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Dynamic Connections of the Northern iota-Aquariids Meteoroid Shower with Near-Earth Asteroids

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The establishment of genetic connections between the Northern iota-Aquariids meteoroid shower and near-Earth asteroids is considered. The author's synthetic method was used. For identified asteroids with a high factor $P \geq 0.6$, a multivariate analysis of their relationship with the Northern iota-Aquariids meteor shower was performed. The research results showed that the near-Earth asteroids 2016EE27, 2015 DT198, 2019GD1, 2006PF1, 2006LA, 2002JS2, 2002PD11, 2003MT9 are connected to the Northern iota-Aquariids shower.

Keywords: meteor shower, asteroids, extinct comet, genetic connections, near-Earth objects.

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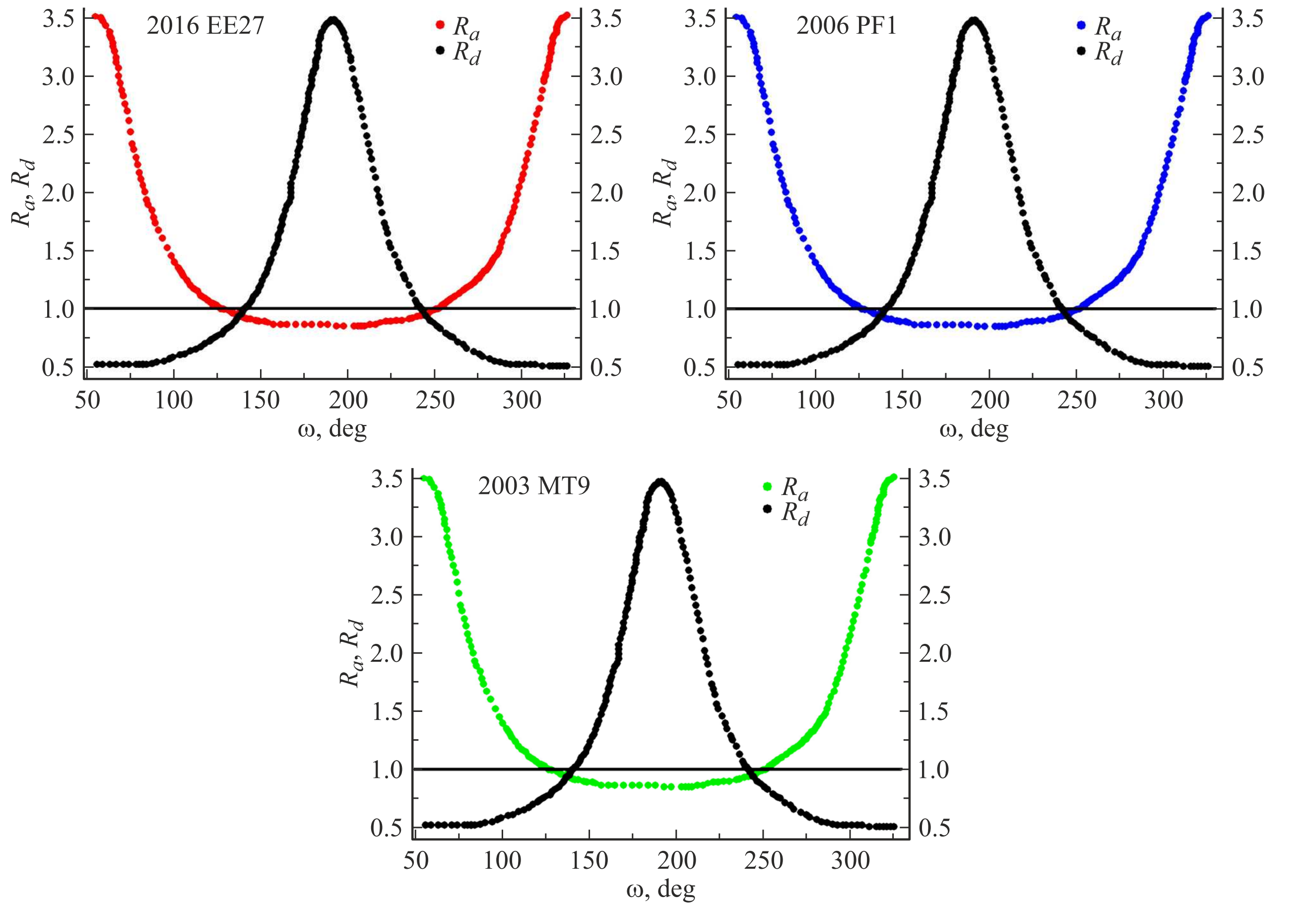
Asteroids, comets and meteoroids together with planets form the population of the Solar System. Asteroids may be rocky, silicon or iron depending on the chemical composition of an object, while comets are a conglomerate of icy dust and gas. When a comet passes the perihelion, gas is released due to heating, and the released dust particles escape the comet's surface. Velocities of the released particles are low and therefore they move on heliocentric orbits similar to the comet's orbit. However, semi-major axes and orbital periods of meteoroids vary at the time of ejection, and solar pressure occurs that changes meteoroids' orbital periods and eccentricities. All this causes initial orbit dispersion under the action of which meteoroids are eventually distributed all over the comet orbit. Some particles at this time do not leave the comet nucleus surface or evaporate and return, thus forming a dusty crust that prevents solar radiation from penetrating the comet nucleus which decelerates and/or terminates the cometary substance outflow. Such comets are called dead or extinct and are hard to be distinguished from normal asteroids during observation. Meteoroidal streams are associated with some of such objects and they are supposed to have formed a meteoroidal stream in the same phase when they existed in the form of active comets. Comet nuclei were formed at the time of formation of the Solar System, while the meteoroidal stream lifetime doesn't exceed several hundred years, therefore they cannot occur simultaneously. Potential decay of the comet nucleus under the action of external forces and an impact (collisional) scenario, when heavenly bodies collide with each other, cannot be excluded. Important research tasks are to investigate separation of extinct comets from among normal asteroids and to develop a method that could be used to identify these objects. Investigations in this area have been already conducted,for example, in [1,2].

We have developed a proprietary synthetic method that is based on using a set of genetic similarity criteria [3,4]. The main difference of the synthetic method from other methods for determining connections between two orbits is the identification of an asteroid with a meteor shower using several criteria simultaneously and assignment of an individual factor by each criterion. Then, the resulting connection factor P is calculated using a pre-defined algorithm that is described in detail in [5]. If P is higher than 0.5, then we assume that the asteroid is connected with meteor showers: the higher P is, the more probable the connection is. An important feature of the synthetic method is the calculation of a mean orbit for a meteor shower and threshold values for each synthetic method criterion using many individual meteoroid orbits, which includes the influence of dispersion when particles are released from a parent body mentioned above.

Genetic connections were investigated for the Northern iota-Aquariids meteor shower with near-Earth Apollo, Aten and Amor asteroids. Connections between asteroids and a meteor shower were found only in the Apollo group. The calculations used asteroid orbits from Jet Propulsion Laboratory's data and meteoroid orbits from CAMS [6,7]. An asteroid was considered to be connected with a meteor shower, if P was higher or equal to 0.6 according to three employed meteor databases at once. Such asteroid objects were included in the investigation, multifactor analysis of connection with the Northern iota-Aquariids meteor shower as parent bodies was conducted for them, and their orbital evolution was examined.

Parent body groups were checked for any connections within the group using the Southworth-Hawkins and Asher criteria. The Southworth-Hawkins and Asher criteria are classical dimensionless criteria that are used to identify the genetic similarity of small bodies of the Solar System.



Dependences of the longitudes of the ascending and descending nodes on the argument of perihelion for three asteroids.

The Southworth-Hawkins criterion is represented in a five-dimensional orbit element space and is highly dependent on the perihelion distance. The Asher criterion is more modified and derived for a three-dimensional orbit element space. For two criteria mentioned above, we assume that bodies are genetically connected, if the value calculated for a pair of orbits is lower than a threshold defined by the criteria authors. Since the longitude of the ascending node Ω and the argument of perihelion ω vary with time, the Southworth-Hawkins criterion may have higher values just due to these changes and therefore becomes unsuitable for calculations within long time intervals. In this case, decision was taken to introduce another test element — the Asher criterion that is used to avoid this uncertainty. Threshold for the Southworth-Hawkins and Asher criteria is $D < 0.2$. With this in mind, asteroids 2016EE27, 2015 DT198, 2019GD1, 2006PF1, 2006LA, 2002JS2, 2002PD11, 2003MT9 were found to be connected with each other. The values of criteria obtained within the parent body groups range from 0.02 to 0.19, which is indicative of connections within the groups of identified parent bodies. The Tisserand parameter with respect to Jupiter — T is another test criterion for parent body group asteroids. It is though that if an object has $T \approx 3$, then its orbit is transitional in nature — comet or asteroid; objects with $T < 3.1$ move on comet-like orbits, objects with T> 3.1 move on asteroid-like orbits. Diameter and albedo analysis was an additional criterion because extinct comets have very low values of albedo (from 0.02 to 0.15).

When meteoroids are released from the parent body, flying particles have different velocity ranges, but their velocities are low than orbital velocities, therefore initially the particles will move on the orbits similar to the parent body orbit. Note that some particles have different semi-major axes and, therefore, the orbital period will differ between a particle and parent body, thus some meteoroids will be left behind and some meteoroids will, vice versa, leave behind their parent by spreading along their orbit. As long as meteoroids located around the parent body will be exposed to planetary disturbances differently, their orbital evolution will go differently. Therefore, variations in the values of ω, longitude of the ascending node Ω and inclination i will be observed. For the meteor shower to be observed from Earth, the meteor shower orbit shall intersect Earth's orbit, and this is only possible for those meteoroids internodal spacing of which is approx. 1 au.

The figure shows dependences of the longitudes of the ascending and descending nodes on the argument of perihelion for three asteroids. A method developed by Babadzhanov and Obrubov and well described in [8] was used. According to the shown dependences, it can be seen that the intersection of Earth's orbit with the meteoroid stream orbit occurs four times for each asteroid because there are four different values of ω, and the values of ω are very close for all given asteroids. According to method [9], it is thought that the number of intersections with Earth's orbit shows the number of meteor showers created by this asteroid. The obtained dependences suggest that all three asteroids form four meteoroid streams — two night and two day streams.

We adhered to the concept that connection with the meteoroid stream is possible for sleeping comet nuclei or comet nucleus fragments [10]. The investigations showed that near-Earth asteroids 2016EE27, 2015 DT198, 2019GD1, 2006PF1, 2006LA, 2002JS2, 2002PD11, 2003MT9 were connected with the Northern iota-Aquariids stream. They were identified with the Northern iota-Aquariids stream and high connection factors $P \geq 0.6$ were obtained for these objects. All asteroids from the parent body groups for the Northern iota-Aquariids stream move on similar orbits. Review of the CNEOS fireball database has shown that the stream had large meteoroids capable of inducing fireballs. Thus, it is suggested that fragments of a decayed comet nucleus exist in the stream. Arguments provided in the work confirm that the Northern iota-Aquariids stream is connected with near-Earth asteroids that probably can be fragments of a decayed comet nucleus.

Since, as mentioned above, one of the important research tasks is to investigate separation of extinct comets from among normal asteroids and to develop a method to be used for identification of these objects and meteoroid streams connected with them. Results of this work make their indispensable contribution to the identification and establishment of connections between small heavenly bodies and will be used in future for creation of a common concept of meteoroidal substance distribution in the near-Earth space. Creation of a common concept of meteoroidal substance distribution and investigation of meteoroidal content are very important for planning various space missions, extrapolation of the meteoroidal situation to flight paths from Earth to Mars and solution of asteroid and comet hazard problems.

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Conflict of interest

The authors declare no conflict of interest.

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