1 The VST photometric Hα and broad-band survey of the Southern Galactic Plane (VPHAS+)

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1.1 Abstract:(10 lines max)

The primary goal of VPHAS+ will be to collect $u'g'r'i'$ broad-band, and Hα narrow-band photometry across the entire southern Galactic Plane within the latitude range $-5^o < b < +5^o$ 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 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 200 million objects. VPHAS+, along with its northern $r'i'H\alpha$ sister survey already more than half complete, will provide a hugely attractive database of Hα imagery to 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:

This proposal began as a close counterpart to the Isaac Newton Telescope Photometric Hα Survey of the Northern Galactic Plane (IPHAS), in which the filters envisaged were $r'i'H\alpha$. At the request of the Public Surveys Panel (PSP), we have added the $u'g'$ filters proposed for UVEX (Groot et al) in order to produce a single Galactic Plane survey of even broader utility. We directly address questions raised by the PSP in the accompanying document. Here we present the modified science case.

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 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.

Present catalogues of e.g. luminous blue variable stars (LBVs), yellow hypergiants, Wolf-Rayet (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, accompanied by comprehensive and contemporaneous broad-band data, has the potential to practically eliminate this problem.

We propose a southern Galactic Plane survey that in part is a companion survey to IPHAS, the photometric $r'i'H\alpha$ Galactic plane survey currently underway on the 2.5-metre Isaac Newton Telescope in La Palma (see http://www.iphas.org/ and Drew et al 2005 MNRAS 362 753). Data obtained over $\sim$ 170 nights, so far, has brought IPHAS to about the 70 percent point, in terms of the fraction of the survey area observed at least once. We anticipate a final IPHAS point-source catalogue of narrow-band Hα, Sloan r' and i' photometry containing around 80 million objects. The proposed VPHAS+ survey, 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 observing strategy applied would be modelled on that which we

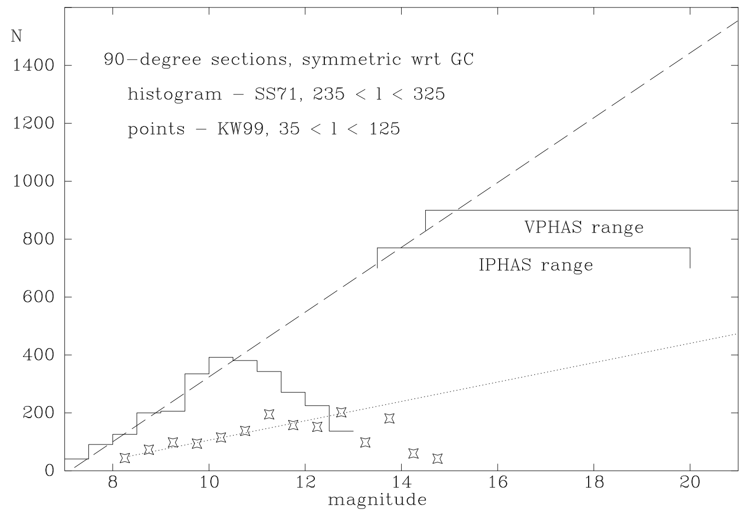

Figure 1: The legacy of photographic Hα point-source surveying in the Galaxy. These are histograms of the catalogued emission line stars, binned by visual magnitude. The data represented by the continuous line are from the southern Stephenson-Sanduleak (1971 PW&SO) catalogue, extracted within Galactic 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 $35^o < \ell < 125^o$. The latter are considered complete to $V \sim 13$. Linear extrapolations into the IPHAS and desired VPHAS+ magnitude range are drawn as dashed lines.

know already gives good results. The outstanding difference would be the addition of the $u'g'$ filters. With only a modest investment of grey time, VPHAS+ can span the entire southern Galactic Plane down to AB magnitudes of 21–22 in all five bands. The combination of IPHAS and VPHAS+ will bridge the yawning gap that still exists between the mainly objective-prism survey work of the middle of the 20th century that reached only ∼13th magnitude (figure 1) and the much more sensitive capabilities of today's advanced CCD imagers. VPHAS+ will amount to a major astronomical legacy, feeding large amounts of new data into a very broad range of Galactic astrophysics research areas. Through its unique exploitation of narrow-band Hα it will also provide a very attractive database of imagery that can be drawn upon to publicise astronomy as a whole (see e.g. the APOD for September 30th 2005, based on IPHAS data).

Simple linear extrapolation of published Hα catalogues (figure 1), and also the picture being built by IPHAS, suggest 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. We can expect a qualitative change, too, in that the intrinsically fainter groups of emission line object (e.g. interacting binaries, active and young later-type stars) are presently scarcely sampled at all as a consequence of the ∼13th magnitude cut-off in existing catalogues. Given the factor of ∼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 optical census of its contents fully up to date.

The deepest currently available Hα survey in the south is the recent UK Schmidt photographic survey of the southern Galactic Plane (SHS, Parker et al 2005 MNRAS 362 689) - the VST with OmegaCam will 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;

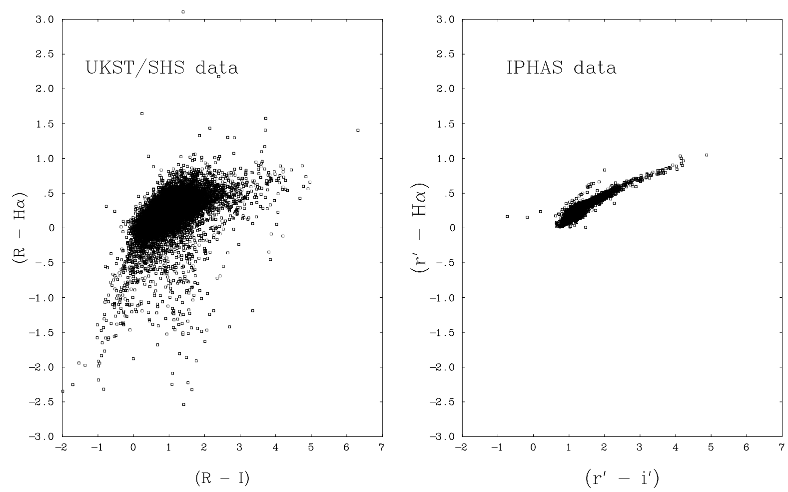

Figure 2: Point-source SHS colours obtained from the existing UKST photographic Hα survey of a $\sim$ 0.25 sq.deg. patch of sky in Aquila are compared with the analogous colours obtained for approximately the same field, obtained as part of the IPHAS survey. Only stars in the magnitude range $13 < R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

greater depth; and assured contemporaneous collection of exposures in all the desired photometric bands within each pointing. A further gain of importance to be achieved in the broadband filter data, with respect to older photographic surveys, is the application of the better designed filter transmission profiles in the Sloan system that give good support to quantitative work.

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 about two or three times more sensitive to extended nebular emission than the SHS, 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 older photographic surveys is associated with spatially unresolved 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 burden of spectroscopic follow-up of candidate emission line objects and other stars of unusual colour (located respectively above or away from the main stellar locus) is greatly reduced. We have found that only 10 percent or so of candidates derived from the SHS, with $R < 16.5$, are typically confirmed by spectroscopic follow-up as genuine emission line objects – a yield that is in line with the norm for photographic surveys.

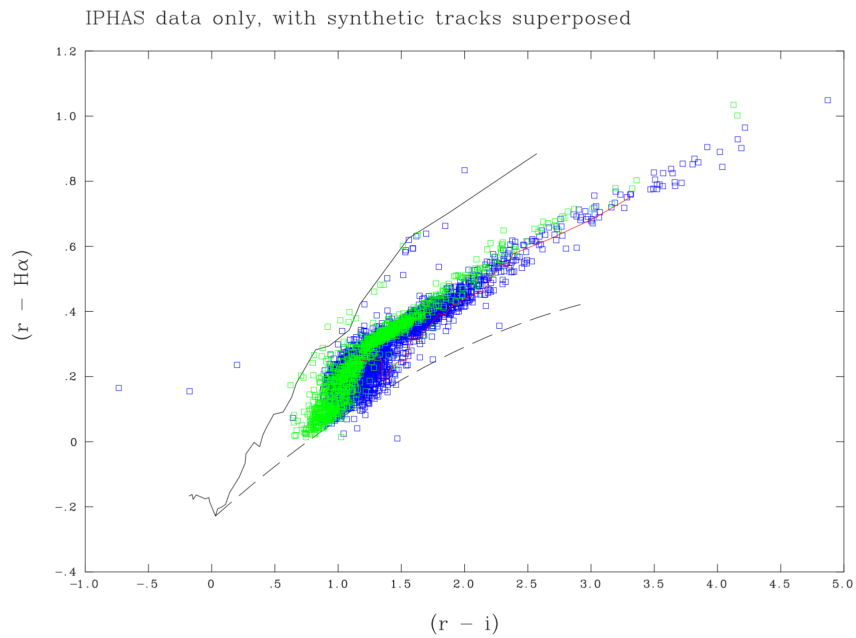

Figure 3: The plot of the IPHAS colour-colour data shown in fig 2 is expanded to show, in addition, synthesised tracks for unreddened main-sequence dwarfs (solid upper line) and giants reddened to $E_{B-V} = 2.0$ (lower solid line, seen in main stellar locus). The dashed black line shows how the colours 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.

UKST/6dF spectroscopy, across a sky area of ∼180 deg^2 suggests that detected Hα emission equivalent widths for confirmed SHS emission line stars 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 IPHAS database is that candidate selection is almost 100 percent efficient down to $r' \sim 20$, and that the threshold Hα equivalent width is more like ∼5 Å. The increasing errors at $R > 16.5$ in the SHS make identification of all but the most extreme emission line objects impractical. VPHAS+ will open up *completely* unexplored territory in the southern Galactic Plane at magnitudes greater than 17.

Second, the excellent definition of the main stellar locus itself emerging from IPHAS catalogue colour data allows quantitative analysis of stellar populations and, most strikingly, even provides reliable access to Hα *deficit* objects. This is not an option using 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 Plane fields), the second – superimposed on the main stellar locus – is a more gently-sloping giant (class III) track accounting plausibly for the reddest objects present, and finally – running along the bottom of the main locus – is the A0V reddening line (representative of A0-A3 dwarfs). Minor populations such as emission line stars, above the main stellar locus, are easily identified, along with the $(r' - H\alpha)$ deficit objects below. This deficit group begins with the early-A dwarfs, but also includes some DA white dwarfs and blue sub-dwarfs at bluer $(r' - i')$ colours, below the main locus, together with brown dwarfs and carbon stars at redder colours. These last two categories of

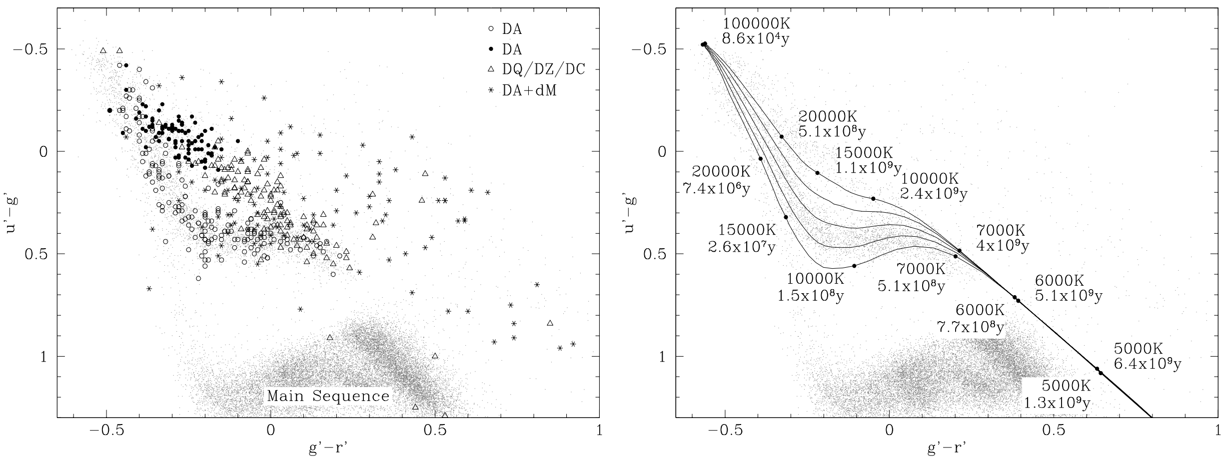

Figure 4: Left: A cut-out of a $u' - g'$ vs $g' - r'$ colour plane from SDSS. The grey dots represent the colour of all stars within the SDSS DR4 for which spectroscopy is available. Overplotted in different symbols are confirmed white dwarfs of spectral type DA (pure hydrogen, open dots), DB (pure helium, solid dots), DQ, DZ, and DC (containing substantial amounts of carbon, metals, or displaying a featureless continuum), and DA+dM (white dwarf plus M-dwarf binaries). The white dwarfs and the main sequence are clearly separated by a gap in $u' - g'$. Right: Again the grey dots show all stars with SDSS spectra. Overplotted are DA cooling tracks for surface gravities $\log g = 7.0, 7.5, 8.0, 8.5, 9.0$ (from left to right). For $\log g = 7.0$ and $\log g = 9.0$, white dwarf temperatures and cooling ages are given.

object stand apart because they both lack the molecular band structure seen in M star spectra.

By adding the u' and g' filters to the VPHAS+ set, a new power to discriminate among the zoo of faint blue objects, either as single stars or in binaries, is acquired (see figure 4). The number of available broadband colours rises from one to six, in principle, opening up a wide range of tools for population, metallicity and extinction law analyses. The Galactic Plane shortward of ∼5000 Å remains little explored. The sensitivity of VPHAS+ at these wavelengths promises the opportunity, finally, to gather and classify large samples of intrinsically faint, blue objects. These populations will include single and binary white dwarfs, subdwarf B stars and interacting close binaries: all remnants of single and binary star evolution. Obtaining a deeper, homogeneous sample of these populations is crucial for answering a number of astrophysical questions: *i)* how do close binaries evolve (e.g. to yield type Ia SNe) and what is the physics of common-envelope evolution, *ii)* what is the star formation history of our Galaxy as written in the population of white dwarfs, *iii)* what is the contribution of compact binaries to the gravitational wave background and which systems can be detected individually, *iv)* what is the luminosity function of galactic white dwarfs? Key to answering these questions is getting a handle on relative and absolute local space densities of these stellar remnants which may be compared with the results of population synthesis models. If present estimates of space densities are anywhere near the truth, more than 10000 white dwarfs will be found, and samples of sdB stars and close binaries will be on the scale of hundreds of objects. The simultaneous data gathering in u' and narrowband Hα will give VPHAS+ a major role in advancing studies of accretion-powered binaries.

For all OBA stars VPHAS+ will go deep enough to fully explore all but the most heavily obscured locations of the southern Plane (where the penetration will still be several kpc). Based on our experience with IPHAS, in the northern hemisphere, we expect to discover numerous Oe/Be stars of many kinds, including classical Be stars ($M_V \sim -3$), LBVs ($M_V \sim -10$) and luminous supergiants ($M_V \sim -6$) with strong winds. For example, we will easily detect faint classical Be stars towards the metal-rich inner regions of our galaxy, tracing the rich active star forming regions, young clusters and associations to be found there. In addition, the southern Galactic Plane has not, so far, been systematically surveyed for WR stars (possible descendants of the LBVs) at red wavelengths, except in a limited way via the SHS and UKST 6dF facility (to $R \sim 16.5$). Recent discoveries by this means, of *(i)* only the fourth known Galactic WO star (Drew et al 2004 MNRAS 351 206), and *(ii)* 5 WC9 stars lying just a few degrees apart on the sky (Hopewell et al astro-ph/0508187), encourage the expectation that many fainter new WR stars will emerge from the VPHAS+ survey. Important overarching scientific objectives served by VPHAS+ are to study massive star formation and evolution in metal rich regimes.

The data flowing from VPHAS+ will allow optical multi-colour cluster studies incorporating Hα, such as that of NGC 3603 ($\ell = 291^o, b = -0.5^o$) by Sung & Bessell (2004 AJ 127 1014) to be conducted without further observations. It is also worthy of note that the structure of the Galactic Plane in the third quadrant, i.e. outside the Solar Circle, remains poorly characterised (see Figure 3 in Russeil 2003 A&A 397 133). VPHAS+ will do much to correct this.

2.2 Immediate objective:

The primary goal of VPHAS+ as a Public Survey will be the gathering of contemporaneous narrow-band Hα, and broad-band $u'g'r'i'$ photometry across the southern Galactic Plane within the latitude range $-5^o < b < +5^o$ down to a point-source AB magnitude of 21–22. For a typical seeing of 1 arcsec, this translates to a nebular surface brightness magnitude at Hα of $\sim$20.8 per arcsec^2. To assure the data quality and correct for incomplete sky coverage due to vignetting and gaps between CCDs, the southern Plane will be observed in double-pass: every field pointing is to be followed immediately by an offset pointing. For massive OBA stars, VPHAS+ is deep enough to fully explore all but the most heavily obscured parts of the southern Galactic Plane. Even in the highly obscured regions, concentrated down into the mid-plane near the Galactic Centre the VPHAS+ view will extend at least a few kpc. These data will increase the known southern emission line objects by an order of magnitude, leading to much better statistical characterisation of a range of rare object types. The inclusion of u' in the filter set will be critical for distinguishing a rich variety of compact stellar remnants. The superior photometric accuracy of VPHAS+ will facilitate large-scale multi-colour stellar population studies across 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 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. To complement the inclusion of $u'g'$ within VPHAS+, a request has recently been submitted (PI Groot) to start a $u'g'r'$ survey of the northern Plane using the INT (to ramp up, as IPHAS ramps down). The closest 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 $\sim$ 15 deg^2. This leaves VPHAS+ great swathes of the Plane for optical identification of X-ray sources found by Chadra, and also XMM and Integral. The Sloan consortium has initiated SEGUE as an SDSS follow-up: the pointings for this survey fall in 12 narrow longitudinal strips (in the northern sky) that are designed to sample the Galaxy Halo much more thoroughly than the Plane.

In highly reddened parts of the Plane, VPHAS+ can combine well with the existing 2MASS JHK database - the combination of the 7 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 an analogous VISTA survey would be fruitful since, at these lesser reddenings, 2MASS will 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.

With their incorporation of narrow-band Hα imaging, the VPHAS+ survey presents an attractive complementarity to the RAVE survey, underway in the south. Where RAVE emphasises radial velocity measurement of later type stars (via the calcium IR triplet in absorption) throughout the Galaxy, VPHAS+ will be very capable in picking out luminous objects at great distances, down to A type. Looking further into the future, the products of VPHAS+/IPHAS, with their astrophysical bias and high spatial resolution, within the crowded Galactic Plane, will be a powerful complement to the eventual work of GAIA (launch scheduled in 2011) – and of course many of the objects observed by VPHAS+ will have their distances determined by GAIA to great accuracy.

4 Observing strategy: (1 page max)

Our **observing strategy** for each VPHAS+ field is to obtain the following sequence of exposures: u', 150 sec; g', 30 sec; r', 30 sec; $H\alpha$, 120 sec; i', 30 sec, one after the other. Obtaining the full set of exposures within a single pointing has several advantages. Chief among these is minimising the impact that point-source time variability might otherwise have on derived colours. This strategy will also maximise the likelihood of equivalent image quality (in terms of PSF, photometric conditions) in each field, and it will facilitate optimal r' image subtraction from Hα emission. Lastly it will simplify final flux calibration of the data, somewhat.

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 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).

A complete VPHAS+ observation should be envisaged as the acquisition of exposures in all 5 filters on each field *and* its offset (i.e. a sequence of 10 exposures altogether, with a position offset taking place after the first run through the five filters). Again, we emphasise it is important to obtain all these data contemporaneously, in order to minimise data matching problems caused by stellar variability that is so common on timescales of hours/days/months.

As calibration observations, VPHAS+ pointings needed to be supplemented by standard (e.g. Landolt or Sloan) field observations through all five 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 (∼100 Å FWHM), (ii) a continuum filter in the same part of the spectrum as $H\alpha$ - here r', (iii) the 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.

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 have begun procurement of an additional four-segment Hα filter, each segment centred on 657 nm with a FWHM of 10nm. We have approached SAGEM, Barr Associates and Asahi for quotes on the basis of a specification provided by U Hoppe (these are still pending). We have also placed a request with D. Baade to use a spare OmegaCam blank filter holder. We will aim to have the filter available by early 2007. This would be made available for general use with OmegaCam (subject to ESO approval).

5 Estimated observing time:

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P78	120	6–14h	grey	<1.2	clear
P79	120	10–18h	grey	<1.2	clear
P80	150	6–14h	grey	<1.2	clear
P81	150	10–18h	grey	<1.2	clear
P82	150	6–14h	grey	<1.2	clear
P83	150	10–18h	grey	<1.2	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 (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 Hα filter is based on the design specification for the SAGEM-provided Hα filter (email communication from U Hoppe).

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 this data quality 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 (see figure 1). In grey time, an Hα 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 Hα 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 Hα:r' exposure time ratio is perfectly workable, for the reason that Hα in-band magnitudes are typically around 0.5 or more brighter than r' magnitudes. This is 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 $\sim$20th 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 Hα 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+ should 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 guess, again based on our IPHAS experience, is 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 %).

For now, we note two pointings per field require $\sim 2 \times 6$ min, so that to expose on all 2100 fields (number of fields justified in the 'Observing Strategy' section) will require a total of 420 hours. If we adopt a likely overhead of 100 percent, we conclude that VPHAS+ requires 840 hours of VST time. 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.

We have chosen 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/).

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/NL
C. Knigge	Data Release	Southampton UNiversity	UK
J. Walsh	Data Release	STECF, München	D
A. Acker	Exploitation (A,B)	University of Strasbourg	F
T. Augusteijn	Exploitation (D)	Nordic Optical Telescope	DK/S/OTHER
M. Barlow	Exploitation (A,B,C)	University College London	UK
M.-R. Cioni	Exploitation (B)	Edinburgh University	UK
B. Gaensicke	Exploitation (D)	Warwick University	UK
P. Groot	Exploitation (D)	Nijmegen University	NL
U. Heber	Exploitation (D)	Erlangen Univeristy	D
L. Magrini	Exploitation (A,B)	University of Firenze	I
A. Mampaso	Exploitation (B)	IAC, Tenerife	E
D. Mardones	Exploitation (C)	Universidad de Chile, Santiago	RCH
R. Napiwotzki	Exploitation (D)	University of Hertfordshire	UK
T. Naylor	Exploitation (C)	Exeter University	UK
G. Nelemans	Exploitation (D)	AIAP Amsterdam	NL
Q. Parker	Exploitation (A,B)	Macquarie University	AUS
S. Phillipps	Exploitation (A,B)	Bristol University	UK
T. Prusti	Exploitation (A,C)	European Space Agency	ESA/NL
D. Steeghs	Exploitation (D)	CfA, Cambridge	USA
P. Woudt	Exploitation (D)	University of Cape Town	SA
A. Zijlstra	Exploitation (B)	Manchester University	UK

Note 1: Science interest areas are coded as follows: A – survey science, structure of the Galaxy; B – evolved intermediate mass stars and their nebulae; C – Young stars, massive stars, their nebulae and cluster environments; D – symbiotics, compact WD, NS and BH binaries, sdB stars, single white dwarfs.
Note 2: The above list is complete only in terms of the institutions and countries represented. The full list of CoIs is about twice as long.

6.2 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 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 a version of the VISTA Data Flow System (VDFS), which although being further developed (see http://www.ast.cam.ac.uk/vdfs/) is a proven working system. The Cambridge Astronomy Survey Unit (CASU) will lead the Pipeline Processing activity. Funding and personnel for processing of UK-led VST public surveys are now in place and the hardware infrastructure for this has been designed as a modest extension of the existing VDFS pipeline processing setup. The pipeline processing components have been scientifically verified 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. It has also been used to process data from the NIR mosaic camera WFCAM on UKIRT at a rate of up to 250GB/night. 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 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.

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 now identifying the styles and organisation of data to go into an early release of photometric catalogues scheduled for mid-2006 (when 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 a final uniform calibration of VPHAS+ data is achieved.

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:

A version of the VDFS pipeline will be used for all processing. This includes the following processing steps:-

1. Instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk, persistence.
2. Sky background tracking and adjustment during image stacking and mosaicing.
3. Combining frames if part of an observed dither sequence or tile pattern.
4. Consistent internal photometric calibration to put observations on a uniform internal system.
5. Standard catalogue generation including astrometric, photometric and morphological shape descriptors and derived Data Quality Control(DQC) information, all with appropriate error estimates.
6. Accurate astrometric calibration based on the catalogues using standard World Coordinate System (WCS) in all relevant FITS headers.
7. Nightly photometric calibration using suitable pre-selected standard areas covering entire field-of-view to monitor and control systematics.
8. Propagation of error arrays eg. weight maps, bad pixels, relative exposure via the use of confidence maps.
9. Nightly average extinction measurements in relevant passbands.
10. Pipeline software version control – version used recorded in FITS header.
11. Processing history including calibration files used 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.

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 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 which is callable through AstroGrid and the emerging Euro-VO portals.

In terms of data volumes, VPHAS+ will generate $\sim$11TB of raw science and calibration data (each exposure of the 32 CCD camera produces 0.5Gbyte). 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.

6.4 Expected data products:

- instrumentally corrected frames along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
- stacked and/or mosaiced data for dithered observations of single targets
- confidence maps for all image products
- derived object catalogues based on a standard VDFS 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

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, u', g', r' and i' photometry on all catalogued point sources (of order 200 million stars). 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. Much smaller 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/absence of proper motion). The construction of these would be undertaken by VPHAS+ consortium members with the relevant specialist interests.

6.5 General schedule of the project:

VPHAS+ will require in the region of 15 weeks VST time. As it links naturally to the northern IPHAS survey aimed at substantially completing observations by 12/2006, we propose a relatively compact time line. Ideally some limited VPHAS+ observations should be gathered in Jan/Feb 2007 (as soon as the new Hα filter is available) to verify that the data meet requirements. Then, $\sim$5 clear weeks' grey-time observing in each of 2007, 2008 and 2009 could see the survey data-taking finished. The final point-source catalogue (DR2) might then be ready by Q2 2010 (timely for cross access and federation with potential early release GAIA photometric catalogues). Specialist point-source catalogues and lists of new compact nebulae could then become available on a similar or slightly longer timetable, depending on follow-up timescales.

7 Envisaged follow-up: (1 page max)

The contemporaneous photometry, in five bands, that will flow from VPHAS+ will be of a quality that can be stand-alone for many purposes. However it has been noted above that there will be much to be gained in federating VPHAS+ to near-infrared JHK surveys. Where reddening is relatively severe (roughly $A_V > 10$), 2MASS is already deep enough to be useful in combination with VPHAS+. The deeper UKIDSS Galactic Plane Survey is now underway and will be more than deep enough to complement VPHAS+ north of dec -15^o. That leaves south of this limit currently uncovered. We therefore consider it desirable that a VISTA Galactic Plane Survey analogous to the current UKIDSS programme is undertaken to complete coverage of the Plane.

A specific plan of consortium members associated with the initially separated UVEX proposal was to perform, with VST, a second-epoch proper motion follow-up in the g' filter only. The goal of this would be to identify more completely the local population of subluminous stars that fail to be picked out directly by means of their photometric colours. With respect to this programme, VPHAS+ would provide the first epoch of g' data.

Otherwise, we anticipate two styles of follow-up to VPHAS+. First, 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. Second, 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 won around 70 nights on a wide range of facilities and apertures, including several using the MMT hectospec wide-field multi-fibre facility. Below we give two contrasted examples illustrating these two styles of follow-up.

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 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 jets are known there. 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 young sources are manifestations of the earliest phases of star formation, and their investigation is one of the main science drivers for ALMA. VPHAS+ should find these objects in sufficient numbers and in good time for the start 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 locate jet sources using clues from emission line kinematics.

Diagnosing cluster/spiral-arm structure using early A dwarfs This is a completely new opportunity made possible by the ability of both IPHAS and VPHAS+ to pick out early-A dwarfs with very high efficiency thanks to these stars' strong Hα absorption. Compared to e.g. OB stars that evolve extremely quickly and in uncertain ways, early-A 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 ($M_V \sim 1$) to be seen to great distances. Multi-colour photometry alone will reveal mean distances, reddening variations and insights on metallicity. But to fully exploit these objects and establish e.g. Galactic abundance gradients, or cluster kinematics, multi-object spectroscopy on the relevant angular scale will become appropriate. Also, on occasion, deeper VST follow-up could be needed to 'push through' dusty regions.

The essential pattern to expect of follow-up spectroscopy is that candidate low-to-intermediate mass evolved emission line stars and nebulae require long-slit spectroscopic follow-up in order to confirm object class and perform quantitative astrophysical analysis (e.g. of abundances and kinematics). The required telescope aperture will scale with source brightness, and in cases of very red ($r' - i' > 3$) objects, it will be better to turn to NIR spectroscopy. For objects that are clustered, as in young and massive associations, multi-object spectroscopy becomes the obvious option. For science of this kind, the role of spectroscopy would more commonly be sampling to derive kinematics and abundances. In the ESO/VLT suite of instrumentation we can envisage programmes using FLAMES or SINFONI, depending on the stellar densities and angular scales. For very wide field work, the consortium is already thinking of developing a programme for AAOmega, on the Anglo-Australian Telescope.