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NUCLEAR TO HOST GALAXY RELATION OF HIGH REDSHIFT QUASARS

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RESUMEN

Se presentan imágenes en el cercano infrarrojo de cuásares a $1 < z < 2$ con una cobertura amplia ($\sim$ 4 mag) de la función de luminosidad de cuásares. Las galaxias anfitrionas de cuásares radio-fuertes (RLQ) y radio-callados (RQQ) tienen luminosidades en el intervalo de las elípticas masivas inactivas entre L^* y 10 L^*. Las galaxias huésped de los RLQ son más luminosas que las de los RQQ. La brecha en luminosidad es independiente de la luminosidad en la banda-U en reposo pero está correlacionada con la luminosidad en la banda-R en reposo. Esta diferencia en el color de RLQ y RQQ es probablemente debida a una combinación de la diferencia intrínseca en sus SEDs y a un efecto de selección debido a la extinción interna por polvo. Hay una correlación razonable entre las luminosidades nuclear y huésped para RLQ pero no para RQQ. Si la banda-R traza la luminosidad bolométrica y si la luminosidad huésped es proporcional a la masa del agujero negro, los cuásares de alto corrimiento al rojo emiten en un estrecho intervalo de potencias con respecto a su luminosidad de Eddington.

ABSTRACT

We present near-infrared imaging of quasars at $1 < z < 2$, covering a large range ($\sim$ 4 mag) of quasar luminosity function. The host galaxies of both radio-loud (RLQ) and radio-quiet (RQQ) quasars have luminosities in the range of massive inactive ellipticals, between L^* and 10 L^*. RLQ hosts are more luminous than RQQ hosts. This luminosity gap is independent of rest-frame U-band luminosity but correlated with rest-frame R-band luminosity. This color difference between RLQs and RQQs is likely a combination of an intrinsic difference in their SEDs, and a selection effect due to internal dust extinction. There is a reasonable correlation between the nuclear and host luminosities for RLQs but not for RQQs. If the R-band traces the bolometric luminosity, and if the host luminosity is proportional to the black hole mass, high redshift quasars emit with a narrow range of power with respect to their Eddington luminosity.

Key Words: galaxies: active — galaxies: evolution — infrared: galaxies — quasars: general

1. INTRODUCTION

Low redshift ($z \leq 0.5$) quasars are predominantly hosted by massive, bulge-dominated galaxies (e.g. Dunlop et al. 2003; Pagani et al. 2003). This is consistent with the fact that nearby massive spheroids host inactive supermassive black holes (BH), 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, BH mass is related to the luminosity and velocity dispersion of the bulge (e.g. Marconi & Hunt 2003; Häring & 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 (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 challenging because the host galaxy rapidly becomes very faint compared to the nucleus. To cope with this, high spatial resolution and S/N, and accurate PSF are needed. These requirements can be fulfilled by ground-based large telescopes.

In Falomo et al. (2004), we carried out ESO VLT/ISAAC imaging of 17 quasars (10 radio-loud quasars [RLQ] and seven radio-quiet quasars [RQQ]) at $1 < z < 2$ to characterize their host galaxies. These quasars 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 correlation between their nuclear and host luminosities. We use H_0 = 70 km s^{-1} Mpc^{-1}, Ω_m=0.3 and Ω_Λ=0.7. For full discussion of results, see Kotilainen et al. (2007).

2. OBSERVATIONS AND ANALYSIS

The low luminosity (LL) quasars were required to have bright stars within 1 arcmin to allow a reliable characterization of the PSF. They are matched in redshift with the high luminosity (HL) quasars

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(Falomo et al. 2004), and the samples cover a large fraction (~ 4 mag) of quasar luminosity function.

Nine RLQs and six RQQs 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 ~ 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.

For each field, we performed a 2D analysis of stars to construct a composite PSF model. For each quasar, their 2D 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

The host galaxies of both RLQs and RQQs, despite their different radio properties, follow the trend in luminosity of massive inactive ellipticals (between L^* and 10 L^*) undergoing simple passive evolution. The cosmic evolution traced by quasar hosts up to $z \sim 2$ disagrees with semianalytic 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 $z = 0$. Note, however, that more recent hierarchical models including e.g. feedback due to AGN and supernovae (e.g. Granato et al. 2004; Bower et al. 2006) are in agreement with the existence of a substantial population of massive ellipticals out to at least $z \sim 2$.

3.1. *The relation between nucleus and host*

If the mass of the central BH is proportional to the mass (luminosity) of the host galaxy bulge, as for nearby inactive early-type galaxies, and if the quasar emits at a roughly fixed fraction of the Eddington luminosity, one would expect a correlation between the luminosity of the nucleus and that of the host galaxy. However, nuclear obscuration, beaming, and/or an intrinsic spread in the accretion rate and accretion-to-luminosity conversion efficiency, could destroy this correlation.

The LL and HL quasar samples explore a large range of nuclear luminosity and can therefore be used to investigate this issue. Both in the LL and HL samples, the nuclear U-band luminosities of the RLQs and RQQs are matched within 0.1 mag. On the other hand, the rest-frame R-band nuclear luminosities of RLQs are higher than those of RQQs by $\sim$ 1 mag. This result, therefore, suggests that there is a systematic color difference between the nuclei of RLQs and RQQs, in the sense that RLQs are redder than RQQs by $\sim$ 0.8 mag in the rest-frame $U - R$ color. Indeed, there is no apparent difference between the UV-to-NIR spectral properties of RLQs and RQQs in the average quasar SED of Elvis et al. (1994), but it is biased toward X-ray and optically bright (i.e. blue) quasars. A possible difference between the SED of RLQs and RQQs was reported by Barkhouse & Hall (2001), who observed a larger NIR-to-optical luminosity ratio in RLQs than in RQQs in a large sample of 2MASS-detected quasars. Furthermore, Francis et al. (2000) found that the optical-NIR continuum is significantly redder in radio-selected than in optically selected RLQs.

This effect may be due to differential extinction by dust or an intrinsic difference of thermal and nonthermal components in the SEDs of RQQs and RLQs. For example, in the case of flat spectrum quasars, one expects to observe enhanced nonthermal (synchrotron) emission which contaminates the SED more in near-IR than in UV. This would suggest that near-IR luminosity is not a good tracer of the bolometric emission. However, Francis et al. (2000) found this effect not to be sufficient to describe the spectral shape of most of their radio-selected quasars: with majority of them more likely to be reddened by dust. We believe that both explanations (synchrotron contamination and dust extinction) are viable; however, for the RLQ sample, the hypothesis of synchrotron contamination is weakened because 1/3 of the objects are steep spectrum radio quasars (viewed further away from the jet axis than flat spectrum radio quasars), and there is no correlation between radio spectral index and $U - R$ (observed $V - K$) color. If indeed dust extinction is the dominant effect, then R-band is a better tracer of the bolometric luminosity than U-band. Moreover, note that in rest-frame UB region, quasar SED is contaminated by the variable thermal emission from the accretion disk (the big blue bump), again indicating that the R-band luminosity is a better indicator of the total nuclear emission.

There is a reasonable correlation between the rest-frame R-band host and nuclear luminosities of the HL and LL quasars, for the combined sample of RLQs and RQQs (Figure 1). This correlation becomes modest for RLQs and disappears for RQQs. Generally, no such correlation has been found at low redshift (e.g. Dunlop et al. 2003; Pagani et al.

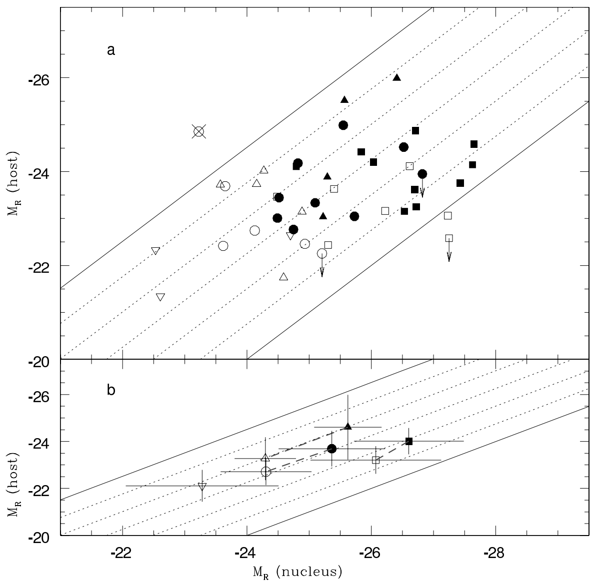

Fig. 1. Upper panel: The absolute magnitude of the nucleus compared with that of the host galaxy. for LL RLQs (filled circles), LL RQQs (open circles), HL RLQs (filled squares) and HL RQQs (open squares). Diagonal lines represent the loci of constant nucleus/host ratio, that can be translated into Eddington ratios. Separations between dotted lines correspond to a factor of 2 difference in the nucleus/host ratio. Lower panel: The average values for the samples. Note that, for each sample, the transition from RQQs to RLQs occurs at a roughly fixed fraction of the Eddington luminosity.

2003). However, similar trend is apparent for a large sample of $z < 0.5$ quasars studied by Hamilton et al. (2002). This indicates that the different trends of the nucleus-host luminosity relation displayed by RLQs and RQQs may be independent of redshift.

Assuming that the correlation between the central BH mass and the host galaxy luminosity holds up to $z \sim 2$ and that the observed nuclear power is proportional to the bolometric luminosity, the observed nucleus – host luminosity correlation can be interpreted as the result of an intrinsically narrow distribution of their Eddington ratio. This range does not appear to depend on redshift or on the radio properties of the quasars. The observed scatter is then enhanced by the dispersion in the bulge luminosity – BH mass correlation and by intrinsic differences in the accretion rates. This is consistent with the relationship between the host galaxy and maximum nuclear luminosity observed at lower redshift (e.g. Floyd et al. 2004).

3.2. *Future work*

Determining the quasar host properties at even higher redshift, around the peak epoch of quasar activity ($z \sim 2.5$) and beyond, requires very high S/N observations with a very narrow reliable PSF. We have an ongoing program to tackle this problem using NIR adaptive optics imaging with NACO on VLT for high luminosity quasars (Falomo et al. 2005, 2008), and NIR non-adaptive optics with ISAAC on VLT for low luminosity quasars (Kotilainen et al., in prep.). Color information for the hosts (e.g. deep R-band imaging to target rest-frame UV emission), spectroscopy to estimate the BH masses of high redshift quasars, and the study of environments as a function of redshift and radio power, will also be addressed in future work.

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