# VST Photometric Hα Survey of the Southern Galactic Plane and Bulge (VPHAS+)

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**The VST Photometric Hα survey of the Southern Galactic Plane and Bulge (VPHAS+) is collecting single-epoch Sloan *u*, *g*, *r*, *i* and Hα narrowband photometry, at arcsecond resolution, down to point-source (Vega) magnitudes of ~ 21. The survey footprint encloses the entire southern Galactic Plane within the Galactic latitude range $-5° < b < +5°$, expanding to $b = \pm 10°$ in the Galactic Bulge. This brief description of VPHAS+ includes sample data and examples of early science validation.**

## Overview

VPHAS+ is the southern counterpart to two existing northern hemisphere surveys: the Isaac Newton Telescope Photometric Hα Survey of the Northern Galactic Plane (IPHAS), which covers the Northern Plane from La Palma in *r*, *i* and Hα (Drew et al., 2005; Barentsen et al. in preparation) and the UV-excess survey of the Northern Galactic Plane (UVEX), which does the same in *u*, *g*, and *r* (Groot et al., 2009). The combination of these three surveys will ultimately provide a 360 × 10 square-degree view of the entire Galactic Plane at roughly one arcsecond spatial resolution. This will result in a photometric catalogue containing approximately half a billion stars — two thirds of which will be captured by VPHAS+, surveying the denser southern Plane and Bulge.

The original motivation for IPHAS was to provide the digital update to photographic Hα surveys of the mid-twentieth century. In the south, VPHAS+ is the digital successor to the UK Schmidt Hα survey (Parker et al., 2005). However, the legacy of VPHAS+ will extend beyond the traditional Hα applications of identifying emission line stars and nebulae. For example, the survey's unique (*r*–Hα) colour, when combined with broadband colours, offers a rough extinction-free proxy for intrinsic stellar colour. This opens the door to a wide range of Galactic science applications, including the mapping of extinction across the Plane in three dimensions (e.g., Sale et al., 2009). VPHAS+ is also efficient in identifying OBA stars on the basis of their blue colours, and it enables comparative studies of clusters using homogeneous data. The final photometric catalogue is likely to achieve an externally validated accuracy of 0.02 to 0.03 magnitudes. The first data release is already available from the ESO archive[1] as images and single-band catalogues, calibrated against nightly standard-star data.

The original survey plan drawn up in 2006 envisaged contemporaneous five-band photometry per survey field, providing optical snapshots of stellar spectral energy distributions. During the commissioning of VST and the camera, OmegaCAM, it became evident that working to this ideal would not permit VPHAS+ to proceed in a timely manner. Hence it was agreed to adopt a more flexible strategy of splitting the data-taking into blue (*u*,*g*,*r*) and red (Hα,*r*,*i*) filter sets that can be combined, post-observation, using the repeated *r*-band exposures as aids to calibration and checks on variability. As a result, VPHAS+ follows an observing strategy that echoes the northern

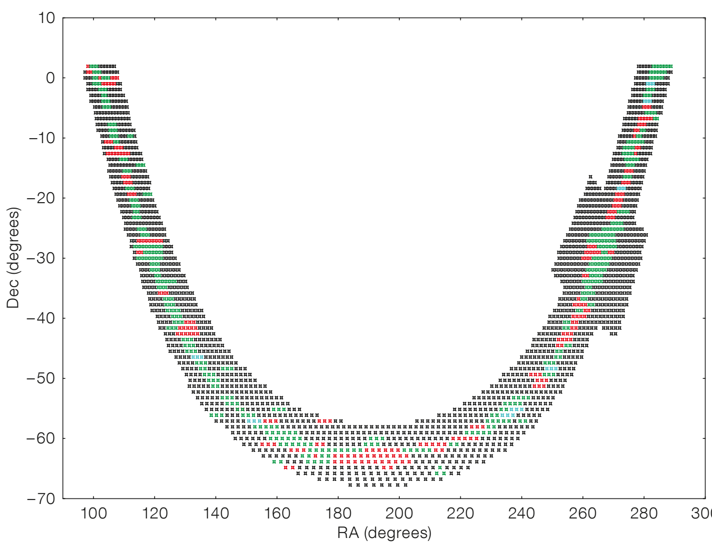


Figure 1. A map of the VPHAS+ survey footprint showing status on 30 September 2013. 2269 fields make up the survey: those shown in black had not yet been observed, while those in green have already been completed. Red is used for fields observed only in the Hα, *r*- and *i*-bands, while blue is used for those only observed in the *u*-, *g*- and *r*-bands.

| Filter | Total exposure time: No. of exposures × exposure (s) | 5σ (Vega) magnitude limit per exposure |
|---|---|---|
| *u* | 2 × 150 | 21.5 |
| *g* | 3 × 30 or 40 | 22.5 |
| *r* | 2 × 25 | 21.6 |
| Hα | 3 × 120 | 20.8 |
| *i* | 2 × 25 | 20.8 |

Table 1. VPHAS+ exposures per field and sensitivity. (The shorter *g* exposure time applies to data first obtained prior to 19 February 2013.)

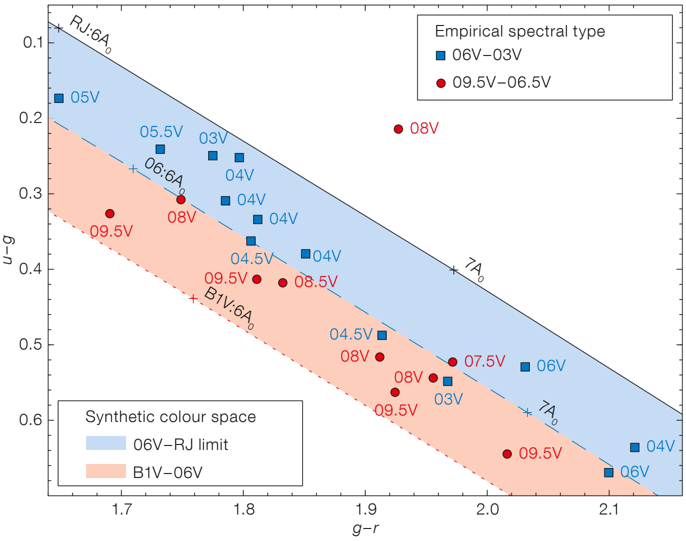


Figure 2. The VPHAS+ (*u*–*g*) *vs.* (*g*–*r*) colour–colour diagram is shown for known O stars in and close to Westerlund 2.

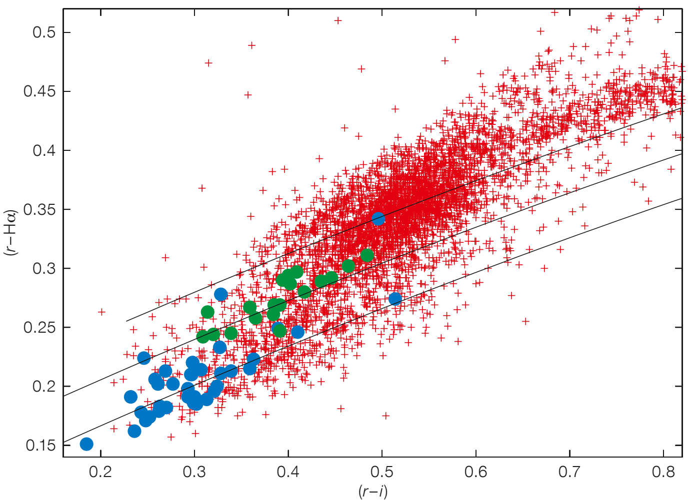


Figure 3. The (*r*–Hα) *vs.* (*r*–*i*) photometric diagram from VPHAS+ field 33 (centred on RA 06 44 16.7, Dec –00 58 04, J2000). Red points represent all stars in the field with magnitude *r* < 16.5. Blue and green points represent stars with spectroscopically determined spectral types in the range A0–3V and F0–1V respectively. The solid lines are, from bottom to top, the model reddening lines corresponding to A2V, F0V and F5V respectively.

hemisphere IPHAS and UVEX survey pair. It remains the case that each filter set delivers a robust contemporaneous colour–colour diagram, straight from the pipeline. At the beginning of October 2013, complete data had been obtained for 404 fields, out of 2269. The blue filters are progressing more slowly than the red because they require darker observing conditions. A map of the survey pointings, picking out those already executed to survey standard, is presented in Figure 1.

The quality of data delivered by OmegaCAM is, in most respects, excellent. We have set the target maximum seeing at 1.2 arcseconds for all except the densest fields, where it is 0.9 or 1.0 arcseconds. The outcome is that the median seeing in all filters, except *u*, is around 0.8 arcseconds. In *u*, the most challenging filter, the median is 0.95 arcseconds. At the same time, image quality across the full square degree of field has also been very good. Bright Moon is avoided for VPHAS+ data-taking because experience with IPHAS has taught us that the mix of diffuse Hα background and bright moonlight can become impossible to separate. Given that the southern Galactic Plane is threaded by even more Hα nebulosity than the north, this is an important precaution. There is room for improvement with respect to scattered light: presently this is significant and variable — to the extent that it has posed a challenge to the photometric calibration. We look forward to the installation of the planned baffles on the VST that should cut this scattered light down substantially.

The Hα filter procured for the VST by the VPHAS+ consortium is named NB-659 and is segmented: four 13.6 × 13.6 square-centimetre pieces of coated glass are held in place in the mount by a pair of blackened T-bars. This creates some extra vignetting — a factor that has been taken to account in our offsetting strategy. The filter's full width at half maximum (FWHM) transmission is close to 10 nm and the transmission at peak is ~ 95 percent, making the filter 20 % more sensitive than its IPHAS/La Palma counterpart. Median magnitude limits achieved in all five bands are set out in Table 1. All VPHAS+ data are processed by the Cambridge Astronomical Survey Unit (CASU), via a pipeline similar to the VISTA Data Flow System that presently delivers flux-calibrated images and aperture photometry. The main features of VPHAS+ will be presented in a forthcoming paper (Drew et al., in preparation).

## VPHAS+ science validation

A well-established technique for identifying O- and early B-type stars is to pick them out above the main stellar locus in the Johnson (*U*–*B*) *vs.* (*B*–*V*) diagram. The same is possible using Sloan (*u*–*g*) vs. (*g*–*r*) and we provide an example that shows that VPHAS+ is ready for the same kind of exploitation — one of the survey aims: Figure 2 shows how known and typed O stars lying within and close to the massive cluster Westerlund 2 fall in this colour–colour plane. The plotted stars range in *g* magnitude from 14 down to 18. It can be seen clearly that there is good, if not perfect, separation between the later- and earlier-type O stars, with one prominent failure — an O8V star that has escaped to above the theoretical Rayleigh–Jeans limit (only because it is in a close blend right at the heart of this very dense bright cluster — others have deblended more successfully). A more profound validation has come from comparing our data on these stars with the results of Vargas Alvarez et al. (2013) from Hubble Space Telescope (HST) data. We conclude, as they do, that the reddening law must be characterised by *R* = 3.8, and find that the mean difference in visual extinction is only 0.13 mag (Mohr-Smith et al., in preparation).

Figure 4. A 12.3 × 7.1 arcminute cut-out image from M8, the Lagoon Nebula, centred on RA 18 09 36, Dec -24 01 51 (J2000), in which *r*, *i* and Hα data are combined. Below left, a 2.5 × 2.5 arcminute zoom into some of the detail. Below right, the same detail as imaged in the *R*-band by the UKIRT Schmidt survey.

The VPHAS+ (*r*–Hα) vs. (*r* –*i*) photometric diagram can be used in a more general way to select samples of stars of different spectral types, capitalising on the sensitivity of (*r*–Hα) to intrinsic stellar colour. Figure 3 illustrates how this can be done: the colour–colour diagram for brighter stars in VPHAS+ field No. 33, centred on RA 06 44 16.7, Dec −00 58 04 (J2000) is plotted. This is a part of the sky that the CoRoT satellite has observed twice and that has also been followed up spectroscopically (Guenther et al., 2012; Sebastian et al., 2012). The blue and green points plotted in the diagram correspond to stars with MK spectral types and luminosities obtained from the spectroscopy, in the A0–3V and F0–1V ranges respectively. Their positions are compared with model reddening lines, including the A2V line which lies along the bottom of the main stellar locus (A2V stars have the strongest Hα absorption of all non-degenerate stars). From this figure it is apparent that most of the early A main sequence stars are confined to a strip ~ 0.05 mag wide, with observational error taking them across the A2V reddening line, while the F0–1V stars are mostly well-separated and cluster around the F0V line.

## Nebulae and diffuse interstellar medium emission

In terms of the integrated light received, the imaging capability of VPHAS+ is not greatly different to that of the UK Schmidt Hα Survey (SHS; Parker et al., 2005). Because of the effort that was made using the SHS to search for well-resolved planetary nebulae, it is unlikely that VPHAS+ will find many more. But there is discovery space in the domain of compact nebulae — which are either very young or very far away — that other ground-based surveys have failed to resolve.

The outstanding advantage of VPHAS+ relative to SHS is the sub-arcsecond seeing commonly encountered at Paranal. Figure 4, showing a portion of M8 (the Lagoon Nebula), provides an example of the refinement of detail relative to the SHS that is apparent even in imagery combining exposures in three different filters. Ionisation fronts, dust lanes and other dynamically revealing structures at the arcsecond scale are now much more readily accessed from the ground.

## Synergies with other surveys now and in the future

The VPHAS+ footprint encloses the entire Variables in the *Via Lactea* (VVV) footprint and hence will provide complementary optical coverage to this near-infrared (NIR) survey of the Galactic Bulge and inner disc. The same synergy exists with respect to the other NIR photometric surveys — the Two Micron All Sky Survey (2MASS) and the UKIRT InfraRed Deep Sky Surveys: Galactic Plane Survey (UKIDSS/GPS). On combining VST optical magnitudes with 2MASS magnitudes, particularly for early-type stars, we are already finding that we can obtain good constraints on sightline reddening laws — such data can play a critical role in three-dimensional extinction mapping of the Milky Way (c.f., the work of Sale, 2012 and Berry et al., 2012). VPHAS+, along with IPHAS and UVEX in the north, already have achieved full optical coverage of the Spitzer and Herschel legacy surveys of the Galactic mid-plane.

The beginning of VPHAS+ data collection closely coincided with the beginning of the Gaia–ESO spectroscopic survey (GES), described by Randich et al. (p. 47). GES needs high-quality photometry of the type VPHAS+ can supply, as input to its target selections programme. There have already been transfers of photometric catalogues, particularly to support open-cluster observations. A major design effort is currently underway in connection with plans to build the next generation of massively-multiplexed spectrographs for Europe's astronomy community — notably 4MOST and MOONS. Homogeneous, astrophysically informative optical photometry will continue to be needed to feed targets to these advanced instruments. VPHAS+, as it transforms into a complete five-band survey catalogue, will be there to meet this need for Galactic Plane and Bulge science.

## References


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## Links

[1] VPHAS+ first data release: http://archive.eso.org/cms/eso-archive-news/first-data-release-of-vst-public-survey-vphas--imaging-data.html