1 Title: VISTA Dark Energy Survey (VDES)

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2 Abstract

The existence of Dark Energy poses one of the greatest challenges to our understanding of fundamental physics and the Universe. We propose to carry out a 5000 sq. degree survey with VISTA in the J and Ks bands to determine the nature of dark energy by accurately measuring its equation of state, $w(z)$. We will achieve this goal through four complementary cosmological probes: clusters of galaxies, Baryon Acoustic Oscillations (BAOs), the Integrated Sachs Wolfe effect, and weak gravitational lensing, all of which require large volumes of space to be surveyed to high redshift. We have chosen to target the Dark Energy Survey (DES) area to take advantage of the deep, optical *griz* photometry from this survey, which will be publicly available. This combined dataset – VISTA Dark Energy Survey (*VDES*) – will improve the photometric redshift errors above $z = 1$ by a factor of 2 compared with the optical data alone and reduce the systematic biases in photo-z estimates as well. These more precise photo-z's at high redshift translate directly into stronger constraints on dark energy by the four methods above. *VDES* will thus probe the nature of dark energy out to $z \sim 2$, providing several measurements of w at the few to 5% level. *VDES* will also deliver a remarkable legacy survey to ESO, covering a large fraction of the South Galactic Cap to unprecedented depths ($\sim$ 5 magnitudes deeper than 2MASS), which will facilitate an array of other projects to be undertaken (e.g., galaxy evolution, high–z quasars, cool stars) as well as providing targets for the next generation of VLT instruments and ESO telescopes.

3 Description of *VDES*

3.1 Scientific Rationale

A major goal of cosmology is to understand what the universe is made of and how it evolves. Both of these questions can be addressed via studies of the content of the universe as the evolution of the Universe is governed by its energy density as described by Einstein's theory of General Relativity (GR). In recent years, we have made tremendous progress in determining the constituents of the Universe, based on multiple observational probes including Type Ia supernovae, the power spectrum of galaxy clustering, gravitational lensing, baryon acoustic oscillations, clusters of galaxies and the Cosmic Microwave Background (CMB). Based on the combination of these data, we now believe that the universe is 5% ordinary baryonic matter, 25% dark matter and 70% dark energy (Spergel et al 2003, Tegmark et al 2004b). Unfortunately, we have little understanding of the nature of this "dark energy" (DE) that dominates the energy–density of the Universe, and its dynamics. This problem is now the most compelling issues in modern physics.

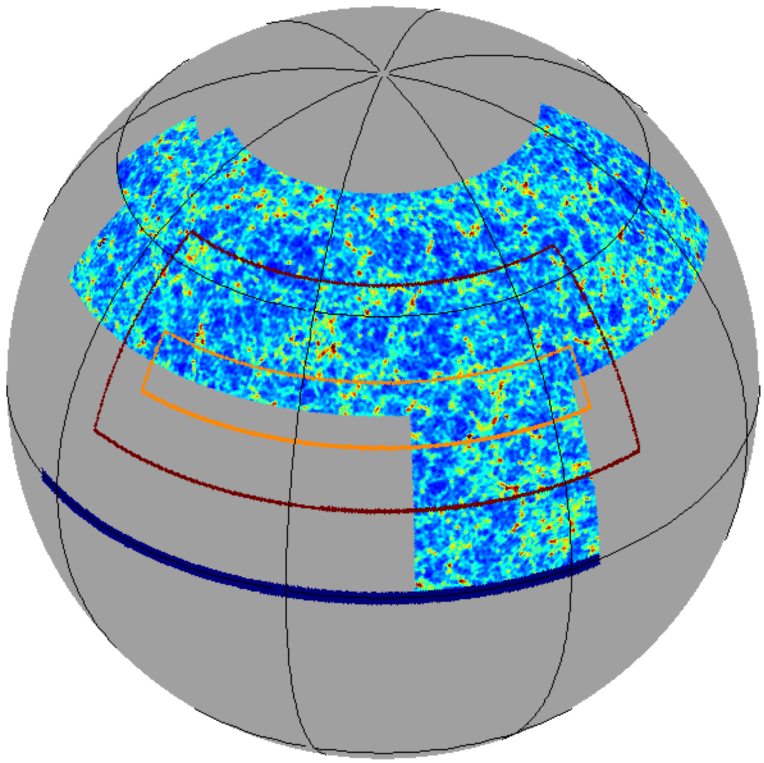

Figure 1: The areal coverage of *VDES* shown as a simulated galaxy density map (and SDSS Stripe 82 as a deep blue line on the equator). Also shown are the survey boundaries for the optical ESO public VST ATLAS (red) and KIDS (yellow) projects. Please note the south pole is at the top of the sphere.

One of the simplest possibilities for the nature of DE is Einstein's Cosmological Constant (Λ), ie., a new form of matter with a negative effective pressure which causes the late–time acceleration of the expansion of the Universe as observed by recent supernovae surveys (Riess et al. 1998; Perlmutter et al. 1999). The theoretical challenge of this picture is the apparent "fine–tuning" of the value of Λ (by $\sim 10^{120}$!) to ensure it only becomes important in the expansion history of the Universe at the present epoch. Several alternatives to Λ have been proposed including Quintessence, Phantom energy and tracker models.

An alternative understanding of DE are modified theories of gravity, thus negating the need for any new form of matter. One of the simplest such modifications is the DGP model (Dvali, Gabadadze & Porrati 2000), that has the same number of free parameters as Λ models, but "self-accelerates" at late times due to the weakening of gravity on large scales as it leaks into higher dimensions. The challenge with such models is to make testable predictions, but significant progress has been made in recent years (see Ishak et al. 2005; Sawicki & Carroll 2005) and these models are now being compared to observations (see Fairbairn & Goobar 2005).

In this proposal, we will explore the nature of DE using a combination of observational techniques. We will focus on methods involving the redshift evolution of the growth rate of gravitational potentials (dg/dz), which is an excellent discriminator of the dark energy parameters (e.g. the equation of state of DE as parameterised by $w = p/\rho$) and is potentially more powerful than other classical tests of DE (eg., distance scale measurements). Furthermore, modified gravity models (like DGP) predict significant differences in dg/dz (at the $\simeq 10\%$ level, Koyama 2006) compared to the standard ΛCDM model, thus providing a critical physical insight, ie., Is dark energy modified gravity or Λ? To exploit the full potential of the dg/dz method, we require new surveys of the sky that sample large volumes of space (to control cosmic variance) out to high redshifts: This therefore demands wide–area surveys to faint magnitude limits.

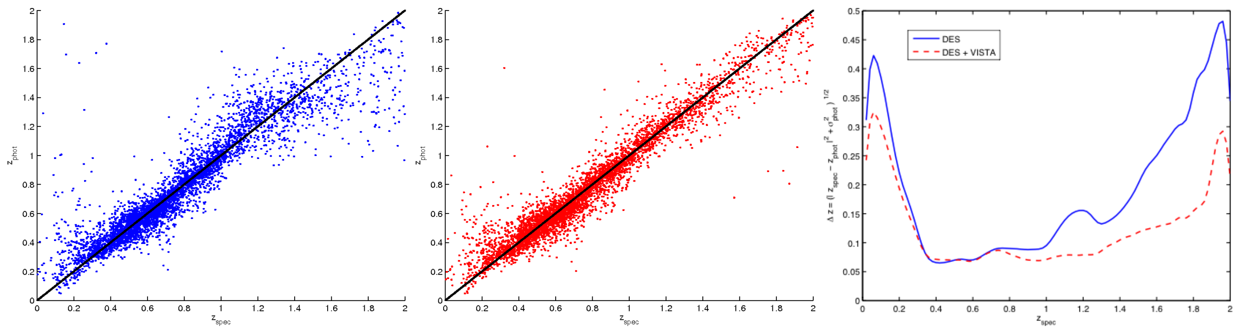

Figure 2: The difference between the photometric redshift and spectroscopic redshift in the mock catalogues discussed in the text. (LEFT) Using the DES *griz* photometry (blue data points). (MIDDLE) Using the *VDES* *grizJK* photometry (red data points). (RIGHT) The rms error distribution as a function of redshift including the photometric errors. Clearly, *VDES* greatly improves the photo–z errors beyond $z = 1$.

3.2 Photometric Redshifts

In order to advance in our understanding of the universe, we propose a new large–area near–infrared (IR) survey of 5000 deg^2 using VISTA. We have designed this IR survey to coincide with the areal coverage of the Dark Energy Survey (DES; see `http://www.darkenergysurvey.org`), South Pole Telescope (SPT) and ESO VST public surveys (KIDS, ATLAS) as shown in Figure 1. In this way, we can combine the deep optical photometry with our proposed J and Ks VISTA photometry to provide excellent sampling of the spectral energy distribution of distant galaxies and thus deliver accurate photometric redshifts (photo-z's). This new VISTA survey is called *VDES* – "VISTA Dark Energy Survey"

The precision to which we can study dark energy fundamentally depends upon the accuracy of the photometric redshifts for distant galaxies. To demonstrate the power of adding the VISTA IR data to the planned optical data, we have constructed mock magnitude-limited galaxy samples (with $20 < i < 24$ and redshifts $0 < z < 2$) based on the observed galaxy luminosity functions and type distributions from Lin et al. (1999), Poli et al. (2003), Capak et al. (2004) and Wirth et al. (2004). We then analyse these mock catalogues using the ANNz photometric redshift software of Collister & Lahav (2005) to determine the likely photo-z errors as a function of the available optical and IR data. Our results are summarised in Figure 2 where we show the photo-z errors (as compared to the true "spectroscopic" redshift in these mocks) with and without the extra VISTA data. The improvement beyond $z = 1$ because of the IR data is evident, as it allows us to constrain the crucial $4000\AA$ break beyond the limit of the optical data. In particular, the *VDES* photo-z error distribution is a factor of 2 better in the range $1 < z < 2$ compared to the optical data alone, ie., reducing the one–sigma errors from $\sigma_z = 0.15$ (for just DES) to $\sigma_z = 0.076$ for *VDES* (68% confidence) over our z range. These statistical errors incorporate errors due to both the network scatter (in the algorithm) and the expected photometric errors. In addition to reducing the statistical errors, Figure 3 also demonstrates that adding VISTA data will reduce the systematic uncertainties (the "wiggles" in the mean of the blue data points). Therefore, the addition of the IR data, will turn DES (and ATLAS & KIDS) into the best available "redshift survey" of the distant ($z > 1$) Universe.

3.3 Four Complementary Techniques

With accurate photometric redshifts in–hand, we will use *VDES* to study the nature of dark energy using four powerful observational techniques; surveys of clusters of galaxies, power spectrum of galaxy clustering, ISW effect and gravitational lensing. We discuss these below.

1) Clusters Surveys: Clusters of galaxies are the most massive virialized objects in the Universe and reside in the exponential tail of the mass function. The total abundance of clusters in the Universe is governed

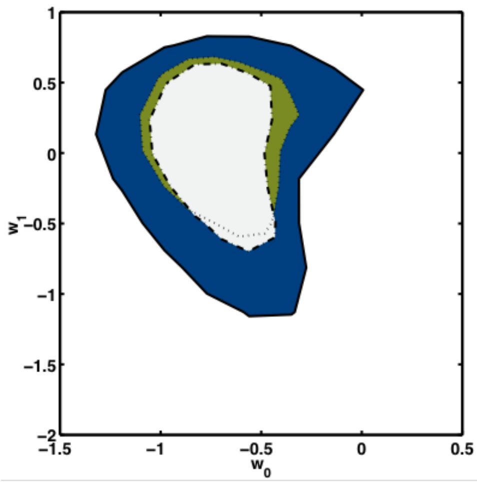

Figure 3: The one sigma error contours in the w_1 and w_0 plane (ie., the parameterization of DE using $w(z) = w_0 + w_1 z$) for the SPT/DES cluster survey. The outer solid region is for $z < 1$ clusters, which is possible with just the DES photo-z's. The inner dotted line is for $z < 1.5$ clusters which is only possible with *VDES*+SPT and clearly demonstrates the power of pushing these cluster surveys to their highest possible redshift using the VISTA data.

by the amount of matter in the Universe (Ω_m) and the normalization of the primordial fluctuation spectrum (known as σ_8), while the redshift distribution of clusters is determined by dark energy ($w(z)$) via dg/dz and the cosmological volume. Therefore, an accurate measurement of the abundance of massive clusters with redshift would immediately provide tight constraints on these cosmological parameters.

There are however several problems associated this technique: *i)* Massive clusters are rare and therefore, one needs to survey large volumes of space to detect enough clusters and control "shot noise" (especially for the most massive systems); *ii)* A homogeneous selection of clusters is required over a wide range of redshifts; *iii)* The mass of clusters must be robustly determined. In recent years, there have been significant advances in solving these problems. For example, the Sunyaev-Zel'dovich (SZ) decrement caused by the inverse Compton–scattering of CMB photons by a hot intracluster gas has the potential to select clusters independent of their redshift, thus free of Malquist bias that plagues the optical & X–ray surveys of clusters. Furthermore, the SZ decrement is linked to the temperature of the gas and is therefore, an excellent proxy for the mass of a cluster.

In this proposal, we plan to study clusters through the combination of SPT and *VDES* data. The former will survey 4.000 $\deg^2$ of the southern sky (same area as DES) and is predicted to detect over 20.000 massive clusters via their SZ decrement. This sample of clusters, out beyond $z = 1.5$, will revolutionize studies of distant clusters and will provide key constraints on the cosmological parameters, as demonstrated in Figure 3.3. This figure also illustrates the power of combining SPT and *VDES*, as the constraints on $w(z)$ will improve considerably if clusters beyond $z = 1$ can be used, ie., we know their photo-z's. *VDES* will also help calibrate the mass scaling relations for these clusters using both the summed IR luminosities of clusters (see Lin & Mohr 2003) and the stacked weak gravitational lensing signal from these clusters. The synergy of *VDES* and SPT is clear and unique.

2) Power Spectrum of Galaxy Clustering: With *VDES*, we will measure the power spectrum of galaxy clustering ($P(k)$) in a series of well–determined photo-z shells for over 300 million galaxies out to $z \sim 2$. This will be an order of magnitude more galaxies than any previous galaxy survey, and thus provides an unparallelled statistical measurement of the growth of large–scale structure in the Universe. Moreover, the galaxy power spectrum contains a number of characteristics scales, which can be used as "standard rulers" in the Universe to measure the angular diameter distance as a function of redshift. As these features depend primarily on the shape of the galaxy power spectrum, they are insensitive to uncertainties in galaxy biasing. In particular, Baryon Acoustic Oscillations (BAOs) are imprinted in the galaxy distribution in the early universe due to oscillations in the coupled photon-baryon fluid and are seen as a series of "wiggles" in the galaxy power spectrum. The BAO have been detected for the first time on large scales in the Sloan Digital Sky Survey (Eisenstein et al. 2005) and 2dFGRS (Cole et al. 2005). In Figure 3, we present our predicted cosmological constraints we will obtain via the detection of the BAOs for both the DES (on its own) and *VDES* power spectrums of galaxy clustering. Clearly, the addition of VISTA data greatly reduces the area of the error ellipse by nearly 50%, and will provide

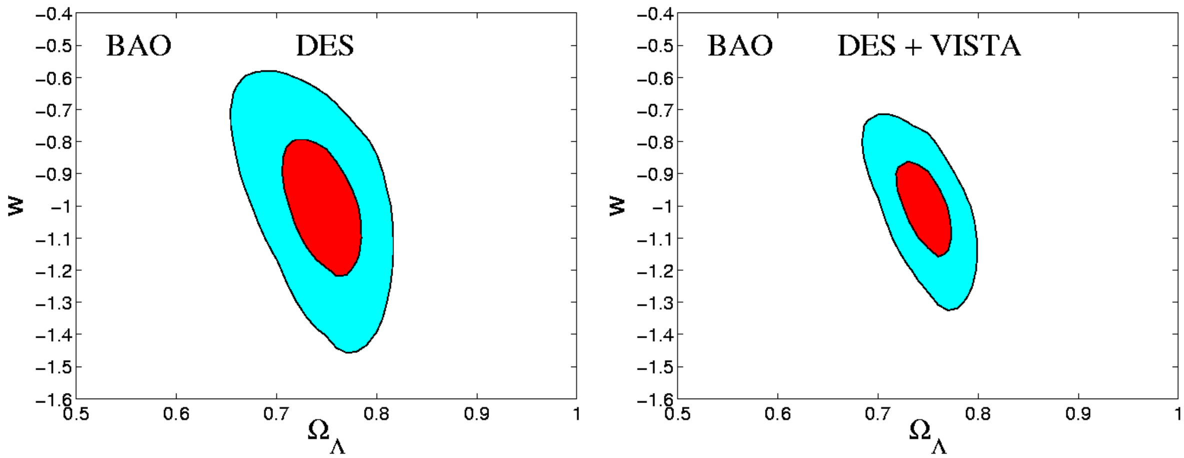

Figure 3: The expected 1σ (red) and 2σ (blue) likelihood contours for w (the equation of state of DE) versus Λ for just the DES (LEFT) and *VDES* (RIGHT) detections of the BAOs. These constraints are based on large N–body simulations assuming the error distributions given in Figure 2. For the DES case, we assume 5000 sq degrees with $z_{max} = 1.3$ and 10 redshift bins of $dz = 0.13$. *VDES* simulation is the same area but with $z_{max} = 1.7$ and 22 redshift bins of $dz = 0.08$. The background cosmological model in the simulations has $\sigma_8 = 0.9$, $\Omega_k = 0$, $\Omega_b = 0.044$, and $h = 0.7$

a constraint on w to $\pm 15\%$ using *just* the BAOs, ie., we are not using any other information from the shape of the power spectrum.

3) Gravitational Lensing: The gravitational lensing of distant galaxies by foreground masses offers a new and powerful method for measuring the distribution of dark matter in the Universe and the nature of DE. The Dark Energy Survey plans to use both shear–shear correlations (known as "cosmic shear") and galaxy-shear correlations to determine w to 10% using just the DES optical data. The *VDES* imaging data will not improve these cosmic shear measurements due to the relatively poor conditions we plan to use and the high sky brightness in the IR, which is more difficult to determine the shapes of distant galaxies in the IR. However, the constraints we can place on DE from our cosmic shear measurements from the optical DES imaging do depend on the accuracy of the photometric redshifts, both their statistical accuracy and bias. As shown in Figure 2, *VDES* will improve the photo–z statistical errors by 50%, as well as reducing the systematic bias at $z > 1$, thus extending the redshift range over which reliable photo–z's are available. This increased redshift baseline will improve the errors on w upto 50%, ie., w to 5% depending on the priors.

4) Integrated Sachs-Wolfe (ISW) Effect: As CMB photons travel to us from the surface of last scattering they can be gravitationally redshifted by time–evolving gravitational potential wells. For example, in an accelerating universe, the energy gained by a photon falling into such potential wells will be more than the energy lost climbing out. This is known as the late–time ISW effect, which has now been detected by several groups via the cross-correlation of the WMAP CMB maps and large galaxy surveys (see Scranton et al. 2003; Boughn & Crittenden 2003; Fosabla et al. 2003). The ISW effect provides a direct and powerful measurement of DE via the growth of structure (Cooray et al. 2004).

The ISW effect is a weak signal and therefore, one may expect it to be limited in its ability to constrain the physics of dark energy. However, the ISW effect is the only avenue for measuring the sound speed (or clustering) of DE (Hu & Scranton 2004; Pogosian 2004), and it provides a critical test for modified gravity models (see Sawicki & Carroll 2005). Finally, Pogosian et al. (2005) demonstrates that the ISW effect measured via DES+Planck will be more powerful at constraining non–constant $w(z)$ models than SNAP+Planck. *VDES* will be even better as the improved photo–z errors will increase the number of photo–z shells available for the analysis. We will also combine *VDES* with SDSS+UKIDSS in the north to measure the ISW effect over most of the extragalactic sky (ie., at high galactic latitudes).

3.4 Legacy Science

VDES will cover a large fraction of the South Galactic Hemisphere to unprecedented depths, approximately 5 magnitudes deeper than 2MASS. Therefore, it will be an awesome legacy dataset and will advance Astronomy and Astrophysics beyond the dark energy and dark matter science discussed above, in a similar fashion as other surveys like SDSS and 2MASS have influenced many areas of astronomy

First and Foremost, *VDES* will facilitate many studies in galaxy evolution as the IR data provides a more robust estimate of the stellar mass of galaxies compared to the bluer optical colors, which are sensitive to recent star–formation. The vaste volume of *VDES*, and sheer number of objects, will allow for accurate determinations of the correlation function of galaxies as a function of many different galaxy properties (color, luminosity, SFR etc.). It will also provide large samples of anomalous galaxies (based on color and morphology) thus providing targets for the next generation of VLT instruments like KMOS.

Secondly, *VDES* will detect millions quasars to $z < 3$, as well as tens of thousands at higher redshift (eg., 60000 with $3 < z < 5$, $\sim$ 2000 with $5 < z < 6$, $\sim$ 100 at $6 < z < 7$ and $\sim$20 at $7 < z < 8$). These quasars will be found on multi–color space, via our new NBC clustering algorithm (Richards et al. 2004), and can be used for cosmology without extensive spectroscopic follow–up, eg., the "cosmic magnification" of distant quasars by foreground structures as traced by galaxies (see Scranton et al. 2005). The highest redshift quasars, as well as close pairs of quasars we find, will be ideal targets for the VLT and 30–meter class telescopes, while the combination of the DES+VISTA imaging data will provide information on quasar variability.

Next, very low mass stars and brown dwarfs are the more numerous objects in our Galaxy but are difficult to detect due to their faintness. They also emit the bulk of their radiation in the near IR, so the combined optical–IR colors in *VDES* will be ideal for detecting a multitude of these objects. Again, they will be ideal targets for the next generation of ESO instruments.

Finally, *VDES* will provide multiple images of a large area of the southern sky over a long time baseline which will be ideal for studying transient objects. On the largest time scales, we will detect proper motions of halo white dwarfs which should move > 0.5" in 5 years. These white dwarfs can be used to date the halo and study their contribution to the halo mass. On shorter time scales, we can study nearby objects and/or Kuiper belt objects. The luminosity of these bodies in the J and Ks bands are dominated by reflected solar radiation which can provide useful information on the presence of silicates in the surfaces of these bodies.

4 Other Surveys

VDES is designed to exploit the synergy with the on–going Dark Energy Survey (DES) and the South Pole Telescope (SPT). The DES data will be made public in regular yearly data releases similar to the SDSS data release policy. Likewise, the SPT project plans to make their survey data publicly available. Therefore, all ESO members will have assess to the DES & SPT data, inconjunction with our proposed IR data. This will provide a unique resource for ESO scientists, providing them with (for example) tens of thousands of clusters (with well–calibrated masses), millions of quasars (out to $z \sim 10$) and hundreds of millions of distant galaxies. This combined dataset will support European satellite missions including finding counterparts for XMM serendipitous sources, Planck point sources, and comparisons with Hershel and GAIA sources.

DES will begin operations in 2009 and will obtain a map of the whole 5000 sq. degrees (shown in Figure 1) every year for 5 years. The SPT expects first–light next year and will have cluster catalogues in–hand by the time DES turns on. Our plan is to begin *VDES* before DES to maximise the science possible with the combined dataset and obstain precision measurements of w before the next generation of DE experiments like SNAP, DUNE, LSST etc.

Even though *VDES* is designed to exploit DES, Figure 1 shows that our IR data will also supplement the ESO VST ATLAS survey, which will survey 3000 sq, degrees of the southern sky to the same depth as the northern SDSS in the same passbands. DES will be significantly deeper than ATLAS (over a larger area), but ATLAS will provide important u–band data over a large region of *VDES*. Likewise, the smaller, but deeper, KIDS survey (southern part) overlaps with the *VDES* area providing further u–band data and an important cross-calibation. This additional UV data (which comes for free) will further improve the photometric redshifts especially at low redshift ($z < 1$), where there is presently significant photo–z errors as shown in Figure 2. Therefore, the combined ATLAS+ *VDES* survey should provide $ugrizJKs$ colors for millions of objects over a much larger area than KIDS. This combined dataset should constrain the photo–z errors to $\sigma_z < 0.1$ for a majority of galaxies over the entire redshift range.

VDES is complementary to VIKING – the VISTA counterpart to KIDS – and the VISTA Hemisphere Survey (VHS). In the case of VIKING, we survey a much larger area which is vital for the main dark energy probes discussed herein, eg., detecting a large number of massive clusters. For dark energy studies, area (and volume) is critically important to control cosmic variance on large scales. Compared to VHS, *VDES* will probe to much higher redshifts and thus be able to study any evolution of the dark energy equation of state. Again, this will be critical to determining the true nature of dark energy. In summary, *VDES* is the optimal combination of depth and area, and thus optimal for studies of dark energy.

VDES will also cover a large fraction of the 2dFGRS, 2QZ, VVDS and DEEP2 surveys, as well as the SDSS Stripe 82 region (the dark blue stripe on the equator in Figure 1). This latter area has significant ancillary information including hundreds of supernovae detected via the SDSSII Supernova Survey, deep ($r \simeq 24$) co–added photometry, $\simeq 25,000$ SDSS spectra and redshifts (see "special plates" in the SDSS Data Release 4) and $\sim 15,000$ faint spectra from the recently finished 2dF–SDSS LRG and QSO (2SLAQ) survey. Stripe 82 will also be observed by UKIDSS and AAOmega provide important cross–checks of the photometry and further faint spectroscopy. In total, we expect 250,000 spectroscopic redshifts in the *VDES* area thus providing vital training sets for the photo–z algorithms

5 Observing Strategy

The science goals of *VDES* demand a large volume of space to faint flux limits and thus exploit the Dark Energy Survey (DES), ATLAS and KIDS (Figure 1) areas. We also need the IR bands to improve the photometric redshifts at $z > 1$ and therefore must reach deep enough to detect such high redshift galaxies. To address this question, we have carried out detailed simulations (see Figure 2) to estimate the optimal depth and combination of optical–IR passbands to achieve the best possible photo–z's. Our best results are shown in Figure 2 which found that the best compromise was to use two IR bands (J and Ks) down to a depth of $Ks \sim 19$ and $J \sim 21$. Other combinations of J, Y, H, Ks delivered similar results and adding the IR data (even one passband) always achieved significantly better photo–z's that using just the optical data. *Therefore, we could still make significant progress in our science goals if we were only allocated a single IR passband over the DES area*

According to the ETC v1.1, we need 320s on source to reach $Ks = 19.0$ and 300s to get to $J = 21$. These values are for point sources in 1.0" seeing conditions measured in a 2" aperture. The actual depth will depend on the seeing, but according to the Paranal seeing statistics, seeing of ≤ 1.0" is reach approximately 75-80% of the photometric time. Therefore, *VDES* does not require good seeing conditions and we will accept a wide range of observing conditions.

The area we wish to cover is shown in Figure 1 and can be divided in 3 patches. The first is the DES/SPT area of 4000 deg^2 with RA coordinates of 20h–7h and DECs of -65deg to -30deg, and RA from 19h–20h and DECs from -65deg to -45deg. The second patch is the DES/SDSS connecting area of 800 deg^2 with RA coordinates from 1h20m to 3h20m and DECs from -1deg to -30deg. The final patch is the SDSS Stripe 82 area of 200 deg^2 with RA coordinates from 20h40m to 3m20m and -1deg to 1deg in DEC.

Our strategy will be to cover this whole area with the Ks filter first and then repeat the area with the J filter. The standard tiling strategy of 6 pawprints to cover a tile of approximately 1.5 deg x 1.0 deg is adequate for our purposes. In fact, it is well-suited to match the width of the DES equatorial strip with two adjacent VISTA tiles.

The expected bad pixels in the detectors is approximately 1.5%, and therefore any position of the sky needs to be observed with more than one pixel to be on the safe side. In the standard 6 pawprints to cover a tile, every position of the sky is imaged by at least two pixels. To avoid problems with bad pixels, we have decided to take three jitters in each tile so that every position of the sky is at least image with six different pixels. More jitters, although desirable, would make the overheads too expensive.

We have thus settled for a strategy in which each tile is taken with 6 pawprints in the standard VISTA fashion. For the Ks band each pawprint pointing is composed of 6 coadds of 9 second detector on-chip integration (DIT) exposure, and we take 3 jitters. This accounts for 324s on source per tile, with total exposure time per tile of 972s and total elapsed time per tile 1310s, with an observing efficiency per tile of 74.2%. For the J band, the maximum DIT time can be longer, and therefore we have settled for 2 coadds of 25s and 3 jitters. This combination gives 300s on source, 900s exposures per tile and a total elapsed time of 1166s with an observing efficiency of 77.2%. See table 5

In order to improve our efficiency, we will finish tiles before slewing to the next tile. Covering for example the area 3 times with a third of the exposure time each time (no jitters but visit the tile 3 different times e.g., once a year) would incur in too onerous overheads. Our strategy would also be to obtain contiguous tiles in each observing night, so as to minimise the slew time.

Although desirable, we do not require good seeing conditions and can observe with up to 1.2" seeing conditions. Photometric conditions are not required. We intend to calibrate our photometry with the 2MASS & UKIDSS surveys and therefore we have no photometric calibration overheads. We can also look for large–scale photometric calibration issues using the DES z band data, eg., studying the optical–IR colors of luminous red galaxies as a function of position over the entire *VDES* area.

Part of *VDES* overlaps with the KIDS survey (480 deg^2 in common). We will gladly coordinate with the VIKING/KIDS team to not re–image this area if their proposal is successful, as they plan to go slightly deeper than we do.

Table 5. Tiling exposure strategy

	Ks	J
Detector on-chip integration (DIT)	9.0 s	25.0 s
Exposure coadds (Ndit)	6	2
Exposure loops (Nexp)	1	1
Jitter pattern (Njitter)	3	3
Number of pointing (Npaw)	6	6
Time on source	324 s	300 s
Total exposure time per tile	972 s	900 s
Total elapsed time per tile	1310 s	1166 s
Observing efficiency per tile	74.2%	77.2%

6 Estimated Observing Time

6.1 Time justification

Our simulations indicate that we can reach our science goals if we reach limiting magnitudes of $Ks \sim 19$ and $J \sim 21$. According to the ETC v1.1, we need 320s in Ks and 300s in J, to reach this depth for point sources in 1.0" seeing conditions measured in a 2" diameter aperture. In fact our simulation are done taking into account these exposure times.

Taking into account the overhead implied by our observing strategy (see previous section) and adding an extra 5% time overhead for slews to acquire tiles, we estimate using the ETC that we need 1310 + 5% = 1375s in Ks and 1166 + 5% = 1224s in J per tile. To cover the DES area, without including the KIDS overlap (ie., 4500 deg^2 in total), we need 3000 tiles of 1.5 deg × 1.0 deg. The whole area thus requires 1146 hours in Ks and 1020 hours in J. The DES area distribution in the sky implies that 38% of the area is best accessed in the April-September semester and 62% in the October-March semester. Assuming ten hours per night in April-September semesters and 8 hours per night in the October-March semesters, the total time amounts to 133 nights for the Ks band and 118 nights in the J band.

In Table 6.1 we specify a possible time distribution per semester required by the survey for a completion time of 5 years. Approximately the first 2.5 years are devoted to the Ks band and the last 2.5 to the J band and assuming a 38% – 62% distribution into the April-Sept and Oct-march semesters with a start in semester P80.

Table 6.1. Estimated observing time for a 5 year survey completion

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P80	270	19h30m-07h00m	bright/grey/dark	1.2	clear
P81	165	19h30m-07h00m	bright/grey/dark	1.2	clear
P82	270	19h30m-07h00m	bright/grey/dark	1.2	clear
P83	165	19h30m-07h00m	bright/grey/dark	1.2	clear
P84	270	19h30m-07h00m	bright/grey/dark	1.2	clear
P85	165	19h30m-07h00m	bright/grey/dark	1.2	clear
P86	270	19h30m-07h00m	bright/grey/dark	1.2	clear
P87	165	19h30m-07h00m	bright/grey/dark	1.2	clear
P88	270	19h30m-07h00m	bright/grey/dark	1.2	clear
P89	165	19h30m-07h00m	bright/grey/dark	1.2	clear

7 Management Plan

7.1 Team Membership

Our team is an international collaboration of European and US scientists. Our team reflects the international composition of DES, which now has significant involvement from scientists across Europe, especially Spain and the UK. In particular, UK and Spanish groups are leading large and important aspects of the DES project, eg., the UK is leading efforts to design and construct the DES optical corrector, while Spain is leading the design and construction of the front–end camera electronics. Together with the CCDs, these are the 3 critical paths for DES success. Finally, there are over 20 European astronomers involved in the science leadership of the DES and *VDES* projects.

DES is in its final concept design review and expects funding in 2006 from both the Spanish and US funding agencies. PPARC (the UK funding agency) has already committed to "seek participation in the Dark Energy Survey project" which will probably involve the funding the aforementioned design and construction of the DES corrector.

The SPT project is fully funded and underway, with first light in 2006. John Carlstrom, the PI of the SPT, is a co-I of this proposal and therefore, we will be able to perform joint *VDES*+SPT analyses.

Therefore, DES/SPT is complementary to ESO's plans. The DES optical data (raw and reduced) will be available to everybody soon after completion, and thus the combination of *VDES*, DES & SPT will provide ESO astronomers with a unique resource with a powerful legacy value.

7.2 Team Management

The PI will be responsible for the managment of *VDES* and will form a small Management Council (MC) to help him manage this project. This MC will provide advice to the PI on all aspects of the *VDES* project, from observing strategy to data release policies and coordination with other surveys. The MC will represent the whole collaboration and will have members from many of the DES institutes and countries. The *VDES* MC will closely coordinate with the DES collaboration and their Management Council, and will provide peroidic reports to DES on the progress of *VDES*. Wherever possible we will share resources with DES. The *VDES* MC will also be responsible for any reporting to ESO and coordination with other ESO VST and VISTA proposals.

7.3 Coordination with the VDFS Team

As with other ESO public proposals, we plan to use the VISTA Data Flow System (VDFS; Emerson et al. 2004, Irwin et al. 2004, Hambly et al. 2004) to provide the ESO and US communities with a "standard" set of data products. The VDFS includes pipeline processing and management, delivery of agreed data products to the ESO Science Archive, production of a purpose-built IVOA compliant science archive with advanced datamining services and enhanced data products including federation of VISTA survey products with SDSS survey products. Standardised agreed data products produced by VDFS will be delivered to ESO, with copies remaining at the point of origin.

The VDFS is a collaboration between the UK Wide Field Astronomy Units at Edinburgh (WFAU) and Cambridge (CASU) coordinated by the VISTA PI (QMUL) and funded for VISTA by PPARC. The CASU team consists of Irwin, Lewis, Hodgkin, Evans, Bunclark, Gonzales-Solares, and Riello, while the WFAU team consists of Hambly, Bryant, Collins, Cross, Read, Sutorius and Williams. We will work closely with this team to maximise the science from *VDES*.

The VDFS is a working systems-engineered system that is already being successfully employed for the UKIRT WFCAM surveys as a test bed for the VISTA infrared surveys, and which is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system. We emphasise the track record over the last decade of both the Cambridge and Edinburgh survey units in processing and delivering large-scale imaging datasets to the community as exemplified by the WFCAM Early Data release (EDR, (`http://surveys.roe.ac.uk/wsa/dboverview.html`) Lawrence et al 2006, Dye et al 2006).

7.3.1 Catalogue Production

CASU will be responsible for the VDFS pipeline processing component of the *VDES* data and this software is already routinely processing data from UKIRT WFCAM at a rate of up to 250GB/night. It has also been used to process ESO ISAAC data e.g. the FIRES survey data and a wide range of CCD mosaic camera data. The pipeline is a modular design allowing straightforward addition or removal of processing stages and will have been tested on a range of input VISTA datasets. The standard processing includes: instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk; sky background tracking and homogenisation during image stacking and mosaicing – possible extras may include removal of other 2D systematic effects from imperfect multi-sector operation of detectors; assessing and dealing with image persistence from preceding exposures if necessary; combining frames if part of an observed dither sequence or tile pattern; producing a consistent internal photometric calibration to put observations on an approximately uniform system; standard catalogue generation including astrometric, photometric, shape and Data Quality Control (DQC) information; final astrometric calibration based on the catalogue with an appropriate World Coordinate System (WCS) placed in all FITS headers; photometric calibration for each generated catalogue augmented by monitoring of suitable pre-selected standard areas covering the entire field-of-view to measure and control systematics; frames and catalogue supplied with provisional calibration information and overall morphological classification embedded in FITS files; propagation of error arrays and use of confidence maps; realistic errors on selected derived parameters; nightly extinction measurements in relevant passbands; pipeline software version control – version used recorded in FITS header; processing history including calibration files recorded in FITS headers.

7.3.2 Science Archiving

The default VDFS science archive will include: individual passband 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. The database will also provide quality control procedures, as required and led by the public survey consortium, and supported by archive team members. All these features are available in the context of a continually updating survey dataset from which periodic releases (as required by the community) can be made.

Moreover, end-user interfaces were catered for from the beginning in the VDFS design process, and the philosophy has always been to provide both simple and sophisticated interfaces for the data. The former is achieved via simple point-and-click web forms, while the latter is achieved via exposing the full power of the DBMS back-end to the user. To that end, full access to Structure Query Language and the relational organisation of all data are given to the user. The science archive also has a high-speed query interface, linked to analysis tools such as TopCat, and advanced new VO services such as MySpace. Data products are being successfully ingested into the WFCAM Science Archive (WSA) in Edinburgh, with the EDR in Feb 2006, and the WSA concept was also demonstrated on the SuperCOSMOS Science Archive (SSA). `http://surveys.roe.ac.uk/ssa/`

The VDFS pipelines and archives will provide a standard set of data products to ESO:

- Instrumentally corrected frames (pawprints, tiles etc) along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
- Statistical confidence maps for each frame
- Stacked image data for dithered observations
- Derived catalogues (source detections from science frames with standard isophotal parameters, model profile fitted parameters, image classification, etc.)
- Data Quality Control database
- 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 re–measurement parameters from consistent list-driven photometry across all available bands in any one field

7.4 Beyond VDFS

In addition to providing the community with the standard set of VDFS data products, the *VDES* collaboration will also provide a series of advanced data products and a specific *VDES* data archive. Firstly, we will measure in the IR upper limits on the flux for any undetected DES, ATLAS or KIDS galaxy as such measurements are vital when working close to the flux limit of these joint surveys as well as for the detection of "dropouts". Likewise, we will provide summed fluxes from the imaging data of DES and SPT detected clusters. This will provide the best proxy for masses of these clusters.

Secondly, we plan to mirror the DES database in Europe using a distributed database between Barcelona and Portsmouth. We are already testing this technology (OGSA-DAI data grid middleware) to distribute the SDSS DR3 catalogue dataset. We will use terabyte storage facilities in Barcelona and Portsmouth to host the DES, VISTA and SDSS datasets next to each other and provide the community with a joined database of these three survey. This will be in addition to the VDFS database.

Finally, we will provide the community with a "Value–Added" (VA) database which will collate and coordinate derived quantities from both the DES and *VDES* surveys. In particular, we will store cluster catalogues, galaxy density maps (for ISW analyses), mask information, quasar probability (based on the NBC algorithm) and, most importantly, the photometric redshifts we will determine for galaxies (and quasars).

This VA database will be publicly available and provide these enhanced products through a simple user–interface. Several such VA databases have been constructed for the SDSS including the CMU–PITT VAGC (see `http://frank.phyast.pitt.edu/dr3/`). These databases greatly increase the science productivity of any survey.

8 References

Boughn, S., Crittenden, R., 2003, Nature 427, 45
Bridger, A., Proc. SPIE, vol. 5493, 411
Cole, S., et al., 2005, MNRAS, 362, 505
Collister, A., Lahav, O., 2005, MNRAS, 361, 415
Cooray, A., Huterer, D., Baumann, D., 2004, Phys.Rev. D69, 027301
Dye S. et al, 2006 in prep, The UKIDSS Early Data Release
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
Eisenstein, D., et al., 2005, astro-ph/0501171
Fairbairn, M., Goobar, A., 2005, astro-ph/0511029
Fosalba, P., Gaztanaga, E., Castander, F. J., 2003, ApJ, 597, 89
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
Hu, W., Scranton, R., 2004, Phys.Rev. D70, 123002
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 & Ishak, M., Upadhye, A., Spergel, D., 2005, astro-ph/0507184
Koyama, K., 2006, astro-ph/0601220
Lawrence A. et al, 2006 in prep, The UKIRT Infrared Deep Sky Survey
Lin, Y., Mohr, J., 2005, ApJ, 617, 879
Perlmutter, S., et al. 1999, ApJ, 517, 565
Pogosian, L., 2004, JCAP, 0504, 015
Pogosian, L., et al. 2005, Phys.Rev. D72, 103519
Richards, G., et al. 2005, ApJS, 155, 257
Riess, A. G., et al. 1998, AJ, 116, 1009
Sawicki, I., Carroll, S., 2005, astro-ph/0510364
Spergel, D., et al. 2003, ApJS, 148, 175
Scranton, R., et al., 2003, astro-ph/0307335
Scranton, R., et al., 2005, ApJ, 633, 589
Tegmark, M., et al. 2004, ApJ, 606, 702
Capak, P., et al. 2004, AJ, 127, 180
Lin, H., et al. 1999, ApJ, 518, 533
Poli, F., et al. 2003, ApJ, 593, L1
Wirth, G.D., et al. 2004, AJ, 127, 3121