The VISTA Kilo-degree Infrared Galaxy (VIKING) Survey: Bridging the Gap between Low and High Redshift

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VIKING is a medium-deep survey of 1500 square degrees over two areas of the extragalactic sky with VISTA in *zYJHKs* bands to sample the restframe optical for galaxies at $z \gtrsim 1$. VIKING complements the two other surveys — VHS with its large area but shallower depth and VIDEO with its greater photometric depth and smaller spatial coverage. In addition to a $0.7 < z < 2$ galaxy survey, the area and depth of VIKING enables other studies, such as detection of distant quasars and low-mass stars and many galaxy clusters and superclusters. The early results are summarised and future prospects presented.

The remarkable improvement in the near-infrared survey speed that VISTA delivers offers the opportunity to study a volume of the distant ($z > 1$) Universe in the restframe optical bands that is many times larger than the Sloan Digital Sky Survey (SDSS). A survey of the full southern sky to reach a depth to detect an L^* galaxy requires more time than is available, but even a few percent of the available area is sufficient for the vast majority of projects.

It was with the goal of creating a legacy dataset with a wide range of science goals that we proposed the VISTA Kilo-degree Infrared Galaxy (VIKING) survey. In conjunction with its sister survey KiDS (Kilo-Degree Survey; Principal Investigator [PI]: K. Kuijken) on the VST, VIKING will cover 1500 square degrees in five bands (*z*, *Y*, *J*, *H* and *Ks*) to an AB depth of 23.1, 22.3, 22.1, 21.5 and 21.2 respectively. This combination of depth and area reaches our science goals for the $z > 1$ Universe and sits neatly between the VISTA Hemisphere Survey (VHS) and VIDEO surveys.

The VIKING survey area is split into two areas: an equatorial strip between right ascension 9 and 15.8 hours and 8 degrees wide; and a strip over the South Galactic Pole between right ascension 22 and 3.5 hours and 10 degrees wide. Our choice of survey area was made to maximise the overlap with existing multi-wavelength datasets that cover > 100 square degrees. The most prominent of these are the Galaxy And Mass Assembly (GAMA) survey (PIs: S. Driver and A. Hopkins) and the Herschel Astrophysical Terahertz Large Area Survey (H-ATLAS) (PIs: L. Dunne and S. Eales) covering over 148 and 360 square degrees of the VIKING area respectively.

Synergy with other surveys — GAMA, H-ATLAS and KiDS

The primary focus of GAMA science is on the combination of imaging and spectroscopy for $z < 0.2$ galaxies to determine the structure and evolution of galaxies over a wide range of mass and environment. The quality of the imaging data is particularly important in this context as the balance of bulge to disc in galaxies is key to our understanding of galaxy structure, but the stellar populations in the two components can differ significantly. Therefore, performing bulge–disc decomposition analysis at many different wavelengths can be used to constrain the evolution of the stellar population in the two components of the galaxy independently. To do this requires relatively deep photometry to constrain the lower surface brightness outer regions of the galaxy. Figure 1 illustrates the improvement in image quality going from the Two Micron All Sky Survey (2MASS), UKIRT InfraRed Deep Sky Surveys: Large Area Survey (UKIDSS LAS) to VIKING for a single galaxy (Andrews et al., 2013). The importance of depth to enhance the science potential in the lower-redshift Universe is just as significant as it is at higher redshift.

H-ATLAS represents the largest investment of time into any Herschel project and it has returned results from the lowest redshift (Burton et al., 2013) to lensed high-redshift galaxies (González-Nuevo et al., 2012). The dusty nature of far-infrared (FIR) selected galaxies means that it is particularly important to use near-infrared (NIR) imaging to identify these sources. Fleuren et al. (2012) find counterparts in VIKING for at least 51% of all 250 µm sources and a substantially higher fraction of sources with FIR fluxes consistent with lower redshift. This fraction is 40% higher than equivalent matches in the optical *r*-band. The VIKING depth is sufficient to make a matched detection with at least the deepest band in the KiDS survey for any $z < 1$ galaxy. However, for more distant galaxies, particularly systems with a low specific star formation rate, then many will be too faint to be detected at the KiDS depth of 24 mag AB. Fortunately, for the equatorial strip, the Subaru Hyper SuprimeCam (HSC) Survey (PI: A. Miyazaki) will cover the same area to at least 1–1.5 mag deeper. This will allow for the selection of an unprecedentedly large sample of Extremely Red Objects (EROs; $[i{-}Ks]_{AB} > 2.45$) that are known to cluster very strongly (Kim et al., 2011) and also trace the most distant clusters of galaxies at $z > 1.6$ (Stanford et al., 2012).

QSO and low-mass star discrimination

The combination of deep optical data and moderately deep NIR data are particularly important when considering the selection of the most distant quasars and the lowest-mass stars. The discovery of the first $z > 7$ quasar (QSO) from the UKIDSS LAS by Mortlock et al. (2011) demonstrated the potential of NIR selection to push back the detection of the most distant active galactic nuclei (AGN), with all the associated insights they provide on the reionisation of the Universe. The combination of depth and area makes VIKING very well suited to the selection of $z > 6.4$ QSOs that fall beyond the grasp of silicon detectors in the optical. Venemans et al. (2013) have amply demonstrated this by the selection of the second, third and fourth most distant QSOs at $z = 6.89$, 6.75 and 6.61 respectively (see Figure 2). The selection of these three QSOs from the first 300 square degrees of the VIKING area required a significant investment of ESO New Technology Telescope (NTT) follow-up time to remove the contamination of low-mass stars and dusty, lower-redshift galaxies, as the KiDS survey had not started in 2011. Now that KiDS has covered the same area as VIKING, this additional screening is not required, so future target selection will be significantly faster. Venemans et al. (2013) predict the discovery of ~ 20 QSOs at $6.44 < z < 7.44$, so the prospects for future constraints on the evolution of QSOs into the epoch of reionisation are very promising.

At the opposite extreme, VIKING offers an excellent combination of bands to select low-mass stars. The differentiation between low-mass stars and distant QSO candidates in (Z-Y) *vs*. (Y-J) colour space means that VIKING data can make a clean selection of L- and T-dwarfs. Adding in Wide-Field Infrared Survey Explorer (WISE) photometry and KiDS/HSC *i*-band data, means that VIKING will recover a significant number of these stars, allowing constraints on their scale height given the range of Galactic latitude and longitude covered by VIKING.

Galaxy and cluster surveys

The bulk of the galaxies detected in VIKING will be at redshifts of 0.7 to 2.0. The volume sampled between these two limits is ~ 20 Gpc^3 which is nearly an order of magnitude larger than that of the SDSS DR10 within $z < 0.3$. Therefore rare objects such as clusters and superclusters will be recovered in large numbers. Given the overlap with Sunyaev–Zel'dovich surveys such as the Atacama Cosmology Telescope (ACT; Marriage et al., 2011) and the substantial increase in X-ray survey depth provided by eROSITA (Predehl et al., 2009), VIKING will provide an important resource for the confirmation of cluster candidates from other techniques, as well as providing clusters selected from their member galaxies alone. The selection of more distant clusters is of particular importance when

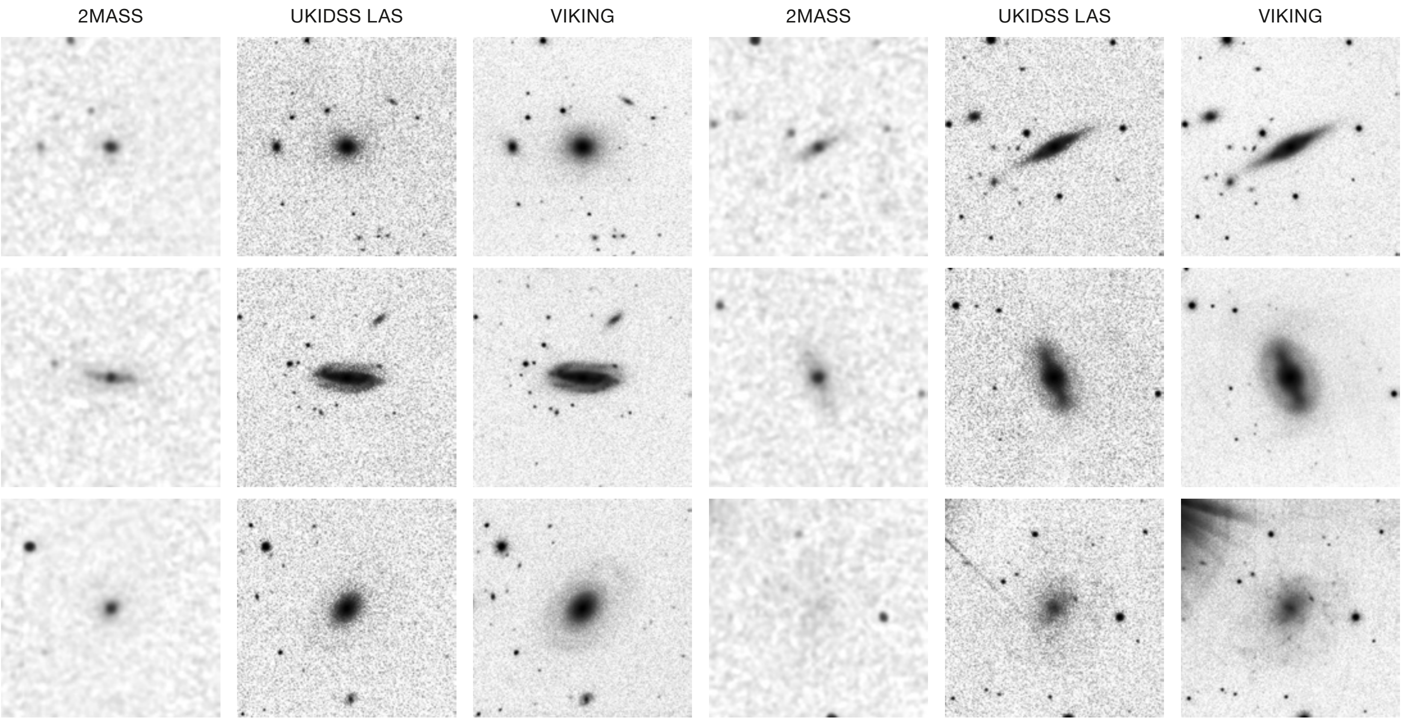

Figure 1. The 2MASS, UKIDSS LAS and VIKING images of six GAMA galaxies in the *Ks*-band. Note the extended, low surface brightness emission that only becomes clear in the deepest data. A full description of these comparisons can be found in Andrews et al. (2013).

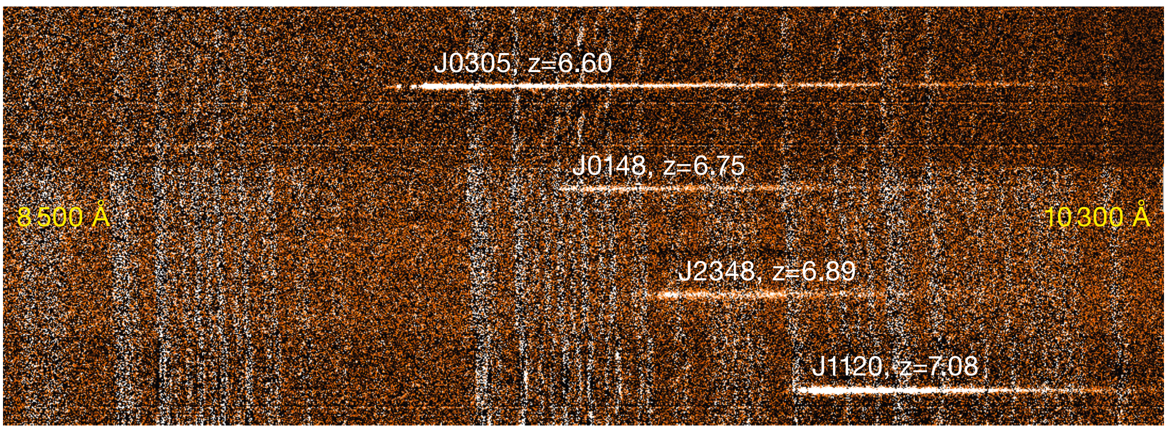

Figure 2. A montage of the 2D FORS2 spectra of the three VIKING $z > 6.5$ quasars with the $z = 7.1$ UKIDSS quasar for comparison. Note the excellent red sensitivity of FORS2 and the very abrupt cut-off blueward of the Lyman-α line in these systems.

considering the cosmological constraints that can be determined from the evolution of the cluster mass function (Eke, Cole & Frenk, 1996). VIKING will recover a significant number of the most massive clusters at $z > 1$ that are only found in small numbers in serendipitous X-ray cluster surveys, such as the XMM Cluster Survey (XCS; Mehrtens et al., 2012), or Spitzer mid-infrared surveys, such as the Spitzer Adaptation of the Red-sequence Cluster Survey (SpARCS; Wilson et al., 2009), which cover much smaller areas of sky.

In addition to clusters, VIKING will select the most massive galaxies within the survey volume and these are known to cluster particularly strongly (Kim et al., 2011). The combination of excellent photometry and the large area coverage of VIKING/KiDS will allow us to trace the angular clustering of massive galaxies at $z > 1$ (where the angular clustering scales are least affected by redshift) in a number of independent redshift slices.

Serendipity and legacy aspects

VIKING will also provide a wide margin for serendipitous discoveries of rare or extreme sources, given the overlap with many other multi-wavelength surveys. For instance, extremely obscured AGN can be selected from WISE photometry relatively easily (Eisenhardt et al., 2012), but are very faint in the optical, so NIR data are essential. VIKING photometry will fill an important niche for a number of projects that need deeper photometry than that provided by UKIDSS LAS or VISTA VHS, but wider area coverage than UKIDSS Deep Extragalactic Survey (DXS) or VISTA VIDEO.

The legacy value of the VIKING/KiDS survey will be extended with the extensive spectroscopic surveys planned in this area using the spectrographs 4MOST, MOONS and Subaru Prime Focus Spectrograph (PFS). The complementary nature of these optical and NIR surveys means that the spectral coverage will be very dense, allowing many new observational strategies related to the lensing and intervening absorption of background objects by a fully constrained foreground to be explored. The vital foundation of these surveys will be the reliable photometric catalogue that VIKING/KiDS provides.

The VIKING data will be made available through the VISTA Science Archive (VSA[1]) and the ESO Phase 3 facility[2], but the VIKING consortium will be creating an additional set of images that are optimised to match the seeing of other optical surveys (SDSS, KiDS and/or HSC) to ensure the best possible aperture photometry is extracted. These additional images will be made available to the community through the VSA. The first 226 square degrees of the VIKING data have been released through the VSA and ESO Phase 3 databases and we encourage the community to contact us if they have any questions.

References

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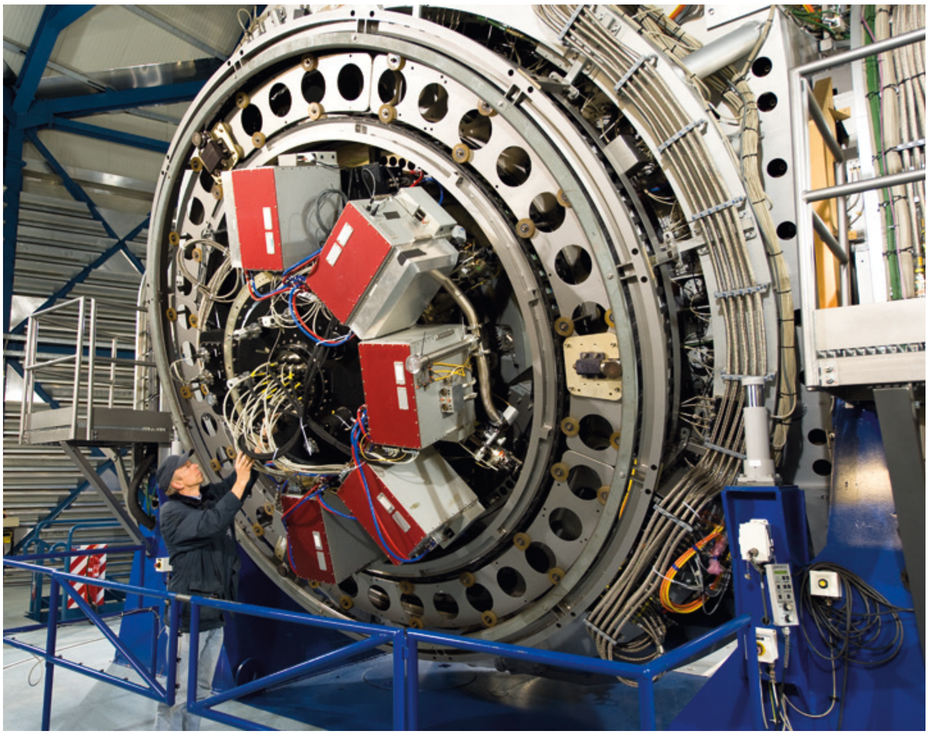
Links

[1] VISTA Science Archive (VSA): http://horus.roe.ac.uk/vsa/
[2] ESO Phase 3 VIKING data release 1: http://www.eso.org/sci/observing/phase3/data_releases/viking_dr1.pdf



View of the Cassegrain focus of VISTA housing the VIRCAM camera. VIRCAM consists of 16 2048 square Raytheon VIRGO HgCdTe 0.84–2.5 μm detectors covering a field of 45 × 45 arcminutes (with inter-detector gaps). This image shows Paranal engineer Gerhard Hüdepohl checking VIRCAM.