

MIGRATION OF BODIES EJECTED FROM MARS, MERCURY, AND VENUS

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Introduction: Large bodies collided with planets during formation of the planets and the Late Heavy bombardment. Some bodies were ejected from planets after such collisions. Impactors with a diameter of about 10 km formed Chicxulub and Popigai craters 66 and 36 Myr ago. Results of my studies of the probabilities of collisions of bodies ejected from the Earth with planets and the Moon were published in [1-2]. Shorter information about probabilities of collisions of bodies ejected from other terrestrial planets with planets is presented in [3-5]. Below I discuss the migration of bodies ejected from Mars, Mercury, and Venus. In each calculation variant, the motion of 250 bodies ejected from a planet was studied for the fixed values of an ejection angle i_{ej} , a velocity v_{ej} of ejection, and a point of ejection. In different variants, i_{ej} varied from 15° to 90° , and v_{ej} varied from the parabolic velocity on the surface of a planet to 20 km/s. Bodies started from one of six opposite points on the surface of the planet. For the points W and B, the bodies started from the forward point on the planet's surface in the direction of the planet's motion and from the back point on the opposite side of the planet, respectively (from apex and antapex). Four other starting points (C, D, F, and U) were located at the intersection of the surface of the planet and the plane which included the centers of the Sun and the planet and was perpendicular to the plane of the orbit of the planet. The motion of bodies was studied during the dynamical lifetime T_{end} of all bodies, which typically (exclusive for small v_{ej}) equaled to a few hundreds of Myr.

Ejection of bodies from Mars: The values of the probability p_{Ma} of a collision of a body ejected from Mars with Mars were mainly about 0.04-0.25 and 0.01-0.02 at $5.05 \leq v_{ej} \leq 5.3$ and $5.5 \leq v_{ej} \leq 20$ km/s, respectively, for the ejection points C, D, F, and U. For these points, the probabilities p_E of collisions of bodies with the Earth were mainly about 0.08-0.16 and 0-0.16 at $5.05 \leq v_{ej} \leq 10$ and $15 \leq v_{ej} \leq 20$ km/s, respectively, and the probabilities p_V of collisions of bodies with Venus were mainly about 0.08-0.2 and 0.02-0.2 at the same intervals of v_{ej} . For the point B, the value of p_{Ma} was typically smaller than for the above points, and p_E could exceed 0.3. For the point W, the values of p_E were in the range between 0 and 0.18, p_{Ma} could exceed 0.3 at $v_{ej}=5.05$ km/s, and $p_{Ma}=0$ at $15 \leq v_{ej} \leq 20$ km/s. Bodies ejected from Mars could collide with the Earth after 0.1 Myr, and some of the bodies could collide with the Earth after hundreds of million years. At $v_{ej} \geq 6$ km/s, the fraction p_{Me} of bodies collided with Mercury was usually less than 0.06 and was greater than p_{Ma} . Usually at $5.1 \leq v_{ej} \leq 8$ km/s more than a half of bodies collided with the Sun. The probability p_{ej} of ejection of a body into a hyperbolic orbit was less than 0.1 at $v_{ej} \leq 6$ km/s, but it could exceed 0.9 at $v_{ej}=20$ km/s.

Ejection of bodies from Mercury: Usually more than a half of bodies that had been ejected from Mercury fall back onto Mercury. Probabilities p_E of collisions of bodies with the Earth typically did not exceed 0.05 and 0.1 at v_{ej} less than 8 km/s and 15 km/s, respectively. For points B, C, D, and F, the probabilities p_V of collisions of bodies with Venus were usually about 0.2-0.4 at $6 \leq v_{ej} \leq 10$ km/s. The values of p_V were greater than p_E typically by an order of magnitude. The difference was greater for smaller ejection velocities. Not more than 20% of bodies usually collided with the Sun. The fraction of bodies ejected into hyperbolic orbits did not exceed 0.02 for most calculation variants. For the ejection point W and $v_{ej} \geq 6$ km/s at some values of i_{ej} and v_{ej} , about a half of bodies can collide with Venus. Rarely at some initial data most of ejected bodies collided with the Sun or left the Solar system.

Ejection of bodies from Venus: For bodies ejected from the points C, D, F, and U on Venus at $10.4 \leq v_{ej} \leq 16$ km/s, the fraction p_{Me} of bodies collided with Mercury was about 0.01-0.2, the fraction p_V of bodies collided with Venus was about 0.3-0.8, and the fraction p_E of bodies collided with the Earth was about 0.04-0.2 (was smaller by a factor of several than p_V). The values of p_V have some tendency (but not at all initial data) to be smaller at greater v_{ej} . The probabilities of collisions of bodies with Mars often did not exceed 0.01 for all considered initial data. For the point B, the values of p_V were about 0.4-0.8, the values of p_E were usually about 0.04-0.2 (but equaled to 0.01 at $v_{ej}=20$ km/s and $i_{ej}=89^\circ$). For the point W at $v_{ej} \leq 12$ km/s, the values of p_{ej} were mainly less than 0.06, p_{Me} was about 0.01-0.1, p_V was about 0.3-0.8, p_E was about 0.1-0.2, and the probabilities p_{Sun} of collisions with the Sun were about 0.1-0.4.

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References: [1] Ipatov S.I. (2024) *Solar System Research* 58:94-111. <https://doi.org/10.1134/S0038094624010040>, <http://arxiv.org/abs/2405.19797>. [2] Ipatov S.I. (2025) *Icarus* 425, id. 116341 (24 p.). <https://doi.org/10.1016/j.icarus.2024.116341>, <http://arxiv.org/abs/2411.04218>. [3] Ipatov S.I. Modern astronomy: from the Early Universe to exoplanets and black holes. 2024. P. 904-909. <https://doi.org/10.26119/VAK2024.143>. <https://arxiv.org/abs/2501.00134>. [4] Ipatov S.I. (2024) *Solar System Research* 58. Suppl. 1. P. S50-S63. <https://doi.org/10.1134/S0038094623600105>. <http://arxiv.org/abs/2411.05436>. [5] Ipatov S.I. (2025) *LPS LVI*, Abstract #1593.