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P/MACHHOLZ 1986 VIII AND QUADRANTID METEOROID STREAM. ORBITAL EVOLUTION AND RELATIONSHIP;

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Abstract. The evolution of the P/Machholz's meteoroid stream was simulated. It shows, that this stream may produce eight meteor showers. There are the known observed meteor showers such as the Quadrantids, Ursids, Northern and Southern δ-Aquarids, Daytime Arietids and α-Cetids. A satisfactory agreement of the theoretical and observed geocentric radiants and orbits allows to conclude, that the above showers could have been resulted from the decay of the P/Machholz nucleus. The age of the stream is estimated to be 7.5 millennia.

Introduction

The Quadrantids are one of the most interesting major meteor showers. Thehigh activity and short duration of the Quadrantids imply the existence of a parent comet. The Quadrantid meteoroid stream is of great interest in respect to dynamics too. It is one of few meteoroid streams which can produce eight related meteor showers. Six of eight meteor showers such as the Northern and Southern δ-Aquarids, Daytime Arietids, Ursids, α-Cetids and Quadrantids are well-known from observations (Babadzhanov and Obrubov 1987, 1989).

In May 1986 D.Machholz discovered a new comet, which had got the designation 1986 VIII. This comet may be a unique object for investigations of the cometary nucleus evolution due to the short orbital period (5.25 yr) and small perihelion distance (0.127 AU). The fact that the comet Machholz was not discovered before 1986 is of interest as well. It seems more surprising since according to Sekanina (1990) 75 % of comet's returns to the Sun were favourable for observations. Sekanina (1990) and Green et al. (1990) assume the comet Machholz to be dormant for a long time till 1986.

Evolution of P/Machholz's orbit

McIntosh (1990) followed the evolution of P/Machholz's orbit over a period of 4 millennia. He found large variations in orbital inclination (from 12 to 80°) and in perihelion distance (from 0.05 AU or even less to about 1 AU) and pointed to the surprising coincidence in orbital variation of P/Machholz with that of the Quadrantids. However, McIntosh did not find a similarity in their orbits at some fixed moment, that could have confirmed on the possible genetic relationship. McIntosh consider the main reason to be in the time shift in variations of e, q, i. Green et al. (1990) have also followed the evolution of P/Machholz's orbit. Although they used more precise orbit, but the results did not differ from those of McIntosh. They did not find any close encounter with the Jupiter either.

It is known that the orbital element determining the body's position in the Keplerian orbit is calculated rather roughly. Thus, the body's position in its orbit becomes uncertain after hundreds or even tens of orbital revolutions Therefore, it is necessary to study the motion of the comet (or test particles) at different initial positions. We have integrated the equations of the perturbed motion of the comet and three test particles back in time. The starting orbit was taken from Green et al. (1990). The starting eccentric anomalies E of test particles were taken to be equal to 90°, 180° and 270°, while for the comet E=0° at the time of perihelion passage in 1986. The integration was carried out by the Runge-Kutta method of the fourth order with the self-adjusting step length at the time interval of about 8 millennia. The perturbations from the Jupiter and Saturn were taken into account, but their motions were supposed to be unperturbed. It is turned out that the motion of two of three test particles suffered a number of close encounters with the Jupiter at the distances Δj less than 0.3 AU. The data on these encounters for the last two millennia are given in the Table 1, where T – the year of encounter, and Δj – the value of encounters in AU.

Table 1. Encounters of P/Machholz's test particles with the Jupiter.

T	Δj	a	e	i	T	Δj	a	e	i
		E=180°					E=270°		
976	0.260	3.184	0.615	81°.0	538	0.209	3.068	0.647	82°.2
692	0.258	3.178	0.567	82.1	360	0.194	3.101	0.649	81.2
16	0.296	3.200	0.618	82.5	253	0.162	3.060	0.699	82.8
					206	0.267	3.006	0.743	81.4

As seen from Table 1, the encounters do not lead to the catastrophic changes in orbits. The data of Table 1 allowed to conclude that P/Machholz had not any close encounters with the Jupiter at least after 976 AD. This confirms the fact that the comet was dormant for a long time till 1986.

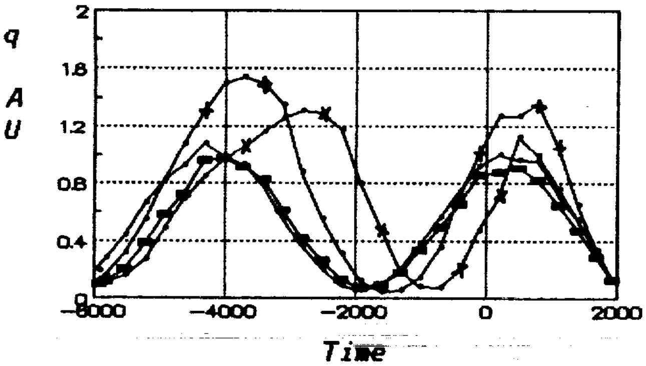

Fig.1. Variations of perihelion distances of P/Machholz – ■, and three test particles: • – E=90°, + – E=180°, x – E=270°. Time in yrs.

Fig.1 presents the variations in perihelion distances of the comet and test particles. As seen, the periods and the ranges of variations have some scatter caused by the different starting positions. This occurs at variations in e and i too. The same results were obtained when the evolution of the Quadrantid meteoroid stream was studied (Williams et al. 1979; Babadzhanov et al. 1991).

The model of the P/Machholz meteoroid stream

It seems very likely that P/Machholz was an active comet in the past. Hence, the meteoroids were being ejected from comet's rotating nucleus at different directions and velocities. To model the meteoroid stream evolution one should choose the initial time moment and give the distribution of meteoroids orbits. The starting time is taken to be 4500 BC under two reasons:

1. Near this moment we have found the most similarity between P/Machholz and mean Quadrantid's osculating orbits, i.e. the D-criterion is equal to 0.14;
2. The radius-vector to the ascending node of the comet's orbit is close to the Jupiter's orbit.

The first reason was chosen because it requires the least ejection velocities responsible for the Quadrantid shower formation. The second because of the likelyhood of the capture of the comet by Jupiter into a short-period orbit. It is known, that the meteoroids' orbits in the same stream differ strongly from the comet's orbit by their semimajor axes and eccentricities. Thus, the initial distribution of the meteoroid orbits was taken to be:

a=2.70 AU	e=0.691	E°= 30 , 270 ;
a=2.80 AU	e=0.702	E°= 10 , 70, 130, 190, 250, 310;
a=3.03 AU	e=0.725	E°= 0 , 60, 120, 180, 240, 300;
a=3.20 AU	e=0.740	E°= 20 , 80, 140, 200, 260, 320.

For all orbits we took q=0.834 AU, i=69°, Ω =283°.3, and ω =170°.7. According to our calculation the comet Machholz had such elements in 4500 BC. This distribution, except of the eccentric anomaly E, corresponds to the meteoroid ejection velocities of up to 300 m/s along and opposite the comet motion in the perihelion, and represents a young flat meteoroid stream.

Then, for all particles we have calculated the perturbations from the Jupiter and Saturn begining from 4500 BC till 3000 AD. By the way all intersections of particles' orbits with the Earth's orbit were fixed. The Earth-crossing orbits can be divided into two groups: the first group includes the orbits with high inclinations (from 67 to 80°) and perihelion distances from 0.9 to 1.0 AU; the second group - the orbits with moderate inclinations (from 19 to 40°) and small perihelion distances - from 0.03 to 0.12 AU.
Each group may be divided into four subgroups according to their perihelion arguments. In the first group the perihelion arguments cluster around the $\omega = 0 \pm 5^{\circ}$ and $180 \pm 6^{\circ}$, and in the second group - around $\omega = 0 \pm 26^{\circ}$ and $180 \pm 30^{\circ}$. So there are eight subgroups of the Earth-crossing orbits, i.e. eight meteor showers, which could be produced by P/Machholz. The names and ranges of orbital elements and geocentric radiants for these eight showers are given in Table 2.

The difference between the simulated Quadrantids and Ursids as well as the Carinids and $\varkappa$-Velids seems to be rather relative because there is no clear line neither among their orbits nor the radiants. In order to distinguish these showers we used some additional dynamical criterion. The orbits with $\omega < 180^{\circ}$ were thought to belong to the Quadrantids and with $\omega > 180^{\circ}$ to the Ursids respectively. For the Carinids - $\omega < 360^{\circ}$ and for the $\varkappa$-Velids $-\omega > 0$. This distinction allows us to determine the direction of secular variations of radii-vectors to the orbital nodes. Moreover, the Quadrantid and Carinid meteoroids collide with the Earth after the perihelion, but the Ursid and $\varkappa$-Velid meteoroids - before the perihelion. Table 2 presents the observed orbital elements and geocentric radiants for six of the eight meteor showers according to the data of different authors. A satisfactory agreement of the theoretical and observed radiants and orbits confirms the possible genetical relationship of all these showers with the comet Machholz.

Table 2. Theoretical (T) and observed (O) ranges of orbital elements of the P/Machholz's meteor showers.

	q	e	i	Ω	ω	α	δ	Vg
	min max							min max
				Quadrantids				
T	.92–1.02	.65–.72	67–72	278–290	159–180	223–243	+42–+54	38–43
O	.97–0.98	.65–.70	69–73	280–283	167–170	219–232	+48–+55	40–43
				Ursids				
T	.92–1.02	.66–.72	68–73	271–282	180–198	215–227	+48–+60	38–46
O	.94–0.95	.64–.85	54–67	260–283	187–206	190–226	+58–+76	33–40
				Carinids				
T	.92–1.02	.66–.71	72–80	86–109	344–360	149–164	−64–−46	41–49
O				Will be recognised ?				
				æ–Velids				
T	.92–1.02	.68–.71	74–80	99–109	0–16	142–160	−61–−50	41–49
O				Will be recognised ?				
				Northern δ–Aquarids				
T	.04–.11	.96–.99	19–40	104–136	326–340	316–340	−10– +2	40–44
O	.06–.12	.95–.98	14–21	128–143	323–334	337–346	−5– +3	40–42
				Southern δ–Aquarids				
T	.03–.12	.96–.99	20–40	296–322	141–160	334–351	−18–−13	39–44
O	.07–.14	.96–.99	23.32	304–322	139–152	339–351	−19–−14	40–44
				Daytime Arietids				
T	.03–.12	.96–.99	20–40	72–87	20–37	42–50	+22–+25	40–44
O	.04–.10	.94–.98	18–46	77–89	19–30	43–50	+22–+26	39–44
				α–Cetids				
T	.04–.12	.96–.99	19–36	249–263	203–216	39–53	+8–+13	39–44
O	.06–.18	.89–.99	20–31	255–269	194–214	44–53	+6–+12	37–39

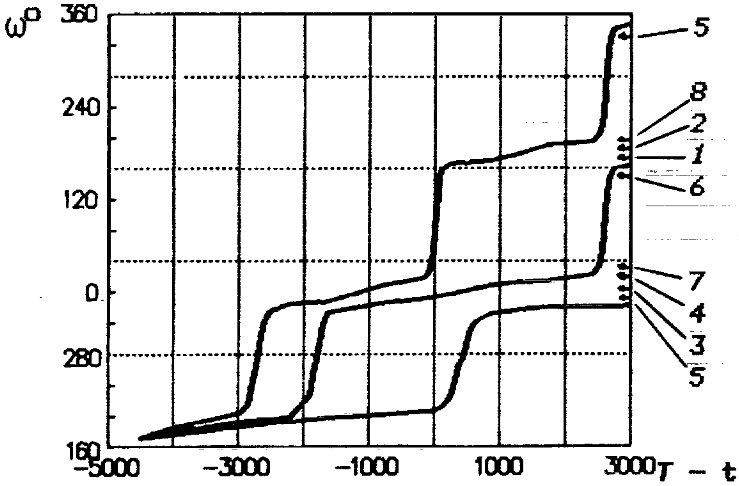

Fig.2. The increase of the dispersion of ω in the simulated P/Machholz's meteoroid stream. The shower perihelion arguments are indicated by arrows: 1– Quadrantids, 2– Ursids, 3– Carinids, 4– æ–Velids, 5–Northern δ–Aquarids, 6– Southern δ–Aquarids, 7– Daytime Arietids, 8–α–Cetids

Simultaneous activity of meteor showers produced by the same parent body is possible if the dispersion of particles' perihelion arguments embraces those of the showers. Fig.2 shows the increase in the dispersion of the perihelion arguments under planetary perturbations for the simulated P/Machholz's meteoroid stream. As seen 7.5 millennia later after meteoroid ejection the dispersion becomes more than 360° (Fig.2). By this moment all the eight meteor showers must manifest their activity. This time interval may be considered to be an evaluation of the P/Machholz stream age. The real stream age might be even less if the initial dispersion in the semimajor axes is assumed to be greater.

Discussion

The simulation of the P/Machholz's meteoroid stream shows clearly that this comet can produce eight meteor showers. At present at least six of eight meteor showers are known from observations and show high activity. Earlier this result was obtained when studing only the Quadrantid meteoroid stream evolution (Babadzhanov and Obrubov 1987, 1989; Babadzhanov et al. 1991). Now we have come to the conclusion that the parent comet of the above six meteor showers is found. It is the comet Machholz 1986 VIII.

A possibility of the relationship of P/Machholz with Daytime Arietids and δ-Aquarids was investigated by McIntosh (1990) too. However, he had doubts about their genetic relationship and about our results concerned the possible interrelations of the observed showers. His doubts are based on the time shift in the orbital variations of the P/Machholz and Quadrantids and on the differences in the directions to perihelia of the meteor shower current orbits.

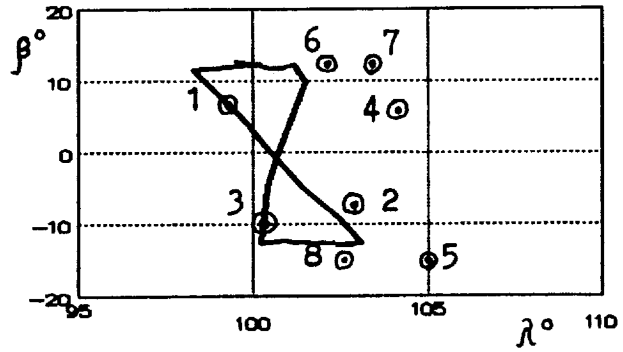

Fig.3. Evolution of the perihelion position of P/Machholz's orbit. Current perihelion positions of the related meteor showers are marked by numbers as in Fig.2.

The observed differences among the meteor shower orbits and in the comet's orbit may have resulted from the differential planetary perturbations. Fig.3 gives the variations in the perihelion position of P/Machholz's orbitduring one period of the perihelion argument variation. As seen, this position changes from −15° to 15° in ecliptic latitude β and from 98° to 103° in ecliptic longitude λ, painting the curve like "eight". Since the dispersion of ω in the meteoroid stream reaches 360° with time, then all directions seem to be possible within these ranges. For all simulated Earth-crossing meteoroid orbits the positions of perihelia are approximately in bounds from −20° to +20°

in β and from 88° to 109° in λ. There are also the observed and theoretical perihelion positions of the P/Machholz meteor showers in Fig.3. As seen, the planetary perturbations explain the dispersion of perihelion positions very well.

According to Babadzhanov et al. (1991) to ensure the observed activity of six meteor showers the comet Machholz must have maximum initial mass of $1.4*10^{18}$ g, that corresponds to the radius about 7 km if the mean density of the cometary nucleus of 0.8 g/cm^3. For comparison McBride and Hughes (1990) obtained the radius of 1 km under assumption that P/Machholz had produced the Quadrantid meteor shower only. According to Sekanina (1990) the current radius of the P/Machholz nucleus do not exceed 2.7 km. If assume the comet to be inside the Jupiter's orbit during 7-8 millennia, then taking into account small perihelion distance, it is not difficult to explain the decrease of its radius from 7 to 2.7 km or even less.

Conclusions

The investigation of P/Machholz orbital evolution gives an evidence that during the nearest 500 yrs the cometary orbit will intersect the Earth's orbit at the place of appearance of the Daytime Arietids and later - at the place of appearance of the Northern δ-Aquarids. Thus, one may expect the increase in the activity of these showers.

The best confirmation of our results would have been a discovery of the Carinid and $\varkappa$-Velid meteor showers. Taking into account the radiant positions of these showers in the Southern hemisphere, we asked prof. W.J.Baggaley (New Zealand) to carry out special showers searches with his new meteor radar and received his kind consent.

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