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Host galaxies, BH masses and Eddington ratio of radio-loud AGNs

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Abstract.

We compare the host galaxies properties of BL Lac objects with those of radio loud quasars (RLQs) imaged by the WFPC2 on board of HST. The considered objects (z<0.5) are always well resolved and their host galaxies satisfactorily modelled by ellipticals. After homogeneous treatment of the data we find RLQs hosts are systematically more luminous (by ≈ 0.7 mag) with respect to the hosts of BL Lacs. Using the $M_{BH}$ - $L_{bulge}$ relation, derived for nearby elliptical galaxies, we have evaluated the central black hole masses of our sample of active galaxies. These data are discussed in conjunction with the nuclear luminosity and the Eddington ratio.

1. Introduction

A clear insight of the galaxies hosting active nuclei is a fundamental ingredient for the understanding of both galaxies and nuclei formation and evolution. A comparison of the host galaxies of different type of AGN can for instance provide a direct test for unification models (e.g. Urry and Padovani 1995) while the relationship between nuclear properties and the immediate environment yields clues for the link between the formation of galaxies and the growth and evolution of a massive black hole (e.g. Kauffmann & Haehnelt 2000).
A good characterization of the host galaxies properties requires images of excellent quality in order to disentangle the light of the galaxy from that of the bright nucleus. To this aim HST images have provided a significant improvement of data on AGN host galaxies at various redshifts (Disney et al. 1995, Bahcall et al. 1996, 1997, Boyce et al. 1998, McLure et al. 1999; Hamilton 2000, Scarpa et al. 2000, Urry et al. 2000, Kukula et al. 2001).

In this paper we have considered two samples of active galaxies imaged by HST including respectively BL Lacs and RLQs. We compare and discuss their host properties in conjunction with the nuclear luminosity, estimated black hole (BH) masses and Eddington ratio. Preliminary results on the arguments discussed here were presented by O’Dowd et al. (2001).

2. The samples

We have collected data for all BL Lacs and RLQs at $z<0.5$ observed with the WFPC2 of HST. These observations were in general secured in different filters and were analyzed using different methods and calibrations. Our analysis has provided a uniform and homogeneous dataset of host galaxies for low z radio loud active galaxies. Most of the observations were obtained in the F702W filter therefore we converted all magnitudes into R (Cousins) band. Color corrections for objects observed in other filters were derived using the expected colors of galaxies given by Fukugita et al. (1995). Absolute magnitudes have been computed assuming for $H_0=50$ Km s$^{-1}$ Mpc$^{-1}$ and of $\Omega_0=0$. In addition K-correction was performed following Poggianti (1997) and galactic reddening corrections as in Scarpa et al. 2000.

2.1. The BL Lac sample

The HST snapshot imaging survey of BL Lacs (Urry et al. 2000, Scarpa et al. 2000) has provided an homogeneous set of 110 short exposure high resolution images through F702W filter. From this dataset we have considered all objects at $z<0.5$ that are resolved by the HST image. This yields 57 sources with $z$ between 0.027 and 0.495 and $<z> = 0.20 \pm 0.11$. Only for three sources at $z<0.5$ the host has not been detected by HST images (see Scarpa et al.). For these 57 objects the associated host galaxy morphology is always well described by elliptical modelling.

2.2. The RLQ sample

There is not a comparable large set of HST observations for higher luminosity RLQ therefore we have constructed a representative dataset for RLQ from collection of various sources reporting RLQ images secured by HST. In order to provide a homogeneous treatment we focussed on data for which apparent magnitudes of the host galaxies were given, so that the calibration procedure could be reproduced. This translates into the collection of RLQs investigated by Bahacall et al. (1997, 1999) (8 objects), Boyce et al. (1998) (6 objects) and McLure et al. (1999) (6 objects).
As in the case of BL Lacs for these objects the host galaxy is always visible and well consistent with an elliptical morphology. In table 1 we report the apparent and absolute magnitudes of the host galaxies. Our evaluation of $M_R$ is consistent with absolute values reported by the quoted authors when galactic extinction and filter transformations is taken into account. However in the case of Boyce et al. subsample a larger difference is noted due likely to a mistreating of k-correction and cosmological transformations.

Our comparison of three subsamples of RLQ show they are indistinguishable, therefore in the following analysis we considered a unique sample of 15 objects, with redshift in the range $0.158 < z < 0.389$ and $< z >= 0.26\pm0.07$, taking averages values for objects observed twice.

| Source     | $z$  | Filt | $m_{host}$ | $R_{host}$ | $M(R)_{host}$ | $A_r$ | Kcorr | Refs. |
|------------|------|------|------------|------------|---------------|-------|-------|-------|
| 3C48       | 0.367| f555w| 17.7       | 17.2       | -25.2         | 0.26  | 0.48  | B     |
| PHL 1093   | 0.258| f675w| *          | 17.2       | -24.4         | 0.14  | 0.3   | McL   |
| PHL 1093   | 0.258| f702w| 17.8       | 17.2       | -24.4         | *     | 0.3   | By    |
| PKS 0202-76| 0.389| f702w| 20.0       | 19.5       | -24.2         | 0.94  | 0.52  | By    |
| 0312-77    | 0.223| f702w| 17.7       | 17.1       | -24.8         | 0.76  | 0.26  | By    |
| 0736+017   | 0.191| f675w| *          | 16.9       | -24.3         | 0.46  | 0.21  | McL   |
| 1004+130   | 0.240| f606w| 16.9       | 16.9       | -24.4         | 0.16  | 0.28  | B     |
| 1004+130   | 0.240| f675w| *          | 16.9       | -24.6         | *     | 0.28  | McL   |
| 3C273      | 0.158| f606w| 16.0       | 15.8       | -24.4         | 0.07  | 0.17  | B     |
| 1302-102   | 0.286| f606w| 18.2       | 18.2       | -23.4         | 0.09  | 0.34  | B     |
| 1302-102   | 0.286| f702w| 18.0       | 17.4       | -24.4         | *     | 0.34  | By    |
| 1425+267   | 0.366| f555w| 18.3       | 17.8       | -24.4         | 0.09  | 0.48  | B     |
| 3C323.1    | 0.264| f606w| 18.1       | 18.1       | -23.4         | 0.19  | 0.31  | B     |
| 3C351      | 0.371| f702w| 18.5       | 18.0       | -24.7         | 0.09  | 0.49  | By    |
| 2135-147   | 0.200| f606w| 17.4       | 17.4       | -23.7         | 0.34  | 0.23  | B     |
| OX169      | 0.213| f675w| *          | 17.2       | -24.1         | 0.36  | 0.24  | McL   |
| 2247+14    | 0.237| f675w| *          | 17.2       | -24.3         | 0.24  | 0.27  | McL   |
| 2349-014   | 0.173| f606w| 16.2       | 16.0       | -24.5         | 0.16  | 0.19  | B     |
| 2349-014   | 0.173| f675w| *          | 15.9       | -24.7         | *     | 0.19  | McL   |

Table 1. Sample of RLQs: we report in column (1) the source, (2) the redshift, (3) the observational filter F, (4) the apparent magnitude in filter F, (5) the apparent magnitude of host galaxy in Cousins filter R, (6) the absolute magnitude of host galaxy in Cousins filter R, (7) the extinction correction in filter R, (8) the K-correction and in column (9) the reference (B=Bahcall et al. 1997; By=Boyce et al. 1998; McL McLure et al. 1999).
3. Results and discussion

3.1. Comparison of host galaxies of BL Lacs and RLQs

The comparison of the distribution of host galaxies luminosities (see Fig 1) shows that RLQ hosts are on average more luminous than those of BL Lacs. This should not be an effect due to selection of objects since both QSO and BL Lacs were chosen basing only on the nuclear properties.

The average host absolute magnitude for the BL Lacs is $<M_R>_{BLL} = -23.7 \pm 0.52$; while for RLQ hosts we find $<M_R>_{RLQ} = -24.32 \pm 0.44$. This systematic difference is not due to the different redshift range covered by the two sample since if we use only BL Lacs in the range $0.15 < z < 0.4$ to match the one of the RLQ sample we find $<M_R>_{BLL} = -23.77 \pm 0.49$.

In the recent analysis of a large sample of low $z$ ($<0.46$) QSOs Hamilton et al. 2001 report absolute V mag for 26 RLQs. After conversion to our cosmology, including correction for galactic extinction and assuming V-R=0.6 the average value of the host luminosity is $<M_R>_{RLQ} = -24.8$, leading to an even larger difference with BL Lac hosts.

4. The masses of the central Black Hole

Dynamical studies of nearby elliptical galaxies have shown that there is a correlation between the galaxy luminosity and the mass $M_{BH}$ of the central black hole (Magorrian et al. 1998; Kormendy and Gebhardt 2001 and references therein). A much tighter correlation was found between the BH mass and the stellar velocity dispersion of the host bulge of the galaxy (Ferrarese & Merritt 2000; Gebhardt et al. 2000). Moreover reverberation mapping estimates (Kaspi et al. 2000) of $M_{BH}$ of nearby AGN seem to indicate that this correlation holds.
Figure 2. Relation between the black hole mass and the absolute magnitude of the bulge component of the host galaxy for a sample of 37 nearby galaxies and linear fit (Kormendy & Gebhardt 2001). The filled and empty circle represent respectively the position corresponding to average values of black hole masses for BL Lacs and RLQs. The ellipses indicate the ranges covered by the two classes of objects

also for massive ellipticals hosting an active nucleus. With this assumption it is therefore possible to estimate the BH mass in AGN from the integrated host luminosity and/or the velocity dispersion (which is much more difficult to measure).

In figure 2, adapted from Kormendy and Gebhardt 2001, the $M_{BH} - M_{B, bulge}$ is reproduced together with the regions covered by the estimated BH masses for our two samples of BL Lacs and RLQs. It turns out that BH masses are in the range $5 \times 10^8$ to $5 \times 10^9$ and cover the region of most massive objects. It also turns out that on average BH masses of RLQ are a factor $\sim 2$ greater than those of BL Lacs as a direct consequence of the different average luminosity of their hosts ($< M_{bh} > = 1.5 \times 10^9 M_\odot$ for BL Lacs and $< M_{bh} > = 2.4 \times 10^9 M_\odot$ for RLQs).

5. Eddington ratios

The estimated BH masses can be used to derive the Eddington luminosity $L_E$ and can be compared with the total luminosity $L$ deduced by the spectral energy distribution (SED), yielding the Eddington ratio $\xi_E = L/L_E$.

For RLQs we assume an average total luminosity of $L \simeq 3 \times 10^{12} L_\odot$ (Elvis et al. 1994). In the case of the BL Lacs, in order to evaluate the intrinsic emitted total luminosity one has to take into account the beaming. We took $L \propto F \times \delta^{-2}$, where $F$ is the observed flux and $\delta$ is the Doppler factor. For the SED of a large sample of BL Lacs we refer to Sambruna et al. (1996) and Fossati et al. (1998).
The average beaming factor is taken $\delta \sim 15$ as suggested by Ghisellini et al. (1998) (see also Capetti and Celotti 1998). The resulting average intrinsic total luminosity for BL Lacs is therefore $L \sim 10^{10} L_\odot$.

By the above arguments the BH masses of the two samples are similar (within a factor of 2) while the intrinsic luminosities of the two classes differ by a factor $\sim 100$. The main inference is thus that the Eddington ratio $\xi_E$, differs by two orders of magnitude in the two classes.

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