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A model of the current stellar perturbations on the Oort Cloud

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Abstract. In a study of the Oort-Cloud dynamics, stellar perturbations should be taken into account. A model of stellar passages around the solar system has to reflect both the frequency and perihelion distribution of passing stars at the same time. We provide such a model for a 1 Gyr period assuming the same Galactic environment in a solar vicinity as it is nowadays for the entire period. The modelling includes the determination of a critical distance within which all stars of a given spectral type should be considered. The resultant data comprise the dynamical characteristics of 41 589 simulated stars passing the solar system over 1 Gyr. These data are available in an electronic form at http://www.astro.sk/caosp/Eedition/FullTexts/vol37no3/pp161-172.dat/. Moreover, we demonstrate that the influence of the Galactic tide on the heliocentric trajectories of the stars, when they perturb the Oort-Cloud comets, can reliably be neglected.

Key words: Oort Cloud – stars: kinematics

1. Introduction

Comets are perturbed by several so-called outer perturbers in their distant reservoir, known as the Oort Cloud. Besides the dominant perturbation by the Galactic tide, comet trajectories are influenced by nearly passing alien stars and interstellar matter concentrated into interstellar clouds.

The tidal action of a more or less smooth distribution of the matter in the Galactic disc is well described by simple formulas. This simplicity is not, however, the case of the gravitational force of passing stars, where we must deal with every individual star. Prior to everything else, we must decide if the perturbation of a given star is significant and should be taken into account. When the perturbation is evaluated as significant, we must know the characteristics of the passage, i.e., the heliocentric trajectory and mass of the passing star, as well as the time of the occurrence of the passage.

In the past, only some approximations of the stellar perturbations were considered. Among these approximations, the impulse method (Öpik, 1932; Oort, 1950; Rickman, 1976) assuming a straight-line stellar trajectory was used most often. In 1994, Dybczyński generalized this method for the Keplerian hyperbolas. His improvement led to reaching a level of precision of the numerical integrations (see, e.g., Rickman et al., 2006). Nevertheless, it has not been proved if the real stellar trajectories are actually the Keplerian hyperbolas, or these trajectories are significantly modified by the Galactic tide, which is the dominant outer perturber of the Oort-Cloud comets. It is obvious that the outer perturbers must also interact with each other.

In this work, we (i) suggest a way of determination of a critical distance within which the stars of a given spectral type, with a characteristic mass, should be considered, (ii) create a model of the stellar passages for 1 Gyr assuming that the solar system has been situated in the current Galactic environment during this period, and (iii) evaluate the importance of the Galactic-tide influence on heliocentric stellar trajectories.

2. The critical distance

At a very large distance, a stellar perturbation can be regarded as a contribution to the smooth perturbative force of the Galactic tide. It begins to gradually break the homogenity of the tidal gravitational field at a certain distance, which we specify as follows. In a dynamical study of Oort-Cloud comets, it is reasonable to constrain the study up to a certain heliocentric distance, which we denote by r_h. With respect to this constraint, we consider as perturbing those stars of a given spectral type which enter a sphere of such a radius $r_{q,i}$ that the magnitude of force from the star on a comet in r_h is much smaller than the magnitude of the dominant z-term of Galactic tide (see Sect. 4). In other words, $[GM_{*i}/(r_{q,i} - r_h)^2]/(4\pi G\rho_{GM} r_h) = \nu \ll 1$ or

$$r_{q,i} = r_h + \sqrt{\frac{M_{*i}}{4\pi\rho_{GM} r_h \nu}}, \tag{1}$$

where M_{*i} is the typical mass of i-th spectral type, G is the gravitational constant, ρ_{GM} is the density of the Galactic matter in a vicinity of the solar system, and ν is the ratio of magnitudes of both stellar perturbation at $r_{q,i}$ and z-term of the Galactic tide.

In an ideal case, $\nu \ll 1$. Considering a very low value of ν is, however, practically impossible due to computational constraints. If we chose $\nu = 1/100$, for example, the total number of perturbing stars would be 898 872 and maximum $r_{q,i}$ would be 9.701×10^6 AU. Even for $\nu = 1/10$, the figures would be 110 570 and 3.136×10^6 AU, respectively. Besides the computational constraints, considering a very low value of ν is not very meaningful also due to the uncertainty of the value ρ_{GM}. Comparing the values of this main parameter characterizing the dominant, Galactic-tide perturbation, recently determined by several authors ($0.11\,\mathrm{M}_\odot \mathrm{pc}^{-3}$ by Pham, 1997; $0.076\,\mathrm{M}_\odot \mathrm{pc}^{-3}$ by Crézé et al., 1998; or $0.102\,\mathrm{M}_\odot \mathrm{pc}^{-3}$ by Holmberg & Flynn, 2000), it can be stated the differences up to 45%. This implies a larger uncertainty of comet orbital dynamics, in the OC, than neglecting very distant stellar perturbations. We suggest that the value of $\nu = 1/3$ appears to lead to a quite sufficient approximation.

To roughly appreciate an impact of the relatively high value of ν on a cometary trajectory, we calculated the maximum velocity impulse delivered to a comet on an orbit with the perihelion distance $q = 1$ AU and aphelion distance $Q = r_h = 10^5$ AU in the limiting case when the comet is in its aphelion and minimum-proximity distance of the perturbing star of a given type just equals $r_{q,i}$. In this calculation, we use the procedure introduced by Rickman et al. (2004), which includes modelling a swarm of 10^4 comets homogeneously situated on the sphere of radius Q (in our case) and calculating the velocity impulse delivered each comet by the impulse approximation. The maximum velocity impulses obtained are listed in Table 1, last column. In the given context, these values can be compared with the aphelion velocity of the comets, which equals about $0.42\,\mathrm{m\,s}^{-1}$. So, the maximum neglected perturbations would deliver an impulse which is about one order of magnitude lower than the actual velocity of any considered comet.

The criterion requiring the appearance of a given star within the distance $r_{q,i}$ means that its perihelion distance is smaller than $r_{q,i}$. Some stars can have perihelion at a distance approaching $r_{q,i}$. If the perturbation of a star is calculated by a numerical integration of its trajectory, it is meaningless to consider the star only on a very short arc of its trajectory. In such a case, we suggest to follow the motion of the star from the moment when it enters the sphere of radius $r_{o,i}$, which is about a distance Δr larger than $r_{q,i}$. (This problem does not occur when an impulse approximation is used.) The enlargement about Δr means that we follow the perturbing star along a path of length equal to about $\sqrt{2r_{q,i}\Delta r}$. The value of Δr should be small in a comparison with an average of $r_{q,i}$, because it would not be very reasonable to follow the perturbing star, passing the Sun just within $r_{q,i}$, from a distance much exceeding this limit on the first side, but to completely neglect the action of another star, passing the Sun just beyond $r_{q,i}$, on the other side. In the present model of stellar passages, we suggest to choose $\Delta r \approx 50\,000$ AU. Another approach is to choose an individual value for every considered stellar type, which is proportional to $r_{q,i}$. Then, it seems to be appropriate to put $\Delta r = \gamma r_{q,i}$, where γ is a factor slightly exceeding unity.

To determine the specific values of $r_{q,i}$ for the individual stellar spectral types, we consider 13 representative spectral types introduced by García-Sánchez et al. (2001). The numerical values of a typical mass for the main-sequence-star types and giants are taken from the monography by Gray (1992; p. 431). The typical mass of white dwarfs is taken from the monography by Hansen & Kawaler (1994; p. 340). The found critical distances, $r_{q,i}$, are given in Table 1.

The importance of the different critical distances for various stellar spectral types can be demonstrated by the following example. A comet at heliocentric distance 50 000 AU receives the impulse from (i) a massive B0 star approaching the Sun to the minimum distance of 750 000 AU and (ii) a red dwarf approaching the Sun to the minimum distance of 100 000 AU. In both the cases, the angle between the radius vectors of a comet and a star is assumed to be $\pi/2$. Assuming also that the mass of the first (second) star is $10\,\mathrm{M}_\odot$ ($0.3\,\mathrm{M}_\odot$) and its velocity is $20\,\mathrm{km\,s^{-1}}$ ($45\,\mathrm{km\,s^{-1}}$), and using the classical impulse approximation, we estimate that the velocity of the comet is changed by about $0.079\,\mathrm{m\,s^{-1}}$ ($0.053\,\mathrm{m\,s^{-1}}$). This simple calculation demonstrates that the perturbation due to a distant passage of a massive star can be larger than the one of a closer approach of a dwarf star.

3. A model of the stellar passages

As already mentioned, we consider a solar-neighbourhood environment being similar to the current environment. It means, we consider the current density of matter in the solar neighbourhood, the current frequency of stellar passages, and no massive interstellar cloud in a vicinity of the solar system.

García-Sánchez et al. (1999, 2001) considered the Galactic force field to describe the motion of the stars in the proximity of the solar system. They determined the stellar characteristics on the basis of Hipparcos observations available at that time, which reflect the characteristics of the real stars. The authors (García-Sánchez et al., 2001) divided the stars into 13 representative spectral types (see Table 8 in their paper or our Table 1). Following them, the frequency of the encounters with the stars of the i-th stellar type within the distance D is given as

$$f_i = \pi D^2 v_i n_{*i}, \tag{2}$$

where v_i is the relative velocity of the encounter with the i-th type and n_{*i} is the number density of the stars of the i-th type. The relative velocity, v_i, is a superposition of the velocity of a star relative to the corresponding local standard of rest (LSR), v_{*i}, and the peculiar velocity of the Sun relative to the LSR, $v_{\odot i}$. The values of the velocity dispersion, $v_{d;i}$, and the peculiar velocity of the Sun, $v_{\odot i}$, both relative the LSR of the i-th type, as well as the frequency f_i per Myr of the i-th type for the sphere of radius $r_u = 1\,\mathrm{pc}$ are given in Table 8 of García-Sánchez et al.'s (2001) paper.

Taking the frequency f_i into account, the number of i-th-type stars entering the sphere of radius $r_{q,i}$ during time t (in Myr) is

$$N_{*i} = \left(\frac{r_{q,i}}{r_u}\right)^2 f_i t. \tag{3}$$

The values of N_{*i} for $t = 1$ Gyrs for each considered spectral type are given in Table 1. We note that García-Sánchez et al. found a smaller frequency of the passages of F5-spectral-type than F0-spectral-type stars. This implies a lower number, N_{*i}, of F5-type stars in comparison with F0-type stars, in Table 1.

Table 1. Some parameters of the stars of the i-th spectral type (S.T.). The types from B0 to M5 on the main sequence in the H-R diagram, white dwarfs (WD), and giants (gs.) are included. These representative stellar spectral types were introduced by García-Sánchez et al. (2001). The remaining symbols in the heading: M_{*i} − typical mass, $M_{i;d}$ and $M_{i;u}$ − the lower and upper limits of M_{*i} dispersion, $r_{q,i}$ − the heliocentric distance of the most distant passage, N_{*i} − the number of the stars of the i-th type with the perihelion distance within $r_{q,i}$ passing the solar system during 1 Gyrs, and $\Delta v_{max,i}$ − maximum velocity impulse, which could be delivered to any considered comet by a star passing the Sun beyond the distance of $r_{q,i}$.

i	S.T.	$M_{i;d}$ [$M_\odot$]	M_{*i} [$M_\odot$]	$M_{i;u}$ [$M_\odot$]	$r_{q,i}$ [AU]	N_{*i}	$\Delta v_{max,i}$ [$m\,s^{-1}$]
1	B0	7.8	13.2	18.6	1762957	334	0.034
2	A0	2.14	2.4	2.66	809087	348	0.028
3	A5	1.72	1.86	2.00	724238	477	0.027
4	F0	1.45	1.55	1.65	669849	1624	0.021
5	F5	1.22	1.32	1.42	625873	758	0.018
6	G0	1.06	1.12	1.18	584399	1795	0.015
7	G5	0.91	0.98	1.05	553114	2482	0.015
8	K0	0.76	0.82	0.88	514477	2112	0.017
9	K5	0.61	0.68	0.75	477440	4535	0.013
10	M0	0.44	0.52	0.60	430062	5611	0.014
11	M5	0.11	0.27	0.43	337835	17138	0.012
12	WD	0.5	0.6	0.7	454544	3467	0.009
13	gs.	2.0	2.2	2.4	778899	908	0.016

Since the masses of the real stars vary smoothly and we want to respect this fact, at least approximately, the masses of the considered individual stars of a given spectral type are generated to be randomly dispersed in the interval from $M_{i;d}$ to $M_{i;u}$ centered at M_{*i}. For types 1 to 11, the half-width of the interval is limited by the lower of the averages $(M_{i*-1} + M_{i*})/2$ and $(M_{*i} + M_{*i+1})/2$ rounded down. The masses of white dwarfs lie in a very narrow interval (Hansen & Kawaler, 1994); we put the half-width of their mass interval equal to $0.1\,M_\odot$. According with Gray (1992; appendix B) the mass of giants outside the main sequence ranges from 2.0 to $2.4\,M_\odot$ so we put the half-width of their mass interval equal to $0.2\,M_\odot$. The specific values of $M_{i;d}$, M_{*i}, and $M_{i;u}$ are presented in Table 1.

Concerning the distribution of the stellar velocity relative to the LSR of i-th-type stars, we assume the Gaussian distribution of the absolute value, v_j,

$$dN_i = \frac{4N_{*i}}{\sqrt{\pi} v_{d;i}} \exp\left(-\frac{v_j^2}{v_{p;i}^2}\right) dv_j, \tag{4}$$

The symbol $v_{p;i}$ stands for the most probable velocity (the peak of the Maxwell distribution). It is related to the velocity dispersion, $v_{d,i}$, given by García-Sánchez et al. (2001) as $v_{p;i} = \sqrt{2} v_{d,i}$. The v_j-distribution is created with the help of a random generator. At first, we find the upper limit of the velocity range, v_{up}, for which dN_i just equals 1, for a chosen width of dv_j and given number N_{*i}. Then, we divide the range from 0 to v_{up} into the integer of v_{up}/dv_j sections. The lengths of the sections are not the same, they are proportional to the corresponding product of $dN_i.dv_j$. Each section corresponds to a specific value of v_j. The section and, thus, value of v_j for a given star is chosen, when generating a random number γ from interval $<0, 1>$. The value of $\gamma.v_{up}$ matches a point in the section.

Having the magnitude of the velocity relative to the corresponding LSR, the magnitude of the velocity relative to the Sun, i.e. the heliocentric velocity, can be calculated in an usual way (e.g. Rickman et al., 2004) as

$$v_{h,j} = \sqrt{v_j^2 + v_{\odot i}^2 - 2 v_j v_{\odot i} \cos\beta}, \tag{5}$$

where the cosine of the angle between the vectors $\boldsymbol{v}_j$ and $\boldsymbol{v}_{\odot i}$, β, is a random value from the interval $<-1, +1>$, it can be generated as $\cos\beta = 2\gamma - 1$. The difference between the velocity $v_{h,j}$ (at infinite distance from the Sun) and the velocity of the j-th star at the heliocentric distance $r_{o,j}$ is obviously negligible, therefore we can identify $v_{h,j}$ with the velocity in the distance $r_{o,j}$.

The orientation of the heliocentric velocity vector is assumed to be random. Its rectangular components are created in the way proposed by Rickman et al. (2004). Specifically,

$$\begin{aligned} v_{hj;z} &= \pm v_{h,j}\gamma, \\ v_{hj;x} &= \sqrt{v_{h,j}^2 - v_{hj;z}^2} \cos\alpha, \\ v_{hj;y} &= \sqrt{v_{h,j}^2 - v_{hj;z}^2} \sin\alpha, \end{aligned} \tag{6}$$

where $\alpha = 2\pi\gamma$ is a random angle from interval $<0, 2\pi>$. The sign on the right-hand side of the relation for $v_{hj;z}$ is also generated in a random way.

The semi-major axis of the orbit of the j-th star with the mass M_j and velocity $v_{h,j}$ can be calculated as

$$a_j = \left[\frac{2}{r_{o,j}} - \frac{v_{h,j}^2}{G(1 + M_j)}\right]^{-1}. \tag{7}$$

To respect the distribution (2) of the stellar passages within the heliocentric distance D, we construct the following distribution of perihelion distance of considered stars. We divide the sphere of radius $r_{q,i}$ into N_{*i} concentric spherical layers with inner radii $r_{1,i} > r_{2,i} > r_{3,i} > ... > r_{N*i,i}$. These radii are chosen in such a way that there is the perihelion of just a single star of the i-th type in the layer between $r_{j,i}$ and $r_{j-1,i}$. This implies that there are j perihelia between $r_{q,i}$ and $r_{j,i}$. In analogy to (3), the number of i-th-type stars entering the sphere of radius $r_{j,i}$ is $N_j = (r_{j,i}/r_u)^2 f_i t$. Using this relation and relation (3), we can calculate $(N_{*i} - N_j)/N_{*i}$, which further equals j/N_{*i}. Then, one can easily find that the inner radius of the j-th sphere is

$$r_{j,i} = \sqrt{1 - \frac{j}{N_{*i}}} r_{q,i}, \tag{8}$$

for j = 1, 2, 3,..., N_{*i}. Having $r_{j,i}$, the perihelion of the j-th star of the i-th type can be generated as

$$q_{*j} = r_{j,i} + \gamma(r_{j-1,i} - r_{j,i}). \tag{9}$$

(Rickman et al. (2004) suggested a simpler way. They put $q_{*j} = r_{q,i}\sqrt{\gamma}$. Since the generated number of stars, even for a 1 Gyr period, is not very high from a statistical point of view, our method leads to a smoother q-distribution. So, we rather prefer the latter.) Due to a random generation of q_{*j} in the inner-most layer, an extremly close stellar encounter can be modelled. However, the planetary region of the solar system does not seem to be influenced by such an extremly close encounter. Moreover, we observe the comets coming from the Oort Cloud, which would not exist if the magnitude of the change of the solar velocity vector by a passing star exceeded about 0.2 km s^{-1} (Levison et al., 2004). To respect these facts, but, at the same time, allow as minimum-distance approach of a star to the Sun as possible, we suggest putting the internal radius of the inner-most layer $r_{N*i,i} = 0.03 r_{N*i-1,i}$ ($r_{N*i-1,i}$ is the inner radius of the second inner-most sphere). The minimum possible approach to the Sun can thus occur for a star of the least massive type 11 at the distance of 71 AU. After a_j and q_j are determined, the corresponding eccentricity can be calculated as $e_j = 1 - q_j/a_j$.

The given star enters the sphere of radius $r_{o,i}$, when its modified galactic coordinates are l_o and b_o. Since we have to satisfy the perihelion distribution corresponding to (2), two degrees of freedom, implied by l_o and b_o, are reduced to a single degree of freedom. The longitude l_o can be chosen as a random value from interval $<0, 2\pi>$. Then, the latitude b_o must be such that the angle ϕ between radius and velocity vectors of the star in $r_{o,j}$ implies the perihelion distance q_j. The value of b_o can be determined in the following way. Using the well-known relations between the Keplerian orbital elements, we can easily find that

$$\sin\phi = \sqrt{\frac{a_j(1 - e_j^2)}{r_{o,j}(2 - r_{o,j}/a_j)}}. \tag{10}$$

Since we look for the stars moving inward to the critical sphere, angle $\phi > \pi/2$, i.e., $\cos\phi < 0$. Therefore, $\cos\phi = -\sqrt{1-\sin^2\phi}$.

The rectangular components of the radius vector of the j-th star, when it is situated at the distance $r_{o,j}$, are related to l_o and b_o by

$$\begin{aligned} x_{o,j} &= r_{o,j}\,\cos l_o\,\cos b_o, \\ y_{o,j} &= r_{o,j}\,\sin l_o\,\cos b_o, \\ z_{o,j} &= r_{o,j}\,\sin b_o. \end{aligned} \tag{11}$$

With the help of the radius and velocity vectors, $\cos\phi$ can be expressed as

$$\cos\phi = \frac{x_{o,j}v_{hj;x} + y_{o,j}v_{hj;y} + z_{o,j}v_{hj;z}}{r_{o,j}v_{h,j}}. \tag{12}$$

Supplying relations (11) into (12) and after some handling, we can find equation

$$(\tan\,b_o)_{1,2} = \frac{Lv_{hj;z} \pm v_{h,j}\sqrt{L^2 - v_{h,j}^2\cos^2\phi + v_{hj;z}^2}}{v_{h,j}^2\cos^2\phi - v_{hj;z}^2}, \tag{13}$$

by which the angle b_o can be calculated. We denoted $L = v_{hj;x}\,\cos l_o + v_{hj;y}\,\sin l_o$. The randomly generated components of the velocity vector may not satisfy the requirement of the inward motion of the star. Consequently, the argument of the square root in (13) can turn out to be negative. In such a case, we simply ignore the just modeled star and repeat the modeling from the beginning until a positive argument appears.

Finally, the time of the perihelion passage of a given star, T_j, can be chosen as a random moment in the period of modeling (1 Gyr in our case). Subsequently, the actual time t_{*j}, when the star enters the sphere of radius $r_{o,i}$, can be calculated by the Kepler equation and other well-known formulas of the celestial mechanics.

The rectangular coordinates and velocity components of the simulated stars for the moment of their entrance the sphere of radius $r_{o,i} = r_{q,i} + 50\,000$ AU are available as a single data file *entrances.dat* at:
http://www.astro.sk/caosp/Eedition/FullTexts/vol37no3/pp161-172.dat/.
An extract from the data can be seen in Table 2. The data are arranged by time t_{*j} of the entrance of a given star into the sphere of radius $r_{o,i}$. The characteristics of each star are given in three lines separated from the characteristics of another star by a blank line. The first line contains the time t_{*j} (in days from the beginning of the considered 1 Gyr period), the seven-digit identification number of the star, its mass (in solar masses), and the perihelion distance (in AU). The first and second digits of the identification number indicate the spectral type of the star (from 01 to 13, see Table 1), while the other five digits represent a serial number of the star within the given type.

Table 2. A sample of the data describing the model of stellar passages around the solar system (see the text at the end of Sect. 3 for a more detailed explanation).

−25739341.	1114252.	0.18786776542664	138640.
0.30596804623574E+05		0.32899058335504E+05	0.38522399584685E+06
0.23788620667228E−02		−0.21234012138523E−02	−0.88714949042223E−02
1404742.	0401435.	1.54581339359283	228884.
−0.10683298997680E+06		−0.30855333482310E+05	−0.71120838538224E+06
0.15608610627794E−01		0.27089074824675E−02	0.30628098876202E−01
22746065.	0500382.	1.29107375264168	441086.
−0.24540558608173E+05		−0.12399294021645E+06	−0.66394878300797E+06
−0.29122565930012E−02		−0.17652550276087E−01	−0.14225492911551E−01
26091327.	1107412.	0.38093517303467	254509.
0.23619858035230E+06		−0.28915330445532E+06	0.10496016687713E+06
0.11769587103823E−01		−0.12376928115130E−01	0.25886266561642E−01
26360392.	0700784.	0.97364036679268	457538.
0.15151946336033E+06		−0.20812914972726E+05	0.58339919698954E+06
−0.22600321137481E−01		−0.81072198253906E−02	0.33149659790007E−01

The second and third lines of the single-star characteristics contain the rectangular coordinates (in AU) and velocity components (in AU day^{-1}), respectively, referred to the modified galactic coordinate system. (The *modified* galactic coordinate system was used in a well-known description of the Galactic tidal force. Its x-axis is oriented outward from the Galactic center, y-axis follows the Galactic rotation, and z-axis is oriented toward the South Galactic pole to keep the coordinate system right-handed.) In total, the data for 41 589 simulated stars, passing the solar system during 1 Gyr, are available.

4. Influence of the stellar trajectories by the Galactic tide

It is well known that the Galactic tide can considerably change the perihelion distance, eccentricity, and angular orbital elements of a comet situated in the Oort Cloud. In Fig. 1, the change of the perihelion distance of such a comet is illustrated. The osculating orbit of the comet has the semi-major axis equal to 10^5 AU. The instantaneous force on the comet from the Galactic tide corresponds with the instantaneous force of the tide on a passing star. In the period from 14.0 to 14.3 Myr, the perihelion distance increases from 7690 to 8350 AU, i.e., about 8.6%, for example. The quite large change of the cometary orbits evokes a question if the tide can also significantly modify the heliocentric stellar trajectories, which are assumed to be Keplerian hyperbolas. The question about the significance of the Galactic-tide influence becomes actual especially in the case of relatively long-lasting, from the distances of almost 2 million AUs, passages of massive stars (see Sect. 2).

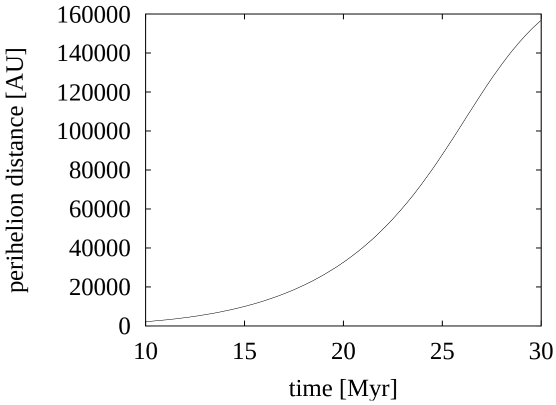

Figure 1. The evolution of the perihelion distance of an Oort-Cloud comet with the semi-major axis equal to 10^5 AU, when its orbit is perturbed by the Galactic tide.

The Galactic tide can be described by the well-known acceleration vector $\{K_x x', K_y y', K_z z'\}$ (Heisler & Tremaine, 1986), where K_x, K_y, and K_z are constants, which can be expressed with the help of Oort's constants, A and B, and density of the Galactic matter in the vicinity of the solar system, ρ_{GM}. The resulting expressions are: $K_x = (A - B)(3A + B)$, $K_y = -(A - B)^2$, and $K_z = -4\pi G \rho_{GM}$ (we neglect the secondary term $2(B^2 - A^2)$ of K_z because of the reason introduced below). The heliocentric rectangular modified-galactic-system coordinates are denoted by x', y', z'.

In our work, we approximately consider a constant linear velocity of the Galactic rotation in the appropriate solar vicinity, i.e. we approximately assume $A \doteq -B$, whereby $A - B = 26\,\mathrm{km\,s^{-1}kpc^{-1}}$ (see also the arguments presented by Levison et al., 2001). If $A \doteq -B$, the secondary z-term of the Galactic-tide force $-2(B^2 - A^2) \doteq 0$. Concerning the density of the near Galactic matter, we use the value $\rho_{GM} = 0.1\,\mathrm{M_\odot pc^{-3}}$.

An influence of the tide can be demonstrated by a difference between the position of the minimum proximity distance star-Sun, when the star is moving on the trajectory perturbed by the tide, and the Keplerian-orbit perihelion. To compare these positions, we numerically integrate all modeled trajectories of the stars of B0 spectral type and the first 1/10 of modeled trajectories of the other types. The integration starts at distance $r_{o,i}$ being about 50 000 AU larger than the corresponding critical $r_{q,i}$. To perform the integration, we use the orbit integrator RMVS3 available within the program package SWIFT (Levison & Duncan, 1994) with a modification including the perturbation by the Galactic tide.

It turns out that no determined difference between the minimum-proximity point and Keplerian perihelion exceeds 0.1 AU. A typical passage of a star around the solar system obviously lasts too short for the Galactic-tide perturbation to be efficient. Another important factor, causing the diversity between the effects of the Galactic-tide perturbation on comets and stars, can be the energy of a given body on unit mass. While the energy of Oort-Cloud comets approaches zero, the stellar energies are much larger. As a consequence, we can well neglect the Galactic tide at a description of the trajectories of stars passing the solar system.

5. Summary

We suggested a method of the determination of a critical distance, $r_{o,i}$, within which all stars of a given, i-th spectral type should be considered, when the stellar perturbations on the Oort-Cloud comets are calculated.

Based on the distances $r_{o,i}$ and the current knowledge of other characteristics of stellar passages around the solar system (García-Sánchez et al., 2001), we created a model of these passages for a period of 1 Gyr. We assumed that the solar system was, during this period, situated in a Galactic environment similar to the current one. The rectangular coordinates and velocity components of the simulated stars for the moment of their entrance the sphere of radius $r_{o,i}$ are available at:
http://www.astro.sk/caosp/Eedition/FullTexts/vol37no3/pp161-172.dat/.

Finally, we demonstrated that the influence of the Galactic tide on the stellar trajectories at a vicinity of the solar system can reliably be neglected.

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