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ON THE NEBULOSITY SURROUNDING THE BL LACERTAE OBJECT PKS 2155−304[1]

R. FALOMO,[2] E. GIRAUD,[3] L. MARASCHI,[4] J. MELNICK,[3] E. G. TANZI,[5] AND A. TREVES[6]

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ABSTRACT

High-resolution imaging of the bright BL Lacertae object PKS 2155−304 reveals a symmetric nebulosity extending up to 15″ from the nucleus and confirms the presence of a faint galaxy located ∼4″ away from the nucleus. We show that the redshift of $z = 0.117$, previously attributed to the BL Lac object, pertains in fact to the companion galaxy. The radial brightness profile of the surrounding nebulosity is consistent with that of an elliptical galaxy of effective radius of 4″.5 which, assuming an absolute magnitude typical of luminous ellipticals, puts the object at $z \sim 0.1$. The field of PKS 2155−304 appears to be rich in galaxies, one of which is at $z = 0.116$. A scenario in which the BL Lac object is hosted by a giant elliptical ($M_V \sim -22.5$), which is the brightest member of a group of galaxies, is suggested by our observations.

Subject headings: BL Lacertae objects — galaxies: individual (PKS 2155−304)

1. INTRODUCTION

PKS 2155−304, one of the brightest BL Lac objects at all frequencies, was discovered some 10 yr ago as the counterpart of a bright *HEAO 1* X-ray source (Schwartz et al. 1978; Griffiths et al. 1979). Since then, numerous observations of the source, from radio to X-rays, have been collected (see, e.g., Treves et al. 1989 and references therein). Direct photographic imaging of the object in the red by Griffiths et al. (1979) showed the presence of an asymmetric nebulosity around the object extended to the east. A spectrum, obtained by Bowyer et al. (1984), through a 2″ slit centered 4″ east of the nucleus, showed stellar absorption features (Ca II, *G*-band, Na I) at redshift of 0.117, the value that has been subsequently assumed to be the redshift of the BL Lac object.

High-resolution images secured with the New Technology Telescope (NTT) at the European Southern Observatory (ESO) by Falomo, Melnick, & Tanzi (1990, hereafter FMT) revealed the presence of a faint ($m_R \sim 20$) object located at ∼4″.5 east of the nucleus, clearly causing the asymmetry noted by Griffiths et al. (1979) and being possibly responsible for the absorption features at $z = 0.117$ detected by Bowyer et al. (1984), at this position.

This prompted new high-resolution imaging and spectroscopy of the object in order to study the properties of the close environment of PKS 2155−304.

2. OBSERVATIONS

The observations were obtained at ESO with the NTT equipped with the second ESO Faint Object Spectrograph and Camera (EFOSC2). We used a 1024 × 1024 CCD detector (Thomson THX 3156) with a pixel size of 19 μm corresponding to 0″.15 on the sky. A first series of nine direct images in the *R* and *I* Gunn filters was obtained on 1990 June 21, with exposure times ranging from 3 s to 3 minutes. A second series of short exposures (10 s) in the *V* and *I* filters were collected on the night of 1990 July 30. At the time of the observations, the object was in a relatively bright state $V = 12.8$ (see also Noble et al. 1990).

In both nights the seeing was excellent, the FWHM of stellar profiles being always less than 0″.7. On June 21 two spectra of the object, exposed for 15 and 30 minutes, were acquired with a grism that covers the spectral range 4500–7200 Å at 146 Å mm^{-1} reciprocal dispersion.

The centering of the slit was checked by using short exposures of the field before and after the integration of the spectrum. Wavelength calibration was provided by a HeAr lamp exposure.

3. RESULTS

3.1. *Imaging*

From visual inspection of CCD frames (see Fig. 1 [Pl. L3]), no clear evidence of the nebulosity around the object is found, while a faint galaxy ($m_I \simeq 18.5$; ellipticity = 0.3) located at 4″.2 east of the BL Lac object (PA = 70°) is clearly apparent, thus confirming the findings of FMT.

To study the image below the sky brightness we have combined three CCD frames of 180 s in the *I* (Gunn) filter into a single image. No recentering and/or resampling of the images were necessary due to the high accuracy of the telescope tracking and guiding system. Surface photometry of the average image was performed using the Numerical Mapping Package (Barbon, Benacchio, & Capaccioli 1976). A few pixels located at the center of the image were omitted from the analysis due to saturation in the CCD. A first-order two-dimensional polynomial was used to fit the sky and then subtracted from the average frame. The sky brightness is $\mu_I(\text{sky}) = 18.8$ mag arcsec^{-2}. Isophotes down to $\mu_I = 20$ mag arcsec^{-2} were computed from the unfiltered image, while fainter isophotes were derived after smoothing of the image. In Figure 2 isophotes down to $\mu_I = 24.2$ mag arcsec^{-2} are reported for a portion of the average CCD frame around PKS 2155−304. The extended nebulosity as well as the faint companion galaxy G1 are clearly apparent.

To study the brightness profile of the nebulosity, each iso-

[1] Based on observations obtained at the European Southern Observatory, La Silla, Chile.

[2] Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio, 5, Padova, Italy.

[3] European Southern Observatory, La Silla, Chile.

[4] Istituto di Fisica, Università di Milano, Italy. Postal address: Dipartimento di Fisica, Via Celoria 16, Milano, Italy.

[5] Istituto di Fisica Cosmica, CNR, Via Bassini 15, 20100—Milano, Italy. Also Osservatorio Astrofisico di Catania, Cittadella Universitaria, CT, Italy.

[6] Scuola Internazionale de Studi Superiori Avanzati, Strada Costiera 11, Trieste, Italy.

PLATE L3

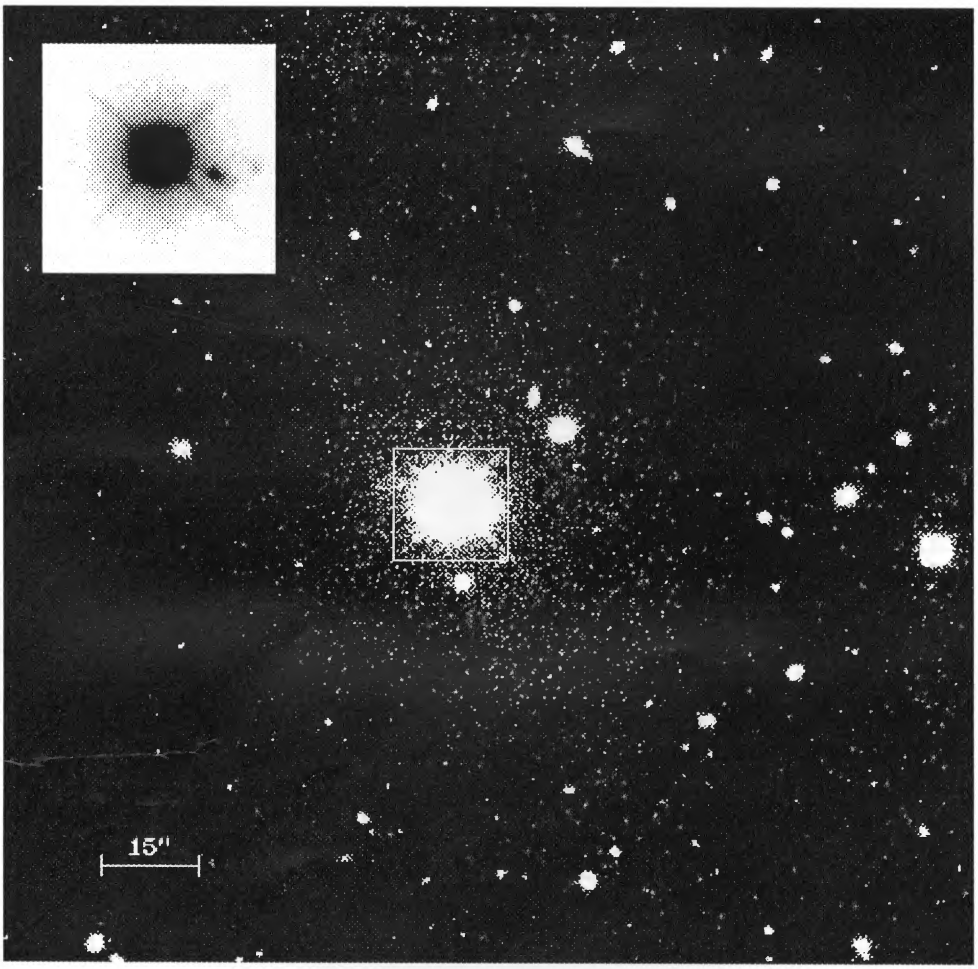

FIG. 1.—Stack of three 180 s exposure CCD images (NTT + EFOSC2 + *I* filter) of the BL Lac object PKS 2155−304 (*brightest object at center*). Field: 2.5 × 2.5 arcmin^2, north is at bottom and east to the right. In the inset, the central portion (18 × arcsec^2) of the frame is reproduced with different gray levels to enhance the image of the companion galaxy G1 (see text).

FALOMO et al. (see 380, L67)

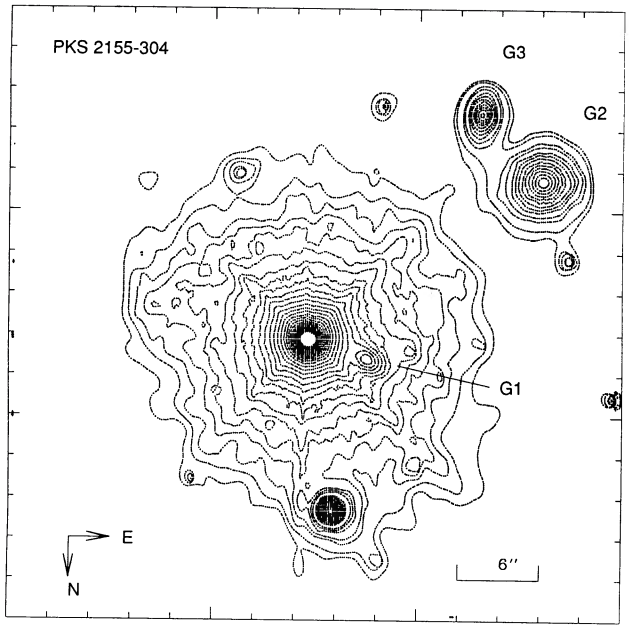

FIG. 2.—Isophotes of a portion of the averaged CCD image in the *I* filter. Lowest isophote level is $\mu_I = 24.2$ mag arcsec^{-2}, and spacing between isophotes is 0.4.

phote was fitted by an ellipse with free parameters. The companion galaxy G1 and the regions affected by the diffraction pattern or by the signal of the star at $\sim 12''$ N of the BL Lac object were excluded. Only the most external isophotes ($r \gtrsim 6$ arcsec) show a small ellipticity ($e \sim 0.1$) suggesting that the nebulosity is possibly elongated at PA $\approx 60°$. The nebulosity appears to be centered on the BL Lac nucleus within $0''.1$. The average surface brightness profile is shown in Figure 3. To derive the properties of the nebulosity from the profile, a detailed analysis of the point-spread function (PSF) is needed. We have modeled the PSF as the sum of two Gaussians to represent, respectively, a core and a wing component, plus an underlying exponential profile to account for the far extended wings. Because no star sufficiently bright to study the PSF down to $\mu_I = 24.2$ mag arcsec^{-2} is present in the CCD frame containing PKS 2155−304, we derived the parameters for the fainter part of the PSF from CCD frames obtained during the same night in similar conditions.

The observed brightness profile (see Fig. 3) is decomposed into a PSF (whose contribution includes unresolved bulge light and the nuclear component) plus an $r^{1/4}$ de Vaucouleurs law or an exponential disk. The $r^{1/4}$ law is more apt to represent the observed data, although the fit with the exponential disk cannot be ruled out.

The best decomposition is obtained for an $r^{1/4}$ law with effective radius $r_e = 4''.5$ and surface magnitude $\mu_e = 21.4$ (see Fig. 3). The corresponding total magnitude (defined *à* la de Vaucouleurs) of the underlying galaxy is $m_I(\text{tot}) = 14.8$.

3.2. *Spectroscopy*

A two-dimensional spectrum was obtained with a grism with a long slit of $0''.7$ width located $1''.5$ N of the nucleus at PA = 90°. This allowed us to record simultaneously the nebulosity and the G1 galaxy. Although the spectrum was obtained $1''.5$ away from the nucleus, it still contains a substantial contribution from the unresolved nuclear nonthermal component. A one-dimensional spectrum was extracted with an effective entrance aperture of 0.7×4 arcsec^{-2} centered on G1. Absorption features (*G*-band, Hβ, and Na I 5892) at $z = 0.117 \pm 0.001$ are clearly detected.

A search for absorption features pertaining to the nebulosity surrounding the BL Lac object was made, on a one-dimensional spectrum from regions $\gtrsim 5''$ away from the nucleus to reduce its contribution and excluding G1. There is a hint of the presence of absorption features at $z \simeq 0.1$. However, because of their weakness and of the presence of other unidentified features of comparable strength, their reality cannot be assessed with the present data.

4. DISCUSSION

Our results clearly indicate that the BL Lac object PKS 2155−304 is surrounded by a nebulosity which extends to $\sim 15''$ from the nucleus and that the object at $4''.2$ (G1) is a galaxy at $z = 0.117$. Our spectrum of G1 is very similar to that reported by Bowyer et al. (1984), and in fact the position of the slit during their observation was such as to contain G1, as was noted already by FMT. We conclude, therefore, that the redshift of PKS 2155−304 is still unknown.

A rough estimate of the redshift of the surrounding galaxy can be derived using the absolute magnitude–effective radius relation for luminous elliptical galaxies (e.g., Romanishin 1986; Sandage & Perlemuter 1990). Following the method outlined by Romanishin (1987), we derive $z = 0.08$–0.13, which brackets the value found for G1. For a redshift of ~ 0.1 the absolute magnitude of the host galaxy is $M_I = -24.2$ ($H_0 = 50$, $q_0 = 0$) and for $V - I = 1.7$ (standard elliptical galaxy of Yoshii & Takahara 1988) $M_V \sim -22.5$, which is typical for ellipticals hosting BL Lac objects (see, e.g., Ulrich 1989).

We note that if PKS 2155−304 and G1 were indeed at the same redshift, their projected separation would be as short as 10 kpc, with possible interaction between the two galaxies. However, our images do not exhibit evidence of such interaction.

The quoted interval of redshifts implies little modification to the discussion of the 600 eV absorption feature discovered by

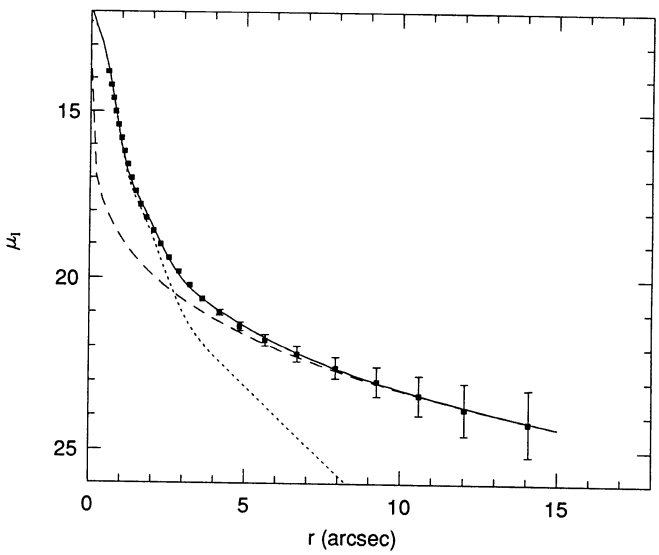

FIG. 3.—Surface brightness profile of PKS 2155−304 in the *I* filter (*filled squares*). The solid line is the sum of a PSF (*dotted line*) plus an elliptical $r^{1/4}$ law (*dashed line*) with $r_e = 4''.5$ and $\mu_e = 21.4$.

Canizares & Kruper (1984) and further discussed by Bowyer et al. (1984) and Krolik et al. (1985). In fact, the interpretation of this feature as an O VIII edge, implying a redshift $z = 0.48$, was excluded by the above authors on the basis of the alleged redshift $z = 0.117$. Our constraints on the redshift reiterate that the absorption cannot be due to the O VIII edge, while the two proposals of Lyα O VIII trough, due to high-velocity ejection from the source, or intergalactic absorption by a hot O-rich medium remain consistent with the proposed redshift range.

We note also that our constraints on the redshift indicate some difficulties in the interpretation of the absorption feature at 1287 Å, detected on *IUE*-averaged spectra, as Lyα absorption ($z = 0.057$) in the galaxy hosting the BL Lac object (Maraschi et al. 1988; Kinney et al. 1991).

As a last point, we wish to comment on the presence of numerous galaxies in the field of PKS 2155−304 (Fig. 1). Galaxy G2 (see Fig. 2) has $m_I \sim 17.5$ and is at $z \simeq 0.116 \pm 0.001$, implying a projected distance from the BL Lac object of ~ 50 kpc. For galaxy G3 no redshift is yet available; we note, however, that its magnitude ($m_I \sim 19$) is close to that of G1. A scenario in which the BL Lac is hosted by a giant elliptical ($M_V \sim -22.5$) which is the brightest member of a poor cluster of galaxies is suggested by our observations. Although a number of cases of possible association of BL Lac objects with clusters of galaxies are reported in the literature (see, e.g., Craine, Tapia, & Tarenghi 1976; Butcher et al. 1976; Weistrop et al. 1983), the nature of the association has not yet been discussed in detail.

A spectroscopic determination of the redshift for the galaxy underlying PKS 2155−304 remains a crucial issue for the physical models of this enigmatic source. Due to the presence of a strong nuclear source, a very narrow PSF and a high S/N are required. These can be obtained either with selected ground-based telescopes in excellent seeing conditions or with the capabilities of the *Hubble Space Telescope*.

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