1 VPHAS – the VST photometric Hα survey of the Southern Galactic Plane

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1.1 Abstract:(10 lines max)

The primary goal of VPHAS as a Public Survey will be the gathering of narrow-band Hα, r' and i' photometry across the entire southern Galactic Plane within the latitude range $-5^o < b < +5^o$ down to a point-source magnitude of $r' \simeq 21$. For A0V stars and intrinsically brighter early-type emission line stars this is deep enough to fully explore all but the most heavily obscured locations of the southern Galactic Plane (where the penetration will still be several kpc). These data should multiply the number of known southern emission line objects by 10 or more, yielding greatly improved statistics on a range of rare short-lived object types. Their superior photometric accuracy will also facilitate large-area stellar population studies within the Plane that have hitherto not been possible. The total final catalogue will contain in the region of 200 million objects. VPHAS, along with IPHAS – its northern counterpart already underway – will provide a hugely attractive database of Hα imagery that can be used to publicise the science of astronomy as a whole.

2 Description of the survey: (Text: 3 pages, Figures: 2 pages)

2.1 Scientific rationale:

HI recombination line emission is the common marker of diffuse ionized nebulae and it is also prominent in the spectra of pre- and post-main-sequence stars, binaries, and the most massive stars. Since these object types, together with those giving rise to extended nebulae, are in relatively short-lived phases of evolution, they are represented by a minority of objects in a mature galaxy like our own at any one time. This scarcity, in turn, has acted as a brake on our understanding of these crucial evolutionary stages that, in youth, help shape the growth of planetary systems and, in old age, determine stellar end states along with the recycling of energy and chemically-enriched matter back into the galactic environment. Hα is the most favourable hydrogen recombination line to target in the optical-IR wavelength range since its absolute emissivity (in nebulae) or emission equivalent width (in stellar spectra) far exceeds that of any other accessible HI transition. That it falls in the red part of the optical spectrum helps in that bright/grey nights can be used for its observation, and the effects of interstellar reddening are less severe than in the blue and visual bands.

Present catalogues of e.g. LBVs, yellow hypergiants, WR stars, interacting and symbiotic binaries typically contain anything from a few, to one or two hundred, sources. This leads to situations in which there is a bewildering zoo of unique or infrequent examples of specific phenomena within an overall classification. In effect, stellar evolutionary studies have been bedevilled by small number statistics and a lack of good demographics. State of the art $H\alpha$ surveying, with appropriate follow-up, has the potential to practically eliminate this problem.

We propose a southern companion survey to IPHAS, the photometric Hα survey of the northern Galactic Plane currently underway on the 2.5-metre Isaac Newton Telescope in La Palma (see http://astro.ic.ac.uk/Research/Halpha/North/index.html). An allocation of ~ 120 nights, so far, has brought IPHAS to about the half-way point. We anticipate a final IPHAS point-source catalogue of narrow-band Hα, Sloan r' and i' photometry containing around 80 million objects. The proposed VST Photometric Hα survey, VPHAS, would be closely analogous: the survey area would encompass all Galactic longitudes south of the celestial equator, within the latitude range $-5^o < b < +5^o$ (as adopted in the north for IPHAS) and the equivalent set of filters would be used. With only a modest investment of grey time, VPHAS can span the entire southern Galactic Plane down to $r \sim 21$, by means of an observing strategy modelled on that which is now proven to work for IPHAS. The combination of IPHAS and VPHAS will bridge the yawning gap that exists currently between the mainly objective prism survey work of the middle of the 20th century that reached only 12-13th magnitude (figure 1) and the much more sensitive capabilities of today's advanced CCD imagers.

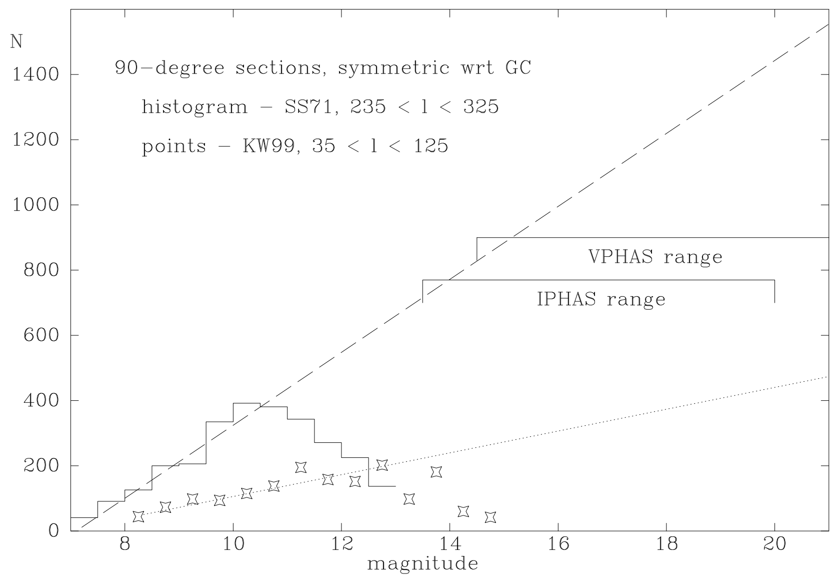

Figure 1: The legacy of the previous generation of Hα point source surveying in the Galaxy. These are histograms of the catalogued emission line stars, binned by visual magnitude. The data represented by the continuous line are from the southern Stephenson-Sanduleak (1971 PW&SO) catalogue, extracted within Galactic longitudes $235^o < \ell < 325^o$. The data represented as points are from the northern hemisphere catalogue of Kohoutek & Wehmeyer (1999 A&AS 134 129), extracted over the longitude range $35^o < \ell < 125^o$. Linear extrapolations into the IPHAS and desired VPHAS magnitude range are drawn as dashed lines. Kohoutek & Wehmeyer (1999) accumulated data, using the Hamburg Schmidt over many decades, and added data published by others: they consider their catalogue to be complete to $V \sim 13$.

Together these Galactic Plane Hα surveys amount to a major astronomical legacy, feeding large amounts of new data into a wide range of Galactic astrophysics research areas, and also providing a hugely attractive database of Hα imagery that can be exploited to publicise the science of astronomy as a whole.

Simple linear extrapolation of published Hα catalogues (figure 1) suggests a haul of around 50,000 new emission line sources awaits discovery in the south, down to $r' \sim 21$. This is a factor of ~ 10 improvement on the existing Stephenson & Sanduleak (1971 PW&SO) catalogue. But this makes no allowance for adding in to the emission line star population the intrinsically fainter groups (e.g. interacting binaries, active and young later-type stars) that are poorly sampled presently because of the 12-13th magnitude cut-off in existing catalogues. Conversely, in the darkest, most dust-obscured reaches of the southern Plane linear extrapolation of the bright-end distribution of emission line objects could be optimistic. So, in reality, prediction of outcome is not easy. Nevertheless, given the factor of $\sim$1000 in sensitivity waiting to be fully realised, and that the southern Plane is home to the Galactic Centre, two-thirds of the Galaxy's stars and much of its nebulosity, it would be a major oversight not to bring the census of its nebulae and emission line objects fully up to date.

The deepest currently available survey in the south is the recent UK Schmidt Hα photographic film survey of the southern Galactic Plane (SHS, see Parker and Phillipps 1998 PASA 15 28) - the VST with OmegaCam can significantly out-perform this in a number of ways: the CCD linearity of response over a much greater dynamic range; higher spatial resolution (0.21 arcsec pixels, as compared with 1–2 arsec resolution from SHS); ease of calibration; greater depth; and assured contemporaneous collection of Hα, r' and i' exposures at each pointing.

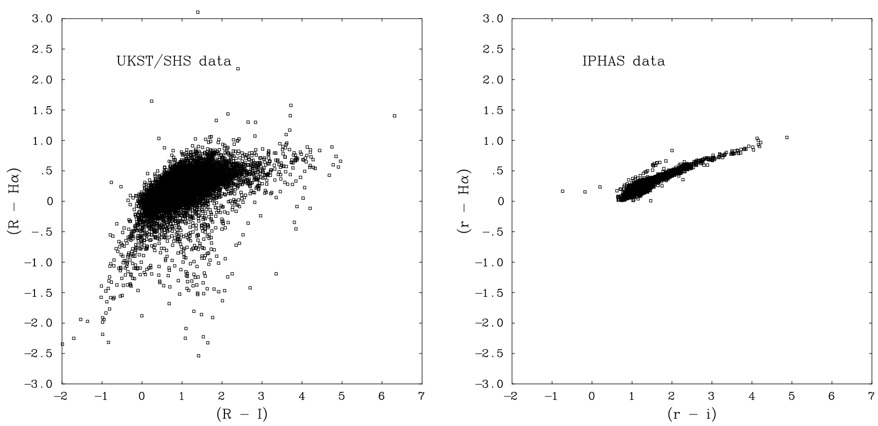

Figure 2: Point-source SHS colours obtained from the existing UKST photographic Hα survey of a ~ 0.25 sq.deg. patch of sky in Aquila are compared with the analogous colours obtained for approximately the same field, obtained as part of the IPHAS survey. Only stars in the magnitude range $13 < R < 19$ are plotted. Note the much tighter definition of the IPHAS stellar locus, revealing 3 very convincing blue Hα-excess objects (candidate interacting binaries).

With regard to studies of extended nebulae, the linearity of response is the main qualitative gain, in that much of the nebulosity imaged in the UKST survey cannot be photometrically calibrated and there is widespread loss of nebular fine structure because of the dynamic range problem. Whilst the SHS survey has discovered a large number of extended nebulae in the southern plane (Parker et al 2003 IAUS 209), there is nevertheless scope for VPHAS to make a major contribution to this area. This is not just because VPHAS will be more sensitive to extended nebular emission than the SHS – direct comparisons indicate that IPHAS reaches surface brightness levels about two times fainter than does the SHS and executing VPHAS in grey sky rather than bright sky conditions should make it more sensitive than IPHAS – but also because the much higher angular resolution of OmegaCAM and the superior seeing conditions at Paranal mean that many new compact nebulae will be resolved by VPHAS which could not be distinguished from stars by the SHS. Compact nebulae are of particular interest as they can correspond to especially transitory and poorly studied phases of evolution, e.g. the post-AGB transition between AGB stars and full-blown planetary nebulae, or phases of mass ejection from binary systems.

The greater gain of VPHAS with respect to the UK Schmidt survey is associated with spatially unresolved emission line objects. We illustrate this in figure 2, where we directly compare SHS and IPHAS catalogue point-source colours for the same patch of sky. It can be seen that definition of the main stellar locus is very good in the IPHAS data, whilst it is much more blurred in the SHS extraction. This difference has two important consequences.

First, the implications for spectroscopic follow-up of candidate emission line objects (mostly located above the main stellar locus), are quite different. Only 10 percent or so of candidates derived from the SHS are typically confirmed as genuine emission line objects – a yield that is in line with the norm for photographic surveys.

We have verified this rate of return in a campaign of UKST/6dF spectroscopy, following up around a dozen SHS $4^o \times 4^o$ deg^2 fields in the magnitude range $12.0 < R < 16.5$. In the spectra obtained we find Hα emission equivalent widths start at around 10–20 Å. In sharp contrast with this, the early signs from WHT/ISIS long-slit and MMT/hectospec multifibre spectroscopic follow-up of the growing IPHAS database is that candidate selection is practically 100 percent efficient down to $r' \sim 20$, and that the threshold Hα equivalent width is about half that for the SHS. The increasing errors at fainter magnitudes in the SHS, will make identification of all but the most extreme emission line objects impractical. In effect, VPHAS will open up unexplored territory in the southern Galactic Plane at $r' > 17$ – almost no SHS point-source spectroscopic follow-up has been attempted at these magnitudes.

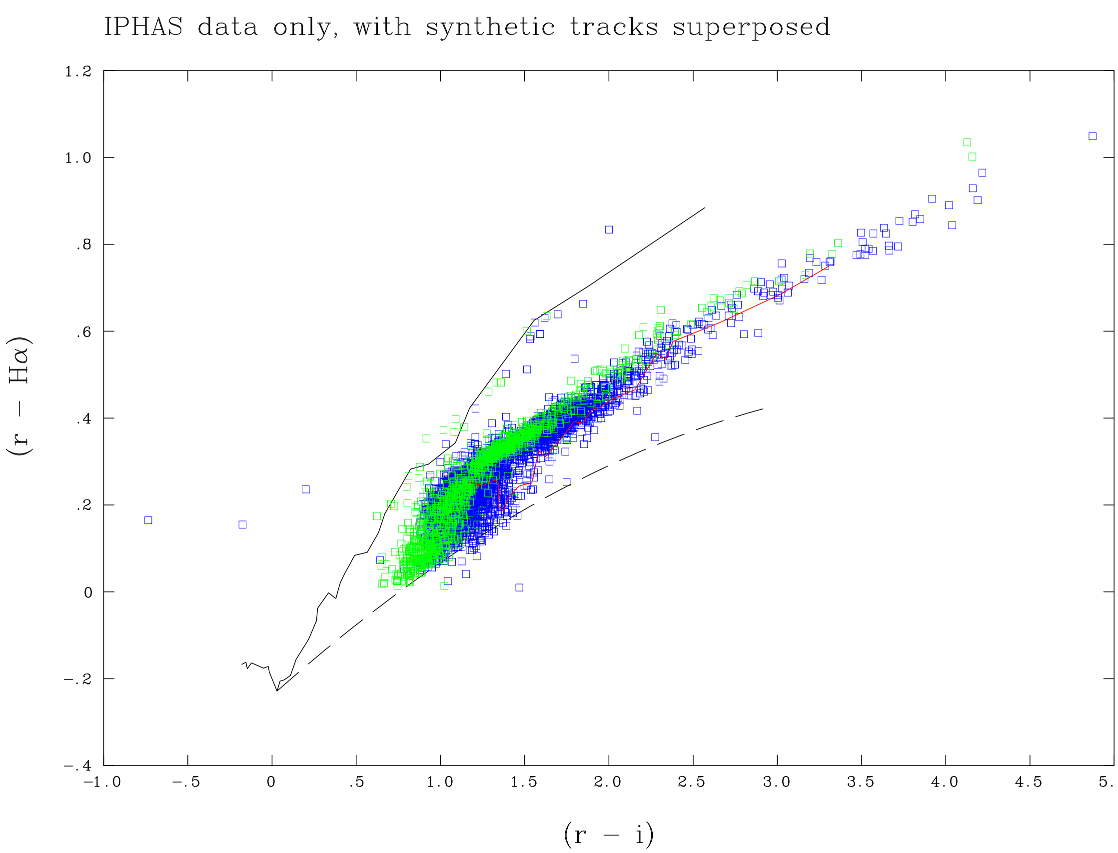

Figure 3: The plot of the IPHAS colour-colour data shown in fig 2 is expanded to show, in addition, synthesised tracks for unreddened main-sequence dwarfs (solid upper line) and giants reddened to $E_{B-V} = 2.0$ (lower solid line, seen in main stellar locus). The dashed black line shows how the colours of an A0V star change as its spectrum is reddened. The data plotting as grey (or green, if viewed in colour) are stars with $13 < r < 17$ while the fainter stars ($17 < r < 19$) are darker (blue, viewed in colour). The expected maximum reddening through the Galaxy at this location is $E_{B-V} \simeq 2$ (Schlegel et al 1998 ApJ 500 525), consistent with the reddest giants and main sequence stars detected.

Second, the excellent definition of the main stellar locus itself emerging from IPHAS catalogue colour data allows quantitative analysis of stellalr populations and, most strikingly, even provides reliable access to Hα *deficit* objects. Exploitation of this type is simply not possible on the basis of SHS data. How it is achieved using IPHAS data is illustrated in figure 3. Shown superposed on the data are three synthetic tracks, calculated by folding IPHAS filter profiles through sequences of flux-calibrated stellar spectra (Pickles 1998 PASP 110 863) and integrating to form colours. The uppermost is an unreddened main sequence (seen in nearly all Galactic fields), the second – superimposed on the main stellar locus – is a more gently-sloping giant (class III) track accounting well and plausibly for the reddest objects present, and finally – running along the bottom of the main locus – is the A0V reddening line. Comparisons of this kind make it possible to establish the range of reddenings present in any field, to distinguish main sequence and higher luminosity stars (e.g. we find fields dominated by luminous objects only, and their converse, fields with no red giants). And it is easy to pick out minor populations such as emission line stars, above the main stellar locus, along with extreme Hα absorption objects below. This deficit group begins with the A0V stars usually lying along the lower boundary to the main locus, and includes white dwarfs and blue sub-dwarfs below the locus at bluer colours, together with non emission line brown dwarfs and carbon stars at redder colours.

Returning to the astrophysics of emission line objects, we now give a flavour for the science role VPHAS can take with respect to specific applications. We give two examples: evolved massive stars, and compact binaries.

Post-MS evolution of massive stars It is striking how sparse the lists of galactic LBVs, hypergiants and extreme B[e] objects remain (Humphreys & Davidson 1994 listed only 5 galactic LBVs, including η Car and P Cyg) As their absolute visual magnitudes range from around -10 (LBVs, hypergiants) down to -6 (B[e] supergiants), the proposed survey can pick them up almost anywhere in the Galaxy, even behind quite high extinctions ($A_V \sim 10$). In addition, the southern Galactic Plane had not been systematically surveyed for Wolf-Rayet stars (possible descendants of the LBVs) at red wavelengths at all, prior to the UKST Hα survey. The recent discoveries of first, only the fourth known Galactic WO star (Drew et al 2004 MNRAS 351 206), and then a group of 5 WC9 stars within just a few square degrees (Hopewell et al in preparation) in the southern Plane, using the SHS and 6dF down to just $r' \sim 16.5$, encourages the expectation that we will detect many fainter new WR stars in the VPHAS survey. The longer wavelengths of our survey filters, compared to traditional WR searches in the blue range, confers a distinct advantage when probing reddened regions of the plane. Almost all massive WR stars are found within 2-3^o of the mid-plane. Our data should allow much more complete demographics to be obtained of these very late phases, giving an impetus to an improved generation of massive-star evolutionary models.

Accretion-powered compact binaries The currently known white dwarf, neutron star or black hole binaries (CVs, symbiotics, LMXBs, SXTs, micro-quasars etc.) have been discovered mainly through large amplitude and/or frequent optical variability, or via their X-ray emission. The typically severe shortfall in the observed frequencies of these objects in the Galaxy, with respect to the predictions of population synthesis, strongly suggests that a significant number of systems evades detection by these means. Poor X-ray detection rates, in particular, are likely to be due to high interstellar extinction in the Galactic disk. A common *spectroscopic* hallmark of practically all interacting binaries is $H\alpha$ emission originating in the accretion flow between the two component stars. We expect that the proposed survey will identify a large number of such systems, and will, thereby, lead to quantitative testing of models of binary star evolution. Of particular importance in a broader context is the identification of SN Ia progenitor systems: white dwarf mergers, symbiotic stars, recurrent novae (RN) and compact binary supersoft sources (CBSS) have all been candidate object types. For example, one prominent theory group (see e.g. Hachisu et al 1999 ApJ) favours the highest luminosity, actively accreting objects, such as RN and CBSS. And yet, respectively, just 8 RN and 2 CBSS are known in the Galaxy (Downes et al 2001 PASP 113 764). If population synthesis models are to be believed, we have yet to find ~ 1000 CBSS alone (Kahabka & van den Heuvel 1997 ARA&A).

We pick out other applications in section 7.

2.2 Immediate objective:

The primary goal of VPHAS as a Public Survey will be the gathering of narrow-band Hα, r' and i' photometry across the entire southern Galactic Plane within the latitude range $-5^o < b < +5^o$ down to a point-source magnitude of $r' \simeq 21$. For a typical seeing of 1 a,rcsec this translates to a nebular surface brightness magnitude of ∼20.8 per arcsec^2. For A0V stars and intrinsically brighter early-type emission line stars this is deep enough to fully explore all but the most heavily obscured locations of the southern Galactic Plane. Even in the highly obscured regions, concentrated down into the mid-plane near the Galactic Centre (essentially the Spitzer/GLIMPSE strip) the VPHAS view will extend a few to ∼10 kpc. These data should increase the known southern emission line objects by an order of magnitude, thereby allowing much better statistical characterisation of a range of rare short-lived object types. Their superior photometric accuracy will also facilitate large-scale stellar population studies within the Plane that have hitherto not been possible.

3 Are there ongoing or planned similar surveys? How will the proposed survey differ from those? (1 page max)

We know of no other planned or ongoing comprehensive optical-NIR surveys of the Galaxy, other than VPHAS and IPHAS, that hinge in the same way on the application of narrow-band imaging. The closest ongoing programme, using an Hα filter, is the deep, limited-area ChamPlane survey (see e.g. Grindlay et al 2003 AN 324 57) that is following up deep Chandra pointings toward different Galactic Plane locations over an area adding up to ~ 15 deg^2. The Sloan consortium is seeking funding to support a comprehensive $u'g'r'i'z'$ survey of the Galactic Plane but has not announced plans to incorporate a narrow-band filter. We note also the Dutch-led UVEX and OmegaBulge VST Public Survey proposals seeking broadband-only Galactic Plane data ($u'g'r'$ and $u'r'i'$ respectively).

In highly reddened parts of the Plane, VPHAS will combine well with the existing 2MASS JHK database - the combination of the 5 broad-band filters with Hα goes essentially all the way to determine reddenings, spectral type, the presence of line emission and/or NIR continuum excesses. Along sightlines where the total Galactic A_V is below 8 to 9 (the majority of the survey area), combination with deeper NIR data from either UKIDSS/GPS (north of $\delta = -15^o$) or VISTA would be fruitful since, at these lesser reddenings, 2MASS will typically not include faint-end VPHAS objects. The VPHAS survey area also encloses within it the majority of the strip surveyed for the Spitzer/GLIMPSE mid-IR project: it will be of interest to tie up the optically-detected emission line objects with their GLIMPSE counterparts.

With their incorporation of narrow-band Hα imaging, the VPHAS/IPHAS surveys present an attractive complementarity to the RAVE survey, underway in the south, and seeking a suitable telescope plus multi-object spectrograph in the north. Where RAVE emphasises radial velocity measurement of later type stars (via the calcium IR triplet in absorption) throughout the Galaxy, VPHAS and IPHAS are particularly capable in picking out luminous early type objects at great distances and, as a new kind of standard candle, A0V stars. Looking a little further into the future, the products of VPHAS/IPHAS, with their astrophysical bias, will amount to a valuable preparation for the eventual work of GAIA (launch due in 2012).

4 Observing strategy: (1 page max)

The primary goal of this proposal is to extend the fully photometric survey of the Galactic Plane that we have initiated in the Northern Hemisphere with the 2.5-m Isaac Newton telescope and its 0.25 square degree Wide Field Camera. The southern extension, pursued in grey time, will reach a magnitude deeper than the northern survey, IPHAS, and will be a huge qualitative improvement on the legacy UKST $H\alpha$ Survey (SHS, see earlier).

Our **observing strategy** for each field is to follow a 120s $H\alpha$ exposure with 30s exposures in the r' and i' filters. Obtaining the full set of exposures at each pointing position maximises the likelihood of equivalent image quality (in terms of PSF, photometric conditions) in each field. This facilitates optimal continuum image subtraction from the line emission, minimises systematic error in photometric colour measurements, and aids final flux calibration of the data.

Experimentation with different tiling patterns for the 10 degree wide, 180 degree long strip of the southern plane leads to an optimal coverage being obtained with 2000 field centres. 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 desirable, 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).

As calibration observations, VPHAS pointings needed to be supplemented by standard (e.g. Landolt or Sloan) field observations through all three filters every two to three hours through each night. We would also like to continue the practice followed for IPHAS that spectrophotometric standards are also obtained at least once a night.

Filter choice The basic observations required for this survey are matched OmegaCam images obtained with (i) a narrow-band $H\alpha$ filter ($\sim$100 Å FWHM), (ii) a continuum filter in the same part of the spectrum as $H\alpha$, (iii) a second continuum filter to enable the determination of the continuum colours of stellar sources. With two continuum bands, important ambiguities due to either interstellar reddening or the development of strong molecular bandhead structure in late type stellar spectra – both capable of giving 'false positive' Hα excess – are minimised. For the continuum filters, we use the Sloan (aka Gunn) r' and i' filters in the OmegaCam filter set, because of their box-like passbands. The broad r' filter, with a central wavelength of $\sim$6200 Å, encompasses rest $H\alpha$, while our second continuum filter is chosen to be i' to lower the practical impact on the survey of moonlight and interstellar reddening.

At first light the OmegaCam will be equipped with a segmented Hα filter in which only one quadrant is designed to pick up Hα 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 Hα narrow band, (the two most redshifted segments miss rest frame Hα). 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. Instead, we plan to purchase an additional four segment Hα filter, each segment centred on 657 nm with a FWHM of 10nm. We understand that SAGEM and BARR are potential suppliers of this filter. (We note that the maximum throughput of the BARR filter may turn out $\sim$10% lower than that from SAGEM, but at considerably lower cost). In discussion with U Hopp, we believe that we would be able to make use of a spare OmegaCam blank filter holder. If this becomes infeasible, we will ensure another is made in conformity with the specifications for the Omegacam filter magazine. We will aim to have the filter available by May 2006 at the latest, allowing the first VPHAS observations to be scheduled towards the end of the 2006 southern Galactic Plane season falling in semester P77.

The Hα filter we intend to procure would be made available for general use with OmegaCam (subject to approval by ESO and VST management).

5 Estimated observing time:

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P77	56	14–19h	bright/grey	<1.3	clear
P78	188	7–14h	bright/grey	<1.3	clear
P79	188	12–19h	bright/grey	<1.3	clear
P80	126	7–14h	bright/grey	<1.3	clear
P81	70	12–19h	bright/grey	<1.3	clear

5.1 Time justification: (1 page max)

To arrive at suitable exposure times, we take 1.0 arcsec seeing at airmass 1.2 against a grey sky as realistic "average" conditions (source: Astroclimatology at La Silla, http://www.eso.org/gen-fac/pubs/astclim/lasilla/seeing/). Our estimates are based on the 'Theoretical S/N plots for OmegaCAM/VST' at http://www.astro.rug.nl/∼omegacam/preparing_obs/snplots.html, and also on 'VST+OmegaCam Exposure Time calculator (VOCET)' by A. Rifatto - INAF/Astronomical Observatory of Capodimonte, Naples (Italy), version Nov 2004 (see http://www.na.astro.it/∼rifatto/vst/vocet_2.htm). These must be presumed liable to change after updates to system efficiency are made, post commissioning of the camera. Our estimates for the throughput of the Hα filter is based on the design specification for the SAGEM-provided Hα filter (email communication from U Hopp).

For the r' filter we set the S/N ratio at a high enough level so as to not introduce noticeable noise when subtracting from the Hα images or when forming point-source colours. Specifically, a S/N ratio of ∼30 at $r' \simeq 21$ (with saturation for $r' \sim 14.5$) is expected if the exposure time on a point source is 30 sec. The same exposure in the i'-band gives a S/N of ∼15 at $i' \sim 21$. This is a sufficient depth for use in our science selections in the $r' - i'$ dimension, in view of the overwhelmingly red colours encountered among faint-end sources. If the Hα exposure time is 4 times longer (120 sec) than for r', i' filters, the S/N on a pure continuum source is very similar to the 'i' value – and the same reasoning regarding need applies.

Our magnitude estimates and the appropriateness of the count levels, especially with respect to the continuum subtraction process, are entirely consistent with the experience we have acquired during our IPHAS observations with the 2.5-m INT, its Wide Field Camera and the equivalent r', i', and Hα filters. For the same exposure times, IPHAS observations typically reach to ∼20th magnitude because much of the allocated time has been bright time. If VPHAS were run as a bright time programme, with no change to the exposure times, the survey depth would be comparable to that of IPHAS.

Estimation of overheads has to be based on preliminary estimates at this stage. Using figures as given in section 3.4.4 'Overheads' of the OmegaCam User Manual - VST-MAN-OCM-23100-3110 Version 1.2 - it would appear that the time to complete each pointing will be ∼8–10m (the main overhead being the current estimate of up to ∼5 minutes to reset to a new pointing centre). Guide stars are located automatically on their dedicated CCDs during exposure. But since even the Hα exposures for VPHAS are only 120 sec, it is worth noting that guiding is not strictly necessary. Hence there is the possibility that we over-estimate the total time requirement for this survey.

For now, we note two pointings per field require ∼18m, so that to observe all 2100 fields (number of fields justified in the 'Observing Strategy' section) will require a total of 37 800 minutes. We assume effective 8-hour nights averaged across the year implying that 79 clear nights, or ∼11 clear weeks, will be needed to complete the survey.

The maximum seeing value that will be acceptable for the survey is 1.3 arcsec. We note that at Paranal, this seeing is bettered 95 percent of the time (see http://www.eso.org/gen-fac/pubs/astclim/paranal/seeing/singcumul.html).

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function	Affiliation	Country
J. Drew	PI	Imperial College London	UK
N. Walton	Pipeline	IoA, Cambridge	UK
M. Irwin	Pipeline	IoA, Cambridge	UK
J. Eislöeffel	Data Release	Thüringer Landessternwarte	D
R. Greimel	Data Release	Isaac Newton Group	UK/E/N
C. Knigge	Data Release	Southampton UNiversity	UK
J. Walsh	Data Release	STECF, München	D
A. Acker	Exploitation (A,B)	University of Strasbourg	F
M. Barlow	Exploitation (A,B,C)	University College London	UK
M.-R. Cioni	Exploitation (B)	Edinburgh University	UK
R. Corradi	Exploitation (B)	Isaac Newton Group	UK/E/N
B. Gaensicke	Exploitation (D)	Warwick University	UK
P. Groot	Exploitation (D)	Nijmegen University	N
D. Lennon	Exploitation (C)	Isaac Newton Group	UK/E/N
P. Leisy	Exploitation (B)	IAC, Tenerife	E
L. Magrini	Exploitation (A,B)	University of Firenze	I
A. Mampaso	Exploitation (B)	IAC, Tenerife	E
D. Mardones	Exploitation (C)	Universidad de Chile, Santiago	C
E. Martín	Exploitation (A,C)	IAC, Tenerife	E
Q. Parker	Exploitation (A,B)	Macquarie University	Au
S. Phillipps	Exploitation (A,B)	Bristol University	UK
T. Prusti	Exploitation (A,C)	European Space Agency	ESA/N
D. Steeghs	Exploitation (D)	CfA, Cambridge	USA
Y. Unruh	Exploitation (A,C)	Imperial College London	UK
A. Zijlstra	Exploitation (B)	Manchester University	UK
A. Zurita	Exploitation (C)	Granada University	E

Note: The IPHAS team is grouped into science interest areas which are: A – survey science and structure of the Galaxy; B – evolved intermediate mass stars and their nebulae; C – Young stars, massive stars and their nebulae; D – symbiotics, white dwarf, neutron star and black hole binaries. These codes are redeployed in the table above.

6.2 Detailed responsibilities of the team:

The PI, Drew, comes to this with the experience of leading the existing IPHAS consortium since its inception in mid 2003. Most of her research effort is now focused on Galactic Plane Hα 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 science exploitation. The PI's institution hosts a public website for IPHAS and would do the same for VPHAS.

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 using the adapted VISTA Data Flow System, which is currently being developed in Cambridge (see http://www.ast.cam.ac.uk/vdfs/) within the Cambridge Astronomical Survey Unit (CASU). CASU already houses the IPHAS pipeline.

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 responsibility for the processing pipeline elements in Cambridge.

Note 2: Funding applications to PPARC are currently proceeding at the UK level to provide additional centralised financial support to allow a unified approach to the processing of data from the VST Public Surveys. Irwin is a lead co-I on these proposals. It is anticipated, that contingent upon successful UK PI involvement in the VST surveys, that there will be a common approach taken to the processing needs of all UK VST surveys. Thus plans contained within this proposal, are liable to alteration, dependent to some extent on the success or otherwise of other proposals to this VST Public Survey Call.

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.

Note 3: 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.

In addition, the PI, with a limited sub-panel of CoIs, 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 is tasked to identify the styles and organisation of data to be released in a first release of (non-uniform) photometric catalogues scheduled for the first half of 2006 (when we hope IPHAS observations will be $\sim$75 % complete). Irwin and Walton will be included in both the IPHAS and VPHAS panels, ex officio. Apart from the PI, the VPHAS panel would comprise Greimel, Knigge, Eislöffel and Walsh. Greimel and Knigge already have in-depth experience through the roles they have taken in IPHAS. Greimel, for instance, has been solely responsible for the INT observing scripts, data quality and progress checking, and initial construction of follow-up catalogues. Taken together the sub-panel team members' own science interests span a large fraction of the broad range of Galactic astrophysics served by VPHAS. This panel would remain in place until the point of achieving a final uniform calibration of VPHAS data is reached.

The wider membership of the VPHAS team would 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.

6.3 Data reduction plan:

It is envisaged that our survey data will be run through the data pipeline, in the same fashion as other successful UK-based VST Public Survey programmes. We note that some initial processing may be carried out within the context of the ESO DFS group's processing. However, the level of service to be provided by ESO is as yet undefined. Standard processing steps are required, leading to the generation of fully reduced (e.g. bias corrected, flat field corrected, cosmic ray corrected, linearity corrected, astrometrically calibrated, flux calibrated) units of data, each unit being a 'natural' 1 square degree tile for each filter.

Through our current IPHAS programme, we have developed in conjunction with CASU, additional pipeline components to enable the PSF fitting and subtraction of the broad band r' images from the Hα images to enable the construction of Hα emission line images.

Our survey 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 catalogues will be generated for each image. These will be based on the catalogues that we routinely generate for IPHAS, and conform to the standards developed for the Vista Science Archive. 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 which is callable through AstroGrid and the emerging Euro-VO portals.

In terms of data volumes, our survey will generate some 6.5TB of raw science data (each exposure of the 32 CCD camera produces 0.5Gbyte of data). Additionally a significant volume of calibration data will be acquired, although elements of that may be common to other programmes depending on how the survey is operated at telescope by ESO. However, this will of course be obtained over several semesters, thus, will not lead to significant data volume pressures on our processing system.

6.4 Expected data products:

After appropriate locally-defined background subtraction to obtain the $H\alpha$ magnitudes, candidate point-source $H\alpha$ emitters will be identified by means of their $(r - H\alpha)$ 'excesses' in plots of $r' - H\alpha$ vs. $r' - i'$ (cf Sung, Chun & Bessell 2000, who used analogous $R - H\alpha$ vs. $V - I$ plots). In limited area searches, wherein the main stellar locus can be expected to be well defined (figure 3), this is an extremely effective way of identifying, at the same time, both $H\alpha$ emission-line stars and strong Hα absorbers.

Our team anticipate two main product releases resulting from the survey, timed at survey start plus 2yr and survey start plus 3–4 years. These will be the DR1 and DR2 catalogue releases and will, finally, incorporate narrow-band Hα, r' and i' photometry on all catalogued point sources (of order 200 million stars, scaling up from IPHAS). DR1 would only be flux-calibrated at the individual field level, whereas the aim for DR2 would be to place the entire survey on a uniform photometric scale.

More specialist catalogues, separating point source and nebulae according to verified type, only become possible after spectroscopic or other follow-up to confirm type (e.g. brown dwarfs and carbon stars will exhibit similar VPHAS colours and must be distinguished by, say, the presence or absence of proper motion). The construction of these would be undertaken by VPHAS consortium members with an interest in the specified object classes.

6.5 General schedule of the project:

Since VPHAS only requires in the region of 11 weeks VST time, and links naturally to the northern IPHAS survey aimed at completing observations by the end of 2006, we propose a relatively compact time line. Ideally some limited VPHAS observations should be gathered in ~May 2006 (as soon as the new Hα filter is available) to verify that the data meet requirements. Then, weather permitting, 5 weeks grey-time observing in each of 2007 and 2008 could see the survey data-taking finished. The final main point-source catalogue (DR2) might then be ready by the end 2009. Specialist point-source catalogues and lists of compact nebulae discovered would likely become available on a similar or slightly longer timetable, depending on follow-up timescales.

7 Envisaged follow-up: (1 page max)

The photometry that will flow from from VPHAS is in large measure stand-alone, with the implication that there is no follow-up required to support VPHAS itself. However it has been noted already that there is much to be gained in federating VPHAS (and IPHAS) to NIR JHK surveys. Where reddening is relatively severe ($A_V > 9$ approx.), 2MASS is already deep enough to be useful in combination with VPHAS/IPHAS. The deeper UKIDDS Galactic Plane Survey is already underway and will be more than deep enough to combine with VPHAS north of dec -15°. That leaves south of this limit currently uncovered. We therefore foresee the need for a VISTA Galactic Plane Survey analogous to the current UKIDDS programme.

Otherwise, we anticipate two styles of follow-up to VPHAS. On the one hand, the availability of the 4-segment 0 km/s Hα filter will open the way to e.g. limited area deep extensions of VPHAS itself and other related VST Galactic/Local Group programmes. On the other, VPHAS will undoubtedly stimulate a wide range of spectroscopic programmes using ESO's VLT and other telescopes. In the north, already, the IPHAS consortium has successfully bid for 14 programmes (~60 nights) on a wide range of facilities, including two using the MMT hectospec multi-fibre facility. Below we give a very few examples of these two styles of follow-up.

Brown dwarfs We expect to detect many young low mass stars and brown dwarfs with (and without) $H\alpha$ emission and red $r' - i'$ colours. From the multiplicity of ways in which it has been suggested brown dwarfs form, it is clear that understanding their formation amounts to putting star formation theories in general to a strong test. One – perhaps the only – way to distinguish the different scenarios is to study the spatial distribution of very low mass stars and brown dwarfs in not yet kinematically relaxed young clusters and star forming regions. This is only feasible if statistically meaningful numbers of objects can be discovered over the full spatial extent of the formation regions. VPHAS can do this in some relevant regions.

In regions like Lower Centaurus-Crux, which has a 10^7 years old (de Geus et al. 1989 A&A 216 44) stellar association at a distance of 120 pc (de Zeeuw et al. 1999 AJ 117 354), the sensitivity of OmegaCam allows detection of young brown dwarfs. We envisage performing deep follow-up observations of a selection of such regions with a high spatial density of young stellar candidates in order to probe the whole brown dwarf mass domain. These observations would amount to follow-up to the main survey, and would complement it by trading depth for area coverage. We also foresee a need for spectroscopic follow-up: whilst $H\alpha$, r' and i' photometry is known to be very effective at identifying candidate young low-mass objects, care has to be taken to ensure cluster membership. To do this, FORS2 on the VLT would be an approprite facility.

Tracing spiral arms using A0 dwarfs This is a completely new opportunity made possible by the ability of both IPHAS and VPHAS to pick out A0 dwarfs with very high efficiency thanks to their strong Hα absorption. Compared to e.g. OB stars in HII regions, A0 dwarfs will serve as uncomplicated standard candles picking out Pop I structures throughout the Galactic Plane. They are late enough in spectral type not to demand NLTE modelling, and early enough to present with very simple spectra that are easily analysed for abundances and radial velocities. They are bright enough to be seen to great distances. VPHAS photometry alone, with some supporting NIR photometry, allows a first cut at mapping out spiral arm structure and sightline distributions of interstellar dust. But to fully exploit these objects and establish e.g. Galactic abundance gradients and compare their kinematics with other markers such as CO, multi-fibre or multi-slit spectroscopy of large samples will be needed. FLAMES on the VLT would be suitable for this as would either AAOmega on the AAT or IMACS on Magellan.

Jets and embedded protostars The VPHAS survey will unravel a large number of Hα emission line filaments in star forming regions. Comparison of Hα with r‘ images will make these filaments stand out against externally illuminated clouds. While many of these Hα-bright filaments trace photo-ionised HII-region gas, others are shock-excited, collimated, bipolar jets and bow shocks – so-called Herbig-Haro objects – emanating from embedded young stars. Although most of the nearby Galactic star forming regions are located in the southern sky, few such jets are known here. Even fewer – compared to the northern sky – are the known deeply embedded young stellar objects, the jet sources. The jets can serve as pointers to the location of these protostars even when so deeply embedded that they are optically invisible. These jets and their protostellar sources are manifestations of the earliest phases of star formation, and their investigation is one of the prime science drivers for ALMA. VPHAS should be able to find these objects in sufficient numbers and in good time for the start-up of ALMA operations. A step along the way will be follow-up spectroscopy (e.g. with EFOSC2 on the ESO 3.6-m) to distinguish Herbig-Haro jets from HII filaments and then to discern likely locations of jet source using clues from emission line kinematics.

8 Other remarks, if any: (1 page max)

VPHAS can use some bright time as well as grey. We have discussed VPHAS here as a grey time programme because it will more quickly reach the proposed limiting magnitude – which is appropriately somewhat deeper for the southern Plane than the northern, in view of the typically higher extinctions present. However, if VST is staffed in bright time this programme can make use of it from ∼February to ∼May each year. At around the solstices, bright time is difficult to use because the full moon is then directly in front of the prime Galactic Plane fields, near the celestial equator.