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Deep Near-Infrared Imaging with the Keck Telescope

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1 Introduction

We present first results from a study of faint field galaxies in deep J and K band images from the Keck Telescope in several fields at high galactic latitudes.[1] The total area of the survey is small (~3e-4 deg^2), but reaches depths of K=24 and J=24.5 for the most compact objects. Compared to other surveys[2,3] at comparable depths, we find that the K band differential counts neither flatten nor steepen beyond K=22, but continue to rise with a slope of log(A) near 0.3. Based on new, empirical models of galaxy counts, we find the *slope* of the faint end of the K band counts is not sensitive to q_0. Our galaxy count analysis is only the first step in probing the galaxy distribution at high redshift.

Deep near-infrared images offer a special regime for the study of distant galaxies for a number of reasons, not the least of which is the fact that κ-corrections are uniform and negative to z~3. Depths achievable in a few hours on 10m-class telescopes are capable of seeing L* galaxies at redshifts well in excess of 2 (assuming no evolution). Perhaps the most appealing aspect of studying distant galaxies in the near-infrared is that we can make predictions about their appearance (colors, sizes, surface-brightness, shapes) based on our extensive knowledge of the optical properties of local galaxies. In contrast, we know little about the ultra-violet properties of galaxies at low redshift. Hence it is very difficult to model reliably the observed galaxy distributions in deep, *optical* images.

To make strictly empirical models of distant galaxies in the near-infrared, we are required to make but one assumption (aside from a choice of cosmology), namely that there is no evolution. We expect this assumption to be wrong if we probe to sufficient look-back times, but it is still well-defined to measure the *difference* between predicted and observed distributions. A difference, if found, will likely have a non-unique interpretation, while the difference itself is an enduring measurement. In this spirit, we introduce an empirical model based on a relatively local galaxy survey[4,5] that we will use in future studies of our deep near-infrared images.

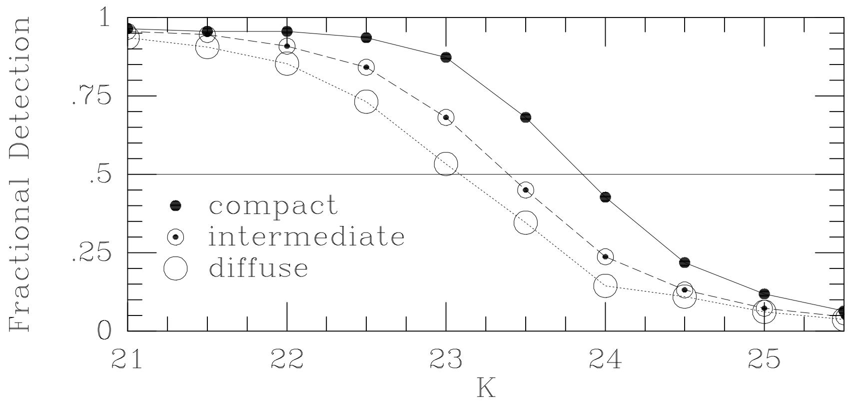

Fig. 1. Detection completeness as a function of image size for our deepest K band image (17,500 sec, 0.55 arcsec FWHM seeing) using FOCAS with detection parameters discussed in [1].

2 Survey limits: Completeness and Image Size

Before discussing galaxy counts, we first emphasize that detection limits in imaging surveys depend critically on both source magnitude and size (i.e. size and surface-brightness). While this may be known in principle, the magnitude of the effect is important to quantify for the particular application of counting sources in deep near-infrared images taken in exquisite seeing. We have performed extensive Monte Carlo simulations using real object images spanning the observed range of galaxy sizes, inserted back into our images at random locations. The fraction of detections as a function of image size and simulated apparent magnitude are shown in fig. 1. Image classes "compact", "intermediate" and "diffuse", as defined by *non*-isophotal sizes, roughly divide the sample of all objects detected to K=23 into thirds. Note there is nearly a one magnitude range in the 50% detection limit for the different image classes, where the completeness function is steepest. Without knowing *a priori* the distribution of galaxy sizes as a function of magnitude, adopting any single completeness function to correct the observed counts would invariably produce a bias near the detection limit.

3 K Band Galaxy Counts

In fig. 2, we have plotted a compilation of galaxy counts from 10<K<23 as well as several models. For our own data[1], corrections for completeness and reliability have been done separately as a function of image size, and the corrected counts then summed. Our photometry is based on aperture magnitudes, corrected to total also as a function of image size. All other data is presented as published except we have applied aperture corrections to the data of Djorgovski *et al.* [3] to make their photometry consistent with our own and other surveys.

At any given magnitude, there is considerable range ($\sim$ a factor of 2) in *normalization* between surveys, but the *slopes* are comparable except at the

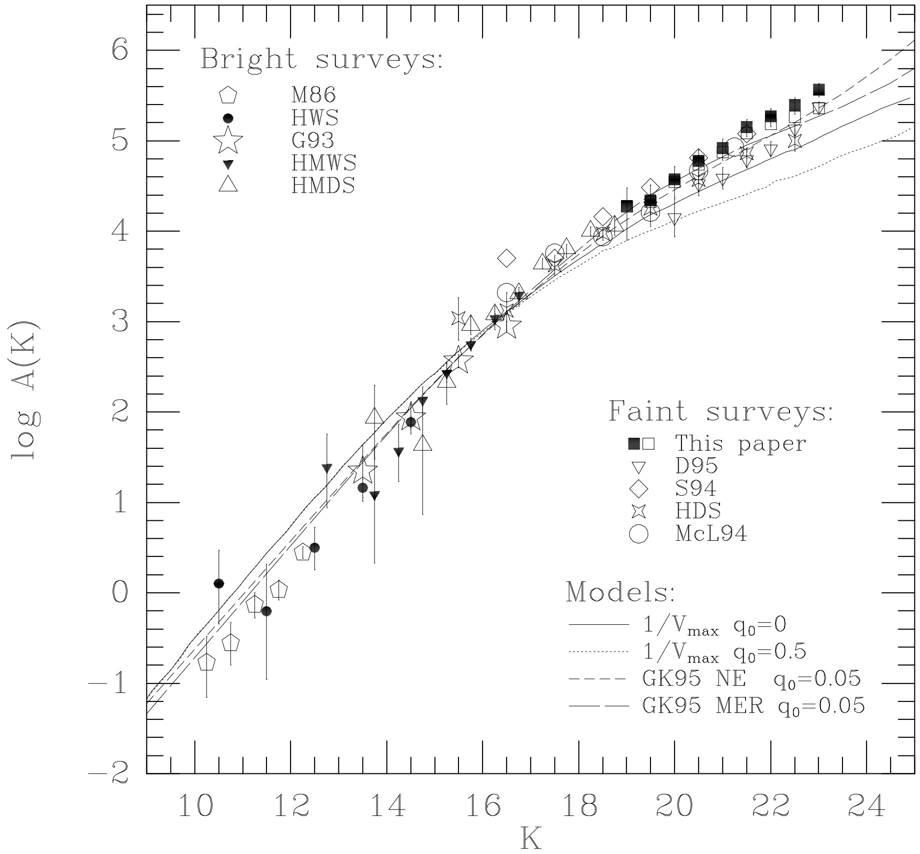

Fig. 2. K Band differential galaxy counts (number mag^{-1} degree^{-2}) from discrete-source surveys. Bright surveys: M86 (Mob), G93 (Glz), HWS, HMWS, and HMDS adopted from [6] and references therein. Faint surveys: McL94 [7], HDS [2] and [6], S94 [8], D95 [3]. Boxes represent our counts [1]; open boxes correspond to our counts prior to corrections for completeness. Models: GK95 [9] NE (no evolution), and MER (mild evolution with reddening), and 1/V$_{max}$ models (see text and [1]).

faintest magnitudes. The 'scatter' may be due to the confluence of two effects: Small numbers of objects at the bright magnitudes, and small field sizes (field-to-field fluctuations) at faint magnitudes. Over the last 1.5 magnitudes of our survey, there is roughly a 50% difference in the counts between our two fields, although the *slopes* are the same. The normalization of our counts at the bright end is in close agreement to McLeod *et al.* [7]; both surveys include fields within 20 arcminutes of each other in SA 57. Had we not applied aperture corrections to Djorgovski *et al.'s* counts, our slope would be in agreement with theirs; both surveys find steeper slopes at the faintest magnitudes than found previously[2].

By design, the models of Gronwall & Koo[9] fit the data to K=22.5 prior to Keck observations[1,3,8], and are a bench-mark for comparison. The 1/V$_{max}$ models[1] underpredict the observed Keck counts and slope for K>20, but yield close to the same slope as the other models *even for q_0=0.5.* The 1/V_{max} models are strictly empirical, based on a real data set[4,5], which is scaled, object by object, by the relative accessible volumes in the input survey and the output simulation. Because the input survey has U through K band photometry, κ-corrections in the K band are determined directly for each simulated object z$\sim$7 (not exceeded at these depths). The input sample, however, contains only L>0.0006L* galaxies in the K band because it is a finite, magnitude-limited sample (roughly B<20.5). Lower luminosity galaxies are expected to be present in significant numbers by $K\sim$20, but the precise contribution depends on the currently unknown faint-end of the K band luminosity function. Inclusion of lower-luminosity galaxies in the 1/V_{max} models (e.g. from larger, deeper local surveys), will only raise and steepen the predicted counts. Therefore the amount of evolution needed to fit the counts may be quite mild, particularly in an open universe. Similar conclusions have been reached using independent no-evolution models.[3,9]

Unlike other no-evolution models[2,3,6], for q_0=0.5 our 1/V_{max} model predicts the counts do *not* role over around K=22, but continue to rise beyond K=25. This reflects a steeper faint-end slope of the K band luminosity function than previously observed, as we will present elsewhere. As a result, the counts at faint magnitudes are increasingly dominated by low-L galaxies at relatively low redshifts. This in turn makes the *slope* of the faint end of the K band counts insensitive to q_0 as well as the cosmological constant.

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