EVOLUTION OF VERY FAINT FIELD GALAXIES AND QUASARS

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This paper reports preliminary results of two long-term redshift surveys that are near completion. One consists of nearly 400 redshifts of field galaxies; the sample is faint enough ($B \lesssim 22$) to test models of galaxy luminosity and color evolution (and possibly cosmology) and to search for the presence of very large-scale structures among distant field galaxies. The other consists of over 60 spectra of quasar candidates of similar faintness; the identifications and redshifts of bona-fide quasars provide strong constraints on the evolution and shape of the luminosity function of distant quasars. Almost all of the observations have been made with the 4m telescope at Kitt Peak National Observatory with the Cryogenic Camera in multiaperture mode. The spectral range covered 4500Å to 7500Å with 15Å FWHM resolution and 4Å per pixel; simultaneous exposures of an hour or two were made for about 10 objects within the 5 arcmin field of view.

The quasar candidate sample is concentrated over an area of 0.3 deg^2 in Selected Area 57 at the North Galactic Pole and consists of all stellar-like objects which lie away from the positions of expected Galactic stars in the UBV two-color diagram (Koo, Kron, and Cudworth 1986). We emphasize that our selection does NOT exclude quasars of high redshift ($z > 2.2$) as in other photometric UV-excess surveys. Among the 77 candidates complete to $B \gtrsim 22.5$, we now have spectra for 64. The 32 genuine quasars have redshifts ranging from 0.9 to 3.1, with a median of 1.5. We also found 11 stars, generally at $B < 21$, as well as 16 narrow emission-line galaxies with redshifts between 0.2 and 0.8. Five remain unidentified.

Details of our spectroscopic work will be published elsewhere. In summary, we find:

1) To $B \sim 22.5$, we have spectroscopically confirmed a quasar surface density of over 100 deg^2, the highest among any existing survey.
2) The redshift distribution among our quasars with $B < 21$ is almost identical to the fainter ones. As already hinted by the predominance of UV-excess candidates, relatively few (7) quasars with $z > 2.2$ were found, supporting the view that high redshift quasars are rare over a large range in luminosities.

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3) The turnover in the number counts of faint quasars is also seen in the shape of the luminosity function of quasars at redshifts $z < 3$, derived by combining our data with those of others from brighter surveys.
4) Using the break from the steeply rising bright portion of the luminosity function as a fiducial point, we find one interpretation to be that luminosity evolution in the form $(1+z)^4$ is dominant over density evolution, at least up to $z \sim 2.5$. In fact, the data suggest that the overall number of quasars may even have been fewer in the past. If so, quasars of $z < 4$ may NOT have ionized the intergalactic medium. If constant, the more rapid drop beyond $z \sim 2.5$ may signal the major epoch of quasar formation.

The galaxies of the field survey were selected randomly within several 5 arcmin areas, with brighter (in the red band) objects given higher weights. These areas were located in three fields of high galactic latitude (SA 57 at 1305+30; SA 68 at 0015+15; and Hercules No.1 at 1720+50) for which we have UBVI photometry from 4m prime focus plates that go deeper than our sample for spectroscopy. Our field galaxy survey represents a six year effort, largely because of our attempt to define and achieve a sample that is "complete", not necessarily in the sense of finishing all objects to a single magnitude limit over a given area of sky, but rather in the sense of having representative (i.e. unbiased by color, surface brightness, or strength of spectral features) subsamples useable for statistical analysis. To date, we have secured over 400 redshifts, with over 300 now constituting a statistically complete sample.

Although the reduction of the redshift survey is still underway because of our desire to improve the accuracy, reliability, and completeness, we are already able to report some interesting, though preliminary, results. One of the most striking is the observed clumpiness of the redshift distributions, especially in SA 57 (see Figure 1a). This field shows both very strong overdensities (clustering) and underdensities ("voids") on scales of ~100 Mpc. Our survey depth is not easily defined, but the faintest galaxies have $B > 22$ and the median redshift is 0.24. A detailed analysis of the clustering (and its evolution) of field galaxies and of its consistency with various cosmological scenarios is underway in a collaborative project with A. Szalay. In the meantime, our data can be compared to cold dark matter N-body simulations (White et al. 1986), which also show large fluctuations in the redshift distribution.

Another result comes from comparing the colors and redshifts of our data for three fields to that predicted from galaxy spectral evolution models, similar to (but not exactly the same as) that of Bruzual and Kron (1980). Our data (Fig. 2) contain far fewer low luminosity galaxies than predicted by our improved models and suggest at most mild luminosity evolution of galaxies at redshifts $z > 0.4$.

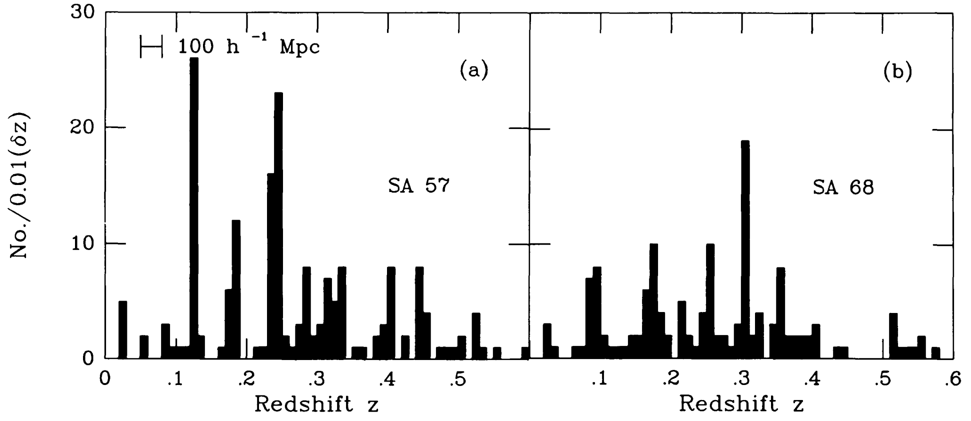

Fig. 1 a) Histogram in bins of 0.01 in z of redshifts for 148 galaxies within a 0.3 deg^2 field at the North Galactic Pole (SA 57). The magnitude and completeness limits are very complex, but roughly represent a sample brighter than B ~ 22. The "void" between z of 0.13 and 0.17 is particularly noteworthy. b) Histogram of 134 redshifts in another 0.3 deg^2 field (SA 68); depth is similar to that in SA 57.

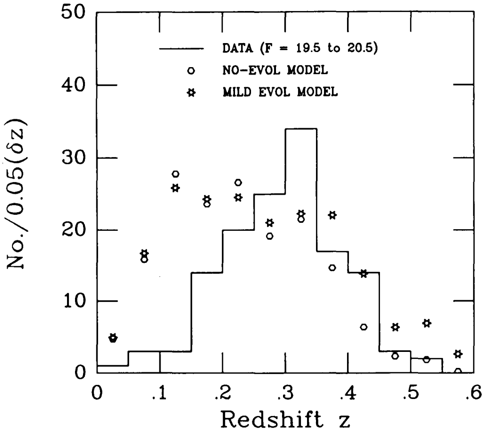

Fig. 2 Histogram of galaxies with red (F) mag between 19.5 and 20.5 in redshift bins of 0.05 compared to that of no-evolution (in color or luminosity) and evolution models that fully account for the completeness (equivalent areal coverage at different mag) and photometric errors of our survey.

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These distant galaxies do, however, appear to be relatively brighter in the rest frame ultraviolet (i.e. bluer) than the current model predictions, an example of which is shown in Table I. Their spectra often possess strong emission lines indicative of substantial star formation (unfortunately, both the spectral energy distributions in the UV and the integrated strengths of emission lines remain uncertain for local galaxies). Not all galaxies have undergone similar color changes, however; our reddest galaxies up to redshifts of ~0.55 possess intrinsic colors that do not differ from those of red galaxies today (see review by Spinrad 1986). Finally, we note that neither the deep QSO nor the deep field galaxy redshift survey has yielded any good candidates for primeval galaxies.

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Table I
Color of Distant Galaxies
(z = 0.35 to 0.45)

Red Mag	DATA		Model Predictions No-Evol		Model Predictions Evol	
	Blue	Red	Blue	Red	Blue	Red
<19	1	0	1	1	3	9
19 - 20	7	3	3	5	8	11
20 - 20.5	4	5	4	7	9	12
Total	12	8	8	13	20	32

Blue and red correspond to observed U - F colors less and greater than 1.5. U(3620 Å) is about 2500 Å rest and F(6100 Å) is about 4400 Å rest. This division is expected to divide galaxies with rest frame B-V colors less and greater than 0.7.

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DISCUSSION

WINDHORST: For what fraction of the field galaxies are the spectra featureless, meaning, that no redshifts have been measured. Is this a serious problem for the determination of the redshift distribution? Do you have any clue from your multicolor analysis what their redshift range might be? (Question directed to both D. Koo and R. Ellis.)

KOO: Our ability to secure redshifts depends on both S/N and the strength of emission and/or absorption features - "featureless" is difficult to define but we do have spectra without strong features. Our redshift distribution is meaningful only for the statistically complete sample. For galaxies without redshifts, multicolors can provide estimates of distances, but these may be unreliable, especially for redshifts greater than about 0.6.

ELLIS: We are statistically complete but only to a brighter limiting magnitude than that adopted in our survey (see previous paper). The most successful redshift feature in our wavelength range is [OII]3727 which we could detect to $z \sim 0.6$ yet our redshift distributions fall well before this limit is reached. Thus I think it unlikely that incompleteness will affect significantly the high z region of the distribution, though we are continually striving to finish off the remaining faint galaxies without redshifts both with the fibre system and our new multislit spectrograph.

FILIPPENKO: Have you checked whether or not known QSOs with $3 \lesssim z \lesssim 4$ have colors which could be confused with stars in your color-color diagrams? If they do, then you may have missed a substantial number of high-z objects.

KOO: Yes, we have looked at all the QSO's with $z \gtrsim 2.5$ with UBV colors in the Veron and Veron catalog, and estimate an incompleteness of ~20%-30% for $z \gtrsim 3$. Marano et al. have checked their multicolor sample against a slitless survey in the same field and conclude that the incompleteness is at this level. Compared to model predictions we have probably not missed substantial numbers, though independent checks are needed to confirm this. An astrometric and variability survey is already underway for this purpose.

SILK: There are many uncertainties in primeval galaxy models which must be evaluated before they can be ruled out even at moderately low redshift by means of optical searches. One of the most serious problems may be that IRAS observations of extreme starbursts suggest that primeval galaxies may be extremely dusty objects.

KOO: I agree totally. Our faint galaxy and quasar survey places a strong constraint on, for example, Meier's model (1976, Ap. J. 207, 343) of primeval galaxies, but it certainly does not rule out others (see my review in 1986 Spectral Evolution of Galaxies, ed. C. Chiosi and A. Renzini, p. 419).

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