

# 1 Title: The VPHAS+ survey of the southern Galactic Plane

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## 1.1 Abstract

The primary goal of VPHAS+ is to collect  $u'g'r'i'$  broad-band, and  $H\alpha$  narrow-band photometry across the entire southern Galactic Plane within the latitude range  $-5^\circ < b < +5^\circ$  down to point-source magnitudes of 21–22. For all massive OBA stars this survey is deep enough to fully explore all but the most heavily obscured locations of the southern Plane (where the penetration will still be several kpc). These data should multiply the number of known southern emission line objects by  $\sim 10$ , yielding much better statistics on important short-lived types of object. Their superior photometric accuracy will also facilitate large-area stellar population studies, tracing structure within the Plane, that have hitherto been impossible. VPHAS+ will trawl the star-formation history of the Galaxy as written in its stellar remnants. The final catalogue will contain in excess of order half-a-billion objects. VPHAS+, along with IPHAS, its northern  $r'i'H\alpha$  sister survey already two-thirds complete, will provide a hugely attractive database of  $H\alpha$  imagery to be used to publicise the science of astronomy as a whole.

This document contains the management plan for the VPHAS+ public survey. Contemporaneous  $u'g'r'i'H\alpha$  imaging of the Galactic Plane will require grey time, and we anticipate a detection rate of half a million point sources per hour of observing. The data will be processed by the Cambridge Astronomical Survey Unit (CASU), where data for the  $\sim 70$  percent complete sister survey of the northern plane, IPHAS, are already dealt with. Within a few months of receipt of data, reduced images and band-merged object catalogues, with photometry calibrated against nightly standards will be available (typical broad-band errors of under 0.05 magnitudes). As data-taking approaches completion, it will be appropriate to begin to correct the whole survey to common zero points to yield the final legacy database.

### Acronyms:

VPHAS: VST Photometric  $H\alpha$  Survey (of the southern Galactic Plane). This was the originally proposed  $r'i'H\alpha$  survey.

VPHAS+: VST PHotometric  $H\alpha$  Survey (of the southern Galactic Plane) with extension to include the  $u'g'$  broadbands. As per the recommendation of the Public Surveys Panel, VPHAS+ is the merger of VPHAS and the UVEX  $u'g'r'$  survey of the Plane.

IPHAS: The INT/WFC Photometric  $H\alpha$  Survey (of the northern Galactic Plane). This is the preceding sister survey to VPHAS+, being carried out using the Wide Field Camera (WFC) on the Isaac Newton Telescope (INT) in La Palma. The Galactic Plane is being imaged in  $r'i'H\alpha$ .

## 2 Survey Observing Strategy

The observations required for this survey are matched OmegaCam images obtained with (i) a narrow-band  $H\alpha$  filter ( $\sim 100 \text{ \AA}$  FWHM), (ii) a continuum filter in the same part of the spectrum as  $H\alpha$  - here  $r'$ , (iii) three remaining continuum filters spanning the optical ( $u'g'i'$ ), yielding the optical colours of stellar sources. The Sloan filter set is the best choice currently available by virtue of their box-like passbands.

Our observing strategy for each VPHAS+ field is to obtain the following exposures:  $u'$ , 150 sec;  $g'$ , 30 sec;  $r'$ , 30 sec;  $H\alpha$ , 120 sec;  $i'$ , 30 sec, sequentially for two pointings at each field centre. Obtaining the full set of exposures within a single sequence has several advantages. Chief among these are minimising the impact that point-source time variability might otherwise have on derived colours and spectral energy distributions, whilst minimising survey overheads. This strategy will also maximise the likelihood of equivalent image quality (in terms of PSF and photometric conditions) in each field, facilitating optimal  $r'$  image subtraction from  $H\alpha$  emission and simplifying the final uniform calibration of the entire survey. The acquisition of images in all five bands makes it necessary to schedule the observations in grey time (as noted in our VPHAS+ proposal

submission to the ESO OPC).

## 2.1 Scheduling requirements

VPHAS+ will require in the region of 16 weeks of VST time. As it links naturally to the INT WFC northern IPHAS survey (Drew et al. 2005) aimed at substantially completing observations by 12/2007, we propose a relatively compact time line. At the time of writing, VST operations are viewed as beginning no sooner than November 2007. Ideally some limited VPHAS+ observations should be gathered early in VST operations (P80, in 2008) to verify that the data meet requirements.

Following that,  $\approx 3$  clear weeks' grey-time observing in P81, and then  $\approx 6$  weeks in each of 2009 and 2010 could see the survey data-taking finished.

The southern Galactic Plane defines our target fields: below the celestial equator they lie in the RA range between 06h50 and 18h50, reaching down to Dec: -68 deg (at RA 12h50). We propose to survey the Plane up to 2.5 degrees above the celestial equator in order to ensure good overlap with the northern survey, IPHAS. Hence the total survey area is defined in Galactic co-ordinates as being all longitudes in the range  $210^\circ \leq \ell \leq 35^\circ$ , passing through the Galactic centre, and all latitudes in the band  $-5^\circ \leq b \leq 5^\circ$ .

Choice of fields to observe on any given night, from among those remaining at the time, need only be governed by air mass ( $< 1.4$ ) and moon distance ( $> 45$  degrees) requirements.

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P80	40	6–14h	grey	$< 1.2$	clear
P81	160	10–18h	grey	$< 1.2$	clear
P82	160	6–14h	grey	$< 1.2$	clear
P83	160	10–18h	grey	$< 1.2$	clear
P84	160	6–14h	grey	$< 1.2$	clear
P85	160	10–18h	grey	$< 1.2$	clear

## 2.2 Observing requirements

A complete VPHAS+ observation for a given field comprises: target acquisition; guide star acquisition; a sequence of exposures in all 5 filters; an offset of several arcminutes; re-acquiring a guide star; a second sequence of exposure in all 5 filters. This, in effect, defines a single OB. Again, we emphasise the importance of obtaining all these data contemporaneously to minimise data matching problems caused by stellar variability, a common problem on timescales of hours/days/months.

Experience with processing data from the INT Wide Field Camera demonstrates that the target + offset field strategy efficiently deals with cosmic-rays and allows almost complete coverage of the gaps between detectors.

### 2.2.1 Dependencies

A contemporaneous sequence of exposures is required in all 5 filters at both the target position and at an offset position several arcmin away.

### 2.2.2 Exposure times and filter choice

The OmegaCam consortium is aiming to purchase a segmented H $\alpha$  filter in which only one quadrant is designed to pick up H $\alpha$  centred at 0 km/s (central wavelengths of the segments will be at 657, 661, 668 and 678nm, each of width 10nm). For our purposes, only the first two segments are usable as our H $\alpha$  narrow band, (the two most redshifted segments miss rest frame H $\alpha$ ). We discount use of this filter for VPHAS+, in that it could only

be used at a 50% efficiency level, whilst introducing unwanted spectral-type dependent calibration problems due to the wavelength shifts between filter segments. In order to meet our needs, we have placed an order with Barr Associates and part-paid for an additional four-segment H $\alpha$  filter, each segment centred on 657 nm with a FWHM of 10nm (specification supplied by U. Hopp). We have also passed on a spare OmegaCam blank filter holder to Barr. We will aim to have the filter tested and available by early 2007. This would be made available for general use with OmegaCam (subject to ESO approval).

To arrive at suitable exposure times, we take 1.0 arcsec seeing at airmass 1.2 against a grey sky (7-day old moon) as “typical” conditions. We also base our estimates on data from the web page describing VOCET, the VST Omegacam Exposure Time Calculator (<http://www.na.astro.it/>) These must be presumed liable to change once the camera is commissioned, and updates to system efficiency are in place. Our estimates for the throughput of the H $\alpha$  filter is based on the design specification for the OmegaCam Consortium H $\alpha$  filter (email communication from U Hopp).

Our aim for all the broadband filters is  $10\sigma$  at an AB magnitude of  $\sim 22$ . For the exposure times we have settled on, we estimate that  $10\sigma$  is achieved for:  $u'(AB) = 21.8$  (150 sec);  $g'(AB) = 22.5$  (30 sec);  $r'(AB) = 22.5$  (30 sec); and  $i'(AB) = 21.8$  (30 sec). We would expect saturation at these exposure times for AB magnitudes of 14, a bright limit close to the faint limit of older-generation objective prism surveys. In grey time, an H $\alpha$  exposure time of 120 sec would be expected to deliver a  $10\sigma$  result for an equivalent AB magnitude of 21.6. To actually match the  $r'$   $10\sigma$  limit in H $\alpha$  would take more telescope time than we know it to be worth. In the exploitation of IPHAS data we are finding that a 4:1 H $\alpha$ : $r'$  exposure time ratio is perfectly workable, for the reason that H $\alpha$  in-band magnitudes are typically around 0.5 or more brighter than  $r'$  magnitudes. This pattern arises from the fact that the great majority of faint stars are significantly reddened and/or intrinsically red.

Our  $10\sigma$  estimates are thus entirely consistent with the experience acquired working with the redder filters used in IPHAS observing with the 2.5-m INT and Wide Field Camera. For the same exposure times, IPHAS observations typically reach 20-21 magnitude because a significant fraction of the allocated time has been bright time. Grey time has become essential for VPHAS+ because of the inclusion of the  $u'$ - and  $g'$ -filter observations, alongside the requirement for contemporaneous observation in all bands. For the purposes of mosaicked image construction from H $\alpha$  and  $r'$  filter data, the use of grey time also offers the considerable benefit of much less variable sky background.

Estimation of overheads at this stage is notional. We note that the short exposure times envisaged for VPHAS+ may remove the need to guide, leaving as the dominant overhead the time to change filters and read out (operations that are routinely performed in parallel for IPHAS observing). Our original guess, based on our IPHAS experience, was that the total overhead is unlikely to be less than  $\sim 100\%$  (for IPHAS, using the more compact Wide Field Camera, it is around 70 %). Since the total integration time for two pointings per field is  $2 \times 6$  min, this would suggest a total time per field (per OB) in the region of 24 mins. To expose on all 2100 fields (number of fields justified in the ‘Observing Strategy’ section) will require a total of 840 hours. If we assume effective 8-hour nights averaged across the January-June observing season, the requirement becomes 105 clear nights, or  $\sim 15$  clear weeks.

However, if (i) read-out time is 40 secs, (ii) filter changes take between 30 and 70 secs (we adopt 50 secs as mean), (iii) and these operations must be sequential, then the overhead totals up to 14.2 minutes per field, or an additional 77 hours (+9%) for the whole survey (assuming 10 read-outs, 9 filter changes) – a little more than the 12 minutes given above that we continue to use for our total time calculation. If filter changes and read-out can be performed in parallel, the overhead per field drops to around 8 minutes – a saving of 140 hours (–17%) with respect to our existing estimate of the total time needed for the survey.

Whilst the overhead for VPHAS+ is significant compared to the time spent exposing, it is worth noting that the rate of information gathering is nevertheless exceptionally high: stellar densities in the plane of the Milky Way are at a level that 5-filter optical photometry on over half a million objects will be collected per hour of telescope operation.

We have chosen to set 1.2 arcsec as the maximum acceptable seeing both because it will ensure good point source separation even in the most crowded Galactic Centre fields, and because it will protect the overall uniformity

of the data products. We note that at Paranal, this is not an onerous constraint since this seeing is bettered 80 percent of the time (see <http://www.eso.org/gen-fac/pubs/astclim/paranal/seeing/seewind/>).

### 2.2.3 Survey coverage

We have experimented with different tiling patterns for the 10 degree wide, 180 degree long strip of the southern plane leading to an optimal design using  $\sim 2000$  field centres. An assumption in this is that the CCD array is oriented at a fixed sky position angle (following on from the practice in place for IPHAS). In order to enable cross calibration with the northern survey, we propose a 5% overlap across the celestial equator, and hence request 2100 field centres (with observations to Dec +2.5).

A second set of overlapping pointings is needed, in order (a) to establish a common calibration across the survey, including making allowance for the different sensitivities of the 32 CCDs forming the camera; (b) to negate problems due to chip blemishes, cosmic rays and – most important – to correct for loss of sky coverage due to gaps between the CCDs and filter mount vignetting. This requirement is most efficiently met with an immediate set of repeat exposures obtained at a small offset from each field centre. We propose offsetting 4 arcmin in RA and 7 arcmin in Dec (i.e. 0.5 of a CCD in each direction). For IPHAS in the north, we use this same method, differing only in the offset angles (5 arcmin in both RA and Dec).

## 3 Survey data calibration needs

### 3.1 Detector characteristics

Standard sequences of bias frames, darks and twilight (or dome) flatfields will be used to remove the gross instrumental signatures.

Fringe frames will need to be constructed for observations in the  $i'$  band. The fringe level is not yet known. However, if it is similar to that encountered on other systems using similar detectors, it will impact at about 2% of sky. As this is an additive correction it requires its own calibration frames for its reduction to an acceptable level. However, since the sky level in our proposed  $i'$ -band exposures will typically be of order 100-200 counts per pixel, this implies that the likely fringe pattern (+/- a few counts) will be more of a cosmetic problem than a serious limitation to photometric accuracy.

A strategy that we have found works to sufficient precision for IPHAS data is to make a small series of master fringe frames over a range of observing conditions and simply use the closest match to the current dataset to reduce the effect to a negligible level. In practice we find that this reduces the level of the fringing by a factor of 10 and puts it into the quantisation noise regime where it no longer affects the photometric analysis. This strategy works well mainly because the  $i'$  region avoids the strongest and most rapidly varying atmospheric OH-bands which are more sensitive to atmospheric water vapour content and solar activity.

Illumination corrections are also needed to ensure uniform photometric calibration across the array - these are in addition to flatfields and correct for effects such as scattered light. These can be characterised using dense large area photometric standard fields or from suitable sub-sampling of photometric fields across the array.

### 3.2 Astrometry

Astrometric calibration will be via the numerous unsaturated 2MASS point sources available in each field. Previous experience for a wide range of telescope systems indicates that a standard ZPN projection with a radially symmetric correction of the form

$$r_{true} = k_1 \times r + k_3 \times r^3 + k_5 \times r^5 + \dots \quad (1)$$

where  $r_{true}$  is an idealised angular distance from the optical axis,  $r$  is the measured distance, and  $k_1$  is the scale at the centre of the field; will provide a good description of the field distortion. Coupled with a linear “plate” constant solution for each detector of the form

$$\xi = a * x + b * y + c \quad \eta = d * x + e * y + f \quad (2)$$

we find that this gives astrometric residuals over the whole field of better than 100mas. The global systematics in 2MASS (on the ICRS system) are also below the 100mas level.

### 3.3 Photometry

For external photometric calibration, VPHAS+ pointings need to be supplemented by standard (e.g. Landolt or Sloan) field observations through all five filters every two to three hours through each night. Regular observations of standards also help determine how photometric a given night is, which is of later help when cross-calibrating contiguous survey observations. At this stage it is not yet clear how far the standard observatory calibration plan will meet these needs. We can supply standard-field OBs as needed.

On photometric nights, when VPHAS+ observations are carried out, we would also like to continue the practice followed for IPHAS that a spectrophotometric standard is also obtained in all five filters. One observation in twilight will suffice.

It is assumed that ESO will provide basic sky quality parameters such as photometric quality and extinction measures at zenith.

Internal calibration of observations uses the flatfield and dark sky characteristics of the detectors to place them all on a common gain system.

For the purposes of quality control (eg. sky transparency and system performance) a photometric zeropoint will be determined for each set of observations by direct comparison of the i'-band instrumental magnitudes with appropriately colour-corrected magnitudes of 2MASS stars. A more accurate nightly photometric calibration will be applied retrospectively given the standard star observations.

The internal gain-correction, applied at the flatfielding stage, should place all the detectors on a common zeropoint system (to  $\approx 1-2\%$ ): hence given a stable instrumental setup, the apparent variation of zeropoint then directly measures the change in “extinction” without the need to rely solely on extensive standard field coverage over a range in airmass.

Therefore for any given observation of a star in a particular passband

$$m^{cal} = m^{inst} + ZP - k(\kappa - 1) = m^{std} + ce^{std} + \epsilon \quad (3)$$

where ZP is the zeropoint in that passband,  $\kappa$  is the airmass of the observation,  $ce^{std}$  is the colour term to convert to the instrumental system and  $\epsilon$  is an error term. This assumes that the second-order extinction term and colour-dependency of  $\kappa$  are both negligible. By robustly averaging the zeropoints for all the matching stars on the frame an overall zeropoint for the observation can be obtained.

On photometric nights the extinction coefficient  $\kappa$  should be constant in each passband. The extinction  $\kappa$  can be monitored through each night either by assuming the true instrumental zeropoint only varies slowly as a function of time or by making measurements over a range of airmass.

Goals for photometric accuracy of individual pointings are  $<5\%$  in all broad bands and  $<10\%$  in  $H_\alpha$  (depending on frequency of spectrophotometric calibrator observations). This is what we are achieving with IPHAS data.

Later downstream, cross-calibration using the overlaps between fields will be used to improve this by about a factor of 2 and bring all survey data onto a common survey-wide flux scale.

### 3.4 Artefacts

The vast majority of these will be dealt with using the pair of offset pointings obtained for each field. For example, temporally variable artefacts such as satellite trails or cosmic-ray hits, can be accommodated using the dual coverage of each region in the survey. Saturated stars are automatically flagged in the processing system and most scattered light or ghosts are dealt with automatically by the catalogue background tracking software.

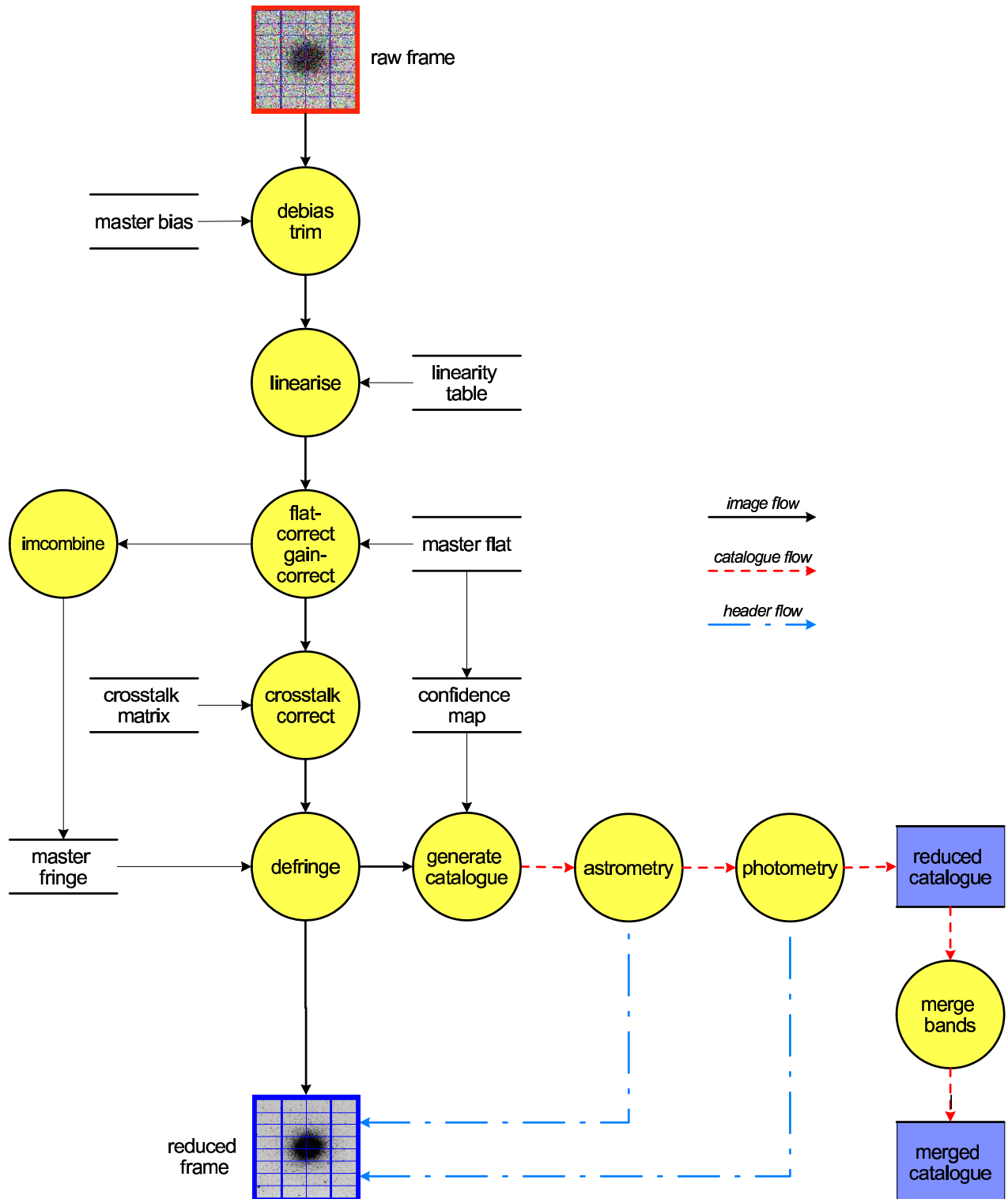
## 4 Data reduction process

The software we will use for the VST pipeline is a variant of the VISTA Data Flow System (VDFS; Emerson et al. 2004, Irwin et al. 2004). It covers all aspects of data processing and management and is a descendant of software originally written at CASU for a range of optical mosaic CCD cameras (e.g. ESO WFI, CFHT 12K and MegaCam, CTIO Mosaic, KPNO Mosaic, AAO WFI, INT WFC and WHT PFC). The Cambridge Astronomy Survey Unit (CASU) will be responsible for the pipeline processing component and first pass calibration. This will be augmented by input from R. Greimel (ING currently, PPARC grant applied for) and L. Morales-Rueda (Nijmegen currently, PPARC grant applied for), especially for product definition, product quality control and delivery to the ESO Science Archive of IVOA-compliant data products.

### 4.1 Pipeline processing

The VST pipeline is a modular design allowing straightforward addition or removal of processing stages and has been tested on a range of input datasets. The standard processing (see figure) assumes availability of the calibration data discussed in section 3. and includes:

- instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk
- consistent internal photometric calibration to put observations on an approximately uniform system
- catalogue generation including astrometric, photometric, and morphological shape descriptors and derived Quality Control (QC) information
- accurate astrometric calibration from the catalogue with an appropriate and World Coordinate System (WCS) in all FITS headers
- nightly photometric calibration from catalogue using suitable pre-selected standard areas covering entire field-of-view to monitor and control systematics
- each frame and catalogue supplied with provisional calibration information and overall morphological classification embedded in FITS files
- propagation of error arrays eg. weight maps, bad pixels, relative exposure via the use of confidence maps
- realistic errors on selected derived parameters
- nightly average extinction measurements in all relevant passbands
- merging of bands within each pointing to form multicolour catalogues
- pipeline software version control – version used is recorded in FITS header
- processing history including calibration files used also recorded in FITS header



We note that some initial quality control processing may be carried out within the context of the ESO DFS group's processing. The required calibration data were identified in section 3.

The intermediate VPHAS+ products will be (i) instrumentally-corrected image frames in all five filters, (ii) homogeneous band-merged object catalogues ( $u'$ ,  $g'$ ,  $r'$ ,  $i'$ ,  $H\alpha$  magnitudes and morphological classifications from single pointings).

## 5 Manpower and hardware capabilities devoted to data reduction and quality assessment

### 5.1 Team members with functional tasks:

Name	Function	Affiliation	Country	% FTE
J. Drew	PI	Imperial College London	UK	20
M. Irwin	Pipeline development	IoA, Cambridge	UK	20
N. Walton	Pipeline + VO compatibility	IoA, Cambridge	UK	10
E. Gonzalez-Solares	Pipeline processing	IoA, Cambridge	UK	50
D. Evans	Astrometric Calibration	IoA, Cambridge	UK	10
S. Hodgkin	Photometric Calibration	IoA, Cambridge	UK	20
R. Greimel (TBC)	Data Quality Assurance	IoA, Cambridge	UK	65
L. Morales-Rueda (TBC)	Data Quality Assurance	Imperial College London	UK	35
PDRA (TBC)	$H\alpha/r'$ Resolved imaging QC	IAC, Tenerife	E	35
J. Eislöeffel	Data Release Oversight	Thüringer Landessternwarte	D	
J. Fabregat	Data Release Oversight	Valencia	E	
P. Groot	Data Release Oversight	Nijmegen	NL	
C. Knigge	Data Release Oversight	Southampton	UK	
A. Mampaso	Data Release Oversight	IAC	E	
J. Walsh	Data Release Oversight	STECF, München	D	
B. Gaensicke	Internal website manager	Warwick	UK	
M. Barlow	Public Outreach	University College London	UK	
A. Zijlstra	Public Outreach	Manchester	UK	

**Note:** The full list of CoIs incorporates a longer list of individuals who have interests in the early exploitation of the survey and who are invited to attend Consortium meetings held at least twice a year. The full list is available from <http://www.vphas.org/>.

### 5.2 Detailed responsibilities of the team:

The PI, Drew, comes to this having led the existing IPHAS consortium since its inception in mid 2003. Most of her research effort is now focused on Galactic Plane surveying and this would naturally continue into the execution of VPHAS+. As with IPHAS, she would liaise closely with the management of the data pipeline, keeping an eye on quality, and she would communicate with the wider team to identify needed manpower and co-ordinate early-stage science exploitation. The PI's institution hosts a public website for IPHAS ([iphas.org](http://iphas.org)) and has added one specifically for VPHAS+ ([vphas.org](http://vphas.org)) and, most recently, for the combined science consortium EGAPS ('European Galactic Plane Surveys', [egaps.org](http://egaps.org)) intended as an umbrella for all new-generation OIR surveying of the Galactic Plane.

Irwin and Walton will lead the management and delivery of the initial reduced data products from the survey. The VST/OmegaCam data will be processed at CASU using pipeline software adapted to the purpose from existing proven and working software (it is a variant of the VISTA Data Flow System – see note below – and related also to the existing IPHAS pipeline software). Funding and personnel for processing UK-led VST public surveys at CASU are now in place and the hardware infrastructure for this has been achieved by modest extension of the existing VDFS pipeline processing setup. The pipeline processing components have been scientifically verified in recent years by processing wide field mosaic imaging data for a range of existing optical CCD mosaic cameras (e.g. Suprime-CAM, ESO WFI, CFHT 12K and MegaCam, CTIO Mosaic, KPNO Mosaic, AAO WFI, INT WFC and WHT PFC). CASU already houses the IPHAS pipeline, which has been routinely reducing, and providing reduced image and catalogue products since 2003.

**Note 1:** The VISTA pipeline is being developed through the VEGA programme, PI Gilmore in Cambridge. Emerson (QMUL) is responsible for the VISTA elements of that programme, with Irwin being the lead co-I with the expertise to take on responsibility for the processing pipeline elements in Cambridge.

**Note 2:** Walton is project Scientist of the AstroGrid Virtual Observatory project in the UK, and now additionally Project Scientist of the Euro-VO's VO Technology Centre (<http://www.eurovotech.org>). This centre is defining many of the VO standards that the ESO SAF will conform to and in turn demand compliance with. Walton works closely with staff in ESO, and in particular with Padovani, Head of the ESO VOSystems Group responsible for the SAF. He is thus well placed to ensure the smooth ingression of VPHAS+ survey products into the ESO SAF.

Irwin and Walton, together with Drew, will have responsibility to ensure that the required level of survey products are provided to the ESO Science Archive Facility (SAF), conforming to the agreed ESO SAF and Virtual Observatory standards. Greimel will provide important support in this, extending his central IPHAS role (where he has been solely responsible for the INT observing scripts, data quality and progress checking). He has also taken the lead in seeking additional spectrophotometry on photometric standards in order to assist the process of clarifying narrow-band  $H\alpha$  zero points. He is one of two named appointments at post-doctoral level for which funding has been sought from PPARC, to start in the second half of 2007 (3 years funding in the first instance). If the grant application is successful, he will move to IoA Cambridge from La Palma, at about the time IPHAS observing is approaching its conclusion. The second named appointment is Luisa Morales-Rueda, who also has an interest in the VST guaranteed time programme, OMEGAwhite (PI Groot). She would be located with the PI at Imperial College London, and help shoulder quality control checking. Funds for a third PDRA specialising in the use of survey data for spatially-resolved nebular imaging will be requested by Mampaso (IAC) and Corradi (ING) at the January 2007 deadline in Spain, to be in place from ~October 2007 for 3 years. Mampaso and Corradi are at the forefront of organising this aspect of exploitation for IPHAS.

The PI, with a sub-panel of CoIs (identified above), will oversee the science requirements for the cataloguing and base-level exploitation of VPHAS+ data products. The IPHAS team is already going down this path in that a panel of 5 team members has identified the styles and organisation of data to go into an early release of photometric catalogues scheduled for September 2006 (when IPHAS observations will be ~70 % complete). Irwin, Walton and Greimel will be included in the VPHAS+ panel, ex officio. Groot will bring to the panel his prominent interest in the  $u'g'r'$  aspects of the survey and linkage to the northern survey in these bands, now underway (UVEX-N), that he leads. Beyond this, the sub-panel team members' own science interests span most of the broad range of Galactic astrophysics served by VPHAS+. This panel would remain in place until a final calibration of VPHAS+ data is achieved. It will be most active, meeting by telecon in between consortium meetings, during the first couple of years of the survey's execution.

Like IPHAS, VPHAS+ will be generating  $H\alpha$  imagery of eye-catching beauty – the UCL and Manchester groups (led by Barlow and Zijlstra) have taken the initiative in generating these, to date. For example, two IPHAS images have already appeared as 'Astronomy Picture of the Day', and a PPARC Frontiers article has appeared. We anticipate this activity becoming more important as VPHAS+ gets underway.

The wider membership of the VPHAS+ consortium will act as a conference of interested scientists making prompt use of VPHAS+ data and instituting early follow-up programmes across a wide range of telescope facilities. Consortium meetings will continue the IPHAS pattern of meeting in person, twice a year at least.

### 5.3 Hardware

Our VPHAS+ team will accept raw SM data as delivered by ESO. There are no specific time requirements on when we would require the data after acquisition at the telescope (e.g. we are not wishing to detect SN, GRBs etc in near real time). Therefore we would anticipate that ESO would provide the data via ftp download from their raw data repository in Munich. Electronic transfer is the preferred option, but we could instead accept data shipped on NGAS disks or on LTO tapes.

In terms of data volumes, VPHAS+ will generate  $\sim 12$  TB of raw science and calibration data (each exposure of the 32 CCD camera produces 0.5 Gbyte). As this will be obtained over several semesters, it will not lead to significant extra data volume pressure on our processing system, which currently deals with  $\approx 25$ – $30$  Tbytes of raw data per year.

Once the data has been accepted in Cambridge, it will be fed into the VST pipeline running at CASU. The processes contained within this are summarised elsewhere in this document (see also Irwin et al, 2004).

Spare disk capacity will be made available by the VPHAS+ team in Cambridge to provide staging storage for the reduced data products as they are produced from the pipeline. It is anticipated that of order 8 TB of disk will be acquired initially for this purpose.

As noted in section 8 below, processed data will be released to ESO on a set timescale. Transfer will be to the ESO SAF, preferably via 'ftp' of the image and catalogue files. It is anticipated that ALL UK processed VST public survey data will be transferred to ESO in an identical fashion, in order to minimise the number of interfaces (to external data product providers) to be managed by ESO.

## 6 Data quality assessment process

After pipeline processing, the data will be tagged with seeing measurements and other QC information (see below). Greimel, Morales-Rueda and Drew will check seeing, limiting magnitudes and sky background level for consistency with survey data quality requirements. OBs failing these checks at a significant level will be reinserted into the observing programme, and noted for report in the 6-monthly progress reviews. This would be the position at the start. As the survey progresses, this pass/fail approach will realistically need some moderation, such that borderline data may require reassigning, in order to bring the survey to conclusion on a practical time scale. The QA review of pipelined data QC parameters will, from the outset, classify data as 'good', 'bad' or 'borderline', but we anticipate that the boundary between 'borderline' and 'bad', in particular, may shift with time. We are entering this phase of reviewing the definition of 'borderline' for IPHAS data in order to bring data-taking to a conclusion in the second half of 2007. This is analogous to, but more nuanced than the (almost) fully automated approach used by SDSS in its more complicated circumstances (leading directly to follow-up survey-managed spectroscopy): see <http://www.sdss.org/dr4/products/general/edr.html/node49.html>.

In advance of data-taking and direct experience of the pipelined out, we would anticipate the following illustrative limits:

**Seeing:** Pipeline derived mean seeing across all exposures in an OB required to be  $\leq 1.2$  arcsec + no single exposure worse than 1.5 arcsec + point-source ellipticity  $< 0.2$  all images (good data), derived mean seeing across all exposures in an OB between 1.2 and 1.5 arcsec + point-source ellipticity  $< 0.2$  all images (borderline), all other cases (bad data).

**Magnitude Limit:** The software currently reports  $5\sigma$  limiting magnitudes. Within an OB we would require limiting AB magnitudes for 'good' data to be e.g. in  $r'$ ,  $\geq 21.7$ , and in  $u'$ ,  $\geq 21$ . The exact set of limits to be used for all bands needs to be based on the real performance of the instrument and telescope, but our goal would be to match the pattern identified in the science programme (i.e. to do best in  $g', r'$ , and accept limits in  $u', i'$  and  $H\alpha$  that are brighter by 0.5-1 magnitude).

**Sky background:** This measure is of most significance to mosaicking and/or continuum subtraction of  $H\alpha$  frames to trace diffuse nebular emission. We would look at establishing an acceptable maximum level in  $r'$  and

$H\alpha$  frames, that is within a factor of two of the median level achieved in nominal grey sky conditions.

**Additional quality flags:** A number of secondary quality indicators will be tracked. These will include the estimate of ellipticity of unresolved images (as indicated above). High ellipticity usually indicates problems with either the optics (eg. focus) or telescope tracking/guiding. Sky noise and aperture correction factors will also be produced by the pipeline, logged and examined as flags of potential problems.

An overview of the status of the processing of the VPHAS+ data will be maintained - giving access to the quality control data, and recording date of arrival of the raw data and date of transfer to the ESO SAF. This overview will be modelled on that currently routinely running for the WFCAM data pipeline - see e.g. [http://apm15.ast.cam.ac.uk/wfcam/report\\_night\\_reduction\\_status?semester=05B&SUBMIT=Submit+Query](http://apm15.ast.cam.ac.uk/wfcam/report_night_reduction_status?semester=05B&SUBMIT=Submit+Query)

## 7 Data products and VO compliance:

VPHAS+ data will be calibrated to ESO agreed standards for the survey, thus the data will be photometrically and astrometrically calibrated to better than 0.05 magnitudes and to 0.1 arcsec rms precision, respectively. Full object merged-band catalogues will be generated for each image. These will be similar to the catalogues that we routinely generate for IPHAS, and conform to the standards developed for the VDFS. It is anticipated that these catalogues will be hosted eventually at the ESO SAF, and additionally in Cambridge. Full global access will be available by ensuring that all products conform to VO standards - as an example see the WFS SIAP service (<http://esavo.esa.int/registry/result.jsp?searchMethod=GetResource&identifier=ivo://org.astrogrid/INT-WFS.SIAP>) which is callable through AstroGrid and the emerging Euro-VO portals.

The following data products will be available:

- instrumentally corrected frames along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
- statistical confidence maps for all image products
- derived object catalogues based on a standard set of object descriptors including astrometric and photometric measures, and morphological classification
- Data Quality Control database including measurements of seeing, average stellar shape, aperture corrections, sky background and noise levels, limiting magnitudes
- homogeneous band-merged catalogues ( $u'$ ,  $g'$ ,  $r'$ ,  $i'$ ,  $H\alpha$  from single pointings).
- federation with the 2MASS point source catalogue

On the short timescale (months after data-taking), the object catalogues derived from different pointings cannot be guaranteed to be photometrically consistent with a common zero point: data obtained in good stable conditions should only show small relative drifts between fields that are no worse than a few hundredths of a magnitude. A policy decision will be needed from the ESO Survey Team on whether this level of calibrated data should or should not be public domain (i.e. ingested into the ESO archive) as soon as it is available. The IPHAS policy has been to collect the better data together for a combined early data release (now scheduled for September 2006, via ASTROGRID), and to plan on a later final release of the entire survey, after uniform photometric calibration has been achieved.

We do not, at this point, envisage the routine production of largescale image mosaics: their production to a high standard is very labour intensive and better driven, in the first instance, by targeted science needs which fall outside the immediate scope of a public survey. Manpower to do this could be found in the future. For now, the consortium certainly envisages the construction of some mosaics as the survey progresses, not least to publicise the quality and beauty of the achieved imaging. A few examples of existing IPHAS mosaics are given at <http://astro.ic.ac.uk/Research/Halpha/North/gallery.shtml> – two have appeared as on the web as ‘Astronomy Picture of the Day’, and others in journal articles (Drew et al 2005, Wareing et al 2006).

## 8 Timeline delivery of data products

Our team can envisage two styles of product release resulting from the survey, the first timed at data acquisition plus 6 months once the survey is established and in routine operation at the telescope, the second to first appear at survey start plus 18 months. These would be the EDR and DRn catalogue releases and will incorporate narrow-band  $H\alpha$ ,  $u'$ ,  $g'$ ,  $r'$  and  $i'$  photometry on all catalogued point sources (of  $\sim 500$  million stars). EDR (early data release) would only be flux-calibrated at the individual pointing level and limited to accepted data, whereas the aim for DR1 and subsequent annual releases would be to take each preceding year of data-taking and progressively place the entire survey onto a uniform photometric scale. The present plan is for Greimel (funds requested) to take the lead role in the final global calibration, drawing upon his now deep familiarity with this style of optical surveying.

In addition to the catalogue releases indicated above, the VPHAS+ team will ensure delivery of the following core data products to the ESO SAF:

- astrometrically and photometrically calibrated, re-gridded images, along with their respective weight maps, in all of the project-relevant filters will be provided on a per pointing basis.
- source catalogues based on individual bands. Associated merged source catalogues linking the parameters of individual objects across all of the observed filter bands will be provided on a pointing by pointing basis, as detailed above.
- these survey products will be supported and characterized by additional 'meta' information providing a full description sufficient for their full scientific exploitation. Documents detailing this for the two types of catalogue have been provided in addition to this document.

These 'core' products will be delivered within 2 months of receipt of the raw data from ESO.

As mentioned above, full status of all data processing and products, together with quality control information will be provided by the VPHAS+ project. Thus the VPHAS+ team will be providing sufficient information to ESO to enable it to carry out its regular six-monthly reviews.

## 9 References

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