Astron. Astrophys. 352, L11–L16 (1999)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Observations of the host galaxies of the BL Lacertae objects H 0414+009 and OJ 287 with FORS1 at VLT−UT1*

J. Heidt[1], K. Nilsson[2], I. Appenzeller[1], K. Jäger[3], W. Seifert[1], T. Szeifert[1,4], W. Gässler[5], R. Häfner[5], W. Hummel[5], B. Muschielok[5], H. Nicklas[3], and O. Stahl[1]

[1] Landessternwarte Heidelberg, Königstuhl, 69117 Heidelberg, Germany
[2] Tuorla Observatory, 21500 Piikkiö, Finland
[3] Universitäts-Sternwarte Göttingen, Geismarlandstrasse 11, 37083 Göttingen, Germany
[4] ESO Santiago, Alonso de Cordova 3107, Santiago 19, Chile
[5] Universitäts-Sternwarte München, Scheinerstrasse 1, 81679 München, Germany

Received 11 August 1999 / Accepted 11 October 1999

Abstract. We present imaging of the host galaxies of H 0414+009 and OJ 287 taken during the commissioning phases of FORS1 at the VLT−UT1. The host galaxy of H 0414+009 is well resolved in R and I, and marginally resolved in B. Based on our 2−dimensional modelling, it is a large and very luminous elliptical galaxy ($M_R = -24.6$, $r_e = 35$ kpc) with colours commonly found in elliptical galaxies (B−R ∼ 1.45 and R−I ∼ 0.45). The results are consistent with previous findings.

The host galaxy of OJ 287 is marginally resolved. A de Vaucouleurs profile is slightly preferred over a disk-type profile. If true, the host galaxy is luminous ($M_R = -23.4$), compact ($r_e = 4.4$ kpc) and has a small offset to the south with respect to the active nucleus. This is consistent with the results obtained by Sillanpää et al. (1999), but different to the findings by Wurtz et al. (1996) and Yanny et al. (1997).

The analysis of the marginally resolved host galaxies was complicated by a point spread function (PSF) varying across the field. Consequently, better results were obtained when using a PSF which varies with field position as compared to a constant PSF. This is possible as long as a sufficient number of stars is present on the images. Masking the central regions mostly affected by the PSF errors may also improve the results. Based on our experience we describe precaution which has to be taken for FORS1 observations and subsequent analysis of marginally resolved targets such as AGN host galaxies or planetary nebulae around young stellar objects.

Key words: methods: data analysis – galaxies: active – galaxies: BL Lacertae objects: individual: H 0414+009 – galaxies: BL Lacertae objects: individual: OJ 287 – galaxies: photometry

1. Introduction

The focal reducer and low dispersion spectrograph (FORS1) at the VLT−UT1 offers a wide variety of observing modes. Of particular interest is the imaging mode, which allows exposures as deep as the Hubble Deep Field within reasonable integration times. FORS1 is also attractive for studying the host galaxies of active galactic nuclei (AGN) at highest redshifts. For that purpose, the determination of the proper point spread function (PSF) is always critical. It may vary across the field and hence affect the decomposition of the observed flux distribution into AGN and host galaxy leading to uncertain results. Naturally, knowing the behaviour of the PSF already in advance is essential to prepare and carry out subsequent observations accordingly.

During the commissioning phases I and II of FORS1 observations of the BL Lacertae objects H 0414+009 and OJ 287 have been carried out. Both are at similar redshifts (z = 0.287 for H 0414+009 (Halpern et al. 1991) and z = 0.306 for OJ 287 (Stickel et al. 1989) and their host galaxies have been studied extensively during the last years. The host galaxy of H 0414+009 could be well resolved in all cases and its morphological parameters could be determined (e.g. Falomo & Tanzi 1991, M^{c}Hardy et al. 1992, Wurtz et al. 1996, Falomo 1996). On the other hand, due to the highly dominating contribution of the AGN, the nature of the host galaxy of OJ 287 is poorly understood and discussed controversially (e.g. Stickel et al. 1993, Wurtz et al. 1996, Benitez et al. 1996, Yanny et al. 1997, Wright et al. 1998, Sillanpää et al. 1999).

In the following, observations of these two BL Lac objects obtained during the commissioning phases of FORS1 will be used to pinpoint and quantitatively understand the behaviour of the PSF. While the frames of H 0414+009 and comparison with previous results will be used to check the reliability of our analysis, the images of OJ 287 will be taken as a test case for disentangling faint features close to bright point sources using PSFs constructed in various ways.

Send offprint requests to: J. Heidt (jheidt@lsw.uni-heidelberg.de)

* Based on observations made with the VLT−UT1, operated on Cerro Paranal (Chile) by the European Southern Observatory

2. Observations and data reduction

The observations of H 0414+009 have been carried out with FORS1 mounted at the cassegrain flange of VLT−UT1 (Antu) during commissioning phase I on the night September 27/28 1998. FORS1 was equipped with a 2K TEK CCD (24 μ pixel) providing a field of view of $6\rlap{.}'8 \times 6\rlap{.}'8$ in standard resolution mode ($0\rlap{.}''2$/pixel). One image of H 0414+009 in Bessel B, R and I filter each was taken with exposure times of 600, 300 and 300 sec, respectively.

The observations of OJ 287 were taken with the same setup during commissioning phase II on the nights December 23/24, 26/27 and 27/28 1998. Altogether 9 images with a total integration time of 865 sec were taken. Since some of the images were acquired for follow-up spectroscopy, OJ 287 was observed in three different position angles.

The individual frames were first corrected for bias. The correction for the pixel-to-pixel variations of the CCD caused some problems. Due to the test character of the commissioning runs, sufficient twilight flats had not always been taken during the nights of the observations of the BL Lac objects. Additionally, the CCD suffers from a condensation on its surface due to outgasing material inside the CCD. This leads to a flatfield pattern that is variable on timescales of weeks. Therefore we used a dedicated strategy to correct for pixel-to-pixel variations across the CCD. First, we created a flatfield for correction of the small-scale pixel-to-pixel variations using twilight flats taken during the individual commissioning run (lasting three weeks each) closely to the BL Lac observations. Then we created a “science flat” by a medianed and smoothed stack of a sufficient number of well exposed science frames in other fields taken during the nights of the observations of the BL Lac objects. Before this the science frames were corrected for small-scale pixel variations. Finally, the combination of the twilight flat and the science flat was used as “superflat” to correct the frames of the BL Lac objects. They were flat to within 0.5% or better. We justified our procedure by reducing images of other science frames taken during the same nights. In all cases our “superflat” provided satisfying results. Moreover, in neither case we found residuals of the variable flatfield pattern. We exactly repeated our flatfield procedure for other nights throughout the observing runs and found again our new created “superflat” for each individual night to be very good.

We used the IRAF tasks GEOMAP and GEOTRAN to align the images of OJ 287. 20 unsaturated stars in the field were used to map the transformation needed to bring all the images to the same position and orientation. The tasks also corrected for the low-order geometric distortion of the field ($\sim 0.16\%$ in the corners of the CCD). After the transformation of the images to common coordinates, they were summed. The FWHM in the final frame is $0\rlap{.}''76$. Since the observations of OJ 287 were taken under partly non-photometric conditions, the photometric zero point was determined from the comparison stars in the field from Fiorucci & Tosti (1996).

The data taken of H 0414+009 were taken under photometric observing conditions. Here standard stars from Landolt (1983) observed during the night were used to measure the zero points. The frames of H 0414+009 have a FHWM of $1\rlap{.}''24$, $1\rlap{.}''18$ and $1\rlap{.}''04$ in B, R and I band, respectively.

3. Data analysis and results

3.1. The point spread function

The most critical issue when deconvolving images into bright point sources and faint features such as galaxies is the choice of the proper PSF. This was important for our image of OJ 287 and the B-band image of H 0414+009, where the host galaxy was marginally resolved as opposed to the R and I-band image of H 0414+009. To overcome this, we used 28 stars in the field of OJ 287 and 10 stars in the field of H 0414+009 roughly spread uniformly over the field, both saturated and unsaturated, to construct a PSF. The unsaturated stars were used for both, the core and the wings, while the saturated stars were used for the wings of the PSF only. The PSF was constructed using DAOPHOT (constant PSF hereafter). Since we wanted to test, if there are changes of the PSF across the CCD, we used DAOPHOTs ability to make a PSF that changes over the field (varying PSF hereafter). For that procedure we assumed that the PSF varies linearly across the field. The reliability of our procedure was tested by subtracting both PSFs from various (but never saturated) stars across the CCD on the image of OJ 287 and the B-band image of H 0414+009. Subtracting the constant PSF resulted always in an oversubtraction of the flux towards the edges of the CCD and an undersubtraction towards the center of the CCD relative to each individual star. This effect showed an radial dependence for the stars, i.e. it was more pronounced with increasing distance from the center of the CCD. Contrary, the varying PSF made always much lower residuals without any radial dependence. However, in neither case we were able to make a perfect subtraction showing that the results of our fitting procedure to the marginally resolved host galaxies should be interpreted with caution. Finally we tested, if our aligning procedure of the individual images of OJ 287 introduced additional variations of the PSF. We created and subtracted constant and variable PSFs within two individual images of OJ 287 rotated with respect to each other as described above and found qualitatively the same behaviour as in the summed image. Therefore we decided to use a varying PSF for further analysis of OJ 287. Although our test indicated that a varying PSF might also be better for the images of H 0414+009 our initial fits to the BL Lac showed that even the varying PSF lead to unreliable results in the B band (for example large decentering of the host with respect to the core). A better result was obtained by creating a PSF using the 4 closest stars to H 0414+009, which we used thereafter for all images of H 0414+009. We conclude that 10 stars in the field of H 0414+009 are insufficient to characterize the variation of the PSF over the field.

3.2. The fitting procedure

The images of the BL Lac objects were decomposed into an AGN described by a point source and a galaxy (de Vaucouleurs

Table 1. Results of the fits to the images of the BL Lac objects. $B^{\star}$ is for a central mask with radius of 3 pixels. The results for OJ 287 are given for a central mask with radius of 4 pixels.

(1) Band	(2) Model	(3) m_{core}	(4) m_{host}	(5) M_{host}	(6) r_e ["]	(7) r_e [kpc]	(8) ϵ	(9) PA	(10) A [mag]	(11) K-corr.	(12) χ^2_{red}
				H 0414+009							
B	de Vauc.	17.84	19.88	−23.37	11.4	66.7	0.40	65	0.62	1.16	1.12
	disk	17.83	20.80	−22.19	3.9	22.6	0.34	67	0.62	0.90	1.11
$B^{\star}$	de Vauc.	17.85	20.12	−23.13	5.9	34.5	0.35	75	0.62	1.16	1.06
R	de Vauc.	17.16	17.45	−24.57	6.1	35.6	0.32	79	0.41	0.14	1.42
	disk	17.09	18.07	−23.95	3.5	20.6	0.29	78	0.41	0.14	1.79
I	de Vauc.	16.69	16.72	−25.00	6.0	35.2	0.36	80	0.25	0.00	1.23
	disk	16.62	17.34	−24.38	3.3	19.4	0.33	80	0.25	0.00	1.58
				OJ 287							
R	de Vauc.	15.71	18.41	−23.41	0.72	4.4	0.16	26	0.04	0.14	3.75
	disk	15.64	19.32	−22.50	1.68	10.2	0.20	22	0.04	0.14	4.99

or disk-type) by means of a fully two-dimensional fitting procedure (see Heidt et al. 1999 and Nilsson et al. 1999 for full details). The results of our fits to H 0414+009 are summarized in Table 1. Column 1 gives the band used, column 2 the galaxy model followed by the magnitude for the core, the host and the absolute magnitude of the host in columns 3−5, respectively. Columns 6 and 7 give the half-light radius $r_e$in arcsec and kpc and column 8 and 9 the ellipticity and the position angle of the host. Column 10 reports the galactic extinction estimated from Burstein & Heiles (1982) and column 11 the K-correction adopted from Bruzual (1983). Column 12, finally, shows the goodness of our fits.

In R and I a de Vaucouleurs profile is preferred over a disk-type profile, whereas in B band neither type is preferred. Furthermore, the results for the half-light radii differ significantly between B and R (and I). This is most likely due to the PSF errors, which are affecting the fits more strongly in the marginally resolved host in B. To eliminate this, we masked the central region with a radius of 3 pixels and fitted again (note that none of the images of H 0414+009 was saturated or close to saturation). The results are also displayed in Table 1 (row $B^{\star}$). Now the host is $\sim$ 0.25 mag fainter and its half-light radius similar to the values found for R and I. Of course, this procedure must be treated with caution. Masking the central pixels results in loss of information in a region, where the signal of the host galaxy is strongest. On the other hand, the host/nucleus ratio is weakest there, so even small errors in the PSF are large compared to the host signal. We believe that masking the region, where the PSF errors dominate and fitting in the region, where is host/nucleus ratio is not too weak results in more reliable parameters. A crude justification of our procedure comes from the reanalysis of our R and I image of H 0414+009, where we also masked the central region with a radius of 3 pixels. The differences to the fits without mask are small, $\sim$ 0.03 mag for the host and the core and $\sim$ 4 pixels for the half-light radius. Since most (perhaps all) of the BL Lac objects are hosted by elliptical galaxies we use in the following the results of the fits with a de Vaucouleurs profile (with the masked region in B and without masking in R and I). Clearly, to justify that procedure, realistic simulations of the PSF changes over the field and analysis of the resulting PSF errors are required.

The host galaxy of H 0414+009 is very bright with absolute magnitudes of −23.13, −24.57 and −25.00 in B, R and I, respectively. Its colours are B−R $\sim$ 1.45 and R−I $\sim$ 0.45. The host is also very large, $r_e\sim$ 35 kpc in all bands. Remarkably, it has a large ellipticity between 0.3 and 0.4 in all filters. The azimuthally averaged 1−dimensional surface brightness profiles as well as the model profiles for B and R are shown in Fig. 1. Based on our modelling with different masked regions we estimate an error for the photometry of $\sim$ 0.1 mag for the resolved images of H 0414+009 in R and I and an error for the half-light radius of $\sim$ 10%. For the marginally resolved host galaxy in B the error grow up to $\sim$ 0.3 mag for the photometry and $\sim$ 30% for the half-light radius.

The decomposition of the image of OJ 287 was very difficult since on some of the individual images of OJ 287 the central pixels (up to 6–10) were saturated or close to saturation (but never bleeding). In order to avoid unreliable fits due to overexposed pixels (or those within the non-linear dynamical range) we masked the central part with radii of 2, 3, 4 and 5 pixels, respectively, before fitting. Our results indicated that a mask with radius of 4 pixels is more than sufficient. The results of our fits to OJ 287 for that mask are given in Table 1.

Similarly to H 0414+009, a de Vaucouleurs profile is slightly preferred over an exponential profile although neither of the fits is satisfying. As already discussed for H 0414+009 this is most likely introduced by the PSF errors. Adopting again a de Vaucouleurs profile as the "correct" representation of the extended flux, the host of OJ 287 is very bright (M_R= −23.41) and compact (r_e= 4.4 kpc) with moderate ellipticity ($\epsilon = 0.16$). The errors are $\sim$ 0.3 mag for the photometry and $\sim$ 30% for the half-light radius similarly to the B band image of H 0414+009. The azimuthally averaged 1−dimensional surface brightness profiles and the model profiles are shown in Fig. 1.

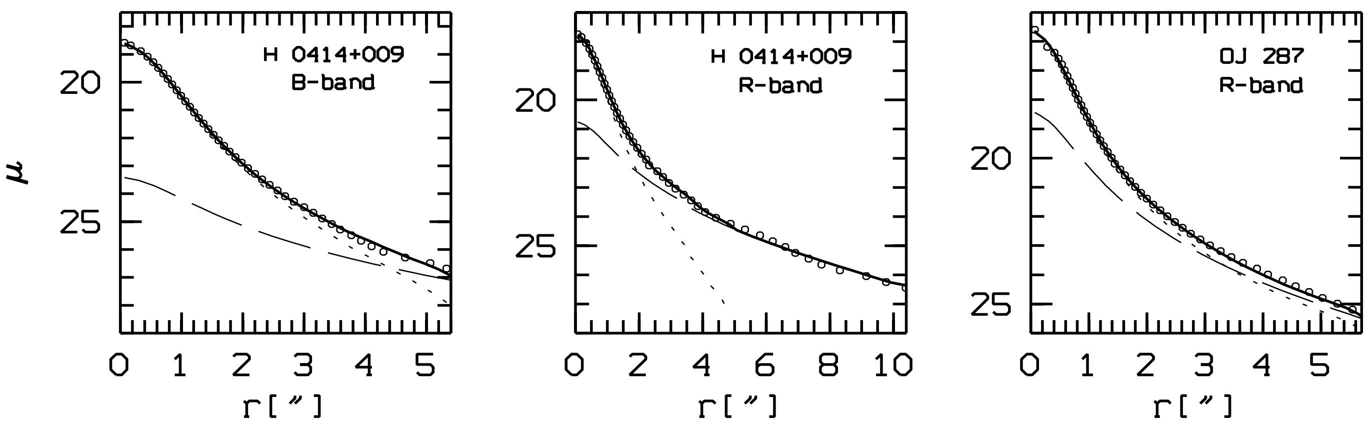

Fig. 1. Azimuthally averaged 1−dimensional surface brightness profiles of H 0414+009 in B (central mask with radius of three pixels) and R and of OJ 287 (central mask with radius of 4 pixels) in R (open circles) compared to the model fits. The short-dashed line give the core (scaled PSF), the long-dashed line the convolved de Vaucouleurs profile and the solid line the sum of both.

Table 2. Results of the fits with a core + de Vaucouleurs model to the comparison stars in the field of OJ 287 to determine the reliability of our results of OJ 287. Stars C1 and C2 are from Fiorucci & Tosti (1996). For comparison the results of OJ 287 are given. The last two columns give the goodness of fit for the core + de Vaucouleurs model (2−comp) and the pure core model (1−comp). See text for details.

Object	m_{core}	m_{host}	r_e ["]	ϵ	χ^2_{red} 2−comp	χ^2_{red} 1−comp
OJ 287	15.71	18.41	0.72	0.16	3.75	20.8
C1	15.57	20.42	1.58	0.40	1.75	2.95
C2	15.77	19.51	0.66	0.25	1.92	4.30
S1	16.24	19.50	0.40	0.46	4.15	5.18

How reliable are our results? As a check, how "bright" galaxies the PSF errors would produce for a stellar object of similar brightness, we fitted two different models (one model with pure core and another with a core + de Vaucouleurs profile) to three stars in the field which are of similar brightness as OJ 287 and within 1.′5 of it. Again we used a central mask with a radius of 4 pixels and the varying PSF. The difference of the goodness of the fit between the two models indicates, whether the host galaxy of OJ 287 is resolved, while the magnitudes of the spurious "galaxies" around the stars give an upper limit of the detectability of galaxies on top of bright sources on our image of OJ 287. The results are given in Table 2.

Several results from Table 2 seem to confirm that our detection of the host galaxy of OJ 287 is real. First, the goodness of the fit improves much more when going from the core to the core + de Vaucouleurs model of OJ 287 as compared to the stars. Next, the host galaxy is $\sim 1.1-2$ mag brighter as the spurious "galaxies" around the stars. The detection limit for galaxies on top of bright point sources is $\sim$ 19 mag. Additionally, the spurious "galaxies" have high ellipticities, indicating that they are just PSF residuals. Final support for the reality of the host galaxy can be gained from an inspection of Fig. 2, where we show the images of OJ 287 and the comparison star C2, which is of similar brightness as OJ 287 before and after subtraction of the scaled varying PSF as returned from the fit with a pure core model.

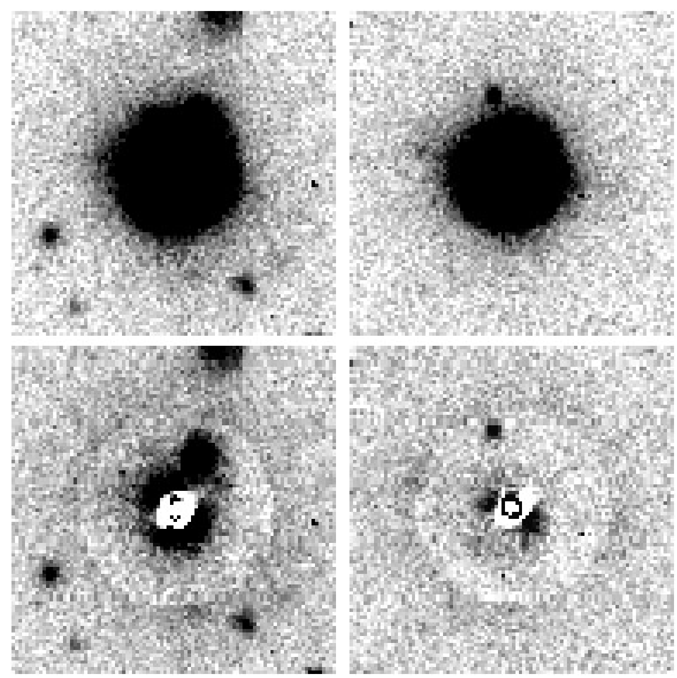

Fig. 2. Top: Observed images of OJ 287 (left) and comparison star C2 (right, from Fiorucci & Tosti 1996). C2 has similar brightness as the core of OJ 287. Bottom: Same images after subtraction of a scaled PSF as determined from the model fit with a pure core model (varying PSF). Note the much higher residual light close to the center of OJ 287 as compared to the comparison star C2, which we interpret as the host galaxy. The well known companion galaxy 3″ to the north is also visible. North is up, east to the left. Field is 20″ × 20″.

4. Discussion and conclusions

The host galaxy of H 0414+009 has been studied extensively in the last years. Already Falomo et al. (1990) noted the presence of an elliptical nebulosity out to 3.″5 around the BL Lac.

Subsequent studies by Falomo & Tanzi (1991) and M^{c}Hardy et al. (1992) confirmed the elliptical nature of the host galaxy of H 0414+009. Excellent images of H 0414+009 have been taken by Wurtz et al. (1996), who determined r_e= 5.″7 and m_r = 17.71 and Falomo (1996), who determined r_e= 5.″0 and m_R= 17.7. Our fits also indicate that the host galaxy of H 0414+009 is elliptical. With r_e= 6.″1 and m_R= 17.45 we are in excellent agreement with previous studies. As such the host of H 0414+009 is a very large and luminous galaxy (M_R= −24.57 and r_e= 35 kpc) roughly a factor of three larger and brighter than the typical BL Lac host (M_R= −23.5, r_e= 10 kpc; Falomo 1996, Heidt 1999). With B−R ∼ 1.45 and R−I ∼ 0.45 the colours of the host of H 0414+009 are consistent with those of normal elliptical galaxies (Peletier et al. 1990, Goudfrooij et al. 1994).

The host galaxy of OJ 287 has also been studied extensively in the last years. Due to the highly dominant core, the results obtained differ significantly. Stickel et al. (1993) described OJ 287 as slightly resolved, but were unable to determine morphological properties. Wurtz et al. (1996) found OJ 287 also slightly resolved and gave r_e= 1.″2 and m_r = 19.83, their fits prefer neither an elliptical nor a disk galaxy. They noted an offset between host galaxy and core to the west. Benitez et al. (1996) detected a nebulosity surrounding OJ 287, which they interpreted as the host galaxy. They estimated a size of 38 kpc for the host galaxy, but do not comment on its morphological class or its magnitude. OJ 287 was also imaged by the HST in I-band (Yanny et al. 1997). They found an underlying nebulosity of elliptical shape and confirmed the offset found by Wurtz et al., but could place only limits on the brightness of the host galaxy. Wright et al. (1998) could resolve the host galaxy in only one of several NIR images, but not in the optical. As the others, they failed to determine a morphological class. The best image of OJ 287 taken under excellent seeing conditions (0.″6 FWHM) has been obtained with the Nordic Optical Telescope (NOT) so far (Sillanpää et al. 1999). After subtraction of a scaled PSF the host galaxy is clearly visible. Contrary to the claims by Yanny et al. and Wurtz et al., the host galaxy is extended to the south with a small offset with respect to the core and appears irregular. These observations led Sillanpää et al. to conclude, that for the analysis of the host galaxy based on HST data the (very difficult) PSF-subtraction produced residuals. These may have mimicked e.g. the offset to the west (we also note that the observations of OJ 287 by Wurtz et al. have been taken under moderate seeing conditions (∼ 1.″1 FWHM)).

Our image, which is even deeper than the NOT image, but of less good seeing, basically confirms the findings of Sillanpää et al. (see their Fig. 1). The host galaxy is clearly visible and has an offset of ∼0.″14 to the south. The small difference of the position angle of the nebulosity to the south on the NOT and VLT images could be due to the not perfect varying PSF. Our model fits indicate, that de Vaucouleurs profile is slightly preferred over a disk-type profile although the fits are far from beeing satisfactory. If of elliptical type, the host galaxy is of typical luminosity of BL Lac hosts (M_R= −23.41), but compact (r_e∼ 4.4 kpc). The latter may be the main reason, why no clear detection of the host galaxy and determination of their morphological parameters was possible up to now. Nevertheless the different results obtained from ground and with HST still lack explanation.

The deep image of OJ 287 image allows us to comment on the nature of the “optical” jet proposed by Benitez et al. (1996). All its components (labelled A−D in Benitez et al.) are easily detected, well separated from each other and the brightnesses we measured in good agreement. However, these components are not co-linear with OJ 287 (especially component A deviates strongly). No emission between the components, which would be expected for a jet-like structure down to a limit of ∼ 28 mag/sq. arsec can be found. Therefore we favour a chance superposition of galactic stars (components B and C are pointlike) and galaxies (components A and D are clearly resolved) instead of a presence of an optical jet. Such a scenario has already been discussed by Heidt (1996) from ground-based images. A similar conclusion have been reached by Yanny et al. (1997) from their HST image. We note, that contrary to our data, they describe component A as pointlike. Judging from their Figs. 1 and 3 it appears that a diffraction spike running through component A may have affected their measurement. We also searched for optical emission 8.″0 to the west of OJ 287 reported by Benitez et al. (1996), which presumably coincides with radio emission detected by Kollgaard et al. (1992) and Perlman & Stocke (1994). Although our image is at least as deep as the combined image of Benitez et al., we do not detect any signs of emission. This is in agreement with Yanny et al. on their ∼ 1 mag less deeper image.

The analysis of the data of the host galaxies of BL Lac objects taken with FORS1 at VLT-UT1 has shown, that the decomposition into core (AGN) and host galaxy can be done reliably for well resolved sources. Due to the varying PSF across the field great care should be taken, however, for marginally resolved targets such as AGN host galaxies or planetary disks around young stellar objects. As long as a sufficient number of stars is available a varying PSF can be used. When stars are lacking, observations of dense stellar fields taken under similar observing conditions (airmass/seeing) before/after the target observations may improve the results.

Acknowledgements. We thank both of the anonymous referees for their instructive comments, which clarified the presentation of the paper. This work was supported by the German Federal Ministry BMBF with grants 053GO10A, 053HD50A and 053MU104, the Deutsche Forschungsgemeinschaft through FR 325/41-1 (KJ) and the Academy of Finland (KN).

References

Benitez E., Dultzin-Hacyan D., Heidt J., et al., 1996, ApJ 464, L47
Bruzual G., 1983, Rev. Mex. Astron. Astrofis. 8, 63
Burstein D., Heiles C., 1982, AJ 87, 1165
Falomo R., 1996, MNRAS 283, 241
Falomo R., Tanzi E.G., 1991, AJ 102, 1294
Falomo R., Melnick J., Tanzi, E.G., 1990, Nat 345, 692
Fiorucci M., Tosti, G., 1996, A&AS 117, 1
Goudfroij P., Hansen L., Jørgensen H.E., et al., 1994, A&AS 104, 179
Halpern J.P., Chen V.S., Madejski G.M., et al., 1991, AJ 101, 818

Heidt J., 1999, Host galaxies and environment of BL Lac objects. In: Takalo L.O., Sillanpää A. (eds.) Proc. BL Lac Phenomenon, PASP 159, p. 367
Heidt J., Nilsson K., Sillanpää A., et al., 1999, A&A 341, 683
Heidt J., 1000, "Near-IR and optical imaging of OJ 287. In: Takalo L.O. (ed.) Proc. Workshop on two yeasr of intensive monitoring of OJ 287 and 3C 66A, Tuorla Observatory reports 176, p. 86
Kollgaard R.I., Wardle J.F.C., Roberts D.H., Gabuzda D.C., 1992, AJ 104, 1687
Landolt A.U., 1983, AJ 88, 439
McHardy I.M.M., Luppino G.A., George I.M., et al., 1992, MNRAS 256, 655
Nilsson K., Pursimo T., Takalo L.O., et al., 1999, PASP, in press
Peletier R.F., Davis R.L., Illingworth G.D., et al., 1990, AJ 100, 1091
Perlman E.S., Stocke J.T., 1994, AJ 108, 56
Sillanpää A., Takalo L.O., Nilsson K., et al., 1999, Host galaxies and environment of BL Lac objects. In: Takalo L.O., Sillanpää A. (eds.) Proc. BL Lac Phenomenon, PASP 159, p. 395
Stickel M., Fried, J.W., Kühr H., 1989, A&AS 80, 103
Stickel M., Fried, J.W., Kühr H., 1993, A&AS 98, 393
Wright S.C., McHardy I.M.M., Abraham R.G., 1998, MNRAS 295, 799
Wurtz R., Stocke, J.T., Yee H.K.C., 1996, ApJS 103, 109
Yanny B., Jannuzi B.T., Impey C., 1997, ApJ 484, L113