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Orbital structure of a meteoric complex in a vicinity of the Earth's orbit by Kazan meteor radar. Types of meteor orbits

S. Kalabanov [a,*], O. Sherstyukov [a], A. Karpov [a], R. Ishmuratov [b]

[a] *Kazan Federal University, 16A Kremlevskaya St., Office. 1404, Kazan, 420008, Russia*
[b] *Kazan State Power Engineering University, Kazan, Russia*

A B S T R A C T

The orbital structure of a meteoric complex in a vicinity of the Earth's orbit is substantially defined by conditions of its observation from the Earth. Orientation of aerials of Kazan meteor radar varied each 15 min to the North, East, South and West – the directions to provide the maximal review of northern celestial hemisphere together with the Earth's rotation. Nevertheless, the antiapex area of celestial sphere was practically inaccessible due to influence of the physical factor of small radar sensitivity to meteors with velocities less than 18 km/s. On the contrary, the meteor streams in which movements are backward compared to the Earth's movement, are quite observationally accessible.

In the given work, the data of meteor radar observation from August to November of 1986 are resulted. The conditions of observation have defined some types of orbits: internal orbits with aphelion distance $Q \sim 1$ AU and with a wide spectrum of perihelion distances and external orbits with perihelion distance $q \sim 1$ AU and with a wide spectrum of aphelion distances. The majority of all observed orbits are close to circular orbits for which $Q \sim 1$ AU and $q \sim 1$ AU. Three-dimensional maps of meteor microstream distribution and numbers of meteors in them by perihelion, by aphelion distances and by inclinations are constructed. Orbital parameters of the most significant meteor streams that have been found out are presented.

1. Introduction

The observed orbital structure of a meteoric complex in a vicinity of the Earth's orbit substantially is defined by conditions of its observation from the Earth, especially when using meteor radars. Radar researches of meteors have more than a semicentenial history of development. A classical engineering of radar researches for the orbital structure was a technique of multi-station receivers for measurement of individual orbits of meteors (Kascheev et al., 1961; Webster and Jones, 2004). However, this technique is quite complex for organizing a long-term monitoring of the orbital structure.

Attempts to use a meteor radar with a goniometer to research meteor streams and sporadic meteors have been undertaken from the very beginning of the radar research (Belkovich et al., 1991). Consecutive steps in this direction are described in works (Jones and Morton, 1977). But till now there was an unsolved problem – the ambiguity of the decision. Because of that we were dealing with low resolution or were studying only major meteor streams. However, in recent years, two scientific teams in Kazan (Belkovich et al., 1997; Sidorov and Kalabanov, 2001; Sidorov et al., 2008) have succeeded in finding an acceptable solution for studying the orbital structure of a meteoric complex based on the goniometric radar measurements.

In this paper we use the results of meteor data computer processing using the original discrete quasi-tomographic method (Sidorov and Kalabanov, 2003). The method is based on the search and analysis of the line intersections of the possible position of observed meteor radiants on the celestial sphere. In this case, the selection of correlated combinations of these intersections is carried out. The method allows to determine small meteor streams ("microstreams") with the number N of more than 6 meteor radio reflections per day (with a discreteness ΔT equal 1 day) and close coordinates of radiants (with angular discreteness $\Delta\psi$, $\Delta\varepsilon$ equal $2^\circ \times 2^\circ$) and close velocities (with a discreteness ΔV equal 3 km/s). On the basis of the results obtained in (Sidorov and Kalabanov, 2003), we proposed the so-called microstream hypothesis. This hypothesis assumes the presence in a meteoric complex of correlated fragments with properties that allow them to be classified as very small stream ("microstream"). The feature of the method is that the decision on the existence of a "microstream" is accepted only if a number of meteors N in a discrete cell of a given resolution ($\Delta\psi$, $\Delta\varepsilon$, ΔV, ΔT) above a certain threshold is detected. Accordingly, it became possible for each detected discrete fragment (microstream) to calculate the average values of the orbit elements.

In work (Sidorov et al., 2004) it is shown that, for the parameters of the Kazan meteor radar, the recorded microstreams can represent

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[*] Corresponding author.
E-mail addresses: kazansergei@mail.ru (S. Kalabanov), rash-i@mail.ru (R. Ishmuratov).

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sporadic background activity if the number of registered meteors in them is from 4 to 6. With 7 meteors and more microstreams represent fragments of meteor streams (partial cluster).

This method, applied to the goniometric observations of a meteoric radar with a wide angular view, taking into account the additional expansion of the field of view due to the Earth's rotation and its orbital motion, makes it possible to build a 4-dimensional orbital structure of a meteoric complex accessible to radar observations from a point located on middle latitudes of the northern hemisphere (Kazan 56°N, 49°E). The purpose of this work was to study the orbital structure of that part of the meteoric complex that adjoins the ecliptic plane on the basis of uniform long-term radar observations in Kazan.

2. Visualization of orbital structures

Assuming that annual changes of seen distribution of meteor radiants and velocities depend primarily on seasonal changes of meteor observations from the fixed geographical point, we have assumed that accumulation of the data for a monthly interval will allow to identify the causes of observed changes. As the primary coordinate system with monthly data accumulated, we have chosen apex coordinate system ε, ψ, v, t, where ε – elongation from apex, ψ – ecliptic longitude, v – meteor velocity, t – time of meteor registration.

The advantages of this system is that it is orthogonal to meteor streams. In this coordinate system the radiant and velocity of a meteor stream practically do not change due to movement of the Earth along the orbit during a stream action. It allows making the averaging of coordinates and velocities during a stream action, that it is especially important at low accuracy of radar velocity measurements.

To demonstrate the advantages of the apex system over the equatorial one we compare the three-dimensional distributions of the observed microstreams and the number of meteors in them in November 1986 in the equatorial (Fig. 1, α δ) and the apex (Fig. 2, ε ψ) coordinate systems.

Comparison of radiant distribution maps of the same data represented in two different coordinate systems shows that in the system (α; δ) the radiants exhibit their compact placement on the celestial sphere, however, it is difficult to trace the connection with the orbital structure. Placing the array of radiants in the coordinate system (ε; ψ) demonstrates their position relative to the ecliptic plane, as well as some orbital characteristics. So it is clear that in November the area adjoining to the ecliptic orbit from anti-Sun side (about ψ = 180°) is accessible to study and here, mainly short-perihelion orbits are observed (the bubbles are colored in blue). Thus, in November, it is possible to study the region adjoining to the ecliptic plane from the anti-sun side (about ψ = 180°), where mainly short-perihelion orbits are observed (the bubbles are colored in dark blue).

It can be seen that in the region perpendicular to the ecliptic plane there are mainly radiants with perihelion distances $q = 0.8–1$ AU, i.e. either circular orbits or external ones that approach Earth at perihelion (like Apollo asteroids orbits). In the apex region ($\varepsilon < 15°$), there are both orbits, however, as we will see later, the backward circular orbits (retrograde orbits) predominate. The horseshoe-like gathering of radiants corresponds to the movement of the region of maximum sensitivity of the radar due to the rotation of the Earth. The fact that this horseshoe is not closed to form a “circle” is due to the low radar sensitivity to meteors with velocities less than 20 km/s due to the physical selectivity factor.

In the antiapex part of the map, meteor radiants are not observed in the range from $100° < \varepsilon < 180°$, so we do not have any information about the meteor streams catching up with the Earth from antiapex. Part of the ecliptic plane from the Sun (about ε = 90°, ψ = 0°) is also inaccessible to observation in November. With such maps can be selected the most informative observation intervals for studying the meteoric complex. The selection of data for analysis can also be performed using a general multidimensional map of the parameter distribution of the microstream orbits.

An example of such a map is shown in Fig. 3 for the full year of 1986. Here i – an inclination, Ω – a longitude of ascending node, N (diameter of bubble) – number of meteors in a microstream. Different colors correspond to different intervals of perihelion distances: dark blue $q < 0.5$ AU; brown 0.5 AU $< q <$ 0.8 AU; light yellow 0.8 AU $< q <$ 1 AU. The largest streams also are highlighted in color: yellow – Quadrantids, green – Daytime Arietids, blue – Geminids.

On this map it can be seen that the orbits with forward movement (prograde orbits) steeply inclined to the ecliptic plane with inclinations $50° < i < 90°$ are observed almost throughout the whole year when Ω varies from 0° to 360°. The lack of data at individual intervals is associated with equipment shutdowns, as well as with periods of activity of Day-time Arietids and Geminids. The latter, perhaps, is associated with the methodological features of simultaneous observation of large and small streams. The area of prograde orbits in the vicinity of the ecliptic plane with inclinations $0° < i < 30°$, which interests us, is observed mainly from May to July and from November to January. Retrograde orbits with inclinations $150° < i < 180°$ are observed from August to November and from February to May. Finally, it can be selected picked retrograde orbits in the interval of $100° < i < 150°$ which are observed in June–August and in November–January. In general, the map is symmetrical relatively Ω = 180°. This symmetry is not violated even by the largest meteor showers of Geminids and Arietids. Because of the marked

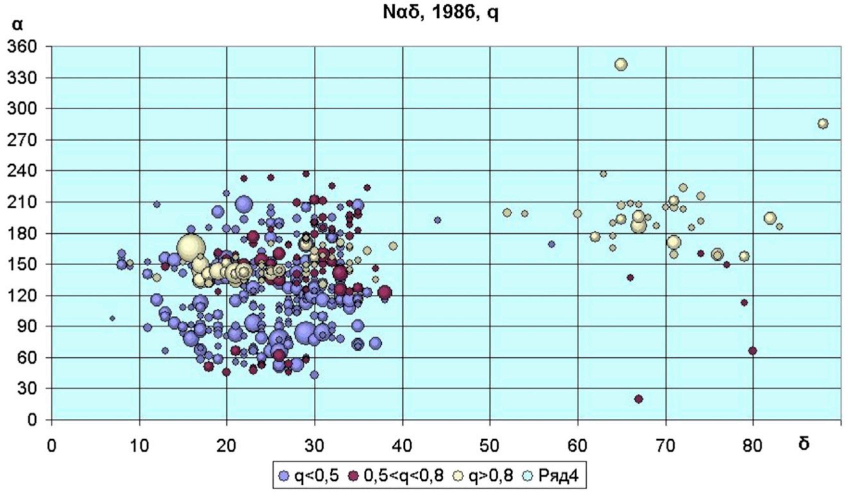

Fig. 1. Distribution of microstream radiants (coordinates of bubbles) and numbers of meteors in them (diameter of bubbles) by coordinates of 2-nd equatorial system (α; δ) for November 1986.