First Scientific Results from the VISTA Hemisphere Survey (VHS)

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The first Galactic and extragalactic results from the VISTA Hemisphere Survey (VHS) are presented. The aim of the VHS is to carry out a near-infrared survey which, when combined with other VISTA public surveys, will result in coverage of the whole southern celestial hemisphere (~20 000 square degrees) to a depth 30 times fainter than the Two Micron All Sky Survey in at least two wavebands (*J* and *Ks*). The VHS vision includes a deep optical survey over the same area and this is now being realised with the VST surveys and the Dark Energy Survey, which has recently started. A summary of the survey progress is presented, with some follow-up results on low-mass stars and high-redshift quasars.

Introduction

The goal of the Vista Hemisphere Survey (VHS[1]) is to carry out a near-infrared (NIR) survey of all of the southern hemisphere (an area of ~ 20 000 square degrees) in at least two wavebands (*J* and *Ks*), with an exposure time of 60 seconds per waveband to produce median 5σ point source (Vega) limits of *J* = 20.2 and *Ks* = 18.1. This is ~ 30 times deeper than the Two Micron All Sky Survey (2MASS; Skrutskie et al., 2006) in the same bands. This total area coverage is achieved by combining with data from other VISTA public surveys, such as VIKING.

In the South Galactic Cap, ~ 5000 square degrees will be imaged more deeply with an exposure time of 120 seconds, and also including the *H*-band to produce median 5σ point source limiting magnitudes of: *J* = 20.6, *H* = 19.8 and *Ks* = 18.5. In this region of the sky, deep multi-band optical (*grizY*) imaging data will be provided by the Dark Energy Survey (DES). The remainder of the high Galactic latitude (|*b*| > 30°) sky will be imaged in *YJHKs* for 60 s per band, to be combined with *ugriz* waveband observations from the VST ATLAS survey.

The medium-term scientific goals of the VHS include:
– the discovery of the lowest-mass and nearest stars;
– deciphering the merger history of the Galaxy via stellar galactic structure;
– measurement of large-scale structure of the Universe out to *z* ~ 1 and measuring the properties of dark energy;
– discovery of quasars with *z* > 7 for studies of the baryons in the intergalactic medium during the epoch of reionisation;
– discovery of the most luminous quasars at all redshifts in the southern hemisphere as probes of the intergalactic medium and the formation of the most massive supermassive black holes in the Universe.

In addition the VHS survey will provide essential multi-wavelength support for the European Space Agency (ESA) Cornerstone missions; XMM-Newton, Planck, Herschel and Gaia.

Survey status

Figure 1 shows the sky coverage of VHS observations completed up to 1 October 2013. A total of 5511 observation blocks (OBs) have been completed. Each OB is equivalent to a single VISTA tile and covers 1.5 square

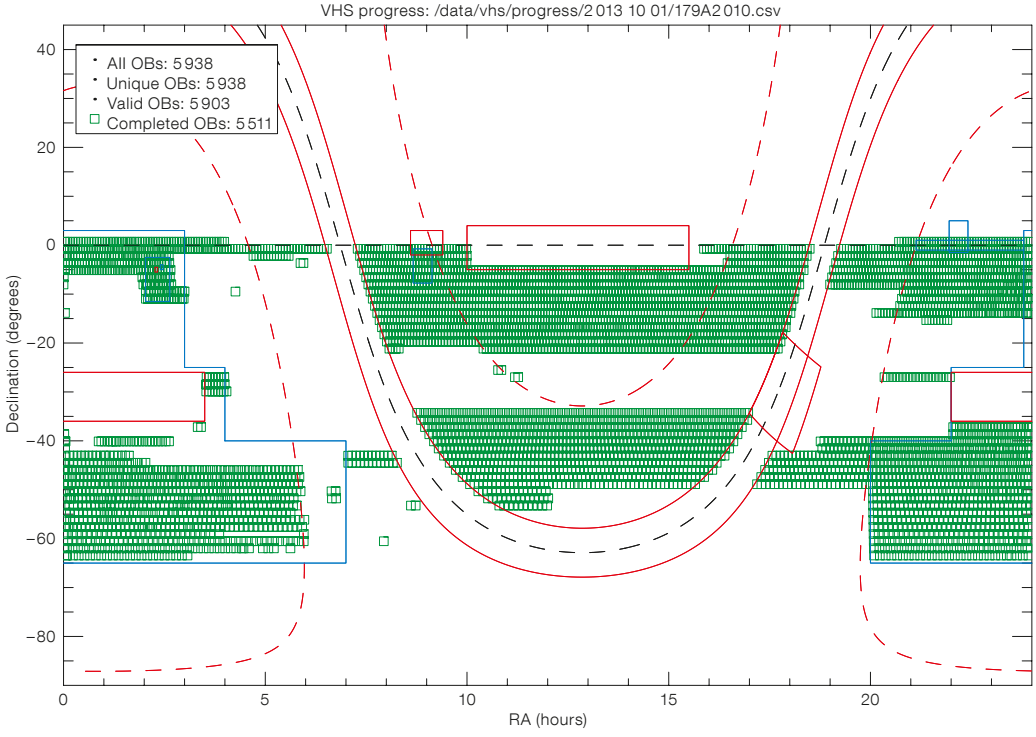


Figure 1. Sky coverage of the VHS survey completed up to 1 October 2013 based on ESO portal report tables. The green rectangles show completed tiles. The red solid lines show nominal regions outside the VHS observing footprint. The dashed red line is Galactic latitude +30, –30 degrees. The blue lines show the provisional DES footprint, circa April 2012.

degrees. The total observed area is around 8300 square degrees. All data is pipeline processed with the VISTA Data Flow System (Irwin et al., 2004; Lewis, Irwin & Bunclark, 2010; Cross et al. 2012) and the science products are available from the ESO Science Archive Facility and the VISTA Science Archive[2].

Scientific results

Many of the proposed scientific programmes for VHS require optical survey data from the VST surveys and DES. These surveys have only recently started and hence scientific exploitation has focused on science that can be carried out without optical data.

Figure 2 shows a comparison between VHS positions and the very long baseline interferometry (VLBI) radio reference frame[3]. The results are summarised in Table 1 and compared with the Sloan Digital Sky Survey (SDSS) and the UKIRT Infrared Deep Sky Survey (UKIDSS): there is a statistically significant systematic error of 0.05 arcseconds in declination. This is consistent with expected proper motions of 2MASS stars (Roeser et al., 2010) due to the ten year difference in epoch between 2MASS and VHS. Note that this systematic error varies depending on the direction in the sky of the Solar System motion with respect to an average 2MASS reference star. Proper motions will be included in future Cambridge Astronomical Survey Unit (CASU) processing based on the Fourth U.S. Naval Observatory CCD Astrograph Catalogue (UCAC4) or PPMXL catalogues (Roeser et al., 2010).

Survey (number of sources)	σ (statistical) (arcseconds)		Systematic uncertainty (arcseconds)	
	RA	Dec	RA	Dec
VHS (563)	0.11	0.09	0.011 ± 0.005	0.051 ± 0.004
SDSS (2308)	0.05	0.05	0.006 ± 0.001	0.003 ± 0.001
UKIDSS (599)	0.10	0.09	−0.031 ± 0.004	−0.068 ± 0.004

Table 1. VHS astrometry comparison with VLBI radio reference frame, contrasted with SDSS and UKIDSS.

Low-mass stars

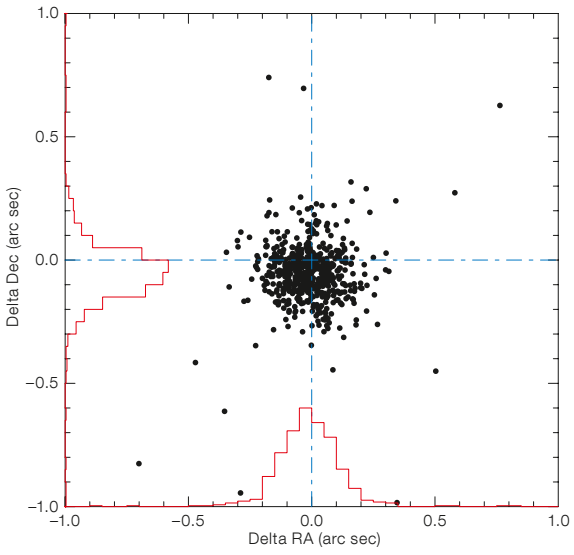
Gauza et al. (2012) are conducting a search for very low-mass common proper motion companions of nearby (< 25 pc) stars using VHS data and the shallower but earlier epoch (baseline around ten years) 2MASS catalogue. A search around the star HD 221356, which lies at a distance of 26.1 pc, has resulted in the discovery of a new common proper motion companion star located at an angular separation of 12.1 ± 0.2 arcseconds, corresponding to a projected distance of ~ 317 astronomical units (au). Figure 3 shows the VISTA discovery image. Near-infrared spectroscopy indicates a L0–L2 spectral type. Evolutionary models combined with an effective temperature of 2100–2300 K indicate a mass of 0.079 ± 0.006 $M_{\odot}$. Since the distance and metallicity of the HD 221356 system are well known, the detailed study of this new ultra-cool companion, which is located close to the frontier between stars and brown dwarfs, can provide valuable constraints on evolutionary models and, in particular, shed light on the properties of objects at the transition from stellar to substellar regime.

Lodieu et al. (2012) are using VHS in a project to improve our current knowledge of the density of T dwarfs and the shape of the substellar initial mass function by identifying a magnitude-limited sample of T-dwarfs in the full southern sky. Lodieu et al. (2012) have used VHS data combined with longer wavelength photometric data from the Wide Infrared Survey Explorer (WISE) satellite mission (Wright et al., 2010) to select candidates with red mid-infrared colours and NIR to mid-infrared colours characteristic of cool brown dwarfs.

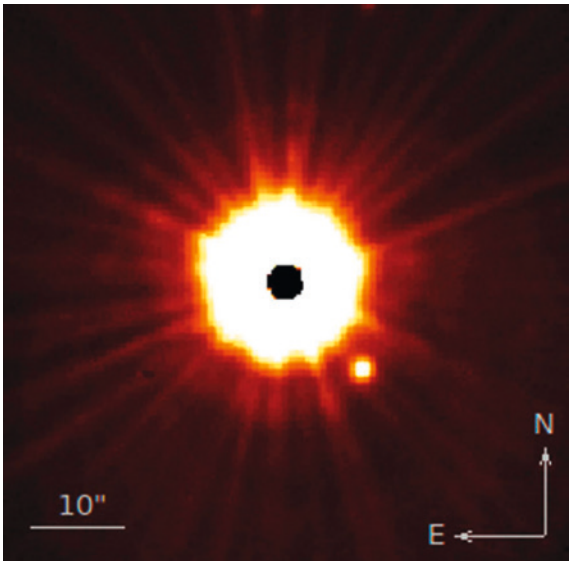
In this first stage of the survey, which only covers a few hundred square degrees, five new T-dwarf stars have been confirmed spectroscopically with the VLT with spectral types between T4.5 and T8 (see Figure 4). Two are estimated to be T6 dwarfs and lie within 16 pc, while a T4.5 dwarf is situated within 25 pc.

Quasars

Banerji et al. (2013) present the first results of a project that uses VHS data combined with WISE data to identify heavily reddened broad-line type 1 quasars in the redshift range 1.5 to 3. This redshift extent represents the cosmological epoch at the peak of star formation activity and accretion onto supermassive black holes as manifested by luminous quasars. Up until now it has been impossible to detect these luminous dust-enshrouded quasars, since existing NIR surveys like 2MASS are too shallow and deeper surveys have not covered enough area. Such luminous quasars



Left: Figure 2. Astrometric comparison between VHS positions and the VLBI radio reference frame[3].



Right: Figure 3. False colour VISTA *J*-band image of HD 221356AD. The angular separation of the newly identified companion is 12.13 ± 0.18 arcseconds and the position angle 222 ± 2 degrees. Saturation in the image centre of the primary star is visible. Scale and orientation are shown.

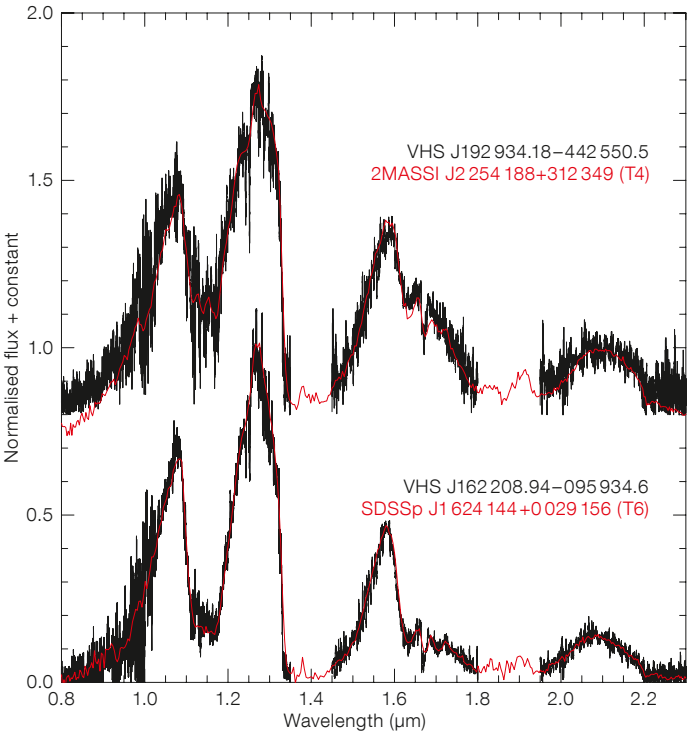


Figure 4. Near-infrared spectra obtained with VLT X-shooter and normalised at 1.265 μm. Overplotted in red are the known T-dwarf T4 and T6 templates that best fit the observed spectra.

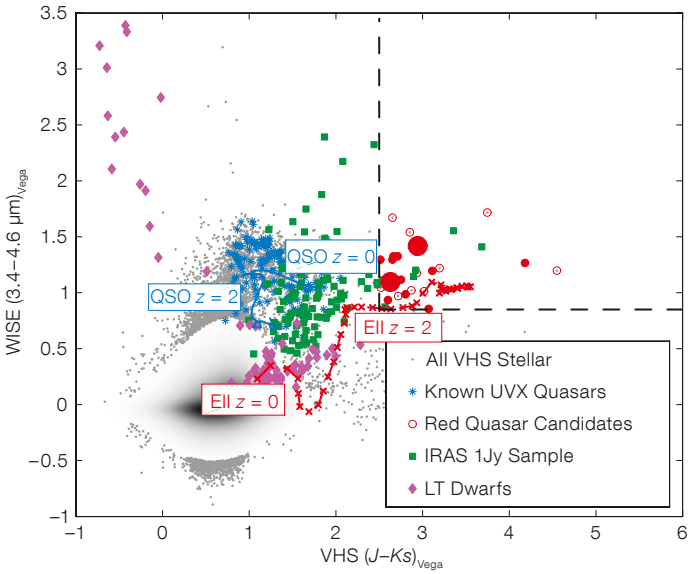


Figure 5. VHS (*J–K*) versus WISE (W1–W2) colour selection of our red quasar candidates are shown. All stellar objects detected over 180 square degrees are shown with greyscale representing the density, while the 1% of outliers in the distribution are shown as the individual grey points. Known UV-luminous quasars, local Ultraluminous Infrared Galaxies (ULIRGs) from the IRAS 1Jy sample and known LT dwarf stars have also been plotted. Also shown are the tracks of a typical unreddened quasar and an elliptical galaxy template with a formation redshift of $z = 5$. Heavily reddened quasars are marked as red circles. The small filled circles represent the spectroscopically confirmed sample from UKIDSS, the large filled circles are two newly confirmed quasars from VHS and the open circles are all candidates detected in the Banerji et al. (2013) study down to $Ks < 17$.

are expected to be in a short-lived transition phase from a heavily reddened dusty starburst to ultraviolet (UV)-luminous quasar. Optical surveys like SDSS and those with the VST are unable to detect quasars in this dusty formation phase due to the restframe UV extinction, which can be larger than 10 magnitudes at observed optical wavelengths.

With the new generation of wide NIR surveys, like UKIDSS and VHS, this field will be transformed. Luminous, heavily reddened, quasars detected by VHS will be ideally suited to follow up with the Atacama Large Millimeter/submillimeter Array (ALMA). Figure 5 shows how VHS and WISE colours are used to select the heavily obscured quasars with extremely red ($J–Ks > 2.5$ mag) colours. At high Galactic latitudes, obscured high-redshift quasars dominate this colour locus at $15 < Ks < 17$. SINFONI spectra have been used to detect broad Hα with line widths that imply supermassive black holes with masses of more than 10^9 $M_\odot$.

References

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Wright, E. L. et al. 2010, AJ, 140, 1868

Links

[1] VHS web page: http://www.vista-vhs.org
[2] VISTA Science Archive: http://horus.roe.ac.uk/vsa/
[3] VLBI radio reference frame: http://astrogeo.org/vlbi/solutions/rfc_2012b