Status Report: The Oxford Deep WFC Imaging Survey

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Review of Scientific Objectives

Our four primary survey objectives are:

1. To investigate in detail the evolution of the angular clustering of galaxies at faint magnitudes as a function of colour.

2. To search for QSOs in the redshift range $5 < z < 6$ at a depth which samples the QSO luminosity function at least as deep as L_*.

3. To generate a catalogue of ~ 1000 rich clusters of galaxies to $z \sim 1$, which will provide a tracer of large-scale structure over this redshift range that is independent of the complex physics of galaxy formation.

4. To investigate the clustering properties of the population of $U-$ and $B-$ band Lyman-break dropout galaxies at redshifts $\gtrsim 3$ and 4 and compare these with our findings from the $z < 1$ cluster survey.

Of these, 1, 3, and 4 are best addressed by a survey which covers large contiguous areas of sky such that the zero points of individual CCD frames can be adjusted to determine a self-consistent solution.

For 2, we investigated the improvement that could be achieved by adding short Z-band exposures (1×600s) for each field. This improvement is illustrated in Figure 2. The $(V-I)$,$(I-Z)$ colour plot provides a clear discriminator between low-mass stars and high redshift QSOs. We therefore decided to add Z coverage for each field to our survey. These exposures are taken during twilight at the beginning and end of each night, and so this improvement is obtained with little or no impact on the rest of the survey. The usefulness of the Z-band data is significantly enhanced by the choice of i instead of I, as discussed in the next section.

Observations to Date

The INT observations to date cover two dark weeks in August 1998 and February 1999. We therefore chose to target three fields which met our criteria of low Galactic extinction and optimum observability for the dates in question ($E(B-V)$ values from ref [5]):

α(2000)	δ(2000)	l	b	$E(B-V)$	Coverage (WFC fields)
00 17 30	+34 30 00	115	-27	0.054	11 $(BVRZ)$
09 09 45	+40 50 00	181	+42	0.017	7 $(BVRiZ)$
16 39 30	+45 24 00	70	+41	0.014	5 $(BVRiZ)$ 1(U)

After careful consideration of the filter characteristics we decided to use the SDSS i filter in favour of RGO I due to the lack of a red cut-off in the latter. This meant that no i data were observed during the August 1998. Exposure times have been fixed at 3×900s (B), 3×1000s

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(V), 3×1200s (R), 3×1100s (i), 600s (Z) and 6×1200s (U). Observing conditions have been either clear (i.e. photometric or very light, sparse cloud), or clouded out, and seeing conditions have been in the range $0.9''$–$1.3''$, with the exception of one night of poor ($> 2''$) seeing in February 1999. Multiple exposures in the same band have been offset by $5''$ to provide sampling of each object by more than one pixel. In each region we have observed fields in a diagonal grid pattern with the camera rotated by 180° for alternate strips of fields to give complete sky coverage and appropriate overlaps between adjacent fields.

At present we have obtained little U-band data. In August 1998 there was a significant amount of dust, which meant that it made little sense to observe deep U-band data, even though the seeing conditions were fairly good. In February 1999 we took U-band data on a single test field, but discovered a problem due to an air bubble in the filter.

These data represent a total of ~ 6.6 deg^2, or about one quarter of our original goal of 10 deg^2 per field. Of the 14 nights we have been allocated to date we have lost at least 4 full nights due to combinations of weather and instrument problems. The forthcoming upgrade of the CCD controllers would effectively give us an additional night of integration time for each observing week. We therefore estimate that to complete a survey of these three regions in $BVRiZ$ will require a further three weeks of clear observing. Some grey time would be acceptable for the i-band part of the survey, particularly for the $0^{\rm h}$ field where we have no i data to date. To complete two regions each of 5 deg^2 in U will require a further 4 dark nights override in good seeing conditions. Allowing for some weather lossage, a reasonable timescale for the completion of the survey is therefore 4 further weeks of observations.

Data Reduction

All the data taken to date have been reduced, including a significant improvement on the removal of fringes from the Z-band data over the pipeline output which will be communicated back to CASU over the next few weeks. Final combined images with photometric and astrometric calibration information are being archived on CDROM. We find detection limits consistent with the numbers in our original proposal. Image detection and photometry is being performed using the Sextractor package, and we aim to produce astrometry based on the USNO catalogue (this week we have received preliminary astrometric calibrations from CASU which are adequate for the purposes of field-field matching) which should be adequate for multi-object spectroscopic follow up with 8m telescopes. We are in the process of optimising the field overlap matching technique (e.g. ref [1]) for these data.

Follow-up Observations and Analyses

In October 1998 we began a pilot follow-up study of a small area of the $0^{\rm h}$ field in K-band using the ONIS 1024×512InSb camera on the MDM 1.3m telescope at Kitt Peak. The primary aim of this study was to extend the cluster catalogue beyond $z \sim 1$. Coverage of parts of the $9^{\rm h}$ and $16^{\rm h}$ fields was obtained in April 1999, and we have just been awarded a substantial allocation of time (26 nights in 99B) on the 1.3m telescope to continue this part of the survey, with the aim of extending our K-band coverage to as much of our WFC survey area as possible. We have detected large numbers of objects (~ 100 deg^{-2}) with $R - K \gtrsim 6$ which can be classified as EROs[2] (Figure 2). We plan to add CIRSI J and H band data from the INT in the near future, and make these and our K-band catalogues publicly available along with the WFC data. Our existing K-band data are all reduced and calibrated. A preliminary catalogue of EROs exists for the $0^{\rm h}$ field.

VLA D-array observations of our three WFC survey regions are in progress, and 30 hours of A-array observations are scheduled for the autumn. We aim to complement these with B/C-array data to reach a confusion-free survey (5-σ limits at 100μJy) over the full survey region. The expected surface density of sources in this region is ~ 1000 deg^{-2}.

These surveys target two populations which are presently very poorly separated, and whose properties and cosmic evolutions are poorly known. The first of these (dominant at

the faintest flux levels) are star-forming spiral galaxies. The second (dominant at the brighter levels) are weak AGNs in elliptical galaxies. Our comprehensive multi-colour optical/near-IR dataset will be essential in decoupling these populations since dust-reddening in the spirals means that crude (one or two colour) separations are unreliable. We expect to separate the populations and to obtain (using mainly photometric methods) their redshift distributions. This will allow the first determination of their relative cosmic evolutions at these epochs, and provide the strongest constraints yet on the collapse redshift of the elliptical population. We will search for correlations between the radio population and the galaxies, clusters and special objects like the EROs in our survey.

A proposal for a detailed study of a sample of these objects has been submitted to UKIRT for 1999B, and has already been awarded 30 hours of VLA time in A-array. We are also planning Keck NIRSPEC observations of the population of ($R-I$ excess) Faint Red Outlier Galaxies (FROGs)[3], which may be related to the dusty spiral class of EROs. We have also submitted a proposal for a medium deep XMM survey to cover a total of 3 deg^2 within the survey with K-band coverage to study clusters and distant AGN.

The optical data are of comparable depth to the recent surveys[5] for Lyman-break galaxies at $z \sim 3$ and 4. We expect to detect the same populations as found by those authors. It is known that the galaxies are strongly clustered[6], and the large contiguous coverage of our survey (much larger than the 0.3 deg^2 of ref [5]) will enable us to make a definitive measurement of the correlation length for comparison with large-scale numerical simulations.

The 9-hr field was centred on new deep images at 74 MHz and 330 MHz observed with the VLA in A-array, aimed at finding the highest redshift radio galaxies which are characterized by very steep spectra. Observations at 74 MHz select $z = 5$ objects at 440 MHz. Previous low-frequency surveys (151 MHz) sample distant objects very nearly in the GHz regime which are depleted by synchrotron and inverse-Compton losses. This is part of an on-going Oxford project to quantify both the co-moving space density and birth-function of powerful classical double radio-sources. Cross-matching our 74 MHz catalogue with our multi-colour optical/near-IR data is ideal for identifying the bulk of the radio sources, thus making spectroscopic follow-up more efficient. A further 24 hours of VLA A-array time has been awarded to obtain further fields at these low frequencies.

Resources:

We currently have a substantial share of the processing power of five 400MHz alpha workstations and a number of high performance PCs, with $\sim$ 100Gb of disk space currently dedicated to this project. Web space is available for the final catalogues to be made easily available.

GD is acting as overall coordinator for this project. JB, KB, GD and JK are working together on the data reduction, image detection/classification, catalogue creation and astrometry. EO, GD, LAM and GW are undertaking the K-band survey and associated ERO follow-up. SR and KB are responsible for the radio observations and reductions. GD and JB are working on the large-scale clustering, and JK is coordinating the high-redshift QSO search. LM and ML are working on sample predictions for Lyman-break galaxies (Figure 3). HT, GD, EO and WS are investigating optimal detection filters for galaxy clusters from the WFC and K-band data.

References:

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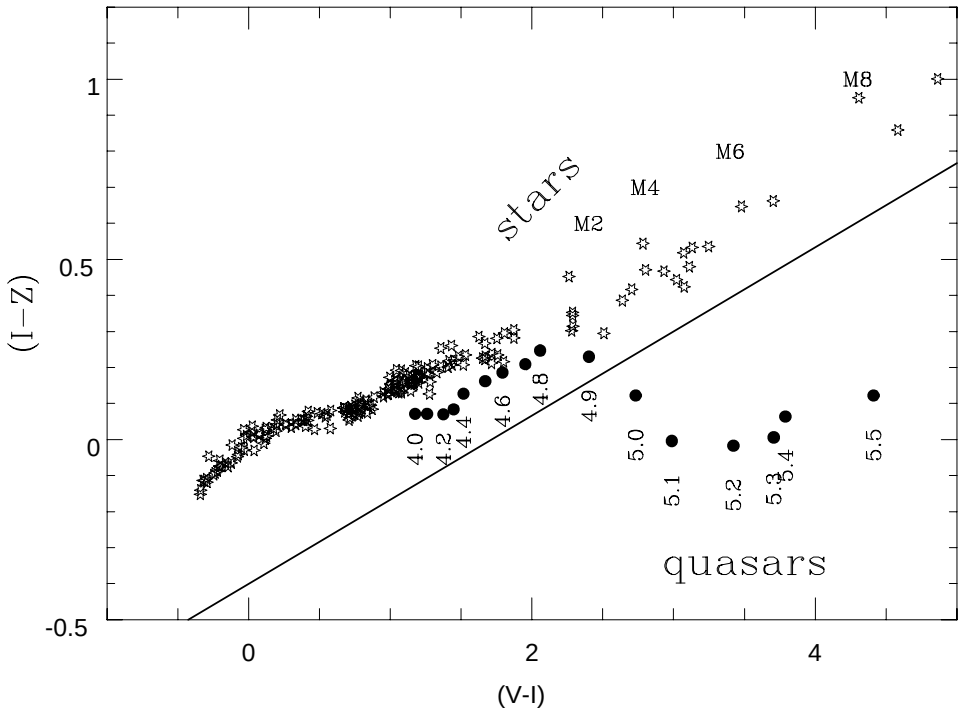

Figure 1: Predicted loci of M-stars and high redshift QSOs in the $(V-I)$,$(I-Z)$ colour plane. A comparison of this figure with Figure 2 of our original proposal illustrates the substantial discriminating power provided by the Z-band data.

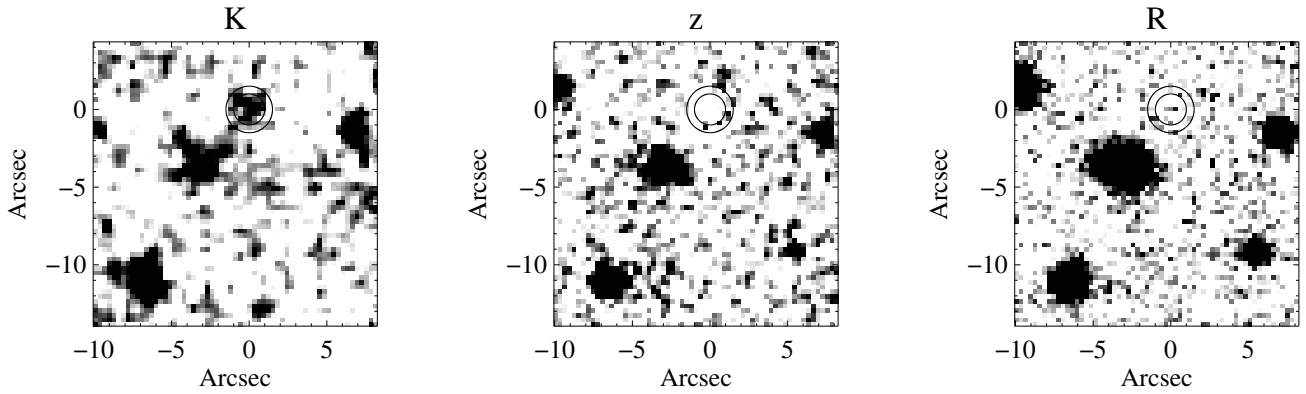

Figure 2: One of the many ERO candidates in our $0^{\rm h}$ field. At $K = 18.5$, it is indeed extremely red at $R-K > 7$ (5σ). We aim to obtain spectra and high resolution JHK imaging with UKIRT to determine the morphological characteristics of a large sample of these objects.

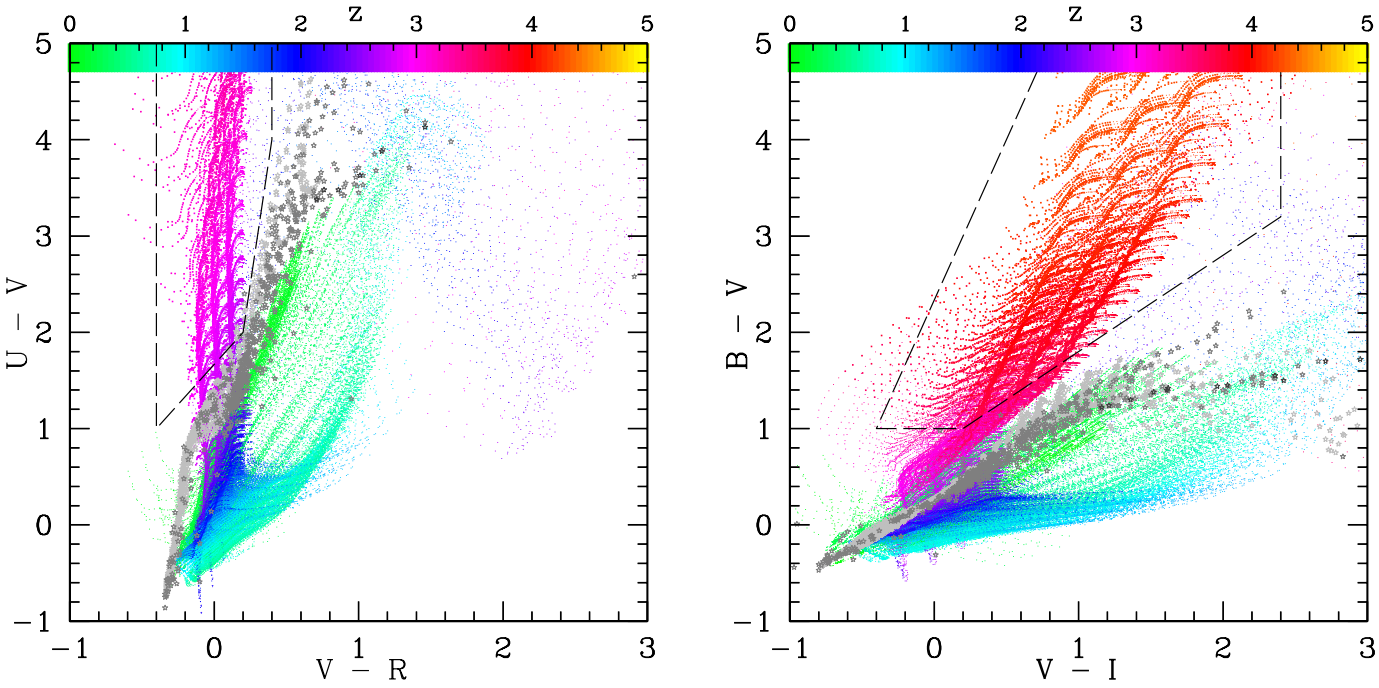

Figure 3: Illustration of the parameters of Lyman-break galaxies in multi-colour space based on models of Fioc & Rocca-Volmerange (1997 A&A 326, 950). The grey symbols in each plot represent Galactic stars.