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VISTA variable survey in the Milky Way

M. Hempel[1], D. Minniti[1], R. Saito[1], P. Pietrukowicz[1] & P. W. Lucas[2]
(for the VVV Science Team)

[1]Pontificia Universidad Catolica de Chile, Departemento de Astronomie y Astrofisica,
Av. Vic. Mackenna 4860, 7820436 Macul, Santiago, Chile
email: mhempel,dante,rsaito,pietruk@astro.puc.cl

[2]Dept. of Astronomy , University of Hertfordshire,
University of Hertfordshire, Hatfield AL10 9AB, UK
email: phyqpwl@herts.ac.uk

Abstract. Over the next 5 years the VVV collaboration (Vista Variable in the Via Lactea) will conduct an extensive survey of the galactic bulge and disk in the near-IR, using the new VISTA telescope. This public survey covers a field of 520 sqr. deg, including not only regions of high star formation, but also 33 known globular clusters and ∼350 open clusters. The final product will be a deep IR atlas in 5 passbands for $\sim 10^9$ point sources among which we expect 10^6 variable stars. These will be produce a 3-D map of the surveyed region using well-understood primary distance indicators such as RR Lyrae stars. 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 the pulsation theory will follow from this survey.

Keywords. surveys, stars: variables: Cepheids, stars: variables: other, Galaxy: bulge, Galaxy: disk

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1. Introduction

Here we describe the VISTA Variable Survey in the Via Lactea (VVV)- a public near-IR survey of the bulge and disk region of our Milky Way, where the bulk of its stars, gas and dust are confined. Studying the structure of the inner Milky Way is severely hampered by extinction and crowding effects. Knowing how the stellar populations are distributed within the Galaxy is essential for such studies and our understanding of Galaxy formation. This survey will cover a 520 deg^2 area (Fig. 1) containing $\sim 10^9$ point sources, and produce the most complete catalogue of variable objects in the bulge, with more than $\sim 10^6$ variables. Chief among them are the RR Lyrae, which are accurate primary distance indicators, and well understood in their chemical, pulsational and evolutionary properties. Although not the sole purpose of this survey, the primary outcome will be a 3-dimensional map of the inner Milky Way. Hereby we will also take advantage of several complementing surveys or instruments, e.g. MACHO, OGLE, EROS, LAMOST, VST, Spitzer, Chandra, INTEGRAL, WISE, Fermi LAT, XMM-Newton, and ALMA.

The Milky Way may well host the best studied spiral bulge, but is still the most difficult to understand with respect to its formation and structure. While its surface brightness shows a barred structure, its stellar population is old (Kuijken & Rich 2002;Zoccali *et al.* 2003) and it has α-element enhancement, characteristic of rapid formation. Zoccali *et al.* (2006) indicate that the chemical composition of the bulge stars is different from that of both thin and thick-disk stars. Thus, the predictions from the formation of the Milky Way bulge through secular evolution of the disk seem to be in conflict with some key

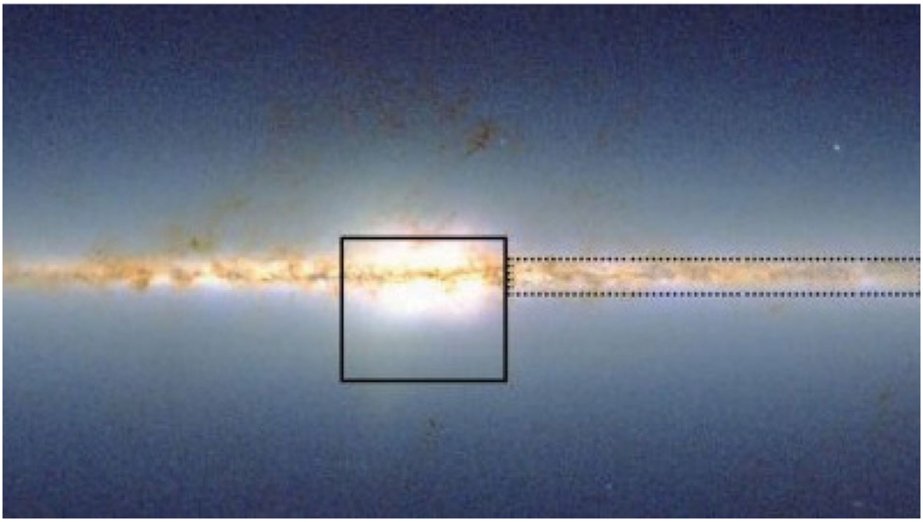

Figure 1. 2MASS map of the inner Milky Way showing the VVV bulge (solid box, between $-10^o < l < +10^o$ and $-10^o < b < +5^o$) and plane survey areas (dotted box, between -65 deg $<$ l $<$ -10 deg and -2 deg $<$ b $<$ +2 deg).

properties of its stellar population. However, Meléndez *et al.* (2008) argued that bulge and disk stars are similar in their chemical composition. Given that the near-IR colors depend strongly on metallicity, the VVV survey will help us solve this puzzle. In the following we will give a short description of the VISTA telescope, its wide-field camera and the schedule of the planned observations (see Section 2) as well as the most pressing science goals of the survey (Section 3).

2. Technical Details & Schedule

The Visible and Infrared Survey Telescope for Astronomy (VISTA) is a 4m-class "wide-field" telescope, located at ESO's Cerro Paranal Observatory in Chile, designed to conduct large-scale surveys of the southern sky at near-IR wavelengths (0.9 to 2.5 μm). The heart of the telescope is its wide-field camera, an array of 16 $\times$ 2048 $\times$ 2048 Raytheon VIRGO IR detectors, with a mean pixel size $0.''34$. Five broad-band filters at $Z\,Y\,J\,H\,K_{\rm s}$ will be used in our survey.

The VVV survey is scheduled over a period of 5 years, and with the exception of the first year, will collect data exclusively in the K_s- band.

• During the first year the whole survey area will be observed in the K_s band (6 epochs) as well as in the Z,Y,J, H filters (1 epoch each). The multi-waveband observations will be carried out quasi-simultaneously. A total of 292 h will be dedicated to this observations (bulge: 151 h, disk: 141 h). The limiting K_s magnitude of a single epoch is K_s=18 mag.

• To create master maps for our variability study we will obtain additional 20 epochs of K_s band observations on the bulge region, as well as 10 epochs on the disk. The total amount of observing time is 217 h.

• The main bulge variability study will be carried out in the third year, during which we will obtain 80 epochs of K_s-band observations for the bulge region, totaling 625 h. A subset of fields can be observed as often as 40 times per night, allowing not only to remove aliasing, but also to search for short time scale variables, and microlensing events.

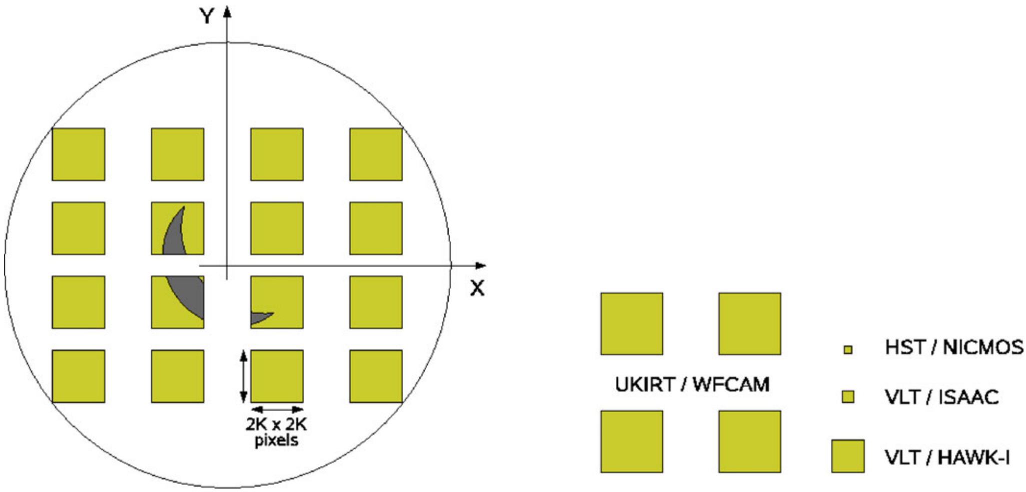

Figure 2. Diagram showing the array of 16 detectors on the VISTA camera. For comparison we also show the fields of view of UKIRT/WFCAM, HST/NICMOS, VLT/ISAAC, and VLT/Hawk-I. In the center of the detector array we sketch the moon as size reference.

• A total of 525 h (70 epochs) of K_s-band observations will be spent on the disk, following a similar strategy as for the bulge.

• During the final year we will obtain additional 12/5 epochs for bulge/disk. The observations will be spread over the full year to allow the search for long-time variables as well as high proper motion objects. The total amount of observing time is 168 h.

3. Scientific Goals

This survey was designed to investigate the 3-dimensional structure of the Galaxy bulge and inner disk, taking advantage of the much reduced absorption of near-IR light compared to optical observation. However, the data quality and extend will allow to address several other problems, some of which are noted here.

• Search for RR Lyrae in the survey area, determine periods, amplitudes and mean magnitudes. The results will be compared to those for halo variables as well as those in nearby daraf galaxies. The derived distances will be compared to those of red-clump giants, excellent tracers of the inner bar of the Milky Way (Stanek *et al.* 1994).

• Identify variable stars in known star clusters: 33 globular clusters and 355 open clusters are located in the VVV-area, containing a large variety of variable sources. For about one third of the clusters the available distances are rather uncertain. Using different types of variables found in clusters will allow us to estimate well defined cluster distances. In addition, we will be able to derive reddening values, metallicities, horizontal-branch types (Catelan *et al.* 2006, Zoccali *et al.* 2003).

• Detect eclipsing binaries: we expect to find $\sim$5x 10^5 binaries, an unmatched dataset, and determine their periods, amplitudes, and mean magnitudes. The database will be used to select extrasolar planet candidates.

• Find rare variable sources, such as cataclysmic variables, eclipsing binary RR Lyrae, luminous blue variables, pre-HB/post He-flash stars. The Galactic center contains many high energy sources, e.g. found with Chandra, or Hess, for which no optical/near-IR counterpart is known. Given that X-ray binaries are usual variable and this variability is well correlated with the one in the near -IR Russell *et al.* (2006), we can use the VVV data to derive the X-ray variability.

• Search for microlensing events, in particular highly reddened, short timescale and high magnification events. Simulations by Kerins *et al.* (2009), have shown, that the VVV survey will able to detect such events. The data will be used to derive the microlensing optical depth τ, which probes the mass distribution in the survey area.

• Monitor variability around the Galactic Center. The galactic center, including the Nuclear Ring, will be the most frequently observed region within the survey area. We expect not only to observe variability due to microlensing events (see above), but also due to black hole accretion (Chanamé *et al.* 2001).

• Search for new star clusters of different ages and identify their variable star members, such as Cepheids, semi-regular variables, W-UMa and δ Sct-type stars. The distribution of the known globular clusters in the Milky Way hints at the presence of additional, as yet undiscovered objects (Ivanov *et al.* 2005). Based on the 2MASS data, already 2 new globular clusters and hundreds of open clusters have been discovered. Our survey will reach 3-4 mag deeper in K_s and hence we expect to detect many new star clusters.

• Provide complementary near-IR multi-color information (reddening, temperatures, luminosities) and time-coverage for the following past and on-going surveys: GLIMPSE-II, VPHAS+, MACHO, OGLE, EROS, MOA, Pan-STARRS1, PLANET, LAMOST.

• Detect variable sources, and in particular RR Lyrae in the Sgr dSph galaxy. This will allow us to derive the depth and/or tilt of the galactic bulge.

• Find high proper motion objects and background QSO's. The variability study will allow us to to identify background quasars, providing an extragalactic reference scale for future proper motions.

• Identify pre-main sequence clusters and associations through variability. IR studies (Carpenter *et al.* 2001) have shown that a large fraction of all pre-MS stars are variable over a wide range of absolute magnitude, therefore a variability survey is well suited to search and identify young stellar objects.

4. Summary

Over the next 5 years we will conduct a near-IR survey aimed at the variable sources in the Milky Way bulge and inner disk. The result, an extensive catalog of variable stars, will allow us to construct a 3-D model of the inner Milky Way.

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