GALAXY NUMBER-COUNTS TO $B = 28^m$

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1. Introduction

Counting the number of galaxies as a function of their apparent brightness is one of the fundamental cosmological tests, providing an important probe of both the geometry and evolutionary history of the Universe. CCD detectors have in recent years enabled astronomers to explore magnitude limits undreamed of a decade or so ago, and where important constraints can be placed on the allowable combinations of q_0 and evolution. Recent work has shown that the B-band counts keep rising with a power-law distribution, with a fivefold excess in the number of galaxies at $B = 26.5$ over that expected from simple non-evolving models. Indeed, it has been suggested that the total numbers of galaxies already seen may be too high for a $q_0 = 0.5$ universe, assuming there is a redshift cut-off in the galaxy distribution caused either by galaxies having strong Lyman limit systems or a low redshift of formation. As $q_0 = 0.5$ is favoured by theoretical arguments, it is important to see if the behaviour of the counts at even fainter magnitudes can be reconciled with a high density universe. Most published counts are unreliable faintward of $B \approx 26$, as the incompleteness corrections required become comparable in size to the data. We have now extended the counts to $B \sim 28$, using a ~ 24 hour CCD exposure taken on the 2.5 m Isaac Newton telescope (INT) on La Palma, together with a ~ 10 hour exposure on a small part of this field taken using the 4.2 m William Herschel Telescope (WHT).

2. Observational Data

2.1 24-HOUR INT EXPOSURE

This image is composed of 55 ½ hour exposures taken with the RCA CCD camera at prime focus of the INT. This gives a field size of 6′ x 4′, at 0.74″/pixel. The individual exposures were flat-fielded using twilight sky, then cosmic rays removed by comparing each frame with a median of 10 other frames. The net effective exposure is about 24 hours, with an average seeing of 1.5″ FWHM. Image detection was done isophotally, but Kron-type aperture magnitudes were then calculated for each of these images, using a local sky determination, and with a minimum limit to the aperture of 3″ diameter (2FWHM). A 3σ detection inside this aperture corresponds to a

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total magnitude (for an unresolved object) of $B = 27.0$. We also have ~ 3 hours of R-band exposure on this field, which reaches a 3σ limit of $R = 25$.

2.2 10-HOUR WHT EXPOSURE

These data were taken with a Tektronix CCD at the cassegrain auxiliary focus of the WHT. Binned to 512 x 512 pixels at 0.22″/pixel this gives a roughly circular field-of-view of radius ~ 1′, and so only covers a small portion of the INT frame. As with the INT, many ½ hour exposures were stacked together, producing a net exposure of 10 hours, with seeing of 0.9″ FWHM. Image analysis was identical to that for the INT frame, except that the better seeing allowed the minimum aperture to be set to 2″, with a resulting improvement in signal-to-noise. A 3σ detection inside this aperture corresponds to a total magnitude (for an unresolved object) of $B = 27.6$. The agreement with the magnitudes of the same objects on the INT frame was excellent.

3. Results

Figure 1 shows a compilation of published B band galaxy counts for $10 < B < 28$. The dashed and dotted lines show high and low q_0 non-evolving models respectively. Our B band counts are still increasing at $B = 27.5$, and are approaching 2×10^5 gal. per sq. deg. per 0.5 mag. After we account for incompleteness in our data (only ≈ 25% for the faintest WHT bins), the best fitting slope for $25.5 < B < 27.5$ is $\Delta \log N_{gal} / \Delta m \approx 0.3$. This is significantly less than at brighter magnitudes, but still much steeper than a standard high q_0 pure luminosity evolution model would predict. The R band slope is ≈ 0.35 at $23.5 < R < 25.5$. A close examination of the cosmological models shows that, even in the non-evolving case, for high q_0 we are at magnitudes in the B band where the slope of the number counts is starting to become dominated by the slope of the faint end of the galaxy luminosity function. This is mainly due to the fact that the rate of increase of the cosmological volume element with distance modulus begins to slow rapidly at $z \approx 1$ (and eventually starts to decrease). Any luminosity evolution pushes this effect to even brighter magnitudes. Now, a slope of ≈ 0.3 corresponds to a Schechter function with $\alpha \sim -1.8$, much steeper than that seen for local galaxies, where α appears to be between -1.0 and -1.2. It therefore seems likely that at $z \sim 1$ - 2 the galaxy luminosity function had a much steeper slope than it has today.

As an example, the solid line in Fig. 1 shows a $q_0 = 0.5$ pure luminosity evolution model with a standard galaxy luminosity function, but in which the faint end slope of the luminosity function has been increased to $\alpha = -1.8$ for all galaxies above $z = 1$. This model also fits the R counts. Although any realistic variation in the faint end slope would be more gradual, such a simple change to the standard models is enough to show how to produce high q_0 models which fit the counts. The only alternative means of achieving a steep count slope is to make M^* fainter in the past and make up the numbers by increasing the space density of galaxies (this allows the counts to increase without shifting the magnitude at which the luminosity function slope dominates brighter). For low q_0 the larger volume available makes fitting the counts easier, although if the B counts continue to rise for another magnitude then this model will run into the same problem as the high q_0 models. It must also be noted that all models which rely on evolution of normal galaxies at high redshift to explain the excess in the counts are being challenged by the latest

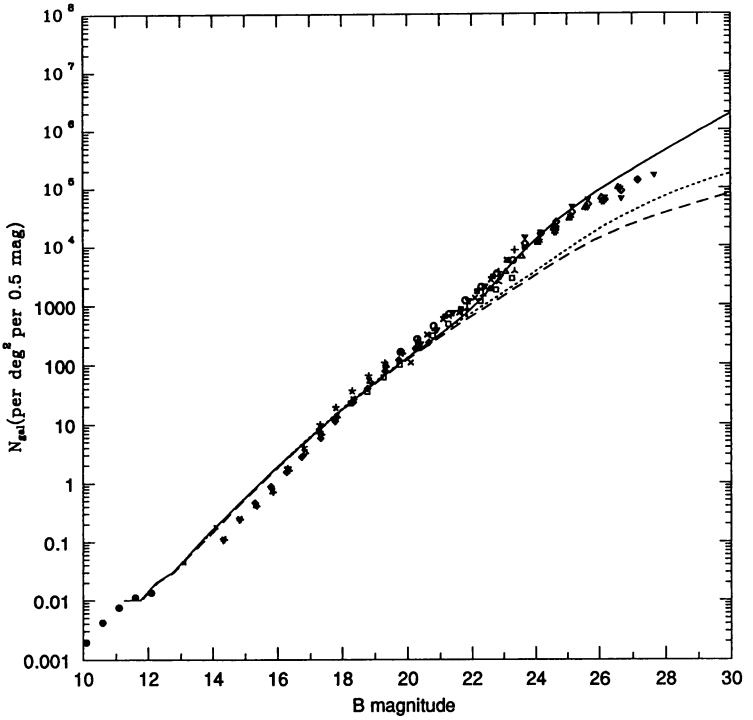

Figure 1.

redshift surveys at $B \approx 23$ - 24, which appear not to detect a significant number of galaxies with $z > 1$.

Figure 1 also indicates vividly the problem at the bright end of the counts — the slope of the data for $16 < B < 19$ is significantly steeper than that predicted by the models. Depending on the choice of normalisation, either there is a large deficit in the count at $B \approx 16$ or a large excess by $B \approx 19$. Either way there is a problem, and the resolution is going to have a significant effect on the amount of evolution needed to interpret the faint counts. There are several possible explanations: the data may be in error — however both major photometry sets agree (the APM survey and the Edinburgh/Durham catalogue) and are supposedly well-calibrated by CCD photometry; there may be a large change (about a factor 2 - 3) in galaxy density below $z \sim 0.2$, either due to some form of evolution (much more than that predicted by standard models), or due to us living in an underdense region of the universe (however, the APM counts cover a large portion of the southern sky, and such a huge underdensity is much larger than is likely in conventionally held views of galaxy clustering); or the local luminosity functions input into the models and/or the k-corrections could be significantly in error. This is unlikely — although the

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behaviour of the luminosity function at faint magnitudes is still uncertain, the faint end of the luminosity function has only a marginal effect on the count slope at bright magnitudes.

As of yet there is not enough data to identify which explanation is correct. Of interest would be well defined bright end counts in redder bands, which one would expect to be less affected by conventional luminosity evolution, but equally affected by the presence of an underdensity. Of course, as a final resort the cosmology could be wrong (but note that a cosmological constant does not help here).