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TIDAL SHOCKS IN GLOBULAR CLUSTERS WITH A BARRED GALACTIC POTENTIAL

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RESUMEN

Se analiza la interacción de marea de cúmulos globulares con el bulbo Galáctico, empleando un potencial Galáctico que incluye una barra. En particular se consideran los cúmulos cuyas órbitas caen en la región de la barra. La fuerza de marea se calcula sobre la órbita real del cúmulo, no con la aproximación usual de trayectoria rectilínea. Con ideas desarrolladas por Gnedin et al. (1999), estimamos la corrección adiabática para el calentamiento interno del cúmulo por medio de un ajuste a la fuerza de marea. La fuerza de marea en un potencial con barra tiene un comportamiento mucho más complejo que en un potencial axisimétrico.

ABSTRACT

The tidal interaction of globular clusters with the Galactic bulge is studied. We employ a Galactic potential that includes a bar. In particular, clusters with orbits residing in the bar region are considered. We calculate the tidal force on the real orbit of globular clusters, rather than the usual straight-line approximation. With ideas developed by Gnedin et al. (1999), we estimate the adiabatic correction for the internal heating of globular clusters using a fit for the tidal force. The tidal force in a barred potential behaves in a more complex way than in an axysimmetric potential.

Key Words: Galaxy: bulge — Galaxy: halo — Galaxy: kinematics and dynamics — globular clusters: general

1. INTRODUCTION

Tidal heating in globular clusters due to the interaction with the Galactic bulge has usually been calculated using the impulse approximation and a straight-path cluster trajectory (e.g. Aguilar, Hut, & Ostriker 1988; Gnedin & Ostriker 1997, 1999; Allen, Moreno, & Pichardo 2006, 2008). A better treatment has been considered by Gnedin, Hernquist, & Ostriker (1999), relaxing the straight-path approximation. These authors use a spherical potential and a fit to the tidal acceleration along the true orbit of the cluster. Here we follow their ideas, taking as a Galactic potential the barred potential developed by Pichardo, Martos, & Moreno (2004), which is a combination of the axisymmetric Galactic potential of Allen & Santillán (1991) and an approximation to the potential of the Galactic bar.

2. THE TIDAL ACCELERATION

To a first approximation, the tidal acceleration $\boldsymbol{M}$ on a star in a globular cluster, with a position $\boldsymbol{r'}$ with respect to the cluster center, is given by

$$\begin{aligned}\boldsymbol{M}(\boldsymbol{r'}) &= \boldsymbol{F}(\boldsymbol{r'}) - \boldsymbol{F}(\boldsymbol{r'}=0) \simeq \boldsymbol{J}\cdot\boldsymbol{r'} \\ &= \boldsymbol{e'}_i x'_j \left(\frac{\partial F_{x'_i}}{\partial x'_j}\right)_{\mathbf{r'}=0}, \end{aligned} \qquad (1)$$

where $\boldsymbol{F}$ is the acceleration due to the Galactic potential, and there is a sum over a repeated index. The coordinates x' are Cartesian coordinates of $\boldsymbol{r'}$. The matrix $\boldsymbol{J}$ is given by

$$\mathbf{J} = \begin{pmatrix} \frac{\partial F_{x'}}{\partial x'} & \frac{\partial F_{x'}}{\partial y'} & \frac{\partial F_{x'}}{\partial z'} \\ \frac{\partial F_{y'}}{\partial x'} & \frac{\partial F_{y'}}{\partial y'} & \frac{\partial F_{y'}}{\partial z'} \\ \frac{\partial F_{z'}}{\partial x'} & \frac{\partial F_{z'}}{\partial y'} & \frac{\partial F_{z'}}{\partial z'} \end{pmatrix}_{\mathbf{r'=0}} . \qquad (2)$$

Using the impulse approximation, the change in the *ith* component of the stellar velocity between two successive apogalactic points in the orbit of the cluster is given by

$$\Delta v'_i = x'_j \int_{t_{ap1}}^{t_{ap2}} \left(\frac{\partial F_{x'_i}}{\partial x'_j}\right)_{\mathbf{r'}=0}, \; dt = x'_j I_{ij} \,, \qquad (3)$$

where the integration is done along the true orbit of the cluster. Assuming spherical symmetry for the cluster mass distribution, the mean change of the

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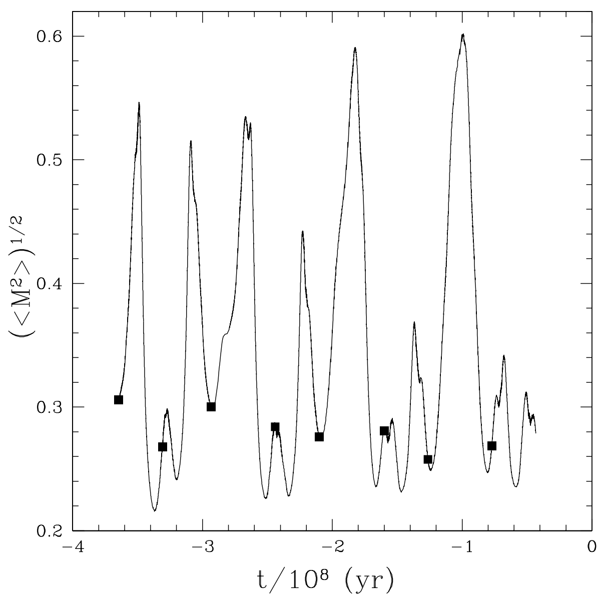

Fig. 1. The *rms* tidal acceleration in NGC 6266. Successive apogalactic points are marked with filled squares.

internal kinetic energy per unit mass is

$$<\Delta K>= \frac{1}{6} <r_c^2> \sum_{ij} I_{ij}^2 \,, \tag{4}$$

where $<r_c^2>$ is the mean square cluster radius.

To take into account the stellar motion within the cluster during its interaction with the Galactic potential in an apogalactic period, an adiabatic factor is employed having the form (Gnedin & Ostriker 1999)

$$\eta(x) = (1+x^2)^{-\gamma} \,, \tag{5}$$

with $x \equiv \omega\tau$; ω is a characteristic stellar angular velocity within the cluster, and τ an effective interaction time. The exponent γ depends on the ratio between τ and the inner dynamical time evaluated at the half-mass radius.

Gnedin et al. (1999) analyze the problem using a Galactic potential with spherical symmetry. They estimate τ making a Gaussian fit of the form e^{-t^2/τ^2} to the tidal acceleration between two successive apogalactic points. We have considered their treatment using the barred Galactic potential of Pichardo et al. (2004). In our case the problem is to make a fit to the *rms* tidal acceleration given by

$$(<\boldsymbol{M}^2>)^{1/2} = \left\{ \frac{1}{3} <r_c^2> \sum_{ij} \left(\frac{\partial F_{x_i'}}{\partial x_j'} \right)^2_{\mathbf{r}'=0} \right\}^{1/2} . \tag{6}$$

Figure 1 shows this *rms* value as a function of time (t = 0 at the present time) over some apogalactic periods, for the cluster NGC 6266. This cluster has its orbit lying near the Galactic bar. Clusters of this type may undergo a complicated interaction with the bar, and an appropriate fit is needed. We are currently working on this treatment.

REFERENCES

Aguilar, L., Hut, P., & Ostriker, J. P. 1988, ApJ, 335, 720

Allen, C., Moreno, E., & Pichardo, B. 2006, ApJ, 652, 1150

________. 2008, ApJ, 674, 237

Allen, C., & Santillán, A. 1991, RevMexAA, 22, 255

Gnedin, O. Y., & Ostriker, J. P. 1997, ApJ, 474, 223

________. 1999, ApJ, 513, 626

Gnedin, O. Y., Hernquist, L., & Ostriker, J. P. 1999, ApJ, 514, 109

Pichardo, B., Martos, M., & Moreno, E. 2004, ApJ, 582, 230