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Resonant Trapping of the Moving Groups G18-39 and G21-22 in the Galactic Halo

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Abstract. Orbital resonances in the Galactic halo have been studied using the Galactic mass model of Pichardo *et al.* (2003, 2004), including a Galactic bar. For the two moving groups of the Galactic halo, G18-39 and G21-22 (Silva *et al.* 2012), the majority of stars in both groups appear trapped in two resonances over the Galactic plane, generated by the bar. We have taken the rotation speed of the bar, Ω_b, as 45-55 $\mathrm{km\,s^{-1}kpc^{-1}}$. So, these two moving groups are part of stellar supergroups which populate these two resonances. The position of these two groups in the Bottlinger diagram can be explained by the mean (U, V) field generated by these two resonances crossing the solar vicinity, in contrast with the alternate explanation of Silva *et al.* (2012), based on the simulations of Meza *et al.* (2005), that these two groups, seen as two peaks in the U Galactic velocity, have been created by the accretion of a dwarf galaxy by the Milky Way, such as that of Ω Centauri.

Keywords. Galaxy: kinematics and dynamics, halo, bar, structure

1. Introduction

The halo moving groups G18-39 and G21-22 are among those detected by Silva *et al.* (2012) using structure (contours) in kinematic-metallicity diagrams such as the Bottlinger, Toomre, and the $[Fe/H], V_{rot}$ diagrams. These two groups suggest a two-peak distribution in the U' Galactic velocity, and Silva *et al.* (2012) draw an analogy with the results of Meza *et al.* (2005), who simulated the capture of a dwarf galaxy by a Milky-Way-like galaxy. Here we suggest an alternate explanation for the two-peak structure of these two halo moving groups: resonant trapping caused by the Galactic bar.

The kinematic parameters for the stars in G18-39 and G21-22 are listed in Silva *et al.* (2012); whenever possible these parameters have been updated using recently published data, such as those in GAIA, APOGEE, and the RAVE survey.

2. Discussion

For the orbital integrations, the Galactic mass model of Pichardo *et al.* (2003, 2004) has been used. Both a Galactic bar and spiral arms can be included; for these halo stars, the spiral arms have not been employed, since these produce negligible effect for the halo.

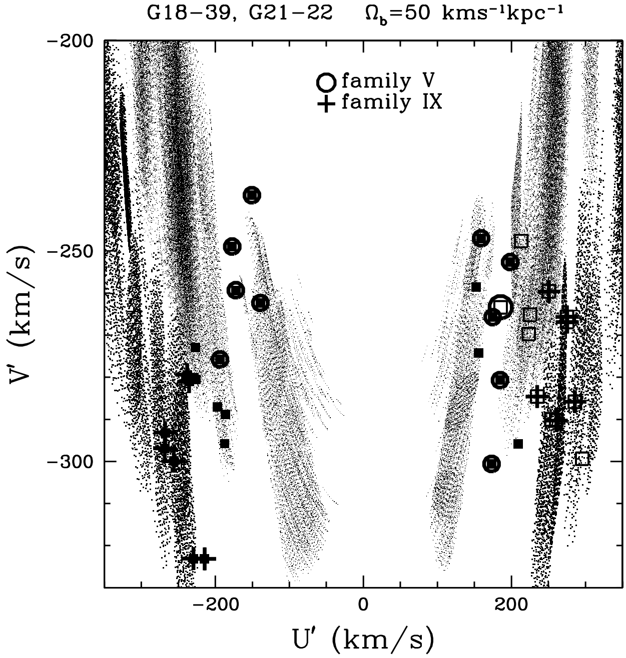

Figure 1. The moving groups G18-39 and G21-22 in the U'-V' plane; $\Omega_b = 50\ \mathrm{km\,s^{-1}kpc^{-1}}$. The black squares correspond to G18-39 and empty ones to G21-22. Circled points correspond to stars trapped by family V and plus signs by family IX. All these points lie in or near the corresponding light and dark regions produced by the simulations of families V and IX. respectively.

The general techniques of this study are those of Paper I (Moreno *et al.* 2015). Figure 1 shows the observed stars of the moving groups in the Bottlinger diagram compared to simulations of families V and IX; see Figs. 2–5 below and similar ones in Paper I.

Some pertinent observations: (a) Resonant trapping may occur in or near the stable parts of a resonant family. (b) There are group points which may be very close to a stable part of a resonant family but are not trapped. (c) Resonant trapping of a given star in a group depends on the value of Ω_b; as noted in Paper I, the distribution of points in a characteristic energy–J diagram varies strongly with the value of this parameter.

3. Conclusions

(a) The majority of stars in both groups, G18-39 and G21-22, are trapped by 2D resonances on the Galactic plane generated by the Galactic bar. (b) There is not a single trapping family in each group; the main trapping families in both groups are the families V and IX, with family IX dominating for G21-22. Thus, it appears that the majority of stars in both groups are members of the supergroups of stars in the Galaxy trapped by the resonant families V and IX. (c) For the group G18-39, the interval 45–55 $\mathrm{km\,s^{-1}kpc^{-1}}$ for Ω_b, the pattern speed of the bar, produces the greatest number of trapped orbits. It seems that there is no favored interval for the group G21-22.

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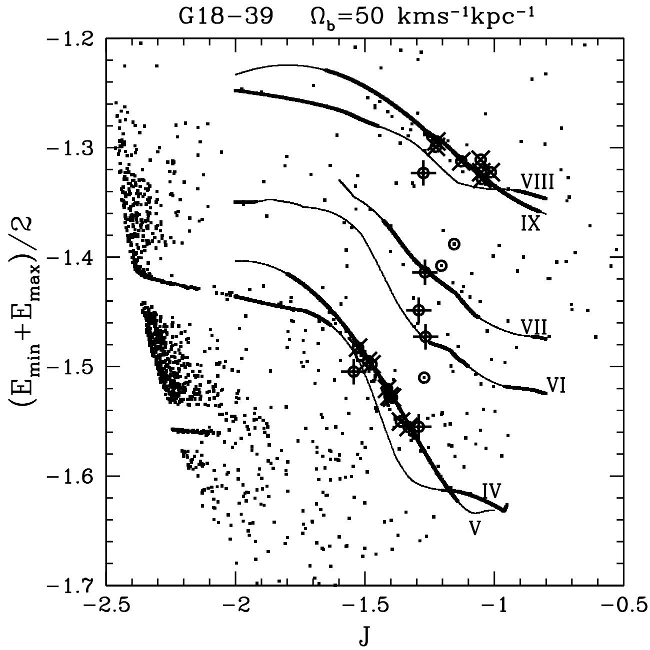

Figure 2. Characteristic energy–J diagram for the group G18-39 using $\Omega_b = 50$ km s^{-1}kpc^{-1}. The units are 10^5 (kms^{-1})^2. The curves are some of the main 2D resonant families generated by the Galactic bar as in Paper I. The dark and light parts of each curve are stable and unstable points along the family, respectively. The circled points belong to G18-39. Of these points, those with a cross represent orbits trapped by resonances for more than 5 Gyr; the points with a plus sign, less than 5 Gyr; points without a cross or plus sign, not trapped by resonances.

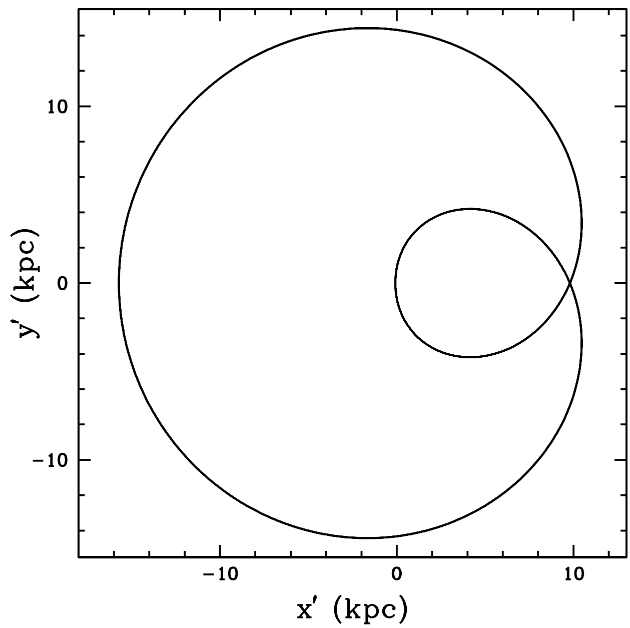

Figure 3. An example of a stable periodic orbit in family IX

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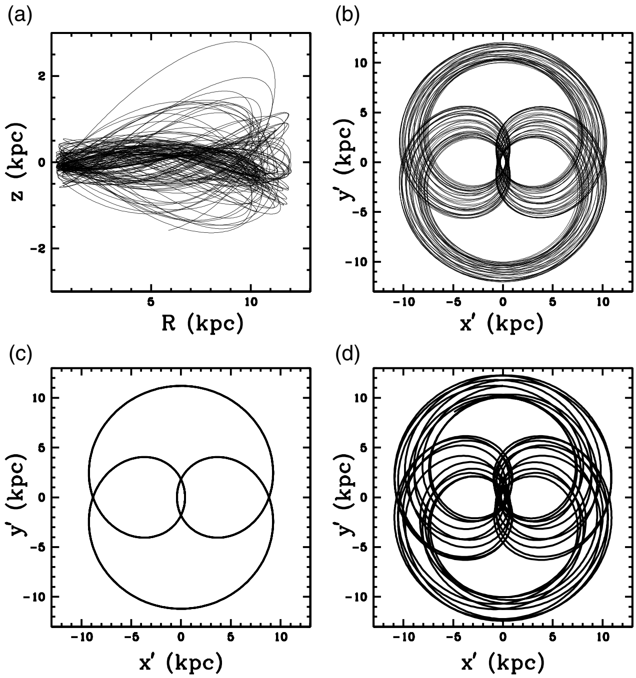

Figure 4. An example of an orbit for a star trapped in the group G18-39; $\Omega_b = 50$ km s^{-1}kpc^{-1}. The meridional orbit is shown in frame (a) and the projected one in (b), with the x'-axis pointing along the major axis of the non-inertial reference frame of the bar. Frame (c) shows the stable resonant orbit in family V with the same value of the Jacobi constant, J, as in the 3D orbit of the star. Frame (d) shows a tube orbit on the Galactic plane around this resonant orbit. A comparison of frames (b) and (d) shows that this 3D stellar orbit is trapped by family V.

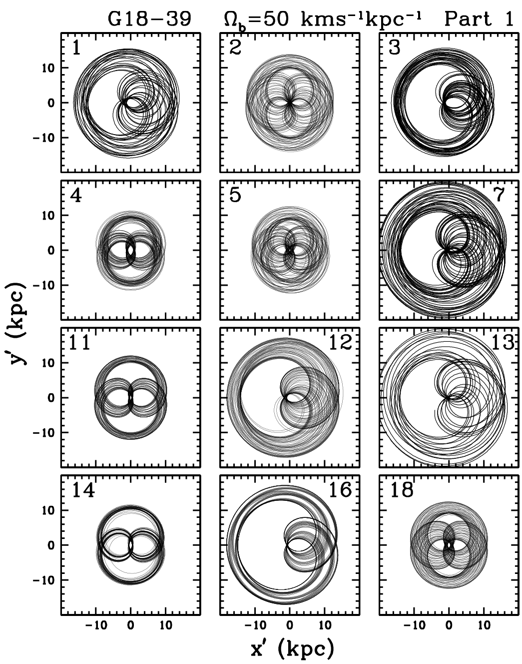

Figure 5. The projected orbits on the Galactic plane in the non-inertial reference frame of the Galactic bar for twelve stars in G18-39. Orbits from families V and IX can be seen.

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