

## CLUSTERING ENVIRONMENTS OF BL LAC OBJECTS

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## ABSTRACT

We report measurements of the amplitude of the BL Lac galaxy spatial covariance function,  $B_{gb}$ , for the fields of five BL Lacertae objects. We present evidence for rich clusters around MS 1207+39 and MS 1407+59, and confirm high richness for the cluster containing H0414+009. We discuss the case of 3C 66 A and find evidence for a poor cluster based on an uncertain redshift of  $z=0.444$ . These data suggest that at least some BL Lac objects are consistent with being FR 1 radio galaxies in rich clusters.

## 1. INTRODUCTION

Currently, two models exist to explain the BL Lac phenomenon. In one, the “jet” model, BL Lac objects are characterized by a Doppler-boosted beamed relativistically moving jet aimed almost exactly in our direction (e.g., Browne 1989). The other model, “lensing,” states that BL Lacs are quasars being gravitationally lensed or microlensed by foreground galaxies (Ostriker & Vietri 1985). There is some evidence that examples of both phenomena have been observed (Abraham *et al.* 1991; Urry *et al.* 1991; Stickel *et al.* 1989, etc.).

Quantitative analysis of the BL Lac clustering environment and host galaxy magnitude and morphology can help separate objects arising from one or the other hypothesis. In particular, for the jet hypothesis, the parent population of BL Lacs is proposed to be FR 1 radio galaxies (e.g., Padovani & Urry 1991). FR 1 hosts are often found to be brightest cluster galaxies (BCGs) and cD galaxies (Owen & Laing 1989). For this scenario, we should find that BL Lac host galaxies are significantly more luminous than  $L_*$  (with  $M_V \lesssim -22.5$ ), that their isophotal profiles are best fit by a deVaucouleurs  $r^{1/4}$  law or power law, that the point source is centered on the galaxy, and that many BL Lacs reside in rich clusters. On the other hand, if BL Lacs are lensed, the galaxy identified as the “host galaxy” would actually be foreground to the BL Lac. In such cases, the host galaxies would not necessarily reside in clusters, nor even be ellipticals [though Ostriker (1989) suggests that the probability of lensing by ellipticals is significantly higher than that of spirals] and they would not necessarily be centered on the point source. In fact, Merrifield (1992) shows that a very well-centered background source would likely produce multiple images, which have not been observed. Photometry of BL Lac host galaxies cited in Ulrich (1988) and performed by Abraham *et al.* (1991), Stickel *et al.* (1993), Wurtz *et al.* (1993), and others, has already

shown that, in general, BL Lac host galaxies in fact are unusually bright ( $M_V \lesssim -22.5$ ) elliptical galaxies. If the beaming model is correct and these are FR 1 radio galaxies, then since FR 1 radio galaxies are found preferentially in rich environments (Prestage & Peacock 1988), BL Lac objects should also provide us with a way of finding clusters at moderately high redshift. Previous searches for rich clusters around moderate redshift BL Lacs have been only partially successful; only two have been suggested to be in rich clusters (3 C 66 A, Butcher *et al.* 1976; and H0414+009, McHardy *et al.* 1992; Falomo *et al.* 1993). However, recent results by Fried *et al.* (1993) indicate that moderate redshift radio-selected BL Lac objects do reside preferentially in richer environments.

We are completing a deep, high resolution optical imaging survey of the galaxy clustering environment and host galaxy morphology of BL Lacs. As part of this survey we obtained CCD images of 51 BL Lac objects at the Canada–France–Hawaii Telescope<sup>2</sup> on Mauna Kea, HI. This survey includes a complete sample of 22 x-ray selected BL Lac objects drawn from the Einstein Medium Sensitivity Survey (hereafter referred to as EMSS; Gioia *et al.* 1990, Stocke *et al.* 1991) plus other x-ray selected BL Lacs, as well as a comparable number of radio-selected BL Lac objects. For those BL Lac objects in the EMSS, we use the redshifts of Morris *et al.* (1991). We have drawn redshifts from the literature for the rest of the sample and have required  $z < 0.7$  for the entire sample we observed.

This paper reports the determination of clustering by means of the amplitude of the spatial covariance function,  $B_{gb}$ , in the fields of five BL Lac objects. These are the first to be analyzed, and were chosen for specific reasons. Two were chosen because previous imaging suggested clusters were present. We have performed the first determination of  $B_{gb}$  for these two fields. The other three appeared by visual inspection to be in fields containing significant numbers of

<sup>1</sup>Guest Observer, Canada–France–Hawaii Telescope.<sup>2</sup>Operated by CNRS of France, NRC of Canada, and the University of Hawaii.

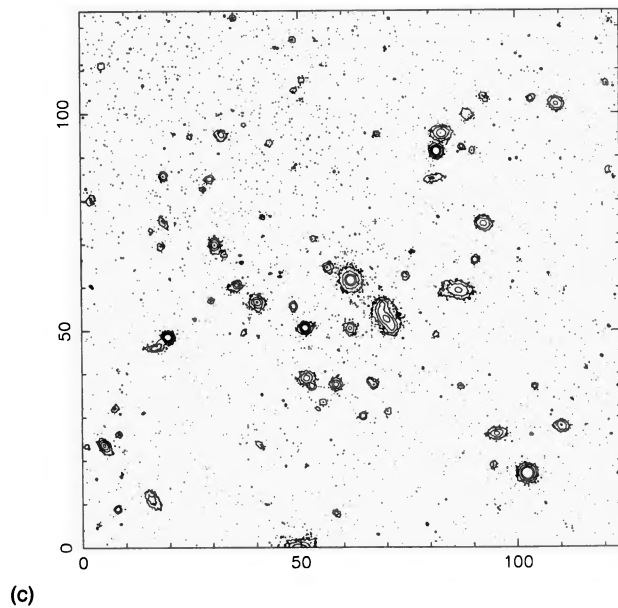
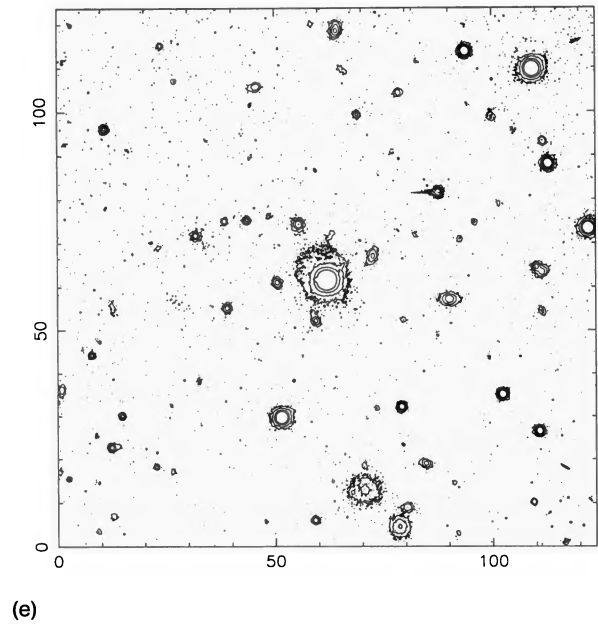
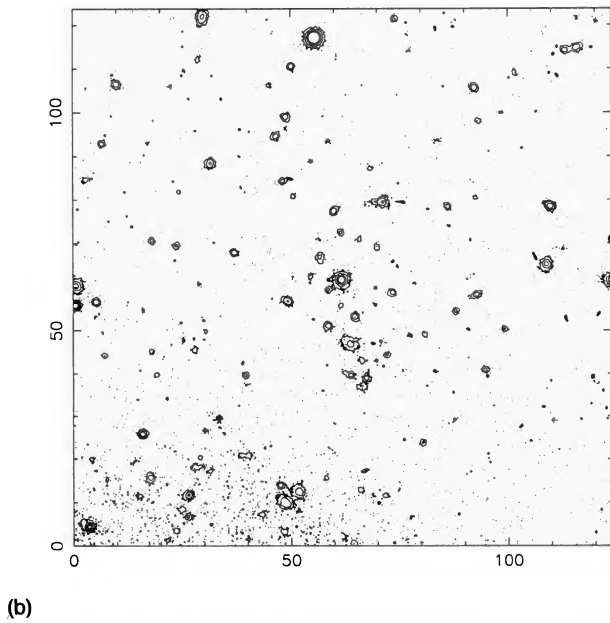
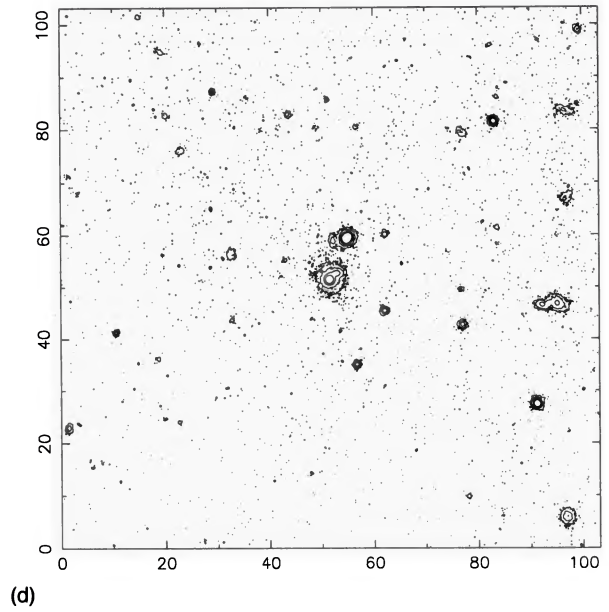
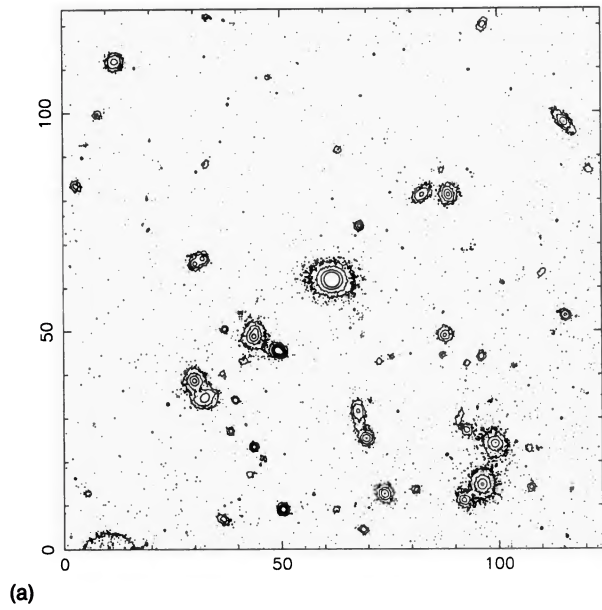


FIG. 1. Contour plots of Gunn  $r$  images of the objects. The BL Lac object is at the center of the image. North is up and east is to the left. The axes are labeled in arcseconds. The lowest contour is  $2.5\sigma$  above sky. See the text for details. (a) 900 s image of the  $2' \times 2'$  field around H0414+009. (b) 1800 s image of the  $2' \times 2'$  field around MS 1207+39. (c) 1440 s image of the  $2' \times 2'$  field around MS 1407+59. (d) 960 s image of the  $100'' \times 100''$  field around MS 0158+00. (e) 1740 s image of the  $2' \times 2'$  field around 3C 66 A.

TABLE 1. Summary of observations.

Name	Date	Int.	Filter	Field size	$m_{lim}^a$	$B_{gb}$	Redshift	Redshift
	(UT)	(s)				( $Mpc^{1.77}$ )		ref.
MS0158+00	17Jan91	960	r	4'.2 × 4'.2	24.15	270 ± 132	0.299	1
3C66A	17Jan91	1740	r	4'.2 × 4'.2	24.41	See text	0.444:	2
	6Aug91	660	r	6'.8 × 1'.3	23.27	...	...	...
H0414+009	16Jan91	900	r	4'.2 × 4'.2	24.17	738 ± 128	0.287	3
	16Jan91	1440	g	4'.2 × 4'.2	24.52	...	...	...
MS1207+39	17Jan91	1800	r	4'.2 × 4'.2	24.77	1092 ± 228	0.615	1
MS1407+59	17Jan91	1440	r	4'.2 × 4'.2	24.53	845 ± 173	0.495	1

Notes to TABLE 1.

<sup>a</sup> 5- $\sigma$  detection.Redshift references: 1. Morris *et al.* (1991), 2. Miller *et al.* (1978), 3. Halpern *et al.* (1991).

excess galaxies. The objects reported herein are therefore not representative. They probably represent the fields with highest  $B_{gb}$ , but there may be other rich clusters in our sample. A uniform, complete subsample of our observations will be reported in full at a later time (Wurtz *et al.* 1993); however, the discoveries reported here suggest that at least some BL Lac objects are at the centers of rich clusters, as suggested by the beamed FR 1 hypothesis. In Sec. 2 we describe the observations and reductions. In Sec. 3 we describe the analysis. Section 4 contains the notes on the individual objects and a discussion follows in Sec. 5.

## 2. OBSERVATIONS AND REDUCTIONS

We observed our sample of BL Lac objects using the FOCAM CCD direct imaging system at prime focus on the 3.6 m Canada–France–Hawaii Telescope during two runs, 1991 January 13–16 and 1991 August 4–6. For all objects, we acquired Gunn *r* images. In addition, for objects with  $z < 0.3$ , we obtained either Gunn *g* or Johnson *B* images as well. During the January run we used the SAIC 1024 × 1024 CCD with an image scale of 0".247 per pixel and a field size of 4'.2 × 4'.2. For the August run we used the Lick 2048 × 2048 CCD with an image scale of 0".206 per pixel and a field size of 6'.8 × 6'.8. We enjoyed subarcsecond seeing ( $\sim 0".9$ ) through most of each run, and the data presented here were obtained under photometric conditions. Gunn *r* images of the fields are shown in Figs. 1(a)–1(e). Table 1 contains a synopsis of the observations.

We used standard CCD image reductions in IRAF to correct for dc variations, bias subtraction, and flatfielding. The dome flat had large-scale variations of about 5% that we characterized by a smooth low order fit to the median of many images. We normalized this image and divided the original images by it. This reduced the sky variation across the images to less than 1%. We performed photometric calibrations by observing four Gunn standard stars (Thuan & Gunn 1976; Kent 1985) in the three filters throughout

the night. We then made a three-parameter solution to the photometry equation, with a typical rms residual of 0.01–0.02 mag. Corrections for galactic extinction were applied based on Sandage (1973) and *K* corrections based on Seibok's (1986) standard elliptical galaxies. Throughout the analysis we adopt  $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$  and  $q_0 = 0.5$  unless otherwise noted.

## 3. CLUSTERING ANALYSIS

Preliminary examination had revealed clear evidence for clustering around the BL Lac object in two fields, MS 1207+39 and MS 1407+59. A third object, MS 0158+00, is located in a field containing a large number of galaxies situated in apparent clumps. Two additional fields, 3C 66 A and H0414+009, had previously been identified as containing clusters by means other than the spatial covariance amplitude (Butcher *et al.* 1976, and McHardy *et al.* 1992 and Falomo *et al.* 1993, respectively), and for comparison we analyzed them as well.

We used the photometry and image-analysis system, *PPP*, developed by Yee (1991) to identify and classify all objects in the field as stars or galaxies down to a *completeness* magnitude of  $r \sim 23$ –23.5. Classification is made by comparing an object's aperture photometry growth curve with a canonical "stellar" growth curve [see Yee (1991) for details]. Classification of borderline objects is determined on a case-by-case basis (e.g., examination of the images of overlapping objects).

After a photometric catalogue of all objects in the field has been created, the BL Lac–galaxy spatial covariance amplitude,  $B_{gb}$  was calculated for each field. Determination of  $B_{gb}$  is based on Longair & Seldner (1979), who used it for radio galaxies, and was further developed by Yee & Green (1987) for quasars at higher  $z$ . This quantity measures the overdensity of galaxies within 500 kpc of the BL Lac, normalized by the expected luminosity and spatial distribution of galaxies at the BL Lac redshift. First, galaxy

counts within a 500 kpc radius of the quasar were computed, and the expected background galaxy counts are subtracted (using the background counts from Yee *et al.* 1986). This calculated overdensity is normalized using an assumed spherically symmetric power-law distribution with a slope of  $-1.77$ , the observed slope of the galaxy-galaxy spatial covariance amplitude (Seldner & Peebles, 1978). In practice, the spatial distribution of galaxies in a rich cluster may depart from this power law, but the choice of a 500 kpc radius will tend to minimize such effects (Ellingson *et al.* 1991). The galaxy luminosity function (LF) used in calculating  $B_{gb}$  is taken from Yee & Green (1987), and is the same used by Ellingson *et al.* (1991). This model includes mild evolution of about 0.6 mag in the observed Gunn  $r$  band by  $z \sim 0.6$ , which matches the observed LFs of galaxies in clusters associated with radio-loud quasars. Note that for consistency with previous work, we use  $q_0 = 0.02$  in calculating  $B_{gb}$ . Our results are summarized in Table 1.

Calculating  $B_{gb}$  provides a quantitative measure of the richness of the galaxy cluster environment of each BL Lac which can be compared for objects of different redshifts. However, this analysis is a statistical assessment, so it leaves open the possibility of a superposition of a foreground or background cluster on the BL Lac. Rough estimates of  $M^*$  for the excess galaxies can be used to try to distinguish such cases. A large value of  $B_{gb}$  for the objects herein is consistent with the conclusion that the galaxy associated with the BL Lac is located near the center of a cluster of galaxies. For comparison with low-redshift galaxy clusters, Prestage & Peacock (1988) give  $B_{gb}$  for clusters of Abell richness class 0, 1, and 2 as approximately 360, 645, and 945  $\text{Mpc}^{1.77}$ , respectively. This is not a direct conversion since the Abell classification is better suited to nearby clusters ( $z < 0.1$ ) where this technique, relying on the magnitudes of the third brightest galaxy, is less likely to be contaminated by field galaxies. At higher redshifts Abell classifications are more sensitive to the number density of field galaxies (i.e., background contamination) and the LF of the unseen galaxies in the cluster.

For the one high- $B_{gb}$  field that we imaged in two colors, H0414+009, we made a color-magnitude diagram of all the field objects classified as galaxies (Fig. 2). The solid lines represent the expected color and magnitude of the brightest galaxies of different Hubble types as a function of redshift. The color-magnitude relationship is obtained by numerically convolving the  $r$  and  $g$  filters' response with the spectral energy distribution of giant E galaxies (Yee & Oke 1978) and spirals from Coleman *et al.* (1980). Absolute  $r$  magnitudes of  $-23.3$ , equivalent to the average first-rank cluster galaxies, for E galaxies; and  $-22.7$  to  $-22.0$  for spiral morphologies assumed. An additional model for elliptical galaxies, assuming a mild luminosity evolution similar to that found by Yee & Green (1987) from galaxies associated with quasars, is also plotted. On this diagram, the presence of a rich cluster containing early type galaxies is signaled by an overdensity of galaxies of similar color, but fainter than that predicted for a first-ranked elliptical galaxy at the cluster redshift (e.g., in a horizontal diffuse

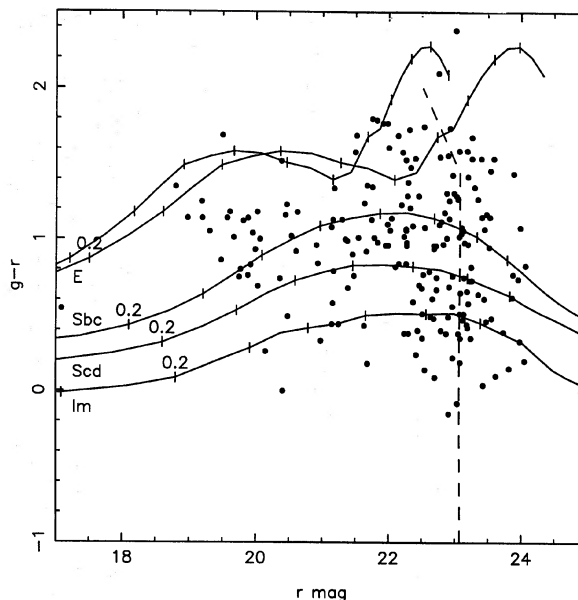


FIG. 2. Color-magnitude diagram of the galaxies in the field of H0414+009. Solid lines denote models of galaxies of different Hubble types at different redshifts. The tickmarks along the curves represent increases of 0.1 in redshift, with  $z=0.2$  marked. For elliptical galaxies, both a nonevolving model and a model including 1 mag of luminosity evolution by  $z \sim 0.1$  are shown. The dashed line represents the completeness limit of the field.

band slightly to the right of the position of the first ranked elliptical). Most field galaxies will be fainter and bluer than this.

#### 4. NOTES ON THE INDIVIDUAL OBJECTS

We present our results in the following order: first, a previously described cluster with a known redshift (H0414+009); second, two newly discovered clusters (MS 1207+39 and MS 1407+59); then an object which appears by visual inspection to be in a rich environment but for which we derived a low  $B_{gb}$  (MS 0158+00); and finally an object of uncertain redshift previously suggested to be in a cluster (3C 66 A).

##### 4.1 H0414+009

In Fig. 1(a) we show the central  $2' \times 2'$  of the field surrounding x-ray selected BL Lac object H0414+009 at  $z=0.287$  (Halpern *et al.* 1991). 500 kpc is  $93''$  at this redshift. Our measurement of  $B_{gb} = 738 \pm 128 \text{ Mpc}^{1.77}$  shows that the object is very likely near the center of a cluster of Abell richness class 1. McHardy *et al.* (1992) analyze clustering around this object using a modified Abell scheme and derive an Abell richness class 0. Falomo *et al.* (1993) use the method of Bahcall (1981) to derive  $N_{0.5} = 13$ , which they translate to an Abell richness of class  $\sim 0$ . Both McHardy *et al.* (1992) and Falomo *et al.* (1993) took spectra of galaxies near the BL Lac object and report five galaxies with  $z \sim 0.284-0.289$ . We fit a deVaucouleurs profile plus point source to derive  $M_r = -24.1$  for

the BL Lac host galaxy, clearly a BCG or cD. McHardy *et al.* (1992) also find that the host galaxy is an elliptical with  $M_V = -23.5$  which, using  $(V-r)_{E,80} = 0.204$  (Sebok 1986), corresponds to  $M_r = -23.7$ .

We present a color-magnitude diagram for galaxies in the H0414+009 field (Fig. 2). As stated above, a cluster is characterized by a band of galaxies extending to the right from the BCG of the proper redshift. In this case, there is such a grouping extending from the BCG tickmark for  $z \sim 0.3$  [along  $(g-r) \sim 1$ ], in good agreement with the BL Lac's redshift of 0.287.

#### 4.2 MS 1207+39

Figure 1(b) shows the  $2' \times 2'$  area around x-ray selected BL Lac object MS 1207+39 at  $z = 0.615$  (Morris *et al.* 1991). There is a very bright star several arcminutes SE of the object, so we chose a lowest contour for the image shown at slightly more than  $2\sigma$  above sky. There is also bleeding in a bad CCD column on an object approximately  $25''$  to the NW of the BL Lac.

MS 1207+39 is clearly situated in the center of a distant cluster. 500 kpc is  $65''$  at this redshift. We measure  $B_{gb} = 1092 \pm 228 \text{ Mpc}^{1.77}$ , corresponding to Abell richness class 2. The rough  $M^*$  we estimate for the excess galaxies inside the counting radius is consistent with clusters associated with quasars at this redshift (Ellingson *et al.* 1991). The host galaxy is resolved in this image and we derive a total magnitude of  $M_r \sim -24$  from fitting a deVaucouleurs profile plus point source. This magnitude is consistent with the host galaxy being a BCG.

#### 4.3 MS 1407+59

As can be seen in Fig. 1(c), MS 1407+59, at  $z = 0.495$  (Morris *et al.* 1991), is clearly situated in a cluster of galaxies. 500 kpc is  $70''$  at this redshift. We measure  $B_{gb} = 845 \pm 173 \text{ Mpc}^{1.77}$  for the field of this object, which corresponds to a cluster of Abell class 1 or 2. The rough  $M^*$  we estimate for the excess galaxies inside the counting radius is consistent with clusters associated with quasars at this redshift (Ellingson *et al.* 1991). The host galaxy is resolved in this image and we derive a total magnitude of  $M_r = -24.2$  from fitting a deVaucouleurs profile plus point source. This magnitude is consistent with the host galaxy being a BCG.

#### 4.4 MS 0158+00

This object at  $z = 0.299$  (Morris *et al.* 1991) is apparently surrounded by a group of fainter galaxies [Fig. 1(d)]. 500 kpc is  $91''$  at this redshift. In fact, the object itself appears to have a close smaller companion to the northwest, and there is another bright galaxy to the north.

The low value of  $B_{gb}$  for this field,  $270 \pm 132 \text{ Mpc}^{1.77}$  (compare this to the other values of  $B_{gb}$  discussed in this paper) suggests that the object is not situated in a rich Abell cluster. However,  $B_{gb}$  for a more compact poor grouping can be measured by decreasing the size of the circle used for excess galaxy counts. We calculate

$B_{gb} = 968 \pm 190 \text{ Mpc}^{1.77}$  within a radius of 0.1 Mpc from the BL Lac object. This is evidence for a smaller, more compact cluster or group of galaxies clustered more strongly than the  $r^{-1.77}$  assumed in calculating  $B_{gb}$ . Interestingly, the total magnitude we derive for the host galaxy  $M_r = -23.2$  from fitting a deVaucouleurs profile plus point source is still in the range of BCGs. However, it is not unusual to find bright ellipticals and even cDs in compact groups (Morgan *et al.* 1975).

#### 4.5 3C 66 A

In Fig. 1(e) we have coadded several deep  $r$  images and so this image shows saturation in the peak and a false halo to the northeast. There is also a "slider" cosmic ray producing a streak in the BL Lac's host galaxy toward the northwest, as well as bleeding in a bad CCD column on the star approximately  $25''$  to the northwest of 3C 66 A.

The redshift of this object is not well determined. The general quoted redshift of  $z = 0.444$  was originally determined from a single "highly uncertain" emission line in the BL Lac spectrum identified as Mg II (Miller *et al.* 1978). A merged *IUE* spectrum of 3C 66 A (Lanzetta *et al.* 1993) does show a probable emission line corresponding to Ly $\alpha$  at  $z = 0.44$ . Therefore, while probable, the redshift remains uncertain.

Butcher *et al.* (1976) used the following method to characterize cluster richness and estimate a redshift. They first assigned cluster membership of nearby field objects based on two-color photographic imaging, removing objects that are too blue or too obviously pointlike, and determined a limiting apparent magnitude for their plates. They then use the methods of Schechter & Press (1976) to determine that the cluster is "rich" and derive a distance modulus for the cluster corresponding to a redshift of  $0.37^{+0.07}_{-0.03}$ .

We can use the results presented here to constrain the redshift. We estimated  $M^*$  for a LF of the excess galaxies based on observations of clusters associated with quasars at  $z \sim 0.4$  (Ellingson *et al.* 1991). This method yields a cluster distance modulus consistent with  $z \sim 0.3-0.5$ . Additionally, by assuming the object's host galaxy is a BCG, the apparent magnitude of the host galaxy light could be used to estimate the distance modulus of the BL Lac. Unfortunately, because our deep images of the BL Lac have serious saturation and haloing problems, and an image created by coadding our short frames is not deep enough to resolve the underlying galaxy well, our attempts to fit the profile of the underlying host are inconclusive at present. Cluster constraints on the redshift notwithstanding, if the object is at  $z = 0.444$ , we measure  $B_{gb} = 404 \pm 160 \text{ Mpc}^{1.77}$ , corresponding to Abell richness class 0 at best.

#### 5. CONCLUSIONS

We measured the BL Lac galaxy spatial covariance amplitude for five BL Lac objects found by visual inspection to be in fields containing excess galaxies. Three x-ray selected BL Lac objects, MS 1207+39, MS 1407+59, and H0414+009, reside near the centers of clusters with Abell

richness class 1–2. A fourth x-ray selected BL Lac, MS 0158+00, resides in a luminous elliptical galaxy, possibly a cD galaxy in a compact poor cluster or group. Finally, 3C 66 A remains a source of speculation due to its uncertain redshift. If at  $z=0.444$ , the cluster surrounding this radio-selected BL Lac is Abell richness class 0 at best. These data suggest that at least some but not all BL Lac objects are consistent with being FR 1 radio galaxies in rich clusters.

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## REFERENCES

- Abraham, R. G., McHardy, I. M., & Crawford, C. S. 1991, *MNRAS*, 252, 482
- Bahcall, N. A. 1981, *ApJ*, 247, 787
- Browne, I. xxx, in *BL Lac Objects*, edited by L. Maraschi, T. Maccacaro, and M.-H. Ulrich (Springer, Heidelberg), p. 401
- Butcher, H. R., Oemler, A., Jr., Tapia, S., & Tarengi, M. 1976, *ApJ*, 209, L11
- Coleman, G. D., Wu, C. C., & Weedman, D. W. 1980, *ApJS*, 43, 393
- Ellingson, E., Yee, H. K. C., & Green, R. F. 1991, *ApJ*, 371, 1
- Falomo, R., Pesce, J. E., & Treves, A. 1993, *AJ*, 105, 2031
- Fried, J. W., Stickel, M., & Kühn, H. 1993, *A&A*, 268, 53
- Gioia, I., Maccacaro, T., Schild, R., Wolter, A., Stocke, J., Morris, S., & Henry, J. P. 1990, *ApJS*, 72, 567
- Gunn, J. E., & Oke, J. B. 1983, *ApJ*, 266, 713
- Halpern, J. B., Chun, V. S., Madejski, G. M., & Chanan, G. A. 1991, *AJ*, 101, 818
- Kent, S. M. 1985, *PASP*, 97, 165
- Lanzetta, K. M., Turnshek, D. A., & Sandoval, J. 1993, *ApJS*, 84, 109
- Longair, M. S., & Seldner, M. 1979, *MNRAS*, 189, 433
- McHardy, I. M., Luppino, G. A., George, I. M., Abraham, R. G., & Cooke, B. A. 1992, *MNRAS*, 256, 655
- Merrifield, M. R. 1992, *AJ*, 104, 1306
- Miller, J. S., French, H. B., & Hawley, S. A. 1978, in *Pittsburgh Conference on BL Lac Objects*, edited by A. M. Wolfe (University of Pittsburgh, Pittsburgh), p. 176
- Morgan, W. W., Kayser, S., & White, R. A. 1975, *ApJ*, 199, 545
- Morris, S. L., Stocke, J. T., Gioia, I. M., Schild, R. E., Wolter, A., Maccacaro, T., & Della Ceca, R. 1991, *ApJ*, 380, 1
- Ostriker, J., & Vietri, M. 1985, *Nature*, 318, 446
- Owen, F. N., & Laing, R. A. 1989, *MNRAS*, 238, 357
- Padovani, P., & Urry, C. M. 1991, *ApJ*, 368, 373
- Prestage, R. M., & Peacock, J. A. 1988, *MNRAS*, 230, 131
- Sandage, A. 1973, *ApJ*, 183, 711
- Schechter, P., & Press, W. H. 1976, *ApJ*, 203, 557
- Sebok, W. L. 1986, *ApJS*, 62, 301
- Seldner, M., & Peebles, P. J. E. 1978, *ApJ*, 225, 7
- Stickel, M., Fried, J. W., & Kühn, H. 1989, in *BL Lac Objects*, edited by L. Maraschi, T. Maccacaro, and M.-H. Ulrich (Springer, Heidelberg), p. 64
- Stickel, M., Fried, J. W., & Kühn, H. 1993, *A&AS*, 98, 393
- Stocke, J. T., *et al.* 1991, *ApJS*, 76, 813
- Thuan, T. X., & Gunn, J. E. 1976, *PASP*, 88, 543
- Ulrich, M.-H. 1989, in *BL Lac Objects*, edited by L. Maraschi, T. Maccacaro, and M.-H. Ulrich (Springer, Heidelberg), p. 45
- Urry, C. M., Padovani, P., & Stickel, M. 1991, *ApJ*, 382, 501
- Wurtz, R., Stocke, J. T., & Yee, H. K. C. 1993, in preparation
- Yee, H. K. C. 1991, *PASP*, 103, 396
- Yee, H. K. C., & Green, R. F. 1987, *ApJ*, 319, 28
- Yee, H. K. C., Green, R. F., & Stockman, H. S. 1986, *ApJS*, 63, 681
- Yee, H. K. C., & Oke, J. B. 1978, *ApJ*, 226, 753