Limits on Dust in Rich Clusters of Galaxies
From the Color of Background Quasars

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Abstract

I measure the $V - I$ color distribution of two samples of radio-selected quasars. Quasars from one sample are projected on the sky within 1° of a rich foreground Abell cluster of galaxies, while quasars from the other sample are more than 3° from any such cluster . There is no significant difference between the color distributions of the two samples. The 90% upper limit on the relative reddening between the two samples is $E(B - V) = 0.05$ mag. This result limits the allowed quantity of smoothly distributed dust in rich clusters, and contradicts previous indications for the existence of such a component.

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1 Introduction

Distant populations such as faint field galaxies and quasars are often viewed through foreground clusters of galaxies, which can distort our view of those populations. Measuring such distortions can be useful for a better understanding of both the background objects and of the mass-content and structure of the clusters.

Clusters can have two opposite effects on the density of background objects seen through a cluster. Gravitational lensing by the cluster potential can cause either an enhancement or a deficit in the number of background objects, depending on the intrinsic number vs. brightness relation of the background population, and the limiting magnitude to which the population is detected (e.g. Rodrigues-Williams & Hogan 1994). Dust in a cluster will obscure and redden a background population, and will therefore reduce the density of background objects down to a given magnitude limit. The detection of dust in rich clusters is of great interest in itself, since it can provide clues to the source of the observed intracluster X-ray emitting gas (e.g. Dwek, Rephaeli & Mather 1990).

Over the past years there have been various reports of overdensities of quasars behind foregound clusters of galaxies (Bartelmann, Schneider, & Hasinger 1994; Bartelmann & Schneider 1993a; Wu & Han 1995; Seitz & Schneider 1995; Williams & Hawkins 1995). Quasar-galaxy associations have also been reported (e.g. Fugmann 1988, 1990; Bartelmann & Schneider 1993b) and, when occuring on large angular scales, are probably evidence for the same phenomenon (i.e. the effect of the clusters in which the galaxies reside). The magnitude of the effect is still controversial. Some workers find an enhancement that is too large to be consistent with the magnification effect of gravitational lensing, given our current assumptions about the quasar population and the masses of clusters (e.g. Williams & Hawkins 1995).

On the other hand, several studies have reported large deficits of distant quasars or clusters of galaxies behind nearby clusters of galaxies, and have proposed extinction by intracluster dust as the cause. Zwicky (1957) first pointed out a deficit of distant clusters behind rich ones. Karachentsev & Lipovetskii (1969) used the same method to derive a mean cluster extinction of $A_V \approx 0.2$ mag. Similarly, Bogart & Wagoner (1973) found that distant Abell clusters are anticorrelated on the sky with

nearby ones. To account for this effect, they argued for an extinction corresponding to $A_V \approx 0.4$ mag and extending to ~ 2.5 times the optical radii of the nearby clusters. Szalay, Holloshi & Toth (1989), confirmed the effect but ascribed it to the difficulty of identifying background clusters, rather than to dust. Boyle, Fong, & Shanks (1988) identified quasars and clusters of galaxies on automatically-scanned plates. They found a $\sim 30\%$ deficit of quasars within $4'$ of the clusters, attributable to an extinction of $A_V = 0.15$ mag. Romani & Maoz (1992, hereafter RM92) found that optically-discovered quasars from the Véron-Cetty & Véron (1989) catalog avoid rich foreground Abell clusters of galaxies, with a deficit of 60% within $20' - 40'$ of the cluster, and $\sim 25\%$ out to a radius of $1°$. Radio-selected quasars are free from this effect. RM92 postulated that there is an average extinction of $A_V = 0.4$ within a $1°$ radius of the cluster, but that it is probably patchy, with many of the lines of sight undergoing as much as 1 mag of extinction. Williams and Hawkins (1995) recently searched for a reddening and obscuration effect in variability-selected quasars behind galaxy clusters identified automatically on UK-Schmidt plates. They find an *overdensity* of quasars behind the clusters, which they attribute to gravitational lensing, and no evidence for reddening, based on the comparison of the $U - B$ color distributions of the quasars that are behind clusters and those in the field.

The various results on extinction in clusters quoted above are not necessarily in conflict, because the experiments are not exactly the same. For example, the galaxy clusters defined by Boyle et al. (1988) consist of tens of galaxies, as opposed to the Abell clusters treated by Bogart & Wagoner (1973) and RM92, which are formed of hundreds of galaxies each. As pointed out by RM92, selection effects in the various identification methods of quasars may have also affected some or all of the above results. Several other workers have searched for evidence of dust in clusters through reddening of elliptical galaxies (Ferguson 1993), IR emission (Annis & Jewitt 1993), and emission-line ratios of cooling flows (Hu 1992), but have come up only with upper limits of $E(B - V) \lesssim 0.1 - 0.2$ mag. An intercomparison of various results on dust in clusters is given by Williams (1995).

In this paper, I search for a signature of dust in rich clusters and attempt to disentangle it from selection effects by testing the following prediction of RM92. If intracluster dust is responsible for the avoidance of rich Abell clusters by optically-

selected background quasars, radio-selected background quasars projected within 1°
of Abell clusters will be redder than those that are not.

The $V - I$ color of quasars is a particularly accessible probe of foreground redden-
ing. The relatively small scatter in the power-law slope of quasars, $\alpha \approx -0.5 \pm 0.4$
(e.g. Richstone & Schmidt 1980), translates into a narrow $V - I$ distribution, with
$V - I = 0.65 \pm 0.25$. The Lyα forest, with its effect on the spectral slope of quasars,
enters the V band only beyond redshift $z \sim 3$, and hence does not affect the $V - I$
color of most known radio quasars. Because of the large wavelength interval between
the V and I bands, $V - I$ is a sensitive reddening indicator. Foreground reddening
will shift the mean of the $V - I$ distribution of quasars, relative to an unreddened
quasar sample. The accuracy to which the mean is measured is limited only by the
number of quasars observed.

2   Sample Selection, Observations, and Analysis

To test for the presence of reddening in clusters I defined two samples of quasars.
Quasars in one sample (hereafter "the obscured sample") are projected on the sky
within 1° of at least one rich and distant ($R \geq 1, D \geq 5$) Abell cluster of galaxies.
(See Abell 1958, for definition of richness and distance classes, R, and D.) These
criteria correspond to the population and the angle of the avoidance effect found by
RM92. The second sample (hereafter "the unobscured sample") consists of quasars
that are at least 3° from any such cluster. Great care was exercised in choosing the
quasar samples and observing them, in order to avoid artificially introducing color
differences between the samples through selection effects or systematic errors, but
also to minimize any noise that may dilute an existing signal.

From Véron-Cetty & Véron (1993) I selected all quasars from the PKS, B2, 3C,
and 4C radio surveys with redshift $z > 0.3$, positive declination, Galactic latitude
$|b^{II}| > 40°$ for longitude $60° < l^{II} < 300°$ and $|b^{II}| > 50°$ otherwise, and apparent
magnitude $V \leq 18.9$. From among these quasars, I then selected all that were either
within 1° of at least one $D \geq 5$, $R \geq 1$ cluster of galaxies listed by Abell (1958), or
more than 3° from any such Abell cluster.

The motivation for choosing radio-selected quasars was that such quasars were

shown by RM92 to *not* avoid clusters, and should therefore be unbiased probes of the reddening induced by the clusters. (For example, if dust extinction causes the avoidance of clusters by optically-selected quasars, then optically-selected quasars near clusters would preferably be those that had escaped extinction, and hence would be relatively unreddened.) Only quasars from the four radio surveys above were chosen, in order to make the sample as homogeneous as possible while not making it too small. The redshift limit on the quasars ensured that they are behind the clusters; Struble & Rood (1991) have shown that the redshifts of the $D \geq 5$ clusters are $0.1 \lesssim z \lesssim 0.3$. Positive declinations were chosen to allow measurements at low airmass, where the error in color determination is smallest. The limits on Galactic coordinates avoided regions of the sky where the Abell catalog is substantially incomplete due to Galactic extinction. This is important especially in choosing the "unobscured" sample, since quasars behind uncatalogued clusters would be mixed into this sample, and hence potentially dilute a difference between the obscured and unobscured samples. The high Galactic latitude of all the quasars also guarantees that the additional scatter induced by Galactic reddening is at most ± 0.02 mag (Burstein & Heiles 1978). The apparent-magnitude limit was chosen to allow accurate measurement of a large sample in a short time. The $1°$ limit corresponds to the radius of the effect found by RM92. The $3°$ radius is the largest that still produces a quasar sample large enough to statistically detect a small ($\gtrsim 0.1$ mag) shift in the color distribution.

Application of the above criteria produced a list of 41 quasars in the obscured sample and 46 quasars in the unobscured sample. Tables 1 and 2 list the names and parameters of the selected quasars. Figure 1 shows the distribution in Galactic coordinates of the quasars and the Abell clusters. Note that the two quasar samples are well mixed on the sky. They are also similar in their redshift and magnitude distributions.

The quasars were imaged with the Wise Observatory 1m telescope on 1995 May 3-4, May 8-9, and July 28-29 UT using a Tektronix 1024×1024-pixel back-illuminated CCD at the Cassegrain focus. Standard Johnson-Cousins V and I filters were used. Photometric standards from Landolt (1992) were observed throughout each night. Exposure times were 300 s in each filter for quasars with estimated catalog magnitudes fainter than 17.9 mag, and 150 s in each filter for the brighter ones. To avoid

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systematic effects, the observations of the obscured and unobscured samples were intermingled as much as possible on each night and between nights.

Standard CCD data reduction was carried out with the IRAF package. The instrumental V and I magnitudes of each quasar were measured with the DAOPHOT (Stetson 1987) task within IRAF, relative to bright stars in the same image that served to model the point-spread function (PSF). Typical uncertainties in the PSF fitting were 0.01 mag for the brighter quasars to 0.04 mag for the fainter ones. Aperture photometry of the standard stars was used to calculate a photometric solution and its errors, which was applied to the quasar measurements to bring them to the Landolt (1992) system. Color-correction terms were small (~ 0.01 mag). The scatter of the standard-star measurements about the photometric solution was 0.02–0.04 mag. This error was combined in quadrature with the DAOPHOT error and with the photometric error as determined from the covariance matrix of the photometric solution, to form the total error on the V and I magnitude. The V and I measurements, the $V - I$ color, and their errors appear in Tables 1 and 2. Typical errors in $V - I$ are 0.07 mag. Due to observing contraints (weather, moonlight, time), 31 quasars from the obscured sample and 40 quasars from the unobscured sample were successfully observed. To reduce scatter, five quasars from the obscured sample and five quasars from the unobscured sample with $V - I$ errors exceeding 0.1 mag will be excluded from the subsequent analysis.

Figure 2 shows the binned $V - I$ distributions of the obscured and unobscured samples. There is no obvious difference between the two samples. A Kolmogorov-Smirnoff (KS) test on the cumulative distributions fails to reject the null hypothesis that the two samples are drawn from the same population. The mean and the standard deviation of the mean is 0.655 ± 0.043 and 0.623 ± 0.048 for the unobscured and obscured samples, respectively. A Student's t-test shows that the two means are consistent. From Student's-t distribution, the 95% (90%) upper limit on the difference between the means of the two samples is $\Delta(V - I) = 0.108$ mag (0.084 mag). There is also no evidence for a bimodality in the distribution of the obscured sample, as would be expected if there was patchy obscuration in the clusters intercepting of order half the lines of sight. There are several abnormally red ($V - I > 1$) quasars, but these exist in equal proportions in both the obscured and the unobscured samples.

To test for systematic effects in the calibration, the $V - I$ distributions of various nights were compared. There are no significant differences based on a KS test or a Student's t-test.

3 Discussion and Conclusions

For Galactic dust, $E(V - I) = 1.60E(B - V) = 0.52A_V$ (Rieke & Lebofski 1985). Assuming such properties for intracluster dust (see Dwek et al. 1990, for a discussion of the suitability of such an assumption), the upper limit on the reddening found above, $E(V - I) < 0.084$ mag, translates to $E(B - V) < 0.053$ mag or $A_V < 0.162$ mag at the 90% confidence level.

RM92 found suggestions in the limited color data for the quasars in the Véron catalog that, if dust is responsible for the avoidance of clusters by quasars, the obscuration is patchy, with about half of the lines of sight suffering a reddening of $E(B - V) \approx 0.3$ mag, or $E(V - I) \approx 0.5$. Such an effect would have been readily apparent in the data presented here, and is strongly ruled out. Similarly, the average $A_B \approx 0.5$ mag (i.e. $A_V \approx 0.4$mag) predicted by RM92 is ruled out. Since most of the quasars measured here are $> 30'$ from the cluster centers, a centrally-peaked dust distribution, with high central reddening and $A_V \approx 0.11$ mag out to $1°$, cannot be ruled out. Dwek et al. (1992) have, however, argued that dust can only survive in the outer parts of the cluster, if at all. Note also that the seven quasars that are $< 30'$ from the clusters do not have unusual color. There is no trend of quasar color with angular separation from the clusters or with angular separation normalized by the Leir & van den Bergh (1977) angular radius of each cluster.

I conclude that, as alternatively proposed by RM92, the avoidance of foreground clusters by optically-discovered quasars is probably a selection effect due to the difficulty of identifying quasars (whether using objective-prism or color excess techniques) in crowded fields. A similar, selection-induced avoidance of Galactic stars by quasars found in objective-prism surveys has been demonstrated by Gould, Bahcall, & Maoz (1993).

Dust in rich clusters might still be accomodated with the present results if both the comoving density *and* the dust content of the clusters do not evolve between $z = 0$

and the mean redshift of the quasars, $z = 1.22$. Under this assumption, the line of sight to the average quasar in either sample passes through the postulated $\sim$ 6-Mpc dust halo of $\sim 2 - 3$ distant clusters, and both samples would be equally reddened. If this were the case, however, one would expect to see at $0.3 < z \lesssim 1.2$ a correlation of quasar $V - I$ color with redshift. I find no such trend in the data, but the number of objects is small.

The results presented here also argue against the extinctions of $A_V \approx 0.2$ mag found by Karachentsev & Lipovetskii (1969) and $A_V \approx 0.4$ mag derived by Bogart & Wagoner (1973) for *nearby* Abell clusters, based on their anticorrelation with distant clusters. The difficulty in identiying several clusters on one line of sight is the likely true cause of the effect. This is not necessarily the case, however, if the dust properties of Abell clusters are strongly evolving, such that dust has appeared in the intracluster medium of nearby clusters by $z \lesssim 0.1$. The results I have shown only marginally rule out the small amount of extinction ($A_V \approx 0.15$) deduced by Boyle et al. (1988), and in any case, that effect was reported for a different (much poorer) population of clusters. That result, however, is challenged by the null detection of reddening for a similar population of clusters by Williams & Hawkins (1995). They propose that Boyle et al.'s (1988) reported underdensity of quasars behind clusters is the result of gravitational lensing by the cluster potential. Such an effect can arise as a result of a faint quasar-detection flux limit combined with a shallow-sloped quasar number-brightness relation.

To summarize, I have shown that radio-selected quasars behind Abell clusters are not redder than quasars that do not have a cluster in the foreground. The 95% upper limit on the reddening exerted by the intracluster medium is $E(V - I) < 0.108$ mag. This result suggests that the avoidance of foreground Abell clusters by optically-selected quasars is, at least in large part, a selection effect rather than a signature of dust extinction. The limit on reddening presented here improves upon previous limits based on null detections of reddening effects, and constrains the mean column density of dust in a rich cluster to $< 6.5 \times 10^{-6}$ g cm^{-2}, and the total dust mass within a 1° radius to $\lesssim 1.5 \times 10^{12} M_\odot$. Smaller amounts of reddening in clusters, as suggested by some studies, are still allowed. The bounds on dust in clusters can be improved by measuring the color distributions of larger samples of quasars.

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Table 1: Quasars $> 3°$ from Abell clusters

Name	R.A.(1950)	Dec.(1950)	z	V	δV	I	δI	$V-I$	$\delta(V-I)$
PKS 0109+17	01:09:09.6	$17°37'56"$	2.157	18.940	0.059	18.083	0.064	0.857	0.087
PKS 0114+07	01:14:49.5	$07°26'30"$	0.861	18.374	0.053	18.091	0.061	0.284	0.081
PKS 0229+13	02:29:02.4	$13°09'40"$	2.065	–	–	–	–	–	–
PKS 0256+075	02:56:47.0	$07°35'45"$	0.893	–	–	–	–	–	–
B2 0901+28B	09:01:30.6	$28°31'31"$	1.121	17.829	0.051	17.211	0.052	0.618	0.072
B2 0941+26	09:41:50.2	$26°08'33"$	2.906	18.591	0.063	17.918	0.057	0.673	0.085
4C 40.24	09:45:50.0	$40°53'43"$	1.252	–	–	–	–	–	–
PKS 0952+179	09:52:11.8	$17°57'44"$	1.472	–	–	–	–	–	–
3C 232	09:55:25.5	$32°38'23"$	0.533	16.546	0.039	16.306	0.040	0.240	0.056
PKS 1012+022	10:12:40.8	$02°13'50"$	1.374	17.493	0.047	16.666	0.045	0.828	0.065
4C 60.15	10:45:23.3	$60°24'37"$	1.722	18.862	0.063	17.731	0.049	1.130	0.080
PKS 1048+24	10:48:46.7	$24°03'58"$	1.270	–	–	–	–	–	–
B2 1104+36	11:04:41.6	$36°32'26"$	0.393	18.942	0.066	18.226	0.069	0.716	0.096
3C 261	11:32:16.3	$30°22'01"$	0.614	18.562	0.051	17.686	0.046	0.876	0.068
PKS 1134+01	11:34:55.7	$01°32'51"$	0.430	18.445	0.115	17.245	0.057	1.200	0.128
B2 1148+38	11:48:53.3	$38°42'33"$	1.299	17.227	0.040	16.544	0.040	0.683	0.057
B2 1204+39	12:04:04.6	$39°57'45"$	1.530	18.357	0.051	17.726	0.055	0.631	0.076
3C 268.4	12:06:42.1	$43°56'02"$	1.400	18.109	0.047	16.934	0.038	1.175	0.061
B2 1211+33	12:11:32.8	$33°26'26"$	1.598	17.551	0.041	16.749	0.042	0.802	0.058
4C 53.24	12:13:01.5	$53°52'36"$	1.065	18.245	0.043	17.799	0.061	0.446	0.075
3C 270.1	12:18:03.9	$33°59'50"$	1.519	18.520	0.048	17.855	0.063	0.664	0.079
B2 1220+37	12:20:42.3	$37°23'39"$	0.489	18.346	0.042	17.756	0.074	0.590	0.085
B2 1225+31	12:25:55.9	$31°45'13"$	2.219	15.866	0.038	15.147	0.036	0.719	0.052
B2 1234+33B	12:34:36.8	$33°30'53"$	1.280	18.426	0.048	18.276	0.093	0.150	0.105
PKS 1236+077	12:36:52.3	$07°46'45"$	0.400	19.180	0.057	17.810	0.046	1.370	0.073
B2 1237+35	12:37:55.4	$35°19'26"$	1.194	17.363	0.036	16.943	0.050	0.420	0.062
4C 44.20	12:39:57.0	$44°12'34"$	0.610	18.289	0.048	17.679	0.063	0.609	0.079
B2 1244+32B	12:44:55.4	$32°25'23"$	0.949	17.509	0.041	17.151	0.042	0.358	0.059
PKS 1252+11	12:52:07.7	$11°57'21"$	0.870	16.802	0.032	16.512	0.044	0.290	0.054
B2 1256+39	12:56:41.9	$39°16'23"$	0.978	19.459	0.085	18.577	0.077	0.882	0.115
B2 1300+39	13:00:29.0	$39°46'08"$	2.436	18.639	0.061	18.261	0.110	0.378	0.126
3C 281	13:05:22.5	$06°58'14"$	0.599	17.347	0.041	16.866	0.042	0.481	0.059
B2 1306+27A	13:06:33.1	$27°24'10"$	1.537	18.337	0.043	17.670	0.060	0.667	0.073
4C 18.36	13:08:29.5	$18°15'34"$	1.689	19.004	0.071	18.216	0.061	0.788	0.093
3C 287.0	13:28:15.9	$25°24'38"$	1.055	17.985	0.039	17.648	0.071	0.338	0.081
3C 286.0	13:28:49.7	$30°45'58"$	0.846	17.271	0.040	16.773	0.038	0.497	0.056
PKS 1335+023	13:35:06.9	$02°22'12"$	1.356	18.386	0.049	17.687	0.086	0.699	0.099
B2 1409+34A	14:09:46.2	$34°29'16"$	1.820	18.457	0.045	17.740	0.044	0.716	0.063
B2 1414+34	14:14:50.0	$34°42'40"$	0.750	17.586	0.032	17.426	0.052	0.161	0.061
4C 46.29	14:15:13.5	$46°20'55"$	1.552	18.150	0.043	17.417	0.045	0.733	0.062
PKS 1421+122	14:21:04.6	$12°13'26"$	1.611	18.377	0.038	17.720	0.064	0.657	0.074
PKS 1427+109	14:27:43.8	$10°56'46"$	1.710	18.872	0.045	18.446	0.111	0.426	0.120
B2 1452+30	14:52:25.0	$30°08'06"$	0.580	19.028	0.053	18.268	0.056	0.759	0.078
B2 1612+37A	16:12:03.7	$37°50'29"$	1.630	18.896	0.043	–	–	–	–
B2 1633+38	16:33:30.6	$38°14'09"$	1.814	17.665	0.033	16.845	0.042	0.820	0.053
PKS 2301+060	23:01:56.3	$06°03'57"$	1.268	18.433	0.045	17.810	0.060	0.623	0.075

Table 2: Quasars $< 1°$ from Abell clusters

| Name	R.A.(1950)	Dec.(1950)	z	V	δV	I	δI	$V-I$	$\delta(V-I)$	Sep.['] (Abell No.)
PKS 0003+15	00:03:25.1	$15°53'07"$	0.450	15.614	0.035	15.270	0.045	0.343	0.057	43.1(0001), 23.6(2705)
PKS 0008+171	00:07:59.4	$17°07'38"$	1.601	17.333	0.037	17.018	0.052	0.315	0.064	17.1(0006)
4C 08.04	00:33:41.0	$07°58'34"$	1.578	19.081	0.078	18.291	0.076	0.790	0.109	56.0(0068)
4C 09.01	00:33:48.3	$09°51'29"$	1.909	18.310	0.052	17.254	0.055	1.056	0.076	59.6(0073)
3C 37	01:15:43.6	$02°42'20"$	0.670	18.817	0.058	17.986	0.053	0.832	0.079	45.3(0172)
3C 47.0	01:33:40.5	$20°42'09"$	0.425	17.905	0.040	17.339	0.049	0.567	0.063	27.7(0213)
PKS 0136+176	01:36:59.3	$17°37'56"$	2.716	19.019	0.060	18.447	0.079	0.572	0.099	34.7(0221), 17.6(0227)
PKS 0158+18	01:58:56.0	$18°22'09"$	0.799	17.714	0.039	17.393	0.049	0.321	0.062	14.7(0288)
PKS 0159+034	01:59:14.7	$03°29'03"$	1.897	17.221	0.039	16.519	0.051	0.702	0.064	04.8(0293)
PKS 0214+10	02:14:26.7	$10°50'18"$	0.408	16.456	0.037	15.993	0.047	0.463	0.060	43.9(0331)
4C 47.29	08:59:40.0	$47°02'57"$	1.462	–	–	–	–	–	–	35.7(0739)
3C 216.0	09:06:17.3	$43°05'58"$	0.668	–	–	–	–	–	–	44.0(0758)
PKS 0922+14	09:22:22.4	$14°57'23"$	0.896	–	–	–	–	–	–	46.0(0795)
B2 0949+36	09:49:26.6	$36°20'12"$	2.050	18.359	0.048	17.693	0.059	0.666	0.076	42.9(0893)
B2 0952+35	09:52:49.3	$35°47'38"$	1.241	19.194	0.112	18.412	0.110	0.781	0.157	42.6(0893)
4C 55.17	09:54:14.3	$55°37'17"$	0.901	–	–	–	–	–	–	12.0(0899)
B2 1009+33	10:09:17.6	$33°24'17"$	2.260	–	–	–	–	–	–	46.8(0943)
B2 1011+25	10:11:05.6	$25°04'10"$	1.636	–	–	–	–	–	–	42.4(0964)
B2 1018+34	10:18:24.1	$34°52'31"$	1.400	–	–	–	–	–	–	04.7(0982)
PKS 1020+191	10:20:11.9	$19°08'46"$	2.136	–	–	–	–	–	–	05.0(0991), 43.2(0994)
B2 1020+40	10:20:14.6	$40°03'27"$	1.254	17.882	0.049	17.236	0.041	0.646	0.064	52.1(0972)
4C 19.34	10:22:01.4	$19°27'34"$	0.828	–	–	–	–	–	–	38.6(0991), 36.5(0994)
4C 09.37	10:47:48.9	$09°41'48"$	0.786	–	–	–	–	–	–	59.4(1093), 25.5(1105), 50.2(1115)
3C 254.0	11:11:53.2	$40°53'41"$	0.734	17.593	0.041	17.147	0.063	0.445	0.075	37.9(1190), 51.6(1203)
PKS 1158+007	11:58:49.5	$00°45'10"$	1.383	18.825	0.087	18.558	0.150	0.267	0.173	53.8(1445)
B2 1204+28	12:04:55.0	$28°11'42"$	2.177	18.426	0.054	17.803	0.046	0.622	0.071	52.0(1455)
B2 1208+32A	12:08:05.6	$32°13'48"$	0.388	16.806	0.039	16.318	0.038	0.487	0.055	55.1(1498)
B2 1343+38	13:43:26.5	$38°38'12"$	1.844	17.847	0.041	16.924	0.038	0.923	0.056	21.1(1785)
B2 1353+30	13:53:26.1	$30°38'51"$	1.018	18.365	0.041	17.498	0.074	0.867	0.085	39.5(1826)
B2 1425+26	14:25:21.9	$26°45'38"$	0.366	16.412	0.030	16.112	0.044	0.300	0.054	36.5(1912)
B2 1426+29	14:26:32.6	$29°32'26"$	1.421	18.644	0.048	18.120	0.055	0.524	0.073	55.2(1929)
3C 309.1	14:58:56.6	$71°52'11"$	0.904	17.269	0.031	17.113	0.100	0.156	0.105	41.8(2037)
PKS 1502+106	15:02:00.1	$10°41'18"$	1.833	19.164	0.063	18.087	0.069	1.077	0.093	56.9(2016)
PKS 1502+036	15:02:35.7	$03°38'08"$	0.413	18.709	0.048	18.000	0.078	0.709	0.091	45.9(2023)
B2 1506+33A	15:06:22.6	$33°58'25"$	2.200	18.744	0.036	17.546	0.063	1.198	0.072	40.5(2034)
B2 1512+37	15:12:46.8	$37°01'55"$	0.370	16.447	0.039	16.095	0.038	0.352	0.054	49.4(2042)
4C 43.39	16:29:38.6	$43°55'03"$	1.167	18.779	0.050	18.392	0.055	0.387	0.074	54.3(2190), 36.0(2198), 42.5(2206)
4C 58.32	16:34:19.8	$58°54'42"$	0.985	18.950	0.058	18.472	0.067	0.478	0.088	48.2(2208)
4C 47.44	16:36:19.2	$47°23'29"$	0.740	18.727	0.040	18.016	0.074	0.711	0.084	55.3(2219)
PKS 2318+02	23:18:14.4	$02°40'34"$	1.968	18.888	0.067	18.506	0.091	0.382	0.113	53.5(2574), 21.7(2582)
PKS 2319+07	23:20:03.9	$07°55'33"$	2.090	18.431	0.050	17.793	0.055	0.638	0.074	39.5(2594)

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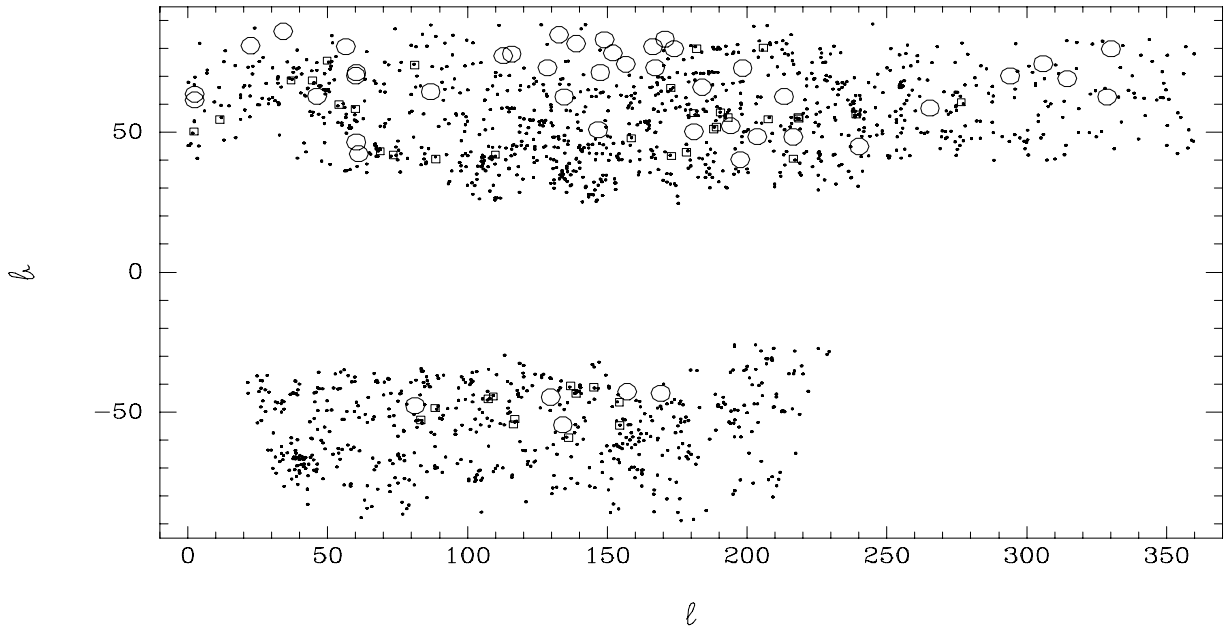
Figure 1: Distribution in Galactic coordinates of quasars and Abell clusters. Points denote all $R \geq 1$, $D \geq 5$ Abell clusters. Squares denote radio-quasars from the "obscured" sample and are $< 1°$ from a foreground cluster. The circles, of radius $3°$, mark the quasars from the "unobscured" sample, which are at least that angular distance from any cluster.
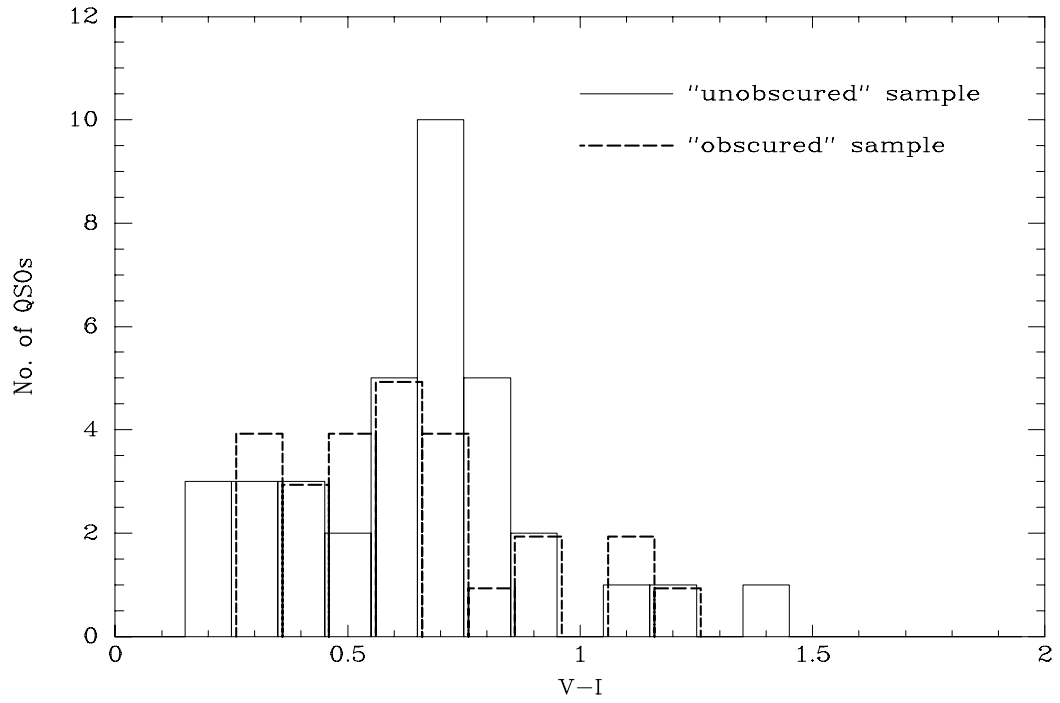
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Figure 2: The observed distribution in $V - I$ of the unobscured sample (solid line) and the obscured sample (dashed line) of quasars. There is no significant difference in the distributions or their means, setting a 95% upper limit of $E(V - I) = 0.108$ on the reddening.