The VISTA variables in the vía láctea survey and the large-scale structure of the Universe

F. Milla[1], J.L. Nilo Castellón[1,2], L. Baravalle[3,4], M.V. Alonso[3,4], C. Valotto[3,4], J. Díaz Tello[5], G. Damke Calderón[1,2] & D. Minniti[6]

[1] *Departamento de Física y Astronomía, Facultad de Ciencias, Universidad de La Serena, Chile*
[2] *Instituto de Investigación Multidisciplinario en Ciencia y Tecnología, La Serena, Chile*
[3] *Instituto de Astronomía Teórica y Experimental, CONICET–UNC, Argentina*
[4] *Observatorio Astronómico de Córdoba, UNC, Argentina*
[5] *Pontificia Universidad Católica de Chile, Chile*
[6] *Universidad Andrés Bello, Santiago, Chile*

Contact / fmilla@userena.cl

Resumen / Presentamos algunos resultados respecto a la búsqueda de fuentes extragalácticas localizadas detrás de la Vía Láctea, basado en datos en el infrarrojo cercano proporcionados por el relevamiento público VISTA Variables en la Vía Láctea. Aplicamos un algoritmo que combina parámetros morfológicos y fotométricos para la detección de fuentes extendidas de naturaleza extragaláctica en cuatro regiones de más baja extinción Galáctica. Hemos detectado cientos de galaxias nunca antes vistas, cúmulos de galaxias y el indicio de una estructura mayor en la dirección del Cúmulo de Norma.
Los buenos resultados hasta ahora obtenidos, nos permitirán extender nuestra búsqueda de objetos extragalácticos a todo el disco Galáctico del relevamiento VVV y su extensión, VVVx.

Abstract / We present some results about the search for extragalactic sources located behind the Milky Way, based on near-IR data provided by VISTA Variables in the Vía Láctea Survey. We applied an algorithm that combines morphological and photometric parameters for the detection of extended sources of extragalactic nature in four regions at lower Galactic extinction. We have detected hundreds of galaxies never seen before, clusters of galaxies and the trace of a major structure in the direction of Norma Cluster.
The good results so far obtained, will allow us to extend our search for extragalactic objects in the Galactic disk of the VVV survey, and its extension, VVVx.

Keywords / catalogs — galaxies: fundamental parameters — galaxies: photometry — surveys

1. Introduction

The Large-Scale Structure (LSS) in the Universe is important to understand how the mass distribution at early times evolved through gravitational instabilities of small fluctuations to the *cosmic web*. This is a mixture of clustered halos, dense peaks of matter connected by filaments, sheets and voids (Zeldovich, Einasto & Shandarin, 1982). The effects generated by this composition create local disturbances to the expansion of the Universe inducing coherent flows of matter in some directions. These flows are present in the movements of the nearby Universe, printed on the map of Cosmic Microwave Background radiation (CMB; Planck Collaboration et al., 2014) as a dipole in the anisotropy distribution map.

In order to study the distribution and dynamics of the LSS of the nearby Universe, we need to find and map the extragalactic sources in all the sky regions. For many years the Milky Way (MW) put a serious limitation to the mapping of the galaxy distributions. Galactic dust distributed along the disk and bulge increases at low Galactic latitudes and towards the Galactic center dimming the radiation coming from the extragalactic sources behind the MW. This area is known as the Zone of Avoidance (ZoA; Shapley, 1961).

In the past, Kraan-Korteweg & Lahav (2000) reviewed the search of galaxies in the ZoA ($| b |< 20°$), where they found more than 8 000 new galaxy candidates in the direction of the CMB radiation dipole using optical, near-IR, far-IR, radio and X-ray wavelengths. Also, the Two Micron All Sky Survey (2MASS; Skrutskie et al., 2006) covered the 91 % of the sky at bright limiting magnitudes. The 2MASS Redshift Survey (2RS; Huchra et al., 2012), presented one of the more detailed maps of the local Universe based on the spatial distribution of more than 43 000 galaxies within a radius of 300 Mpc (97.6 % of completeness) and limiting magnitude of $K_s = 11.75$ mag.

Although earlier efforts, the map of the LSS is still incomplete and important signs of structures encourage new studies. In this project, we propose to contribute to the study of the distribution of galaxies analyzing the near-IR data provided by one of the deepest surveys available on the bulge and the region of the disk of the MW: The VISTA Variables in the Vía Láctea Survey (VVV; Minniti et al., 2010).

2. The IR Data

The VVV is a public European Southern Observatory (ESO) near-IR variability survey carried out at the VISTA telescope in Chile, using five near-IR bands (Z, Y, J, H, K_s). VVV covered two sections of the MW divided in 196 regions (or tiles) in the bulge ($-10° < l < +10°$ and $-10° < b < +5°$), and 152 in the disk ($-65° < l < -10°$ and $-2° < b < +2°$), producing an area of 562 square degrees, with 348 of them covering an important section of the ZoA.

Since the main goal of VVV survey is to identify stellar variability in the Galaxy, the photometry generated by Cambridge Astronomy Survey Unit (CASU) is oriented to stellar types. In this frame, it becomes necessary to generate our own catalogs to obtain morphological parameters of the detected sources.

Our work is based on the application of high performance computational techniques, on near-infrared images provided by the VVV survey. We applied SExtractor v2.19.1 (Bertin & Arnouts, 1996) + PSFEx v3.17 (PSF Extractor; Bertin 2011) on the VVV images to obtain astrometric, photometric and morphological parameters of the sources in the Y, Z, J, H and K_s passbands.

To separate the extended sources from the stellar objects, we followed the procedure described in detail in Baravalle et al. (2018). The algorithm first identify extended sources by a combination of several morphological parameters such as the radius that contains 50 % of the total flux $R_{1/2}$, the concentration index (C; Conselice et al., 2000), and the parameters *CLASS_STAR* and *SPREAD_MODEL*. The magnitudes and colors obtained were corrected by extinction along the line of sight using maps of Schlafly & Finkbeiner (2011) and Catelan et al. (2011) for the VVV IR passbands. Some extended sources are detected in passbands at longer wavelengths (J, H, K_s) and are very faint or not visible at shorter wavelengths (Z, Y), while the stellar objects are visible in the five passbands of the survey. SExtractor + PSFEx may confuse faint objects with single objects or clump of stars in the MW. To minimize the false detections the color criteria were added: $0.5 < (J - K_s) < 2.0$ mag; $0.0 < (J - H) < 1.0$ mag; $0.0 < (H - K_s) < 2.0$ mag and $(J - H) + 0.9(H - K_s) > 0.44$ mag. If the source has detections in Z and Y passbands, it should also satisfy: $-0.3 < (Y - J) < 1.0$ mag and $-0.3 < (Z - Y) < 1.0$ mag.

3. Results

We applied the mentioned procedure in four regions of interest behind the MW disk.

The first two (tiles d010 and d115) are described in Baravalle et al. (2018). They are at low Galactic extinctions (K_s-values lower than 1 mag) with no previous detections in other surveys as the Extended Source Catalog (2MASSX; Jarrett et al., 2000). We found 345 and 185 extragalactic candidates, for the tiles d010 and d015, respectively, resulting in a total of 530 sources, all visually inspected and confirmed to be galaxies (Baravalle et al., 2018).

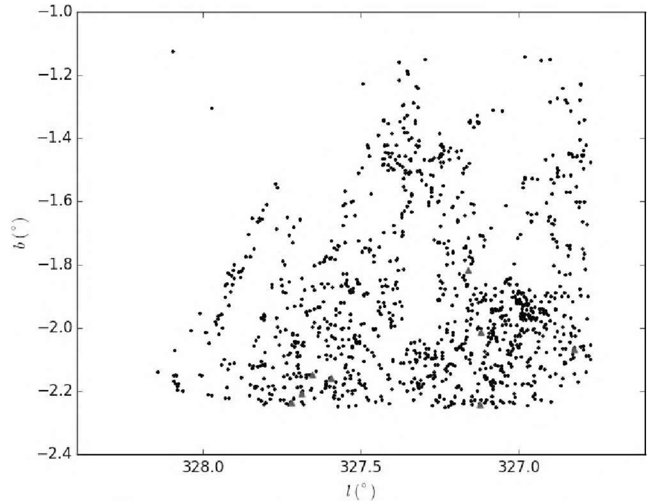

Figure 1: Spatial distribution of the extragalactic objects detected in tile d023. Red triangles correspond to the sources below.

The third studied tile, d015 contains 933 extragalactic sources detected (Baravalle et al., 2019). For the first time, using only photometric data we found a cluster of galaxies VVV-J144321-611754 based on the clustering analysis and the presence of the cluster Red Sequence (RS; Yee, Gladders & López-Cruz 1999). In a region of 30 × 30 $arcmin^2$, centered in the brightest galaxy, 25 extragalactic sources were detected and visually inspected. The median morphological parameters and near-IR colors of these galaxies are: $R_{1/2} = 1.59 \pm 0.16$ *arcsec*; C = 3.01 ± 0.08; $\epsilon = 0.30 \pm 0.03$; Sersic index, n = 4.63 ± 0.39; (H - K_s) = 0.34 ± 0.05 mag; (J - H) = 0.57 ± 0.08 mag and (J - K_s) = 0.87 ± 0.06 mag. They are consistent with the properties of early-type galaxies. We estimated the photometric redshift of the brightest galaxy as $z = 0.196 \pm 0.025$ modeling the spectral energy distribution (Mancone & Gonzalez, 2012). For the two brighter galaxies we also obtained spectroscopic data using the near-IR imaging spectrograph, FLAMINGOS-2 at Gemini South telescope, in the long-slit, low resolution R ∼ 1200 mode. The estimated spectroscopic redshift of the concentration is $z = 0.234 \pm 0.022$ and we performed the K-correction to obtain the RS in the rest-frame near-IR color–magnitude diagram. The obtained slope is consistent with a galaxy cluster at redshift of 0.2. Based on all these results, we conclude that the galaxy concentration VVV-J144321-611754 found in the VVV tile d015 is a bona fide galaxy cluster.

The fourth tile, d023 was selected to start the study of the galaxy distribution in the Norma region. After a visual inspection of the tile, we applied the photometric procedure of Baravalle et al. (2018). Here we found over 500 extragalactic candidates with a half-light radius of about 5 *arcsec*. Our preliminary analysis is consistent with their results. Fig. 1 shows the distribution of the extragalactic candidates of the d023 tile in Galactic coordinates. The spatial distribution is not uniform. For instance, the left-upper part has empty regions with higher extinctions (A_{Ks}=0.045) and the right-bottom part has clear concentrations with lower extinctions (A_{Ks}=0.018). There is also a prominent concentration at (l,b) = (326.97°, -1.96354°) corresponding to 41 detected sources. This strong distribution in the south-west region of the tile, probably is an indicative of *a bridge structure* that begins in the Norma Cluster (Kraan-Korteweg et al., 1996) and emerges at (l,b) = (323°, +2°). Fig. 2 shows color-composed images of some examples of the extragalactic sources represented with red triangles in Fig. 1. We will continue this work by analyzing an adjacent area to the tile d023 (300° < l < 330° and -2° < b < 2°), corresponding to 83 tiles in order to determine a major structure behind the disk of the MW.

4. Final Comments

Using the morphological and photometric methodology to find extragalactic sources we expect to increase the number of galaxies behind the MW. As part of this project, our main goal is to study the galaxy distribution in the projection of Norma Cluster. We will also use clustering techniques that allow us to separate real extensive, concentrated galaxy clusters from the distributions. We plan to search for extragalactic sources in the Galactic disk of the VVV survey and the extension (VVVx), and map the Large-Scale Structure in the nearby Universe beyond the Milky Way.

Acknowledgements: We are grateful to have access to the data of the ESO Public Survey (Program ID 179.B-20002) obtained with the VISTA telescope, and data products from the Cambridge Astronomical Survey Unit (CASU). Also, we thank to the organizing committee for the opportunity to present our work, the grant awarded for participation and University of La Serena for the financial support from Programa DIDULS PT17145.

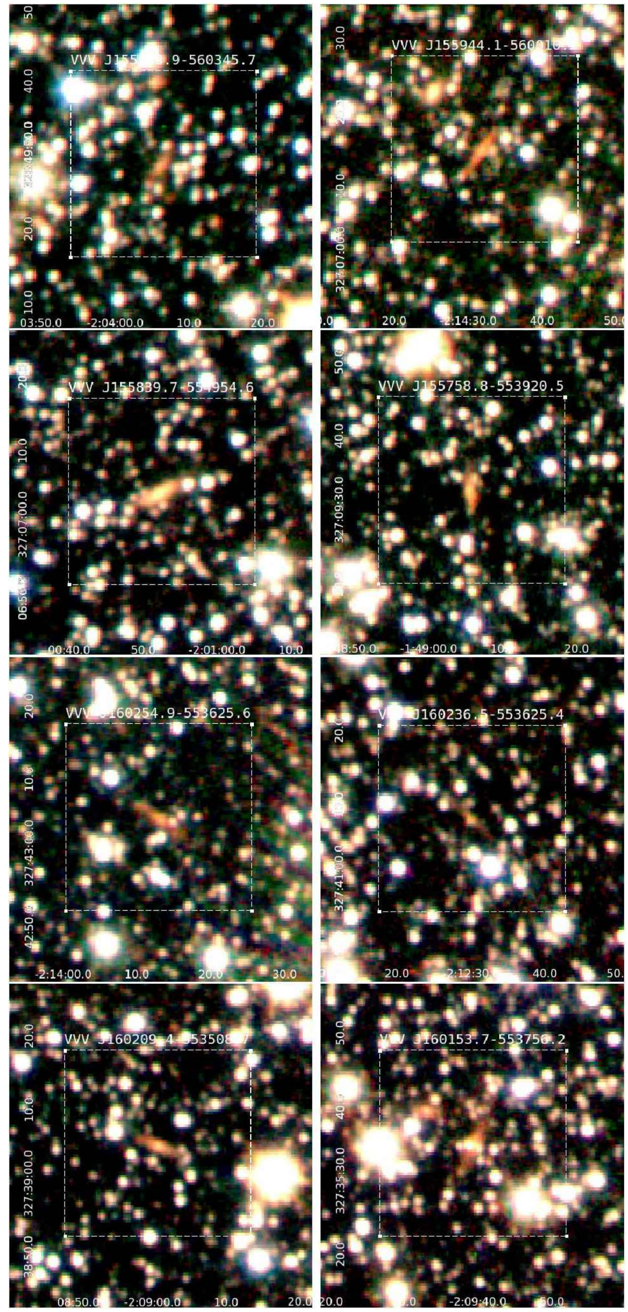

Figure 2: Color-composed images (J, H and K_s) of the extragalactic sources detected in tile d023 and represented by red triangles in Fig. 1. Each image has a box size of 44×44 arcsec^2. White dashed-line box represents an area of 25×25 arcsec^2.

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