VVV WIN 1733–3349: a low extinction window to probe the far side of the Milky Way bulge

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ABSTRACT

Windows of low extinction in the Milky Way (MW) have been used along the past decades for the study of the Galactic structure and the stellar population across the inner bulge and disk. Here we report the analysis of another low extinction near-IR window discovered by the VISTA Variables in the Vía Láctea Survey. VVV WIN 1733–3349 is about half a degree in size and is conveniently located right in the MW plane, at Galactic coordinates \((l, b)\) = \((-5.2, -0.3)\). The mean extinction of VVV WIN 1733–3349 is \(A_{Ks} = 0.61 \pm 0.08\) mag, which is much smaller than the extinction in the surrounding area. The excess in the star counts is consistent with the reduced extinction, and complemented by studying the distribution of red clump (RC) stars. Thanks to the strategic low-latitude location of VVV WIN 1733–3349, we are able to interpret their RC density fluctuations with the expected overdensities due to the presence of the spiral arms beyond the bulge. In addition, we find a clear excess in the number of microlensing events within the window, which corroborates our interpretation that VVV WIN 1733–3349 is revealing the far side of the MW bulge.

Key words: Galaxy: bulge — Galaxy: structure — dust, extinction — Surveys — Catalogues

1 INTRODUCTION

Windows of low extinction in the Milky Way are very important in Astronomy. A classical example, relevant to the study of star forming regions, is the low optical extinction window that allowed the deep exploration of the innermost part of the Orion Giant Molecular Cloud revealing the secrets of the Trapezium cluster and imaging the first protoplanetary disks with the Hubble Space Telescope (HST; O’dell, & Wen 1994; O’dell, & Wong 1996). Another important example is Baade’s window, an optical extinction window of roughly half a degree in size centred at Galactic coordinates \((l, b) = (1, -4)\) deg, that allowed the study of the bulge stellar populations (Baade 1946; Baade, & Gaposchkin 1963; Blanco, & Blanco 1985) and it continues to be used as a reference field due to its detailed characterisation (see Barbuy et al. 2018 for a review).

Some other well known examples of low extinction windows used to study Galactic structure and stellar populations are: Sgr windows (Baade, & Gaposchkin 1963; Lloyd Evans 1976), Plaut’s window (Plaut 1970; Oort, & Plaut 1972).
The advent of large IR surveys such as the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006), the VISTA Variables in the Vía Láctea Survey (VVV; Minniti et al. 2010) in the near-IR, the Spitzer Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE; Benjamin et al. 2003), and the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) in the mid-IR, enabled to make detailed reddening and extinction maps, to obtain a more global view of inner Galactic structure and stellar populations, and also to search for additional windows of low extinction located at low Galactic latitudes.

Our VVV Survey in particular has recently produced a variety of extinction maps towards the Galactic bulge (Gonzalez et al. 2011, 2018; Schultheis et al. 2014; Minniti et al. 2014, 2018; Alonso-Garcia et al. 2018; Soto et al. 2013, 2019). Using these near-IR extinction maps we have recently reported the discovery of VVV WIN 1713–3939 (a.k.a. Dante’s window), located at (l, b) = (347.4, –0.4) deg, that allowed the identification of the spiral arm structure in the far side of the Milky Way (Minniti et al. 2018).

In this paper we present the characterisation of another low extinction near-IR window of roughly half a degree in size, located in the Galactic plane at Galactic coordinates (l, b) = (−5.2, −0.3) deg, that exhibits not only an overdensity in the star counts, but also a clear excess of microlensing events with respect to its surrounding regions.

2 OBSERVATIONS

The ESO VISTA Variables in Vía Láctea (VVV) survey has recently completed near-IR observations of 562 sq. deg. area of the MW bulge and the adjacent plane. The VVV strategy consisted in two sets of quasi simultaneous observations of the MW bulge and the adjacent plane. The VVV strat-

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Figure 2. $K_s$ vs $(J - K_s)$ colour magnitude diagram (CMD) for the window (left-panel) and control field (central-panel). In the CMD for the control field a dashed line mark the slope of $A_{K_s} = (0.612 \pm 0.018) \times E(J - K_s)$ measured for the reddening vector. Top-right panel: distribution of selected RC versus distance moduli of VVV WIN 1733–3349 (blue line) and of the control field (red line). The polynomial fit used to subtract the background LF of VVV WIN 1733–3349 is also shown with a dashed line. Bottom-right panel: multi Gaussian fit for the distribution of window RC stars after subtracting a polynomial fit to the luminosity function. Information about the three peaks are listed in Table 1.

The extinction is roughly twice as in the window, with $A_{K_s} = 1.20 \pm 0.18$ mag. This symmetric area at positive latitude can be used as a control field because there is negligible disk warping at these coordinates (e.g., Momany et al. 2006). Considering similar stellar populations in both regions above and below the plane (window and control field, respectively), the differences observed in comparing them can be interpreted as caused by different extinction levels.

Fig. 2 shows the $K_s$ vs $(J - K_s)$ colour magnitude diagram (CMD) for VVV WIN 1733–3349 (left-panel) and the control field (right-panel). The difference in the extinction level is remarkable, with the CMD for the control field stretched along the reddening vector. While producing the CMDs, an examination on the stellar density shows a higher density of sources within WIN 1733–3349 in all VVV filters when compared to the control field. Indeed, the stellar density in the window is about two times larger than that of the control field. The difference in the stellar density is even larger in the optical Gaia DR2 data (Gaia Collaboration et al. 2018), with about four times more stars within the window compared with the control field. Similar ratio is also seen in the optical Pan-STARRS1 (Chambers et al. 2016) and DECaPS data (Schlafly et al. 2018).

Fig. 3 presents in the mid panel a density map for the optical Gaia DR2 data. The spatial distribution shows an overdensity in agreement with the location and size of the of WIN 1733–3349 as seen in the extinction map (see Fig. 1). The distribution in distance for the Gaia DR2 sources according to Gaia DR2 as $M_{K_s} = -1.605 \pm 0.009$ and $(J - K_s)_0 = 0.66 \pm 0.02$ mag (Ruiz-Dern et al. 2018) and the slope of the reddening vector measured directly from the control field CMD which yields to $A_{K_s} = (0.612 \pm 0.018) \times E(J - K_s)$. With those values the distance modulus for the RC stars is given by $\mu = -5 + 5 \log d(pc) = K_s - 0.612 \times (J - K_s) + 2.009$ mag. The slope of the reddening vector is flatter than $A_{K_s} = 0.725 \times E(J - K_s)$ from Schlegel et al. (1998), but steeper than $A_{K_s} = 0.528 \times E(J - K_s)$ from Nishiyama et al. (2009). These values are much steeper than the slope in Alonso-Garcia et al. (2017) and Minniti et al. (2018), where $A_{K_s} = 0.428 \times E(J - K_s)$ and $A_{K_s} = 0.484 \times E(J - K_s)$, re-
respectively. The use of a different extinction law causes the distance scale to shrink/expand.

The luminosity function (LF) for the WIN 1733–3349 RC stars compared with the control field RC stars is shown in the top-right panel of Fig. 2. The distributions are quite different, with many more RC stars in the window LF, which peaks much farther when compared with the control field and presents a composite distribution. In order to subtract the background and enhance possible peaks of the RC along the line of sight, in order to subtract the background and enhance possible peaks of the RC along the line of sight, we applied a polynomial + multi Gaussian fit, as shown in the bottom-right panel of Fig. 2. The resulting peaks due to the different RC are fitted with a Levenberg-Marquardt optimization algorithm (e.g., Kanzow et al. 2004) in order to obtain their mean distances and respective standard deviations, which are listed in Table 1.

At the magnitude range of the fainter RC stars the completeness of the VVV PSF data on Galactic plane is over 80% (e.g., Saito et al. 2012; Surot et al. 2019). Following the discussion presented in Gonzalez et al. (2018), we assume that secondary peaks in the RC distributions are not caused by the red giant branch bump (e.g., Nataf et al. 2011, 2013). In contrast with the distances from Gaia DR2 as estimated by Baier-Jones et al. (2018), the distances to the RC giants measured from the VVV near-IR photometry clearly penetrates through the Galaxy, out to ~14 kpc. Using a flatter reddening vector in our calculations scales the RC distribution even to larger distances. For instance, with $A_{K_S} = 0.428 \times E(J - K_s)$ from Alonso-García et al. (2017) the distances to the RC are ~15% larger. This difference in slopes with previous VVV measurement could be due to the small number of RC stars at a given color in our control field, which, along with the relative closeness of the RC of the bulge and of the background spiral arm at these longitudes (Minniti et al, in prep.), complicates its accurate measurement.

### 3.2 Microlensing

Navarro et al. (2018, 2019) searched for microlensing events in bulge fields along the Galactic plane. They discovered several hundreds of events in a large area covering about 21 sq. deg. (within $-10.00 < l < +10.44$ deg, and $0.46 < b < +0.65$ deg). The analysis of the spatial distribution of these microlensing events revealed an unexpected excess in the surface density of events at $(l, b) = (-5.2, -0.3)$ deg, in an area that corresponds to the location of the present window (see Fig. 4). This excess in the number density of events above the neighboring area is a 3 sigma result.

The traditional microlensing configurations (bulge-bulge, bulge-disk and disk-disk events) should produce an excess of events in the very center of the MW due to the higher stellar density (Navarro et al. 2017), but not in this area. The most straightforward explanation is that we are seeing all the way through the bulge, including additional events that have lenses in the bulge and sources in the far disk. The first event with this new far disk-bulge event configuration was discovered by the United Kingdom Infrared Telescope Survey (UKIRT) at $(l, b) = (-0.12, -0.33)$ (Shvartzvald et al. 2017, 2018). Another candidate for far disk event at very low latitude was reported by Bennett et al. (2018) at $(l, b) = (0.90, -1.97)$. A more comprehensive study seems to be confirmed by the larger estimated distances of the RC sources in this region (Navarro et al. 2020, in preparation).

We take this excess number of microlensing events in this area as additional evidence supporting the conclusion that VVV WIN 1733–3349 is a window of low near-IR extinction piercing deep through the entire bulge region.

### Table 1. Distances for the RC peaks from the multi Gaussian + polynomial fit to the window RC luminosity function.

| RC peaks | Interpretation                  |
|----------|---------------------------------|
| $\mu (K_s)$ [mag] | Dist. [kpc] |
| 14.376 ± 0.373 ($-13.51$) | 7.50 | Scutum-Centaurus arm |
| 14.988 ± 0.742 ($-14.13$) | 9.94 | Galactic bar |
| 15.689 ± 0.236 ($-14.85$) | 13.73 | Sagittarius arm |

### 4 CONCLUSIONS

We present the further characterisation of another window of low extinction in the Galactic bulge, VVV WIN 1733–3349 (a.k.a. Oscar’s window). This window is strategically located in the plane, at $(l, b) = (-5.2, -0.3)$ deg, and has a diameter of about 24’. The window is clearly seen in the VVV extinction maps for the region as well as in the distribution of Gaia DR2 sources.

We use the deep VVV PSF photometry to measure the
distance distribution of RC giants along the line of sight. The RC giants can be seen out to \( \sim 14 \) kpc, in the far disk well beyond the bulge. A multi Gaussian fit shows the presence of three peaks, interpreted as the Scutum-Centaurus arm in the foreground disk, the Galactic bar and the Sagittarius arm (that is seen wrapping around behind the Galactic centre), at the distance of \( d = 7.06, 9.37 \) and \( 12.92 \) kpc, respectively. The distance of the Galactic bar and the Sagittarius arm coincide with distances for RC stars measured by Gonzalez et al. (2018) for the region within \( |b| < 1.5 \) deg.

We also find a clear excess of microlensing events in this window from the sample of Navarro et al. (2018, 2019), that is probably due to additional events that have lenses in the bulge and sources in the far disk. That is in agreement with our interpretation of the RC distribution, revealing the far side of the Milky Way bulge.

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