INFRARED PHOTOMETRY OF THE NEBULOSITY AROUND QUASARS

G. NEUGEBAUER, K. MATTHEWS, B. T. SOIFER, AND J. H. ELIAS

Palomar Observatory, California Institute of Technology

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ABSTRACT

Measurements of the nebulosity around quasars have been carried out in the near-infrared. The colors of the host galaxies found in these observations are consistent with those of normal galaxies. The luminosities are also similar to those of normal galaxies but are slightly brighter than average.

Subject headings: galaxies: photometry — infrared: sources — quasars

I. INTRODUCTION

The existence of nebulosity around some quasars, commonly presumed to be evidence for the presence of host galaxies, has been known for several years. Hutchings *et al.* (1984) and Hutchings, Crampton, and Campbell (1984) have summarized optical imaging of some 75 quasars; host galaxies are resolved in all but seven of the quasars. Visual images of nebulosity around more limited selected samples of quasars have also been obtained by Wyckoff, Wehinger, and Gehren (1981), Stockton (1982), Tyson, Baum, and Kreidl (1982), Gehren *et al.* (1984), and Malkan, Margon, and Chanan (1984). Boroson and Oke (1982), Boroson, Oke, and Green (1982), Balick and Heckman (1983), and Boroson and Oke (1984) have obtained spectra of the nebulosity around several quasars. Both the spectroscopic and the imaging studies point strongly to the conclusion that the nebulosities represent host galaxies around the quasars. Many of the observations are consistent with the interpretation that the nebulosity represents spiral galaxies, but there is no overwhelming consensus that all host galaxies are spiral galaxies.

In this paper, near-infrared observations of the nebulosity around 16 quasars are reported. The purpose of the observations was to estimate the contribution that such nebulosity could make to the observed energy distributions of quasars and to determine whether the infrared properties of the host galaxies associated with quasars were in any way unique.

II. OBSERVATIONS AND RESULTS

All the observations were carried out at the 5 m Hale telescope of the Palomar Observatory. A solid nitrogen cooled InSb detector was used at the Cassegrain focus of the f/70 chopping secondary. Photometry with filters defining the standard *J* (center wavelength = $\lambda_0 = 1.3 \mu\text{m}$), *H* ($\lambda_0 = 1.65 \mu\text{m}$), and *K* ($\lambda_0 = 2.2 \mu\text{m}$) magnitudes was done using standard stars given by Elias *et al.* (1982). In all cases, the reference beam positions were 15" to the north and south of the object being measured.

Two methods of observation were used to measure the nebulosity. The majority of the measurements were made using an annular diaphragm with an opaque inner disk of 5" diameter centered within a 10" diameter circular diaphragm to measure the nebulosity. Separate measurements using a 5" diameter circular diaphragm were used to obtain the flux in the central 5". For four of the observations, the flux measured through a circular diaphragm 5" in diameter and centered on the quasar was compared with the flux measured through diaphragms

either 10" or (in 1982 December) 11" in diameter. These measurements, as can be seen in Table 1, are of somewhat lower accuracy.

All the observations were carried out by alternating measurements of the quasar and of a nearby star of similar infrared brightness. Typically, the comparison star was within 60" of the quasar. The visual seeing in all cases was required to be better than 2" full width at half-maximum and the amount of spill into the annular region outside of 5" diameter for a centered star was typically about 3%. Most of this spill appears to be due to scattering in the telescope and instrument rather than to atmospheric seeing, and was thus quite stable ($\pm 0.3\%$). Nebulosity in the 5"–10" annulus which is $\ll 3\%$ of the quasar flux would not, however, be readily detectable. Typically, four separate sets of measurements on the quasar and on the nearby star were carried out at each wavelength on each night.

The journal of observations and the measured results are given in Table 1. The objects are identified by their truncated 1950 equatorial coordinates. The primary measurement is the ratio of the flux in the annulus to that in the central 5" (F_a/F_c). The flux in the annulus has been corrected for the spill from the central object by assuming the spill when the quasar was centered in the diaphragm was equal to that when the nearby star was centered. The 1982 observations have been corrected to a 10" diameter diaphragm assuming the surface brightness of the nebular component varies as radius⁻¹. When the flux in the annulus was less than 3 times its uncertainty, the magnitude limit of 3 times the uncertainty is quoted in Table 1.

The uncertainties quoted in Table 1 are standard deviations derived from the internal consistency of the measurements only. They are purely a measure of the uncertainty in the measurement of the nebulosity relative to that of the quasar. The effects of variable seeing are included in these uncertainties, although the annular measurements of the comparison stars indicate that the dominant source of uncertainty is usually photon statistics in the measurement of the weak fluxes seen in for the quasar annuli. There is an additional uncertainty of ~ 0.05 mag associated with the absolute photometry of the quasar. Measurements of the annular flux on more than one night indicate that the measurements of brighter objects are accurate to about 10%. This is true both for objects like 0833+770 and 0906+487, where the annular flux is roughly 20%–40% that of the quasar, and for objects like 1251+640 and 1545+210, where the annular flux is proportionately much less.

Since the system was calibrated with respect to point, rather than extended, sources, systematic uncertainties up to $\sim 5\%$

TABLE 1
OBSERVED FLUX RATIOS AND MAGNITUDES

Object Date		1.3 μ m		1.6 μ m		2.2 μ m		J-K		H-K	
		unc		unc		unc		unc		unc	
0026+129 27Jul83	F _a /F _c Cnt(mag) Neb(mag)	0.044 13.89 17.28	0.004 0.09	0.046 13.36 16.70	0.004 0.09	0.027 12.36 16.29	0.002 0.08	 1.53 1.06	 - 0.12	1.00 0.48	 -
0043+039 22Oct83	F _a /F _c Cnt(mag) Neb(mag)	0.026 14.82 18.78	0.008 0.29	0.030 14.34 18.15	0.004 0.14	0.015 13.51 >17.56	0.008 	 1.31 < 1.22	 - 	0.83 < 0.59	 -
0838+770 03Dec82	F _a /F _c Cnt(mag) Neb(mag)	0.444 14.65 15.53	0.025 0.06	0.376 13.89 14.95	0.020 0.06	0.232 12.84 14.43	0.050 0.21	 1.81 1.11	 - 0.22	1.05 0.53	 -
0838+770 22Oct83	F _a /F _c Cnt(mag) Neb(mag)	0.387 14.60 15.63	0.006 0.02	0.341 13.86 15.03	0.003 0.01	0.222 12.86 14.49	0.001 0.00	 1.74 1.14	 - 0.02	1.00 0.53	 -
0838+770 14Apr84	F _a /F _c Cnt(mag) Neb(mag)	0.336 14.58 15.76	0.020 0.06	0.326 13.84 15.06	0.030 0.10	0.188 12.79 14.60	0.020 0.11	 1.79 1.16	 - 0.13	1.05 0.45	 -
0906+484 04Dec82	F _a /F _c Cnt(mag) Neb(mag)	0.261 14.54 16.00	0.021 0.08	0.216 13.79 15.45	0.019 0.09	0.171 12.74 14.66	0.020 0.12	 1.80 1.34	 - 0.15	1.05 0.80	 -
0906+484 08May84	F _a /F _c Cnt(mag) Neb(mag)	0.242 14.53 16.07	0.003 0.01	0.199 13.72 15.47	0.011 0.06	0.126 12.64 14.89	0.008 0.07	 1.89 1.18	 - 0.07	1.08 0.58	 -
1211+143 21May83	F _a /F _c Cnt(mag) Neb(mag)	0.021 13.11 17.30	0.005 0.23	0.007 12.41 17.80	0.001 0.14	-0.013 11.33 >16.13	0.004 	 1.78 <1.17	 - 	1.08 < 1.67	 -
1351+640 04Dec82	F _a /F _c Cnt(mag) Neb(mag)	0.069 13.43 16.33	0.007 0.10	0.069 12.91 15.81	0.004 0.06	0.051 11.92 15.15	0.005 0.10	 1.51 1.18	 - 0.15	0.99 0.66	 -
1351+640 22Apr83	F _a /F _c Cnt(mag) Neb(mag)	0.071 13.42 16.29	0.006 0.09	0.081 12.72 15.45	0.004 0.05	0.049 11.91 15.18	0.003 0.06	 1.51 1.11	 - 0.11	0.81 0.26	 -
1435-067 21May83	F _a /F _c Cnt(mag) Neb(mag)	0.059 14.58 17.65	0.010 0.17	0.055 13.81 16.96	0.002 0.04	0.026 12.60 16.56	0.005 0.19	 1.98 1.09	 - 0.26	1.21 0.40	 -
1501+106 24May83	F _a /F _c Cnt(mag) Neb(mag)	0.160 12.93 14.92	0.005 0.03	0.136 12.15 14.32	0.001 0.01	0.072 11.16 14.02	0.003 0.04	 1.77 0.90	 - 0.06	0.99 0.30	 -
1501+106 08May84	F _a /F _c Cnt(mag) Neb(mag)	0.140 12.79 14.92	0.002 0.02	0.125 12.08 14.34	0.002 0.02	0.087 11.13 13.78	0.006 0.07	 1.66 1.14	 - 0.07	0.95 0.56	 -
1535+547 24May83	F _a /F _c Cnt(mag) Neb(mag)	0.088 13.24 15.88	0.003 0.04	0.063 12.40 15.40	0.001 0.02	0.036 11.33 14.94	0.002 0.06	 1.91 0.94	 - 0.07	1.07 0.46	 -
1545+210 23Jun83	F _a /F _c Cnt(mag) Neb(mag)	0.088 14.68 17.32	0.012 0.14	0.079 13.93 16.69	0.006 0.08	0.069 12.84 15.74	0.014 0.20	 1.84 1.58	 - 0.24	1.09 0.94	 -
1545+210 08May84	F _a /F _c Cnt(mag) Neb(mag)	0.080 14.69 17.43	0.003 0.04	0.064 13.96 16.94	0.008 0.13	0.056 12.85 15.98	0.009 0.16	 1.84 1.45	 - 0.17	1.11 0.97	 -
1700+518 21May83	F _a /F _c Cnt(mag) Neb(mag)	0.016 13.80 18.29	0.005 0.30	0.018 13.02 17.38	0.004 0.22	0.004 11.74 >16.54	0.004 	 2.06 <1.75	 - 	1.28 <0.84	 -
1704+608 22Apr83	F _a /F _c Cnt(mag) Neb(mag)	0.004 14.30 >18.00	0.011 	0.018 13.74 18.10	0.005 0.27	0.008 12.70 >16.89	0.007 	 1.60 -	 - 	1.04 <1.21	 -
1718+481 25May83	F _a /F _c Cnt(mag) Neb(mag)	0.018 13.42 >17.78	0.006 	0.012 13.02 >17.58	0.005 	0.019 12.51 >16.21	0.011 	 0.91 -	 - 	0.51 -	 -

TABLE 1—Continued

Object		1.3 μ m		1.6 μ m		2.2 μ m		J-K	H-K	
Date		unc		unc		unc		unc	unc	
2200+420	F _a /F _c	0.170	0.002	0.169	0.004	0.101	0.005			
25May83	Cnt(mag)	12.74		11.89		10.99		1.75	-	0.90
	Neb(mag)	14.66	0.01	13.82	0.03	13.48	0.05	1.18	0.05	0.34
2200+420	F _a /F _c	0.129	0.003	0.114	0.001	0.084	0.001			
26Jul83	Cnt(mag)	12.69		11.87		10.97		1.72	-	0.90
	Neb(mag)	14.91	0.02	14.23	0.01	13.66	0.01	1.25	0.03	0.57
2200+420	F _a /F _c	0.103	0.001	0.093	0.001	0.073	0.002			
19Oct83	Cnt(mag)	12.50		11.67		10.79		1.71	-	0.88
	Neb(mag)	14.97	0.01	14.25	0.01	13.63	0.03	1.34	0.03	0.62
2209+184	F _a /F _c	0.333	0.016	0.305	0.005	0.259	0.004			
24May83	Cnt(mag)	13.96		13.27		12.50		1.46	-	0.77
	Neb(mag)	15.15	0.05	14.56	0.02	13.97	0.02	1.19	0.05	0.59
2209+184	F _a /F _c	0.347	0.011	0.289	0.007	0.230	0.006			
18Oct83	Cnt(mag)	13.97		13.28		12.49		1.48	-	0.79
	Neb(mag)	15.12	0.03	14.63	0.03	14.09	0.03	1.03	0.04	0.54
2302+029	F _a /F _c	0.004	0.011	0.017	0.007	0.019	0.005			
25Jul83	Cnt(mag)	14.84		14.43		13.80		1.04	-	0.63
	Neb(mag)	>18.54		>18.62		18.10	0.25	>0.44		>0.52
2302+029	F _a /F _c	0.012	0.006	0.006	0.004	0.013	0.006			
19Oct83	Cnt(mag)	14.85		14.45		13.78		1.07	-	0.67
	Neb(mag)	>19.21		>19.25		>18.14		-		-
2302+029	F _a /F _c	0.015	0.010	0.022	0.010	0.003	0.013			
22Oct83	Cnt(mag)	14.88		14.50		13.90		0.98	-	0.60
	Neb(mag)	>18.69		>18.31		>17.42		-		-

NOTE.—* Measured through two separate circular diaphragms. The rest were measured using an annulus of 5" inner diameter and 10" outer diameter.

may be present in the measurements of colors. Measurements of beam profiles indicate that these effects, if present, would make the colors appear redder than they actually are. It is possible that there are some systematic effects involved in centering the quasars and comparison star in the annulus as a result of their different visual brightness or colors which would lead to spurious detections of nebulosity. Estimates place this effect at less than 1% of the flux level of the quasar.

The quasars were selected for observation primarily on the basis of brightness, low redshift, and availability. Some were also chosen because optical and infrared measurements of the quasars made with diaphragms of different diameters gave apparently discordant results; see, e.g., Neugebauer *et al.* (1979). All but PG 0906+484 and 2200+420 (BL Lac) are included in the Palomar Bright Quasar Survey (Schmidt and Green 1983). The object PG 0906+484 belongs to the larger Palomar-Green Survey but was omitted from the Palomar Bright Quasar Survey because it was fainter than the completeness limit in its area.

Two of the quasars listed in Table 1, 0906+484 and 1351+640, have been observed in the *R* and *B* optical passbands by Hutchings, Crampton, and Campbell (1984). In both, there is clear optical evidence for host galaxies with generally circular appearance. A red plate of the quasar 1700+518 by these same authors indicated no nebulosity to a limit one-thirtieth that of the quasar light. Optical spectra of three quasars in the present sample—1501+106, 1535+547, and 2209+184—have been obtained by Boroson, Oke, and Green (1982). All show the presence of optical continuum and are consistent with the spectra of spiral galaxies.

III. DISCUSSION

It is seen from Table 1 that the flux in the near-infrared contributed by the nebulosity within a 10" diameter diaphragm of the quasar is in some cases a significant fraction of the infrared flux from the quasar itself. The observed *J-K* colors of the measured nebulosities are shown as a function of redshift in Figure 1. They are compared with the *J-K* colors of some 19 optically selected galaxies measured by Ellis and Allen (1983). It is seen that within the limited number of objects, the two distributions are the same. Aaronson (1977) has shown that the infrared colors of spiral and elliptical galaxies are very similar; thus the present measurements cannot distinguish between different morphological galaxy types.

The *V-K* color of the nebulosity surrounding BL Lac (2200+420) can be obtained by comparing the infrared results with the observations of Thuan, Oke, and Gunn (1975) who measured the *V* magnitude with a 3"7–10" diameter annular diaphragm. If their observed *V* magnitude, corrected for reddening and the spill from the obscuring disk, is normalized to a 5"–10" annulus, a color of *V-K* = 3.7 mag is obtained. Although this is redder than most normal galaxies, it is not extreme (Aaronson 1977).

The absolute magnitudes—*M_J*, *M_H*, and *M_K*—of the host galaxies were derived assuming a Hubble constant of 50 km s⁻¹ Mpc⁻¹ and a deceleration parameter, *q*₀, of 0.0. Two corrections, besides those relating directly to the distance factors, were applied to the observed magnitudes listed in Table 1 to bring them to absolute magnitudes: a redshift correction (the *K*-correction) and an estimate of the galaxy flux originating

TABLE 2
ABSOLUTE MAGNITUDES

OBJECT	z	1.3 μ m		1.65 μ m		2.2 μ m	
		M_J (mag)	L_Q/L_G	M_H (mag)	L_Q/L_G	M_K (mag)	L_Q/L_G
0026+129.....	0.142	-24.0 ± 0.3	3.8	-24.5 ± 0.3	3.8	-24.5 ± 0.3	10.8
0043+039.....	0.384	-24.5 ± 0.4	6.1	-25.1 ± 0.3	5.8	> -24.8	> 16.9
0838+770.....	0.131	-25.6 ± 0.3	...	-26.2 ± 0.3	...	-26.3 ± 0.3	0.7
0906+484.....	0.118	-25.0 ± 0.3	...	-25.5 ± 0.3	...	-25.8 ± 0.3	1.1
1211+143.....	0.085	-22.9 ± 0.3	8.8	-22.3 ± 0.3	29.4	> -23.8	> 20.8
1351+640.....	0.087	-24.0 ± 0.3	2.2	-24.6 ± 0.3	2.1	-24.8 ± 0.3	4.3
1435-067.....	0.129	-23.4 ± 0.3	2.6	-24.0 ± 0.3	3.0	-24.1 ± 0.3	10.3
1501+106.....	0.036	-23.6 ± 0.3	0.8	-24.1 ± 0.3	1.0	-24.4 ± 0.3	2.3
1535+547.....	0.038	-22.7 ± 0.3	1.6	-23.1 ± 0.3	2.6	-23.5 ± 0.3	5.4
1545+210.....	0.266	-25.2 ± 0.3	1.6	-25.7 ± 0.3	2.2	-26.0 ± 0.3	4.6
1700+518.....	0.292	-24.4 ± 0.4	11.3	-25.2 ± 0.4	10.9	> -25.5	> 29.0
1704+608.....	0.371	> -25.2	> 4.7	-25.0 ± 0.4	10.2	> -25.5	> 17.0
1718+481.....	1.084	> -27.8	> 5.6	> -27.7	> 8.9	> -28.2	> 8.7
2200+420.....	0.070	-25.1 ± 0.3	1.0	-25.8 ± 0.3	1.2	-26.1 ± 0.3	2.2
2209+184.....	0.070	-24.8 ± 0.3	...	-25.3 ± 0.3	...	-25.6 ± 0.3	...
2302+029.....	1.044	> -26.1	> 6.8	-26.0 ± 0.4	10.8	-25.9 ± 0.3	21.4

outside the annular diaphragm. The derived absolute magnitudes are listed in Table 2.

The K -correction applied to the nebulosity was calculated by Persson (1984) for a first-ranked elliptical galaxy with rest frame colors $R-J=2.31$ mag, $J-K=1.02$ mag, and $H-K=0.17$ mag. The size of this term is typically 0.07, 0.01, and -0.4 mag for the J , H , and K bands at the median redshifts $z=0.13$; a tabulation of the K -corrections used is given in Table 3. No K -correction has been applied to the quasar. This correction is small, however, since for a power-law spectrum the K -correction equals $(1+z)^{(1+\alpha)}$, where α , the power law of the flux density with frequency, is close to -1 for quasars.

The correction for the galaxy flux inside the inner annulus radius was estimated through an iterative procedure. The total absolute blue magnitude, M_B , of the galaxy was estimated assuming that $M_B - M_H = 4$ mag (Persson, Frogel, and Aaronson 1979), while the iterative procedure was started assuming an initial absolute H magnitude equaling that measured in the annulus minus 2 mag. The effective radius of the galaxy was then found using the mean relationship for the effective radius as a function of the total blue magnitude as given by Binggeli, Sandage, and Tarenghi (1984) for galaxies in the Virgo cluster or non-Virgo cluster elliptical galaxies. Finally, the contribution within the radius of the annulus was found relative to that measured in the annulus by assuming that the galaxy surface brightness followed the Hubble law (Hubble 1930) and that the peak brightness was centered on the quasar. The core radius was taken as 0.093 the effective radius (Kormendy 1977). The flux thus derived as arising from the galaxy inside the inner annulus radius was typically 3 times that actually observed in the annular diaphragm; the ratio ranged from 1.9 to 3.8.

FIG. 1.—The $J-K$ colors of the host galaxies vs. redshift. The optically selected sample used for comparison is from Ellis and Allen (1983). The colors of Ellis and Allen have been transformed to those of the Caltech system using the precepts of Elias *et al.* (1982).

TABLE 3
 K -CORRECTIONS^a

Redshift	$K(J)$ (mag)	$K(H)$ (mag)	$K(K)$ (mag)
0.00.....	0.00	0.00	0.00
0.05.....	0.03	-0.01	-0.17
0.10.....	0.06	0.01	-0.30
0.15.....	0.08	0.01	-0.41
0.20.....	0.10	0.01	-0.51
0.25.....	0.12	0.01	-0.59
0.30.....	0.11	0.02	-0.65
0.40.....	0.18	0.06	-0.69
0.50.....	0.27	0.11	-0.68
0.60.....	0.31	0.13	-0.67
0.70.....	0.39	0.15	-0.67
0.80.....	0.48	0.19	-0.65
0.90.....	0.55	0.24	-0.62
1.00.....	0.60	0.30	-0.59
1.10.....	0.64	0.34	-0.57
1.20.....	0.69	0.40	-0.55

^a Calculated by S. E. Persson 1984 for first-ranked elliptical galaxies.

The contribution to the total flux from the galaxy outside the outer 10" diameter of the annulus was approximated by assuming the surface brightness $I(r)$, as a function of the radial distance r from the nucleus, was of the form $I(r) \propto I_0 r^{-2}$. This dependence is in keeping with the optical observations of Gehren *et al.* (1984) and was assumed to hold out to an outer radius such that the flux arising between the effective radius and the outer radius would be half the total flux of the galaxy. This contribution to the total flux was approximately twice the flux observed in the annulus.

The process of estimating the total flux was repeated iteratively until the final total absolute H magnitude agreed with that initially assumed and the flux outside the effective radius was half the total. The same contributions for the galaxy inside and outside of the annulus were used at all three infrared wavelengths.

The correction for the flux inside a 5" diameter is consistent with an extrapolation of the mean curve of growth for elliptical and spiral galaxies measured at 2.2 μ m by Frogel *et al.* (1978). Numerical tests made with various model parameters show that the solutions with these adopted models are probably uncertain by $\pm 25\%$. If, however, the surface brightness were proportional to r^{-1} , the flux inside the annulus would be equal to, rather than ~ 3 times, the flux in the annulus.

For the objects PG 0838+770, PG 0906+484, and PG 2209+184 the model used is probably incorrect since the results imply the galaxy contributes 0.81, 0.62, and 0.73 of the flux within a 5" diameter diaphragm at 1.3 μ m, and such nebulaosity should have removed the sources from the PG sample. In these cases, at least, the surface brightness of the galaxy may not follow the Hubble law, the galaxy may not be centered on the quasar, or multiple nuclei may be present. Also, in cases where the nebulaosity contributes much of the flux inside a 5" diameter diaphragm, the simplistic fit to correct for the spill from the central obscuration into the annulus will be incorrect.

The estimated total galaxy magnitudes are clearly model dependent and quite uncertain. Other models would give different estimates, but whether better estimates would generally be obtained is not *a priori* certain. The assumptions used probably give too large estimates of the total galaxy flux. It is reassuring that Thuan, Oke, and Gunn (1975) derive a value of $M_V = -22.6$ mag for BL Lac implying a corrected color $M_V - M_K = 3.5$ mag, a color completely consistent with normal galaxies. This may be taken as an indication that the procedures used to estimate the total absolute magnitudes are not too much in error.

The ratios of the infrared luminosity of the quasars to that of the host galaxies L_Q/L_G are similar to those observed in the blue. In Figure 2 the infrared luminosity ratios at 1.6 μ m are compared with those obtained by Hutchings *et al.* (1984) in the blue. The three quasars listed above whose galaxy contribution dominates the flux inside 5" diameter are arbitrarily excluded from the figure and Table 2. Although the range of the ratio in the visible is perhaps slightly wider than in the infrared, this slight difference can be accounted for by the different techniques. Although the apparent similarity in the two distributions may be a result of various selection effects determining the two samples, it is disturbing. Since the mean $B-H$ color of a wide range of galaxy types lies between 3.5 and 4.1 mag (Persson, Frogel, and Aaronson 1979) while that of quasars is ~ 2.4 mag, the ratio L_Q/L_G should be systematically lower in the infrared than in the blue by a factor between 3 and 4. It is encouraging that the two galaxies measured in common with

FIG. 2.—Histograms of the ratio of the luminosity ascribed to the host galaxy to that ascribed to the quasar in the H and B wavebands. The three galaxies where the models indicate the galaxy dominates the flux within a 5" diameter diaphragm have been omitted; see text. The B ratios have been obtained from Hutchings *et al.* (1984).

Hutchings *et al.* (1984) have K -corrected colors $M_B - M_H = 3.6$ mag (PG 0906+484) and 3.7 mag (PG 1351+640).

The K -corrected colors of the host galaxies, for the subset of galaxies where the colors are well measured, are shown in Table 4. The colors lie close to those measured by Frogel *et al.* (1978) for E and S0 galaxies, but differ by ~ 0.1 mag tending to be bluer in $J-H$ and $J-K$ and correspondingly redder in $H-K$. Although the statistics are not sufficiently understood at this time to warrant drawing major conclusions from them, they may reflect color changes with radial distribution in the galaxies. Note that these colors do not depend upon the correction for the galaxy outside the annular diaphragm.

The absolute magnitudes of the host galaxies, as given in Table 2 and plotted in Figure 3, are typical of bright galaxies, but are certainly not extreme. The distribution of galaxy luminosities is similar in extent to that of normal galaxies ($-27 < M_H < -22$ mag), but there is an evident bias toward higher luminosities. The median absolute H magnitude is $M_H = -25.4$ mag. If $M_B - M_H \approx 3.8$ mag, the corresponding median absolute B magnitude of the sample is $M_B = -21.6$

TABLE 4
 K -CORRECTED GALAXY COLORS

Object	$M_J - M_H$ (mag)	$M_H - M_K$ (mag)	$M_J - M_K$ (mag)
0026+129	0.51 ± 0.13	0.01 ± 0.12	0.52 ± 0.12
0838+770	0.57 ± 0.07	0.11 ± 0.04	0.68 ± 0.07
0906+484	0.51 ± 0.11	0.33 ± 0.16	0.84 ± 0.18
1351+640	0.63 ± 0.09	0.20 ± 0.09	0.83 ± 0.11
1501+106	0.56 ± 0.03	0.26 ± 0.05	0.83 ± 0.05
1535+547	0.45 ± 0.04	0.34 ± 0.07	0.79 ± 0.07
1545+210	0.47 ± 0.12	0.32 ± 0.16	0.78 ± 0.17
2200+420	0.68 ± 0.08	0.33 ± 0.06	1.01 ± 0.08
2209+184	0.50 ± 0.05	0.35 ± 0.04	0.85 ± 0.06
Mean	0.54 ± 0.08	0.25 ± 0.12	0.79 ± 0.13
E and S0 ^a	0.68 ± 0.04	0.20 ± 0.03	0.88 ± 0.05

^a From Frogel *et al.* 1978.

FIG. 3.—The absolute magnitudes at H of the host galaxies plotted against that of the quasars. The uncertainties are typically assumed to be of order 0.3 mag. The three galaxies where the models indicate the galaxy dominates the flux within a $5''$ diameter diaphragm have been omitted; see text. The figure is similar to Fig. 7 of Hutchings *et al.* (1984). The limit is for the galaxy PG 1718+481 and represents a 3σ limit. The actual measurement was 2.4σ .

mag, brighter than typical field or cluster galaxies (e.g., Schechter 1976).

Figure 3, the counterpart to Figure 7 of Hutchings *et al.* (1984), shows that the correlation, including the slope, between host galaxy and quasar luminosity previously noted in the B waveband extends to the infrared. Selection effects are clearly important in considering the total range of absolute flux densities associated with the nebulosity. As noted by Hutchings *et al.*, the top left-hand area of the diagram is empty since galaxies lying here would have caused the source to be classified as a

Seyfert 1 galaxy rather than a quasar, and the source would not have been included in the sample. The absence of sources in the bottom right-hand area suggests a lower bound on the ratio of host galaxy to quasar luminosities, strengthening the conjecture made by Hutchings *et al.* It is interesting that none of the measurements except PG 1718+481 resulted in less than 3σ limits at $1.65\mu\text{m}$, the most sensitive infrared wavelength for detecting nebulosity, when the observations over several nights were averaged; see Table 2. The detection of nebulosity around PG 1718+481 was at the 2.4σ level. Nebulosity at B was not detected around PG 1700+518 by Hutchings *et al.* (1984) to a limit corresponding to only $M_B - M_H > 2.8$ mag. Further observations of higher luminosity quasars are needed to see whether there are a significant number of faint galaxies hosting quasars.

IV. CONCLUSIONS

Measurements of the near-infrared flux densities of the nebulosity around several quasars have shown that in some quasars the nebulosity within $10''$ diameter contributes a significant fraction of the near-infrared flux of the quasar. The observations are consistent with the host galaxies being normal elliptical or spiral galaxies. The galaxies have luminosities similar to those observed from normal galaxies at the redshifts of the quasars, but are on the bright end of the distribution.

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REFERENCES

- Aaronson, M. 1977, Ph.D. thesis, Harvard University.
 Balick, B., and Heckman, T. 1963, *Ap. J. (Letters)*, **265**, L1.
 Binggeli, B., Sandage, A., and Tarenghi, M. 1984, *A.J.*, **89**, 64.
 Boroson, T. A., and Oke, J. B. 1982, *Nature*, **296**, 397.
 ———. 1984, *Ap. J.*, **281**, 535.
 Boroson, T. A., Oke, J. B., and Green, R. 1982, *Ap. J.*, **263**, 32.
 Elias, J. H., Frogel, J. A., Matthews, K., and Neugebauer, G. 1982, *A.J.*, **87**, 1029.
 Ellis, R. S., and Allen, D. A. 1983, *M.N.R.A.S.*, **203**, 685.
 Frogel, J. A., Persson, S. E., Aaronson, M., and Matthews, K. 1978, *Ap. J.*, **220**, 75.
 Gehren, T., Fried, J., Wehinger, P. A., and Wyckoff, S. 1984, *Ap. J.*, **278**, 11.
 Hubble, E. 1930, *Ap. J.*, **71**, 231.
 Hutchings, J. B., Crampton, D., and Campbell, B. 1984, *Ap. J.*, **280**, 41.
 Hutchings, J. B., Crampton, D., Campbell, B., Duncan, D., and Glendenning, B. 1984, *Ap. J. Suppl.*, **55**, 319.
 Kormendy, J. 1977, *Ap. J.*, **218**, 333.
 Malkan, M. A., Margon, B., and Chanan, G. A. 1984, *Ap. J.*, **280**, 66.
 Neugebauer, G., Oke, J. B., Becklin, E. E., and Matthews, K. 1979, *Ap. J.*, **230**, 79.
 Persson, S. E. 1984, private communication.
 Persson, S. E., Frogel, J. A., and Aaronson, M. 1979, *Ap. J. Suppl.*, **39**, 61.
 Schechter, P. 1976, *Ap. J.*, **203**, 297.
 Schmidt, M., and Green, R. 1983, *Ap. J.*, **269**, 353.
 Stockton, A. 1982, *Ap. J.*, **257**, 33.
 Thuan, T. X., Oke, J. B., and Gunn, J. E. 1975, *Ap. J.*, **201**, 45.
 Tyson, J. A., Baum, W. A., and Kreidl, T. 1982, *Ap. J. (Letters)*, **257**, L1.
 Wyckoff, S., Wehinger, P., and Gehren, T. 1981, *Ap. J.*, **247**, 750.

J. H. ELIAS, K. MATTHEWS, G. NEUGEBAUER, and B. T. SOIFER: Downs Laboratory of Physics 320-47, California Institute of Technology, Pasadena, CA 91125