Anglo-Australian Time Assignment Committee

Semester:
AATAC Reference:
Date Stamp:

Anglo–Australian Observatory, PO Box 296 Epping NSW 1710
Contact: Helen Woods, hmw@aao.gov.au, +61 (02) 9372 4812

1. **Names and Institutions of Applicants** **Possible Observer?**

M.J. Drinkwater, (UQ), T. Shanks, (Durham), B.J. Boyle (ATNF), R.D. Cannon (AAO), M.M. Colless (AAO), W.J. Couch (UNSW), S.M. Croom (AAO), G.B. Dalton (Oxford), G.P. Efstathiou (Cambridge), A. Hopkins (Sydney), O. Lahav (UCL), S.J. Maddox (Nottingham), R.C. Nichol (Portsmouth), J.A. Peacock (Edinburgh), K. Pimbblet (UQ), I. Roseboom (UQ), E.M. Sadler (Sydney), R.G. Sharp (AAO)

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Are the observations required for the completion of a student's thesis? no

Name of Student(s): Name of Supervisor(s):

2. **Project Title: The AAΩ Luminous Red Galaxy Redshift Survey**

Summary of Scientific Objectives:

We propose to make a redshift survey of 450000 Luminous Red Galaxies (LRGs) out to $z < 0.8$. The project is unique and will produce a decisive lead for AAO in several fundamental physics areas. A prime aim is to measure the equation of state of the dark energy at $z \approx 0.7$ via the position of the 'baryon wiggles' in the LRG power spectrum; the nature of dark energy represents perhaps the biggest current issue in physics. The form of the power spectrum will further lead to new constraints on the neutrino masses. The survey will also put new constraints on the dynamical evolution of galaxy clustering and the cosmic evolution of rich galaxy clusters and radio galaxies. The AAΩ LRG survey will be primarily based on new imaging photometry from the ESO VST ATLAS, specifically designed to complement AAOmega spectroscopic surveys. This combination of these state-of-the-art, wide-field spectroscopic and imaging survey facilities will provide the new benchmark for cosmological surveys, well in advance of the era of wide-field spectroscopy on 8-10 metre class telescopes.

3. **AAT Focal station, Instrument and Detector**

Focal station:	Instrument(s):	Detector(s):	Gratings/Filters:
f/3.3	AAOmega	EEV	385R, 580V

All users must also fill out the AAT Instrument Request Form on the WWW. If you have any special instrumentation requirements please describe them in that form *and* in the technical case of this application.

4. **AAT Scheduling Information**

Proposers must ensure that all AAT time requests include a 33% allowance for weather.

	Dark:	Grey:	Bright:	
Number of nights requested *this semester*	5	2		
Minimum useful allocation *this semester*	3	1		
Additional nights required to complete project in future	180	60		Long term status requested: x

Preferred dates:	Feb
Impossible dates: *(NB: astronomical reasons will have scheduling priority)*	May-July Wrong RAs + pilot results needed for 06B AATAC meeting.
Special scheduling constraints *(e.g. clashes with other applications, lunar position or quarter, daytime observing, requirements for multiple instruments)*	

5. **Observations requested in Service?** yes: ☐ no: ☒ maybe: ☐

Under a special arranangement with PPARC, UK AAOmega MOS proposals will be performed in service as standard. Otherwise, justify service mode in proposal text.

Will real-time analysis by a Service Observer, or real-time interaction of proposers with a Service Observer be required? yes: ☐ no: ☒ maybe: ☐

If so a member of the proposing team may be required to attend observing at the AAT.

6. **Observing Requirements**	
Average signal-to-noise ratio required:	SNR=4.4 per 1.6Å pixel with 385R grating
Any seeing limitations:	< 2.5 arcsec
Required spectral resolution (if applicable):	5.4Å with 385R grating

7. **Support Astronomer Required** no: [ ] first night only: [x] (Night assistant & technical backup provided at all times.)

8. **List of Principal Targets** *(add pages if more than twelve targets need to be listed)*
RA: 09h40-15h30, Dec: 0 deg, Mag: $i_{AB} < 20.5$, Colour: $r' - i' > 1.2$, Exp. Time: 3600s, Priority: 1

9. **Other applications for this (and related) projects in this semester**

Telescope/satellite	Title of programme

10. **Report on previous applications for time for this (and related) projects**
Show all requests for AAT time, as well as time on other ATAC/PATT telescopes, in the past 4 semesters.

Ref.No.(if known)	**Allocation**	**% useful**	**Comments (Data OK?, publications? etc.)**

11. **Complete if the observations are associated with a current PPARC grant** *(UK only)*

Grant title:
Grant number: **Principal investigator:**

12. **Non-standard Travel & Subsistence** *(UK only. Justify T&S for more than one person, and/or other unusual costs)*

13. **Scientific & Technical Justification:** Attach a case (including technical information, figures and references) of no more than 3 pages, with font no smaller than 11pt. An extended 5 page case may be submitted for long-term programs, providing permission has been requested and granted from the AATAC Secretary (hmw@aao.gov.au).

1 Introduction

We propose to use AAOmega to make a redshift survey of up to 450000 Luminous Red Galaxies (LRGs) in a 4500deg^2 area of sky out to $z < 0.8$. The spectroscopic survey will be based on the VST ATLAS, a new CCD imaging survey purpose-designed to complement AAOmega. The prime aim is to make a precise measurement of the LRG power spectrum in order to determine the scale of the acoustic oscillations and hence measure the equation of state of the dark energy and constrain its evolution with redshift. This feature has been recently detected in a survey of ≈ 45000 SDSS LRGs with average redshift $z \approx 0.35$ by Eisenstein et al (2005, astro-ph/0501171). Baryon wiggles are seen in the power spectrum at large $\approx 100\mathrm{h}^{-1}$Mpc scales well into the linear regime where they have the crucial advantage that their scale is immune to evolutionary effects with z. We shall also be exploiting the high bias and strong clustering of LRGs, in similar fashion to Eisenstein et al. Our aim here is to make a measurement of the acoustic scale with $\approx 3\times$ better precision ($< 2\%$) at $z \approx 0.7$. This will give an error of $< 10\%$ in the dark energy equation of state parameter, w, at approximately twice the redshift ($z \approx 0.7$) of the SDSS result. The survey will have many other uses including such fundamental aims as measuring the neutrino mass, probing the dynamical evolution of galaxies and tracking the spatial distribution of galaxy clusters throughout the survey's $\approx 3\mathrm{h}^{-3}\mathrm{Gpc}^3$ volume.

1.1 Dark Energy Equation of State

The current standard model of cosmology suggests that the Universe has zero spatial curvature and $\Omega_m = 0.3$. This implies that there is a cosmological constant with vacuum energy density, $\Omega_\Lambda = 0.7$. The vacuum energy density associated with the cosmological constant is small compared to the energy density in radiation just after inflation ends, at just one part in $\approx 10^{100}$. This has prompted the suggestion that the vacuum energy density may change with time (quintessence) and this 'dark energy' density, ρ, may evolve, perhaps via a coupling to a rolling scalar field, ϕ, as for inflation. The dark energy density could then be in much bigger ratio to the radiation energy density at early times, and thus look more natural. This evolving dark energy would then have an equation of state, $P = w\rho$, and this equation of state may also evolve with time. Our ultimate aim here is to constrain the form of the dark energy equation of state by making the most accurate measurement yet, taking into account both systematic and statistical uncertainties, of the parameter, w.

The acoustic oscillations of the baryon-radiation mixture produce wiggles in the matter power spectrum that can act as a standard measuring rod and allow us to probe the dark energy equation of state. Essentially, if we know Ω_m and h from other observations such as the CMB power spectrum, then the comoving scales of the acoustic peaks can be calculated and used as a standard rod. The main advantage of the LRGs for pursuing baryon wiggles is their known high bias with respect to other galaxies. Fig. 1 shows that the power spectrum of the SDSS DR2 LRGs has a much higher amplitude than that of 2dFGRS galaxies (Cole et al 2005, MNRAS, 362, 505), despite having a higher average redshift.

Our first aim will be to establish the magnitude of w, assumed to be a constant. The simulations of Blake & Glazebrook (2003, ApJ, 594, 665) suggest that measuring the acoustic peak positions to $\approx 2\%$ accuracy at $z \approx 1$ will allow w to be measured to $\approx 10\%$ accuracy. Their Fig. 3 suggests that if their survey volume is as big as that proposed here, then we shall need 10^6 galaxies with bias, $b = 1$, to reduce the shot-noise enough to make a 2% measurement of peak positions possible. With $b \approx 2$ as for the LRGs, this number will reduce to ≈ 250000, although systematic effects may increase this number.

These broad conclusions are supported by three estimates of the accuracies of fitting the peaks in a survey of 450000 $0.4 < z < 0.8$ LRGs. The first comes from the previous DR2 LRG $\xi(s)$ of Eisenstein et al (2005, astro-ph/0501171) which used 45000 LRG redshifts at $z \approx 0.35$ (see Fig. 2). Simply scaling by the $\approx 10\times$ increased volume of the new survey gives a peak position error consistent with the above calculation. We have also applied a similar scaling process to the approximate (window function uncorrected) $P(k)$ determined from ≈ 10000 2SLAQ LRGs and again scaling the errors according to the increased volume, we find similar error estimates. Finally, we have estimated the error using a mock catalogue containing 450000 galaxies with similar bias to LRGs from the Hubble Volume simulation of the Virgo Consortium. Fig. 3 shows the model power spectrum normalised by a baryon-free reference spectrum with data points with (FKP) errors taken from the mock catalogue. The baryon wiggles are detected at high S/N and we have again checked these are at a level consistent with obtaining $\pm 2\%$

accuracy in the peak positions. Fig. 4 compares the mock correlation function, $\xi(s)$, to the result of Eisenstein et al. Here the jack-knife errors are approximately $3\times$ smaller than those of Eisenstein et al., again as expected.

1.2 The advantages of a survey to $z = 0.8$

If the dark energy density is a constant with redshift, then our proposed average redshift of $z \approx 0.7$ is ideal to measure w because the dependence in both the radial and angular directions of the peak positions maximise at $z > 0.5$ (see Blake & Glazebrook 2003, Fig. 5). This means that the accuracy of the test for w obtainable from this survey will be improved over a similar survey at SDSS LRG survey redshift ($z \approx 0.35$) by about 30%. The higher survey redshift makes it also easier to access an order-of-magnitude bigger survey volume than for the SDSS LRGs within a limited area of sky. Furthermore, the combination of the $z \approx 0.35$ SDSS survey and the new survey at twice the redshift, $z \approx 0.7$, will lead to possible new constraints on the z dependence of w. However, we view the prime aims of the current proposal to make a definitive detection of the existence of the wiggles and to make a definitive measurement of w. The survey will also lay a sound foundation for future high redshift galaxy surveys such as those from Subaru/Gemini WFMOS to measure the evolution of w.

Of course, there are still many issues in terms of the underlying cosmological model. The 'zeroth' order aim of this project will therefore be to check the parameters of the standard cosmological model. The wiggles are a generic prediction in many models and so their position can be used to make a basic, standard rod, check of the SNIa results for Ω_Λ in a way which is less prone to systematic errors such as dust and evolution than the SNIa Hubble diagram. Working out to $z \approx 0.8$ rather than at $z \approx 0.35$ also maximises our chances of being able to *reject* the cosmological constant, since the higher the redshift, the more we are able to discriminate between the standard model and e.g. an Einstein-de Sitter model.

1.3 Advantage over photometric redshift surveys

There are also possibilities to detect the baryon wiggles via photometric redshift surveys. This may be possible within the VST ATLAS but also using surveys such as KIDS and DES. The aim here is to get redshift errors down to $\pm 100h^{-1}$Mpc so that the correlation function features on these scales are still resolvable. However, even the best medium-band surveys such as COMBO-17 struggle to obtain such a low error and the more bands the more time the survey will take. Also for deep surveys, the accuracy of photo-z's requires increased exposure times to maintain photometric accuracy. The photo-z route allows no information on the peak position to be determined from the radial direction, only from the angular directions. Since the photo-z survey can therefore be regarded as a semi-projected clustering analysis, it is vital to keep the sample selection across the full imaging area homogeneous to a few percent to allow the small clustering contrasts to be detected. So far, there is no survey which has demonstrated both the required photo-z accuracy while simultaneously maintaining homogeneity of selection over several thousands of square degrees. Some authors have suggested this may be a competitive route with $> 10000\text{deg}^2$ sky area (Blake & Bridle, 2004, astro-ph/0411713). Detecting weak wiggle features essentially via semi-projected correlation functions will be challenging, particularly in terms of maintaining photometric consistency to a few percent in all bands over significant sky areas.

1.4 Comparison with other approaches

The observational case for the LRG programme is compelling, since much of the observational uncertainty has been removed by the success of the 2SLAQ project. By working in an approximately volume limited survey out to $z < 0.8$ we gain the benefit of a significant increase in redshift over SDSS and 2SLAQ, while the 4000Å break will continue to be detected in a relatively clean sky region ($\lambda < 7200$Å.) The proposed survey will always also have a significant numerical advantage over the SDSS LRG survey, even though the latter may ultimately include 70000 LRGs. The AAΩ LRG survey will therefore maximise the advantage from AAOmega and complement future surveys from UKIDSS/Subaru FMOS which will take LRG surveys to significantly higher redshifts ($z \approx 2$). However, such surveys cannot compete in terms of galaxy numbers with the field-of-view of the 2dF coupled to AAOmega.

The AAΩ LRG survey has clear advantages over using the clustering of lower-luminosity galaxies as an approach to baryon wiggles. The LRGs can fill the AAOmega fibres with the brightest objects and most clustered objects in the Universe. Therefore as a route to both the vital ingredients required for the statistical accuracy required to measure weak clustering features, namely large volumes and high S/N clustering, the LRGs may have no rival. The exposure time required to reach LRGs at $z \approx 0.8$ is also close to the minimum fibre reconfiguration time of AAOmega. Any other survey using unbiased galaxies would require $4\times$ as many galaxies and exposure times. The LRG selection is also tried and tested to $z = 0.8$ (for the brightest LRGs) in the 2SLAQ survey, using the previous 2dF spectrographs.

In terms of the AAOmega Emission Line Galaxy (ELG) survey approach to baryon wiggles, it will be interesting to see via the requested 06A pilot programmes how this compares to the LRG approach. Although emission line galaxies might be expected to have low luminosity and hence low bias, by selecting Lyman-break candidates of high enough luminosity to be detected by AAOmega, then a high bias sample may be available. Indeed, there may be some overlap with the LRG sample since the 2SLAQ LRGs may start to show emission at high redshifts. Certainly, we intend to have full interaction with the ELG collaboration to decide on the optimum approach to measuring wiggles with AAOmega in advance of the 06B AATAC meeting.

2 Other aims of the survey

The LRG survey will produce many other fundamental results including:

- **New limits on the neutrino mass** - the detailed form of the LRG power spectrum will also provide powerful upper limits on neutrino masses. As the spectrum becomes more precise, detailed information even on the mass of each neutrino species will start to be a possibility. Massive neutrinos may well contribute to the matter density of the Universe. Even if the effect of light neutrinos on the evolution of cosmic structure is small, the upper limits derived from large-scale structure could help significantly to constrain the absolute scale of the neutrino masses. It is also important to know the sum of neutrino masses as it is degenerate with the values of other cosmological parameters, e.g. the amplitude of fluctuations σ_8 and the primordial spectral index, n_s. The suppression of the power spectrum due to neutrinos is $dP(k)/P(k) \approx -8\Omega_\nu/\Omega_m$. Current results from cosmology (galaxy redshift surveys, the CMB and Lyman-α clouds) set an upper limit on the sum of the neutrino masses of ~ 1 eV, somewhat depending on the data sets used in the analyses and assumed priors on cosmological parameters (for review see Elgaroy & Lahav, NJP, 7, 61, 2005; astro-ph/0412075). The next step is to bring down the upper limits to the sub-eV level. In this way Cosmology via the AAΩ LRG survey could resolve the mass scale of neutrinos.

- **Cosmology via z-space distortions** - the AAΩ LRG survey will be used to constrain the dynamical evolution of galaxy clustering via z-space distortions and cosmological parameters via the Alcock-Pacynzki effect. At higher redshifts, z-space distortions have been been applied in LBG redshift surveys at $z \approx 3$ (eg da Angela et al, 2005, MNRAS, 361, 879) but also in QSO surveys such as 2QZ (Hoyle et al 2002, MNRAS 336, 168). The QSO surveys suffer from shot-noise because of their low surface density and the LBG surveys from low galaxy numbers. Nevertheless, robust methods to break degeneracies between dynamical infall and cosmology have been developed in these analyses which could prove powerful when applied in the proposed $z < 0.8$ LRG survey. So far the aim has been to estimate Ω_m, but if an accurate value of Ω_m became known from the CMB then these same techniques could be used to estimate other cosmological parameters including w. Given that most of these redshift distortion results would arise at $\approx 10\mathrm{h}^{-1}$ Mpc then these results would give an almost independent handle on w from the baryon wiggles. The information on $\beta = \Omega^{0.6}/b$ could also be used to track the dynamical and bias evolution of galaxy clustering.

- **LRG cluster catalogue** - over the huge volume of $\approx 3\mathrm{h}^{-3}\mathrm{Gpc}^3$, the LRG survey will trace the location of ≈ 20000 rich galaxy clusters out to z≈0.8. By determining precisely the evolution of the largest bound structures and provide new constraints on all the cosmological parameters, including the neutrino mass. Although the VST ATLAS is specified to have 60s exposures in all bands, it may be supplemented by having $10\times$ longer r band exposures; this may be offered as part of a project to detect the ISW effect (PI L. Infante) using part of the Chilean 10% of VST time. In this case, it will be possible to search for the faint members of clusters whose brightest members are LRGs. Many of these clusters could then be followed-up in X-rays by XMM-Newton and Chandra.

- **A survey of early-type radio galaxies** - about 3% (ie ≈ 14000) of the LRGs are expected to be detected as radio sources in existing (SUMSS/First/NVSS) and future (ATCA with wide bandwidth receivers) radio surveys. We will be able to test whether these moderately powerful AGN undergo the same strong evolution as QSOs and also compare their clustering properties. Combining wide-field redshift surveys with large-area radio continuum surveys provides a powerful way to measure the radio LF of galaxies to unprecedented accuracy. This has already been done using the 2dFGRS (Sadler et al 2002, MNRAS 329, 227) out to $z = 0.3$ and 2SLAQ to $z = 0.5$. The AAΩ LRG survey will extend these studies to $z = 0.8$, allowing a direct comparison of the evolution of radio galaxies and QSOs over the same range in cosmic time.

- **Spectral evolution of galaxies** - the large, uniform spectral database of LRGs that the AAΩ LRG survey will create also offers an unprecedented resource for studying galaxy evolution through their stellar populations. These results are accessible via the 'stacking' of low S/N spectra as a function of LRG redshift, luminosity and colour class. In 2SLAQ this technique has revealed a striking increase with redshift in the fraction of LRGs showing post-starburst stellar features (e.g. Hδ). The improved spectral coverage and resolution that AAOmega offers will allow searches for other spectral features (e.g. MgII at 2800Å rest and Mgb at 5198Å) and the NUV continuum which is sensitive to the presence of intermediate age stars. In particular, the co-added spectra will provide important constraints on the mean age of the stellar populations in the target LRGs as a function of look-back time, environment and absolute magnitude.

3 AAΩ LRG Survey Parameters

At 1hr per field and observing 300 LRGs per field, the LRG redshift rate would be ≈ 2500 LRGs per night, so 450000 LRGs (+100000 QSOs or 50000 ASTRO-F galaxies) could be observed in 3 years with 60 clear nights per year (240 nights in total including 33% weather allowance). Even if AAOmega performs below specification by $2\times$, then a survey of 300000 LRGs could be done in 4 years.

In the default LRG survey at sky density 95deg^{-2}, ≈ 70 fibres will remain available for other projects. By reducing LRG survey speed by 20%, this number could rise to 130. This would allow a redshift survey of 100000 $g < 22$, $z < 3$ QSOs to be done alongside the LRG project. The main aim here would be to better define the luminosity and clustering evolution of QSOs but there would also be significant advantage in using the spectroscopically confirmed QSOs in studies of foreground group masses via QSO lensing magnification. There are other possibilities for companion surveys including ASTRO-F galaxies, and intrinsically fainter red galaxies at the 2SLAQ redshift limit.

4 Case for a pilot study in 06A

We are here requesting time to make a pilot study for the AAΩ LRG project in semester 06A. The first reason for this is that the project is large (180 clear nights) and the instrument is as yet untested, so we have to demonstrate feasibility, particularly in terms of survey speed. Secondly, we are aware that there is also the AUS survey which includes a high redshift LRG survey and also the emission line galaxy (ELG) wiggles survey which proposes to detect the baryon wiggles via the clustering of emission-line galaxies out to $z \approx 1$. The pilot may allow a joint pilot to be allocated for both the AUS and LRG wiggles project and also to decide whether the LRG or emission line route is more promising for detecting baryon wiggles. In terms of this proposal, the main aims are to check that the estimated exposure time of 1 hour is reasonable and also to check the completeness and degree of contamination of the $z < 0.8$ LRG sample. An increasing fraction of the 2SLAQ LRG survey may also show OII 3727Å emission at high redshift; therefore we shall also test whether the LRG selection might be extended to $z \approx 1$ using these LRG emission line features.

5 Observational Strategy

Here we are requesting a pilot programme in 06A to test the feasibility of the above programme. The first ingredients are the imaging surveys - primarily the the new VST ATLAS, supplemented in the first year of the AAΩ LRG survey by publicly available SDSS data in the Equatorial regions.

5.1 VST ATLAS

The initial aim of the VST ATLAS is to survey 4500 deg^2 of the Southern Sky at high galactic latitudes to comparable depths to the SDSS in the North. The VST ATLAS will be the first step towards a panoramic digital survey of the Southern Sky in the optical bands. The ATLAS will complement the VISTA IR ATLAS proposed in the South. Although the prime science driver is to determine the dark energy equation of state via the AAΩ LRG z survey proposed here, other uses include the colour selection of QSO candidates out to $z \approx 7$. Further potential dark energy probes exist including LRG z-space distortion, the Integrated Sachs-Wolfe Effect and the dependence of QSO lensing on redshift. Finally, the VST ATLAS+AAOmega will feed VLT with rare galaxy and QSO targets for high resolution spectroscopy, constituting a new and uniquely powerful tool for survey cosmology.

The VST ATLAS will form a panoramic survey of the Southern sky to the approximate depth of the SDSS imaging survey in the North (e.g. Abazajian et al, 2004, AJ, 128, 502). Initially, we are proposing to make a *ugriz* survey of area 4500 deg^2 during the first three years of VST. This ATLAS survey could be the first step towards a complete S. Hemisphere digital imaging and spectroscopic sky survey - a 'Southern Sloan'. The 4500 deg^2 area of the initial ATLAS comprises 2 areas:- Southern strip (3000deg^2): RA: 21h30-04h00, Dec: $-50 < \delta < -15$, Northern strip (1500deg^2): RA: 10h00-15h50, Dec: $-20 < \delta < -2.5$.

The status of the ATLAS is that it has been accepted by the ESO Public Surveys Panel as one of three Core Programmes for ESO VST. The VST is expected to be assembled at the end of 2005 and the surveys will start in mid-2006. However, there need be no delay in commencing the AAΩ LRG survey, since there are about 1500deg^2 of publicly available SDSS imaging data in the Equatorial regions. Therefore, as the VST ATLAS ramps up, the SDSS data can be used for the first year of the AAΩ LRG survey. It is relatively easy for VST+OmegaCam to feed AAOmega at the required rate, since it can produce about 300deg^2 of imaging per night in one band.

5.2 Required Survey Size

We have used mock catalogues generated from the Hubble Volume N-body simulations to demonstrate the feasibility of achieving the science aims. The mock has an area of 4500deg^2 and contains ≈ 450000 galaxies and is designed to be volume limited out to $z < 0.8$ with an average redshift of $z \approx 0.7$. The galaxies were selected to be biased to have constant amplitude of clustering (comoving) consistent with the behaviour of observed LRGs ($r_0 \approx 11\mathrm{h}^{-1}$Mpc). The correlation function obtained from this mock LRG catalogue is compared to that from the 45000 $z \approx 0.35$ SDSS LRGs of Eisenstein et al (2005) in Fig. 4. As expected, the jack-knife error bars are $3\times$ smaller in proportion to the square root of the sample size/volume, as well as giving measurements of the 100h^{-1}Mpc 'wiggle' at significantly higher redshift. The errors from the power-spectrum analysis of the mock catalogue is also shown in Fig. 3. The wiggles are clearly visible at this S/N and the accuracy of determining their location has been checked to be good to $\pm 2\%$ as expected, although it should be noted that the effect of the actual survey window function may be slightly more complicated in the Northern and Southern strips than for the contiguous 4500deg^2 area simulated here.

5.3 Required Survey Depth

To increase our average redshift from the current $z \approx 0.55$ for the 2SLAQ survey to the proposed $z \approx 0.7$ to achieve an increase in the LRG sky density from 53deg^{-2} to 95deg^{-2} will require increasing the 2SLAQ magnitude limit from $i_{AB} = 19.8$ to $i_{AB} = 20.5$. SDSS has a 90% completeness detection limit of $i_{AB} = 21.3$ and with 30% higher throughput and 16% better seeing, the VST ATLAS should reach $i_{AB} = 21.6$. Therefore the main issue is whether the single-scan SDSS imaging can select $z < 0.8$ LRGs as faint as $i_{AB} < 20.5$. We have therefore checked the accuracy of the SDSS photometry versus the very deep photometry of the WHDF. The results (see Fig. 5) show that the *gri* photometry remains well-defined to the required limits for $i_{AB} < 20.5$. (Ignore the zeropoint offsets which are due to plotting SDSS AB mags versus WHDF Vega mags.) For example, in the i band there is virtually no increase in the photometric error between the new limit marked by the dashed line and the 2SLAQ limit, 0.7mag brighter. The same is true in the g and r bands.

5.4 LRG Selection

For LRGs to the 2SLAQ limit of $i_{AB} < 19.8$ and with $z \approx 0.55 \pm 0.15$, the same $g-r:r-i$ cuts will be made as successfully used previously, yielding a galaxy sky density of 53deg^{-2}. We then wish to increase this density to 95deg^{-2} using predominantly higher redshift $0.6 < z < 0.8$ galaxies. We have therefore tested our LRG selection techniques by using the early-type galaxies selected out to $z \approx 1$ in the ≈ 0.3deg^2 S11 field of the COMBO-17 survey (Wolf et al, 2003, A&A, 401, 73, Bell et al, 2004, ApJ 698, 752). This field overlaps the SDSS DR4 survey area. The SDSS $g-r:r-i$ colours for the COMBO-17 early-type sequence galaxies with $19.8 < i_{AB} < 20.5$ is shown in Fig. 6. The 2SLAQ $g-r:r-i$ cuts have already been applied and these show a similar z distribution to the full 2SLAQ LRG dataset (shown as points) as might be expected. The most straightforward way to select predominantly the higher redshift galaxies appears to be to make a further cut with $r-i > 1.2$ in this fainter sample. The fraction of galaxies with $z > 0.6$ then increases to $\approx 75\%$ of the sample from $\approx 25\%$ in 2SLAQ. With this cut the LRG density in the fainter sample would be $\approx 60 \pm 12$deg^{-2} in the S11 field. We have further used the COMBO-17 data to check that the contamination in this fainter sample is only $\approx 30\%$ when objects not included in the COMBO-17 early-types are included as well as the $z < 0.6$ COMBO-17 galaxies. The selection prescription is thus suggested to be to use the 2SLAQ selection cuts in *gri* to the $i_{AB} = 19.8$ limit; then use the additional, $r-i > 1.2$ selection limit to pick up the higher redshift galaxies in the range $19.8 < i_{AB} < 20.5$.

5.5 AAOmega Technical Setup

Since we believe these checks show that is indeed feasible to select $z < 0.8$ LRGs from the single scan SDSS (and VST) data, the feasibility of achieving the factor of ≈ 3 improvement in the baryon wiggle errors ultimately depends on the performance of AAOmega. The (pre-commissioning) AAOmega ETC suggests that for an $i_{AB} < 20.5$, ($i_{Vega} < 20.1$), $z < 0.8$ LRG, a 1hr exposure with the 385R grating and the red camera with $2''$ FWHM images should give a SNR/1.6Å pixel of 4.4 or a SNR/5.4Å resolution element of 8.0. For the 2SLAQ survey, the exposure time was 4hrs at $i_{AB} < 19.8$ or $r_{AB} = 20.3$; in the same 1hr exposure time as proposed here, the previous 2dF ETC gave SNR/2.2Å pixel of 3.6 at $r_{AB} = 20.3$, a factor of $1.5\times$ down even though the effective limit is 0.7mag fainter. With the 385R grating in the red arm, the wavelength coverage is 5600-8800Å which covers the H+K break throughout our whole $0.4 < z < 0.8$ redshift range. In the blue arm of the spectrograph we request the 580V grating to observe in the 3700-5800Å spectral region at 3.5Å resolution and 1Å per pixel. The dichroic at 5700Å will affect the LRG redshift range $0.4 < z < 0.43$ but fortunately the LRGs at these redshifts have the brightest apparent magnitudes and we therefore envisage no serious incompleteness problem.

5.6 Aims of Pilot Study in 06A

The pilot programme will therefore test first if these exposure time estimates are realistic. Second the pilot will test our projected completeness and the average redshift, given the photometric accuracy of the SDSS imaging data. The data taken will also allow the decision between the full $z < 0.8$ survey of 450000 LRGs and the 'extended 2SLAQ' survey of 250000 LRGs. We shall use publicly available SDSS DR4 *gri* imaging data available in the equatorial region (Dec=0deg) between RA: 09h40 -15h30 as the basis for the pilot study.

6 Management Plan

6.1 Collaboration

This collaborative project is envisaged to work in the same manner as the previously successful 2dFGRS and 2QZ surveys. The AAΩ LRG survey has so far obtained strong support from Australian institutes including AAO, ATNF, UNSW, University of Queensland and University of Sydney. It has also received strong support from the UK Universities of Cambridge, Durham, Edinburgh, Imperial College, Nottingham, Oxford, Portsmouth, Queen Mary University of London, Sussex and UCL/MSSL. We are particularly keen to seek further Australian collaborators for the AAΩ LRG project.

6.2 Scientific Management

M.J. Drinkwater is also the Australian PI for the 2SLAQ LRG survey. T. Shanks is also the UK PI for the 2SLAQ QSO survey and was formerly the UK PI of the 2QZ survey. T. Shanks is also the PI of the EU RTN network 'Spectroscopic and Imaging Surveys for Cosmology' (SISCO) and the PI of the ESO VST ATLAS proposal. The project will be managed by frequent meetings of the project management team, consisting of the Australian and UK Co-I's under the chairmanship of the PIs. These meetings will most frequently use telecon and video conferencing formats but also take place in person. The PIs will be responsible for applying for telescope time via AATAC and liaising with the AAT Board.

6.3 Planning of Observations

Responsibility for the planning of the observations will taken by the project management team, working in close cooperation with AAO staff. The VST ATLAS ipeline data reduction and archiving will be the responsibilities of the Cambridge and Edinburgh groups. We shall investigate the efficiencies to be gained by using a tiling algorithm for the AAOmega observations but if these are less than 15% we may choose a simpler observing strategy as employed for the 2SLAQ survey. Our collaboration includes many of the architects of the successful 2dFGRS/2QZ/2SLAQ surveys.

6.4 Observing, Data Reduction, Quality Control

Observing will be the joint responsibility of the all co-I's at both UK and Australian institutes. PATT-linked grants will fund observing trips at the UK Universities. With 2250deg^2 in the Northern strip and 3750deg^2 in the SGP, we intend observing to be a year-round activity as for the 2dFGRS/2QZ survey. Basic 2dFDR pipeline reduction will be supervised by AAO staff to ensure uniformity with help from Australian and UK observers in attendance at each observing run. Checks of the pipeline data reduction will be made at Durham, Nottingham, Oxford, Queensland, Sydney, UNSW etc.

6.5 Data Release

We intend to release data, via a VO compliant archive, on a yearly basis with the first year's data being released 6 months after the first year's observing has ended. This policy of early data release has worked very successfully in the 2dFGRS/2QZ, SDSS and HDF/UDF projects.

6.6 Data Analysis, Exploitation and Publication

Initial data analysis and exploitation will be carried out by the collaborating universities and institutes. The various science areas will be led by specific institutes to be identified in the project planning phase. Again the style will be similar to that adopted in the 2dFGRS/2QZ project. Further exploitation will be done by external institutes when the data becomes public. Publication of survey results will be in major scientific journals such as *Nature, ApJ, MNRAS* etc.

6.7 Overall Funding Strategy

The funding strategy for the above activities is to apply for grants via the normal routes at each University. In the UK these include PPARC Rolling and Standard grants, EU network grants such as SISCO and its successors, Leverhulme grants etc. In Australia, funds will be sought from similar sources. These sources will address the issues of the PDRA support needed to make a success of this project. We are very aware of the planned decline in UK funding for the AAO over the next few years. If other sources of UK funding cannot be found, then we shall seek to apply for direct PPARC funding for half of the required time per year (30 clear nights). We shall also seek extended stays (1-2 months) for UK PDRAs and Fellows at AAO to support the survey. We also note that the survey will give Australia advance involvement in use of the VST ATLAS imaging data and we may also be able to negotiate joint use of any VLT follow-up time which may arise from the VST ATLAS imaging survey.

7 Project Timeline

We take one possible model for the project which is to survey simultaneously 250-300 LRGs + 70-130 QSOs in each 1hr AAOmega exposure. The QSOs could be substituted by $\approx$ 100 ASTRO-F selected star-forming galaxies in the third year of the survey, depending on the agreed science priorities.

1/2/06-31/7/06 After AAOmega commissioning and tests, our requested pilot programme takes place in semester 06A, preferably in February, March or April, so that the results may be available for the AATAC meeting in June. We are hoping that the pilot for the AUS and ELG wiggles programmes may also be available early so that a joint future strategy for all these proposals may be presented.

1/8/06-31/7/07 LRG redshift survey starts in equatorial regions based on available SDSS single-epoch imaging data. Approximately 750 deg^2 of SDSS imaging is available with $\delta < +5$ deg in the RA: 09h40-16h equatorial region and 750 deg^2 is similarly available in the RA: 21h30-04h region. Hence 30 clear AAT nights to observe a total of 150000 LRG redshifts will be requested in each of semesters 06B and 07A.

Meanwhile, VST ATLAS imaging ramps up at ESO VST, with the aim of covering 1500deg^2 in ugriz in $\approx$30 VST nights in the first year after VST commissioning in early 2006. VST ATLAS pipeline data reduction proceeds at CASU, Cambridge followed by archiving at WFAU, Edinburgh. If the VST ATLAS goes slower than expected, the backup plan is to use all available SDSS data at $\delta < +15$, which covers $\approx$ 3000deg^2 of sky and is accessible to AAT. Ultimately VST imaging data from surveys such as the VST KIDS proposal may also become available in the SGP.

1/8/07-31/7/09 The LRG survey continues now based on VST ATLAS imaging data in both Northern Equatorial zone and the SGP. The target areas are RA: 10h00-15h50, Dec: $-20 < \delta < -2.5$deg (1500deg^2) and RA:21h30-04h, Dec: $-50 < \delta < -15$deg (3000deg^2). Hence 30 clear AAT nights to observe a total of 300000 LRG redshifts will also be requested in each of semesters 07B, 08A, 08B and 09A.

VST ATLAS imaging covers another 3000deg^2 in the above areas in 60 VST nights in this 2 year period.

Data reduction and analysis of AAOmega redshifts proceeds leading to the staged data release of 150000, 300000 LRG redshifts at **1/2/08, 1/2/09**. The same data release points would apply for simultaneously observed QSOs, FIR galaxies etc and achieving these data release points would also serve as the project milestones. There would be catalogue and analysis papers plus accompanying press releases plus public outreach at all stages.

1/2/10 Final data release of 450000 LRG redshifts with final catalogue and analysis papers plus accompanying press releases plus further public outreach. End of project.

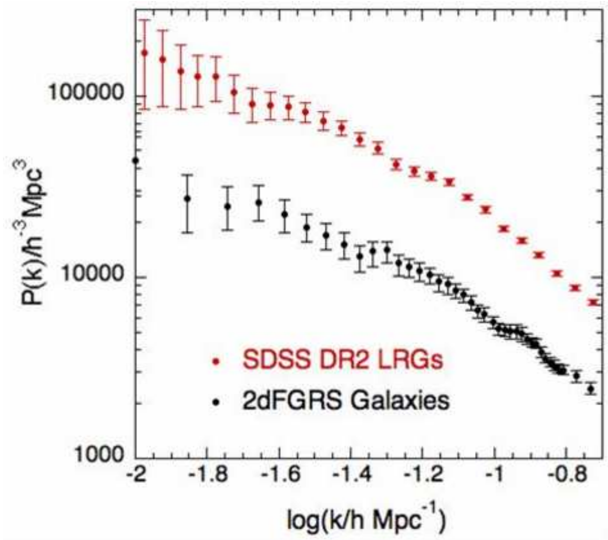

Fig. 1. SDSS DR2 LRG and 2dFGRS power spectra showing the $\approx 4\times$ higher amplitude of the LRGs.

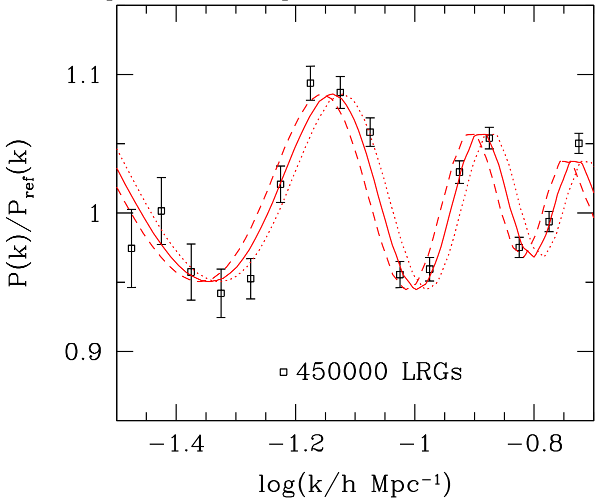

Fig. 3. Normalised P(k) using errors from mock catalogue of 450000 LRGs showing the clear detection of the baryon wiggles. The dashed lines show $\pm 4\%$ (or $\pm 2\sigma$) variation in the peak positions.

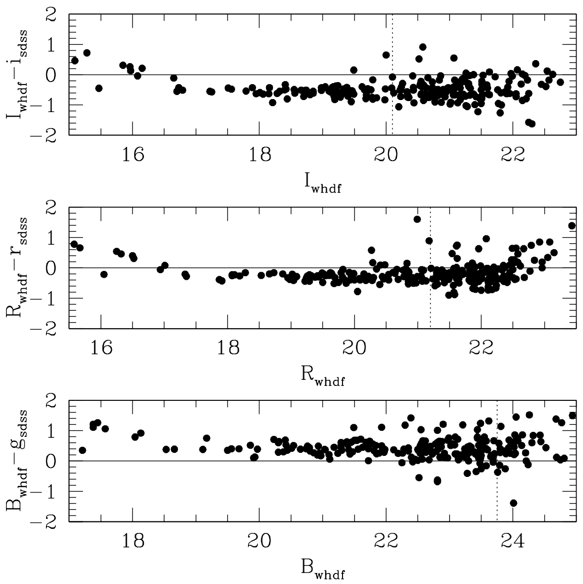

Fig. 5. SDSS gri (AB) photometry vs deep WHDF BRI (Vega) photometry, showing that the photometric errors remain small within the range required to select $z < 0.8$ LRGs (vertical dashed lines).

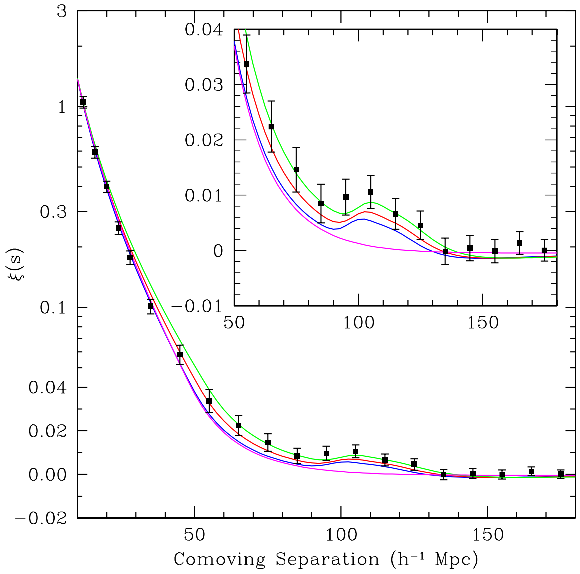

Fig. 2. $\xi(s)$ of 45000 SDSS LRGs at $z \approx 0.35$ from Eisenstein et al. (2005) showing the 'baryon wiggle' detected at $s \approx 100\mathrm{h}^{-1}\mathrm{Mpc}$.

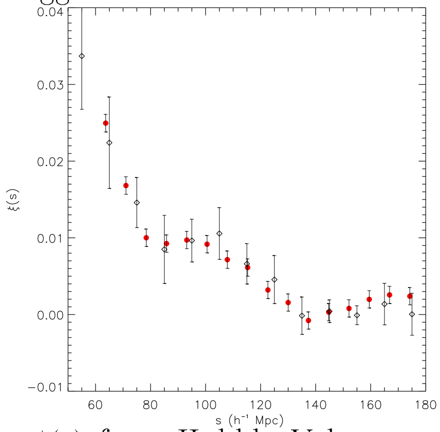

Fig. 4. $\xi(s)$ from Hubble Volume mock catalogue of 450000 LRGs compared to the SDSS LRG result of Eisenstein et al. and showing $3\times$ smaller errors at the $\approx 100\mathrm{h}^{-1}\mathrm{Mpc}$ wiggle scale.

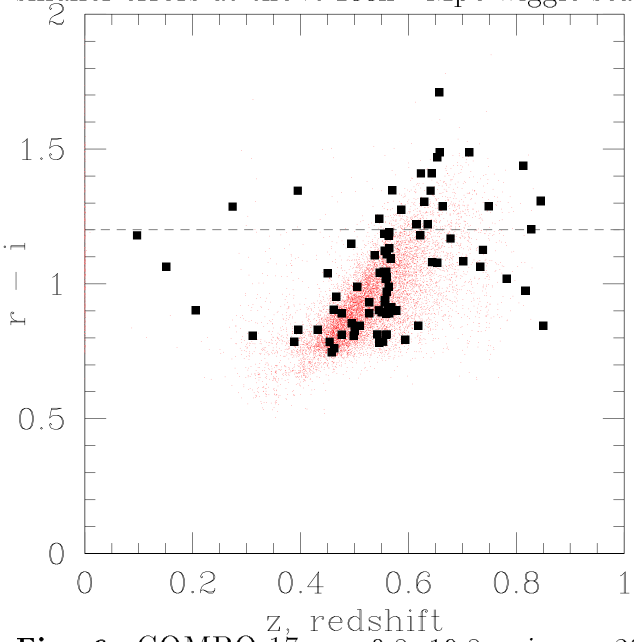

Fig. 6. COMBO-17 $z < 0.8$, $19.8 < i_{AB} < 20.5$ early-types showing $r' - i' > 1.2$ cut to select predominantly (75%) $z > 0.6$ LRGs from SDSS *gri* data (filled squares). 2SLAQ LRGs are also shown (points).