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NEAR-INFRARED OBSERVATIONS OF EXTENDED EMISSION AROUND PG 1545+210

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ABSTRACT

Infrared images at H and Ks of the quasar PG 1545+210 clearly show both extended emission centered on the quasar and a companion galaxy. The magnitudes of the extended emission deduced from these observations depend strongly on the model adopted for the emission. Both an exponential disk model and a de Vaucouleurs model provide adequate fits to the extended emission. If it is assumed to follow an exponential disk galaxy, these measurements imply that the host galaxy has absolute magnitudes comparable with those of a Schechter L* galaxy. With this assumption for the intrinsic light distribution, the H magnitude and the *Hubble Space Telescope* limit on the V magnitude are inconsistent with color predictions for unreddened spiral galaxies at the redshift of the quasar. If the data are fitted to a de Vaucouleurs model, the extended emission dominates the total energy of the system and significantly exceeds that of an L* galaxy. The companion galaxy has colors consistent with its being at the redshift of the quasar, but its luminosity is at most a small part of that of the entire system. If the companion is at the redshift of PG 1545+210, its absolute magnitude is $M_H \sim -22$ mag, significantly fainter than that of an L* galaxy.

Subject headings: galaxies: photometry — infrared: galaxies — quasars: general — quasars: individual (PG 1545+210)

1. INTRODUCTION

Recent *Hubble Space Telescope* (*HST*) searches for extended galaxy emission around low-redshift quasars by Bahcall, Kirhakos, & Schneider (1995, hereafter BKS95) are, in some cases, seemingly in contradiction with ground-based near-infrared observations (see references in BKS95) in that often no bright visual host galaxy is detected in the *HST* data. In this Letter, we present new near-infrared observations of PG 1545+210 = PKS 1545+210 = 3CR 323.1 = 4C 21.45, a quasar at a redshift of 0.266 with seemingly disparate measurements between BKS95 and McLeod & Rieke (1994a, b [hereafter MR94], 1995). McLeod & Rieke find a host galaxy at H (1.65 μm) the absolute magnitude of which exceeds significantly that of a Schechter L* galaxy (Schechter 1976) while BKS95 detect no host galaxy at V but do find a faint companion galaxy within 2″.6 of the quasar.

The present observations are part of a program of observing low- and high-redshift quasars for the presence of extended near-infrared emission with the Palomar and Keck telescopes. Because of the difficulty of obtaining the measurements and because the present results are illuminating as to the true situation, it is appropriate to present these limited results at this time. Throughout this Letter we have adopted $H_0 = 75$ km s^{-1} Mpc^{-1}, $q_0 = 0$.

2. OBSERVATIONS AND RESULTS

Observations were made at the 200 inch (5.08 m) Hale telescope at the Palomar Observatory on the night of 1995 July 13 using the Cassegrain near-infrared camera. The array in the camera was a 256 × 256 InSb array with a scale of 0″.125 pixel^{-1}. Data were obtained in the K-short (Ks) (2.00–2.30 μm) and H (1.5–1.8 μm) filter bands. The median seeing was 0″.7 FWHM at H and Ks. The observations were done in 15 sequences, each of four exposures—an image of a star 90″ from the object (the point-spread function [PSF]), an image of the object, an image of the blank sky 30″ from the object, and another image of the PSF—thus providing measurements of the PSF bracketing that of the object. There is a star ~11″ to the east of the quasar, but unfortunately it is too faint to use as the PSF in the analysis. Each individual exposure was 30 s in duration. An offset-guider was used that applied a "tip-tilt" correction based on the visual position of the guide star; the same guide star was used for both PG 1545+210 and the PSF. The images were subsequently linearized, flat-fielded, and sky-subtracted following standard procedures. Three sequences with significantly larger FWHM in both the object and the PSF image were discarded and the remaining images combined in mosaics at H and Ks. The resulting mosaic at H is shown in Figure 1 (Plate L15).

In order to emphasize the low surface brightness emission, azimuthal averages as a function of radial distance from the center of the quasar were derived from the mosaic image. The radial profiles at H and Ks are shown in Figure 2 along with similar profiles for the PSF; the presence of extended emission above the PSF is clear.

The companion object 2″.6 to the west of the quasar identified by BKS95 is clearly resolved from the quasar in both the H and Ks images; it is hidden in the wings of the quasar profile in MR94. Although it is extended in the *HST* image of BKS95, the companion is too faint in the infrared image to distinguish its shape.

Photometry of PG 1545+210, done relative to stars quoted in Elias et al. (1982), resulted in $H = 14.01$ mag and $Ks = 13.23$ mag for the flux within a beam diameter of 10″ centered on the quasar. The measured H and Ks magnitudes and colors fall well within the range of previous observations obtained at Palomar since 1980; there is evidence that PG 1545+210 has varied by as much as 0.3 mag at H and K during that time (G. Neugebauer 1995, private communication). The H magnitude is in good agreement with that given by MR94. Photometry of the companion within a 1″ diameter beam yields magnitudes $H = 17.6$ mag, $Ks = 17.0$ mag. The beam effect was partially taken into account by using the star ~11″.4

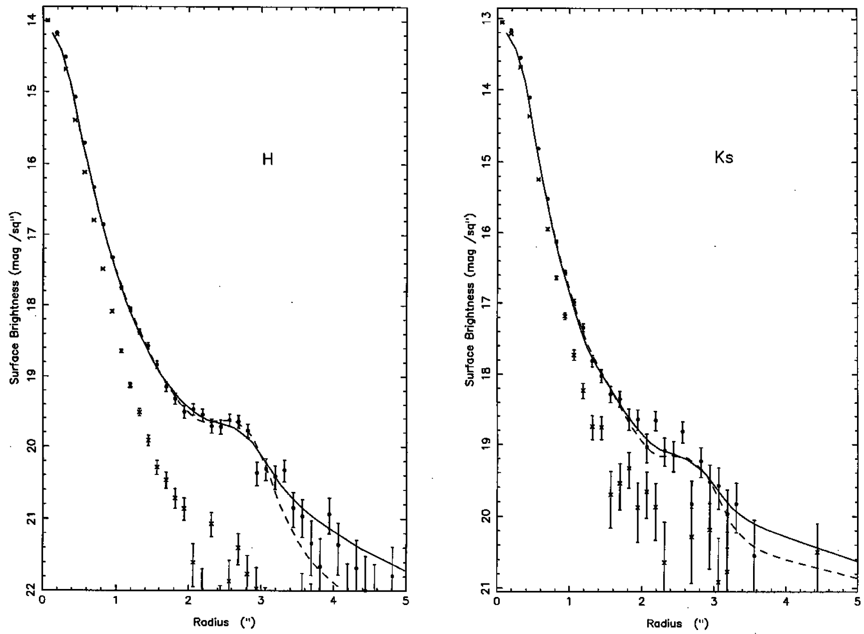

FIG. 2.—Azimuthally averaged radial profiles for the *H*-band mosaic (*left*) and the *Ks* mosaic (*right*). The upper points (*circles*) are for PG 1545+210; the lower points (*crosses*) are for the PSF. The profile of the latter has been normalized to that of the quasar. The solid line represents the best fit to a de Vaucouleurs–model profile while the dashed line represents the best fit to an exponential disk profile.

to the west in the frames as a secondary calibrator. The uncertainty in the photometry is, however, significant, at least 20%–30%, because of the companion's proximity to the quasar and because of its unknown extent.

3. DISCUSSION

The present observations show a more complex picture than that presented by BKS95 or MR94 but with features in agreement with both data sets. Specifically, the companion galaxy detected by BKS95 is clearly seen as well as extended emission roughly centered on the quasar and significantly in excess of the PSF. The array observations thus confirm the findings of MR94 and previous observations of the extended infrared emission in an annulus between 5″ and 10″ diameter beams made with a single-element detector (Neugebauer et al. 1985).

The mosaic images at *H* and *Ks* were analyzed by assuming two models for the intrinsic emission: (1) a central point source (the quasar) plus an exponential disk galaxy $[B(r) = B_0 \exp(-r/r_d)]$ centered on the quasar plus a companion galaxy offset by 2″.6 with the same form of surface brightness and (2) a central point source plus a de Vaucouleurs–model host galaxy $(B(r) = B_e \exp\{-7.67[(r/r_e)^{0.25} - 1]\})$ centered on the quasar plus a companion galaxy offset by 2″.6; see Binney & Tremaine (1987) and references therein. An azimuthally averaged radial profile derived from the convolution was fitted to the profiles in Figure 2; the relative amplitudes of the components and the scale lengths of the extended emission and of the companion galaxy were free parameters in the fitting. The companion galaxy was included in the fitting because of its unknown extent. Radial profiles excluding a 50° wedge centered on the companion were also calculated and gave results for the central extended emission completely consistent with those described below. As a check of the systematic effects, the same convolution procedure and fitting were applied to the object in the image ~11″ to the east of the quasar. Based on its photometry and appearance, it is a star with about 1/6 the amplitude of the quasar at *H* and 1/10 the *Ks* amplitude. The best-fit model to this source yielded no extended emission, with a limit ~3 mag below that of the star.

The derived decomposition of the observed surface brightness into various components depends critically on the functional form of the intrinsic model for the system. As emphasized by McLeod & Rieke (1995), the magnitudes also depend critically on the analysis algorithms used. When tested against the data within about a 6″ radius of the quasar, both models gave essentially equally good fits for the extended emission. With the de Vaucouleurs–model galaxy, $H = 14.1$ mag and $Ks = 13.2$ mag, i.e., most of the luminosity of the system is emitted by the host galaxy. The color, $H - Ks = 0.9$ mag, exceeds slightly the color ($H - Ks = 0.6-0.8$ mag) expected of an elliptical galaxy at a redshift $z = 0.266$ (Bruzual 1983; Bruzual & Charlot 1993). Calculations with model elliptical galaxies at redshifts of 0.266 predict an observed color $V - K = 4.3$ mag, which implies an expected *V* magnitude of 17.5 mag. The limit of the *HST* data for a de Vaucouleurs–profile host galaxy is $V \sim 18$ mag (D. P. Schneider 1995, private communication); thus a slightly reddened elliptical galaxy could easily be hidden in the *HST* data.

The best-fit scale length for the de Vaucouleurs model is $r_e \sim 1''$, corresponding to 3.5 kpc, a value that is slightly smaller than typical for this parameter (Binney & Tremaine 1987). The absolute magnitudes of the de Vaucouleurs–model extended emission are $M_H = -26.0$ mag and $M_{Ks} = -26.5$ mag, significantly brighter than those of an L* galaxy, which has $M_H^* = -24.0$ mag and $M_K^* = -24.2$ mag (Mobasher, Sharples, & Ellis 1993).

The magnitudes of the host galaxy derived from the exponential model are $H = 15.5$ mag and $Ks = 14.9$ mag, i.e., fainter by ~1.5 mag than the magnitudes derived by assuming a de Vaucouleurs model. The resulting color, $H - Ks = 0.5$ mag, is at the lower end of the range of colors expected for normal spiral galaxies at a redshift of 0.266 (Mobasher, Ellis, & Sharples 1986). The derived absolute magnitudes, $M_H^* = -24.5$ mag and $M_K^* = -24.8$ mag, are correspondingly fainter than those calculated above but are still in excess of that of an L* galaxy by ~0.5 mag. The uncertainties in the fitting of a particular model are on the order of 0.1 mag, but clearly, the systematic uncertainty ascribed to the choice of model is far greater. The present data cannot distinguish between these two models for the host galaxy. The curves corresponding to the best fits are included in Figure 2.

The exponential disk model is considered by both MR94 and BKS95, and thus it forms a basis for comparison between the two data sets. If the surface brightness of the intrinsic galaxy follows an exponential profile, the best-fit magnitude implied for the central extended emission within a 10″ beam ($H = 15.5$ mag) is fainter by about ~0.7 mag than that deduced by MR94. This difference may be attributable to differences in deriving the parameters of the exponential model in the presence of the comparably sized PSF, but it is within the uncertainties; see the discussion in McLeod & Rieke (1995). A spiral galaxy redshifted to $z = 0.266$ would be expected to have a color $V - K \sim 2.0$ mag (Aaronson 1977; Coleman, Wu, & Weedman 1980). BKS95 find that a host galaxy with an exponential surface density associated with this quasar would have a V magnitude $V > 19$ mag. A normal spiral galaxy with $V - K \sim 2.0$ mag should therefore have been easily detected by BKS95. The absence of extended emission in the *HST* image thus places severe doubts on this model, or implies that the host galaxy must be highly reddened.

With either model for the host galaxy, the companion is faint relative to the other components of the system, so it does not affect the total energetics significantly. The scale lengths derived for the companion were small, well within the seeing FWHM, although the image in BKS95 indicates the companion is extended. The best fits to the convolutions give $H \sim K \sim 17$–18 mag, although the K magnitude is especially uncertain; see Figure 2. The near-infrared color of either fit is $H - K \sim 0.4$ mag, close to that expected from a normal field galaxy at a redshift of 0.266. If the V magnitude from BKS95 is combined with the present data, the companion object has a color $V - H \sim 3$ mag, so the color of the companion is consistent with its being an elliptical field galaxy at the redshift of the quasar. If the companion is at the redshift of PG 1545+210, its absolute magnitude is $M_H \sim -22$ mag, significantly fainter than that of an L* galaxy.

4. SUMMARY

Images at H and K of the quasar PG 1545+210 made with 0″.7 seeing confirm the presence of both extended emission centered on the quasar and a companion galaxy. The companion galaxy has a $V - H$ color consistent with its being at the redshift of the quasar, but it is faint and does not affect the energetics of the system. The derived magnitudes of the extended emission depend critically on the assumed intrinsic profile. Either a highly reddened L* spiral at the redshift of the quasar ($z = 0.266$) or, alternatively, a very luminous elliptical galaxy with essentially normal colors would be consistent with the *HST* data as presented by BKS95.

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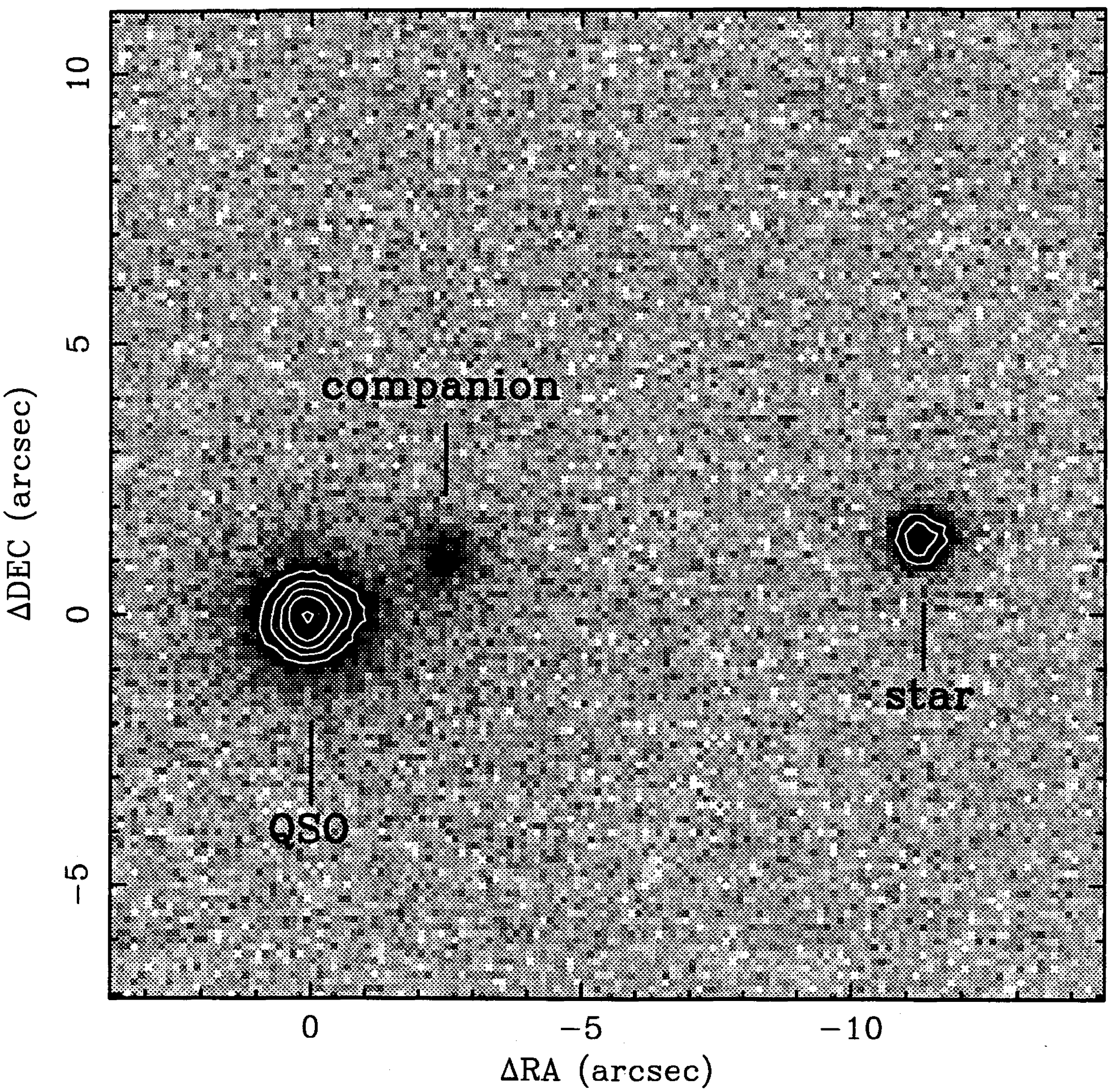

FIG. 1.—Mosaic of *H*-band images of PG 1545+210 taken with the 200 inch telescope. North is up and east is to the left. Contours are logarithmic, each a factor of 2 above the previous one. The highest contour level is ~95% of the peak emission of the quasar. The companion galaxy west and slightly north of the quasar is evident. The star ~11.″4 to the west illustrates the quality of the seeing.

NEUGEBAUR, MATTHEWS, & ARMUS (see 455, L123)