Research Article

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On the role of collisions with meteoroids in splitting and acceleration of heliocentric velocity of comets

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Abstract: The hypothesis on the role of the meteoroid impacts in the comet nuclei splitting as well as acceleration of their heliocentric velocity are considered. Inclinations of the orbits of split comets relative to the movement planes of 100 known meteoroid streams are calculated. The analysis is carried out for the cases: when the cometary nodes are located from the meteoroids orbit < 0.1 AU; MOID-values less than 0.1 AU. In the case of split long-period comets irregularity (maximum near 180°) of the distribution of the inclinations has been found. Comets, constituting this maximum, could have head-on collisions with meteoroids. A similar analysis is carried out relatively to the hyperbolic comets (HCs). Analysis is based on the assumption that the acceleration of the heliocentric velocities of the comet also is caused by collisions with meteoroids. The inclinations of the orbits of 300 HCs relative to 100 known meteoroid streams have the significant maxima in the interval of 90° – 101.5°. Acceleration of comet velocity might be the result of "slanting" collisions with meteoroids.

Keywords: split comets, meteoroids, collisions, hyperbolic orbits

1 Introduction

According to modern notions the cause of the splitting of cometary nuclei into secondary fragments can be various external and internal factors associated with comets and the conditions of their movement (changes in the sectoral structure, solar activity, tidal influence of the Sun, rotational instability, irregular sublimation et al.). This process and its observational aspects were discussed in detail in the works by Sekanina (1997); Boehnhardt (2004); Gronkowski and Wesolowski (2012); Pittich and Solovaya (2013); Kleyna et al. (2016); Manzini et al. (2016).

Another possible mechanism of comet splitting and origin of the short-perihelion comet groups as result of such processes has been advanced by the one of authors of this article (Guliyev 2016, 2017). According to this mechanism, splitting can occur due to the passage of comet nuclei (parental bodies) through meteoroid streams. Another paper (Guliyev and Nabiyev 2017) substantiated the working hypothesis that collisions with meteor particles could also lead to an increase of the heliocentric velocity of the comets and also to the formation of osculating hyperbolic orbits. Some aspects of the collision of comets and meteoroids were considered by Matsuura (1976) and Boehnhardt (2004). In this paper we demonstrate some new arguments for this idea.

In this paper we try to analyze distributions of the angles between the split and hyperbolic comets on one side and the meteoroids on other during the possible collisions. If these angles are very large, it increases a possibility of comets' collapse. The limiting case of such process could be a head-on collision. In addition, we will try to find out – under what conditions heliocentric velocity will increase after possible collisions.

In subsequent calculations, we will proceed from the assumption that the collision angle cannot be less than the inclination of the orbit of the comets relatively to the movement plane of the selected meteoroid streams. Accepting this thesis as a basis, we will analyze the values of the inclinations I' of the orbits of 114 comets underwent to splitting

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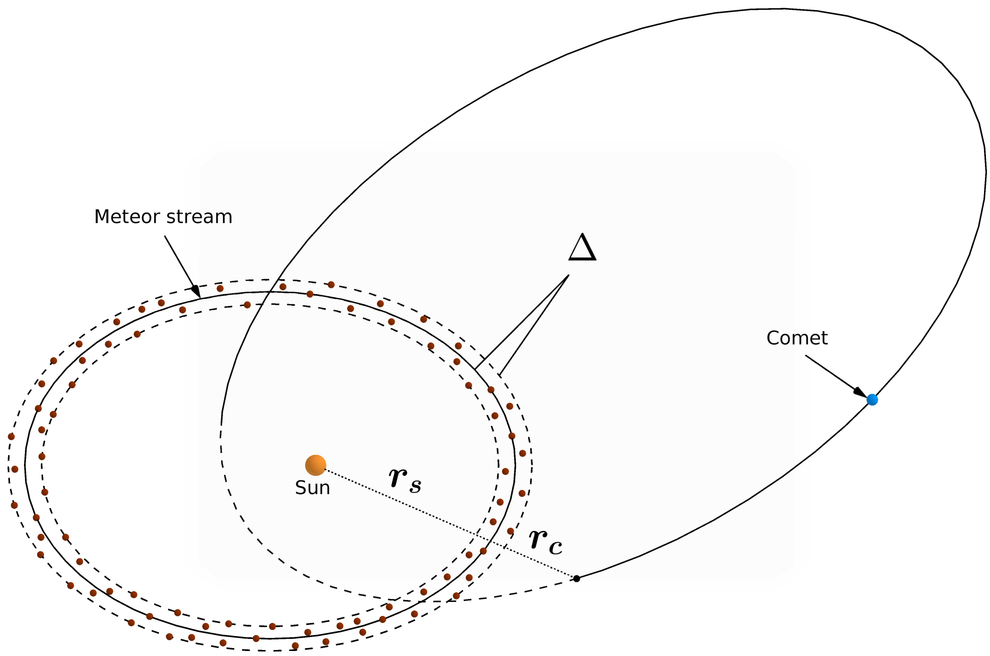

Figure 1. To the definition of the parameters r_s and r_c

and 300 hyperbolic comets relatively to 100 meteor streams from IAU Meteor Data Center[1].

2 Calculation method

The value of I' can be obtained by the following formula of the spherical astronomy:

$$I' = \arccos\left(\cos i \cos i_s + \sin i \sin i_s \cos\left(\Omega - \Omega_s\right)\right)$$

where i_s and Ω_s – are elements of a stream orbit, i and Ω – are elements of cometary orbit.

Since this work is a development of the idea of our previous ones (Guliyev 2016, 2017), values of I' according to the considerations from sited papers, will be calculated for comets having the parameter:

$$\Delta = |r_c - r_s|$$

up to 0.1 AU. We remind that r_c – heliocentric distance of close or distant node of the cometary orbit, r_s – heliocentric distance of a stream in the direction of the according node of the cometary orbit (Figure 1).

To calculate MOID-values for the comet-stream case, we can use the following simplified formula:

$$r^2 = R^2 + \left(\frac{q(1+e)}{1+e\cos v}\right)^2 - 2R\left(\frac{q(1+e)}{1+e\cos v}\right)\sqrt{(1-\sin^2 i)\sin^2(\omega - v)} \quad (1)$$

where R is the heliocentric distance of the stream in the direction of the nearest comet node, q and e are non-invariant elements of comet orbit, i and ω are the angular elements of comet orbit and v is the true anomaly of the comet, which ranges from 0° to 360° with an interval of 1°. Angular elements and the parameter R are calculated relative to the plane of the stream, where the reference point is the ascending node of the stream's orbit. For clarity, it should be kept in mind that the parameter r is the scalar quantity of the difference of the vectors Sun-comet and Sun-stream.

To determine the boundaries of I' intervals, we will proceed from the principle of equal-distances of the cometary orbits' poles by applying the statistics of the I'. It means that for statistics of inclinations frequency the whole interval $\cos I'$ $(-1; 1)$ needs to be divided into equal parts.

1 https://www.ta3.sk/IAUC22DB/MDC2007/

Table 1. Results of statistics of the parameter I' for split long-periodic and periodic comets in the case $\Delta < 0.1$ AU

I'(deg)	36.9	53.1	66.4	78.5	90	101.5	113.6	126.9	143.1	180
N_1	59	63	44	57	64	57	42	57	59	71
N_2	161	115	90	112	111	109	90	93	101	140
N_3	84	13	8	14	10	13	6	6	9	16
N_4	297	81	97	118	120	62	78	38	47	73

Table 2. Results of analysis of the nodes and MOID-values for the 300 hyperbolic comets relatively to the orbits of the 100 meteoroid streams

I'(deg)	36.9	53.1	66.4	78.5	90	101.5	113.6	126.9	143.1	180
N_5	109	116	97	104	117	124	88	101	108	111
N_6	459	390	395	407	441	492	448	383	421	453

3 Results for split long-period and periodic comets

Due to almost random distribution of the LPCs inclinations, thereby their analysis is very important for the considered task. For this reason, we decided to analyze the inclinations of the orbits of split comets relatively to the planes of movement of the known meteoroid streams from the IAU Meteor Data Center. It should be noted that 73 of the 114 comets that underwent to splitting, have periods $P > 200$ years.

According to our calculations, the number of I' parameter values under the condition $\Delta < 0.1$ AU, is 573. Results of statistics for these comets are shown in Table 1.

One of the peculiarities of the obtained distribution N_1 for the orbital nodes, is the maximum (71) in the interval of $143.1^\circ - 180^\circ$. It means that within the event of possible collisions of the considered comets and meteoroid particles, frontal collisions occur most often. This feature might be considered as satisfactory agreement for our proposed mechanism of comet nucleus splitting.

Results of the MOID-analysis (Table 1, N_2) partially confirm the correctness of the conclusion about the split long-period comets. Analysis of N_2 values in the range from 36.9° to 180°, shows that the absolute maximum corresponds to the interval $143.1^\circ - 180^\circ$. As for the first maximum, it has no physical meaning. Its existence may be related to the fact that most of the considered streams have small inclinations to the ecliptic.

Application of the above analysis for the periodic comets might be associated with some difficulties. It is known that such comets have small orbital inclinations. Therefore, this feature of the periodic comets, a priori, must have an impact on the distribution of I'. It can be previously predicted that the maximum of such distribution will correspond to the first interval. Therefore, the detection of the second and local maximum in the diapason of the large values of I' can be considered as an additional argument in favor of the discussed hypothesis.

Results of the corresponding calculations for 41 periodic comets that underwent to splitting, are given in the Table 1 (N_3). As expected, the number N_3 in the first interval ($0^\circ - 38.9^\circ$) clearly dominates over the other values in the distribution. However, the local maximum in the diapason of $141.1^\circ - 180^\circ$ ($N_3 = 16$) is also noticeable. Its existence is qualitatively agrees with the discussed hypothesis.

However, the MOID-analysis have given uncertain results in the case of periodic comets (Table 1, values of N_4). Perhaps it is due to the fact that the simplified formula (1) provides relatively large errors in the case of small inclinations of the cometary orbits and meteoroid streams.

4 Results for “Hyperbolic comets”

Analogical calculations have been carried out regarding to 300 comets having osculating hyperbolic orbits to 2017. Cometary data have been taken from Marsden and Williams (2008) catalog and the issues of MPEC for the period 2008-2016. In the paper (Guliyev and Nabiyev 2017), was advanced the following hypothesis regarding to the origin of these comets: long-period comet passing through meteoroid streams, may get an additional impulse after its bombing by small particles which can lead to increasing of e – eccentricity and transform the orbit into hyperbolic one. Some dynamic characteristics and distinctive properties of the considered comets are also given in the cited paper.

The results of calculations for nodes of cometary orbits in the case $\Delta < 0.1$ AU are given in the second line of Table 2 (values of N_5). It radically differs from the analogous distribution of the above considered 73 long-period comets and is characterized by a maximum in the interval

$(90^\circ - 101.5^\circ)$. 124 nodes corresponding to this interval are 17 percent higher than the norm in the case of uniform distribution.

According to the proposed hypothesis, received results could mean that, slanting impacts from meteoroids on cometary nuclei some times lead to the conversion of comets into the category of hyperbolic ones.

Analogical results have been received in the case of the MOID-values analysis (Table 6, values of N_6). In the interval of $90^\circ - 101.5^\circ$, the number of these values (492) is more than the other intervals.

5 Discussion

In this work, we proceeded from the real precondition that meteoroids' impacts on comet nuclei can occur at an angle greater than the orbital inclination I'. Based on this observation, we carried out an analysis I' for two groups of comets: underwent to the nucleus' disintegration and having osculating hyperbolic orbit. Noticeable maximum of the inclinations' distribution of the split long-period comets was found. It corresponds to the high values of this parameter which in turn confirms the correctness of the considered mechanism. Similar maximum was found in the case of the periodic comets, but it has secondary character. Independent MOID-analysis of the comets and meteoroid streams confirms the reality of these maxima. They mean that the splitting of cometary nucleus occurs more often when collisions of comets and meteoroid particles take place at very large angles, for example during the head-on collisions. The mutual velocity in such collisions can reach enormous values, for example 50-70 km per second. At such velocities, a meteoroid with a smaller size is able to destroy a cometary nucleus.

A detailed study of such processes taking into account the mass, size, velocity of the meteoroid body and the cometary nucleus itself is required in the future. This work should be considered only the first step in this direction.

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References

Boehnhardt H. 2004. Split comets. Comets II. 745:301–316.

Gronkowski P, Wesolowski M. 2012. Collisions of comets and meteoroids: the post stardust-next discussion. Astron Nachr. 333(8):721–726.

Guliyev A. 2016. Meteoroid streams and comet disintegration. In: Roggemans A, Roggemans P. Editors. Proceedings of the International Meteor Conference, 2016 Jun 2-5, Egmond, the Netherlands, p. 94–95.

Guliyev A. 2017. Collision with meteoroids as one of possible causes of cometary nucleus splitting. Planet Space Sci. 143:40–42.

Guliyev A, Nabiyev S. 2017. Collisions with meteoroid streams as one possible mechanism for the formation of hyperbolic cometary orbits. Adv Space Res. 60(1):199–203.

Kleyna JT, Ye Q-Z, Hui M-T, Meech K, Wainscoat R, Micheli M, et al. 2016. The progressive fragmentation of 332p/ikeya–murakami. ApJ. 827(2):L26.

Manzini F, Oldani V, Hirabayashi M, Behrend R, Crippa R, Ochner P, et al. 2016. Comet c/2011 j2 (linear) nucleus splitting: dynamical and structural analysis. Planet Space Sci. 126:8–23.

Marsden B, Williams G. 2008. Catalogue of Cometary Orbits, 17-th edition. International Astronomical Union, Central Bureau for Astronomical Telegrams/Minor Planet Center Minor Planet Center, Smithsonian Astrophysical Observatory, Cambridge, MA (USA).

Matsuura OT. 1976. Collision of comets with meteoroids. Icarus. 27(2):323–329.

Pittich EM, Solovaya NA. 2013. Collisions of small bodies as a source of hyperbolic meteoroids in the solar system. In: Gyssens M, Roggemans P. Editors. Proceedings of the International Meteor Conference (31st IMC), 2012 Sep 20-23, La Palma, Canary Islands, Spain, International Meteor Organization, p. 182–186.

Sekanina Z. 1997. The problem of split comets revisited. A&A. 318:L5–L8.