Nearby Quasar Galaxies *

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1 Abstract and Introduction

In this paper four questions will be addressed:
(a) Are the best ground based and HST data on quasar hosts in agreement ?
(b) Do radio quiet quasars occur in elliptical galaxies as well as in spirals ?
(c) Are the colours of quasar galaxies on average bluer than typical gE galaxies, indicating that recent star formation has taken place ?
(d) Is the optical luminosity function of radio quasars and strong radio galaxies more or less the same ?
The answer to all questions will turn out to be affirmative. The implications for unified models will be discussed and a scenario for quasar evolution proposed.

2 HST and Ground Based Data

Much has been made in the recent literature and also in the press about the discovery of "naked" quasars and more in general about the large differences between quasar hosts observed with HST and from the ground. On closer inspection, however, a very satisfactory agreement is found, although of course the HST data show fine structure not seen in the ground based images. We shall here make a detailed comparison between the data we obtained previously (Véron-Cetty & Woltjer, 1990, VW) and the data obtained by Bahcall et al. (1995a,b) and by Disney et al. (1995) with HST for the radio quasars PKS 1302-102 (z=0.286) and PKS 2349-014 (z=0.173).

2.1 PKS 1302-102

We recall that VW determined the amount of light in an annulus with radii of 12.5 and 25 kpc and then adopting the best fitting de Vaucouleurs law calculated the difference between the total magnitude of the galaxy (0-∞) and the magnitude of the annulus which turned out to be not too sensitive to the effective radius of the model. For PKS 1302-102 the radii of the annulus are $1.''5$ and 3" and VW found i = $19.^{m}2$. All the i magnitudes in VW have to be corrected by $-0.^{m}16$ because earlier measurements of the calibration star (LTT 3218) were erroneous (see appendix). Adopting a normal colour for a gE we have V_0-i_0 =

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$0.^m49$, $k_i = 0.^m25$ from Schneider et al. (1983) and $k_V = 0.^m72$ from Pence (1976) and V = 20.0 for the annulus. Since the redshitfted V band is not very far from the i band, errors in the adopted colours would not have much effect.
The HST data of Bahcall et al. (1995b) show that PKS 1302-102 has two close companions at 1."1 (m = 20.6) and at 2."2 (m = 21.9) where the magnitudes refer to the F606W filter. According to these authors, for a gE type spectrum at z = 0.286, the V values should be $0.^m38$ higher than these m values; we then find for the total contribution of the two to the light in our annulus (taking into account the 1" seeing) V = $21.^m8$ and upon correction for this, our annulus would have V = 20.2, which, with the effective radius r_e = 1", corresponds to V = 18.5 for the host galaxy and $M_V = -23.^m6$.
Bahcall et al. (1995b) have made simulations to see what galaxies they should be able to detect. Simulation 5e in table 3 corresponds to a galaxy with a de Vaucouleurs $r^{1/4}$ law and r_e = 1."2 and shows that a galaxy fainter than m = 17.9, corresponding to V = 18.3, would not have been noticed. There is, therefore, no contradiction with our result. The apparent problem has only arisen because the limits given in table 1 of Bahcall et al. are based on the *average* of eight simulations. However, what counts in establishing a definite limit is not this average, but the simulation which yields the smallest m.
The same quasar has been observed with HST by Disney et al. (1995) who obtain with the F702 Filter m = $21.^m3$ and $22.^m0$ for the two companions and M_{host} = -23.5, where M_V "could be a few tenths of a magnitude brighter". Therefore, within the uncertainties due to the different photometric systems there is agreement with our result and no contradiction with that of Bahcall et al. There is, however, a substantial difference with the ground based result of Hutchings & Neff (1990) who obtain $M_R = -25.^m2$ which, with V-R = 0.7 for gE galaxies, would yield $M_V = -24.^m5$, about a magnitude brighter than the other results.

2.2 PKS 2349-014

While in the preceding object Bahcall et al. only found an upper limit, for PKS 2349-014 a positive result was obtained (Bahcall et al. 1995a). It is interesting to compare the HST images for this source with the ground based image of VW. The asymmetry of the galaxy with respect to the quasar and the two (tidal ?) arms to the north are evident in both cases, though, of course, the HST image shows more detail in the inner parts. The HST image shows a companion at 1."8 which should not affect the photometry in the 12.5-25 kpc (2."5-5") annulus of VW. They found in the annulus i = 17.6, to be corrected with $-0.^m16$ because of the calibration change, and with $k_i = 0.^m16$, $k_V = 0.^m33$ and V_0-$i_0 = 0.^m49$, V = 18.1 in the annulus and V = 16.3 for the galaxy. Bahcall et al. found in an annulus between 0."5 and 9", m = 16.8 which at z = 0.173 should correspond to V = $16.^m6$. With r_e = 2."6 as found in VW, V = $16.^m4$ is found for the whole galaxy, in close agreement with the VW result. Since the galaxy is asymmetric and perturbed (like many quasars in the VW sample) some deviations from an $r^{1/4}$ law could be expected.
We conclude therefore, that the HST data are in very good agreement with the

quantitative results obtained by VW for the luminosities of the quasar galaxies. In passing we also note the claim of Abraham et al. (1992) that VW had underestimated the effects of the subtraction of the PSF. Since VW only used PSF's determined on the CCD frame containing the quasar this cannot be the case. The conclusion of Abraham et al. resulted from the application of a PSF determined at La Palma to the La Silla data. In fact, it appears that for the same half power seeing disk diameter the wings were frequently higher in their data.

3 "Radio Quiet" Quasars in Ellipticals

It has frequently been stated that since spirals are generally not very strong radio sources, radio quasars may be taken to be in ellipticals, while since Seyfert nuclei usually are found in spirals, the same might be assumed to be the case for the radio quiet quasars (QQ). However VW showed that the difference in M_V between radio quasars and QQ could also be understood if the latter were in ellipticals and if their relatively weak radio emission followed the standard relation between radio power and M_V for moderately weak radio galaxies. Such an argument shows that nothing stands in the way of QQ being ellipticals, but, of course, does not prove this either.

Meanwhile some more direct evidence has become available. Véron-Cetty et al. (1991) studied the object F9 ($z = 0.045$) which at discovery had a luminosity in the quasar range and at other times has been weaker. The radio emission was found to be weak ($P_{5GHz} < 5\ 10^{22}$ W Hz^{-1}), but the luminosity profile follows that of a gE with M_V = -23.0. In passing we note that the image of F9 shows a remarkable similarity with that of PKS 2349-014 discussed before. Also our new data for the nearby QQ Ton S180 ($z = 0.062$) show a rather accurately followed $r^{1/4}$ luminosity profile with $r_e \approx$ 17kpc for a modest galaxy (M_V = -22.0).

With HST, Disney et al. showed the QQ 2215-037 host to have the general appearance of an elliptical and to follow an $r^{1/4}$ law quite well, while Bahcall et al. (1996) found the QQ PHL 909 to be associated with an elliptical.

Not all QQ are associated with ellipticals. Véron-Cetty et al. (1991) found 09149-6206 ($z = 0.057$) to have a host with a profile like an Sa (M_V = -23.0), while Bahcall et al. (1996) found with HST that PG 0052+251 was situated in a rather normal looking Sb with M_V = -22.8. Apparently both luminous ellipticals and spirals can produce quasars; in what proportion as a function of the luminosity of the quasars remains to be seen.

4 Colours of Host Galaxies

Much evidence has accumulated that quasar hosts and radio galaxies are frequently bluer than gE. Sandage (1972) has already noticed this in photoelectric observations of radio galaxies, but the role of a possible blue nucleus made the situation unclear. Smith & Heckmann (1989) subsequently showed that B-V colours too blue by $0.^m2$ are not at all exceptional. If we average their data for the colours of 38 strong radio galaxies ($\log P_{5GHz} > 24.7$) outside a 10 kpc radius, $<B_0\text{-}V_0> = 0.^m83$ is found, $0.^m14$ bluer than brightest cluster galaxies. Quasar galaxies appear to be relatively blue. Malkan (1984) found the quasar galaxy of 3C 48 to be very blue with v, g, r colours corresponding to an Sc or Sd galaxy. VW measured R-i colours for 5 radio quasar galaxies. The average is $0.^m17 \pm 0.^m09$ bluer than a gE, corresponding with typical spectral distributions to $(B_0\text{-}V_0) \approx 0.^m6$. Boroson and Oke (1984) and Boroson et al. (1985) obtained spectral scans for 9 radio quasar galaxies and 3 radio quiet quasar galaxies which yielded rough colours averaging $(B_0\text{-}V_0) = 0.^m5$. Taking these data at face value, the quasar galaxies would on average be bluer than the radio galaxies.

Important evidence that quasar galaxies have spectral distributions which are very different from those of giant ellipticals comes from observations of absorption lines by Miller (1981), who observed the Mg Ib (5180Å) line in BL Lacs, N-galaxies and quasars. Assuming the galaxies in question to have normal gE spectra, he determined the amount of galaxy light present or an upper limit to it in case the feature was so diluted as to be invisible. For 5 BL Lac objects (Mark 180, AP Lib, Mark 501, 3C 371, BL Lac) with recent imaging data we obtain from his measurements $<M_V> = \text{-}23.^m0$, while from the imaging data by Abraham et al. (1991), Baxter et al. (1987) and Stickel et al. (1993) for the same objects we have $<M_V> = \text{-}22.^m9$. Apparently these galaxies have the standard Mg Ib absorption for their luminosity. If indeed the BL lacs are FR I radio galaxies as proposed in the unified models, this should be no surprise since the latter are mainly associated with fairly normal ellipticals. In 6 N systems with detected Mg Ib Miller's data give $<M_V> = \text{-}22.^m0$, while the imaging data of Smith & Heckman (1989) for the same objects yield $<M_V> = \text{-}23.^m1$. The simplest way to interpret this result is to say that the Mg Ib line is a factor 2.8 too shallow for a gE galaxy. For quasars, Miller only finds upper limits. For four quasars with $M_V < \text{-}23.0$ and with imaging data, his results yield for the hosts $<M_V> > -22.^m0$, while the imaging data give $<M_V> = -23.^m4$. Apparently the Mg Ib absorption is a factor of > 3.6 too shallow. In addition, in the quasar 3C 459 Miller found the Balmer lines in absorption, corresponding to a young stellar population. Further confirmation comes from the scans of Boroson and Oke (1984) who measured the Mg_2 index (Mg I + Mg H) in some radio quasar galaxies. In 3C 37.43 and 3C 48 values of $0.^m098$ respectively $0.^m058$ were measured, while the values for gE are typically between $0.^m25$ and $0.^m35$; however, in the quasar 4C 31.63 a value of $0.^m344$ was found. Also in 3C 48 Balmer lines were seen in absorption. The straightforward interpretation of these data is that the spectra of the quasars (and N-galaxies) are different from those of gE, with a much larger contribution from young stars - consistent with the evidence for bluer colours.

Recently Dunlop et al. (1993) and McLeod & Rieke (1994a,b) have observed quasar hosts in the K respectively H bands with array detectors. As pointed out by these authors, the IR is a particulary suitable place to image quasar hosts because the contrast galaxy/quasar nucleus is favorable.

For six of the radio quiet quasars observed by McLeod & Rieke (1994 a,b) reliable optical data (assembled in table 7 of VW) are available which yield a very blue mean V_0-H_0 = $2.^m1$, while for the RQ PKS 1302-102 V_0-H_0 = $2.^m7$ is found from VW's observations. Normal early type galaxies have about V_0-H_0 = $2.^m9$. From comparisons between different samples McLeod & Rieke (1994b) concluded that QQ averaged up to about half a magnitude too blue, but they concluded later (McLeod & Rieke 1995) from a comparison with HST data that, within the errors, a small sample of RQ and QQ was not noticeably different from "normal" early type galaxies. Probably it has some advantage to compare ground based IR samples with ground based optical samples in which very nearby companions are included in the same way and in which precise photometry in a well calibrated system can be more easely obtained.

Very recently, Taylor et al. (1996) published an improved version of the Dunlop et al. (1993) data. For 8 RQ treated as ellipticals, also studied by VW or Smith et al. (1986),$<V_0$-$K_0>$ = $3.^m1$, while for 3 QQ, treated as spirals, $<V_0$-$K_0>$ = $2.^m3$. The average of all 11 yieds $<V_0$-$K_0>$ = $2.^m85 \pm 0.^m21$. For 5 radio galaxies in common with Smith & Heckman (1989), $<V_0$-$K_0>$ = $3.^m42 \pm 0.^m35$; of particular interest in these samples is the QQ 2215-037 which Disney et al. showed (section 3) to have the properties of an elliptical, but which has V_0-K_0 = $2.^m5$, nearly a magnitude less than "old' gE's.

For radio galaxies, Eisenhardt & Lebofsky (1987) obtained approximate V and K magnitudes simultaneous through identical apertures. They found radio galaxies with z < 0.2 to have V-K colours $0.^m12$ bluer than brightest cluster galaxies. The result could still be influenced by contributions from undetected nuclei.

In fact in many cases only small deviations from "normal" V-K colours should be expected. For example recent models by Tantalo et al. (1996) show that a burst of star formation occuring 1-5 Gyr ago should have a Δ(V-K) equal to about 0.8Δ(B-V), where Δ denotes the deviation from the colour of an old gE. The Δ(B-V) = $0.^m14$ found by Smith and Heckman for radio galaxies therefore is consistent with the Δ(V-K) result of Eisenhardt & Lebofsky. The Δ(B-V) of $0.^m3$-$0.^m5$ noted earlier for quasar galaxies would then correspond to Δ(V-K) of $0.^m2$-$0.^m4$ entirely compatible with the results discussed before.

Some quasar galaxies are very blue. The quasar Mark 1014 is generally regarded as a QQ though with $P_{5GHz} = 10^{24}$ W Hz^{-1}, its radio emission is well above that for normal spirals. Smith et al. (1986) found the associated galaxy to be extraordinarily luminous, with M_V = -$25.^m1$ while McLeod & Rieke (1994b) found it to have a very blue colour V_0-H_0 = $1.^m4$. A mass of molecular gas of $10^{11.1}$ $M_\odot$ has been found in this object (Sanders et al. 1988a). Apparently extensive star formation is taking place. From the models of Tantalo et al. (1996) it follows that a burst of star formation has very blue V-K colours only until about 10^8 years, after which a drastic reddening takes place very rapidly. If the light of some of the quasar galaxies is, in fact, dominated by such young stars, the optical light to mass ratio would also be large, and the masses need not be larger than for more typical gE.

The overall impression from the colour and spectral data is that quasar galaxies are rather blue, on average more so than radio galaxies. If so, quasars may well

represent statistically more recent merger products than strong radio galaxies, with the FR I radio galaxies and BL Lac's being still more ancient. While this is not in agreement with a strict unification model, it does not exclude that many radio galaxies are, in fact, obscured quasars. A mixture of evolutionary and orientation effects certainly can account better for the observations, including those on luminous infrared galaxies, some of which might represent an even earlier evolutionary stage (Sanders et al. 1988b).
Another important aspect in evaluating the effects of evolution is the gas content. The high surface densities of the gas in objects like Mark 1014 make it clear that star formation must be taking place. However, also atomic hydrogen may be an important constituent, though more difficult to observe in strong radio sources. An example is the gE radio galaxy PKS 1718-649 in which Véron-Cetty et al. (1995), following earlier observations of Fosbury et al. (1977), detected an asymmetric disk of gas with a diameter of 180 kpc containing 3 10^{10} $M_\odot$ of atomic hydrogen. However, recently Morganti et al. (1996) discovered 2.4 10^{10} $M_\odot$ of HI in the luminous elliptical or S0 galaxy NGC 5266 spread out over 280 kpc; this object is not a radio galaxy. Until larger samples will be available it is difficult to be sure about the implications of such curiosities.

5 Radio Quasars and Strong Radio Galaxies

In table 1, we summarise the data on quasar galaxies for a sample of luminous quasars (-24.6 $>$ M_V $>$ -26.6), the high luminosities reducing selection effects also for the QQ. The zero point error of $0.^m16$ has been corrected and we have adopted B_0-V_0 $= 0.^m6$. If a spectral distribution appropriate for a standard gE had been adopted, the mean M_V would have been only $0.^m06$ fainter. The results for radio quiet quasars are based on exponential disk models; ellipticals would be $0.^m4$ more luminous. Also given in table 1 are the results for a sample of strong radio galaxies based on CCD imaging by Smith & Heckman (1989). Results for some other samples of AGN may be found in VW.

Table 1. Numbers, mean galaxian M_V and rms dispersion in samples of radio quasars, radio quiet quasars and radio galaxies.

Sample		N	$<M_V>$*	Dispersion
VW	RQ	20	-23.48 $\pm$0.12	$\pm$0.50
VW	QQ	16	-22.55 $\pm$0.15	$\pm$0.8
Smith & Heckman	RG	72	-23.34 $\pm$0.08	$\pm$0.65

*) for galaxy from 0-∞ and with H_0 = 50 km s^{-1} Mpc^{-1} and q_0 = 0; the quoted errors do not include systematic photometric and modelling errors.

From the results in table 1 we conclude that the average luminosity and

its dispersion for strong radio galaxies and radio quasars galaxies are not very different. This would appear to be consistent with unified models since the absorption effects invoked in such models affect only a very small region ($\approx$ 1pc) near the centre. In passing we note that the comparison between radio galaxies and radio quasars from ground based data includes for both the possible effects of unresolved companions. However, in the unified models these effects should be expected to be statistically the same for quasars and radio galaxies.
Also in the comparison between quasars and strong radio galaxies, the BL Lac objects should be excluded. If the unified models are correct, most BL Lac's are intrinsically relatively weak radio galaxies which are known to have lower luminosities than the strong radio galaxies (see Ulrich, 1989, Woltjer 1989).

6 Conclusion

They are three ways in which radio quasars and radio galaxies may be related to each other.
a) *Orientation.* Depending on the angle of the line of sight with respect to the axis of an absorbing torus around the centre, the nucleus would be visible (quasars) or obscured (radio galaxies). If a relativistic jet is present and if the angle of the jet axis with respect to the line of sight is small, a BL Lac or a OVV might result. In these cases, the properties of the host galaxies should be the same, unless an absorbing layer pervades large parts of the galaxy. The negligible difference in M_V between radio quasars and radio galaxies supports such a model (table 1), but the colour differences are difficult to accomodate.

b) *Variability* is generally neglected. However most quasars are optically variable ($\approx 0.^m1$-$0.^m3$ or more) on timescales of a decade or less. Variations might be larger on longer time scales and one could easily envisage the change of a radio quasar into a radio galaxy by the temporary extinction of the nucleus. The host galaxies would again remain unchanged, as in 6.a.

c) *Evolution* must occur in quasars and radio galaxies on time scales no longer than that for the evolution of the population of such objects. The fact that many quasar galaxies have spectral distributions that are rather blue suggests that they evolve on timescales of one or a few times 10^8 years, the less blue radio galaxies being, on average, somewhat older than quasars. Since the space density of strong radio galaxies is only three times that of radio quasars of the same radio power, their lifetimes could not be much longer than those of the quasars. In agreement with this, in some cases, the synchrotron lifetimes of the relativistic electrons are seen to be of the order of 10^8 years. The somewhat smaller sizes (Barthel 1989) of the quasar radio sources, if not an accidental sample effect, would fit an evolutionary model as well as the orientation dependent models.

Undoubtedly all three effects play a role. Only infrared observations of the effects of an absorbing torus can demonstrate the importance of 6.a, while spectral

observations with HST should further establish various aspects of 6.c.
The relation of the QQ to other AGN is more uncertain. The quasars in spiral galaxies may well represent a high luminosity extension of the Seyferts. Seyfert galaxies seem too abundant to represent recent mergers and, in fact, most Seyferts without the nuclei would not look very different from non-Seyfert spirals. It therefore seems plausible that Seyferts and quasars associated with spirals represent an accretion process fuelled by gas from within the galaxy, perhaps slightly perturbed by neighbouring galaxies.
The quasars in ellipticals appear to be very different. The galaxies frequently look perturbed and are too blue. In many cases, even without the nucleus, one would be able to see that the galaxy is not a normal gE. Here it seems that a short lived phenomenon has shaken up the galaxy, presumably a major merger. Since violents events tend to produce objects with an $r^{1/4}$ profile (Barnes 1988), the antecedents of the merger are not obvious, but at least one gas rich galaxy must be involved. There then would be two different kinds of objects: the internally fuelled Seyfert sequence involving at most minor mergers and the catastrophic mergers producing young looking elliptical like objects.
Blandford (1990) has suggested that strong radio sources are associated with rapidly rotating black holes and that only accretion at rates close to the Eddington limit could spin up the black holes to such rotation. In Seyferts the gas will presumably be supplied rather slowly, accretion rates would be low, radio emission weak and the nuclear luminosity due to dissipation in the accretion disk. In major mergers involving a gas rich galaxy, the situation would be very different. Star formation would result in an elliptical with a blue colour for a few 10^8years (e.g. QQ 2215-037, sect. 3&4), while much gas could be transferred to the nucleus (Barnes & Hernquist 1991), the hole spun up on an Eddington time scale (few 10^8years) and a strong radio source produced. *Strong radio emission would not so much be a property of ellipticals, as a consequence of the process that forms (some of ?)them.* It would only occur if in the later phases enough accreting matter remains available to complete spin up. Radio quiet quasars then would be on average younger with more perturbed hosts, and potentially more numerous than RQ. Also the evolution of the quasar population fits naturally into such a scenario. After the termination of the intense accretion phase the quasar luminosity would diminish, while radio emission could continue for a longer time in aging, normal looking ellipticals.

7 Appendix

The calibration of the data in VW was based on observations of the star LTT 3218 for which Eggen (1979) obtained in the Kron system R_K = 12.08 and I_K = 12.04. With the formulae of Eggen (1971) and Cousins (1980) this becomes R_{KC} = 11.98 and I_{KC} = 11.85 in the Kron-Cousins system now generally used. Subsequent data show the Eggen result to be erroneous. Landolt (1992) obtained R_{KC} = 11.753 and I_{KC} = 11.643, while Hamuy et al. (1992) found R_{KC} = 11.762 and I_{KC} = 11.651. We then obtain i = 12.31 instead of i = 12.47 adopted by Moorwood et al. (1986). Consequently, all i-magnitudes in VW should be diminished by $0.^{m}16$. Since the R-magnitude of Eggen also should be corrected, the effect on the R-i colours given in VW is small.

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