Velocities of RR Lyrae Stars in the Sagittarius Tidal Stream

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Abstract. We have measured radial velocities and metallicities of 16 RR Lyrae stars, from the QUEST survey, in the Sagittarius tidal stream at 50 kpc from the galactic center. The distribution of velocities is quite narrow ($\sigma = 25$ km/s) indicating that the structure is coherent also in velocity space. The mean heliocentric velocity in this part of the stream is 32 km/s. The mean metallicity of the RR Lyrae stars is [Fe/H] = −1.7. Both results are consistent with previous studies of red giant stars in this part of the stream. The velocities also agree with a theoretical model of the disruption of the Sagittarius galaxy.

1. Introduction

Numerous observations have shown that the Sagittarius dwarf spheroidal galaxy (Sgr) is being disrupted by the tidal forces of the Milky Way. A long stream of its tidal debris has been observed multiple times in different parts of the sky. Many of these observations are described elsewhere in these proceedings. They include an all-sky view of M giant stars (Majewski et al. 2003), RR Lyrae stars (Vivas et al. 2001, Ivezic et al. 2000), A stars (Yanny et al. 2000), halo turnoff stars (Newberg et al. 2002) and main-sequence stars in color-magnitude diagrams (Martínez-Delgado et al. 2001). Each of these observations detects the stream as an over-density of the tracer above the halo background. Simulations of the disruption of satellite galaxies by the Milky Way show that tidal streams should be seen not only as over-densities but also as coherent structures in velocity space (e.g., Harding et al. 2001).

The QUEST survey for RR Lyrae stars (Vivas et al. 2001, 2003, see also Zinn et al. in this volume) has observed part of the Sgr stream in a long, 2.3°-wide strip near the celestial equator. We present here a study of the radial velocities of a sub-sample of 16 RR Lyrae stars in the Sgr tidal stream. RR
Lyrae stars stand out as one of the best tracers of the old halo stellar population because they are bright standard candles. Thus, they can provide excellent views of the stream in both the three-dimensional spatial distribution and the radial velocity distribution.

2. The Data

The 16 RR Lyrae stars belong to the clump located at \( \sim 50 \text{ kpc} \) from the galactic center which has been related to the leading arm of the Sgr tidal stream. The QUEST survey found 84 stars in the Sgr stream, a factor of 10 higher than the background of halo stars. The spatial distribution of the clump indicates that is quite wide in right ascension, about 36°, from 13h0 to 15h4. We included in this study stars along all the stream in order to confirm its true size. All stars have mean magnitudes of \( V \sim 19.2 \).

Because RR Lyrae stars are pulsating stars with periods of \( \sim 0.5 \text{ days} \), exposure times of spectra should be kept short (\( \leq 30 \text{ min} \)) in order to avoid excessive broadening of the spectral lines by the changing pulsational velocity. Given the faintness of the stars in the clump, a large telescope was needed. Spectra of the 16 stars were taken with FORS2 at the VLT-Yepun in Paranal, Chile, during June-Aug 2002. We used grating 600B which gives a resolution of \( \sim 6 \text{ Å} \), and covers a spectral range from 3400-6300Å. Exposure times varied between 20 and 30 minutes. For each star we obtained two spectra taken at random times on different nights. This allowed us to make measurements at two
different phases during the pulsation cycle. A few radial velocity standards were also observed with the same instrumental setup.

3. Radial Velocities

Radial velocities of RR Lyrae stars change during the pulsation cycle by up to $\sim 100$ km/s. Thus, it is important to know the exact phase at which the spectrum was taken in order to separate the systemic velocity of the star from the velocity due to the pulsations. We obtained phase information from the QUEST RR Lyrae catalog (Vivas et al. 2003) which provides accurate ephemerides for all the stars in our sample. We determined the radial velocities by cross-correlation with each of the observed radial velocity standards. The error in a single measurement is estimated to be $\sim 20$ km/s. For each star we fitted a radial velocity curve template following the procedure described in Layden (1994). In a few cases, the spectra was taken near the phase of maximum brightness of the light curve. We did not use these observations since there is a strong discontinuity in the radial velocity curve at this point.

The results are shown in Figure 1a. The histogram shows the distribution of the heliocentric radial velocities of the 16 stars. Taking out the two obvious outliers, the distribution is quite narrow, with a mean of 32 km/s and a standard deviation of only 25 km/s. The distribution does not resemble the one expected for a random sample of halo stars, which is the dashed, Gaussian curve in Figure 1a. For comparison we also show the distribution of velocities of four red giant stars from the Spaghetti survey (Dohm-Palmer, et al. 2001) which seem to be also associated with the Sgr stream in a region of the sky very close to ours. The presence of two outliers is not surprising. If the Sgr stream lies within a smooth distribution of halo stars following a $r^{-3}$ power-law, we expect 1-2 halo RR Lyrae stars in this volume of the sky.
There is also good agreement between our observations and the predictions of the models of the disruption of Sgr. We compare with one of these models (Martínez-Delgado et al. 2003) in Figure 1b. The red giants from the Spaghetti survey are also included.

4. Metal Abundances

The metal abundances of the stars were measured using the modified $\Delta S$ technique described by Layden (1994), which is based on the equivalent widths of the Ca II K line and the Balmer lines. The error in a single measurement of [Fe/H] is 0.2 dex. The distribution of metallicities of the 16 stars of our sample is shown in Fig 2. Our results are in very good agreement with the 4 red giants from the Spaghetti survey. The mean metallicity of the RR Lyrae stars is [Fe/H] = −1.7. Notice however that the mean metallicity of the stream is significantly lower than in the core of the Sgr galaxy. This could be explained if Sgr once had a radial gradient in metallicity, an age-metallicity relation (since the RR Lyrae variables are exclusively very old stars) or a combination of both.

5. Conclusions

We have measured VLT spectra for 16 RR Lyrae stars belonging to a part of the Sgr tidal stream, located at 50 kpc from the galactic center. The distribution of radial velocities is quite narrow, indicating that the Sgr clump is a coherent structure in velocity space. We do not find significant gradients of radial velocities or metallicities along the stream.

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