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# CCD Photometry of 1218+304, 1219+28 and 1727+50: Point Sources, Associated Nebulosity and Broadband Spectra

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**Point Sources, Associated Nebulosity and  
Broadband Spectra**

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## ABSTRACT

We have obtained visual and far-red surface photometry of two X-ray emitting BL Lacertae objects, 1218+304 (2A1219+305) and 1727+50 (I Zw 187), as well as the highly variable object 1219+28 (ON 231, W Com). The intensity distribution for 1727+50 can be modelled using a central point source plus a de Vaucouleurs intensity law for an underlying galaxy. The broad band spectral energy distribution so derived is consistent with what is expected for an elliptical galaxy. The spectral index of the point source is  $\alpha = 0.97$ . New VLBI and X-ray data are also reported for 1727+50. There is nebulosity associated with the recently discovered object 1218+304. Assuming this nebulosity is an elliptical galaxy of  $M_V = -22.4$  mag., we estimate the redshift to be  $z = 0.13 \pm 0.05$ . The spectral index of the point source alone is  $\alpha = 0.91$ . We find no nebulosity associated with 1219+28. If it is in fact associated with an elliptical galaxy, a lower limit of  $z = 0.10 \pm 0.03$  may be placed on its redshift. The point source has a spectral index of  $\alpha = 1.7$  independent of the assumption of an associated elliptical galaxy. A nearby extended object does not have colors consistent with its being a galaxy. Comparison of our results with observations at X-ray and radio frequencies suggests that all the emission from 1727+50 and 1218+304 can be interpreted as due solely to direct synchrotron emission. If this is the case, the data further imply the existence of relativistic motion effects and continuous particle injection.

## I. Introduction

Evidence from spectrophotometry (Oke 1978; Ulrich 1978, and others; see Weistrop, Smith, Reitsema, 1979, Paper I, for a list) aperture photometry (Kinman 1978), polarimetry (Maza, Martin and Angel 1978), and direct imaging (Paper I) suggests that the nebulosity surrounding many BL Lacertae objects is an associated galaxy. Discovery and study of these galaxies will 1) determine the redshift and distance to these objects, 2) provide insight into galaxy evolution and its relation to the BL Lac phenomenon, 3) help separate the sources of optical emission, so that emission from the point source alone can be compared to emission in other wavelengths. To determine whether there is nebulosity associated with all BL Lac objects, and to study the nature of that nebulosity, we have undertaken a program of direct imaging of several BL Lac objects. Our first results, for PKS 0548-322, were presented in Paper I. We report here our observations for three more objects: the X-ray emitting sources 1218+304 (2A1219+305) and 1727+50 (I Zw 187), and the highly variable source 1219+28 (also known as ON 231 and W Com). In sections II and III, we discuss the observations and reductions and the analysis technique, which has evolved since Paper I. The analyses for the three objects are presented in sections IV-VI; and the results are discussed in section VII.

## II. Observations and Reduction

The observations were made May 1-4, 1979 with a CCD (charge coupled device) camera mounted on the 90-inch telescope at the University of Arizona's Kitt Peak observing station. The detector in this instrument

is a 500 x 500 pixel (picture element) CCD developed by Texas Instruments. For the three sources direct imaging was obtained in broad passbands centered at 0.53 $\mu$ m ( $\sim$ V), 0.75 $\mu$ m and 1.0 $\mu$ m. For 1727+50 a broadband observation centered at 0.45 $\mu$ m ( $\sim$ B) was also made. Each frame was corrected for dark count, which is low at the temperature at which the instrument is operated, and variations in pixel sensitivity. The latter are a function of chip manufacture and incident wavelength and are sometimes referred to as "flat field corrections". With the f/9 cage the plate scale at the 90-inch is 9".76/mm, and the observed field with the CCD is approximately 73" x 73". The scale on the CCD is 0".18/pixel, so that the seeing disk is well sampled.

The data in B and V were calibrated using observations of stars of known magnitude: Ross 640 (Eggen and Greenstein 1965), HD 108285 (Klemola 1962), 1727+50 H (Craine, Johnson and Tapia 1975), and ON 231 A (Wing 1973). The stars 1727+50 H and ON 231 A appear on the CCD frames with the BL Lac objects 1727+50 and ON 231, respectively, and also were used to define the point spread function for these objects in the analysis. The 0.75 $\mu$ m and 1.0 $\mu$ m data were calibrated from observations of stars with known spectral energy distributions: Ross 640 and SA 29-130 (Oke 1974). Because of limited observing time and the requirement that comparison stars be near the program objects in the sky, to determine seeing accurately, it was not possible to use only stars that are photometric standards for calibration. The uncertainties in the stellar magnitudes are included in the photometric errors cited below. For the B and V observations we find a difference between magnitudes calibrated from known broadband magnitudes and from known absolute spectral energy

distributions. For V, the difference is  $(V_{\text{std}} - v_{\text{flux}}) = 0.10$  mag., in good agreement with the value obtained in Paper I (0.09 mag.), while  $(B_{\text{std}} - b_{\text{flux}}) = 0.22$  mag. The probable causes for this difference, variation in the gray extinction during observation of the absolute spectral energy distributions, and use of narrow band continuum fluxes to calibrate broadband observations, have been discussed in Paper I. While the formal errors are relatively small, we believe a realistic estimate of the mean error in the derived magnitudes is about 0.1 mag. The observed magnitudes of the BL Lac objects are given below. All integration times were relatively short, 15 min or less in B and 1.0 $\mu$ m, 10 min or less for V and 0.75 $\mu$ m. The B and V magnitudes given throughout are on the standard system unless otherwise noted.

### III. Analysis

We wish to determine whether the observed spatial and spectral intensity distribution of the BL Lac objects can be modelled by a point source plus giant elliptical galaxy, the latter taken as a de Vaucouleurs intensity distribution (de Vaucouleurs 1953). There are three parameters in such a model: the redshift, and the absolute magnitudes of the galaxy and the point source. The observations in each wavelength are modelled independently. Then these results are used to determine whether the spectral energy distribution of the components is consistent with the model. There are two observables in each wavelength to be satisfied by the model, the relative spatial intensity distribution, which determines the relative intensity of the galaxy and the point source, and the total observed flux, which fixes the values of the observed fluxes from

the galaxy and the point source. For PKS 0548-322 (Paper I) and 1727+50 (below) the redshifts are known and we are able to derive the parameters for the point source and associated galaxy. However, for 1219+28 and 1218+304, the redshifts are unknown. By assuming a typical value for the absolute magnitude of the galaxy, we are able to estimate the redshift for 1218+304, which is extended, and set a lower limit to the redshift for 1219+28, if it has an associated galaxy.

One of the most critical aspects of the modelling procedure is proper representation of the atmospheric smearing, usually determined from the image of a point source. In Paper I we represented this point spread function (PSF) as the sum of two Gaussians, determined by fitting the observed intensity distribution of a star. There are two problems with that approach: 1) it assumes circular symmetry in the image and that the intensity distribution really can be represented by the sum of two Gaussians, 2) if the star is not in the same field as the object, seeing changes may occur between observations. In our current work we have eliminated these problems. For all three objects there is at least one star in the image field which has been used to determine the PSF. Instead of fitting the sum of two Gaussians to the stellar distribution to represent the PSF, a two-dimensional array consisting of the normalized data from the star itself is used. The assumed model is convolved with this array, and then compared to the observed intensity distribution. Use of a directly observed PSF has another advantage for this data set. Due to problems in the telescope optics, stellar images in certain parts of the sky were not circularly symmetric. With the observed PSF we can directly compare the models with the observed images. These comparisons

indicate that all the observed asymmetries in the spatial distribution can be attributed to the telescope problems. That is, to the limit of our observations, circularly symmetric models are a good representation of the data.

#### IV. 1727+50 (I Zw 187)

Oke (1978) has reviewed recent observations of 1727+50 and determined its redshift,  $z = 0.0554 \pm 0.0003$ , from spectra of the associated galaxy. Historically, this object has varied up to 2.1 blue photographic magnitudes (Hall and Usher 1973). While more recent observations do not indicate such large magnitude changes, there is a suggestion of short-term variability of a few percent in the data of Craine, Johnson and Tapia (1975); Tapia, Craine and Johnson (1976); and Sandage (1967). Since there is a known redshift for 1727+50, we have used the spatial intensity distribution and total observed flux to determine the fluxes in each wavelength from the point source and galaxy. Star 1727+50 H, in the field, was used to determine the PSF. In Fig. 1 we compare the observed light distribution with that derived from the models for B, V, 0.75 $\mu$ m, and 1.0 $\mu$ m. The agreement is excellent. In Table 1 the observed magnitudes are compared to those predicted by the models within  $\theta$ , the diameter of the circle within which the flux has been integrated. The agreement is within 0.02 mag. for each passband. Table 1 also presents the apparent magnitudes predicted by the models for the point source and galaxy individually. The errors represent the uncertainty due to the model fit and photoelectric calibration. The galaxy magnitudes are given to Sandage's 'standard diameter' (about 86 kpc for  $H = 50$  km/s/Mpc), which is 58" at this redshift (Sandage 1972).

The interstellar absorption was determined from Sandage's model (1973) and the extinction curve given by Bless and Savage (1972). Sandage's model gives the same  $E(B-V)$  as the Burstein and Heiles model (1978) at the position of 1727+50. The adopted values for galactic absorption are  $A_B = 0.10$  mag.,  $A_V = 0.08$  mag.,  $A_{0.75} = 0.05$  mag.,  $A_{1.0} = 0.02$  mag. Values for the K correction were taken from Whitford (1975). Assuming  $H = 50$  km/s/Mpc, the absolute magnitude of the galaxy is  $M_{Vc} = -21.9$  mag., in good agreement with the results of Oke (1978),  $-21.9$  mag., and Kinman (1978),  $-21.7$  mag. The correction to  $M_{Vc}$  for a different value of  $H$  is  $+5 \log h$ , where  $H = 50 h$  km/s/Mpc. In Fig. 2 the broad band spectral energy distribution of the galaxy is compared with the known distribution of a giant elliptical galaxy (Whitford 1971). The absolute magnitude of the point source corrected for galactic absorption but with no K correction applied is  $M_V = -20.7$  mag., in good agreement with the results of Miller, French and Hawley (1978),  $M_V > -19.9$  mag., for  $H = 75$  km/s/Mpc. The value given by Miller, French and Hawley has been averaged over their observations; the agreement therefore may indicate the absence of any recent variability in the point source, or may merely be fortuitous. The spectral index of the point source,  $\alpha$ , where  $F(\nu) = \nu^{-\alpha}$ , is  $0.97 \pm 0.15$ , in good agreement with Kinman's values of 0.80-0.93 (1978) but smaller than Oke's value of 1.6 (1978).

In Fig. 3 we compare our optical and far-red fluxes for the point source with observations of 1727+50 at other wavelengths. The data at 2.7 GHz and 5 GHz indicate no radio variability from 1972 to 1978 (LeSquerén, Biraud and Lauqué 1972; Owen, Spangler and Cotton 1980;

Weiler and Johnston 1980), although BL Lac objects with flat radio spectra generally are variable (Wardle 1978). The 90 GHz points (Landau, Epstein and Rather 1980) suggest variability, but the uncertainty in the observations (one is an upper limit, the other  $0.3 \pm 0.2$  jansky) makes their significance questionable. There is no evidence for recent large optical variations in this object.

The flat radio spectrum of 1727+50 is indicative of a compact radio source. We observed this object briefly with the Mark III VLBI system on 13 April 1980 at 2.3 and 8.4 GHz. At 2.3 GHz, we detected the source at a level of  $0.16 \pm 0.02$  Jy on a  $22 \times 10^6$  wavelengths baseline in P.A.  $\sim 40$  deg. between NRAO and Owens Valley Radio Observatory (OVRO). We do not have a concurrent measure of the total flux density, but if we use the 2.7 GHz measurement of Owen, Spangler and Cotton (1980) and assume no variability, our visibility is  $\sim 0.84 \pm 0.15$ , indicating a source size  $\leq 0''.003$  in P.A.  $\sim 40$  deg. The correlated flux density was  $\leq 0.11$  Jy in P.A.'s 129, 105 and 83 deg. An elongated source in P.A.  $\sim 130$  deg. is consistent with these observations. At 8.4 GHz, the source was not detected on any baselines between NRAO, OVRO and Haystack; but our sensitivity was only comparable to the total flux density ( $\sim 0.15$  Jy).

The HEAO-1 experiment A-2<sup>†</sup> detected an X-ray source at a position consistent with 1727+50 at  $> 5$  sigma significance on days 56-68 of 1978. The source was detected at  $\sim 3$  sigma on days 242-250 of 1977. The best fit power law of the form,

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<sup>†</sup>The A2 experiment on HEAO-1 was a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT with collaborators at GSFC, CIT, JPL and UCB.

$$dF/dE = NE^{-\alpha} \text{ ergs/cm}^2/\text{sec/erg}$$

has  $N = .007$ ,  $\alpha = 1.3 (+.6, -.4)$  (68% confidence errors). The 2-10 keV flux was  $1.14 \times 10^{-11}$  erg/cm/cm/sec for the observation on days 56-68. We represent our X-ray data in Fig. 3 as a hatched area, which indicates the uncertainty in the X-ray spectral index and flux. Snyder (1980, private communication) reports variations of a factor 3 in the X-ray flux from 1727+50 in the observations six months apart (Sept. 1977-March 1978) made with HEAO-1-A1. Within the accuracy of the observations not only is the X-ray flux predicted by an extension of the optical spectrum, but, contrary to the situation observed in 3C 273 and Seyfert 1 galaxies, so is the value of the X-ray spectral index, suggesting a common origin for the optical and X-ray emission.

#### V. 1218+304 (2A1219+305)

X-ray observations first brought the BL Lacertae object 1218+304 to our attention (Cooke et al. 1978). Wilson et al. (1979) have reported X-ray, optical and radio observations which indicate X-ray variability and a power law spectrum in the optical region with  $\alpha = 1.90$ . They were unable to determine a redshift although some very weak features may be present in the spectrum. Observations in the spectral range  $0.36\mu\text{m}$  -  $3.5\mu\text{m}$  show a spectral break at about  $1.0\mu\text{m}$ , possibly due to the presence of an associated galaxy (Ledden et al. 1980). Additional X-ray observations have been discussed by Worrall et al. (1980).

Our observations indicate 1218+304 is extended (Fig. 4). We estimate the redshift for this object by assuming an associated giant elliptical galaxy of a given absolute magnitude, and adjusting its redshift and the intensity of the point source until the best fit to the spatial intensity distribution is obtained. For the absolute magnitude of the galaxy, we assume  $M_V = -22.4$  mag.;  $M_{0.75} = -23.0$  mag.; and  $M_{1.0} = -23.5$  mag.; magnitudes defined to Sandage's (1972) "standard diameter" of the galaxy. These estimates are derived from the magnitudes of the galaxies associated with 1727+50 and PKS 0548-322 (Paper I) and Oke's values for 1727+50, 3C371 and BL Lac (1978). The best fit to the observations is obtained with a redshift  $z = 0.13 \pm 0.03$  and a point source with  $V = 16.31$  mag.,  $m_{0.75} = 15.92$  mag.,  $m_{1.0} = 15.57$  mag. ( $M_V = -23.2$  mag.), at the center of the galaxy. At this redshift, the apparent magnitude of the galaxy integrated to the "standard diameter" is  $V = 17.26$  mag. At the high galactic latitude of this object, we have assumed no galactic absorption. Two frames were taken in the 0.75 $\mu$ m band, and reduced independently. The difference in the magnitudes of the point source at this wavelength is 0.04 mag., which indicates the internal accuracy of the observations and procedure. The spectral index of the point source is  $0.91 \pm 0.21$ . This value is essentially independent of redshift, since the flux is dominated by the point source, not the galaxy. If we assume there is no galaxy, and all the emission is from the point source, we find  $\alpha = 1.06 \pm 0.21$ , the same, within the error, as the value derived assuming the presence of a galaxy.

The two principal sources of uncertainty in the results are the accuracy of the absolute magnitudes assumed for the galaxy and the

fitting procedure. The range of absolute magnitudes considered for the galaxies is  $M_V = -22$  to  $-23$  mag., which produces a range  $z = 0.12$ - $0.14$ , i.e. for  $\Delta M = 0.5$  mag., the change in  $z$  is about 10%. The dependence of  $z$  on the assumed absolute magnitude is a complicated function, since our analysis requires the galaxy and point source to reproduce the observed intensity distribution of the object. A larger uncertainty than the galaxy absolute magnitude is produced by the fitting procedure. Because our integration times were relatively short, the signal from the galaxy is weak and noisy, and we cannot distinguish among models with redshifts in the range  $z = 0.13 \pm 0.03$ . Future observations with longer integration times and better signal to noise should enable us to reduce this uncertainty.

Our observed  $V$  magnitude (Table 2) is about 0.2 mag. brighter than that obtained by Ledden et al. (1980), which is probably not significant. The spectral index found by Ledden et al. for the observed optical emission,  $\alpha = 1.15 \pm 0.1$ , is in good agreement with our value assuming all the emission is from the point source, i.e. there is no associated elliptical galaxy. This is not surprising since Ledden et al. ignore the possibility of an associated galaxy in their "broken power-law" model. Their "single power-law plus low-redshift galaxy" model suggests the observed  $\mu_m$  spectral break may be explained by a point source with spectral index  $\alpha = 0.8 \pm 0.1$  and a galaxy of magnitude  $V = 17.6 \pm 0.2$  mag. These predicted values are in reasonable agreement with our results and suggest that the observed spectral break is due to the presence of the galaxy, not intrinsic to the power law source. Our observed  $V$  magnitude is 0.2 mag. fainter than that of Wilson et al.

(1979). This is a one-to-two sigma variation and is probably not significant. However, we do find the spectrum to be substantially flatter than their value of  $\alpha = 1.90$ . Ledden et al. (1980) consider several reasons for this difference, including the possibility that the photometry may be contaminated by scattered light from a nearby star. The difference cannot be explained by a large contribution from the galaxy in the 22" aperture used by Wilson et al. We have 'corrected' their V,R,I data assuming the galaxy characteristics derived above, and find the spectral index of the remaining point source to be about 1.8, still significantly steeper than our result. A third possibility is that the optical spectral index may in fact vary.

For  $z = 0.13$  the absolute magnitude of the point source is  $M_V = -23.2$  mag., about one magnitude brighter than the point source in 0548-322 (Paper I), and in the middle of the range of absolute magnitudes for point sources in BL Lac objects (Miller, French and Hawley 1978). Worrall et al. (1980) have reported variability in the X-ray spectral index and flux from 1218+304. The spectral indices observed in Dec. 1977 and May 1978,  $1.1 \pm 0.9$  and  $1.03 (+0.2, -0.1)$  respectively, agree quite well with our optical spectral index. The extrapolation of the optical index predicts an X-ray flux lower than the observed flux, but is consistent with the reported one magnitude variability of the source in both optical and X-ray regimes. Our spectral index also compares well with the X-ray index given by Schwartz et al. (1979), and in this case the reported X-ray flux is approximately what we would predict (Fig. 5). Worrall et al. also report an X-ray spectral index of  $3.0 (+1.8, -0.9)$  for Dec. 1978, which agrees, within the errors, with the

optical spectral index reported by Wilson et al. Further observations of this source in optical, X-ray and radio wavelengths, preferably simultaneously will have to be made before any relationship of the emission at various wavelengths can be sorted out.

#### VI. 1219+28 (ON 231, W Com)

Browne (1971) proposed the optical identification of 1219+28 and suggested this source might be a BL Lac object. Its historical optical variability (1931-1952) has been studied by Pollock et al. (1974), who find evidence in 1939-1941 for a one magnitude optical pulse of half width about three years, with rapid variations of about one magnitude superposed. Strittmatter et al. (1972) report a range of visual magnitudes of about 5 mag., and Tapia, Craine and Johnson (1976) find short term variability of about 0.2 mag. Recent studies suggest 1219+28 was beginning a period of optical activity in 1978-1979 (Pollock et al. 1979). The object is stellar with a faint 'galaxy-like' object 10"-12" from the source (Browne 1971; Strittmatter et al. 1972). ON 231 has a flat radio spectrum and variable radio flux (Wardle 1978, Altschuler and Wardle 1976, Dent and Kapitzky 1976). At this time there is no definite X-ray detection, with an upper limit of  $2 \times 10^{-11}$  erg/sec/cm<sup>2</sup> for the 1977-78 epoch (Marscher et al. 1979). There are also no observed spectral lines from which to determine the redshift (Strittmatter et al. 1972).

We observed 1219+28 in standard V and our 0.75 $\mu$ m and 1.0 $\mu$ m bands. Unfortunately the comparison star saturated on the long integrations in V and 0.75 $\mu$ m, so only the short integrations could be modelled for these

filters. In the short integrations in V and  $0.75\mu\text{m}$  (48 sec and 30 sec respectively) and the long  $1.0\mu\text{m}$  observation (15 min), no nebulosity is observed surrounding 1219+28 (Fig. 6). The photometry for ON 231 and two other objects in the field, ON 231 I, the aforementioned 'galaxy-like object', and ON 231 II, located about  $25''$  SW of ON 231, is given in Table 3.

If we assume that 1219+28 does in fact have an associated giant elliptical galaxy, a lower limit can be placed on the redshift. With the galaxy magnitudes used for the 1218+304 analysis, and the absence of observed diffuse matter surrounding ON 231, we find a lower limit  $z = 0.10 \pm 0.03$  for the redshift. This value is consistent with Usher's lower limit of  $z = 0.1$ , which is derived from the assumption that the faintest observed B mag. of ON 231 is due to an underlying galaxy (1978). If all the observed emission is from the point source, the spectral index is  $\alpha = 1.69 \pm 0.21$ . If  $z = .10$  and we assume the presence of a standard galaxy, the spectral index is essentially the same,  $\alpha = 1.68 \pm 0.21$ . This is not surprising, since even if a galaxy is present, the emission from the entire object is dominated by the point source. Assuming  $z = .10$  and the galaxy as defined above, approximately 6% of the visual light within a  $10''$  aperture would be due to the galaxy. If  $z = .10$  the absolute magnitude of the point source is  $M_V = -23.6$  mag., about the middle of the range of absolute magnitudes for point sources in BL Lac objects (Miller, French and Hawley 1978). It is assumed there is no reddening at this galactic latitude ( $b = +83$  deg.).

Because of the variability of ON 231, our photometry cannot be compared with that of other authors. Adopting  $(B-V) = 0.6$  mag. (Tapia,

Craine and Johnson 1976; Kinman 1976), we estimate  $B \sim 15.8$  mag. in May 1979, which extends and is consistent with the result of Pollack et al. (1979) of increasing brightness in 1978. Within the errors, our spectral index agrees with those found by O'Dell et al. (1978) for Jan. 1977 ( $\alpha = 2.05 \pm 0.22$ ) and March 1977 ( $\alpha = 1.50 \pm 0.14$ ), although the difference between those two spectral indices, combined with the change of 0.8 mag. in the  $.547\mu\text{m}$  observation, is suggestive of real variation in the spectral index.

ON 231 has been observed at 10.7 GHz by a long-baseline interferometer comprised of Haystack Observatory and OVRO in June, 1978 (Shaffer, in preparation). On this baseline of  $\sim 140 \times 10^6$  wavelengths, the source is partially resolved. It is extended approximately east/west with an apparent Gaussian size of  $0''.0006$  (FWHM). Nearly all the 10.7 GHz emission comes from this very small source.

The objects ON 231 I and II are considerably fainter than ON 231; the photometry is therefore less certain. The spatial and spectral energy distributions of ON 231 II indicate it is probably a star. The spatial distribution of ON 231 I is extended in the V and possibly  $0.75\mu\text{m}$  image, consistent with results cited above (Browne 1971, Strittmatter et al. 1972). The  $1.0\mu\text{m}$  image is too noisy to draw any definite conclusion. The broadband spectral energy distribution of this object, however, does not resemble that of an elliptical galaxy (Fig. 7). ON 231 I may be a jet or blob producing non-thermal emission and may be associated with ON 231. In this connection we note that the radio spectrum of ON 231 is flat (Wardle 1978; Weiler and Johnston 1980; Owen and Mufson 1977) similar to the optical spectrum of ON 231 I ( $\alpha = 0.1 \pm 0.2$ ). The optical data are

at the limit of detectability with the integration times used. Longer integration times are necessary before any definitive conclusions can be drawn concerning ON 231 I.

## VII. Discussion

We have obtained broadband images for three BL Lac objects, 1727+50, 1218+304 and 1219+28. The absolute magnitude and spatial intensity distributions of the galaxy associated with 1727+50 are consistent with its being a giant elliptical galaxy. The spectral index of the point source alone is 0.97. Its absolute magnitude is  $M_V = -20.7$  mag., on the faint end of the range of absolute magnitudes of the point sources in BL Lac objects (Miller, French and Hawley 1978).

Assuming the nebulosity associated with 1218+304 is an elliptical galaxy, we estimate the redshift for this object to be  $z = 0.13 \pm 0.03$ . The absolute magnitude of the point source is  $M_V = -23.2$  mag., with optical spectral index 0.91. The absolute magnitude is typical of that found for point sources in BL Lac objects. We note that the integrated luminosities ( $10^9$ - $10^{19}$  Hz) of the point sources in 1727+50 ( $\sim 10^{45}$  ergs/s) and in 1218+304 ( $\sim 10^{46}$  ergs/s) are 1-2 orders of magnitude less than that for the quasar 3C273 ( $10^{47}$  ergs/s, Ulrich et al. 1980). This result is not surprising since 3C273 is one of the intrinsically brightest quasars.

The BL Lac object 1219+28 is stellar, suggesting a lower limit to the redshift of  $z = 0.10 \pm 0.03$  if there is an associated elliptical galaxy. The corresponding absolute magnitude of the point source is  $M_V \leq -23.6$

mag. The spectral index of an associated extended object, ON 231 I, suggests it is not a galaxy, but may be a jet or other source of non-thermal emission.

The agreement of the spectral indices of the non-stellar components in the optical and X-ray for 1727+50 and 1218+304 is quite similar to the situation in M<sub>k</sub> 501 (Kondo et al. 1981). This suggests that the continuation of the "nonthermal" continuum from optical to X-ray frequencies may be a common occurrence in BL Lac objects. As Kondo et al. point out the spectral shape is a strong argument for a synchrotron or Compton origin of the nonthermal emission. Since, as opposed to M<sub>k</sub> 501, the optical flux is predicted by the radio spectrum in these objects (see below), we shall interpret the total radio, optical and X-ray emission in these objects as due to direct synchrotron emission.

As is well known (Kardashev 1962 and Tucker 1967) when particles do not have their pitch angles re-isotropized, synchrotron emission from an object with continuous injection is approximated by 3 values of the local power law slope  $\alpha$ ,  $\alpha + 1/2$  and  $(4/3)\alpha + 1$ . For 1727+50 the best fit radio, optical and X-ray indices of 0.4, 0.97 and 1.3 are consistent with this picture. For 1218+304 the radio spectral index is not well determined, but a fit to the available data suggests radio, optical and X-ray indices of 0.1, 1.0 and 1.1. These values imply that the  $\alpha + 1/2$  part of the spectrum lies in the IR-millimeter band as is also suggested by the intersection at  $\sim 10^{13.0}$  Hz of the power law fits to the optical and radio data.

If this scenario is correct the change in slope between the radio, optical and X-ray is due to a combination of injection timescales, synchrotron and Compton losses, and the pitch angles of the particles

not being re-isotropized in these objects. Assuming spherical geometry and no relativistic effects (an assumption we will check below), the lifetime of a particle of energy  $\gamma m_0 c^2$  against synchrotron losses is  $\tau_s \sim 16/\gamma B^2$  years (where  $B$  is the strength of the magnetic field in gauss) and the lifetime against Compton losses is  $\tau_c \sim 0.9/\gamma U$  years (where  $U$  is the energy density in cgs units). We can estimate the energy density in 1727+50 and 1218+304 by setting  $U = L/R^2 c$  where  $L$  is the luminosity in ergs/s and  $R$  a characteristic size in cm. The size can be estimated either from observations of variability or from VLBI measurements. For particles to produce photons at a frequency  $\nu_0$  the relation  $\nu_0 \sim 4 \times 10^6 \gamma^2 B$  must be satisfied. For a source which exhibits a low frequency turnover due to synchrotron self-absorption one can calculate the magnetic field and the  $\gamma$  of the particles emitting at the turnover frequency  $\nu_m$ . According to Marscher et al. (1979)

$$B \sim 10^{-5} K_B (\alpha) \theta_V^4 \nu_m^5 S_m^{-2} (1+z)^{-1} \delta \text{ gauss}$$

$$\gamma_m \sim 3.5 \times 10^3 \theta_V^{-2} \nu_m^{-2} S_m (1+z) \delta^{-1}$$

One can derive estimates of these quantities for 1727+50 and 1218+304. For 1727+50  $\theta \sim 3$  mas,  $S_m \sim 0.2$  Jy,  $\nu_m \leq 3$  GHz and  $\alpha \sim 0.4$ . These values give  $B \sim 5$  gauss,  $\gamma_m \sim 10$ . This is a very high value of  $B$  and a very low value of  $\gamma_m$  when compared to the sample of Marscher et al. For 1218+304 we estimate a physical size of  $\leq 1.5 \times 10^{17}$  cm from the X-ray variability timescale (Wilson et al. 1979) which implies  $\theta \leq 0.02$  mas. With  $S_m \sim 6 \times 10^{-2}$  and  $\nu_m \leq 3$  GHz, this gives  $B \sim 1 \times 10^{-7}$  and  $\gamma \sim 6 \times 10^4$  which is similar to the values of many of the sources in Marscher et al. We therefore speculate that there exists a component smaller than 3 mas in 1727+50.

These values of  $B$  and  $\gamma$  enable us to estimate the lifetime of the particles emitting synchrotron photons. For 1727+50 we derive  $t_s \sim 0.065$  yrs and  $t_c \sim 1000$  yrs., and for 1218+304  $t_s \sim 3 \times 10^{10}$  yrs,  $t_c \sim 30$  sec for the particles radiating in the radio band at  $\nu_m$ . Since the frequency at which most of the flux produced by particles with energy  $\gamma m_0 c^2$  is radiated is proportional to  $\gamma^2$ , and  $t_{\text{loss}} \sim \gamma^{-1}$ , the particles radiating in the X-ray region have  $(\nu_x/\nu_m)^{1/2}$  shorter timescales ( $\sim 5 \times 10^{-5}$ ), than those radiating in the radio region. We therefore conclude, for both of these objects, that continual injection is a necessity if the X-rays are due to the synchrotron process. If the small size ( $\sim 6$  light months) of 1218+304 is real, and not due to energy loss phenomena, this suggests that the X-ray measurements should place strong limits on synchrotron self-Compton (SSC) X-rays. Following Marscher et al. (1979) we predict an X-ray flux of

$$F_x (2-10)_{\text{Kev}} \sim 10^{-9} s_m^{2(\alpha+2)} \delta^{-2(2\alpha+3)} \nu_m^{-(3\alpha+5)} \delta^{-2(\alpha+2)} \text{ erg cm}^{-2} \text{ s}^{-1}$$

where  $\delta$  represents possible effects due to relativistic motion. For 1218+304 one finds  $F_x \sim 10^{-6} \delta^{-4}$  erg/cm<sup>2</sup>/sec which is five orders of magnitude higher than the observed X-ray fluxes. Therefore  $\delta \sim 15$  (remember  $\delta \sim (\Gamma[1-\beta \cos\phi])^{-1}$ , where  $\phi$  is angle to the line of sight,  $\beta$  is the bulk velocity and  $\Gamma = [(1-\beta^2)]^{-1/2}$ ). This is a value of  $\delta$  similar to the range of values found by Marscher et al. for variable radio sources. For 1727+50 the predicted self-Compton X-ray flux is considerably below our upper limits so there is no need for relativistic effects. The break frequency is roughly (Tucker 1967)  $\nu_B \sim 1.6 \times 10^{10} B^{-3} t_i^{-2}$  Hz (where  $t_i$  is the time in years since injection began). For 1727+50 with  $\nu_B \sim 10^{13.5}$  and  $B \sim 5$ , we find  $t_i \sim 2 \times 10^{-3}$  yrs. For 1218+304 with  $\nu_B \sim 10^{13.5}$

but  $B \sim 10^{-7}$  one finds  $\tau_1 \sim 7 \times 10^8$  yrs (if  $\delta = 0$ ). If we use the fact that the lack of hard X-ray emission implies  $\delta \sim 10$ , then  $B \sim 10^{-6}$  and  $\tau_1 \sim 2 \times 10^7$  yrs. The lower value of  $\gamma$  implied if  $\delta \sim 10$  for 1218+304 also increases the Compton lifetime to  $\sim 300$  sec, but does not eliminate the need for continuous injection. Many of these parameters depend on  $B$ ,  $\theta$ , and  $v_m$  to very high powers. Therefore, we stress that the values implied by these formulae are not exact and are only indicative of the problems posed by these sources.

We can therefore consider that the X-ray spectrum of 1218+304 implies the existence of relativistic motion effects (perhaps a jet) and of continuous injection. For both 1727+50 and 1218+304 the fact that the total spectrum is consistent with a synchrotron spectrum in which the particle pitch angles have not been re-isotropized also argues for directed bulk motion of the particles. This is similar to the scenario proposed by Konigl (1980) for BL Lac objects in general. This scenario does not require a "thermal" accretion disk and provides strong evidence for a "non-thermal" origin of the total emission from BL Lac objects if the total spectrum is due to a single process.

Finally, we note the apparent absence of other galaxies near the BL Lacertae objects discussed here. No associated galaxies were visible on the CCD frames. Abell's catalogue (Abell 1958) lists no clusters centered near these objects at appropriate redshifts. (If ON 201 has a redshift significantly larger than  $z = 0.1$ , this argument does not apply.) If the BL Lac objects are associated with rich clusters of galaxies, the clusters should be visible on the Palomar Sky Survey. Since luminous elliptical galaxies are usually found in clusters, this result suggests

that the BL Lac phenomenon may preferentially avoid a cluster environment. BL Lac objects may be like quasars of small redshift, which tend not to be associated with clusters of galaxies (Hintzen and Scott 1978). There is at least one counter example, however; the BL Lac object 3C66A, which has been reported to be associated with a rich cluster of galaxies at  $z \sim 0.37$  (Butcher et al. 1976). More deep imaging of fields near BL Lac objects is necessary to establish the frequency of association between BL Lac objects and galaxy clusters.

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TABLE 1  
Photometry for 1727+50

$\lambda_{\text{obs}}$	Obs. Mag. $\theta = 10''$	Model Mag: $\theta = 10''$	Point Source	Galaxy (Std. Diam.)
0.45 $\mu\text{m}$ (B)	16. <sup>m</sup> 69 $\pm$ .10	16. <sup>m</sup> 71	17. <sup>m</sup> 29 $\pm$ .10	16. <sup>m</sup> 67 $\pm$ .12
0.53 (V)	16.27 $\pm$ .10	16.27	17.02 $\pm$ .10	15.88 $\pm$ .11
0.75	15.57 $\pm$ .10	15.59	16.54 $\pm$ .10	15.21 $\pm$ .11
0.99	15.05 $\pm$ .10	15.05	16.18 $\pm$ .10	14.65 $\pm$ .11

TABLE 2  
Photometry for 1218+304

$\lambda_{\text{obs}}$	Obs. Mag. $\theta = 10''$	Model Mag. $\theta = 10''$	Point Source
0.53 $\mu\text{m}$ (V)	16.06 $\pm$ .10	16.08	16.31 $\pm$ .10
0.75	15.65 $\pm$ .10	15.66	15.92 $\pm$ .10
0.99	15.23 $\pm$ .10	15.25	15.57 $\pm$ .10

TABLE 3

## Photometry of ON 231 Field

$\lambda_{\text{obs}}$	ON 231 Obs. Mag. $\theta = 10''$	ON 231 I Obs. Mag.	ON 231 II Obs. Mag.
0.53 $\mu\text{m}$ (V)	15. <sup>m</sup> 25 $\pm$ .10	19. <sup>m</sup> 08 $\pm$ .15	19. <sup>m</sup> 62 $\pm$ .15
0.75	14.64 $\pm$ .10	18.81 $\pm$ .15	19.49 $\pm$ .15
0.99	14.01 $\pm$ .10	19.06 $\pm$ .15	19.36 $\pm$ .15

## FIGURE CAPTIONS

Fig. 1. Comparison of the observed spatial intensity distributions of 1727+50 (filled circles) with models (solid line) and PSF (dashed line).

Fig. 2. Comparison of the broadband spectral energy distribution of the galaxy associated with 1727+50 and the distribution for a known giant elliptical galaxy.

Fig. 3. Optical and far-red fluxes from the point source in 1727+50 (e) compared to observations at other wavelengths. The solid line indicates spectral index  $\alpha = 0.97$ . Data sources: (x) LeSqueren, Biraud and Lauque (1972), (o) Owen, Spangler and Cotton (1980); (e) Landau, Epstein and Rathier (1980); (+) Weiler and Johnston (1980); ( $\Delta$ ) Snyder private communication (1980), (hatched area) this paper.

Fig. 4. Same as Fig. 1 for 1218+304.

Fig. 5. Same as Fig. 3 for point source in 1218+304. Solid line indicates  $\alpha = 0.91$ . Data sources: (e) this paper; (x) Wilson et al. (1979); (---) Morrall et al. (1980),  $\alpha = 1.0$ ; (e) Snyder private communication (1980); ( $\Delta$ ) Schwartz et al. (1979).

Fig. 6. Comparison of the observed spatial intensity distributions for 1219+28 (filled circles) and the PSF (dashed line).

Fig. 7. Fluxes for ON 231 (x) and ON 231 I (o) compared to radio observations (Owen, Spangler and Cotton 1980) (e). The spectral index of ON 231,  $\alpha = 1.69$ , (---), and the spectral distribution of an elliptical galaxy with the same V magnitude as ON 231 I (—) are also shown.













