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On the Existence of Long-Period Comet Families of the Giant Planets

A. S. Guliyev[1*] and R. A. Guliyev[1]**

[1]*Shamakhy Astrophysical Observatory, National Academy of Sciences of Azerbaijan, Shamakhy, Azerbaijan*

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Abstract—We analyze the minimum orbital intersection distances (MOIDs) for a sample of long-period comets (1360) and the giant planets of the Solar System. Our calculations have revealed a considerable number of long-period comets that may have had close encounters with the giant planets: Jupiter (268), Saturn (176), Uranus (81), and Neptune (75). Among them there are 107 cases where the comet approaches two or more planets. Besides, we have also performed an analysis of the cometary orbits based on Tisserand's criterion, which showed that more than 10% of the comets from the group of Jupiter have $2 < T < 3$. There are such values in slightly smaller quantities in the groups of other planets as well. We have also tested our statistical results and conclusions.

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INTRODUCTION

The hypothesis about the existence of long-period comet (LPC) groups of the giant planets has a long history (see, e.g., Opik 1975; Vsekhsvyatskii 1966; Guliyev 2007; etc.). However, this question was studied most objectively by Konopleva (1980). Having studied the minimum orbital intersection distances (MOIDs) of LPCs with respect to Jupiter and Saturn based on an appropriate catalogue, she confirmed that this hypothesis was realistic by specific distributions. According to her estimates, the family of Saturn is more impressive in composition. Subsequently, Drobyshevskii (1980) used Konopleva's data to construct his own cosmogonic concept. There are two reasons for the importance of this question: in the studies of the dynamics of cometary orbits Jupiter is considered as the main perturbing body and, consequently, the existence of comet groups of other giant planets, by this logic, is questioned. If the fact of the existence of other families is confirmed, then it can be used in theoretical searchers for unknown planets. For these reasons, in this paper we return to the above question using up-to-date cometary data and computational resources.

THE COMETARY DATA AND COMPUTATIONAL RESOURCES

Our work is based on an analysis of the MOIDs for LPCs with respect to Jupiter, Saturn, Uranus, and Neptune. We used data for 1360 comets observed until early 2020 with aphelion distances greater than 30 AU. In what follows, for brevity, this list will be called the total set (TS). In our analysis we used data from the cometary catalogue by Marsden and Williams (2008), separate data from MPEC for 2008–2019, and data from JPL HORIZONS. At the same time, we took into account the fact of comet disintegration (used data for only one fragment called A). No data for sungrazing comets were used. Our TS begins with comet 1P and ends with object C/2019 Y1.

As regards the computational resources to determine the MOIDs of LPCs for the giant planets, in our work we used the Wisniowski–Rickman numerical method (Wisniowski and Rickman 2013) and the classical method by Gronchi (2005). The former is used in the case of elliptical (including the comets with extreme eccentricities $e \approx 0.99$) and hyperbolic ($e > 1$) orbits; the latter is used for nearly parabolic ($e \approx 1.0$) cometary orbits. As the limiting distances in our analysis for each planet we used the radii of the sphere of action (Abalkin et al. 1976) that are determined from the formula

$$h = a_{\rm p}\sqrt[5]{\left(\frac{M_{\rm p}}{M_{\rm S}}\right)^2},$$

where $a_{\rm p}$ is the semimajor axis of the planet in AU, $M_{\rm p}$ is the mass of the planet, and $M_{\rm S}$ is the mass of the Sun. Recall that these radii for Jupiter, Saturn, Uranus, and Neptune are 0.322, 0.364, 0.347, and 0.58 AU, respectively.

*E-mail: quliyevayyub@gmail.com
**E-mail: rustamdb@gmail.com

Table 1. Statistics of LPC orbital inclinations for the four selected groups

Planet	Intervals of i, deg						Percentage by T (interval 2–3)
	0–30	30–60	60–90	90–120	120–150	150–180	
Jupiter	41	42	51	53	47	34	11.1/8.2
Saturn	38	27	28	26	27	30	2.3/2.0
Uranus	23	8	13	10	9	18	1.2/0.9
Neptune	20	11	7	8	12	17	4.0/1.7

RESULTS OF OUR CALCULATIONS

Our MOID calculations performed for each planet revealed a considerable number of LPCs that, judging by their orbital characteristics, could have close encounters with them. A record number of corresponding MOIDs was revealed with respect to Jupiter (268 cases). In this regard the second, third, and fourth places belong to Saturn (176 cases), Uranus (81 cases), and Neptune (75 cases), respectively. Our analysis showed that there is a considerable number of cases (107) where the comet has the required MOID with respect to two or more planets.

Table 1 gives the distributions of cometary orbital inclinations for each selected group. First of all, note that approximately the same number of prograde and retrograde orbits is encountered in all four groups. In this regard the selected groups do not differ from the TS.

Do the selected groups differ from the TS in mean distance q? Our calculations showed that there are virtually no noticeable differences in this attribute. The TS and the four groups are characterized by the following $q_{\rm mean}$ and its root-mean-square deviation (σ): 2.149 and 1.866 (TS), 2.188 and 1.581 (Jupiter's group), 2.356 and 1.999 (Saturn's group), 2.066 and 1.524 (Uranus's group), and 1.951 and 1.583 (Neptune's group), respectively. Without resorting to special comparison criteria, it can be argued that these values do not differ noticeably between themselves.

The distribution of values of Tisserand's constant (T) for the comets of the selected groups with respect to the corresponding giant planets also arouses some interest. Our calculations show that the number of values of this constant lying in the interval from 2 to 3 is 30 (11.2%). For comparison, note that for the TS of LPCs this number is 8.2 (112 of 1360). This is circumstantial evidence that the selected comets or some of them are dynamically bound to the planet. The percentage data for other giant planets given in the last column of Table 1 also demonstrate slight superiority of the selected groups. The greatest contrast is seen with respect to Neptune.

VALIDITY OF THE HYPOTHESIS ABOUT THE EXISTENCE OF LPC FAMILIES

The existence of a considerable number of comets with specific MOIDs for the giant planets under conditions where these distances are less than h is not surprising. Here, it is required to determine the degree of randomness of the numerical data found. If the effect is really absent, then the numerical composition of the selected groups must be random.

Let us explain the essence of this requirement using the outermost giant planet, Neptune, as an example. The MOIDs for the 1360 comets under consideration in this case change within up to 30 AU. Imagine a sphere with the same radius inside which 2720 points (1360 × 2) are distributed. Concurrently, imagine a belt along the orbit of Neptune with twice the radius of its sphere of influence. This belt may be considered as the locus of projections of the points of the closest LPC–planet encounter. The ratio of the areas of the spherical belt and the sphere multiplied by the number of points will then be the expected number. Thus, the areas of the sphere and the belt will be defined by the formulas

$$S_1 = 4\pi a_{\rm p}^2, \quad S_2 = 2\pi a_{\rm p} \cdot 2h.$$

Here, $a_{\rm p}$ and h are the semimajor axis and the radius of the planet's sphere of action, respectively. It is easy to verify that

$$k = \frac{S_2}{S_1} = \frac{h}{a_{\rm p}}.$$

Multiplying k by the total number of points, we find that it can be assumed in the case of Neptune that the expected number of comets must be 52.6. The real number of MOIDs (75) exceeds this value by almost a factor of 1.43. Needless to say, there is no randomness here.

In the case of Uranus, k is 0.018 and this implies that the expected number of MOIDs for a uniform or chaotic distribution of points must be 49.2, although the real number is 81, i.e., greater than the expected one by a factor of 1.65. Our calculations for Saturn give $k = 0.038$, which is equivalent to 104 MOIDs, while in reality there are 176 of them, i.e., the superiority being discussed in this case is a factor of 1.7. In the case of Jupiter, we can deduce $k = 0.062$, corresponding to 168 MOIDs (in reality, there are 268 of them, while their superiority over the expected one is a factor of 1.6). To summarize, it can be stated that the real frequencies of the MOIDs for LPCs with respect to the giant planets exceed their expected frequencies by almost a factor of 1.4—1.7.

Here, apparently, it would be well to take into account the fact that the region in which the distance to the planetary orbit is less than the specified value is the interior of the three-dimensional torus around the planet's orbit. Therefore, the probability of a chance "close" comet passage increases only slightly due to the torus "thinness" compared to the sphere. However, in addition, we disregard the fact that at low inclinations (near 0° and 180°) to the plane of motion of the giant planet some comets can have two MOIDs that do not exceed the radius of its sphere of influence, while in our statistical calculations we use only one of them. This factor, on the contrary, slightly increases the confidence probability of the working hypothesis under consideration.

CONCLUSIONS

The comet–planet MOIDs were studied in more detail using periodic comets and Jupiter as an example (Tancredi 2014). In the LPC case, a similar question was studied with regard to the giant planets (Guliyev 2007) and, in particular, for Uranus (A. Guliyev and R. Guliyev 2013). However, not the minimum orbital intersection distances, but the distant nodes of cometary orbits were used in these two papers.

Our calculations and analysis of the MOIDs performed for the first time for 1360 LPCs with respect to the four giant planets revealed 600 cases where the MOIDS are smaller than the sizes of the spheres of action of the latter. Even if we take into account the repetitive 107 cases where a LPC can cross the sphere of action of two or more planets, it is expected that about a third of the comets under consideration can potentially be bound to the giant planets. We showed that this exceeds the limit of an admissible level of randomness by a factor of 1.4–1.7. The revealed comets differ from the remaining LPCs primarily by relatively favorable values of Tisserand's constant. These facts should be taken into account in cosmogonic models for the origin of comets.

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