Astron. Astrophys. 348, 113–116 (1999)

ASTRONOMY AND ASTROPHYSICS

1ES 1741+196: a BL Lacertae object in a triplet of interacting galaxies?*,**

J. Heidt[1], K. Nilsson[2], J.W. Fried[3], L.O. Takalo[2], and A. Sillanpää[2]

[1] Landessternwarte Heidelberg, Königstuhl, D-69117 Heidelberg, Germany
[2] Tuorla Observatory, FIN-21500 Piikkiö, Finland
[3] Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

Received 4 May 1999 / Accepted 11 May 1999

Abstract. We present subarcsecond resolution imaging and spectroscopy of the BL Lac object 1ES 1741+196 and neighboring galaxies. Based on 2−dimensional modelling, the host galaxy of 1ES 1741+196 is a very bright and large elliptical galaxy ($\mathrm{M_R}$ = −24.85, $\mathrm{r_e}$ = 51.2 kpc) whose overall luminosity distribution deviates significantly from a de Vaucouleurs profile. It is one of the most luminous and largest BL Lac host galaxies known.

Closeby to 1ES 1741+196 we found two companion galaxies at the same redshift as the BL Lac itself. They are at projected distances of 7.2 and 25.2 kpc, respectively. The closer companion galaxy can be best modelled by a Sa-type galaxy, whereas the more distant companion galaxy is an elliptical. This is supported by their spectra. We detected a tidal tail emerging from the closer companion galaxy which is possibly connected with the more distant galaxy. Its surface brightness increases towards the closer companion galaxy, which suggests that material has been released from that galaxy due to tidal forces.

The flat luminosity profile (β = 0.15), high ellipticity (ϵ = 0.35) of the host galaxy of 1ES 1741+196 as well as its position angle along the impact parameter to the neighboring galaxies can be the result of tidal interaction. 1ES 1741+196 may be a BL Lac object in a triplet of interacting galaxies.

Key words: galaxies: photometry – galaxies: interactions – galaxies: BL Lacertae objects: individual: 1ES 1741+196 – galaxies: active – methods: data analysis

1. Introduction

Studies of the host galaxies and close environment of BL Lac objects provide important insights into the mechanism, which could be responsible for the extreme properties of these extragalactic objects. Following the standard model, the mass accreting Black Hole in the center of AGN host galaxies accounts for the extraordinary energy output of these objects. Hence, the fuelling mechanism of the central engine and the role played by tidal interaction with neighboring galaxies has to be clarified. Due to the loss of angular momentum by tidal forces either material from a gas-rich neighbor or the gas in the host galaxy itself could fuel the nucleus. Evidence for such a scenario have been claimed e.g. by Hutchings & Neff (1992).

While the nature of BL Lac host galaxies (at least at low-redshifts) is well understood (see e.g. Heidt 1999 for a recent review), the immediate environment ($<$ 50 kpc) is as yet poorly studied. This is mainly due to the faintness of most neighboring galaxies (3−5 mag fainter than the BL Lac) as well as the limited resolution available from ground. However, in recent years, a noticeable number of BL Lac objects with close companion galaxies (e.g. Falomo et al. (1990, 1991, 1993), Falomo (1996), Heidt et al. (1999)) or signs of interaction have been observed (e.g. Falomo et al. 1995, Heidt et al. 1999). This can be taken as evidence that tidal interaction is potentially important to the BL Lac phenomenon at least in these sources.

1ES 1741+196 (z = 0.083) is a member of the Einstein Slew Survey sample of BL Lac objects (Perlman et al. 1996), whose host and environment has not been studied so far. Therefore we carried out an an imaging and spectroscopical study the results of which are presented here. Throughout the paper $\mathrm{H_0} = 50$ km $\mathrm{s^{-1}\ Mpc^{-1}}$ and $\mathrm{q_0} = 0$ is assumed.

2. Observations and data reduction

High-resolution imaging data of 1ES 1741+196 were taken with the Nordic Optical Telescope on the night July 12/13 1996. A 1k CCD (scale $0.176''$/pixel) and an R filter was used. We observed the BL Lac for 840 sec in total, split in several exposures to avoid saturation of the BL Lac. The night was photometric, standard stars from Landolt (1983) were frequently observed to set the zero point. The data were reduced (debiased, flatfielded using twilight flatfields), cleaned of cosmic ray tracks, aligned and coadded. The FWHM on the final coadded frame is $0.78''$.

A longslit spectrum of 1ES 1741+196 and two nearby companion galaxies was taken with the Calar Alto 3.5m telescope

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

* Based on observations made with the Nordic Optical Telescope, operated on the island of La Palma, jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Institute de Astrofisica de Canarias.

** Based on observations collected at the German-Spanish Astronomical Centre, Calar Alto, operated by the Max-Planck-Institut für Astronomie, Heidelberg, jointly with the Spanish National Commission for Astronomy

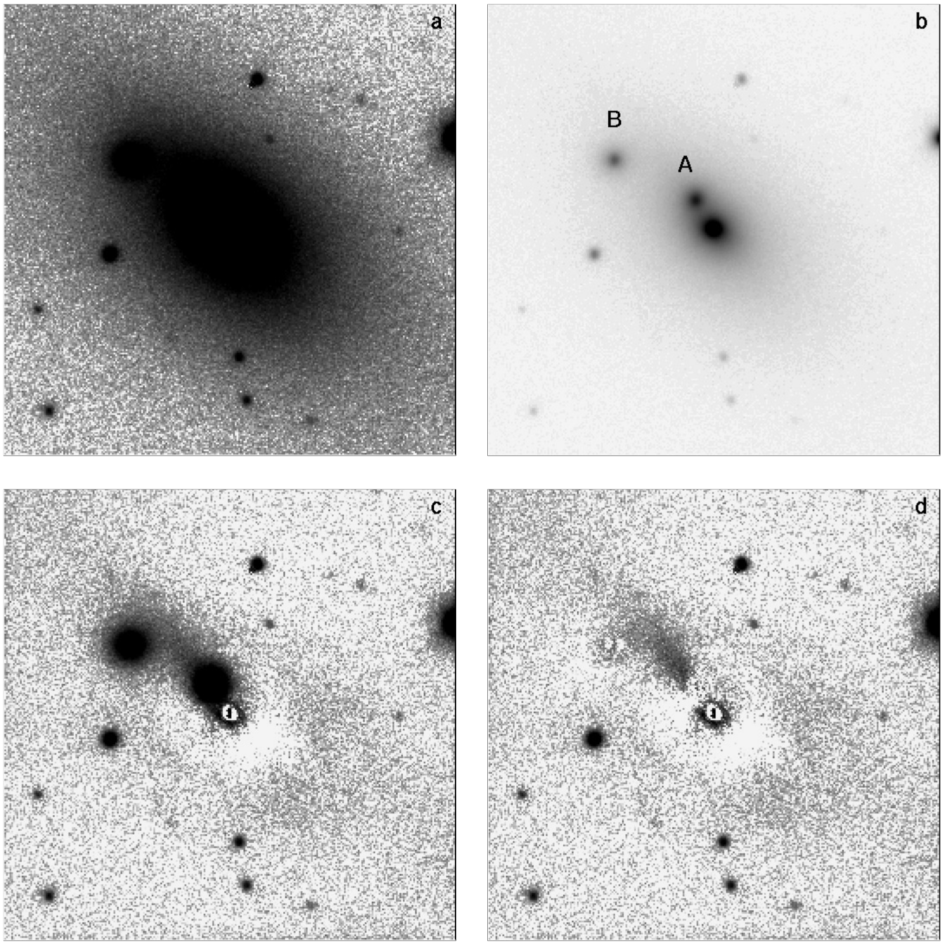

Fig. 1. a Image of 1ES 1741+196 in order to show the full extent of the host galaxy. Field is $46'' \times 46''$ (100×100 kpc at z = 0.083). North is up, east to the left. **b** Same as **a** but with different dynamic range to show the two nearby companion galaxies. They are labelled "A" and "B". **c** Same image after subtraction of the model for the host galaxy of 1ES 1741+196 and the core. Note the tidal tail emerging from galaxy A possibly connected to galaxy B. **d** Same as **c** with the models for the two companion galaxies subtracted to show the tidal tail more clearly.

on the night April 21/22 1998. The focal reducer MOSCA with a 2k CCD (scale $0.32''$/pixel) and grism GREEN_500 ($\lambda\lambda \sim 4000$–8000 Å with 1.9 Å/pixel) was used. The instrumental resolution with the $2''$ slit was 14 Å. The slit was oriented at PA = $57°$ to cover the centers of the two nearby companion galaxies and the host galaxy of 1ES 1741+196. Two spectra of 1800 sec each were taken. They were bias-subtracted, flat-fielded, corrected for night sky background and averaged. Wavelength calibration was carried out using HgAr calibration lamp exposures. Flux calibration was derived from observations of the standard star BD+33°2642 (Oke 1990).

3. Data analysis and results

Figs. 1a and b display 1ES 1741+196 and its close environment with two dynamical ranges to show the extent of the host galaxy (a) and the two nearby companion galaxies (b). The two nearby companion galaxies (labelled "A" and "B" in Fig. 1b) are at projected distances of $3.3''$ and $12''$, respectively.

In order to model the BL Lac and its host as well as the two companion galaxies we applied a fully 2−dimensional fitting procedure to the images (for details see Heidt et al. 1999). Before fitting companion galaxies A and B the uneven background produced by the host galaxy of 1ES 1741+196 has to be removed. To achieve this, we used the ellipse fitting task ELLIPSE in IRAF to model the core and host of 1ES 1741+196. This model was subtracted from the image resulting in a flat background. After masking projected stars etc. the two companion galaxies were fitted. Next we subtracted the models for the companion galaxies from the original image, masked the central regions of the subtracted companions (which show some residuals) and fitted then the host and core of 1ES 1741+196. To verify the results of our fitting procedure, we subtracted the models for the companion galaxies from the original image, and repeated the procedure above (i.e. made a model of 1ES 1741+196 with ELLIPSE, subtracted the model etc.). The results for the fit parameters between iteration 1 and 2 differ less than 1%.

We used seven different models (three galaxy models with and without a nuclear point source and a bulge+disk model) for the analysis. They were described by a generalized surface

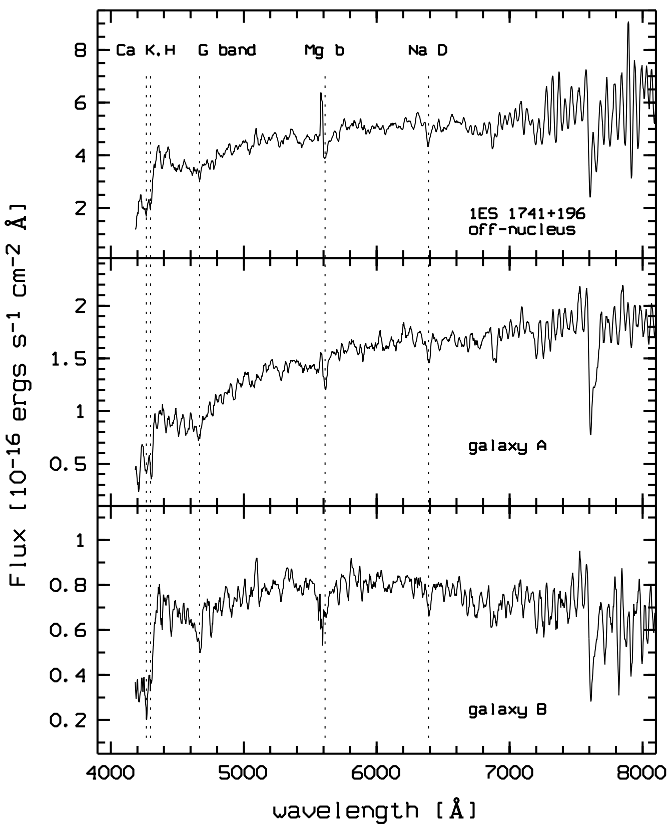

Fig. 2. Spectra of the host of 1ES 1741+196 and the companion galaxies A and B. The identified absorption lines are marked.

brightness distribution with a shape parameter β (Caon et al. 1993). We have chosen β = 1 (disk galaxy), β = 0.25 (de Vaucouleurs) and β as free parameter. All galaxy models were convolved with the observed PSF, which was obtained by averaging several well exposed stars on the frame. For the nuclear point source a scaled PSF was used. PSF variations were proven to be negligible except in the central regions ($\leq$ 2 pixel). Absolute magnitudes of the galaxies were calculated using K−corrections adopted from Bruzual (1983), the galactic extinction was estimated from Burstein & Heiles (1982).

The results of our fits are summarized in Table 1. The best fit for the host of 1ES 1741+196 was obtained with an elliptical galaxy model with β = 0.15. The host is very bright ($\mathrm{M_R}$ = −24.85), extremely large ($\mathrm{r_e}$ = 51.2 kpc) and has a relatively high ellipticity (ϵ = 0.35) with position angle PA = $48°$. The fit with the de Vaucouleurs model (β = 0.25) was less satisfactory ($\chi^2_{\rm red}$ = 1.76 vs. 1.32), but even then the host is very bright and large ($\mathrm{M_R}$ = − 24.45, $\mathrm{r_e}$ = 25.4 kpc). The decentering (host versus core centroids) is negligible for both models ($\leq$ 0.04$''$). For comparison we give the results of both fits in Table 1. We determined the significance of the best fit with β = 0.15 by numerical simulations (see Heidt et al. 1999 for a description of the procedure). The result for β = 0.15 is statistically significant at a 10 σ level.

Galaxy A can best be fitted by a system consisting of a disk and a bulge ($\mathrm{m_R}$ (bulge) = 18.37 and $\mathrm{r_e}$ (bulge) = 1.2 kpc, $\mathrm{m_R}$ (disk) = 18.27 and $\mathrm{r_e}$ (disk) = 1.8 kpc), which is typical for a Sa-type galaxy. The best fit for galaxy B was obtained with a de Vaucouleurs model ($\mathrm{m_R}$ = 18.04, $\mathrm{r_e}$ = 3.5 kpc).

Table 1. Results of our fits to the host of 1ES 1741+196 and the two companion galaxies.

Object	β	$\mathrm{m_R}$	$\mathrm{M_R}$	$\mathrm{r_e}$ [$''$]	$\mathrm{r_e}$ [kpc]
1ES 1741+196	0.15	14.07	−24.85	23.4	51.2
	0.25	14.47	−24.45	11.6	25.4
Galaxy A (bulge)	0.25	18.37	−20.55	0.56	1.2
Galaxy A (disk)	1	18.27	−20.65	0.81	1.8
Galaxy B	0.25	18.04	−20.88	1.6	3.5

In Fig. 1c we show the image after subtraction for the model of 1ES 1741+196. The two companion galaxies A and B and a low surface brightness feature between the two companion galaxies are clearly visible. In order to examine the nature of the low surface brightness feature, we further subtracted our models for the two companion galaxies from the image. The result is displayed in Fig. 1d. The feature is still present, the surface brightness at peak is 24.5 mag/sq. arcsec. Its appearance is suggestive of a tidal tail, indicating current interaction between both companion galaxies. It is more condensed towards companion galaxy A, which might imply that material is being stripped from that galaxy. We emphasize that the tidal tail is a real feature and not an artifact caused by our modelling procedure. It always shows up irrespective of the models used (either IRAF/Ellipse task or our own procedure which both produce smooth models).

Since the spectra of the two companion galaxies are contaminated by the contribution from the BL Lac host, we adopted a decomposition procedure to extract the 1-dimensional spectrum for each of the galaxies. Perpendicular to the dispersion, we fitted column by column three Gaussians representing the contribution from the host of 1ES 1741+196 and the companion galaxies to the flux distribution by a least-squares method. The integrated flux of each Gaussian for each column was then used to derive the 1-dimensional spectra. This gave us confidence that the lines found in the spectra of the companion galaxies are not caused by the host of 1ES 1741+196. The spectra are shown in Fig. 2.

All three spectra show Ca K+H, G-band, Mg b and Na D in absorption typical for bulge-dominated galaxies. This is consistent with the results of our fits to the images. No emission lines were detected. From the absorption lines we derive z = 0.084$\pm$0.001 for 1ES 1741+196 and companion galaxy A and z = 0.085$\pm$0.002 for companion galaxy B. All three galaxies are at the same redshift within the errors (actually the redshifts differ by z = 0.0005). Our redshift for 1ES 1741+196 is in accordance with the value (z = 0.083) given by Perlman et al. (1996), who measured the same absorption lines.

4. Discussion

With $\mathrm{M_R}$ = − 24.85 and $\mathrm{r_e}$ = 51.2 kpc, the host of 1ES 1741+196 is one of the brightest and largest BL Lac hosts known to date.

This is true even when the de Vaucouleurs model is used. Then $\mathrm{M_R}$ = $-$24.45 and $\mathrm{r_e}$ = 25.4 kpc, which is still considerably brighter and larger than the typical BL Lac host ($\mathrm{M_R}$ = $-$23.5 and $\mathrm{r_e}$ = 10 kpc, Heidt 1999). Similar half-light radii have been found e.g. for PKS 0301-243 and PKS 0548-322 in R-band (Falomo 1995) and H0414+009, MS 0419+197 and and PKS 1749+096 in r-band (Wurtz et al. 1996). However, only PKS 0548-322 is of similar brightness (Falomo 1995). It is remarkable that the results for PKS 0548-322 obtained by Falomo (1995) and Wurtz et al. (1996) differ considerably ($\mathrm{r_e}$ = 51 kpc versus 13.77 kpc and $\mathrm{M_R}$ = $-$ 24.2 versus $-$23.25, respectively).

According to our simulations, the deviation of the galaxy profile of the host of 1ES 1741+196 from a de Vaucouleurs profile is significant. A β of 0.15 represents flatter light distribution than β = 0.25. This can be explained by tidal interaction with the two neighboring galaxies, which a) have the same redshift as 1ES 1741+196 and b) are at projected distances of 7.2 kpc (galaxy A) and 26.3 kpc (galaxy B), respectively and are thus within the half-light radius of the host of 1ES 1741+196. During an encounter of galaxies, initial orbital energy of the galaxies is transferred into internal energy, which in turn perturbes the initial mass distribution. The galaxies expand along their impact parameter and contract perpendicular to their impact parameter. Finally, the galaxies blow up and their luminosity profiles become flatter (Madejski & Bien, 1993). The results of our fits to the host of 1ES 1741+196 are consistent with this scenario. The luminosity profile is flat, the galaxy is rather elliptical and the PA = 48° is approximately along the impact parameter between 1ES 1741+196 and the companion galaxies. This effect is not pronounced for the two companion galaxies, but here the situation is complicated due to the interaction by the galaxies themselves.

An interesting observation is the tidal tail emerging from galaxy A possibly connected to galaxy B. It is more condensed towards galaxy A, which would suggest that material has been released from this galaxy. Since galaxy A is most likely a bulge-dominated disk system, the material could well be a mixture of stars and gas. Unfortunately, no emission lines, which would be expected for Sa-type systems or which could be signs of recent star formation induced by tidal interaction can be found in the spectra. This is not unexpected, however. First, the slit had a width of $2''$ thus probing the inner part of the galaxy dominated by the bulge. Secondly, the slit orientation covered the tidal tail only in part. Finally, the whole system is polluted by the host galaxy of 1ES 1741+196, which makes it very hard to detect emission lines unless they are very strong.

The observations of 1ES 1741+196 presented here and the observations of 1ES 1440+122 and 1ES 1853+671 (Heidt et al. 1999) may offer an unique opportunity to study nuclear activity induced by tidal forces in BL Lac objects. All objects have relatively bright companion(s) within 10 kpc projected distance. Whereas 1ES 1440+122 has a very bright companion at the same redshift (M. Dietrich, priv. com.) perhaps approaching the BL Lac, 1ES 1741+196 seems to be in an ongoing state of interaction with its companion galaxies and 1ES 1853+671 has a companion which seems to be merging with 1ES 1853+671 itself. Thus these three objects may form a homogeneous sequence from an early to a late stage of interaction. Unfortunately, the redshift of the companion galaxy to 1ES 1853+671 is not known, which makes this consideration a bit speculative.

One might ask, if these three BL Lac objects are typical for their class. Close companion galaxies have often been observed (e.g. Falomo 1990, 1996, Heidt et al. 1999), but in most cases they are relatively faint and redshifts are unknown. As such the three 1ES BL Lac objects are not untypical except the brightness of their companion galaxies.

A major drawback of this consideration is a clear demonstration that activity in BL Lac objects is triggered or maintained by gravitational interaction. The discussion on this subject and its relevance to AGN has a long and contrary discussed history. In one of the last papers dealing with this issue, De Robertis et al. (1998) compared the environments of a well defined sample each of Seyfert and "normal" galaxies and found essentially no difference. Such a comparison has not been conducted yet for any kind of radio-loud AGN. As already discussed in Heidt et al. (1999) this is a tricky work, but urgently needed.

Acknowledgements. We thank the referee (Dr. J. Stocke) for his critical comments. This work was supported by the DFG (Sonderforschungsbereich 328) and the Finnish Academy of Sciences.

References

Bruzual G., 1983, Rev. Mex. Astron. Astrofis. 8, 63
Burstein D., Heiles C., 1982, AJ 87, 1165
Caon N., Capaccioli M., D'Onofrio M., 1993, MNRAS 265, 1013
De Robertis M.M., Yee H.K.C., Hayhoe K., 1998, ApJ 496, 93
Falomo R., 1996, MNRAS 283, 241
Falomo R., Melnick J., Tanzi, E.G., 1990, Nat 345, 692
Falomo R., Giraud E., Maraschi L., et al., 1991, ApJ 380, L67
Falomo R., Pesce J.E., Treves A., 1993, AJ 105, 2031
Falomo R., Pesce J.E., Treves A., 1995, ApJ 438, L9
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
Hutchings J.B., Neff S.G., 1992, AJ 103, 1746
Landolt A.U., 1983, AJ 88, 439
Madejski R., Bien R., 1993, A&A 280, 383
Oke J.B., 1990, AJ 99, 1621
Perlman E.S., Stocke J.T., Schachter J.F., et al., 1996, ApJS 104, 251
Wurtz R., Stocke, J.T., Yee H.K.C., 1996, ApJS 103, 109