NUMERICAL MODELING OF GLOBULAR CLUSTERS TIDAL DISSOLUTION

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ABSTRACT. Numerical model of dynamical evolution of globular clusters (GCs) is described, with an emphasis of the mass loss rate in tidal interactions with the Galaxy. On a set of models dependence of the tidal destruction on cluster parameters and initial conditions, such as: the initial cluster mass, its initial position in the Galaxy, the eccentricity of the orbit – are studied. An analytical description of tidal destruction of GCs and simple estimate of their lifetimes is proposed.

Key words: globular clusters – tidal perturbations: destruction.

1. Introduction

GCs have recently attracted attention of researchers (both observers and theorists) from the point of view of their origin and evolution in the Milky Way Galaxy. This interest is driven by the fact that GCs are amongst the oldest stellar population of the Galaxy, and therefore carry information about the very early evolution of the Galaxy and the Universe as a whole. Even though these circumstances is well known long time, only last several years the interest has been reanimated mostly due to recent development of observational techniques.

A principally important feature of dynamical evolution of GCs is determined by the fact that GCs throughout evolution undergo strong damaging effects from the galactic gravitational field. It is natural to assume therefore that the observed population of GCs is only a remaining part of a much larger population that existed in the earliest stages of the Galaxy evolution.

Recent observations of the GC Palomar 5 showed that the influence of the galactic tidal field can be quite substantial, so that during the evolution it could lose up to 95% of its initial mass. The problem is thus to reproduce the initial state of the huge cluster with a tiny remnant in hands.

2. The method

Numerical modeling has been performed using the NBODY6 code. The galactic potential is accepted in the form of a three-component model that includes the bulge, Miyamoto-Nagai disk (Miyamoto & Nagai, 1975), and logarithmic halo potential.

3. Loss of stars

In the present work a set of models with different initial parameters and conditions for the clusters (the mass, radius, position, velocity) has been run. Some of their galactic orbits are shown in Fig. 1.

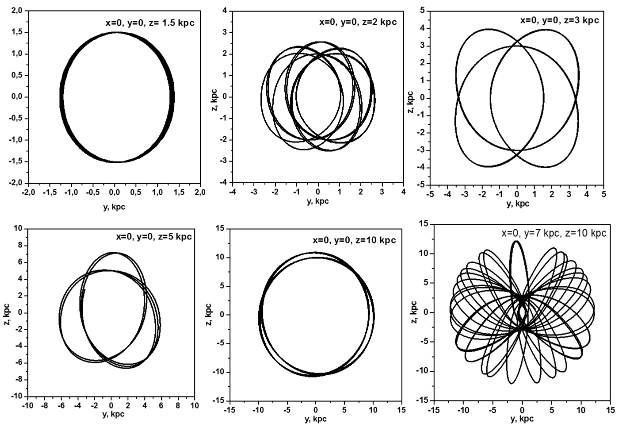

Figure 1: Examples of orbits in the $Y - Z$ plane.

To investigate the dissolution of GCs, time dependence of the number of stars gravitationally bound to their parent clusters have been calculated. Fig. 2 shows these dependencies for the clusters with orbits presented on Fig. 1. The figure demonstrates a nonmonotonic star loss rate of given GCs, with a series of well pronounced spikes.

4. Effect of the disk and the perigalacticon

Figure 3 shows time dependence of the number of stars in a GC, its position above the plane and the distance to the center of the galaxy for GC model with the initial coordinates $x = 0$, $y = 7$ kpc, $z = 10$ kpc.

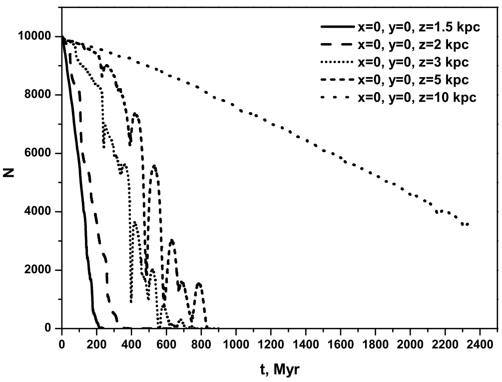

Figure 2: The dependence of the number of gravitationally bound stars vs. time for the orbits shown above in Fig. 1.

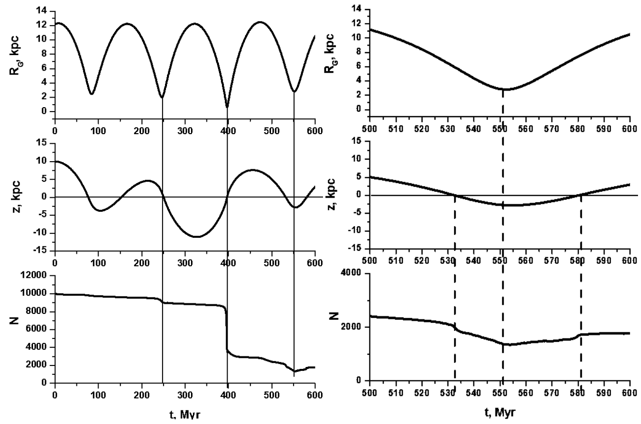

Figure 3: Time dependence of the number of stars in a GC, its position above the plane of the disk and the distance to the Galactic center (bottom to up); time interval in the range of 500 – 600 Myr is zoomed on the right panel.

Fig. 3 shows that the highest star loss occurs in moments of passing through the disk and perigalacticon. However, for most of our models these events are weakly separated in time. In order to make them seen clearer the acceleration of a GC from the Galactic gravitation $|\Phi'|$, and the magnitude of the tidal forces acting on it $|\Phi''|$ is depicted on Fig. 4. Despite the fact that the tidal force peaks when the cluster passes through the disk, its destructive action is too short, such that the dominant destructive effect comes from the perigalacticon domain.

5. GC dissolution model

Assuming that the instantaneous rate of GC dissolution depends on the current number of stars N, their mean mass m, GC radius R_c and the magnitude of the tidal forces Φ'', one can qualitatively write the equation

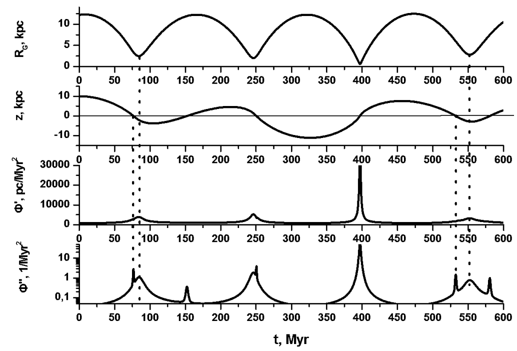

Figure 4: Time variations of the galactic acceleration and tidal force along the GC orbit.

for dN/dt as

$$\frac{dN}{dt} = -\alpha(N) \cdot \Phi''^{A} \cdot R_c^B \cdot G^C \cdot m^D$$

(G is gravitational constant), and dimensional analysis gives easily

$$\frac{dN}{dt} = -\alpha(N) \cdot \sqrt{\Phi''} \cdot \left(\frac{R_c^3 \Phi''}{Gm}\right)^{-C},$$

or in the general case

$$\frac{dN}{dt} = -\sqrt{\Phi''} \cdot f\left(N, \frac{R_c^3 \Phi''}{Gm}\right). \qquad (1)$$

The function f can be assumed as a power low

$$f\left(N, \frac{R_c^3 \Phi''}{Gm}\right) \sim \alpha N^p \left(\frac{R_c^3 \Phi''}{Gm}\right)^q$$

for which the best approximation among the existing set of calculated models with different parameters and initial conditions (GC mass, the position in the Galaxy, the eccentricity of the orbit) is

$$\alpha \sim 25, \quad p \sim 1/6, \quad q \sim 1/3.$$

Similarly, the radius of the cluster is estimated as

$$R_c \sim R_0 (N/N_0)^{-3/2}.$$

Thus, the best agreement between the qualitative description and numerical calculations is given by the expression

$$\frac{dN}{dt} \sim -25 N^{-4/3} \Phi''^{5/6} R_0 N_0^{3/2} (Gm)^{-1/3}. \qquad (2)$$

Assuming that the tidal field varies weakly along the GC orbit $\Phi'' = \text{const}$ (as, for example, for a circular orbit in the plane of the galactic disk), the equation (2) reduces to

$$dN/dt = -\beta \cdot N^{-p},$$

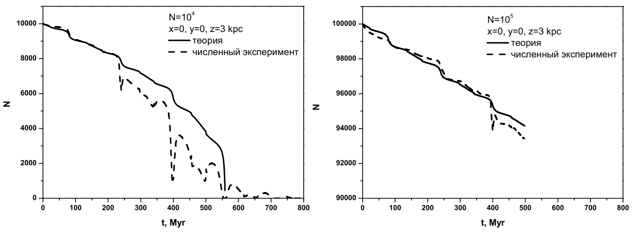

Figure 5: Comparison of numerical calculations and theoretical predictions by (2).

so

$$N(t) = N_0 \left(1 - \frac{t}{T}\right)^{1/(p+1)}$$

and GC lifetime is

$$T \sim N_0^{p+1}/[(p+1)\beta].$$

If one fixes the initial radius of the cluster $R_0 =$ const, then the dependence of the lifetime on the initial mass (i.e. number of particles) is given by

$$T \sim 0.02\,(Gm)^{1/3} R_0^{-1} \Phi''^{-5/6}\, N_0^{5/6},$$

and at a fixed density $n_0 =$ const

$$T \sim 0.03\,(Gmn_0)^{1/3} \Phi''^{-5/6}\, N_0^{1/2},$$

which is close to the relation $T \sim N_0^{0.4}$ from (Baumgardt & Makino, 2003).

6. Resistance to dissolution

To investigate GC stability, the parameter, equal to the ratio of the average value of the tidal forces to the average attractive forces within the cluster, can be introduced

$$\omega = \frac{\Delta F_G}{F_c} = \frac{R_c \cdot dF_G/dR}{F_c} = \\ = \frac{R_c \cdot md^2\Phi/dR^2}{GM_c m/R_c^2} = \frac{R_c^3 \Phi''}{GM_c}.$$

In the case of the point mass potential

$$\omega = \frac{M_G}{M_c} \left(\frac{R_c}{R}\right)^3.$$

The parameter ω coincides to within a factor $1/N$ with the dimensionless parameter, being the second argument in (1).

On Fig. 6 gray circles shows the value of the stability parameter ω for the observed GCs, depending on the galactocentric distance R_G. The lines correspond to the dependence of ω on R_G for clusters with a constant density. The density increases from the bottom to the top. Under the assumption that the orbits are circular,

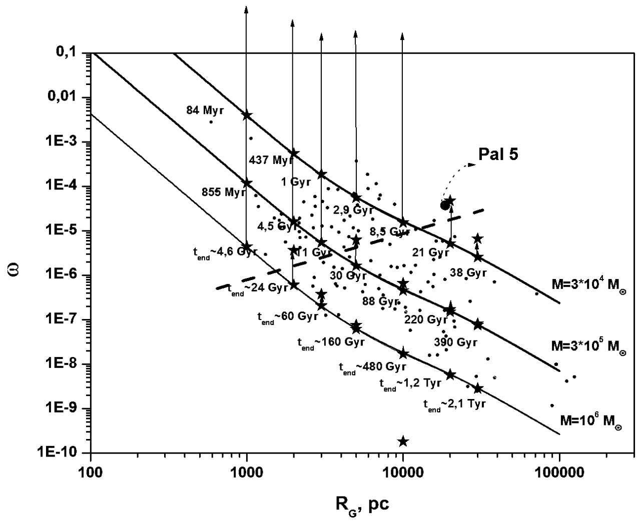

Figure 6: The parameter of GC resistance to tidal dissolution, depending on the galactocentric distance.

estimates for GCs ages (see section 5) are given on Fig. 6 for various ratios of ω and R_G at the initial time, the arrows show the direction of increase of ω in time.

7. Conclusions

We have estimated the effects of the disk and perigalacticon on destruction of GCs. For elongated orbits the effect of passing through perigalacticon is greater.

Estimates of the star loss rate of GCs and their lifetime due to the tidal field of the galaxy are given.

The evolution of the stability parameter of GC against tidal destruction, and comparison with observational data may indicate that approximately half of the Galactic GCs will be destroyed soon.

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