**The VPHAS+ Consortium proposes a constraint modification, and a ∼10% extension to the original VPHAS+ survey area:-**

## A) Additional crowded field seeing constraint.

Experience with the Northern Galactic Plane (IPHAS & UVEX) shows that in areas with very high stellar surface densities considerable confusion is setting in, the magnitude of which is highly dependent on the actual seeing. Fig. shows that, at densities $\Sigma_{\rm stars} > 5\,10^5 (\log\Sigma = 5.7)$ (sq.degr.)$^{-1}$ a seeing of $1\farcs2$ causes confusion, whereas at a seeing of $0\farcs7$ the crowding correction is only ∼20%. The correction function is a steep function of both seeing and stellar surface density. Therefore, we propose that for those fields where $\Sigma_{\rm stars} > 5\,10^5$ (sq.degr.)$^{-1}$ we adjust our seeing requirements to the 'good seeing' category, i.e. $< 0\farcs8$ in the $r$-band. We would determine this on a field by field basis and anticipate it would be needed for under 10 percent of the survey area (concentrated in the Galactic Centre region within $|b| < 5°$).

## B) Galactic Bulge Extension

The VPHAS+ Survey on the VST will map the Southern part of the Galactic Plane at $|b| < 5°$ in $u, g, r, i, H\alpha$ down to r∼ 22 (and equivalent fluxes) across all longitudes falling below the celestial equator. We here propose to extend the VPHAS+ survey footprint by ∼10% to include the Bulge, and fully cover the inner part of the Galaxy in the Galactic coordinate range, $|\ell| < 10°, |b| < 10°$. The added area of 200 square degrees requires ∼ 220 additional field centres (see Fig. 2). Estimating the times required on the same basis, this amounts to 11 more nights, on top of the main VPHAS+ survey, requiring 105 nights.

**Science justification**

The Galactic Bulge can be viewed as the nearest example of a present-day descendant of the first phase of galaxy building in the Universe. For this reason there continues to be strong interest in understanding its structure, including its relation to the central bar, and the properties of its stellar content. It is seen as having formed rapidly, early in the life of the Milky Way, and is known to exhibit a range of metallicities ($-1 < [Fe/H] < +0.5$, see e.g. Zoccali et al 2008, Cescutti & Matteucci 2010). Interestingly it is also acknowledged as containing a range of stellar populations, that may or may not be a product of the dynamical interaction that has taken place in the Bulge with the central Bar (Zoccali et al 2008). A path to fully charting this population spread would be to collect and sort a range of high quality colours, across the major part of the Bulge – permitting in due course the followup spectroscopy that could also map their kinematics.

From the outset, the footprint of VPHAS+ included the parts of the Bulge closest to the Galactic Centre, within the latitude range $|b| < 5°$. Since the original OPC approval of this public survey, VISTA has been comissioned and VVV, a NIR public survey of the Galactic Centre and Bulge region, has begun taking data with the aim of analysing structure via stellar variability. This survey stretches down to $b = -10°$ within the longitude range $|\ell| < 10°$ – taking in a part of the Bulge that is also an easy target for optical surveying (the column-integrated visual extinction here is in the range 1 to 2 magnitudes, only). This presents the opportunity to add to the footprint of VPHAS+ in order to create a legacy dataset encompassing 9 OIR bands, plus narrowband H$\alpha$. We propose to go to the logical conclusion of also adding the northern part of the Bulge (typically reddened by 2–3 visual magnitudes), by squaring off the VPHAS+ footprint out to $b = +10°$.

The VPHAS+ consortium, via its northern hemisphere activities, has been developing methods of 3D extinction and stellar density mapping (see e.g. Sale et al 2009, 2010) that can readily be adapted to analysis of the lightly reddened Bulge regions outside $|b| = 5$. In the southern Bulge it will be of interest to compare, check and perhaps merge what is learned from the different constraints derivable from the optical VPHAS+ filters and from VVV's NIR variable-star lightcurves. Experience with the northern Galactic Plane indicates that we can certainly expect to resolve and order major structures within the Bulge on the kiloparsec scale, which is sufficient to address issues raised by OGLE-III V,I results, again mainly in respect of the Bulge at latitudes $b < -5°$(Nataf et al 2010, see also McWilliam & Zoccali 2010).

Fig. 3 shows that with the VPHAS+ depth we can detect any object with $L \gtrsim L_\odot$ in the Galactic Bulge, including at many locations in the less well-studied positive latitudes, $b > 5^\circ$. This means that all evolved stellar populations are accessible: RGB and AGB stars; horizontal branch stars; naked post-AGB stars and PNe; a broad range of compact evolved binaries.

*SN Type Ia progenitors*
The growing diversity in luminosity and environment of Supernovae Type Ia explosions as evidenced by sub- and superluminous events (e.g. McClelland et al., 2010; Yuan, F., et al., 2010;,Hachinger et al., 2009) as well as events in starbursting and in elliptical galaxies (e.g. Sullivan et al., 2010; Krüger et al., 2010), makes the question on the nature of their progenitors ever more urgent. The delay-time distribution appears to show a $t^{-1}$ distribution pointing to low-luminosity (old) systems as the progenitors of a substantial component of the SN Ia population (Maoz et al., 2010). Many of the candidate white dwarf binary systems (see e.g. Parthasarathy et al. 2007), either single or double degenerate, are of modest luminosity ($L \sim L_\odot$): cataclysmic variables (CV), AM CVn stars, subdwarf B-binaries. Our understanding of the Galactic populations of these systems as well as their evolution shows large gaps in e.g. the physics of the common-envelope, and also the phase of direct impact mass transfer.

The only place in the local Universe where we can resolve these populations in an environment that resembles that of elliptical galaxies is the Galactic Bulge. Using our Galaxy model, combined with our population synthesis code (see Groot et al., 2009), we have simulated the expected distribution of CVs, subdwarf B stars and X-ray binaries in the proposed Bulge extension. This model includes a generalized version of the Schlegel et al (1998) reddening maps, and takes into account the VPHAS+ survey limit of $g$=22.5. Fig. 4 shows the histogram over Galactic latitude of the expected detectable population, which confirms that the Bulge sightlines at $5^\circ < |b| < 10^\circ$ are the very best to search for them. The expected numbers of e.g. CV also greatly exceeds the currently known number ($\sim 5\times10^5$ vs. $\sim 10^3$, summing all types and luminosities), which implies these sightlines yield superior opportunities for statistical studies of compact binary populations.

*Symbiotic binaries*
Symbiotic stars may very well be SN Ia progenitor systems. For this reason estimating the number of them in the Galaxy is of interest (e.g Di Stefano 2010). Our IPHAS experience has shown us that the optical filters proposed for VPHAS+, coupled with near-IR photometry (either from 2MASS or VVV) facilitate efficient detection of them (Corradi et al 2008, 2010). However a large fraction of symbiotics belong to a relatively old population and are located in the Bulge (Munari & Renzini 1992). A thorough survey of the Bulge can reveal how large this population is and also allow an eventual comparison of the properties of Bulge symbiotic binaries to those in the Galactic disk. Are they drawn from the same progenitor mass ranges? How do their orbital periods compare, and are their mass transfer characteristics similar? The VPHAS+ extension will enable a definitive comparison to be made.

*Subdwarf B-stars*
Single subdwarf B-stars in the Bulge, themselves most likely the product of an uncertain binary evolutionary path, also hold a particular interest for the study of elliptical galaxies. A well known observational fact is the 'UV-upturn' in such galaxies: namely, an unexpected brightening of the system over expectation for a collective stellar population SED, of the appropriate age, at UV rest wavelength (see O'Connell 1999 for a review). The origin of this extra flux is still unclear. Recent studies have shown that many elliptical do have a very low-level star-formation rate, which may produce a 'sprinkling' of high mass stars. The only other plausible explanation is a large population of sdB stars (see e.g. Brown et al., 2000; Han et al., 2010). As in the SNIa progenitor case, the closest population in which to test this idea is the Galactic Bulge. As Fig. 4 also shows, the distribution of sdBs in the Bulge down to the VPHAS+ limit of $g$=22.5 peaks at $3 < |b| < 7$, and we therefore need to probe well around this peak to be able to pick up this population and assess its importance for the UV-upturn in elliptical galaxies. We expect to detect $10^5 - 10^6$ sdBs, hugely enhancing the number known in our Galaxy (currently $\sim$2 000 from the SDSS). Fig 5 shows how these objects are likely to be distributed.

*Planetary Nebulae*
The MASH catalogue has already added significantly to the known Bulge PNe (Parker et al 2006). VPHAS+

coverage of the same region will raise the chances of separating formation channels there - specifically the traditional single star evolutionary option in which the nebula is ejected at the top of the AGB, and the binary interaction model that is now much debated within the community (De Marco 2009). For low mass O-rich stars, there appears to be a metallicity cut-off below which dust will not drive the wind needed for conventional ejection of a nebula (Lagadec & Zijlstra 2008). Hence for such objects PN formation via the binary scenario, at lower luminosity typically, should be favoured. Such a population should coexist in the Bulge, along with the brighter, not so compact, nebulae already preferentially present in the MASH catalogue. Spectroscopic follow-up will be required, of course, to establish abundance patterns and identify metallicity effects.

*Hypervelocity stars*

One of the larger surprises in recent years out of wide field surveys, and, particularly, the Sloan Survey, is the discovery of seemingly normal, B-stars that are traversing the Galaxy at speeds exceeding the Galactic escape velocity. The supermassive black hole in the center of Galaxy is often seen as the source of these hypervelocity stars (HVS). If so, the distribution of HVS should be concentrated on the Galactic Center.

Gnedin et al. (2005) showed that a sample of HVS with accurate proper motions could be used to constrain the potential and dark matter distribution of the Galactic halo. However, this depends critically on the assumption of an origin in the Galactic centre. Recently, it was shown that for at least a few HVS this origin can be ruled out (HD 271791, Heber et al 2008; HIP 60350, Irrgang et al. 2010). On the other hand a very precision proper motion measurement (Brown et al. 2010) shows that HE 0437−5439, previously thought to be ejected from the LMC, *can* be traced back to the Galactic centre.

The Galactic Bulge would be the place to identify HVS, since no star formation is ongoing there: comprehensive optical coverage, incorporating the $u$ and $g$ bands, will be an efficient way of identifying candidates.

*Legacy value:*

A full $u, g, r, i, H\alpha$ coverage of the Galactic Bulge will have a long lasting legacy value, for reasons beyond the scientific justifications given above. X-ray and radio surveys are targeting the Galactic Center and Bulge region for transient and low-luminosity interacting binaries. Examples include the Galactic Bulge and Galactic Latitude Surveys, the Integral Galactic Bulge monitoring and the MeerKAT and ASKAP radio transient monitoring programs. The Bulge extension will provide a very powerful 'reference frame' for these surveys.

Currently no other optical survey is even planning to target the Galactic Bulge fully, mostly because of crowding and extinction issues. However, the VPHAS+ team has the experience to deal with these challenges. Gaia will provide excellent astrometrics to Bulge sources, but the accuracy of its spectrophotometry will be severely limited because of crowding. The VPHAS+ Bulge extension will provide an excellent reference frame for Gaia photometry. This is also a strong driver to include the Bulge extension now, as part of the first generation of VST surveys.

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# Figures

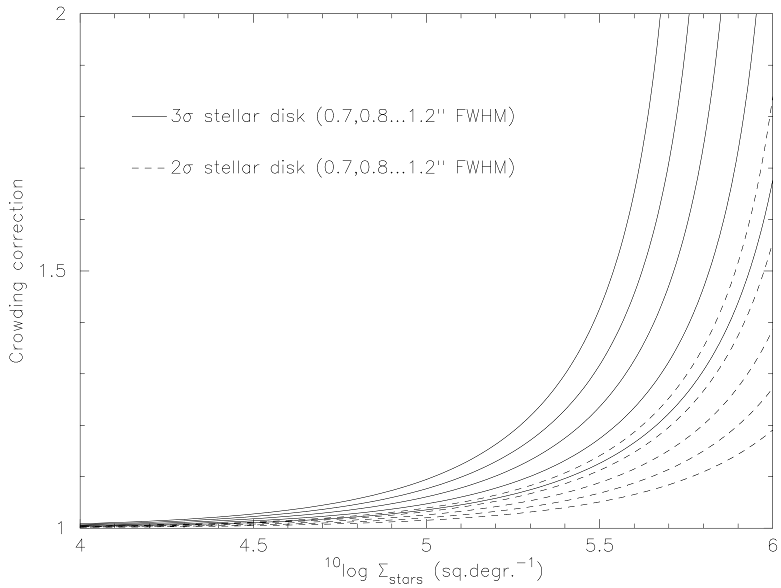


Figure 1: Correction factor needed to correct for loss of stars caused by crowding as a function of stellar surface density and seeing for 2-$\sigma$ and 3-$\sigma$ stellar disks used in the photometry. At a surface density of e.g. $5 \times 10^5$ stars/sq.degr. ($\log \Sigma$ = 5.7, 3-$\sigma$ disk) a seeing shift from 1.2$''$to 0.7$''$is the difference between highly confused and well separated. Adapted from Irwin & Trimble (1984).

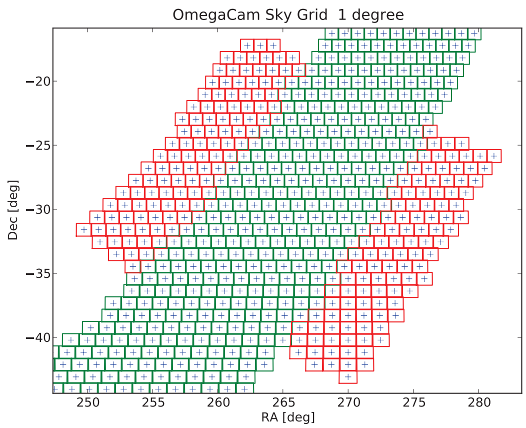


Figure 2: Proposed tiling of the Galactic Bulge extension, shown in red, in equatorial coordinates. The original VPHAS+ tiling of the disk in the Galactic Center area is shown in green.

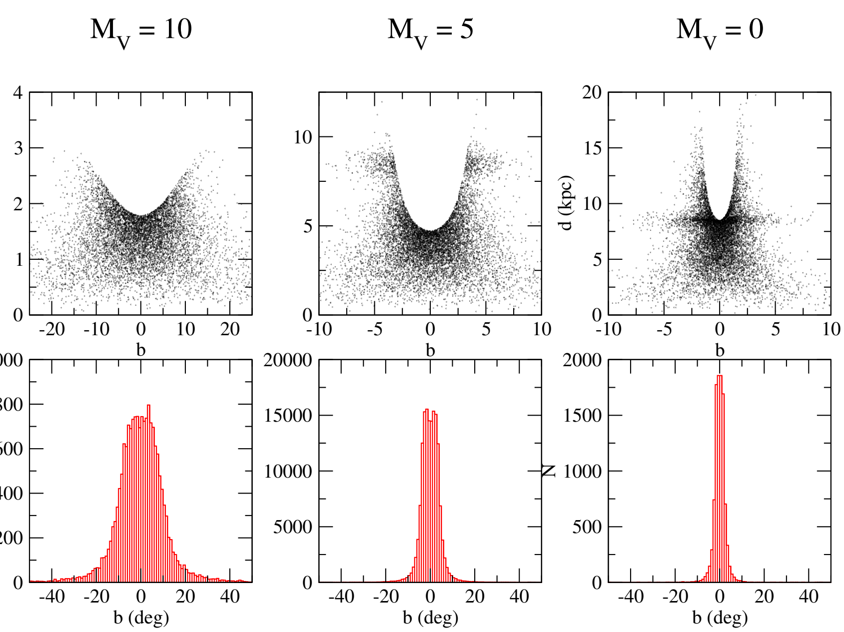


Figure 3: Simple Galactic model including a Sandage-type extinction down to $g$=23, showing the sensitivity for picking up sources in and towards the Galactic Bulge (at $d$=8kpc, top panels) for a survey such as VPHAS+ for source populations with $M_{\rm V} = 0, 5, 10$. $M_V \gtrsim 5$ is appropriate for sdB stars and high-state interacting binaries. Adapted from Groot et al., 2009.

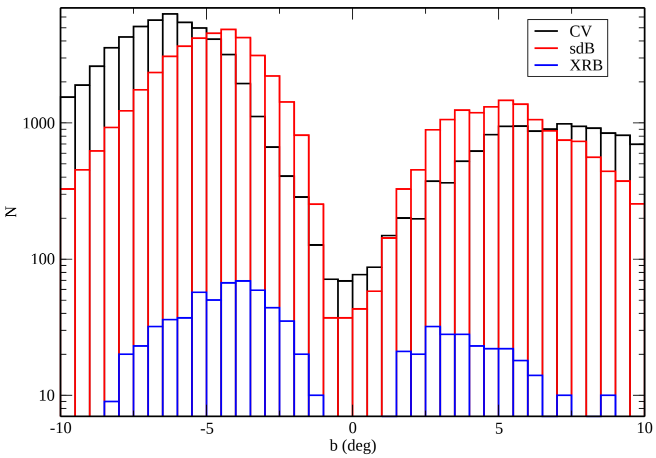


Figure 4: Histogram of the detectable numbers of sdBs, CVs and X-ray binaries over Galactic Latitude, assuming a Galaxy model updated with a Schlegel-type dust distribution.

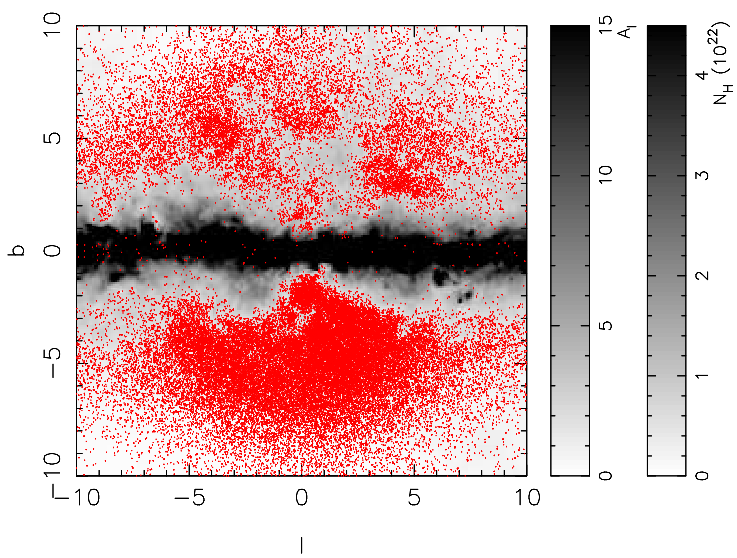


Figure 5: Sky view of the proposed Bulge extension region, showing the Schlegel extinction map in greyscale and the distribution of subdwarf-B stars as red point.