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GALACTIC ORBITS OF GLOBULAR CLUSTERS IN A BARRED GALAXY

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RESUMEN

Se estudia el efecto de una barra en las órbitas de cuarenta y cinco cúmulos globulares con movimientos propios absolutos conocidos. Se comparan las características de las órbitas con las obtenidas en el caso de un potencial galáctico axisimétrico. Se calculan y se discuten los radios de marea obtenidos en ambos casos.

ABSTRACT

We study the effect of a bar in the galactic orbits of forty-five globular clusters whose absolute proper motions are known. The orbital characteristics of the orbits are compared with those obtained for the case of an axisymmetric galactic potential. Tidal radii are computed and discussed for both cases.

Key Words: **GALAXY: HALO — GALAXY: KINEMATICS AND DYNAMICS — GLOBULAR CLUSTERS: GENERAL**

1. INTRODUCTION

A sizable number of absolute proper motions for globular clusters has been obtained, largely due to the work of Dinescu et al. (1997;1999a;1999b;2003). Using their full space motions it is now possible to study the galactic orbits of a good fraction of the existing globular clusters.

Some of the first efforts in this direction include the work of Keenan, Innanen, & House (1973) and Keenan & Innanen (1975), who computed orbits for M67, NGC 188, Omega Cen, and NGC 2420 in a Schmidt-type potential. Using a more realistic galactic potential that included a massive halo, Allen & Martos (1988) and Allen (1990) provided orbits for a total of 15 clusters. With an improved version of their axisymmetric potential, Allen & Santillán (1993) recomputed these orbits and added those of a further six clusters that had been measured in the intervening years. In recent years, vastly improved measures for a significant number of clusters have become available (Dinescu et al. 1997, 1999a, 1999b, 2003). These authors computed galactic orbits in several axisymmetric potentials and derived a number of interesting conclusions.

On the other hand, evidence for our galaxy harboring a bar has become increasingly convincing. For this reason, this study will make an important contribution to examine the influence of this bar on the galactic motions of the clusters as obtained from their full space velocities and a galactic potential, including a bar.

2. THE GALACTIC POTENTIAL AND THE INITIAL CONDITIONS

For our study, we will employ the galactic potential developed by Pichardo et al. (2004). These authors provide a model which uses an underlying axisymmetric potential from Allen-Santillán model; but they replace 70% of the bulge mass of this model with a bar of 3.13 kpc length and an axial ratio of 1.7:0.64:0.44, which moves with an angular velocity of 60 km/s/kpc. This bar closely approximates Model S of Freudenreich (1998). Throughout this study, we will use their "superposition" model, which is the most accurate; albeit the most numerically complicated model.

In their study, Pichardo et al. obtained galactic orbits for three clusters, NGC 5139, NGC 6093, and NGC 6218. These clusters were selected because their orbits in axisymmetric potentials indicated that they reside mostly within the region of the bar; therefore, the influence of the bar on their orbits was expected to be large, as indeed, it turned out to be. We now extend this study to the complete sample of clusters.

For the initial conditions, we take the absolute proper motions provided by Dinescu et al. (1999b;2003) but, for 47 Tuc and M4 the values derived from HST measures (Anderson & King 2003; Bedin et al. 2003) were adopted. Other data are taken from the compilation by Harris (1996). We integrate the orbits backwards in time for 1.6 $\times 10^{10}$ years.

3. THE GALACTIC ORBITS

We have computed orbits for the full sample of 45 clusters. Figures 1 to 3 show a few meridional

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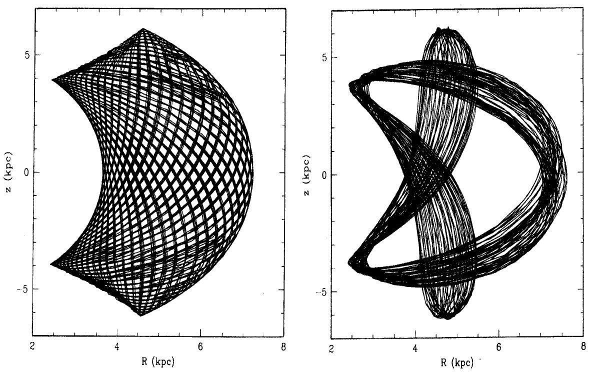

Fig. 1. Meridional orbit of NGC 7099. Left: without bar. Right: with bar.

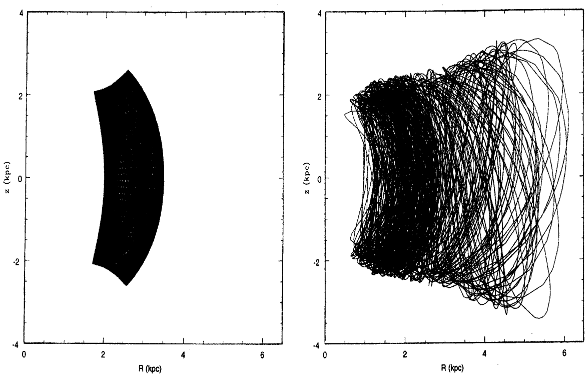

Fig. 2. As in Fig. 1, but for NGC 6171.

orbits as representative examples. They are always shown along the orbit in the axisymmetric case.

Most orbits are not noticeably affected by the bar. This is true for all "outer" clusters, i.e., those with orbits residing entirely outside the bar region. Figure 1, corresponding to NGC 7099, shows a case where the bar traps the cluster into a near-resonance; the opposite case can also occur, that is the bar can destroy a near-resonance. Figure 2 (NGC 6171) and Figure 3 (NGC 6232) are examples of a frequent occurrence among clusters that reside within the bar region. The bar tends to push the orbit outwards and makes it chaotic.

Plots of the run of energy and z-component of the angular momentum as a function of time were obtained for all clusters. In most cases, there appears to be no secular exchange of energy or angular momentum between the cluster and the bar. However, Figure 4 (NGC 6093) shows an exception. On top of the nearly periodic changes, a jump occurs. Consequently, the angular momentum changes to higher

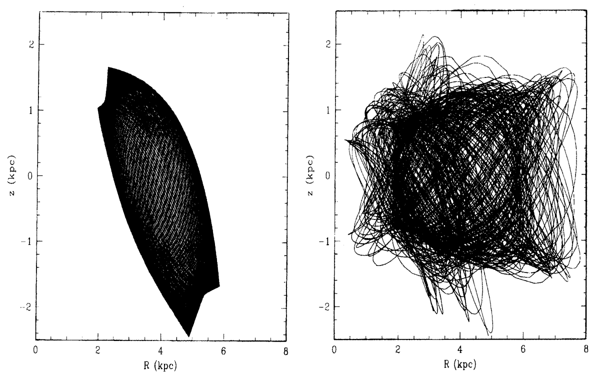

Fig. 3. As in Fig. 1, but for NGC 6362.

values. A similar plot is obtained for the energy. This plot indicates a net increase of the energy of the cluster orbit at the expense of the bar.

4. TIDAL RADII

As a first step in assessing the effects of the bar on the internal dynamics of the clusters, we have computed tidal radii. The correct formula to use for the purpose of comparing the theoretical tidal radii with the observed limiting radii is a matter of some controversy (Brosche et al. 1999 and references therein). We have computed tidal radii in a non-inertial reference frame with origin at the cluster center and the Cartesian x-axis pointing to the Galactic center. However, we are well aware of the fact that a tidal radius is only a very coarse approximation to the dynamical processes occurring in the cluster.

We use the expression

$$r_t = \left[\frac{GM_c}{\left(\frac{\partial F_x}{\partial x}\right)_c + \dot{\theta}^2 + \dot{\varphi}^2 \sin^2 \theta} \right]^{1/3} \tag{1}$$

with F_x the x-component of the acceleration due to the Galactic mass distribution and the partial derivative evaluated at the cluster's center. θ and φ are the polar and azimuthal spherical coordinates of the cluster in an inertial frame. M_c is the cluster's mass.

In (1) we numerically evaluate the quantities appearing in the denominator for each pericenter of the trajectory. In such a way, all cluster tidal radii were obtained. Figure 5 shows our results in graphical form: we plot in the ordinate the computed tidal radii averaged over the orbit pericenters, and in the abscissa, the observed limiting radii. Full symbols denote the axisymmetric case and the empty symbols denote the bar. A considerable scatter is shown in the graph, but three outliers contribute most of

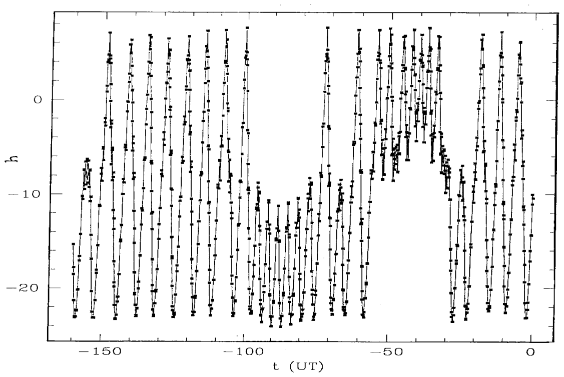

Fig. 4. Run of h as a function of time for NGC 6093.

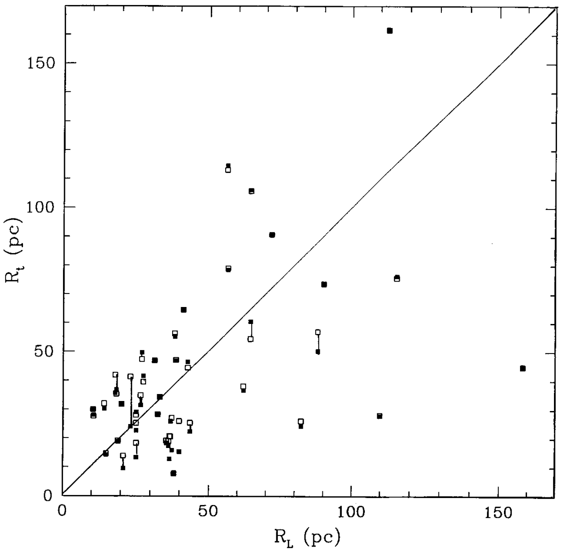

Fig. 5. Limiting radii versus computed tidal radii.

the noise: the points lying in the lower right-hand side of the diagram. These points correspond respectively to NGC 6144, Pal 5 and NGC 5466. All three are low-mass and low-concentration clusters. Pal 5 appears to be in the final stages of total dissolution (Koch et al. 2004) and there are hints that NGC 5466 is also dissolving (Caimmi & Secco 2003).

5. SOME CONCLUSIONS

We have obtained orbits for 45 globular clusters in both a barred and an axisymmetric galactic potentials. The orbits of outer clusters (those with pericentric distances greater than about 4 kpc) are largely unaffected by the bar. The largest changes were found to occur for "inner" clusters, i.e., those whose orbits reside mostly within the bar region. The main changes the bar causes in the orbits are larger vertical and radial excursions, and far more chaos. In general the bar causes no net global changes in the energy or the z-component of the angular momentum. However, there are cases where jumps in these quantities do occur, even causing a temporary reversal of the sense of rotation of the orbit. Tidal radii have been computed with a new expression and with a numerical evaluation of the relevant quantities along the orbit. No noticeable changes due to the bar were found for most of the clusters. When changes do occur, they generally make the computed tidal radii somewhat larger in the presence of a bar. Thus, we concur with the result given by Long et al. (1992) who state that the tidal radii of clusters cannot be used to exclude the presence of a bar in our galaxy.

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