1 Title: The VISTA Hemisphere Survey(VHS)

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1.1 Abstract:(10 lines max)

We propose to carry out a panoramic Infra-Red survey, which when combined with other VISTA Public Surveys will result in coverage of the whole southern celestial hemisphere ($\sim$20,000deg^2) to a depth $\sim$4 magnitudes fainter than 2MASS/DENIS in at least two wavebands J and K. In the South Galactic Cap, $\sim$5000deg^2 will be imaged to a higher depth, including H band, and will have supplemental deep multiband grizY imaging data provided by the Dark Energy Survey (DES). The remainder of the high galactic latitude sky will be imaged in YJHK to be combined with the VST ATLAS survey. The medium term scientific goals include: a huge expansion in our knowledge of the lowest-mass and nearest stars; deciphering the merger history our own Galaxy; measurement of large-scale structure out to $z \simeq 1$ and measuring the properties of Dark Energy; discovery of the first quasar with z>7; In addition the survey will provide essential support for the ESA Cornerstone missions; XMM-Newton, Planck, Herschel and GAIA.

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

2.1 Scientific rationale:

The primary aim of the VISTA Hemisphere Survey(VHS) is to provide a fundamental resource for European astronomers, which will be a springboard for research for many years to come. VISTA is the very first facility to make a deep IR sky survey plausible. This is therefore a key 21st century opportunity for astronomy. However, we can also anticipate several strands of direct scientific benefit, which we have used to determine the flux limits of the VHS.

2.1.1 The case for a 21st century IR sky atlas

Sky surveys are the core of astronomy. They represent a basic resource, are the main engine of discovery, are an efficient use of resources, and provide the very large statistical samples needed to address many problems. These strengths apply to any large survey project, but apply *a fortiori* to a **complete sky atlas**, and especially so as the age of the Virtual Observatory becomes a reality. The survey we propose has wider wavelength coverage than 2MASS and is also fifty times deeper. It is therefore the true IR equivalent of the historic Palomar-UK-ESO Schmidt visible light sky surveys of the second half of the 20th century, and we would expect it, like those surveys, to be a fundamental reference source for several decades. The following are the general advantages of a complete hemisphere survey :

(i) Any astronomical object or event found elsewhere can be searched for in the IR, regardless of location. (ii) In Euclidean space, time spent on increasing area increases *sample volume* much faster than spending time going deeper. The same argument applies to large statistical samples. (iii) Some rare but very important objects (eg z=7 QSOs, very nearby free floating planetary mass objects) may be present in only a handful of cases over the whole sky (iv) The chance of completely serendipitous discoveries is maximised, as is the realisation of new classes of object. (v) Some key scientific goals require intrinsically large angular area. The first key example is the structure of the Milky Way; the second is the large scale structure of the Universe, where we wish to minimise "cosmic shot noise". (vi) The same dataset can be used many times for many different projects. This is true at the design stage, as we demonstrate in the following sections, but will continue to be true for many years. This advantage of surveys in general is maximised for a hemispheric survey.

A true IR sky survey is clearly very desirable, but is plausible? The minimum sensible depth is essentially set by when overheads began to dominate. For a combination of overheads and science reasons we adopted four bands with the baseline sensitivity limits given in Table 1. The 20,000 square degree VISTA hemisphere survey to these depths can be completed within seven years on the schedule given in Table 3. This is ambitious but not unreasonable. This is therefore the first opportunity in history to construct a genuine deep IR sky atlas.

2.2 Selected Science Highlights

We highlight some of the key science goals that highlight the power of the VHS:

1. Cosmology with large-scale structure out to $z \simeq 1$ and the characterization of Dark Energy
2. Galactic structure and Galaxy Genesis; deciphering the merger history of our Galaxy.
3. The nearest star and lowest mass stars; the bottom of the stellar main sequence and the brown dwarf planet transition zone
4. Physics of the epoch of Reionization; Luminous high redshift($z>6.5$) quasars as probes of the epoch of reionization and the baryonic content of the high redshift Universe; The first $z>7$ quasar.
5. Synergy with VST ATLAS, KIDS/VIKING, AKARI(Astro-F), WISE, eROSITA

6. Supporting the ESA cornerstones, XMM-Newton, Planck, Herschel, and GAIA.
7. Legacy value, serendipity, curiosity and new classes of object, 21st century Infra-Red equivalent of the Palomar-UK-ESO Schmidt Surveys.

2.2.1 Cosmology with large-scale structure out to $z \simeq 1$ and the characterization of Dark Energy

A major goal of cosmology is to understand what the Universe is made of and how it evolves. Based on modern observational data, we now believe that the Universe is 5% ordinary baryonic matter, 25% dark matter and 70% dark energy. Our observations also reveal that the universe is accelerating. Unfortunately, we have little understanding of the nature of this "dark energy" (DE) that dominates the energy–density of the Universe, and its dynamics causing it to accelerate. This problem is now the most compelling issue in modern physics.

In the last months, the US Dark Energy Task Force and the ESA-ESO working group on fundamental cosmology have released their final reports. Both coincide in the need of wide field optical and near-IR imaging surveys to tackle the study and characterization of the DE equation of state $w(z)$ and highlight four complementary techniques to achieve this goal: large scale structure of the galaxy distribution including baryon acoustic oscillations, clusters of galaxies, weak lensing and supernovae. Each technique probes DE in a different way either sampling the expansion rate of the universe (standard candles, standard rodes and volume markers) and/or the growth rate of structure. Complementary to these thecniques, the Integrated Sachs-Wolfe (ISW) effect which can be probed cross-correlating the galaxy distribution with the CMB, provides an additional constraint on DE. All these techniques require large sample volumes and therefore large area at sufficient depth.

Moreover, given that the limiting factor will most probably be systematic errors in each individual technique, it is necessary to carry out as many techniques as possible. In addition, if we are to differentiate between different DE scenarios: a strange fluid with negative pressure or modified gravity; at least two methods sampling the expansion rate and the growth rate of structure are necessary. The Dark Energy Survey (DES; see appendix) fits perfectly in this framework as it is specifically designed to carry out these four techniques. An important ingredient is its overlap with the South Pole Telescope (SPT, see appendix) survey. Its main limitation is the lack of infrared data which limits its sampling power at redshifts $z > 1$. The current proposed survey provides the perfect synergy as it covers the same area in the South Galactic Cap, providing the necessary infrared data to achieve accurate photometric redshifts at high redshift $z \sim 1$.

Photometric Redshifts and constraints on w

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 DES 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 have carried out extensive simulations varying the total amount of time imaging in the near IR (J,H and Ks) and the distribution of this time between the filter combination used. We then analyse these mock catalogues using the ANNz photometric redshift software of Collister & Lahav (2005) and the BPZ code of Benítez (2000) to determine the likely photo-z errors as a function of the available optical and IR data. The four main techniques to characterize DE require accurate photo-z's to be able to constrain its equation of state, w. Our simulations show that at least 600s total exposure on the near IR bands is a good compromise to sufficiently improve the photo-z's and thus the constraints on DE. The distribution of the total time between the filters is not as important as the total time used. To illustrate the improvement with the addition of near IR data, we show in Figure 1 the constraints imposed on the w .vs. Ω_Λ plane using the Baryon Acoustic Oscillations (BAOs) imprinted on the galaxy distribution. The addition of the VISTA JHK data (total exposure of 600s) to DES data reduces the error ellipse by ∼50%.

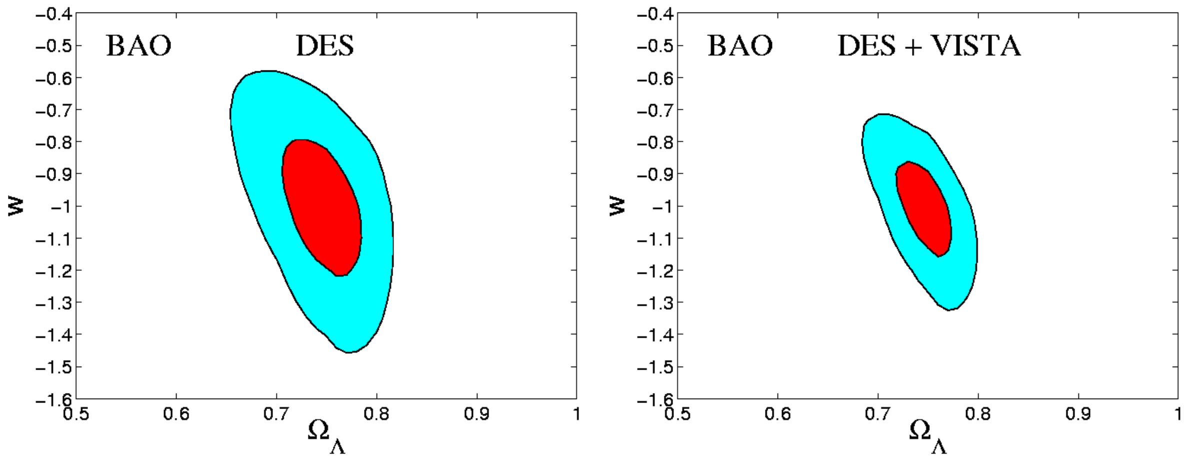

Figure 1: The expected 1σ (red) and 2σ (blue) likelihood contours for w (the equation of state of DE) versus Λ for just the DES (LEFT) and DES+VISTA (RIGHT) detections of the BAOs. These constraints are based on large N–body simulations. For the DES case, we assume 5000 sq degrees with $z_{max} = 1.3$ and 10 redshift bins of $dz = 0.13$. The DES+VISTA 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 $h = 0.7$

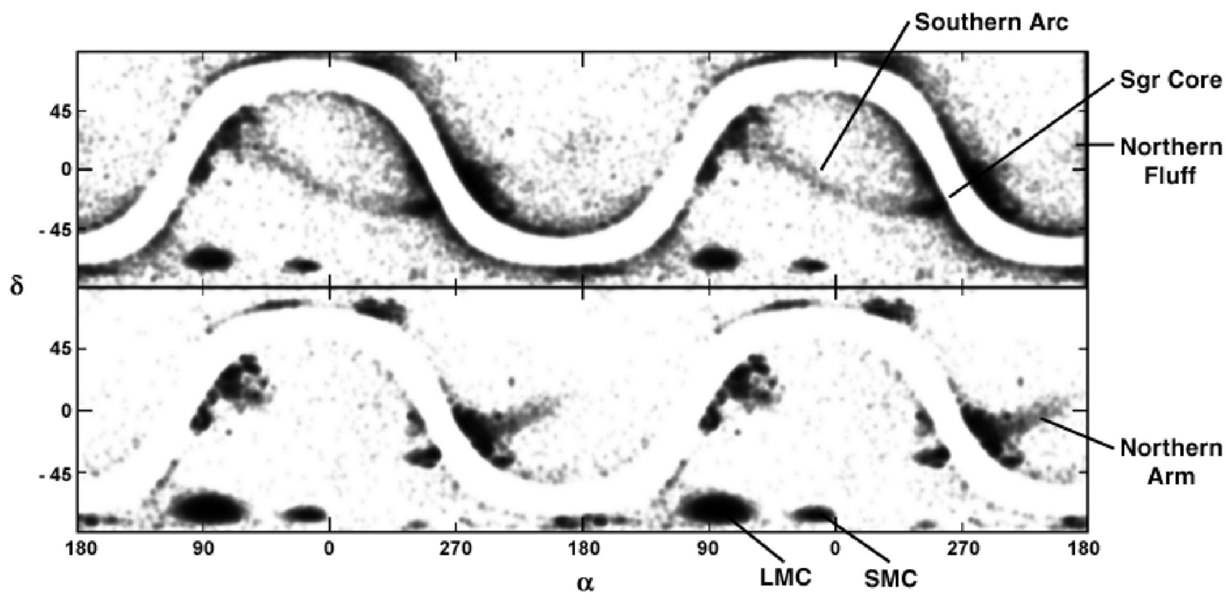

Figure 2: From Majewski etal. 2003; Smoothed maps of the sky in equatorial coordinates for two color-magnitude windows of the (nondereddened) 2MASS point-source catalog filtered optimally to show the Sagittarius dwarf(Ibata, Gimore & Irwin, 1994) southern arc (top) and the Sagittarius dwarf northern arm (bottom): 11 < Ks < 12 and 1.00 < J-Ks < 1.05 (top) , and 12 < Ks < 13 and 1.05 < J-Ks < 1.15 (bottom). Two cycles around the sky to demonstrate the continuity of features.

2.2.2 Galactic structure and Galaxy genesis

The origin and evolution of our own Galaxy is among the key unanswered questions in astrophysics. The Local Group of galaxies is thought to be typical of the general field population of the Universe and hence provides

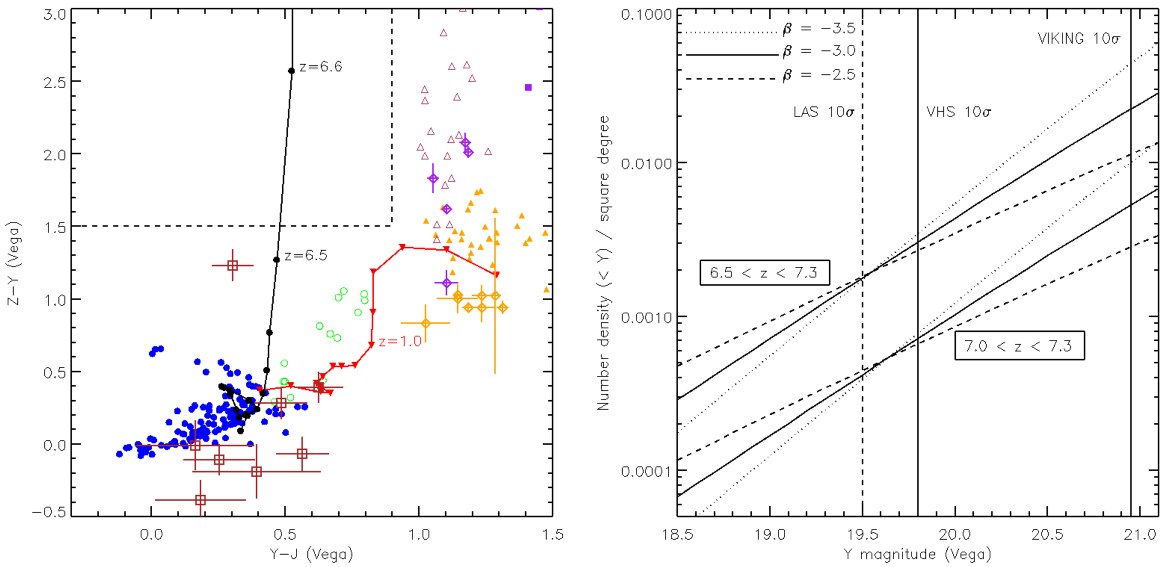

Figure 3: Left(a): z>6.5 quasar selection diagram; Z-Y vs Y-J diagram in Vega system with symbols as in (a). Note the isolated quasar near the z>6.5 selection boundary. This is the highest redshift quasar known(z=6.4). Right(b): Predicted surface density of z>6.5 quasars for VHS is the upper set of lines; the different linestyles are different bright end slopes as indicated. The lower set of lines shows the expected surface density of z>7 quasars. The predictions use the Fan etal(2004) space density at z∼6 and the Schmidt, Schneider, Gunn(1995) density evolution, decreasing with redshift, in the quasar space density. The two vertical lines indicate the 10σ Y[Vega] limits for the UKIDSS LAS and VISTA VHS and VIKING respectively

a unique opportunity to study the genesis of one galaxy in great detail. Although significant observational progress has been made recently we are still a long way from answering these questions.

λCDM cosmologies demonstrate the ubiquity of hierarchical merging as the main driver in galaxy formation and evolution, and the discovery of the tidally disrupting Sagittarius dwarf (Ibata et al. 1994) provided the first compelling nearby evidence of this. However, the detailed process by which large galaxies such as the Milky Way arrive at their current state is still largely speculative (eg. Abadi et al. 2003, 2006; Bullock and Johnston 2005; Font et al. 2006) despite recent observational and theoretical progress.

Existing large area surveys such as 2MASS and SDSS illustrate the crucial importance of all-sky coverage in deciphering the complex merger history of local structure in the outer disk and halo of our Galaxy (see Figure 2. However, 2MASS, although providing a new impetus to this subject (eg. Majewski et al. 2003; Martin et al. 2004), is limited in depth to relatively nearby structures in the Galaxy, particularly those seen in projection close to the Galactic Plane; while SDSS (and even the SEGUE extension) lack both the extinction penetration and areal coverage necessary to deliver a complete census of nearby substructure.

The combination of large area and NIR photometric coverage provided by the VHS provides enormous leverage in attacking these problems by enabling a range of structural probes in a multi-parameter space sensitive to both density and spectral types of objects. With the VHS we will be able to probe a factor of $\sim$ 40 fainter than 2MASS or a factor of 6 further in distance out to 50kpc for the stellar streams remnants of merger events associated with the formation and genesis of our Galaxy.

2.2.3 The lowest mass stars and the nearest star

SDSS and 2MASS have revolutionised studies of ultra-cool stars and brown dwarfs in the field, with the discovery of numerous L and T dwarfs in the solar neighbourhood. These surveys however, could only detect objects down to ∼1000K within 10pc of the Sun. Most of the late-L and T dwarfs discovered to date appear to be relatively young, relatively high-mass brown dwarfs (Burgasser et al 2003, 2006). Older, lower-mass objects are cooler, and remain as yet undiscovered, though they should exist in large numbers. To identify the coolest stars we need a survey in ZYJK bands to select objects which are red in ZYJ and blue in J−K due to methane. The main science goals are:

1. To identify the nearest and coolest brown dwarf to the Sun
2. To discover objects cooler than the T-dwarfs and define the new Y spectral class.
3. To measure the field brown dwarf luminosity function down to objects cooler than 400K, and thus derive the field substellar mass function down to the lowest mass objects that can form as stars.
4. To investigate the birth rate, galactic distribution and kinematics of cool field brown dwarfs.
5. To search for population II brown dwarfs.

The VISTA Hemisphere Survey has been carefully designed to detect objects as faint as 400K, corresponding to a $10M_J$ brown dwarf at an age of 1GYr (or a $20M_J$ brown dwarf at 5GYrs). Objects this cool have spectra dominated by H2, H20, CH4 and NH3 opacities and are brightest in the J-band, and are detectable in both the Y and J filters out to at least 15 parsecs. In the 10000 square degrees with Y band observations, the volume surveyed for 400K Y-dwarfs is $> 9000pc^3$, which is larger than the volume ($\sim 4000pc^3$) surveyed for T-dwarfs in the 2MASS all-sky survey. We also note that the VHS survey is more sensitive to Y-dwarfs than

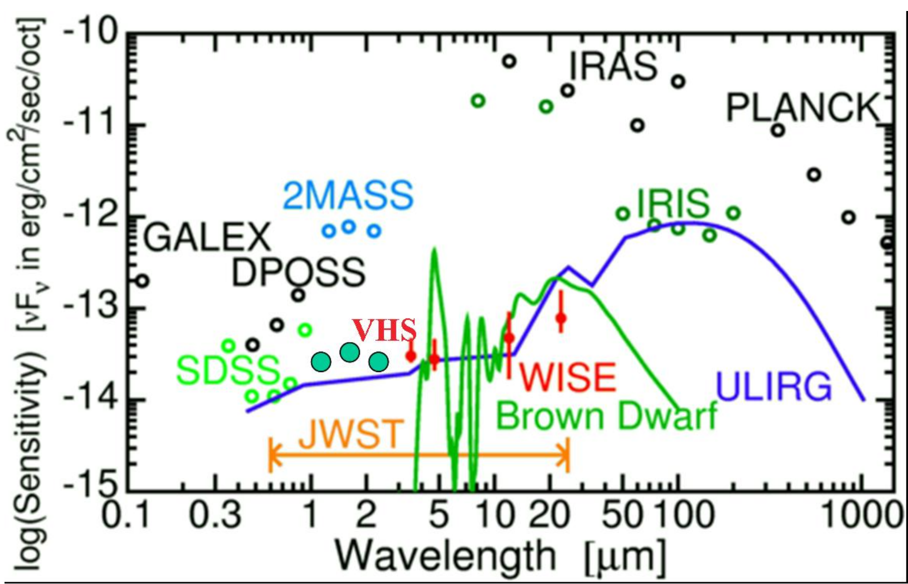

Figure 4: Sensitivity of various existing and planned sky surveys versus wavelength. This figure has been adapted (with permission) from that on the WISE web page at http://www.astro.ucla.edu/˜wright/WISE/. Note that "IRIS" here refers to AKARI, i.e. Astro-F, and are not the most up to date sensitivity figures. The vertical axis is νF_ν in units of energy per second per d(ln). The Brown dwarf is a model from Burrows etal of a 200K BD at a distance of 1.3 pc. VHS limits are large green circles.

the proposed NASA WISE 3.5-23 μm all-sky survey, which can only detect 450K Y-dwarfs out to 9pc in two passbands (Kirkpatrick 2003).

Y-dwarfs are predicted to be unusually red in Z/Y-J, and should be largely distinguishable from their Y-J colours alone. (see Figure **??**. Ultimately, a VHS proper motion survey (repeating one band, probably J, after $\sim$ 5 years) will be an additional efficient way to detect the nearest and coolest stars (Hambly & Deacon 2006), whilst also providing kinematic information. A second pass over the DES region would be ideally suited.

2.2.4 Probing the end of the dark ages; The first z>7 quasar and the baryonic state of the Universe during the era of reionization

After the epoch of recombination at z$\sim$1000, the Universe remained almost neutral until the first generation of luminous sources (massive stars, galaxies, accreting black holes formed. Quasars are the most luminous objects in the Universe and have been discovered out to a maximum redshift of z$\sim$6.4 by the SDSS. A single quasar at a redshift of above 7 would be of immense value and would allow us to determine the metal content, and ionization state of the the IGM at these redshifts.

However, the SDSS is unlikely to find any quasars beyond z$\sim$6.5 since the z waveband which is the reddest band in the SDSS survey is absorbed away by the Lyman-α forest. The VHS has been designed with the goal of extending surveys beyond z=6.5. Figure 3b show how the VHS will use the Z-Y versus Y-J to identify higher redshift(z>6.5) quasars. The Y-J colour is ESSENTIAL since the so called 'rare' L and T dwarfs outnumber the quasars by a factor of 200:1 based on the well established space densities of the foreground L and T dwarfs.

The proposed VHS survey will have a 10σ limit in Y of 20.4[Vega]; see Table 1. To distinguish quasars with z>6.5 from the more numerous galactic foreground L and T dwarfs requires Y$-$J<0.9. The Y-Z>1.5 constraint for Y=20.4 corresponds to a Z limit of 21.5(5σ). A 5σ rather than a 3σlimit is required to minimise Gaussian scattering of false positives. The expected surface densities as a function of redshift is shown in Figure **??**b.

BOTH Z and Y are required as show by Figure **??**a. Without the Y band one cannot distinguish the z>6.5 quasars from the more numerous L and T dwarfs which outnumber the expected number of quasars >100:1. A more speculative goal would be the discovery of z>7.5 quasars with Y$-$J>1.5(i.e. Y-drops) on the basis of selection using the YJK bands. The expected surface density of z>7.5 is 3 per 10,000deg^2 at the VHS 10σ J limit.

2.2.5 Synergy with other survey projects

The VISTA Hemisphere surveys is an excellent match with several other ongoing or imminent projects. Several of the key opportunities are with ESA missions - XMM-Newton, GAIA, Herschel, and Planck. These are discussed in Section 2.2.6 Other key opportunities are :

(i) *VST Atlas.* The VHS will be a useful resource for all VST surveys, but the best match is with the "VST Atlas" programme. This aims to cover 4500 sq. deg at *u g r i z* to the same depth as SDSS. VHS will of course detect redder and higher-redshift objects than ATLAS.

ii) *AKARI (Astro-F).* AKARI is a Japanese mission with some UK, ESA and Dutch involvement. It will make an all-sky FIR survey with resolution 30". Amongst other things it will produce a sample of 10^6 luminous IR galaxies to z$\sim$ 1. The match to VHS depth is excellent, yielding the prospects of photometric redshifts for more or less the whole of this key sample.

(iii) *WISE.* This is a NASA Midex mission, committed to making a public all-sky MIR survey from 3.5 to 23 microns. WISE is currently under construction and should be launched in 2009, part-way through the VHS programme. The match to VHS is excellent.

(iv) *eROSITA* This an MPE hard X-ray imaging survey(timescale about 2010-2012) which will discover some 10000 clusters of galaxies by means of their X-ray emission.

VST-ATLAS+SDSS together with VHS, WISE, and AKARI make a fantastic atlas dataset covering two decades of wavelengths. Figure 4 shows the expected survey depths.

2.2.6 Support for ESA missions; XMM-Nwwton, Herschel, Planck and GAIA

Europe has invested in a remarkable series of space astronomy missions. The VISTA Hemisphere Survey will help to extract the maximum value from these world-leading facilities.

(i) *XMM-Newton*. We are currently in a new golden age of X-ray astronomy, with *Chandra* and *Newton* between them representing unprecedented sensitivity and resolution. All XMM-Newton observations are being systematically processed and a serendipitous catalogue is being generated. The soon to be released 2XMM catalogue covers 600 square degrees (spread over the whole sky) and almost 10^5 X-ray sources, and this resource will continue to grow until 2010. A significant fraction of counterparts will be invisible in VST surveys - for example reddened quasars, and many stellar X-ray sources in the Milky Way - and other objects, such as distant clusters of galaxies, are more efficiently found in the IR, where the contrast is better.

(ii) *Herschel-Planck*. Planck and Herschel will be launched together in 2008 and represent a huge advance in FIR-submm astronomy. Herschel is a pointed mission operating from 60um to 670um. A significant fraction of sources found will have no counterparts at visible wavelengths. Of course many will require deeper K-band data to identify, but the VHS will be the first port of call before applying for deep observations. Planck will survey the sky at mm wavelengths. It is will also produce the first ever all-sky catalogue of mm-wave sources. Cross-matching with VHS will be a very high priority. Furthermore a key project will be cross-correlating the CMB with the galaxy clustering foreground measured by VHS, to measure the ISW effect.

(iii) *GAIA*. When launched in 2011, GAIA will make a revolutionary three dimensional map of the Milky Way. As well as astrometry of unprecedented accuracy for a huge number of stars, it will produce a photometric catalogue which VHS will extend into the IR. This can for example yield a three dimensional map of the extinction in the Milky Way - the parallaxes from GAIA give a distance, but the spectral type will often be unclear because of reddening; the visible-IR colour combination then gives spectral type, reddening, and absolute magnitude. VHS of course can also see things that GAIA can't - such as L, T and Y dwarfs, and their proper motions, and luminous objects such as Miras clean through the Galaxy. Adding VHS to GAIA then gives a more complete picture of the Milky Way. The NIR bands of the VHS will help to determine the extinction and to determine intrinsic stellar parameters, in particular the effective temperature and ultimately the intrinsic luminosity (the larger wavelength coverage also provides a more accuracte bolometric correction). In addition, the VHS data, when combined with Gaia optical photometry and astrometry, will increase significantly the number of cluster brown dwarfs and field ultra cool dwarfs discovered by either survey.

2.2.7 Legacy value

We have primarily made the scientific case for this survey in terms of medium-term science, which promises very large returns. However, we hope that these will be dwarfed by the science from projects we cannot yet anticipate. We expect the VHS to have a very long lifetime as a scientific tool. A replacement will only be created when one can obtain significantly deeper data, which means large amounts of 8-m telescope time. Since no such surveys are even in the planning stages, VHS is likely to be the premier near IR resource for 10 to 20 years. We have kept this in mind when designing the survey. A survey of the entire hemisphere means that astronomers will always be able to find their objects, or upper limits in the survey.

2.3 Immediate objective:

A prime objective for the VHS is to provide targets for follow-up with the VLT. By surveying a large area one can identify the brightest objects in any class of astrophysical object. Area is better than depth in the Euclidian regime since it maximises the survey volume.

The design of the VHS has been optimised to meet the shorter term needs of the science goals. The VHS sky coverage have been divided into 3 regions for planning purposes.

1. VHS-NGC (North Galactic Cap); $b > 30°$; $\delta < 0°$ (2500deg^2) Propose to start with the VST ATLAS region, excluding the VIKING region. Baseline exposures of 60secs per band.
2. VHS-SGC (South Galactic Cap); $b < -30°$; $\delta < 0°$ (8000 deg^2) JHK for 100secs over DES region on the assumption that the DES project will project provide matching Y and Z. YJHK for 60secs over the remainder of the SGC starting with region covered with VST ATLAS areas.
3. VHS-GPS (Galactic Plane Survey); $5 <| b |< 30$ deg (8500deg^2); J and K for baseline expsoures of 60secs per band.

We propose that initially the VHS-DES region is surveyed initialy with exposures of 100secs per band and then a second pass is is obtained in order to reach the full depth requested by the VDES proposal. This data will also provide a proper motion survey.

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

The VHS is similar in depth to the UKIDSS LAS survey, The VHS aims to cover a larger area to a similar depth over the same period of time.

The VISTA public survey VIKING shall cover a smaller area around a magnitude deeper. VIKING plans to survey in ZYJHK also,.

Below we summarise the magnitude limits proposed for the VHS.

Table 1: Baseline VHS Survey median sensitivity limits

Band	λ_{eff} (μm)	Exp (secs)	Seeing ”	Vega(AB) 10σ	Vega(AB) 5σ	Vega(AB) 3σ	Δ(Vega − AB)	μJy 5σ
Z	0.88	180	1.0	21.1(21.6)	21.9(22.4)	22.4(22.9)	0.53	6.9
Y	1.03	180	1.0	20.4(21.0)	21.2(21.8)	21.7(22.3)	0.63	7.6
Z	0.88	60	1.0	21.1(21.6)	21.9(22.4)	22.4(22.9)	0.53	6.9
Y	1.03	60	1.0	20.4(21.0)	21.2(21.8)	21.7(22.3)	0.63	7.6
J	1.25	60	1.0	19.4(20.3)	20.2(21.1)	20.7(21.6)	0.94	10.0
H†	1.63	60	1.0	18.4(19.8)	19.2(20.6)	19.7(21.1)	1.38	19.0
K_s	2.20	60	1.0	17.3(19.2)	18.1(20.0)	18.6(20.5)	1.90	36.3

Notes: † H band was not included in the original baseline VHS survey. (i) Limiting magnitude is for point sources in seeing of 1.0” and a software aperture with diameter 2.0”. (ii) The AB=0 normalisation in Jy is 3630Jy (iii) For 180sec add 0.6mags to 60sec depth and vice versa (iv) For 10σ limits subtract 0.75mags from 5σ limits. (iv) For 3σ limits add 0.50mags to 5σ limits. (v) For 1.4” seeing in 3.0” diameter aperture, exposures time to reach the same limits are 50 % longer ie. 90secs in J/K. (vi) might expect nominal K seeing to be better than Z seeing by 20% since seeing varies as $\lambda^{-1/5}$. (viii) ETC v1.3 using default 'Dark Sky Brightness' of Z = 18.2 Y = 17.2 J = 16.0 H = 14.1 KS = 13.0 and airmass 1.2. (ix) λ_{eff} and AB to Vega normalisation from Hewett, Warren, Leggett, Hodgkin etal, 2006.

3.1 UKIDSS Large Area Survey(LAS)

The UKIRT Infra-Red Deep Sky Survey(UKIDSS) started in May, 2005. UKIDSS is a multi-survey project and the element of UKIDSS that most closely relates to the VHS is the UKIDSS Large Area Survey(LAS). The LAS has already covered around ∼300deg^2 in YJHK of which ∼25deg^2 is public.

Our proposed VHS differs from the UKIDSS LAS in a number of different ways:

Table 2: UKIDSS LAS Survey; Median limits(5sigma in 2arcsec aperture)

band	sec	seeing median	Sky Brightness	Vega	AB	μJy	comments
					5σ		
i'	55	1.4	-	22.1	22.4	4.0	SDSS
z'	55	1.4	-	20.3	20.9	15.8	SDSS
Y	40	0.84	17.3	20.2	20.8	17.4	
J	2x40	0.83	16.0	20.0	20.9	15.8	
H	40	0.80	14.1	18.8	20.2	30.2	
K_s	40	0.74	13.5	18.2	20.1	33.1	

Notes: (i) UKIDSS limiting magnitudes are Median values are derived from data taken during the period May 2006 to Jan 2007. (ii) The J limit is an extrapolation from the current limits for the 40sec single epoch observations. (iii) SDSS limits are derived from actual data and are median limits for region covered by UKIDSS EDR. Also SDSS magnitudes are PSF magnitudes.

- UKIDSS LAS uses SDSS z' with a median 5σ limit(Vega) of 20.3. The VHS survey will have a Z(Vega) limit of 21.9 which is 1.6 magnitudes deeper. The extra depth comes from higher QE, and longer exposure times.
- The VHS Y band limit(5σ) is 21.2 compared with the UKIDSS LAS limit(5σ) of 20.2. The extra depth comes from higher QE and longer exposure times.
- The K limit for VHS is 0.1mag brighter than the LAS limit. This is a due to a combination of the brighter sky at Paranal and the poorer seeing assumed for the VHS(1.0 versus 0.8)

Overall, VISTA can survey sky faster than WFCAM by a factor of 3 neglecting weather so even for the same survey depth parameters the VHS could overtake the UKIDSS LAS in survey area.

3.2 VST ATLAS

TThe VST Atlas survey is aimed at surveying 4500deg^2 of the Southern Sky at comparable depths to the Sloan Digital Sky Survey (SDSS). This would be the first step at surveying the entire Southern Sky in the optical bands. VHS is a natural complement to the ATLAS survey.

3.3 Other VISTA surveys

The total survey requirements outlined in Table 4, assumes that no other VISTA survey is carried out. We are aware of a number of large area survey that each cover >100 deg^2; VVV(PI:Minniuti), GPS(PI: Lucas) and VMC(PI: Cioni) surveys, VIKING(PI: Sutherland).

The boundaries of these surveys are shown on Figure **??** Whilst VHS does not need to cover the areas that are covered by these surveys there may to be some observing time scheduled, if the different surveys use different filter combinations to ensure that colour-magnitude diagrams can be cross-calibrated for each survey.

4 Observing strategy: (1 page max)

The science goals require that we cover the whole southern sky in a minimum of two wavebands and ZYJHK and over the high galactic latitude sky. In the first instance Z will come for the VST ATLAS survey or the CTIO DES project.

We assume 1.0" seeing in each filter and 5sigma detection limits in a 2arcsec diameter aperture. Baseline exposure times of 60 seconds in all all bands are assumed except over the DES region where we propose 100secs in JHK.

Because of potential variables we ideally wish to get at least two (ideally more) filters observed within 20 minutes of each other by having them in the same OB. For example studies of the variability in a 4Myr-old OB association by Naylor (priv comm) finds that more than 1 percent of the stars have varied by more than 0.05 mags within 2 hours. So if you are looking for rare objects, say if you expect 1 in a hundred stars to deviate from some colour relationship by 0.05 mags, a time separation of 2 hours destroys such a study because 1% will have varied by that amount in 2 hours.

But for the increased Z and Y background in bright time we would do a tile in all 4 filters which would fit within a one hour OB. However experience with WFCAM on UKIRT suggests the increased sky background at bright in Z and Y is significant so we content ourselves with getting at least two filter in the same OB. OBs containing Y will be carried out away from bright time. OBs containing J H and K_s can be carried out even in bright time.

There is little speed to be gained in shortening exposure times much below 60secs since overheads such as read out, disk i/o and telescope motion start to dominate.

We not jitter for the 60sec obseravtions relying on the 2nd pawprint of the tile to cover any bad pixels on the first. In the longer exposure DES region observatins 2 jitters are proposed.

The distribution of observing time request with period over the first 10 Periods is given in Table 3 assuming a 14 period length of the whole survey. It includes steps towards the 20,000 sq deg single coverage and additionally each Period 41 hrs in Z and Y and 17 hrs in J and Ks for the repeats on the 300 sq deg dec=0 strip for variability and proper motions.

Table 3: VHS Observing Time Request by Observing Period

Period	Time (h)	Mean RA	Moon	Seeing	Transparency	Comment
P79(Apr'07 - Sep'07)	422 (ZY)	18h	dark	0.8-1.4	THIN, CLEAR	
P79(Apr'07 - Sep'07)	176 (JKs)	18h	bright	0.8-1.4	THIN, CLEAR	
P80(Oct'07 - Mar'08)	422 (ZY)	06h	dark	0.8-1.4	THIN,CLEAR	
P80(Oct'07 - Mar'08)	176 (JKs)	06h	bright	0.8-1.4	THIN, CLEAR	
P81(Apr'08 - Sep'08)	422 (ZY)	18h	dark	0.8-1.4	THIN, CLEAR	Planck, Herschel launch
P81(Apr'08 - Sep'08)	176 (JKs)	18h	bright	0.8-1.4	THIN, CLEAR	
P82(Oct'08 - Mar'09)	422 (ZY)	06h	dark	0.8-1.4	THIN, CLEAR	Planck, Herchel reach L2
P82(Oct'08 - Mar'09)	176 (JKs)	06h	bright	0.8-1.4	THIN, CLEAR	
P83(Apr'09 - Sep'09)	422 (ZY)	18h	dark	0.8-1.4	THIN, CLEAR	
P83(Apr'09 - Sep'09)	176 (JKs)	18h	bright	0.8-1.4	THIN, CLEAR	
P84(Oct'09 - Mar'10)	422 (ZY)	06h	dark	0.8-1.4	THIN, CLEAR	WISE launch
P84(Oct'09 - Mar'10)	176 (JKs)	06h	bright	0.8-1.4	THIN,CLEAR	
End of first 3 year plan	N.B. We will choose VST-ATLAS fields early to match it					

5 Estimated observing time:

5.1 Time justification: (1 page max)

Table 4 gives the parameters of the survey and the elapsed hours required to complete it.

In practise (see strategy above) we will use OBs each containing 2 filters and allowing for the 25 sec filter change

Table 4: VHS Original Survey parameters

	Z	Y	J	H	K_s
Detector Integration Time (DIT) s	45	45	10	-	10
Exposure co-adds (Ndit)	1	1	3	-	3
Exposure loops (Nexp)	1	1	1	-	1
Jitter pattern (Njitter)	2	2	1	-	1
Microsteps	none				
pawprints	6				
Time per object s	180	180	60	-	60
Depth (5 σ) Vega	21.9	21.2	20.2	-	18.1
Total exposure time per tile s	540	540	180	-	180
Total Elapsed time per tile s	710	710	284	-	284
Observing efficiency % per tile	76.1	76.1	63.4	-	63.4
Time for 20,000 sq deg = 13,333 tiles of 1.5 sq deg					
Total Elapsed Hours	2,667	2,667	1,111	-	1,111

Table 5: VHS DES Survey parameters

	Z	Y	J	H	K_s
Detector Integration Time (DIT) s	45	45	10	10	10
Exposure co-adds (Ndit)	1	1	3	3	3
Exposure loops (Nexp)	1	1	1	1	1
Jitter pattern (Njitter)	2	2	1	1	1
Microsteps	none				
pawprints	6				
Time per object s	180	180	60	-	60
Depth (5 σ) Vega	21.9	21.2	20.2	-	18.1
Total exposure time per tile s	540	540	180	-	180
Total Elapsed time per tile s	710	710	284	-	284
Observing efficiency % per tile	76.1	76.1	63.4	-	63.4
Time for 20,000 sq deg = 13,333 tiles of 1.5 sq deg					
Total Elapsed Hours	2,667	2,667	1,111	-	1,111

each will take 2*710+25 elapsed time, so that 13,333 tiles in Z and Y will take 5,333 hours.

Similarly for J and K_s allowing for the 25 sec filter change each would take 2*284+25 elapsed time, so that 13,333 tiles in J and K_s will take 2,222hours.

If this is spread over 14 observing periods we require 381 hours in Z and Y and 159 hours in J and K_s in each period. We shall need no time for photometric calibration since we shall use the general VISTA calibrations and use 2MASS for the photometric calibration.

Clearly there may be other VISTA Public surveys of significant parts of the hemisphere, for example the galactic plane, the VST-KIDS area, the VST-ATLAS area, the bulge, the Magellanic clouds etc and it will be necessary for efficiency to share data between the various surveys covering the same areas to different depths. The details of how to do this will be discussed with other surveys as directed by the PSP in due course, and the areas required to be covered in the VHS here could be reduced in the observational sense, though still included in the released survey to a uniform depth.

Table 6: VHS ATLAS Survey parameters

	Z	Y	J	H	K_s
Detector Integration Time (DIT) s	45	45	10	10	10
Exposure co-adds (Ndit)	1	1	3	3	3
Exposure loops (Nexp)	1	1	1	1	1
Jitter pattern (Njitter)	2	2	1	1	1
Microsteps	none				
pawprints	6				
Time per object s	180	180	60	-	60
Depth (5 σ) Vega	21.9	21.2	20.2	-	18.1
Total exposure time per tile s	540	540	180	-	180
Total Elapsed time per tile s	710	710	284	-	284
Observing efficiency % per tile	76.1	76.1	63.4	-	63.4
Time for 20,000 sq deg = 13,333 tiles of 1.5 sq deg					
Total Elapsed Hours	2,667	2,667	1,111	-	1,111

Table 7: VHS GPS Survey parameters

	Z	Y	J	H	K_s
Detector Integration Time (DIT) s	45	45	10	10	10
Exposure co-adds (Ndit)	1	1	3	3	3
Exposure loops (Nexp)	1	1	1	1	1
Jitter pattern (Njitter)	2	2	1	1	1
Microsteps	none				
pawprints	6				
Time per object s	180	180	60	-	60
Depth (5 σ) Vega	21.9	21.2	20.2	-	18.1
Total exposure time per tile s	540	540	180	-	180
Total Elapsed time per tile s	710	710	284	-	284
Observing efficiency % per tile	76.1	76.1	63.4	-	63.4
Time for 20,000 sq deg = 13,333 tiles of 1.5 sq deg					
Total Elapsed Hours	2,667	2,667	1,111	-	1,111

6 Data management plan: **(3 pages max)** *[Based on VDFS DMP v3.0]*

6.1 Team members:

6.2 Detailed responsibilities of the team:

We will 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 IVOA compliant science archive with advanced datamining services; 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 VDFS is a working systems-engineered system that is already being successfully employed for the UKIRT WFCAM sur-

Table 8: Responsibilies and Group Leaders

Name	Function	Affiliation	Country
R. McMahon	PI	University of Cambridge	UK
A. Lawrence	Deputy/Co-PI	University of Edinburgh	UK
J. Emerson	VDFS PI	Queen Mary University of London	UK
CASU (VDFS) team†	Pipeline processing	University of Cambridge	UK
CASU (VDFS) team†	Data Quality Control-I	University of Cambridge	UK
WFAU (VDFS) team‡	Science Archive	University of Edinburgh	UK
WFAU (VDFS) team‡	Data Quality Control-II	University of Edinburgh	UK
N. Walton	VO Standards	University of Cambridge	UK
VHS Survey specific tasks			
TBD	OB Preparation Working Group		
TBD	Survey Progress Working Group		
T. Naylor	VISTA Surveys cross-calibration Working Group	University of Exeter	UK
R. McMahon	Data Quality control and validation Group	University of Cambridge	UK
TBD	Astrometry Working Group		
TBD	Galaxy Photometry Working Group		
TBD	Stellar Photometry Working Group		
F. Castander	DES Cordination Working Group		
F. Carrera	XMM-Newton Working Group	Santander	Spain
C. Bailer-Jones	GAIA Working Group	MPIA	De
J. Emerson	Photometric Calibration Working Group	UK	
S. Oliver	Herschel Working Group	Sussex	UK
G. Lagache	Planck Working Group	IAS, Paris	Fr
H. Rottgering	LOFAR and radio surveys Working Group	Leiden	NL
N. Lodieu	Galactic Cluster Working Group	Leicester	UK
TBD	Nearby Galaxy Working Group		
TBD	Galaxy Cluster Working Group		
TBD	Solar System Working Group		

Notes: † The CASU (VDFS) team consists of Irwin, Lewis, Hodgkin, Evans, Bunclark, Gonzales-Solares, Riello. ‡ The WFAU (VDFS) team consists of Hambly, Bryant, Collins, Cross, Read, Sutorius, Williams.

veys 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).

The observation planning team is a sub-set of the Data Processing and Quality control teams. They are responsible for generating the OBs using the Survey Area Definition Tool and P2PP and for revising these and monitoring survey progress using a local Data Quality Control database as necessary.

Experience shows that the a full scientific validation is only possible when people start trying to do science with the data. Thus we will also have a number of Scientific Working groups (following the themes of the goals listed in the Objectives). Any problems found by these teams will be addressed by the appropriate Functional Working Groups.

6.3 Data reduction plan:

The data reduction will be using the VDFS, operated by the VDFS team, and augmented by individuals from the VHS co-Is, especially for product definition and product Quality Control. We divide the plan into two distinct but intimately related parts: pipeline processing and science archiving. Much greater detail can be found in the SPIE papers cited previously,

6.3.1 Pipeline processing

The Cambridge Astronomy Survey Unit (CASU) are responsible for the VDFS pipeline processing component which has been designed for VISTA and scientifically verified by processing wide field mosaic imaging data from UKIRT's NIR mosaic camera WFCAM and is now routinely being used to process data from the 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.

The pipeline processing centre hosts a data quality database that is updated daily with the data quality control information for pipeline processed products.

6.3.2 Science archiving

The concept of the science archive (SA, Hambly et al. 2004 and references therein) is key to the successful exploitation of wide field imaging survey datasets. The SA ingests the products of pipeline processing (instrumentally corrected images, derived source catalogues, and all associated metadata) into a database and 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 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. Archive curation includes 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.

We have developed a generalised relational model for survey catalogue data in the VDFS. The key features to note are the normalised design with merged multi-waveband catalogue data (the table of most use for scientific queries) being part of a related set of tables that allow the user to track right back to the individual source images if they require to do so; and also that the merged source tables (as derived either from individually analysed images, or consistently across the full passband set available in any one field) are seamless, and present the user with a generally applicable science-ready dataset. Similar relational models describe the organisation of all data in the science archive (image, catalogue, calibration metadata, etc.) - see Hambly et al. (2004) and references therein. The science archive has a high-speed query interface, links 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/*

6.4 Expected data products:

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 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 survey observations
T0+4months; ESO-wide release of science products from first month of survey observations
T0+6month; ESO-wide release of science products from first 3 months of survey observations
Thereafter we would hope that science products can be released 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

7 Envisaged follow-up: (1 page max)

We summarise below the types of follow-up observation that are envisaged for the science highlights identified in section 2.

7.1 Large scale structure

Much of the core science in this area can be performed with photo-z estimates alone. It will be important to have an extensive set of spectroscopy to calibrate these. At the brighter level, this exists via the 2MASS-selected 6dF Galaxy Survey. For fainter objects, a variety of large Southern galaxy redshift surveys are currently being proposed using AAOmega on the AAT. These may be expected to provide spectroscopic datasets at an appropriate depth for VHS (roughly r=20-21) of order a few times 100,000 objects over the next five years. In the longer term, as VHS progresses, there will be a case for seeking to use AAOmega to carry out larger-scale VHS-selected surveys, which will be deeper analogues of the 6dFGS.

7.2 Galactic structure and Galaxy Genesis

Deeper imaging may be required to corroborate any streams that are identified. The main follow-up will be velocity disperion work which could use FLAMES or FORS1/2.

7.3 HZQs

Will require candidate screening with ISAAC imaging and spectroscopy. Also X-Shooter for detailed follow-up; 1night per object; upto 10nights for 'best' objects.

7.4 Cool and low mass stars

Additional deep H, and possibly deeper K, imaging will be used to confirm Y dwarfs candidates, before proceeding to NIR spectroscopy with e.g. ISAAC.

7.5 Galactic Cluster Survey

The surveys conducted in each cluster will provide hundreds of candidates to be followed up spectroscopically. Many contaminants will be rejected on the basis of their Z-K, and J-K colours. Second epoch observations will provide proper motions for several clusters and weed out field dwarfs. Follow-up observations include multi-fibre optical spectroscopy with AAOmega on the AAT, Flames on the VLT, as well as near-infrared spectroscopy of the faintest and coolest members. Low-resolution optical spectroscopy will provide Hα equivalent width measurements to infer chromospheric activity, equivalent widths for gravity-sensitive doublets, and lithium measurements. Higher resolution optical spectroscopy will determine the radial velocities, yielding another criterion for membership assessment. The main goal is to obtain complete population of spectroscopically confirmed stellar and substellar members in open clusters and star-forming regions. We can also derive lithium age for open clusters with ages between 30 and 100 Myr.

8 Other remarks, if any: (1 page max)

Our team is large as befits such an undertaking. We have a broad range of science experience from cosmology, weak lensing, large surveys, high-redshift quasars, galaxy properties to Galactic science. The VISTA PI, VISTA Project Scientist, and VISTA Camera Scientist, and the leaders of the VDFS Pipeline and Archive are co-Is and and so we have extensive experience with the technical issues for VISTA and its data handling. We are well equipped to deliver a high-quality science product and believe that the VHS survey will have lasting long-term value to the whole ESO, and indeed world, community.

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Appendix A The Dark Energy Survey(DES) and South Pole Telescope(SPT)

In this appendix we provide a brief description of the Dark Energy Survey and the South Pole Telescope that complement the current proposal.

A.1: The Dark Energy Survey(DES)

The Dark Energy Survey project is led by Fermilab and includes groups from Spain and the UK. The main science goal of the Dark Energy Survey (DES, http://www.darkenergysurvey.org) is to characterize dark energy measuring its equation of state through four independent probes: galaxy clusters, weak lensing, galaxy clustering and baryon acoustic oscillations and supernovae.

In order to achieve this goal, the survey needs to sample large volumes at different redshifts (needs wide area coverage and depth); needs to have good spectral coverage and good photometry; needs to deliver good image quality and needs to perform repeat imaging for SNe. For that purpose, the DES collaboration is building a large camera, the Dark Energy Camera (DECam). Figure 5 shows a cross section of DECam. The major components of the instrument are a 500 megapixel optical CCD camera, a wide-field optical corrector (2.2^o diameter field of view), a 5-band filter system with SDSS g, r, i, z and Y filters, guide and focus sensors mounted on the focal plane, low noise CCD readout, a cryogenic cooling system to maintain the focal plane at 180 K as well as a data acquisition and instrument control system to connect to the Blanco observatory infrastructure.

The camera focal plane will consist of sixty-two 2K x 4K CCDs (0.27"/pixel) arranged in a hexagon covering an imaging area of 3 deg^2. Smaller format CCDs for guiding and focusing will be located at the edges of the focal plane (see Figure 5. To efficiently obtain the z and Y band images at high redshift ($z \sim 1$) we selected the fully depleted, high resistivity, 250 micron thick silicon devices that have been designed and developed at the Lawrence Berkeley National Laboratory (LBNL) (Holland et al, 2003). The QE of these devices is $> 80\%$ QE in the z band and $\sim 50\%$ in the Y band, considerably higher than traditional thinned astronomical devices. The optical corrector design consists of five fused silica lenses that produce an unvignetted 2.2 deg diameter image area, which is calculated to contribute < 0.4" FWHM to the point-spread function. There will be some space between elements 3 and 4 to allow the filters to be individually rotated in and out of the optical path. DECam will be installed in a new prime focus cage. We have adopted the Monsoon CCD readout system developed by NOAO that is being tested and adapted to DECam at FNAL and Spain.

The DES will use DECam to cover 5000 deg^2 of the Southern Hemisphere divided in three subareas (see Figure 1a). The SPT overlapping area will be 4000 deg^2, the SDSS equatorial stripe 82 will cover 200 deg^2 and a connecting area of 800 deg^2. The survey is to be completed in 5 years using 30% of the Blanco time. To carry out the SN program, there will be a 40 deg^2 area sampled every three nights in one filter and every six nights in two filters. The survey will be done in 5 bandpasses, $grizY$. The limiting AB magnitudes will be $g \sim 24.6$, $r \sim 24.1$, $i \sim 24.3$, $z \sim 23.8$ and $Y \sim 21.6$, for small galaxies at 10σ. There will be several exposures in each filter to ensure an efficient tiling and proper coverage. The whole area will be imaged in the five filters in the first two years so that substantial science can be delivered early. Observations will be taken in 525 nights

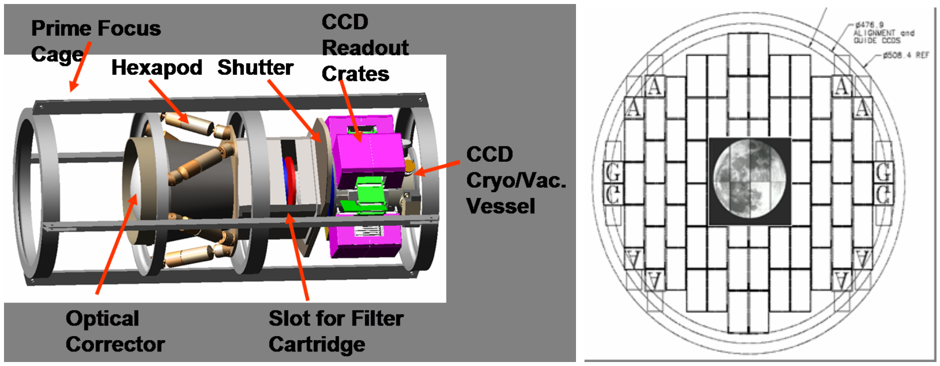

Figure 5: Left: Cross-section of the DECam. Right: Focal plane arrangement of the CCDs in DECam

during the September-February period, starting in 2010 and finishing in 2015. The data will be public with an expected release schedule similar to the SDSS, e.g. one year.

Table 8. Five filter survey strategy

Year	filter	Area deg^2	Total tilings	Integration time	Total integration time	AB magnitude 10σ
1	g	5000	1	100	100	23.8
	r	5000	1	100	100	23.3
	i	5000	2	200	200	23.3
	z	5000	2	200	200	22.6
	Y	5000	2	200	200	21.2
2	g	5000	2	100	200	24.2
	r	5000	2	100	200	23.7
	i	5000	4	200	400	23.6
	z	5000	4	200	400	23.0
	Y	5000	4	200	400	21.6
3	g	5000	4	200	400	24.6
	r	5000	4	200	400	24.1
	i	5000	6	200	600	23.8
	z	5000	6	200	600	23.2
	Y	5000	4		400	21.6
4	g	5000	4		400	24.6
	r	5000	4		400	24.1
	i	5000	10	400	1000	24.1
	z	5000	10	400	1000	23.5
	Y	5000	4		400	21.6
5	g	5000	4		400	24.6
	r	5000	4		400	24.1
	i	5000	12	200	1200	24.3
	z	5000	16	600	1600	23.8
	Y	5000	4		400	21.6

8.1 A.2 The South Pole Telescope(SPT)

The DES will overlap by design with the South Pole Telescope (SPT, http://spt.uchicago.edu) survey. This synergy will greatly enhance the cluster science that can be delivered by both surveys.

Starting in 2007, the SPT will conduct a deep, wide area (4000 deg^2) galaxy cluster survey using the Sunyaev-Zeldovich (SZ) effect. The SPT is a 10-meter submillimiter-wave telescope, located in Antartica and designed to conduct large surveys with high sensitivity to low surface brightness emission such as SZ measurements and CMB temperature and polarization anisotropy. To this end the telescope uses an off-axis optical design, has a large field of view ($\sim$1 deg^2 at λ=2mm), employs three levels of shielding and is sited under the exceptionally clear and stable atmosphere at the South Pole. The SZ survey will be conducted with a 1000 element bolometric focal plane array. The survey is expected to start in 2007. The survey goal is to cover 4000 deg^2 (overlapping with the DES) with 10 μK sensitivity per 1' pixel to the SZ effect at an effective frequency of 150 GHz. The survey is expected to yield $\sim 10^4$ clusters with masses greater than 2×10^{11} $M_\odot$.

Appendix B: Response to PSP Report

PSP Panel Issue 1 The proposal aims to image the entire Southern celestial hemisphere in four bands. The panel agreed that the proposal has a large legacy value. However the total time required is very large and the PSP believes that covering the sky in J+K is a considerably higher priority than Z+Y.

Response: The original VHS proposal was a 7 year program which aimed to survey the full 20,000deg^2 of southern celestial hemisphere with exposure times of 180, 180, 60, 60 seconds in Z, Y, J and K respectively. This required a total time of 7359hrs based on VISTA ETC(v1.1). With the new VISTA ETC(v1.3) this reduces to a total of 6750hrs.

In this resubmission we have excluded the regions that will be covered by VIKING(1500deg^2), the Magellanic Clouds(200deg^2) and galactic plane region with $\mid b \mid < 5\,\mathrm{deg}$ (1800deg^2). In the case of the Galactic plane, this region is either covered by the VVV proposal or confusion may be an issue. This is an issue that needs to be evaluated in the future.

We have reduced the exposure time request in Y and Z per band from 180secs to 60secs. The deeper exposure science goals can be partially met in the short term by the VIKING proposal. We have retained the Y and Z observations over the region that will be covered by VST ATLAS.

Part of the South Galactic Cap will be surveyed by the DES project with the CTIO 4m in z so the current VHS submission takes this into account. The DES project is committed to include the Y filter in their survey if VISTA images the DES area in the near IR to a sufficient depth. See letter from the DES Project Director.

PSP Panel Issue 2 At the beginning of the proposal, it is mentioned that 7500 deg2 could be surveyed in Z+Y initially, but the proposal does not explicitly discuss which 7500 deg2 of the sky are considered.

Response: The specific 7500deg^2 was intentionally left vague except to specify that VHS should cover the VST ATLAS regions.

PSP Panel Issue 3 The proposers do not discuss the science goals behind the annual scan of the SDSS SGC equatorial strip. How much time is being devoted to this? Is it important to do this in all filters?

Response: We have removed the multi-epoch part of the proposal. However we have retained a single epoch for the purposes of photometric redshift calibration with SDSS, 2DF and other redshift surveys in this region. This training set is essential for the large scale structure studies based on photometric redshifts.

PSP Panel Issue 4 The proposers discuss prioritizing the targets but it is not clear why that particular strategy was selected, nor what scientific gains would accrue. Since this approach would certainly have an impact on the efficiency of the survey, the proposers should discuss the detailed observing plan and the perceived advantages and costs .

Response: Due to space requirements we did not give an lengthy description but provided these as examples of how in the short term, the scientific return of an large area survey could be maximised. In section 2.2.6 we had described in detail the case for galactic clusters.

The list of high scientific value fields has been removed since we accept that this may be impractical due to scheduling constraints and observing efficiency.

PSP Panel Issue 5 The Panel strongly recommends that the PI submits a new proposal which focused on the science that can be achieved by covering the whole southern sky in J+K only. If the PI wishes he could add, as an option to be implemented at a later date, the additional observations in the Z+Y filters. Of course the incremental scientific objectives that could be achieved with these observations should also be part of the optional proposal. The panel felt that this strategy could provide a legacy database at the earliest opportunity.

Response: Many of the science goals proposed by the survey team are not satisfied by a survey that is in J+K bands alone. After careful consideration we have therefore retained an element of the Z and Y program in the proposal. We believe that this approach would both, deliver more scientific return in the short term and also deliver a higher value legacy survey for the ESO community.

The VHS sky coverage have been divided into 3 regions:

1. VHS-NGC (North Galactic Cap); $b > 30°$; $\delta < 0°$ (2500deg^2) JKs and (Z)YH for 60secs per band. Propose to start with the VST ATLAS region, excluding the VIKING region.
2. VHS-SGC (South Galactic Cap); $b < -30°$; $\delta < 0°$ (8000 deg^2) JHK for 120secs over DES region on the assumption that the DES project will project provide matching Y and Z. (Z)YJHK for 60secs over the remainder of the SGC starting with region covered with VST ATLAS.
3. VHS-GPS (Galactic Plane Survey); $5 <| b |< 30\,\mathrm{deg}$ (8500deg^2); J and K for 60secs per band

We propose that initially the VHS-DES region is surveyed with expsoures of 120secs per band and then a second pass is is obtained in order to reach the full depth requested by the VDES proposal.

PSP Panel Issue 6 The panel asks the PI to contact Castander to discuss the Z+Y imaging in the area of the sky proposed by Castander (to be observed by DES) and to determine how this would add to the scientific objectives of the survey.

Response: The PI and Castander have met and discussed the Z+Y imaging.

The proposed CTIO 4m DES survey will cover 5000deg^2 of the South Galactic Cap. The DES design reference survey strategy is to survey the full 5000deg^2 in year 1 for 200secs per band reaching 10sigma limits[AB mags] in g, r, i and z of 24.1, 23.7, 23.3 and 22.6 respectively. The same strategy is planned in year 2. The goal for the full 5 years is a total exposure of 400, 400, 1200, 2000 secs in g, r i and z respectively with 10sigma limit of 24.6, 24.1, 24.3 and 23.9.

Thus in principle the DES 'z' band data can be used to provide the z band data proposed for VHS. The DES project is currently reviewing whether DES could also obtain 'Y' data. On this basis that in the long term, Z and Y can be provided by the DES project we no longer request Z and Y in the SGC region covered by DES. At a later date e.g. the two year review we propose that the PSP reconsider this decision. Further information about the DES project is provided in Appendix A.

Castander and McMahon agreed that a goal for VHS could be to:

1. cover full DES region (excluding the region of DES covered by VIKING i.e. around 500deg^2 with VHS by end of 2009 i.e. First 3 VISTA seasons. Thus by the end of the first season of DES we would have 5000deg^2 in grizY(DES) + JK(VHS). Note that some of the DES region would also be covered by VST ATLAS so that independent of DES, VHS would be getting optical data over part of this region.
2. propose to PSP that to double the VHS Baseline exposures in J and K from 60secs to 120secs in the DES region.