

The colour of the narrow line Sy1-blazar 0324+3410

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ABSTRACT

Aims. We investigate the properties of the host galaxy of the blazar J0324+3410 (B2 0321+33) by the analysis of B and R images obtained with the NOT under good photometric conditions.

Methods. The galaxy was studied using different methods: Sersic model fitting, unsharp-masked images, $B-R$ image and $B-R$ profile analysis.

Results. The images show that the host galaxy has a ring-like morphology. The $B-R$ colour image reveals two bluish zones: one that coincides with the nuclear region, interpreted as the signature of emission related to the active nucleus, the other zone is extended and is located in the host ring-structure. We discuss the hypothesis that the later is thermal emission from a burst of star formation triggered by an interacting/merging process.

Key words. galaxies: active – galaxies: peculiar – galaxies: photometry

1. Introduction

The blazar J0324+3410 (B2 B0321+33) is a relatively strong radio source, with a flat spectrum stretching up to high frequencies, the spectral energy distribution showing the synchrotron peak at the optical band (e.g. Antón et al. 2004). Recently Zhou et al. (2007, hereafter Zhou et al.) presented a thorough analysis of its properties and concluded that it is a blazar in a narrow line Seyfert 1 galaxy (NLS1). In terms of the host galaxy morphology, they noted a ring like structure and suggested that it might be an asymmetric spiral arm.

The nature of NLS1 objects is not well understood, particularly the narrowness of the permitted lines. There are results suggesting that NLS1s are similar to the Broad emission Line Seyfert 1 (BLS1) but with a face-on disk-like broad emission line region (BLR; McLure & Dunlop 2002), or with a partly obscured BLR (Smith et al. 2002). But there are also works that argue that NLS1s may be Seyfert galaxies in their early stage of evolution, with low mass black holes, but high accretion rate (e.g. Boroson 2002; Mathur 2000). Most of the NLS1 objects are radio quiet (Zhou et al.) and very rarely show ring structures (Ohta et al. 2007). It is therefore interesting that J0324+3410 is a radio-loud object and its host shows a ring-like structure. Ring galaxies belong to the class of galaxies that suffer a bullseye collision with another galaxy (see the review of Appleton & Struck-Marcell 1996). It is of obvious interest the case of a galaxy showing disturbed morphology that harbours an active galactic nuclei, as the role of interactions/mergers in triggering AGN is on debate (e.g. Alonso et al. 2007), plus the fact that according to some NLS1 models (see above), the black hole of J0324+3410 might be in a growing phase.

Here we present B and R images of J0324+3410 that were obtained with the 2.6 m Nordic Optical Telescope (NOT) during a project designed to examine the host properties of the 200-mJy sample (Antón 2000; Antón et al. 2002), a low luminosity radio-loud sample, of which J0324+3410 is a member. In that

sample we found that most of the objects had very similar large-scale properties, like host-galaxy type and environment. We also found few objects with interesting features, J0324+3410 being one of them. Here we analyse its $B-R$ colour image and its radial colour profile, and we discuss the origin of the ring-like structure. Throughout this paper it is assumed $H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$.

2. The observations and data reduction

In August of 1997 we obtained B and R images¹ of J0324+3410 with the NOT using the HiRAC camera which has a 2k Loral CCD, giving a field view of $3.7 \times 3.7 \text{ arcmin}^2$ and a pixel scale of 0.11 arcsec. The exposure time for B and R filter was of 720 and 480 s respectively. The conditions were photometric throughout the observations with seeing ~ 0.7 arcsec. The data reduction was performed with IRAF, following the standard procedures: the images were debiased, trimmed and flatfielded. Aperture photometry was performed for the standard stars, and standard calibrations were computed to obtain the zero point magnitudes: $B_{\text{st}} = 0.54 + B_{\text{ins}} - 0.27 \cdot X$ and $R_{\text{st}} = 0.22 + R_{\text{ins}} - 0.11 \cdot X$, where X represents the air mass, “st” means the calibrated magnitude, “ins” means the observed magnitude. The statistical error of the calibrations is $\text{rms} = 0.03$ for B magnitudes and $\text{rms} = 0.02$ for R magnitudes. A Point Spread Function (PSF) model was derived independently from each image, using daophot tasks. As many stars as possible were included, even the very faint ones, in order to achieve a higher PSF dynamic range. The colour image $B-R$ was obtained as $B-R \sim \frac{(R-R_{\text{backg}})/t_R}{(B-B_{\text{backg}})/t_B}$, where “backg” and “ t ” refer to background counts and exposure time respectively. In order to

¹ B and R filter characteristics, respectively: central wavelength of 4280 and 6310 Å, $FWHM$ of 1050 and 1210 Å, maximum transmittance of 62% and 71%.

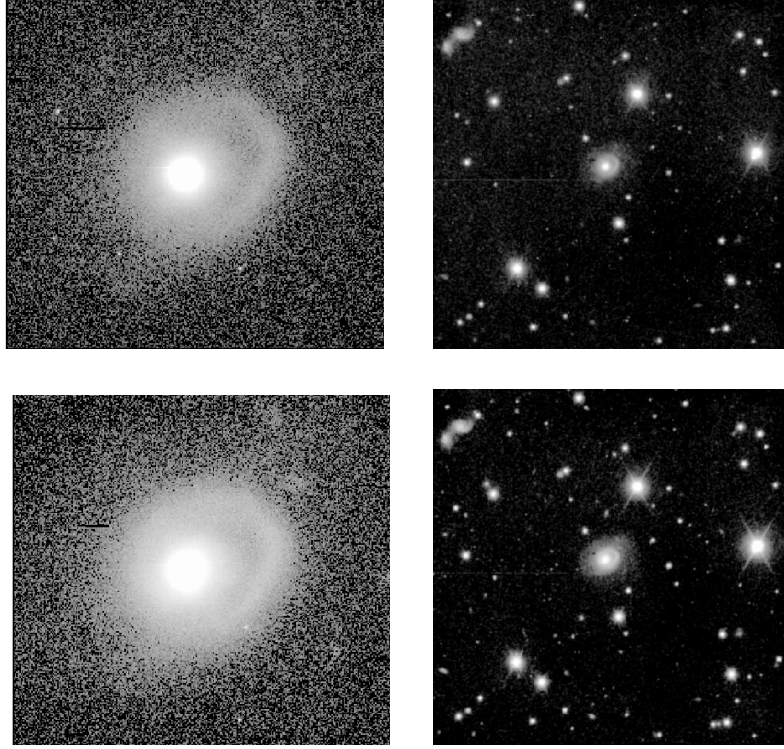


Fig. 1. 0324+3410: *top left* – B image of the object (field of view of $29'' \times 30''$) and *top right* – the object is centred in a field of view of $3.3' \times 3.3'$, *North is up and East is left*; *bottom* – as before, in R band.

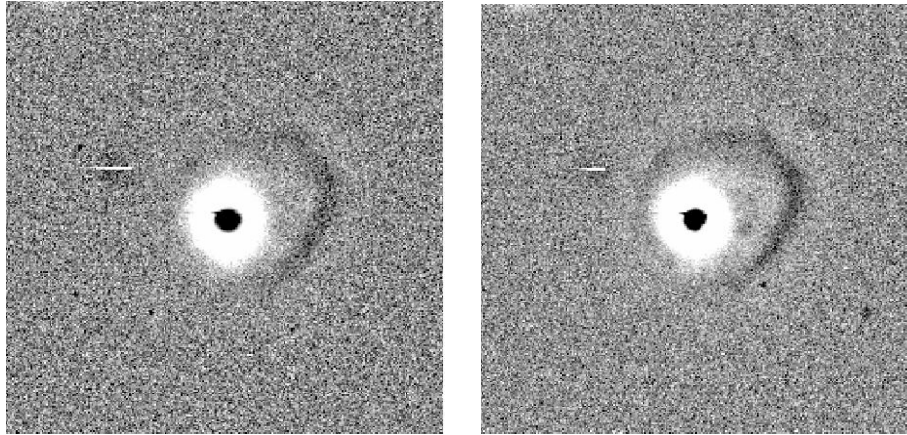


Fig. 2. 0324+341: *left* – unsharp-masked B image, *right* – unsharp-masked R image. Darker/lighter pixels correspond to brighter/dimmer regions respectively.

check that the colour features were not artifacts we examined the inner structure of objects that we were confident to be stars. The colours of all the field (non-saturated) stars did cancel well. Isophotal profiles were obtained through the IRAF routine ellipse, which is based on the method developed by Jedrzejewski (1987). From the radial isophotal profiles effective radii r_e were estimated (semimajor axis of the isophote enclosing half of the total light): $r_e(B) = 1.2$ kpc and $r_e(R) = 1.7$ kpc. The colour profile was obtained by subtracting the isophotal profiles in the two bands. The profile is determined up to a maximum radius which is the smallest of the two radii corresponding to the sky brightness of $3 \times \sigma_{\text{sky}}$ in each band. We note that both $B - R$ image and profile were built with a shifted and degraded R image: the R image was shifted in position to get a perfect matching between the frames. Galactic stars were used to obtain the registration of the

frames, then, the shifted R image was smoothed with a Gaussian filter in order to match the slightly worse resolution of B image; the task Gauss, which convolves an image with an elliptical Gauss function, was used for this purpose. In order to highlight any features in the host galaxy we analysed the images through 2-D fitting, using two different methods: a) we fitted a Sersic model to each image, and analysed the image after that model was subtracted; and b) we created an unsharp-masked image. The Sersic model was constructed based on GALFIT package (Peng et al. 2002). The best model fitting was obtained with a three component Sersic model with indexes of 8, 4 (Vaucouleur profile) and 0.1 for both B and R bands. The unsharp-masked image was built by dividing each image by that image convolved with a Gaussian function of $\sigma = 8$ pixel – the task Gauss, was used for this purpose.

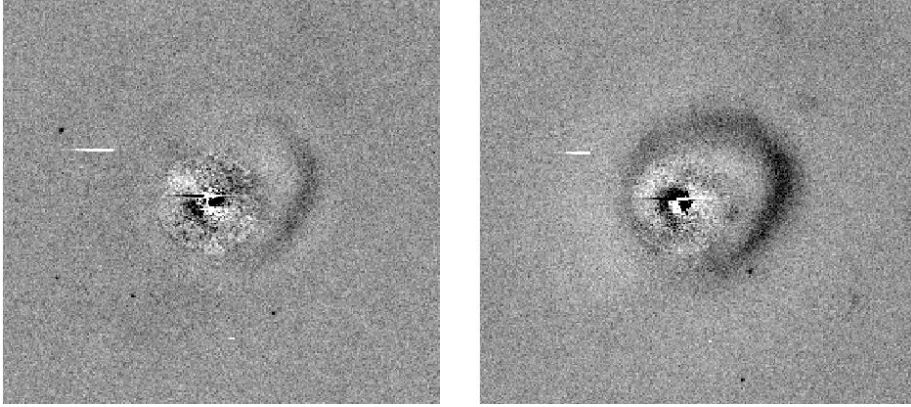


Fig. 3. 0324+341: residual images obtained by subtracting a Sersic profile to the *left* – *B* image, and *right* – *R* image. Darker/lighter pixels correspond to brighter/dimmer regions respectively.

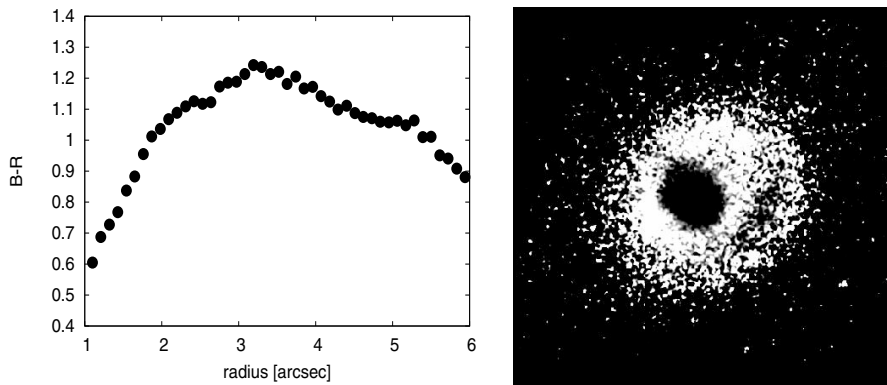


Fig. 4. *Left* – *B* – *R* colour profile *right* – *B* – *R* colour image. *North is up and East is left*, and the field of view is $28'' \times 28''$.

3. Discussion

B and *R* images of J0324+3410, plotted with a logarithmic scale, are presented in Fig. 1. We also present the same images but with a larger field of view. Both *B* and *R* images show a faint outer asymmetric disk-like emission. It is also quite clear that the host galaxy of J0324+3410 has a peculiar morphology of approximately $15''$ projected diameter (~ 17 kpc), which is consistent with Zhou et al. findings. These authors present an HST image taken with WFPC2 with the *F702W* filter, and they suggest that the host galaxy looks like a one-armed spiral. We draw attention to its ring-like appearance and suggest that it resembles the ring found in the inner region of the interacting galaxy Arp 10 (Charmandaris & Appleton 1996, hereafter CA 96). The ring-like feature is clearly shown in the unsharp-masked *B* and *R* images, Fig. 2, and also in the residual images obtained by subtracting the Sersic model (as described in the previous section) to the galaxy, Fig. 3. Note that in order to best display the ring-shape feature the images are displayed with inverted code: darker/lighter pixels correspond to brighter/fainter regions respectively.

Colour images can be useful for tracing gradients in the stellar population, reddening by dust, or even scattering in the nuclear regions of AGNs (see Kotilainen & Ward 1997). The *B* – *R* image and profile are presented in Fig. 4. Darker pixels represent bluer colours and lighter pixels represent redder colours in the colour image. The later was smoothed with a Gaussian function, with a kernel radius of 3, and the contrast was adjusted in a way that highlights the features discussed in the following. If

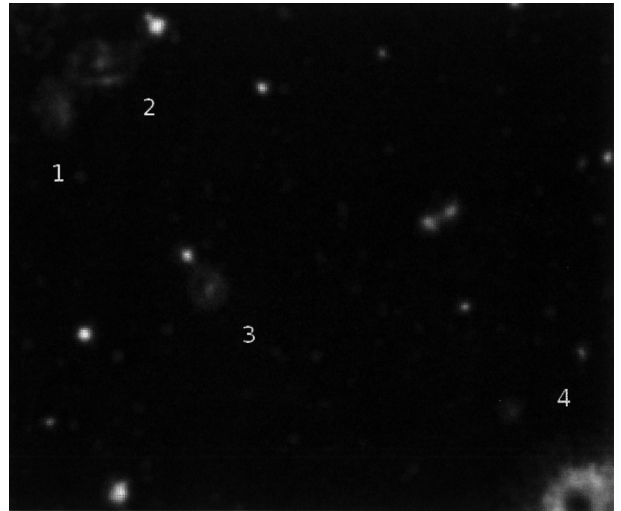


Fig. 5. *B* – *R* colour image of the galaxies (labeled as 1, 2, 3) in the field of view of 0324+3410 (labeled as 4). Field of view is $1.7' \times 1.3'$.

we fit J0324+3410 profile, Fig. 4, between $3 < r(\text{arcsec}) < 6$, we obtain $\Delta(B - R)/\Delta(\log r) = -0.6 \pm 0.03$ (magnitudes per arcsec^2 per decade in radius), i.e. the object becomes bluer in the outer regions. Elliptical galaxies in general, and low luminosity radio galaxies in particular, show a systematic trend to become bluer at the outer regions. For example radial colours $\langle \Delta(B - R)/\Delta(\log r) \rangle$ of -0.20 ± 0.04 and -0.16 ± 0.17 are found among radio galaxies (Govoni et al. 2000; Mahabal et al. 1999) whereas

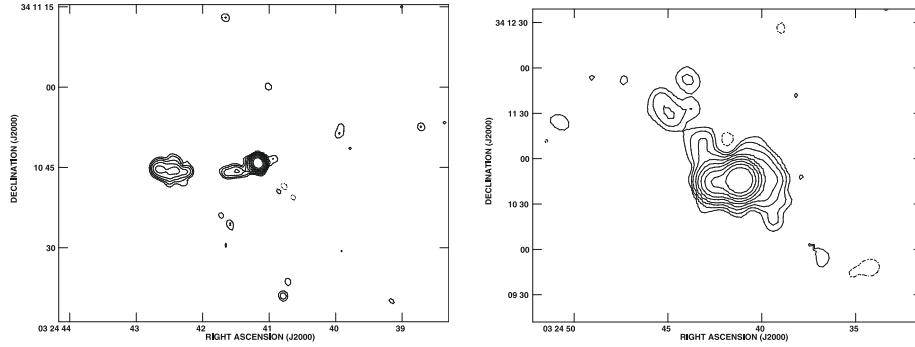


Fig. 6. VLA 1.4 GHz maps of 0324+3410 in A (*left*) and C (*right*) configurations. The contours increase in factors of 2 from 0.0004 Jy/beam for the A-configuration and 0.0005 Jy/beam for the C-configuration.

$\langle \Delta(B - R) / \Delta(\log r) \rangle = -0.09 \pm 0.07$ is cited for non-radio emitting galaxies (Peletier et al. 1990). Therefore the colour gradient of J0321+3410 is consistent with the above trends, but perhaps a more extreme example.

There is a colour reversal, a blue-ward swing, at radial distances $r(\text{arcsec}) < 3$, clearly visible in the colour image and profile, Fig. 4. The radial colour gradient is $\Delta(B - R) / \Delta(\log r) = 0.3 \pm 0.02$. Since we are dealing with an AGN the obvious interpretation is that the blue emission is AGN light. This is the extra light that reduces the 4000 Å break contrast below that expected for pure starlight. But it is important to note that this blue emission is not point-like as the nuclear region becomes bluer at a radius $\sim 2\text{--}3$ arcsec. Thus it is possible that a circumnuclear starburst component exists near the AGN. We have also computed the ratio between the effective radii $r_e(B)/r_e(R)$, following Mahabal et al. (1999), and we obtained $r_e(B)/r_e(R) = 0.69$, i.e. the central surface brightness in B is larger than that of R . That is consistent with the observed colour gradient and with Mahabal et al. (1999) findings for a sample of radio galaxies $\langle r_e(B)/r_e(R) \rangle = 0.87 \pm 0.15$, in contrast with early-type galaxies $\langle r_e(B)/r_e(R) \rangle = 1.25 \pm 0.1$. There is a bluish patch in J0324+3410, at a distance of 4–5'' from the centre which shows up as a dip in the radial profile and a dark arc in $B - R$ image. That patch coincides with the ring region. Blue dips are observed in $B - R$ profiles of galaxies with strong star formation (see Fig. 22 in Barton et al. 2003) and in ring galaxies, e.g. Arp 10 (see Fig. 20 in Appleton et al. 1997). The interpretation is that the blue dips are regions of star-formation. If we interpret the bluish patch in J0324+3410 as composed by clumps of young blue stars, it suggests triggering by interactions/collisions and mergers.

Is there independent evidence for an interaction in J0324+3410? Examination of the field surrounding J0324+3410, see Figs. 1 and 5, shows a pair of interacting galaxies in the northeast (labeled as “1” and “2” in Fig. 5)². They have a disrupted morphology seen in B and R images, and are also both bluish in colour. There is a third galaxy (labeled as “3” in Fig. 5), between the pair of galaxies and J0324+3410, that shows a colour gradient, being bluer in the region that is nearest to the pair of galaxies. If this group of galaxies lies at the same redshift as our object then the pair would be at a projected distance of approximately 145 kpc. Considering a typical relative velocity of 300 km s^{-1} that would mean that the galaxies could have been interacting in the last $\sim 10^8$ years. Given that the age of star forming clumps in interacting and merging systems range between few mega-years and 10^8 yrs

(see Hancock et al. 2007, and references in-there), this time scale is consistent with the possibility that the ring emission comes from an interaction-induced starburst in J0324+3410. We have mapped L -band VLA data from the archive, Fig. 6. There is a core plus a two-sided structure, an unusual morphology for a blazar, suggesting that the AGN axis makes a larger angle with the line of sight than is typical (i.e. $< 30^\circ$). Note that this is consistent with the models that argue that NLS1 are objects seen at large angle. A lower limit on the age of the source might be estimated through the radio size plus an assumption on the lobe advance speed. The radio (unprojected) size is ~ 15 kpc, assuming a typical speed of $0.01c$, that gives an age between $10^7\text{--}10^8$ years, for angles with the line of sight between $30\text{--}80^\circ$. It is interesting the consistency between the estimates of the time scales of interaction and radio activity, suggesting a correlation between the two, but note the caveat of the lack of redshift for the field galaxies.

On the other hand, and by analogy with Arp 10 (CA96), J0324+3410 might be a merger remnant. As in Arp 10, J0324+3410 shows a faint outer asymmetric disk-like emission. The colour gradient magnitude and the colour of the structure inside and across the ring-morphology of J0324+3410 is very similar to that seen in collisional ring galaxies, in particular to that of Arp 10. The later may be in the intermediate stage of a merger, and this could also be the case of J0324+3410, a minor merger involving a small companion which has already been absorbed into the core of the central object and leading to a ring-like structure.

4. Summary

We have combine B and R NOT images of J0324+3410 to study its host galaxy. Analysis of the images shows a ring structure that resembles the inner region of interacting/merger systems. The $B - R$ colour image and $B - R$ profile of J0324+3410 reveal that: a) the object is bluer towards its centre, and we interpret it as emission from the AGN plus circumnuclear starburst b) the ring contains blue regions interpreted as clumps of star forming regions c) there is a large colour gradient, that is consistent with those detected in collisional ring galaxies. In many aspects J0324+3410 is similar to the ring galaxy Arp 10. We discuss scenarios in which J0324+3410 is a merger remnant, or part of an interacting system in the last 10^8 years.

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² No redshifts are available.

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