Data Collection	VPHAS-DR2
Release Number	2
Data Provider	J. E. Drew
Date	07.05.2015

Abstract

The primary goal of the VST Photometric Ha Survey of the Southern Galactic Plane and Bulge (VPHAS+) is to collect single-epoch ugri broad-band and Ha narrow-band photometry across the southern Galactic Plane within the latitude range $-5^o < b < +5^o$ down to point source magnitudes of ~21 or better. The VPHAS+ footprint also includes the inner Galactic Bulge, defined as a 20 x 20 deg^2 box around the Galactic Centre: this assures optical coverage of the full VVV footprint. For all massive OBA stars this survey is deep enough to explore all but the most heavily obscured locations of the southern Plane, reaching to >4 kpc from the Sun. These data will increase the number of known southern emission line stars by up to an order of magnitude, yielding much better statistics on important short-lived types of object. The wide-area uniform photometry obtained will also facilitate stellar population studies, capable of tracing structure over much of the southern Plane. VPHAS+ will trawl the star-formation history of the Galaxy as seen in stellar remnants of all types.

At survey end, a well-validated catalogue will be made available that provides 5 optical photometric data points per source at an external (systematic) precision of 0.02—0.03 magnitudes on more than 300 million objects.

The present release is a superseding data release covering the first 21 months of data-taking in which 24% of the survey footprint has been observed to sufficient quality. These pointings have favoured the Galactic equator and open clusters in common with the Gaia-ESO Survey. Reduced images and unstacked single-band source lists are provided.

Overview of Observations

The originally-proposed survey plan identified a preference for obtaining contemporaneous 5-band photometry in all fields. These data were visualized as optical snapshots of stellar spectral energy distributions that would lend themselves well to federation with NIR photometric catalogues, so serving a broad range of Galactic Plane science applications. As the VST was commissioned, it became clear that observations seeking exposures from u- to i-band would be too heavily constrained to allow the survey to proceed at a tolerable rate. Hence it was agreed to adopt the back-up strategy included in the original proposal 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 r-band repeats as aids to calibration and checks on variability. This permits tailoring of the requested observations to suit the filters in each set, with the Moon constraints on u, g, r being more exacting than those on Hα, r, i. As a result of this difference, and the fact that it is impractical to constrain the elapsed time between the acquisition of the blue and red data, the latter are being collected more rapidly than the former. This split also has repercussions for the ease of preparation and timescale for the delivery of user-friendly merged and calibrated 5-filter source catalogues .

The plot below shows the full VPHAS+ survey footprint, and picks out the fields that are included in this release. This shows that more red observations than blue have been completed so far.

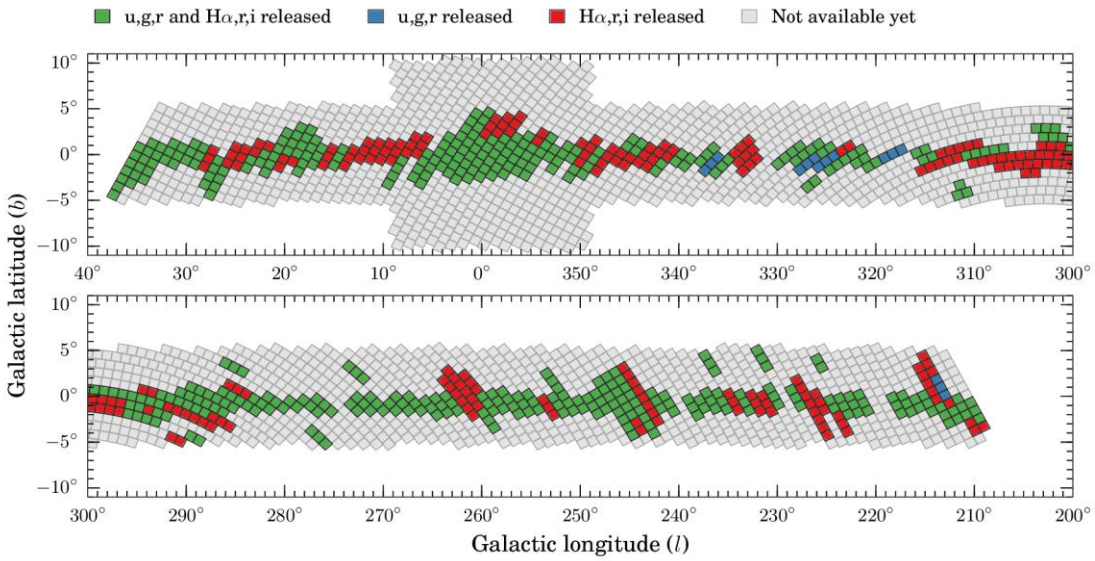

Fig 1: The VPHAS+ footprint), with the fields in this release picked out. The 424 fields shown in green are those for which both blue and red filter set are available (19% of footprint). In addition, there are 205 fields for which just the red-filter data are released. Another 15 have blue-filter data only.

Two exposures are obtained per field in the u,r,i broadband filters, with the second taken at an offset with respect to the first of -588 arcsec in RA, and 660 arcsec in Dec. In the case of narrow-band Ha, three exposures are obtained (to deal with the extra vignetting of this segmented filter), such that the second and third are offset by -300, -588 arcsec in RA and 350, 660 arcsec in Dec with respect to the first pointing. It should be noticed that since r-band data are obtained at two essentially random epochs, there are in fact two 'duplicate' sets of images and catalogues in this one band. Since February 2013 a third g band exposure has been added, using the same offset pattern as for Hα, and the exposure time is now 40 secs (it was 30 secs). These changes were made to better capitalize on the high sensitivity of the OmegaCam g band – enabling deeper penetration of the reddened Galactic Plane.

Hence the pattern of exposure times per filter from early 2013 is:
u: 2x150 sec
g: 3x40 sec
r: 2x25 sec (at each of 2 epochs)
i: 2x25 sec
Hα: 3x120 sec

Fields observed in the blue filters before this change are having third exposures taken separately in a process of 'catch-up'.

Release Content

This release covers data obtained between 28/12/2011 and 30/09/2013. The aim of DR2 is to maximize the publicly available data, supplying complete filter sets for as many fields as possible (including, in some cases, data where e.g. the measured psf in one filter is outside the normally required constraint).

Reduced images are one of the two components of this release. These are presented as native 32-CCD OmegaCam pawprint, each representing a tile of 1 x 1 sq.deg. These are not stacked. Altogether there are 629 x 7 Hα/r/i images plus 6 fortuitous repeat Hα exposures, and 439 x 6 u/g/r images plus 133 third g exposures. For fields 0720 and 0721, the u exposures are very poor quality due to great extinction and so have been omitted – for these fields, 3 g and 2 r reduced images are available. The total collection comprises 7172 images altogether.

The other component is the single-band catalogues extracted by the CASU pipeline from the reduced image data. There are as many of these as there are images (i.e. 7172), with the number of detected objects in each them ranging from ~ten thousand up to hundreds of thousands, depending on pointing and filter.

The sky region covered is shown in Figure 1. It is a little over 424 sq.deg covered in all survey filters, and a further 220 sq.deg observed in either the red or the blue filters only. The frame-to-frame overlap achieved in the single-pass pattern of field centres has been kept small at 1.5 arcmin – the stronger linkage between adjacent fields is achieved via the ~10, 11 arcmin offsets used to achieve double pass.

Figure 2 below shows the cumulative distribution of seeing achieved in the released dataset according to filter. In all filters the median is better than 1 arcsec (in most fields the OB seeing constraint is set at 1.2 arcsec). As expected, the greatest challenge at the telescope is presented by u, drawn in blue. Among the other filters the systematic differences are modest.

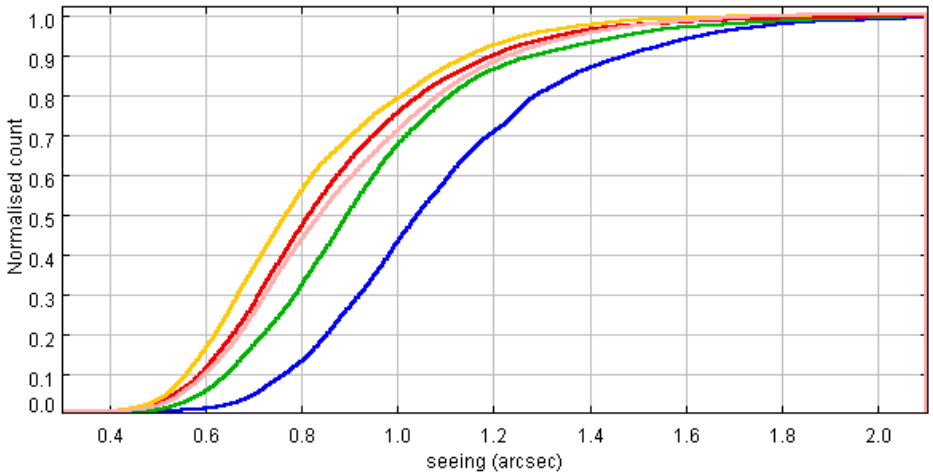

Figure 2: Cumulative distributions of the measured seeing in arcsec, colour-coded according to filter. The curves are: i, gold; Ha pink; r red; g green; u blue.

The ellipticity of the point spread function is in general well-behaved, with 0.05—0.06 being typical. The aim is to keep it below 0.2, although occasionally values higher than this are accepted. The pattern of 5σ limiting Vega magnitudes in this release is illustrated next, in figure 3.

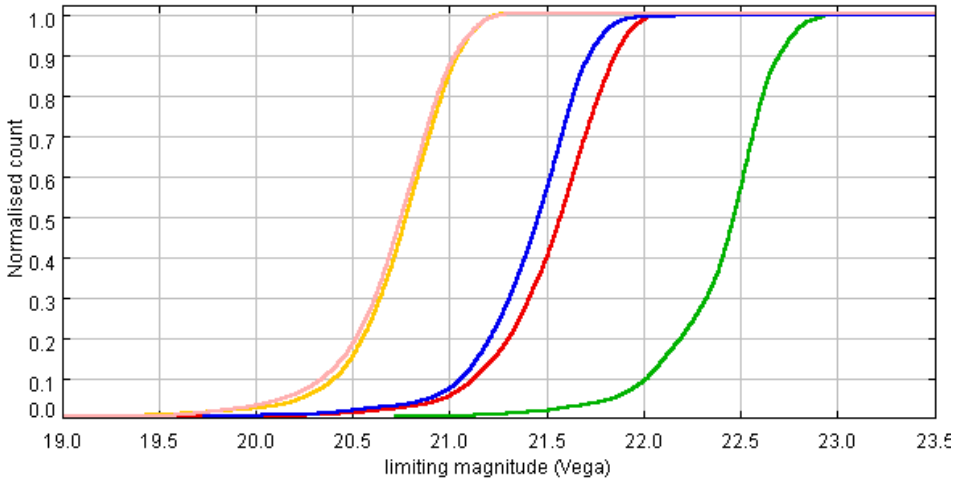

Figure 3: Cumulative distributions of 5-sigma limiting magnitudes reported per CCD per exposure by the data pipeline. Colours used are as in Figures 2 and 3. Note that in u, the final calibrated magnitude is expected to be ~0.3 mags brighter than shown.

The leftmost curves in gold and pink, indicating the brightest limiting magnitudes, are for the i and narrowband Ha filters respectively. The u and r cumulative curves (drawn in blue, and red) reach 0.7—0.8 magnitudes fainter.. Finally, going one magnitude deeper and drawn in green, is the curve for the g filter exposures. The progression of fainter magnitude limits from i to g is by design to combat the high reddening encountered in much of the Galactic plane, thereby achieving better comparability of source numbers in these key broad bands. The somewhat brighter limiting magnitudes in both Ha (relative to r) and u (relative to g) – the filters exposed for longest – are the expected consequence of the practical compromise that renders this survey feasible. The sensitivities achieved through these lower-transmission filters are sufficient to provide the good discrimination of special object types that was a leading motivation for VPHAS+.

The total number of uploaded files is 14447 (of which 103 are confidence maps). The total data volume is 1.6 TB.

Release Notes

Data Reduction and Calibration

The data pipeline used to process the raw survey data is operated by the Cambridge Astronomical Survey Unit (CASU) and has many features in common with the VISTA Data Flow System. The latter is described at:
http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/data-processing.
Specifics relating to VST data are presented at:
http://casu.ast.cam.ac.uk/surveys-projects/vst/technical

In brief, the current method of source detection is aperture photometry, applied to the images after the adaptive removal of 'smooth' background due to both telluric and astronomical sources (nebulosity) using CASU's *nebuliser* software. The pipeline includes the morphological classification of all detected sources that distinguishes a range of object morphologies, ranging from high-probability point objects (stars) through to clearly extended objects and noise-like features. At this still early stage, with under one quarter of the survey's final volume included in this release, higher level data products are not yet available – the work on this is expected to begin by January 2015 and the aim will be to build a preliminary seamless catalogue that goes a step beyond simple band-merging to a more user-friendly product. We will provide some advice on the survey website (http://www.vphas.eu/data/) for users accessing the ESO Science Archive on how to perform custom band merges of the published single-band catalogues.

The astrometric calibration is achieved by reference to the 2MASS catalogue. The current photometric calibration of the (Vega) zeropoint is established using nightly standards. As a by-product of making the illumination correction, the calibration of the extracted source fluxes is improved by making comparisons with APASS stellar photometry. Zeropoints in the AB system are now included in headers. The calibration of the Hα data is tied to that of the r–band data, a practice already used to good effect in the IPHAS survey (Drew et al 2005, Gonzalez-Solares et al 2008). No reddening corrections are applied.

Data Quality

The astrometric quality as measured in the pipelining is very good, and uniform across the large field – typical mean RMS errors with respect to 2MASS are 70-80 mas, with much of this error being dominated by the RMS error intrinsic to the 2MASS catalogue . At this early stage the photometric calibration is provisional and only as good as the comparisons with APASS allow. This means in practice that g, r and i are expected to be relatively secure with external errors comparable to those of APASS (~0.03 magnitudes). In the u band, tests indicate the pipeline-assigned VST internal Vega magnitude scale differs by ~0.3 magnitudes from a "true" Vega system due to non-linearities in the colour transformation from the Johnson-Cousins system to VST u (see the

representative example discussed in the survey description of Drew et al 2014). There is a good uniformity from CCD to CCD across the native 32-CCD OmegaCam pawprint, which justifies a working presumption of a common photometric scale across the full square degree for most purposes.

In preparing this release, we have computed the median and standard deviation of all single-filter magnitude differences ($m_1 - m_2$), in the magnitude range 12 to 19 for i and Hα, 13 to 20 for u and r, 14 to 21 for g, between the different offset exposures covering the same field, to look for unstable observing conditions and other problems that might cause unwanted measured flux variations within tiles and hinder their ultimate calibration. In the vast majority of single-band catalogue pairs, the median absolute difference is below 0.01: the distribution of this quantity has an interquartile range running from 0.002 to 0.007. The scatter in the individual-star offsets as measured by the mean of the standard deviations is 0.048 +/- 0.018. In the occasional presence of video card problems this second measure is much larger (see below).

Figure 4 repeats one of the illustrative photometric diagrams presented in the DR1 release document, that was constructed from catalogues for a pointing toward a moderately-dense well-reddened field, with some moderate Hα nebulosity. It was observed in ~third quartile conditions (i.e. a bit worse than median in seeing and/or limiting magnitude) a few degrees away from the Galactic centre. The data have been 'cleaned' to the extent of limiting the selection to probable stars (morphology codes -1,-2), requiring average confidence better than 90 percent, and better than 10-sigma detection in the noisiest filter included. It testifies to the uniformity of the extracted data that the plots are this sharp for the *entire* 1x1 sq.deg field.

To produce well-behaved photometric diagrams it is recommended that average-confidence and morphology-class cuts are always applied in source selection (as well as magnitude and/or error-level cuts). The specific cuts mentioned above usually give good results. Thresholding on average confidence is particularly effective at ensuring the impact of vignetting due to the CCD-electronics covering strips, field edges and Hα segment dividers is minimal.

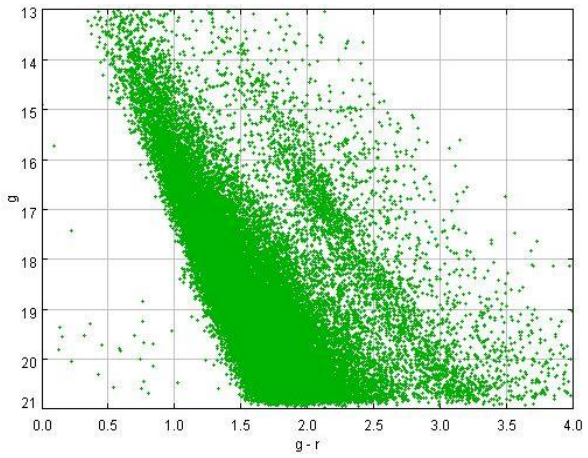

Figure 4. A photometric diagram for the 1x1 sq.deg field centred on RA 17 54 58 Dec -24 58 40 (J2000): g versus g-r for 44,500 stars. The cleaning applied here reduces the detected objects by factors of two to three. More diagrams for this field were given in the DR1 release document.

Known issues

From mid-March through May 2012 there was an intermittent video card problem that resulted in significant zero-level flux offsets in, most commonly, CCD 10. Inevitably this affected both sky exposures and flat fields from time to time. When it happens, it is visible in the image data and is especially prone to introduce deviant CCD-10 magnitudes, which are easily spotted by comparing single-filter offset pointings. Since the main sky offset we use is greater than the individual CCD dimension, there is almost always alternative photometric measurements of the affected sources available. In the lists accompanying this document, that are also available as downloads from http://www.vphas.eu/data/, known instances of this are tagged with the comment '(filters) videocard'.

A second occasional issue is that of pick-up, or bands of periodic electronic noise across the images. Because of their regularity, these bands usually have little impact on the extracted photometry. A software solution to this problem has been implemented by CASU and is available for general use. We note that images are not routinely corrected for pick-up by the pipeline.

Lastly we note a minor issue that affected 26 sets of narrowband Hα images obtained up to late January 2012: in this first month of operation, the specified offset pattern contained an error such that none of the three Hα frames is at the same (intended) offset as the *second* broad band exposures . This was fixed in time for all data taken from the beginning of February 2012.

The following issues are mainly encountered in u band data. Very occasionally, the processing pipeline finds too few stars in a CCD frame to report a sound evaluation of the source point-spread function. In such cases, the keyword PSF-FWHM is set equal to -1. As this value can be set for other reasons, it is advisable to inspect the image for peculiarities. More commonly, but still infrequently, the pipeline encounters insufficient nightly standard-star calibration data to enable the routine measurement of photometric zero point. When this happens, the keyword PHOTZPER is also set to -1. In the g, r, i source files, the use made of APASS data circumvents this absence.

Release documentation

This release document is supported by two csv lists separately covering the red and blue filter sets, in which the names and on-sky centres of the fields included in this release are identified. These lists, available from http://www.vphas.eu/data/ as machine-readable files, include a comment column with notes on fields where there are known issues with the data. Advice on using the data, and customizable bandmerging software, is also provided on the website.

A principle at work in DR2, that is consistent with the goals of VPHAS+, is that each field observed is represented within the release by one set of contemporaneous observations (the set currently judged as the best available) for each filter set. It is recommended that users of these archived data, collect the above-mentioned lists of DR2 filter sets for reference.

Previous Releases: DR1.

This release supersedes DR1 mainly in adding data from a further full year's observation, more than doubling the volume available. In addition some previously-archived data with alternatives judged to be of better overall quality have been replaced with re-observations (this affects red-filter data for VPHAS+ fields 0021, 0022, 1680 and 1681). Also the images and catalogues for 4 exposures suffering adverse technical impacts that mistakenly appeared in DR1 are no longer included in DR2 (these are o20120122_00113, o20120223_00216, o20120226_00030 and o20120324_00129).

Data Format

File Types

There are two major file types: (i) reduced fits images, (ii) single-band fits catalogues of detected objects. Calibration files are also provided. They are named according to a simple unique convention that specifies the date on which the night of observation started, and the run number for the night.
Image naming format: o<yyyymmdd>_<runno>.fits.fz
Catalogue naming format o<yyyymmdd>_<runno>_cat.fits.fz
Calibration files, e.g. confidence maps: <filter>_<conf>_<date>.fits.fz

Also see: *http://casu.ast.cam.ac.uk/surveys-projects/vst/technical/naming-convention*
Note that 'pawprint' and 'tile' are synonymous in the VST/VPHAS+ context.

Catalogue Columns

For a specification of the layout, see
http://casu.ast.cam.ac.uk/surveys-projects/vst/technical/catalogue-generation

Acknowledgments

The appropriate journal reference for the use of VPHAS+data is to: Drew et al, 2014, MNRAS, 440, 2036. If making use of data from this release, please use the following statement in the acknowledgements: "Based on data products from observations made with ESO Telescopes at the La Silla Paranal Observatory under public survey programme ID, 177.D-3023" .