Limits on Cosmology from Infrared Galaxy Number Counts

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We analyze deep number counts in the H-band and compare them with the predictions of various cosmological models. Our data favor low density universes with $\Omega_M < 0.3$ and $\Omega_\Lambda < 0.5$ with galaxies forming early.

1 Introduction

Galaxy number counts as a function of apparent magnitude have long been used as a cosmological probe (e.g., Sandage 1961). The local luminosity function is integrated over the cosmological volume element, assuming an appropriate redshift distribution (i.e., evolutionary history) for galaxies to yield an estimate of the number counts to some magnitude limit. Inverting the problem yields a geometrical estimate of q_0 which is largely independent of the scale factor.

Counts in the B-band have long been known to exceed the predictions of the simplest no–evolution model by a factor of 5 at $B > 18$. Unfortunately, galaxy evolution in the optical bands and uncertain $k-$corrections have hampered application of the number count method to yield meaningful limits to cosmology (e.g., Koo & Kron 1992 for a review).

Infrared passbands are regarded as a panacea for these studies. Infrared number counts are dominated by a population of passively evolving early type galaxies formed at high redshift, extinction and starbursts are of little importance and $k-$corrections are known to be small and to vary only slowly with redshift and Hubble type (Shimasaku & Fukugita 1998 and references therein). Using available data, Shimasaku & Fukugita and Jimenez & Kashlinsky (1999) argue that the Universe must have low density and galaxies must form at comparatively high redshift, but are unable to set constraints on cosmological parameters.

In a recent paper (De Propris & Lineweaver 2000) we use deep H-band counts from the Hubble Deep Field South and number counts models by Gardner (1998), which take into account galaxy evolution, k-corrections, mergers and dust extinction, to set broad limits on

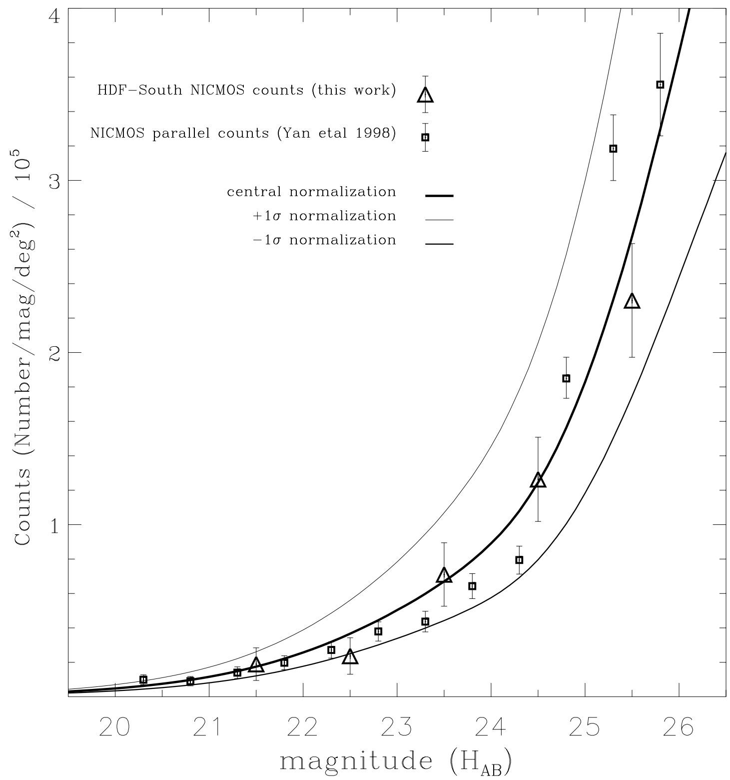

Figure 1: H-band number counts and best model, plus two models to show the range allowed by uncertainties in the normalization and 'shape' parameters of the local luminosity function. These models have $\Omega_M = 0.1$, $\Omega_\Lambda = 0.0$, $z_f = 15$ and the morphological mix found in the K band survey of Gardner et al. 1997.

Ω_M,Ω_Λ and the redshift of galaxy formation (z_f). Although the best fit models have unacceptably high χ^2 values, our results are most consistent with a low density universe with $\Omega_M = 0.1$ and $\Omega_\Lambda = 0.0$ where $z_f > 8$.

2 Data and Models

We used the latest version of the H-band image of the Hubble Deep Field South. Photometry was carried out using v.2.0.15 of the SExtractor software (Bertin & Arnouts 1996). We carried out a series of simulations to derive completeness and photometric errors. Details on the procedures followed may be found in De Propris & Lineweaver (2000).

The results are shown in Figure 1 together with counts from the parallel NICMOS survey of Yan et al. (1998). There is good agreement between the two sets of data. The slope of our number counts is 0.31 ± 0.02 which is in reasonable agreement with the 0.29 reported by Yan et al. and with other infrared number counts (e.g., Bershady et al. 1998).

We compared our results with predictions from models by Gardner (1998), varying cosmological parameters, the redshift of galaxy formation, the morphological mixture and the local luminosity function within reasonable errors. For each of these models we calculated a χ^2 following the procedures discussed in Lineweaver (1998). The best model has $\Omega_M = 0.1$,$\Omega_\Lambda = 0.0$ and $z_f > 8$ (we lose sensitivity to z_f for higher redshifts). This is shown in Figure 1 as a thick solid line. In Figure 1 we also show (as thin solid lines), the effect of varying the luminosity function normalization and shape parameters within their 1σ errors bars.

In Figure 2 we show the results of varying Ω_M, Ω_Λ, z_f and the morphological mixture [where a 'red' mixture is composed of all early type galaxies and a 'blue' mixture is that ap-

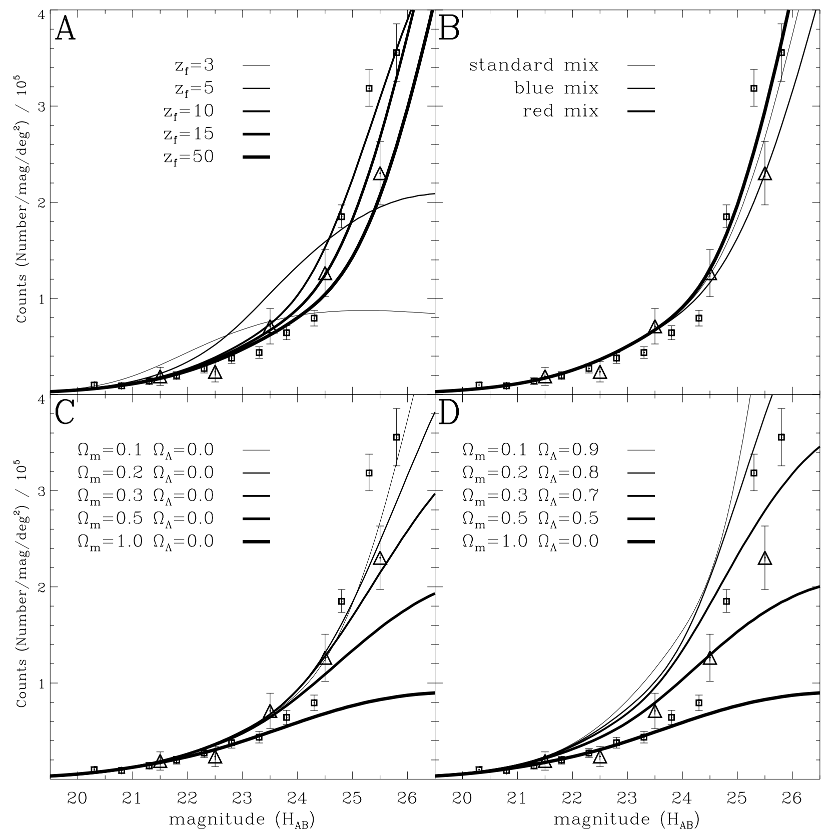

Figure 2: Variation in the number counts as a function of the parameters explored. Unless otherwise specified parameters are those used in Figure 1. Panel A shows the dependence on z_f. Panel B on variations in the morphological mixture. Panel C shows the dependence on Ω_M with no Ω_Λ and panel D shows $\Omega_M + \Omega_\Lambda$ dependence

propriate to B-band counts used by Yoshii & Takahara (1988)]. We can see that low Ω_M, Ω_Λ models with high z_f are most favored.

Although the model in Figure 1 appears to provide a reasonably good fit to the data, it has $\chi^2/\nu >> 1$. Other models, however, which stray away from the low Ω_M, Ω_Λ high z_f region, yield much worse fits, such that the difference in reduced χ^2 with respect to our best model is much greater than 1. This is a good reason to believe that our 'best' model is reasonably close to the 'correct' values, since the paramount difficulty, for all the models is simultaneously fitting the flat portion of the counts at $H < 23$ and the sharp rise at low luminosities. Apparently, only a small change in the luminosity function parameter or the galaxy evolution models is required to provide a good fit, but our simulation strategy was not designed to explore these regions of parameter space, which will be dealt with in our forthcoming study of K-band data.

3 Discussion

Our results are in some weak conflict with the recent evidence for non-zero Λ (e.g., see the review by Wu presented in this volume; but cf. the arguments by Juszkiewicz).

On the other hand, we have to consider what this result tells us about galaxy evolution, assuming that, as for optical counts, our sensitivity to cosmology is diminished by uncertainties in the local luminosity function or by galaxy evolution. The steep rise in infrared number counts has been noted by Saracco et al. (1999) and ascribed to a population of faint dwarfs at moderate redshift. Given that the faint end of the luminosity function in clusters is seen to steepen (e.g., De Propris & Pritchet 1998 and references therein), this is an attractive hypothesis. However, the field K luminosity function recently derived by Loveday (2000) shows no steepening at the faint end.

Our assumption of pure passive evolution may be questioned: on the other hand, there is considerable evidence that field E/S0 galaxies have formed at high redshift and are evolving passively, with little age differences between cluster and field samples (e.g., Bernardi et al. 1998 - see discussion in De Propris & Lineweaver 2000).

It is possible that the large number of faint galaxies seen in our data represents a population of mergers at high redshift. In this case, our objects would be good candidates for the elusive population of high redshift proto-ellipticals. Of course, if that were correct, we would expect a lower clustering amplitude for these objects. Brainerd & Smail (1998) claim an approximately constant clustering amplitude for $I < 25$ galaxies which is not consistent with this scenario.

The present status of knowledge, therefore, favors low density cosmologies with values of Ω_Λ lower than the currently popular value ~ 0.7 and high redshift galaxy formation from galaxy number counts in the near infrared. Further investigations will be needed to shed light on this issue.

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