

# 1 Title: The VST ATLAS

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## 1.1 Abstract:(10 lines max)

We propose to make an ATLAS survey with VST. The initial aim is to survey 4500 deg<sup>2</sup> 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 a proposed VISTA IR ATLAS in the South. A prime science driver is to determine the dark energy equation of state by detecting ‘baryon wiggles’ in the power-spectrum of  $\approx 450000$   $z \approx 0.7$  Luminous Red Galaxies (LRGs), selected from the VST ATLAS for spectroscopy via the new AAOmega instrument. 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.

## 2 Description of the survey: (Text: 3 pages, Figures: 2 pages)

### 2.1 Scientific rationale:

The aim here is to make a panoramic ‘ATLAS’ 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<sup>2</sup> 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’.

1. A prime scientific goal for the survey is to measure the dark energy equation of state as a function of redshift. Establishing the nature of the dark energy is perhaps the biggest current question in Physics, far less Astronomy. The suggestion is that the dark energy density may have been different in the past; if the energy density decreased with time, for example, then this would address one of the fine-tuning problems associated with a cosmological constant term, specifically its small present size compared to the energy density in radiation after the inflation epoch. This potential evolution in the equation of state is encoded in the dark energy equation of state  $p = w\rho$  where  $w$  may be a function of  $z$  and  $w = -1$  for the case of the cosmological constant.

The powerful combination of VST and AAT AAOmega (<http://www.ao.gov.au/AAO/local/www/aaomega/>) offers a unique opportunity to make the first determination of the evolution of  $w(z)$  over a significant redshift range. The prime route is via a redshift survey of Luminous Red Galaxies (LRGs) based on VST imaging data. The method is based on obtaining precise measurements of the LRG clustering power spectrum or correlation function to detect the ‘baryon wiggles’ caused by acoustic oscillation of scales below the baryon Jeans’ scale in the pre-recombination Universe. These features can be used as ‘standard rods’ to measure how the angular diameter distance,  $d_A$ , varies with  $z$ . The  $z$  dependence of  $d_A$  can then be used to constrain  $w(z)$ . Other routes such as the SNIa Hubble Diagram using proposed instruments such as SNAP have the disadvantage that

SNIa are susceptible to luminosity evolution with redshift. Baryon wiggles are seen in the power spectrum at large  $\approx 100h^{-1}\text{Mpc}$  scales well into the linear regime where they have the crucial advantage that their scale is immune to evolutionary effects with  $z$ .

We then exploit the very high bias of the LRG population to help measure the scale of the baryon wiggles; the strong clustering of LRGs (see Fig. 1) makes it more easy to make accurate measurements of the size and scale of these features. A basic proof of concept is that at lower redshifts ( $z \approx 0.35$ ), 45000 SDSS LRGs have been recently used to detect the baryon wiggles in an LRG correlation function (Eisenstein et al, 2005, astro-ph/0501171, see Fig. 2). The aim here is to improve these constraints by approximately doubling the redshift range out to  $z \approx 0.7$  and using an order of magnitude more LRGs (450000) which implies an initial VST ATLAS survey area of  $4500\text{deg}^2$  to a depth of  $i_{AB} < 20.5$ . The justification for these parameters are given below. The AAOmega observational set-up will be close to that successfully implemented for the present SDSS-2dF  $z$  survey of 10000 LRGs (2SLAQ, Edge et al. 2005 in prep., see Fig. 3).

**2.** The VST+AAOmega LRG  $z$  survey could also be used to track dark energy via redshift space distortions and the Alcock-Paczynski effect. Essentially, the expected spherical symmetry of galaxy clustering is used to test cosmological models. These methods are already producing results in the current generation of galaxy and QSO surveys where the techniques have evolved to break the degeneracy between the geometric effect of cosmology and dynamical infall to provide interesting constraints on  $\Omega_m$  and  $\beta$ , which measures the rate of dynamical infall. In an LRG  $z$  survey an order of magnitude bigger than those currently available, it may be possible to provide  $z$ -space distortion constraints on  $w(z)$  via these methods.

**3.** The VST ATLAS survey will also allow an exploration of the possibility of detecting baryon wiggles using only photometric redshifts. 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 of order  $\pm 0.01$  mag in all bands over significant sky areas. But it is a long-term goal to extend the ATLAS to a  $> 10000\text{deg}^2$  area and ultimately to address this issue but over a longer period than the initial 2-3 years.

**4.** The most interesting highest redshift LRGs will also be targets for further high resolution VLT spectroscopy. There, the equivalent widths of OII emission lines, which are increasingly apparent at higher redshift in the current SDSS-2dF survey, can be precisely measured. Similarly the equivalent widths of Balmer absorption lines will allow accurate characterisation of the E+A population, believed to be post-starburst galaxies and which are also detected with increasing frequency at higher redshifts. In addition, there is also the prospect of using VLT to probe fainter down the luminosity function of high redshift galaxy clusters whose brightest galaxies appear in the LRG surveys.

**5.** The survey will also provide the base for future QSO surveys. The ATLAS will form the base for  $ugr$  colour-selected QSO surveys out to  $z \approx 3$ . One possibility is that AAOmega may also make a new survey of  $\approx 100000$  QSOs out to  $z = 2.2$  aimed at the Alcock-Paczynski  $z$ -space distortion test and QSO magnification lensing.  $Z$ -distortion requires further redshift information whereas QSO magnification lensing studies only require the basic photometry. Candidate wide separation QSO lensed pairs will also be found for further VLT follow-up.

**6.** The VST ATLAS will also contain  $\approx 1000$   $z > 4$  QSOs. Colour selected candidates will be spectroscopically confirmed by AAOmega before follow-up at high resolution with VLT UVES to map QSO absorption lines. Further, the data will be able to be used to search for high redshift QSOs at  $5.5 < z < 6.5$  where the SDSS team has found a handful of QSOs. The data will be used further to establish the evolution of the QSO LF in this redshift range, bridging the gap to the VISTA surveys at  $z > 7$ . These higher redshift QSOs would again be targets for VLT for confirmation in the first instance and then higher resolution spectroscopy.

**7.** The VST ATLAS will also complement a (to be) proposed NIR Atlas with the VISTA telescope which will reach  $K=18.2$  over the  $20000\text{deg}^2$  of the Southern Sky. Null detections in the VST  $ugriz$  bands plus detections in the NIR YJHK bands will enable powerful searches for QSOs at  $z > 7$ . The combination of the VISTA JHK bands and the  $ugriz$  bands will also make for more accurate broad band photometric redshifts, improving the chances of detecting baryon wiggles in the imaging data alone. These ultra-high redshift QSOs will again make natural targets for VLT high resolution spectroscopy to probe the ionisation history of the Universe.

8. Via cross-correlation of galaxy surveys with CMB surveys such as Planck, the VST will also be able to search for the ISW effect in the Southern Hemisphere. Independent confirmation of the claimed detections of this effect in the SDSS-WMAP analysis is vital to place further constraints on the nature of dark energy. Cross-correlation with the high resolution Planck data will also further test claims of detections of an extended SZ effect in the cross-correlation of WMAP and galaxy cluster catalogues.

9. The VST ATLAS will therefore be the springboard for a multiplicity of unique astronomical projects. The fundamental prize on offer is an unrivalled new understanding of the equation of state of dark energy via an associated AAT 2dF/AAOmega spectroscopic survey to detect baryon wiggles, with further constraints on dark energy arising from  $z$ -distortion, QSO lensing magnification and the ISW effect. But the survey will also provide significant follow-up opportunities for VLT spectroscopy to understand better special objects such as evolved bulge dominated galaxies, high redshift QSOs, wide angle QSO lensed pairs and high redshift galaxy clusters. Indeed, the combination of VST+AAOmega(+VISTA) ATLAS harnessed to the light-grasp of VLT will help set the new standard for the next generation of cosmological surveys.

## 2.2 Immediate objective:

A prime objective of the ATLAS is to provide targets for a Southern Spectroscopic Redshift Survey of LRGs. This motivates the size of the survey and so some attention should be paid to the justification. The simplest estimate is based on the empirical detection of the wiggles in the SDSS LRG Redshift Survey by Eisenstein et al (2005). This contains  $\approx 45000$  LRGs with an average redshift of  $z = 0.35$ , a sky density of  $12\text{deg}^{-2}$  and a space density of  $65000\text{ h}^3\text{ Gpc}^{-3}$ . They claim a peak position accuracy of  $\pm 4\%$ . Therefore, taking approximate account of a slightly higher LRG space density, an order of magnitude increase in the sample size to 450000 LRGs will provide  $\approx \pm 2\%$  accuracy in the peak positions. At the current 2SLAQ 2dF-SDSS limits of  $i < 19.8$  the sky density of  $z \approx 0.55$  LRGs is  $53\text{deg}^{-2}$  this rises to  $\approx 100\text{deg}^{-2}$  if we extend the  $z$  range to  $0.35 < z < 0.8$  (increasing our average  $z$  to  $z = 0.7$ ) while keeping the LRG space density approximately the same. Then we have 300 LRGs per 2dF Field and observing 450000 will take  $\approx 180$  clear AAOmega nights. Even a minimum number of 300000 LRGs will provide significantly improved accuracy for the determination of the equation of state at twice the redshift of the SDSS LRGs of Eisenstein et al. (2005). The proposed average redshift of the survey is close to the redshift of maximum sensitivity of standard rod tests for  $w$ , at least if  $w$  is a constant and close to  $w = -1$  (see Fig. 4, after Blake & Glazebrook 2003, ApJ, 594, 665).

Other calculations support this completely empirical estimate. Blake & Glazebrook's simulation results can be corrected for the higher bias of the LRGs as opposed to field galaxies. Assuming a realistic bias of  $b = 2$ , rather than their assumed bias of  $b = 1$ , their Figure 3 then suggests that a survey of 250000 LRGs will be enough to detect baryon wiggles to  $\pm 2\%$  accuracy. The calculations of Seo & Eisenstein (2003, ApJ, 598, 720) in their Tables 1,3, again suitably corrected to  $b = 2$ , also suggest that  $\approx 300000$   $z \approx 0.6$  LRGs will provide  $\pm 2\%$  accuracy in peak positions. Blake & Glazebrook indicate that  $\pm 2\%$  accuracy in the peak positions will lead to  $\pm 10\%$  accuracy in the derived precision of  $w$  at  $z \approx 0.6$ . A redshift survey of 450000  $0.35 < z < 0.8$  LRGs at a sky density of  $100\text{deg}^{-2}$  therefore motivates the  $\approx 4500\text{ deg}^2$  area for the VST ATLAS.

The expected numbers of  $5.5 < z < 6.5$  QSOs to be detected are based on the SDSS sky density of  $0.003\text{ deg}^{-2}$  from 9 spectroscopically confirmed QSOs with  $z > 5.7$  (Fan et al. 2004, AJ, 128, 515). The ATLAS survey would therefore detect 10-15 QSOs in this redshift range more than doubling the currently known numbers for high redshift QSO LF analysis and for VLT follow-up at high resolution.

Similarly, the ATLAS is expected to contain  $\approx 1000$   $z > 4$  QSOs with  $\approx 3 - 10$  candidates per square degree. The brighter QSOs confirmed by AAOmega could be followed up by VLT UVES to provide, for example, a comprehensive picture of the high redshift Lyman- $\alpha$  forest over multiple sightlines.

The VST ATLAS will be capable of selecting  $z < 3$  QSOs to a limit  $g < 22$ , which may also be observed with AAOmega. For a dedicated redshift survey, this would reach sky densities of  $\approx 70\text{deg}^{-2}$ , requiring 200 AAOmega fibres, similar to the current 2SLAQ survey. QSO Redshift Surveys simultaneous with an LRG survey may also be possible either by only targetting QSOs to the  $g < 21$  limit ( $\approx 35\text{ deg}^{-2}$ ) of the previous 2QZ survey or by reconfiguring fibres at the half-way point of a 2-hour exposure. The VLT ATLAS will therefore contain

210000-350000 QSOs in a 3000-5000deg<sup>2</sup> area and allow an order of magnitude increase in the size of QSO redshift surveys at this faint depth in 200-300 AAT nights.

The area of the survey will be split between the South Galactic Cap and the Northern Equatorial Zone so that year-round observing will be possible at VST, AAT and VLT. In the latter case we shall target the strip to the south of the current SDSS and SDSS-2dF areas.

A crucial aspect of the initial ATLAS survey is that it can be done on short enough timescales to exploit the AAT when upgraded by AAOmega in 2006. Expressions of interest have been solicited by AAO for large proposals (up to 100 nights per year, extending over several years) to start in semester 06A/06B (1/2/06-31/1/07). Approximately 750 deg<sup>2</sup> of SDSS imaging is available with  $\delta < +5$  deg in the RA: 10h-16h equatorial region and 750 deg<sup>2</sup> is similarly available at in the RA: 21h30-4h region. This is enough to allow a further survey of 35000 LRGs in the current  $z$  range or 65000 with the increased  $z$  range allowed by AAOmega. At  $\approx 1$  hr AAOmega exposure per field this would require  $\approx 60$  AAT clear nights. Since AAOmega is scheduled to be implemented in the first half of 2006, this means that SDSS imaging will be available while the VST ATLAS survey is ramping up. To match the capability of AAOmega at the 100 nights per year level will require 1200deg<sup>2</sup> of VST imaging per year. At 300 deg<sup>2</sup> per night for one band, this means that the VST rate is approximately 20 clear nights per year. To maximise the lead in the spectroscopic follow-up, will also require the VST ATLAS to be in production by late 2006. Clearly the spectroscopic surveys will require their imaging also to be outside areas previously surveyed by SDSS and 2dF. This makes a powerful argument for the VST ATLAS to be run alongside deeper VST imaging programmes; it will take the deeper surveys too long to produce the data required to maintain the spectroscopic initiative at the AAT and ultimately also at VLT.

### 3 Are there ongoing or planned similar surveys? How will the proposed survey differ from those? (1 page max)

The VST ATLAS will reach at least 2 mag fainter in all bands than the previous photographic Southern Sky surveys. These fainter limits are crucial for almost all of the main science drivers in the VST ATLAS survey.

The crucial difference between the VST ATLAS and the SDSS survey, apart from the Southern Declination, is the link to uniquely powerful spectroscopic follow-up, first at the AAT (2dF+AAOmega) and then at the VLT (VIMOS+UVES). The value of the link to the AAT is demonstrated already by the current use of 2dF by the SDSS team to do spectroscopic follow-up of the higher redshift SDSS LRGs and faint QSOs. There is simply no other spectroscopic follow-up 4-m telescope in the world that can compete with the 3deg<sup>2</sup> field-of-view of 2dF, especially after its AAOmega upgrade.

The VST ATLAS Survey will also perfectly complement the SkyMapper survey being proposed for a 1.3-m telescope at Siding Spring by the Australia National University. The SkyMapper survey will be based on 5 epochs covering 20000 sq. deg and the first epoch will only reach  $g = 21.6$ , which is not deep enough for the LRG survey. The telescope and camera is also barely started construction, so VST is likely to have at least a 2 year earlier starting time than SkyMapper for any survey that is capable of sustaining the LRG project. Thus a  $> 3000$ deg<sup>2</sup> VST ATLAS will be crucial for the timely success of any attempt to measure the cosmic equation of state. The VST ATLAS will form an early first generation deeper epoch for the 5 epochs ultimately to come from SkyMapper and so these surveys can add significant value to each other in terms of nearby supernova searches etc.

The VST ATLAS survey will also complement proposed deeper VST surveys such as KIDS. KIDS is aimed at an area of 1700deg<sup>2</sup> which is too small to provide useful data for AAOmega LRG redshift surveys aimed at baryon wiggles. Total exposure times are proposed to be  $\approx 2$  hrs per field to cover ugriz. This means a total exposure time of 425 clear VST nights. Effectively, KIDS will cover just over a single AAOmega field per night which is clearly slower than the spectroscopy we are proposing with AAT which will require 4 AAOmega fields per night. This applies even taking into account the higher fraction of clear nights at VST than AAT because of KIDS' requirement for good seeing ( $< 0.7$ arcsec FWHM).

In addition, KIDS will target the Northern Equatorial strip already observed by 2dF and already imaged by

band	$\lambda$	$\Delta\lambda$	Limiting	Mag.
			AB	Vega
<i>u</i>	3550	570	22.0	21.0
<i>g</i>	4750	1390	22.8	22.9
<i>r</i>	6230	1370	22.3	22.1
<i>i</i>	7620	1530	21.8	21.4
<i>z</i>	9130	950	20.7	20.2

Table 1: VST ATLAS limiting magnitudes, defined as the  $10\sigma$  limit (converted from Rifatto VOCET table).

SDSS. This high priority part of KIDS will thus not add to the area of Southern Sky available for spectroscopic follow-up of LRGs. KIDS is also aimed at weak shear galaxy lensing and requires good seeing conditions. VST ATLAS is not aimed at lensing and can use 1-1.4arcsec seeing not usable by KIDS and so these surveys complement each other well.

## 4 Observing strategy: (1 page max)

Our proposed ATLAS survey for VST will assume 60sec exposures in each of the ugriz bands with  $\approx 30$ s overhead per exposure. Because of the higher efficiency of VST+OmegaCam this will easily reach the Sloan magnitude limits already used in the current SDSS-2dF LRG survey. Our assumption of 30sec overhead is reasonable because in our requested conditions of 1-1.4 arcsec seeing then we shall on-chip bin  $2 \times 2$  to give  $0.42 \times 0.42$  arcsec<sup>2</sup> pixels. The unbinned read-out time for OmegaCam is currently 52secs (E. Valentijn, priv.comm.). On-chip binning may reduce readout time by up to a factor of  $4 \times$  ( $\approx 13$ secs). Thus, if in 1-1.4arcsec seeing there is no need to autoguide for a 60sec exposure then the overhead could even be less than 30sec. Thus we estimate that a 4500 sq. deg. survey would take only take 90 clear VST nights for even the full 5 band survey. Grey and even bright time could be used for the *i* and *z* bands, although care would have to be taken to ensure survey uniformity. Seeing of 1-1.4arcsec FWHM could be used, since this is an improvement over the 1.4arcsec FWHM median seeing for the SDSS imaging data used as the base for the current equatorial SDSS-2dF LRG survey. The estimated limiting magnitudes for the VST ATLAS are listed in Table 1.

Our basic targets would be the RA range between RA: 10h00-15h30 at Dec:  $-20 < \delta < -2.5$  deg to give  $\approx 1500$ deg<sup>2</sup> in the Northern Galactic Cap and RA: 21h30-04h at Dec:  $-50 < \delta < -15$  deg to give  $\approx 3000$ deg<sup>2</sup> in the Southern Galactic Cap for the full 4500deg<sup>2</sup> survey. The third year of the survey would therefore focus mainly on the Southern Galactic Cap. The Large Programme proposed here for Periods 77-80, would therefore produce a survey of 3000deg<sup>2</sup> split evenly between the Northern equatorial and SGC areas; time to complete the final 1500deg<sup>2</sup> would be requested in Periods 81, 82.

An exciting further possibility is that the Chileans (PI L. Infante) have proposed a collaboration between VST ATLAS and their 'ISW-VST Chile Survey'. The Chileans would use part of their 10% of VST time to extend the ATLAS exposure in the *r* band from 60secs to 600secs over 4500deg<sup>2</sup>. This would be part of a survey of total area 6000deg<sup>2</sup> to measure the ISW effect via cross-correlation with CMB data from WMAP and Planck. In this case, it may be possible to use the Chilean time to make the *r*-band observations and increase the ATLAS exposure time in another band, possibly, *g*, from 60 to 120secs. While negotiations with the Chileans on seeing requirements, data release etc are proceeding we shall maintain our present request for 60s ugriz exposures for VST ATLAS. Nevertheless the Chilean survey and offer of collaborative help represents an exciting potential development for the VST ATLAS project.

## 5 Estimated observing time:

Our estimated observing time for the VST ATLAS is given in Table 2.

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P77	80+55	10h00-15h30, 21h30-4h00	dark+grey/bright	< 1.4	clear(+ some phot.)
P78	80+55	10h00-15h30, 21h30-4h00	dark+grey/bright	< 1.4	clear(+ some phot.)
P79	80+55	10h00-15h30, 21h30-4h00	dark+grey/bright	< 1.4	clear(+ some phot.)
P80	80+55	10h00-15h30, 21h30-4h00	dark+grey/bright	< 1.4	clear(+ some phot.)
P81	80+55	21h30-4h00	dark+grey/bright	< 1.4	clear(+ some phot.)
P82	80+55	21h30-4h00	dark+grey/bright	< 1.4	clear(+ some phot.)

Table 2: Requested Observing Time for VST ATLAS to cover sky area of 4500deg<sup>2</sup> in *ugriz*.

band	$\lambda$	$\Delta\lambda$	Limiting	Mag.
			AB	Vega
<i>u</i>	3550	570	22.0	21.0
<i>g</i>	4750	1390	22.2	22.3
<i>r</i>	6230	1370	22.2	22.0
<i>i</i>	7620	1530	21.3	20.9
<i>z</i>	9130	950	20.5	20.0

Table 3: SDSS Completeness Limits, defined as the limit for 95% completeness for point sources in 1.''4 seeing.

## 5.1 Time justification: (1 page max)

Completeness limits for the SDSS survey are given in Table 4. The SDSS telescope has a 2.5-m aperture and uses a 55sec exposure in each band. The limiting magnitudes for VST ATLAS are intended to match SDSS limits. But since CCD throughput is  $\approx 10\%$  higher at all wavelengths and also taking into account average seeing of 1.''2 FWHM, our proposed exposure of 60s will make the corresponding VST ATLAS limit  $\approx 0.3$ mag fainter in all bands, although the use of grey/bright time to observe *i/z* will reduce the VST ATLAS advantage there.

We next estimate the time required to survey 1500deg<sup>2</sup> per year to the above depths. This rate is approximately the rate required to feed AAOmega for a variety of projects and in particular the LRG Redshift Survey (2hrs AAT exposure per 3deg<sup>2</sup> field). Over 2 years this rate means we can survey 3000 deg<sup>2</sup> containing 300000 LRGs and in 3 years we can survey 4500 deg<sup>2</sup> containing 450000 LRGs. Deeper VST surveys such as KIDS will only add a small area to this 3 year total; even with 100 VST nights per year such surveys would only cover 350 deg<sup>2</sup> per year, implying a ten year timescale to cover 3000deg<sup>2</sup>, a rate which would compromise the competitiveness of the spectroscopic surveys

Our assumptions are as follows:-

- $2 \times 2$  binning  $\Rightarrow 0.''42 \times 0.''42$  pixels
- 30secs of overheads per exposure
- 10% overlap per pointing  $\Rightarrow$  effective area per pointing of 0.78deg<sup>2</sup>
- 9hrs per night between astronomical twilights (average of 8hrs per night Oct-Mar and 10hrs Apr-Sep)
- Dark time; 60secs in *u, g, r*  $\Rightarrow 10.4$ deg<sup>2</sup> per hour
- $\Rightarrow 32$  dark nights for 3000 deg<sup>2</sup>.
- Grey time; 60secs in *i, z*  $\Rightarrow 15.6$ deg<sup>2</sup> per hour
- $\Rightarrow 22$  grey/bright nights for 3000 deg<sup>2</sup>. [ $> |5|$  nights from full moon]

We shall probably need to allow 10% more for calibration observations, implying that the total number of nights that will be needed to cover 1500deg<sup>2</sup> per year is 18 dark nights per year and 12 grey/bright nights per year.

## 6 Data management plan: (3 pages max)

We shall use the VISTA Data Flow System (VDFS; Emerson et al. 2004, Irwin et al. 2004, Hambly et al. 2004) for all aspects of data management, including: pipeline processing and management; delivery of agreed data products to the ESO Science Archive; production of a purpose-built VO compliant science archive with advanced datamining services; enhanced data products including federation of VST survey products with UKIDSS survey products. Standardised data products produced by VDFS will be delivered to ESO, with a copy remaining at the point of origin (in the Science Archive run by WFAU in Edinburgh).

The VDFS is a collaboration between QMUL, Edinburgh and Cambridge funded by the PPARC e-science programme. It is a systems-engineered project to produce an end-to-end data flow for the UKIRT WFCAM and VISTA infrared surveys, which are scientifically complementary to VST public surveys in the optical. The VDFS is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system.

The VDFS system, although still developing, is a proven working system. The Cambridge Astronomy Survey Unit (CASU) will lead the Pipeline Processing activity. Funding and personnel for pipeline processing of UK-led VST public surveys are now in place and the hardware infrastructure for this has been designed as a modest extension of the existing VDFS pipeline processing setup. The pipeline processing components have been scientifically verified by processing wide field mosaic imaging data for a range of existing optical CCD mosaic cameras e.g. Suprime-CAM, ESO WFI, CFHT 12K and MegaCam, CTIO Mosaic, KPNO Mosaic, AAO WFI, INT WFC and WHT PFC. It has also been used to process NIR data such as the ESO ISAAC FIRES survey, and is now routinely being used to process data from the NIR mosaic camera WFCAM on UKIRT at a rate of up to 250GB/night. Data products are being successfully ingested into the WFCAM Science Archive (WSA), with the first public release imminent. The archive component is an advanced science archive facility, with a high-speed query interface, links to analysis tools such as TopCat, and advanced new VO services such as MySpace. The WSA concept has already been demonstrated on the SuperCOSMOS Science Archive (SSA), is working now, and will be available to European users very shortly.

### 6.1 Team members:

Name	Function	Affiliation	Country
J. Emerson(VDFS and VISTA PI)	Chair of Oversight Committee	Queen Mary University of London	UK
R. McMahon(VDFS co-I)	Data Quality Control Manager	University of Cambridge	UK
M. Irwin(VDFS team)	Pipeline Design	University of Cambridge	UK
E. Gonzalez-Solares(VDFS team)	Pipeline Manager	University of Cambridge	UK
P. Williams(VDFS team)	Local Manager	University of Edinburgh	UK
N. Hambly(VDFS team)	Science archive architect	University of Edinburgh	UK
M. Read(VDFS team)	User interface design	University of Edinburgh	UK
E. Sutorius(VDFS team)	Archive operations	University of Edinburgh	UK

### 6.2 Detailed responsibilities of the team:

see Table above

### 6.3 Data Flow System

The data flow system will be produced by the current VDFS team, who will be responsible for the main data products and for delivering data products to agreed specification to the ESO Science Archive. The VDFS team will also merge the data products with UKIDSS and VISTA data products in the VISTA Science Archive (VSA) which will follow on from the WSA. The VSA will offer advanced facilities to the world community, not just

for data access but also online analysis and datamining, all of which will of course be offered as VO compliant services. The VDFS team are closely related to the AstroGrid project, which is providing the agreed technical infrastructure for Euro-VO.

The VDFS pipeline will be used for all processing. This includes the following processing steps, but as it is a modular design extra stages not directly used for normal VDFS processing are easily added. All the steps have been tested on a range of input datasets.

- instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk, persistence
- sky background tracking and adjustment during image stacking and mosaicing
- combining frames if part of an observed dither sequence or tile pattern
- consistent internal photometric calibration to put observations on a uniform internal system
- standard catalogue generation including astrometric, photometric and morphological shape descriptors and derived Data Quality Control(DQC) information, all with appropriate error estimates
- accurate astrometric calibration based on the catalogues using standard World Coordinate System (WCS) in all relevant FITS headers
- nightly photometric calibration using suitable pre-selected standard areas covering entire field-of-view to monitor and control systematics
- propagation of error arrays eg. weight maps, bad pixels, relative exposure via the use of confidence maps
- nightly average extinction measurements in relevant passbands
- pipeline software version control – version used recorded in FITS header
- processing history including calibration files used recorded in FITS header

The concept of the science archive (Hambly et al. 2004 and references therein) is key to the successful exploitation of wide field imaging survey datasets. The science archive ingests the products of pipeline processing (instrumentally corrected images, derived source catalogues, and all associated metadata) into a database. Furthermore, the science archive system then goes on to curate them to produce enhanced database-driven products. In the VDFS science archive, the curation process includes, but is not limited to, the following: individual pass-band frame association; source association to provide multi-colour, multi-epoch source lists; global photometric calibration; enhanced astrometry including derivation of stellar proper motions; consistent list-driven photometry across sets of frames in the same area; cross-association with external catalogues; and generation of new image products, e.g. stacks, mosaics and difference images etc., all according to prescriptions set up for a given survey programme.

#### 6.4 Expected data products:

- Instrumentally corrected frames along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
- stacked and/or mosaiced data for dithered observations of single targets
- confidence maps for all image products
- derived object catalogues based on a standard VDFS set of object descriptors including astrometric and photometric measures, and morphological classification



- Data Quality Control database including measurements of seeing, average stellar shape, aperture corrections, sky background and noise levels, limiting magnitudes
- Database-driven image products (stacks, mosaics, difference images, image cut-outs)
- frame associations yielding a survey field system; seamless, merged, multi-colour, multi-epoch source catalogues with global photometric calibration, proper motions (where appropriate)
- source remeasurement parameters from consistent list-driven photometry across all available bands in any one field

## 6.5 General schedule of the project:

- T0: Start of observations
- T0+4months; Public release of science products from first month of survey observations
- T0+8month; Public release of science products from first 6 months of survey observations
- Thereafter we would hope that science products can be released to the ESO community within 1-2 months of raw data arriving in the UK.
- Optional reprocessing of data based on improved knowledge of instrument would also be considered.

### References:

Emerson J.P. et al., 2004, “VISTA data flow system: overview”, in *Optimizing scientific return for astronomy through information technologies*, eds. P.J. Quinn & A. Bridger, Proc. SPIE, vol. 5493, 401

Irwin M.J. et al., 2004, “VISTA data flow system: pipeline processing from WFCAM and VISTA”, in *Optimizing scientific return for astronomy through information technologies*, eds. P.J. Quinn & A. Bridger, Proc. SPIE, vol. 5493, 411

Hambly N.C. et al., 2004, “VISTA data flow system: survey access and curation; the WFCAM science archive”, in *Optimizing scientific return for astronomy through information technologies*, eds. P.J. Quinn & A. Bridger, Proc. SPIE, vol. 5493, 423

## 7 Envisaged follow-up: (1 page max)

The follow-up that will be required from ESO VLT will be mainly spectroscopic. Medium resolution spectroscopy from FORS1/2 will be required to obtain higher signal-to-noise spectra of high redshift emission line and E+A LRGs than are obtainable from 4-m class telescopes such as the AAT. The VIMOS IFU may also provide spatially resolved spectra which may be useful in these cases. FORS1/2 will be required to obtain higher signal-to-noise spectra of candidate wide-angle lensed QSO pairs and also to obtain confirming spectra for high redshift  $4 < z < 7$  QSO candidates. VLT UVES would also be needed to provide high resolution spectra the brighter  $z > 4$  QSOs and also occasionally for LRGs with anomalous spectra from AAOmega.

We estimate that 6 dark nights per year will be required for follow-up. These will be split mainly between the VLT UVES, FORS1, FORS2 and VIMOS spectrographs. We understand that these 6 dark nights and our data release schedule may be the subject of negotiation between our team and ESO if this ATLAS proposal is accepted. We envisage that we shall start to apply for the VLT time in Period 79. We do not apply for it as part of this Large Programme proposal because of the inevitable uncertainties associated with the timescale of VST and OmegaCam commissioning. More details of the justification for our requested VLT follow-up will therefore be made available in the specific VLT proposals likely to start in Period 79.

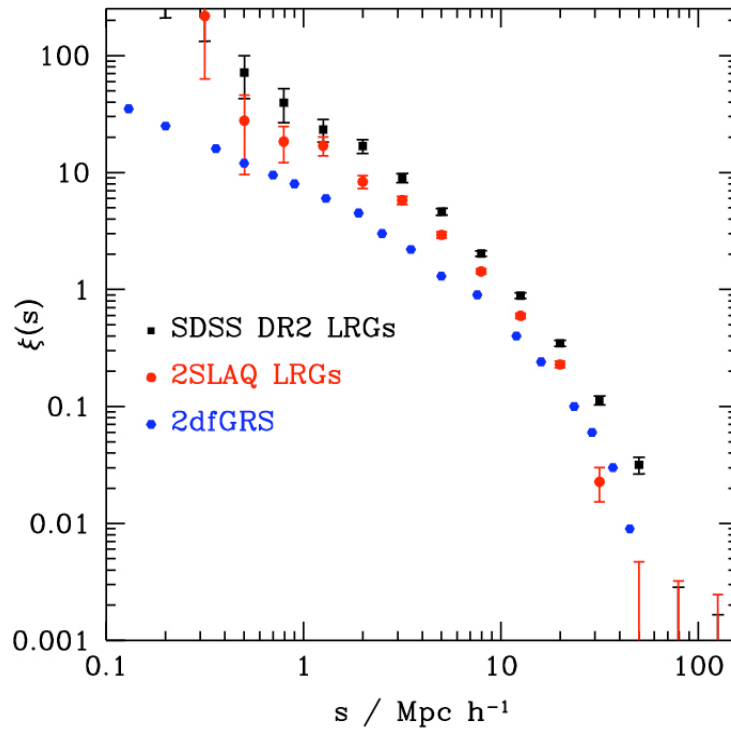


Figure 1: The redshift-space correlation functions for  $z \approx 0.35$  SDSS DR2 (filled squares) and  $z \approx 0.6$  2SLAQ LRGs (open circles) are significantly higher than for the 2dFGRS galaxy survey (filled circles).

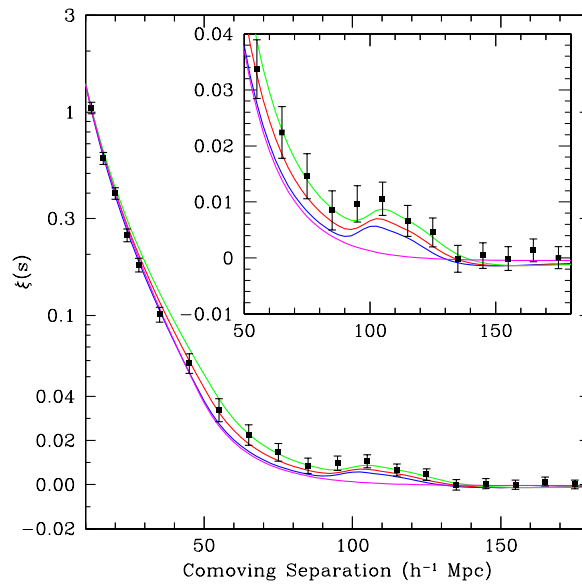


Figure 2: The redshift-space correlation function of 45000 SDSS LRGs (filled squares) from Eisenstein et al (2005) showing the detection of a baryon wiggle at a separation of  $\approx 100h^{-1}$  Mpc compared to  $\Lambda$ CDM model predictions with and without baryons (lines).

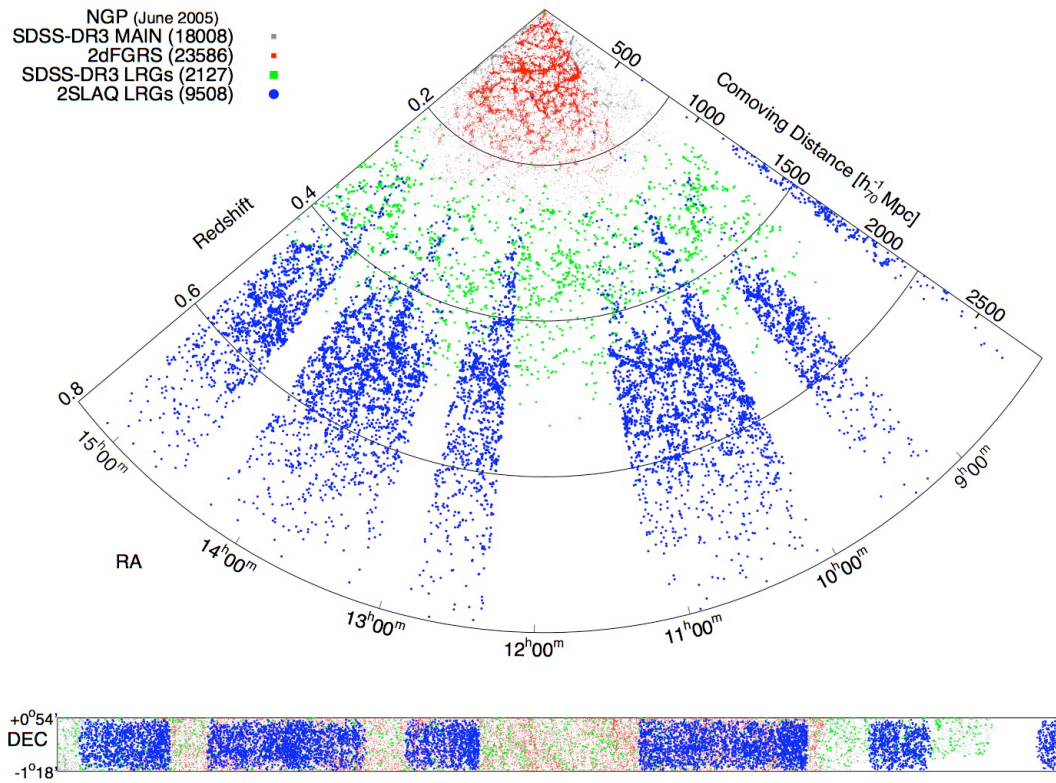


Figure 3: The Northern Equatorial strip containing 2dFGRS galaxies (red), SDSS LRGs (green) and 2SLAQ LRGs (blue). Note the significantly higher redshift of the 2SLAQ LRGs ( $z \approx 0.6$ ) compared to the SDSS LRGs ( $z \approx 0.35$ ).

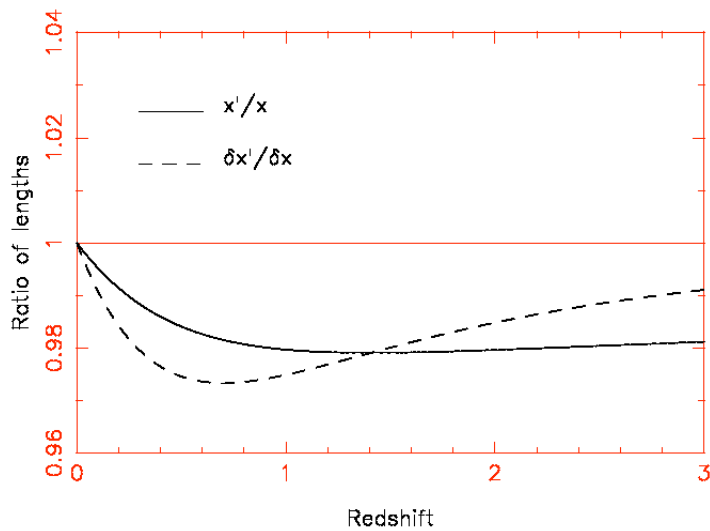


Figure 4: The length distortion of a rod as a function of redshift in the radial (dashed) and angular (solid) directions. The ratio of lengths represents the difference measured in  $w = -1$  and  $w = -0.9$  (constant) models assuming an  $\Omega_m = 0.3, k = 0$  cosmology. The difference maximises at  $z \approx 0.65$ , our average LRG redshift.