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Halo Structure Traced by SDSS RR Lyrae

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Abstract. We discuss the density and radial velocity distributions of over 3000 RR Lyrae stars selected by various methods using Sloan Digital Sky Survey data for about 1000 deg^2 of sky. This is more than 20 times larger a sample than previously reported by SDSS (Ivezić et al. 2000), and includes RR Lyrae stars out to the sample limit of 100 kpc. A cut-off in the radial distribution of halo RR Lyrae at ∼50–60 kpc suggested by the early SDSS data appears to be a statistical anomaly confined to a small region (∼100 deg^2). Despite the large increase in observed area, the most prominent features remain those associated with the Sgr dwarf tidal stream. We find multiple number density peaks along three lines of sight in the Sgr dwarf tidal stream plane that may indicate several perigalactic passages of the Sgr dwarf galaxy.

1. The Sample

The Sloan Digital Sky Survey (SDSS) is making significant contributions to studies of Galactic structure. Extensive information about the SDSS can be found in Azebajian et al. (2003, and references therein). Here we discuss a sample of 3127 candidate RR Lyrae stars selected in ∼1000 deg^2 of sky using color and variability information obtained from multiple SDSS imaging and spectrophotometric data. Details about the selection of candidate RR Lyrae stars using SDSS can be found in Ivezić et al. (2000, hereafter I00). This new sample is over 20 times larger than that analyzed by I00, and offers significant new clues about Galactic halo structure. The estimated sample completeness is about 35%, and its efficiency (the fraction of true RR Lyrae stars) is about 90%. Additional analysis of the same sample is presented in a companion paper (Ivezić et al. 2003, hereafter I03). Here we attempt to answer the following questions:

- Is the cut-off in the radial distribution of halo RR Lyrae at ∼50–60 kpc suggested by the early SDSS data (I00) supported by the enlarged sample discussed here?

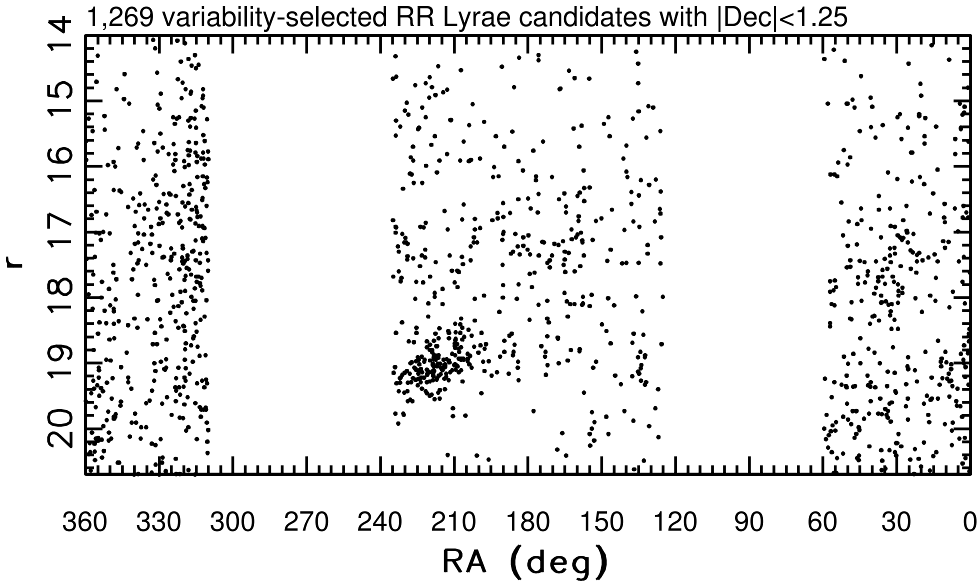

Figure 1. The r vs. RA distribution for ∼1000 SDSS candidate RR Lyrae stars along the Celestial Equator (|Dec| < 1.25°).

- Are there additional halo substructures comparable to those associated with the Sgr dwarf tidal stream?
- Is there evidence for the multiple perigalactic passages of the Sgr dwarf galaxy?

2. Analysis

2.1. The Apparent Magnitude Distribution of the Selected Candidates

The distribution of a subsample of 1269 RR Lyrae stars along the Celestial Equator (|Dec| < 1.25°) in r vs. RA diagram is shown in the top panel in Figure 1. The region studied by I00 corresponds to the range 160° < RA < 235°. As discernible from the figure, there seems to be an abrupt decrease in the number of selected candidates with $r > 19.5$ in this region. However, the new data indicate that this is an anomaly; outside that region candidates are found all the way to the sample faint limit at $r = 20.7$, including other directions on the sky not shown in the figure (see the companion paper, I03).

2.2. Halo Substructure as Traced by RR Lyrae Stars

The distribution of selected stars shown in Figure 1 is very inhomogeneous. Especially prominent features are the clump associated with the Sgr dwarf tidal tail (leading arm) at RA ∼200°–230°, $r \sim 19$, the Pal 5 globular cluster and associated tidal debris (RA ∼ 230°, $r \sim 17.4$), and a clump at RA ∼180°, $r \sim 17$. The latter is also detected by Vivas et al. (2001) using a complete sample of confirmed RR Lyrae stars discovered by the QUEST survey. Another prominent feature is the so-called "southern" clump, also associated with the Sgr dwarf tidal

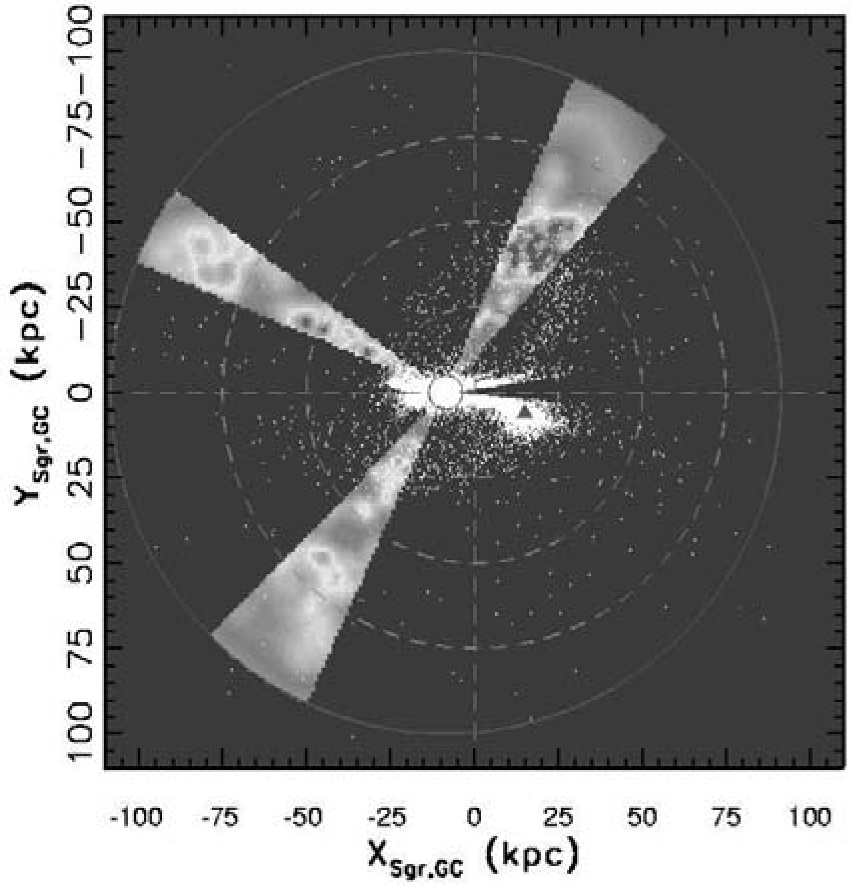

Figure 2. The number density multiplied by the cube of the galactocentric radius (logarithmic scale with dynamic range of 1000, from light blue to red), for 923 RR Lyrae stars within 10° from the Sgr dwarf tidal stream plane. The 2MASS M giants discussed by M03 are marked by the white dots. The solid circles show the sample distance limits (5 kpc and 100 kpc), and the dashed circles, centered on $(X = 0, Y = 0)$, are added to guide the eye. The red triangle marks the Sgr dwarf core.

tail (trailing arm), and discovered using A-colored stars by Yanny et al. (2000). We note another, previously unreported, overdensity of fainter stars ($r \sim 19$–20, $D \sim 60$–70 kpc) in approximately the same region (RA $\sim 30°$–$60°$). The increased number of stars around RA $\sim 320°$ coincides with the point where the sampled part of the Celestial Equator is closest to the Galactic Center and is an expected consequence of the r^{-3} density distribution (Wetterer & McGraw 1996, and references therein). In summary, although the sample is increased by a factor of 20, the Sgr dwarf tidal stream remains by far the strongest detected feature.

2.3. The Properties of the Sgr Dwarf Tidal Stream

About 1000 RR Lyrae stars from the sample discussed here are found within 10° from the Sgr dwarf tidal stream plane, as defined by Majewski et al. (2003, hereafter M03). We use this subsample to search for evidence of multiple perigalactic passages, which should manifest themselves as multiple peaks in the number density along a line of sight that is in the orbital plane. The smoothed distribution of these stars is shown in Figure 2 (the employed coordinate system is same as in figure 11 from M03). For unsmoothed data points, and histograms of the distance and radial velocity distributions see I03.

As is evident, there are multiple peaks along each of the three lines of sight. The strongest clump is a part of the leading arm of the Sgr dwarf tidal tail. The weakest features visible in this figure are still marginally statistically significant (2–3σ), as determined by simulations of random samples of the same size. These multiple peaks suggest that the Sgr dwarf may have experienced multiple perigalactic passages, as predicted by some models (e.g., Ibata et al. 2001), but not all (Martınez-Delgado et al. 2003). Alternatively, comparison with an all-sky view of M giants (M03), shown by the white dots, indicates that perhaps some of the new clumps are part of the main trailing arm that extends from the Sgr core through the southern Galactic hemisphere, curves back toward the Galactic plane, and continues through the northern Galactic hemisphere (see also Newberg et al. 2003). The clumps at (X, Y) coordinates $(-25, 25)$ and $(-80, -40)$ are consistent with this hypothesis, but the clumps at $(-45, 55)$ and $(-45, -20)$ remain unexplained. On the other hand, the structures at large radii could be fluctuations unrelated to the Sgr dwarf tidal stream (see, for example, Bullock, Kravtsov, & Weinberg 2001). For example, analogous analysis (such as that illustrated in Figure 2) of candidates along the Celestial Equator (see Figure 1) reveals only slightly weaker overdensities that are more than 30° away from the Sgr dwarf tidal stream plane. A more detailed statistical analysis is required to draw definitive conclusions and will be presented in a forthcoming publication.

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