The host galaxies of low luminosity quasars at high redshift

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Abstract

We present VLT/ISAAC near-infrared imaging of the host galaxies of 15 low luminosity quasars at $1 < z < 2$. This work complements our studies to trace the cosmological evolution of the host galaxies of high luminosity quasars. The radio-loud (RLQ) and radio-quiet (RQQ) quasars have similar distribution of redshift and luminosity, and together the high and low luminosity quasars cover a large range of the quasar luminosity function. Both RLQ and RQQ hosts resemble massive inactive ellipticals undergoing passive evolution. However, RLQ hosts are systematically more luminous than RQQ hosts, as also found for the high luminosity quasars. The difference in the host luminosity remains the same from $z = 2$ to $z = 0$. For the entire set of quasars, we find a correlation between the nuclear and the host luminosities, albeit with a large scatter. The correlation is less apparent for the RQQs than for the RLQs.

Key words: galaxies: active, galaxies: evolution, infrared: galaxies, quasars: general

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1 Introduction

Low redshift ($z \leq 0.5$) quasars are predominantly hosted by massive, bulge-dominated galaxies (Bahcall et al., 1997; Dunlop et al., 2003; Pagani et al., 2003). This is consistent with the fact that nearby massive spheroids host inactive supermassive black holes (BH) (Ferrarese, 2002), and suggests that episodic quasar activity may be common in galaxies and that the nuclear power depends on the mass of the galaxy (Kauffmann et al., 2003).
At low redshift, the BH mass is related to the luminosity and velocity dispersion of the bulge (Marconi & Hunt, 2003; Bettoni et al., 2003; Haring & Rix, 2004). Furthermore, the strong cosmological evolution of quasars is similar to the BH mass accretion rate and the evolution of the cosmic star formation history (Madau et al., 1998; Barger et al., 2001; Yu & Tremaine, 2002). Therefore, determining the properties of quasar hosts close to the peak of quasar activity is crucial to investigate the fundamental link between the formation and evolution of massive galaxies and the nuclear activity.

The detection of the host galaxies of high redshift quasars is very challenging because the host galaxy rapidly becomes very faint compared to the nucleus. To cope with this, high spatial resolution and S/N, and a well defined PSF are needed. All these requirements can be fulfilled by ground-based 8m class telescopes. We recently carried out a systematic VLT/ISAAC imaging study of 17 quasars (10 radio-loud quasars [RLQ] and seven radio-quiet quasars [RQQ]) at $1 < z < 2$ to characterize their host galaxies (Falomo et al., 2004). The evolution of both RLQ and RQQ hosts until $z \sim 2$ is consistent with that of massive ellipticals undergoing passive evolution. There is no significant decrease in the host mass as would be expected in hierarchical formation models (Kauffmann & Haehnelt, 2000). RLQ hosts are more luminous by $\sim 0.6$ mag than RQQ hosts at all redshifts.

The quasars in (Falomo et al., 2004) belong to the bright end of quasar luminosity function. Here we present imaging of quasars that have on average lower luminosity by $\sim 2$ mag, to study the dependence of host properties on nuclear luminosity. We use $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.

2 Sample, observations and analysis

The low luminosity quasars were extracted from Veron-Cetty & Veron (2003), requiring $1.2 < z < 1.9$, $M_B < -25.5$ at $z < 1.5$ up to $M_B < -26.7$ at $z = 1.9$, and having bright stars within 1 arcmin of the quasar to allow a reliable characterization of the PSF. Nine RLQs and six RQQs were observed. Their redshift and luminosity distributions are shown in Fig. 1. They are matched in redshift with the high luminosity quasars (Falomo et al., 2004), and together the samples cover a large fraction ($\sim 4$ mag) of the quasar luminosity function.

The quasars were imaged in the $H$- or $K$-band using VLT/ISAAC, with total integration time of 36 minutes per target. The seeing was excellent during the observations (median $\sim 0.4$ arcsec FWHM). Images were taken using random jitter with 2 minute exposure per frame. Pipeline data reduction included flat fielding, median sky subtraction and co-addition of aligned frames.
Fig. 1. Low luminosity RLQs (filled circles) and RQQs (open circles), high luminosity RLQs (filled squares) and RQQs (open squares) from Falomo et al. (2004), and RLQs (filled triangles) and RQQs (open triangles) from HST/NICMOS study by Kukula et al. (2001) in the $z - M_B$ plane, compared with all quasars (small dots) in Veron-Cetty & Veron (2003). The solid line shows the luminosity limit applied between the low and high luminosity samples.

For each field, we performed a 2D analysis of all stars to construct a composite PSF model. For each quasar, we measured its 2D luminosity distribution, masking regions affected by companions. The luminosity distributions were modeled, using an iterative least-squares fit, into a point source (PSF model) and an elliptical galaxy ($r^{1/4}$), convolved with the PSF.

3 Results

3.1 The evolution of quasar hosts

For all the low luminosity quasars, except one RQQ, the host galaxy is resolved. The average absolute magnitude of their host galaxies is $< M_K >_{\text{(host)}} = -26.3 \pm 0.3$ (RLQ) and $< M_K >_{\text{(host)}} = -25.7 \pm 0.3$ (RQQ), compared with those for high luminosity quasars (Falomo et al. 2004): $< M_K >_{\text{(host)}} = -26.8 \pm 0.2$ (RLQ) and $< M_K >_{\text{(host)}} = -26.0 \pm 0.3$ (RQQ).
Fig. 2 shows the average luminosities of the host galaxies in quasar samples at $z < 2$, from HST or ground-based data. The host galaxies of both RLQs and RQQs, despite their different radio properties, follow the passive evolution of massive ellipticals. Similar luminosity evolution is seen in radio galaxies at least out to $z \sim 2.5$ (Pentericci et al. 2001; Willott et al. 2003). This passive evolution is also consistent with spectroscopic studies of low redshift quasar hosts and radio galaxies (de Vries et al. 2000; Nolan et al. 2001), indicating that their stellar content is dominated by an old stellar population.

The cosmic evolution traced by quasar hosts up to $z \sim 2$ disagrees with semi-analytic hierarchical models of AGN and galaxy formation and evolution (Kauffmann & Haehnelt, 2000), which predict fainter (less massive) hosts at high redshift, which merge and grow to form low redshift massive spheroids. Thus, if quasar hosts undergo passive evolution, it is likely that their mass remains essentially unchanged from $z \sim 2$ up to $z = 0$.

For both low and high luminosity quasars, RLQ hosts are systematically more luminous than RQQ hosts by $\sim 0.6-0.8$ mag. There is no significant change in this luminosity gap with redshift. If the host luminosity is correlated with the BH mass, this indicates that the BHs in RLQs are more massive than those in RQQs. Furthermore, to produce the same luminosity, the BHs in RLQs must be accreting less efficiently than those in RQQs.
3.2 Nuclear versus host properties

In Fig. 3 we compare the $K$-band host and nuclear luminosities of the low and high luminosity quasars. For the entire set of quasars, we find a reasonably strong nuclear luminosity dependence of the host galaxy luminosity, with a rather large scatter. Separating the two quasar types, a modest correlation can still be seen for RLQs, which is hardly present for RQQs. Since no or little correlation has generally been found at low redshift (Dunlop et al., 2003; Pagani et al., 2003), it must have its onset at relatively high redshift.

Assuming that the $K$-band host luminosity is proportional to the BH mass (as observed at low redshift) and that the $K$-band nuclear luminosity is proportional to the bolometric luminosity, the $K$-band nucleus/host ($N/H$) luminosity ratio is proportional to the Eddington ratio $L/L_E$. For low luminosity quasars, the average log $N/H$ ratios are: 1.04 ± 0.40 (RLQ) and 1.00 ± 0.44 (RQQ), compared with those for high luminosity quasars (Falomo et al., 2004): 1.36 ± 0.33 (RLQ) and 1.32 ± 0.37 (RQQ). This indicates that high redshift quasars radiate with a wide range of $L/L_E$, irrespective of radio power. Similarly wide range was found for low redshift RLQs (Pagani et al., 2003), suggesting that the spread does not depend on redshift either. This is consistent with the evolution of quasars being mainly produced by a density evolution of BH activity due to increased merger and fuelling rate at high red-
shift. $L/L_E$ appears, however, to depend on quasar luminosity. This indicates a smaller accretion efficiency in low luminosity quasars.

4 Open questions

To determine quasar host properties at even higher redshift, close to the peak epoch of quasar activity ($z \sim 2.5$) and beyond, requires very high S/N observations and a very narrow reliable PSF. We have an ongoing program \cite{Falomo2005} to tackle this using adaptive optics imaging with VLT/NACO (see also Falomo et al., in these proceedings). Colour information for the hosts, spectroscopy to estimate BH masses, and environments as a function of redshift and radio power will also be topics of future work.

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