THE GALACTIC DISK TIDAL FORCE: SIMULATING THE OBSERVED OORT CLOUD COMETS[*]

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1 Introduction

In previous papers (Prętka and Dybczyński, 1994; Dybczyński and Prętka, 1996) we presented detailed analysis of selected examples of the long-term evolution of the orbit of Oort cloud comets under the influence of the galactic disk tidal force, as well as some statistical characteristics of the simulated observable comet population. This paper presents further improvements in our Monte Carlo simulation programme which allow us to represent in a better way the real processes of production of observable comets due to galactic perturbations.

2 Simulation Method Improvement

In our second paper (Dybczyński and Prętka, 1996), following some other authors (see for example (Matese and Whitman, 1989, 1992)), we treated a comet as observable when its osculating perihelion distance decreased below some adopted observability limit (5 AU in our case). Limiting the investigation to the evolution of osculating elements allowed us to use very fast and efficient averaged Hamiltonian equations of motion in our simulation. However, further detailed analysis of the problem showed that the adopted observability definition was insufficient: what makes a comet observable is not its osculating perihelion distance but its true distance from the Sun, smaller than some adopted threshold value. It may happen that when the osculating perihelion distance is at its smallest, the comet is around its aphelion distance. An example of such a situation is shown in Figures 1a,b,c. All three parts of this figure present the long-term evolution of the osculating perihelion distance (thick line) and the heliocentric distance of the comet (thin line) in three different scales. In Figures 1b,c the horizontal line denotes the limit of observability. The highest magnification (Figure 1c) reveals the osculating perihelion distance changes in the vicinity of two consecutive perihelion passages of the comet. One can see that when the osculating perihelion distance passes below the 5 AU limit the comet is nevertheless pretty far from the Sun.

The most efficient way to follow the true distance of a comet from the Sun in our problem is to integrate numerically the basic equations of motion in rectangular coordinates. In the present case, which includes so far only the galactic disk tidal perturbations, these equations are very simple (Heisler, 1990):

$$\ddot{x} = -\frac{\mu}{r^3}x \ , \qquad \ddot{y} = -\frac{\mu}{r^3}y \ , \qquad \ddot{z} = -\frac{\mu}{r^3}z - 4\pi G\rho \cdot z \qquad (1)$$

with $\rho = 0.185 M_\odot/pc^3$ (Bahcall, 1984). As the aim of our research is to describe the simulated population of observable comets resulting from galactic disk tidal action so we

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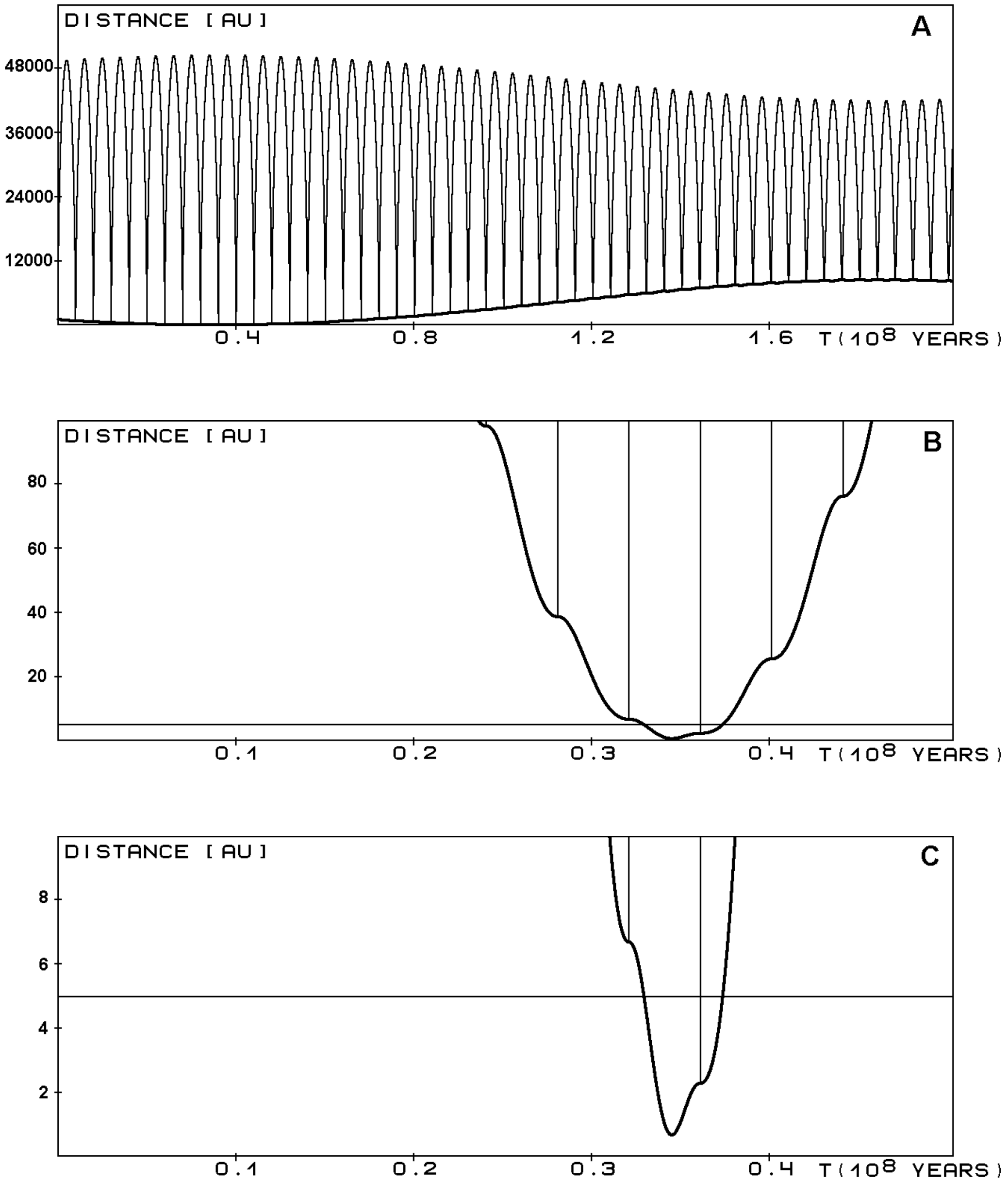

Figure 1: Long-term evolution of the osculating perihelion distance (thick line) and the heliocentric distance of the comet (thin line).

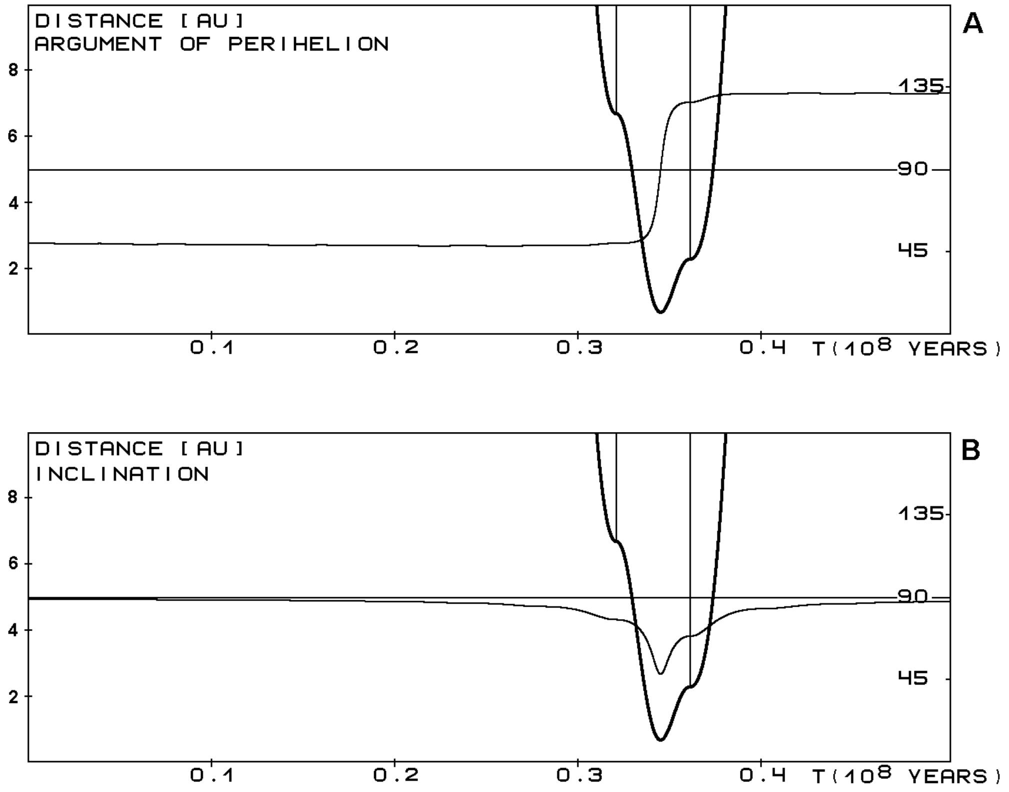

Figure 2: Long-term evolution of the osculating perihelion distance and the heliocentric distance of the comet. Additional curves present changes in: argument of perihelion (A) and inclination (B). Both are related to the galactic disk plane.

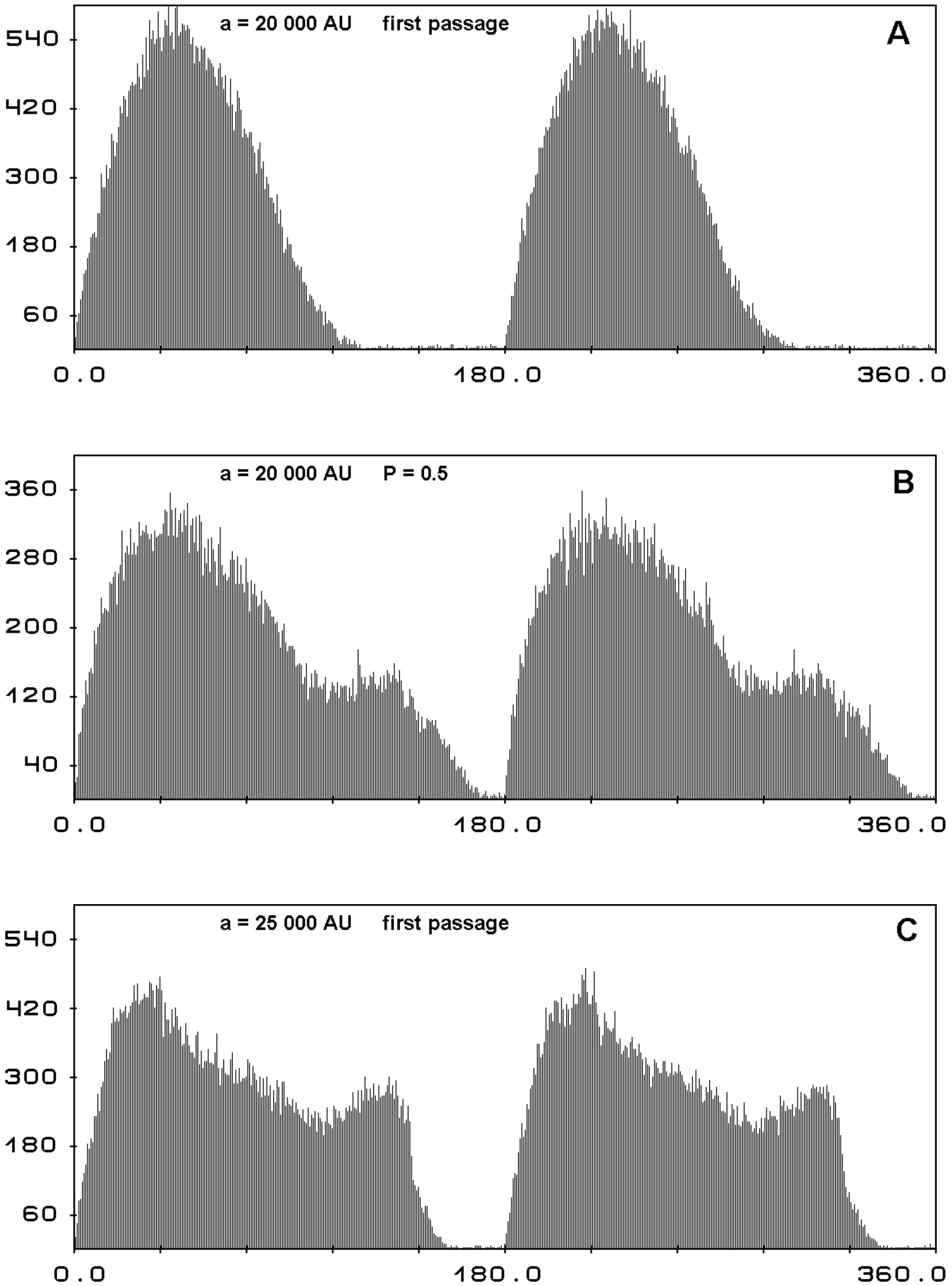

Figure 3: Argument of perihelion distributions for simulated observable comets for three different simulation rules.

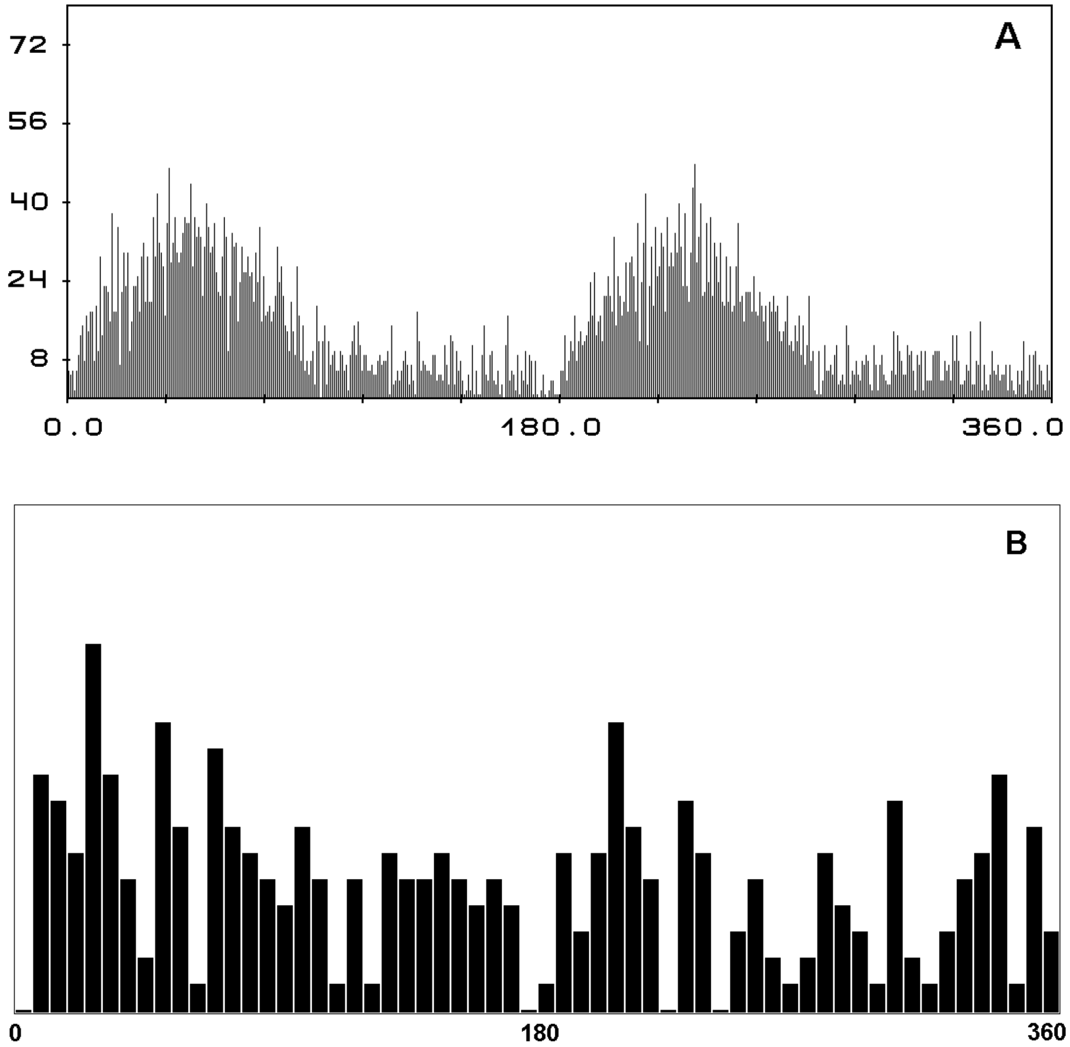

Figure 4: Argument of perihelion distributions for simulated (A) and really observed (B) comets. Part B presents 289 one-apparition cometary orbits from the Marsden catalogue.

used our Monte Carlo simulation programme as follows: we generated initial conditions from the adopted Oort cloud 'steady state' orbit distribution and integrated the motion of this single comet during 500 million years, recording the osculating orbital elements whenever the comet appeared in the region of observability. The Oort cloud 'steady state' distributions of semimajor axis and eccentricity were adopted from the important paper by Duncan et al. (1987). For the angular elements we adopted uniform distributions for the argument of perihelion and the cosine of inclination. Given the axial symmetry of the problem, the longitude of the ascending node does not play any role here.

From Figure 2 one can guess, that it would be very interesting to examine the argument of perihelion and inclination distributions for the simulated observable comet population. The action of the galactic disk tidal perturbation forces rapid changes in these osculating elements just when the osculating perihelion distance is around its minimum. But, a comet may be observed before, during or after the time of occurrence of this minimum. Thus, when we observe comets before the minimum of the osculating perihelion distance we always observe the argument of perihelion to be less than 90° (or 270° in the symmetrical case), but when observing after minimum we registered this osculating element as greater than 90° (or 270°). For comets with smaller semimajor axes (say several thousand AU) we may be sure to observe it before the minimum of the osculating perihelion distance because there exist (typically) several, sometimes more than a dozen perihelion passages with perihelion distance less than the observability threshold before the minimum occurs. When the semimajor axis of a comet is larger (several tens of thousands of AU) the probability of observing a comet before and after perihelion minimum becomes equal. The changes of the osculating perihelion distance are much faster in this case so that we can typically observe (in the sense described previously) only one or sometimes two perihelion passages during a single minimum.

Another question arises: should we record only the very first perihelion passage (and afterwards treat that comet as lost from the Oort cloud) or should we allow (with some probability) some comets to return to the Oort cloud and to be observed (and registered in our distributions) again? It is obvious that some real observed comets do not experience strong planetary perturbations and return to the Oort cloud without any change in their orbits. In our simulation programme we decided to introduce a mechanism which allows a comet to be observed and registered again with some (so far constant) probability. For the test simulations we adopted this probability equal to 0.5 (we call this parameter the Solar System transparency coefficient). This means that we registered all the first perihelion passages of comets passing the observability sphere, half of all the second perihelion passages, a quarter of the third and so on.

3 Results and Conclusions

We performed several different simulations to compare the importance of some parameters and the adopted rules for producing observable comet distributions. In Figures 3a,b one can compare distributions of the argument of perihelion for fixed semimajor axis (a=20 000 AU) with different simulation schemes: in Figure 3a we registered only the very first perihelion passage through the observability region of each comet and in Figure 3b we allowed for several consecutive perihelion passages of the same comet with probability equal to 0.5 (we call this probability the planetary system transparency coefficient). As was stated, the first perihelion passage (even for the not very small semimajor axis here) occurs almost always when the argument of perihelion lies in the first (or third) quarter. One can observe this osculating element in the second (fourth) quarter when one allows for the second, third and subsequent perihelion passages of the same comet to be registered (as 'observed').

However, in Figure 3c one can observe that slightly increasing the (again fixed) semimajor axis can lead to a result very similar to that shown in Figure 3b, but with only the first perihelion passage registered. We recognize this problem as very delicate and as we stated the final result of the simulation (with semimajor axis randomly chosen from the adopted distribution) will be strongly dependent on the 'steady state' Oort cloud distribution and the planetary system transparency coefficient. We performed such a simulation with the initial distributions described earlier and obtained the argument of perihelion distribution of observable comets shown in Figure 4a. For comparison we present in Figure 4b the distribution of the same element for the real actually observed one-apparition comets taken from the Marsden catalogue (Marsden and Williams, 1996). Among the conclusions we want to state also, that the solar system transparency coefficient plays an important role in the investigation of the long term orbital evolution of the Oort cloud comets. Further investigations on its value and dependence on orbital elements are necessary.

References

Bahcall, J.: 1984, 'Self-consistent determinations of the total amount of matter near the Sun'. *ApJ* **276**, 169–181.

Duncan, M., T. Quinn, and S. Tremaine: 1987, 'The Formation and Extent of the Solar System Comet Cloud'. *AJ* **94**(5), 1330–1338.

Dybczyński, P. A. and H. Prętka: 1996, 'The Statistical Effects of Galactic Tides on the Oort Cloud'. *Earth Moon and Planets* **72**, 13–18.

Heisler, J.: 1990, 'Monte Carlo Simulations of the Oort Comet Cloud'. *Icarus* **88**, 104–121.

Marsden, B. G. and G. V. Williams: 1996, *Catalogue of Cometary Orbits 11th Edition.* Cambridge, Mass.: Minor Planet Center.

Matese, J. J. and P. G. Whitman: 1989, 'The Galactic Disk Tidal Field and the Nonrandom Distribution of Observed Oort Cloud Comets'. *Icarus* **82**, 389–401.

Matese, J. J. and P. G. Whitman: 1992, 'A model of the galactic tidal interaction with the Oort comet cloud'. *Celestial Mechanics and Dynamical Astronomy* **54**, 13–35.

Prętka, H. and P. A. Dybczyński: 1994, 'The Galactic Disk Influence on the Oort Cloud Cometary Orbits'. In: K. Kurzyńska, F. Barlier, P. K. Seidelmann, and I. Wytrzyszczak (eds.): *Dynamics and Astrometry of Natural and Artificial Celestial Bodies.* Poznań, Poland, pp. 299–304, Astronomical Obs. of the A.Mickiewicz Univ.