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On the galaxy surrounding the BL Lacertae object MS 0205.7+3509⋆

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Abstract. We present high spatial resolution optical images of the BL Lac object MS 0205.7+3509 in the R filter, that allow us to discuss and clarify its anomalous properties. The source was previously claimed to be surrounded by a nebulosity decentered with respect to the bright nucleus. In addition the host was claimed to be a disc dominated galaxy, contrary to the large majority of the hosts of BL Lacs. We find that there is a companion galaxy at about 2″ from MS 0205.7+3509, which is responsible for many of the anomalous properties reported for this source. The observations are discussed in the context of the microlensing hypothesis for BL Lacs.

Key words: BL Lacertae objects – galaxies: individual, MS 0205.7+3509

1. Introduction

BL Lac objects are commonly believed to reside in the nuclei of giant elliptical galaxies. Their extreme properties (e.g. high amplitude and rapid flux variability, strong non-thermal emission and polarization, and superluminal motion; see e.g. Kollgaard 1994 and references therein) are mainly attributed to the presence of a relativistic jet closely aligned with the line of sight to the observer (Blandford & Rees 1978). Misaligned BL Lacs would then appear as "normal" radio galaxies, probably of F-R I type (see e.g. Urry & Padovani 1995 and references therein). In this hypothesis, the host galaxy would then be a bulge dominated system. The properties of the host galaxies and their environments would then be the same as those of parent radio galaxies (see Falomo 1996; Wurtz, Stocke, & Yee 1996, hereafter WSY96; Pesce, Falomo & Treves 1995; Smith, O'Dea, & Baum 1995). Moreover, the luminosity functions of BL Lacs and FR I galaxies appear to be consistent, taking into account the beaming effects (e.g. Urry and Padovani 1995).

An alternative hypothesis put forward by Ostriker & Vietri (1985) to explain the extreme properties of BL Lacs, proposes that at least a fraction of BL Lacs are OVV quasars seen behind a foreground galaxy that induces gravitational microlensing. In this case, a small off-centering is expected between the BL Lac object and the surrounding nebulosity.

While most of the galaxies hosting BL Lacs are well centered onto the nucleus (Abraham, McHardy, & Crawford 1991; Falomo 1996; Wurtz, Stocke, & Yee 1996) , some individual cases of significant de-centering have been reported so far: AO 0235+164, PKS 0537-441, W1 0846+561 (Stickel, Fried and Kühr 1988a,b; 1989), PKS 1413+135 (McHardy et al.1991) and MS 0205.7+3509 (Stocke, Wurtz & Perlman 1995; hereafter SWP95). In addition, some cases of disc dominated host galaxies have been reported (Halpern et al.1986; WSY96; Abraham et al.1991). Some of these cases have not been, however, confirmed by other investigations (e.g. Romanishin 1992; Stocke et al.1992, WSY96; Nilsson et al.1996). The presence of spiral hosts and de-centering of the nucleus may also be related (e.g. WSY96).

Since many of the cases above are controversial, it is important to study the properties of the hosts with the best possible spatial resolution. As a part of a program (Falomo & Kotilainen, in preparation) aimed at studying the host galaxies of BL Lacs selected by the Einstein Medium Sensitivity Survey (EMSS; Gioia et al.1990; Stocke et al.1991), we obtained at the Nordic Optical Telescope (NOT) on La Palma, high resolution images of the intriguing object MS 0205.7+3509 (tentative z = 0.312; Morris et al.1991). Another set of high resolution images were secured with the same instrument configuration during a program (Pursimo et al, in preparation) aimed at studying the host galaxies and close companions of the radio-selected 1 Jy sample (Stickel et al 1991) BL Lacs. The BL Lac nucleus of MS

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⋆ Based on observations collected at the Nordic Optical Telescope, La Palma.

0205.7+3509 was claimed by SWP95 to be significantly ($\sim 1''$) de-centered with respect to its nebulosity, whose luminosity profile was well fitted by a disk model. In this paper we present the results obtained from our images that lead to a different interpretation for this object. We found that the asymmetry of the nebulosity is due to the presence of a companion galaxy and, after removing the companion, that the underlying galaxy is well centered onto the BL Lac nucleus. The host galaxy of MS 0205+35 is found to be consistent with an elliptical as is typical for most of the BL Lac objects.

2. Observations and data analysis

A first set of images (total exposure time 4200 sec) was obtained on October 23, 1995 at the 2.5m NOT telescope equipped with the BroCam 1024x1024 pixels CCD imaging camera ($0.17''$ /pixel in the sky) The images were taken under sub-arcsec seeing and photometric conditions through the Cousins R filter. A second set of 1200 sec observations with the same setup and sub-arcsec seeing was obtained on 23 December 1995. In total we observed the target for 6600 seconds with seeing between $0.65''$ and $0.7''$.

All images were reduced in the standard way (bias subtraction, flat fielding and cosmic ray cleaning) using IRAF procedures. Photometric zero point for both sets of observations was set from observations of standard stars in the Landolt fields (Landolt 1992). The sky brightness during observations was $\sim$20 magnitude arcsec^{-2} (R filter). Reduced frames of each observation run were first combined, and then the two datasets were combined together into a final average frame. The subsequent analysis was performed identically on the averages of both data sets and on the average of all observations. Since all observations have very similar seeing conditions, the latter can be used without losing spatial resolution while improving the signal-to-noise ratio at the faintest levels. No discrepant results were found comparing the results of the different data sets.

3. Results

The $27'' \times 27''$ field of the final average frame surrounding the BL Lac is shown in Fig. 1 (with different grey scales). The image of MS0205.7+3509 exhibits an asymmetric elongation at PA $\sim 300^\circ$ that extends for $\sim 2.5''$ away from the BL Lac nucleus. In order to understand the nature of this elongation we have subtracted a scaled Point Spread Function (PSF) from the image. The PSF model was derived from several field stars visible in the same frame after checking that variations across the frame are not significant. We then scaled the PSF model requiring that the residual image yields a monotonically increasing radial profile towards the center. The result of the PSF subtraction (Fig. 2) indicates that, in addition to a nebulosity around the nucleus there is a resolved companion object at $\sim 2''$ (PA = 310°) from the BL Lac object. The presence of such a companion is already marginally visible in the unsubtracted image (Fig. 1b).

As an alternative approach to investigate the surrounding nebulosity we performed surface photometry of the field around

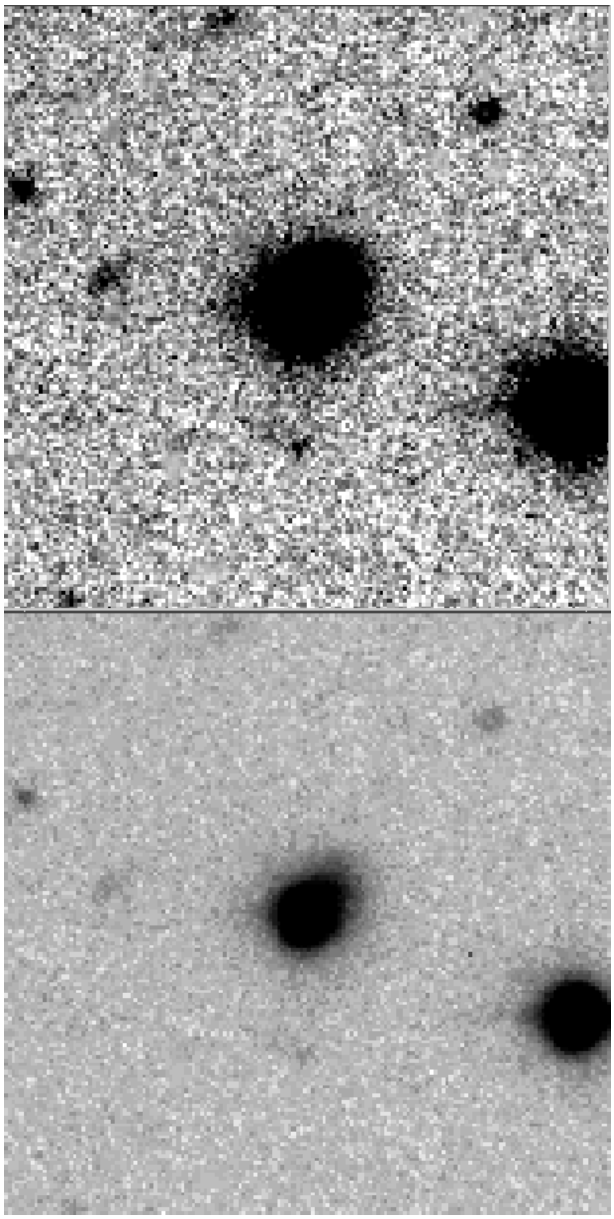

Fig. 1. The central portion (field 27×27 arcsec) of the combined images (see text) of the BL Lac object MS 0205.7+3509 in the R filter. North is up and East to the left. The field is reproduced with different grey scales in order to enhance features of low surface brightness (*a*) and close to the bright nucleus (*b*).

MS 0205.7+3509. This was done using an interactive numerical mapping package AIAP (Fasano 1994). Isophotes were fitted down to $\mu_R = 26.5$ mag arcsec^{-2} by ellipses with free parameters. This analysis yields the surface brightness profile, ellipticity, position angle, and ellipse center. At about $1''$ radius from the center the ellipticity begins to increase and a significant de-centering is apparent (Fig. 3). The de-centering ($\sqrt{\Delta X^2 + \Delta Y^2}$ where X and Y are the differences of the ellipse center with respect to the nucleus) reaches a maximum at $\sim 2.5''$; at larger distances (and lower surface brightness), the ellipticity decreases

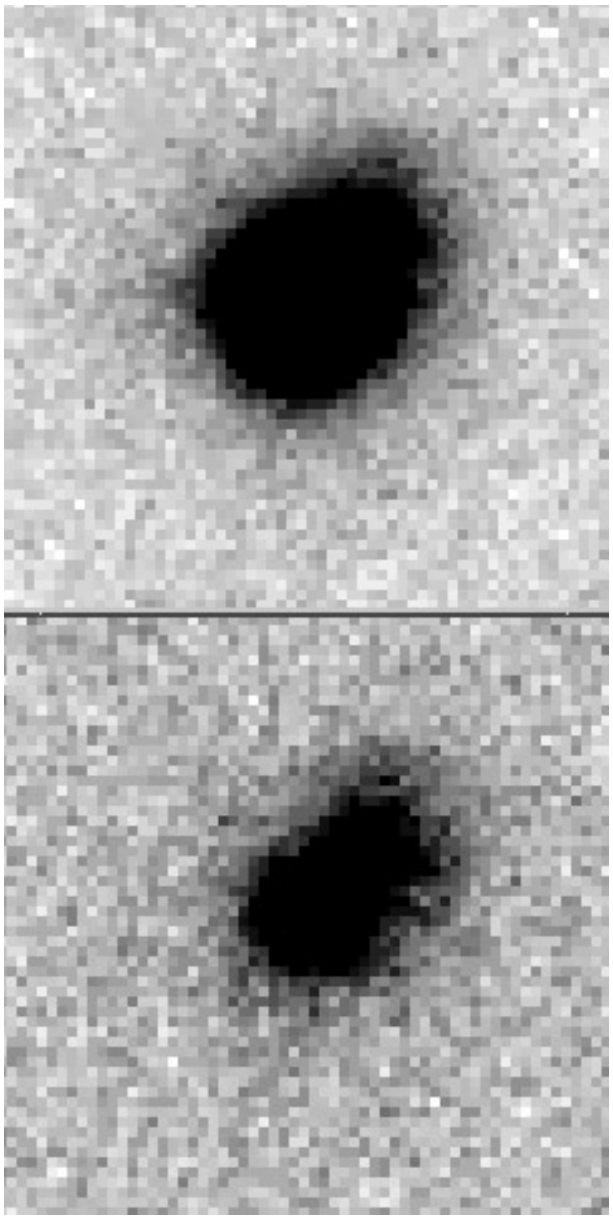

Fig. 2. Image of MS 0205.7+3509 before (*top*) and after (*bottom*) subtraction of a scaled Point Spread Function derived from stars in the same frame. Field is 10×10 arcsec and orientation as in Fig. 1. The residual image (*bottom*) shows both the surrounding nebulosity and a companion object at PA = 310° .

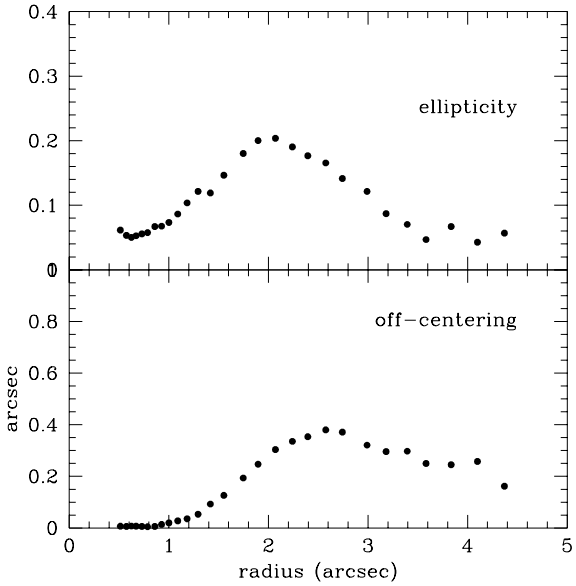

Fig. 3. Ellipticity and de-centering profile derived from the surface photometry analysis of the combined image of MS 0205.7+3509. Both ellipticity and de-centering becomes insignificant at large radii.

and the de-centering becomes insignificant. This suggests that at large radii ($r \sim 4''$; corresponding to brightness levels $\mu_R \sim$ 25.5 mag arcsec^{-2}) the nebulosity is symmetric around the BL Lac nucleus.

We argue that the de-centering, together with the ellipticity behavior is due to the presence of the close companion object. To further test this hypothesis we have masked the regions of the image contaminated by the companion and then fitted again the isophotes. This procedure yields a model of the BL Lac source (point source + nebulosity) that was subtracted from the original frame to obtain the companion object. The image of the companion object was then subtracted from the original frame and the analysis was repeated recursively until an acceptable convergence was obtained for both components. The result of this two component recursive fitting is shown in Fig. 4. The companion object is a well resolved galaxy that is located 2.3″ (PA = 320°) from the BL Lac nucleus. It is clearly elongated in the direction PA ∼40°. We estimate an apparent magnitude m_R = 21.8 for the companion galaxy.

There are a number of galaxies with magnitude and size similar to those of the companion object in the field around MS 0205.7+3509. Therefore the companion may just be a chance superposition with the BL Lac source. Since we do not have a redshift for the BL Lac companion and even the redshift of MS 0205.7+3509 is uncertain, the possibility that the two objects are physically un-associated cannot be excluded.

After subtraction of the companion galaxy we have studied the radial luminosity profile of the BL Lac object in order to derive the properties of the host galaxy. We find the source is well resolved but the deviations from the PSF are small (Fig. 5) even at subarcsec resolution. This prevents us from clearly distinguishing between an elliptical or disk galaxy model. Assuming the elliptical model, the host galaxy has observed m_R(total) = 19.1 and $r_e \sim 1.2''$. This corresponds to M_R = –23.2 at z = 0.318, after correction for galactic extinction (A_R = 0.25) and k-correction (K_R = 0.34). The host luminosity is ∼ 0.5 mag fainter than the average but within the range of BL Lacs's host luminosity (Falomo 1996, WSY96). If a disc model is assumed for the host galaxy, the resulting total magnitude is ∼ 0.5 fainter (M_R = –22.6) than the elliptical model. This is expected due to the different behavior of the two models in the galaxy core (see also Abraham, Crawford & McHardy 1991). SWP95 favor a

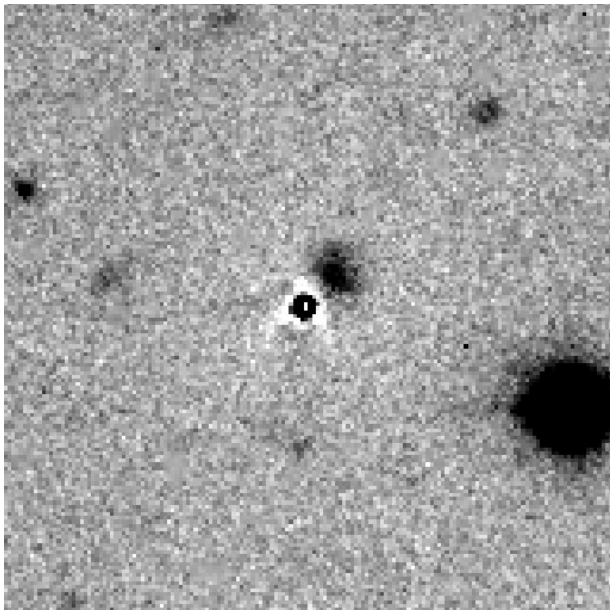

Fig. 4. The field (27×27 arcsec) around the BL Lac MS 0205.7+3509 after subtraction of a model for the main object (point source plus host galaxy). A companion galaxy is well apparent at 2.3″ from the nucleus. The residual at the center is an artifact of the subtraction procedure

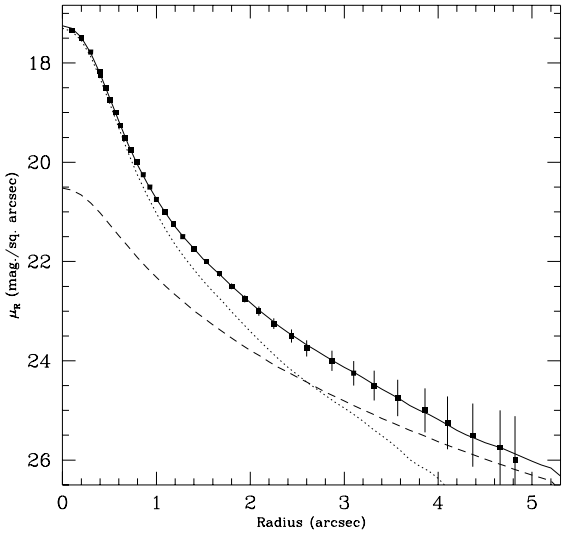

Fig. 5. Radial brightness profile of the BL Lac object MS 0205.7+3509 (*filled squares*) after removing the contribution of the companion. The profile can be well fitted by a point source (PSF; *dotted line*) plus an elliptical host galaxy (*dashed line*) convolved with the PSF. The solid line gives the best fit to the data.

disc model for the host galaxy based on the radial brightness profile of the object after recentering of the whole nebulosity (including the companion) on the point source. They obtained an underluminous galaxy (Mr = –21.7; gunn r filter) with large effective radius (7 kpc). We believe that their result is partly affected by the presence of the companion galaxy. While our data are not able to rule out a disc model for the host galaxy, there are no reasons to prefer it to an elliptical host. In addition the analysis of the a_4 Fourier coefficient describing deviations of isophotes from ellipses (see e.g. Nieto et al.1992) does not show any signature of a disc component.

4. Conclusions

We have reported deep sub-arcsec optical imaging of the X-ray BL Lac object MS 0205.7+3509 that shows the presence of a close diffuse companion object at ∼2″ (P.A. = 300°) away from the BL Lac. The companion itself is elongated at P.A. = 40° . We believe the companion is responsible for the apparent off-centering of the surrounding nebulosity with respect to the BL Lac nucleus. After removing this companion galaxy, the BL Lac object is well centered with respect to its nebulosity. The properties of this nebulosity are consistent with those of a moderately luminous elliptical galaxy at the probable redshift of z = 0.318.

Our conclusions are profoundly different from those reported by SWP95, who proposed the BL Lac is behind an off-centered spiral galaxy. The companion galaxy may still be a foreground galaxy close to the BL Lac, but the properties of the host galaxy of MS 0205.7+3509 do not appear anomalous with respect to other BL Lacs. The halo of the possible foreground galaxy may be responsible for the large absorption detected in X-ray data (SWP95).

The discovery of the companion galaxy close to MS 0205.7+3509 leads to reconcile the apparent discrepancy of off-centered nebulosity and lack of multiple images predicted by the microlensing hypothesis in the case of foreground galaxies (Ostriker & Vietri 1985). With the present data we believe the observational evidence of microlensing in MS 0205.7+3509 is rather weakened.

The number of BL Lacs with observational indication of microlensing is rather small (AO 0235+164, PKS 0537-441, W1 0846+561, PKS 1413+135 and MS0205.7+3509; Stickel, Fried and Kühr 1988a,b; 1989; Abraham et al.1993; McHardy et al.1991; SWP95, 0138-097; Heidt et al 1996)) and many of them are disputed or controversial (Yanny, York & Gallagher 1989; Stocke et al.1992; Falomo, Melnik & Tanzi 1992, this work). The discrepant results are often due to the presence of companion objects or inaccurate evaluation of the PSF that is extremely critical for this kind of study. High resolution Hubble Space Telescope imaging of these objects together with deep ground based imaging would be able to establish a firm conclusion on the nature of these sources.

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