SESSION 8

Chairman: P. B. Babadžanov

44. INVESTIGATION OF PERTURBED MOTION OF THE LEONID METEOR STREAM

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ABSTRACT

The investigation is based on a system of elements, obtained from the best observations made in England during the maximum of the meteor shower 1866. This system represents the most probable orbit of that part of the stream, which passed perihelion during the years 1864–67 and was later given the name of Ortho-Leonids. Seventeen points (meteor groups) have been chosen on this orbit, and differential equations of their motion have been integrated on the electronic computer BESM-2 by Cowell's method of quadratures, taking account of perturbations from eight planets (Venus–Pluto), with a variable step from 0·001 to 40 days and taking account of differences through to the 4th order. The motions of two groups (XI and XII) have been investigated in an interval of 300 years (1700–2000), and the motions of the rest of the groups for a space of 135 years (1866–2000). All the close approaches of these groups to the Earth, Jupiter, Saturn and Uranus have been determined. The results of integration are given in the tables, which clearly represent the evolution of the orbit of every group. It has been found that the basic factors determining the evolution of separate groups, and of the stream as a whole, are the close approaches to the outer planets. The perturbations by these planets, especially by Jupiter and Saturn, determine the conditions for an encounter of the meteor groups with the Earth, and cause a change in the activity of the Leonid shower at different apparitions. Apparitions of the Leonids have been investigated for the last millennium, and in more detail for the last 180 years. It has been stated that the orbit of the Ortho-Leonid stream remained stable over the interval of 1000 years; its stability has been confirmed by calculations during the last 300 years, and the limits of changes of its elements have been computed. The perturbing influence of the Earth on the motion of meteor bodies in its sphere of action has been investigated. It turns out that at exceptionally deep penetrations of meteor bodies into this sphere of action, at a distance of some 1000 km from the Earth, its perturbations can essentially transform the orbit of a meteor body, e.g. reduce its period of revolution by some years, and materially change the eccentricity of the orbit, its inclination, etc. Conditions for an encounter of the stream with the Earth in the period 1898–2000 have been clarified, and forecasts have been made for the times of maximum activity of the shower in the years 1966–68. In 1967 the maximum activity of the Leonids is predicted to occur from November 17, 18^h to November 18, 1^h UT.

1. Short Historical Information

The 33rd return to perihelion of the densest part of the Leonid meteor stream, counting from its first apparition recorded by historians in 899–902, will take place in 1964–68.

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The great meteor shower in 1799 caused a steep rise of interest in meteors, and during the following decades, Humboldt, Arago, Chales, Perry, Herrick and Biot collected in their works descriptions of meteor phenomena in literary sources from Europe and the Far-East dating both from ancient times and from the Middle Ages. Quételet (1861) gave a summary of these. H. Newton (1863, 1864) for the first time found there six dates of previous apparitions of the Leonids and supplemented them in later work by seven more apparitions. Later, Svjatskij (1915) detected and specified a series of dates based on an investigation of Russian publications, and Sekiguchi (1917) of Korean. Hirayama (1929) published some observations which a year before were published in a Japanese edition. Kanda (1935) gave new information from Japanese chronicles. Iba (1934) and Yamamoto (1936) also cited some dates from chronicles of South-Eastern Asia. Imoto and Hasegawa (1958) (Calendar Association of Japan in Osaka and Institute for Astronomical Computation in Shimizu) translated into English ancient observations from China, Korea and Japan, and published a list of 118 great meteor showers for 36 centuries (1809 B.C. – 1798 A.D.). Among them are 27 accounts covering 18 different apparitions of the Leonids.

An examination of the data on the past activity of the Leonids leads to the following conclusions:

(a) During 33 revolutions, i.e. 10^3 years, one observes a remarkable stability of the Leonid stream;

(b) At several apparitions, great meteor showers recurred in the course of 3 years;

(c) It has been noted that the duration of the maxima of the shower amounted to from a quarter of an hour (1966) to 24 hours and more (1533 and 1625);

(d) Double maxima were observed in 1602, on November 6 and 11, and similarly in 1818, on November 13 and 19;

(e) Sometimes there is no information whatever available about the shower for the space of a century (apparitions Nos. 8–9 in 1133–66, Nos. 12–14 in 1266–1333, No. 26 in 1733);

(f) Secondary condensations in the stream have been observed, deviating from the date of the basic maximum by 4, 5, 8 and even 12 years.

Kirkwood in 1885 pointed out that there possibly may exist three meteor condensations in the orbit of the Leonids: with periods $P = 33{\cdot}25$ years (Newton-Adams), $P = 33{\cdot}31$ years (Humboldt-Quételet) and $P = 33{\cdot}11$ years. According to Kirkwood, the maxima of the years 1582, 1813, 1846–49, 1877–80 correspond to this last period, deduced by him from observations during 1850–80; and the maxima of 1787, 1818–22, 1852, etc. – to the second period. According to modern investigations, the great meteor showers of the years 902, 931, 934, 967, 1002, 1035, 1037, 1101, 1199, 1202, 1237, 1298, 1366, 1399(?), 1465, 1466, 1532, 1533, 1566, 1602, 1698, 1766, 1799, 1832, 1833, 1866, 1867, 1868, 1901, 1934, and 1966 represent the main condensation ($P = 33{\cdot}25$ years).

Important investigations on the Leonid shower have been given by Wright (1951), based on photographic observations, and Murakami (1959, 1961), based on visual observations during 1929–58, carried out in Japan according to a general national program. Some results and basic problems of the study of the Leonid shower, with regard to its present return to perihelion, are stated in a paper by Astapovič and Terenteva (1966).

2. Statement of the Problem

At present there is special interest in the investigation of the perturbed motion of the Leonids over great time intervals, using modern computational techniques. The following problems have been raised in this connection:

(a) To obtain a most probable initial system of elements of the Leonid meteor stream;

(b) To investigate, on the basis of this system and using electronic computers, the motion and evolution of the orbit of the stream for a period of more than 100 years, taking full account of planetary perturbations and using one of the most precise numerical methods of celestial mechanics;

(c) To ascertain the part which outer planets play in the evolution of the Leonid stream, as well as the influence of their perturbations on the change in activity of the shower at different apparitions;

(d) To investigate the stability of the orbit of the stream;

(e) To study the motion of the meteor groups in the Earth's sphere of action and after they leave this region;

(f) To investigate the activity of the Leonid shower and the conditions of an encounter of the stream with the Earth in a series of apparitions, and to give a forecast of the maximum activity of the stream during 1966–68.

3. Initial System of Elements of the Leonid Stream

Up to now, the motion of the Leonid meteor stream has been investigated by Adams (1867), Berberich (1898), and Stoney and Downing (1899).

Adams based his investigations on those of H. Newton, who proposed a series of possible periods of revolution of the Leonids. His analysis gave a most probable period of 33·25 years; secular perturbations of the orbit's node, computed on the basis of this period, proved to be in full agreement with observations. Adopting this period, and having found the coordinates of the radiant from several observations at the maximum of the great meteor shower in 1866, Adams computed a system of elements of the stream and defined their secular perturbations by Gauss' method.

Stoney and Downing, using Adams' elements, computed by the method of variation arbitrary constants for the perturbations from four planets (Mars, Jupiter, Saturn and Uranus) for one revolution (1866–1900) of that part of the stream which encountered the Earth in November 1866, and obtained a system of elements for the year 1900.

The valuable investigations of Adams, Stoney and Downing became fundamental in the problem to be studied. But it was inappropriate to use their results as a basis for further investigations for the following reasons:

(a) In determining coordinates of the radiant from six independant observations, Adams did not take into consideration some good observations made in England;

(b) Concepts of zenith attraction and diurnal aberration of the radiant were not yet introduced into meteor astronomy at this time, and the method by which Adams accounted for the Earth's influence on the motion of a meteor particle in the stream remains unknown;

(c) Stoney and Downing used currently obsolete values of the masses of Jupiter (1/1047·879 instead of 1/1047·355) and Uranus;

(d) They neglected perturbations from Venus and the Earth which, in spite of their insignificant values at each step of the integration, become appreciable over a full revolution of the stream;

(e) Integrating the differential equations of motion by hand, using the very laborious method of variation of elements, they inevitably increased the integration steps over a wide range near the aphelion of the stream (using 216 days instead of 40 days), which led to a certain misrepresentation of the perturbations, especially those from Jupiter.

In computing a new initial system of orbital elements for the Leonid stream, we have taken as a basis the same period of revolution as Adams. For the determination of the radiant we have used independant observations (Herschel, 1866; Adams, 1867) made in England during the maximum of the great Leonid meteor shower in 1866. The apparent radiant has been taken as the weighted mean of 12 of the best positions. The final coordinates of the corrected geocentric radiant, taking account of the corrections for zenith attraction and daily aberration, are:

$$\left.\begin{array}{ll}\alpha = 149°13', & \delta = +23°00',\\ \lambda = 143°23', & \beta = +\ \ 9°50',\end{array}\right\} 1866{\cdot}0 .$$

The ecliptical coordinates of the heliocentric radiant are:

$$\lambda' = 144°17', \quad \beta' = +17°00', \quad 1866{\cdot}0 .$$

Thus, the initial system of orbital elements of the stream has been found to be:

$$\begin{aligned} T &= 1866,\ \text{November } 14.\ 0569\ \text{UT}\\ M &= 0\overset{\circ}{.}1208\\ \left.\begin{aligned}\omega &= 174\overset{\circ}{.}354\\ \Omega &= 231\overset{\circ}{.}4847\\ i &= 162\overset{\circ}{.}987\end{aligned}\right\} & \ 1866{\cdot}0\\ n &= 0\overset{\circ}{.}0296429\\ e &= 0{\cdot}904584\\ a &= 10{\cdot}3402\\ P &= 33{\cdot}250\ \text{years}\end{aligned}$$

The epoch of osculation, *T*, is equal to the moment of maximum of the great meteor shower in 1866, November $14^{d}1^{h}22^{m}$ UT.

4. Investigation of the Motion and Evolution of the Leonid Meteor Stream, with an Account of the Perturbations from Eight Planets, Venus–Pluto

The system of elements obtained has been considered as the most probable orbit of the dense part of the Leonid stream that Stoney and Downing named the 'Ortho-Leonids'. The extent of the Ortho-Leonids along their orbit has been defined by the duration of their passage through perihelion (1864–67).

Seventeen points have been chosen, spaced more or less regularly along the orbit of the Ortho-Leonids, and concentrated in the vicinity of the point, which the Earth encountered on November 14, 1866. These points have been considered as groups of meteor bodies which experience equal planetary perturbations within the limits of the stated computational accuracy.

Table 1a of the (1967) paper by the authors contains the moments of the perihelion passages of 11 basic meteor groups (I–XI). Corresponding moments for another 6 groups (XII–XVII), studied in addition, are given in Table 1b. The reference numbers in each table correspond to the sequence in time of the moments of their perihelion passages.

Table 1a

Basic meteor groups on the orbit of the Ortho-Leonids

Designation of the group	Time of perihelion passage (ET)	Designation of the group	Time of perihelion passage (ET)
I	1864, November 9·901	VII	1866, November 7·980
II	1865, November 9·507	VIII	1866, November 9·978
III	1866, April 24·962	IX	1867, February 17·934
IV	1866, August 2·980	X	1867, May 29·985
V	1866, September 21·982	XI	1867, November 10·251
VI	1866, October 31·982		

Table 1b

Additional meteor groups on the orbit of the Ortho-Leonid stream

Designation of the group	Time of perihelion passage (ET)	Designation of the group	Time of perihelion passage (ET)
XII	1866, November 9·580	XV	1867, July 8·987
XIII	1867, April 29·984	XVI	1868, July 17·070
XIV	1867, June 28·987	XVII	1868, November 9·320

Integration of the differential equations of motion of all the groups has been performed on the electronic computer BESM-2 by Cowell's method of quadratures, taking account of the perturbations from eight planets (Venus–Pluto) and of high-order terms through the 4th order. Integration has been performed according to the program described in the paper by Beljaev (1967), in three approximations with eight decimals and a variable step, which changed over very wide limits – from 1 min (in the depth of the Earth's sphere of action) to 40 days (in a part of the orbit remote from the Sun and at considerable distances from Jupiter and Saturn). The assumed system of planetary masses is that given in Table 2 of the (1967) paper by the authors.

The evolution of two groups (XI and XII) has been studied over an interval of 300 years (1700–2000), the evolution of the remaining 15 groups for a space of 135 years (1866–2000).

The basic results of integration are represented in a series of tables, constructed on the following principles. The epochs of osculation are given in the first column, followed by the corresponding osculating elements in the next seven columns. In the ninth column is the variable integration step, expressed in days and in the last four columns are given the minimum distances (AU) from the centre of the meteor group to the centres of the Earth, Jupiter, Saturn and Uranus respectively, at the periods of approach.

Owing to the fact that the elements are listed in the tables according to the times of approach, the perturbing influence of every planet on separate elements, as the result of each individual approach, as well as the part played by all the outer planets in the evolution of the orbit as a whole, can easily be determined.

The evolution of the orbits of four meteor groups (I, II, VIII and IX) is shown in Tables 3–6 of the authors' (1967) paper. The evolution of groups IV, VII and XI is represented in Tables 2–4 of the present paper.

Groups IV, VII and VIII passed perihelion in 1866, on August 3, November 8 and November 10 respectively (Table 1a), the abundant meteor shower of 1866 November 14 being caused by group VIII. Hence, these three meteor groups formed a vast region in the central part of the Ortho-Leonids with an extent of about 100 days along the stream's orbit. A comparison of Table 5 of the authors' (1967) paper with Tables 2 and 3 of the present paper leads to the conclusion that this whole region is characterized by common regularities of evolution for a space of 135 years. In fact, in 1870 and 1895, all three groups had insignificant approaches by two's with Saturn, then in 1898 they approached Jupiter to a minimum distance of 0·9 AU. The first approaches to Saturn moved the perihelia of the meteor orbits away, beyond the limits of the Earth's orbit, and the great perturbations from Jupiter transferred them in the direction towards the Sun, a considerable distance inside the Earth's orbit. Thus, conditions of possible encounters of these meteor groups with the Earth changed considerably, and unfavourably, under the influence of approaches to Jupiter. Further unimportant approaches of these groups to Jupiter in 1901, and approaches to Uranus of 0·8 AU in

Table 2

Evolution of the orbit of meteor group IV of the Ortho-Leonid stream in the interval 1866–2010, taking account of perturbations from eight planets, Venus–Pluto. Mean Equinox 1950·0

T(ET)			M	ω	Ω	i	e	P	q	w	Δ_E	Δ_J	Δ_S	Δ_U
1866	XI	15·0	3°·08	174°·32	232°·63	162°·98	0·90458	33·249	0·98661	2·5				
1869	V	23·0	30·38	174·44	232·72	162·97	0·90426	33·236	0·98964	40·0			2·845	
1870	*I*	*18·0*	37·43	174·65	232·86	162·91	0·90403	33·305	0·99349	40·0			*1·784*	
1870	X	25·0	45·70	174·85	233·06	162·80	0·90401	33·311	0·99382	40·0			2·977	
1895	I	7·0	308·14	174·83	233·23	162·80	0·90391	33·227	0·99314	40·0			2·955	
1895	*X*	*14·0*	316·55	174·86	233·24	162·81	0·90430	33·280	0·99015	40·0			*1·621*	
1896	V	1·0	322·52	174·92	233·24	162·81	0·90485	33·291	0·98469	40·0			2·339	
1898	IV	21·0	344·03	174·97	233·36	162·86	0·90560	33·623	0·98341	20·0		1·433		
1898	*VII*	*10·0*	346·46	175·39	233·88	163·05	0·90576	33·820	0·98558	10·0		*0·906*		
1898	IX	28·0	348·69	175·95	234·33	163·20	0·90555	33·536	0·98220	10·0		1·452		
1899	X	3·0	359·57	176·13	234·41	163·22	0·90539	33·321	0·97964	2·5	1·116			
1899	*X*	*30·5*									*0·0934*			
1901	IV	6·0	15·84	176·50	234·64	163·16	0·90488	33·342	0·98541	20·0		1·447		
1901	*IV*	*26·0*	16·45	176·57	234·70	163·15	0·90476	33·315	0·98611	20·0		*1·440*		
1901	V	16·0	17·06	176·64	234·76	163·12	0·90464	33·278	0·98661	20·0		1·483		
1932	IX	10·0	359·97	176·88	235·12	163·01	0·90408	32·972	0·98624	2·5	1·174			
1932	*X*	*12·5*									*0·219*			
1965	*II*	*14·0*									*0·713*			
1965	IV	30·0	359·91	176·76	235·17	163·01	0·90329	32·755	0·99002	2·5				
1980	III	22·0	163·63	176·78	235·23	162·96	0·90351	32·711	0·98695	40·0				2·694
1981	*VII*	*15·0*	178·32	176·78	235·25	162·87	0·90376	32·701	0·98414	40·0				*0·761*
1982	XII	17·0	194·37	176·76	235·28	162·74	0·90440	32·689	0·97738	40·0				2·695
1997	*XII*	*10·5*									*0·125*			
1998	I	27·0	0·97	176·64	235·26	162·80	0·90437	33·052	0·98494	2·5				
2010	V	4·0	134·76	176·65	235·37	162·79	0·90459	33·062	0·98283	40·0				

Table 3

Evolution of the orbit of meteor group VII of the Ortho-Leonid stream in the interval 1866–2007, taking account of perturbations from eight planets, Venus–Pluto. Mean equinox 1950·0

T(ET)			M	ω	Ω	i	e	P	q	w	Δ_E	Δ_J	Δ_S	Δ_U
1866	*XI*	*14·0*									*0·0477*			
1866	XI	15·0	0°.21	174°.32	232°.63	162°.98	0·90458	33·249	0·98661	0·312	0·0858			
1866	VII	2·0	28·69	174·42	232·69	162·98	0·90428	33·237	0·98954	40·0			2·933	
1870	*IV*	*8·0*	36·90	174·68	232·88	162·89	0·90409	33·323	0·99319	40·0			*1·774*	
1870	XII	4·0	43·98	174·84	233·05	162·80	0·90413	33·329	0·99287	40·0			2·931	
1895	V	7·0	308·71	174·83	233·21	162·80	0·90409	33·236	0·99143	40·0			2·584	
1895	*XI*	*23·0*	314·71	174·84	233·21	162·80	0·90439	33·270	0·98896	40·0			*1·891*	
1896	VIII	29·0	323·06	174·90	233·19	162·79	0·90500	33·285	0·98302	40·0			2·983	
1898	VI	10·0	342·53	174·92	233·30	162·83	0·90569	33·631	0·98262	10·0		1·453		
1898	*IX*	*8·0*	345·32	175·37	233·83	163·04	0·90629	33·957	0·98268	10·0		*0·904*		
1898	XI	7·0	347·03	175·85	234·19	163·17	0·90654	33·849	0·97798	10·0		1·235		
1899	*XII*	*29·5*									*0·230*			
1900	I	21·0	359·85	176·12	234·31	163·21	0·90657	33·626	0·97340	2·5	0·923			
1901	*VI*	*25·0*	15·05	176·77	234·79	163·08	0·90614	33·739	0·98007			*1·244*		
1933	*II*	*22·0*									*0·804*			
1933	VI	17·0	0·92	177·14	235·31	162·94	0·90556	33·374	0·97897	2·5				
1966	*II*	*19·0*									*0·754*			
1966	VI	4·0	0·77	177·09	235·38	162·95	0·90432	33·030	0·98502	2·5				
1980	VI	10·0	153·91	177·08	235·41	162·90	0·90438	32·917	0·98216	40·0				2·697
1981	*X*	*3·0*	168·51	177·08	235·44	162·81	0·90459	32·904	0·97974	40·0				*0·828*
1983	IV	16·0	185·67	177·05	235·47	162·69	0·90512	32·888	0·97397	40·0				2·921
1999	*I*	*22·0*									*0·438*			
1999	IV	12·0	0·81	176·94	235·49	162·77	0·90451	33·119	0·98475	2·5				
1999	*VII*	*26·0*									*1·321*			
2007	V	20·0	88·84	176·98	235·65	162·66	0·90576	33·141	0·97238	40·0				

1981, do not cause significant alterations of their perihelion distances. Therefore, as may be seen from columns Δ_E of all the three tables, during 1898–2000 there is not a single close approach of these groups to the Earth during its passage through the descending nodes of the meteor orbits. Hence, at least until 2000 A.D., the whole vast region of the Ortho-Leonids under review has lost its capacity to produce a meteor shower.

It is also interesting to note that approaches to Jupiter in 1898 caused analogous perturbations in other orbital elements of the three meteor groups IV, VII and VIII: about 1° in the perihelion argument, about 1° in the longitude of the node, about $0\overset{\circ}{.}3$ in the inclination of the orbit, and from 0·1 to 0·2 years in the period of revolution.

The evolution of the meteor group XI, shown in Table 4, presents an essentially different picture.

This group passed perihelion in 1867 on November 10. The table involves 9 revolutions of the group XI and 10 of its perihelion passages in an interval of more than 300 years (1696–2000). Within this period it had four approaches to Jupiter, the most important of which reached its minimum of 0·90 AU in 1732, three approaches to Saturn, and three to Uranus.

As may be seen from the column defining the evolution of the perihelion distance, perturbations from Jupiter in 1732 and 1898 visibly diminished this distance and evidently prevented close approaches of the meteor group to the Earth. The approach to Saturn in 1865 produced, on the contrary, an encounter of this group with the Earth in 1867 (the minimum distance to the Earth reached on November 15 of that year was 0·0273 AU). Looking down column Δ_E over a space of 300 years, we see eight approaches to the Earth at minimum distances $\Delta_E \leqslant 0{\cdot}3$ AU. There are no important approaches during the first 100 years, but during the last 200 years we count six approaches with $\Delta_E < 0{\cdot}2$ AU, three of which, in 1834, 1867 and 1999, are especially close, amounting to 0·0424, 0·0273 and 0·0782 AU respectively. Thus, there is every reason to assume that, in these three apparitions, the Leonid showers are caused by those groups of the stream that are located at short distances from group XI.

It is also interesting to trace the evolution of other elements of the meteor orbit during 300 years. Looking through columns 3–7 of Table 4, we clearly see the continuously increasing perturbations of the longitude of the ascending node, which reach $5\overset{\circ}{.}2$; analogous changes, though with smaller oscillations, of the argument of perihelion; insignificant perturbations of the orbital inclination; and more important fluctuations of the eccentricity and the period of revolution of meteor group XI.

Comparing all the lines of Table 4, we get an idea of the evolution of the orbit as a whole in the interval 1696–2000. Figures 1 and 2 represent the evolution of the ascending node and perihelion distance of group XI over an interval of about 300 years.

The authors' (1967) paper discusses in detail the evolution of meteor groups I and II, which passed perihelion on November 10, 1864 and November 9·5, 1865. We

Table 4

Evolution of the orbit meteor of group XI of the Ortho-Leonid stream in the interval 1696–1999, taking account of perturbations from eight planets, Venus–Pluto. Mean equinox 1950·0

T(ET)			M	ω	Ω	i	e	P	q	w	Δ_E	Δ_J	Δ_S	Δ_U
1696	XI	25·0	323°·51	171°·70	229°·54	162°·83	0·90643	33·389	0·97022	40·0				
1700	IV	19·0	0·16	171·67	229·56	162·83	0·90742	33·823	0·96822	2·5				
1725	*XII*	*4·0*	273·15	171·74	229·81	162·82	0·90748	33·953	0·97012	40·0				*2·544*
1732	VI	30·0	342·91	171·85	229·94	162·87	0·90827	34·263	0·96770	10·0		1·254		
1732	*VIII*	*29·0*	344·78	172·12	230·25	163·02	0·90886	34·552	0·96690	10·0		*0·900*		
1732	XI	17·0	347·06	172·66	230·62	163·18	0·90944	34·498	0·95975	20·0		1·325		
1734	*I*	*6·0*									*0·304*			
1734	I	11·0	359·06	172·87	230·70	163·20	0·90953	34·316	0·95534	2·5	0·357			
1735	*V*	*26·0*	13·35	173·44	231·10	163·12	0·90940	34·513	0·96044	20·0		*1·212*		
1739	XI	1·0	60·33	173·93	231·59	163·00	0·90801	34·120	0·96769	20·0				
1768	*I*	*18·0*									*0·401*			
1768	II	2·0	359·04	174·07	231·94	163·03	0·90819	33·990	0·96342	2·5	0·679			
1801	VIII	8·0	359·02	174·15	232·08	163·04	0·90632	33·519	0·97389	2·5				
1801	*X*	*9·5*									*0·193*			
1813	II	6·0	123·64	174·10	232·04	163·06	0·90487	33·224	0·98312	40·0				2·828
1814	*VI*	*1·0*	137·90	174·17	232·13	162·94	0·90524	33·212	0·97911	40·0				*1·104*
1815	XI	3·0	153·51	174·22	232·22	162·79	0·90586	33·184	0·97210	40·0				2·854
1834	*XI*	*10·5*									*0·0424*			
1834	XI	18·0	0·36	174·14	232·26	162·89	0·90482	33·181	0·98285	1·25	0·265			
1864	VI	18·0	323·19	174·16	232·36	162·80	0·90500	33·192	0·98121	20·0			2·653	
1865	*II*	*13·0*	330·38	174·21	232·50	162·91	0·90474	33·274	0·98553	20·0			*1·264*	
1865	X	11·0	337·44	174·32	232·60	162·97	0·90460	33·217	0·98575	40·0			2·841	
1867	XI	10·0	359·99	174·33	232·64	162·98	0·90452	33·230	0·98689	0·625	0·177			
1867	*XI*	*15·0*									*0·0273*			
1870	II	27·0	25·23	175·24	232·67	163·05	0·90334	32·785	0·99013	20·0			2·924	
1870	*IX*	*15·0*	31·17	175·37	232·77	163·01	0·90339	32·859	0·99108	40·0			*2·092*	
1871	IV	3·0	37·12	175·48	232·90	162·95	0·90355	32·889	0·99004	40·0			2·783	
1896	*II*	*11·0*	310·44	175·47	233·04	162·94	0·90376	32·780	0·98574	40·0			*2·472*	
1898	*XII*	*17·0*	342·12	175·64	233·23	163·02	0·90558	33·336	0·97803	20·0		*1·394*		
1900	VIII	9·0	359·88	175·96	233·37	163·07	0·90647	33·406	0·97011	2·5				

Table 4 (continued)

T(ET)	M	ω	Ω	i	e	P	q	w	Δ_E	Δ_J	Δ_S	Δ_U
1900 IX 25·5									*0·318*			
1901 IX 23·0	11·86	176·46	233·76	162·99	0·90685	33·741	0·97266	10·0		*1·200*		
1933 XII 19·0									*0·165*			
1934 I 3·0	359·83	176·96	234·48	162·86	0·90656	33·432	0·96969	2·5	0·623			
1966 XII 18·5									*0·171*			
1967 I 30·0	0·61	177·00	234·60	162·85	0·90509	33·037	0·97724	2·5				
1980 V 1·0	145·59	176·99	234·61	162·81	0·90487	32·870	0·97615	40·0				2·910
1981 XI 12·0	162·65	176·99	234·66	162·68	0·90510	32·852	0·97342	40·0				*0·815*
1983 IV 16·0	178·60	176·98	234·69	162·56	0·90559	32·832	0·96797	40·0				2·902
1999 X 29·0	0·05	176·88	234·72	162·65	0·90471	32·984	0·98010	2·5	0·359			
1999 XI 5·5									*0·0782*			

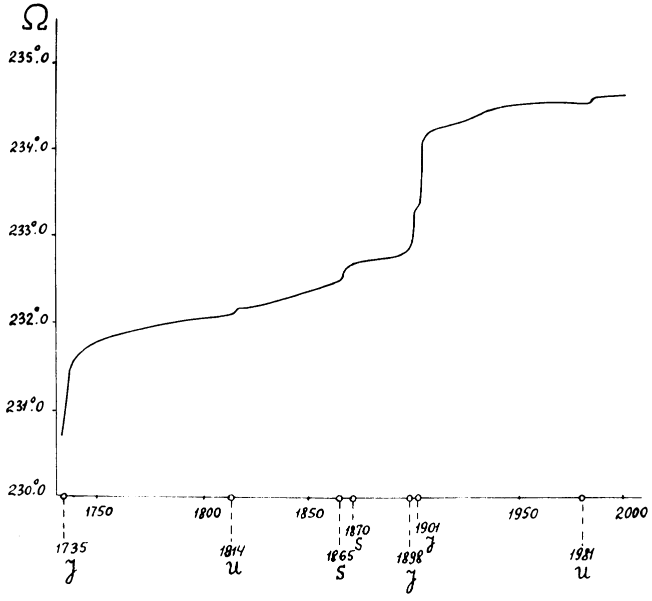

Fig. 1. *Evolution of the longitude of the ascending node of the orbit of meteor group XI of the Ortho-Leonid stream, taking account of perturbations from eight planets (Venus–Pluto) in the interval 1750–2000.*

summarize here only the most interesting results of these investigations. For the space of more than 130 years, beginning with 1866, the first and the second meteor groups have not a single approach to Jupiter, but two or three approaches to Saturn, and one each to Uranus, 0·8 AU in 1981. Especially important are: approaches of group I to Saturn (0·725 AU) towards the end of 1894 and of group II (0·849 AU) in the middle of 1895. The first of these approaches moved the perihelion of group I out beyond the limits of the Earth's orbit ($q = 1{\cdot}004$ AU), owing to which this group will not produce the apparition of even a single meteor shower till 2006 A.D. This approach to Saturn led also to noticeable perturbations in the orbital elements of orientation and in the period of revolution of group I.

The evolution of meteor group II is characterized by still more interesting peculiarities. Its first approach to Saturn in 1869 moved the perihelion slightly out beyond the limits of the Earth's orbit, but during the second approach (in 1895) Saturn moved the perihelion of the meteor orbit back again towards the Sun, nearly equating the perihelion distance of group II with the heliocentric radius-vector of the Earth. Owing to this, conditions were created for an approach of this group to the Earth in the vicinity of the perihelion and of the descending node of the meteor orbit in November 1898 ($\Delta_{\mathrm{E_{min}}} = 0{\cdot}0662$ AU) and, especially, in November 1996 ($\Delta_{\mathrm{E_{min}}} = 0{\cdot}0223$ AU). Thus perturbations by Saturn produce the possibility of apparitions of a meteor shower in the stated years.

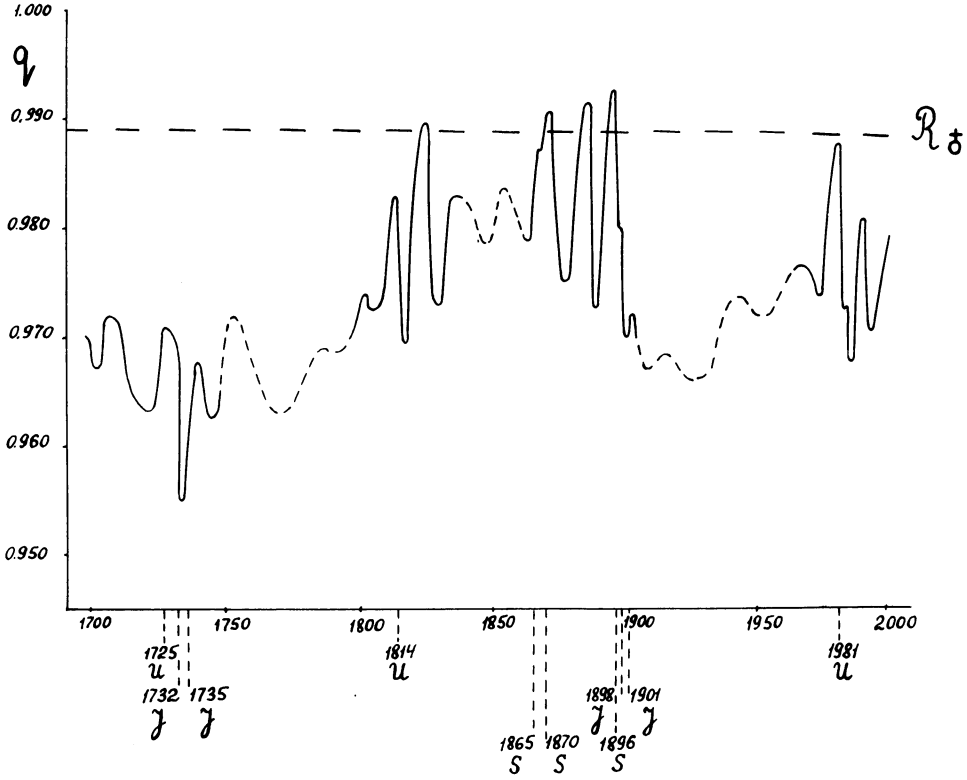

FIG. 2. *Evolution of the perihelion distance of meteor group XI of the Ortho-Leonid stream, taking account of perturbations from eight planets (Venus–Pluto), in the interval 1700–2000.*

5. Role of the Outer Planets in the Evolution of the Leonid Stream and the Influence of Their Perturbations on a Change in Activity of the Shower at Different Apparitions

On the basis of the results obtained, we can draw some conclusions and generalizations:

(a) Approaches of separate groups of the Ortho-Leonid stream with the outer planets, especially with Jupiter and Saturn, are the chief factors determining the evolution of these groups and of the stream as a whole, during several centuries.

(b) These approaches produce more or less important perturbations of the longitude of the descending node and of the perihelion distance, and thereby they influence the encounters of these groups with the Earth and the change in activity of the Leonid shower at different apparitions during the centuries.

Figures 1 and 2 illustrate and confirm these conclusions.

(c) The number and characteristics of the approaches of meteor groups with the outer planets predetermine individual peculiarities in the evolution of these groups;

they also cause the sequence of the moments of their perihelion passages, changing in time with different apparitions (see Table 8). This in turn affects the density of different parts of the Ortho-Leonid stream and its whole structure.

6. Stability of the Orbit of the Ortho-Leonid Stream

In Section 1 of the present paper it has been pointed out that during 33 revolutions of the Leonid stream, i.e. over the interval of 1000 years, we observe a remarkable stability of this stream.

It is interesting to prove the stability of the Ortho-Leonid orbit by numerical integration of the equations of motion of selected meteor groups, and to find the limits within which the orbital elements of the stream change during one or several centuries. These limits, found on the basis of investigations of the orbits of 16 meteor groups for the period 1866–2000, are shown in Table 5. The quantity Q designates the aphelion distance of the orbit of the stream.

Table 5

Limits of changes in the orbital elements of the Ortho-Leonid stream, taking account of perturbations from eight planets (Venus–Pluto) for the period of 1866–2000

Elements	Limits of changes	Elements	Limits of changes
ω	[174°.3–177°.1]	a	[10·21–10·54]
Ω	[232°.6–235°.7]	P(years)	[32·62–34·24]
i	[162°.5–163°.4]	q	[0·9674–1·0035]
e	[0·9023–0·9078]	Q	[19·44–20·12]

Integration of the equations of motion of two groups has been performed for a period of 300 years and has confirmed these conclusions.

Thus, thanks to the retrograde motion of the stream, the elements of individual meteor orbits suffer only insignificant perturbations, which do not disturb stability of the mean orbit of the Ortho-Leonid stream.

7. On the Origin of Sporadic Meteor Particles in the Passing of Groups of the Ortho-Leonid Stream through the Earth's Sphere of Action

The investigation of large perturbations of the orbital elements of a body passing through the sphere of action of a major planet is a very difficult problem. In celestial mechanics much attention has been paid to the methods of solution. The problem of large perturbations in the orbits of comets and meteors has always taken a central place in investigations of the motion of those comets or meteor streams that have had a close approach to Jupiter. On the other hand, the perturbing action of the Earth on the motion of meteor bodies in its sphere of action was always considered insignificant, and this problem has been given far less attention.

The authors have set themselves the following objective: to investigate by the precise numerical method of celestial mechanics possible transformations of meteor orbits under different conditions of deep penetration of the meteor body into the Earth's sphere of action, especially in the immediate vicinity of the perigee, at short distances from the surface of the Earth.

To this purpose a series of experimental investigations has been carried out on changes in the orbits of different meteor groups of the Ortho-Leonid stream during their passages through the Earth's sphere of action. The present paper contains short results of only one of these investigations.

We studied the evolution of the orbit of meteor group XII over an interval of 310 years (1700–2010), taking account of perturbations from eight planets (Venus–Pluto). The integration of the equations of motion of this group (forwards and backwards in time) began one day before its entry in the Earth's sphere of action, on November 13, 1866.

In the interval 1700–1866, this group had two approaches to Jupiter, in 1732 and 1735, with minimum distances from Jupiter of 1·16 and 1·18 AU, one approach to Saturn in 1864, $\Delta_{S_{\min}}$ being equal to 2·22 AU, and two approaches to Uranus in 1726 and 1814, with minimum distances $\Delta_{U_{\min}}=2{\cdot}5$ and 1·02 AU. Perturbations of the longitude of the descending node and of the perihelion distance of the Ortho-Leonid stream occurred during the periods of these approaches, which favoured two approaches of the meteor group to the Earth in 1767 and 1833, with minimum distances of $\Delta_{E_{\min}}=0{\cdot}21$ and 0·17 AU. On the whole, the evolution of group XII, though possessing some individual peculiarities, proceeded much like the evolution of the other meteor groups in the interval 1700–1866.

But a substantially different picture appeared from that time on, when group XII penetrated into the sphere of action of the Earth, which it crossed in less than 5 hours. Integration inside the sphere has been carried out with a variable step, which automatically reduced to 0·001 days near perigee, distant about 3000 km from the surface of the Earth. A disastrous transformation of the orbit of this meteor group occurred just at this point.

Table 6 contains a summary of group XII elements for four basic epochs, the two middle ones referring to the precise epochs of immersion of the group into the sphere of action of the Earth, and emersion from it (the radius of this sphere is 0·006 AU).

As may be seen from Table 6, for the whole period of sojourn in the Earth's sphere of action the argument of perihelion dropped by $0\overset{\circ}{.}9$, the inclination of the orbit increased by $2\overset{\circ}{.}6$, the semi-major axis diminished by 1·7 AU, the period of revolution was reduced from 33·6 to 25·5 and the aphelion distance changed from 19·8 to 16·4 AU. Thus the aphelion of group XII, situated till 1866 beyond the limits of the orbit of Uranus, shifted by a noticeable distance inside this orbit, which prevented the possibility of further close approaches to Uranus. But the longitude of the node and

Table 6

Orbital elements of meteor group XII taking account of perturbations from eight planets, Venus–Pluto

T(ET)			M	ω	Ω	i	e	a	P	q	Q	Δ_E
1701	III	5·0	359°.1	172°.5	230°.3	163°.1	0·9051	10·32	33·14	0·9792	19·66	
1866	XI	13·9	0·1	174·3	232·6	163·0	0·9052	10·41	33·59	0·9866	19·83	0·006
1866	XI	14·1	0·2	173·4	232·6	165·6	0·8863	8·67	25·53	0·9858	16·36	0·006
2010	VI	13·0	251·6	173·7	233·9	165·3	0·8826	8·53	24·91	1·0010	16·06	

the perihelion distance remained unchanged, which left possible new encounters of sporadic meteor particles of this origin with the Earth, at the same time of year as the appearance of the Ortho-Leonid stream.

Integration of the equations of motion of group XII in the interval 1866–2000, led to the following results: the transformed orbit proved to be stable (see Table 6); there were no approaches to Jupiter at all; in 1870 there was one approach to Saturn at a minimum distance of 1·53 AU, in 1981 there will be one non-significant approach to Uranus, $\Delta_{\mathrm{U_{min}}}=2{\cdot}75$ AU; two among four approaches with the Earth ($\Delta_{\mathrm{E_{min}}}\leqslant 0{\cdot}2$ AU) were most remarkable: one on November 1, 1942, $\Delta_{\mathrm{E_{min}}}=0{\cdot}098$ AU and the other on December 18, 1967, $\Delta_{\mathrm{E_{min}}}=0{\cdot}148$ AU. Hence it appears that as result of a deep penetration of meteor bodies into the Earth's sphere of action, a scattered meteor group can be formed which, under favourable conditions of encounters with the Earth, may produce sporadic meteors or faint showers in the same months, though in different years, or even on the same or neighbouring dates, as the Ortho-Leonids.

8. Activity of the Leonid Shower and Conditions for an Encounter of the Stream with the Earth at a Number of Apparitions. Forecast of the Maxima of Activity of the Shower in 1966–68

Table 7 and Figure 3 represent the activity of the Leonid shower for the last 180 years (1787–1966), according to literature data.

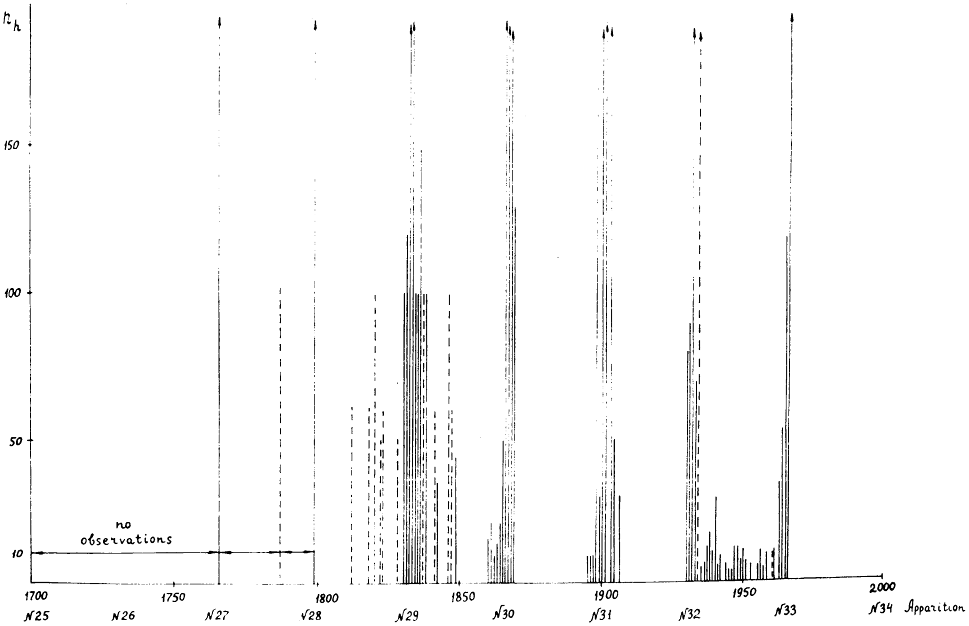

FIG. 3. *Activity of the Leonid shower in 1787–1966.*

Table 7

Activity of the Leonid shower in 1787–1966

Date	Place of observation	Observer (or Author)	Hourly rate, n_h	Notes
1787 XI 9, 10	Mannheim, S. Germany	Hemmer	–	'Great number of meteors'
1799 XI 11	Atlantic, W. Europe, Greenland, N. and S. America, Labrador	Humboldt *et al.*	$\sim 30 \cdot 10^3$	$\rho \approx 2{\cdot}7$
1812 XI (before 15)	Coblenz-Bonn	Fournet		'Considerable number'
1818 XI 12–13	Germany	Humboldt		'Considerable shower'
1818 XI 19 (!)	Germany	Kaemtz		'Many meteors'
1820 XI 12	Russia	Kaemtz		'Plenty of...'
1822 XI 12	Germany	Olbers		'Great number of meteors'
1823 XI 12–13	–	Humboldt		'Considerable meteor shower'
1826 XI 6–7 (?)	Teneriffe	Kaemtz		'Many fireballs'
1828 XI 11–12	Izère, France	Arago		'Great number of meteors'
1830 XI 12	–	Lardner		'Numerous...attract attention'
1831 XI 12–13	S. Europe	Dérard *et al.*	120	'Numerous'
1832 XI 11, 12, 13	W. Siberia, Ural, E. and W. Europe	Neggerath, Gotier *et al.*	$20 \cdot 10^3$	$\rho = 2{\cdot}5$. 'Very remarkable phenomenon'
1833 XI 12–13	N. America	Herrick, Olmsted *et al.*	$(60–150) \cdot 10^3$	$\rho = 3{\cdot}0–3{\cdot}4$. Most active shower of 19th century
1834 XI 13–14	N. America	Quételet *et al.*		'Many meteors and fireballs'
1835 XI 13	N. America	Quételet *et al.*		'Many meteors and fireballs'
1836 XI 13–14	Düsseldorf, Germany	Quételet *et al.*	300	In France $n_h = 170–200$
13–14	U.S.A.	Herrick	150	In South Africa the same
1837 XI 12, 14, 15	N. America	–	–	Considerable number
1838 XI 13–14	Leyden, Holland	Brême	–	'Considerable meteor shower'
13, 14	England, Germany, America	–	–	'Considerable number'
1841 XI 12–13	Europe	Humboldt	–	'Considerable shower'
1842 XI 10–11	Montpellier	Marcel	35	
11–12	Parma	Colla	–	During the night 54; Quételet in Brussels: 'few'
13–14	Paris	Gaudin	20	

Table 7 (continued)

Date	Place of observation	Observer (or Author)	Hourly rate, n_h	Notes
1846 XI 12–13	Europe (?)	Humboldt		‘Remarkable phenomenon’
1847 XI 12–13	Benares, Hindustan	Arago		‘Very numerous’ In New-Haven no meteors
1849 XI 12–13	Wroclaw	Boguslavsky *et al.*	44	
13–14	Wroclaw	Boguslavsky *et al.*	34	
1860 XI 12	England a.o.	Maltzev according to materials of Denning	16	
1861 XI 12			22	
1862 XI 13			10	
1863 XI 13			14	
1864 XI 12			21	
1865 XI 12			50	
1866 XI 13	England and America	Many persons	(5–7)·10³	In maximum 1ʰ22ᵐ UT (XI 14) ρ = 2·1 (England)
1867 XI 13	N. America	Olivier	2184	
1868 XI 13	N. America	Olivier	$\leqslant$ 1200	
1869 XI 13	England	Denning *et al.*	80	
1895 XI 13, 14, 15	England a.o.	Denning *et al.*	$<$ 10?	Shower is poor
1896 XI			$<$ 10?	Shower is poor
1897 XI			$<$ 10?	Shower is poor
1898 XI 14–15	N. America	Pickering	$\leqslant$ 180	
1899 XI 14, 15	Russia, Europe a.o.	Glasenap, Hnatek	20–30	Flat maximum
1900 XI 15–16	Hudson Bay	–	$>$ 1000	Towards morning XI 16; panic of local population
1901 XI 15	England	–	144·10³	Short abundant shower towards morning
	California	–	$\leqslant$ 800	
1902 XI –	–	–	–	Poor observations, Moon
1903 XI 15–16	England	King, Lovell	$\leqslant$ 250	
1904 XI 14	–	–	20–50	
1906 XI 16	–	–	20–30	
1930 XI 16	England	Brit. Astr. Ass.	30–80	
1931 XI 16	England	Brit. Astr. Ass.	30–90	
1932 XI 16–17	England	Brit. Astr. Ass.	240	
1933 XI 17	Japan	Murakami, Orient. Astr. Ass.	70	

Table 7 (continued)

Date	Place of observation	Observer (or Author)	Hourly rate, n_h	Notes
1934 XI 17	Japan	Murakami, Orient. Astr. Ass.	16	
17–18	Sarkand, Kazahstan	Ermolaeva (According to Svjatskij)	–	‘Abundant fall before sunrise’
1935 XI 14	Japan	Murakami, Orient. Astr. Ass.	5	
1936 XI 17	Japan	Murakami, Orient. Astr. Ass.	7	
1937 XI 16	Japan	Murakami, Orient. Astr. Ass.	13	
1938 XI 16	Japan	Murakami, Orient. Astr. Ass.	17	
1939 XI 16	Japan	Murakami, Orient. Astr. Ass.	11	
1940 XI 16	Japan	Murakami, Orient. Astr. Ass.	30	
1941 XI 17	Japan	Murakami, Orient. Astr. Ass.	6	
1942 XI 16	Japan	Murakami, Orient. Astr. Ass.	8	
1944 XI 17	Japan	Murakami, Orient. Astr. Ass.	6	
1945 XI 17	Japan	Murakami, Orient. Astr. Ass.	4	
1946 XI 17	England	Lovell	2–4	Radar
1947 XI 15	Japan	Murakami, Orient. Astr. Ass.	12	
16	England	Lovell	3	Radar
1948 XI 14	England	Lovell	11	Radar
1949 XI 16	England	Lovell	7	Radar According to Murakami $n_h = 9$

Table 7 (continued)

Date	Place of observation	Observer (or Author)	Hourly rate, n_h	Notes
1950 XI 16	England	Lovell	11	
19	Japan	Murakami, Orient. Astr. Ass.	11	
1951 XI 17	England	Lovell	<8	Radar
1953 XI 14	England	Lovell	<7	Radar
1955 XI 19	Japan	Murakami, Orient. Astr. Ass.	6	
1956 XI 17	Japan	Murakami, Orient. Astr. Ass.	11	
1957 XI 15	Japan	Murakami, Orient. Astr. Ass.	5	
1958 XI 15	Japan	Murakami, Orient. Astr. Ass.	10	
1960 XI 17	U.S.A.	–	~ 10?	
1961 XI 16–17	U.S.A.	–	>10	
1963 XI	U.S.A.	–	<30	
1964 XI 17	U.S.A.	–	30	n_h reduced to the radiant in zenith
17	Bjurakan, U.S.S.R.	Terenteva	53	n_h reduced to the radiant in zenith
1965 XI 16	Kislovodsk, U.S.S.R.	Astapovič, Terenteva	~ 400	Moon 21^d
1966 XI 17.5	Kitt Peak, U.S.A.	Kuiper *et al.*	$140 \cdot 10^3$	Radiant near zenith
17.50	Arctic, U.S.S.R.	Lubouhin, Kločkov	$20 \cdot 10^3$	
18.0	Dušanbe, U.S.S.R.	Baharev	300	
18.0	Ašhabad, U.S.S.R.	Savruhin	71	
18.1	Bjurakan, U.S.S.R.	Astapovič, Terenteva	55	

The value of the hourly rate n_h of the meteors is subject to the influence of moonlight, twilight, zenith distance of the radiant, latitude of the site, meteorological conditions, etc. The cited values of n_h are therefore to some extent tentative; in the presence of several estimations, the maximum has been chosen. Many qualitative descriptions of previous apparitions afford no possibility at all of expressing the activity by an hourly rate. Low activity corresponds to $n_h \leqslant 3\text{–}5$, mean activity to $n_h \approx 10\text{–}15$ and high activity to $n_h > 60\text{–}70$. Beginning with $n_h = 600$, we introduce the concept of the rank of activity $\rho = \lg_{10} n_m$, where n_m is the number of meteors per minute. The ranks of activity may differ by some orders.

On the basis of Table 7 and Figure 3 we can state the following:

An increase of activity by one order, relative to the annual display, is observed approximately 2 years before and after the chief maximum. Between maxima the value n_h seldom rises higher than 10, and the activity of the Leonids is low (Clino-Leonids).

Little is known of the maxima at the end of the 31st and the 32nd apparition of the shower in 1900 and 1934 (observations in Hudson Bay, North America, and in Sarkand, Kazahstan).

The apparitions in 1832 and 1833 were the most powerful of the 19th century, with ranks of activity $\rho = 2{\cdot}5$ and up to $\rho = 3{\cdot}4$ respectively. The maxima in 1866 and 1867 were weaker ($\rho = 2{\cdot}1$ and $\rho = 1{\cdot}6$). The highest value in the 20th century, $\rho = 3{\cdot}4$, refers to the great Leonid meteor shower of short duration in 1966, on November $17^{d}11\overset{h}{.}9$ UT.

As a result of the integration of the differential equations of motion of the selected meteor groups, we obtained systems of osculating elements of each group for all passages through perihelion during the time interval 1898–2001 (Table 8).

These data made possible the computation of the distances Δ (listed in the same table) between the orbit of the Earth and the corresponding meteor group at the descending node.*

On the basis of the data of Table 8, we found by auxiliary computations those parts of the stream which the Earth encounters in the middle of November of every year during the apparitions of the shower 1898–1900, 1930–34, 1963–67 and 1996–2000. A comparison of these results with the data of Table 7 shows the following: Observations in 1864, 1865, 1897, 1898, 1930, 1931, 1963 and 1964 give evidence of a low concentration of meteor particles in the region of groups I, II and III, which caused the apparition of the shower in these years. Passage through the descending node of the orbit of a part of the stream in the vicinity of groups X and XI, on the contrary, was accompanied by a rise of activity of the shower in 1867, 1900, 1934 and 1966 (see Table 7) even at great distances Δ. The width of the stream in the region of groups X and XI is about 0·018 AU.

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* $\Delta = r - R$, where r and R are the radius-vectors corresponding to the meteor group at the descending node and the Earth respectively.

Meteor group VIII ('Segment A' of the Ortho-Leonids, which produced an abundant shower in 1866) and the adjacent parts of the stream, will not be able to cause a shower till the future apparition of 1998.

The great meteor shower on November 17, 1966 was produced by a group of the stream which passed through the descending node approximately two months earlier than group XI (at $\Delta \approx -0{\cdot}009$ AU).

It has been pointed out in the 1967 paper of the authors that in 1967 the Earth will encounter that part of the stream, which will have passed the descending node a month earlier than group X, at a distance from the Earth's orbit $\Delta \approx -0{\cdot}008$ AU.

Further, we have investigated the evolution of just this part of the stream, having denoted it in Table 1b by group XIII (see above). In fact it turned out that it will pass through the descending node at such a small distance from the Earth, that it will cause a shower in 1967 with a possible Leonid activity of up to some hundreds and more meteors per hour.

In 1968 the activity of the shower will be lower, and n_h will amount to only some tens of meteors per hour.

In Table 9 are listed the times of maximum activity of the shower corresponding to the passage of the Earth through the descending node of the orbit of the stream in November 1966, 1967 and 1968. The computations have been made in three ways:

(a) by the formula of H. Newton, determining the longitude of the ascending node and taking account of secular perturbations:

$$\Omega = 231^\circ 17'.7 + 1'.711\,(T - 1850);$$

(b) by the same formula, but taking account of the empiric correction to the longitude of the node, obtained from observations of the great meteor shower of 1966, amounting to $\Delta\Omega = +4'.8$ or to the moment of maximum $\Delta T = +1^h.9$;

(c) by the results of the integration of the equations of motion of the corresponding meteor groups by Cowell's method on the computer BESM-2.*

Conditions are very favourable for the encounter of the Ortho-Leonid stream with the Earth during the apparition 1996–2000. In 1997, 1998 and 2000 the shower will be connected with passages through the descending node of meteor groups IV, V, VIII, X and the meteors in their vicinities, the distance from the Earth's orbit being small (from $-0{\cdot}003$ to $-0{\cdot}002$ AU); in 1999 the part of the stream near to group XI will be near the Earth. The showers of 1999 and 2000 will probably be most active.

At the present stage of the investigation there is evidence that the stream is not a static formation, but represents a dynamic system, the structure of which is defined to a considerable extent by the perturbing actions of the outer planets, especially during the periods of close approaches to them of one or other part of the stream. As a result an alteration of the relative location of the meteor groups and of the sequence of their

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* Computations for 1968 will be published later.

Table 8

Orbital elements of meteor groups of the Ortho-Leonid stream in the interval 1898–2001, taking account of perturbations from eight planets, Venus–Pluto. Mean equinox 1950·0

Design. of group on the stream orbit	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
*T*ET	1898	1898	1899	1899	1899	1900	1900	1900	1900	1900	1900
	I 12·64	XI 30·52	VI 8·44	X 17·69	XII 15·63	I 25·24	I 27·28	I 19·89	V 14·96	VIII 26·29	VIII 12·06
ω	175° 17'	175° 24'	175° 40'	176° 08'	176° 12'	176° 08'	176° 07'	176° 09'	175° 38'	175° 13'	175° 57'
Ω	233 35	233 42	234 01	234 24	234 25	234 19	234 19	234 20	233 49	233 26	233 22
i	163 25	163 11	163 06	163 13	163 14	163 13	163 12	163 13	163 03	162 56	163 04
e	0·90330	0·90472	0·90462	0·90542	0·90611	0·90657	0·90657	0·90645	0·90732	0·90737	0·90647
P	33·050	33·129	33·113	33·335	33·511	33·634	33·626	33·578	33·874	33·912	33·406
q	0·99587	0·98281	0·98352	0·97965	0·97596	0·97356	0·97340	0·97372	0·97025	0·97046	0·97011
Δ	+0·0087	−0·0045	−0·0038	−0·0079	−0·0117	−0·0140	−0·0142	−0·0139	−0·0171	−0·0167	−0·0176
*T*ET	1930	1931	1932	1932	1933	1933	1933	1933	1934	1934	1934
	IX 19·13	VIII 14·93	II 8·98	IX 11·02	II 5·21	V 16·51	V 16·76	IV 18·19	II 5·30	VII 27·57	I 8·74
ω	175° 27'	175° 39'	176° 08'	176° 53'	177° 07'	177° 09'	177° 09'	177° 09'	176° 49'	176° 23'	176° 58'
Ω	233 50	233 59	234 29	235 07	235 18	235 19	235 19	235 19	235 03	234 43	234 29
i	163 20	163 05	162 58	163 00	162 59	162 57	162 56	162 57	162 48	162 48	162 52
e	0·90254	0·90356	0·90329	0·90408	0·90495	0·90555	0·90556	0·90540	0·90682	0·90726	0·90656
P	32·787	32·784	32·745	32·972	33·216	33·379	33·374	33·315	33·750	33·873	33·432
q	0·99835	0·98787	0·98982	0·98624	0·98216	0·97918	0·97897	0·97940	0·97315	0·97087	0·96969
Δ	+0·0111	+0·0005	+0·0023	−0·0015	−0·0056	−0·0087	−0·0089	−0·0084	−0·0146	−0·0167	−0·0182
*T*ET	1963	1964	1964	1965	1965	1966	1966	1966	1967	1967	1967
	V 5·75	II 29·25	VII 28·34	V 2·95	XII 11·30	V 10·84	V 9·30	III 23·43	V 28·87	XII 23·02	I 9·42
ω	175° 17'	175° 29'	175° 59'	176° 46'	177° 02'	177° 05'	177° 05'	177° 05'	176° 53'	176° 34'	177° 00'
Ω	233 54	234 02	234 31	235 10	235 22	235 23	235 22	235 23	235 10	234 56	234 36
i	163 17	163 04	162 57	163 01	163 00	162 57	162 57	162 57	162 47	162 45	162 51

Table 8 (continued)

Design. of group on the stream orbit	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
e	0·90323	0·90356	0·90295	0·90329	0·90387	0·90431	0·90432	0·90421	0·90532	0·90565	0·90509
P	32·935	32·767	32·642	32·755	32·918	33·036	33·031	32·987	33·347	33·449	33·037
q	0·99431	0·98750	0·99121	0·99002	0·98740	0·98523	0·98502	0·98522	0·98088	0·97952	0·97724
Δ	+0·0072	+0·0003	+0·0038	+0·0023	−0·0004	−0·0026	−0·0027	−0·0025	−0·0068	−0·0082	−0·0108
TET	1996 IV 3·34	1996 XI 19·43	1997 II 26·76	1997 XII 25·63	1998 IX 20·43	1999 III 18·79	1999 III 15·65	1999 I 15·49	2000 VI 20·69	2001 II 3·22	1999 X 27·25
ω	175° 24'	175° 28'	175° 55'	176° 38'	176° 53'	176° 57'	176° 57'	176° 56'	176° 47'	176° 30'	176° 53'
Ω	234 04	234 08	234 37	235 16	235 28	235 29	235 29	235 29	235 18	235 05	234 43
i	163 08	162 51	162 43	162 48	162 48	162 46	162 46	162 46	162 37	162 35	162 39
e	0·90543	0·90539	0·90456	0·90437	0·90442	0·90450	0·90451	0·90451	0·90459	0·90451	0·90471
P	33·493	33·251	33·065	33·052	33·089	33·122	33·119	33·095	33·194	33·192	32·984
q	0·98267	0·97834	0·98318	0·98494	0·98515	0·98498	0·98475	0·98433	0·98549	0·98627	0·98010
Δ	−0·0046	−0·0089	−0·0042	−0·0027	−0·0026	−0·0027	−0·0030	−0·0034	−0·0022	−0·0014	−0·0078

Table 9

Times of maximum activity of the Leonid shower in 1966–68

Year	On the basis of an account of the secular motion of the node by H. Newton's formula				As a result of integration by Cowell's method	
	Ω	T (UT)	$\Omega+\Delta\Omega$	$T+\Delta T$ (UT)	Ω	T (UT)
1966	234°36′·2	Nov. $17^{d}10^{h}\cdot0$	234°41′·0	Nov. $17^{d}11^{h}\cdot9$	234°40′·0	Nov. $17^{d}11^{h}\cdot5$
1967	234 37·9	Nov. 17 16·5	234 42·7	Nov. 17 18·4	234 58·8	Nov. 18 0·8
1968	234 39·6	Nov. 16 23·1	234 44·4	Nov. 17 01·0	–	–

passages through perihelion arises (see Tables 2–4 and 8), a redistribution of the meteor matter takes place along the orbit, as well as in other directions, and the width of the stream and its structure change.

The study of the perturbed motion of the Leonid stream, and a comparison with data from observations made through past centuries, will permit us to understand more fully its structure and evolution.

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DISCUSSION

Guth: Do the perturbations by the Earth of the Leonid major axis result from one or several approaches to the Earth?

Bronšten: The change of elements of group XII on November 14, 1866, was caused by a close approach to the Earth, with a penetration into its sphere of action. The minimum distance was 3000 km from the Earth's surface. Naturally, such approaches are quite rare.