**POSSIBLE MIGRATION OF THE GIANT PLANETS' EMBRYOS.** S.I. Ipatov, *M.V. Keldysh Institute of Applied Mathematics, Moscow, USSR.*

V.N. Zharkov and A.V. Kozenko [1] suggested that the forming Jupiter ejected a massive embryo with the mass $m_e \sim m_\oplus$ (where $m_\oplus$ is the Earth's mass) from it's supply zone to the Saturn's supply zone. By accreting gas and planetesimals this embryo turned into the massive proto–Saturn. After the formation of Jupiter and Saturn some planetesimals from the supply zones of these giant planets began to move in orbits with eccentricities larger than 0.6 and become Uranus's and Neptune's embryos. Zharkov and Kozenko consider that these embryos acquired hydrogen envelopes with masses equal to $\sim(1–1.5)m_\oplus$ when they were in Jupiter's and Saturn's zones and total masses of these embryos exceeded $3m_\oplus$.

Our results of computer simulation of the evolution of disks of gravitating bodies moving about the Sun and coagulating under collisions [2] testify in favour of A.V. Vityazev's and G.V. Pechernikova's suggestion that besides the embryos of Jupiter and Saturn other large (equal to a few Earth's masses) planet embryos initially could form in the zone of these planets. Not evaluating the probabilities of different ways of orbital evolution of such embryos let us consider the question: could giant planets move in orbits of present eccentricities if they had formed according to Zharkov's and Kozenko's suggestion?

Such a model was analysed by using computer simulation. At the initial time the embryo and 999 bodies moved about the Sun in the same plane. Initial eccentricity of embryo's orbit exceeded 0.6 and bodies' orbits were circular. It was assumed that the body coagulated with the embryo when the distance between them became equal to the radius of action sphere. Mutual bodies' influence was not taken into account. The total mass of initial bodies was chosen so that during evolution the embryo's mass reached the mass of the corresponding planet.

Computer simulation results showed that if Saturn was formed according to the hypothesis by Zharkov and Kozenko then for $m_e \leq 10m_\oplus$ it could acquire present eccentricity equal to 0.056. Real Saturn accreted mainly gas but not bodies. The planet moving in gas decreases it's eccentricity not only due to gas accretion but also due to gas resistance. That is why the eccentricity of the planet accreting gas becomes even less than the one of the planet coagulating the bodies with the same total mass.

The results obtained also showed that the eccentricities of Uranus' and Neptune's orbits were obtained only for initial masses of their embryos less than $2m_\oplus$ and $m_\oplus$, respectively, even if one considered the secular changes of the orbits of giant planets.

The orbital eccentricity of the growing planet becomes greater and we must take lesser initial masses of the embryos if we also take into account mutual gravitational influence of bodies and the possibility of mutual coagulations of bodies. When the embryos of Uranus and Neptune had been formed there was a little gas in the zones of these planets and probably it could not essentially decrease eccentricities of these embryos.

Another model of the formation of Uranus and Neptune was

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also considered. The evolution of some disks initially consisted of almost-formed planets, except Uranus, Neptune and Pluto, of a few hundreds of identical bodies with semimajor axes from 8 to 32 AU and also of two or three embryos with masses about $3m_{\oplus}$ or $5m_{\oplus}$ was investigated by using computer simulation. Initial values of semimajor axes of orbits of Jupiter, Saturn and these bodies were taken equal to 5.5, 6–7 and 6–7.5 AU, respectively. In one of the computer runs two embryos with masses each equal to $10m_{\oplus}$ and semimajor axes equal to 8 and 10 AU were considered. The total mass of initial bodies ranged from $150m_{\oplus}$ to $300m_{\oplus}$. Initial orbits of the planets were circular and initial orbital eccentricities of the bodies and the embryos were equal to 0.02. In the investigated model the interaction of bodies was taken into account. It was assumed that the bodies coagulated under collisions. Mutual gravitational influence of bodies was taken into account by the method of spheres of action, i.e., no account was made for the gravitational influence of the Sun within the sphere of action, and for the gravitational influence of bodies outside the sphere.

Investigating the evolution of these disks we obtained that some bodies migrated to Jupiter which ejected most of them into hyperbolic orbits. The planet embryos changed their orbits due to gravitational interactions with the migrating bodies and sometimes with Jupiter and Saturn. During this evolution the semimajor axes of orbits of some embryos became less than Jupiter's semimajor axis. These embryos were ejected into hyperbolic orbits or could collide Jupiter. Other embryos moving in orbits with small eccentricities increased semimajor axes of their orbits up to 20–30 AU and could become the embryos of the Uranus and Neptune accumulation. At this time the semimajor axis of almost-formed Saturn could increase from 6–7 AU to its present value.

The number of initial bodies for computer simulation did not exceed 1000 and was less than the number of real planetesimals, while the bodies' masses were considerably greater than the average masses of planetesimals. In the considered models the evolution of semimajor axes of planets or their embryos depended mainly on the total mass of the bodies. Orbital eccentricities acquired by the planets or their embryos during evolution were lesser for lesser bodies' masses. To form present masses of Jupiter and Saturn as a result of computer simulation we must take embryos' masses of $\sim 10m_{\oplus}$. For smaller masses of planetesimals their migration and initial masses of embryos should be smaller. The obtained results testify in favour of the hypothesis that Uranus' and Neptune's embryos with initial masses equal to a few Earth's masses could migrate from the Saturn's supply zone, moving in orbits of low eccentricity.

Not only the large planet embryos but also smaller planetesimals which penetrated from the supply zones of Uranus and Neptune during the formation of Jupiter and Saturn influenced the process of accumulation of bodies moving beyond the Saturn's orbit.

*References:* [1] Zharkov V.N. and Kozenko A.V. (1990) *Sov. Astron. Lett.* **16**, N 2. [2] Ipatov S.I. (1987) *Earth, Moon, and Planets.* **39**, 101.