EVOLUTION OF ORBITS AT THE 2:3 RESONANCE WITH NEPTUNE. S. I. Ipatov (Institute of Applied Mathematics, Miusskaya sq. 4, Moscow 125047, Russia; ipatov@spp.keldysh.ru), J. Henrard (Department of Mathematics, Facultés Universitaires Notre-Dame de la Paix, Rempart de la Vierge, 8, Namur B-5000, Belgium; jhenrard@math.fundp.ac.be).

We investigate the evolution of orbits at the 2:3 resonance with Neptune. The six-body problem (the Sun, four giant planets, and a test body) is integrated using the symplectic "Swift integrator" of Levison and Duncan [1]. The initial conditions of the major planets are those proposed by these authors. The integration span is 20 Myr. Depending on the type of behaviour of the difference $\Delta\Omega = \Omega - \Omega_N$ between the longitudes of the ascending nodes of the body and Neptune and the argument of perihelion ω, we can consider several types of orbits: DI, ID, II, LI, et al. Here, the first letter corresponds to the behaviour of difference $\Delta\Omega$ and the second letter to the behaviour of ω; a letter "I" corresponds to an increase of $\Delta\Omega$ or ω, a letter "D" corresponds to a decrease of these elements, "L" is for the case of libration, and "S" is for relatively small variations (not more than 360° during 20 Myr). For example, the type IL corresponds to the case when $\Delta\Omega$ increases and ω librates. In contrast to the type L, at the type S the variations don't look like as exact dependence of sin on time. The type of behaviour of $\Delta\Omega$ and ω can change during the time span of 20 Myr.

Variations in eccentricity e, inclination i, and semimajor axis a were relatively small for some initial data. For other initial data, they were large; some bodies left the resonance, and others were ejected into hyperbolic orbits. Even variations in initial orbital orientations and initial positions in orbits can cause large variations in dependencies of e, i, and a on time. For example, at $a_\circ = 39.3$ AU, $e_\circ = 0.15, i_\circ = 5°$, we considered 14 different values of $\Omega_\circ, \omega_\circ$, and $M_\circ$ (where M is the mean anomaly, and starting values for a body are designated by "$\circ$") and obtained that 8 of these bodies left the resonance. Among these 8 nonresonant orbits, there were 6 of the type DI, one of the type SI, and one of the type LI. The type ID was obtained for three resonant orbits, and for other three resonant orbits the type changed: $SI \rightarrow IL, SD \rightarrow SI \rightarrow ID \rightarrow IS$, and $SS \rightarrow SI \rightarrow SS \rightarrow SI \rightarrow IL$. The time spent inside the Kozai resonance (i.e., $\omega \approx$ const) was equal to several million years.

At $\Omega_\circ = \omega_\circ = M_\circ = 60°$, $e_\circ = 0.15$, and $i_\circ = 5°$, we made runs for different values of $a_\circ$. We obtained the type ID at $39.1 \leq a_\circ \leq 39.3$ AU, the type DI at $38.5 \leq a_\circ \leq 38.9$ AU and $39.6 \leq a_\circ \leq 39.9$ AU, and changes in types ($SI \rightarrow DI$, $ID \rightarrow SD$, and $DI \rightarrow SD$) at $a_\circ$ equaled to 39.0, 39.4, and 39.5 AU. At $i_\circ = 5°$ for $e_\circ$ from 0 to 0.3 (with a step equaled to 0.05), the following types were obtained: $SI \rightarrow SD$, $LI \rightarrow LD$, LD, ID, ID, II, and ID. At $e_\circ = 0.15$, we had the type ID for $0 \leq i_\circ \leq 15°$ and the types IL, ID, and II or some combination of these types for $30° \leq i_\circ \leq 90°$. For most of the runs, variations in the critical angle σ exceeded 180°. For nonresonant orbits we usually obtained the types DI, II, or LI. The types DD and DL were not obtained in our runs.

For orbits with a small amplitude of σ-libration, regions of i and e corresponding to the η_{18} ($\Delta\Omega \approx$ const) and Kozai resonances are presented in Fig. 5 in [2]. These regions are located far from each other: $e < 0.03$ and $i < 10°$ for the η_{18} resonance, and $e > 0.2$ at $i < 10°$ for the Kozai resonance. In one our run at $e_\circ = 0.05$ and $i_\circ = 5°$, $\Delta\Omega$ librated around 180° with an amplitude $\sim$ 180° and at the same time ω librated around 270° with an amplitude $\sim$ 100° during 6 Myr. For other values of $\Omega_\circ$, $\omega_\circ$, and $M_\circ$ at $e_\circ = 0.05$ and $i_\circ = 5°$, we usually obtained the type LI, but sometimes also the type DI. According to Fig. 5 in [2], ω decreases at $e < 0.2$ and $i < 10°$. We obtained a lot of orbits with increasing ω at these values of e and i. A region of values of e and i, for which the η_{18} resonance was obtained, was much larger than that in this figure.

For many runs, i varies quasi-periodically with time with a period equal to several million years, and $\Delta\Omega$ changes by 360° during this period. In this case, if $\Delta\Omega$ decreases during evolution, then $\Delta\Omega = 0$ when i reaches its maximum value, and $\Delta\Omega = 180°$ when i reaches its minimum value. If $\Delta\Omega$ increases, than we have 180° and 0 for maximum and minimum values of i, respectively. We often obtained variations in e and i with a period equaled to $T_\omega/2$, where T_ω is the time, during which ω decreased or increased by 360°. For all considered runs, maximum values of e and i exceeded 0.07 and 3°, respectively. Interval $\Delta a = a_{max} - a_{min}$ of variations in a for the resonance is about 1 AU.

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[1] Levison, H.F., and Duncan, M.J.: 1994, *Icarus*, **108**, 18-36.
[2] Morbidelli, A., Thomas, F., and Moons, M.: 1995, *Icarus*, **118**, 322-340.