Vista Variables in the Via Láctea (VVV): current status and first results

R.K. Saito[1], M. Hempel[1], J. Alonso-Garcia[1], I. Toledo[1], D. Minniti[1,2], P.W. Lucas[3], J.P. Emerson[4], A.V. Ahumada[5,6,7], M.V. Alonso[6], E. Amores[11,42], R. Angeloni[1], J.I. Arias[9], R.M. Bandyopadhyay[10], R.H. Barbá[9], B. Barbuy[11], J.C. Beamin[1], L.R. Bedin[12], E. Bica[13], C.M. Bidin[22], J. Borissova[14], L. Bronfman[15], G. Carraro[1], M. Catelan[1], J.J. Clariá[6], C. Contreras[1], N. Cross[16], R. de Grijs[17,18], I. Dékány[1], J.E. Drew[3,20], C. Fariña[21], C. Feinstein[21], E. Fernández Lajús[21], R.C. Gamen[9], D. Geisler[22], W. Gieren[22], B. Goldman[23], O. González[24], G. Gunthardt[9], S. Gurovich[6], N.C. Hambly[16], M. Hanson[43], M.J. Irwin[25], V.D. Ivanov[7], A. Jordán[1], E. Kerins[26], K. Kinemuchi[9,22], R. Kurtev[14], M. López-Corredoira[27], T. Maccarone[28], N. Masetti[29], R. Mennickent[22], D. Merlo[6], M. Messineo[30,31], I.F. Mirabel[32,33], L. Monaco[8], L. Morelli[34], N. Padilla[1], T. Palma[6], M.C. Parisi[6], P. Pietrukowicz[35], G. Pietrzynski[22], G. Pignata[36], M. Rejkuba[24], A. Rojas[1], A. Roman-Lopes[9], M.T. Ruiz[15], S.E. Sale[1,14], I. Saviane[6], M.R. Schreiber[14], A.C. Schröder[37,38], M. Smith[39], L. Sodré Jr.[11], M. Soto[9], A. Stephens[41], M. Tamura[40], C. Tappert[14], M.A. Thompson[3], E. Valenti[24], W. Wiedmann[5] and M. Zoccali[1]

(Affiliations can be found after the references)

Vista Variables in the Via Láctea (VVV) is an ESO near-IR variability public survey scanning the Milky Way bulge and an adjacent section of the mid-plane. VVV observations started in October 2009 with Science Verification. Regular observations for the Period P85 have been conduced since February and it will cover a total area of 520 deg^2 in five passbands and five epochs. Here we address the first results obtained from the VVV Survey as well as the current status of the observations.

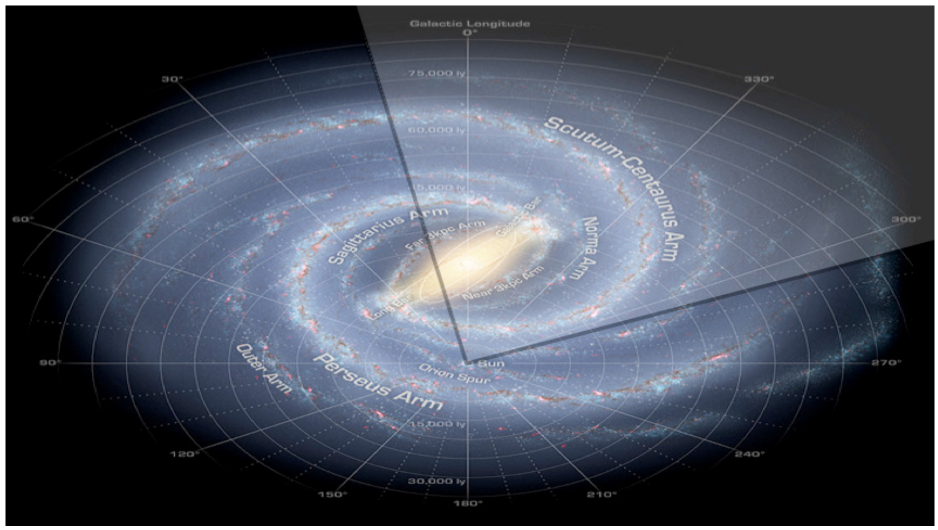

Fig. 1. *Illustration showing our Galaxy and the area being observed by the VVV Survey. (based on Fig. 16 of Churchwell et al. 2009)*

VISTA Variables in the Via Láctea (VVV) is one of the six ESO Public Surveys selected to operate with the new 4-meters Visible and Infrared Survey Telescope for Astronomy (VISTA). VVV is scanning the Milky Way bulge and an adjacent section of the mid-plane where star formation activity is high. The survey will take 1929 hours of observations during five years (2010–2014), covering ~10^9 point sources across an area of 520 deg^2, including 33 known globular clusters and ~350 open clusters. The final product will be a deep near-IR atlas in five passbands (*Z, Y, J, H* and K_s) and a catalogue of more than 10^6 variable point sources (Minniti et al. 2010). Detailed information about the VVV survey can be found at http://vvvsurvey.org/

Science Verification

VVV Science Verification (SV) data were obtained during October 19-30, 2009, following the same strategy as the later VVV survey. The observations consisted in multi-color imaging (*Z, Y, J, H* and K_s bands) for a field at Galactic coordinates L=2.2, B=-3.1. It is one of the most crowded fields in the Galactic bulge allowing us to test whether there are too many saturated stars, using the same exposure times as in the regular observations, it also contains numerous variable stars, allowing us test their detectability. Along the SV area, we took 3 extra tiles in the bulge, observed in the K_s-band since this is where the sky subtraction is most crucial and most difficult.

Regular Observations

Regular VVV observations started in February 2010 (corresponding to the ESO period P85) and will cover the total survey area in *Z, Y, J, H* and K_s passband, additional 5 K_s-band exposures will also be taken. This will provide reliable near simultaneous fluxes and colours. Table 1 shows the number of Observational Blocks (OBs) scheduled to be observed during the first period as well as the current status of the observations. OBs can contain multiple observations either in colour or epoch.

Bulge	**Planned**	**Executed**	**%**
Color ZY	196	3	2
Color JHKs	196	139	71
Variability	1004	57	6
Disk			
Color ZY	152	83	54
Color JHKs	152	152	100
Variability	760	317	42
TOTAL	**2460**	**751**	**31**

Table 1. *Overview of our observations for the first period (ESO period P85). Updated on June 30.*

The pipeline processing and calibration for the VVV data have been performed by the Cambridge Astronomy Survey Unit (CASU) and the Wide Field Astronomy Unit's (WFAU) VISTA Science Archive (VSA) in Edinburgh. The Science Archive is responsible for (i) image stacking to produce stacked and differenced tiles, and source merging, (ii) quality control, and (iii) identification of variables sources. Direct point source photometry will also be performed for the first year data in all filters to be used as reference. Our project take advantage both into the VDFS team experience handling the WFCAM/UKIRT and VISTA data, and the experience of the VVV team members who are leading participants in other surveys such as OGLE and in the routine data processing and delivery to ESO.

Fig. 2 (upper panels) shows a cutting of a VVV image for the globular cluster Palomar 6 in comparison with 2MASS (Skrutskie et al. 2006). The images were obtained combining *Z*, *H* and K_s observations. Even though the survey is not designed to detect or map emission line objects, it turns out that planetary nebulae (PN) are also prominent in the VVV images. As an example, the lower panels of Fig. 2 show the color image of the bulge PN NGC 6629, located in field centered at *L*=9.8, *B*=-5.3. The color is typical of most PN, due to the intense emission lines present in our filters, specially: SII 9069 in the *Z*-band, Paschen Beta in the *J*-band, and Bracket Gamma in the K_s-band. There would be a few hundred PN identified in our fields in the inner disk and bulge.

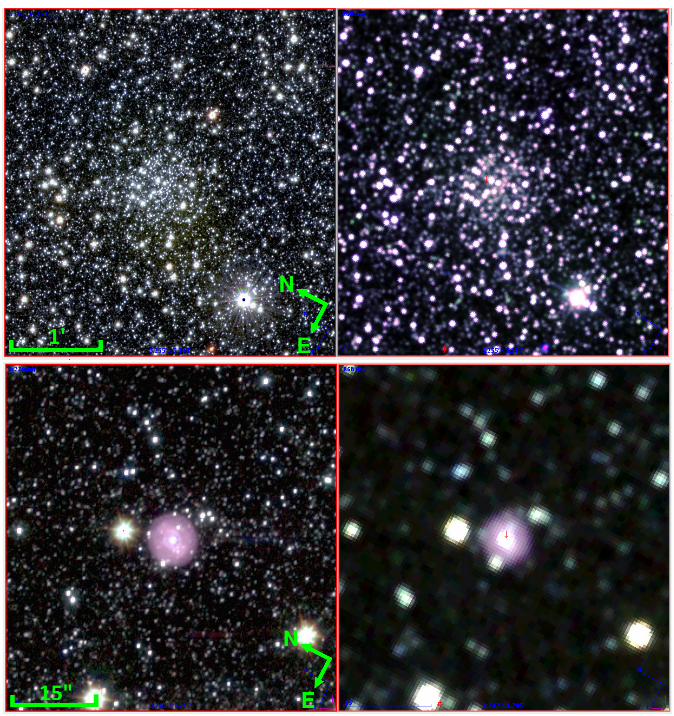

Fig. 2. *Upper panels: Comparison between VVV (left) and 2MASS (right) images for the cluster Palomar 6. Lower panels: VVV image for the planetary nebulae NGC 6629 in comparison with 2MASS.*

Color-Magnitude Diagrams

The left panel of Fig. 3 shows a Color-Magnitude Diagram (CMD) for the SV field in the bulge located at *L*=2.2, *B*=-3.1, in one of the most crowded regions of our galaxy. In spite of the high stellar density and large number of giants, accurate photometry is possible over most of the field. This figure shows the dominant bulge red giant branch along with the main-sequence of the foreground disk, and it is evident that the VVV photometry is about 4 magnitudes deeper than 2MASS in this field, almost reaching the bulge main sequence turn-off. About a million stars are measured in total in this 1.5 deg^2 field. CMDs like this one can be used to study the stellar populations across the MW bulge, as well as the 3-D structure of the inner MW.

The right panel of Fig. 3 illustrates the CMD of the first Galactic plane field observed located at *L*=295.4, *B*=-1.7, at the outskirts of Carina, with large and very inhomogeneous extinction. The disk main-sequence dominates, and numerous reddened giants are also seen. We stress that the 2MASS database is very complementary, not only provides an external calibration, but it also gives photometry for the brighter sources (K_s<10), which saturate even in the short (4 sec) VVV exposures. The depth of this VVV CMD is such that we can see all the way through the MW plane; and in fact, very often shows numerous background galaxies. There are about half a million stars measured in this 1.5 deg^2 field.

Taking into account that the VVV survey covers over 520 deg^2 in total, we would provide photometry for 5×10^8 sources for the bulge and disk of our Galaxy. CMDs of the MW plane like these can also be used to study the 3-D structure of the MW plane, as well as the spiral arms, the edge of the disk and the outer warp.

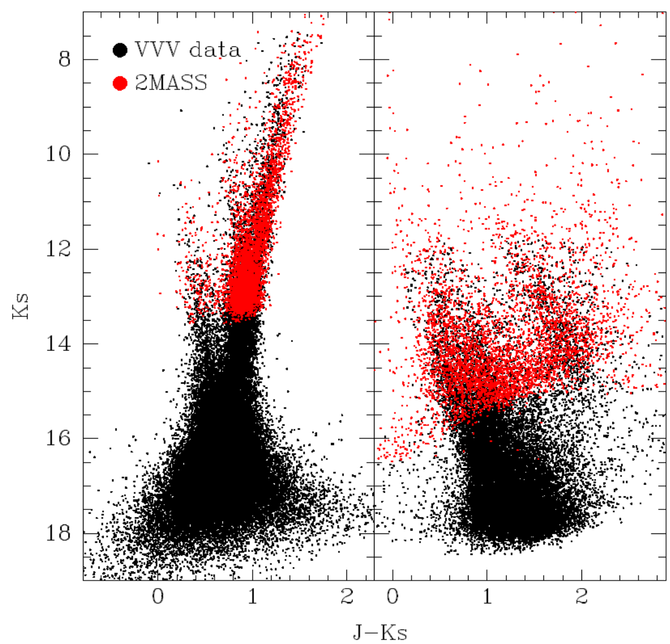

Fig. 3. *Color-Magnitude Diagrams comparing VVV data (black) and 2MASS (red) for two extreme examples. The left panel shows one of the most crowded bulge fields (SV field) while the right panel shows one of the disk fields with most heavy and inhomogeneous extinction (see text).*

First VVV RR Lyrae Light-curve

The detection of variable stars and the monitoring of their variability is the main goal of the VVV survey. In Fig. 7 we present the first light-curve for a RR Lyrae star obtained from the VVV SV data. The object corresponds to OGLE 189770, a RR Lyrae sub-type RRab with a period *P*=0.72949 days and an amplitude A_I=0.33 mag (Collinge et al. 2006). In K_s the minimum magnitude is K_s~14.2 with an amplitude A_{Ks}~0.20 mag, smaller than the observed in *I*-band.

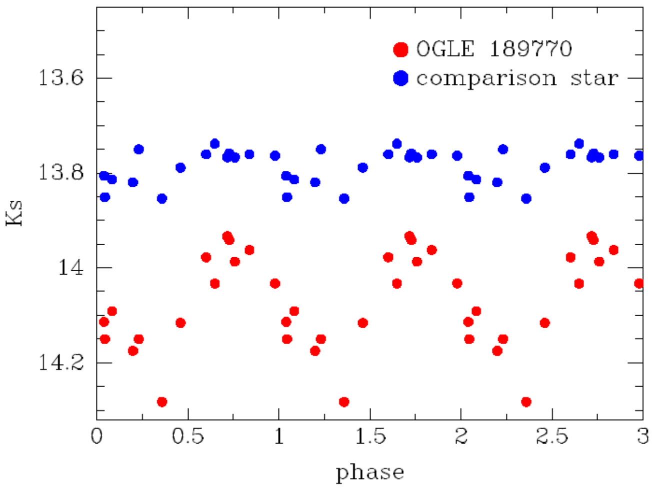

Fig. 4*. First VVV light curve of a bulge RR Lyrae obtained from the SV data. This RR Lyrae was identified from the OGLE sample, and has period P=0.72949 days (Collinge et al. 2006).*

First Moving Object

The VVV Survey will allow the detection of Solar System objects down to about K_s=18. We are searching for Trans-Neptunian Objects (TNOs), Jupiter Trojan Asteroids (L5Js), Neptune Trojan Asteroids (N5Js), Main-Belt Asteroids (MBAs), and Near-Earth Objects (NEOs). Satellite tracks are also common and readily identified, even in the short VVV exposures.

As an example, Fig. 5 shows the MBA 199 Byblis, the first moving object detected by the VVV Survey while making the color tiles. The sequence of observations in this case taken on 23 Oct 2009 was first the H-band filter (green), 3 min later the Ks-band filter (red), and finally 13 min later the Z-band filter (blue). The object was also recovered in Ks-band images acquired on 22 Oct 2009 and 24 Oct 2009. 199 Byblis shows a magnitude of K_s=12.12 and a motion of about 0.22 arcmin/day. The excellent VISTA image quality (typically FWHM < 1 arcsec) and scale (about 0.34 arcsec/pixel), would also allow us to identify high-proper motion stars with the survey baseline of 4-5 years for faint objects, and with a baseline with 2MASS of more than 10 years for bright objects. As a complementary project, we will also search for background QSOs in some selected fields, in order to provide an extragalactic frame for accurate astrometry.

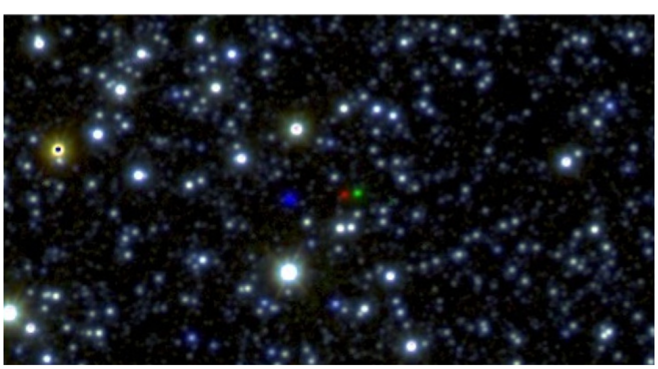

Fig. 5. *MBA 199 Byblis, first moving object detected by the VVV Survey. This is the central object in seen from left to right in filters Z (blue), K_s (red), and H (green). Bright saturated stars have K_s<10, and show a black dot in the center.*

Searching for New Clusters

One of the main goals of the VVV is to search for new star clusters of different ages. In order to trace the early stages of star clusters formation we carrying out a survey of infrared star clusters and stellar groups in the directions of known massive star formation regions associated with methanol maser emission and hot molecular cores. Using Longmore et al. (2009) list of star forming regions so far we have already identified by visual inspection 25 small star cluster candidates. Almost all of them seem to be indeed very young, because most of the mass is still concentrated in the gas. A typical example of newly identified cluster candidate is shown in Fig. 6.

Fig. 6. *Cluster candidate detected by the VVV. This cluster is located in a disk field. The faintest stars in this picture have K_s~17.*

Acknowledgements

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[1] Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Casilla 306, Santiago 22, Chile
[2] Vatican Observatory, Vatican City State V-00120, Italy
[3] Centre for Astrophysics Research, Science and Technology Research Institute, University of Hertfordshire, Hatfield AL10 9AB, UK

[4] Astronomy Unit, School of Mathematical Sciences, Queen Mary, University of London, Mile End Road, London, E1 4NS, UK
[5] Observatorio Astronómico de Córdoba, Universidad Nacional de Córdoba, Laprida 854, 5000 Córdoba, Argentina
[6] European Southern Observatory, Av. Alonso de Córdova 3107, Casilla 19, Santiago 19001, Chile
[7] Consejo Nacional de Investigaciones Científicas y Técnicas, Av. Rivadavia 1917 - CPC1033AAJ - Buenos Aires, Argentina
[9] Departamento de Física, Universidad de La Serena, Benavente 980, La Serena, Chile
[10] Department of Astronomy, University of Florida, 211 Bryant Space Science Center P.O. Box 112055, Gainesville, FL, 32611-2055, USA
[11] Universidade de São Paulo, IAG, Rua do Matão 1226, Cidade Universitária, São Paulo 05508-900, Brazil
[12] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA
[13] Universidade Federal do Rio Grande do Sul, IF, CP 15051, Porto Alegre 91501-970, RS, Brazil
[14] Departamento de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Ave. Gran Bretaña 1111, Playa Ancha, Casilla 5030, Valparaíso, Chile
[15] Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile
[16] Institute for Astronomy, The University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, UK
[17] The Department of Physics and Astronomy, University of Sheffield, Hick Building, Hounsfield Road, Sheffield, S3 7RH, UK
[18] National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing 100021, China
[19] Konkoly Observatory of the Hungarian Academy of Sciences, H-1525 Budapest, PO Box 67, Hungary
[20] Astrophysics Group, Imperial College London, Blackett Laboratory, Prince Consort Road, London SW7 2AZ, UK
[21] Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata, and Instituto de Astrofísica La Plata, Paseo del Bosque S/N, B1900FWA, La Plata, Argentina
[22] Departmento de Astronomía, Universidad de Concepción, Casilla 160-C, Concepción, Chile
[23] Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
[24] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany
[25] Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
[26] Jodrell Bank Centre for Astrophysics, The University of Manchester, Oxford Road, Manchester M13 9PL, UK
[27] Instituto de Astrofísica de Canarias, Vía Láctea s/n, E38205 - La Laguna (Tenerife), Spain
[28] School of Physics and Astronomy, University of Southampton, Highfield, Southampton, SO17 1BJ, UK
[29] Istituto di Astrofisica Spaziale e Fisica Cosmica di Bologna, via Gobetti 101, 40129 Bologna, Italy
[30] Chester F. Carlson Centre for Imaging Science, Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester NY 14623, USA
[31] The Astrophysics and Fundamental Physics Missions Division, Research and Scientific Support Department, Directorate of Science and Robotic Exploration, ESTEC, Postbus 299, 2200 AG Noordwijk, the Netherlands
[32] Service d'Astrophysique - IRFU, CEA-Saclay, 91191 Gif sur Yvette, France
[33] Instituto de Astronomía y Física del Espacio, Casilla de Correo 67, Sucursal 28, Buenos Aires, Argentina
[34] Dipartimento di Astronomia, Universitá di Padova, vicolo dell'Osservatorio 3, 35122 Padova, Italy
[35] Nicolaus Copernicus Astronomical Center, ul. Bartycka 18, 00-716 Warszawa, Poland
[36] Departamento de Ciencias Fisicas, Universidad Andres Bello, Av. República 252, Santiago, Chile
[37] Department of Physics & Astronomy, University of Leicester, University Road, Leicester, LE1 7RH, UK
[38] Hartebeesthoek Radio Astronomy Observatory, PO Box 443, Krugersdorp 1740, South Africa
[39] The University of Kent, Canterbury, Kent, CT2 7NZ, UK
[40] Division of Optical and Infrared Astronomy, National Astronomical Observatory of Japan 2-21-1 Osawa, Mitaka, Tokyo, 181-8588, Japan
[41] Gemini Observatory, Northern Operations Center, 670 N. A'ohoku Place, Hilo, Hawaii, 96720, USA
[42] Faculdade de Ciências da Universidade de Lisboa, Ed. C8, Campo Grande, 1749-016, Lisboa, Portugal
[43] Department of Physics, University of Cincinnati, Cincinnati, OH 45221-0011, USA