THE APPLICATION OF THE STUDY OF GALAXIES ASSOCIATED WITH QUASARS TO OBSERVATIONAL COSMOLOGY

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ABSTRACT. CCD direct imaging of fields around quasars is used as a method for locating galaxy clusters and groups associated with quasars. Average galaxy counts in the sky obtained from control fields are used to correct for background galaxies in the quasar fields. This correction allows one to derive the luminosity function (LF) of the associated galaxies at the redshifts of the quasars. It is demonstrated that using the derived LF and average galaxy count data, self-consistent models of the evolution of the LF and galaxy counts can be obtained. Current data are best fitted, with a large uncertainty, by a q_o between 0.0 and 0.5 and an evolution in M* of -0.9 ± 0.5 mag. It is found that the average environment of radio-loud quasars at $z\sim0.6$ is about three times richer in galaxies than that of quasars at $z\sim0.4$.

In a study of the global environments of quasars, Yee, Green and Stockman (1986) obtained images of fields around a sample of quasars having redshifts between 0.3 and 0.65 in Gunn r (6500 ± 500 Å) and i (8200 ± 600 Å) using a CCD camera at the Steward 2.3 m telescope. Observations of control fields 1° N of the quasars through the r filter were also obtained to provide self-consistent background/foreground galaxy count corrections. In this paper, I present the analysis of the differential luminosity function (LF) of galaxies at redshifts between 0.2 and 0.6 and the results of galaxy count models computed using the derived LF and the control field galaxy counts.

Galaxies from fields of three subsamples of radio-loud quasars are used to derive the LF of galaxies at redshift bins of $\langle z \rangle = 0.61$ (9 fields), $\langle z \rangle=0.42$ (10 fields), and $\langle z \rangle=0.24$ (fields of 10 quasars with 0.15 z 0.3 from the data of Green and Yee, 1984). Throughout this paper, a H_o of 50 km/sec/Mpc is used. For each field, galaxies are binned according to the absolute magnitudes computed at the observed r band of all galaxies by assigning the quasar redshift to the galaxies. The LF is determined by subtracting the background galaxy counts in the equivalent apparent magnitude bins. LFs in the three redshift bins are formed by summing the results. This is performed for three choices of q_o: 0.02, representing the open universe; 0.5, the closed universe; and

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1.6, the value obtained by Kristian, Sandage and Westphal (1978, KSW) using first rank cluster galaxies and assuming no evolution. The results for the $\langle z \rangle = 0.42$ and $\langle z \rangle = 0.61$ subsamples are shown in Fig. 1.

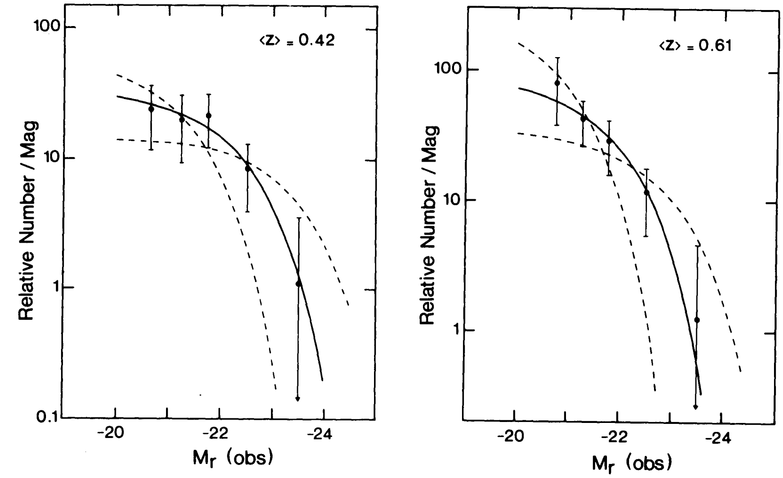

Figure 1. LFs of galaxies associated with quasars at $\langle z \rangle = 0.42$ and $\langle z \rangle = 0.61$ for $q_o = 0.02$ at the observed r band. Solid lines are best fitting Schechter functions with $\alpha = -1.0$. Dashed lines represent the fits with M^* changed by $\pm 2\sigma$.

Local galaxy LFs for different morphological types derived by King and Ellis (1985, hereafter, KE) and Sebok (1986) are used for comparison with the observed LFs. KE and Sebok fitted LFs for various morphological types to Schechter functions (Schechter, 1976) of α of -1.0 and -1.2, respectively. The observed LFs of galaxies associated with quasars are fitted to the same forms. Using the KE and Sebok LFs, model M^*'s of the total LF with no evolution are computed for the observed r band at the three redshift bins using the K-corrections for the various morphological types listed in Sebok. These model M^*'s are then compared with the observed M^*'s. The results are shown on Table 1. The differences in M^*'s can be interpreted as a combined evolution of luminosity and colours of galaxies. Note that for $q_o = 1.6$, in agreement with KSW, no evolution in M^* is observed.

If we made the assumptions that (1) the galaxies associated with the quasars are representative of the galaxies counted in our r band control fields, and (2) the shape of the LF does not evolve, then we can use the observed LFs to calculate galaxy count models; i.e.

$$N(m) = \frac{1}{4\pi} \int \sum_i \Psi_i \left[M_i^*(z)\right] dV$$

where N(m) is the average galaxy counts in the sky, Ψ_i is the integral LF of the i^{th} morphological types. For computation of the integral, linear fits to the ΔM^*'s listed on Table 1 as a function of z are used. The normalization constant of the LF is determined by matching the computed counts at r=20.0 to the observed counts. The resultant fits

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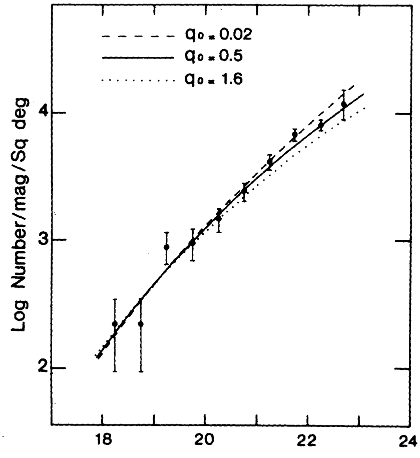
TABLE 1

$\langle z \rangle$	Model M^*_r's	M^*_r (observed)-M^*_r (Model)		
			q_o	
		0.02	0.5	1.6
King and Ellis (1985) α=-1.0				
0.0	-21.88	--	--	--
0.24	-21.67	-0.19±0.35	-0.15±0.40	+0.39±0.40
0.42	-21.37	-0.84±0.52	-0.54±0.47	-0.23±0.71
0.61	-20.86	-0.87±0.52	-0.51±0.47	-0.21±0.48
Sebok (1986) α = -1.2				
0.0	-21.79	--	--	--
0.24	-21.56	-0.48±0.35	-0.44±0.44	+0.11±0.42
0.42	-21.22	-1.26±0.59	-0.93±0.52	-0.33±0.74
0.61	-20.61	-1.32±0.58	-0.94±0.51	-0.22±0.53

are shown in Figure 2 for the KE LF and the Sebok LF. The best fitting line for the Sebok LF is the q_o=0.5 case, and for the KE LF, the q_o =0.02 case. Both best fitting cases give a colour+luminosity evolution of M^* at z~0.6 of -0.9±0.5 mag. The large uncertainty in the control field counts (from a total area of ~100 sq arcmin) produces a



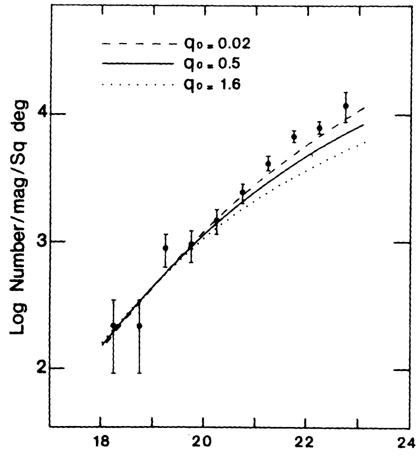


Figure 2. Background galaxy count models using the Sebok (left) and KE (right) LF for local galaxies.

one σ uncertainty in q_o of ~0.5. The counting statistics can be easily improved with more data. However, note that the uncertainty in α of the LF produces a further uncertainty of ±¼ in q_o.

Using the method outlined in Yee and Green (1984), and the best fitting galaxy count models, spatial covariance amplitudes (B_{gq}'s) for the quasars are derived. It is found that the average B_{gq} for the $\langle z \rangle$

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=0.61 sample is more than three times that of the low z subsamples and about 8 times that expected for field galaxies. Some radio-loud quasars at z>0.5 are found in clusters of richness similar to those of Abell class 1 clusters. Since low z radio-loud quasars are not found in clusters (e.g., Yee and Green, 1984), this suggests that physical conditions in some rich clusters have changed significantly between z~0.6 and z~0.4.

Using the average environment of quasars, we can also estimate the effect of assumption (1) above. Dressler (1980) estimated that at 10 times the density of the field, the fraction of E+S0 galaxies increases form 0.2 in the field to 0.3. Thus, given the large uncertainty in the LF determination, the effect of possibly having a different population from the field is not significant.

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DISCUSSION

MILEY: Do you have enough data to draw any conclusions about possible differences in the clustering properties of lobe-dominated radio quasars (steep spectra) with those of core-dominated radio quasars (flat spectra)?

YEE: No, not at the present time. Hopefully, with the CTIO survey of the Parkes quasars, we can say something definitive concerning radio morphology and environments. There is a very tentative suggestion that the extended (i.e. resolved) objects may have a tendency to have richer environments.

SILK: Will you be able to obtain any information about any evolution in the shape of the galaxy luminosity function?

YEE: We now have over 5 times more data in the process of being reduced. I estimate that M^* with an accuracy of ~ ± 0.2 mag can be obtained. However, because the background galaxy counts are always rising faster than any reasonable LF of galaxies, without redshift

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information, it would be difficult to get good information on the LF 1 or 2 magnitudes past M*. For this reason, it could be difficult to observe any evolution in the shape of the LF except at the very bright end.

FILIPPENKO: In those fields which you have observed through three filters (g,r,i), do you see any differences in the colors of the QSO host galaxies at different redshifts? Also, do the colors of galaxies in a given field depend on their projected distance from the QSO?

YEE: Because our sample contains fairly bright quasars, it is doubtful that any reliable color information of the fuzz can be obtained at $z \gtrsim 0.3$. I have not looked at the r-i colours of the galaxies in the quasar fields carefully yet. However, the few closest companions all appear to have r-i colours similar to the r-i colours expected for early type galaxies at the redshifts of the quasars.

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