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INFRARED OBSERVATIONS OF THE SEYFERT RING GALAXY NGC 985

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ABSTRACT

NGC 985 is a ring galaxy containing a Seyfert nucleus embedded in a bright optical knot which is seen as part of the ring. We present near-IR observations of NGC 985 which show that the knot containing the Seyfert nucleus lies at the center of an extended luminosity distribution with IR colors very different from those of the surrounding ring. The *K*-band light distribution of the knot is shown to have an $r^{1/4}$ law profile and has a central surface brightness consistent with that of the bulge of a small early-type galaxy. Previous optical studies have shown a peculiar twisted "arm" structure extending from the Seyfert nucleus. However, after removing the bulge light from the IR images, we have found that (*a*) the "arm" is actually a linear structure which originates at a possible second nucleus that is 3".3 from the Seyfert core and (*b*) the ring classification of NGC 985 is probably incorrect since the ring is incomplete and the overall morphology is more consistent with a tightly wrapped one-armed spiral. Wisps of low-surface-brightness emission are also seen to the southeast of the galaxy. Such material, when taken together with the evidence for a second nucleus, strongly suggests NGC 985 is composed of two colliding galaxies.

Subject headings: galaxies: individual (NGC 985) — galaxies: interactions — galaxies: photometry — galaxies: Seyfert — galaxies: structure

1. INTRODUCTION

The possible relationship between nonthermal activity in the nuclei of galaxies and collisions and interactions between them has been the subject of much debate in recent years (see Heckman 1990 for a review). Ring galaxies are examples of a rare but relatively symmetrical collision between two galaxies (e.g., Toomre 1978). Only three out of the few dozen known ring galaxies contain Seyfert nuclei. These are Wakamatsu's ring (Wakamatsu & Nishida 1987; Appleton, Schombert, & Robson 1990), Arp 118 (Huchra, Wyatt, & Davies 1982) and NGC 985 (de Vaucouleurs & de Vaucouleurs 1975; hereafter DD). NGC 985 is known to contain heavily obscured star-forming regions in and around the nucleus and was chosen as the subject of our near-IR imaging study.

NGC 985 (= VV 298, Mrk 1048) was classified as a Seyfert I by DD. The Seyfert nucleus is embedded in the bright knot which lies on the southern edge of an otherwise empty ring of emission. DD originally suggested that the knot is the displaced nucleus of a disk galaxy which was struck by an intergalactic cloud (see also Freeman & de Vaucouleurs 1974). However, a more popular theory for the formation of ring galaxies is that they are formed as a result of a head-on collision between a small galaxy and a disk system (Lynds & Toomre 1976; Theys & Spiegel 1976, 1977). In this case the knot containing the Seyfert nucleus is likely to be the intruder galaxy seen in projection against the ring. The Seyfert nucleus dominates the galaxy at almost all wavelengths including the far-IR (Appleton & Struck-Marcell 1987a), UV (Wu, Boggess, & Gull 1983) and X-ray regimes (Ghigo, Wardle, & Cohen 1983). NGC 985 also contains a weak (2.5 mJy) radio source (Ulvestad & Wilson 1984).

NGC 985 has recently been the subject of detailed optical studies (Rodrigues-Espinosa & Stanga 1990 hereafter RES; Stanga, Rodriguez-Espinosa, & Mannucci 1991). These authors obtained Hα images of the galaxy and spectra across the Seyfert nucleus and along a luminous twisted "arm" which extends westward from the Seyfert nucleus. The strength of the emission implies the existence of large numbers of massive stars in the region of the "arm."

In this paper we present for the first time near-IR images of NGC 985. We discuss the structure, intensity, and colors of the starforming regions in the ring. After removal of the extended $r^{1/4}$ law component from the "bulgelike" emission associated with the Seyfert nucleus, we show that the "arm" is remarkably linear and originates from a possible second nucleus which lies 3" from the Seyfert core. We also present evidence of faint extended emission to the southeast of NGC 985 which supports the view that NGC 985 is a composite system of two galaxies.

The systemic velocity corrected for the motion of the local group of NGC 985 is 12,948 km s^{-1} (de Vaucouleurs, de Vaucouleurs, & Corwin 1976). Adopting a value for $H_0 = 100$ km s^{-1} Mpc^{-1} we assume throughout the paper a distance to the galaxy of 129 Mpc.

2. OBSERVATIONS

Observations of NGC 985 were made in 1990 October with the IRCAM2 InSb infrared array camera (62 × 58 pixels) attached to the 3.8 m UKIRT telescope on Mauna Kea,

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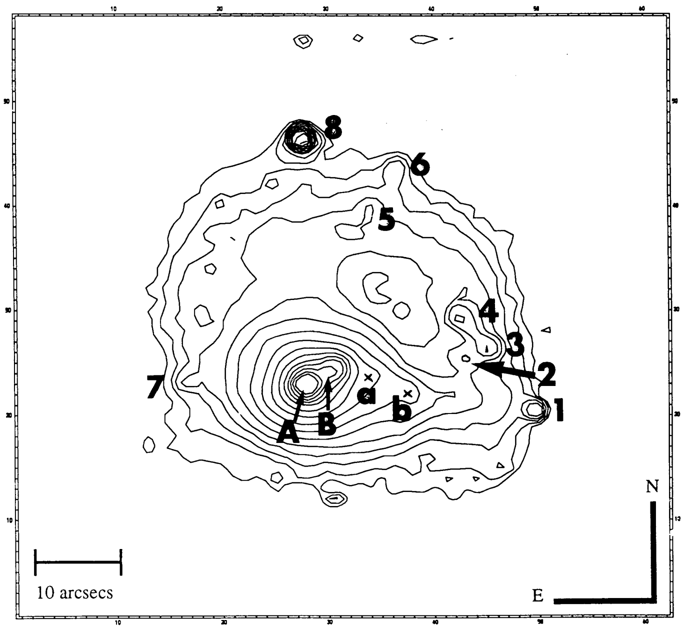

FIG. 1*a*

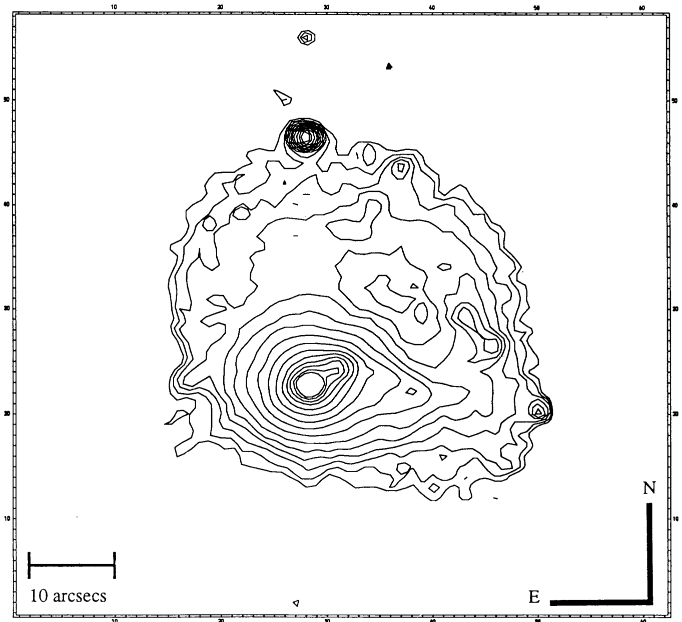

FIG. 1*b*

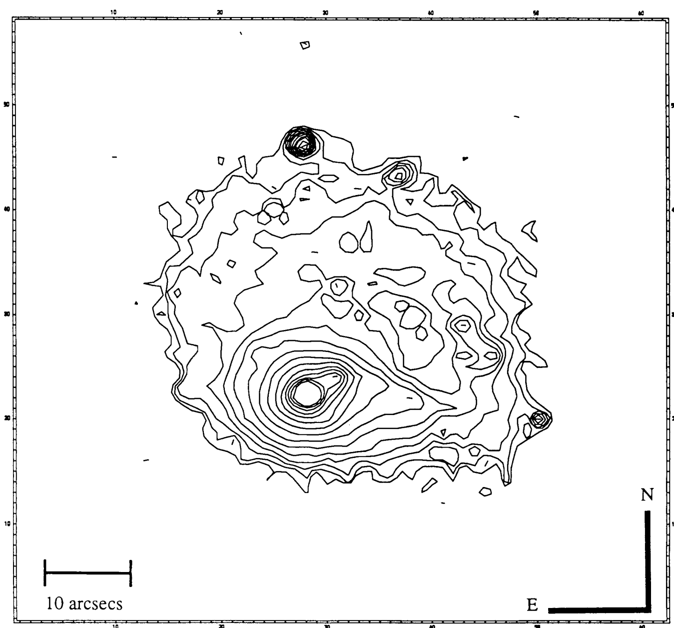

FIG. 1*c*

FIG. 1.—Contour maps of the near-IR emission from NGC 985. The observations were obtained with IRCAM2 and UKIRT. The image scale is 1.24 arcsecs pixel^{-1} and the images have dimensions 58 × 62 pixels^2. The contour levels are in units of log (adu s^{-1} pixel^{-1}) ranging from 0.2 to 2.3 in units of 0.15. The lowest contour represents the 2.5 σ level. (*a*) The *J*-band (λ1.25 μm) image with various "knots" identified 1–8 (see text); (*b*) *H*-band (λ1.65 μm); (*c*) *K*-band (λ2.2 μm) image.

Hawaii.[3] Images were made in the broad-band *J* (λ1.25 μm), *H* (λ1.65 μm), and *K* (λ2.2 μm) filters with a pixel size of 1".24 and a field of view (FOV) of 74 × 70 arcsec^2. Integration times were 1500 s at *K* band and 1200 s at *J* and *H* band.

[3] The United Kingdom Infrared Telescope (UKIRT) is operated by the Royal Observatory, Edinburgh, and the Science and Engineering Research Council of the UK.

The analysis of the images followed standard procedures (e.g., Appleton, Schombert, & Robson 1992). After dark subtraction and bad pixel removal, the object frames were flat-fielded using median filtered sky frames obtained frequently in regions of sky adjacent to NGC 985. Finally a constant background level was removed from each frame and the observations were corrected for air mass using average absorption coefficients for the UKIRT site (C. Aspin, personal communication, 1990). The seeing was determined to be 2".

Additional higher resolution observations of the nuclear regions of NGC 985 at *J*, *H*, and *K* bands were obtained with the NASA 3 m Infrared Telescope Facility (IRTF) on the night of 1991 October 21, under conditions of good (1") seeing. The images and colors shown here were obtained with ProtoCAM (InSb 62 × 58 array) providing a pixel scale of 0.35 arcsecs pixel^{-1}. Total integration times were 960 s at *K* band and 600 s *J* and *H* bands.

3. RESULTS

3.1. *Global Morphology*

Figures 1*a*–*c* show contour maps of the *J*, *H*, and *K*-band images of NGC 985 and Figures 2*a*, 2*b*, and 2*c* (Plates 12–14) show grayscale representations of the images. A number of interesting features arise from these data.

1. NGC 985 has an apparent double nucleus which is also seen in the low signal-to-noise narrow-band red continuum image of RES. The more prominent component (marked "A" in Fig. 1*a*) corresponds to the Seyfert nucleus and the fainter component ("B" in Figure 1*a*) is observed 3".3 to the northwest of "A". The two components have very different $H-K$ colors (§ 3.4). The two components are clearly resolved in the higher resolution IRTF image of Figure 3. Component "A", the Seyfert nucleus, is unresolved at the scale of 1", but component "B" is marginally resolved, with a FWHM of 1".5.

2. Extending away to the west from the Seyfert nucleus is a bright curved ridge of emission. This region (called the "arm" by RES) emits strong Hα line emission and RES concluded that the light from this arm must suffer significant extinction

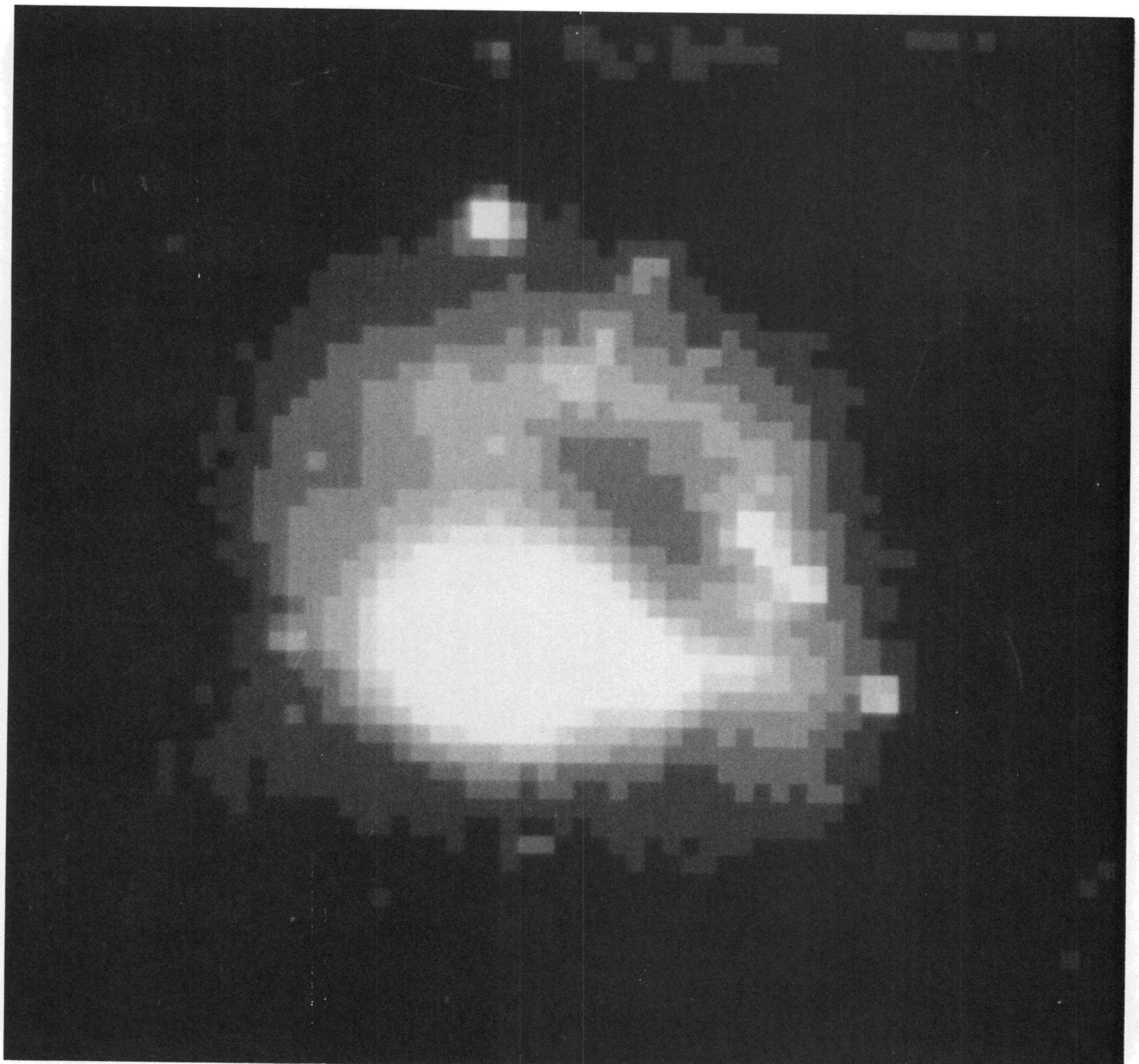

FIG. 2a

FIG. 2.—Gray-scale representations of the near-IR images of NGC 985 shown as contour maps in Figs. 1a–1c. (a) The J-band (λ1.25 μm) image; (b) H-band (λ1.65 μm); (c) K-band (λ2.2 μm) image.

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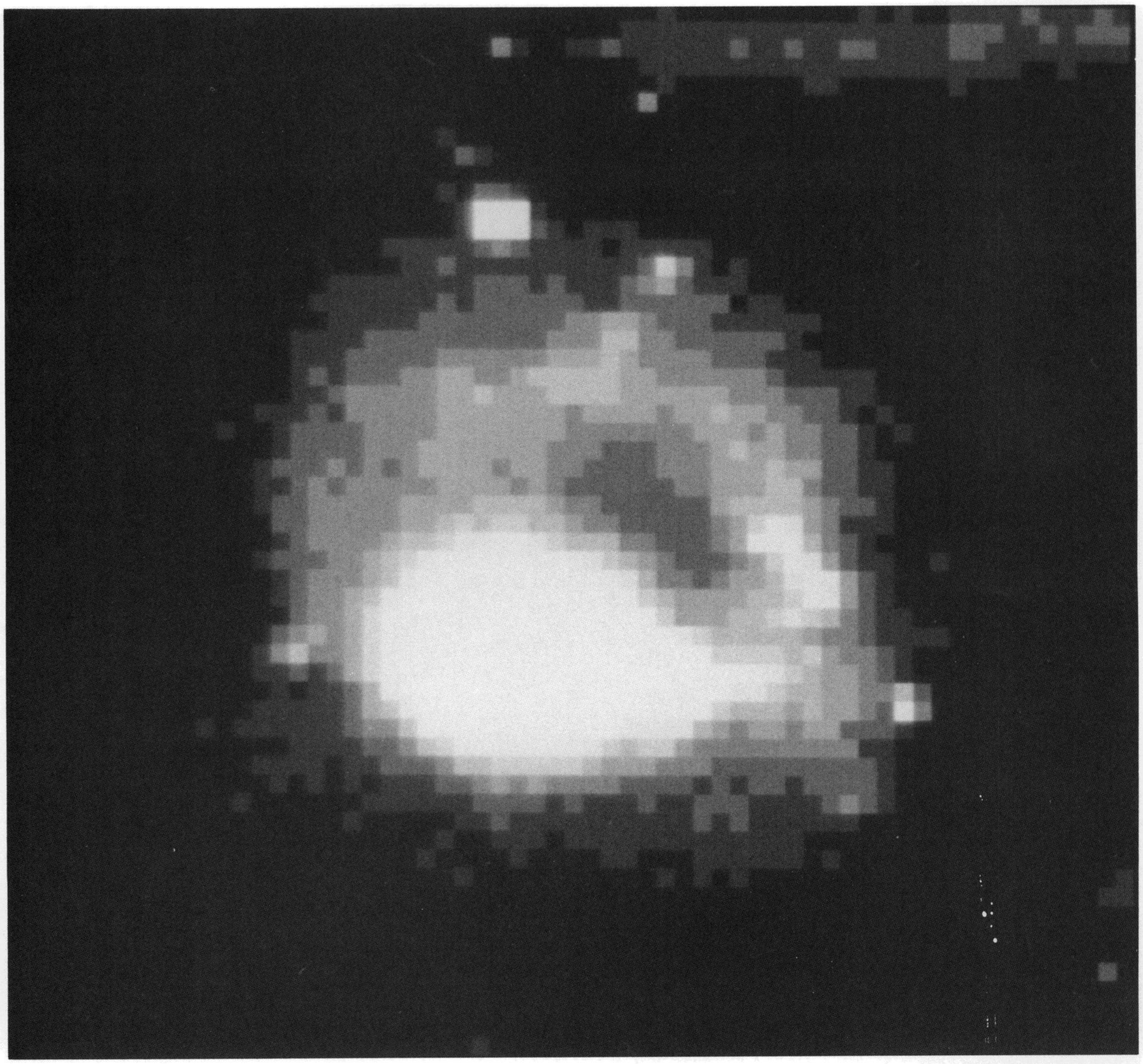

FIG. 2*b*

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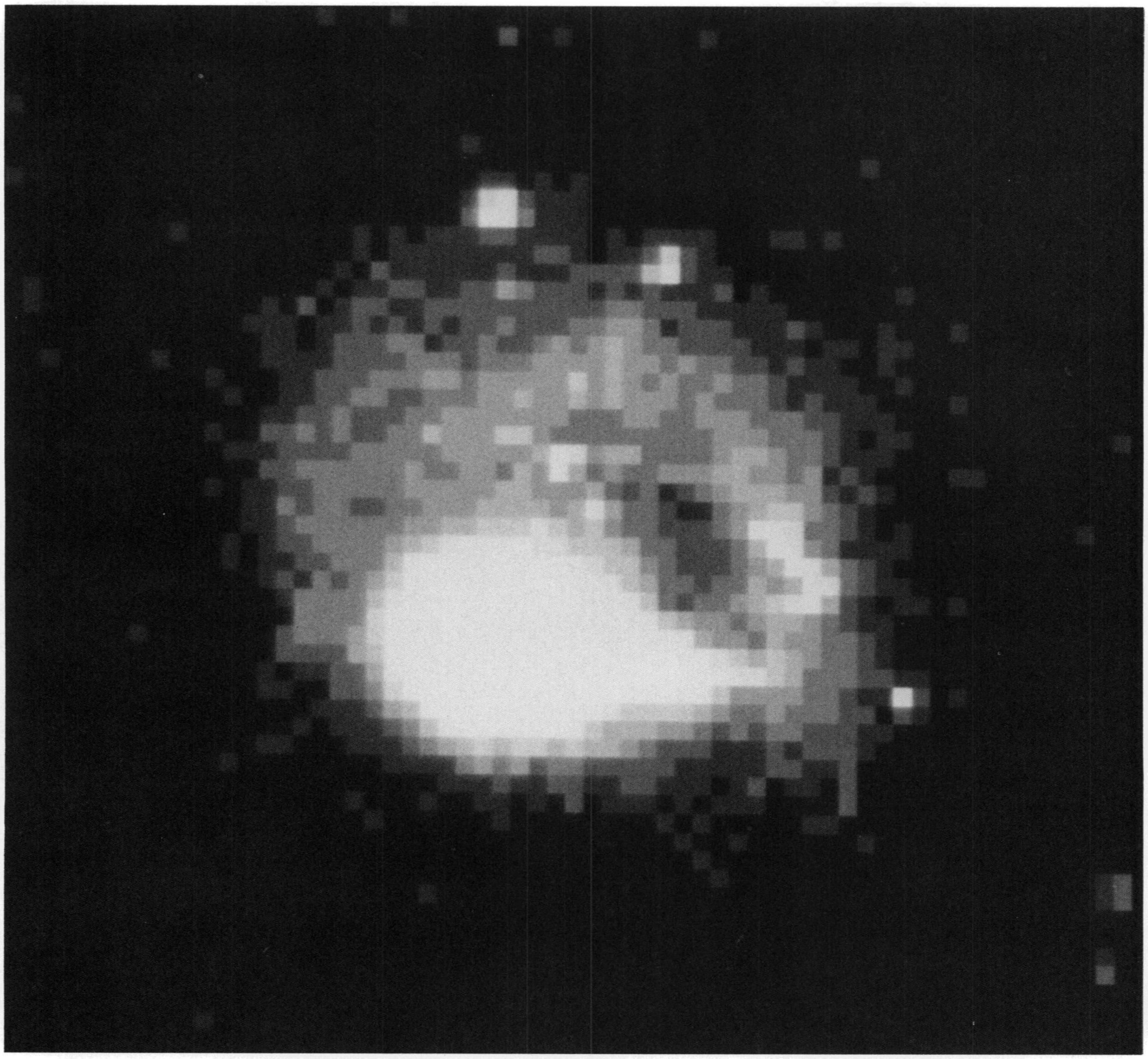

FIG. 2c

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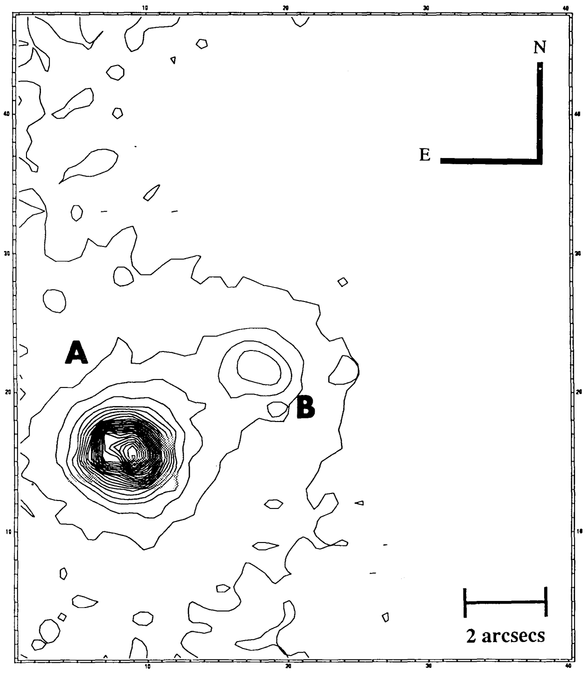

FIG. 3.—Contour map of the nucleus of NGC 985 made with high resolution using ProtoCam on the IRTF at K band. The image scale is 0.35 arcsec pixel^{-1} and the seeing was 1″. Note the double nucleus (labeled A and B, see text) hinted at in the UKIRT images.

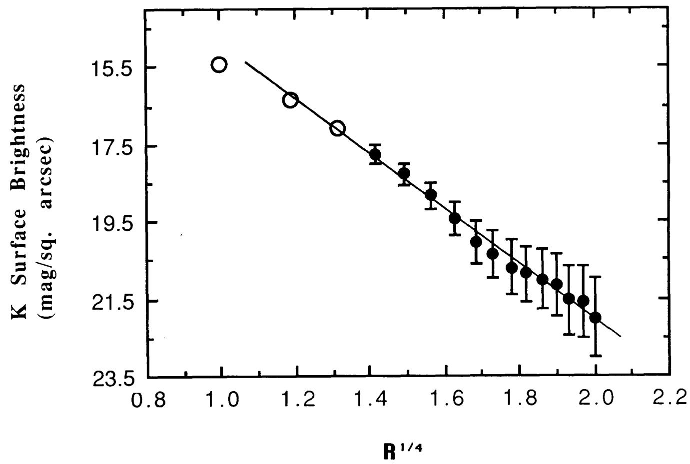

FIG. 5.—(*a*) A plot of the K-band (λ2.2 μm) radial surface brightness of the bulge of NGC 985 against $r^{1/4}$ (*solid line*). The solid line shows a least-squares fit to these data as discussed in the text. The open circles indicate data points potentially contaminated by the effects of seeing and the bright Seyfert core and were not used to constrain the fit. The very bright central pixel containing the Seyfert core is not shown.

($A_V > 4.6$ mag) based on an upper limit to the Balmer decrement from this region. We will later show (§ 3.3) that the curvature in the "arm" is a result of the superposition of a linear structure with an off-axis $r^{1/4}$ law "bulge" component. Furthermore, the linear structure appears to be connected to the second nucleus "B" rather than to the Seyfert core "A."

3. The raw images show that the outer structure is that of a ring. However, after removal of the "bulge" component surrounding the Seyfert nucleus, the ring takes on the appearance of a tightly wrapped one-armed spiral, being incomplete to the east.

4. Faint emission, at the level of 21.4 mag arcsec^{-2} at J band, is seen to the southeast of NGC 985. Figure 4 (Plate 15) shows a grayscale representation of the (heavily smoothed) J-band image emphasizing the lowest significant levels of emission. Both the J and H-band (not shown here) images show the same very faint wispy emission extending toward the southeast from the direction of the Seyfert nucleus. Wispy emission of this kind is typical of the debris associated with galaxies undergoing tidal interaction and is additional evidence that NGC 985 is indeed a colliding system.

3.2. *The Extended Light Associated with the Seyfert Nucleus*

In this section we investigate the possibility that the extended light distribution surrounding the Seyfert nucleus has an $r^{1/4}$ law luminosity profile. Such a form would be expected if the Seyfert nucleus lies either in a displaced nuclear bulge of the original host disk or in an elliptical galaxy seen in projection against the ring.

A two-dimensional least-squares fitting algorithm was written which found the best fit to an $r^{1/4}$ law profile of the form $\log I(r) = a - r^{1/4}$, where $I(r)$ is the intensity at a distance $r = (bx^2 + cy^2)^{0.5}$ from the center. Here $a = \log I_0$, I_0 is the central surface brightness and b and c govern the ellipticity of the isophotes. The position angle of the major axis of the elliptical light distribution was also allowed to vary.

One of the difficulties of fitting a functional form to the extended light surrounding the Seyfert nucleus is the existence of both the second nuclear component "B" and the bright "arm" and other ring emission to the northwest of the nucleus. In order to avoid such bright features, we restricted the fit to the smoothly declining region of the bulge from a position angle (N through E) of 45° to 225° (cf. the SE half of the bulge). The isophotes in this "uncontaminated" region are not very flattened (implying a spheroidal distribution of stars) and so the assumption that the bulge light is symmetrically reflected about a position angle of 45° is probably a good one.

Figure 5 shows the azimuthally averaged radial fit to an $r^{1/4}$ law distribution (in the K band) for the Seyfert "bulge" region. Points close to the Seyfert core (the inner 3 pixels) shown as open circles were not used in the fitting. The figure shows that an $r^{1/4}$ law is a good description of the luminosity distribution of the "bulge" light over almost 2 decades of intensity and out to the edge of the IR array. We conclude that the background light distribution which hosts the Seyfert nucleus is consistent with either a spiral bulge or an elliptical galaxy distribution. The interpolated central surface brightness of the best-fit profile was $\mu_k = 11.0$ (± 0.3) mag arcsec^{-2}. Assuming a $V-K = 3$, which is typical of spiral bulges or elliptical galaxies, this corresponds to $\mu_V = 14$ mag arcsec^{-2}. The absolute magnitude of the bulge at K band is $M_K = -23.5$ or a corresponding V magnitude of $M_V = -20.5$. In a study of the properties of elliptical and spiral bulges at optical wavelengths, Kormendy (1987) has shown that the central surface brightness and luminosity of elliptical and spiral bulges follow a well-defined sequence. The parameters for the extended light around the Seyfert core fall in the transition region between bright spiral bulges and low-luminosity ellipticals.

3.3. NGC 985 *without the* $r^{1/4}$ *Law Nuclear Bulge*

As a next step, we removed the model $r^{1/4}$ law intensity distribution from the images at J, H, and K in order to investi-

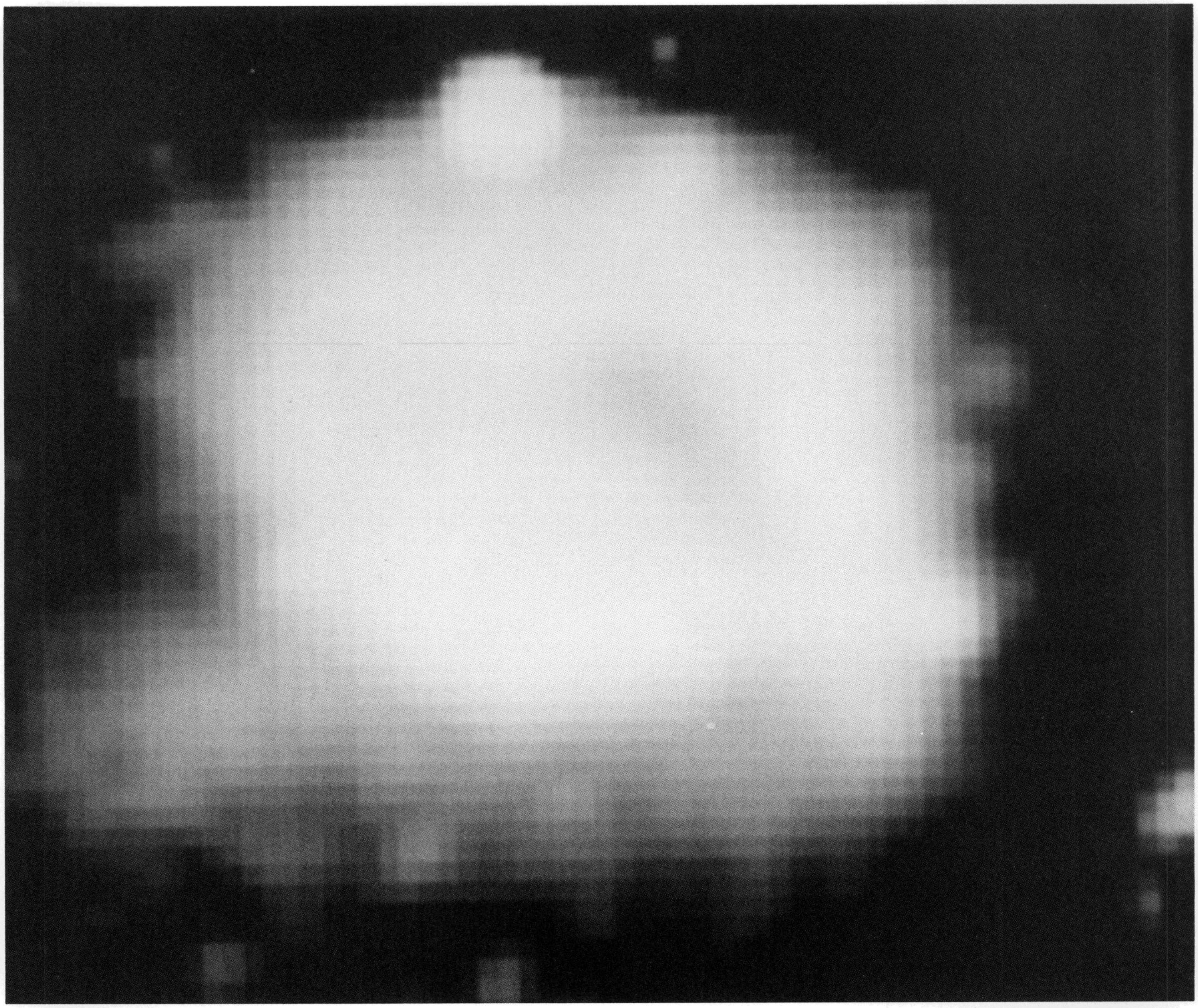

FIG. 4.—Near-IR J-band ($\lambda 1.25\ \mu$m) image of NGC 985 (as in Figs. 1a and 2a) but smoothed to an effective resolution of 3".5 FWHM to accentuate the faint diffuse emission present. Note the faint wispy emission to the southeast which is also present in the H-band images (not shown here). The faintest emission seen on this image (2.5 σ level) has a surface brightness of 21 mag arcsec^{-2}.

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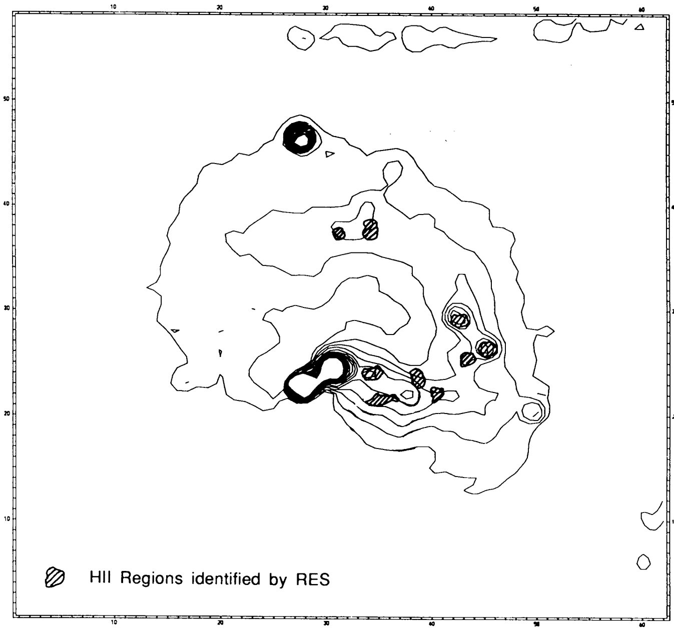

FIG. 6*a*

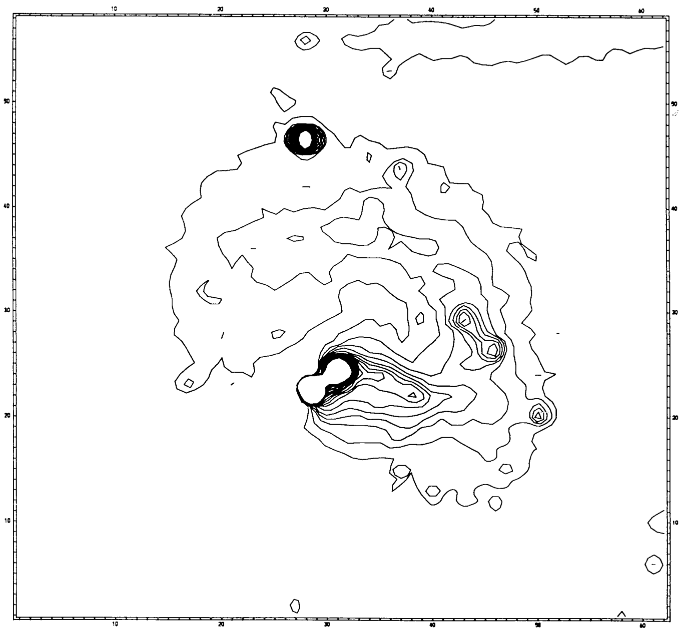

FIG. 6*b*

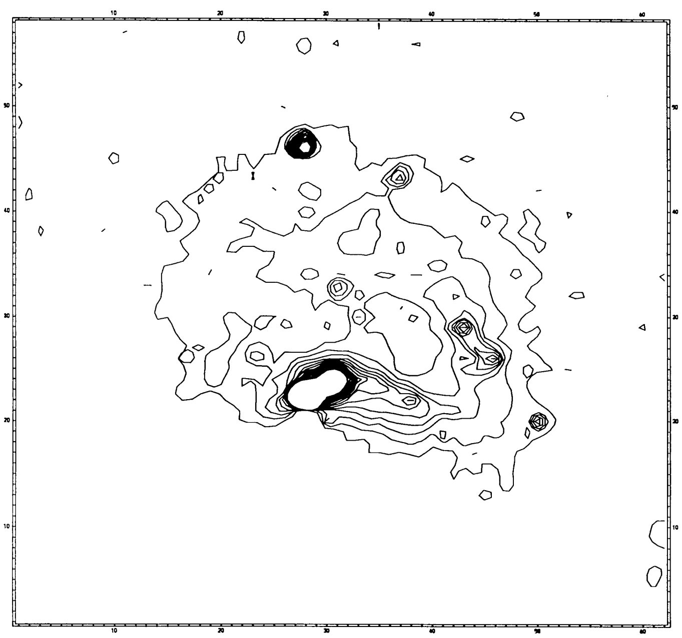

FIG. 6*c*

FIG. 6.—Contour maps of the near-IR emission from NGC 985 after the removal of the $r^{1/4}$ model profile from the images as discussed in the text. Note the clear indication of a second nucleus and a linear feature emanating from it. Contour units are adu s^{-1} pixel $^{-1}$ in the range 1 to 39 in intervals of 2 adu s^{-1} pixel^{-1}. (*a*) The *J*-band ($\lambda 1.25$ μm) image. Shaded regions show the position of H II regions identified by RES which lie along the length of the linear structure. (*b*) *H*-band ($\lambda 1.65$ μm); (*c*) *K*-band ($\lambda 2.2$ μm) image.

gate the underlying structure of the galaxy, especially in the region of the nuclear sources "A" and "B" and the star-forming "arm." In Figures 6*a*, *b*, and *c* we present contour maps of the resultant images of NGC 985. The *J*-band image is also presented in Figure 7 (Plate 16) as a grayscale image. The bulge-substracted images show (*a*) the second component "B" is unresolved in these observations; (*b*) component "B" lies at the end of a linear emission feature which points away from it. Since this structure appears to originate at "B" and does not extend beyond it to the east, it is likely that component "B" and the "arm" are physically related. (*c*) The morphology of the underlying galaxy more closely resembles a tightly wrapped one-armed spiral than that of a ring. Indeed the overall morphology is very similar to that of the galaxy Arp 107 which appears to be a strongly interacting system. The tightly wrapped spiral arm has its strongest emission to the southwest, and its strength decreases rapidly along the northern portion of the arm where it eventually breaks up into faint diffuse material in the east.

Figure 6*a* also shows the position of the H II regions discovered by RES superposed schematically on the *K*-band image. After bulge removal it is clear that the Hα emitting knots of RES tend to be symmetrically positioned on either side of the ridge line of *K*-band emission, suggesting that they may be causally related. Although the linear structure is unusual for a classical ring galaxy, in off-center collisions a variety of sharp-edged "caustic" structure can form (Struck-Marcell 1990).

Three bright H II regions discussed by RES (knots 2, 3, and 4 indicated in Fig. 1*a*) are also associated with bright knots of IR emission on the western side of the ring. While quite prominent optically, knot 5 is barely visible as a distant IR source above a broader background of emission.

3.4. *The Compact Sources of IR Emission*

The bright nuclear emission components "A" and "B" and several knots (1–7) as well as two giant H II regions lying in the "arm" identified by RES are indicated in Figure 1*a* (H II regions a–b). Table 1 lists infrared magnitudes and colors of the various features. Column (1) gives the name of the feature identified in Figure 1*a*; column (2) shows the *K*-band magnitude and columns (3) and (4) give the $J-H$ and $H-K$ colors of each feature. The colors have been corrected for Galactic extinction assuming $A_B = 0.2$ from RC2 and adopting average

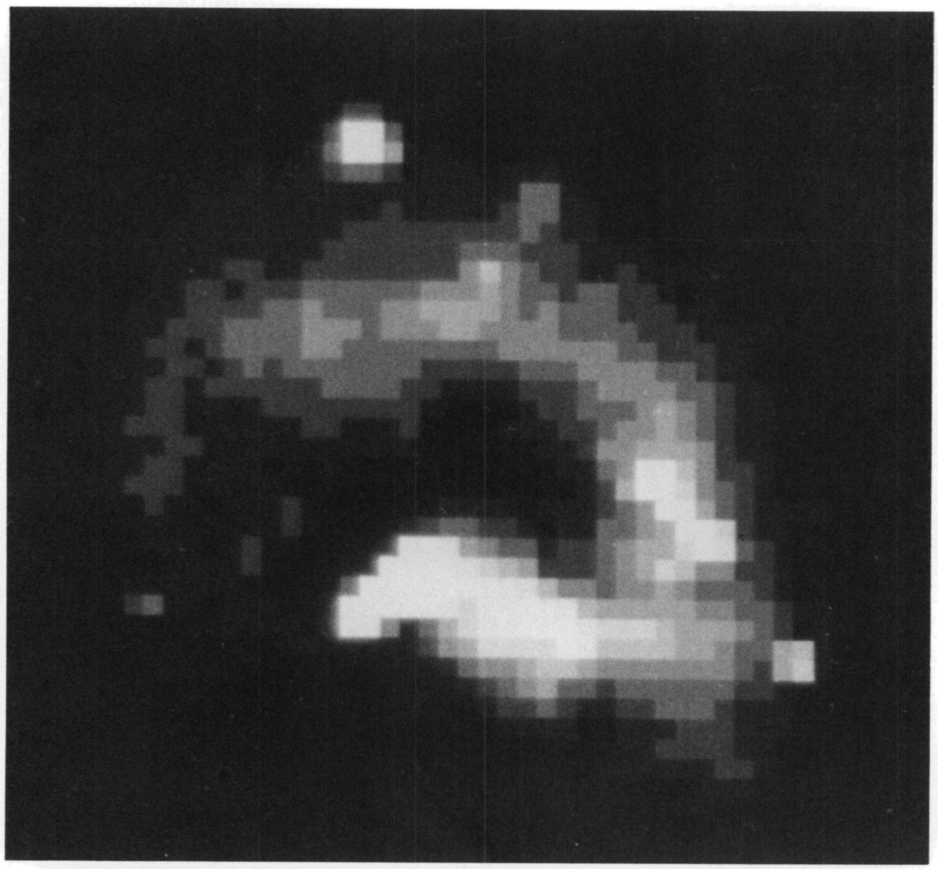

FIG. 7.—A gray-scale image of Fig. 6*a* (*J* band near-IR) showing the structure of the ring and nucleus of NGC 985 after removal of the $r^{1/4}$ law bulge. Note the double nucleus and barlike structure extending from the second nucleus along a direction to the NW. After bulge removal it is interesting that ring morphology is more spiral-like than has previously been recognized and may represent the "transition" from ring to spiral evident from the simulations of Toomre (1978).

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TABLE 1

IR PHOTOMETRY OF THE KNOTS[a]

Knot (1)	K (mag) (2)	$J-H$ (mag) (3)	$H-K$ (mag) (4)	Comment (5)
1	16.60 ± 0.15	0.6	0.1	Only seen in IR
2	15.2 ± 0.1	0.6	0.4	RES knot C
3	15.1 ± 0.1	0.8	0.4	RES knot B
4	15.0 ± 0.1	0.6	0.4	RES knot A
5	15.5 ± 0.1	0.6	0.4	RES knot D
6	16.1 ± 0.1	0.7	0.6	IR knot (+ background ring)
7	16.1 ± 0.1	0.5	0.7	IR knot
8	15.0 ± 0.1	0.7	0.0	Probable foreground star
H II Region a	15.4[b] $\pm$ 0.1	0.9	0.4	RES knot E
H II Region b	15.5[b] $\pm$ 0.1	0.8	0.4	RES knot H
Nucleus A	11.80[c] $\pm$ 0.03	0.5[c]	1.0[c]	Seyfert Nucleus "A"
Nucleus B	14.51[c] $\pm$ 0.05	0.5[c]	0.5[c]	Comp. "B" of double nucleus?
NGC 985	10.43 ± 0.02	0.20	0.03	Entire galaxy

[a] Photometry determine through a constant software aperture of radius 3″ centered on each knot.
[b] Near to nuclear bulge. Therefore we evaluated the magnitudes and colors after removal of $R^{1/4}$ law bulge (see text).
[c] Data obtained with the higher resolution IRTF ProtoCAM array. Magnitudes are colors are for circular software aperture of radius 2″ for "A" and "B."

values for the interstellar extinction curve given by Bessell & Brett (1988). A small K-correction (Frogel et al. 1978) was also applied to take into account the relatively high redshift of NGC 985 ($z = 0.04$). The second nuclear source "B" was too close to the Seyfert nucleus, "A," for its color to be accurately measured from the low-resolution UKIRT measurements. However, the higher resolution IRTF observations provide more accurate colors for the nuclear sources. These results are presented in Table 1. The two H II regions "a" and "b" and knot 7 in Figure 1*a* were also embedded in the bulge, and so their colors were obtained from the images after the bulge subtraction had been performed. The other knots shown in Table 1 were sufficiently far removed from the bulge center that their colors were not significantly affected by the presence of the bulge light.

Figure 8 shows a $J-H$, $H-K$ color-color diagram for the emission regions presented in Table 1. A striking difference in

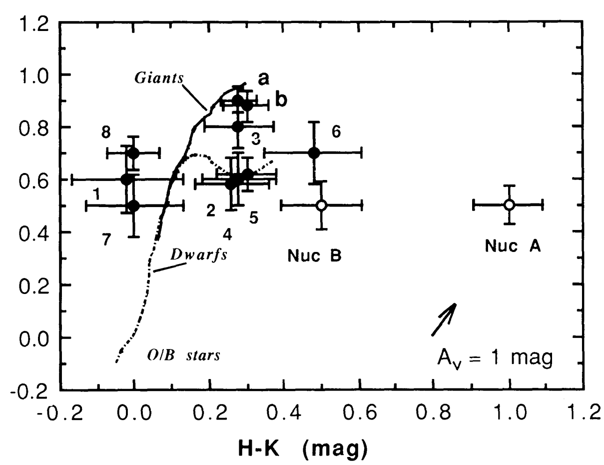

FIG. 8.—$J-H$, $H-K$ color-color diagram of various knots and emission regions identified by number in Fig. 1*a*. Also shown are the loci of colors for main-sequence stars, giants, and supergiants from Bessel & Brett (1981). Nuclei A and B are colors derived from the IRTF observations of the double nucleus shown in Fig. 3. Knots 1–8 are identified in Fig. 1*a*. Colors are also presented for "*a*" and "*b*," two giant H II regions seen by RES to lie along the linear "arm" (See Fig. 6*a*). Also shown is the reddening vector for an A_v of 1 mag.

the near-IR colors is noted between the Seyfert nucleus "A" and the weaker nuclear component "B." Component "A" has the colors typical of a Seyfert galaxy (Sanders et al. 1988), whereas component "B" has colors closer to those of other knots in the ring. While component "B" could be a foreground star, its spatial position at the end of the linear structure implies that it is related to the star formation regions. In addition, the source appears somewhat extended in the higher resolution IRTF observations, arguing against it being a foreground star.

Also in Figure 8 we show the colors of other knots seen in the ring. The reddest of these is knot 6 which lies to the red of the main-sequence and giant branch colors (see Bessell & Bret 1988) in the region normally assumed to be dominated by free-free and dust emission at K band (e.g., Joseph et al. 1984). The source is observed in the outer part of the "ring" and may be a heavily embedded H II region. No optical counterpart is known.

The majority of the other compact sources lies closer to the loci of colors associated with stellar populations. Knot 8 (which lies outside the disk of NGC 985) is probably a foreground star (either a K6–7 dwarf or K3–4 giant) and unlike knot 1, is very prominent in all images made of this galaxy to date. Knot 1 is not prominent optically but has been independently confirmed at I-band by J. Hidgon (private communication). If knot 1 is a foreground star, it would be classified from its infrared colors as either a K5 dwarf or a K1–2 giant (Bessell & Brett 1988). The rather faint source knot 7 may also be a faint foreground star.

Knots 2, 3, 4, and 5 lie closer to the locus of colors associated with a late stellar population (either supergiants or late-type dwarfs). They are seen along the northwestern edge of the ring and are directly associated with strong emission-line regions. The H II regions "a" and "b" which lie on the "arm" near the Seyfert nucleus also have colors similar to that of later type giant or supergiant stars.

3.5. *Global Colors in the Ring*

In Figures 9*a* and 9*b* (Plate 17–18) we present $J-H$ and $H-K$ color maps of NGC 985 after bulge subtraction. The image was made by registering the J, H, and K images, and smoothing them to a resolution of approximately 7″ (FWHP).

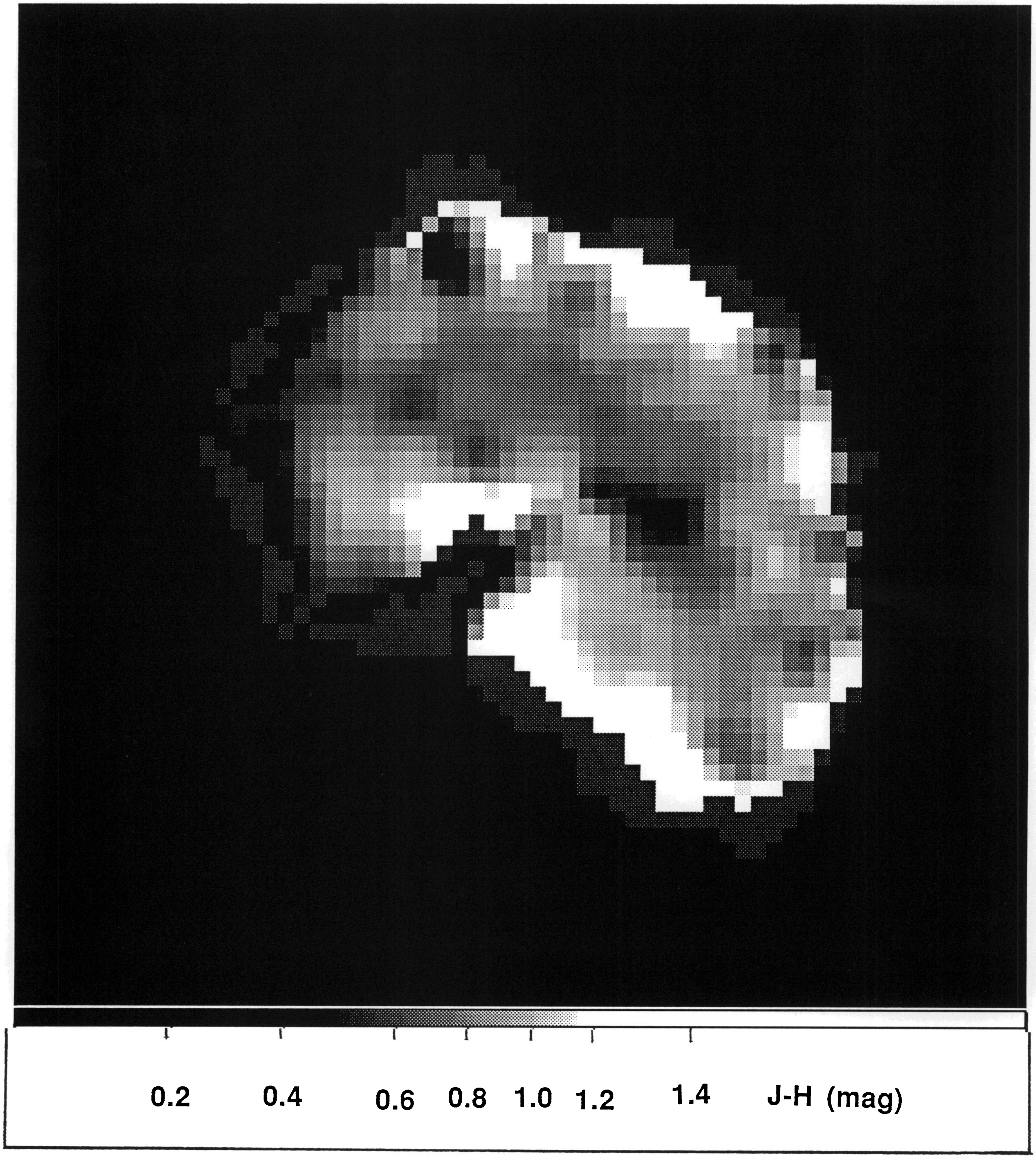

FIG. 9*a*

FIG. 9.—(*a*) Map of the $J-H$ colors in NGC 985 after removal of the bulge light (see text). (*b*) Map of the $H-K$ colors in NGC 985.

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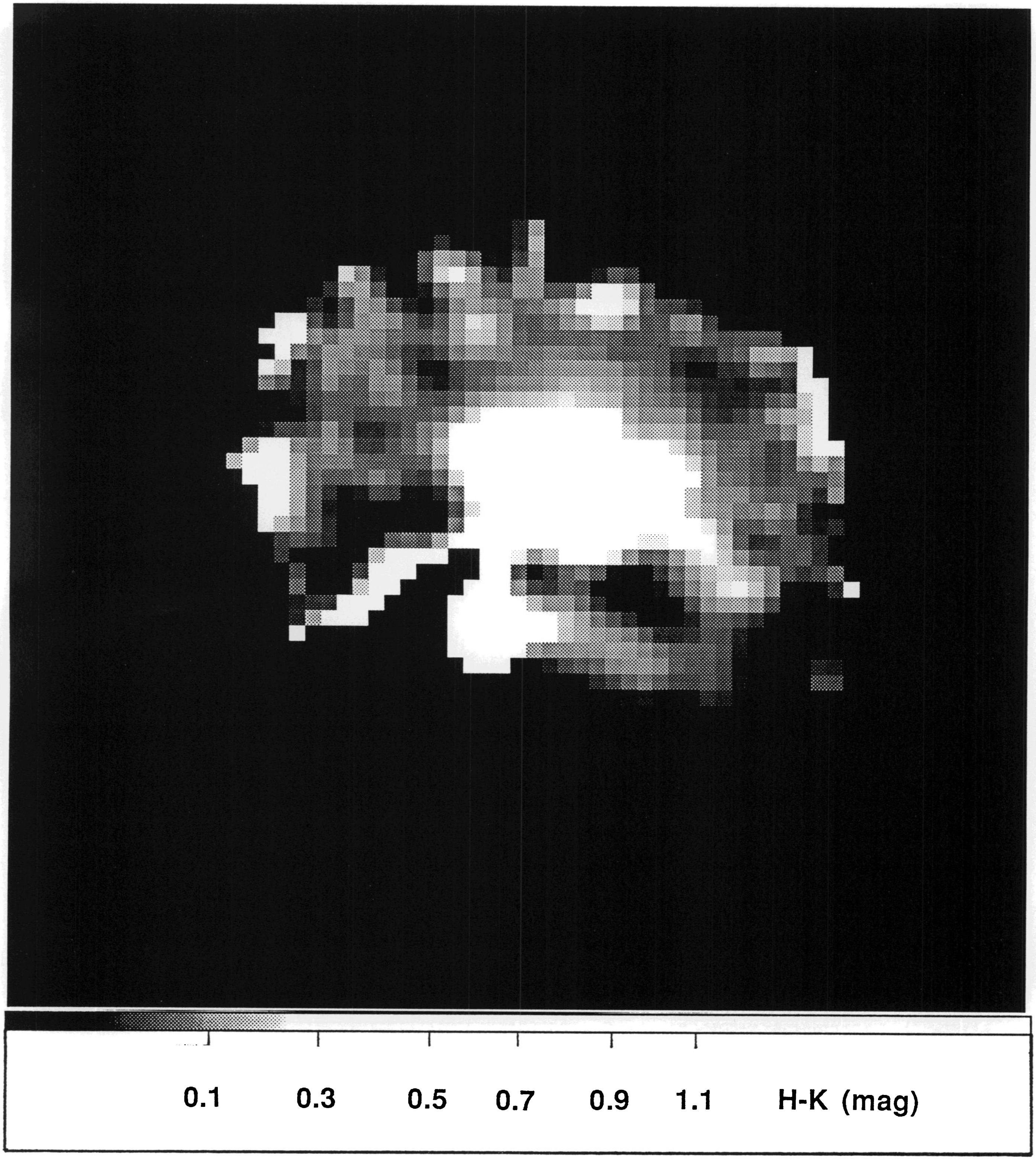

FIG. 9*b*

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The images were scaled appropriately and colors were calculated at each point. The colors have not been corrected for Galactic extinction. Only points in each image which were brighter than 3 times the rms noise in each image where included in the calculation. The region in and around the Seyfert nucleus shows sharp gradients due to the strong point-like nuclear source "B." The color images show (i) in the $J-H$ colors (Fig. 9*a*), the outer disk and knots of NGC 985 tends to be redder than the center of the nominal ring with a gradual change from $J-H=1$ to $J-H=0.4$ as one proceeds toward the center. On the other hand, a weaker but reverse trend is seen in the $H-K$ colors (Fig. 9*b*). Here the red outer knots tend to be superposed on bluer disk ($H-K=0.2$) which becomes redder as one proceeds toward the nominal ring center ($H-K=0.8$). (Note that after bulge removal these radial trends are not centered on the position of the Seyfert nucleus, additional confirmation that we are observing two galaxies rather than one.) (ii) No azimuthal trends are obvious from the maps. In particular, there are no color variations along the barlike structure or along the spiral arm/ring. (iii) Color gradient in the $J-H$ colors are seen across (perpendicular to the length of) the barlike structure which extends from the second nucleus (see Fig. 9*a*). The outer southern edge of the barlike structure is redder ($J-H=1.2$) than the inner edge ($J-H=0.7$). A similar trend is not seen in the $H-K$ color. This implies that the color variations in $J-H$ color across the structure may be the result of differential internal reddening, a result consistent with the optical spectroscopy of that region (RES).

4. DISCUSSION

4.1. *Are the Star-forming Knots Young or Old?*

The interpretation of the near-IR colors of the star forming knots in NGC 985 is hampered by our lack of detailed knowledge of the degree of internal reddening within the knots. The spectroscopy of RES was performed only on knot 4 and yielded a value for A_V of 1 mag. Figure 8 shows that most of the star forming knots have similar IR colors (with the exception of knot 6) and we will assume that all the knots are reddened by at least 1 mag. Interpreting the dereddened colors literally, the knots would have the colors of stars of spectral type K0 for $A_V=1$ mag. In order for O and B stars to dominate the IR light, a visual extinction of $A_V=5$–6.5 mag would be required. Although large values for A_V are likely from the evidence of previous optical spectroscopy, near-IR is desirable to distinguish between the possible extremes.

The balance of evidence favors the interpretation of the IR emission arising within star clusters dominated by young rather than old stars. Very high values of optical extinction are likely in this galaxy since RES placed a lower limit of $A_V=4.6$ mag for the brighter "arm" region. A significant quantity of cool dust in the galaxy is consistent with the large far-IR luminosity measured for NGC 985 (Appleton & Struck-Marcell 1987a). Given the extremely high star formation rates derived by RES from Hα observations, we therefore hypothesize that the near-IR emission arises within heavily obscured young star clusters rather than from star clusters dominated by intermediate late-type stars.

Some support for this picture comes from estimates of the total luminosity from individual knots at optical and IR wavelengths. For example, the estimated Hα flux from knot 4 ($A_V=1$) is 7.6×10^{-15} ergs s^{-1} cm^{-2}, implying a total luminosity from OB stars of 1.6×10^{42} ergs s^{-1} (see RES for discussion). The total K-band luminosity from the same knot can also be calculated from our IR observations if we similarly adopt a value for $A_V=1$, and assume $A_k=0.11\ A_V$ (Bessel & Brett 1988). Given the K-band flux, f_k, for knot 4 of 9.2×10^{-13} ergs s^{-1} cm^{-2}, then the total K-band luminosity, $L_k=4\pi D^2 f_k=1.88\times10^{42}\,[100/H_0]^2$ ergs s^{-1}. The similarity in the OB star and K-band luminosities for knot 4 implies that the source of energy output in the near-IR is of the same order of magnitude to that of the young stellar population and may derive from the same cause, namely young stars. Therefore, both the IR luminosity of the knots and their colors are consistent with our hypothesis that the IR emission arises in heavily obscured star forming regions. This might be expected if the star formation is being triggered in an expanding density wave similar to the mechanism which generates classical ring galaxies. However, we emphasize that this hypothesis cannot be proved without definitive measurements to determine the precise degree of reddening in all the knots in the ring (VLA radio observations have recently been made at three frequencies by Appleton & Ghigo, in preparation).

4.2. *The Nature of the Barlike Emission and the Possible Double Nucleus of NGC 985*

The observations presented here have shown that NGC 985 is not a geometrically simple ring galaxy, but contains interesting continuum structure in the form of (*a*) a possible double nucleus, (*b*) a very linear barlike structure which extends from the second nuclear component, and (*c*) a rather spiral-like outer structure which does not close to form a complete ring.

The existence of a possible second nucleus "B" was hinted at in the low signal-to-noise red continuum CCD image of RES. Since their observations also failed to detect Hα emission from component "B" its extragalactic nature is not confirmed. Our observations strongly indicate that there is a second, slightly extended, source near the Seyfert nucleus and that it has infrared colors significantly redder (in $H-K$ color) than other H II regions in the galaxy. The high values of optical extinction inferred from the spectroscopy of the adjacent "arm" are consistent with the second "nucleus" being highly obscured by dust. The fact that this possible second nucleus lies at the end of the linear barlike structure further supports the view that it is extragalactic.

Working on the assumption that the second nucleus "B" is indeed at the distance of the galaxy, we note that the appearance of the second nucleus, the barlike structure, and the outer ring/spiral arm are similar to that of a one-armed barred spiral (see especially Fig. 7). It seems likely that the second nucleus is the center of the parent galaxy which has been struck by a small bulge-dominated early-type galaxy containing the Seyfert nucleus "A." The early simulations of Toomre (1978) and more recent models (Appleton & James 1990; Struck-Marcell 1990) has shown that off-center but nearly vertical collisions between two galaxies can drive ringlike or tightly wrapped one-armed spiral density waves into the disk of the dominant disk system. In a sequence of models of increasing impact parameter (Toomre 1978), it was shown that if the intruder strikes the disk at about the distance of the softening length of a simple potential, the ringlike behavior normally found at small impact parameters is replaced with a spiral pattern. NGC 985 may be just such a transition object. The Seyfert nucleus appears to lie at the center of an elliptical-like intruder galaxy which is probably seen in projection in front of the disk system. This is consistent with the low values of reddening found against the Seyfert nucleus (RES).

The discovery of the possible second nucleus at the end of this "bar" would further confirm that two galaxies rather than one are involved in the creation of the ringlike structure. This appears to rule out the original picture of DD that NGC 985 was the result of a collision of an intergalactic (IGC) cloud with a disk system. Further evidence that two galaxies are involved comes from existence of faint extended IR emission to the southeast of the galaxy which has the appearance of stellar tidal debris. Stellar debris would not be expected in the case of a collision between an IGC and a disk galaxy. The simulations of Appleton & James (1990) and those of Heisler & White (1990) show that head-on collisions between two galaxies will often eject stellar material along the path of the intruder's orbit. The minor-axis wispy material seen at faint levels in the southeast of the galaxy is consistent with this picture.

5. CONCLUSIONS

Near-infrared images have been obtained of the peculiar Seyfert ring galaxy NGC 985. The observations show the following.

1. As seen in the K-band light, the Seyfert nucleus lies at the center of an extended luminosity distribution exhibiting an $r^{1/4}$ law luminosity profile. This luminous component, which is centered on the southern edge of the ring galaxy, has red JHK colors, a high central surface brightness (excluding the bright Seyfert core), and total luminosity consistent with that of the bulge component of a small early-type galaxy.

2. After removal of a model $r^{1/4}$ law profile from the images, these data shows that the Seyfert nucleus has a double structure (component "A" and "B"). Component "A" has the infrared colors typical of a Seyfert nucleus and component "B" is significantly bluer and is slightly extended spatially compared with a point source. Component "B" may therefore be a heavily obscured nucleus of a second galaxy.

3. The bulge removal also reveals that the star forming "arm" discussed by RES is very barlike. It is extremely linear over an angular extent of 10–12 arcsec (6–8 kpc if $D = 129$ Mpc) and giant H II regions are distributed along its length. The possible association of the linear structure with component "B" further supports the idea that "B" lies at the distance of NGC 985 and is not a foreground star.

4. The removal of the bulge-like emission also reveals that the ringlike nature of NGC 985 is not an accurate description of the underlying disk component. The ring is incomplete to the east. (Indeed the morphology of the underlying disk may be better described as a one-armed spiral with a very low pitch angle.) This morphology is probably closely related to those of collisional ring galaxies, being similar to the forms produced in the larger impact-parameter central collisions of Toomre (1978).

5. The colors of the star forming knots are consistent with a population of heavily reddened O/B star complexes. If this interpretation is correct then up to 6.5 mag of optical extinction is present within the knots. This is not inconsistent with published optical spectroscopy of the galaxy.

6. The radial distribution of IR colors in the nearly ringlike component of the galaxy show radial trends similar to those seen in the Cartwheel ring galaxy (Marcum, Appleton, & Higdon 1992). Radial color gradients are predicted in the collision ring galaxy picture if young stars are formed in the ring as it expands into the disk (Appleton & Struck-Marcel 1987b; Struck-Marcell & Appleton 1987).

7. Faint extended IR emission is detected to the southeast of NGC 985 which further supports a double-galaxy collision picture for the peculiar morphology of NGC 985. Such emission would not be expected if the system resulted from a collision between a IGC and a gas-rich disk.

Infrared spectroscopy of NGC 985 will significantly enhance our understanding of the nature of the possible second nucleus in NGC 985 and will lead to a more complete understanding of the rate of star formation in this apparently dusty Seyfert galaxy.

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