IMAGING OF LOW REDSHIFT PG QUASARS AND THEIR COMPANIONS

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ABSTRACT. Images of 16 PQ quasars with $z < 0.2$ were obtained using the CCD camera at the 2.3 m telescope of Steward Observatory. It is found that about 35% of the quasars have one or more close companions (at $r \leq$ 100 kpc). The data also suggest that the companion galaxies are almost always redder than the nebulous components of the quasars. This is consistent with previous findings by other investigators that companion galaxies of quasars do not have high level of activity.

Several recent investigations have suggested that quasars and Seyfert galaxies tend to have a high probability of being found with a close companion, (e.g., Hutchings, Crampton and Campbell 1984 and Dahari 1984). In particular, Heckman et al. (1984, hereafter HBBS) obtained redshifts for close companions of 15 quasars and found that 95% of the companions are in fact associated with the quasars. In this paper, I will report on some preliminary results concerning companions of quasars using CCD imaging data of low redshift quasars obtained at the Steward Observatory. An H_0 of 50 km/sec/Mpc is used throughout this paper.

The sample of quasar observed consists of low redshift ($0.05 < z < 0.2$) radio-quiet quasars from the Palomar-Bright-Quasar Survey (PG, Schmidt and Green, 1983). Observations were made using a non-thinned RCA CCD imagers through the Gunn filters, g (4950± 400 Å), r (6500± 500 Å) and i (8200± 600 Å) (Thuan and Gunn 1976, and Wade et al. 1978) at the 2.3 m telescope of Steward Observatory. For each quasar, images in g and one of r or i were obtained. Typical integration time for each filter totalled 900 sec. This program is a back-up program to an extensive imaging program to study the association of galaxies with moderately high redshift quasars. More details concerning the instrumentation and observational and data reduction procedures can be found in Yee, Green and Stockman (1986). Because this is a back-up program, some of the data are not photometric. The photometry for these fields is tied to multi-channel scan data from the Palomar 5m telescope (Nuegebauer et al. 1986) and is subject to systematic uncertainties of

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the order of about a tenth of a magnitude. Exemples of the images are shown in Figure 1.

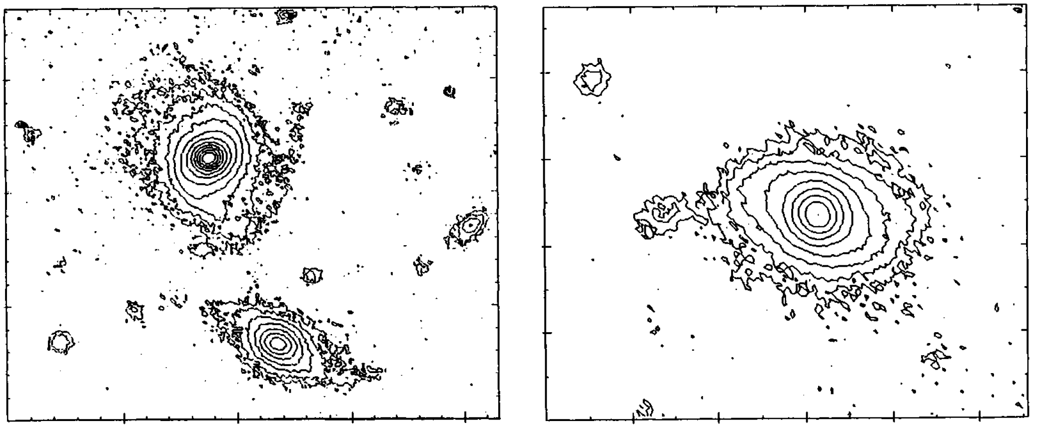

Figure 1. Examples of CCD images of quasars and their companions. Tick marks represents 10 pixels with a scale of 0.291 arcsec/pixel. Contours are plotted at half-power levels starting from the peak brightness of the quasars. Left panel: PG0844+34; right panel: PG1404+22. NE is upper left.

The existence of companions to quasars and Seyfert galaxies is often cited as evidence that interaction plays an important part in the triggering and maintenance of quasar activity. However, results in the current literature are often qualitative, with neither a properly defined sample nor quantitative data concerning the companions. HBBS shows that a close neighbour ($r \leq 50$ kpc with $H_0=100$) is almost always a physical companion. Thus, one useful criterion for defining a neighbour as a companion is the distance from the quasar. However, the probability that such a galaxy is an optical pair (i.e., chance projection of foreground or background galaxies) is a function of the brightness of the galaxy. The high percentage of galaxies found to be associated with the quasars by HBBS is at least in part due to the fact that they had chosen to observe relatively bright neighbours.

In this work, two criteria are used to define a close companion. The first is proximity: the companion galaxy must be within a radius of 100 kpc ($H_0=50$) of the quasar. The second is the condition that $R_{nn}/r \leq 3.0$, where r is the distance between the quasar and the neighbour galaxy and R_{nn} is the expected nearest neighbour distance of a galaxy with apparent magnitude brighter than or equal to the galaxy in question. Assuming a Poisson distribution for galaxies, the distance from a reference point to the nearest neighbour brighter than m is (e.g. see Rose 1977):

$$R_{nn} = \frac{1}{2\sqrt{\sigma(m)}}$$

where $\sigma(m)$ is the surface density of galaxies up to the magnitude m. Thus, the second criterion requires fainter galaxies to be closer to the quasar to be considered as a companion. For the purpose of the determination of R_{nn}, the average background galaxy counts in $\underline{r}$ from Green and Yee (1984) are used. Applying these two criteria, 8 out of the 16 quasars in the sample are considered to have close companions. Table 1 list the 8 quasars along with the relative position and magnitude of the companions.

Table 1

Companions of quasars

Name	z		Distance to Quasar (kpc)	m($\underline{r}$)	M(r)
PG 0119+22	0.053		16	17.3	-20.3
PG 0844+34	0.064		43	17.2	-20.9
PG 0923+22	0.190	A	48	19.3	-21.5
		B	49	18.1	-22.6
		C	67	19.4	-21.3
PG 1307+08	0.155		83	17.7	-22.4
PG 1322+65	0.168		49	18.7	-21.6
PG 1404+22	0.098		25	20.0	-19.0
PG 1411+44	0.089		17	18.8	-20.0
PG 1613+65	0.129	A	7	~18.0	-21.7
(MKN 876)		B	68	17.5	-22.2

To estimate the probability of occurrence of chance projection of background galaxies, I performed the same search using the 108 control fields reported in Green and Yee (1984). For these fields, the central point of the frame is used as the reference point and an artificial redshift of 0.15 is assigned to each field. It is found that 14% of the control fields have "companions" to the reference points satisfying the two criteria. Thus, we may conclude that ~ 35% of the low redshift PG quasars have an associated close companion galaxy. this percentage is similar to the result of 30% obtained by Hutchings, Crampton and Campbell (1984) for 23 optical quasars. From a sample of 103, Dahari (1984) estimated that ~15% of Seyfert galaxies have physical companions. Dahari used a search radius of 3 times the major-axis of the Seyferts. On the average this radius is probably smaller than the 100 kpc radius used in this investigation. Because of the different criterion used and the smallness of the quasar sample, it is not certain whether the difference between the results for quasars and Seyferts is significant. Turner (1976) found only ~3% of galaxies in the UGC catalogue to be physical pairs with separation less than 8'. Assuming the average distance to the galaxies in Turner's sample to be ~50 Mpc, the separation of 8' is comparable to the distance criterion used in this

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paper. Thus, quasars are ~10 times more likely to be found with a close companion than the average field galaxies.

Imaging data in two colours are available for 7 of the 8 quasars with close companions. Using apertures of concentric rings, I derived colour gradients in g-r or g-i for the quasars and their companions. Examples of the colour gradients are shown in Figure 2.

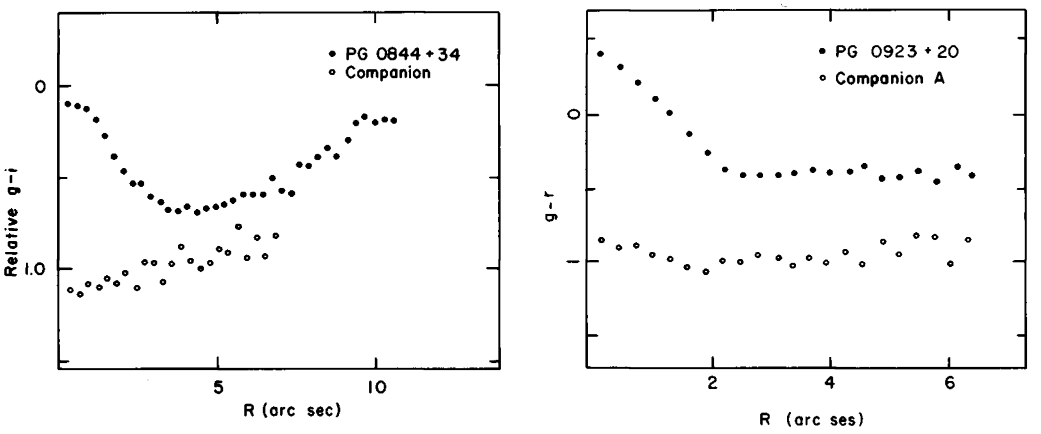

Figure 2. Colour gradients for PG0844+34 and PG0923+20 plus their companions.

Because of the low redshift of the quasars, the colour of the nebulous component (i.e., the host galaxy) can often be derived. A typical example is the colour gradient of PG0923+20 shown on Figure 2. As expected, the nucleus of the quasar is considerably bluer than the outer part and is rapidly varying as a function of radius. This change can be simply interpreted as due to the changing relative contribution of the nuclear and host galaxy colours. At radii greater than 2.5", the colours become relatively constant as a function of radius. This outer region is then considered as not contaminated by the nuclear light and is used to measure the colour of the quasar fuzz. Table 2 lists the results for the 3 quasars with photometric data. Also produced are colours for E/SO and Sbc galaxies to be used as references. These reference colours are computed by convolving filter response functions with spectra of the standard E galaxy from Yee and Oke (1978) and Sbc galaxy from Coleman, Weedman and Wu (1980). For the objects without photometric data, Table 2 lists the relative differences in colours between the quasar fuzz and companions. For all 7 quasars, the colours of the host galaxies are always bluer or as blue as those of the companions. For the 3 photometric cases, close neighbours of both PG0923+20 and MKN 876 (PG1613+65) have colours consistent with being early-type galaxies. The colours of the host of PG0119+22 and its

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companion are similar to that of Sbc galaxies. (However, althought it is in the PG catalogue, PG0119+22 is probably not a bona fide quasar according to Keel [private communication]). Thus, using colour as an indication of activities such as star formation and the existence of ionized gas, we can conclude that the companions in general are not very active objects, at least compared to the host of the quasars. This result is in complete agreement with that obtained by HBBS from their spectroscopic survey of close companions.

Table 2

Colours of Hosts and Companions

Name	g-r	g-r (E/S0)	g-r (Sbc)	Δ(g-r)	Δ(g-i)
PG 0119+22	0.3				
Companion A	0.3	0.54	0.28	0.0	---
PG 0844+34	---				
Companion A	---			---	-0.25
PG 0923+22	0.4				
Companion A	0.95	0.84	0.42	-0.55	---
Companion B	0.9			-0.5	---
Companion C	0.9			-0.5	---
PG 1307+08	---				
Companion A	---			-0.6	---
PG 1404+22	---				
Companion A	---			---	-0.2
PG 1411+44	---				
Companion A	---			---	-0.3
PG 1613+65	0.5				
Companion A	0.8	0.68	0.34	0.3	---
Companion B	0.5			0.0	

The difference in colours between the hosts and companions can be viewed with two opposing scenarios. One is that we can assume that bluer galaxies have a higher propensity to become quasars with a longer active cycle. This may be expected on the ground that these galaxies are likely to contain a larger amount of internal gas which can be used as fuel for the quasars for a longer duration. Such an interpretation also supports, purely on a statistical basis, the finding that the companions often have spectra (HBBS) or colours consistent with being earlier-type galaxies, in the sense that gas-poor galaxies may have a lower probability of becoming active. The opposing view, equally valid, is that the bluer colour of the host is the result of the existence of the quasar in the center of the galaxy; i.e, it is a manifestation of enhanced star-formation and the existence of ionized gas due to the quasar. However, Filippenko (1985) pointed out that the gas in the close companion should also show the effect of the radiation from the quasar. Most likely, both of the above scenarios are in operation to a certain degree. A considerably larger and more detailed data-base is needed to determine whether certain type of galaxies are more susceptible to quasar activity and how much effect bright quasars exert on their host and neighbours.

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DISCUSSION

KHACHIKIAN: How about the collisions of nuclei of galaxies. Did you calculate the probability of that? How do you imagine the nature of these nuclei (where and how do they arise) and the way of bringing them to the collision?

YEE: I prefer to use the description "interaction of galaxies". The popular scenario does not require collisions in the strict sense, but rather a perturbation of the gravitational potential of the galaxy hosting the central engine. De Robertis (1985, A.J. 90, 998) has made estimates of the rate of interaction. He came to the conclusion that using "reasonable values" for parameters such as galaxy density, impact parameters efficiency, and quasar life-time, one could in fact arrive at the ~20/Gpc^3 space density of local quasars. Of course, many of these parameters are not well determined at all, and there are many degrees of freedom to make any model fit the equally poorly determined value for the space density of quasars and AGNs.

WILSON: Seyfert galaxies tend to be found in early-type, rather than late-type spirals. Perhaps one should consider other reasons for the blue colours of the quasar-galaxy disks, such as the interaction triggering a burst of star formations in an otherwise early type system.

YEE: In the first of the three scenarios I presented, I did not mean to imply that late-type galaxies form quasars, but rather if two galaxies come together it is the later-type one that has a higher probability of forming a quasar. In fact, of the three quasars fuzz with photometric measurements, one has a colour consistent with being Sa and another Sbc. I have been advised by Dr. Keel that the third which also has a colour of Sbc galaxies, is in fact a star-burst galaxy rather than a quasar. The g-r colours derived are not different from those of Markarian Seyferts (see Yee, 1983, Ap.J.). It is certainly possible that the colour of the fuzz is bluer than the actual morphological type would indicate. But at this point, there is no way to determine the morphological type independently by imaging.

TERLEVICH: If most galaxies are luminous late type spirals, they probably have large amounts of gas, maybe $10^{10-11}M_\odot$. Why so much gas is needed to feed the "monster" and switch on the AGN? According to my understanding only a small amount of gas is necessary to produce the photometric luminosities in the AGN "monster" scenario.

YEE: Please see answer to Dr. Wilson's question.

KOMBERG: Is the system you described a gravitational lens or a double interacting system?

YEE: I did not study specifically this system. In the system studied by me there are strong evidences of interaction of host galaxies around QSO with neighbouring galaxies.