BL Lac OBJECTS AND THEIR ASSOCIATED GALAXIES

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ABSTRACT

CCD photometry of five BL Lac objects indicates that at least three, and possibly four, are located at the centers of giant elliptical galaxies. The redshift for one of these objects, 1218+304, is estimated. A lower limit is placed on the redshift of 1219+28, for which no associated galaxy has been detected. Separation of the galaxy emission from the total observed flux makes possible comparison of the optical - far red flux from the point source alone with radio and X-ray data. This comparison suggests the emission from 1727+50 and 1218+304 can be interpreted as due to direct synchrotron emission. Observations of a small group of galaxies associated with the BL Lac object 1400+162 are also discussed.

I. INTRODUCTION

Investigations of the galaxies associated with BL Lacertae objects are important for several reasons. First, we wish to determine whether all BL Lac objects are embedded in galaxies. For those which are located in the centers of galaxies, determination of the galaxy redshifts will establish the distance. Comparison of the galaxy redshift with the redshift determined from the point source, where possible, will confirm or disprove the cosmological nature of the BL Lac redshifts. By separating the flux from the galaxy from the total optical emission, the optical flux arising in the point source alone can be compared to the compact radio source and X-ray observations. For example, the unreddened composite spectral index of PKS 0548-322 is 1.4 ± 0.2, [$F_\nu \propto \nu^{-\alpha}$]. The point source alone for this object has a spectral index α = 0.3 ± 0.2 (Weistrop, Smith and Reitsema 1979). Thus, eliminating the emission due to the associated galaxy can significantly effect the visible spectral index, and conclusions drawn concerning the nature of the underlying emission. Observations of the underlying galaxies help to define the role of the BL Lac phenomenon in galaxy evolution. Investigations of the nature of galaxies near BL Lac objects are useful to study the environment of the BL Lac's.

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The observations consist of direct imaging of BL Lac objects with a charge-coupled device (CCD) in three or four broad passbands, centered at 0.45 μm (B), 0.53 μm (V), 0.75 μm, and 1.0 μm. The CCD is ideally suited to this project, since it has high quantum efficiency, especially in the red, spectral sensitivity from 0.4 - 1.1 μm, low noise characteristics, and is a linear device. Observations were obtained both with the 4.0 m telescope at CTIO and the University of Arizona's 2.3 m telescope. Where possible, an object known to be a star is included in the field, so that the point spread function can be defined. By comparison with the point spread function, we can determine whether the observed intensity distribution from a BL Lac is due to a point source alone or can be modelled using a point source plus elliptical galaxy intensity distribution. The exact procedure has been described elsewhere (Weistrop, Smith and Reitsema 1979 and Weistrop et al. 1981). The results are demonstrated by Fig. 1, which compares the point spread function, adopted models, and observations for the BL Lac object 1727+50.

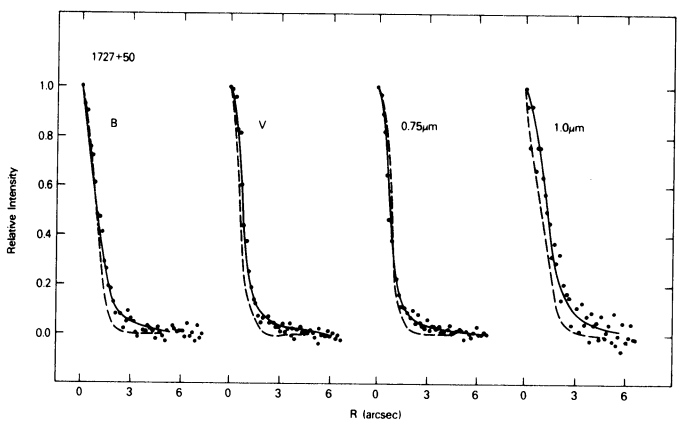

Figure 1. Comparison of the observed spatial intensity distribution of 1727+50 (filled circles) with models (solid line) and point spread function (dashed line).

II. RESULTS FOR INDIVIDUAL OBJECTS

A. 1727+50 and PKS 0548-322

Both of these objects are resolved and have known redshifts, so that by fitting the observed spatial intensity distribution and total fluxes with a point source plus giant elliptical galaxy model, the absolute magnitudes and broadband spectral distributions are obtained (Weistrop, Smith and Reitsema 1979 and Weistrop et al. 1981). In both cases, the absolute magnitudes determined for the associated galaxies are similar to those of bright galaxies, and the galaxies found associated with other BL Lac objects (Table 1). The broadband spectral energy distributions are consistent with the indentification of the

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Table 1. Absolute Magnitudes for Associated Galaxies

Object	M_V	z
1727 + 50	-21.9 mag	0.0554
0548 - 322	-22.1	0.069
		H_o = 50 km/sec/Mpc

associated galaxies as giant ellipticals (Fig. 2). It should be emphasized that the model fitting is done independently in each passband so that the broadband spectral energy distribution is a result of the analysis. The radio and X-ray data reveal a difference

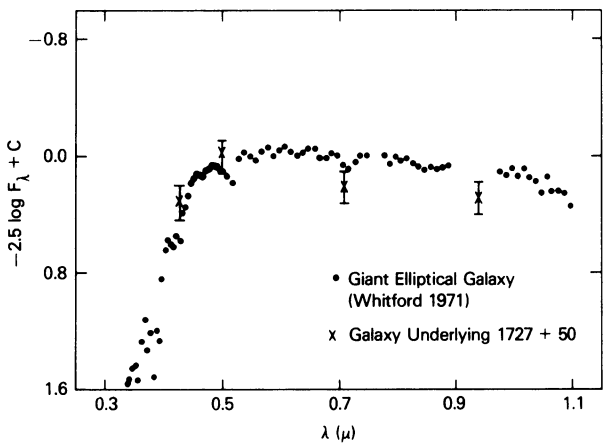

Figure 2. Comparison of the broadband spectral energy distribution of the galaxy associated with 1727+50 with the distribution for a known giant elliptical galaxy.

between the two point sources. Extrapolation of the optical data predicts the X-ray flux of 1727+50 (Fig. 3), while the high energy flux of 0548-322 is considerably fainter than would be expected from the extrapolation of the optical data (Fig. 4). The 0548-322 results can be understood in terms of a common synchrotron origin for the radio and optical data, with inverse Compton scattering the source of the high energy tail. The 1727+50 results can be interpreted as due solely to direct synchrotron emission.

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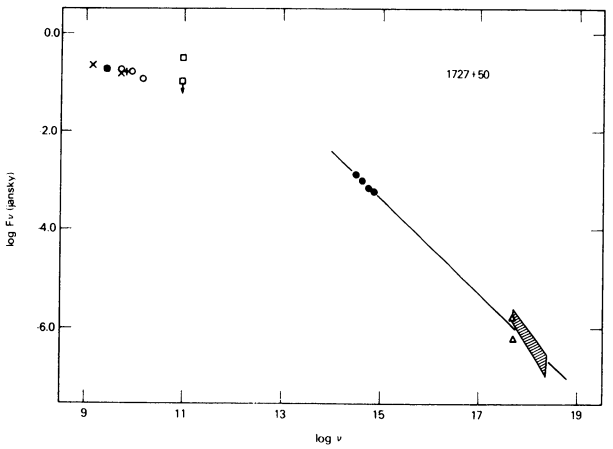

Figure 3. Comparison of the flux at several frequencies from the point source in 1727+50. The solid line indicates α = 0.97. The symbols indicate the source of the data (see Weistrop et al. 1981).

B. 1218+304

The BL Lac 1218+304 was first brought to our attention when X-ray observations were obtained (Cooke et al. 1978). The spectrum may contain some very faint features, but no redshift has been determined (Wilson et al. 1979). The image is extended on the CCD frames. By assuming the associated nebulosity is actually a giant elliptical galaxy of absolute magnitude M_V = -22.4, a typical value for galaxies in which BL Lac objects have been found to be embedded, the redshift can be estimated to be z = 0.13 ± 0.03 (Weistrop et al. 1981). Changes of 0.5 mag in the assumed absolute magnitude of the galaxy change the redshift by about 10%. The spectral energy distribution from radio to X-ray for the point source alone is similar to that for 1727+50, although the radio coverage is much sparser. As in the case of 1727+50, the radio, optical and X-ray emission can be interpreted as due solely to direct synchrotron emission with continuous particle injection. For all these sources, the X-ray optical and radio observations discussed were not obtained simultaneously, so care must be taken not to overinterpret the data.

C. 1219+28

The observations do not indicate any extended features associated with this BL Lac object. If it is in fact located in the center of a giant elliptical galaxy, a lower limit of z = 0.10 ± 0.03 can be placed on its redshift. The spectral index is rather steep, α = 1.7, independent of the presence of an elliptical galaxy (Weistrop et al. 1981). There is a diffuse object 10- 12 arcsec from 1219+28. Because of its low surface brightness and the relatively short integration times

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of the frames, it cannot be determined from these data whether the object is an elliptical galaxy or non-thermal source.

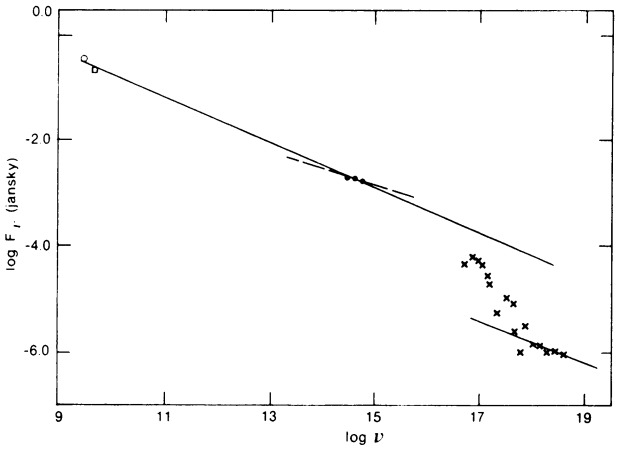

Figure 4. The flux at several frequencies for the point source in PKS 0548-322. Values of α = 0.3 (dashed line) and 0.4 (solid line) are indicated. See Weistrop, Smith and Reitsema (1979) for data sources.

D. 1400+162

The analysis of these observations is still preliminary, and will be discussed only briefly. The BL Lac object is the only one for which the apparent association with a group of galaxies has been confirmed by redshift data (Baldwin et al. 1977). There are nine objects plus the BL Lac itself in the field. It is assumed that all nine are galaxies, although a statistical estimate indicates one or two of them are probably stars (Bahcall and Soneira 1980). From the data available, it is not possible to determine which objects may be stars. The broadband spectral energy distribution suggests two of the galaxies are late-type spirals or irregulars, and the remainder ellipticals or early spirals. Thus the fraction of late-type galaxies in this distant group is similar to that found for nearby rich clusters. The luminosity function of the galaxy group may be deficient in bright galaxies compared to the groups studied by Turner and Gott (1976). There is great temptation to speculate that the BL Lac is in the center of such a bright galaxy. The steep spectral index of the BL Lac (Table 2) lends some support to such a speculation, but further observations are needed to verify this hypothesis.

III. CONCLUSIONS

Visual and far red surface photometry has been obtained for five BL Lac objects. Three have extended images that can be fit by models consisting of a bright point source plus giant elliptical galaxy.

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Table 2 presents the absolute magnitudes and optical-far red spectral indices for the point sources alone, assuming the indicated redshift. For at least two BL Lac objects, 1727+50 and 1218+304, the optical flux distribution predicts the flux in X-rays. This may also be the case in 1400+162, although further observations are necessary to determine whether an associated galaxy is influencing the observed optical spectral energy distribution and to define more precisely the X-ray energy distribution.

Table 2. Data for Point Sources

Object	M_V	α	z
1727+50	-20.7 mag	0.97 ± 0.15	0.0554
0548-322	-22.2	0.3 ± 0.2	0.069
1219+28	$\lesssim$-23.7	1.7 ± 0.2	$\gtrsim$0.10*
1218+304	-23.3	0.9 ± 0.2	0.13*
1400+162	-24.0+	1.6 ± 0.2	0.244
		H_o = 50 km/sec/Mpc	
		q_o = +0.1	

*Absolute magnitude of galaxy assumed to derive redshift.
+Assumes no emission from associated galaxy.

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