Application of CNOC2 Calibrated Photometric Redshifts to a 6 Square Degree BVRI Survey

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**Abstract.** Using the NOAO Mosaic camera, we have carried out a 6 deg\(^2\) BVRI\(_e\) imaging survey in and around fields of the CNOC2 Redshift Survey, in order to obtain a well-calibrated photometric-redshift sample of some 40000 \(R_e < 21.5\) galaxies. We present some first results on photometric redshift calibration and luminosity function measurement, using a subset of 2000 \(R_e < 21.5\) CNOC2 galaxies with both spectroscopic redshifts and preliminary Mosaic survey photometry. Specifically, we will demonstrate the viability of using our photometric-redshift sample to constrain LF evolution parameters.

1. Introduction and Survey Details

A number of recent spectroscopic redshift surveys have begun to characterize the evolution of galaxies at intermediate redshifts \(z \sim 0.2 – 1\), finding at a fundamental level differences in the character of the evolution of the luminosity function (LF) and luminosity density for different galaxy populations, in particular the contrast between bluer, later-type, star-forming galaxies vs. redder, earlier-type, more quiescent objects (e.g., Lilly et al. 1995; Ellis et al. 1996; Heyl et al. 1997; Cowie et al. 1999; Lin et al. 1999). Yet, though the qualitative picture seems to be in place, there are still some unresolved quantitative discrepancies among surveys, even with respect to a basic and simple statistic like the LF, and even with survey samples now containing thousands of galaxies at these redshifts (e.g., see discussion in Lin et al. 1999). Moreover, even for the largest surveys, strong quantitative constraints on the LF evolution for different galaxy populations are still somewhat elusive (Lin et al. 1999).

At least for the latter issue, obtaining even larger samples would be one means to significantly improve upon the constraints, but obtaining spectroscopic

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redshifts for this purpose would be observationally quite expensive. Acquiring photometric redshifts would be a much quicker alternative, particularly when combined with the recent advent of large, wide-field mosaic CCD cameras, and the use of an already existing large database of spectroscopic redshifts for calibration. That database, in particular, is available to us in the form of the CNOC2 Field Galaxy Redshift Survey, the largest such sample at $0.1 < z < 0.7$, containing 5000 galaxy redshifts at $R_c < 21.5$ (the nominal survey completeness limit; see Yee et al. 1998 and Carlberg et al. 1998 for the CNOC2 survey details). CNOC2 consists of 4 widely separated sky “patches,” and already includes $UBVR_cI_c$ photometry, but only over the survey’s comparatively small total area of about 1.5 deg$^2$. We thus planned a new wide-field imaging survey in order to obtain an order-of-magnitude larger CNOC2-calibrated photometric-redshift sample, which would allow us to significantly improve upon LF evolution constraints.

Our $BVR_cI_c$ survey data were obtained during 15-18 September 1998, using the KPNO 0.9m and the NOAO Mosaic camera, with a 1 deg$^2$ field of view. We imaged 6 deg$^2$, to 5σ point source depths of approximately $B = 24.5$, $V = 24.3$, $R = 24$, and $I = 23$. There is full coverage of 2 CNOC2 patches (0223+00 and 2148–06), including some 2500 $R_c < 21.5$ galaxies with spectroscopic redshifts that can be used for photo-z calibration. Our full survey contains an estimated 40000 $R_c < 21.5$ galaxies. Data reduction is still in progress, and here we will only present results using a subset of 2000 $R_c < 21.5$ CNOC2 calibration galaxies which have preliminary Mosaic survey photometry. Full details of the data reduction will be described at a later date.

2. Photometric Redshifts and LF Evolution

Photometric redshifts are derived using the polynomial fitting method of Connolly et al. (1995), using up to quadratic terms in the $BVR_cI_c$ magnitudes. In order to reduce systematic biases caused by photometric errors, we have first split our sample into several bins in apparent magnitude ($R_c$) and color, and then used independent polynomial fits for each bin. For our 2000 CNOC2 calibrators, Figure 1 shows the difference between photometric and spectroscopic redshift, plotted against spectroscopic $z$, apparent magnitude $R_c$, and SED type. The photometric redshift scatter behaves as expected, with increased scatter for fainter apparent magnitudes and for bluer, later-type galaxies, which have weaker spectral breaks. For the full sample the rms redshift dispersion is $\sigma_z = 0.07$, increasing from 0.04 for $R_c < 19.5$ to 0.08 for $20.5 < R_c < 21.5$. Overall, there are no strong systematic biases (perhaps the most conspicuous is a positive offset at $z \sim 0.1$), and in future work we will characterize the photometric redshift error distribution in detail, as well as explore use of other photo-z fitting methods (note our current method involves a somewhat arbitrary choice of binning), in particular a modified SED fitting technique being developed by one of us (M. Sawicki).

We next compare the luminosity function fits derived from photometric vs. spectroscopic redshifts. We use the same simple evolving Schechter function parameterization used by Lin et al. (1999) for the CNOC2 spectroscopic-redshift
Figure 1. Difference between photometric and spectroscopic redshift, plotted vs. spectroscopic redshift, apparent $R_c$ magnitude, and CWW SED type, for 2000 $R_c < 21.5$ CNOC2 galaxies with preliminary Mosaic survey photometry. The rms photometric redshift dispersion is $\sigma_z = 0.07$, and the horizontal lines show $\pm 2\sigma_z$ and $\pm 3\sigma_z$.

sample, specifically

$$
M^*(z) = M^*(0) - Qz
$$

$$
\alpha(z) = \alpha(0)
$$

$$
\rho(z) = \rho(0)10^{0.4Pz},
$$

(27)

where $M^*$ is the characteristic magnitude, $\alpha$ is the faint-end slope, $\rho$ is the galaxy number density, and $P$ and $Q$ are parameters which characterize number density evolution and luminosity evolution, respectively. We derive separate LF fits for 3 galaxy categories: “early,” “intermediate,” and “late,” as determined by fits of the $BVR_cI_c$ magnitudes to the SEDs of Coleman, Wu, & Weedman (1980; CWW). Please see Lin et al. (1999) for a full description of the details. Note for the photometric-redshift sample fits, we of course explicitly re-derive galaxy absolute magnitudes and SED types using the photometric $z$ in place of the spectroscopic $z$. We plot our LF fit comparison, split by galaxy type and
redshift, in Figure 2, where the photo-$z$ results are shown by points, and the spectroscopic-$z$ results by lines. Qualitatively there is a good match between the photometric- and spectroscopic-redshift results, and the LF changes seen in the spectroscopic-redshift fits, particularly for early- and late-type galaxies (relative to the dotted-line fiducials), are preserved in the photometric-redshift fits. Quantitatively (and not unexpectedly) we find small biases in the best-fit values of the LF parameters, for example $\Delta P \approx -0.5$ and $\Delta Q \approx -0.5$ (photometric minus spectroscopic fit), as well as shallower faint-end slopes for the photometric-$z$ fits, though these effects are somewhat hard to see in Figure 2. We caution that these biases are likely specific to the particular photo-$z$ fitting scheme we have adopted here, and may be different if another fitting method is used. Nonetheless, our large CNOC2 calibration sample permits us to determine and correct for any such biases accurately, and in future analysis we will also

Figure 2. $B$-band luminosity functions for the same CNOC2 sample as in Figure 1. The results are split by galaxy-type and redshift. Photo-$z$ results are shown by points with $1\sigma$ errors. Spectroscopic-$z$ results are shown by solid curves, and the dashed curves show fit extrapolations below the CNOC2 survey flux limit. The dotted curves are fiducial fits reproduced from the lowest redshift bins in the top row.
use LF fitting methods explicitly designed to account for photometric-redshift errors (e.g., SubbaRao et al. 1996).

Finally, in Figure 3 we show the improved LF constraints we anticipate using the 40000 $R_c < 21.5$ photometric redshifts from our full 6 deg$^2$ of data. We do this by comparing the expected $2\sigma$ $P$-$Q$ error contours for the full Mosaic survey against those derived using the first 2 analyzed patches of the CNOC2 spectroscopic sample (note the $P$-$Q$ results plotted here are from an older version of the analysis and differ slightly from those in Lin et al. 1999). The projected Mosaic survey results are derived using actual CNOC2 photometric redshifts for the same galaxies, but overcounting each galaxy to simulate the much larger Mosaic survey sample size. We also correct for the small $P$ and $Q$ biases using simple offsets. One sees from Figure 3 that the spectroscopic sample results show that the character of the LF evolution depends on galaxy type: the early and intermediate galaxy LFs primarily change in luminosity or $M^*$, while the
late-type galaxy LF changes mostly in number density. Nonetheless, we are
hampered from drawing stronger conclusions because the error contours for the
spectroscopic sample results are large, though eventually using the full 4-patch
CNOCS sample will help improve the constraints. On the other hand, using the
order-of-magnitude larger Mosaic sample, we should be able to determine \( P, Q \),
and the other LF parameters much more precisely. As we have seen above, our
first results are encouraging, showing that we can derive accurate photometric
redshifts and LF parameters and that we can readily quantify and control sys-
tematic effects. Work is now progressing on finishing basic data reduction and
on improving our photo-z and LF fitting techniques, and ultimately we plan to
derive from the full Mosaic survey a much improved quantitative picture of LF
evolution for different galaxy populations at intermediate redshifts \( z < 1 \).

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