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Constraining The Mass of The Milky Way Halo

---- with Blue Horizontal Branch Stars in Sloan Digital Sky Survey

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1. Abstract

We derive new constraints on the mass of the Milky Way's dark halo by using an extensive set of halo stars from Sloan digital sky survey (SDSS)[8] as kinematic tracers. Our final sample contains 1811 rigorously selected blue horizontal branch (BHB) stars with distances up to 60 kpc from the Galactic center, with photometry and spectra drawn from DR5 and SEGUE. With distances accurate to ~5% and velocities accurate to 7 km/s, this sample enables us to construct the full radial velocity distribution at different Galactocentric radii. We use a cosmological galaxy formation simulation in an ~ 2×10^{12} $M_\odot$ halo to see how the halo star velocity distribution in a radial bin is related to the escape velocity, $P(V_{rad}/V_{esc}(r))$. Through suitable scaling to match the observed radial velocity, this distribution derived from the simulations allows observational estimates of the escape velocity at different Galactocentric distances. These V_{esc} estimates match the radial profile expected for a NFW halo and can be used to determine the Milky Way halo mass. The most likely virial mass from this method is $7\pm1\times10^{11}M_\odot$. Our halo mass is more reliable than solar neighborhood estimates because it is derived from the escape velocity curve not just one escape velocity point.

2. Motivation

Galaxies are all embedded in dark matter halos, but there are still many uncertain characteristics of the dark matter halos, so it is extremely important for modern astrophysics to study the dark matter halos. Of course it is of particular interest to extract as much information as possible about the Milky Way halo. BHB stars are excellent tracers of the structure of the Galactic halo, because they are bright enough to be observed in the distant halo and their constant absolute magnitude allows accurate distances to be determined. As a result we use BHB stars in SDSS/SEGUE as kinematic tracers to explore the features of the Milky Way dark halo.

3. Sample selection (see Sirko et al. 2004 for details).

To select an uncontaminated sample of BHB stars, we combine previously established color cuts[5,7], with two Balmer line analysis methods[1,5] :

The scale width-shape method – fit Balmer line with Sérsic profile[3] $y=1-a*\exp[-(|x-x_0|/b)^c]$.

$D_{0.2}$ method – measure the width ($D_{0.2}$)and depth (f_m) of the Balmer line labeled in Fig2.

We show the color cut in Figure 1 and a normalized spectrum of a BHB star in Figure 2. The criteria of the two Balmer line analysis methods are shown in Figure 3 and Figure 4. We take the stars that pass color cut, the $D_{0.2}$ method and the scale width-shape method be BHB stars.

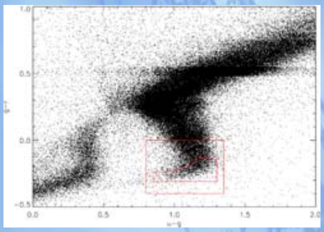

Fig.1. color-color diagram showing all stars with spectra. The box is the color cut for bright stars (g < 18). The piano shape is the stringent color cut for faint stars (g > 18).

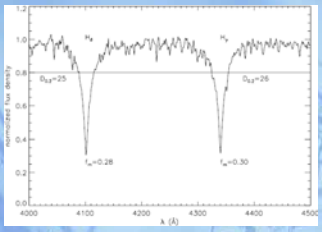

Fig.2. A part of the normalized spectrum of a BHB star. The parameters ($D_{0.2}$, f_m) that are used for the sample selection are labeled for Balmer lines.

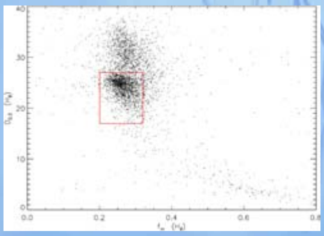

Fig.3. The parameters f_m and $D_{0.2}$ as determined from the H_δ line for stars that pass the color cut from Fig1. The red box is used as the BHB selection criterion for the $D_{0.2}$ method.

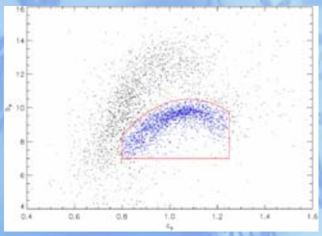

Fig.4. The parameters c and b as determined from the H_δ line for the same stars in Fig1. The region enclosed by the red lines is the criterion for the scale width-shape method . The blue dots are the stars passing both methods.

BHB stars have nearly constant absolute magnitude ~ 0.7 ^{m}, which makes their positions be determined accurately. Our final sample consists of 1811 BHB stars with heliocentric radial velocities accurate to 7 km/s and distances accurate to 5%. To compare with cosmological galaxy simulation we need to transfer the velocities and positions from heliocentric standard of rest (HSR) frame to Galactic standard of rest (GSR) frame. Figure 5 shows the distribution of our BHB stars in the Milky Way, and Figure 6 shows the distribution of the radial velocity with the distance.

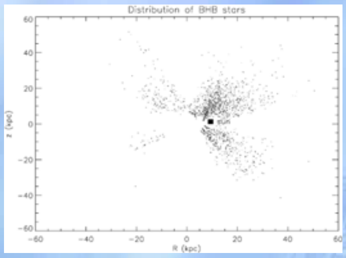

Fig.5. The distribution of our BHBs sample. $R=\sqrt{x^2+y^2}$ for x>0 and $R=-\sqrt{x^2+y^2}$ for x<0.The black dots are the BHB stars.

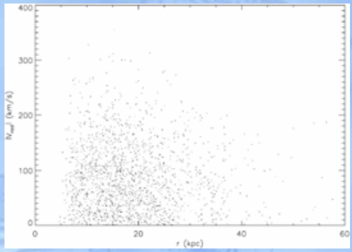

Fig.6. The distribution of radial velocity with the distance. The black dots are BHB stars and radial velocity and distance are in GSR frame.

4. Modeling

In the galaxy simulation we put the sun in (8.5, 0, 0) to extract the radial velocities of the simulation stars. We divide the radii into 8 bins to make sure the number of BHB stars in each bin to be ~200. In each radial bin the velocity distribution of the simulation $P_{sim}(V_{rad}/V_{esc})$ is ready, and we need make up the velocity distribution of the observation $P_{obs}(V_{rad}/V_{esc})$ by assuming a series of V_{esc}. Compare $P_{sim}(V_{rad}/V_{esc})$ to a series of $P_{obs}(V_{rad}/V_{esc})$, and take the V_{esc} of the best-fit P_{obs} (V_{rad}/V_{esc}) to be the estimate of the escape velocity in this radial bin. Figure 7 shows an example to see how P_{sim} matches with P_{obs}. The estimates of escape velocities are shown in Table 1.

Fig.7. The velocity distribution

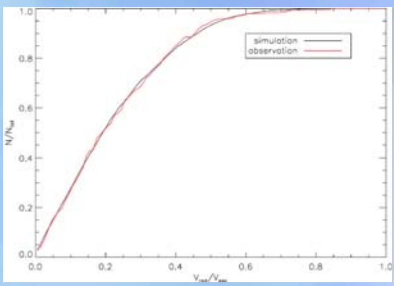

Table 1

Radial bins (kpc)	V_{esc} (km/s)
4.7~10.0	474
10.0~13.0	479
13.0~15.5	421
15.5~18.0	381
18.0~21.0	358
21.0~25.0	346
25.0~34.0	358
34.0~60.0	301

5. Result

We use the escape velocities at different radial bins to constrain the virial mass of the dark matter halo according to $V_{esc}(r)=\sqrt{2|\Phi(r)|}$. We adopt a spherical Hernquist[6] disk, a Miyamoto & Nagai bulge and a NFW[4,2] halo model, so the escape velocity is the function of radius (r), with parameter virial mass (M_{vir}). M_{vir} can be easily determined by curve fitting.

(1) Fit $\Phi_{tot}=\Phi_{bulge}+\Phi_{disk}+\Phi_{NFW}$ to the escape velocity curve, and get $M_{vir}=6.1\times10^{11}M_\odot$
(2) Just fit Φ_{NFW} to the escape velocity curve, and get $M_{vir}=8.2\times10^{11}M_\odot$

Figure 8 shows our estimates of V_{esc} and vitial mass.

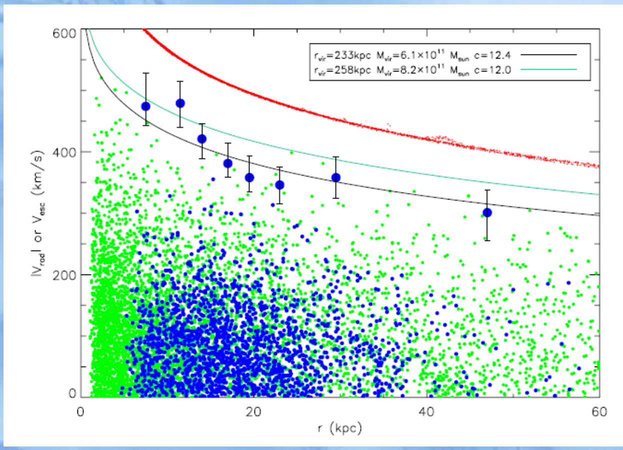

Fig.8 The big blue dots are estimates of escape velocities and the small blue dots are BHB stars. The green dots are simulation stars, and the red line is the escape velocity curve of simulation stars.

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