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ScienceDirect
New Astronomy Reviews 50 (2006) 732–735
New Astronomy Reviews
www.elsevier.com/locate/newastrev

The evolution of radio loud quasar host galaxies: AO observations at $z \sim 3$

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Available online 9 August 2006

Abstract

We report on ESO VLT adaptive optics imaging of one radio-loud quasar at $z \sim 3$. In spite of the large distance of the object we are able to detect its surrounding extended nebulosity the properties of which are consistent with an underlying massive galaxy of $M_K \sim -27$ and effective radius $R_e = 7$ kpc. As far as we know this is the clearest detection of a radio loud quasar host at high redshift. The host luminosity is indicative of the existence of massive spheroids even at this early cosmic epoch. The host luminosity is about 1 magnitude fainter than the expected value based on the average trend of the host galaxies of RLQ at lower redshift. The result, which however is based on a single object, suggests that at $z \sim 3$ there is a deviation from a luminosity–redshift dependence regulated only by passive evolution.

PACS: 98.54.Aj

Keywords: Galaxies: active; Galaxies: evolution; Quasars: general

Contents

1. Introduction

It is well known that at low redshift quasars are hosted in otherwise normal luminous (and massive) galaxies (Bahcall et al., 1997; Dunlop et al., 2003; Pagani et al., 2003) characterized by a conspicuous spheroidal component that becomes dominant in radio loud objects (RLQ). These galaxies appear to follow the same relationship between the bulge luminosity and the mass of the central black hole observed in nearby inactive elliptical galaxies (Ferrarese, 2002). If this link keeps also at higher redshift the observed

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doi:10.1016/j.newar.2006.06.028

population of high z quasars traces the existence of $\sim 10^9 M_\odot$ super massive BHs and massive spheroids at very early (<1 Gyr) cosmic epochs (Fan et al., 2001, 2003; Willott et al., 2003).

Indeed this idea seems also supported by the discovery of molecular gas and metals in high z quasars (Bertoldi et al., 2003b; Freudling et al., 2003), that are suggestive of galaxies with strong star formation. In this context it is therefore important to push as far as possible in redshift the direct detection and characterization of QSO host galaxies. In particular, a key point is to probe the QSO host properties at epochs close to (and possibly beyond) the peak of quasar activity ($z \sim 2.5$).

Till few years ago, due to the severe observational difficulty, the properties of quasar hosts at high redshift were very poorly known (e.g. see the pioneering papers by Hutchings, 1995; Lehnert et al., 1992; Lowenthal et al., 1995). Uncertain or ambiguous results, were produced because based on inadequate quality of the images (modest resolution; low S/N data; non optimal analysis).

In this work we present first results of a program aimed at imaging the host galaxies of quasar at $z > 2$ using adaptive optics at 8m class telescopes. Throughout this work we use $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

2. Adaptive optics imaging of distant QSO

In order to characterize the properties of high z quasar hosts, it is of fundamental importance to combine high spatial resolution (narrow PSF) with very good sensitivity to detect and measure the faint nebulosity surrounding the bright QSO nuclei. Adaptive optics (AO) opened a new window in this field, though the first generation of AO systems at 4m class telescopes enabled the detection of details on the host at low z they did not allow much improvements for distant quasars (Hutchings et al., 1998, 1999; Marquez et al., 2001; Lacy et al., 2002).

It was the recent introduction of sophisticated AO systems at 8m class telescopes that, for the first time, provided the spatial resolution and the adequate sensitivity for pushing the detection of QSO hosts at $z > 2$, and it did not take long for new results to appear in the literature. Croom et al. (2004) using the AO system at the Gemini North telescope were able to resolve and characterize one radio quiet quasar (RQQ) at $z = 1.93$, finding for the host an absolute magnitude of $M_K = -27.3$. In a pilot program at the ESO–VLT equipped with the AO system (NACO), Falomo et al. (2005) resolved a radio loud quasar at $z \sim 2.5$. The absolute magnitude of the host was found $M_K = -27.6$. In both cases the host galaxy luminosity appears to be consistent with the trend followed at lower redshift (Falomo et al., 2004; Kotilainen et al., 2005). RQQ and RLQ host luminosity–redshift dependence follows that of massive spheroids undergoing simple passive evolution. Up to $z \sim 2$ the average host luminosity is about 4L* for RLQ and 0.7 mag fainter for RQQ.

In order to investigate the properties of quasar hosts at $z > 2.5$ and to explore the region near the peak of QSO activity we have carried out a new program to secure K band images of quasars in the redshift range $2 < z < 3$ using the AO system at ESO VLT.

3. Object selection, observations and data analysis

Adaptive optics systems employing natural guide stars imply that only the targets that are sufficiently close to relatively bright stars (used as reference for AO correction) can be actually observed. In order to find an adequate number of targets for AO observations we searched the Veron-Cetty and Veron (2003) catalog of quasars to collect suitable objects in the redshift range $2 < z < 3$ and $\delta < 0$, for sources having a star brighter than $V = 14$ within 30″. Under these conditions the system is expected to deliver

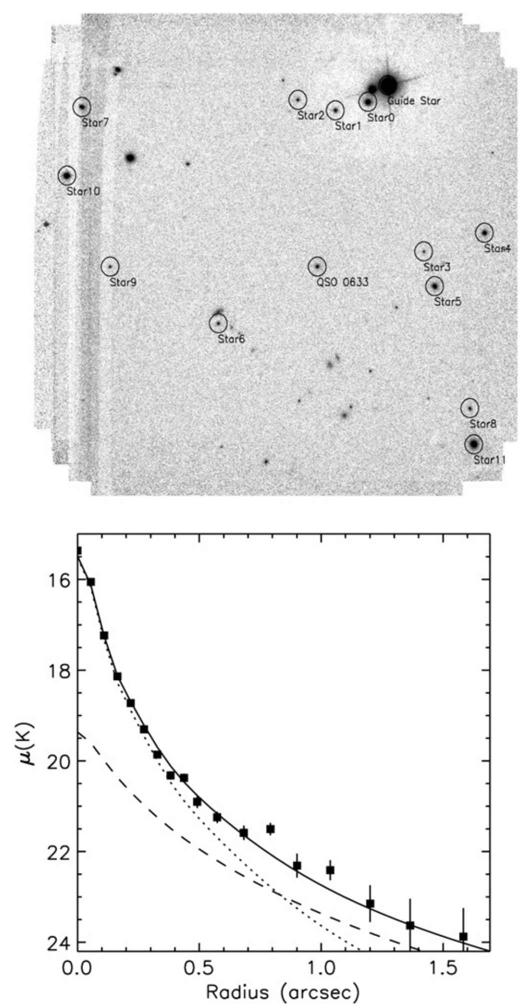

Fig. 1. *Top:* The K-band image of the radio loud quasar ($z = 2.928$) WGA J0633.1-2333. *Bottom:* The radial brightness profiles (filled squares), superimposed to the fitted model (solid line) consisting of the PSF (dotted line) and an elliptical galaxy convolved with its PSF (dashed line). The image decomposition was performed by AIDA (see text). The associated errors are a combination of the statistical photometry in each bin and of the uncertainty on the background level.