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ρ-Geminids meteor shower and its connection with near-Earth asteroids

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Abstract. In this work, genetic connections (GC) of the small meteor shower ρ-Geminids with near-Earth objects (NEOs) of the Apollo group were studied using the author's multiparameter method. The multiparameter method for determining GC of meteor showers with probable parent bodies is based on the use of a set of criteria for identifying orbits, such as: D-criterion by Drummond, Kholshevnikov's metric, Tisserand's parameter, μ and ν quasi-stationary parameters of the restricted three-body problem, longitude of perihelion π of meteor orbit. The method of identifying meteoroids with asteroids involves computational procedures and the calculation of critical values for each of the criteria used, which increases the reliability of finding the GC for the objects under study. The catalogues of meteor orbits: Meteoroid Orbit Database v3.0, CAMS and EDMOND 5 v.04 of the European Meteor Network were used as source material in the work.

Keywords: meteor showers, near-Earth asteroids, orbits of small celestial bodies, genetic relationships between meteor showers and asteroids

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Метеорный поток ρ-геминиды и его связь с околоземными астероидами

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Аннотация. В работе были исследованы генетические связи (ГС) малого метеорного потока ρ-Гееминиды с околоземными астероидами группы Аполлона с применением авторского многопараметрического метода. Многопараметрический метод установления ГС метеорных потоков с вероятными родительскими телами основан на использовании совокупности критериев отождествления орбит.

Ключевые слова: метеорные потоки, околоземные астероиды, орбиты малых небесных тел, генетические связи метеорных потоков и астероидов

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Introduction

For many large meteor showers, parent bodies were identified, while for small meteor showers, the parent body is unknown [1]. Large meteor showers include a great number of meteors, and their orbits can be determined with higher accuracy, while small meteor showers have a low zenithal hourly rate (ZHR) and average orbital elements of the shower are determined with less accuracy [2–5]. Besides, the parent body of a meteor shower can be small, which makes it difficult to observe and, consequently, determine its orbit [6–7]. The orbits of meteoroids and the orbits of the parent bodies evolve rapidly [8], which makes it very difficult to identify the meteoroids of the shower with the orbit of the parent body. The search and identification of possible connections between meteor showers and presumed parent bodies play an important role in the theory of the origin and evolution of meteoroid bodies allowing to understand the mechanism of the decay of the parent body, the process of meteoroid ejection, and to determine potential sources of meteorites [9, 10].

At a moment, it is believed that the formation of meteor showers is possible either due to the decay of the cometary nucleus, or the meteor shower is a derivative of an asteroid. There is also a hypothesis according to which some asteroids are dormant cometary nuclei. The greatest difficulty is the search for methods for separating such objects into comet nuclei, that actually lost their activity, and real asteroids that were formed in the main asteroid belt. Among the ways that can confirm or disprove this hypothesis is a low albedo, a large eccentricity or inclination, but the orbit can be changed under the influence of gravitational perturbations.

According to available data from space missions, the surface of small asteroids is covered with regolith and stones, has splits and cracks, as well as craters. Consequently, at rotation, under the influence of external forces, under the action of centrifugal force and under the influence of the gravitational force of planets, such asteroids can be destroyed, and regolith can be separated from their surface. Under the influence of the tidal force from the Earth, which acts on the asteroid at the moment of their close approach, the shape of the asteroid can change, and the stones and dust located on its surface can be released into interplanetary space. Hoffmeister suggested in 1937 that asteroids produce meteoroids of various size, from dust to large debris. Such asteroids can be extinct comets with low cometary activity as well. Asteroidal meteoroids can also be generated by tidal disruption or asteroid collisions, which can create short and narrow dust trails. The study of these NEOs is important since they pose a danger to our planet having a low tensile strength, but due to their low activity, such small planets are easier to study than the ones of the Jupiter family.

For the first time, Fred Whipple identified an asteroid as the parent body of a meteor shower in 1961; he established that the 3200 Phaeton is associated with the Geminids meteor shower. Recently, 2003 EH1 has been considered the parent body of the Quadrantida meteor shower. The orbits of these objects have a strong orbital inclination about 72°, which excludes their random connection. Later, the minor planet 2003 WY2 was found to be moving in a cometary orbit similar to that of comet D/1819 W1 (Blanpain), this comet was lost, as indicated by the letter D in its name. However, at its appearance, the comet had good activity and its outbursts were accompanied by fragmentation. Thus, it can be assumed that the parent bodies of meteor showers can be searched for among asteroids of near-Earth groups, since among these objects, perhaps, there are extinct comets that lost their volatile component, or fragments of decayed cometary nuclei, and formed bonds are also possible as asteroid-comet complexes.

Materials and Methods

The purpose of the study is finding genetic connections the small meteor showers with near-Earth objects. The objectives of the study is investigation the meteor shower ρ-Geminidsand the Apollo group asteroids. The small meteor shower ρ-Geminids (rho Geminids, RGE, #94) was discovered in 1952–1954 by Southworth and Hawkins under the Harvard meteor program. ρ-Geminids are active from December 28 to January 28, the maximum occurs around January 8, the secondary maximum occurs on January 21. The parent body of the shower is not defined. It is a small meteor shower that has a low zenith hourly rate (ZHR): about 20 meteors per hour. In publications, observations and radiants of the ρ-Geminids are given, but there are few publications on the establishment of GC due to its low abundance. Meteoroids were analyzed and their chondrite nature was determined. Chondrites are stone objects interspersed with small chondrules, i.e. spherical formations up to 1 mm in size. Chondrites are the most common group of asteroids.

Optical video observations of meteors began in the 1970s using TVs and VCRs. For the first time this method was used by observers from Netherlands and Japan, and subsequently in connection with the advent of image intensifiers, this method was actively developed. The video method of observation has a number of advantages over the photo method, since it is possible to determine the speed of a meteor and its duration reliably [11].

In addition, in video observations, to determine the initial orbit of the meteoroid, the triangulation method is used and the observation is carried out simultaneously from several stations, which increases the accuracy of a certain orbit. Meteor orbit catalogues were used as source material: Meteoroid Orbit Database v3.0, CAMS (hereinafter CAMS), and EDMOND 5 v.04 of the European Meteor Network (hereinafter EDMOND). The CAMS catalogue includes information on 110521 meteoroid orbits from magnitude -2^m to $+4^m$ (median is $+1.2^m$). Accuracy is < 2° (median is 0.24°) in determining the direction of the radiant and < 10% in determining velocity (median values are 0.31 and 0.51 km/s, approximately 2%). The CAMS catalogue lists errors in measuring the orbital elements of meteoroids.

The version of the EDMOND database (v5.04, February 2018) contains 322,566 meteoroid orbits from 2001 to 2016. There is no information about errors in determining the elements of meteoroid orbits in the catalogue.

Table 1 shows data on the number of selected orbits of ρ-Geminids meteoroids in the catalogues, as well as the elements of average orbits are determined from the orbital characteristics of separate meteoroids and their root mean square errors σ (RMS) (errors and weights are calculated according to the CAMS catalog; according to the EDMOND catalog – excluding them).

To establish a connection between the orbits of meteoroids and their potential parent bodies,

Table 1

Mean orbits of the ρ-Geminids (angular elements for epoch J2000.0)

Catalogue	Number of Orbits	q±σ (au)	a±σ (au)	e±σ	i°±σ°	Ω±σ°	ω±σ°	π±σ°
CAMS	10	0.590 ±0.027	2.373 ±0.188	0.749 ±0.024	2.893 ±0.815	279.777 ±3.513	266.191 ±3.177	289.428 ±3.454
EDMOND	32	0.558 ±0.077	2.167 ±0.310	0.737 ±0.043	2.679 ±1.359	264.214 ±47.481	242.881 ±1.359	185.968 ±1.377

Notations. In Table, q, a, e, i, Ω, ω, π are perihelion distances, semi-major axis, eccentricities of the orbit, inclination, longitude of the node of the orbit of a small body, argument of perihelion and longitude of perihelion.

we use a multivariate analysis methods described in detail in [1]. For analysis, we use a data sample from two catalogues of meteor orbits CAMS and EDMOND; in calculations, we use the average shower orbit calculated from 10 meteors in the CAMS catalogue and 32 meteors in the EDMOND catalogue (Table 1). To determine the similarity of the orbits, a set of criteria for the proximity of the orbits of small bodies is used. Drummond criterion [2]:

$$D^2 = \left(\frac{e_2 - e_1}{e_2 + e_1}\right)^2 + \left(\frac{q_2 - q_1}{q_2 + q_1}\right)^2 + \left(\frac{I_{21}}{180^\circ}\right)^2 + \left(\frac{e_2 + e_1}{2}\right)^2 + \left(\frac{\theta_{21}}{180^\circ}\right)^2, \quad (1)$$

where $\theta = \arccos\left(\sin\beta_2 \sin\beta_1 + \cos\beta_2 \cos\beta_1 \cos\left(\lambda_2 - \lambda_1\right)\right)$, $\lambda = \Omega + \mathrm{arc\,tg}(\cos i \,\mathrm{tg}\,\omega)$; 180° is added if cos ω < 0, $\beta = \arcsin\left(\sin i \sin\omega\right)$, where *I*, *e*, *q* are mutual inclination, eccentricities and perihelion distances of the orbits of two bodies, for which the calculation is carried out.

The Kholshevnikov metric ρ [3], which is defined in the three-dimensional phase factor space as

$$\rho^2 = \left(1 + e_1^2\right) p_1 + \left(1 + e_2^2\right) p_2 - 2\sqrt{p_1 p_2}\left(e_1 e_2 + \cos\left(i_1 - i_2\right)\right), \tag{2}$$

where p_1, p_2 are focal parameters.

It is believed that the physical dimension of ρ is the root of the length unit, so in what follows we calculate ρ^2 (au). Therefore, for the Drummond criterion (1), we calculate D^2, since we need a dimensionless quantity. We will accept the hypothesis about the proximity of the orbits of two small bodies *x* and *y* if the condition

$$\begin{gathered} D_c^2(x, y) \le D_c^2, \\ \rho_c^2(x, y) \le \rho_c^2, \end{gathered} \tag{3}$$

where D_c, ρ_c are upper critical values of the Drummond criterion *D* and the Kholshevnikov metric ρ.

The critical values of and ρ_c are determined as the calculated average values of *D* (1) and ρ (2) for the pairs of orbits: meteoroid orbit – average shower's orbit [1] (Table 2). Table 2 provides the upper critical values of the Drummond criterion D_c and the Kholshevnikov metric ρ_c and their standard deviations calculated from the CAMS and EDMOND catalogues for ρ-Geminids.

To characterize the dynamics of small bodies, the Tisserand's parameter relative to Jupiter is used. The value of this parameter determines the rate of approach to Jupiter, since this parameter is kept constant in the circular restricted three-body problem. Jupiter has T_j = 3. Main belt asteroids have $a < a_j$ and $T_j > 3$.

Table 2

Critical values of the Drummond criterion D_c and the Kholshevnikov metric ρ_c for ρ-Geminids

Catalogue	$D^2_c \pm \sigma$	$\rho^2_c \pm \sigma\sigma$
CAMS	0.035±0.012	0.024±0.009
EDMOND	0.064±0.027	0.011±0.011

We also use parameters whose values change insignificantly during the orbital evolution of small bodies: the Tisserand's parameter with respect to Jupiter [4]

$$T = a^{-1} + 0.16860a(1 - e^2)^{1/2}\cos i \tag{4}$$

and two quasi-stationary parameters [5, 6]:

$$\mu = \sqrt{a(1 - e^2)}\cos i, \tag{5}$$

$$\nu = \left(1 - e^2\right)\left(0.4 - \sin^2\omega \sin^2 i\right), \tag{6}$$

where *a*, *e*, *i*, ω are semi-major axis, eccentricity, inclination, argument of perihelion and longitude of the node of the orbit of a small body.

Also longitude of perihelion

$$\pi = \omega + \Omega, \tag{7}$$

which also remains constant [11] over long-time intervals. The average values of the parameters *T*, ν, μ, and π for ρ-Geminids are given in Table 3.

Table 3

Average values of Tisserand's parameter *T*, quasi-stationary parameters μ and ν perihelion longitude π for ρ-Geminids

Catalogue	T±σ	μ±σ	ν±σ	π±σ
CAMS	3.1030.218±	1.0140.024±	0.1740.019±	185.9681.619±
EDMOND	3.3360.403±	0.9790.080±	0.1800.030±	203.3458.128±

The selection of asteroids with close orbits is carried out according to the algorithm described in detail in [1]. If condition (3) is observed for a pair of orbits (x is the asteroid's orbit, y is the average shower's orbit), then the Drummond criterion (1) and the Kholshevnikov's metric (2) are assigned the factors $P_1 = 1$, $P_2 = 1$. If condition (3) is satisfied taking into account RMS±σ, ±2σ, etc., then criteria (1) and (2) are fulfilled with the values of the factor $P_1 = 0.9$, $P_2 = 0.9$, $P_1 = 0.8$, $P_2 = 0.8$, etc. respectively.

The fulfillment of criterion (4) on the Tisserand's parameter T for a pair of two orbits is also evaluated on the basis of standard deviation (Table 4) and criterion (4) is fulfilled with the factor $P_3 = 0.9$, $P_3 = 0.8$, etc.

Similarly, the reliability of the fulfillment of criteria (5–7) is assessed based on their RMS (Table 3) with the assignment of factors P_4, P_5 and P_6, respectively. The value of unity is not assigned to the factors P_3, P_4, P_5 and P_6, since for criteria (5–7) it is the interval scatter of the values of T, μ, ν, π between the asteroid orbits and the average shower's orbit, and not their complete coincidence that is estimated. The overall measure of fulfillment of all criteria (2–7) was estimated as the product P_i of all factors $i = 1, ...,6$.

Results and Discussion

As a result of all calculations, asteroids were selected for which criteria (2–7) are met with factors $P_i \geq 0.8$ (taking into account rounding to tenths), i.e., the parameters of the criteria do not exceed the 2σ value of their average values. When implementing this approach, the total measure P_i of the fulfillment of all criteria in the aggregate amounted to a value ≥ 0.5 for the two catalogues CAMS and EDMOND. Selected asteroids with close orbits for ρ-Geminids are shown in Table 4, which also presents the results of other sources.

Table 4

Asteroids with orbits close to the ρ-Geminids (RGE #94)

Selected Asteroids	Catalogue	Factor P	Data on publications of other authors
506859 (2007VW137)	CAMS EDMOND	0.7 0.5	506859 (2007VW137), 2010 AG30
2014 XJ3	CAMS EDMOND	0.6 0.5	
2010 AG30	CAMS EDMOND	0.5 0.5	

ρ-Geminids meteors were analyzed and identification was carried out using the Southworth-Hawkins D criterion. As a result, asteroids 506859 (2007VW137) ($D_{SH} = 0.09$) and 2010 AG30 ($D_{SH} = 0.13$) were identified. For the D criterion of Southworth-Hawkins, the restriction $D_{SH} < 0.15$ was used, which the authors adopted.

Orbital elements and a number of physical parameters for the asteroids we have chosen are placed in Table 5.

It is assumed that objects with the value of the Tisserand's parameter relative to Jupiter $T < 3.1$ move in cometary orbits, if $T > 3.1$ then in asteroid orbits, and objects with $T \approx 3$ have a transfer orbit. The average orbit of the ρ-Geminids shower has the value of Tisserand's parameter $T_{\Pi} = 3.273$ for the EDMOND catalog and $T_{\Pi} = 3.075$ for CAMS, which makes it possible to search for connections between the proximity of orbits among asteroids, since it is impossible to unambiguously determine the type of its orbit, i.e., cometary or asteroid.

Table 5

Orbital elements (2000.0) and physical parameters of identified asteroids

Asteroid	a, au	e	q, au	i°	Ω°	ω°	T, year	T_{jup}	Earth MOID, au
506859 (2007VW137)	2.229	0.739	0.581	5.943	299.655	245.071	3.327	3.212	0.039
2014 XJ3	2.134	0.727	0.582	1.223	22.312	161.671	3.118	3.317	0.020
2010 AG30	2.261	0.695	0.690	2.088	103.581	84.624	3.399	3.249	0.006

All selected asteroids by the value of the Tisserand's parameter have an asteroid type of orbit. The selected asteroids are potentially dangerous, approaching the Earth less than 900 thousand km and, therefore, fall into the sphere of its gravitational influence. There are no data on the size of asteroids and geometric albedo, which does not allow us to assess the degree of their danger to the Earth. There are also no data on the physical and chemical characteristics of asteroids, which makes it difficult to identify them with a meteor shower and requires further additional research.

Conclusion

In this paper, we searched for possible parent bodies for the poorly studied small meteor shower ρ-Geminids among near-Earth asteroids of the Apollo group. The method of multivariate analysis, described in detail in [12], was applied. As the initial base of meteor orbits, two television catalogues of meteor orbits CAMS [13] and EDMOND [14] were involved, on the basis of which, using the set of the criteria, asteroids 506859 (2007VW137), 2014 XJ3, and 2010 AG30 were selected. Since the ρ-Geminids is a poorly studied meteor shower, only one publication was found on a similar research topic, with which a comparison was made. According to, it should be taken into account that meteoroids are of chondrite nature, which means that the parent body should be searched for in a similar taxonomic class of objects [14]. Since the identified asteroids lack such important parameters as size, geometric albedo, and taxonomic index (Table 5), a more detailed analysis of their relationship with the ρ-Geminids meteor shower is required [15].

To determine the asteroids dangerous for our planet, it is necessary to carry out work to establish genetic relationships between small celestial bodies and meteor showers.

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