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Young Meteor Swarms Near the Sun: I. Statistical Correlation of Meteors with Families of Short-Perihelion Comets

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Abstract—We examine the hypothesis about the formation of meteor streams near the Sun. Families of short-perihelion orbit comets, many of which pass just a few radii from the solar surface at perihelion and have high dust production efficiencies, are assumed to be candidates for the parent bodies of these meteor streams. Our statistical analysis of orbital and kinematic parameters for short-perihelion meteoric particles recorded at the Earth and comets from the Kreutz family and the Marsden, Kracht, and Meyer groups led us to certain conclusions regarding the proposed hypothesis. We found a correlation between the ecliptic longitude of perihelion for comet and meteor orbits and the perihelion distance. This correlation may be suggestive of either a genetic connection between the objects of these two classes or the result of an as yet unknown mechanism that equally acts on short-perihelion comet and meteor orbits. A reliable conclusion about this genetic connection can be reached for the meteors that belong to the Arietids stream and the Marsden comet group.

INTRODUCTION

According to currently available data, a comet produces about 99% of dust in a short perihelion arc of its orbit (Levin, 1956; Lowell, 1958). For most of the comets that are generally recognized as the parent bodies of meteor streams (the long-period comets Swift–Tuttle, Tempel–Tuttle, and Thatcher; the short-period comet Encke etc.), the perihelion distances are not less than 0.3–0.4 AU. At such distances (about 60–70 solar radii $R_{\odot}$), the Sun itself may be considered to be a distant object that mainly exerts only a gravitational influence on a celestial body. The production of dust particles at such distances obeys the laws of cometary physics. The situation becomes different if a dust particle was formed in a region up to 10 $R_{\odot}$. In this case, the Sun represents a dynamical phenomenon with its own magnetic field, activity cycles, temperature and flare regimes. So far, most of the authors have considered the circumsolar region (the near corona–thermal corona and part of the *F*-corona, on average, up to 30 $R_{\odot}$) as a region where the final evolutionary stage of meteoroid dust takes place, as a result of the disintegration of meteor streams and meteor associations under the secular action of nongravitational effects. Some of the authors suggested the hypotheses about the formation of short-lived (several thousand years) meteor associations through the gravitational focusing of the orbits of a sporadic circumsolar cloud, which have not been developed further (J. Trulsen, V.V. Emelyanenko).

Can a meteor stream be formed by the parent body at distances of several solar radii? Under what conditions will a newly formed stream survive and be observable from the Earth or near-Earth orbital stations? There is no doubt that the particles of such a stream will differ both by physical (composition, density, size) and by orbital and kinematic parameters. The main significance of the discovery of such streams is their youth and compactness, which is important for studying the structure and evolution of meteor streams and their genetic connections with small bodies of the Solar system (mainly comets). Such meteor streams are commonly called young streams. In such streams, the dispersion of meteoroid orbital elements does not exceed the initial dispersion attributable to the stream at the time of its formation. One might expect the orbital elements of the parent body and the particles in a young stream to be similar. The dust particles of young streams are also of considerable interest in the physics of meteoric material.

In this study, w searched for the meteoroids of young meteor streams. A statistical analysis of various parameters for the possible parent bodies of young meteor streams and short-perihelion meteoric particles must reveal a correlation between them.

FAMILIES OF SHORT-PERIHELION COMETS

What small bodies of the Solar system can be proposed as candidates for the parent bodies for young meteor streams formed in the circumsolar region? According to present views on the genetic connections between meteor streams and small bodies of the Solar system, from 90 to 99% of interplanetary dust is produced during ejections from cometary nuclei (Kashcheev *et al.*, 1967; Lebedinets *et al.*, 1972; Voloshchuk *et al.*, 1989). This contribution of cometary material to the total mass of the interplanetary material slightly varies, depending on the estimation techniques and the observational data used for estimation. Nevertheless, it is clear that a large fraction of material, especially small

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particles, which are observed in the Earth's atmosphere as faint radar meteors, is cometary in origin. No minor planets with perihelion distances less than 40–50 $R_\odot$ have been discovered; most likely, they do not exist at al. Consequently, families of comets with very small perihelion distances can be the possible candidates for the parent bodies of young meteor streams formed in the circumsolar region. These include the Kreutz family, which has been very small until recently, as well as the Marsden, Kracht, and Meyer comet groups discovered in 2002.

The comets of the Kreutz family have extremely small perihelion distances, $q < 0.01$ AU (on the order of several solar radii). Many of these comets pass at distances on the order of 50–80 thousand km from the solar photosphere. That is why the comets of this family were nicknamed sungrazers. Despite the high temperatures and the intense solar radiation, some of the comets survive and pass through the perihelion. We know cases where comets fell into the Sun; these falls were accompanied by active coronal mass ejections that lasted several tens of minutes (hours) after the fall. Studies of the physics of such processes show that once a comet has entered the relatively dense photosphere, a series of fragmentations and outbursts take place in the cometary nucleus until its complete disintegration (Sekanina, 1982).

Most of these comets are faint, with an absolute magnitude of about $+20^m$. Therefore, they are very difficult to observe from Earth. In addition, a comet becomes visible (if at all) from Earth in a very short segment of the orbital arc that it traverses at a high velocity and disappears behind the Sun. It is best to observe comets of this family with orbital coronographs, because they allow the motion of comets to be followed almost up to 0.5–1 $R_\odot$. This technique was verified by the SMM (Solar Maximum Mission) and SOLWINF missions in the early and late 1980s, respectively. The search observations during these missions increased the number of discovered comets from 8 to 24. However, this program was efficiently implemented by SOHO (Solar and Heliospheric Observatory). Thanks to SOHO, the number of discovered Kreutz comets currently exceeds 500. Nevertheless, the information about the physical properties of these comets is still insufficient. It may be noted that the sizes of their nuclei do not exceed 20 m (with the application of a sublimation model to space observations), and the density of the cometary material is low, being on the order of 0.5 g/cm^3 (Grigoryan *et al.*, 1997).

The comets of the Marsden, Kracht, and Meyer groups have large perihelion distances compared to the Kreutz family, about 0.04–0.05 AU (8–10 $R_\odot$). The detailed studies of these comets, particularly their physical properties, are at an initial stage.

OBSERVATIONS OF SOHO COMETS

SOHO is a joint project of the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) (SOHO sites, "The First Results from SOHO"). SOHO was placed by the Atlas-IIAS spacecraft (December 2, 1995) in a nearly circular orbit near the Lagrangian point L1 (in the Earth–Sun system) located at a distance of 0.01 AU from the Earth. It has carried out regular observations for almost seven years.

SOHO completely justifies its name (Solar Observatory). Its main goals and objectives are to investigate the solar corona and surface, magnetic fields, and the solar wind. SOHO is an open project for the scientific community. All of the observations performed from the satellite are made available after their primary reduction.

LASCO (Large-Angle and Spectrometric Coronograph) has made it possible to observe short-perihelion orbit comets. This instrument is a system of three coronographs with mutually overlapping fields of view: C1 (1.1–3 $R_\odot$ observations), C2 (1.5–6 $R_\odot$ observations, 2.91° field of view), and C3 (3.7–30 $R_\odot$ observations, ~15.56° field of view). The main objective of LASCO is to monitor the solar corona up to 30 $R_\odot$ and to investigate its active structures.

LASCO observations in the form of FITS, GIF, and MPEG (with a factor of 2 lower quality) files are made available on the Internet by the SOHO Corporation. Daily MPEG films are used to search for short-perihelion orbit comets in SOHO images. The discovery of a faint comet in the C2 and C3 coronograph images was first reported in May 1997. More than 540 objects, 70% of which are comets of the Kreutz family and 11% are comets of the Marsden, Meyer, and Kracht groups, have now been discovered in SOHO images by this method. Amateurs take an active part in searching for short-perihelion orbit comets in SOHO images. A whole search team has been formed. A search can be conducted directly on the Internet, where SOHO observations appear with a delay of one day. Comet hunters—J.D. Shanklin, D. Lewis, T. Lovejoy, M. Oates, M. Boschat, X. Leprette, M. Meyer, and others—considerably help professional comet researchers who would not cope with the reduction of this huge material without a regular analysis of observations by amateurs (IAU sites). Faint comets that are visually unseen in images can be found by special software. A report on the discovered comet is sent to the Central Bureau for Astronomical Telegrams at the International Astronomical Union. Subsequently, experts process the images to determine the equatorial SOHO-centric positions of the new comet and, in conclusion, compute and, if possible, improve its orbit. Biesecker and Hammer measure the images; Marsden processes and reduces the positions and calculates and corrects the orbits. Preliminary positions and information about the discoverer are published in International Astronomical Union Circulars (IAUGS); orbital elements and SOHO-centric positions of comets are published in IAU Minor Planet Circulars (MPECs). Both types of circulars are accessible in electronic form at IAU sites.

STATISTICAL FEATURES IN THE DISTRIBUTIONS OF ORBITAL PARAMETERS FOR SHORT-PERIHELION COMETS

The orbital elements of the Kreutz comets are very similar. The comet orbits, as it were, are aligned along a straight line in space; in other words, they have a common line of apsides (Sekanina, 1982). Figure 1 shows the distributions of orbital parameters for sungrazing comets obtained by analyzing the catalog of Kreutz comet orbits that we compiled from MPEC data. The general conclusion that can be drawn from the derived distributions concerns their compactness, which provides evidence for the hypothesis that the Kreutz family originated from the disintegration of a giant comet in the 4th century B.C. (Sekanina, 1967; 1982). The comets have retrograde motions ($i \sim 144°$), and their orbital planes deviate by a large angle from the plane of the ecliptic (~40°) and the comets are insensitive to the gravitational influence of the major planets (Sekanina, 1967).

Although more than 450 comets of this family are known to date, the accuracy of determining the orbital elements for sungrazing comets is low, because the comets are observed in a narrow perihelion orbital segment. Almost all orbits of the Kreutz comets are parabolic. In particular, the elements for the so-called SOHO comets, to which the Marsden, Kracht, and Meyer comets belong, can be computed only in the approximation of parabolic orbits.

To analyze the spatial distribution of Kreutz comet orbits, it is convenient to use the ecliptic coordinates of their perihelia. They can be calculated by using the formulas derived from a spherical triangle:

$$\sin B = \sin\omega \sin i,$$

$$\cos B \cos(L - \Omega) = \cos\omega,$$

$$\cos B \sin(L - \Omega) = \sin\omega \cos i,$$

where L is the ecliptic longitude of the perihelion, B is the ecliptic latitude of the perihelion, i is the orbital inclination, ω is the argument of perihelion, and Ω is the longitude of the ascending node.

Calculation of the longitude from the simplified formula $\tan(L - \Omega) = \tan\omega \cos i$ does not always yield the correct result.

The dependence of ecliptic longitude (L) on perihelion distance (q) gives an overall pattern of the spatial distribution of orbits as a function of their size. The dependence $L(q)$ (see Fig. 2) serves to identify groups and subgroups within the Kreutz family. The best-known division of the family into two groups was made by Marsden in 1967 using twenty known orbits of sungrazers (Marsden, 1967; 1989). This division is still commonly used at present. For our purposes, it would be more appropriate to break down the family into two large groups by ecliptic longitude of perihelia. We denote these groups by I and II; each of the groups I and II can be divided into subgroups along straight lines of the form $L = aq + b$, where a and b are the subgroup parameters.

Pairs or triples of comets with similar orbital elements and very close epochs of perihelion passage are identified. These comets are assumed to have a common origin; for example, they originate from the fragmentation of the nuclei of larger comets as they pass through the perihelion. In the course of time, some of these comet pairs and triples turn into whole groups; for example, the Marsden, Meyer, and Kracht groups were formed in this way.

The first comets of the Meyer group (34 comets are now known), the Marsden group (14 comets are now known), and the Kracht group (14 comets are now known) were discovered in January, February, and March 2002, respectively. The comet orbital elements within each of the three groups have a relatively small dispersion (see Fig. 1), suggesting that the comets within the groups have a common origin. The separation into groups can be seen in the $L(q)$ diagram (see Fig. 2). The close positions of points in the $L(q)$ diagram for the Marsden and Kracht comets are indicative of their possible genetic connection. In contrast to the representatives of the Kreutz family, the comets of all these groups have prograde motions ($i \sim 73°$, ~26°, and ~13° for the Meyer, Marsden, and Kracht groups, respectively). The Marsden comet group has yet another distinctive property: in June, one month after perihelion passage, the comets of this group closely approach the Earth's orbit. There may exist small comets belonging to this group that are unobservable when they approach the Earth and that can be considered as candidates for the so-called minicomets. This question requires a separate consideration.

SEARCHING FOR STATISTICAL CORRELATIONS

To find out whether the particles produced near the Sun can be observed from the Earth, we analyzed the catalogs of meteor orbits.

We analyzed the orbits of individual meteors obtained over a period of about half a century (from 1957 until 2001). Photographic, radar (about 70% of all data), TV, and video observations are among the available data. These observations cover a wide range of meteoroid particle masses, from bright fireballs ($-2 \ldots -1^m$) to very faint radar meteors ($+12^m$). The data were subjected to careful primary reduction and analysis at the IAU Meteor Data Center in Lund, Sweden (Lindblad, 1988; Lindblad *et al.*, 1993). The catalogs contain orbital elements, meteor detection times, extraatmospheric velocities, radiant coordinates, masses (for photographic meteors), and atmospheric parameters. Most of the data (radar observations) have a low accuracy. For this reason, the characteristic condition imposed on the orbital elements

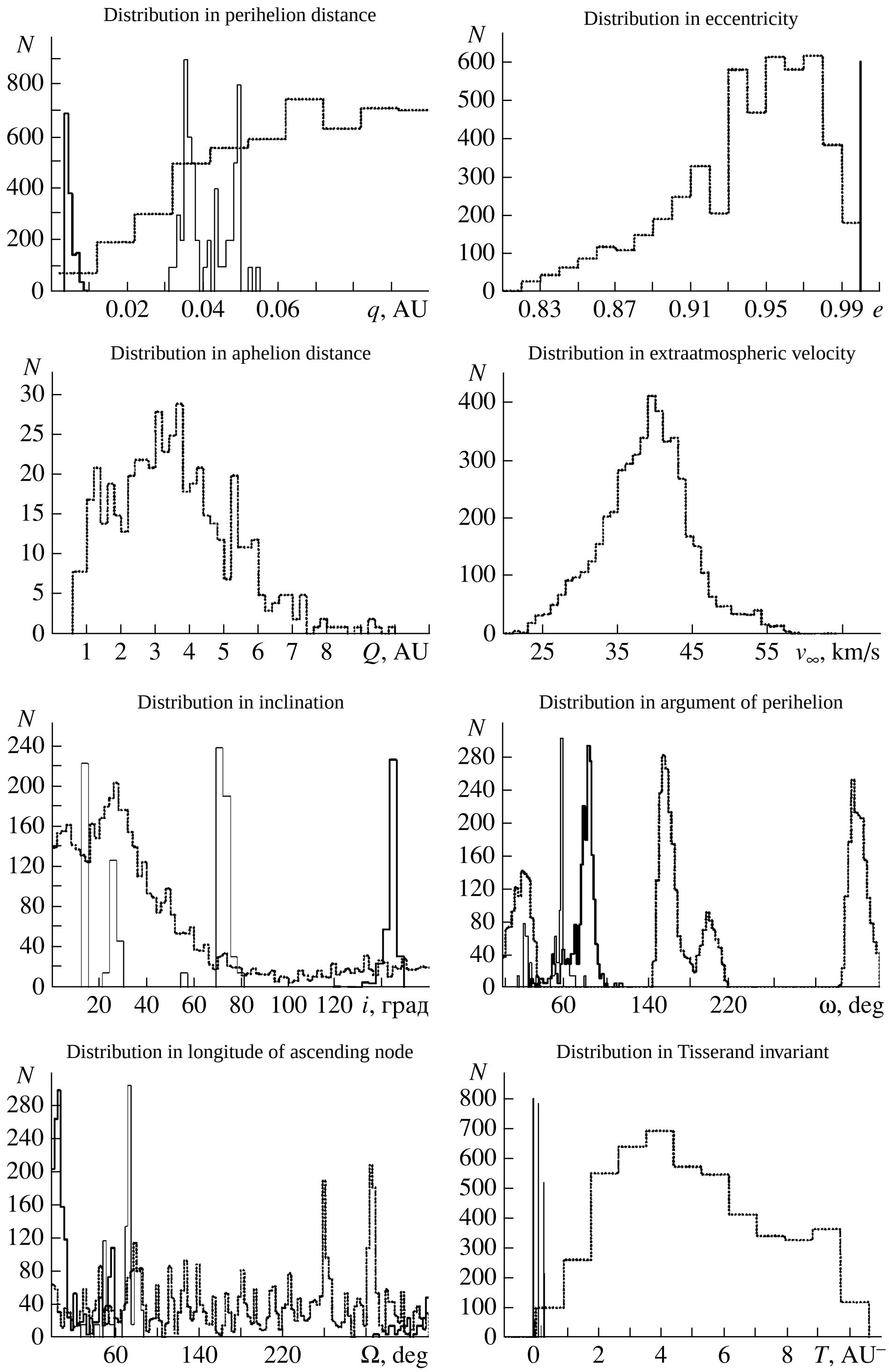

Fig. 1. The distribution of orbital and kinematic parameters for short-perihelion orbit comets and meteors. The thin solid lines represent the distributions for comets of the Marsden, Meyer, and Kracht groups; the heavy solid lines represent the distributions for comets of the Kreutz family; the dotted lines represent the distributions for meteors. *N* is the number of meteors; the number of comets was reduced to the number of meteors.

of meteoroids and caused by the necessity of the meteoroid encounter with the Earth:

$$0.983 \le \frac{p}{1 \pm e\cos\omega} \le 1.017, \qquad (1)$$

where *p* is the parameter of the meteor orbit, and *e* is its eccentricity, is not satisfied for approximately 1% of all radar orbits. Nevertheless, the high statistical significance of the results obtained when analyzing the radar observations is attributable to their enormous number

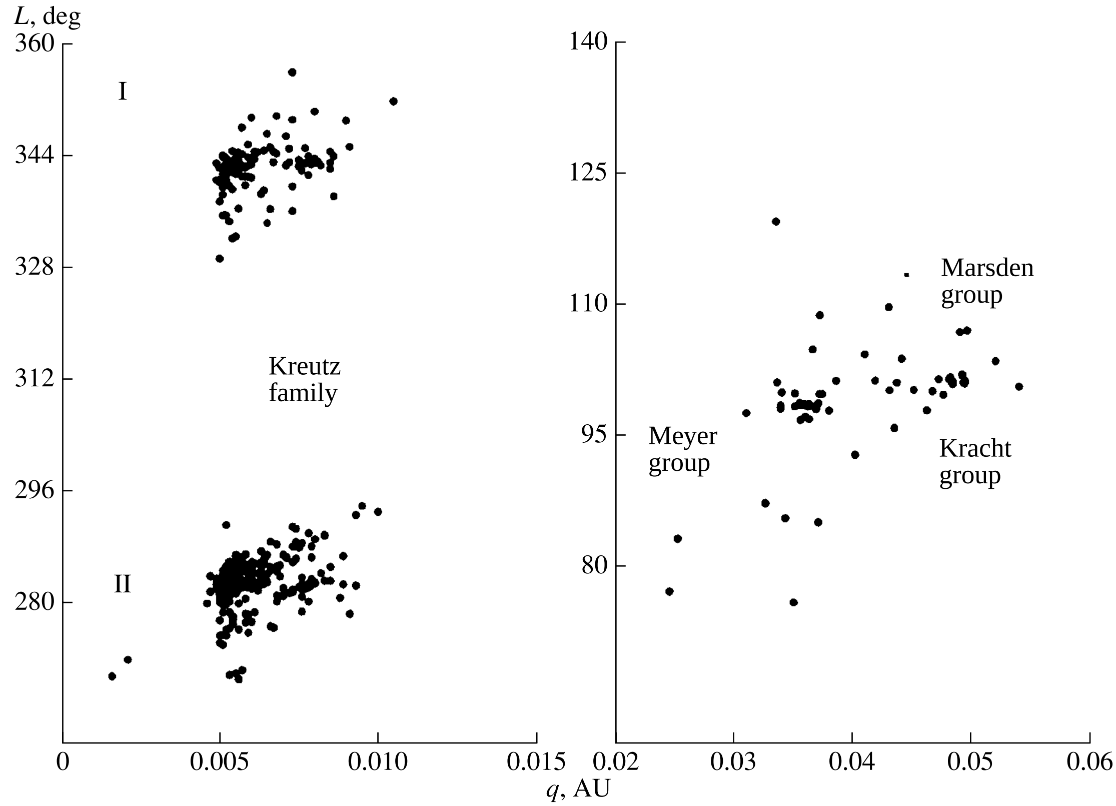

Fig. 2. The separation of short-perihelion orbit comets into groups by the ecliptic longitude of perihelia. The Roman numerals denote the two main groups of the Kreutz family.

(more than 65 thousand orbits). The recent photographic and video observations performed by the Dutch and Nippon Meteor Societies are of interest in their own right. In contrast to previous catalogs, these catalogs contain a large number of hyperbolic orbits.

When analyzing the meteor data, it should be remembered that they are selective. The geometric selection factor is expressed by condition (1). The time discreteness of radar observations, the directivity of an antenna or photographic cameras, the selectivity of instrumentation, etc. also affect the data obtained.

To search for the meteors that arrived at the Earth from the circumsolar region in the catalogs, we selected meteor orbits with small perihelion distances, $q \leq 0.1$ AU. The derived distributions are plotted in Fig. 1. All particles have prograde motions; the orbital planes of most of the particles are offset by more than 20° from the plane of the ecliptic. The distributions in perihelion distance, argument of perihelion, and longitude of the ascending node are significantly distorted by selectivity. The distribution in Tisserand invariant is rather flat, suggesting a various origin of meteors. A comparative analysis of the derived distributions for short-perihelion meteoric particles and comets of the Kreurz family as well as the Meyer, Marsden, and Kracht groups reveals no close similarity.

By analogy with short-perihelion orbit comets, we constructed the dependence $L(q)$ for all of the selected meteors. Several inclined strips can be found when analyzing the dependence. These are the strips of almost equal ecliptic longitude of the perihelia. In space, these strips are represented by a number of coaligned orbits with a broad spectrum of small perihelion distances. If we plot the corresponding data for Kreutz comets on this diagram, then they will compactly cluster in the upper left corner of the diagram.

The diagram exhibits no correlation in the distribution of meteor and comet data. The situation changes if we plot not the ecliptic longitude of the perihelia of meteor orbits but instead $L' = L + 180°$ (see Fig. 3a). Imagine that we change the direction of the line of apsides of a meteor orbit in space by 180° relative to its initial position. The new longitude L' corresponds to the position of the aphelion of the meteor orbit but without any change in ecliptic latitude. One of the strips formed by the meteor data is now extended to the region of small perihelion distances by the clusters of points that pertain to the group I comet orbits.

If we now pass to the coordinates $B(L)$, where the longitude of aphelion L' has the same meaning as L for the meteor data, then we will be able to see the cluster of perihelion points for meteor orbits that had the shape of a strip in Fig. 3a in the plot under the cluster

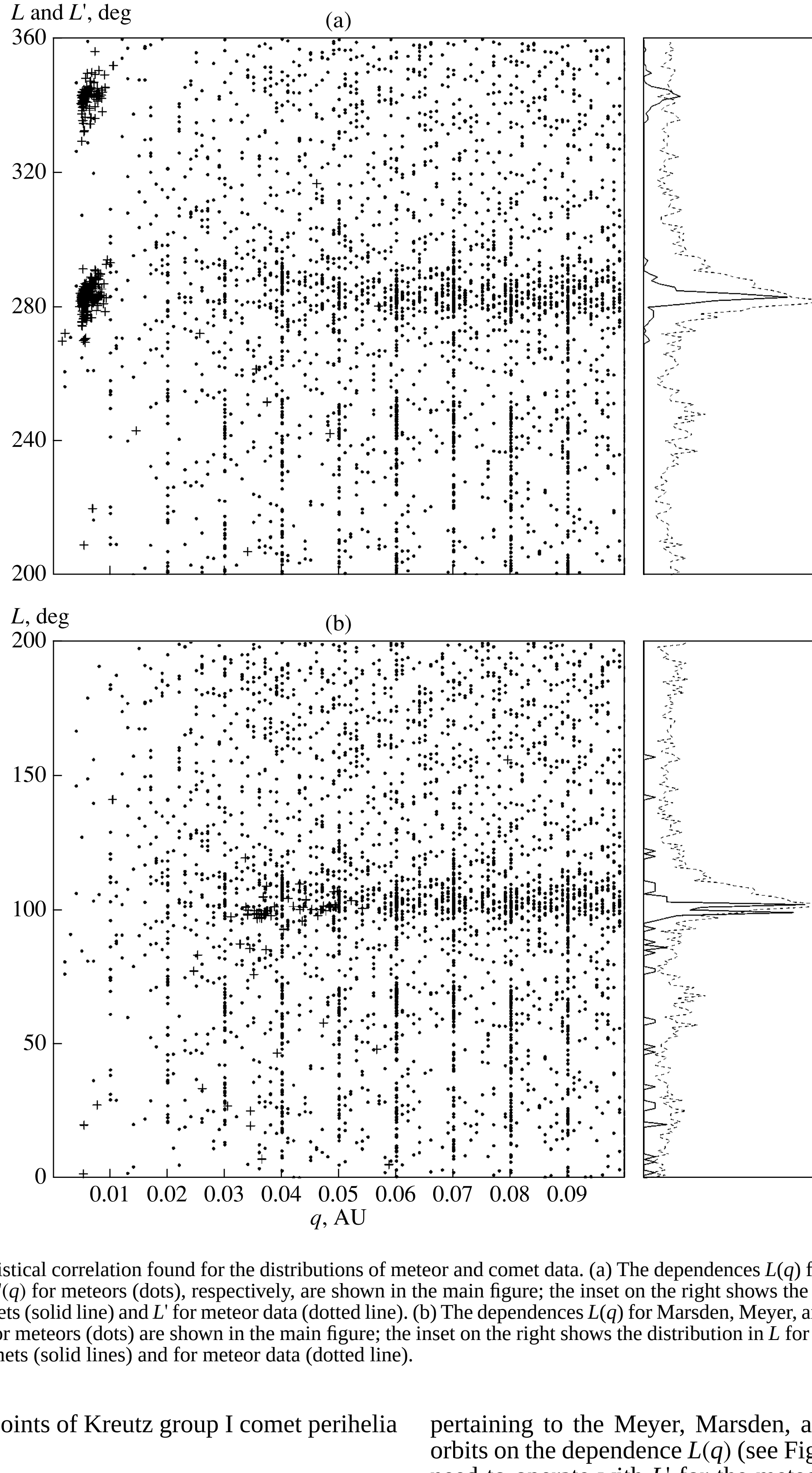

Fig. 3. The statistical correlation found for the distributions of meteor and comet data. (a) The dependences $L(q)$ for Kreutz comets (crosses) and $L'(q)$ for meteors (dots), respectively, are shown in the main figure; the inset on the right shows the distributions in L for Kreutz comets (solid line) and L' for meteor data (dotted line). (b) The dependences $L(q)$ for Marsden, Meyer, and Kracht comets (crosses) and for meteors (dots) are shown in the main figure; the inset on the right shows the distribution in L for Marsden, Meyer, and Kracht comets (solid lines) and for meteor data (dotted line).

formed by the points of Kreutz group I comet perihelia (see Fig. 4a).

A significant correlation in the L–q diagram can be observed if we plot the corresponding values of L and q pertaining to the Meyer, Marsden, and Kracht comet orbits on the dependence $L(q)$ (see Fig. 3b). There is no need to operate with L' for the meteor orbits to find a correlation. We see from Fig. 3b that the clusters of points pertaining to the comet orbits occur precisely in

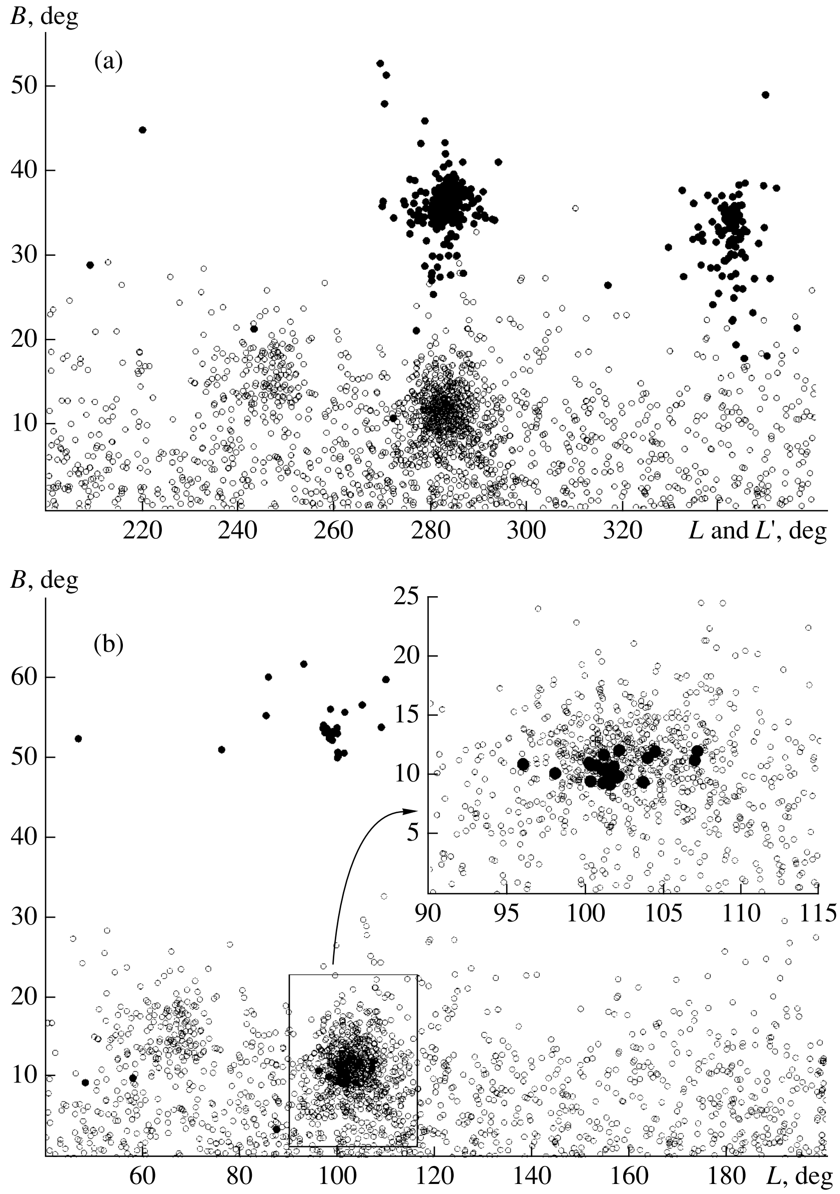

Fig. 4. The statistical correlation found for the distributions of meteor and comet data. (a) The dependences *B*(*L*) for Kreutz comets (dots) and *B*(*L*') for meteors (circles), respectively. (b) The dependences *B*(*L*) for Marsden, Meyer, and Kracht comets (dots) and for meteors (circles) are shown in the main figure; the enlarged region from the main figure for the Marsden and Kracht groups is shown in the upper right corner.

the strip of meteor data. Figure 3b (on the right) shows the distribution in perihelion longitude for the orbits of Meyer, Marsden, and Kracht comets and short-perihelion meteoric particles. We see from this diagram that the peaks in the distribution of the ecliptic longitude of perihelion for the orbits of Marsden and Kracht comets and meteors coincide, to within half a degree. The pattern found is confirmed by Fig. 4b, which shows the distribution of perihelions for meteors and comets in the space of ecliptic coordinates. We see that the cluster of perihelia for the orbits of Marsden and Kracht comets is very compact and coincides with the cluster of perihelia for meteor orbits. The perihelia for Meyer comets are shifted by several degrees relative to the meteor cluster in longitude and by more than 40° in latitude.

Let us investigate the meteor complex that exhibits a correlation in the *L*, *B*, and *q* distributions with the corresponding comet values. To this end, we separate out the meteor orbits of this complex by using the dependence *B*(*L*). The longitudes and latitudes of the orbital perihelia for the complex range from 97° to 110° and from +7° to +18°, respectively. Let us analyze the orbital parameters of the meteors belonging to this complex statistically.

The meteors of this complex are observed in the Earth's atmosphere in compact groups (see Fig. 5) in

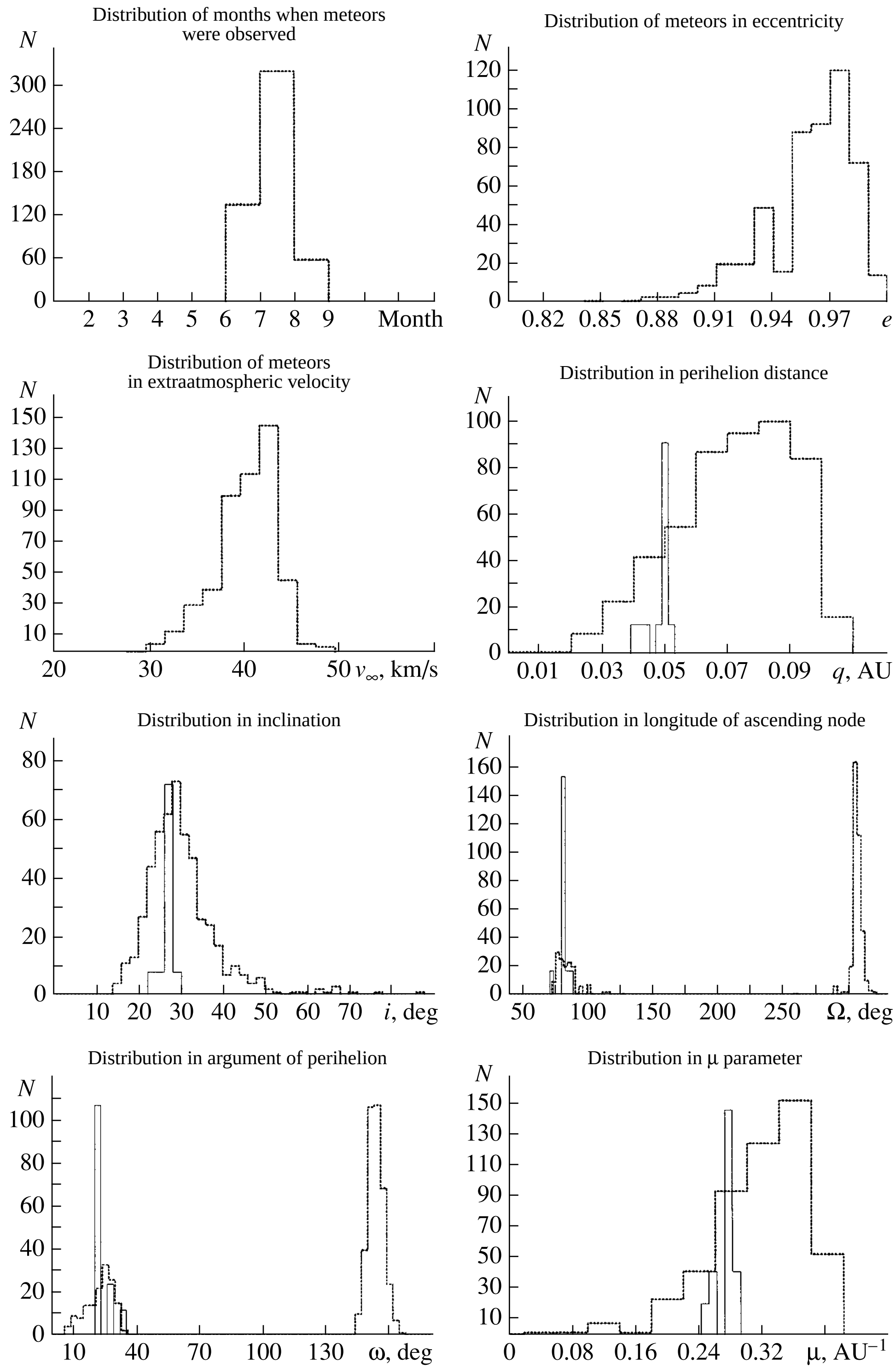

Fig. 5. The distributions of orbital and kinematic parameters for the meteor complex (dotted lines) and the Marsden comet group (solid lines). *N* is the number of meteors; the number of comets was reduced to the number of meteors.

June–July. The observations were mainly obtained in 1969 during a Soviet meteor expedition (1968–1970). The southern latitudes and the active program of observations created favorable conditions for detecting these meteors. The bulk of the complex has a revolution period of ~3 years. Most of the distributions are compact, suggesting that the meteoroids are genetically connected (curiously, the Tisserand invariant and the quasi-stationary parameters $\mu = \sqrt{q(1+e)}\cos i$ and $\nu = e^2(0.4 - \sin^2\omega \sin^2 i)$, which are indicators of genetic

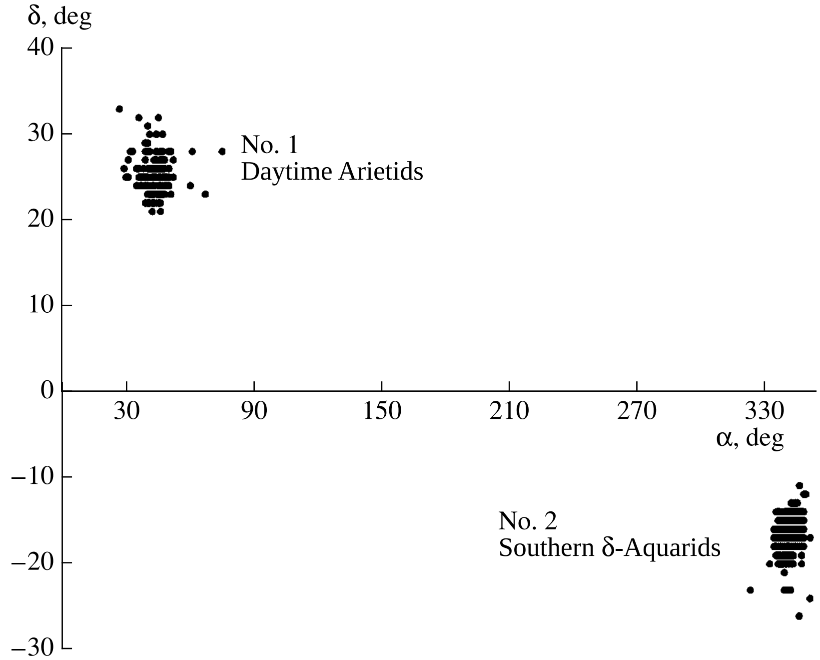

Fig. 6. The individual radiants of meteors from the complex. The Arabic numerals denote the two twin streams.

connection, have a wide range of values; all meteors have a highly eccentric orbits and prograde motions.

The distributions of the argument of perihelion and the longitude of the ascending node and our analysis of the positions of individual radiants (see Fig. 6) show that the complex breaks up into two twin streams in the Earth's atmosphere (with radiants that are roughly symmetric relative to the ecliptic). After the search for the mean radiants of these streams in the catalogs of radiants, for example, in Kashcheev *et al.* (1967), we identified shower no. 1 (see Fig. 6) with the June, or Daytime, Arietids ($\alpha = 43°$, $\delta = +23°$, the activity period May 4–June 20). The meteors of stream no. 2 belong to the Southern δ Aquarids ($\alpha = 341°$, $\delta = -16°$, the activity period July 14–August 14). The Daytime Arietids stream is observed only by the radar method, while the Southern δ Aquarids stream is also observed by the photographic, video, and TV methods.

Let us analyze once again the distributions in orbital parameters for the meteor particles belonging to the complex. Let us compare these distributions with those for Meyer, Marsden, and Kracht comets. Above, we have pointed out that the distributions in orbital elements and Tisserand invariant for meteors and comets of the Kreutz family are rather dissimilar; a large difference is primarily characteristic of the inclination and the argument of perihelion. Let us now analyze the same distributions for the comets of the Meyer, Marsden, and Kracht groups. It follows from Figs. 1 and 5 that the distributions constructed for the Marsden comet group and the part of the meteor complex responsible for the Daytime Arietids stream almost coincide. For the Meyer and Kracht comet groups, we see no clear correlation with the distributions of the same meteor parameters.

Note that our analysis of the dependences $L(q)$ and $B(L)$ as well as the distributions in orbital and dynamical parameters for all of the long- and short-period comets with $q > 1$ AU reveals no correlation with the meteor data. This is also true for known comets with small perihelion distances, such as those of 1680, 1689, 1816, and 1954 II that do not belong to the Kreutz family and the Meyer, Marsden, and Kracht groups.

How can the derived dependences be interpreted? Two alternative hypotheses are possible. First, we may assume that a part of the complex under study is genetically connected with the Kreutz comets. Taking into account the small distances to which the comets approach the Sun and the physical conditions in this region, we may assume that the dust production efficiency for these comets should be enormous. A number of meteor streams are associated with large comets of this family (e.g., about 6 streams are associated with comet 1882 II; Kramer *et al.* (1963)). It is not necessary to attribute the discovered complex to a particular comet; this is most likely the result of the dust production of several (or several tens of) comets that passed through the filters of solar pressure, sublimation, gravitational attraction as well as the result of the selectivity of ground-based observations. If this is the case, then this complex is a tiny fraction of the once produced material near the Sun from the nuclei of suicide comets.

The mean orbital planes of meteoric dust particles and Kreutz comets intersect at a large angle, ~ 20°. The distributions of orbital elements, Tisserand invariant, and quasi-stationary parameters and the application of empirical criteria (*D*-criterion) to the detected objects reveal no genetic connection. It is commonly assumed that the orbits of meteor streams and their parent bodies are very close and that the ejection velocities of material from a cometary nucleus do not exceed 100 m/s (Kulikova, 1975).

This empirical law holds for the perihelia of comets far from the Sun. What if a stream is produced under the conditions typical of the Kreutz comets whose velocities reach about 500 km/s at perihelion? A collision with microparticles in the circumsolar region, a momentum transferred by an active solar event, etc. can trigger an ejection of the meteor dust from the nucleus. At such velocities, the ejection energy is so high that the difference between the orbit of a new young stream and the parent orbit can be very large.

A model for the dynamics of the material ejected from a cometary nucleus at distances of several solar radii is difficult to develop. Numerical models of this type can be found in a number of papers (Krivov *et al.*, 1998); the results of the calculations based on these models differ greatly, depending on the assumed particle parameters (mass, size, reflectivity, etc.) Therefore, any numerical estimates to confirm the hypothesis without detailed information about the physics of Kreutz comets are meaningless.

On the other hand, we can propose an alternative hypothesis that would explain the statistical results obtained. The meteor and comet orbits of this type may be affected by effects (their nature is yet to be elucidated) that align the orbits of this type in certain directions (along the lines of equal ecliptic longitudes). Neither the Lorentz force, nor the relativistic spinning of the line of apsides, no the secular Poyinting–Robertson or Yarkovskii–Radzievskii nongravitational effects can be this effect.

Conclusions of such a type can be applied to the Meyer comet group. As regards the Marsden group, the observed similarity in the distributions of orbital elements can be explained by the genetic connection between the Arietids stream and the Marsden comets. The application of empirical criteria based on analysis of orbital elements, for example, the *D*-criterion, confirms this conclusion. Figure 7 shows the result of applying the Olson-Steel method (1988) to the particle orbits of the Arietids stream and the mean orbit of the Marsden group ($\langle q \rangle = 0.048$ AU, $\langle e \rangle = 1$, $\langle i \rangle = 26°$, $\langle \omega \rangle = 24°$, $\langle \Omega \rangle = 82°$). We will not describe the Olson-Steel method in detail, but only note that it is based on the following suppositions. The longitude of the ascending node (Ω) for the orbit of the comet suspected to be genetically connected with the meteor stream ranges from 0° to 360° at a chosen step. For each Ω of the comet orbit, the number of meteors (*N*) from a sample of meteors for which the *D*-criterion was below its threshold value (down to 0.3) was searched for. If the function $N(\Omega)$ at Ω equal to the real longitude of the ascending node for the comet orbit exhibits a distinct local maximum, then this meteor stream and the comet may be considered to be genetically connected. In our case, we assumed the threshold value of the *D*-criterion to be very low (down to 0.1), and we nevertheles have a picture similar to that in Fig. 7. The coincidence in position of the maximum of $N(\Omega)$ with $\langle \Omega \rangle$ for the Marsden group to within half a degree can be interpreted as clear evidence that the objects are genetically connected.

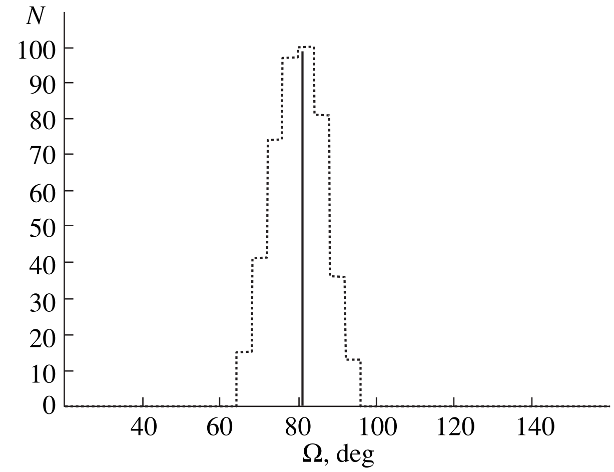

Fig. 7. The dependence $N(\Omega)$ of the orbital elements for meteors from the complex that belong to the Daytime Arietids obtained by the Olson–Steel method. The vertical line indicates the longitude of the ascending node for the mean orbital plane of the Marsden comet group.

The clear coincidence in the distributions of orbital elements may serve as evidence not only for the genetic connection but also for the relative youth of the Arietids meteor stream. For most of the known meteor stream and their progenitor comets, no such coincidence in orbital elements is observed, which is primarily attributable to the age of the stream. Note once again that the region where the dust particles of this meteor stream and the possible progenitor comets move at perihelion is characterized by the extreme conditions associated, as we already pointed out above, with the proximity of the Sun. It is even more surprising that the meteor stream "remembers" the parent body (bodies). As regards the Kracht group, in our view, there is no need to subject the parameters of the comets from this group to a separate analysis, because this group is most likely the branch of the Marsden group that separated through a cataclysm.

Since planetary perturbations over a long period distort the orbits of Kreutz comets only slightly, we attempted to find additional arguments for one of the hypotheses and analyzed the distributions of the nodes of meteor orbits in the mean orbital plane of the group I comets ($\langle i \rangle = 144°$, $\langle \omega \rangle = 67°$, $\langle \Omega \rangle = 46°$). The coordinates of the nodes for meteor orbits can be calculated by using the formulas

$$A = R_x^0 P_x + R_y^0 P_y + R_z^0 P_z,$$

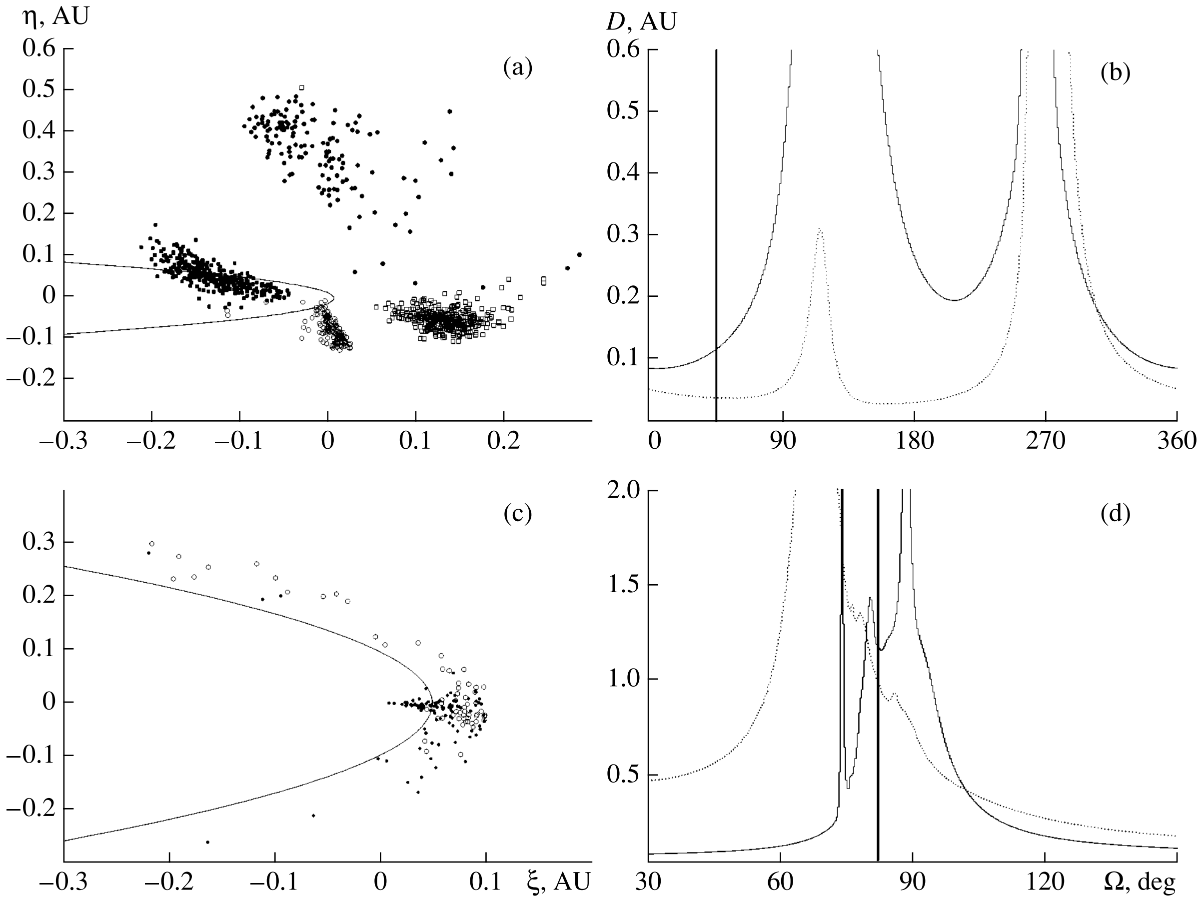

Fig. 8. Illustrations of our celestial-mechanical calculations obtained by analyzing the meteor complex and comets. (a) The nodes of meteor orbits with the mean orbital plane of the Kreutz comet group I. The dots and circles denote the ascending and descending nodes for the part of the meteor complex that forms the Daytime Arietids stream in the Earth's atmosphere; the filled and open squares denote the ascending and descending nodes for the part of the meteor complex that forms the Southern δ-Aquarids stream in the Earth's atmosphere. The solid line represents the mean orbit of the Kreutz comet group I. (b) The test function for the mean orbital plane of the Kreutz comet group I and meteors of the complex that belong to the Daytime Arietids. The solid and dotted lines are for the ascending and descending nodes, respectively; the vertical line indicates the longitude of the ascending node for the mean orbital plane of the Kreutz comet group I. (c) The nodes of meteor orbits with the mean orbital plane of the Marsden comet group. The dots and circles denote the ascending and descending nodes for the part of the meteor complex that forms the Daytime Arietids stream in the Earth's atmosphere. The solid line represents the mean orbit of the Kreutz comet group I. (d) The same as (b) but for the Marsden comet group.

$$B = R_x^0 Q_x + R_y^0 Q_y + R_z^0 Q_z,$$

$$\cos v_* = \frac{B}{\sqrt{B^2 + A^2}}, \quad \sin v_* = \frac{-A}{\sqrt{B^2 + A^2}},$$

where R_x^0, R_y^0, and R_z^0 are the direction cosines of the comet orbit; P_x, P_y, P_z, Q_x, Q_y, and Q_z are the direction cosines of the meteor orbit; v_* is the true anomaly of one of the nodes; and the anomaly of the other node differs by 180°.

Figure 8a plots the positions of the nodes for meteor orbits with the comet orbital plane in orbital coordinates. We see from this figure that the dispersion in the cluster of the nodes for meteor orbits that are close to the mean comet orbit is lower than the dispersion for the nodes offset by 180°. The compact clustering of the nodes for meteor orbits and their proximity to the comet orbit are a necessary condition for the existence of a genetic connection between the comet and the meteors. Thus, this condition is satisfied for the meteor complex and group I of the Kreutz family.

Figure 8c shows a similar plot for the nodes of orbits for the meteor complex pertaining to the Daytime Arietids with the mean plane of the Marsden comet group. We clearly see that the ascending nodes are clustered in compact groups. The positions of the nodes for meteoric particles pertaining to the Southern δ-Aquarids are not shown in this figure, because they are scattered in a wide strip and are well away from the mean comet orbit. Thus, Fig. 8c confirms the conclusion regarding the reliable genetic connection "Daytime Arietids—Marsden group."

Let us verify the following. If the region where the stream was formed once existed in the comet orbit, then the distribution of meteor nodes must "remember" the birthplace. Therefore, if we vary the position of the comet orbit in space, then the dispersion in the positions of the meteor nodes must be at a minimum for the orbit of the progenitor comet. It will suffice to vary one of the angular elements of the comet orbit. As an angular element, we chose the longitude of the ascending node as the parameter of meteor orbits that is least distorted by selection. The root-mean-square deviation (D) was taken as a measure of compactness of the distribution of meteor nodes in the comet plane:

$$D = \sqrt{\frac{\sum[(x_i - X)^2 + (y_i - Y)^2]}{N}},$$
$$X = \frac{\sum x_i}{N}, \quad Y = \frac{\sum y_i}{N}, \qquad (2)$$

where x_i and y_i are the coordinates of the nodes in the comet plane, and N is the number of meteors in the complex.

Let us apply the above considerations to the mean plane of the Kreutz group I comet orbits and the discovered meteor complex. For each Ω of the comet orbital plane from 0° to 360° at 5° steps, we obtain its own D calculated with formulas (2). The dependence $D(\Omega)$ is a type of a test function to be subjected to further analysis. We see from Fig. 8b that at the longitude characteristic of the comet orbit, the diagram shows a flat local minimum. The fact that the minimum is not deepest should not cause confusion: it is related to symmetry in space and is observed even for streams and comets with a reliable genetic connection. The presence of a minimum in the test function $D(\Omega)$ at Ω of the comet orbit characteristic of the mean orbit for group I of the Kreutz family is indicative of the satisfaction of yet another necessary condition for the confirmation of the genetic connection "Meteor complex of Daytime Arietids and Southern δ-Aquarids–group I of Kreutz family."

CONCLUSIONS

The discovery of new comets using SOHO-type space missions entails a revision of many problems in meteor astronomy, in particular, the formation of meteor streams. Despite their small sizes, these comets contribute significantly to the interplanetary dust cloud, because they are very numerous and the conditions near the Sun are favorable for active dust production. A small fraction of the short-perihelion orbit comets, whose total number is estimated to be several thousand, have likely been discovered to date.

Thus, our analysis leads us to conclude that the discovered meteor complex could be both the result of the direct dusting of short-perihelion orbit comets as they move near the Sun and the result of an unknown mechanism that equally affects the comet and meteor orbits. The two hypotheses are equivalent for the group I comets of the Kreutz family. Our analysis of orbital parameters suggests that the necessary conditions for the possible genetic connection "meteor complex of Daytime Arietids and Southern δ Aquarids–group I of Kreutz family" are satisfied.

For the Marsden group, we may conclude with confidence that there is a genetic connection between the comets of this group and the part of the meteor complex that is observed in the Earth's atmosphere as the Daytime Arietids stream. This conclusion has been confirmed by all of the statistical and celestial-mechanical studies that can be carried out at present if approximate and limited information about the comets of this group is available.

Regular radar observations in June–July near the radiants of the Daytime Arietids and the Southern δ Aquarids are required for further conclusions to be reached. Another direction of research is the physics of short-perihelion orbit comets.

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