

# 1 The VISTA Large Kilo-degree IR Imaging survey (VALKIRI /VIKING ?)

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## 1.1 Abstract:

We propose a survey with VISTA covering the  $1500 \text{ deg}^2$  of the VST-KIDS survey in the 5 broadband filters Z,Y,J,H,K<sub>s</sub>. Combined with KIDS, this will yield a 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<sub>s</sub> bands has numerous motivations including the highest redshift quasars, brown dwarfs, improved photometric redshifts, 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-VALKIRI survey is a natural intermediate between the shallower SDSS, VST-ATLAS and UKIDSS-LAS, and the deeper  $\sim 30 \text{ deg}^2$  surveys. Some part of it is observable year-round from Paranal, providing a rich source of targets for VLT followup.

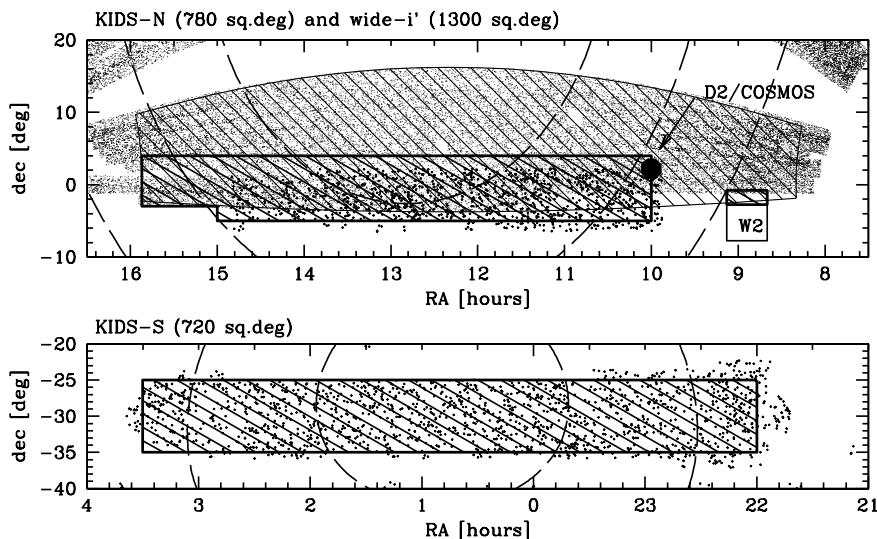


Figure 1: The sky coverage of the KIDS and VALKIRI surveys (thick line) in the North (top) and South (bottom) galactic caps. Small dots are a random subsample of SDSS/2dFGRS redshifts.

## 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  $\approx 2$  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, so for example 2MASS has a much shallower limit than SDSS. 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 telescope will provide a  $\sim 6$ -fold gain in survey capability over these Northern counterparts.

The Z-band<sup>1</sup> 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<sub>s</sub> to the baseline KIDS survey, which we outline below.

#### 2.1.1 Weak lensing

One of the top-priority aims of KIDS is weak lensing. 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 for precise shape measurements.

However, adding near-IR data can enhance the weak lensing program in several ways:

- Improved star-galaxy separation. Reliable star-galaxy separation is crucial for weak lensing to avoid 'diluting' the shape measurements with misclassified stars, but morphological classification alone is sub-optimal in median ground-based seeing. Adding K<sub>s</sub> data is particularly useful, since there is a very clean separation of stars and galaxies in 2-colour diagrams involving K<sub>s</sub> (Daddi *et al.* 2004); this occurs since the H<sup>-</sup> opacity minimum for giant stars redshifts across the K<sub>s</sub> band.
- Improved photometric redshifts. Photometric redshifts clearly improve with the addition of more bands giving improved leverage on spectral type; the near-IR bands are particularly useful at redshifts  $\geq 1$  where the 4000 Å 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.
- 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 relation between halo mass, stellar mass and star-formation rate separately. With the very large KIDS lensing sample, this will enable fine binning and good sensitivity to subtle effects.

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<sup>1</sup>We denote this band by 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

Constraining the equation of state of dark energy via baryon oscillations is another major goal of KIDS. Again this is possible using *ugriZ* data alone, but will similarly benefit from the improved photometric redshifts, in particular a reduction of the fraction of catastrophic outliers. Area coverage is very important for this goal, so this provides a strong motivation for near-IR coverage of the full KIDS area.

More precise 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  $z \sim 15$  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  $> 1 \mu\text{m}$  as the Ly $\alpha$  break redshifts beyond the Z passband. In principle the quasars can be selected with just two passbands spanning redshifted Ly $\alpha$  e.g. Z-J, but contamination from the much more numerous foreground L dwarfs is problematic unless the Z band exposures are extremely deep.

A more efficient method is to discriminate the quasars from the L-dwarfs using another passband, and the Y passband has been optimised for this purpose (Hewett *et al.* 2006). Adding the K<sub>s</sub> band provides extra leverage, and also flags contaminating compact ERO galaxies, but Y band provides the cleanest separation between quasars and brown dwarfs (Figure 2).

Therefore, selecting the highest redshift quasars while keeping brown-dwarf contamination manageable requires at least 3 bands typically Z,Y,J. Here 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<sub>s</sub> discriminate among these, so candidates can be prioritised for spectroscopic followup.

In addition, we can select quasars at  $z \sim 6$  to a limit  $\sim 1.5$  mag fainter than the existing SDSS sample, via similar *i-Z* colour selection techniques to those used by SDSS and using the more sensitive KIDS+VALKIRI *i,Z,J* data to push 1.5 mag further down the luminosity function. (The SDSS selection (Fan et al 200x) used followup snapshots in J, which are provided automatically in our survey).

### 2.1.4 Brown Dwarfs

As a byproduct of the quasar search, the survey will contain a very large number of brown dwarfs,  $\sim 3000$  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  $> 2$  (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  $10\sigma$  limit  $r = 24.4$  is expected to be  $z_{\text{med}} \sim 0.8$ , 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, very important for direct

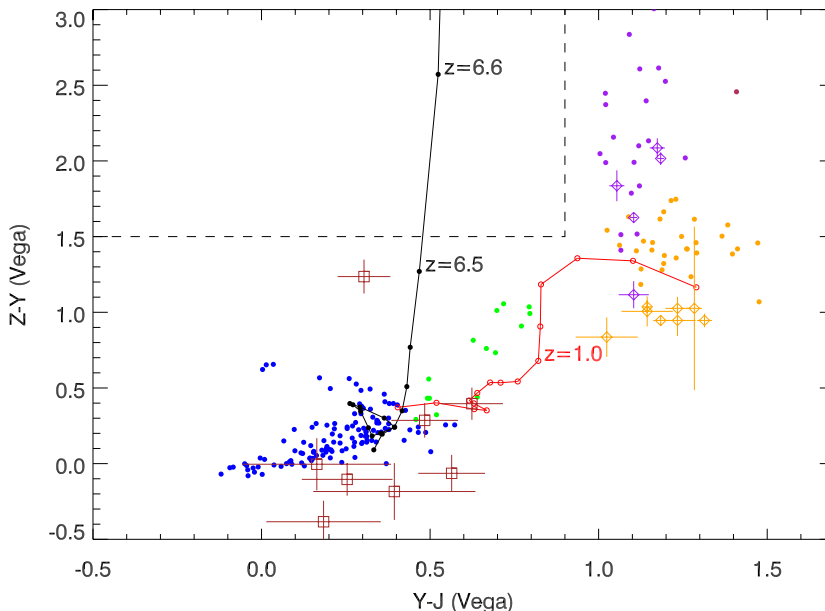


Figure 2: Selection of high-redshift quasars with Z/Y/J colours. Black line is quasar locus; dots show model colours for A-K stars (blue), M stars (green), L dwarfs (yellow) and T dwarfs (purple). Red line is early-type galaxy locus. Squares show measured values from UKIDSS SV data for known quasars and BDs.

comparisons with the  $r$ -selected local SDSS sample. Likewise, the  $K_s$  band will sample rest-frame  $1.0 - 1.5 \mu\text{m}$  across the typical redshift range, which gives an excellent measurement of stellar mass with minimal dependence on star-formation rate and extinction, allowing direct comparison with local 2MASS J-selected samples.

Therefore, adding NIR data delivers SEDs spanning **rest-frame** wavelengths  $0.3 - 1.2 \mu\text{m}$  for the majority of galaxies in the sample; combined with the photometric redshifts, this enables investigation of galaxy LF evolution across the above rest-frame wavelengths without significant k-correction uncertainties or extrapolations. ( Given  $ugriZ$  alone, only the window of rest-frame  $0.3 - 0.45 \mu\text{m}$  remains in common to most KIDS galaxies). Also,  $\sim 600 \text{ deg}^2$  of our area overlaps with the GALEX Medium Imaging Survey (MIS), providing good UV coverage.

This should provide a very important stepping-stone for galaxy evolution at intermediate redshifts between the very large local samples (SDSS + UKIDSS), 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 VALKIRI 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 structure

The VISTA-KIDS 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  $\sim 1$  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. In total the proposed VISTA-KIDS survey 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.

It is also worth stressing the fundamental advantage of VISTA's near-IR passbands over optical data: firstly, dust not only attenuates light but does so in a manner dependent on inclination and radius, fundamentally modifying the measured light profile shapes in an irreversible manner. As the dust attenuation is negligible in the near-IR this immediately overcomes this limitation. This is particularly critical for accurate fitting of the profile and identification of any nucleus component. Secondly the H and  $K_s$  fluxes closely correlate with stellar mass (dominated by low mass populations), hence the near-IR light profile is a direct measure of the stellar density profile. Thirdly, the smoother distribution of the old stellar population which dominates the near-IR makes the profile fitting significantly easier minimising the number of local minima that plague the multi-dimensional fitting process. Finally the depth probed (1.4 mag/arcsec<sup>2</sup> 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.

Near-infrared (JHK) imaging also allows to look for evidence of non-axisymmetric components (e.g. bars) in galaxies hosting an active nucleus (AGN): these features should contribute to the transport of gas from the outer parts of the galaxy down to the nucleus. Compared to optical images, the near-infrared allows a much better separation of such components as both the contamination from the active nucleus and absorption by dust are much smaller.

### 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 Å break starts to redshift into the Z band and optical-based selection gets much harder; adding at least one band at  $\geq 1 \mu\text{m}$  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  $\sim 1.4$  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 Galactic structure

(i) Detecting streams at unprecedented depth to probe the Halo shape

There is compelling evidence that at least part of our stellar halo has been built up via the accretion of smaller satellite galaxies. The most notable example is the Sagittarius (Sgr) dwarf galaxy (discussed above). The kinematics of the stream stars can be used as test particles along the orbit through the outer regions of the halo, and can be thus used to investigate properties of the halo (Martinez-Delgado et al. 2004). The shape of the dark-matter halo is fundamental because it is dependent on the nature of the dark matter particles themselves - i.e hot, self-interacting or cold. On the other hand, if the observed flat rotation curves exist because of a modified form of gravity rather than from dark matter (i.e. MOND, Milgrom 2001, Bekenstein 2004) then the dark component is massless and spherical.

(ii) The Mass and Extent of the Galaxy

Streams can tell us the formation history and evolution and give us clues to the shape, but what about stars not in streams? Can they give us clues to the dark matter fraction? We cannot quantify the fraction of dark matter within a 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 highly 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+VALKIRI data will be an impressive advance allowing us to probe at least four stellar halo populations (above) simultaneously out to the edge of the stellar halo. The KIDS data will be used to isolate the BHB and RR Lyrae stars and the deep YJHK<sub>s</sub> bands will isolate the M giants and carbon stars. This survey will comprise the deepest stellar population map ever undertaken.

### 2.1.9 Ultracool white dwarfs

The ultracool white dwarfs (WDs), with  $T_{\text{eff}}$  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<sub>2</sub> 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 near-IR flux. It is therefore evident that adding Z,Y,J,H,K<sub>s</sub> measurements to the  $u, g, r, i$  magnitudes from KIDS will greatly improve the capability to detect ultracool WDs and will allow a spectrophotometric determination of their effective temperature.

Near-IR measurements will also be important to better constrain the SED of “normal” cool WDs (4000 K  $\lesssim T_{\text{eff}} \lesssim 7000$  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 .  $\Delta m_{lim}$  is the approximate **gain** in limiting magnitude relative to SDSS (optical) or UKIDSS-LAS (IR).

Survey	Hemisphere	Bands	Area (deg <sup>2</sup> )	$\Delta m_{lim}$	Completion
DENIS	South	IJK	20,000	-3	2003
2MASS	N + S	JHK	40,000	-3	2002
SDSS	North	<i>ugriz</i>	10,000	$\equiv 0$	2008
UKIDSS-LAS	North	YJHK <sub>s</sub>	4,000	$\equiv 0$	2012
VST-ATLAS	South	<i>ugri</i>	4,500	0	2010
VISTA-VHS	South	JK <sub>s</sub> (Y,H?)	4,500 - 20,000	0	proposed
Skymapper	South	<i>ugriz</i>	20,000	0	2012 ?
<b>KIDS</b>	South	<i>ugri</i>	1,500	+2	2011 ?
<b>VALKIRI</b>	South	ZYJHK <sub>s</sub>	1,500	+1.4	2011 (proposed)
DES	South	<i>griz</i>	5,000	+2.2	2014 ?
CFHTLS-Wide	North	<i>ugriz</i>	150	+3.3	2008
UKIDSS-DXS	North	JK	35	+2.8	2012
VISTA-VIDEO	South	ZYJHK <sub>s</sub>	30	+3.5	proposed
VST-16	South	16 bands	20?	?	2012 ?

The nearest existing analogues to KIDS + VALKIRI 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  $\sim 2$  mag deeper and will have much better resolution. Likewise, VALKIRI will be  $\sim 1.4$  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 deg<sup>2</sup> 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 may aim to cover the entire Southern hemisphere to UKIDSS-LAS depth in 2 or 4 bands, and will likely prioritise the VST-Atlas area first. Again, if approved this will be substantially wider but shallower and is likely to use poorer seeing than VALKIRI.

The numerous deeper surveys e.g. CFHTLS-Wide, UKIDSS-DXS and VISTA-VIDEO are all much narrower  $\sim 30 - 150$  deg<sup>2</sup>, and approximately 1.0 - 2.0 mag deeper than KIDS+VALKIRI.

Therefore, overall the KIDS+VALKIRI 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 comparable directly competing survey at present; the nearest analogue to KIDS will be the US-led Dark Energy Survey which aims to survey 5,000 deg<sup>2</sup> in the SGP to similar depth to KIDS, starting in 2009.

## 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 deg<sup>2</sup>. 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 access 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 and do not make the most of 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 VALKIRI 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 serious scheduling clashes with popular targets near this RA range, e.g. SWIRE fields, Magellanic Clouds).

There is however some flexibility for tradeoffs e.g. slightly unequal exposure times between NGP and SGP strips or reducing the baseline exposure time at the most oversubscribed RAs ; this can be discussed at the Public Survey Panel stage.

### 4.2 Bands, seeing, scheduling

Our strategy is to observe the full KIDS area in the 5 broadband filters , Z,Y,J,H,K<sub>s</sub>. From Section 2, the Z-band is critical for much of the KIDS science; the Y and J bands are critical both for the quasar and brown dwarf selection and for red-sequence galaxies at  $z > 1$ , while the K<sub>s</sub> band forms a long-wavelength benchmark and gives maximal leverage for galaxy masses and star-galaxy separation.

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  $\leq 1.0$  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 at 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<sub>s</sub> 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  $\sim 400$  sec of exposure time per object. Given VISTA's default tiling strategy, this is 200 sec per pawprint, which is naturally split into 4 jitter steps. We anticipate most VALKIRI data will have seeing in the range 0.7 – 1.0 arcsec, so microstepping is not needed. Resampling onto  $\sim 0.25$  arcsec pixels during pipeline reductions is an option, but is not essential.

Our 4 jittered exposures at  $\sim 50$  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  $\approx 400$  sec per galaxy per filter, with slightly more for Z,  $K_s$  and less for H. This matches the Z intended for KIDS, and is reasonable since red objects (e.g. passive galaxies) have SED's which are roughly flat  $f_\lambda$  at rest-frame  $0.6 - 1.2 \mu\text{m}$ , and equal exposure time per band gives quite similar  $f_\lambda$  sensitivity for VISTA.

Assuming 0.8 arcsec median seeing, an aperture diameter 2.0 FWHM and median Paranal sky brightness, the VISTA ETC v1.1 gives the following sensitivity limits in Table 2 :

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

Filter	Exp. time (sec)	Med.seeing (arcsec)	$5\sigma, 2''$ (AB)	aperture mag. (Vega)	$f_\lambda$ ( $10^{-20} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$ )	UKIDSS (Vega; actual)
Z	500	0.8	23.1	22.6	75	–
Y	400	0.8	22.4	21.8	104	20.2
J	400 (2 × 200)	0.8	22.2	21.4	87	19.6
H	300	0.8	21.6	20.3	87	18.7
$K_s$	500	0.8	21.3	19.5	70	18.2
<i>i</i> (KIDS)	1080	0.7	24.1	23.8	40	–

The total time request for VALKIRI is given in Table 3. We assume 25% overheads as per the ETC, and the default average 9 hours per clear night. (NB: this appears pessimistic for an IR system which can observe 30 mins after sunset or before sunrise ).

Table 3: Time requested

Patch	Filter	Time (h)	Time(n)	RA range	Area	Moon	Seeing	Transp
KIDS-N	Z/Y/J1	560	62	10-16	780	d/g	< 1.0	thin
KIDS-N	J2/H/ $K_s$	560	62	10-16	780	any	< 1.0	thin
KIDS-S	Z/Y/J1	520	58	22-3.5	720	d/g	< 1.0	thin
KIDS-S	J2/H/ $K_s$	520	58	22-3.5	720	any	< 1.0	thin
Total	Z/Y/J1		120		1500	d/g	< 1.0	thin
Total	J2/H/ $K_s$		120		1500	any	< 1.0	thin

The total time request is thus **240 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/ $K_s$  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  $\sim 0.02$  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: (3 pages max)

### 6.1 Team members:

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

Name	Function	Affiliation	Country
<b>VDFS team</b>			
CASU (VDFS) team	Pipeline processing	Cambridge Univ.	UK
CASU (VDFS) team	Data Quality Control-I	Cambridge Univ.	UK
J. Emerson	VDFS Coordinator	QMUL	UK
WFAU (VDFS) team	Science Archive	Edinburgh Univ.	UK
WFAU (VDFS) team	Data Quality Control-II	Edinburgh Univ.	UK
N. Walton	VO Standards	Cambridge Univ.	UK
<b>VALKIRI team ; Data quality control-III</b>			
W. Sutherland	VALKIRI 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
R. McMahon	High-z quasars	Cambridge	UK
J. Liske	Galaxy structure	ESO	Germany
R. Silvotti	Ultracool WDs	INAF, Capodimonte	Italy
J. Peacock	Baryon oscillations	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 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 surveys as a test bed for the VISTA infrared surveys, and which is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system. We emphasise the track record over the last decade of both the Cambridge and Edinburgh survey units in processing and delivering large-scale imaging datasets to the community as exemplified by the WFCAM Early Data release (EDR, (<http://surveys.roe.ac.uk/wsa/dboverview.html>) Lawrence et al 2006, Dye et al 2006).

### 6.3 Data reduction plan:

The data reduction will be using the VDFS, operated by the VDFS team, and augmented by individuals from VALKIRI, 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.

#### 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/>

VALKIRI 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” bad data (e.g. trailed images, telescope out of focus, 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 with primary responsibility for assessing the data with regard to that science topic. The main point of contact will be the VALKIRI 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.

+ DON'T FORGET XXX survey specific products

## 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 quasi-linearly over time and much of the science analysis can progress in parallel without waiting for completion. (The baryon oscillations are a possible exception which require the full area).

Our time request is approximately 2/3 of that for KIDS, so assuming the allocations per year are in proportion, the two can progress at a similar rate. If VALKIRI were scheduled for  $\sim 25\%$  of the VISTA Public Surveys time (e.g. most of the 3rd quartile seeing), we would anticipate completion around 2012, with phased data releases. XXX

T0: Start of observations

T0+4months; Release of science products from first month of survey observations

T0+8month; Release of science products from first 6 months of survey observations

Thereafter we anticipate that standard science products can be released to the PIs within 1-2 months of raw data arriving in the UK.

Optional reprocessing of data based on improved knowledge of the instrument would also be considered

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

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

In some “core” areas, VLT followup will be essential to deliver the full science goals of KIDS+VALKIRI, 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 *sim*6500 photometric redshifts using VIMOS spectra to  $I_{VEGA} = 24$  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  $\sim 10$  colour-selected QSOs at  $6 < z < 7.4$ . 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 higher SNR. As we gain experience with the bright subsample, we can push towards the  $10\sigma$  limit  $J = 20.8$ ; using HAWK-I Z,Y images to improve the colour measurements, in advance of spectroscopic confirmation with X-Shooter.
- **Ultra-cool brown dwarfs:** At  $J \sim 20$  (an excellent  $20\sigma$  detection), non-detection at  $5\sigma$  in Y implies  $Y - J > 2$ . 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 J,K images of  $\sim 600$ s 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.
- Providing an input catalogue for massive next-generation redshift surveys for improved precision on baryon oscillations.
- 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.
- Identification of sources from future all-sky surveys e.g. WISE, to a fainter limit than reached by SDSS/LAS/VHS.

**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-VALKIRI survey will have lasting long-term value to the whole ESO community.

## Appendix: Photometric redshifts with VISTA NIR observations

We performed new simulations of the combined KIDS+VISTA 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 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 “VISTA” cases, with and without H band, plus one “UKIDSS” case (approximately one magnitude shallower than VISTA in the NIR bands and with Z coming from VISTA). The exposure times and the relative limiting Vega magnitudes ( $10\sigma$  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  $\Delta z_{68}$ . 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  $\Delta z_{68}$  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  $\sigma$  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  $5\sigma$  detections.

The table (and Fig. 3) shows that the VISTA NIR data do improve the precision of the photometric redshifts with respect to the UKIDSS depth. The  $\Delta z_{68}$ , the percentage of the failures (with the exception of the  $r < 25$ ,  $z_{lim} = 6$  case, where, however, the UKIDSS  $\Delta z_{68}$  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  $\Delta z_{68}$ . In this case the VISTA 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
5 bands	500	400	400	300	500
no H	620	540	540	0	550

Table 5:  $10\sigma$  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<sub>s</sub> as above.

Cases	Z	Y	J	H	K
VISTA Z + LAS YJHK	22.18	19.8	19.7	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

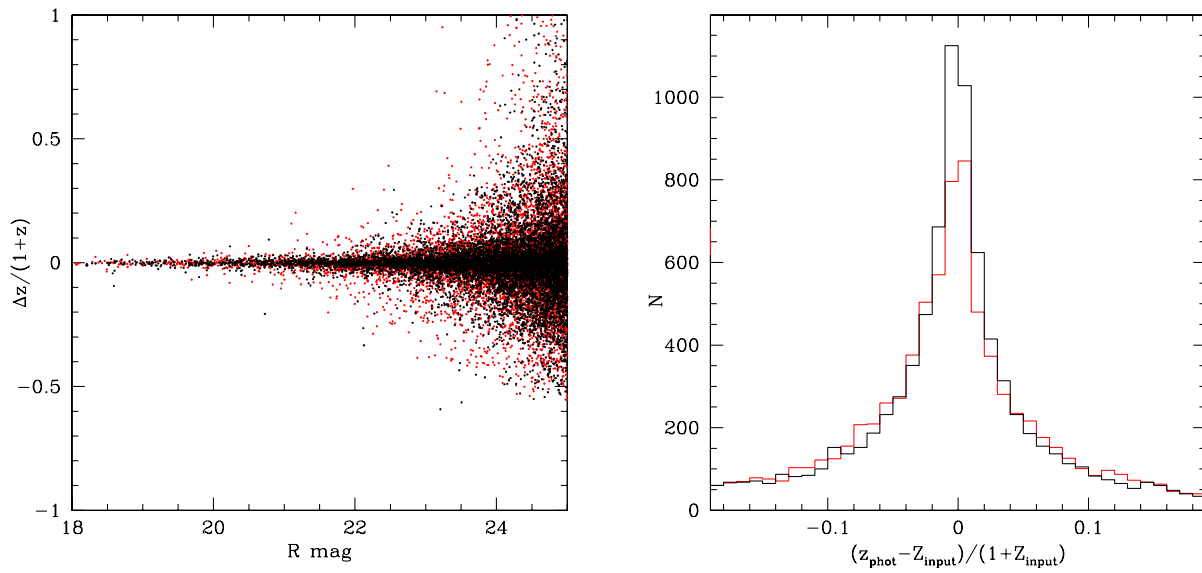


Figure 3: **Left:** The black dots show the redshift differences  $\Delta z$  down to  $z_{lim} = 1.5$  as a function of the r magnitude for the VISTA 5-band case. The red dots show the same for the VISTA Z + LAS data. **Right:** the histogram of the differences  $\Delta z$  for the VISTA (black line) and the UKIDSS (red line) data down to  $z_{lim} = 1.5$  and  $r_{lim} = 25$ .

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