HST snapshot imaging of BL Lac objects

R. Falomo

Osservatorio Astronomico di Padova, Italy

C. Megan Urry & Riccardo Scarpa

Space Telescope Science Institute

Joseph E. Pesce

Department of Astronomy, Pennsylvania State University, USA

Aldo Treves

University of Como, Italy

Abstract. Snapshot images of ~ 100 BL Lac objects were obtained with WFPC2 on HST. Sources from various samples, in the redshift range 0.05 to 1.2, were observed and 61 resolved (51 with known z). The high resolution and homogeneity of the images allow us to address the properties of the immediate environments of BL Lacs with unprecedented capability. Host galaxies of BL Lacs are luminous ellipticals (on average 1 mag brighter than L*) with no or little disturbed morphology. The nucleus, that is always well centered onto the galaxy, contributes in the optical (R band) to about half of the total luminosity of the object (range of the contribution from 0.1 to 10). The undisturbed morphology suggests that the nuclear activity has marginal effect on the overall properties of the hosts. Nonetheless several examples of close companions have been detected. The luminosity distribution of host galaxies is compared with that of a large sample of FR-I radio galaxies.

1. Introduction

Imaging of the galaxies hosting active galactic nuclei (AGN) is an important tool for the understanding of the activity phenomenon itself. This study is often hampered by the presence of the bright nucleus that swamps the light from the host galaxy. This is clearly a more serious problem for distant objects where the Point Spread Function (PSF) of the nuclear source becomes comparable with the size of the host galaxy.

The use of HST data has improved the capability to investigate the galaxies hosting nuclear activity and in fact a number of specific studies of nearby and intermediate redshift AGN have been pursued (see e.g. Disney et al. 1995 ;

Bahcall et al. 1997; Hooper, Impey & Foltz 1997; Malkan Gorjian and Raymond 1998).

BL Lac objects are radio loud AGN seen closely along the jet emission (see e.g. the review by Urry and Padovani 1995). The beaming properties of the jets suggest that low-luminosity radio galaxies are the corresponding misaligned population. Observations of the host galaxies are a direct probe of this unification hypothesis.

We report here some results on $\sim$ 100 BL Lac objects imaged with HST during a snapshot program (see Urry et al 1999b for full discussion). Previous imaging studies of BL Lacs using HST (GO programs) have been performed only for a limited number of sources (see Falomo et al 1997, Januzzi et al 1997 and Urry et al 1999a).

Taking advantage of high spatial resolution, homogeneity of data quality and analysis and sizeable data set, we are able to progress substantially on the luminosity distribution and morphological type of host galaxies, on the issue of the centering of the nucleus on the main body of the galaxy (microlensing) and on relevance of interactions with close companions.

2. Observations and data analysis

We have obtained HST snapshot images for 97 BL Lac objects from six samples (see Urry et al 1999b). Images of the targets were collected using the WFPC2 camera and the F702W (roughly R) filter. For each source we obtained typically 2-3 images with exposure time ranging from 2 to 10 minutes. The objects were centered in the PC CCD. After data reduction following the standard *HST* pipeline processing we have combined individual frames of the same object and used photometric calibration converted to Cousins R band as described in Scarpa et al (1999).

In order to understand if the sources are resolved and to derive the properties of the host galaxy a reliable model for the PSF is needed. The Tiny Tim model (Krist 1995) gives an excellent representation of the PSF shape within $\sim 2-3$ arcsec from the center. Outside this range, there is an extra emission due to the scattered light that affects the PSF wings. To account for this we used observations of saturated stars from the HST archive and modeled the extra emission with an exponential component (see Scarpa et al 1999 for more details).

The properties of the BL Lac host galaxies were derived both from azimuthally averaged radial profiles and from two-dimensional surface photometry (isophote fitting) when enough signal was present. We fitted the luminosity profile as a function of radius with models consisting of a nuclear unresolved source plus a galaxy (de Vaucouleurs $r^{1/4}$ law for an elliptical or exponential law for a disc), convolved with the PSF. Surface photometry analysis give us in addition the ellipticity, position angle and centers of ellipses as a function of radius. Fourier coefficients describing deviations from pure ellipses yield information about the galaxy sub-structures (see Falomo et al 1999).

3. Results

For 64 sources the redshift is known while for three only lower limits exist based on intervening absorption lines. All the objects with $z < 0.5$ but two (OJ 287 and 0954+658) are resolved in the HST images. The detection of the host galaxy of OJ 287 in a GO HST image was claimed by Yanny et al (1997) but this is disputed by Sillanpää et al. (this conference), while for second source the redshift of is dubious. We detected the host galaxy for 61 objects, 51 of which with known redshift. Two additional objects (0446+449 and 0525+713) are also well resolved but their classification as BL Lacs is uncertain (see Scarpa et al 1999). In the following we concentrate on the 51 resolved BL Lacs of known z. Results for the unresolved sources as well as for peculiar objects are given in Scarpa et al (1998,1999).

For all these objects the luminosity profile is well represented by an elliptical galaxy model (convolved with the PSF) plus the contribution of an unresolved nuclear source. In no case a disc dominated (spiral) galaxy model gave a significantly better fit to the data. The superior spatial resolution of HST compared with ground based data also helps to detect possible high contrast structures (e.g. spiral arms) in the host galaxy. In none of the resolved objects such structures have been detected, supporting the elliptical morphology classification. The point source is always well centered onto the image of the galaxy within

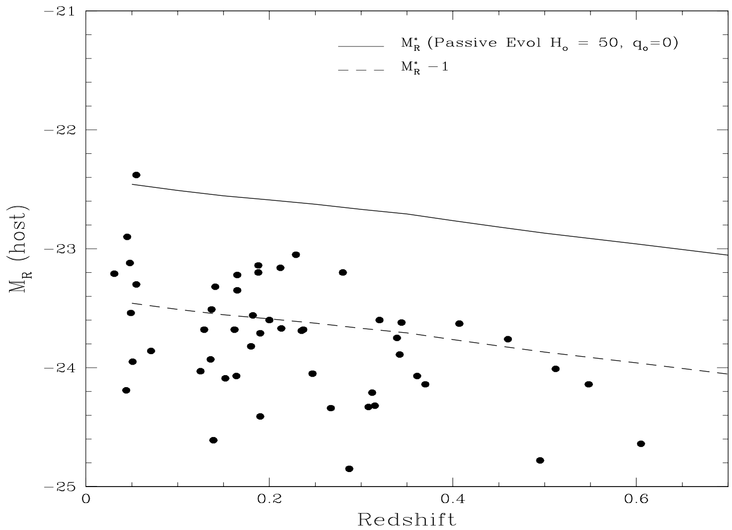

Figure 1. Absolute magnitude of host galaxies of BL Lacs vs redshift. The solid line represents the luminosity of M^*_R through passive evolution by Bressan et al 1994. Dashed line is the same for M^*_R −1.

an accuracy of 0.05 arcsec. This argues against microlensing playing an important role in BL Lac objects, since in case of lensing by a foreground galaxy an off-centering of the nucleus with respect to the surrounding nebulosity would be observed (Ostriker & Vietri 1985).

Using the results from the fitted profiles we have determined the luminosity of the host galaxies for each source. This is derived integrating the fitted elliptical

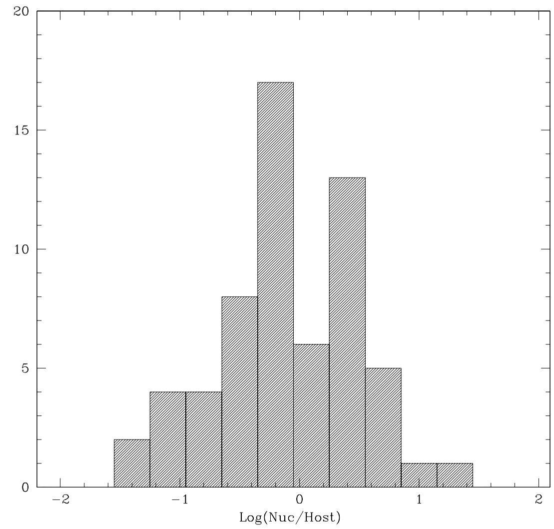

Figure 2. Distribution of the nuclear/host luminosity.

model to infinity (yielding total magnitude *a la* de Vaucouleurs). K-correction was applied using a spectrum of a standard elliptical convolved with observed passband and galactic extinction was taken into account using the Bell Lab Survey of neutral hydrogen N_H converted to $E_B - V$ (Stark et al 1992; Shull & Van Steenberg 1985). H_0 = 50 km s^{-1} kpc^{-1} and $q_0 = 0$ are adopted.

In Figure 1 we plot the absolute magnitude of the host galaxy M_R(host) as a function of the redshift. For comparison we show the expected luminosity of a M_R^* elliptical with the passive evolution model by Bressan et al 1994. With only one exception all measured hosts are brighter than M_R^*. It is noticeable that the points follow the expected trend of galaxy evolution. The mean value of the absolute magnitude of the hosts corrected for evolution ($<M_R$(host)$>$ = -23.6 $\pm$ 0.4) is $\sim$ 1 mag brighter than M_R^*. This value is consistent with previous findings from ground based observations (Falomo 1996; Wurtz, Stocke & Yee 1996) and robustly confirms that host galaxies of BL Lac are luminous ellipticals, on average brighter than L^* but not as bright as brightest cluster members.

The ratio of the nuclear over host luminosity for the resolved sources is reported in Figure 2. The distribution peaks at $\sim$ 1 ($<$ Log[Nuc/Host]$>$ = -0.1). On average therefore in the R band the nuclear source has a luminosity similar to that of the galaxy. The nucleus/host luminosity ratio ranges from 0.1 (typical for radio galaxies) to 10 (typical of quasars).

We show in Figure 3 the luminosity of the host versus that of the nuclear source. While the spread of the magnitude of the host galaxies is $\sim$ 1.5, the nuclear sources span over 5 magnitudes. We note there is some deficit of host galaxies fainter than M_R(host) = −23.5 objects with the nucleus brighter than M_R(nuc) = −23.0. Since host galaxies in this region should be detectable this suggests a tendency for the brightest galaxies to host the most luminous nuclei. However, because a number of sources have not been resolved this point should be furthermore investigated including upper limits of the host galaxies.

The overall morphology of host galaxies of BL Lacs is little perturbed and appears, in this respect, different from the case of radio loud quasars and powerful radio galaxies (e.g. Hutchings and Neff 1992; Smith and Heckman 1989)

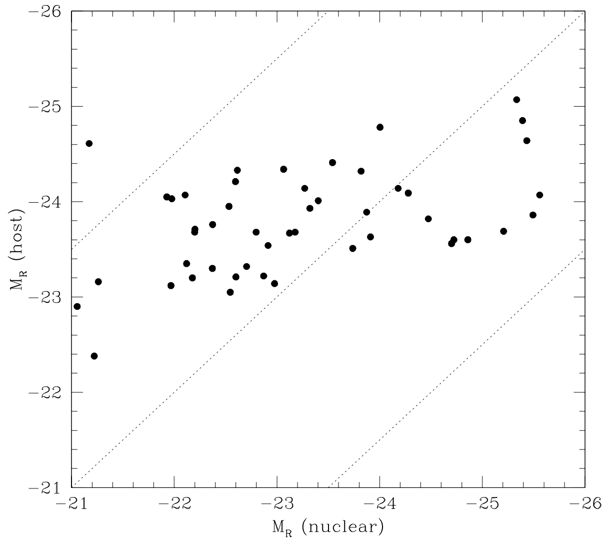

Figure 3. M_R(nuc) versus M_R(host) of BL Lacs. The lines represent the loci of host/nucleus luminosity ratio corresponding to 0.1, 1, and 10 (bottom to top).

In spite of the smoothness of host galaxy for many objects we have detected close companions, consistently with previous suggestions (Falomo 1996). Two of them are very close (< 0.5 arcsec) to the nucleus (see Scarpa et al 1998) and are extremely difficult to detect from the ground. Further scrutiny of these features is needed to understand their nature and the role for the BL Lac phenomenon.

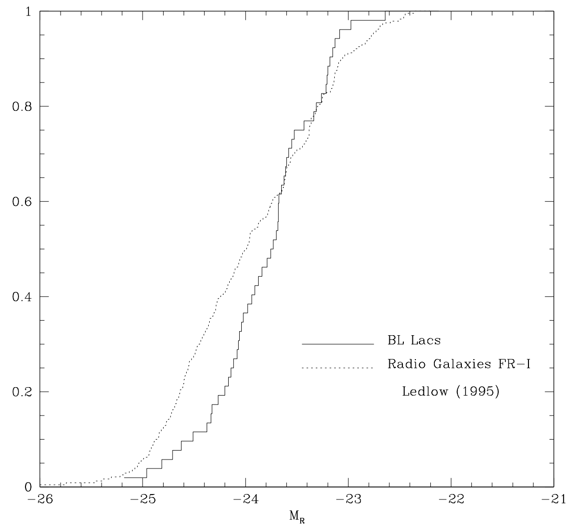

Figure 4. Cumulative distributions of absolute magnitude of BL Lacs hosts (*solid line*) and radio galaxies (*dotted line* Ledlow & Owen).

Comparison with optical properties of radio galaxies is limited by the lack of a large homogeneous data set in a wide range of redshifts. Moreover to perform an unbiased comparison one has to take into account systematic effects like different observed spectral band, K-correction, reddening and definition of galaxy magnitude. Optical studies of radio galaxies often use isophotal magnitudes and no correction is done for possible presence of the nuclear sources. This translates into a spread of properties comparing different samples of radio galaxies (Govoni et al 1999).

We have compared our distribution of host galaxy luminosity with that of radio galaxies by Ledlow & Owen (1995). This is largest homogeneous dataset of optical photometry of radio galaxies (mainly FR I radio galaxies in Abell clusters). The two cumulative distributions are compared in Figure 4. For $M_R > -23.5$ the two distributions are similar while at higher luminosities a deficit of BL Lac hosts with respect to radio galaxies is apparent. This can be related to the fact that FR I radio galaxies studied by Ledlow & Owen are members of clusters.

References

Bahcall, J. N., Kirhakos, S., Saxe, D. H., & Schneider, D. P. 1997, ApJ, 479, 642

Bressan,A., Chiosi,C., Fagotto,F., 1994, ApJS 94, 63

Disney, M. J., et al. 1995, Nature 376, 150

Falomo, R. 1996, MNRAS, 283, 241

Falomo, R., et 1997, ApJ, 476, 113

Falomo, R, et al., 1999, in preparation.

Govoni, F., Falomo, R., Fasano, G. & Scarpa, R.,1999, in preparation.

Jannuzi, B., et al. 1997, ApJ, 491, 146

Holtzman, J. A., et 1995, PASP, 107, 1065

Hooper, E. J., Impey, C. D., & Foltz, C. B. 1997, ApJ, 480, L95

Hutchings, J.B. & Neff, S.G., 1992, AJ, 104, 1.

Krist, J. 1995, in *Astronomical Data Analysis, Software*

Ledlow, M.J. & Owen, F.N. 1995, A.J., 109, 853

Malkan M.A., Gorjian V. & Raymond T. 1998, astro-ph/9803123.

Scarpa, R., et al 1998, this conference.

Scarpa, R., Urry, C.M., Falomo, R., Pesce, J. E., & Treves, A. 1999, in preparation.

Stark, A. A., et 1992, ApJS, 79, 77

Ostriker, J. P., & Vietri, M. 1985, Nature, 318, 446

Shull J.M., & Van Steenberg M.E. 1985, ApJ 294, 599

Smith, E. P., & Heckman, T. M. 1989, ApJ, 341, 658

Urry, C. M., & Padovani, P. 1995, PASP, 107, 803

Urry, C.M. et al 1999a, ApJ, in press.

Urry, C.M., et al 1999b, in preparation.

Wurtz, R., Stocke, J. T., Ellingson, E., & Yee, H. K. C. 1997, ApJ, 480, 547