The SDSS-2dF Luminous Red Galaxy Survey and Prospects for FMOS

A. C. EDGE and SDSS-2dF Survey Consortium
Institute for Computational Cosmology, University of Durham

Abstract
The SDSS-2dF Luminous Red Galaxy (LRG) Survey will ultimately contain 10,000 galaxies between 0.45$< z <$0.70 selected photometrically from SDSS imaging over 200 $\Box^\circ$. The aims of this survey are to determine the clustering of these massive galaxies and constrain their photometric and spectral evolution. We have so far obtained $>$3,000 galaxies in the relevant redshift range from 30 nights of AAT time and we have at least 38 more nights to come in the next 3 semesters. The results from this survey illustrate that the combination of UKIDSS-DXS imaging and Subaru-FMOS spectroscopy can extend this concept to redshifts of 1$< z <$2.

1.1 Introduction

With the release of the first WMAP results, we now know the geometry of the Universe to better than 10% accuracy. This knowledge will be the foundation for a greater understanding of the physics of galaxy formation and evolution, as we are no longer uncertain about the overall age, geometry and energy–density of the Universe. A key component of this greater understanding will be the construction of high precision surveys of galaxies that span a wide range of redshift and possess a well–understood selection function. Surveys of massive galaxies satisfy these criteria for two reasons: *1)* They lack any recent star-formation, implying they have evolved little since $z \sim 1$; *2)* The most massive galaxies at high redshift are, *in most cases*, the progenitors of the most massive galaxies at low redshift. At present, we have only begun to test these assumptions at the low redshift (with SDSS and 2dFGRS) and new surveys are required to extend these tests to higher redshifts.

1.2 The SDSS-2dF LRG Survey

With the end of the 2dFGRS, it was clear that there was scope for more, but slightly more modest, surveys using the AAT 2dF. The depth of both the 2dFGRS and SDSS surveys limits the maximum redshift of passive galaxies to around 0.3–0.4. The most obvious approach is to target fainter galaxies to study more distant galaxies. In order to ensure that the majority of the targets are more distant some photometric selection is required (2dFGRS and the standard SDSS surveys are both magnitude limited). The nature of the strong 4000A break in 'passive', non-star forming galaxies results in a clear photometric signature which can be used to select more distant galaxies through to their red colours. This has been done as part of the SDSS survey itself using their g, r, i photometry but is limited in magnitude by the length of the standard survey spectroscopic exposure of 45mins.

In 2002, we applied for AAT 2dF time to target SDSS galaxies with systematically redder colours than those selected by SDSS and a magnitude fainter ($i < 19.8$ as opposed to $i < 18.5$) with a moderate (600V) grating to adequately resolve the spectral features in the galaxies. The surface density of LRGs is around 150 per 2dF field and much less than the total number of available fibres (400). However, the double spectrograph design of the 2dF allows us to target LRGs at moderate resolution *and* QSOs (also selected from SDSS) at low resolution in each spectrograph. This combination of galaxy and quasar target lists was very successful in the 2dFGRS and 2QZ surveys and is proving itself again now.

Our 2002 proposal was successful and we have so far had 24 AAT nights from PATT and the AAT Director with a further 8 PATT nights and 36 ATAC nights to come.

The results have been excellent with over 3,000 LRG redshifts now obtained in 27 fields and observed in a total of 30 nights (of which 15 were clear).

1.3 Future AAOmega Surveys

In late 2005 the AAT 2dF system will be given a new spectrograph that will feature a dramatically improved, bench-mounted spectrograph. This upgraded spectrograph is called AAOmega and will allow nod-and-shuffle sky subtraction for all fibres and have much better spectral resolution, throughtput and stability.

The AAOmega upgrade offers the chance to make reliable sky-subtraction in the optical OH bandheads with a fibre system and hence allow absorption line features such as Ca H+K to be detected in the $0.8 < z < 1.2$ range. The sensitivity improvements should allow the same absolute magnitude range as the SDSS-2dF LRG survey to be covered over this redshift range. The selection of LRG candidates will be dependent on a combination of optical and near-infrared data (SDSS deep strips and UKIDSS Large Area Survey probably). It is the selection of candidates that will limit the speed to these surveys. The choice of fainter candidates, and hence more targets per 2dF field, will make it necessary to use all 400 fibres for LRGs but, in all probability, the "design philosophy" of obtaining galaxy and quasar samples in the same area (2dFGRS/2QZ, SDSS-2dF LRG/QSO) will continue but with the addition of other shallow, large area multi-wavelength samples (e.g. *GALEX*, GMRT/ATAC radio, *Spitzer* detections).

1.4 Future FMOS Surveys

Moving to higher redshift still requires a more radical change than a spectrograph upgrade. The combination of a larger telescope and near-infrared spectral coverage means that FMOS can target galaxies of the same absolute magnitude range as sampled in the SDSS-2dF LRG survey at $1.2 < z < 2.0$. However, to ensure that these galaxies are selected in the same rest-frame optical bands moderately deep optical and NIR imaging are required. The NIR imaging will be available in the next year from the UKIDSS Deep eXtragalactic Survey (DXS) which will cover 35 $\square^\circ$ to J=23 and K=21 in four fields spread over RA (see www.ukidss.org for details). Combining this J and K data with optical V, R and/or I data will allow galaxies at $z > 1$ to be selected by their 4000A break.

Being able to combine LRGs with other deeper multi-wavelength selected targets (such as *ASTRO-F, Spitzer, XMM-Newton*, VLA, SCUBA and SCUBA-2) in the DXS "standard survey areas" will greatly enhance the value of any FMOS survey. Being able to link the clustering of 'passive' and 'active' galaxies in the same survey volume will allow limits to be set on their triggering and ubiquity.

1.5 Science Aims

To avoid being charged with putting "the cart before the horse" by focussing on the technical and logistical aspects of any new AAOmega and FMOS surveys in uniformly selecting luminous galaxies from $z = 0$ to 2, I should take some time to outline why the effort and expense of performing these surveys is justified in terms of the science return.

First, the stellar population of a galaxy can be used as a 'clock' as to when the bulk of its stars were formed. Making a consistent selection of galaxies of the same optical luminosity over a large redshift range (and hence look-back time) can be used to make a global estimate for the star-formation history of galaxies independent of the more direct methods of determining current star-formation (dust continuum, Hα, [OII], UV continuum, radio) which all have some inherent uncertainties. The vast majority of our current estimates of the star formation rate as a function of redshift (the Lilly/Madau plot) are based on star formation in the most massive galaxies. Studying the stellar population of massive galaxies to the peak or plateau of this star formation rate ($z \approx 2$) is vital.

Also, the UV properties of old stellar populations can de used as a 'delayed trigger' as there is a strong UV increase 11–13 Gyr after the bulk of the stars are formed. The UV survey of the high galactic latitute sky by GALEX will provide important new data on this in the very near future for both individual galaxies and statistical ensembles of galaxies.

Second, the clustering of massive galaxies can be used to investigate their bias with respect to the underlying mass distribution. The magnitude and evolution of this bias are strongly dependent on cosmological parameters but also on the subtleties of galaxy formation. Using semi-analytical models (e.g. Benson et al. 2003, MNRAS 343, 679) it is possible to predict the strength of the clustering of LRGs using a variety of recipes for the formation of galaxies. The differences between models are most significant at the highest redshifts ($z > 1$) so being able to determine the cluster of LRGs at these redshifts would be of considerable importance. The most accurate way of doing this is to measure >5,000 LRG redshifts at high redshift.

Third, the implication of the Magorrian relation is that the most massive galaxies should contain the most massive black holes. It is clear that the vast majority of these black holes are not significantly accreting mass at the present day but establishing if this is true at redshifts of greater than one would be of considerable interest. This can be done in a number of ways. First from the strength of the [OIII] line, which falls in the FMOS spectral range for $0.8 < z < 2.6$, and is sensitive to ionisation of gas close to the centre of the galaxy and is relatively rare in SDSS LRGs. Second, from radio emission from non-thermal jets (mostly low luminosity FR-I radio sources) that is available for all of the SDSS-2dF LRG survey from *First* (>1mJy at 1.4GHz) and in the near future from GMRT (>3mJy at 230MHz, Blundell and Rawlings, priv. comm.). For deeper FMOS surveys there are likely to be high sensitivity VLA observations in at least some of the fields which could match the radio powers sampled by *First* at lower redshifts. Finally, dust continuum in the FIR or sub-mm from *Spitzer* or SCUBA-2, which will cover many of the possible FMOS survey areas, will select obscured AGN and star formation. Each of these tracers of AGN activity has advantages and disadvantages so a combination of all of them would be an interesting exercise to test the reliability of one compared to the others.

Fourth, the ability to draw galaxies with unusual or very typical properties from a larger sample for further study is one of the lasting legacies of any large survey. An LRG survey, where by definition the brightest galaxies at any particular redshift are identified, is especially powerful in this respect. We have already obtained deeper high quality Gemini-S spectroscopy for a sample of 17 z =0.45-0.66 SDSS-2dF LRGs to begin an investigation of the Fundamental Plane of elliptical galaxies. The remarkable scaling of size, stellar velocity dispersion and optical surface brightness can be used as another indirect test of galaxy formation models. There are a number of other follow-on projects (e.g. post-starburst, radio-detected or possibly lensing LRGs) that the SDSS-2dF LRG consortium are keen to pursue. Using a similar, more distant sample of LRGs will undoubtedly be put to very good use!

1.6 Conclusions

The importance of careful photometric selection in any spectroscopic survey can never be underestimated. The uniformity and depth of Sloan has allowed us to make a reliable redshift selection of $0.45 < z < 0.7$ elliptical galaxies. At higher redshifts, the standard SDSS imaging survey depth is too shallow and dependent on the unavoidable seeing variations along and between SDSS strips to ensure uniformity of selection. The deeper SDSS survey strips in the Southern Galactic Cap are likely to be the best regions to target for future, deeper AAOmega surveys but FMOS surveys will require even deeper optical data (i.e. SuprimeCam observations and future VST surveys). The advent of large NIR imaging surveys with UKIDSS and, in the not so distant future, Vista will be key to the success of FMOS so it is important that the coordination of imaging (optical and NIR) should be central to the overall FMOS Survey plan.

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