square arcsecond. Slightly more than half of the objects in the 1-Jy sample have tail lengths of 10 kpc or less, indicating an advanced merger.

(d) Interaction Classification

We have classified each object in the 1-Jy sample in 5 different categories according to their morphology (from early to later stages of the tidal interaction, see details in Paper II): I. First Approach, II. First Contact, III. Pre-Merger (IIIa. Wide Binary, IIIb. Close Binary), IV. Merger (IVa. Diffuse Merger, IVb. Compact Merger), V. Old Merger.

We find none of the 1-Jy sources appears to be in the early stage of an interaction (I and II). Most (56%) of the ULIGs harbor a single nucleus and are therefore in the later stages of the merger. This is a very significant result: the ULIG phase is triggered only after the first close encounter between the two galaxies and generally when the two galaxies have coalesced into a single object. The fraction of singles to doubles in the 1-Jy sample varies with infrared luminosity, increasing steeply for the most extreme ULIGs with log $[L_{\rm IR}/L_\odot]$ > 12.5. This fraction seems to decrease when considering lower luminosity systems with log $[L_{\rm IR}/L_\odot] = 11$ – 11.99 (Ishida 2002). Most of these systems fall interaction classes of I to III.

Figure 1 shows that the interaction class is a strong function of the optical spectral type. We find that all ten Seyfert 1s are advanced mergers (class IVb or V) and that half (50%) of the Seyfert 2s are early or advanced mergers (class IVa, IVb, or V). On the other hand, LINERs and H II region-like galaxies show no preference in interaction class (other than to avoid classes I and II).

V. PROPERTIES OF THE HOST GALAXIES

(a) Surface Brightness Profiles

Ellipse fitting to the PSF-subtracted images was performed to characterize the R and K' surface brightness profiles of the host galaxies in the ULIGs of the 1-Jy sample. Figure 2 shows the fraction of single-nucleus objects (i.e. merger remnants with interaction class IV or V) in the 1-Jy sample with pure disk-like (D: 2%), pure elliptical-like (E: 35%), elliptical/disk-like (E/D: 38%), and ambiguous (A: 26%) radial profiles. "E/D" profiles are defined as being equally well fit by an exponential or de Vaucouleurs profile, while neither fits galaxies with "ambiguous" profiles. Both E/D and A profiles are quite common among ULIGs. The large number of E/D galaxies in our sample probably reflects the limitations of our data: images with a larger dynamical range in surface brightness (i.e. higher spatial resolution to probe the nuclear region and fainter surface brightness limits to map the outer portions of the galaxies) would help rule out one type of profile over the other. The large fraction of ambiguous profiles probably reflects the residual effects of the galaxy interaction on the morphology of the merger remnants. If we combine the E and E/D galaxies, we find that 73% of the single-nucleus objects are fit adequately by a de Vaucouleurs profile.

We find that the hosts of most merger remnants with Seyfert 1 (83%) or Seyfert 2 (69%) optical characteristics are E-like. A similar trend is seen among warm objects (10 out of the 13 objects with $f_{25}/f_{60} \geq 0.2$ or 77% are E-like). Starburst and LINER systems, on the other hand, show no preference between disk-like and E-like hosts. As expected in the merger scenario for elliptical galaxy formation, E- and E/D profiles are more common in the later phases of interaction [class V (27%) and especially class IVb (49%)] while ambiguous profiles are more often seen in early mergers (IVa, 59%).

(b) Absolute Magnitudes

The median and mean R absolute magnitudes of the single-nucleus system ULIGs are –21.77 and –21.77 $\pm$ 0.92 respectivelly. Same for the K' absolute magnitudes are –24.81 and –25.03 $\pm$ 0.94 respectivelly. If we convert these absolute magnitudes to the charateristic luminosity (L^*), then the median and mean R-band luminosities are 1.69 and 1.69 $\pm\, ^{2.25}_{0.97}\, L^*$, and the median and mean K'-band luminosities are 1.92 and 2.36 $\pm\, ^{3.24}_{1.38}$).

We find that the host galaxies of Seyferts are brighter by about 0.8 – 1.0 mag. on average at both R and K' than the hosts of LINERs and H II region-like galaxies. These results can be attributed to real differences in the host luminosities of AGNs vs non-AGNs, or may be due to the fact that AGN activity plays an important role to the total luminosity.

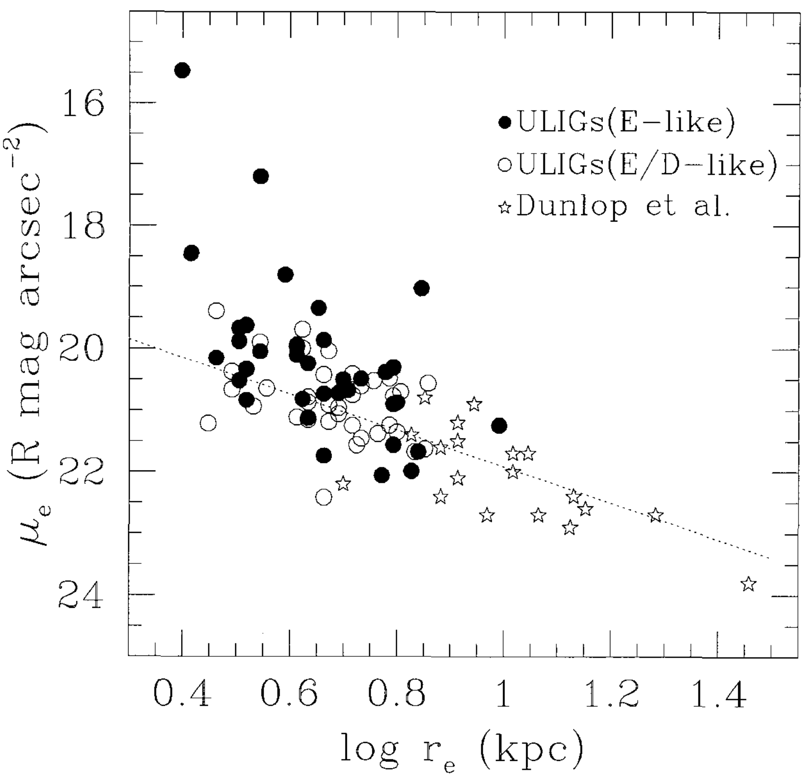

Fig. 3.— Surface brightnesses, μ_e, as a function of the effective radii, r_e for the ULIGs and QSOs (see details in text).

The host magnitudes of ULIGs can be compared with that of the quasars. At R, the host galaxies in ULIGs appear slightly less luminous on average than those measured by Dunlop et al. (2002) in radio-quiet quasars (–22.35 ± 0.15 mag., adjusted to $H_0 = 75$ km s^{-1} Mpc^{-1}) and radio-loud quasars (–22.85 ± 0.10 mag.). However, if we focus our analysis on the subset of objects with log [$L_{IR}/L_\odot$] $\geq$ 12.3, $f_{25}/f_{60} \geq$ 0.2, and with Seyfert characteristics at optical wavelengths, the apparent shift in host galaxy R magnitudes between these ULIGs and the quasar dataset of Dunlop et al. disappears. At K', the low-luminosity sample of quasars of McLeod & Rieke (1994a) have an average host magnitude $M_{K'} \approx -24.3 \pm 0.6$, while the high-luminosity quasars have $M_{K'} \approx -25.1 \pm 0.7$. The host galaxies in the 1-Jy ULIGs are therefore comparable in luminosity to those of the *high*-luminosity quasars. So even though we found that the 1-Jy ULIGs have lower *integrated* K' luminosities than the high-luminosity quasars of McLeod & Rieke (1994b), we find that they have host galaxies with similar K' luminosities. This good agreement is also found in the more recent analysis of the high-luminosity sample by McLeod & McLeod (2001).

(c) Luminosity Ratios in Binary Systems

Simulations suggest that minor mergers comprised of objects with mass ratios of order ~ 10 are predicted to have only benign effects on the main component of the system (e.g., Walker, Mihos, & Hernquist 1996; Bendo & Barnes 2000; Naab & Burkert 2001) whereas major mergers with mass ratio of ~ 3 or less appear to be needed to create a ULIG (e.g., Mihos & Hernquist 1996). We find that most of the Class III systems have a magnitude difference of less than 1.5 (median = 0.38) or a luminosity ratio of less than 4, in general agreement with the predictions from numerical simulations of galaxy mergers if mass scales linearly with luminosity.

(d) Colors

In contrast to the nuclear colors, the median color of the underlying galaxies of ULIGs is only slightly redder than that of normal galaxies or the host galaxies of quasars [$(R - K')_{\rm host}$ = 3.0 for either H II galaxies, LINERs, or Seyfert 2 galaxies compared to 2.6 and 2.5 for normal galaxies and quasars, respectively; de Vaucouleurs & Longo 1988; Dunlop et al. 2002]. This result confirms that the obscuring gas and dust is preferentially concentrated within the inner 4 kpc of ULIGs (e.g., Scoville et al. 2000). The slightly redder colors of Seyfert 1 hosts [with median $(R-K')_{\rm host}$ of 3.4] may be due to contamination at K' by hot dust emission from the AGN or residuals from the bright central source subtraction procedure. The colors of ULIG hosts are similar to those found by Surace et al. (2001) among infrared-excess PG quasars.

(e) Effective Radii and Effective Surface Brightnesses

The median and mean of r_e (seeing-deconvolved effective radius) at R are 4.60 kpc and 4.80 ± 1.37 kpc (1 σ), while at K' we find 3.55 kpc and 3.48 ± 1.39 kpc (1 σ). These effective radii are virtually indistinguishable from those measured at H by McLeod & McLeod (2001) in the eight E-like "high-luminosity" quasars of their sample ($< r_e > = 3.39 \pm 1.90$ kpc). On the other hand, the values measured by Dunlop et al. (2002) among high-luminosity radio-quiet quasars (7.63 ± 1.11 kpc adjusted to $H_0 = 75$ km s^{-1} Mpc^{-1}) and radio-loud quasars (7.82 ± 0.71 kpc) appear to be significantly larger than those measured in the 1-Jy ULIGs, although there is some overlap between the two distributions.

As shown in Figure 3, the E-like host galaxies of the 1-Jy ULIGs have slightly brighter R-band surface brightnesses than the hosts of the quasars studied by Dunlop et al. Nevertheless, the elliptical-like host galaxies of ULIGs appear to follow the $\mu_e - r_e$ relation of normal ellipticals, although with considerable scatter. In this figure, we used the fit (dotted line) of Hamabe & Kormendy (1987) and shifted it in magnitude by $V - R = 0.5$ mag (keeping the slope constant). Galaxies with E/D-like profiles show a tendency to fall slightly below the data for E-like galaxies.

(f) A4 Coefficient

The departure of the isophotes from a perfect ellipse can be measured by the A_4 coefficient of the cos 4ϕ term in Fourier expansion formular. Typical values for ellipticals normalized to the major-axis length, a, range from −0.02 to +0.03 (e.g., Bender et al. 1989), where the negative values indicate boxy isophotes and positive values indicate disky isophotes. Ellipticals with boxy isophotes are generally luminous (massive) radio-loud ellipticals with X-ray halos, very slow stellar rotation and a distinct cuspy cores, whereas ellipticals with disky isophotes are low-to-moderate luminosity (mass) lenticular and elliptical galaxies which are generally radio-quiet, show little or no X-ray emission, and exhibit significant rotational support and a power-law surface brightness profile on small scales (e.g., Kormendy & Bender 1996; Faber et al. 1997; Pahre, de Carvalho & Djorgovski 1998 and references therein). It found that the distributions of A_4/a in elliptical-like (E and E/D) ULIGs has no clear preference between positive and negative values. The median and mean of A_4/a are +0.005 and +0.014 ± 0.059. The broad range of A_4/a values in ULIG hosts probably reflects the residual effects of the violent merger that took place in these galaxies.

VI. SUMMARY

The results from the analysis of R- and K'-band images were presented in this paper. The followings are main conclusions:

1. All but one object in the 1-Jy sample show signs of a strong tidal interaction/merger in the form of distorted or double nuclei, tidal tails, bridges, and overlapping disks.
2. Objects with red $R - K'$ colors and large nuclear-to-total luminosity ratios show a tendency to host Seyfert nuclei.
3. None of the 1-Jy sources appears to be in the early stages of a merger. Most (56%) of them harbor a single disturbed nucleus suggesting they are in the late stages of a merger. The fraction of advanced mergers with a single nucleus increases above infrared luminosities of $10^{12.5}$ $L_\odot$ and decreases below 10^{12} $L_\odot$.
4. All Seyfert 1s and most of the Seyfert 2s are advanced mergers. LINERs and H II region-like galaxies show no preference between pre-merger and advanced merger phases.
5. The hosts of single-nucleus ULIGs have mean absolute magnitudes (luminosities) of −21.77 ± 0.92 mag. ($1.69 \pm ^{2.25}_{0.97}$ L^*) at R and −25.03 ± 0.94 mag. ($2.36 \pm ^{3.24}_{1.38}$) at K'. There is a considerable overlap between the host galaxy luminosity distribution of single-nucleus ULIGs and that of quasars.
6. An analysis of the surface brightness profiles of the host galaxies in single-nucleus ULIGs reveals that about 35% and 2% of the R and K' surface brightness profiles are fit adequately by an elliptical-like $R^{1/4}$-law and an exponential disk, respectively. Another 38% are equally well fit by either an exponential or an elliptical-like profile. The remainder (26%) of the single-nucleus sources cannot be fit with either one of these profiles. Elliptical-like hosts are most common in merger remnants with Seyfert 1 nuclei (83%) and Seyfert 2 characteristics (60%).
7. The hosts of ULIGs have effective radii ($< r_e >= 4.80 \pm 1.37$ kpc at R and $< r_e > = 3.48 \pm 1.39$ kpc at K') which are similar to those measured by McLeod & McLeod (2001) in quasar hosts. The hosts of 1-Jy systems follow with some scatter the $\mu_e - r_e$ relation of normal ellipticals at R. Elliptical-like hosts in the 1-Jy sample show a broader range of A_4/a values than normal ellipticals.
8. The results from this study, with some exceptions, are generally consistent with the evolutionary scenario in which ULIGs are the results of a merger of two gas-rich galaxies which first goes through a starburst-dominated pre-merger phase when the

system is seen as a binary, next reaches a dust-enshrouded AGN-dominated merger phase once the two nuclei have merged into one, and then finally ends up as an optical (post-ULIG) AGN where the host is elliptical-like and shows only limited signs of the merger.

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REFERENCES

Barger, A. J., Cowie, L. L., & Sanders, D. B. 1999, ApJ, 518, L5

Bender, R., Surma, P., Döbereiner, S., Möllenhoff, C., & Madejsky, R. 1989, A&A, 217, 35

Bendo, G. J. & Barnes, J. E. 2000 MNRAS 316 315

Blain, A. W., Kneib, J.-P., Ivison, R. J., & Smail, I. 1999, ApJ, 512, L87

Bushouse, H. A., et al. 2002, ApJS, 138, 1

Colina, L., et al. 2001, ApJ, 563, 546

De Vaucouleurs, A., & Longo, G. 1988, Catalog of optical and infrared photometry of galaxies from 0.5 micrometer to 10 micrometer (1965 – 1985) (Austin: Univ. of Texas)

Dunlop, J. S., et al. 2002, MNRAS, in press (astro-ph/0108397)

Eales, S., Lilly, S., Gear, W., Dunne, L., Bond, J. R., Hammer, F., Le Fvre, O., & Crampton, D. 1999, ApJ, 515, 518

Efstathiou, A., et al. 2000, MNRAS, 319, 1169

Elias, J. H., Frogel, J. A., Matthews, J. A., & Neugebauer, G. 1982, AJ, 87, 1029

Elston, R., Rieke, G. H., & Rieke, M. J. 1988, ApJ, 331, L77

Faber, S. M., et al. 1997, AJ, 114, 1771

Goldader, J. D., Joseph, R. D., Doyon, R., & Sanders, D. B. 1995, ApJ,

Hamabe M. & Kormendy, J. 1987, in Structure and Dynamics of Elliptical Galaxies, IAU Symp. No. 127, p379, ed. T. de Zeeuw (Dordrecht: Reidel)

Hughes, D. H., et al. 1998, Nature, 394, 241

Ishida, C. M. 2002, Ph. D. Thesis, University of Hawaii

Kawara, K., et al. 1998, A&A, 336, L9

Kim, D.-C., Veilleux, S., & Sanders, D. B. 1998, ApJ, 508, 627

Kim, D.-C., Veilleux, S., & Sanders, D. B. 2002, ApJS, December issue (Paper I)

Kormendy, J., & Bender, R. 1996, ApJ, 464, L119

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

Landolt, A. U. 1992, AJ, 104, 340

Matsuhara, H., et al. 2000, A&A, 361, 407

McLeod, K. K., & McLeod, B. A. 2001, ApJ, 546, 782

McLeod, K. K., & Rieke, G. H. 1994a, ApJ, 420, 58

McLeod, K. K., & Rieke, G. H. 1994b, ApJ, 431, 137

McLure, R. J., et al. 1999, MNRAS, 308, 377

Mihos, J. C., & Hernquist, L. 1996, ApJ, 464, 641

Murphy, T. W., Jr., Soifer, B. T., Matthews, K., Armus, L., & Kiger, J. R. 2001b, AJ, 121, 97

Naab, T., & Burkert, A. 2001, in ASP Conf. Ser. 230, Galaxy Disks and Disk Galaxies, ed. J. G. Funes & E. M. Corsini (San Francisco: ASP), 451

Pahre, M. A., de Carvalho, R. R., & Djorgovski, S. G. 1998, AJ, 116, 1606

Puget, J. L., et al. 1999, A&A, 345, 29

Scoville, N. Z., et al. 2000, AJ, 119, 991

Serjeant, S., et al. 2001, MNRAS, 322, 262

Smail, I., Ivison, R. J., & Blain, A. W. 1997, ApJ, 490, L5

Surace, J. A., Sanders, D. B., & Evans, A. S. 2001, AJ, 122, 2791

Taylor, G. L., Dunlop, J. S., Hughes, D. H., & Robson, E. I. 1996, MNRAS, 283, 930

Toomre, A., & Toomre, J. 1972, ApJ, 178, 623

Veilleux, S., Kim, D.-C., & Sanders, D. B. 1999a, ApJ, 522, 113

Veilleux, S., Kim, D.-C., & Sanders, D. B. 2002, ApJS, December issue (Paper II)

Veilleux, S., Sanders, D. B., & Kim, D.-C. 1997, ApJ, 484, 92

Veilleux, S., Sanders, D. B., & Kim, D.-C. 1999b, ApJ, 522, 139

Walker, I. R., Mihos, J. C., & Hernquist, L. 1996, ApJ, 460, 121