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Migration of asteroids from the 3/1 and 5/2 resonances with Jupiter to the Earth

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Last years many scientists used symplectic integrators [1], which are much faster than usual integrators. For asteroids, a step of integration for a symplectic integrator usually was taken in a range between 7 and 30 days. Some scientists compared the results obtained with different integration steps, but usually they did not compare these results with those obtained with a usual integrator. We have made series of computer runs of the orbital evolution of asteroids for the 3/1 and 5/2 resonances with Jupiter using both the symplectic integrator RMVS3 [1] and the Bulirsh-Stoer method [2] (BULSTO). The results obtained with different integrators and different integration steps d_s were compared in order to understand what error we usually make if we use a symplectic method for investigations of orbital evolution of resonant main–belt asteroids. For BULSTO the error ε per integration step was taken to be less than 10^{-8} or 10^{-9}. For RMVS3, we have made integrations with d_s equal to 3, 10, and 30 days. In each run we considered the Sun, 7 planets (except Mercury and Pluto) and N asteroids moving in the 3/1 or 5/2 resonances with Jupiter ($a_\circ = 2.5$ or $a_\circ = 2.823$ AU). Initial eccentricities and inclinations were the same in all runs: $e_\circ = 0.15$ and $i_\circ = 10°$. Initial values of the mean anomaly and the longitude of the ascending node were different. The considered time interval T_S is equal to several Myr.

Using orbital elements obtained with a step equal to 500 yr, we calculated the probabilities of collisions of asteroids with the terrestrial planets and obtained (for all time intervals and all bodies) the total probability P_Σ of collisions with a planet and the total time interval T_Σ during which the perihelion distance q of asteroids was less than a semi–major axis of the planet. The values of $P_r = 10^6 P = 10^6 P_\Sigma/N$ and $T = T_\Sigma/N$ are presented in the Table together with the ratio r of the total time interval when orbits were of Apollo type (at $a > 1$ AU, $q = a(1-e) < 1.017$ AU, $e < 0.999$) to that of Amor type ($1.017 < q < 1.33$ AU); r_2 is the same as r but for Apollo objects with $e < 0.9$.

Table: Values of T (in kyr), $P_r = 10^6 P$, r, r_2, and r_{hc} for the terrestrial planets (Venus = V, Earth = E, Mars = M) at $N = 144$, $T_S = 10$ Myr (except for the first line for each resonance, for which $T_S = 50$ Myr).

		V	V	E	E	M	M	–	–	–
		T	P_r	T	P_r	T	P_r	r	r_2	r_{hc}
3/1	10^{-8}	739	529	1227	626	2139	116	2.05	1.78	7.41
3/1	10^{-8}	628	488	1056	589	1922	114	2.05	1.53	7.67
3/1	10^{-9}	699	322	1160	413	2012	69	2.14	1.83	6.9
3/1	10	631	574	1015	675	1736	108	2.48	2.16	0.38
3/1	30	925	3580	1366	2763	2189	167	2.44	2.15	0.84
5/2	10^{-8}	109	54.5	223	92.0	516	19.4	1.28	1.15	34.5
5/2	10^{-8}	108	54.2	221	91.4	510	19.2	1.29	1.11	33.8
5/2	10^{-9}	203	155	334	174	644	32.3	1.68	1.24	16.5
5/2	10	79	50.4	158	73.9	330	15.8	1.66	1.44	9.6
5/2	30	308	2330	475	696	703	56	2.82	2.41	6.1

For the asteroids initially located at the 3/1 resonance with Jupiter, we found that the ratio r_{hc} of the number of asteroids ejected into hyperbolic orbits to that collided with the Sun is much larger for BULSTO than for RMVS3. Besides the values of r_{hc} presented in the Table at $N = 144$, for the 3/1 resonance at $N = 24$ we obtained r_{hc} equal to 4.0, 1.7, 0.33, 0.4, and 0.7 at $\varepsilon = 10^{-8}$, 10^{-9}, $d_s = 3$, 10, and 30 days, respectively. So in some cases a symplectic method can give large errors. For the 5/2 resonance, the ratio of the values of r_{hc} obtained by BULSTO and RMVS3 also was not small (> 3). The difference in values of T and P_r was not considerable for RMVS3 at $d_s = 10$ days and for BULSTO. For $d_s = 30$ days at the 5/2 resonance, 78% of the probability of collisions with the Earth were caused by 3 asteroids (64%, by two asteroids) and 52% of all collisions with the Earth were from Aten orbits.

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