ANALYSES OF DEEP GALAXY SAMPLES

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A. INTRODUCTION

The combination of deep photography using fine-grain emulsions and fast automated plate-measuring machines is proving to be a valuable tool in studying galaxy evolution. Until recently, the favoured method for monitoring evolution was the spectroscopic study of one type of galaxy at various redshifts (see Spinrad 1977 for a review). It is considerably more economical, however, to derive evolutionary information from the statistical properties of the numerous faint images detectable on deep plates. The drawbacks are that the data at each apparent magnitude involves galaxies of different types seen over large redshift ranges. Also to interpret the statistics, we need to know the properties of large numbers of galaxies, for example their luminosity function, ultraviolet spectra and, particularly, the morphological variations in such properties.

Photography provides us with number-magnitude, colour-magnitude and colour-colour data. These topics have been discussed at this symposium by both Tyson and Kron. As Kron (1979) has emphasised, the automatic measurement and detection of faint images is a young subject and it is not clear which of the many procedures adopted by the numerous research groups active in this field is the most appropriate. The technical side of the issue has been discussed by Kron in some detail. A topic which has received less attention and which is even more important is concerned with the difficulties in interpreting the counts and colours, regardless of how they are measured, because of the poor knowledge of the fundamental properties of galaxies.

In addition to demonstrating the effects of these uncertainties, I shall outline a further use of deep galaxy data, namely studies of galaxy clustering. Until now, correlations of galaxy positions have been studied only using samples taken from Schmidt plates. This is because very large areas are required to avoid "fair sample" problems. The conclusions I reach will hopefully stress the need to continue this aspect of galaxy analysis with 4-metre plates and eventually with the Space Telescope.

G.O. Abell and P. J. E. Peebles (eds.), Objects of High Redshift, 23–30.

B. INTERPRETATION OF NUMBER-MAGNITUDE COUNTS

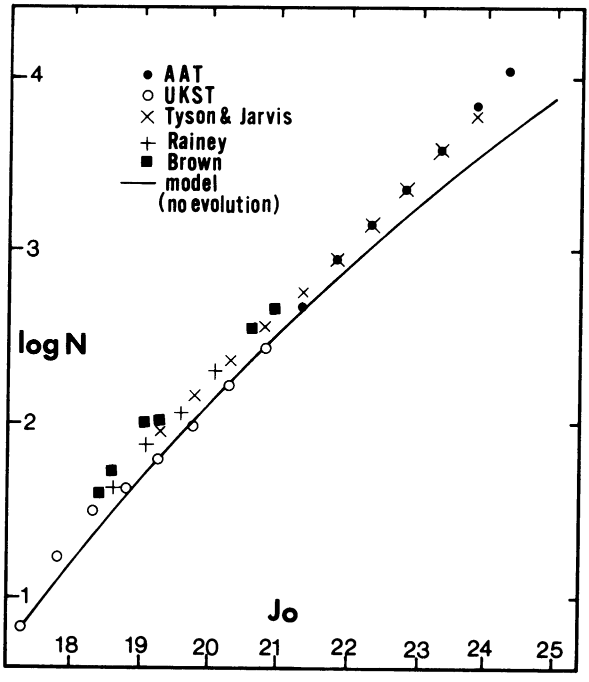

Figure 1. Differential galaxy counts per deg^2 per 0.5 mag interval in a isophotal J (IIIaJ plus Schott GG385) system.

Figure 1 shows counts from some deep 4-metre and Schmidt plates. AAT/UKST refers to work described by Peterson, Ellis and Kibblewhite (1979). These counts agree well with those of Tyson and Jarvis (1979) and also with those of Kron when allowance is made for his different photometric techniques. To derive evolutionary information from such counts, one must first predict the counts in the absence of any evolution. This requires accurate K-corrections, luminosity functions and the variations in these properties from one type of galaxy to another.

Consider first the K-correction. When comparing data with models the crucial factor in assessing the presence of evolution is the count slope. As galaxies are being lost from these samples typically over redshifts $0.3 < z < 1.0$, reliable galaxy fluxes are required for wavelengths around 2500 Å for work involving the J band. It is well-known that ultraviolet galaxy measurements when compared are often discrepant. Even with one detector, Code and Welsh (1979) have shown the variation within one galaxy type displaying similar optical colours may be ∿ 2 mag at 2500 Å. Ultraviolet data on normal galaxies, particularly spirals, is very much in short supply. This intrinsic scatter means that a large number of each type will have to be studied before reliable K-corrections can be provided.

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What effect does the present scatter in the UV fluxes have on our interpretation of the number counts? Figure 2 shows the effect of using K-corrections as determined from the fluxes of some early-type galaxies. This difference represents the minimum effect we can expect.

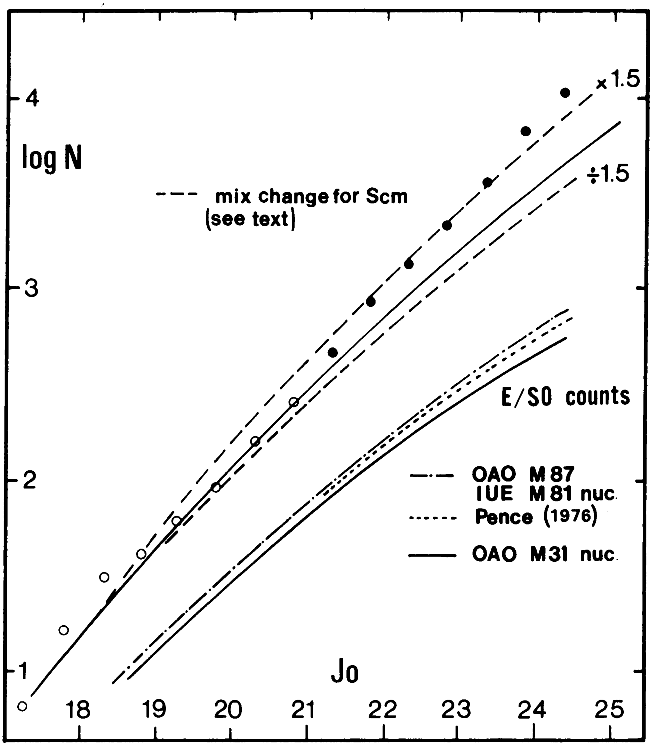
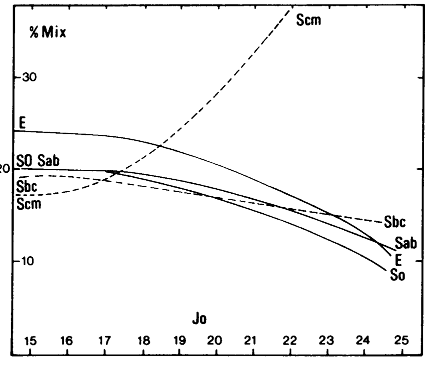


Figure 2. The effect of various uncertainties on the predicted number magnitude counts for the J band. The lower curves represent predictions for E/SO galaxies only.

For the later types, which form a less homogenous sample in the visible, the scatter is likely to be much larger and their contribution to the counts (see below) is more important. At present UV measurements of spirals are so few we cannot even estimate the scatter.

This imbalance of knowledge between early and late types is disastrous, for by far the greatest proportion of galaxies seen on deep plates are late-type spirals which have small K-corrections (Figure 3).



It is vital, therefore, to know their true mix and K-corrections as accurately as possible. A 50% perturbation on their true mix produces the dashed lines in Figure 2 thus drastically changing our interpretation of the data. The apparent mix would be modified in the reverse sense if there were evolution of the kind envisaged by Tinsley (1978) whereby early types were substantially brighter at moderate redshifts. Ironically such evolution cannot be confirmed until the no-evolution prediction is accurately defined.

Figure 3. Apparent galaxy mix at various limiting J magnitudes.

The model presented together with the data in Figure 1 utilises the K-corrections of Pence (1976) and a galaxy mix consistent with the sample of Kirschner, Oemler and Schechter (1979) limited at 15.5 in their J system. The galaxy luminosity functions for each of 6 types are of the Schechter (1976) form adopting Felten's (1977) overall normalisation. If this model is correct, the data shows clear evidence for some luminosity evolution. On the pessimistic side, Kron (1979) has argued that technical problems such as systematic and random errors could mimic the effect of evolution by artificially steepening the count slope. In any case the above discussion makes further interpretation of Figure 1 rather pointless. What can perhaps be said (see Ellis 1979) is that the counts are unlikely to be consistent with the very strong evolutionary models where all galaxy types were substantially brighter in the past as a result of a rapidly declining star formation rate (Tinsley 1977).

On the optimistic side, some effort is now being directed towards filling in the missing details on galaxy properties. Far more effort is needed however. The literature is full of information on peculiar objects; we tend to forget the universe is populated primarily by normal galaxies about which we know very little indeed! Several groups are constructing larger redshift samples from which a better understanding of the galaxy luminosity function and its morphological variations should follow. Ultraviolet spectra of spirals with IUE will also soon be available. This will enable us to converge, albeit slowly, to the true K-corrections appropriate to the large samples on the deep plates.

C. GALAXY CORRELATIONS

Statistical measures of galaxy clustering are important not only in describing the distribution of visible matter but also because they can be compared with model predictions starting from various initial conditions (see Fall 1979 for a review).

The two-point correlation function $\xi(r)$ is defined as the excess probability of detecting two galaxies r Mpc apart; an equivalent angular function $W(\theta)$ can be defined for the projected distribution. The relationship between ξ and w involves geometrical projection (Limber 1953, Phillipps et al. 1978). In the gravitational instability picture of galaxy formation with isothermal (matter only) perturbations, $\xi(r)$ is expected to resemble two power-laws over the observable range (David, Groth and Peebles 1977). At small r where ξ is large the clusters are bound and do not evolve in proper space. At large r the function should fall off more rapidly. The junction of the two regimes defines a "feature" whose position is highly Ω-dependent. The feature should not be seen in the observable range $0.5 < r < 50\ h^{-1}$ Mpc unless $\Omega \sim 1$ (Efstathiou 1979).

The observed correlation function is indeed of this two power-law form. Groth and Peebles (1977) find evidence for such a feature in the distribution of the Shane-Wirtanen catalogue at an angle corresponding to $9\ h^{-1}$ Mpc. Its reality is not clear, however, because over such large angles the distribution may be affected by Galactic obscuration and plate-plate variations. The reality can be checked with deeper samples where the corresponding angle is much smaller.

Another important application of the correlations on deep plates is to check whether the amplitudes of the bound regime agree with those expected on the basis of local results. This scaling tests the uniqueness of ξ over large volumes of space. It might also be possible to monitor evolution in the clustering over these look-back times. Such evolution is expected to be small unless galaxies formed very recently, which is unlikely in view of the modest luminosity evolution detected in Figure 1.

Using 5 UKST plates forming two red (IIIaF) - blue (IIIaJ) pairs together with a third J plate, the galaxy distribution has been studied by Shanks et al. (1980) over a total area of $\sim 40\ deg^2$ to limits of $J = 21.5$ and $R = 19.75$. The angular correlation functions were fitted by power-laws of index -0.8 over the range $0.005 < \theta < 0.1$ deg. The amplitudes for the ensemble average J samples at 3 limiting magnitudes are compared with the corresponding amplitudes for shallower samples in Figure 4. The data is in good agreement with the virial prediction implying the locally derived distribution holds to very large depths ($\sim 700\ h^{-1}$ Mpc). This is convincing evidence for the isotropy and homogeneity of the Universe on very large scales. With substantially deeper data covering large areas, it might be possible to monitor the evolutionary trends modelled in Figure 4.

On larger scales the correlation functions for all 5 plates show good evidence for a feature (Figure 5). The functions drop rapidly beyond $\theta \sim 0.3$ deg. The effect is not due to noise as the scatter is small. The drop-off is not caused by the self-normalisation of $w(\theta)$ as can be shown from the number densities involved. In Shanks et al. (1980) we compare the entire ensemble-average functions with those for the Shane-Wirtanen and Zwicky catalogues, thereby checking the reproducibility of the feature at various depths. Internally in our data sets the feature is at the same spatial separation, $3\ h^{-1}$ Mpc, to within 30%. Its position is 3 times smaller than that for the S-W catalogue

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(though in reasonable agreement with that for Zwicky). The important point is that all analyses find the feature. Considering the problems in compiling the shallower catalogues, this discrepancy in position may not be too serious. A complete redshift sample of several hundred galaxies would be a convincing way to pinpoint its precise position.

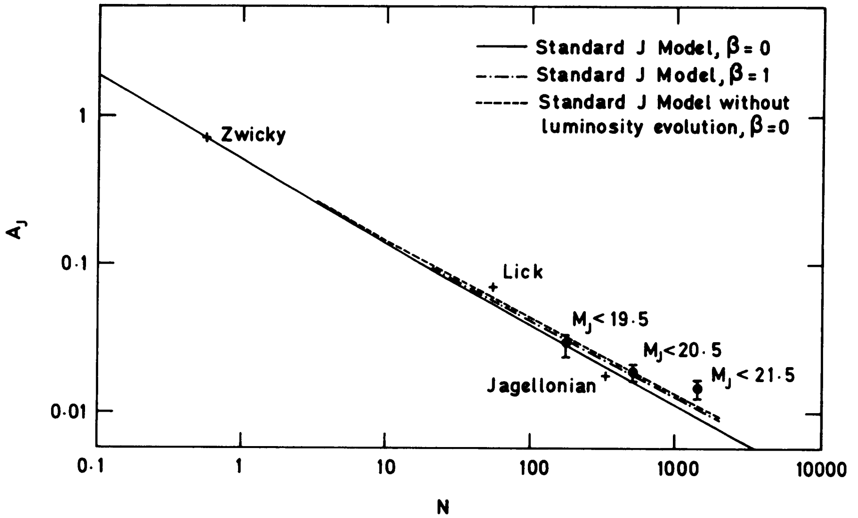

Figure 4. Correlation amplitudes appropriate to 1 degree versus galaxy density deg^{-2}. The solid line represents the expectation for virialised clusters.

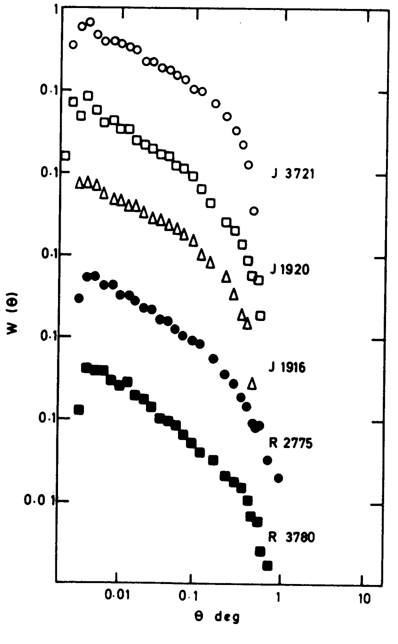

Figure 5.
Angular correlation functions for 5 UKST plates.

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DISCUSSION

Davis: How much extinction is indicated by the band of low galactic density across the Schmidt plate?

Ellis: The band is seen on both J and R plates of this field and is over 3 degrees in length and 0.5 degrees in width. The extinctions of 0.25 mag in J and 0.12 mag in R are consistent with that produced by an interstellar cloud. The deficiency of galaxies makes other areas on the field look overdense on large scales. Consequently, it is only after applying a moving-average filter to this distribution that we obtain a feature at the position seen in the analysis of the other plates.

Tyson: 1. Analysis of deep 4-meter plates by J. Jarvis and me shows significant variation in galaxy number counts in different high latitude areas, over and above that expected from photometry errors and known clustering. These variations may be caused by high latitude clumped extinction, and are similar to those just mentioned by R. Ellis seen at brighter limiting magnitudes.

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2. We have obtained 2-point correlation functions for our 11 fields (approximately 50,000 galaxies) and find preliminary evidence for less clustering at a limit of J = 24th magnitude.

Ellis: 1. If extinctions of $\gtrsim$ 0.25 mag in J were common at high latitudes, it would indeed produce fluctuations of $\gtrsim$ 30% in deep counts. Structure might not be seen in the smaller areas covered by 4-meter plates.

2. We also analysed the correlations on our single 4-meter plate but found large discrepancies which we believe are related to sampling problems rather than evolution (Ellis 1979: Proc. Roy. Sci., in press).

Abell: The galaxies were identified with the COSMOS engine at Edinburgh, were they not?

Since you and Tyson both use J magnitudes, you should agree on the counts at the bright end (J $\approx$ 18); do your data also show the bright excess reported by Tyson?

Ellis: The U.K. Schmidt counts were determined from COSMOS scans of three IIIa-J plates. Even with such a large area, the galaxies are few in number brighter than J = 17. Over the region 17 $\leq$ J $\leq$ 21 becomes noisy at J ~ 16, but I suspect that this relates to sampling problems or individual clusters in the KOS fields (as the authors commented), rather than a very large supercluster such as Tyson suggested.