The host galaxies of flat-spectrum quasars⋆

Matt J. Jarvis [a,b] Ross J. McLure [c]

[a] *Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, The Netherlands*

[b] *Oxford Astrophysics, Keble Road, Oxford, OX1 3RH, UK*

[c] *IfA, University of Edinburgh, Royal Observatory, Edinburgh EH9 3HJ, UK*

Abstract

We present the results of deep VLT-ISAAC K_s-band imaging of four $z \sim 1.5$ flat-spectrum quasars selected from the Parkes half-Jansky flat spectrum sample. We find that the hosts of these flat-spectrum quasars are consistent with lying on the $K-z$ Hubble relation for radio galaxies. This implies that the flat-spectrum quasar hosts fall in line with the expectations from orientation based unified schemes and also that they contain black holes of similar mass. Moreover, the width of the Hβ broad emission line in these objects tends to be narrower than in their misaligned (low-frequency selected quasar) counterparts, implying that the width of the Hβ broad emission line depends on source inclination, at least for radio-loud quasars, in line with previous studies.

Key words: galaxies: active - galaxies: fundamental parameters - radio continuum: galaxies

1 Introduction

It is now widely believed that active galactic nuclei (AGN) are powered by accretion on to a supermassive black hole. However, it is still not yet known why some of these active galaxies exhibit powerful radio emission. The mass of the central black hole appears to play at least a minor rôle in generating powerful ($P_{5GHz} > 10^{24}$ W Hz^{-1} sr^{-1}) radio emission [e.g. Dunlop et al. (2003)], but this is certainly not the only parameter, with accretion rate and possibly black-hole spin playing crucially important rôles [e.g. see the review by McLure (2003)].

⋆ Based on observations performed at the European Southern Observatory, Chile [programme ID: 69.B-0197(A)].

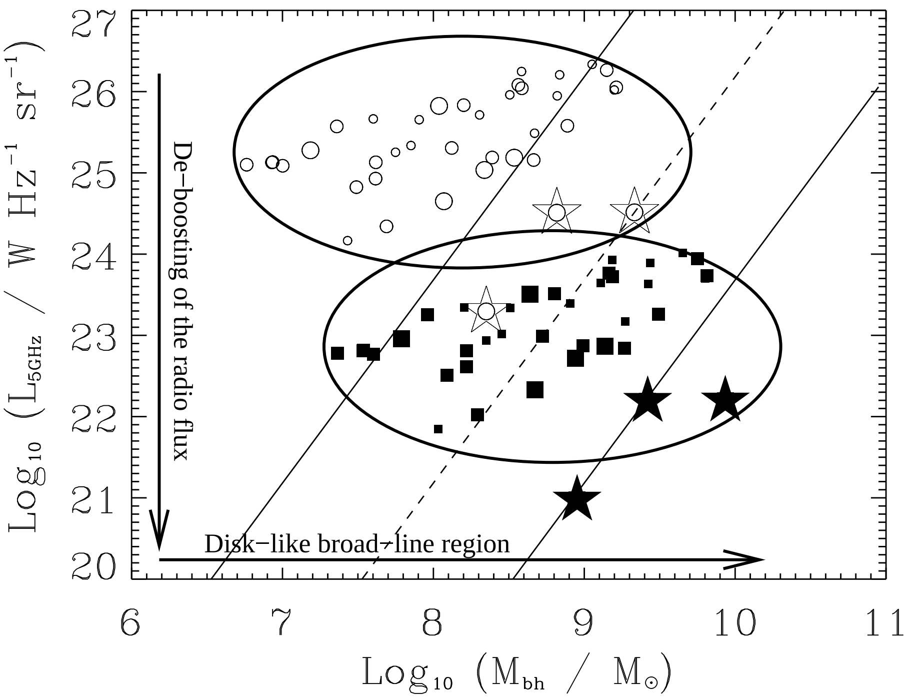

Fig. 1. The black-hole mass – radio luminosity plane adapted from Jarvis & McLure (2002), where full details can be found. Open symbols represent points from the study of Oshlack, Webster & Whiting (2002), the filled symbols represent where these points would lie after a moderate Doppler boosting correction and consideration of a disk-like geometry for the broad-line region. The large stars are anomolous steep-spectrum objects and are probably not dominated by the core emission.

It has recently been suggested that the host galaxies of flat-spectrum, high-frequency selected quasars, inhabit less massive host galaxies than their low-frequency selected (and therefore selected independent of orientation) radio-loud quasar counterparts and also their optically selected counterparts, Oshlack, Webster & Whiting (2002). This in turn leads to the implication that the black holes in the flat-spectrum quasars (FSQs) fall below the upper envelope in the radio power – black-hole mass plane proposed by Dunlop et al. (2003), if the bulge luminosity – black-hole mass relation holds out to cosmologically significant redshifts. This suggests that radio power may not be correlated with the mass of the supermassive black hole, and must be due to some other physical process.

This idea was re-investigated by Jarvis & McLure (2002) who suggested that the orientation of the FSQs, with the radio jets preferentially orientated along the line-of-sight to the observer, may also be a factor. They conclude that by taking into account the effects of Doppler boosting and also by assuming the broad-line region may have a disk-like geometry (Brotherton, 1996) that the black-holes in FSQs may be consistent with the upper envelope in black-hole mass (e.g. Fig. 1).

To investigate this question further we have embarked upon a study of both

Table 1
Flat-spectrum quasars considered in this paper. Typical error on the host magnitudes is $\sigma \sim 0.5$ mag.

Source	Redshift	$K_{\rm host}$
PKS1532+016	1.435	18.3
PKS1548+056	1.422	16.9
PKS1602-001	1.624	18.0
PKS2021-330	1.471	18.0

the host galaxies and emission-line properties of FSQs selected from the Parkes half-Jansky flat-spectrum sample (Drinkwater et al., 1997). In this paper we present some initial results on the host galaxies of four of these quasars at a redshift of $z \sim 1.5$.

2 The Observations

We have obtained deep K_s-band observations of seven $z \sim 1.5$ FSQs from the Parkes half-Jansky flat-spectrum sample (Drinkwater et al., 1997) with VLT-ISAAC. The observations were taken in photometric conditions with typical seeing of 0.5 arcsec. Each object was observed for a total time of 1.5 hours. A detailed account of the observations of the complete sample of 7 $z \sim 1.5$ flat-spectrum quasars will be presented in a forthcoming paper (Jarvis & McLure in prep.). The depth of the observations have allowed us to accurately determine the point-spread function for each source, allowing accurate modelling and subtraction of the quasar nucleus. This has subsequently enabled us to determine detailed characteristics of the underlying host galaxies in these objects. Furthermore, we have obtained 1.5 hours of J-band spectroscopy on each object, again with ISAAC, to determine the width of the broad Hβ line in each these objects which should enable us to estimate the mass of the central supermassive black hole via the virial black-hole mass estimate (Peterson & Wandel, 2000; Onken & Peterson, 2002; McLure & Jarvis, 2002)

3 The host galaxies

We have performed detailed modelling of the host galaxies of all of the FSQs in our sample using the modelling technique described in McLure, Dunlop & Kukula (2000). Full morphological parameters of the FSQs will be presented in a subsequent paper.

In this paper we focus on the K-band magnitudes determined for the host galaxies and compare these with the radio galaxy host magnitudes which are uncontaminated by the bright point source resulting from the quasar nucleus. Table 1 lists the sources with there relevant properties, Fig. 2 shows that all of these sources are consistent with lying on the radio galaxy $K-z$ Hubble diagram (Eales et al., 1997; Jarvis et al., 2001; Willott et al., 2003) implying that the hosts of these powerful radio selected quasars are some of the most massive galaxies in the Universe, i.e. $> 3\ L_{\star}$.

This is in apparent opposition to the conclusions reached by Oshlack, Webster & Whiting (2002). From their analysis of lower redshift flat-spectrum radio-loud quasars they suggested that the radio-loud quasars possibly reside in less luminous galaxies in comparison to their optically selected quasar counterparts. Although this may well be true to some degree with respect to the optical selection biases, we find that genuinely powerful radio-loud AGN (i.e. $P_{5\mathrm{GHz}} > 10^{24}$ W Hz^{-1} sr^{-1}) do seem to inhabit super-$L^{\star}$ galaxies over all cosmic epochs.

4 Black hole masses

In this section we utilize the correlation between black-mass and bulge luminosity ($M_{\mathrm{bh}} - L_{\mathrm{bulge}}$) to estimate the black-hole masses in these FSQs.

Using the relation between black-hole mass and bulge luminosity given in McLure & Dunlop (2002), i.e.

$$\log(M_{\mathrm{bh}}/M_{\odot}) = -0.50(\pm 0.02) M_R - 2.96(\pm 0.48),$$

we can estimate the mass of the central supermassive black holes in these quasars. Assuming that the host galaxies evolve along the tracks shown in Fig. 2 then the host galaxies of the FSQs are all larger than 3 $L_{\star}$ (using $M_K^{\star} = -23.52$ from Kochanek et al. 2001). Using $R - K = 2.7$ for local ellipticals we find that according to the $M_{\mathrm{bh}} - L_{\mathrm{bulge}}$ relation that all of our FSQs contain black-holes with $10^8\ \mathrm{M}_{\odot} < M_{\mathrm{bh}} < 10^9\ \mathrm{M}_{\odot}$.

This is in line with the upper envelope in the black-hole mass – radio power plane proposed by Dunlop et al. (2003), where genuinely powerful radio-loud sources are powered by black holes with mass $> 10^8 \mathrm{M}_{\odot}$.

This implies that targeting *powerful* radio-loud quasars or radio galaxies allows one to probe the upper bounds in black-hole mass at any given epoch.

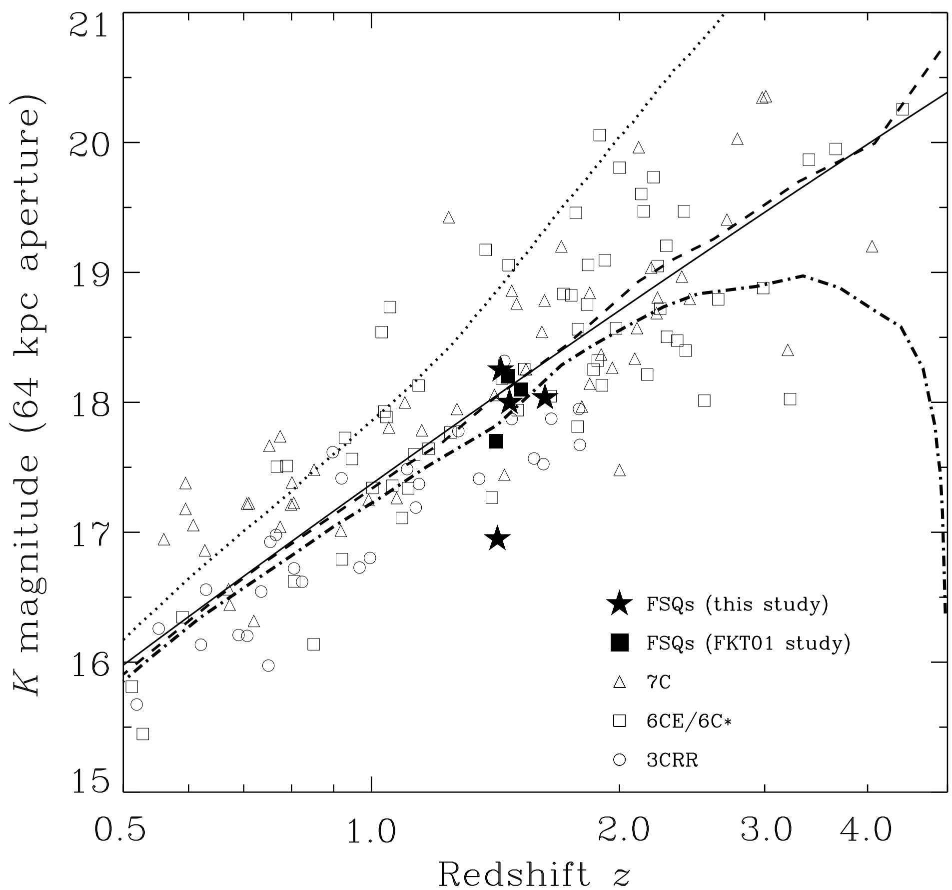

Fig. 2. The $K-z$ relation for radio galaxies from low-frequency selected radio samples. 3CRR (open circles, Laing, Riley & Longair 1983), 6CE/6C* (open squares, Eales et al. 1997; Jarvis et al. 2001), 7C (open triangles, Willott et al. 2003; Lacy et al. 2000), the Parkes flat-spectrum quasars from this study (filled stars) and those from the study of Falomo, Kotilainen & Treves (2001; filled squares, adjusted to K magnitude using $H-K=0.5$ at $z\sim1.5$). The curves represent various evolutionary models for a 3 $L_{\star}$ galaxy (see Willott et al. (2003) for full details).

5 The virial black-hole mass estimator: a word of caution

In this section we briefly discuss the possible orientation bias in using the virial black-hole mass estimator. It has been shown that the width of the broad emission lines in radio-loud quasars are dependent on the orientation of the source (e.g. Wills & Browne 1986; Brotherton 1996; Vestergaard, Wilkes & Barthel 2000), with the more pole-on sources, i.e. those with high radio core-to-lobe flux ratios, having narrower broad lines. Therefore, according to most forms of the orientation based Unified Schemes for active galaxies, the flat-spectrum quasars, which are presumed to be pole-on powerful radio-loud quasars, should exhibit the narrowest broad lines.

The FSQs from the sample of Oshlack et al. (2002) have a mean FWHM of the Hβ broad emission line of ~ 3500 km s^{-1}. On the contrary, the low-frequency selected quasars from the Molonglo Quasar Sample (Baker et al. 1999), where the low-frequency gives an orientation independent selection technique, has a mean FWHM(Hβ) ~ 7000 km s^{-1}. This at least implies that orientation may need to be considered when using the virial black-hole mass estimator, at least for radio-loud quasars. In a subsequent paper we investigate this further for our sample of $z \sim 1.5$ FSQs with deep $J-$band spectroscopy around the Hβ emission line.

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