1 The VISTA Kilo-degree Infrared Galaxy survey (VIKING)

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1.1 Abstract:

We propose a survey with VISTA covering the 1500 deg^2 of the VST-KIDS survey in the 5 broadband filters Z,Y,J,H,K_s. Combined with KIDS, this will yield a unique 9-band optical-IR survey with depth approximately 2 mag deeper than Sloan and 1.4 mag deeper than UKIDSS-LAS.

The Z-band data forms an integral part of KIDS and has been moved from VST to VISTA following the recommendation of the PSP. Adding the Y,J,H,K_s bands has numerous motivations including the highest redshift quasars, brown dwarfs, improved photometric redshifts for weak lensing and baryon oscillations, improved star-galaxy classification, $z > 1$ clusters, stellar masses for the KIDS lensing objects, and studying galaxy evolution and clustering over the interval $0 < z < 1.2$.

In area and depth, the KIDS+VIKING survey is a natural intermediate between the shallower SDSS, VST-ATLAS and UKIDSS-LAS, and the deeper $\sim 20\,\mathrm{deg}^2$ surveys. Some part of it is observable year-round from Paranal, providing a rich source of new targets for VLT followup.

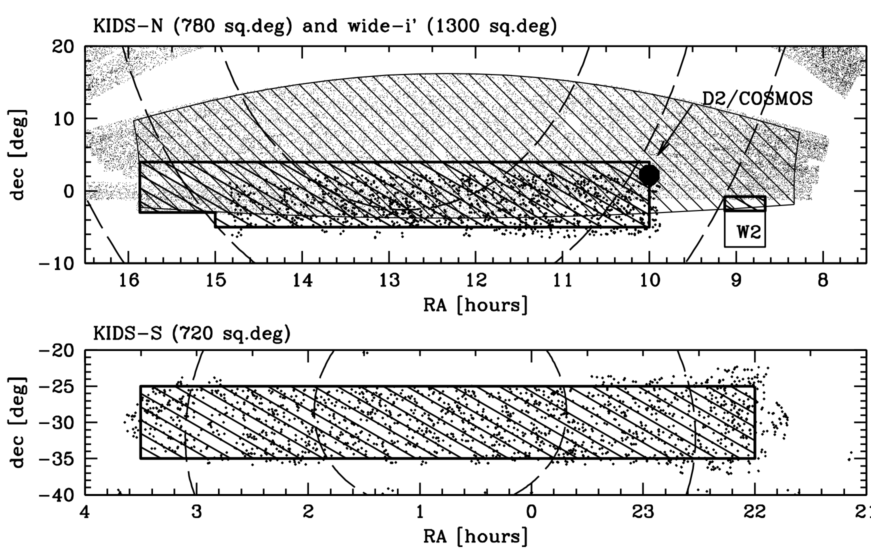

Figure 1: The sky coverage of the KIDS and VIKING surveys (thick line) in the North (top) and South (bottom) galactic caps. The thin line shows the KIDS wide−i extension. The CFHLS-W2 and COSMOS fields are labelled. A random subsample of SDSS (small dots) and 2dFGRS (large dots) redshifts are plotted.

2 Description of the survey:

2.1 Scientific rationale:

Large-area multi-colour imaging surveys are a cornerstone of observational astronomy, with the wealth of results from the Sloan Digital Sky Survey and 2MASS being the most recent examples. ESO's forthcoming VST and VISTA survey telescopes are expected to enable substantial advances over existing imaging surveys: the approved VST-KIDS public survey will yield a substantial improvement over SDSS by ≈ 2 mags in depth and $2\times$ better resolution, and has a broad range of science goals both to select VLT spectroscopic targets and to provide standalone science from the imaging data.

Until recently, near-IR surveys have been very limited by the small detector areas compared with CCDs. This is now changing with the advent of large mosaics in WFCAM and WIRCAM. When operational, VISTA with its 16 near-IR detectors, high efficiency and full-time survey operation will provide a ~ 6-fold gain in survey capability over these Northern counterparts.

The Z-band[1] was an integral part of the KIDS proposal as it is critical to photometric redshift measurements. For good technical reasons, it was recommended by the PSP to move this to VISTA. Essentially VISTA's $3\times$ higher QE, $2\times$ larger collecting area and $0.6\times$ instantaneous field of view mean that overall VISTA will survey $\sim 3\times$ faster than VST at Z-band. Also, VISTA's near-IR detectors should have much less fringing than CCDs, and Z band will generally be observed in dark/grey time on VISTA rather than bright time on VST.

There are numerous motivations for adding the longer wavelengths Y,J,H,K_s to the baseline KIDS *ugri*Z survey, which we outline below.

2.1.1 Studying dark matter and dark energy via weak lensing

One of the top-priority aims of KIDS is weak lensing, i.e. the small systematic shape distortion of background galaxies induced by foreground dark matter concentrations. In particular, galaxy-galaxy lensing can probe the galaxy-mass correlation function over a wide range of scales and environments. The KIDS survey will allow averaging over many millions of background galaxies, giving an accurate probe of the mean dark halo profile for galaxies, groups and clusters, as a function of galaxy type and luminosity.

The primary weak lensing measurements from KIDS will be made in the optical $r-$band where the sky is darker and the signal-to-noise per unit time is most favourable. However, adding near-IR data can enhance the weak lensing program in several ways:

- Improved photometric redshifts. Photometric redshifts clearly improve with the addition of more bands: the near-IR bands are particularly useful at redshifts ≥ 1 where the $4000\,\AA$ break feature is redshifting into the Z band. In Appendix A we provide photo-z simulations with our planned survey parameters, showing a typical improvement of $1.5 - 2\times$ in errors and much reduced failure rate for KIDS+VIKING compared to KIDS+UKIDSS.

- Stellar masses. The typical KIDS lenses will be at redshift $z \sim 0.2 - 0.5$, so near-IR measurements will provide accurate stellar masses for each object, as opposed to the optical measurements which are sensitive to star-formation rate and dust content. Slicing the foreground galaxies by near-IR luminosity as well as optical-NIR colours will allow probing of the relations between halo mass, stellar mass and star-formation rate separately.

- Improved star-galaxy separation. Reliable star-galaxy separation is crucial for weak lensing to avoid 'diluting' the shape measurements with misclassified stars. Adding K_s data is particularly useful, since there is a very clean separation of stars and galaxies in 2-colour diagrams involving K_s (Daddi *et al.* 2004).

[1] We denote this band by uppercase Z since the delivered VISTA Z will be slightly different from Sloan z for technical reasons. This also avoids confusion with z = redshift.

2.1.2 Baryon acoustic oscillations and dark energy

Constraining the equation of state w of dark energy via baryon acoustic oscillations is another major goal of KIDS, and as explained in detail in the KIDS proposal, VISTA data form an integral part of this project. The acoustic features are less prone to systematic error compared to e.g. supernovae, and are visible in the angular power spectrum of galaxies in sufficiently thin redshift slices. This requires accurate photometric redshifts with low systematics. The addition of the VISTA IR data is required to bring the redshift accuracy to below 3%, and reduce the incidence of 'catastrophic failures' in the redshift determinations (see Appendix). Wide area coverage is crucial for an accurate power spectrum measurement, and the requirements for this project were used to set the area of the KIDS survey, giving rms error 0.08 on the dark energy equation of state w (Figure 2).

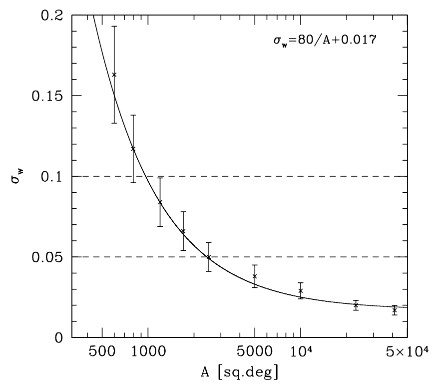

Figure 2: Simulated 1σ error on a redshift-independent dark energy equation of state w, from angular baryon oscillation measurements, as a function of survey area.

Higher precision probing of the baryon oscillations is anticipated from next-generation redshift surveys with AAOmega and later WFMOS, surveying $\sim 250,000$ to 2 million galaxies at $z \sim 0.6 - 1.1$; our survey will provide a high-quality input catalogue for these.

2.1.3 The highest redshift quasars

Understanding the epoch of reionization is one of the key outstanding questions in cosmology, with major implications for the first generation of galaxies. Results from SDSS and WMAP give tantalising indications of an extended reionization era between $z \sim 10$ and $z \sim 6$.

There is thus a very strong motivation for discovering quasars beyond the current redshift limit $z \simeq 6.4$, and to accomplish this it is essential to survey at wavelengths $> 1\,\mu$m as the Lyα break redshifts beyond the Z passband. In principle the quasars could be selected with just two passbands spanning redshifted Lyα e.g. Z-J, but contamination from the much more numerous foreground L dwarfs becomes problematic. Discriminating the L-dwarfs requires another passband, and the Y passband (Hewett *et al.* 2006) has been optimised for this purpose (Figure 3). Our K_s data will provide extra leverage and flag contaminating compact ERO galaxies, but Y band is essential here. Therefore, the J band becomes the primary "selection" band; selecting objects redder than M9 stars i.e. Z–J > 2.3 (including Z-dropouts) gives a sample of both quasars and brown dwarfs, then the other NIR colours Y–J and J–K_s discriminate among these, so candidates can be prioritised for spectroscopic followup. Number count models (Figure 3) predict VIKING should contain ~ 4 quasars with $6.5 < z < 7.3$, J < 19.5 ($\sim 20\sigma$ Y,J detections !), and ~ 20 quasars with J < 20.3 (still 10σ detections, but brown dwarf contamination may become more challenging).

In addition, we can probe the quasar luminosity function at $5.8 < z < 6.4$ to a limit ~ 1.5 mag fainter than the existing SDSS sample. This will use similar i,Z,J selection to SDSS with the improved depth of KIDS+VIKING. (The SDSS selection (Fan et al 2001) used followup snapshots in J, which are provided automatically in our survey).

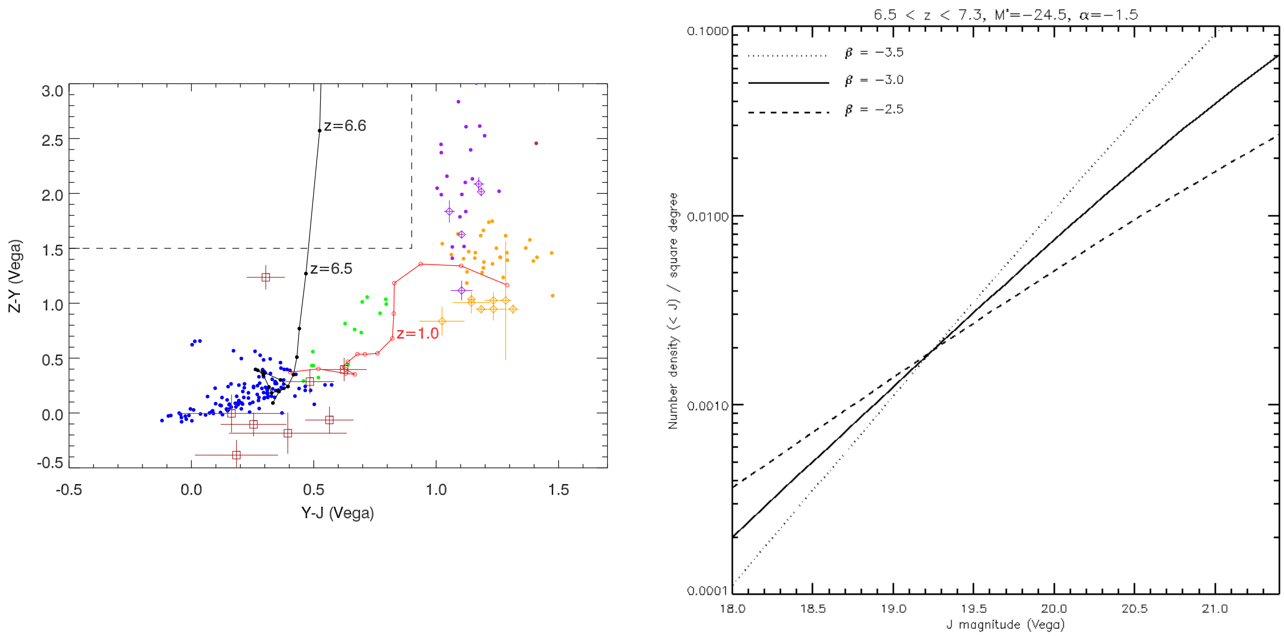

Figure 3: (Left) Selection of high-redshift quasars with Z/Y/J colours. Black line is quasar locus; dots show model colours for A-K stars (blue), M stars (green), L dwarfs (yellow) and T dwarfs (purple). Red line is the early-type galaxy locus. Squares with error bars show measured values from UKIDSS SV data for known $5.8 < z < 6.4$ quasars (brown) and L/T dwarfs. (Right) Predicted quasar number counts vs J magnitude for $6.5 < z < 7.3$, for three values of the LF bright-end slope β, normalised to SDSS at $z \sim 6$.

2.1.4 Brown Dwarfs

As a byproduct of the quasar search, the survey will contain a very large number of brown dwarfs, ~ 3000 by extrapolation from the 2MASS sample. This can provide excellent statistics of the brown dwarf luminosity function, and offers the possibility of detecting objects cooler than the currently known limit of T8, i.e. the predicted Y spectral type. Candidate objects with Y-J > 1.8 (if any) would be extremely interesting, as no known stellar objects are this red and the only predicted objects here are Y dwarfs or $z > 7.7$ quasars.

2.1.5 Galaxy evolution

Addition of near-IR data to the KIDS survey will be of major benefit in measuring galaxy rest-frame red and near-IR light at significant redshifts, enabling optimal estimates of stellar masses and spectral types without biases from dust, star formation etc.

The median redshift of KIDS galaxies at the 10σ limit $r = 24.4$ is expected to be $z_{\rm med} \sim 0.8$, with a tail to $z \sim 1.3$. At these redshifts, the Y and J bands will measure the rest-frame r and i emission, while our K_s band will sample rest-frame $1.0 - 1.5\,\mu$m.

Therefore, adding NIR data delivers SEDs spanning **rest-frame** wavelengths $0.3 - 1.2\,\mu$m for the majority of galaxies in our sample; combined with the photometric redshifts, this enables investigation of galaxy LF evolution across the above rest-frame wavelengths, and a direct comparison to SDSS $r-$selected and 2MASS

J-selected samples without significant k-correction uncertainties or extrapolations. (Given $ugri$Z alone, only the window of rest-frame $0.3 - 0.45\,\mu$m remains in common to most KIDS galaxies). Furthermore, $\sim 600\,\mathrm{deg}^2$ of our area has UV coverage in the GALEX Medium Imaging Survey.

This should provide a very important stepping-stone for galaxy evolution at intermediate redshifts between the large local surveys, and the narrower samples focused on $z \sim 1 - 2.5$ (VVDS, DXS, SWIRE, VIDEO etc). Moderate redshifts are important since half the age of the Universe has elapsed since $z = 0.8$, and there has been a rapid fall in the star-formation rate density over this era which is poorly understood.

The VIKING J-band limit corresponds to a passively-evolved $0.5\,L^*(r)$ galaxy at redshift $z \approx 1$; assuming that the photometric redshifts can be calibrated accurately, the space density of fairly massive $\sim L^*$ galaxies can be traced with superb statistics from redshift 1 to the present, and the "downsizing" phenomenon for low-luminosity galaxies can be explored since $z \sim 0.5$.

2.1.6 Galaxy morphology

The VISTA-VIKING survey combined with VST-KIDS will provide an unprecedented insight into galaxy structure on the 20 kpc–1 kpc scales. This is precisely the scale over which Cold Dark Matter theory, which provides such an excellent match to large scale structure, begins to struggle, in part due to lack of available empirical data. The observational evidence is overwhelming that bulges and disks have formed via distinct mechanisms on distinct timescales (Driver et al 2006). Hence simple global structural measurements are misleading and not necessarily useful. Our intention is to decompose all galaxies with $z < 0.1$ and known redshifts into the kinematically distinct nucleus, bulge and disk components using a combination of Nuker, Sersic and exponential light profile fitting. The isophotal depth probed will enable the measurement of any truncation radius, outer disk, or tidal features.

At $z \sim 0.1$ the physical scale is ~ 1 kpc/arcsec and hence the anticipated sub-arcsecond PSF will deliver sub-kpc resolution for all galaxies and sub-100pc resolution for a significant fraction. This is sufficient to robustly decompose galaxies into any nucleus, bulge and disk components. KIDS+VIKING will include over 100,000 galaxies to $z < 0.1$ with known redshifts (2dFGRS, SDSS, MGC, 2SLAQ) and the data will extend the largest structural studies to date (Tasca & White 2006; Allen et al 2006) by over two orders of magnitude, and a factor of two in resolution.

The broad wavelength coverage from u to K_s from KIDS and VIKING will allow simultaneous study of the structural parameters of the bulk populations with little extinction and reduced AGN contamination (from the IR), and its relation to the optical properties of the galaxies (colour gradients, young populations, spiral arms and asymmetries, extinction, etc). The depth probed (1.4 mag/arcsec^2 deeper than UKIDSS) will provide the highest possible signal-to-noise images essential for obtaining high quality reliable fits. This will provide a *comprehensive* and quantitative structural reference catalogue, probing all environments from the richest clusters to sparse groups to voids, for comparison to the next generation numerical simulations, and the zero redshift benchmark for comparative evolutionary studies with HST and JWST.

2.1.7 High-redshift clusters.

KIDS will provide a large sample of clusters beyond $z > 1$, either selected from optical/NIR data alone or in conjunction with large S-Z surveys e.g. from the Atacama Cosmology Telescope; the cluster abundance can provide a sensitive probe of cosmological parameters including the dark energy equation of state w , as long as the cluster masses can be calibrated statistically to good accuracy.

At $z > 1.1$, the $4000\,\AA$ break starts to redshift into the Z band and optical-based selection gets much harder; adding at least one band at $\geq 1\,\mu$m is a great asset, with J being marginally the most sensitive per unit time. The relatively shallow UKIDSS LAS data can only pick up the extreme tail of the galaxy luminosity function at $z \sim 1$; our deeper VISTA data will reach ~ 1.4 mag fainter than LAS and pick up many more galaxies for any given cluster, enabling us to push the cluster detection to $z \sim 1.3$.

2.1.8 AKARI and WISE synergy

The AKARI (formerly ASTRO-F) satellite was launched in Feb 2006, and will provide an all-sky far-IR survey $\sim 5\times$ deeper than IRAS. The WISE satellite will provide a mid-IR all-sky survey around 2010. Clearly, wider and shallower surveys than KIDS+VIKING will provide the most coverage of these by number; however, a significant and interesting minority of AKARI and WISE sources (especially ULIRGs/HLIRGs at $z \sim 1$) are expected to be fainter in the optical/NIR than the limits of SDSS, UKIDSS-LAS etc. The KIDS+VIKING data should provide near-complete AKARI+WISE identifications and accurate photometric redshifts, for a substantial subsample of $\sim 8\%$ of the high-latitude sky.

2.1.9 Galactic structure

We cannot quantify the fraction of dark matter within our galaxy until we know its total mass and size. Further, the accurate measurement of the mass profile provides important clues to the nature of the dark matter. For example, does the profile follow a Navarro, Frenk & White (NFW) profile throughout most of the halo (Navarro, Frenk & White 1997) as many fundamental predictions of cold dark matter (CDM) models predict? Stellar populations provide a powerful probe of the properties of the Milky Way dark matter halo. This fundamental issue can only be addressed when a sufficiently large number of probes of the outer halo of the Galaxy are available. The results are controversial.

There are a number of halo tracers that have been used to probe the halo such as: RR Lyrae stars (Kinman 1996); carbon stars (Toten & Irwin, 1998); M giants (Majewski et al. 2003) and BHB stars (Clewley et al. 2006).

The 9 band KIDS+VIKING data will be an impressive advance, allowing us to probe several stellar halo populations (above) simultaneously out beyond 100 kpc radius. The KIDS data will be used to isolate the BHB stars, and the deep $\mathrm{YJHK_s}$ bands will isolate the M giants and carbon stars. This survey will comprise the deepest stellar population map ever undertaken.

2.1.10 Ultracool white dwarfs

The ultracool white dwarfs (WDs), with $T_{\rm eff}$ below 4000 K, are very rare, old and faint stellar remnants that contain crucial information on the genesis of our Galaxy (initial mass function, star formation rate). Presently the number of known ultracool WDs is less than a dozen (Gates et al. 2004), and to increase their statistics is of fundamental importance to improve their model atmospheres and the accuracy of the theoretical WD cooling times. Uncertainties of the order of 1 Gyr on these theoretical cooling times are currently the main error source for the determination of the age of the galactic disk through the WD luminosity function (Leggett et al. 1998, Prada Moroni & Straniero 2002, see also Fontaine et al. 2001 for a review).

The ultracool WDs are expected to be bluer than their warmer counterparts, due to H_2 collision-induced absorption (CIA) bands in their atmospheres (Hansen 1998). This results in unique colours that stand out from the Galaxy population, and that can only partially overlap with high-redshift ($z > 3$) QSOs. The effect of CIA (that can occur also with neutral helium in He-rich environments characterized by high atmospheric pressures, Bergeron & Leggett 2002) is to strongly reduce the flux longward of r/i bands. Therefore, adding especially Z,Y measurements to the u, g, r, i magnitudes from KIDS will greatly improve the capability to detect ultracool WDs and determine their effective temperature. (Most are likely to be non-detections at $\mathrm{J,H,K_s}$).

Near-IR measurements will also be important to better constrain the SED of "normal" cool WDs (4000 K $\lesssim T_{\rm eff} \lesssim$ 7000 K) and to detect possible IR excesses due to WD cool companions (see e.g. Nitta et al. 2005).

Finally, when combining optical-IR colours, magnitudes and proper motions data (either from SDSS and/or 2nd epoch g-band KIDS measurements), it will be possible to study separately disk and halo WD populations (see e.g. Bergeron et al. 2005) and to determine whether old halo WDs could contribute significantly to the halo dark matter, as suggested by microlensing surveys towards the Magellanic Clouds.

3 Are there ongoing or planned similar surveys? How will the proposed survey differ from those?

We summarise the properties of various ongoing and planned surveys in Table 1 ; this includes major optical and NIR surveys at high galactic latitudes. Two facilities not shown are PanSTARRS (program not yet determined), and LSST (beyond the timescale considered).

Table 1: Parameters of existing and planned wide to medium-deep optical and near-IR surveys . Δm_{lim} is the approximate **gain** in limiting magnitude relative to SDSS (optical) or UKIDSS-LAS (IR).

Survey	Hemisphere	Bands	Area (deg^2)	Δm_{lim}	Completion
DENIS	South	IJK	20,000	−3	2003
2MASS	N + S	JHK	40,000	−3	2002
SDSS	North	*ugriz*	10,000	≡ 0	2008
UKIDSS-LAS	North	$YJHK_s$	4,000	≡ 0	2012
VST-ATLAS	South	*ugri*	4,500	0	2010
VISTA-VHS	South	JK_s (Y,H?)	20,000 (5000)	0	proposed
Skymapper	South	*ugriz*	20,000	0	2012 ?
KIDS	South	*ugri*	**1,500**	**+2.0**	2011
VIKING	South	$ZYJHK_s$	**1,500**	**+1.4**	2011 (proposed)
DES	South	*griz*	5,000	+2.2	2014 (proposed)
CFHLS-Wide	North	*ugriz*	150	+3.3	2008
UKIDSS-DXS	North	JK	35	+2.5	2012
VISTA-VIDEO	South	$ZYJHK_s$	15	+3.5	proposed

The nearest existing analogues to KIDS + VIKING are the Sloan Digital Sky Survey in the optical bands and the overlapping UKIDSS-LAS in the near-IR, both mainly in the Northern hemisphere. Compared to SDSS, the KIDS survey is ~ 2 mag deeper and will have much better resolution. Likewise, VIKING will be ~ 1.4 mag deeper than LAS, as desirable to make the most of the KIDS improvement over SDSS. Ideally we might like a 2 mag gain over LAS, but this is impractical in VISTA time; we aim to cover the full area in a realistic time while retaining a very substantial improvement over LAS, $\sim 4\times$ fainter flux limit.

In the South, the approved VST ATLAS survey (PI: Shanks) aims to use the poor-seeing VST time (rebinned to 0.4 arcsec pixels) to survey $4,500\,\mathrm{deg}^2$ at SDSS-like depth and resolution. Somewhat later, the Australian Skymapper telescope (under construction) aims to obtain comparable optical data over the entire Southern hemisphere.

We are also aware of a "VISTA Hemisphere Survey" proposal; this aims to cover the entire Southern hemisphere to UKIDSS-LAS depth in J,K_s, with deeper coverage in the SGP area. Again, if approved this will be substantially wider but shallower and is likely to use poorer seeing than VIKING.

The leading deeper surveys e.g. CFHTLS-Wide, UKIDSS-DXS and VISTA-VIDEO are all much narrower $\sim 15 - 150\,\mathrm{deg}^2$, and approximately 1.0 – 2.0 mag deeper than KIDS+VIKING.

Therefore, overall the KIDS+VIKING combination very naturally fills the large gap in parameter space between the existing and proposed "wide" and "deep" surveys; it will be substantially deeper and give better resolution than the wide surveys SDSS, LAS and Southern counterparts, while covering $10 - 50\times$ more area than the deeper surveys such as CFHTLS, DXS and VISTA-VIDEO.

There is no similar ongoing survey at present; the nearest future analogue to KIDS will be the US-led Dark Energy Survey which aims to survey $5{,}000\,\mathrm{deg}^2$ in the SGP to similar depth to KIDS, starting in 2010.

4 Observing strategy:

4.1 Sky coverage

Our sky coverage is the full KIDS area, i.e. **both** the NGP and SGP stripes totalling $1500\,\mathrm{deg}^2$. This area gives high galactic latitude sky with Sloan + 2dFGRS redshifts, a large fraction has GALEX-MIS coverage, and some part of it is observable from Chile at airmass < 1.5 at **any** sidereal time. The SGP stripe is ideally placed just South of the Paranal zenith to minimise problems with wind and the Moon, while the NGP stripe is along the equator giving good visibility from both hemispheres.

As with KIDS vs Sloan, there is minor duplication as our NGP stripe will be covered (shallower) by UKIDSS-LAS. There is good motivation for increased depth, since the 40 sec LAS exposures match SDSS rather than the high-quality KIDS data. Our overlap with LAS is clearly beneficial for cross-calibration, and gives proper motion and variability data for the brighter objects. (Concentrating more VIKING time on the SGP strip was considered, but the loss of area would be severe for many science goals, and it would probably lead to significant scheduling clashes with other targets near this RA range, e.g. SWIRE fields, Magellanic Clouds).

4.2 Bands, seeing, scheduling

From Section 2, multi-band coverage is vital to cover the full range of our science goals, so we will survey in all 5 broadband filters Z,Y,J,H,K_s. The best seeing is not critical since most of the morphological measurements will come from the $r-$band, but we don't want poor seeing to degrade colours measured in a 2 arcsec aperture; therefore, we adopt a seeing threshold ≤ 1.0 arcsec for all bands.

Mostly, the time lag between optical and NIR observations is not critical, but it is desirable to take Z and J bands near simultaneously to avoid variable stars or asteroids causing spurious Z-band dropouts. However, it is very important for KIDS that Z coverage doesn't lag far behind optical u, g, r, i: this argues against trying to do all 5 bands in a single visit.

Therefore, our baseline is to **visit each field twice** and split the J-band into half its time at each visit, with Z,Y,J1 at the first visit (avoiding bright moon) and J2,H,K_s at the second visit (any lunar phase, as long as the Moon is > 30 deg from the field). This ensures that the Z,Y,J1 coverage should readily keep up with KIDS u, g, r, i; since the J-band will be the "primary" selection band for the rare objects e.g. quasars, brown dwarfs, etc, contamination by asteroids and variable stars can be minimised.

4.3 Jittering and overheads

Our baseline plan requires ~ 400 sec exposure per object per filter. Given VISTA's default tiling strategy, this is 200 sec per pawprint, which is naturally split into 4 jitter steps. We anticipate most VIKING data will have seeing in the range $0.7-1.0$ arcsec, so microstepping is not needed. Resampling onto ~ 0.25 arcsec pixels during pipeline reductions is an option, but is not essential.

Our 4 jittered exposures at ~ 50 sec duration and 2 pawprints per object is well suited for VISTA's hardware. It gives enough jitters for good removal of bad pixels and background-subtraction, and long enough dwell time to keep the overheads modest. A full tile (6 pawprints) can be completed in the nominal 2.5 passbands within a 1-hour Observing Block.

5 Estimated observing time:

Our planned exposure times (Table 2) are ≈ 400 sec per object per filter, with slightly more for Z,K_s and less for H. This matches the Z depth intended for KIDS, and is reasonable since red objects (e.g. passive galaxies) have SED's which are roughly flat f_λ at rest-frame $0.6 - 1.2\,\mu$m, and equal exposure time per band gives quite similar f_λ sensitivity for VISTA.

Assuming 0.8 arcsec median seeing, an aperture diameter 2.0 arcsec and median Paranal sky brightness, the VISTA ETC v1.3 gives the following sensitivity limits in Table 2 :

Table 2: Exposure time, magnitude and flux limits per filter for VIKING and UKIDSS; KIDS (*i* only) shown for comparison).

Filter	Exp. time	Med.seeing	$5\sigma, 2''$ aperture mag.		f_λ	UKIDSS
	(sec)	(arcsec)	(AB)	(Vega)	($10^{-20}\,\mathrm{erg\,s^{-1}\,cm^{-2}\,\AA^{-1}}$)	(Vega; actual)
Z	500	0.8	23.1	22.6	75	–
Y	400	0.8	22.3	21.7	114	20.2
J	400 (2 × 200)	0.8	22.1	21.3	94	19.6
H	300	0.8	21.5	20.2	94	18.7
K_s	500	0.8	21.2	19.4	77	18.2
i (KIDS)	1080	0.7	24.1	23.8	40	–

The total time request for VIKING is given in Table 3. We assume 30% overheads as per the ETC, and the default average 9 hours per clear night. (NB: this may be pessimistic for an IR system which can observe 30 mins after sunset or before sunrise).

Table 3: Time requested

Patch	Filters	Time (h)	Time(n)	RA range	Area	Moon	Seeing	Transp
KIDS-N	Z,Y,J1	573	64	10–16	780	d/g	< 1.0	thin
KIDS-N	J2,H,K_s	520	58	10–16	780	any	< 1.0	thin
KIDS-S	Z,Y,J1	530	59	22–3.5	720	d/g	< 1.0	thin
KIDS-S	J2,H,K_s	480	53	22–3.5	720	any	< 1.0	thin
Total	Z,Y,J1	1103	123		1500	d/g	< 1.0	thin
Total	J2,H,K_s	1000	111		1500	any	< 1.0	thin

The total time request is thus **234 nights** in better than 1 arcsec / 75th percentile seeing, of which at least half should be dark or grey. (cf the 212 dark and 172 bright VST nights requested for KIDS).

As outlined above in Section 4, the observing strategy is a good match to VISTA's capabilities i.e. gives observing efficiency close to the ceiling set by necessary readout and jittering overheads. Each tile can be completed in two ∼ 1−hour visits with near-simultaneous Z,Y,J1 in one visit and J2,H,Ks in the other; this ensures that the Z-band coverage can keep up with corresponding progress on VST-KIDS, and gives variability leverage.

The KIDS-N area overlaps with UKIDSS-LAS and thus the brighter objects will get 4 epochs at J-band. An additional "J3" pass over KIDS-S at the end of the survey could be considered for proper motions, and would take an extra 14 nights.

Non-photometric time can be used, since the main photometric calibration is expected to be zeropointed from 2MASS, accounting for static colour terms between the 2MASS and VISTA filters. This is currently working at the ∼ 0.02 mag level for WFCAM, and VISTA will have correspondingly more 2MASS stars per pointing. Due to the "stripe" observing strategy of 2MASS, any one VISTA pointing will contain data from numerous 2MASS stripes so the 2MASS random errors should average down.

6 Data management plan:

6.1 Team members:

Here we provide a list of VDFS and Science team members responsible for survey strategy, OB preparation, data handling, pipeline processing, quality control and science assessment. The VIKING team will be responsible for science assessment of processed data in the Science Archive, and providing feedback to VDFS via the VIKING PI to enable timely correction of known problems.

Name	Function	Affiliation	Country
Survey Strategy			
W. Sutherland	VIKING PI; strategy	Cambridge	UK
K. Kuijken	KIDS PI; optical-IR coordination	Leiden	NL
Pipeline and Archive			
CASU (VDFS) team	Pipeline processing	Cambridge	UK
CASU (VDFS) team	Data Quality Control-I	Cambridge	UK
J. Emerson	VDFS Coordinator	QMUL	UK
WFAU (VDFS) team	Science Archive	Edinburgh	UK
WFAU (VDFS) team	Data Quality Control-II	Edinburgh	UK
Science verification; data quality control-III			
W. Sutherland	VIKING PI	Cambridge	UK
K. Kuijken	KIDS PI ; optical-IR coordination;	Leiden	NL
P. Schneider	Weak lensing	Bonn	Germany
Y. Mellier	Weak lensing	IAP	France
R. Saglia	Photometric redshifts	MPE	Germany
P. Schuecker	Baryon oscillations	MPE	Germany
R. McMahon	High-z quasars	Cambridge	UK
J. Liske	Galaxy morphology	ESO	Germany
S. Driver	Wide-area redshift followup	St. Andrews	UK
R. Silvotti	Ultracool WDs	INAF, Capodimonte	Italy
J. Peacock	Galaxy evolution	Edinburgh	UK
L. Clewley	Galactic halo	Oxford	UK
M. Bremer	High-z clusters	Bristol	UK

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.

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 KIDS 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 surveys as a test bed for the VISTA infrared surveys; e.g. the WFCAM Early Data release (EDR, (*http://surveys.roe.ac.uk/wsa/dboverview.html*) Lawrence et al 2006, Dye et al 2006). The system is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system.

6.3 Data reduction plan:

The data reduction will be using the VDFS, operated by the VDFS team, and augmented by individuals from VIKING, especially for product definition and product Quality Control. We divide the plan into two distinct but intimately related parts: pipeline processing and science archiving. More 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, designed for VISTA and scientifically verified by processing WFCAM data 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 be tested on a range of 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 with World Coordinate System (WCS) in all FITS headers; photometric calibration for each catalogue, augmented by monitoring of suitable pre-selected standard areas to 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; processing history including software version and calibration files recorded in FITS headers.

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 curates them to produce enhanced database-driven products. The VDFS Archive curation includes 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 Data Releases can be made.

Moreover, end-user interfaces are built into 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 required; and also that the merged source tables 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/`

VIKING is intrinsically a multi-wavelength project; most science will come from the linking of VISTA data with KIDS data, and the WSA is designed to enable such links.

6.3.3 Science quality assessment

The initial data quality control for rejection of obviously problematic data (e.g. clouds, trailed images, telescope problems, etc) will be the responsibility of VDFS.

However, based on extensive experience with previous large surveys, it will be very important especially in the early stages of the survey to have rapid assessment of the data by science-team members to test for more subtle problems with the data, and provide feedback to VDFS or ESO as necessary so these can be minimised as far as reasonably possible.

Therefore, for each of the main science topics we have assigned one member of the science team (see Section 6.1 with primary responsibility for assessing the data with regard to that science topic. The main point of contact will be the VIKING PI, who is also the VISTA Project Scientist and has detailed knowledge of the end-to-end system.

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 jittered 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.

Since the optical-IR colour measurements will be of great importance for many of the science goals, the KIDS and VIKING teams are working on PSF homogenisation tools which can be used in both Astro-WISE and VDFS pipelines, and we will ensure that data from both KIDS and VIKING is compatible with VO standards.

6.5 General schedule of the project:

Clearly the rate of progress of our survey will depend on the fraction of time scheduled, which is dependent on the balance of surveys selected by the PSP. Each field will reach the final depth in all bands after its two visits, so the survey area should build up roughly linearly over time and much of the science analysis can progress in parallel without waiting for completion. (The baryon oscillation measurements are an exception which require a large fraction of the full area).

Our total time request is approximately 2/3 of that for KIDS, so if the nights allocated per year are also in 2/3 proportion, the two can progress at a similar rate. We plan phased data releases at intervals during the survey, as follows:

T0: Start of observations
T0 + 6 months: EDR release of science products from first month of survey observations
T0 + 12 months: DR1 release of science products from first 6 months of survey observations, incorporating improved reductions based on experience in science verification.
T0 + 18 months: DR2 release of products from first year.
Thereafter we anticipate that standard science products can be released to the PIs within 6 months of raw data arriving in the UK.

Optional reprocessing of data based on improved knowledge of the instrument would also be considered; the VDFS system has been designed with sufficient capacity headroom to allow this to happen, while simultaneously handling incoming new data.

7 Envisaged follow-up: (1 page max)

The combined KIDS+VIKING survey will be a rich source for VLT followup; while existing instruments will be useful, we note there is a particularly good synergy with forthcoming instruments, especially HAWK-I for deeper imaging at high resolution, X-Shooter for spectroscopy of rare objects, and in the longer term also KMOS.

In some "core" areas, VLT followup will be essential to deliver the full science goals of KIDS+VIKING , while there are many other possible spinoff areas where the followup will involve the wider community using the Archive to extend beyond our initial science goals in ways not yet planned.

7.1 Core followup

Our core followup will be mainly to calibrate the photometric redshifts with a spectroscopic sample , and to confirm the various rare-object candidates by deeper imaging or spectroscopy with VLT.

- **Photo-z's:** We aim to calibrate ~ 6500 photometric redshifts using VIMOS spectra to $\mathrm{I_{VEGA}} = 24$ in 16 fields chosen to span a range of foreground absorption. Experience with the FORS deep field shows that such a detailed comparison is essential for full accuracy (Gabasch et al. 2004).
- **High-z QSOs:** We aim to confirm ~ 10 colour-selected QSOs at $6.5 < z < 7.4$. The number and contamination rate are significantly uncertain at present, but to $J < 19.5$ our contamination should be much lower than the SDSS-LAS combination due to high SNR. As we gain experience with the brighter subsample, we can push towards the 10σ limit $J = 20.7$; using HAWK-I Z,Y followup to improve the colour measurements, followed by spectroscopic confirmation with X-Shooter.
- **Ultra-cool brown dwarfs:** At $J \sim 20$ (an excellent 20σ detection), non-detection at 5σ in Y implies colour $\mathrm{Y - J} > 1.8$. Such candidates, if any, are likely to be Y dwarfs or $z > 7.5$ quasars and will be followed up at high priority.
- **z > 1 clusters:** To confirm our high-redshift cluster candidates, followup i,J,K images of $\sim$ 600s with FORS2 and HAWK-I will reach below L^* at $z \sim 1.25$ (Moorwood *et al.* 2004), providing precise photometric redshifts and a more detailed view of the red sequence; the best clusters will be targeted by FORS2 spectroscopy and later will be excellent KMOS targets.

7.2 Spinoff projects

The wide and sensitive 9-band survey is likely to be a major resource for future observational projects beyond our immediate science goals from Section 2. Some examples might be as follows:

- Targeting high-z clusters with KMOS integral field units to explore the assembly history of the red and blue sequences.
- Very deep imaging of these clusters offers the prospect of detecting strongly lensed background $z > 5$ galaxies as r-dropouts; these would be excellent targets for spectroscopic followup.
- Some of us (PI: Driver) are pursuing a $300\,\mathrm{deg}^2, \mathrm{K_s} < 16.2$ redshift survey using AAOmega in the NGP strip.
- Providing an input catalogue for massive next-generation redshift surveys with AAOmega, FMOS and WFMOS for improved precision on baryon oscillations and dark energy.
- Selection of new samples of gravitational lenses for time-delay measurements.
- Selecting specific types of object (e.g. quasars) with bright neighbouring stars, useful for natural guide star adaptive-optics imaging.
- Followup of selected interesting objects discovered by identification of AKARI or WISE sources.

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

Our team is led by the VISTA Project Scientist, contains most of the VST-KIDS team and the VISTA PI and Camera Scientist as co-Is, so we have extensive experience with the technical issues both for VISTA and VST. We have a broad range of science experience from cosmology, weak lensing, large surveys, high-redshift quasars, galaxy properties to Galactic science; thus, we are well motivated to deliver a high-quality science product and we believe that the combined KIDS+VIKING survey will have lasting long-term value to the whole ESO community.

We are aware of a possibility of accelerating the rate of the KIDS survey to expand the baseline $1500\,\mathrm{deg}^2$, particularly for improving constraints on Dark Energy and increasing the overlap with the forthcoming S-Z survey from the South Pole Telescope. In this event, there will clearly be a need for VIKING to match the increased KIDS rate. This is practical if the VIKING allocation can be increased pro rata, since VIKING requests approximately 2/3 as much VISTA time compared to VST-KIDS, and VIKING's seeing and Moon constraints are somewhat more relaxed compared to KIDS. Both KIDS and VIKING intend to prioritise the South Pole Telescope overlap region in our first years of operation.

Appendix: Photometric redshifts with VISTA NIR observations

We performed new simulations of the combined KIDS+VIKING dataset, to explore the effects of the deeper magnitude limits reached with respect to the UKIDSS case and assess the importance of the H band. The NIR filter set comprises the Z, Y, J, H, and K_s bands. The new simulations follow the ones described in the KIDS proposal, but use a lognormal redshift distribution peaked around redshift 0.7.

We consider three cases, all with optical exposures as in the approved KIDS project (i.e. 900s, 900s, 1800s, 1080s in *ugri*). There are two "VIKING" cases, with and without H band, plus one "UKIDSS" case (approximately 1.4 mag shallower than VIKING in the NIR bands and with Z coming from VISTA). The exposure times and the relative limiting Vega magnitudes (10σ in a 1.5 arcsec diameter aperture) are listed in Tables 4 and 5.

Table 6 lists the results of the simulations. As for the KIDS project, we compute the differences between input redshifts and photometric redshifts $\Delta z = (z_{phot} - z_{input})/(1 + z_{input})$, evaluate the median of the differences and the 68% absolute deviant from the median Δz_{68}. Moreover, we list the percentage of total failures, defined as the fraction of redshifts deviant by more than $7\Delta z_{68}$. Additionally, this quantity is estimated using the Δz_{68} value of the UKIDSS and the results are given in parenthesis. Finally, similar to the FDF case (Gabasch et al. 2004, A&A, 421, 41), we compute the σ of the Gaussian fit to the values $|\Delta z| < 0.2$. We discuss the cases $z_{input} < 1.5$ and $z_{input} < 6$, $r < 23.5$, $r < 24$ and $r < 25$ separately, to match the different scientific cases considered in the KIDS proposal. The objects with $r < 24$ and $r < 25$ correspond to the 10 and 5σ detections.

The table (and Fig. 4) shows that the VIKING NIR data do improve the precision of the photometric redshifts with respect to the UKIDSS depth. The Δz_{68}, the percentage of the failures (with the exception of the $r < 25$, $z_{lim} = 6$ case, where, however, the UKIDSS Δz_{68} is much larger, see below) , and the the sigmas from the Gaussian fits are always smaller. The improvement in the percentage of failures is even more pronounced when calculated using the UKIDSS Δz_{68}. In this case the VIKING NIR data give always the smallest failure rate.

The comparison between the "All bands" and the "no H" cases shows that the differences are minimal and probably not significant. Therefore, the option of dropping the H band observation (re-allocating its time between the other bands) appears effectively neutral with regard to photometric redshifts. Retaining the H band has the advantage of homogeneity, i.e. of providing a survey with the same bands as UKIDSS.

Table 4: VISTA exposure times in seconds, for baseline 5-band survey and a 4-band case (no H).

Cases	Z	Y	J	H	K_s
5 bands	500	400	400	300	500
no H	620	540	540	0	550

Table 5: 10σ magnitude limits for three example cases for NIR data: VISTA Z plus UKIDSS-LAS YJHK, our baseline 5-band survey, and a third case with no H but extra time in Y,J,K_s as above.

Cases	Z	Y	J	H	K_s / K
VISTA Z + LAS YJHK	22.18	19.8	19.1	18.0	17.7
VISTA, 5 bands	22.18	21.3	20.8	19.7	18.9
VISTA, no H	22.15	21.5	21.0	-	19.0

Table 6: Precision of the photometric redshifts at different r limits using KIDS u, g, r, i data plus the three IR cases above. Figures in parentheses are failures using the $7\Delta z_{68}$ value from the LAS case, giving like-for-like comparison with the LAS column.

r'_{lim}	z_{lim}	Near-IR data setup			
		VISTA Z + LAS	VISTA 5 bands	VISTA no H	
23.5	1.5	0.043	0.023	0.023	68%
		2.3%	2.1% (0.4%)	2.2%	Failures
		0.038	0.029	0.03	Gaussian fit
24	1.5	0.07	0.036	0.039	68%
		3.0%	2.0% (1%)	2.2%	Failures
		0.04	0.035	0.034	Gaussian fit
25	1.5	0.17	0.13	0.13	68%
		4.7%	4.5% (4.1%)	4.4%	Failures
		0.059	0.044	0.045	Gaussian fit
23.5	6	0.032	0.022	0.02	68%
		4%	2.1% (0.9%)	2.3%	Failures
		0.036	0.031	0.031	Gaussian fit
24	6	0.048	0.031	0.031	68%
		5.3%	2.9% (1.9%)	2.8%	Failures
		0.04	0.035	0.034	Gaussian fit
25	6	0.12	0.09	0.085	68%
		4%	5.9% (3.2%)	6.5%	Failures
		0.054	0.043	0.043	Gaussian fit

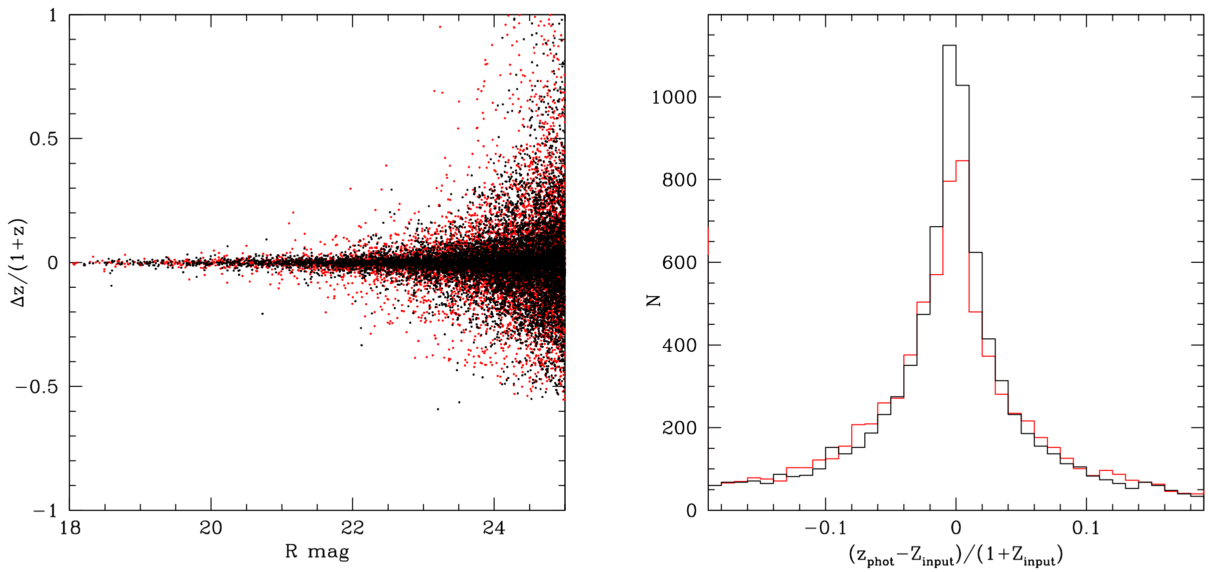

Figure 4: **Left:** The black dots show the redshift differences Δz down to $z_{lim} = 1.5$ as a function of the r magnitude for the VIKING 5-band case. The red dots show the same for the VISTA Z + LAS data. Right: the histogram of the differences Δz for the VIKING (black line) and the UKIDSS (red line) data down to $z_{lim} = 1.5$ and $r_{lim} = 25$.

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