Data Collection	VPHAS-DR4
Release Number	4
Data Provider	J. E. Drew, for the VPHAS+ consortium
Date	14.10.2019

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. For reasons of resource limitations, the survey terminated in August 2018, omitting some parts of the 3rd Galactic quadrant. The VPHAS+ footprint 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 an incremental and final data release adding data acquired since the 2015/10/01 semester start, bringing the total fraction in the public domain to 92% of the originally-planned survey footprint. 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 suitable for federation with NIR photometric catalogues, to serve 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 observing conditions 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 accumulating 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, picking out the fields that have been observed and released.

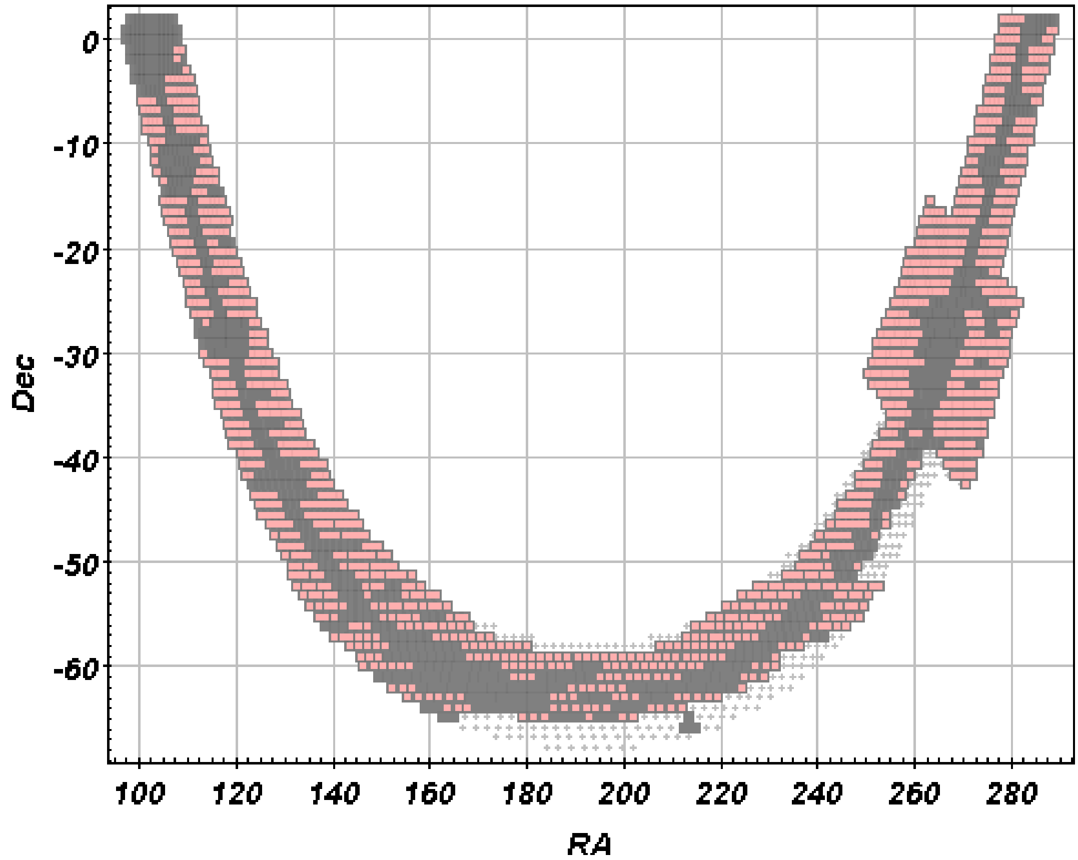

Figure 1: The VPHAS+ footprint, with the fields finished prior to the previous release DR3 shown in grey. The fields finished since and appearing in DR4 are coloured pink. The grey dots mark the positions of field centres in the original footprint that have not been observed.

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 Hα, 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 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 g 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

The frame-to-frame overlap achieved in the single-pass pattern of survey field centres has been kept small at 1.5 arcmin – the stronger linkage between adjacent fields is achieved via the -588, +660 arcsec offsets in use.

Release Content

This release covers data obtained between the dates 19/11/2015 and 14/08/2018. The aim of DR3 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). For a small number of fields, one or more exposures may have been excluded if found to be defective due to e.g. a pointing shift mid-exposure or sudden poor seeing.

Reduced images are one of the two components of this release. These are presented as native 32-CCD OmegaCam pawprints, each representing a tile of 1 x 1 sq.deg. These are not stacked. Altogether there are 929 x 7 Hα/r/i images plus a further 2 x 9 where there are extra r images (altogether 6521), and 1266 x 7 u/g/r images plus a further 9 sets with missing or extra images (altogether 8918). In addition, DR4 includes repeats of problematic exposures appearing in earlier releases (95 images). Altogether, the DR4 collection comprises 15534 images. We note that for 3 fields (VPHAS+ field serial numbers 156, 157 and 158), there is incompleteness in that, for none of them, are the u observations usable and in the case of 158, only the r frames are of a publishable standard. These make a 3x1 deg constant-declination strip centred on RA 276.2668, Dec -3.87097.

The other component of the release 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, 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 by this release, added to DR2 and DR3, is shown in Figure 1. With this final incremental release, approximately 2080 sq.deg are now covered in all survey filters.

Table 1, below, provides the interquartile ranges in seeing achieved in the survey according to filter. In all filters the median is 1 arcsec or better (for u, the most challenging filter, the median is 1.01 arcsec). This pattern is a consequence of the OB constraint on seeing being set at 1.2 arcsec in most fields – in the fields with extreme stellar density, the constraint is tighter. Figure 2 gives more detail on the spread in seeing encountered.

Band	Seeing: IQ range		5σ limiting magnitude: IQ range			
	Arcsec		Vega/nightly		AB/APASS	
u	0.88	1.13	21.30	21.59	21.90	22.19
g	0.72	0.97	22.46	22.80	22.35	22.69
r	0.64	0.88	21.53	21.89	21.63	21.99
i	0.64	0.91	20.72	21.03	21.09	21.40
Hα	0.62	0.91	20.65	20.94	20.87	21.16

Table 1: Interquartile ranges on the achieved seeing and estimates of limiting magnitudes in the DR4 period..

The ellipticity of the point spread function is in general well-behaved, with 0.04—0.07 being the inter-quartile range. The aim is to keep it below 0.2, although for ~1% of CCD images values higher than this are accepted.

The pattern of 5σ limiting magnitudes in this release is also set out in Table 1. The brightest limiting magnitudes are associated with the i and narrowband Hα filters (a median of ~20.8 in the Vega system). The u and r band limits are up to a magnitude fainter, while the g filter exposures are always the most sensitive, reaching to ~22.6 in both the Vega and AB systems. The progression of fainter magnitude limits from i to g is by design to partially offset 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 Hα (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 the special object types that were a leading motivation for VPHAS+.

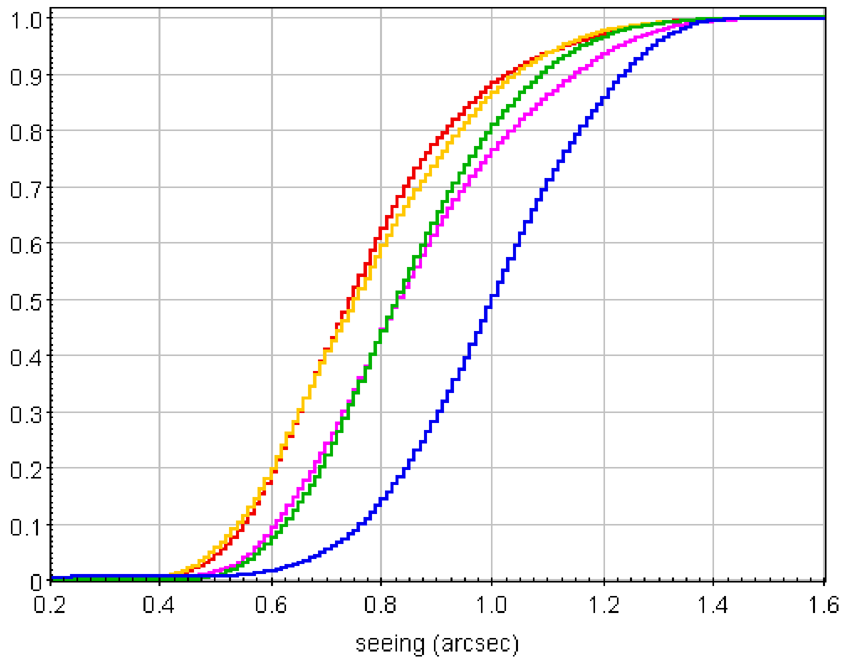

Figure 2: Normalised cumulative distributions of the seeing in the 5 filters during the DR4 period. Blue is used for u, green for g and red for r. The yellow curve indicates the i band, and magenta Hα narrowband.

The total number of uploaded files is 32093 (of which 1025 are confidence maps). The total data volume is 3.86 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. In a linked release, a user-friendly bandmerged seamless catalogue, processed by WFAU (Edinburgh), will be supplied. As before, potential users of the data are also encouraged to visit the survey website (http://www.vphas.eu/data/) for further advice on data use and machine-readable lists of released sky pointings.

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 byproduct 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 available in the individual source-list headers also. 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. At the present time, the photometric calibration of the u band is still relatively uncertain: it is known that the Vega u zeropoints are typically optimistic by ~0.3 magnitudes, while the AB u zeropoints are arrived at by extrapolation from the longer wavelength bands which may be unreliable, depending on atmospheric conditions (see Patat et al 2011 A&A 527 A91).

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 . The photometric calibration remains provisional and rests mainly on comparisons with APASS. 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, as mentioned above, tests indicate the pipeline-assigned VST internal Vega magnitude scale differs by ~0.3 magnitudes from a "true" Vega system (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 DR3, we 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 close enough to zero to suggest negligible systematics in the relative photometric calibration of the offsets: at the same time, the distribution of this quantity (the MAD of the MAD, in effect) has an interquartile range that is 0.014 – 0.021 (g and r), 0.016 – 0.028 (i) and 0.021 – 0.030 (u and Hα). These figures are indicative of the relative photometric quality of the different bands making up the survey. The best-behaved bands are g and r.

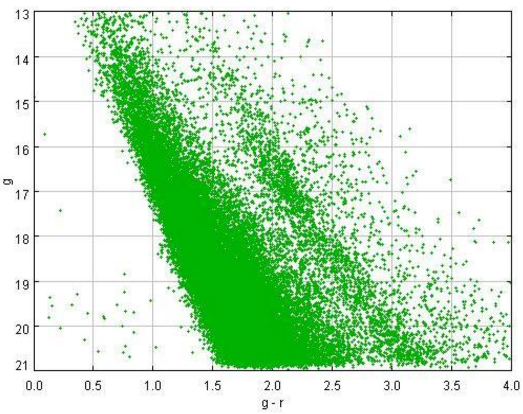

Figure 3. A photometric diagram for the 1x1 sq.deg field centred on RA 17 54 58 Dec -24 58 40 (J2000): g versus g-r for 44,500 stars. The cleaning applied here reduces the detected objects by factors of two to three. More diagrams for this field were given in the DR1 release document.

Figure 3 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.

Known issues

An 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.

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 prevents this from happening.

Release documentation

This release document is supported by a csv list, 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. It is recommended that users of these archived data, download this information to keep for reference.

Previous Releases: DR1, DR2, DR3

DR4 adds to the archive a further 3 years of observation, doubling the sky coverage compared to the total up to and including DR3..

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

For further information on naming conventions 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" .