40. INVESTIGATION OF MINOR METEOR STREAMS

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ABSTRACT

The paper consists of three sections:

(1) In continuation of a previous paper by the author, on 154 minor meteor streams, elements of orbits and other data are presented for an additional 95 minor streams (most of them less active). These streams have been found both by the studies of the photographic orbits of meteor bodies known before, and from the visual radiants of faint showers.

(2) The problems of a possible family of six minor meteor streams associated with the Lexell comet 1770-I, and the connection between nine other minor streams and long-period comets, are examined. The assumption is made that nearly-parabolic comets may be accompanied by meteor streams of considerable width.

(3) Radiants and elements of the orbits for 30 meteor bodies of the Cyclids are described, as were established by photographic data. Perturbed motion of one such meteor body is investigated by numerical integration of differential equations of motion on the electronic computer BESM-2, using Cowell's method of quadratures and taking account of perturbations from six planets (Venus–Uranus) and of high-order terms through to the 4th order. Over the time interval studied of 45 years the orbit of the Cyclids has been stable. Perturbing action of the Earth does not lead to any substantial changes in the elements of the orbits. Even at close approaches of the order of 0·003 AU the changes in the angular elements are not greater than about 1°.

This paper is a continuation of the author's investigation (1966*a*) on minor meteor streams, based on the analysis of more than 3700 photographic orbits of individual meteor bodies, published before 1967 (from observations made since 1936), and on information from visual observations (those with velocity determination) of some 2000 radiants of faint showers during the 19th and 20th centuries.

1. On 95 New Minor Meteor Streams

The earlier paper – referred to above – contains detailed information about 154 minor streams, the majority of which are quite active. The orbits of these streams are now confirmed, and supplemented by later photographic observations, so that more than half are represented by 3–5 orbits, and about three score by 6–16 orbits.

Data supplied here concern an additional 95 minor streams found by the author. These are fainter showers, but on the whole no less reliable. The number of individual photographic orbits in each stream ranges from 3 to 11 for 28% of the streams, but is only 2 for 65%.

Table 1 contains mean values of the coordinates for the corrected geocentric radiant

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R_g, the extra-atmospheric velocity V_∞, the heliocentric velocity V_h, and the orbital elements from photographic determinations for 95 streams (Nos. 155–249). The date of each shower's activity has been found jointly from visual and photographic observations. The abbreviated designation of the shower (by the star next to the centre of the area of radiation) has been formed, as before, from the international three-letter designation of the constellation with addition of the ending -ds, for example, α-UMids, 1H-Drads, 16-Lyrds, N-Hyąds. Compound showers consisting of separate branches (N, Q, S) or groups (a, b, c) sometimes have been given double names, for instance, Peg-Sclds, CVn-Leods, α-CVn-ι-Antds.

The reference numbers of photographic meteors and visual radiants (from corresponding sources) referring to a given stream are listed in Table 2 for each stream. Reference numbers of separate meteors or visual radiants, that may bear some kind of relation to the stream, are shown in the column 'Notes'.

A question not yet investigated by us is the extent to which chance plays a part in finding the 95 streams. If every individual orbit were independent, the probability of the accidental coincidence of two such orbits with 5 elements, within the limits of deviations generally accepted as permissible, would be extremely small. But in reality the orbits possess a preferential distribution, concentration of inclinations to the ecliptical plane, and so on. On the other hand, many minor showers are well known from visual observations, so that a coincidence of their dates, velocities and positions of radiants, even with two photographic radiants, greatly increases the chances of the reality of a stream. Such considerations lead to the conclusion, that among the 95 minor streams the proportion of chance coincidences will be less than 1/5.

It is well known that a meteor stream can cross the Earth's orbit twice – at the ascending node Ω, and at the descending node ☋ of the orbit, if the argument of perihelion ω equals approximately 90° or 270°. The streams Nos. 158, 159, 160, 189, 197, 211, 215, 231, 234, 235, 240 and 242 satisfy these conditions with a permissible deviation of less than 10°. We succeeded in identifying the following pairs: Nos. 189 and 242, 193 and 240, 164, and 235. The meteor streams 193 and 240 form a single stream, about 0·2 AU in width, and with an orbit nearly perpendicular to the ecliptic plane. In the last case (long-periodical streams with reverse motion, Nos. 164 and 235) we must assume a considerable width of the stream, not less than 0·5 AU. This follows from the epochs of visibility and from the values of perihelion distances. Let us remember that there is an analogous phenomenon for the η-Aquarids and the Orionids, and the separation of the two nodes differs from 180° by 18° at least. The presence of an appreciable quantity of meteoric matter, dispersed over such a distance, makes it possible to assume that the parent comet was at one time of considerable size. In this case it was Halley's Comet, and other examples are the comet Encke, which has given rise to the Taurids, and the now unknown comet which formed the δ-Aquarids. The same may be said with respect to some minor streams found by us. Planetary perturbations increase the width of a stream of course, and if the concentration of

Table 1

Orbital parameters of 95 minor meteor streams (Equinox 1950·0)

No.	Stream		Date	Corr. Rad. $R_g(\alpha, \delta)$		V_∞ (km/sec)	V_h (km/sec)	a (AU)	e	q (AU)	ω	Ω	i
1	2		3	4		5	6	7	8	9	10	11	12
155	τ-Erids		I 1–17	52°	−30°	15·0	37·7	2·36	0·58	0·98	6°	114°	12°
156	ζ-Perds	(a)	I 1–15	55	+31	12·4	34·8	1·50	0·36	0·96	206	287	2
		(b)		62	+25	16·2	39·3	3·57	0·74	0·92	210	288	2
157	α-UMids		I 2–17	80	+86	23·5	39·1	3·26	0·72	0·92	212	289	30
158	α-CMids		I 11–16	116	+10	26·1	37·6	2·30	0·76	0·55	92	113	9
159	χ-Gemds		I 13–20	121	+32	13·6	31·3	1·08	0·26	0·80	266	296	3
160	33-Lynds		I 19–21	127	+34	23·4	36·3	1·83	0·68	0·60	268	300	10
161	1H-Drads		I 5–21	132	+76	14·2	32·4	1·18	0·22	0·91	234	293	14
162	21-LMids		I 4–16	146	+34	41·8	39·2	3·27	0·94	0·21	309	290	46
163	ο-Leods		I 1–31	147	+14	40·2	36·7	2·22	0·95	0·10	328	297	11
164	γ-Hyads		I 4–21	200	−24	72·4	43·1	−18·70	1·06	0·95	342	112	156
165	d-Drads		I 15–23	276	+56	14·1	31·0	1·06	0·09	0·96	138	299	16
166	Cncds	(a)	II 3–18	130	+10	19·4	36·8	2·04	0·62	0·76	66	141	3
		(b)		137	+35	21·1	36·9	2·11	0·65	0·72	252	316	10
		(c)		148	+48	22·3	38·2	2·68	0·70	0·78	240	322	18
167	ρ-Leods		II 5–18	156	+ 8	32·6	37·9	2·51	0·87	0·33	116	143	2
168	67-Leods		II 12–17	168	+27	27·6	35·0	1·56	0·71	0·46	288	326	20
169	η-CrBds		II 3–26	225	+25	61·2	43·6	−13·89	1·10	0·87	220	324	109
170	τ-Herds		II 12–20	244	+46	14·9	27·8	0·86	0·14	0·74	350	327	18
171	ζ-Herds		II 4–20	248	+36	52·1	–	122·6	0·99	0·98	175	323	87
172	16-Lyrds		II 2– 8	286	+45	31·3	39·6	4·06	0·77	0·90	142	316	44
173	γ-Cncds		III 13–20	130	+24	13·6	36·3	1·93	0·50	0·97	203	356	1
174	30H-Camds		III 6–12	130	+81	18·0	38·4	2·84	0·66	0·98	189	348	19
175	α-Cncds		III 5–12	135	+11	17·2	38·7	3·17	0·71	0·90	38	167	3
176	α-Sexds		III 8–21	152	± 0	18·6	37·5	2·44	0·65	0·83	55	174	5
177	23-LMids		III 14–22	154	+30	17·4	38·4	2·97	0·69	0·90	219	358	6
178	k-Leods	(a)	III 5– 6	158	+16	20·1	36·6	2·02	0·62	0·75	250	344	3
		(b)		161	+15	23·4	38·6	3·02	0·77	0·69	253	345	4
179	6-CVnds		III 5– 9	182	+36	27·6	39·6	4·08	0·82	0·69	251	346	24

Table 1 (continued)

1	2		3		4		5	6	7	8	9	10	11	12
180	10-CVnds		III	20	190°	+38°	22·6	37·4	2·35	0·66	0·80	240°	0°	21°
181	ϑ-Virds		III	19–24	199	−8	39·4	39·4	3·80	0·95	0·17	314	1	5
182	ι-Virds		III	2–8	216	−6	63·8	44·5	–	1·04	0·20	305	346	154
183	ϑ-CrBds		III	20–31	226	+34	42·4	41·8	28·16	0·97	0·68	248	0	62
184	γ-Camds		III	14–17	57	+69	14·7	37·2	2·22	0·55	1·00	172	354	11
185	32-Lynds		IV	13–16	123	+36	16·4	41·6	34·86	0·96	1·00	180	24	4
186	N-Hyads		IV	1–6	176	−27	24·4	38·1	2·76	0·74	0·70	72	194	17
187	ηβ-Virds	(a)	IV	7–16	178	−3	17·7	36·6	2·07	0·60	0·84	55	199	2
		(b)			182	−5	21·6	39·6	4·48	0·82	0·80	237	23	3
188	77-UMads		IV	10–13	190	+54	15·5	35·8	1·80	0·46	0·98	203	22	14
189	ζ-Virds		IV	7–8	202	+2	26·4	37·0	2·23	0·76	0·54	274	18	9
190	9-Boods	(a)	III	28–IV 11	209	+25	17·0	33·0	1·30	0·38	0·81	252	21	14
		(b)			210	+32	20·5	33·7	1·40	0·46	0·76	257	12	21
191	η-Boods		IV	14–16	210	+16	24·6	37·6	2·62	0·73	0·69	254	25	17
192	λ-Ophds		III	31–IV 8	243	+1	57·0	41·4	–	0·98	0·29	296	14	111
193	υ-Cygds		IV	9–10	318	+33	49·2	42·0	–	1·00	0·68	112	20	80
194	π-Leods		IV	30–V 6	148	+6	12·6	35·6	1·78	0·44	1·00	7	222	1
195	CVn-Leods	(a)	IV	26–V 18	162	+12	15·2	39·3	4·14	0·76	0·99	196	42	2
		(b)			188	+28	17·1	38·8	3·63	0·73	0·97	204	41	10
196	Virds	(N)	IV	26–V 5	214	−10	24·0	37·9	2·74	0·76	0·66	259	41	3
		(S)			208	−16	23·6	37·9	2·77	0·76	0·67	77	219	3
		(N′)			219	+4	25·2	39·4	4·40	0·84	0·70	250	44	12
197	3-Serds		IV	30–V 8	224	+7	15·5	31·8	1·18	0·33	0·79	262	42	8
198	δ-Boods		IV	28–V 7	228	+36	39·0	50·5	−1·12	1·76	0·86	221	42	40
199	10-Serds		V	1–6	231	+1	15·7	30·6	1·08	0·34	0·72	280	42	8
200	ϑ-Drads		IV	22–V 3	239	+60	17·3	33·8	1·44	0·31	0·99	200	37	22
201	ν-Scods		IV	26–V 12	243	−14	24·0	29·7	1·03	0·66	0·35	310	44	6
202	Herds		IV	9–23	285	+17	56·0	37·8	2·66	0·65	0·92	217	32	108
203	η-Lyrds	(a)	IV	21–V 10	289	+43	46·9	42·5	−120·0	1·06	1·00	192	48	76
		(b)			288	+52	42·3	43·0	−10·86	1·10	1·01	181	45	66
		(c)			287	+52	35·2	37·4	2·55	0·59	1·01	177	37	58
204	α-UMids		VI	3–10	188	+85	19·3	35·7	1·88	0·48	0·97	151	76	24
205	95-Virds		V	27–VI 4	209	−11	15·3	37·1	2·38	0·60	0·94	215	69	1

Table 1 (continued)

No.	Stream	Date	Corr. Rad. $R_g(\alpha, \delta)$		V_∞ (km/sec)	V_h (km/sec)	a (AU)	e	q (AU)	ω	Ω	i
1	2	3	4		5	6	7	8	9	10	11	12
206	α-Drads	V 22–VI 7	218°	+67°	19·2	37·7	2·72	0·62	1·01	178°	68°	24°
207	δ-CrBds	V 22–VI 8	237	+30	16·3	34·6	1·61	0·41	0·94	221	69	16
208	μ-Serds	VI 4–8	240	−5	21·1	–	3·12	0·75	0·79	241	75	8
209	16-Drads	VI 4–9	243	+50	13·6	32·0	1·23	0·18	1·00	202	76	14
210	39-Herds	VI 2–6	248	+26	20·6	36·5	2·13	0·58	0·88	230	73	22
211	12-Ophds	V 18–VI 4	250	−1	16·8	31·2	1·14	0·38	0·70	276	65	10
212	c-Herds	V 28–VI 8	254	+36	24·6	37·8	2·78	0·68	0·90	224	72	32
213	74-Herds	V 29–VI 11	258	+48	28·6	40·3	8·70	0·87	0·96	208	74	40
214	36-Ophds	V 27–VI 8	259	−26	32·8	38·6	3·48	0·89	0·36	111	250	6
215	η-Ophds	VI 8–10	259	−16	27·2	37·9	2·87	0·82	0·53	274	78	6
216	γ-Drads (a)	V 25–VI 11	276	+52	32·4	38·6	3·58	0·72	0·98	201	64	50
	(b)		275	+50	39·3	44·9	−3·68	1·30	0·98	202	76	56
217	ϑ-Serds	VI 4?–13	283	±0	45·0	41·3	–	0·99	0·26	300	77	57
218	β-UMads	VI 22–VII 5?	170	+57	16·3	36·8	2·29	0·57	0·98	156	94	14
219	70-Herds	VI 27–VII 6	259	+26	18·7	36·5	2·17	0·57	0·93	220	100	19
220	o-Drads	VII 8–13	288	+61	26·3	–	1·85	0·46	1·01	195	108	42
221	k-Aqlds	VI 9–VII 5	294	−9	44·8	42·3	−18·14	1·01	0·16	313	92	35
222	15-Vulds	VI 25–VII 10?	301	+28	43·6	42·6	−20·60	1·05	0·67	250	102	64
223	δ-Cygds	VI 24–30	301	+36	34·1	34·6	1·63	0·54	0·75	256	97	56
224	ι-Cepds	VII 1–10	346	+65	49·4	43·1	−9·42	1·12	0·99	161	104	81
225	Peg-Casds (a)	VI 23–VII 12	347	+29	64·5	41·6	–	0·99	1·00	192	95	126
	(b)		354	+47	58·8	42·2	−52·08	1·04	1·01	174	105	106
226	μ-Perds	VII 24–31	71	+49	56·5	40·9	11·69	0·97	0·41	77	126	109
227	33-Cygds	VII 15	306	+54	38·8	40·4	–	0·88	0·97	206	112	61
228	31-Pegds	VII 15–19	334	+12	28·0	22·8	0·73	0·79	0·16	338	115	36
229	α-Casds	VIII 20–27	10	+47	56·6	41·8	–	0·99	0·73	243	152	103
230	γ-Casds	VIII 28–30	13	+62	52·2	41·0	14·29	0·96	0·91	217	156	89
231	τ-Pscds	VIII 8–24	18	+29	59·5	35·8	1·88	0·70	0·56	274	140	138
232	α-UMids	VIII 2–14	54	+83	43·1	41·1	15·56	0·94	0·91	142	131	69
233	73-Drads	VIII 13–25	300	+78	38·8	41·2	16·05	0·94	1·01	176	146	61

Table 1 (continued)

1	2	3		4		5	6	7	8	9	10	11	12
234	2-Pegds	VIII	10–13	320°	+24°	36·2	41·4	23·7	0·98	0·57	263°	139°	42°
235	ζ-Perds	IX	13–19	48	+28	66·9	43·8	–	–	0·43	278	174	158
236	58-Aurds	IX	9–14	104	+41	67·0	42·1	–	1·01	0·70	113	169	144
237	β-Drads	IX	3–25	266	+48	19·9	37·3	2·79	0·64	1·00	181	173	25
238	76-Drads	IX	12–17	292	+83	38·5	39·9	5·14	0·80	1·00	181	172	62
239	δ-Andds	X	12–23	6	+28	17·7	34·5	1·51	0·50	0·76	254	204	10
240	k-Perds	X	19–22	56	+57	47·2	39·8	4·68	0·90	0·46	278	208	78
241	25-Monds	X	9–11	111	−3	67·9	41·9	56·6	0·97	0·97	341	16	138
242	ζ-Boods	X	19–XI 3	206	+28	25·5	33·9	1·40	0·58	0·59	84	206	28
243	Peg-Sclds (N)	X	10–22	327	+26	16·1	37·4	2·33	0·60	0·94	212	199	11
	(Q)			342	±0	15·2	37·8	2·50	0·63	0·93	215	204	2
	(S)			354	−33	17·1	39·0	3·46	0·73	0·93	33	21	9
244	12-And-ι-Cetds (a)	X	7–23	346	+38	21·4	38·2	2·76	0·70	0·83	233	201	20
	(b)			359	−2	17·0	36·9	2·14	0·60	0·84	54	21	2
245	β-Camds	XI	2–20?	75	+52	46·6	42·0	–	0·99	0·32	291	229	66
246	Cam-Colds (N)	XII	10–14	48	+64	15·7	34·3	1·43	0·38	0·89	231	262	14
	(S)			78	−39	18·1	34·5	1·47	0·38	0·91	44	80	22
247	λ-Erids	XII	8–13	76	−9	23·6	38·4	2·78	0·74	0·73	67	80	19
248	α-CVn-ι-Antds(N)	XII	13–15	196	+37	56·3	37·2	2·12	0·54	0·97	162	261	109
	(S)			160	−39	54·3	37·4	2·20	0·56	0·96	338	83	103
249	ω-Drads	XII	11–29	275	+72	26·1	38·9	3·04	0·68	0·98	188	270	37

Table 2

Photographic and visual observation data sources for 95 minor meteor streams

Stream No.	Photographic data	Visual data	Notes
1	2	3	4
155	6062, 6231 (1)	176 (16), 4 (17)	Shower of slow fireballs. See 6298 (1)
156	(a): 9875, 6125 (1) (b): 9895, 6160 (1)	140, 164 (16)	
157	9900, 6227 (1)		
158	10070 (2), 6199 (1)		
159	6116, 6270 (1)		
160	6260, 6296 (1)		
161	10031, 6312 (1)		284 (16)
162	10007, 6206 (1)		
163	9891, 6154, 6239, 6251, 6262, 6282, 6302, 6310 (1), 1992 (3)	391[a] (16), 10[a], 25 (17)	Broad stream
164	10001, 6320 (1)		10022 (4)
165	6193, 6340 (1)		
166	(a): 12765, 6393, 13295, 13299, 6405 (1), 630574 (5) (b): 12233, 12680, 12682 (1) (c): 6387, 6491 (1)		Obvious connection with stream 15 (15)
167	12672 (1), 630584 (5)		
168	6416, 6469 (1)		
169	12239, 4020 (1), 109 (6)	544 (16), 41 (17)	Possible connection with stream 25 (15)
170	6426, 6525 (1)		
171	12643 (4), 6516 (1)		Possible connection with stream 25 (15)
172	12225, 13288 (1)		
173	6834, 3054 (1)		10215 (1)
174	590541 (6), 6795 (1)		
175	6770, 6778, 6805 (1)		
176	16789, 7046 (1)		
177	6875, 3076 (1)		
178	(a): 6766, 10208 (1) (b): 6776, 10270 (1)		
179	10237, 10317 (1)		6861 (1)
180	3056, 7040 (1)		
181	3058 (1), 41 (6)	64 (19)	
182	2993, 9809 (1)	25 (18)	
183	7026, 7044 (1)	545 (16), 61 (17)	7049 (1)
184	2913, 3129 (3)		
185	7252, 7368 (1)		292 (16)
186	10478 (1), 10365 (2)		

[a] Visual estimation of velocity '$\omega = 2$' and 'M' are clearly understated.

Table 2 (continued)

1	2	3	4
187	(a): 7110, 7207 (1)		7324 (1)
	(b): 10542, 7367 (1)		
188	7179, 7265 (1)		7254 (1), 484 (16)
189	10524, 7118 (1)		10430 (1)
190	(a): 7237, 7244 (1)		
	(b): 3046, 7098 (1)		7155 (1)
191	7291, 7385 (1)		
192	1071 (3), 114 (6)		93 (19)
193	7161, 10094 (1)		
194	11213, 7481 (1)		
195	(a): 11188, 11960 (1)	410 (16)	
	(b): 11168, 11206, 7504, 7529 (1)		7661 (1)
196	(N): 11786, 11824 (1)		7562 (1)
	(S): 3251 (1), 11825 (2)		
	(N′): 7465, 7471 (1)		
197	11229, 7557 (1), 8361 (7)		Possible connection with stream 65 (15). See 7587 (1)
198	11198, 7535 (1)		7457 (1)
199	11797, 11991 (1)		
200	8093 (7), 11865 (1)		
201	3244, 11996, 7641 (1)		
202	3268 (1)	6 (17, Table 1)	10147 (1)
203	(a): 7598, 12068 (1)		
	(b): 11970, 11994 (1)		7524 (1)
	(c): 11838 (1); (8)		
204	12442 (1), 118 (6)		12326 (1)
205	12150 (1), 7734 (2)		Possible connection with stream 77 (15)
206	3307, 12515 (1)		12495 (1)
207	3300, 12382, 12532 (1)		
208	7729 (1), 7788 (4)		
209	12490, 7821 (1)		
210	12405, 7777 (1)		10589 (1)
211	7688, 12468 (1)		
212	12292, 7790 (1)		Probable connection with stream 76 (15)
213	12318, 12570 (1)	139 (19)	
214	12177, 7808 (1), 591232 (6)		See streams 86 and 96 (15). See also 12448 (1), 577 (16), 145 (17)
215	12536 (1), 2[a] (9)		
216	(a): 4092, 12140 (1)		679 (16)
	(b): 7731, 12572 (1)		12370 (1)
217	7806, 12561 (1), 20131 (7)	668 (16)	
218	4141 (2), 123 (6)	417 (16)	
219	591774 (6), 12874 (1), 7946 (2)		573 (16)
220	7959 (4)	680 (16)	7941 (1)

[a] The value q — 0·330 in paper (9) is erroneous.

Table 2 (continued)

Stream No. 1	Photographic data 2	Visual data 3	Notes 4
221	12620 (1)	130[a] (17), 159, 170 (19)	
222	12886 (1), 124 (6)	716 (16)	
223	12722 (1)	701 (16), 137 (17)	
224	1 (11), 20712 (7)		
225	(a): 4177 (1), 120 (6)		
	(b): 4196 (1), 3601 (10), 20531 (7)	164 (19)	
226	3491 (1)	197 (16), 94 (18)	
227	8018 (1), 44 (6)		
228	8028, 3356 (1)		788 (16)
229	156 (6), 5 (9)	25 (16)	8581 (1)
230	19[b] (6), 3861 (1)		231 (19)
231	64, 582652 (6)	38, 63 (16)	61 (16), 64 (6)
232	620511 (5), 8215 (2)	180 (16)	
233	8464, 3800 (1)		713 (16)
234	2073 (3), 582624b (6)		778 (16)
235	43 (12), 85[c] (6)	166 (16)	149 (18), 4586 (1)
236	612992 (5), 2450 (3)		
237	4513, 4528 (1), 621234 (5)		Possible connection with stream 126 (15). See 593 (16), 230 (17)
238	583135 (6), 4341, 4380 (1)		227 (17), 4677 (1)
239	9039, 5159 (1)		
240	4930, 5091 (1)		220 (16), 267 (17)
241	621973 (5), 23271 (7)		
242	(13)	525 (16)	Shower of fireballs
243	(N): 4734, 4787 (1), 583777 (6)		
	(Q): 1514 (3), 5058 (1)		622215 (5), 9107 (1)
	(S): 4791 (1)		
244	(a): 8924, 8991, 5136 (1)		Possible connection with stream 131 (15). See 10941 (7)
	(b): 4926, 4842 (1), 124a (14)		4905, 5047 (1)
245	9149, 9311 (1), 584591a (6)	249 (16), 309 (17)	See (15): stream No. 143. See also 280, 287 (17)
246	(N): 5876, 5935 (1)		134 (16), 321 (17)
	(S): 5587, 9735 (1)		320 (17)
247	614715 (5), 5742, 5880 (1)		9387, 9406 (1)
248	(N): 5864 (1)		448 (16)
	(S): 9789 (1)		
249	622713 (5)	615 (16)	

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[a] Radiant see in note to No. 130 (17).

[b] Date misprint: instead of '57 VIII 18·843' read '57 VIII 28·843'.

[c] Date misprint: instead of '58 XI' read '58 IX'.

meteor particles becomes very low, so that the hourly numbers drop below 0·3, the shower becomes undetectable. But if the minor shower is sufficiently active, and its width considerable, then the above is confirmed.

A considerable number of minor meteor streams undergo comparatively fast evolutionary changes. This necessitates their constant re-observation – a sort of minor-showers service. The rate of stream evolution is determined by a number of causes and depends on the spatial location of the orbit with regard to the orbits of the large planets and the possibility of close approaches to them. For example, preliminary studies of the radiants of minor showers which are known to-day, compared to observations of ancient times, indicate that long-period streams with great inclinations undergo no significant changes over the period of a millennium; whereas short-period ecliptical streams with aphelia in the vicinity of Jupiter's orbit evolve from a compact stream to a dispersed association within a period of several hundred years, and some of them undergo these changes in less than a century.

It is important to know each minor stream as fully as we know any of the great streams recognized at present. It is only natural that more attention is paid to the most prominent minor streams, of which there are several scores. One of the major problems for investigation is the study of stream structure, its dynamic development and general evolution.

In many cases we observe now only relics of once great streams. In some cases there is almost no doubt that the minor streams originate from great ones, or from comets corresponding to great streams. It is necessary to clarify precisely by means of the numerical methods of celestial mechanics the process of stream disintegration due to the perturbing effect of the outer planets, and to explain the formation in the stream of separate branches and groups as well as other observable phenomena.

Photographic observational data available at present are unfortunately far from comprehensive: the required 3-year observation cycle (to avoid lunation effect) has not been adhered to; there is not sufficient observation during the pre-dawn hours; the Baker Super-Schmidt cameras are installed only on one of the continents. It is, therefore, clear that for a comprehensive study of the minor streams the number of photographic orbits should be increased by at least one order of magnitude. In addition to this, the solution of a series of problems in the field of meteor astronomy by the methods of celestial mechanics requires a drastic increase (by at least three orders of magnitude) in the precision of determining the elements of meteor orbits, so that

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Note:

References to Table 2 are marked as follows: (1) – McCrosky and Posen (1961); (2) – Jacchia and Whipple (1961); (3) – Whipple (1954); (4) – Hawkins and Southworth (1958, 1961); (5) – Babadžanov *et al.* (1966); (6) – Babadžanov and Kramer (1963); (7) – Ceplecha *et al.* (1964); (8) – Ceplecha (1952); (9) – Katasev (1950); (10) – Ceplecha (1958); (11) – Demjanenko *et al.* (1964); (12) – Katasev (1957); (13) – Ceplecha and Rajchl (1965); (14) – Plavcová and Plavec (1960); (15) – Terenteva (1966); (16) – Astapovič (1956); (17) – Astronomical Yearbook (1962); (18) – Proskurina (1949); (19) – Proskurina (1957).

the velocity values can be obtained with an accuracy of 0·1 m/sec and the orbital elements with an accuracy to the sixth decimal.

2. On the Connection between Minor Meteor Streams and Comets

The problem of investigating the connection between a meteor stream and a comet can be solved by using the method of numerical integration of the differential equations of motion of meteor bodies, and by following this motion backward, to the moment when the distance between the given body and the comet becomes zero. A detailed study of the perturbed motion of a great number of meteor particles must be carried out for a sufficiently great space of time, a millennium or more. But as long as the techniques for the determination of meteor velocities do not ensure sufficient accuracy, as has been pointed out above, this problem must be postponed to the future. The solution of such problems will depend on the results of a search for the most probable connection between meteor streams and comets.

Considering theoretical comet radiants (Kramer, 1953), and taking into account the history of the comet and the given stream and applying Tisserand's criterion, we suspect a connection between some comets and groups of minor streams. We have already reported on one of such comet-meteor families (Terenteva, 1966*b*). We give here an example of a possible connection between the well-known comet Lexell 1770-I and five minor streams: Ophiuchids (Northern and Southern), ξ-Serpentids, Scutids, γ-Scutids, and η-Aquilids. The author mentioned formerly (1965) a connection between the α-Capricornids and this comet. Table 3 (see also Figure 1) shows the orbital elements of the comet, according to Porter's catalogue (1961), and of five meteor streams, according to a paper by the author (1966*a*). The last column contains the value C of Tisserand's constant. C is taken for the streams as the mean from n values (n being the number of individual orbits in the stream) with arithmetical mean deviations.

As it is well known, comet Lexell catastrophically changed its orbit under the influence of perturbations at near approaches to Jupiter in 1767 and 1779; in 1770 it had an exceptionally close approach to the Earth, q being $=0{\cdot}67$ AU, $\Delta=0{\cdot}015$ AU (Kazimirčak-Polonskaja, 1961), owing to which it was detected with absolute stellar magnitude $+7{\cdot}7$.

Not a single comet of Jupiter's group approached the Earth within such a small distance. Great perturbations caused by a close approach to Jupiter in 1779 moved the comet's orbit away from the Earth's, and since that time the comet had not been observed. The streams in question may have remained as relics of this comet, and the corresponding showers continue to be observed, but with a large spread in the date of activity (June–August) and in the position of radiants (up to 45°). It should be noted, that the similarity of physical properties of the meteors in these showers always amazed observers, like e.g. Denning and Astapovič. Pokrovsky (1901), in his unfin-

Table 3

Possible family of minor meteor streams associated with comet Lexell 1770-I (Equinox 1950·0)

Comet and meteor streams	a (AU) e q (AU)	π Ω i	P (years) C n
Lexell (1770-I)	–	358°·8	5·60
	0·786	133·9	0·5020
	0·674	1·6	–
North Ophiuchids (94)	2·74	336·8	–
16 VI–3 VII	0·712	89·9	0·57 ± 0·05
	0·763	6·9	4
South Ophiuchids (94)	3·48	338·7	–
16 VI–3 VII	0·770	278·0	0·49 ± 0·04
	0·793	4·0	3
ζ-Serpentids (95)	2·86	352·7	–
22 VI–6 VII	0·758	95·2	0·54 ± 0·04
	0·678	5·5	4
Scutids (96)	3·24	10·0	–
12–29 VI	0·848	91·8	0·47 ± 0·04
	0·482	9·2	4
γ-Scutids (114)	2·65	350·0	–
5–14 VIII	0·645	133·0	0·59 ± 0·03
	0·935	3·0	2
η-Aquilids (117)	3·04	15·0	–
1–16 VIII	0·740	133·0	0·52 ± 0·01
	0·783	13·5	2

ished monograph, noted a probable connection of comet Lexell with the periodic comet Finlay, 1960-VIII ($C = 0{\cdot}5033 \pm 0{\cdot}0002$). A relation may perhaps exist between these two comets and comet Barnard (3), 1892-V.

In Table 4 nine of the streams, Nos. 155–249 from the list cited above, are linked with comets (Porter, 1961) with which they may be physically connected.

As in the case of the great streams, the period of revolution of a minor stream is less than the period of revolution of the comet connected with it. If the great comet Flaugergues 1811-I was really 'great', and can be connected with the stream No. 226, his had a width of 0·6 AU. In the rest of the cases, for an encounter with the Earth to be possible, the width of the stream must be at least 0·01–0·15 AU judging from values of q, and at least 0·02–0·29 AU, if we take into account the differences in Ω. A connection between streams Nos. 193 and 240 has been pointed out in the foregoing section.

Favourable conditions in the examples cited are the great value of the inclination i of the stream, and the nearly parabolic character of the orbits of the comets, permitting easy identification. In this case the influence of planetary perturbations is

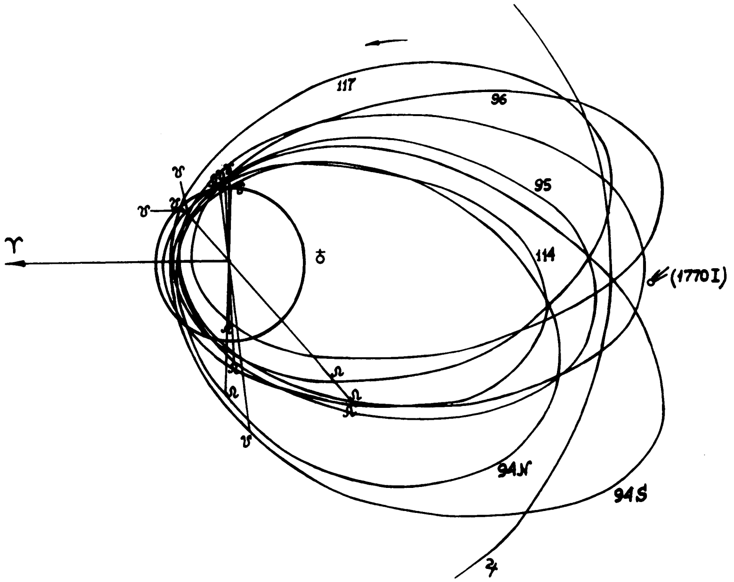

FIG. 1. *Possible family of minor meteor streams associated with comet Lexell 1770-I (projection on the ecliptic plane).*

Table 4

Correspondence between minor streams and comets (Equinox 1950·0)

Stream and comet	i	Ω	ω	q (AU)	e	a (AU)
Stream 169	109°	324°	220°	0·87	1	–
Comet 1947-X	106	312	221	0·75	1	–
Stream 172	44	316	142	0·90	0·77	4·06
Comet 1854-IV	41	326	130	0·80	0·992	106
Stream 193	80	20	112	0·68	1	–
Comet 1886-I	83	37	127	0·64	1	–
Stream 202	108	32	217	0·92	0·65	2·66
Comet 1864-III	110	33	232	0·93	0·999	1451
Stream 225 (a)	126	95	192	1·00	0·99	100
Comet 1822-IV	127	95	181	1·15	0·996	310
Stream 226	109	126	77	0·41	0·97	11·7
Comet 1811-I	107	142	65	1·04	0·995	212
Stream 229	103	152	243	0·73	0·99	73
Comet 1871-IV	98	148	243	0·69	0·996	162
Stream 232	69	131	142	0·91	0·94	15·6
Comet 1737-II	62	135	130	0·83	1	–
Stream 236	144	169	113	0·70	1	–
Comet 1790-I	150	175	114	0·75	1	–

comparatively small. If the connection of these streams with comets is real, we must admit the possibility of the existence of meteor streams formed by comets with exceedingly elongated orbits to thousands of AU and more. Possibly, with sufficiently long periods of revolution (scores of millenniums) these nearly parabolic comets may be accompanied by meteor streams reaching a considerable width, of the order of the distance of the Earth from the Sun. This means that, in passing the perihelion of such a stream, the Earth's orbit may be entirely inside it. Schiaparelli calculated that the passage of such a stream may take centuries, owing to the difference in solar attraction on its nearest and remotest parts. Hence, during a year, the Earth can continuously encounter meteors from the stream; its geocentric radiant will describe a closed curve in the sky, and the geocentric velocity will change smoothly. Knowing the direction towards the aphelion of the stream and the nearly parabolic stream velocity, we can obtain an ephemeris of the geocentric radiant and the corresponding velocity, and compare them with observations. The density of meteor particles may be different in various parts of the stream, and here and there it may be zero. A more detailed examination of this matter is of interest.

3. Cyclids and the Perturbed Motion of one of these Meteor Bodies

It is well known that meteor bodies whose orbits almost exactly coincide with the Earth's orbit have been detected by the photographic method. Southworth and Hawkins (1963) give five such orbits, and all the meteor bodies moving in these orbits they conventionally name 'Cyclids'.

Table 5 contains information on 30 Cyclids, found by us in the *Catalogue* of McCrosky and Posen (1961); in other sources, comprising more than 1000 photographic orbits, such meteors have not been detected. Therefore we limit ourselves to eccentricities $e \leqslant 0 \cdot 14$, aphelion distances $q' \leqslant 1 \cdot 2$ AU and inclinations $i \leqslant 15°$.

Obviously, the Cyclids do not constitute some physical system in which the bodies are united by common nature and origin as is the case for ordinary meteor streams. They are an example of a set of evolving orbits, selected by their current similarity with the Earth's orbit. The ways by which this similarity is attained may be quite different for each orbit. It may be assumed that such physical factors in the orbit's perturbations, as the effects of Poynting-Robertson and Radzievskij, leading to a decrease of the semi-major axis and the eccentricity, are of great importance in this evolution.

A spiral-forming, nearly circular orbit changes gradually from value of $a > 1$ to $a < 1$; the place of particles passing nearer the Sun is taken by new particles from the external regions, so that the Cyclids' 'system' remains in dynamic equilibrium.

The Cyclids possess unique properties, not encountered anywhere else in meteor astronomy. The difference between the heliocentric velocities of the Cyclids and the Earth is very small, therefore their observed geocentric (extra-atmospheric) velocity is

Table 5

Parameters of Cyclids' orbits (Equinox 1950·0)

Date		Corr. Rad. α	Corr. Rad. δ	V_∞ (km/sec)	V_h (km/sec)	a (AU)	e	q (AU)	q' (AU)	ω	Ω	i	π
1		2		3	4	5	6	7	8	9	10	11	12
53 I	15·19	119°	−17°	12·1	29·9	0·98	0·11	0·86	1·1	101°	115°	5°	216°
53 I	23·52	280	+55	13·5	31·0	1·06	0·09	0·96	1·1	135	303	14	78
53 II	4·15	103	+25	10·8	31·2	1·07	0·09	0·98	1·2	208	315	0	163
54 II	5·37	171	+73	11·7	30·9	1·05	0·08	0·96	1·1	226	316	6	182
53 II	7·21	129	−15	10·2	30·3	1·01	0·05	0·96	1·1	68	138	2	206
53 II	12·46	245	+45	13·6	27·7	0·86	0·14	0·74	1·0	359	323	15	322
53 II	18·44	181	+3	11·3	28·8	0·92	0·11	0·82	1·0	320	329	0	290
54 II	26·26	251	+37	12·5	27·7	0·87	0·14	0·74	1·0	1	337	9	338
54 III	1·39	184	+36	12·3	29·9	0·99	0·14	0·86	1·1	277	340	6	257
53 III	6·12	129	−64	11·9	29·8	0·99	0·02	0·97	1·0	108	165	8	274
54 IV	7·41	236	+38	11·2	29·4	0·98	0·03	0·95	1·0	324	17	3	341
53 IV	15·25	133	+11	10·9	30·4	1·05	0·05	1·00	1·1	350	205	0	195
53 IV	21·40	211	+6	11·7	30·2	1·04	0·13	0·91	1·2	261	31	3	292
54 V	3·29	252	+71	11·9	30·5	1·07	0·06	1·01	1·1	168	42	8	210
53 V	7·34	253	+32	8·2	29·1	0·98	0·04	0·93	1·0	321	46	4	7
53 V	8·34	241	+19	11·5	29·3	0·99	0·07	0·92	1·1	289	47	4	337
53 V	12·20	263	+33	9·4	29·1	0·98	0·03	0·95	1·0	343	51	2	34
53 V	12·31	260	+37	13·4	28·9	0·96	0·12	0·85	1·1	301	51	13	352
52 V	19·21	64	+37	11·4	30·3	1·06	0·13	0·92	1·2	104	58	2	162
54 V	28·27	327	+73	13·6	29·5	1·01	0·09	0·91	1·1	81	66	14	147
53 VI	5·31	265	+43	14·1	30·2	1·06	0·12	0·94	1·2	254	74	15	328
54 VI	11·42	265	−6	11·6	29·2	1·00	0·13	0·86	1·1	287	80	3	6
53 VI	20·42	289	+60	12·3	28·9	0·97	0·05	0·93	1·0	343	89	11	72
52 VI	24·21	289	+36	13·4	28·4	0·95	0·14	0·82	1·1	301	93	12	40
52 IX	17·40	6	−25	11·5	29·9	1·02	0·13	0·89	1·1	92	354	3	86
52 X	24·32	62	+58	11·2	29·1	0·95	0·07	0·88	1·0	317	211	2	168
52 XI	12·23	23	+33	11·4	30·9	1·06	0·11	0·94	1·2	239	230	2	109
52 XI	20·37	186	−19	11·5	29·3	0·94	0·05	0·90	1·0	201	58	1	259
52 XII	13·34	13	+84	13·3	31·4	1·09	0·14	0·93	1·2	235	261	13	136
53 XII	31·28	99	+64	11·8	30·8	1·04	0·12	0·92	1·2	249	279	5	168

near the parabolic limit. The geocentric radiants of the Cyclids are distributed over the whole area of the celestial sphere, displaying no regularity, although the heliocentric radiants may be fairly compact. Cyclids can be observed all through the year.

Our aim is to investigate the perturbed motion of one of the Cyclid meteor bodies over a space of time of several scores of orbital revolutions. The investigation has been based on the orbit of the meteor body No. 4084 (Hawkins and Southworth, 1958, 1961), shown together with other orbits of the Cyclids in Figure 2.

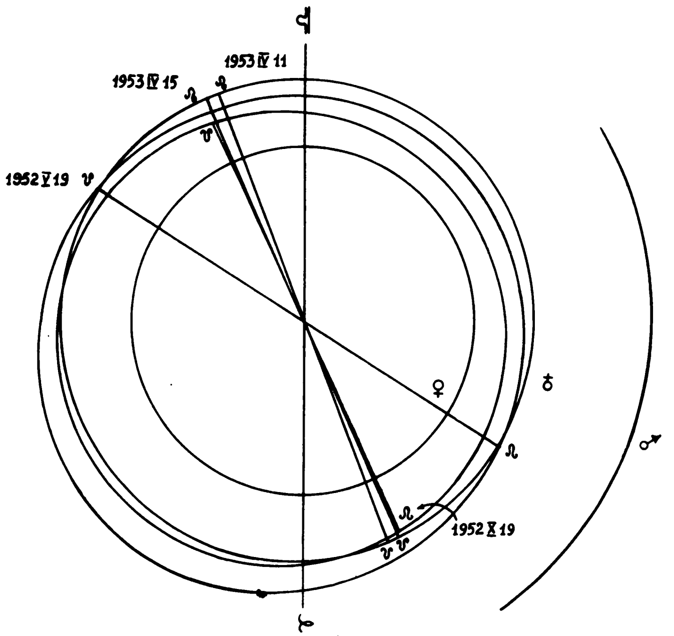

Fig. 2. *Orbits of four Cyclid meteor bodies. 1952 V 19 – No. 4084 (Hawkins and Southworth, 1958, 1961); 1952 X 19 – No. 4952 (Jacchia and Whipple, 1961); 1953 IV 11; 1953 IV 15 – (Southworth and Hawkins, 1963).*

We assumed the following initial system of elements:

$$T = 1952 \text{ May } 18{\cdot}0 \text{ ET}$$

$$\begin{array}{lll} M = 73^{\circ}\!.30 & & n = 0{\cdot}94286 \\ \omega = 90^{\circ}\!.60 & \left.\begin{array}{l} \\ \\ \\ \end{array}\right\} 1950{\cdot}0 & e = 0{\cdot}1310 \\ \Omega = 58^{\circ}\!.1420 & & a = 1{\cdot}030 \text{ AU} \\ i = 0^{\circ}\!.80 & & P = 1{\cdot}045 \text{ years} \end{array}$$

Numerical integration of the differential equations of motion of the given meteor body has been performed on the electronic computer BESM-2 by Cowell's method of quadratures taking accurate account of perturbations from six planets (Venus–

Table 6

Orbit evolution of Cyclid meteor body over the period from 1907 to 1952 taking account of perturbations from 6 planets (Venus–Uranus) (Mean equinox 1950·0)

T(ET)			M	ω	Ω	i	e	a (AU)	q (AU)	P (years)
1			2	3	4	5	6	7	8	9
1907	IX	22·0	344°·74	88°·74	59°·89	0°·74	0·1180	1·016	0·8964	1·025
1911	X	1·0	318·75	88·71	59·90	0·74	0·1179	1·016	0·8966	1·025
1918	XII	23·0	337·77	88·71	59·92	0·74	0·1179	1·016	0·8965	1·025
1924	XII	31·0	289·74	89·77	58·80	0·73	0·1188	1·024	0·9027	1·037
1939	IX	14·0	353·57	89·87	58·89	0·73	0·1188	1·024	0·9028	1·037
1941	X	13·0	355·96	89·83	58·90	0·73	0·1187	1·024	0·9029	1·037
1948	I	10·0	2·77	89·80	58·92	0·73	0·1187	1·025	0·9030	1·037
1950	II	8·0	5·00	90·05	58·90	0·73	0·1187	1·024	0·9023	1·036
1951	II	3·0	348·06	89·71	58·71	0·73	0·1191	1·025	0·9026	1·037
1952	III	9·0	8·79	89·52	58·53	0·73	0·1189	1·024	0·9025	1·037
1952	V	18·0	73·30	90·60	58·14	0·80	0·1310	1·030	0·8951	1·045

Uranus) and of high-order terms through to the 4th order. The program of integration is reported in Beljaev's paper (1967). The integration has been carried out in three approximations, with eight decimals and a variable step. The computations have been performed at our request by Beljaev (Institute for Theoretical Astronomy, Leningrad), to whom the author is greatly indebted.

The motion of this meteor body has been investigated for the time-interval from 1952 backward to 1907. The integration results are listed in Table 6. The epochs of osculation, T, are shown in the first column, the following columns contain the corresponding osculating elements: mean anomaly, M, perihelion argument, ω, longitude

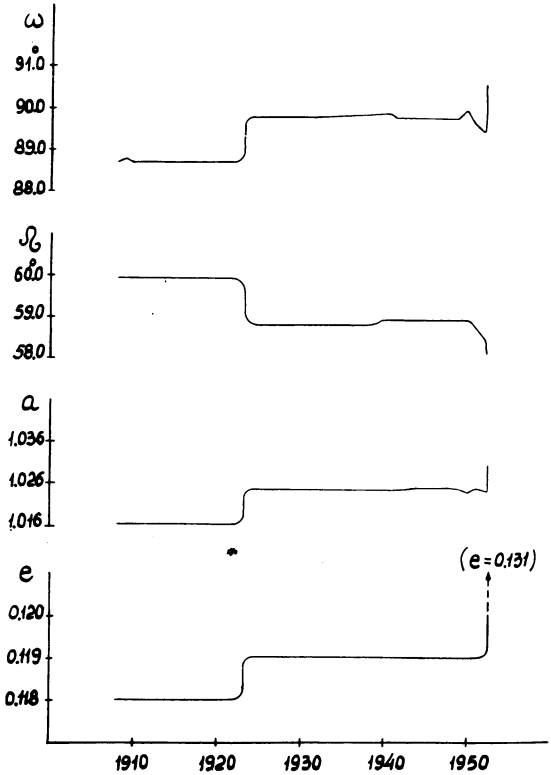

FIG. 3. *Evolution of the orbital elements ω, Ω, a and e of a meteor body of the Cyclids for the period from 1907 to 1952, taking account of perturbations from six planets (Venus–Uranus).*

of the ascending node, Ω, inclination, i, eccentricity, e, semi-major axis, a, perihelion distance, q, and period of revolution, P.

Figure 3 shows the evolution of the orbital elements, ω, Ω, a and e of the meteor body for the period of time studied.

The perturbing actions on the part of Venus are practically imperceptible. The

Cyclid approached Venus to a minimum distance $\Delta = 0{\cdot}2052$ AU in 1950, March 5·0. All the more or less perceptible perturbations (see Figure 3) in the motion of the Cyclid are caused by the Earth, but the influence of these is practically negligible. Approaches to the Earth at $\Delta = 0{\cdot}0949$ AU (1950, October 26·0) and $\Delta = 0{\cdot}0787$ AU (1951, January 29·0) led to changes in the angular orbital elements of the Cyclid by not more than $0\overset{\circ}{.}3$, and by $+0{\cdot}0012$ part of a year in the revolution period. Changes in the angular elements do not exceed about 1°, even for penetrations into the Earth's sphere of action to a distance of the order of 0·003 AU.

The following limits of changes in the Cyclid's orbital elements have been found for the interval 1907–52, taking account of perturbations from six planets (Venus–Uranus): ω [$88\overset{\circ}{.}71$–$90\overset{\circ}{.}60$] ; Ω [$58\overset{\circ}{.}14$–$59\overset{\circ}{.}92$] ; i [$0\overset{\circ}{.}73$–$0\overset{\circ}{.}80$] ; e [0·1179–0·1310] ; a [1·016–1·030] ; q [0·8951–0·9030] ; P [1·025–1·045] .

From the above it follows that for the period of time under investigation, the orbit of the Cyclids remains stable.

It can be assumed that the perturbing action of the Earth on meteor bodies like the Cyclids does not lead to important changes in their orbits for approaches of the type discussed here. However, at deeper penetrations into the Earth's sphere of action, the meteor bodies may experience considerable perturbations.

Further conclusions about the evolution of orbits of the Cyclid meteor bodies necessitate the studies of the motion of a great number of objects over a long time period.

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