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# SUB-STRUCTURES IN THE MILKY WAY'S HALO TOWARDS VIRGO

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## RESUMEN

Estudiamos la distribución de velocidades radiales de estrellas RR Lyrae en la misma región del cielo en donde SDSS ha detectado una gran sobre-densidad de estrellas de la secuencia principal. Nuestros resultados indican que varias corrientes estelares separadas coexisten en la región y que algunas de ellas podrían estar relacionadas con estructuras más distantes reportadas en otros trabajos. Ninguna de las estructuras detectadas en este trabajo parece estar relacionada con la cola de marea delantera de la galaxia enana de Sagitario.

## ABSTRACT

We study the distribution of radial velocities of RR Lyrae stars in the same region of the sky where a large overdensity of main sequence stars have been detected by SDSS. Our results indicate that several independent stellar streams co-exist in the region and that some of them may be related with more distant features reported in other works. None of the features we detect seem to be related with the leading tail of the Sagittarius dwarf galaxy.

*Key Words:* Galaxy: halo — Galaxy: kinematics — Galaxy: structure — stars: variables: other

## 1. INTRODUCTION

In the hierarchical models of formation of galaxies, large galaxies like the Milky Way formed trough multiple mergers of small building blocks. These models predict the existence of sub-structures in the present day halos of galaxies, which are the remains of ancient mergers (see for example Bullock & Johnston 2005). In recent years, sub-structures have been indeed detected in the halo of the Milky Way (Vivas et al. 2001; Newberg et al. 2002; Majewski et al. 2003; Vivas & Zinn 2006; Belokurov et al. 2006, among others). These features are interpreted as debris from small galaxies or globular clusters disrupted by the tidal forces of our Galaxy. Undoubtedly, the streams associated with the disrupting Sagittarius (Sgr) dwarf spheroidal (dSph) galaxy are the most prominent in the halo of the Milky Way, crossing over all the sky (Majewski et al. 2003).

Here we investigate the kinematics of bright RR Lyrae stars (RRLS) from the QUEST survey in the direction of the Virgo constellation. The region is interesting because the following halo sub-structures have been found at different distances, and the relationship among them, if exists, is not clear:

- An excess of RRLS around 19 kpc was found by the QUEST survey (Vivas et al. 2001; Vivas 2002). Several of those stars share a common velocity in the sky, the *Virgo Stellar Stream* (VSS, Duffau et al. 2006).
- SDSS revealed an excess of F-type (halo turnoff) stars (S297+63-20.5) at about the same distance and location as the RRLS overdensity (Newberg et al. 2002). SEGUE spectroscopy of stars in this group shows many of them have a similar (but not equal) velocity as the VSS. Other velocity sub-sub-structures are also present in the region (Newberg et al. 2007).
- More recently, Jurić et al. (2008) found a huge ($\sim$ 1000 sq deg) overdensity of main sequence stars (*the Virgo Overdensity, VOD*) in the same direction of the sky but spanning a larger distance range (6 to 20 kpc) than either the VSS or S297+63-20.5.
- Part of the Sgr stream lies in the background of the above features, at $\sim$ 50 kpc (Vivas & Zinn 2006). Some models predict that the leading tail would be detected in this region at the same distances as the VOD (Martínez-Delgado et al. 2007).

The stars we are studying here have distances from the Sun $<$ 12.5 kpc. Thus, they lie in front of both VSS and S297+63-20.5, but overlap the VOD. Our goal is to investigate the origin of the VOD, and the posibble link among the above sub-structures.

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## 2. OBSERVATIONS

We obtained spectra of 44 QUEST RRLS (Vivas et al. 2004) brighter that $V_0 = 16.1$, and in the range of right ascension $169\overset{\circ}{.}5 < \alpha < 212\overset{\circ}{.}3$ which is the region overlapping with the VOD. The observations were obtained with the SMARTS 1.5 m telescope at CTIO, the 1.5 m telescope at La Silla, and the WIYN telescope at KPNO. Details of the observations and the methods for measuring radial velocities and metallicities can be found in Vivas et al. (2008).

## 3. RESULTS

Shaded histograms in Figure 1 show the distribution of radial velocities of the RRLS in the galactic rest frame, $V_{\rm gsr}$, in three distance bins. The velocities of the RRLS in the two lower panels do not behave as normal distributions. Several peaks are detected, indicating that different features coexist in this region. The peaks are reinforced when plotting the velocities of 38 blue horizontal branch (BHB) stars in the region (dotted histograms), most of which come from SDSS data (Sirko et al. 2004), and a few ones come from our own QUEST photometry (Vivas et al. 2008). Although RRLS and BHB stars do not trace exactly the same type of stellar populations, both types are found (with different ratios) in most of the dSph galaxies around the Milky Way. Thus, any velocity sub-structure may be seen more clearly by combining both samples.

The most remarkable feature in our data is an excess of stars with very high positive velocity ($\sim +215$ km s$^{-1}$). Very few halo stars are expected to have such high velocities, and we find 19% of our RRLS have $V_{\rm gsr} > +180$ km s$^{-1}$. The narrow metallicity range of the RRLS in this group ( $\langle[{\rm Fe/H}]\rangle = -1.55$, $\sigma = 0.15$ dex) suggests the group is debris from a disrupted globular cluster, rather than from a dwarf galaxy. Other remarkable feature appears at $V_{\rm gsr} = -65$ km s$^{-1}$ and $6.5 < r_\odot < 10.5$ kpc. This is the most populated group we find in our data. Other, more marginal, group detections are located at velocities $-174$ and $+143$ km s$^{-1}$, both present in the most distant bin (lower panel). The last one may be an extension toward shorter distances of the VSS and/or S297+63-20.5. Similar velocity peaks are seen among more distant F stars studied by Newberg et al. (2007).

Our data indicates that the VOD, rather than a single merging event, seems to be explained as the collection of several sub-structures that co-exist in the same region of the sky.

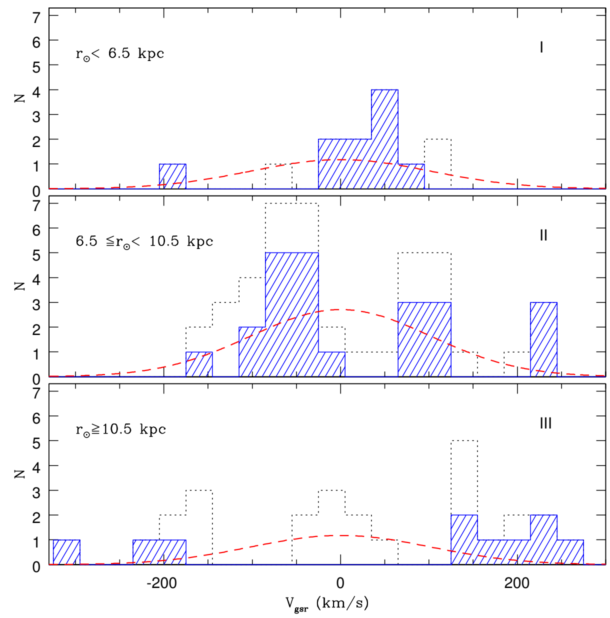


Fig. 1. Histogram of $V_{\rm gsr}$ of RRLS (shaded) and BHB stars (dotted line) in three bins of distance from the Sun $r_\odot$. The Gaussian curve represents a smooth halo normalized to the number of RRLS in each bin of distance.

The lack of stars with highly negative velocities in our data rejects the claims that the VOD is part of the Sgr leading tail falling onto the solar neighborhood, as it was proposed by Martínez-Delgado et al. (2007).

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