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RESEARCH ARTICLE

Different Scenarios of the Formation of Meteor Showers from the Decay of Cometary nuclei

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Abstract

It is known that the meteor showers come from comets decay, but decay simulation shows that the resulting flows should be narrow, under reasonable assumptions on the rates of release of meteoroid particles of cometary nuclei. The size of the actually observed meteor showers cannot even explain the result of a long evolution of particle orbits under the influence of perturbations of the major planets .

Proposed mechanism of formation of meteor showers due to the collapse of the parent comet nucleus has more complex scenarios. In particular, it occurs when parent comet nucleus splitting into several fragments and further evolution of the orbits of the fragments in the Earth's gravitational field at close to its passage. The orbit parameters of individual fragments can vary greatly. The resulting meteor shower will be a combination of several narrow meteor showers resulting from decays of individual fragments of the parent comet. The observed "parental" old comet meteor showers should be considered as lived to our time fragments of the parent comet. In the absence of the parent comet, meteor showers only shows its full decay and may not be a reason for the search of the parent body among the asteroids.

INTRODUCTION

According to modern ideas about the evolution of comets major meteor showers occur as a result of their collapse, and many of these showers found parent comet. Some streams cannot be associated with any parent bodies [1-3]. This can be explained by the fact that pre-existing parent body is by now completely collapsed and no longer exist. The fact of collapse of comets, which leads to the appearance of meteor showers, has a direct observational confirmation of both the decay of cometary nuclei and the emergence of previously observed meteor showers [4, 5].

Development of the theory of cometary nuclei decay to form meteoroids is presented on many papers, such as [6]. In particular, it was shown that a simple evaporation of the volatile compounds from the nuclei of comets due to the heating from the sun can throw it out of the refractory particles only at low speeds [7]. This leads to the fact that the theoretical dimensions of the radiant flows are substantially less than its actually observed. Even the annual passage across the Earth orbits cannot expand the orbits' tube by gravitational scattering enough for the resulting stream could be -observed for a few weeks. In addition, the low emission energy of meteoric particles of cometary nuclei cannot explain the significant difference between the orbital parameters of the parent comet and its associated meteor shower [8]. realistic agreement can achieve acceptable only under the assumption unrealistic ejection velocities of up to several kilometers per second [8], or incomprehensible in terms of energy release of the entire mass of a single meteor particles and subsequent evolution of the orbit of a meteor shower due to gravitational perturbations by the major planets. [9] But this assumption should lead to a very difficult testable consequences: if the emission of particles from the parent body occurred on a remote section of the Earth's orbit on its own orbit, the particles ejected are in accordance with the laws of celestial mechanics, could not cross the orbit of Earth and observed as meteors in the atmosphere. In this case, would have to admit the existence of a huge number of interplanetary meteoroid streams, or come up with a mechanism for release of meteoric particles from the comet's nucleus extremely close to Earth's orbit. By the way, this last point can be regarded as an important argument against the nature of the asteroid meteor showers.

In fact, just the lack of the meteor stream close to the orbital parameters of the parent comet has led to the assumption of birth meteoroid streams as a result of collision of bodies in the asteroid belt [10]. Being suspicious of this approach should be from the fact that shock destruction of the colliding bodies shards fly in a very wide range of angles, and the observation of meteors as a narrow stream automatically assumes that a significant portion of the fragments in the swarm could not be observed. Consequently, the total mass of the particles in such a flow must be several orders of magnitude higher than the mass of the alleged parent asteroid. Furthermore, the growing bank direct images until the surfaces of asteroids has never confirmed the existence of these least noticeable "chips" [11].

Apparently, the origin of meteor showers in no way associated with asteroids, or at least those that are similar in structure and composition of matter are analogues of meteorites..

In developing the theory of the origin of meteor showers should be based on three basic statements:

1. Meteor showers are a consequence of the collapse of cometary nuclei as a result of the loss of volatile compounds.
2. Meteor showers consist of refractory particles of meteoric species included in the cometary nuclei.
3. Refractory inclusions are ejected from the comet nucleus jets evaporating gases, i.e. with velocities less than one meter per second.

The first position is the observational fact that must necessarily be reflected in the theory of the formation of meteor showers.

The second position is also observational fact arising from the duration of the existence of meteoric particles in the same orbit. The theory of sublimation shows that ice particles evaporate in the size of centimeters in the solar radiation at a distance of 1 AU from the sun for a few tens of seconds, and when meteor showers observed over the years and centuries. Only the refractory particles may exist for so long. Cometary substance is considered as preserved to this day as the matter of the protoplanetary disk that is composed entirely of primary substance: dust and volatile compounds [12-14]. Because you cannot assume the mechanism of formation of monolithic refractory particles directly during the decay of the comet's nucleus, it is necessary to proceed from the hypothesis of the existence of refractory intrusions into the body of cometary nuclei. Supervisory example of a cometary nucleus with lots of chondrite inclusions can bolide body that produced Chelyabinsk (meteoritic storm) in 2013 [15, 16].

The third position is based on the physical understanding of the process of sublimation of volatile substances from the surface of cometary nuclei under the influence of solar radiation. Thermal energy is consumed by evaporation of these compounds and release of vaporized molecules with thermal velocities. All refractory material leaves the cometary nucleus exclusively as a result of entrainment of particles in vacuum evaporating gases. Small light spots with a fractal structure [17] and a low ratio of mass to area can get involved with speeds comparable to the speed of the gas jets. Dense and heavy meteoroid particles practically addicted to gas flows with extremely low density, and they cannot disseminate the results of measurements of the velocity of particles of dust carried by spacecraft [18].

It was estimated [19], small ejection velocity of meteoroids from the parent body at any point of its orbit lead to the formation of very narrow meteor showers that the earth should pass within a few minutes. Accordingly, the area of radiation flow model is also obtained extremely low, it is ten times less than that of actual meteor showers. This discrepancy between theory and observations should be explained.

A multi-phase decay of parent comets:

We propose a scenario under which can be explained by the origin of the wide meteor streams under framework guidelines. Leaving the scope of this work, the issue of the origin of meteoritic matter in cometary nuclei, we consider planetesimals of the second generation as parent bodies of meteor showers [20]. These planetesimals can take the form of individual clusters "snowballs", loosely coupled to each other by mutual gravitation and gentle bond. The decay of such comets takes place in several stages. Initial cometary nucleus can be divided into stretched out along the orbit chain of separate fragments due to tidal or other forces. Such events have been repeatedly observed [21, 22], so this stage looks quite normal. Fragments speeds of "recession" are difficult even to estimate because the unknown forces break the link between the fragments. In the case of the collapse of Comet Shoemakers-Levy 9 had formed clearly linear chain fragments with minor deviations from the provisions of their parent's orbit (Fig. 1), and fragments of the comet 73/P Schwassmann-Wachmann-3 formed a swarm (Fig. 2).

Each fragment of the broken comet nucleus moves independently in full compliance with the laws of celestial mechanics, and its trajectory can be calculated theoretically with great accuracy. However, in these calculations the initial parameters are the initial orbital parameters of individual fragments and relative position of the planets at the time of the start of integration. All of these parameters on the "parent body" meteor showers are free and arbitrary, as fundamentally cannot reproduce all the uniquely original states of the bodies in the past. However, we can show that, as a result of gravitational interaction separate fragment of a Comet with the Earth, you can identify the conditions under which this fragment will be moved into orbit really observed a meteor shower filament. To demonstrate this approach, we consider a simplified model situation in which the Earth's orbit and the orbit of the comet disintegrated fragments lie in the same plane, and the fragments themselves are located exactly in the same orbit as a chain, as shown in Fig. 1.

Fig. 1. Chain fragments of Comet Shoemaker-Levy 9 was stretched out in one line.

Fig. 2. Fragments disintegrated comet 73/P Schwassmann-Wachmann-3 formed a swarm far departed from the parent comet’s orbit.

Perturbing changes in the orbits of the parent comet fragments:

Depending on the time that has elapsed since the first stage of decay, the length of chain fragments can make a wide range of distances. When a chain of large fragments pass close to the Earth, its gravity change their orbits, and the stronger the closer fragment extends from the planet. Velocity increment of such effects is described by:

$$\Delta V = \frac{2 \cdot G \cdot M_{\oplus}}{V \cdot r_0},$$

where G – gravitational constant, $M_{\oplus}$ – mass of the Earth, V – velocity, and r_o – minimum approach distance.

Fragment velocity increment causes changing in the parameters of its orbit. Part of a parent comet has almost the same speed, but variations of span distances (encounter distances) could get a fan of ensemble fragments of different widths. If the final disintegration of cometary fragments to the stage of formation of meteoroid swarm occurs without the perturbations of the earth's gravity, the meteoroids of all fragments of the parent comet will remain close to the parent's orbit. Meteor swarm will "narrow" (width of the swarm will be determined only by the initial spread of cometary fragments in the first phase of decay). If the formation of meteoroid streams of particles was preceded with drag of cometary fragments differing orbits, then formed meteor swarms will have different, but equal orbital parameters. Each swarm will have its narrow radiant and observed in its meaning longitude of the Sun, but the ensemble of these swarms, having a common origin, will be seen as wide meteor shower with a noticeable diurnal drift radiant position.

Simulation of the flow Perseids meteor orbits:

As an example of the proposed approach, consider the formation of a meteor shower the Perseids. The existence of the meteor shower indicates that the orbit of its parent body intersects the Earth's orbit, and hence there is reason to assume that the gravitational deviations of orbits of parent comet fragments were in the plane of the initial orbit of the comet. The Earth's orbital velocity is 30 km/sec and the orbital velocity of the fragments is 40 km/sec then geocentric velocity of the particles that flow V=60 km/sec, and the need for such a model closer to $r_o=2.6\times10^6$ км, to get an extension of the beam orbits to the size of the fragments up to 40 million km along the Earth's orbit ($\Delta V=7.7$ km/sec). This is just the size of the area in which there has been a stream of the Perseids. Thus, the observed flow settings of the Perseids can be explained by a close passage of parent comet chain fragments near (by?) the Earth. Its length can be estimated from the following considerations. Now observed Perseids slowly increases its activity for almost three weeks, and after the maximum activity falls. To get a picture, you must assume that the Earth passed the end of the chain (the edge of the swarm) at a distance of 2.6 million km , and the other end (edge) has passed from it at a distance of 5 million kilometers (otherwise the variation of the activity would not have been close linear). Earth passes by a swarm of 8×10^5 sec, which gives an estimate of the length of a swarm chain of 4.8 million km.

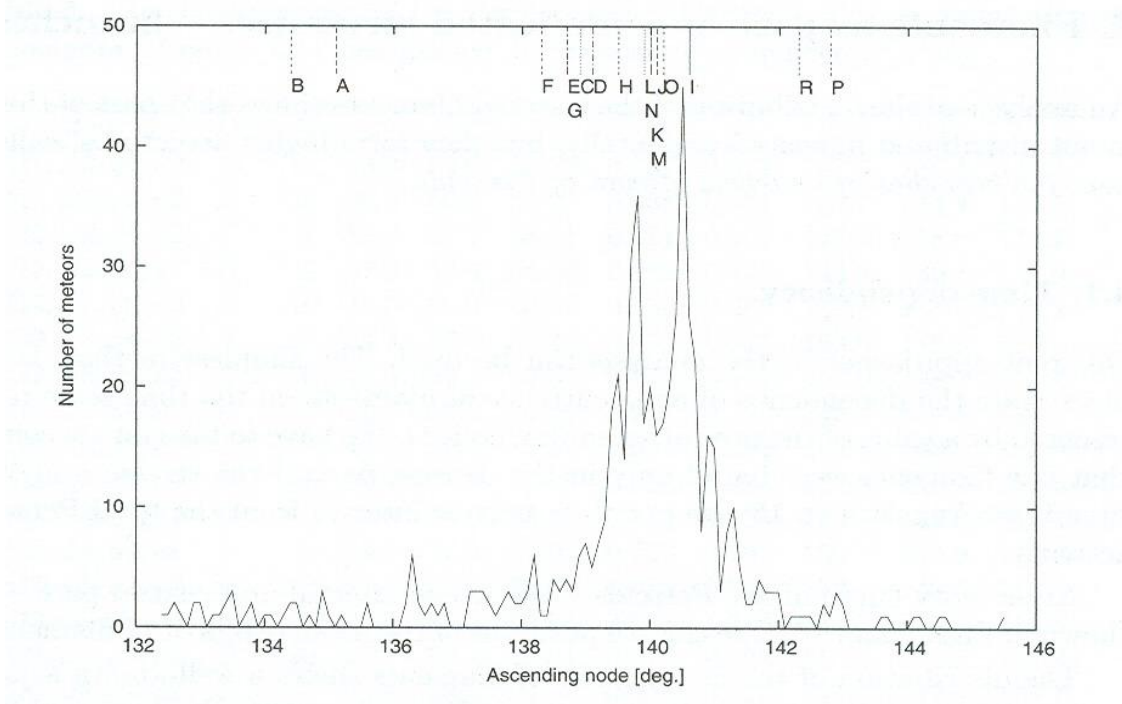

Fig. 3. Profile of the Perseids meteor shower activity [23], which clearly distinguish a set of individual peaks.

$d.rs.$	Q	N	α	δ	V_g	q	e	ω	Ω	i
$\Omega1, \omega3, q2, e2$	A	15	43.3	57.9	58.70	0.937	0.971	147.7	135.1	111.4
$\Omega1, \omega5, q4, e2$	B	36	39.3	56.8	59.27	0.958	0.981	152.7	134.4	112.5
$\Omega2, \omega2, q1, e2$	C	7	50.0	57.7	58.61	0.921	0.907	143.9	138.9	113.2
$\Omega2, \omega2, q2, e1$	D	8	47.3	57.4	56.56	0.935	0.744	144.9	139.1	111.9
$\Omega2, \omega3, q2, e2$	E	10	48.0	59.2	58.39	0.936	0.959	147.6	138.7	110.7
$\Omega2, \omega5, q4, e2$	F	23	44.3	57.8	59.45	0.959	0.985	153.0	138.3	113.0
$\Omega2, \omega6, q5, e2$	G	10	42.3	57.3	59.35	0.974	0.958	157.0	138.7	113.3
$\Omega3, \omega1, q1, e1$	H	3	49.7	57.7	56.10	0.917	0.722	140.7	139.5	111.5
$\Omega3, \omega2, q2, e1$	I	7	49.7	57.5	57.35	0.931	0.795	144.7	140.1	112.8
$\Omega3, \omega3, q2, e2$	J	53	50.0	57.8	59.05	0.936	0.933	147.5	140.1	113.6
$\Omega3, \omega4, q3, e2$	K	47	48.9	58.0	59.45	0.945	0.975	149.7	140.0	113.4
$\Omega3, \omega4, q4, e1$	L	5	45.9	57.3	57.04	0.956	0.762	150.1	139.9	112.4
$\Omega3, \omega5, q4, e2$	M	242	47.1	57.9	59.32	0.956	0.958	152.2	140.0	113.3
$\Omega3, \omega5, q4, e3$	N	21	48.5	57.5	62.84	0.956	1.214	153.7	140.0	115.8
$\Omega3, \omega6, q5, e2$	O	40	45.1	57.4	60.01	0.971	0.993	156.4	140.2	114.3
$\Omega4, \omega3, q2, e2$	P	17	53.8	58.3	59.07	0.936	0.927	147.4	142.8	113.7
$\Omega4, \omega5, q4, e2$	R	16	50.1	58.3	59.20	0.957	0.939	152.5	142.3	113.5

Table. 1. The orbital parameters of individual branches of the stream of the Perseids [23]. (d.r.s. – designation of combination of range, Q – destination of filament, N – number of used orbits).

The Perseid meteor shower itself is a superposition of many individual small swarms (Fig. 3) with its narrow peaks. Approximately 64% of all meteors forms 17-substreams branches [23]. Each substream its own orbit, whose parameters are listed in Table. 1.

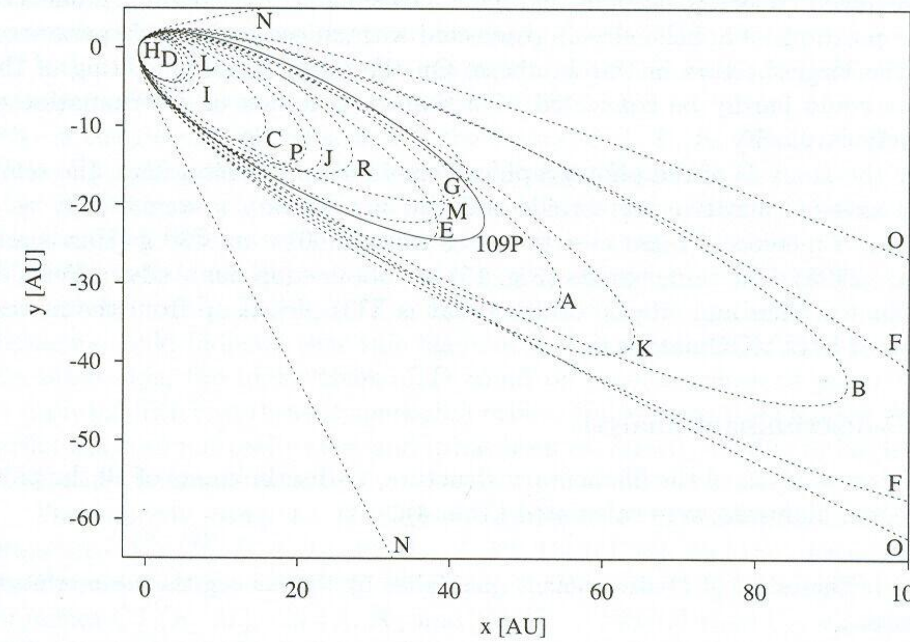

Fig. 4. Mutual arrangement of the main branches of Perseid meteor shower orbits and the "parent" comet 109P/Swift-Tuttle [23]

Earth's gravity can speed up or slow down the passing of its body with a speed of 60 km/sec and by no more than 7.9 km/sec. This value completely covers the range of particle velocities in separate branches of the Perseids. Therefore, we can easily calculate the location of "parent" comet fragments formed of a single chain in the simulation of the whole chain close passage near the Earth to obtain the observed orbits of the ensemble formed by the branches of a meteor shower .

Here it is necessary to stipulate that the periods of the earth and fragments of the parent comet around the Sun are not multiples of each other, and after a close passage near the Earth fragment may take a very long time until the next rapprochement. During this time, a fragment can completely dissolve and form an extended swarm of meteoric particles. This swarm will maintain its orbit, even after many of his close passages from the earth, as its gravitational effects may affect only the closest flying by particles, but not on the swarm as a whole. Therefore, we can consider only one close encounter chain fragments parent comet near Earth.

Calculation of chain structure fragments and its location relative to the Earth by the gravitational action on it (i.e. the set of orbits obtained) from a mathematical point of view is non-correct problem, allowing the set of solutions. We can consider an arbitrary location picture fragments in orbit and sets the initial speed of the whole chain. Seems the most realistic by-pass velocity of the parent comet nucleus, will be for flown from the Kuiper belt. If the fragments cross the orbit of the planet Earth ahead it, its gravity slows their heliocentric velocity, and if after - accelerates. In other words, gravity assist can translate some fragments on domestic solar orbits, and others - to throw out of the solar system. In this case, the actual set of Perseids orbital parameters substreams can be obtained if part of the chain fragments held ahead of Earth in its orbital motion and accelerate and part - behind and slow down. In Table 2 shows the results of such calculations for fragments geocentric velocities of 59 km/sec and 71 km/sec (corresponding to a heliocentric velocity 41.7 km/sec and 42.1 km/sec). In it, there are the actual values of semi-major axis and the velocities of individual particles at a distance of 1 AU from the Sun, and the calculated impact parameters r_o, in which the parent body gets its orbital characteristics substream. Here are the parameters of the orbit of the comet 109P/Swift-Tuttle and conditions under which it receives modern orbit, being one of the common parent comet fragments. Designation branches Perseids in Table 2 is the same as in Fig. 3, Fig. 4 and Table 1.

Name of fragment	a	$V_{r=1}$	V = 71 km/s		V_0 = 59 km/s	
			ΔV	$r_o \cdot 10^6$, km	ΔV	$r_o \cdot 10^6$, km
A	32.31	41.80	- 0.30	3.74	+ 0.10	13.5
B	50.42	41.91	- 0.19	5.91	+ 0.21	6.43
C	9.90	41.04	- 1.06	1.06	- 0.66	2.05
D	3.65	39.13	- 2.97	0.38	- 2.57	0.53
E	22.83	41.66	- 0.44	2.55	- 0.04	33.8
F	63.93	41.96	- 0.14	8.01	+ 0.26	5.19
G	23.19	41.67	- 0.43	2.61	- 0.03	45.0
H	3.30	38.80	- 3.30	0.34	- 2.90	0.47
I	4.54	39.74	- 2.16	0.43	- 1.96	0.69
J	13.97	41.36	- 0.74	1.52	- 0.34	3.97
K	37.80	41.84	- 0.26	4.31	+ 0.14	9.64
L	4.02	39.42	- 2.68	0.42	- 2.28	0.59
M	22.76	41.66	- 0.44	2.55	- 0.04	33.8
N	-	>42.1	0		+ 0.41	3.29
O	138.7	42.05	- 0.05	22.4	+ 0.35	3.86
P	12.82	41.29	- 0.81	1.39	- 0.41	3.29
R	15.69	41.45	- 0.65	1.73	- 0.25	5.40
109P/Swift-Tuttle	26.09	41.72	- 0.38	2.95	+ 0.02	67.5

Table. 2. Calculated distance approach to Earth individual fragments of the parent comet for observables semiaxes of substreams Perseids (two variants of primary orbit).

The above scheme allows calculating the position of the individual fragments of the parent comet orbit. Figure 5 shows the location of the parent bodies of the various branches Perseid meteor shower on the assumption that the orbit of the parent comet at aphelion reaches the Kuiper Belt. The total length of the main chain of the fragments of the splitted comet is 15 million miles. Fragments N and O were supposed to be far ahead of the entire group, and pass by the Earth to the planet to go to close to a parabolic orbit.

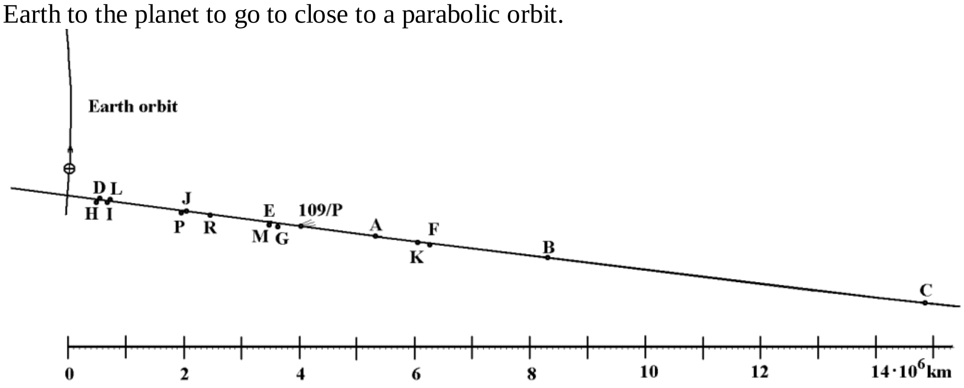

Fig. 5. Relative positions of the fragments in the event of crossing the Earth's orbit of the planet behind. Position of fragments N and O falls outside the picture.

Calculation shows that the chain of parent comet fragments at the time of its interaction with the Earth was very compact, like a swarm of bodies after the splitting of the comet 1999 S4 LINEAR. Approximation to the minimum distance from the Earth had fragments of H, D, I and L, which is about 500,000 km. It was enough to put these bodies in orbits with semi-major axis 3.3 … 4.5 au.

Several other provisions would be a picture elements in a swarm of fragments, if the Earth crossed the middle of the swarm. Figure 5 shows the relative positions of these fragments calculated for the initial orbit with semi major axis 30 AU. Some of the fragments acquired an additional speed and increased the size of their orbits and the other - lost speed and moved to the lower heliocentric orbit. Simulated in this embodiment, a swarm in its compact part has a size of about 30 million km - longest chain constituting very small part of the initial orbit.

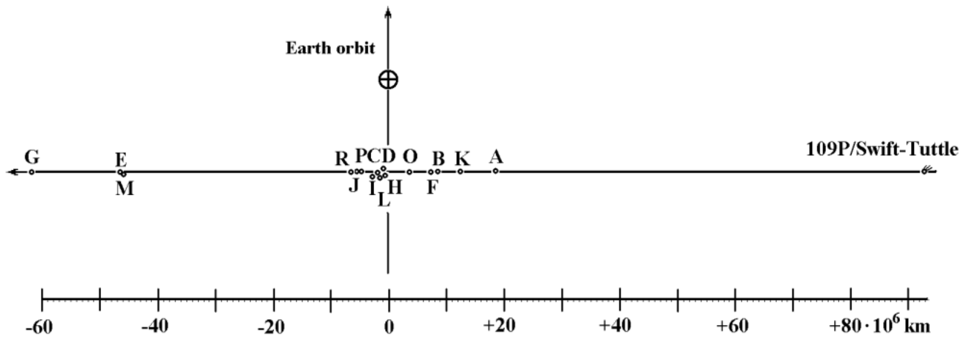

Fig. 5. Relative positions of fragments in case of their having initial orbit with a=30. Then Earth had to cross their orbit at the middle of main grope. Positions of fragments N and O are beyond boundaries of the scheme.

A detailed study of the fine structure Perseids would allow fuller picture of the formation to restore this flow and clarify some of its stages, in particular, to perform three-dimensional modeling process.

Since the minimum time required for the currently observable homogenous filling the entire tube orbits by Perseid particles with differential speeds of the order of 1 m/sec, it takes about 3×10^5 years, it is difficult to assume that during this time the parent comet could survive about 5000 revolutions around Sun. Therefore 109R/Svifta-Tuttlya comet that is now recognized Perseids parent comet, apparently, is preserved for some reason fragment of disintegrated common parent body, that has only recently become again show cometary activity.

It does not follow that all fragments of the parent comet must completely disintegrate simultaneously. Perfectly valid option, in which some fragments of "fade" thorns heatproof dust crust and cease to show cometary activity. Thickness of the porous dust cover, in which the cometary nucleus can withstand even heating of the solar radiation at a distance of 0.4 AU from the Sun is only 1.5 meters, so it is possible the existence of elements of the meteor swarm of cometary bodies structure several meters in diameter and more. Extinct comet sub-nucleus being member of meteor stream cannot be activated by collisions with particles of his own meteoric swarm as relative speed among them up a few meters per second. To destroy the five-foot bark dust and expose the core of the volatile substance requires a hit with much greater speed. The probability of collisions of small bodies in the solar system is small, and some fragments of the parent comet may exist undefeated indefinitely. Quite possible that the car Chelyabinsk 2013 represented just such a "canned" parent comet nucleus fragment preserved in orbit, which did not even have enough meteoric particles to form a meteor shower.

Forming wide meteor shower without structural divisions:

In the case of a close passage by Earth chain of parent bodies may form sub streams on noticeably different orbits. If a single parent body completely disintegrated and formed a compact meteor swarm, its passage near the Earth should lead to the formation of an ensemble of orbits of meteoroids, little structured, but having a large width.

Crossing stretched along the orbit of the Earth meteoroid swarm due to the limited range of distances at which the Earth's gravity affects the particle orbits, should lead to a change in orbits very small number of particles, and the total width of the tube orbits flow should not change noticeably. After this interaction the main swarm maintains its compactness in a direction transverse to the orbit, but some of the particles fall into its surroundings and "extend" the period of his observations of meteors stream. Approximately the picture corresponds Leonid meteor shower: flow itself is observed annually for several days, but the density of particles in the flow (as an indicator of which can be considered ZHR) in normal years is small. When the Earth crosses the central Leonid swarm, its compactness is manifested in a short crossing time swarm - (about 2 hours), and the density of particles in the swarm is so high that each intersection of the central part of the swarm isshoting star rain (storm)

Note also that the gravitational influence of other planets on the evolution of meteor streams should be very little. For example, the Perseid meteor shower at its inclination orbits of almost 60 degrees, never coming to Jupiter closer than 4 AU, and at such a distance away from the gravitational resonance effects are negligible.

Gravity assists and captures short-period comets to orbit:
Single body at close passage near the massive planet can significantly change their orbital parameters. As a result of this interaction subsequently modified orbit body will always go through the interaction point, what would not have orbital parameters. This property is disturbing maneuver well explains the existence of "families" of comets, which are associated with large planets families - Jupiter, Neptune and others capture the short-period comets orbit on the occasional interaction with a large planet in terms of energy exchange between the bodies looks more natural than the "progressive" change the orbit of a cometary body with prolonged accumulation micro changes on cosmogonic time scales.
Furthermore, the concept of one-time interactions can naturally explain the existence of comets with nearly parabolic orbits. You do not want to attract the idea of the existence of the Oort comet cloud, which is difficult to explain in terms of the standard cosmogony theory [12-14]. If we proceed from the fact that the comet nucleus is stored since the formation of the solar system in the Kuiper belt [20] , the evolution of their orbits without changing the integral energy can lead to significant eccentricities and, as a consequence, the possibility of a close encounter with the comet's nucleus next to a large planet. As a result of the gravitational interaction between them can take place not only capture the short-period comet orbit, but to translate it into a very high orbit up to parabolic one.

Conclusion:
Presented simulation shows that the dynamic effects on the orbit of the parent bodies of the swarm under the influence of Earth's gravity can fully explain the existence of the fine structure of meteor streams and their width.
Recurrent major planets gravitational interaction with cometary nuclei explains the origin of the bodies of comets families of the Kuiper Belt, and also explains the existence of comets on nearly parabolic orbits without invoking the concept of the tank as a comet Oort cloud.

Refrences:

1. Astapovich I.S. “Meteoric Phenomena in the Earth's atmosphere”, Moscow: Fizmatgiz, 640 C, 1958. (in Russian)
2. Babadzanov P.B. “Meteors and their observation”, Moscow: Nauka, 192C, 1987. (in Russian)
3. Astapovich I.S. “Twenty-six of meteor streams associated with comets”, Astron. Circ. , 30 Sep-№ 142. - P. 6-10, 1953. (in Russian)
4. Babadzanov P.B., Obrubov Y. “Studying of Meteoroid swarms, evolution and communication with comets and asteroids”, Astron. vestn. V. 25, No 4. Pp. 387-407, 1991. (in Russian)
5. Wiegert P.A., Brown P.G., Vaubaillon J. and Schijns H. “The τ Herculid meteor shower and Comet 73P/Schwassmann–Wachmann 3”, Mon. Not. R. Astron. Soc. 361, 638–644 ,2005.
6. Ryabova G.O. Modeling of large dust particles release from the nucleus of Halley's comet. / / Astron. Herald of the RAS. T. 31. № 4. S. 314-326, 1997.
7. Kulikova N.V. “Draconid meteor swarm (modeling)”, Astr. Vestn, 23. № 4. C. 289—296, 1989. (in Russian)
8. Kulikova N.V., Myshev A.V. and Pivnenko E.A., “Cosmogony of small bodies” Moscow: Kosmosinform, 176, 1993. (in Russian)
9. Ryabova G.O., “Mathematical model of the Geminid meteor stream formation”, Proceedings of the Meteoroids 2001 Conference, Swedish Institute of Space Physics, Kiruna, Sweden, 6-10 August 2001, ESA SP-495, p. 77-82, November 2001.
10. Ryabova G. O., “Asteroid (1620) Geographos as a possible parent body for a meteor stream”, Proceedings of the Meteoroids 2001 Conference. // ESA SP-495, p. 63-70, November 2001.
11. Bagrov A.V., “Astronomical problems of the Earth protection against dangerous asteroids”, Proceedings of IV ISTC Scientific Advisory Committee Seminar on "Basic Science in ISTC Activities", Academgorodok, Novosibirsk, April 23-27, 2001 // Novosibirsk: Budker Inst. of Nuclear Physics SB RAS, p.285-291, 2001
12. Levin B.Yu. On the comet origin. // The Cosmogony Problems, 1963. – v. 9.- pp. 215-231 (in Russian)
13. Makalkin A.B., Ziglina I.N. Planetezimales formation in Trance-Neptune region of proto-planetary disk. // Astron. Vestnik, 2004. - vol. 38. – N 4. – pp. 330-343. (in Russian)

14. Safronov V.S. Minor bodies accumulation at external border of planetary system. // Astron. Vestnik, 1996. – vol. 30. – pp. 291-298. (in Russian)
15. Bagrov A. V., Leonov V. A. and Popelenskaya N. V., "The Chelyabinsk bodies as a proof of cometary nature of Earth orbit crossing bodies", Program and Abstracts: Meteoroids 2013 Conference, 26-30, August 2013, Poznań, Poland, p. 070, 2013.
16. Bagrov A.V, Leonov V.A., Popelenskaya N.V. Studying of structure and composition of the main body of the Chelyabinsk bolide. / "The Chelyabinsk Meteorite – one year on the Earth": Proceedings of All-Russian Scientific Conference. Ed. N.A.Antipin // Chelyabinsk, 2014. pp. 310-319. ISBN 978-5-905081-09-5 (in Russian).
17. Bisikalo D.V., Shematovich V.I. Kinetic model of the internal cometary coma. // astron. Circ., 1987. – No 1507. – pp. 1-3. (in Russian)
18. Keller H. U., Britt D., Buratti B. J., and Thomas N., "In Situ Observations of Cometary Nuclei ", COMETS II, Edited by Michel Festou, H. Uwe Keller, and Harold A. Weaver ,the University of Arizona Press, p. 211–222, 2005.
19. Bagrov A.V., Sorokin N.A., Bolgova G.T., Kartashova A.P., Leonov V.A. "Theoretical estimation of meteor radiation region dimension for young meteoroid stream.", Memorial International Coference CAMMAC-2008, September 28 - October 3, 2008, Vinnitsa: Programm and Dook of Abstracts // Vinnitsa. p. 27-28, 2008.
20. Bagrov A.V. , "Two generations of comet nuclei and observable difference in results of their disaster", The Near-Earth Astronomy – 2003. Proceedings of conference held September 8-13, 2003, Peak Terskol, Russia, Institute of Astronomy RAS, p.125-133, 2003. (in Russian)
21. Sekanina Z. , "The problem of split comets in review", Comets (ed. L.L. Wilkening), P. 251-287, 1982.
22. Hughes D.W. and McBride N., "Short-period comet splitting", J. Br. Astron. Assoc., 102, No 5, p.265-268, 1992.
23. Kanuchova Z., Svoren J. and Neslusan L., "The observed structures in the meteoroid stream of Perseids in the range of photographic meteors", Contrib. Astron. Obs. Skalnate Pleso 35, 135-162, 2005.