30. FIREBALL RADIANTS OF THE 1st–15th CENTURIES

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ABSTRACT

The works of E. Biot, published by the Institut National de France in 1848, made it possible to study material recorded in volumes 191 and 192 of the well-known 13th-century *Encyclopaedia* of Ma Touan-lin as well as records from other sources. They contain observational data of 24 centuries (especially from the 11th century) on more than 1500 fireballs, with descriptions of their positions with respect to the stars as well as descriptions of their physical, kinematic and other properties. The observation dates of the lunar calendar have been converted by Biot into dates of the Julian Calendar.

We have been able to process data on 1220 fireballs. As a result of this radiants were obtained for 153 meteor showers, seven of which belong to great showers. Out of the remaining 146 radiants of the minor showers, 80 radiants are more certain than the remainder.

The radiants were deduced from observations on dates recorded in short intervals from several years to several decades. First the dates of visibility were obtained along with the activity and radiants of great showers which are still active. In the Leonid shower, with retrograde motion, a shift of visibility dates to a much later period has been noted corresponding to a forward motion of the orbit's node, whereas a retrograde motion of the node is observed in the Quadrantids ($i < 90°$). In the Lyrids and Perseids, whose orbits are nearly perpendicular to the ecliptic plane, the nodes experienced no perturbations, and the visibility epochs for the showers remained the same during a period of 1000 years and longer. The motion of apsides resulted in a shift of the radiant; the increase of the ecliptical latitude indicated secular augmentation of the orbit's inclination (Geminids, η-Aquarids, Orionids, Leonids). The radiant of the Perseids was located in Cassiopeia, where the radiant of the present-day Cassiopeids is to be found. It appears that the Perseid stream began to cross the orbit of the Earth in 830 A.D.

In the δ-Aquarids the North branch was active, while there is no evidence that the South branch had existed earlier than 900 years ago. The Virginids, Librids, Scorpionids, Sagittarids and Aurigids were quite appreciable and their studies furnish much interesting data. Particularly active were the Taurids; their North and South branches were observed over 1000 years back. The South Taurids were about half as active as the North Taurids (at present this relation is reversed). Very active were the Cygnids (July–August), which presented at that time a compact shower, now disrupted into a series of minor showers with radiants spread over a large area of the celestial sphere. Of definitive interest is the radiant of the great meteor shower observed in 1037 (August 21 by the Julian Calendar, September 9 by the Gregorian Calendar, 1950·0), $\alpha = 324°$, $\delta = +1°$(1950·0).

Some of the showers active in these early centuries are now unknown; on the other hand, some showers which are well known now were not observed in the Middle Ages. In the past millennium only those streams have survived whose orbits were so situated with respect to the orbits of the outer planets, that they were not subjected to any considerable perturbations produced by these planets.

After Denison Olmsted discovered the phenomenon of a meteor radiant during the great Leonid meteor shower of 1833, several investigators began the search for information about meteors recorded in past centuries. A summary of the most

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important information was compiled by Quetelet (1861). The catalogue of observations of fireballs, obtained by E. Biot from the *Encyclopaedia* of Ma Touan-lin (a historian of the pre-Mongolian period at the close of the 13th century) and from other sources, should also be considered as containing historical evidence. This work (Biot, 1848) was published in three parts by the Institut National de France in Paris. The first part contains observations before 960 A.D. (vol. 191 of the above *Encyclopaedia*), with only the most remarkable meteoric phenomena being described. The second part is made up of observations from 960 A.D. to 1275 A.D. (vol. 192); they were carried out systematically at every lunation and are the best. Observations from 1275 A.D. to 1647 A.D. are included in the third part.

Altogether Biot's Catalogue contains information on observations of more than 1500 fireballs during 24 centuries (most come from the 11th century – over 1000 fireballs), with a description of their positions with respect to stars, as well as some of their physical characteristics and other properties. The main part of the observations were made in the vicinity of latitude +40°.

Thanks to the simple and strict rules of the lunar calendars of those days, their dates are quite accurate. By means of the tables of Klaproth and Gaubil, Biot converted them into dates of the Julian Calendar.

Since the positions of the fireballs are given with respect to stars in the early catalogues, and not in another system such as the equatorial or ecliptic systems, these positions are free from the influence of precession. The observer defined the position of the apparent trajectory of the fireball relative to minor groups of stars, which at that time played the part of small constellations numbering some 200 in all. Biot interpreted the designations of stars into Bayer's system, using Reeves' comparative tables, the celestial chart of the Japanese *Encyclopaedia* of Pou Thien-ko, and information supplied by Gaubil and Noël.

Preliminary processing of some data of Biot's catalogue was undertaken earlier (Astapovič, 1951, 1960). It was mainly a reconnaissance as to adaptability of the method. A study of 224 fireballs on 28 dates of the activity of the great showers gave 16 radiants, to which 122 fireballs (i.e. 54 %) belonged.

In our work we endeavoured to determine the certain and the possible radiants of meteor showers by a complete and final processing of fireball observations recorded in Biot's three catalogues.

Let us consider the fireballs and bright meteors from a single stream in the solar system. Successive encounters of the Earth with the stream will take place after the lapse of one sidereal year (not a tropical year, as is usually assumed). The position of the heliocentric and the geocentric radiant relative to stars (taking no account of perturbations for the present) will remain unchanged. Hence, the positions of the fireballs in relation to the star background will give identical positions of the radiant, which means that we can process together observations of fireballs of neighbouring dates, but in different years, until the action of planetary perturbations begins to take effect. Under the influence of the latter, the date of shower activity can change, the position of the radiant can shift, or the shower can become invisible. As will be shown below, all these cases have actually taken place.

The time coordinate of the Julian Calendar system needs some corrections. First, there is the correction Δ_1 for the discrepancy in the duration of the Julian year and the tropical year. This correction corresponds to the conversion of the Julian date into the Gregorian date. Second, if we have to deal with great time-intervals of the order of centuries, we must take account of the correction Δ_2 for the difference between the length of the sidereal and the tropical year. This amounts to one day in 70·61334... years, generally not taken into consideration in the treatment of modern meteor observations embracing a short space of time of several years or some scores of years. The total correction $\Delta = \Delta_1 + \Delta_2$ can be found by using Newcomb's values for the lengths of the tropical and the sidereal years (in mean solar days):

$$\text{Tropical year} = 365{\cdot}24219879 - 0.0000000614\,(T - 1900{\cdot}0);$$
$$\text{Sidereal year} = 365{\cdot}25636042 - 0{\cdot}0000000011\,(T - 1900{\cdot}0),$$

We have computed values of Δ_1 and Δ_2 and drawn up a table of the reduction of Δ to equinox 1950·0. Thus, for the year 352 Julian date July 21 $\Delta_1 = +1^d$, $\Delta_2 = +23^d$, and the total reduction $\Delta = +24^d$. Hence, the Gregorian date reduced to the equinox 1950·0 is year 352, August 14. For year Julian 1076 date October 8, $\Delta_1 = +6^d$ and $\Delta_2 = +12^d$. Hence, the date finally obtained is 1076, October 26.

Trajectories of fireballs have been processed with the help of celestial charts (equinox 1950·0) in the gnomonic projection, composed by E.M. Proskurina and published by the U.S.S.R. Academy of Sciences in 1950. In some cases, information for a reliable determination of the apparent path of a fireball was insufficient, therefore we succeeded in processing only 1220 positions of fireballs.

As a result we obtained radiants of 153 meteor showers, seven of which belong to well-known great showers. A list of the 80 most certain radiants of minor showers is given in Table 1.

Here we shall confine ourselves to short remarks, concerning some great and minor showers.

Geminids. This great shower is represented by 14 fireballs in the years 1038–99, and two fireballs in 381 and 1163. The fireballs of the 11th century gave a definite radiant $\alpha = 103°$, $\delta = +26°$ (December 6–18)*, the early fireball of 381, December 13 passing 5° to the South of it. The above-mentioned radiant, in its turn, lies more to the South and to the East than the present radiant, $\alpha = 113°$, $\delta = +32°$. No other shower similar to this one has been observed in this region, at this epoch of visibility. Apparently there has occurred a secular increase of the orbital inclination (its present value is $i = 23°$) and a change in the line of apsides.

* Here and forthwith all radiant coordinates, dates and solar longitudes are given for the equinox 1950·0.

The shower was more compact in the 11th century and gave a sharp maximum on December 13 and 14. At present this maximum is wider and embraces the dates from December 10 to 14. Hence, the node of the orbit remained practically unchanged in the course of nine centuries.

The triple control by date, activity and position of radiant supports the assumption that the Geminid shower existed and was well represented by observations in the 11th century.

Quadrantids of those times gave, as they do at present, a scattered area of radiation with diameter $D=13°$, and centre $\alpha=232°$, $\delta=+52°$ (January 9), coinciding with the position of the present radiant.

The orbital node has shifted through 6° by retrograde motion in 900 years, or $\Delta\Omega=-0°, 7$ in a century.

Lyrids. The most ancient appearance of this shower goes back, according to Biot, to the great meteor shower of 687 B.C., April 22 (equinox 1950·0). The orbital node has not materially changed its position for more than 2600 years. The orbital plane of the stream is nearly perpendicular to the plane of the ecliptic ($i\approx 80°$). This makes the planetary perturbations small.

The period of comet 1861 I associated with the Lyrids is 415 years. The last great meteor showers of the Lyrids in 1803 and 1922 were apparently caused by local condensations. As is now known, the maximum of the shower predicted by Malcev for 1952 (assuming the hypothetical period $P=30$ years), did not take place. Hence, the question of the period of revolution of the stream remains undecided.

η-Aquarids had a very low activity in the 8th–11th centuries. By our determinations for May 5 they give a radiant $\alpha=336°$, $\delta=-4°$ ($D=1°$). According to the ephemeris of R. A. McIntosh for 1935, the radiant $\alpha=336\overset{\circ}{.}6$, $\delta=-0\overset{\circ}{.}9$ corresponds to this date.

The extremely low activity of another shower from Halley's Comet (1910 II), the Orionids, also deserves attention. Because of the small number of fireballs it is difficult to speak about the reality of the coordinates of this radiant, but nevertheless the existing information for each shower independently indicates a secular increase of i.

Imoto and Hasegawa (1958) came to the conclusion that there was a systematic increase in the longitudes of the nodes both of the two streams and of Halley's Comet. However, this increase is faster in the two streams than in the comet. This can be easily explained by the fact that, as is well known, the periods of revolution of the streams from photographic and radar determinations are smaller than the comet's, therefore both streams are more subject to the perturbing influence of the outer planets, though to a different degree.

Perseids were quite noticeable in the 11th century and had a radiant $\alpha=6°$, $\delta=+58°$ (August 9–12), located in Cassiopeia, near the radiants of the present Cassiopeids. These are active nearly simultaneously with the Perseids, and are similar to them in velocity and physical properties.

The shower of Perseids became active suddenly after 830 A.D. July 22, Julian

Table 1

Radiants of minor showers from observations of fireballs of past centuries

Equinox 1950·0

No.	Date	App. Rad. α	App. Rad. δ	D	$n_1(n_2)$	Observation years	Notes
1	2	3		4	5	6	7
1	Jan. 9–11	83°	+36°	2°	5(3)	1023–1099	
2	Jan. 19–26	116	+27	–	(2)	1049–1216	Great shower
	Jan. 30–Feb. 5	125	+22	3	(8)	1005–1098	
3	Jan. 28–Feb. 5	39	− 3	7	(3)	1020–1081	Probably one shower
	Jan. 30–31	44	− 6	5	(3)	1080–1105	
4	Feb. 19–23	115	+23	15 × 10	7(4)	1043–1073	Ecliptic, diffused. Observed since 991
5	Feb. 20–26	189	− 5	3	7(5)	1074–1105	Two out of five fireballs on the same date – 1105, Feb. 20
6	March 1– 8	204	+17	< 3	5(4)	1070–1094	
7	March 7–12	87	+40	4	5(3)	1071–1097	
8	March 11–18	125	+47	< 3	5(3)	1076–1087	
9	March 22–30	112	+21	3 × 2	5(4)	1071–1188	Most active of showers appearing at end of March – beginning of April (22 % of fireballs). Not active at present. Antiapex region
	March 31–Apr. 4	111	+27	4	(4)	1062–1126	
	April 9–15	118	+26	5	4(3)	1062–1123	
10	March 29–April 10	183	+26	8 × 3	8(6)	1015–1099	Observed in 565, April 22
11	April 2–10	151	+17	2 × 1	5(4)	1030–1099	
12	April 2–11	170	−15	1	4(3)	1086–1099	Craterids. Observed in 712, March 27
13	April 10–16	234	+30	5	7(4)	1023–1099	Coronids. Was active from March 22
14	April 29–May 9	250	+84	3	8(7)	1039–1132	Rich, compact, well defined. Fireball 1132, May 3 – stationary
15	May 8–12	292	+56	2	(4)	1046–1070	Compact
16	May 23–27	153	+18	5 × 4	8(4)	1040–1083	Was active up to June 12. Observed in 178
17	May 25–31	273	−28	< 2	(3)	1038–1078	Sagittarids. Known ecliptic shower. See No. 23
18	May 25–June 1	240	−20	1	4(3)	988–1068	Scorpionids. Large ecliptic shower; noted in 354
	June 14–19	246	−26	0	4(3)	995–1076	Fireball 1066, May 25 – stationary
19	May 27–June 18	198	−22	0	(3)	1084–1098	Two stationary fireballs 1096 June 17 and 1098 June 18
20	June 6–14	235	−13	1	6(4)	1032–1077	Was active from May 30
21	June 7–19	260	−11	< 1	5(4)	1037–1102	Ecliptic

Table 1 (continued)

No.	Date	App. Rad.		D	$n_1(n_2)$	Observation years	Notes
		α	δ				
1	2	3		4	5	6	7
22	June 20–21	214	−14	–	(2)	1079–1111	
	July 5–17	225	−13	<1	(4)	1048–1104	
23	June 22–July 17	283	−23	<2	5(4)	1080–1098	Sagittarids. Observed up to 1269. See No. 17
24	June 27–July 7	343	−16	<2	5(4)	1022–1095	
25	July 13–16	246	−26	0	(4)	1069–1236	July Scorpionids. Except for the fireball 1236, July 16 the remaining 3 fireballs over the interval 1069–76
26	July 25–Aug. 18	306	+40	4 × 1	15(12)	1059–1098	Cygnids. Active shower
27	Aug. 3–15	225	−12	4	10(7)	1068–1243	Noted in 578. Four fireballs over the interval 1068–99 Fireball 1243, Aug. 3 – stationary
28	Aug. 7–15	45	+15	2	5(4)	1063–1077	
29	Aug. 7–15	54	+45	2 × 1	9(6)	1052–1092	
30	Aug. 7–15	82	+38	2	11(6)	1019–1092	Observed up to 1267
31	Aug. 9–14	211	+49	3	6(4)	1082–1091	
32	Aug. 10–13	148	+55	<1	5(4)	1010–1098	Fireball 1098, Aug. 13 – stationary
33	Aug. 11–19	31	+53	<2	6(5)	1010–1092	
34	Aug. 22–25	222	+14	4 × 1	6(4)	1057–1169	Except for the fireball 1169, Aug. 22, the three remaining ones – over the interval 1057–78
35	Aug. 22–31	8	+59	2	(4)	1053–1097	
36	Aug. 24–30	356	+18	>1	(6)	1042–1094	
37	Aug. 25–30	15	+58	<2	6(3)	1054–1069	
38	Aug. 25–Sept. 13	307	+39	5 × 4	14(11)	1042–1098	Cygnids. Rich shower. Daily displacement +1°.0. Fireballs 1163, Sept. 5 and 1334 Sept. 9 were observed as well
39	Aug. 28–Sept. 2	338	+ 6	5 × 4	8(4)	1062–1164	Observed from 578 (?). Except the fireball 1164, Aug. 29, the three remaining ones – over the interval 1062–1086
40	Sept. 3– 9	33	+38	3	5(3)	1046–1069	Fireball 1068, Sept. 3 – stationary
41	Sept. 5–10	20	− 8	<1	(4)	1042–1084	
42	Sept. 5–12	283	+35	5	6(4)	1163–1215	Clearly defined in the 12th–13th centuries
43	Sept. 7–12	45	+23	6	6(3)	1084–1096	
44	Sept. 11–17	307	+11	1	(4)	1055–1076	

Table 1 (continued)

No.	Date	App. Rad. α	δ	D	$n_1(n_2)$	Observation years	Notes
1	2	3		4	5	6	7
45	Sept. 19–27	333	± 0	6 × 3	12(9)	1053–1163	Ecliptic, diffused. Daily displacement (?) $\sim +1^\circ$. Over the interval 1053–81 – eight fireballs
46	Sept. 20–24	257	+ 51	< 2	(3)	1068–1074	Fireball 1068, Sept. 20 – stationary
47	Sept. 21–26	307	+ 4	1	(3)	1045–1097	
48	Sept. 21–Oct. 16	50	+ 50	1	9(8)	1041–1077	
49	Sept. 23–Oct. 1	0	+ 38	1	(5)	1009–1252	Three fireballs over the interval 1071–75
50	Sept. 23–Oct. 12	234	+ 29	1	(5)	1010–1180	Fireball 1180, Oct. 7 – stationary
51	Sept. 23–Oct. 12	283	− 26	0	(4)	1071–1163	
52	Sept. 24–30	304	− 14	0	(3)	1045–1068	Two fireballs on the same date, Sept. 24
53	Sept. 24–Oct. 6	147	+ 54	< 1	(4)	1058–1098	
54	Oct. 4–12	216	+ 53	2	(5)	1041–1308	Four fireballs over the interval 1041–96. Fireball 1096, Oct. 5 – stationary
55	Oct. 5–19	19	+ 31	~ 2	5(4)	1041–1077	Noted in 823
56	Oct. 9–19	342	− 16	2 × 1	(6)	1022–1163	Fireball 1102, Oct. 9 – stationary
57	Oct. 10–17	346	+ 20	< 1	(5)	1041–1163	
58	Oct. 11–15	128	+ 20	3?	(3)	1059–1178	Two fireballs on the same date, 1059, Oct. 11
59	Oct. 13–18	33	+ 36	< 2	6(4)	1074–1076	Three fireballs over the interval of five nights: 1076, Oct. 13, 17 and 18
60	Oct. 15–16	321	+ 66	5	(3)	1073–1096	Two fireballs on the same date, Oct. 16
61	Oct. 22–Nov. 6	8	+ 60	1	17(14)	1032–1357	Ten fireballs in the 11th century. Observed from 616
62	Oct. 29–Nov. 2	28	+ 20	3 × 2	11(5)	966–1090	Arietids. Duration of visibility Oct. 25–Nov. 17. Possible daily displacement $\sim +0\overset{\circ}{.}6$
63	Oct. 29–Nov. 5	50	− 10	< 1	(4)	1052–1093	
64	Oct. 30–Nov. 3	80	+ 38	4 × 2	17(6)	1032–1083	Aurigids. Was active from Oct. 19 to Nov. 16. Fireball 1083, Nov. 1 – stationary
65	Oct. 30–Nov. 3	145	+ 54	< 2	9(4)	1024–1096	Duration of visibility – Oct. 23–Nov. 17
66	Oct. 30–Nov. 6	306	+ 40	< 1	10(4)	1034–1097	Observed up to Nov. 26
67	Oct. 31–Nov. 6	33	− 4	4 × 3	9(5)	1026–1098	Cetids. Was active up to Nov. 16. Observed also in 710 and 994. Fireball 1098, Nov. 2 – stationary
68	Nov. 2–18	101	+ 20	< 2	9(6)	1026–1098	Observed from Oct. 26
69	Nov. 8–13	83	± 0	0	7(3)	1053–1082	Duration of visibility Oct. 26–Nov. 21

Table 1 (continued)

No.	Date	App. Rad. α	App. Rad. δ	D	$n_1(n_2)$	Observation years	Notes
1	2	3		4	5	6	7
70	Nov. 10–17	2	+15	~5	20(9)	1022–1198	Eight fireballs over the interval 1022–93. Was active from Oct. 26
71	Nov. 11–18	265	+52	1	10(6)	1022–1097	Was active from Oct. 30
72	Nov. 12–17	342	−14	0	5(3)	1068–1094	
73	Nov. 19–Dec. 7	43	+4	1	11(9)	1052–1170	Eight fireballs over the interval 1052–85. Daily radiant displacement ~ +0°.4
74	Nov. 21–25	55	+25	~0	4(3)	1062–1095	Noted in 1213
75	Nov. 21–26	54	+48	<1	6(4)	978–1079	
76	Nov. 23–29	142	+84	<2	4(3)	1037–1080	
77	Nov. 29–Dec. 7	305	+42	1	6(4)	1038–1091	Observed from Nov. 19 to Dec. 14
78	Dec. 1–5	149	+34	<2	12(5)	1074–1167	Observed from Nov. 27 to Dec. 14
79	Dec. 1–6	82	+38	<1	6(4)	1045–1076	Three fireballs over the interval 1074–76
80	Dec. 29–Jan. 5	347	+27	2	(4)	1068–1085	

Cal. (=August 11, Greg. Cal., 1950·0)*, and was seen at least 11 times during the following century. Obviously, the meteor stream began to cross the Earth's orbit in 830.

Thus, the present radiant of the Perseids ($\alpha=46°$, $\delta=+57°$) has shifted with respect to the radiant of the 11th century through some 20° in the direction of greater longitudes, and the position of the orbital node has not changed during the time from the 9th to the 20th centuries.

An interval of 94 years elapsed between the maxima of the Perseids of 830 and 924; a value of the semi-major axis $a=20{\cdot}67$, i.e. $1/a=0{\cdot}04838$ corresponds to this period. From photographic determinations Wright and Whipple (1953) gave $1/a=0{\cdot}048\pm0{\cdot}016$ $(\mathrm{AU})^{-1}$.

Leonids of the 11th century had a distinct radiant $\alpha=152°$, $\delta=+18°$ ($D<1°$) for the date of maximum November 3. The present position of the radiant ($\alpha=153°$, $\delta=+22°$), as in other cases, points to a secular increase of the orbital inclination of the stream.

The longitude of the Sun $\lambda_\odot=220°$ (1950·0) corresponds to the date of maximum in the 11th century. The present maximum 1966 November 17^d, $11^h\!.9$ UT falls at $\lambda_\odot=234°\!.6$ (1950·0). From this we find the shift the orbital node $\Delta\Omega=+1°\!.6$ per century. Results of the numerical integration by Cowell's method (Kazimirčak-Polonskaja *et al.*, 1967), taking account of perturbations from 8 planets over the interval from 1696 to 1999, gives $\Delta\Omega=+1°\!.7$. Both values are in very good agreement.

In addition to the seven great showers mentioned above, information was also obtained from Biot's Catalogue about the δ-Aquarids and Taurids, showers well known at present.

δ-Aquarids were quite active in the 11th century. During the period from July 19 up to August 17 three successive radiant positions were obtained which revealed positive diurnal displacement. The mean radiant position for the corresponding observation date of August 2 is equal to $\alpha=333°$, $\delta=-3°$. However, these results refer to those shower radiants which now constitute the so-called Northern branch of the δ-Aquarids; no data were obtained which might suggest the existence 900 years ago of the Southern branch, the most active at present.

Apart from a rich display of the δ-Aquarid shower in 714, July 15, Julian Cal. (=August 5, Greg. Cal., 1950·0), when according to Biot's description a great meteor shower was observed, the mediaeval chronicles make no mention of any other maxima of activity. Already in 784, July 10, Julian Cal. (=July 31, Greg. Cal., 1950·0) the shower was not nearly as rich as in 714.

Taurids were the most powerful shower of the year in the 11th century (with 42 fireballs belonging to them) and no shower, not even the great ones, could be compared with them as to activity.

The Northern and Southern branches of the shower existed already at that time and

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* It is not likely that the shower in 36 A.D. July 17, Julian Cal. (= August 11 Greg. Cal.; Imoto and Hasegawa, 1958) belongs to the Perseids.

were active almost simultaneously (October 20–November 18 and October 25–November 17 respectively). Their radiant coordinates were:

Northern Taurids $\alpha = 56°$, $\delta = +24°$, $D = 6° \times 1°$;
Southern Taurids $\alpha = 54°$, $\delta = +\ 8°$, $D = 3°$.

A comparison with the photographic data of Wright and Whipple shows a secular decrease in the inclination of the orbit of the Southern Taurids, whereas for the Northern Taurids this is almost imperceptible.

In the 11th century the Southern Taurids were approximately one half as active as the Northern Taurids; at present this relation is reversed. On the whole the activity of the present Taurids is much more modest than it was in the 11th century.

Of definitive interest is also the radiant of a great meteor shower, $\alpha = 324°$, $\delta = +1°$, which occurred in 1037, August 21, Julian Cal. (= September 9, Greg. Cal., 1950·0).

Data concerning 80 radiants of minor showers are given in Table 1. In the first column of the table number of the radiant is given; in the second – the date of activity according to the Gregorian Calendar (equinox 1950·0), based on the number of fireballs n_2 (see below); in the third – coordinates α, δ of the apparent radiant R (equinox 1950·0); in the fourth – diameter D of a near-circular radiation area (in the case of an elliptical radiation area, both large and small diameters are indicated); in the fifth column – n_1 shows the number of all fireballs belonging to the given radiant, n_2 (in parentheses) – the number of fireballs from which the radiant coordinates were obtained; in the sixth column the interval of years is shown for the given n_2 observations; the seventh column contains notes (information about individual fireballs refers to n_2).

The radiants were deduced from observations made on neighbouring dates (the usual interval being only a few days – see Column 2, Table 1) and from an interval of years extending up to several scores of years (see Column 6, Table 1). In some cases there were grounds for allowing a greater interval between the dates (see, No. 23 Sagittarids, Nos. 26 and 38 Cygnids, Nos. 48, 50, 51, 73).

The comparison of these results with the data about minor showers available to date is a separate investigation and is so far not completed. In the column 'Notes' are indicated only some showers most active in the past and those active at present.

The ecliptical shower of Scorpionids, now rich in fireballs (Nos. 18, 25, Table 1), has been observed since 354 A.D., i.e. more than 1600 years, and already in the 10th and 13th centuries it presented a system of separate sub-showers, active in May–June–July.

The Sagittarids (Nos. 17, 23, Table 1) active now in the same period as in the 11th century, present a series of changing or simultaneously active radiants of fireballs and ordinary meteors. Like the Scorpionids, Virginids and Librids, they are a constituent part of the ecliptic 'group' of the short period orbits.

Two powerful compact radiation centres of the 11th century (Nos. 26 and 38,

Table 1), from July 25 to September 13, deserve attention. They comprise 15 and 14 fireballs, respectively. No other radiants were observed over a large region of 2300 sq. deg. ($\alpha = 250°$ to $330°$, $\delta = +20°$ to $+80°$) from the end of July to the middle of September. Radiant No. 42 (Table 1) began to be active quite suddenly in the 12th century, but it was some 2·5 times less active than those mentioned above.

Visual observations of the 19th and 20th centuries within the indicated region (2300 sq. deg.) reveal a single active portion of the shower with an area of some 1000 sq. deg. The centre is displaced with respect to radiants Nos. 26 and 38 approximately 25° towards the smaller longitudes. Over two scores of related radiants of bright meteors and fireballs are active in this area (besides ordinary and faint meteors). According to data of Niessl and Hoffmeister's Catalogue, nine radiants of fireballs of 1859–1921 are to be found here. Present photographic observations show that in this active area an extremely complex system of separate minor streams, decidedly of common origin, exist (streams Nos. 102, 109, 110, 112, 113, 115, 116; Terenteva, 1966).

We arrived at a conclusion that in the 11th century a very active, young, compact shower of Cygnids was visible. This disintegrated over the following centuries and formed a system of minor showers observed at present over a considerable area of the celestial sphere from July 23 to August 29. The time interval during which this disintegration must have taken place is less than seven centuries. Detailed investigation of this system's past evolution would be of great interest.

Thus, the study of the radiants of showers known today, using observations of past centuries, makes it possible to trace their evolution. An interval of nine centuries is quite sufficient for this evolution to be noticeable. As we have already pointed out, even the great showers have undergone changes in the position of the radiant, the date of visibility and the degree of activity. These are mainly in the inclination of the orbit, orientation of the line of apsides, node longitude, and concentration of meteor particles in the stream.

Minor streams, the majority of which are located less favourably with respect to the orbits of perturbing outer planets, experience more substantial changes.

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DISCUSSION

Kresák: Have the ancient dates of maximum activity and radiant coordinates been checked by perturbation computations? I ask because there are some perturbation computations for the Geminid stream by Plavec which indicate that the Geminid shower should not have been observable earlier than about 1750.

Fedynskij: As far as I know the authors did not use these calculations, particularly for the Geminids.

Cook: In line with the perturbation computations mentioned by Dr. Kresák, I wish to point out that Geminids are barely detectable in Schiaparelli's observations, i.e. they are in their present form a recent development.

Fedynskij: As noted in the paper presented, the first observed appearance of the Geminids was in 1038 A.D. (perhaps even 381, when one fireball from this radiant was observed). Therefore the perturbations were not so strong to prevent one appearance of the shower in the 11th century.

Marsden: How was the semi-major axis of the Perseids determined?

Fedynskij: It was determined from the revolution period of the stream – 94 years, given by two maxima – 830 and 924 A.D.

Guth: About the perturbations of Lyrids I should like to remark that regardless of the high inclination of the shower, the orbits of the Lyrids pass near to the orbit of Saturn and some meteors of this shower could penetrate the sphere of activity of this planet.

Fedynskij: The results given in the paper by Astapovič and Terenteva do not show noticeable perturbations by Saturn.