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VISTA VARIABLES IN THE VÍA LÁCTEA (VVV): FIRST RESULTS AND PERSPECTIVES

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RESUMEN

VISTA Variables in the Vía Láctea (VVV) es un *survey* público de la ESO para el estudio en el infrarrojo cercano de objectos variables del bulbo de la Vía Láctea y de una sección adyacente del plano del disco. El *survey* empleará 1929 horas de observaciones con el telescopio de 4 m VISTA durante cinco años $(2010-2014)$, abarcando $\sim10^9$ fuentes puntuales en una área de 520 grados^2. A continuación se muestran los primeros resultados obtenidos por el VVV Survey, así como una visión de las posibilidades para el uso de un atlas profundo en cinco bandas en el infrarrojo cercano y un catálogo de más de 10^6 fuentes variables. Esperamos utilizar los datos para encontrar tránsitos planetarios en estrellas de secuencia principal de tipo tardío. Se discuten también la búsqueda de planetas y las futuras observaciones de seguimiento.

ABSTRACT

VISTA Variables in the Vía Láctea (VVV) is a public ESO near-IR variability survey scanning the Milky Way Bulge and an adjacent section of the mid-plane. The survey will take 1929 hours of observations with the 4 m VISTA telescope during five years (2010–2014), covering $\sim10^9$ point sources across an area of 520 deg^2. Here we address the first results obtained from the VVV Survey as well as a glimpse into the possibilities for using a deep near-IR atlas in five passbands and a catalogue of more than 10^6 variable point sources. We expect to use the data to find planetary transits of late-type main-sequence stars. We discuss the planet searches and future follow-ups.

Key Words: Galaxy: bulge — Galaxy: disk — planets and satellites: general — stars: variables: general — surveys

1. INTRODUCTION

VISTA Variables in the Vía Láctea (VVV) is an ESO Public Survey selected to operate with the new 4-meter Visible and Infrared Survey Telescope for Astronomy (VISTA, Emerson & Sutherland 2010). 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 $\sim10^9$ point sources across an area of 520 deg^2. 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 in K_s-band (Minniti et al. 2010a). Detailed information about the VVV Survey can be found at `http://vvvsurvey.org/`.

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2. CURRENT STATUS AND FIRST RESULTS

While some VVV data were obtained on October 2009, during ESO Science Verification of VISTA (Arnaboldi et al. 2010), the regular observations for the first year started in February 2010 and are covering the total survey area in the five passbands. An additional five K_s-band epochs are also being taken for the whole area. About 60% of the observations scheduled for the 1st year are already secured. The data calibration is performed by the VISTA Data Flow System (VDFS) pipeline at the Cambridge Astronomy Survey Unit (CASU)[5], using unsaturated 2MASS stars present in the VVV images, even for Z and Y filters (not observed by 2MASS), for which colour equations are applied.

Among the first results obtained to date for the VVV Survey we can cite the analysis of known open clusters (Peñaloza et al. 2011); the discovery of new open and globular clusters (Minniti et al. 2010b; Borissova et al. 2011); and the study of the Galactic disk edge (Minniti et al. 2011).

[5]VISTA Surveys page at the Cambridge Astronomical Survey Unit (CASU): `http://casu.ast.cam.ac.uk/surveys-projects/vista`.

TABLE 1

JOURNAL OF THE VVV VARIABILITY CAMPAIGN

	1st year (2010)	2nd year (2011)	3rd year (2012)	4th year (2013)	5th year (2014)	Total Phase Points
Bulge	05	12	60	—	12	89
Disk	05	08	—	70	05	88

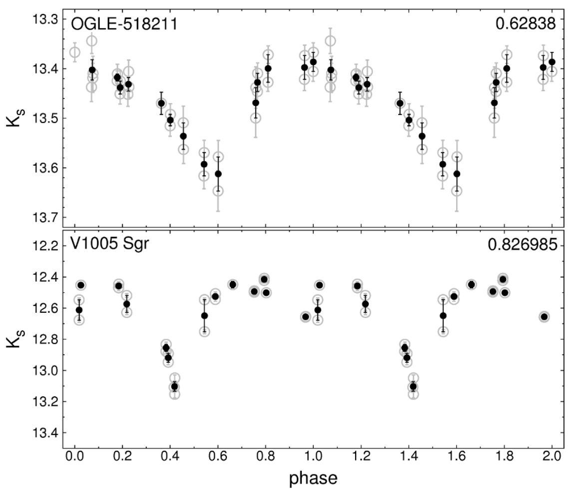

Fig. 1. Examples of VVV light curves obtained from the Science Verification data. In the top we show the light curve of OGLE-518211, a fundamental-mode RR Lyrae with a period of $P = 0.62838$ days. The bottom panel shows the light curve of V1005 Sgr, an Algol-type eclipsing binary with an orbital period of $P_{\rm orb} = 0.826985$ days. The data points are shown twice in phase for better visualization.

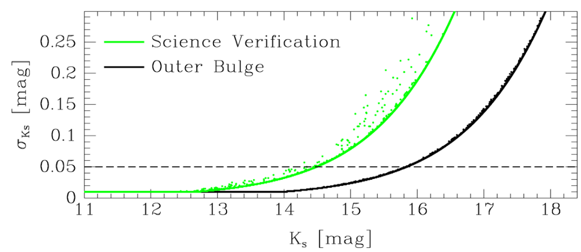

Fig. 2. Photometric accuracy as a function of magnitude for the Science Verification area and for an outer Bulge field observed during the first year of the VVV variability campaign.

3. VARIABILITY CAMPAIGN

The VVV variability campaign is being conducted in $K_{\rm s}$-band and will cover a total of five years, with a total of 89 phase epochs for the Bulge area and 88 points for the disk. Table 1 shows the observational strategy of the variability campaign. Extra observations of a few selected fields over a short timescale (i.e., 10–40 times per night) will also be taken during the fifth year. These observations will allow us to find short period variables, planetary transits and microlensing events. Our survey will give the most complete catalogue of variable objects in the inner Milky Way, with $\sim 10^6$ variables.

Figure 1 shows light curves made from the VVV data. The data used were obtained during the VISTA Science Verification, in a total of 14 $K_{\rm s}$-band phase points. In the top panel we show the light curve of OGLE-518211, a fundamental-mode RR Lyrae with a period of $P = 0.62838$ days. The object shows a minimum magnitude of $K_{\rm s} \sim 13.6$ mag, with an amplitude of $A_{K_{\rm s}} \sim 0.24$ mag. The bottom panel shows the light curve of V1005 Sgr, an Algol-type eclipsing binary with $K_{\rm s} \sim 12.4$ and an orbital period of $P_{\rm orb} = 0.826985$ days.

In order to properly classify the variable stars an automated classification scheme is currently being developed (Catelan et al. 2011). This requires high-quality, well-sampled template light curves for the many different types of variable stars that are present in the surveyed fields. Unfortunately, since the VVV Survey is the first of its type to be carried out in the near-IR, light curve templates in this wavelength range are, for the most part, not available. Thus, in parallel with the main survey, we are also building a large database of high-quality light curves for different variability classes in the $K_{\rm s}$-band, using a variety of other telescopes.

4. PERSPECTIVES ON EXTRASOLAR PLANETS STUDIES

The VVV observations will also allow us the detection of a large number of extrasolar planets, transits and microlensing events. Our simulations show that $\gtrsim 10^2$ microlensing events and $\gtrsim 10^3$ planetary transits should be detected using the five years vari-

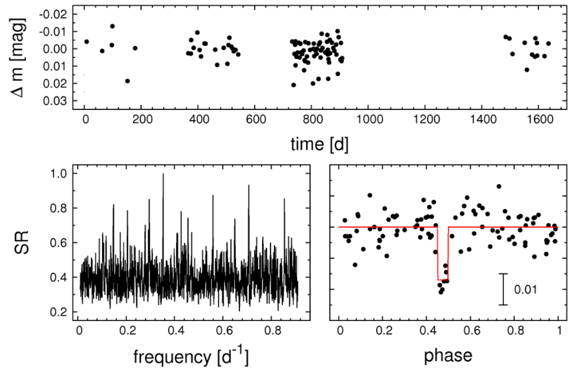

Fig. 3. Simulation of a planetary transit in the VVV five years variability campaign. The planet has a period of $P_{\rm orb} = 2.8$ days and produces an eclipse depth of 1.7%. The photometric accuracy is the typical shown by a $K_{\rm s} = 14.5$ mag stars in the Science Verification field (or $K_{\rm s} = 16.0$ mag in the outer Bulge area, see Figure 2). Top panel: light curve as a function of time, corresponding to the schedule of the $K_{\rm s}$ observations in the Bulge. The bottom-left panel shows the power spectra of the simulated data and the bottom-right panel the phase-folded light curve with the period of the transit.

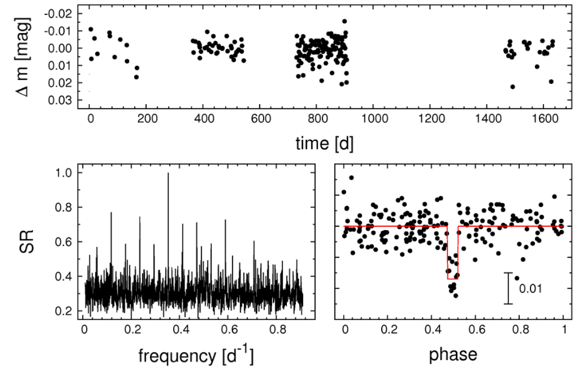

Fig. 4. Simulation of a planetary transit in the VVV five years variability campaign plus the extra observations during the fifth year (see text). The notation is similar to that of Figure 3.

ability campaign plus the extra observations in the fifth year (see § 3).

The typical transiting planets detected to date are "hot Jupiters" orbiting Sun-like stars, showing short orbital periods ($P_{\rm orb} \sim 3$ days), and eclipses depth $\gtrsim$1.5%. Beside the large area covered by the VVV Survey (520 deg^2), that will allow us to detect a large number of planetary transits; our observations will extend the planetary hunting ground beyond to 1 kpc, while the current searches using small aperture telescopes are, in general, limited to few hundred parsecs. Moreover, a large aperture IR telescope such as VISTA will even allow us to detect planets around faint low-mass stars, including late K- and M-dwarfs.

To demonstrate the high quality of the photometric data, Figure 2 shows the photometric accuracy of the VVV $K_{\rm s}$-band observations as a function of magnitude for the Science Verification area, one of the most crowded fields in the Galactic Bulge (Saito et al. 2010), and for an outer Bulge field observed during the first year of the variability campaign. In order to detect a planetary transit, the signal (difference in brightness) produced by the planet transiting in front the stellar disk must be greater than the accuracy at the given star magnitude.

In Figure 3 we show the in the top panel the simulated light curve as a function of time for a planetary transit of period $P = 2.8$ days, 1.7% deep, and the typical photometric accuracy of a $K_{\rm s} = 14.5$ mag star in VVV observations of the inner Bulge (e.g., Science Verification area), or a $K_{\rm s} = 16.0$ mag star in outer Bulge area (see Figure 2). The data points correspond to the schedule of the VVV observations in the Bulge, taking into account the seasonal change in visibility. The transit signals were simulated with pure Gaussian noise, and a frequency analysis of these signals was performed using the Box-fitting Least-Squares (BLS) method (Kovács et al. 2002), in order to test their detectability. The bottom panels of Figure 3 show the power spectra of the simulated data (bottom-left) and the phase-folded light curve with the period of the transit (bottom-right).

Figure 4 shows the simulation of the same planetary transit shown in Figure 3, but taking into account a double data points coverage, corresponding to the five years variability campaign plus the extra observations during the fifth year. A double coverage is also present on Bulge and Disk areas, in the overlapping regions between the VVV "tiles" (see Minniti et al. 2010a), in a total of $\sim$25 deg^2.

The magnitude and depth used in the simulations would correspond to a Jupiter size planet around a G2-dwarf (e.g., Sun) at the distance of $\sim$1.4 kpc. Interestingly, these parameters would also correspond to a Super-Earth planet around a M6-dwarf at the distance of $\sim$100 pc, showing the potential of the VVV survey in finding rocky planets.

Since the detection limit of the VVV observations is $K_{\rm s} \gtrsim 18$ mag (single epoch), planets around more distant stars will be detected if the relation planet/star size is greater than that the photometric accuracy at the given magnitude (e.g., a Jupiter size planet around a M-dwarf). On other hand, VVV observations saturate at $K_s \lesssim 10$, that allow the detection of even smaller rocky planets, such as Earth analogs around dwarfs in the Solar vicinity ($d < 100$ pc).

5. FOLLOW-UP OBSERVATIONS

Follow-up observations are mandatory in order to confirm the planet candidates detected by the VVV Survey. These studies can be done using the astronomical facilities located in Chile. High-cadence photometry combined with radial velocities measurements are able to define all the basics planet parameters (i.e., mass, radius, period, inclination and semi-major axis). In order to characterize faint objects the upcoming Extremely Large Telescopes (ELT's) may be used. One example is the use of the SIMPLE spectrograph for the European ELT, designed to detect atmospheric features of exoplanets during eclipses (Origlia et al. 2010).

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