1 Title: VISTA VARIABLES IN THE VIA LACTEA (VVV)

PI: Dante Minniti, Universidad Catolica, Chile
Co-PI: Phil Lucas, Univ. of Herthfordshire, UK

1.1 Abstract:(10 lines max)

We propose a public IR variability survey of the Milky Way bulge and an adjacent section of the mid-plane where star formation activity is high. This would take 1920 hours, covering $\sim 10^9$ point sources within an area of 520 sq deg, including 33 known globular clusters and ~ 350 open clusters. The final products will be a deep IR atlas in 5 passbands and a catalogue of $\sim 10^6$ variable point sources. These will produce a 3-D map of the surveyed region (unlike single-epoch surveys that only give 2-D maps) using well-understood primary distance indicators such as RR Lyrae stars. It will yield important information on the ages of the populations. The observations will be combined with data from MACHO, OGLE, EROS, VST, SPITZER, HST, CHANDRA, INTEGRAL, and ALMA for a complete understanding of the variable sources in the inner Milky Way. Several important implications for the history of the Milky Way, for globular cluster evolution, for the population census of the bulge and center, and for pulsation theory would follow from this survey.

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

2.1 Scientific rationale:

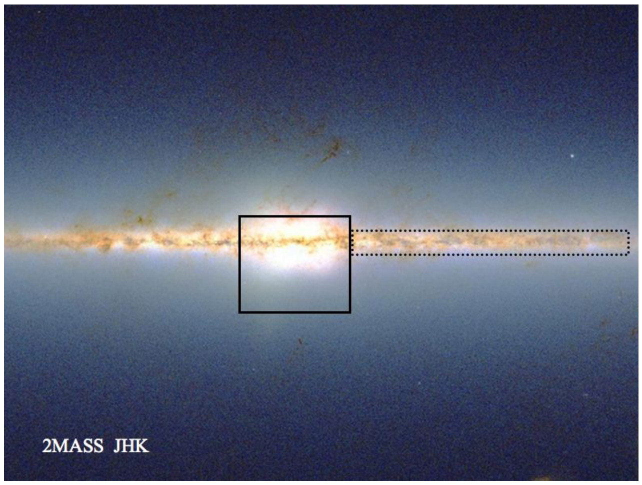

Figure 1: 2MASS map of the inner MW showing the VVV bulge survey area between $-10^0 < L < 10^0$ and $-10^0 < B < 5^0$, and VVV plane survey area between $-10^0 < L < -65^0$ and $-2^0 < B < 2^0$.

2.1.1. The Bulge: Most of the stars, gas and dust in the Milky Way are confined to the bulge and plane of the Galaxy. For this reason, extinction and crowding make it difficult to unveil the inner structure of the Milky Way and to study in detail the formation and evolution of this representative galaxy. Traditional distance indicators have been used with varied success in the past. The approach was to concentrate in the clear "windows", where optical surveys can be carried out (MACHO, OGLE, EROS). With VISTA, it is now possible to map the whole bulge systematically for several epochs in the near-IR. We propose to cover a 300 sq deg area (Fig. 1), containing $\sim 5 \times 10^8$ point sources. Our survey will give the most complete catalogue of variable objects in the bulge, with $\sim 10^6$ variables. Chief among them are the RR Lyrae, which are accurate primary distance indicators, being well understood from their chemical, pulsational and evolutionary properties. For the sake of space and coherence we concentrate on the RR Lyrae (goal 1 below) and the star clusters (goal 2 below), noting that similar worthy studies can be done for many of the other populations of variable objects (goals 3-10).

Existing, single-epoch near IR surveys (e.g., COBE) have proven that the Galactic Bulge is boxy and contains a bar (Dwek et al. 1995, ApJ, 445, 716). Presently, the only model we have for the formation of boxy/barred bulges is via secular evolution of a pre-existing disk. This scenario is believed to be the dominant channel of formation of bulges in late-type spirals (Sbc), whereas early-type spiral bulges (S0/Sa) show structural and kinematic evidence for an early, rapid collapse, which seems to be confirmed by the old age of their stellar population (see Kormendy & Kennicutt 2004, ARA&A, 42, 603).

However, the best studied spiral bulge, in the Milky Way, is precisely the most problematic one to understand in this context. While its surface brightness shows a barred structure, its stellar population is old (Kuijken & Rich 2002, AJ, 124, 2054; Zoccali et al. 2003, A&A, 399, 931) and it has α-element enhancement, characteristic of a rapid formation. Most importantly, the chemical composition of bulge stars is different from that of both thin and thick disk stars (Zoccali et al 2006, A&A Letters, in press). Thus, the formation of the Milky Way bulge via secular evolution of the disk seems to be in contrast with the properties of its stellar population.

A large survey of the RR Lyrae in the Galactic bulge will allow us to map its 3-D structure (unlike the single-epoch surveys that can provide only 2-D maps) *and* will give us key information on the age of its population, given that RR Lyrae are tracers of the old population. This will allow us to make an important step forward in the solution of this puzzle. In the case of the bulge, the peak of their luminosity distribution defines the distance to the Galactic Center (Carney et al. 1995, AJ, 110, 1674). With the present project, the peak and width of the distribution can be measured with the required precision to determine the 3-D structure not only of the bulge, but also of the Sgr galaxy located behind the Milky Way (Alard 1996, ApJ, 458, L17).

At the same time, a comparison between the RR Lyrae (and type II Cepheids as well) in the field and in the globular clusters may hold precious information about the formation of the bulge. Modern ΛCDM cosmology predicts that large galaxies such as the Milky Way formed by accretion of hundreds of smaller "protogalactic fragments" perhaps not unlike the progenitors of the present-day dwarf spheroidal satellites (e.g. Abadi et al. 2003, ApJ, 591, 499). Interestingly, two very massive globular clusters in the Galactic bulge, NGC 6388 and NGC 6441, have recently been suggested to be the remains of ancient dwarf galaxies that were accreted in the course of the Galaxy's history (Ree et al. 2002, ASP, 265, 101). These clusters might, in this sense, prove similar to the cases of M54, in the center of the Sagittarius dwarf spheroidal galaxy, which is currently being incorporated by the Milky Way (Ibata et al. 1995, MNRAS, 277, 781), and of ω Cen, which has long been suspected to be the remnant nucleus of a dwarf galaxy (e.g. Altmann, Catelan & Zoccali 2005, A&A, 439, L5).

Our proposed search for RR Lyrae and type II Cepheid stars in the Galactic bulge will reveal the presence of any debris related to the accretion events that might have left behind the present-day NGC 6388 and NGC 6441. These globular clusters are both well known to contain anomalous RR Lyrae populations, with periods that are much longer than those of known field RR Lyrae stars of similar high metallicity (e.g. Pritzl et al. 2000, ApJ, 530, L41; Pritzl et al. 2003, AJ, 126, 1381). In particular, the presence of the unusually long-period ($P > 0.45$ d) RRc (first overtone) variables, which have so far not been found in the general field but are present in large number in both these globular clusters (e.g. Catelan 2004, ASP, 310, 113), should provide the "smoking gun" for the presence of NGC 6388/NGC 6441-related debris in the general bulge field. In like vein, long-period RRab stars (fundamental pulsators) occupying the appropriate position in the period-amplitude diagram should also provide us with a strong indication of prior membership to such a protogalactic fragment.

2.1.2. The Plane: In order to understand the Milky Way populations globally (and to account for the disk contribution along the line of sight), it is necessary to survey the inner Galactic plane. In addition to the Bulge Survey, we therefore propose to survey an adjacent region of the mid-plane in order to provide a Legacy Database and 3-D Atlas of a large Population I region. We have selected the inner Galaxy region at $-65 < L < -10$, $|B| < 2$ (Figure 1), where star formation activity is high and there will be complementary optical, mid-IR and far-IR data from VPHAS+ and the SPITZER GLIMPSE and MIPSGAL surveys. The addition of this region will also permit us to settle the controversial question of inner Galactic structure, discriminating between models with a long bar and a ring and triaxial Bulge models with no long bar.

The large survey area will allow several outstanding astrophysical problems to be addressed. For example, the environmental dependence of star formation and in particular the IMF at low masses is presently unknown. This issue will be addressed statistically by observing hundreds of star formation (SF) regions and cross-correlating luminosity functions (LFs) with cluster density, the presence of high-mass stars and galactocentric distance. Other important parameters such as velocity dispersion and metallicity would be determined by follow-up observations. In addition, the LF of the clusters themselves will be measured, both for star forming clusters and more evolved open clusters.

These issues cannot be addressed with optical surveys, owing to the high extinction in the plane. The SPITZER data will be invaluable for detecting the most obscured high-mass protostars within SF regions. However, a near-IR survey will be more sensitive to all but the reddest objects, and the superior spatial resolution of this waveband will be essential to resolve distant clusters and the crowded field population.

The Plane Survey will also be a multi-epoch survey, with the aims described in the goals below. Extinction maps for clusters will be provided by an initial single epoch of $ZYJHKs$ imaging. Distances will then be derived using a variety of methods, e.g. main sequence fitting for mature clusters and analysis of foreground star counts vs. extinction for SF regions. For the field population, the use of several reddening-independent indices such as $(J - H) - (Y - J)$ will be used to probe changes in the stellar population along every line of sight, statistically measuring the ratios of dwarfs to giants and hot stars to cool stars. The multi-colour data will also be valuable for robust detection of rare objects and characterisation of every type of stellar population.

2.2 Immediate objective:

The major VVV survey products will be a high-resolution $ZYJHKs$ colour atlas of the bulge and plane regions, and a catalogue of variable point sources, including positions, mean magnitudes, and amplitudes. This database would be public, a significant treasure for the whole community to exploit for a variety of scientific programmes. The top 10 scientific goals of the VVV survey are:

1. To find RR Lyrae in the bulge, which will allow to: determine periods and amplitudes, measure accurate mean magnitudes, make the Bailey diagram, interpret the results of the variability analysis in terms of stellar pulsation and evolution models, and compare the pulsation properties of bulge variables with those of similar variables in the halo and nearby dwarf galaxies (e.g. Catelan 2006, astro-ph/0507464). The distances measured and RR Lyrae counts can be compared with the clump giants, which are excellent tracers of the inner bar (Stanek et al. 1994, ApJ, 429, L73). This would define the geometry of the inner bar and of additional structures (like a potential second bar; Nishiyama et al. 2006, ApJ, 621, L105), and explore the radial dependence of the density (e.g. Minniti et al. 1999, ASP, 165, 284), or trends with Galactic latitude-longitude, to finally unveil the structure of the bulge. The microlensing surveys that we have been involved in (OGLE and MACHO) have discovered about 10% of the existing bulge RR Lyrae stars (e.g. Figure 2, see Alcock et al. 1998, ApJ, 492, 190; Udalski et al. 2002, AcA, 52, 129). Our final survey will find more than 50% of the bulge RR Lyrae.

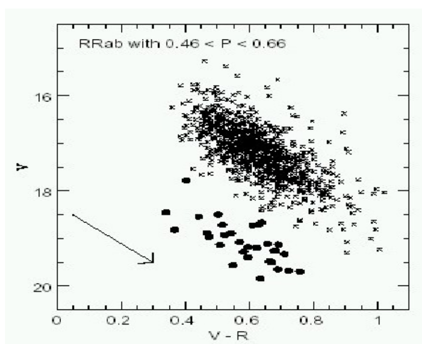

Figure 2: Optical colour-magnitude diagram for bulge RRab (crosses), showing the sequence belonging to the Sgr dwarf galaxy (circles) located behind the bulge (Alcock et al. 1997, 474, 217). Differential reddening is very significant even in the bulge clear windows. The direction of the reddening arrow illustrates that the optical sample of RR Lyrae quickly becomes incomplete. There are about 2000 RR Lyrae known in the unreddened windows of the bulge, while the total population is estimated to be an order of magnitude larger than that.

2. To identify variable stars belonging to known star clusters. There are 33 globular clusters and 355 open clusters located in the VVV area (Figure 3), that would contain: RR Lyrae, type I and II Cepheids, Semiregulars, and EBs. Distances, reddenings, metallicities and horizontal branch (HB) types will be obtained for these clusters from a homogeneous dataset (e.g. Catelan et al. 2006, MemSAIt77, 202; Zoccali et al. 2003, A&A, 399, 931). In some favourable cases, ages can be measured. Table 4 at the end lists the globular clusters to be covered, giving positions in equatorial and galactic coordinates, and distances from the Sun. The asterisks in the last column indicate that more than one third of these clusters have uncertain distances. We will improve the distances for these globulars, and confirm the previous estimates for the rest of the open and globular clusters.

3. To find eclipsing binaries in large numbers. We expect roughly 5×10^5 binaries, an unprecedented database that will allow to: determine periods, amplitudes, mean magnitudes, study stellar properties, and also select extrasolar planetary transit candidates. In particular, YY Gem-like systems can be identified to constrain the lower main-sequence parameters (e.g. Torres & Ribas 2002, ApJ, 567, 1140), and selected transit fields can be followed frequently to identify and measure extrasolar giant planets (Udalski et al. 2002, AcA, 52, 317).

4. To find rare variable sources. The massive variability dataset and multicolour atlas will allow us to search for: CVs (novae, dwarf novae) and other eruptive variables (e.g. RSCVn), eclipsing binary RR Lyrae, pre-HB/post

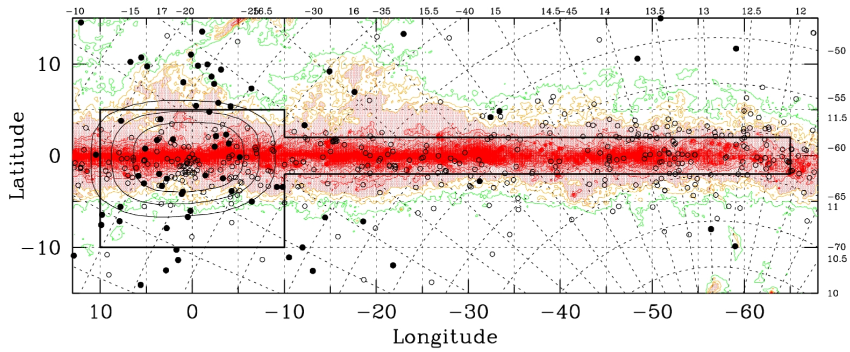

Figure 3: Map of the globular and open cluster positions (full and empty circles) towards the Milky Way bulge and plane. Included in the VVV area are the 33 globular clusters listed in Table 4 (Harris 1996, AJ, 112, 1487), and 355 open clusters (Dias et al. 2006, A&A, 446, 949; Bica et al. 2003, A&A, 400, 533, and A&A, 404, 223). The bulge contours are indicated, as are the extinction contours of Schlegel et al. (1998, ApJ, 500, 525).

He-flash stars, eclipsing binary clump giants, binary microlensing events, LBVs, FU Ori protostars undergoing unstable accretion, and AGB stars at the stage of unstable shell burning. With the advent of Chandra, XMM, INTEGRAL, and the Cerenkov telescopes, a number of persistent and transient high-energy sources have been discovered towards the inner Milky Way, with their locations pinpointed accurately (Aharonian et al. 2006, A&A, in press; Kuulkers et al. 2006, astro-ph/0603130). We will also be able to identify the counterparts of high energy (X-ray and γ-ray) sources: accreting black holes, microquasars (e.g. Mirabel & Rodriguez 1998, Nature, 392, 673), binary pulsar companions, LMXBs, and HMXBs. In particular, this survey may finally reveal the still undetected counterparts of the most luminous persistent hard X-ray/jet sources in the Galactic Center region, 1E 1740.7-2942 (Mirabel et al. 1992, Nature 358, 215) and GRS 1758-258 (Rodriguez, Mirabel & Marti 1992, ApJ 405, L15). A caveat is that although we would identify and monitor the counterparts of several variable high-energy sources, we do not claim to be able to determine orbital periods for all XRB counterparts given the sampling. However, the possibility of other time-variable serendipitous discoveries is open.

5. To search for microlensing events, especially: reddened events, short timescale events, and high magnification events in obscured high density fields. The spatial dependence of the microlensing optical depth τ has been modelled (Bissantz et al. 1997, MNRAS, 289, 651), and can probe directly the mass distribution contained in the inner regions. Unfortunately, current microlensing searches do not cover the whole bulge or the plane, and miss the inner regions where this optical depth is higher, poorly constraining the models (Bissantz & Gerhard 2002, MNRAS, 330, 591; Bissantz et al. 2004, ApJ, 301, L155). A map of microlensing optical depth for the whole bulge can be made, allowing also to search for asymmetries in τ. In addition, we expect to detect microlensing of source stars in the Sgr dwarf galaxy (e.g. Popowski et al. 2005, ApJ, 631, 879).

6. To monitor the variability around the Galactic Center: an area of 1.5 sq deg around the Galactic Center including the 180 pc-Nuclear Ring (Messineo et al. 2002, A&A, 393, 115) will be the most frequently monitored field, for a total of 200 epochs spanning 5 years. Expected variability due to high magnification microlensing, or flares due to black hole accretion, can arise (e.g. Chaname et al. 2001, ApJ, 563, 793). The BH flares easily reach $K \sim 16$ mag, with a typical duration of 10-30 min. The expected flare rate is 2-6 per day (Genzel et al. 2003, Nature, 425, 934; Eisenhauer et al. 2005, ApJ, 628, 246), in addition to a longer timescale variation predicted by the accretion simulations (Cuadra et al. 2006, MNRAS, in press). We also expect some Wolf Rayet variability in the population of massive stars and clusters in this region, and will search for eclipsing WR stars.

7. To search for new star clusters of different ages and identify their variable star members, such as: Cepheids, Semiregulars, W UMas, and δSct. The asymmetric distribution of the known globulars in the Galactic Center region hints at the presence of about 10 undiscovered objects (Ivanov et al. 2005, A&A, 442, 195). Our team members have already carried out successful campaigns searching for new clusters in the 2MASS Point Source Catalog (Ivanov et al. 2002, A&A, 394, 1; Borissova et al. 2003, A&A, 411, 83; Bica et al. 2003, A&A, 408,

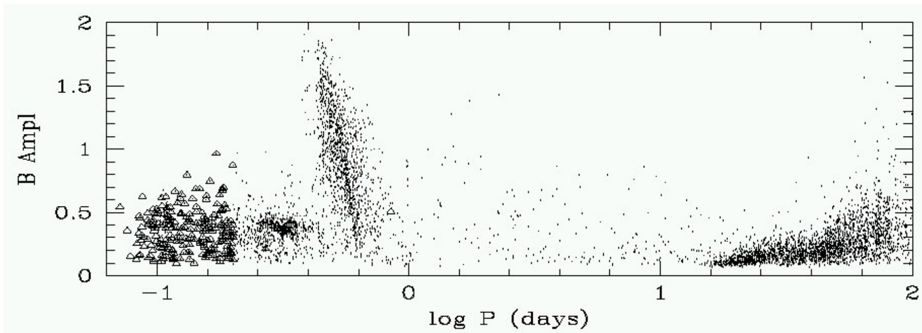

Figure 4: Optical period-amplitude diagram for pulsating bulge variables observed nightly. The IR period-amplitude diagram will be similar, but with smaller amplitudes ($\Delta K \sim 0.25\Delta B$), which on the one hand makes detection harder, but on the other hand gives more accurate mean magnitudes and less sensitivity to reddening and metallicity effects. Note that it is possible to phase variables with periods of 0.1 day (triangles), that are an order of magnitude shorter than the sampling period (1 day), provided about 100 epochs are observed. This diagram allows the automatic classification of different types of variable stars: from left to right the groups seen are δSct, RRc, RRab, and Semiregular stars. Cepheids would be located in the empty regions with intermediate periods (few intervening disk Cepheids are expected). Variables showing aliasing problems (periods $1/n$ days or n days) were removed. Eclipsing binaries are also not plotted; they cover the whole range of periods and amplitudes in this diagram, but they can be discriminated based on the light curves and colours.

127). Note that 2MASS with a $K_{lim} = 14.5$ in the bulge discovered hundreds of open cluster candidates, plus two new globular clusters. Because we will reach 3-4 magnitudes deeper, we expect many new clusters.

8. To provide complementary IR multi-colour information (for reddening, temperatures, luminosities) and time coverage to the following past and on-going surveys: GLIMPSE-II and VST PHAS Hα survey (both limited to the Galactic plane), MACHO, OGLE, EROS, MOA, and PLANET. Near-IR photometry is important for the microlensing events discovered by these microlensing surveys. For old events or new ones, our VVV survey will give field reddening and a baseline colour and magnitude that can immediately be translated to temperature and luminosity for the source star. The characterization of the source is essential for refining the microlensing light curve parameters and the lens physical properties (e.g. Beaulieu et al. 2006, Nature, 439, 437).

9. To find variable stars in the Sgr dwarf: Figure 2 shows that the Sgr RR Lyrae are well within reach and can be readily identified. RR Lyrae would give the 3-D structure of Sgr (e.g. Alard 1996, ApJ, 458, L17; Alcock et al. 1998, ApJ, 492, 190). In order to measure the depth and the tilt of Sgr along the line of sight, mean RR Lyrae magnitudes good to 0.01 mag are necessary. This can be achieved in the bulge fields provided enough epochs are observed. We will also detect and measure Carbon stars, Semiregulars, and eclipsing binary members of the Sgr dwarf galaxy (type-II Cepheids are expected in the bulge, but classical Cepheids are not, these would be found in the disk).

10. To identify high proper motion objects and background QSOs: this last goal links the –seemingly unrelated– intrinsically faintest and brightest objects in the Universe. On the faint end we would use proper motions to find nearby late M-type stars, brown dwarfs (L and T types), and high-velocity halo stars. The proper motions will probably turn up some of the most interesting low-mass objects, and UKIDSS, DENIS and 2MASS will be used in some cases to extend the time baseline. On the intrinsically bright end, variability would also allow us to identify background quasars, providing an extragalactic reference scale for future proper motions (e.g. Piatek et al. 2005, AJ, 130, 95). QSOs have a relatively broad colour range depending on their redshift, and their intrinsic variability increases monotonically with increasing time lags (de Vries et al., 2005, AJ, 129, 615); their amplitudes should be > 0.2 mag in the IR (Enya et al. 2002, ApJS, 141, 45). We estimate that we will find > 500 AGN assuming a surface density of $2/deg^2$ with $K < 15.5$ (Leipski et al. 2005, A&A, 440, L5) in the regions above and below the disk where $A_K < 0.5$ mag.

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

There is no similar large IR variability survey towards the Milky Way bulge and inner disk. We have argued that this is a wonderful undertaking, then why has it not been done before? Because of major problems, namely:

Extinction: this problem devastates optical surveys, confining them to pencil beam observations through "windows". The available UKIDSS GPS data at L=15-40 shows that 60% of the galactic plane has $A_V < 10$ mag even at latitude B=0.0, increasing to 90% at B=4.5. Due to the greater sensitivity of VISTA at 0.8-2.5 μm, the number counts in all 5 of the ZYJHKs bands will be similar in most fields. Color information in 4 different IR filters is often necessary to measure the extinction and luminosity for individual sources of unknown. E.g. giant stars follow a sequence parallel to the reddening vector in the (J-H) vs. (H-Ks) diagram. Here the Y band will be invaluable to measure extinction, and Z band will greatly improve temperature estimates.

Confusion/crowding: decreases the effective magnitude limit. The single-epoch photometry of 2MASS and DENIS was confusion-limited in the bulge fields, reaching only $K = 14.5$.

Aliasing: periods that are multiples of a day give aliasing. A short campaign is hardly sufficient to remove this, the microlensing surveys have demonstrated that a long campaign (as proposed here) is necessary.

Wide area: Technological difficulties in manufacturing large IR arrays and wide-field IR imagers that are necessary to cover the entire Milky Way bulge and inner disk repeatedly in a reasonable timescale.

VISTA now allows us to attack these problems systematically. It is a larger telescope than used by 2MASS; with a smaller duty cycle, it can map a large area to deeper magnitudes. Short VISTA exposures in $JHKs$ pierce through the bulge, and the higher resolution represents a huge advantage in the crowded fields. Simulations with the Besançon Galactic models allow to predict the stellar density, giving about 2×10^6 stars per square degree to $K = 18$ at Baade's window (e.g. Robin et al. 2003, A&A, 409, 523), giving about one star per 25 pix^2. At the expected RR Lyrae magnitudes ($Ks = 14.5$), they will not be significantly affected in fields like that. The situation degrades for fields closer to the Galactic center in the infrared, but for the densest regions even though incompleteness sets in at brighter magnitudes, we will use both PSF fitting and difference image analysis (DIA) to detect variable sources. Even though there is no similar survey, there are several interesting that will provide complementary observations:

GALACTIC PLANE SURVEYS: UKIDSS-GPS is mapping $\pm 5^0$ in Galactic latitude in the northern plane, but at only 3 epochs; VPHAS also offers Galactic plane coverage in optical and Hα using the VST.

GLIMPSE and MIPSGAL: These multiband SPITZER public surveys with IRAC (mid-IR) and MIPS (far-IR) respectively cover the mid-plane ($|b| < 1$) at $10 < l < 65$ and $-65 < l < -10$. The southern half of these surveys overlap with the plane component of this proposal, and the GLIMPSE survey is already complete. The main goals are the detection and characterisation of star formation regions and to probe the structure of the inner disc of the Galaxy. In optically obscured regions the IRAC data complement both the VVV survey and the VST/VPHAS+ survey by tracing the influence of the most massive stars on star formation. GLIMPSE-II: is a 150 hr SPITZER program to image the central $\pm 10^0$ deg of the plane in 4 bands with IRAC. The main goals are to determine the content and distribution of stars, the stellar populations, and interaction of the strong nuclear wind with the ambient ISM above and below the nucleus, and the rate and location of current star formation. We would provide variability information in the overlap region.

WISE: A proposed NASA all sky mid-IR survey with similar sensitivity to GLIMPSE. This mission has been delayed until 2010, increasing the importance of the present coverage of GLIMPSE regions.

MICROLENSING SURVEYS: MACHO, OGLE, EROS: optical bands, with limited or no colour information, limited in regions with high extinction. Useful variability information in the overlap regions.

INTEGRAL: Survey of the whole Galactic bulge for high energy sources (Kuulkers et al. 2006, astro/ph0603130).

CHANDRA: The Chandra Multiwavelength Plane (ChaMPlane) Survey will identify X-ray sources located to arcsec precision in deep ($>$ 20 ksec) Galactic center and plane fields ($-10^0 < B < 10^0$), including CVs, quiescent LMXBs, Be X-ray binaries, and stellar coronal sources. It includes a NOAO long-term VRIHα survey.

4 Observing strategy: (1 page max)

The strategy devised here allows to deliver interesting data to the community, enabling follow-ups throughout the survey. It also facilitates VISTA scheduling of other Public Surveys (e.g. VIKING) by alternating between the Bulge region (RA=17.0-18.75h) in year 3 and the Plane region (RA=11.7-17.4h) in year 4.

- cover the whole bulge and inner plane in $ZYJHKs$ to 3-4 magnitudes deeper than 2MASS in the first season

- find the first variable point sources in the second season

- classify bulge and disk variable stars, microlenses, etc., and measure their amplitudes and periods in the third and fourth seasons

- obtain final measurements based on light curves with 50-200 epochs for a large subset of the initial variables, and high proper motion objects at the end of the survey.

In order to cover the bulge between $-10^0 < L < 10^0$ and $-10^0 < B < 5^0$, and the disk between $-10^0 < L < -65^0$, and $-2^0 < B < 2^0$ we ask for a total of 192 nights over 5 years, distributed as shown in the Table below.

The final survey will cover 300 square degrees in the Galactic bulge and 220 square degrees in the inner plane. During the first year (2007) the whole bulge area will be observed once per night in Ks for 6, nights and in the following nights it will be mapped at $ZYJHKs$, stepping through all 5 filters in each OB to provide near simultaneous fluxes and reliable colours in each field. The strategy will be repeated for the whole plane field, alternatively through fields of varying density for optimal sky subtraction (see Tables 1 and 2 at the end).

Using only one filter per night maximizes returns, allowing to cover the whole areas, yielding deep $ZYJHKs$ maps of the whole bulge and inner plane. Being fully aware of the confusion and background limits, the observing plan would circle alternatively through fields of varying density for optimal sky subtraction.

During the second year (2008) each field will be observed once per night in Ks, for a period of 6 nights. The observing strategy is designed to cover 300 sq deg per night. In that way the whole bulge and plane are observed again the second year, allowing the identification of variable sources (but not the phasing). These data will also allow the creation of deeper master maps in Ks, in order to fine tune the strategy for the main campaign of the following year.

The main bulge variability campaign is carried out during 75 nights in the third year (2009). We ask for consecutive nights during this season, although in practice there will be a few holes due to weather and to the unfortunate fact that 2-3 nights per month are useless because the Moon transits in front of the bulge. We will use the Ks-band to map the whole bulge and inner plane over and over (see Table 3 at the end). A subset of the fields can be observed more frequently (4 or 8 times per night). This strategy allows to partly remove aliasing and to improve the periods, while being more sensitive to smaller timescale variables and microlensing events. We have compared the specific advantages of doing the variability survey in J and Ks. On the one hand, the J-band gives better photometric precision, higher RR Lyr amplitudes ($\Delta J \sim 1.5\Delta K$), and deeper magnitudes. On the other hand, the Ks-band filter permits more coverage in heavily reddened regions, yields better distances, and gives tighter PSFs, on average by 0.1 arcsec, which would make a difference in the crowded regions. Based on photometry and light curve simulations we adopt the Ks filter for this proposal, noting that we would optimize the strategy after the first year's $ZYJHKs$ data are in hand.

During the fourth year (2010) the main plane variability campaign is carried out using 55 nights. in Ks, following a similar strategy as in the case of the previous year.

Finally, during the fifth year (2011) we will observe for 20 and 14 nights the bulge and plane fields, respectively, but with observations spread over the season. This allows the measurement of longer-timescale variables, and the search for high-proper motion objects. A subset of the fields can be observed much more frequently (10-40 times per night). This strategy allows to find short-period variables and planetary transits.

We do not discard the possibility of extending the variability search for a sixth year if the coverage is incomplete due to scheduling or weather.

5 Estimated observing time:

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P79	220	12:00–19:00 h	any	0.8	clear
P81	60	12:00–19:00 h	any	0.8	clear
P83	750	12:00–19:00 h	any	any	thin
P85	550	12:00–19:00 h	any	any	thin
P87	340	12:00–19:00 h	any	0.8	clear

5.1 Time justification: (1 page max)

The area covered in the bulge will be $20^0 \times 15^0$ in size, between $-10^0 < L < 10^0$ and $-10^0 < B < 5^0$.

For the bulge variability, each field will be observed in the Ks-band with DIT=4 sec, NDIT=1, Njitter=2, Npaw=6, with the observing efficiency per tile of 30%. This gives a full $1.5^0 \times 1.0^0$ field covered every 162 sec, down to a magnitude of $Ks = 18$ at $S/N = 3$ for each object (ETC v1.2). Our strategy yields about 30 sq deg per hour, or 300 degrees per night. The bulge is observable in June-July for more than 10 hr, and no other major overheads are expected due to the simplicity of the program (e.g. we observe only in one filter per night). The combined epochs will reach $J = 21.5$, $Ks = 20$, which is three magnitudes fainter than the unreddened bulge main-sequence turnoff, although the densest fields will be confusion-limited. However, applying both PSF fitting and differential imaging (DIA) we will recover the light curves of most objects down to $J = 19.5$, $Ks = 18$, $J = 19.5$ even in moderately crowded fields. This is more than 3 mag fainter than the unreddened RR Lyrae at the Galactic bulge. We expect to find RR Lyrae even in fields with $A_V = 10$ mag.

The Table below lists some reference Ks-band magnitudes at the distance of the bulge for a range of extinction and reddening values. These typical magnitudes were obtained from Carney et al. (1995, AJ, 110, 1674), Alard (1996, ApJ, 1996, 458, L17), Alcock et al. (1998, ApJ, 492, 190), and Zoccali et al. (2003, A&A, 399, 931). As a reference point, for Baade's window $E(B-V) = 0.5$ mag, then $A_V = 1.5$ mag, $A_J = 0.4$, and $A_K = 0.2$ mag (Rieke & Lebofsky 1985, ApJ, 288, 618). This table shows that the tip of the bulge RGB will saturate, but for the RGB clump giants, and even for the tip of the RGB of the Sgr galaxy, the VVV survey will be able to see giants throughout the bulge, even in the most obscured regions. The bulge RR Lyrae and the Sgr galaxy clump giants will also be detected even for the regions with highest extinction ($A_V > 10$) at low Galactic latitudes. Finally, the RR Lyrae of the Sgr galaxy and the bulge main-sequence turnoff will be detected only in the regions with low absorption ($A_V < 10$) at higher latitudes.

Bright point sources with $Ks < 10.0$ will be saturated in the individual images. Thus, most unreddened bulge Mira variables will be saturated, but Miras in the Sgr dwarf galaxy can be monitored, as well as Miras located in regions with very high extinction (e.g. next to the Galactic center). In addition, bright star saturation, persistence effects or cross talk may be an issue, but we estimate that in the worst fields only a small portion of the field would be rendered useless. For example, in the optical microlensing surveys where CCD bleeding is comparatively worse, less than 5% of the most crowded bulge fields is lost.

The area covered in the plane is $4^0 \times 55^0$ in size, between $-10^0 < L < -65^0$ and $-2^0 < B < 2^0$. We will acquire deeper $ZYJHKs$ images for the disk survey, as the confusion limit is deeper. The Ks strategy is for example $DIT = 10$ sec, $NDIT = 2$, $Njit = 2$, $Npaw = 6$, for a total time of 80 sec on target, and an elapsed time of 366 sec per tile. Accurate crowded-field IR photometry are illustrated in Figure 5 below. The left panel shows NTT + SOFI photometry of the transit of the extrasolar planet OGLE-TR-113, which has a mean magnitude $Ks = 13.5$ and a depth of transit of $A_K = 0.03$ mag. The right panel shows NTT+SOFI photometric errors as function of J and Ks. See more simulations at $http://wiki.astrogrid.org/bin/view/VISTA/VVV$

Observing details for bulge and plane are illustrated in Tables 1 and 2 at the end.

POPULATION	$A_V = 0$ $A_J = 0$ $A_K = 0$ E(B-V)=0	$A_V = 1.5$ $A_J = 0.4$ $A_K = 0.2$ E(B-V)=0.5	$A_V = 5.0$ $A_J = 1.4$ $A_K = 0.6$ E(B-V)=1.5	$A_V = 10.0$ $A_J = 2.8$ $A_K = 1.1$ E(B-V)=3.2	$A_V = 15.0$ $A_J = 4.2$ $A_K = 1.7$ E(B-V)=4.8
Bulge RGB tip	K=8.0*	K=8.2*	K=8.6*	K=9.0*	K=9.7
Sgr RGB tip	K=10.5	K=10.7	K=11.1	K=11.6	K=12.2
Bulge RGB Clump	K=12.9	K=13.1	K=13.5	K=14.0	K=14.6
Bulge RR Lyrae	K=14.3	K=14.5	K=14.9	K=15.4	K=16.0
Sgr RGB Clump	K=15.4	K=15.6	K=16.0	K=16.5	K=17.1
Sgr RR Lyrae	K=16.8	K=17.0	K=17.4	K=17.9	K=18.5*
Bulge MS TO	K=17.0	K=17.2	K=17.6	K=18.1	K=18.7*
* = beyond detection					

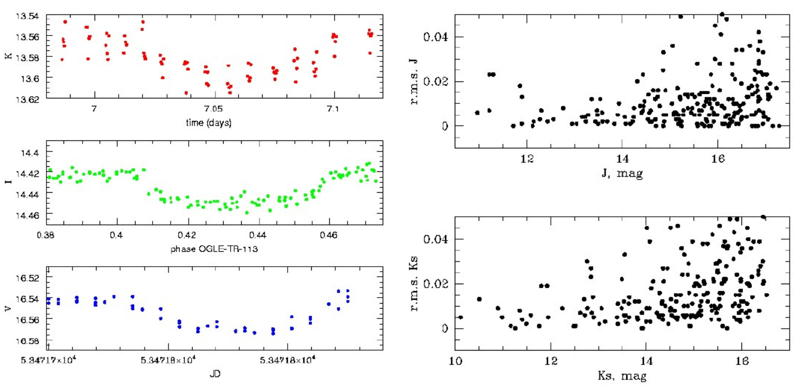

Figure 5: LEFT: Light curve of star OGLE-TR-113 during a planetary transit with amplitude $\Delta K = \Delta I = \Delta V = 0.03$ mag, as measured with VLT + VIMOS in the V-band by us (bottom), by OGLE in the I-band (middle), and with NTT + SOFI by us (top). This star is located right on the Galactic plane in the Carina field, a moderately crowded region. The NTT + SOFI observations were acquired with a similar strategy as proposed here. This Ks-band light curve with $rms < 0.01$ mag illustrates the quality of photometry possible with VISTA for the VVV survey. RIGHT: Accuracy of the relative photometry that we have obtained with SOFI as a function of magnitude. The total integration time was 30 sec, and the limiting magnitudes are 2 mags fainter. The magnitudes and the r.m.s. are calculated with two iterations, removing the $> 10\sigma$ outliers.

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function	Affiliation	Country
Dante Minniti	PI, photometry, light curves, bulge	University Catolica	RCH
Phil Lucas	Co-PI, photometry, GPS	University of Herthfordshire	UK
Manuela Zoccali	Photometry, analysis, bulge	University Catolica	RCH
Marcio Catelan	Theory, light curves, bulge	University Catolica	RCH
Lorenzo Morelli	Astrometry, light curves, bulge	University Catolica	RCH
Claus Tappert	Photometry, light curves, bulge	University Catolica	RCH
Giuliano Pignata	Pipeline, astrometry, bulge	University Catolica	RCH
Maria Teresa Ruiz	Astrometry, photometry, bulge	University of Chile	RCH
Giovanni Carraro	Astrometry, photometry, bulge	University of Chile	RCH
Simon Casassus	Astrometry, photometry, bulge	University of Chile	RCH
Leonardo Bronfman	Astrometry, photometry, bulge	University of Chile	RCH
Rodolfo Barba	Reductions, Pipeline, bulge	University of La Serena	RCH
Roberto Gamen	Reductions, Pipeline, bulge	University of La Serena	RCH
Wolfgang Gieren	Photometry, light curves, bulge	University of Concepcion	RCH
Douglas Geisler	Photometry, analysis, bulge	University of Concepcion	RCH
Grzegorz Pietrzynski	Photometry, astrometry, light curves	University of Concepcion	RCH
Ronald Mennickent	Photometry, astrometry, light curves	University of Concepcion	RCH
Radostin Kurtev	Reductions, pipeline, bulge	University of Valparaiso	RCH
Jordanka Borissova	OB Prep, photometry, light curves	University of Valparaiso	RCH
Felix Mirabel	Photometry, analysis, bulge	European Southern Observatory	ESO
Valentin Ivanov	OB Prep, Data Quality Control III	European Southern Observatory	ESO
Ivo Saviane	OB Prep, Pipeline, bulge	European Southern Observatory	ESO
Leonardo Vanzi	OB Prep, Pipeline, bulge	European Southern Observatory	ESO
Lorenzo Monaco	OB Prep, Reductions, bulge	European Southern Observatory	ESO
Marina Rejkuba	Simulations, light curves, bulge	European Southern Observatory	ESO
Maria Messineo	Simulations, light curves, bulge	European Southern Observatory	ESO
Luigi Bedin	Astrometry, simulations, bulge	European Southern Observatory	ESO
Andrew Stephens	Simulations, photometry, bulge	Hawaii	USA
Beatriz Barbuy	Photometry, analysis, bulge	University of Sao Paulo	Other
Eduardo Bica	Photometry, analysis, bulge	University of Porto Alegre	Other
Juan Jose Claria	Photometry, analysis, bulge	University of Cordoba	Other
Andrea Ahumada	Pipeline, photometry, bulge	University of Cordoba	Other
Jim Emerson	VDFS Coordinator, bulge	Queen Mary University London	UK
CASU (VDFS) team	Pipeline Processing, bulge	University of Cambridge	UK
CASU (VDFS) team	Data Quality Control I , bulge	University of Cambridge	UK
WFAU (VDFS) team	Data Quality Control II, bulge	University of Edinburgh	UK
WFAU (VDFS) team	Science archive, bulge	University of Edinburgh	UK
Janet Drew	Galactic plane survey	Imperial College London	UK
Martin Lopez-Correidora	Galactic plane survey	IAC	Spain
Eduardo Martin	Galactic plane survey	IAC	Spain
Bertrand Goldman	Galactic plane survey	MPIA Heidelberg	Germany
Teresa Gianinni	Galactic plane survey	Rome Observatory	Italy
Jochem Eisloeffel	Galactic plane survey	Thueringer Landessternwarte	Germany

Name	Function	Affiliation	Country
Paul Groot	Galactic plane survey	Nijmegen University	The Netherlands
Juan Fabregat	Galactic plane survey	Universidad de Valencia	Spain
Nigel Hambly	Galactic plane survey	Royal Observatory Edinburgh	UK
Andy Longmore	Galactic plane survey	Royal Observatory Edinburgh	UK
Nic Walton	Galactic plane survey	Cambridge University	UK
Richard de Grijs	Galactic plane survey	IoA Cambridge	UK
Melvin Hoare	Galactic plane survey	Leeds University	UK
Anja Schroeder	Galactic plane survey	Leicester University	UK
Tim Naylor	Galactic plane survey	Exeter University	UK
Mike Barlow	Galactic plane survey	University College of London	UK
Albert Zijlstra	Galactic plane survey	Manchester University	UK
Glenn White	Galactic plane survey	Open University	UK
Andrew Gosling	Galactic plane survey	Oxford University	UK
Katherine McGowan	Galactic plane survey	Southampton University	UK
Andy Adamson	Galactic plane survey	Joint Astronomy Center	USA
Reba Bendyopadhyay	Galactic plane survey	University of Florida	USA
Mark Thompson	Galactic plane survey	University of Hertfordshire	UK
Mark Cropper	Galactic plane survey	Mullard Space Science Lab.	UK
John Lucey	Galactic plane survey	Durham University	UK
Eammon Kerins	Galactic plane survey	Liverpool John Moores Univ	UK
Simon Hodgkin	Galactic plane survey	IoA Cambridge	UK
David Pinfield	Galactic plane survey	University of Hertfordshire	UK

6.2 Detailed responsibilities of the team:

We will use the VISTA Data Flow System (VDFS; Emerson et al. 2004, SPIE, 5493, 401; Irwin et al. 2004, SPIE, 5493, 411; Hambly et al. 2004, SPIE, 5493, 423) for all aspects of data management, including: pipeline processing and management; delivery of agreed data products to the ESO Science Archive; production of a purpose-built IVOA compliant science archive with advanced data-mining services; enhanced data products including federation of VISTA survey products with SDSS survey products. Standardised agreed data products produced by VDFS will be delivered to ESO, with a copy remaining at the Science Archive in Edinburgh.

The VDFS is a collaboration between the UK Wide Field Astronomy Units at Edinburgh (WFAU) and Cambridge (CASU) coordinated by the VISTA PI (QMUL) and funded for VISTA by PPARC. The VDFS is a working systems-engineered system that is already being successfully employed for the UKIRT WFCAM surveys as a test bed for the VISTA infrared surveys, and which is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system. We emphasise the track record over the last decade of both the Cambridge and Edinburgh survey units in processing and delivering large-scale imaging datasets to the community as exemplified by the WFCAM Early Data release (EDR, *http://surveys.roe.ac.uk/wsa/dboverview.html*; Lawrence et al 2006 and Dye et al 2006, in preparation).

The CASU (VDFS) team consists of Irwin, Lewis, Hodgkin, Evans, Bunclark, Gonzales-Solares, Riello. The WFAU (VDFS) team consists of Hambly, Bryant, Collins, Cross, Read, Sutorius, Williams.

In addition to the UK VDFS, the VVV survey team involves astronomers of Chilean institutions, and of the European Southern Observatory. Our Chilean team includes experienced members from the microlensing surveys (OGLE, MACHO, EROS), as well as staff ESO members experienced in all aspects of IR imaging and instrumentation. We have capable people in charge of the data reduction, pipeline, photometry, astrometry, database, light curves, and simulations.

DM and PL will manage and be involved in all aspects of the project, and JE for the VDFS. VI, MZ and MC will aid deciding the data taking strategy and scientific priorities. VI and RB will lead the OBs preparations efforts, aided by RG, JB, IS, LM, RK, GC. All members of the collaboration will be involved in the photometry led by GP and DG (both PSF fitting photometry and DIA photometry), and will support MR, AS, MM in making the Monte-Carlo simulations to compute detailed photometric and sampling efficiencies. The astrometry will be carried out by GC, LM and MTR. RM and WG will decide on variability and phasing criteria, along with AA, JJC, BB, FM. LM and EB will take charge of creating the variability catalogue, including LK, GC, CT, AS, CP, GB.

6.3 Data reduction plan:

VISTA will produce about 1 TB of data per night for our survey, larger than the nominal average because of the short exposures. Longer exposures are not useful because the main limitation is crowding and the number of saturated stars will increase. For us the first two years of the survey represent the steeper effort in terms of manpower and resources. The data reduction will be carried out using the VDFS, operated by the VDFS team, and augmented by Chilean and ESO scientists, especially for product definition and product Quality Control. We divide the plan into three distinct but intimately related parts: pipeline processing, science archiving, and variability search.

Pipeline processing: The Cambridge Astronomy Survey Unit (CASU) is responsible for the VDFS pipeline processing component which has been designed for VISTA and scientifically verified by processing wide-field mosaic imaging data from UKIRT's NIR mosaic camera WFCAM and is now routinely being used to process data from the WFCAM at a rate of up to 250GB/night. It has also been used to process ESO ISAAC data, e.g. the FIRES survey data and a range of CCD mosaic camera data. The pipeline is a modular design allowing straightforward addition or removal of processing stages and will have been tested on a range of input VISTA datasets. The standard processing includes: instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk; sky background tracking and homogenisation during image stacking and mosaicing – possible extras may include removal of other 2D systematic effects from imperfect multi-sector operation of detectors; assessing and dealing with image persistence from preceding exposures if necessary; combining frames if part of an observed dither sequence or tile pattern; producing a consistent internal photometric calibration to put observations on an approximately uniform system; standard catalogue generation including astrometric, photometric, shape and Data Quality Control (DQC) information; final astrometric calibration based on the catalogue with an appropriate World Coordinate System (WCS) placed in all FITS headers; photometric calibration for each generated catalogue augmented by monitoring of suitable pre-selected standard areas covering the entire field-of-view to measure and control systematics; frames and catalogue supplied with provisional calibration information and overall morphological classification embedded in FITS files; propagation of error arrays and use of confidence maps; realistic errors on selected derived parameters; nightly extinction measurements in relevant passbands; pipeline software version control – version used recorded in FITS headers; processing history including calibration files recorded in FITS headers.

Science archiving: The concept of the science archive (SA, see Hambly et al. 2004, SPIE, 5493, 423) is key to the successful exploitation of wide-field imaging survey datasets. The SA ingests the products of pipeline processing (instrumentally corrected images, derived source catalogues, and all associated metadata) into a database and then goes on to curate them to produce enhanced database-driven products. In the VDFS science archive, the curation process includes, but is not limited to, the following: individual passband frame association; source association to provide multi-colour, multi-epoch source lists; global photometric calibration; enhanced astrometry including derivation of proper motions; consistent list-driven photometry across sets of frames in the same area; cross-association with external catalogues; and generation of new image products, e.g. stacks, mosaics and difference images etc., all according to prescriptions set up for our VVV survey. Archive curation includes quality control procedures, as required and led by the public survey consortium, and supported by archive team members. All these features are available in the context of a continually updating survey dataset from which periodic releases can be made. Moreover, end-user interfaces were catered for from the beginning in the VDFS design process, and the philosophy has always been to provide both simple and sophisticated interfaces for the data. The former is achieved via simple point-and-click web forms, while the latter is achieved via exposing the full power of the DBMS back-end to the user. To that end, full access to Structure Query Language and the relational organization of all data are given to the user. We have developed a generalized relational model for survey catalogue data in the VDFS. The key features to note are the normalized design with merged multi-waveband catalogue data (the table of most use for scientific queries) being part of a related set of tables that allow the user to track right back to the individual source images if they require to do so; and also that the merged source tables (as derived either from individually analyzed images, or consistently across the full passband set available in any one field) are seamless, and present the user with a generally applicable science-ready dataset. Similar relational models describe the organization of all data in the science archive (image, catalogue, calibration metadata, etc. – see Hambly et al. 2004, SPIE, 5493, 423). The science archive has a high-speed query interface, links to analysis tools such as TopCat, and advanced new VO services such as MySpace. Data products are being successfully ingested into the WFCAM Science Archive (WSA) in Edinburgh, with the EDR in Feb. 2006, and the WSA concept was also demonstrated on the SuperCOSMOS Science Archive (SSA) (*http://surveys.roe.ac.uk/ssa/*). Ours is intrinsically a multi-wavelength project and most science will come from the linking of VISTA data with other large catalogues, and the WSA is designed to enable such links.

Variability: The first year will cover 520 sq deg in the bulge and inner plane in $ZYJHKs$. Using the initial photometry in these fields, we will be able to fine tune the cuts that automatically flag variables to produce the catalogue of variable sources, which could be subsequently integrated to the VDFS for the rest of the programme. The variability catalogue will be made in Chile, where we count with a Beowulf cluster, and similar equipment is available in Brazil and Argentina. The data for the first two years is manageable, but we plan to expand the capabilities and storage space for the third year, when the most intense campaign is carried out. The renovation of our national Chilean Astronomy Project FONDAP will provide the resources. The final bulge and disk light curves will have 50 to 200 epochs, depending on the location, as some fields will be monitored more frequently (e.g. the Galactic Center and selected transit fields). Phasing the light curves of $\sim 5 \times 10^8$ point sources to find $\sim 10^6$ variables will be one of our major tasks. The large number of epochs requested will aid in discriminating different variable star populations, determining accurate ephemerides for periodic variables and securing completeness of the samples (see Figure 4). Another related task that must not be underestimated are the Monte-Carlo simulations to determine the final survey efficiency. We envisage two strong dependences: photometric efficiency and sampling efficiency. The photometric efficiency has to be modeled on a field-by-field basis, as the limiting magnitudes and crowding vary widely across the bulge and plane. The sampling efficiency will also depend on the field, but must take into account the models of variables with different light curves.

6.4 Expected data products:

– Instrumentally corrected frames (pawprints, tiles etc) along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
– Statistical confidence maps for each frame
– Stacked image data for dithered observations
– Derived catalogues (source detections from science frames with standard isophotal parameters, model profile fitted parameters, image classification, etc.)
– Data Quality Control database
– Database-driven image products (stacks, mosaics, difference images, image cut-outs)
– Frame associations yielding a survey field system; seamless, merged, multi-colour, multi-epoch source catalogues with global photometric calibration, proper motions
– Source remeasurement parameters from consistent list-driven photometry across all bands in any field
– Catalogue of bulge variable point sources, including positions, mean magnitudes, and amplitudes, and matched catalogues with other surveys.

6.5 General schedule of the project:

We anticipate that standard science products can be released to the PIs within 1-2 months of raw data arriving in the UK, and expect the yearly release of public VVV science products about 6 months after that. The timeline is:

• FIRST YEAR: – observations of 520 sq deg in all filters (for deep CMDs and good seeing first-epoch proper motions); – image pipeline basic reductions; – image tiling and combination to produce the first $ZYJHKs$ atlas; – photometric measurements for the individual epochs; – establishment of criteria for automatic detection of variability; – photometric efficiency Monte-Carlo simulations.

• SECOND YEAR: – observations of 520 sq deg, 3 epochs in Ks; – image pipeline basic reductions; – photometric measurements for the individual epochs; – search for variable point sources (PSF fitting and difference image analysis).

• THIRD YEAR: – observations of bulge 300 sq deg, 75 nights in Ks. – image pipeline basic reductions; – photometric measurements for the individual epochs; – search for variable point sources (difference image analysis); – phasing the light curves; – catalogue of variables made.

• FOURTH YEAR: – observations of plane 220 sq deg, 55 nights in Ks; – image pipeline basic reductions; – photometric measurements for the individual epochs; – search for variable point sources (difference image analysis); – phasing the light curves; – catalogue of variables made.

• FIFTH YEAR: – observations of selected bulge fields, 20 nights in Ks, and plane fields, 14 nights in Ks (with reasonable seeing for last epoch of proper motions); – image pipeline basic reductions; – photometric measurements for the individual epochs; – re-phasing of light curves; – sampling efficiency Monte-Carlo simulations; – final catalogue of variables; – image tiling to produce deep Ks-band maps of the whole bulge; – astrometric search and identification of high proper motion objects.

7 Envisaged follow-up: (1 page max)

In Chile we have access to a variety of facilities for follow-up of the VVV survey that our team members are interested in. An important point is that some of the follow-up observations can be carried out early, before the completion of the whole survey. The most straightforward examples are listed below, where only current capabilities are mentioned. In addition to this current instrumentation, we will have access to the second-generation instruments at VLT, GEMINI and MAGELLAN, and we also expect our VVV survey to feed interesting targets to ALMA and the giant 25-100 m ground-based telescopes.

• RR Lyrae:

Our high priority follow-up project would be the kinematics and chemical abundances of bulge RR Lyrae with FLAMES at the VLT and MIKE-Fibers at Magellan.

• Microlensing Events:

Spectroscopy with a moderate-size telescope needed for the full characterization of the source star (EMMI at the NTT or Goodman spectrograph at SOAR). In the special parallax events, follow up with a space telescope (refurbished HST) might allow the detection of the lens directly.

• Transit candidates:

Extrasolar planetary transit candidates need to be followed up spectroscopically, either with UVES at the VLT or MIKE at Magellan.

• Galactic Center:

Flares or lensing might be followed up with high-resolution imaging and spectroscopy with NACO and SINFONI at the VLT in Rapid Response Mode.

• New cluster candidates:

Deep imaging and spectroscopy, likely in the IR (e.g. with SOFI at the NTT), in order to determine the distances and total masses. For the massive star clusters and star forming regions in the Galactic center region, NACO and SINFONI will be more appropriate.

•Eclipsing binaries:

Suitable interesting targets would be observed spectroscopically (Echelle at the du Pont, FEROS or EMMI at the NTT, HARPS at the 3.6m telescope) in order to obtain Keplerian masses.

•CVs and pre-CVs:

Optical spectroscopy with NTT+EMMI to confirm the classification, and (for confirmed CVs) additional time-resolved spectroscopy to measure the orbital periods. In the case of pre-CVs this will also yield white-dwarf parameters ($T_{\rm eff}$, $\log g$) and the spectral type of the red dwarf.

• High proper motion objects:

Imaging in subsequent years to refine the proper motion measurements (with SOFI at the NTT), and spectroscopy for spectral typing of late-M stars and Brown Dwarfs, or radial velocities to obtain the orbital parameters around the Galaxy for high-velocity halo stars (e.g. with FORS at the VLT).

• QSOs:

Variability-selected background quasars and AGN need to be confirmed spectroscopically with FORS at the VLT or GMOS at GEMINI-S in order to determine class and redshift. They will provide an absolute frame for astrometric purposes.

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

This is mainly a variability programme, and our strategy has been designed to cover the maximum area without loss of scientific objectives, and time flexibility as much as possible. However, because it is a variability survey it is different from other VISTA surveys, and there are some key issues that we would like to stress:

Data homogeneity is important: given the huge stellar density gradient and nonuniform interstellar absorption in the bulge and inner disk, the casual reader will immediately be tempted to define an observing strategy that changes from field to field. However, this has a catastrophic impact in a massive variability search.

Areal completeness is important: we need to map the whole bulge and inner plane. Only this will allow the definitive analysis of the spatial distributions (structure, gradients), and comparisons of the different populations in situ. Pencil-beam surveys have been very useful insofar as a whole scale map is available for calibration.

Time completeness is important: we need light curves with 50-200 epochs, obtained with the proposed time spacing, spanning several years. Otherwise our light curves will not allow detailed pulsation studies (e.g. Blazhko effect, double-mode RR Lyrae), aliasing will plague the data, and in general the determination of physical parameters for the different populations of variable objects will suffer.

Scheduling is important: during the main bulge variability campaign to be carried out in year 3 we need observations using consecutive whole nights centered in the bulge season. About 2.5 months centered in June 2009 need to be blocked for the VVV survey in year 3. Year 4 is also intensive for the variability search in the disk, but the fields are spread out between March and June. We leave the scheduling of the other years flexible.

Again, in spite of the added complexity of the time domain exploration that other VISTA surveys do not have, the VVV public database would be a significant treasure for the whole community to exploit for a variety of scientific programmes.

Simulations: At the request of the PSP, we made simulations of:

– the CMDs along different bulge and disk lines of sight, using the Bensancon models to check stellar densities and populations.

– the photometric efficiency, simply using the VISTA ETC for widely different parameters,

– the ability to retrieve variable objects and phase them with adequate periods. For these simulations we added artificial stars to real near-IR data available from UKIDSS.

The results of these simulations improved this proposal, for example in deciding to do the variability survey in the Ks-band as opposed to the J-band.

The addition of the Galactic Plane Survey suggested by the PSP has also greated benefited the final proposal, that would now deliver a more complete view of the Milky Way. The disadvantage is the lack of space to properly explain several details while keeping strictly to the page limits. Therefore, additional simulations, figures and descriptions are available in the web at: $http://wiki.astrogrid.org/bin/view/VISTA/VVV$

Table 1: 1st Yr Mapping VVV Bulge Fields

	Z	Y	J	H	K_s
Time & depth					
Time per object s	40	40	48	16	16
Depth (3 σ) Vega	21.6	21.0	20.6	18.2	18.1
Tiling strategy					
Detector Integration Time (DIT) s	10	10	6	4	4
Exposure co-adds (Ndit)	1	1	2	1	1
Exposure loops (Nexp)	1	1	1	1	1
Microsteps (Nmicro)	1	1	1	1	1
Jitters (Njitter)	2	2	2	2	2
Pawprints in tile (Npaw)	6	6	6	6	6
Tile Efficiency/tile					
Total Exposure sec/tile	120	120	144	72	72
Total Elapsed sec/tile	233	233	270	162	162
Observing efficiency /tile	50	50	54	30	30
Time for 300 sq deg = 200 tiles of 1.5 sq deg in the MW Bulge					
Total Elapsed Hours per filter	13	13	15	9	9
J exposures of all fields repeated 3 more times = 45hs total					
Ks exposures of all fields repeated 5 more times = 45hs total					

Table 2: 1st Yr Mapping VVV Plane Fields

	Z	Y	J	H	K_s
Time & depth					
Time per object s	180	180	60	60	60
Depth (5 σ) Vega	21.9	21.2	20.2	18.2	18.1
Tiling strategy					
Detector Integration Time (DIT) s	20	20	10	10	10
Exposure co-adds (Ndit)	1	1	2	2	2
Exposure loops (Nexp)	1	1	1	1	1
Microsteps (Nmicro)	1	1	1	1	1
Jitters (Njitter)	2	2	2	2	2
Pawprints in tile (Npaw)	6	6	6	6	6
Tile Efficiency/tile					
Total Exposure sec/tile	80	80	80	80	80
Total Elapsed sec/tile	354	354	366	366	366
Observing efficiency /tile	30	30	30	30	30
Time for 220 sq deg = 147 tiles of 1.5 sq deg in the MW Plane					
Total Elapsed Hours per filter	16	16	16	16	16
Ks exposures of all fields repeated 2 more times = 32hs total					

Table 3: 3rd-4th Yr Variability VVV Fields – SINGLE EPOCH

	Z	Y	J	H	K_s
Time & depth					
Time per object s	-	-	-	-	16
Depth (3 σ) Vega	-	-	-	-	18.1
Detector Integration Time (DIT) s	-	-	-	-	4
Exposure co-adds (Ndit)	-	-	-	-	1
Exposure loops (Nexp)	-	-	-	-	1
Microsteps (Nmicro)	-	-	-	-	1
Jitters (Njitter)	-	-	-	-	2
Pawprints in tile (Npaw)	-	-	-	-	6
Total Exposure sec/tile	-	-	-	-	16
Total Elapsed sec/tile	-	-	-	-	162
Observing efficiency /tile	-	-	-	-	30
Time for 300 sq deg = 200 tiles of 1.5 sq deg in the MW Bulge					
Total Elapsed Hours per filter	-	-	-	-	9
Time for 220 sq deg = 147 tiles of 1.5 sq deg in the MW Plane					
Total Elapsed Hours per filter	-	-	-	-	7

Table 4

ClusterID	RA	DEC	L(deg)	B(deg)	$D(kpc)$	
Terzan 2	17 27 33.1	-30 48 08	356.32	2.30	8.7	
Terzan 4	17 30 39.0	-31 35 44	356.02	1.31	9.1	*
HP 1	17 31 05.2	-29 58 54	357.42	2.12	14.1	*
Liller 1	17 33 24.5	-33 23 20	354.84	-0.16	9.6	*
NGC 6380	17 34 28.0	-39 04 09	350.18	-3.42	10.7	
Terzan 1	17 35 47.2	-30 28 54	357.56	0.99	5.6	
Ton 2	17 36 10.5	-38 33 12	350.80	-3.42	8.1	*
NGC 6401	17 38 36.6	-23 54 34	3.45	3.98	10.5	
Pal 6	17 43 42.2	-26 13 21	2.09	1.78	5.9	
Djorg 1	17 47 28.3	-33 03 56	356.67	-2.48	12.0	*
Terzan 5	17 48 04.9	-24 46 45	3.84	1.69	10.3	*
NGC 6440	17 48 52.7	-20 21 37	7.73	3.80	8.4	
NGC 6441	17 50 12.9	-37 03 05	353.53	-5.01	11.7	
Terzan 6	17 50 46.4	-31 16 31	358.57	-2.16	9.5	*
NGC 6453	17 50 51.7	-34 35 57	355.72	-3.87	9.6	
UKS 1	17 54 27.2	-24 08 43	5.12	0.76	8.3	*
Terzan 9	18 01 38.8	-26 50 23	3.60	-1.99	6.5	*
Djorg 2	18 01 49.1	-27 49 33	2.76	-2.51	6.7	*
Terzan 10	18 02 57.4	-26 04 00	4.42	-1.86	5.7	*
NGC 6522	18 03 34.1	-30 02 02	1.02	-3.93	7.8	
NGC 6528	18 04 49.6	-30 03 21	1.14	-4.17	7.9	
NGC 6540	18 06 08.6	-27 45 55	3.29	-3.31	3.7	
NGC 6544	18 07 20.6	-24 59 51	5.84	-2.20	2.7	
NGC 6553	18 09 17.6	-25 54 31	5.25	-3.03	6.0	
2MS- GC02	18 09 36.5	-20 46 44	9.78	-0.62	4.0	*
NGC 6558	18 10 17.6	-31 45 50	0.20	-6.02	7.4	
Terzan 12	18 12 15.8	-22 44 31	8.36	-2.10	4.8	*
NGC 6569	18 13 38.8	-31 49 37	0.48	-6.68	10.7	
NGC 6624	18 23 40.5	-30 21 40	2.79	-7.91	7.9	
NGC 6626	18 24 32.9	-24 52 12	7.80	-5.58	5.6	
NGC 6638	18 30 56.1	-25 29 51	7.90	-7.15	9.6	
NGC 6642	18 31 54.1	-23 28 31	9.81	-6.44	8.4	
NGC 6656	18 36 24.2	-23 54 12	9.89	-7.55	3.2	
* = uncertain distances						