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On the Association among Periodic Comet 96P/Machholz, Arietids, the Marsden Comet Group, and the Kracht Comet Group

Katsuhito OHTSUKA
Tokyo Meteor Network, 1-27-5 Daisawa, Setagaya-ku, Tokyo 155-0032
ohtsuka@jb3.so-net.ne.jp
Syuichi NAKANO
Liaison in Japan of the Minor Planet Center, 1-3-19 Takenokuchi, Sumoto, Hyogo 656-0011
and
Makoto YOSHIKAWA
The Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510

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Abstract

The orbital energies (a^{-1}) of released meteoroids (or fragments) from the periodic Comet 96P/Machholz must be slightly different from that of 96P. This results in the differences in their evolutional rates; therefore, the time-lags of the orbital evolutions should apparently occur in the course of time, stably holding the same amplitude in their orbital variations. In the present study, integrating the motion of 96P, we found that the orbital elements of 96P at epoch 2319 correspond to those of both the Arietids and the Marsden comet group, currently observed, and those of 96P at epoch 2408 agree with those of the Kracht comet group, similarly observable now. We also estimated a difference of the perihelion times, ΔT, as: ~ 320 yr for 96P – Marsden comet group; ~ 360 yr for 96P – Arietids; and ~ 410 yr for 96P – Kracht comet group, respectively. These may indicate such time-lags of orbital evolutions between 96P and released meteoroids (or fragments) from 96P. As a consequence, we conclude that 96P, Arietids, the Marsden group, and the Kracht group are further possibly associated with each other now.

Key words: comets: comet group — comets: individual (96P/Machholz) — meteors, meteoroids — orbital evolution — solar system: general

1. Introduction

It is considered that dust particles, isotropically released from a short-period comet with not chaotic but stable cyclic orbital evolutions of some millennia or more, should move away from the comet as time passes by, and eventually should fill up around the whole space drawn by such cyclic orbital motions of the comet under planetary perturbations and non-gravitational effects (e.g., Poynting–Robertson effect, Yarkovsky effect, etc.). Indeed, this can be supported by the existence of an associated stream complex as an indirect evidence. One of such examples is the association between the periodic Comet 96/Machholz (hereafter 96P) and likely the Quadrantid stream complex (Babadzhanov, Obrubov 1992). The orbital elements of 96P drastically vary with a long-period perturbation cycle of ~ 8000 yr, in which a large-amplitude oscillation between perihelion distance (q) and inclination (i) arises, synchronizing each other with a cycle of ~ 4000 yr. The semimajor axis (a) of ~ 3.03 AU and the direction of line of apsides are stable, and close encounters with Jupiter are avoided by some protection mechanisms. Therefore, 96P remains in the $9/4$ resonance with Jupiter in the long-term (e.g., Gonczi et al. 1992)[1]. Among the stream complex member candidates, the Quadrantid meteor shower is a strong night-time member, active in early-January. The possible association with 96P was suggested earlier than for any other members (McIntosh 1990). The data of their semimajor axes, i.e., their orbital periods, reduced by precise photographic observations, also show near the $9/4$ commensurability with Jupiter (Ohtsuka et al. 1995). Another complex member candidate, the Arietids, active in early–mid June, are the strongest day-time meteor shower along with the highest flux number density, with an hourly rate (HR) of ~ 60 (Kronk 1988); the derived information depends only upon radar observations. Most of the observations and investigations for the Arietids were concentrated in the mid-20th century, which fully informs us about their profiles. Afterward, the Arietids have scarcely attracted our notice, and additional data were not obtained so much in recent years. However, Seargent (2002) recently noticed an orbital similarity of the Marsden comet group, discovered by Marsden (2002), with the Arietids; it thus reminds us of the existence of the Arietid meteor shower again. Moreover, Kracht (2002) found the Kracht comet group, discovered by him, to possibly be a subgroup of the Marsden comet group, because their perihelion coordinates are similar to each other. However, they do not demonstrate their dynamical relationship sufficiently.

In the first stage of stream complex formation, the orbital energies (a^{-1}) of released meteoroids (or fragments) from 96P must be slightly different from that of 96P. This results in the differences in their evolutional rates; therefore, the time-lags of the orbital evolutions between 96P and released meteoroids (or fragments) should apparently occur in the course of time, stably holding the same amplitude in their orbital variations (e.g.,

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[1] See also the catalog by A. Carusi, Ľ. Kresák, and G. B. Valsecchi at ⟨http://www.ias.rm.cnr.it/ias-home/comet/catalog.html⟩.

Gonczi et al. 1992). In the present study, integrating the motion of 96P, we found the future evolutional phases of 96P with orbital elements similar to those of the Arietids, the Marsden group, and the Kracht group, currently observable. We could also estimate differences of the perihelion times (ΔT) between 96P and each, which may indicate such time-lags of orbital evolutions between 96P and the released meteoroids (or fragments) from 96P. As a consequence, we conclude that 96P, Arietids, the Marsden group, and the Kracht group are further possibly associated with each other now.

2. Data Selection

A splitting of cometary nuclei has often been observed, which should be a trigger to produce some comet group along with orbital motions closely resembling each other. The Kreutz sungrazing comets ($q \sim 0.006$ AU, $i \sim 140°$) are the most well-known comet group, probably disrupted near the sun. From ancient times up to the present, more than 10 major members have been witnessed and recorded so far (Marsden 1989; Hasegawa, Nakano 2001). Furthermore, since 1979, more than 300 minor Kreutz members have been detected by three space-borne coronagraphs: Solwind, SMM, and SOHO. However, no ground-based observations for such minor Kreutz members have been reported yet, because of their smallness: probably a few tens of meters at most in diameter. For that reason, most vanished away before their perihelion passages (e.g., Sekanina 2002).

Non-Kreutz comet groups, the above-mentioned Marsden group (12 members) and the Kracht group (4 members), detected by SOHO, are also in a nearly sungrazing state; their parabolic orbits were computed by Marsden, based on short-arc astrometric data obtained only by SOHO. These orbital data along with the mean data and standard deviations (S.D.), are given in table 1 (selected out and collected by M. Meyer[2] as of 2002 May). Unlike minor Kreutz comets, most of the members have not vanished, despite severe heliospheric environment; they were recognized again even post-perihelion on SOHO's field of view[3], probably due to their somewhat larger q.

Regarding the Arietids, their orbital data have not been very deeply analyzed yet. Hence, using the D-criterion by Southworth and Hawkins (1963), we selected out and evaluated the orbital data of 10 Arietid streams from among several meteor stream catalogues, as shown in table 1. The D-criterion has often been applied when investigating an orbital similarity, like a distance, between meteors, or a comet and meteors. We discriminated them using $D(M,N) \leqq 0.2$, where $D(M,N)$ represents the D-value between a mean orbit (M) and an individual meteor (N). $D \leqq 0.2$ means both orbits are within a possible association range. We also confirmed $D(M,N)$ for each individual member of the Marsden group and Kracht group to be within 0.2.

In our investigation below, we deal mainly with the mean orbital data as representations, since it is more reliable than each individual one. It can be seen in table 1 that all of the perihelion coordinates, L and B, among the Arietids and two comet groups are entirely overlapping within 1 S.D. and are also similar to that of 96P, which means that their lines of apsides are almost in the same directions. Since the direction of 96P's line of apsides would seem to be almost stable in the evolutional history, it is possible that these objects are dynamically closely related to each other. It should also be noted that both the orbital data of the Marsden group and Arietids, except for q and eccentricity (e), are quite coincident with each other, as pointed out by Seargent (2002), although their ΔT differ by ~ 40 yr. Their D of 0.074 means being within the probable association range.

3. Computations

Next, we traced whether or not there are any evolutional phases of 96P with orbital elements similar to those of the Arietids, the Marsden group, and the Kracht group, searching the minimum D ($D_{\min}$) between 96P and each. For that purpose, we performed backward and forward numerical integrations of the motion of 96P during the term of BC 1000–AD 3000, including non-gravitational effects, probably due to relativity effects. As the integrator, Schubart and Stumpff's (1966) method in double precision was applied along with a time step of 64^{-1} d. The orbital data of 96P at epoch 2002 January 6, solved by S. Nakano, were taken as initial data (see table 1). The eight major planets from Mercury through Neptune, Earth and Moon separately, and three larger asteroids, (1) Ceres, (2) Pallas, and (4) Vesta, were included as perturbing bodies. Since the semimajor axes of the Arietids, the Marsden group, and the Kracht group were rather imprecisely reduced, we did not trace their long-term motions in our present study.

4. Results

As a result, shown in table 2, we found that the orbital elements of 96P at epoch 2319 correspond to those of both the Arietids and the Marsden group, and those of 96P at epoch 2408 agree with those of the Kracht group. Therefore, we can estimate ΔT to be ~ 320 yr for 96P – Marsden group; ~ 360 yr for 96P – Arietids; ~ 410 yr for 96P – Kracht group, respectively. Especially, both data of 96P at epoch 2255 and the Arietid swarm, 61·6·1 (Nilsson 1964, see also tables 1 and 2), are quite identical to each other, only $D_{\min} = 0.011$ being in the certain association range; further, their ΔT is 294 yr, smallest among all the Arietids data. These results may indicate the time-lags of orbital evolutions between 96P and the released meteoroids (or fragments) from 96P.

During the integration term, there are no close encounters of 96P to Jupiter within 0.1 AU; however, occasional encounters with Earth within 0.1 AU occurred; the next encounter will occur around 2229 up to 0.08 AU. The minimum nodal distance of ~ 0.05 AU between 96P and Earth around 2280 may activate some meteor shower at solar longitude = $82.^{\circ}1$, radiated from R.A. = $48.^{\circ}3$, Dec. = $+24.^{\circ}8$ (J2000.0) with the geocentric velocity of $44\,\mathrm{km\,s^{-1}}$, substantially almost the same as the presently observable Arietid meteor shower.

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[2] ⟨http://www.comethunter.de/groups.html⟩.

[3] ⟨http://www.t-online.de/home/R.Kracht/marsdentracks.htm⟩.

Table 1. Orbital data of the Arietids, Marsden group comets, Kracht group comets and 96P/Machholz (J2000.0).

Name	T (TT)	q (AU)	e	ω (°)	Ω (°)	i (°)	L (°)	B	References
Arietids (10 swarms)									
Ari1951	1951	0.09	0.94	29	77.5	21	104.9	10.0	Lovell (1954)
39	1961–65	0.094	0.95	29.5	78.7	27.9	105.3	13.3	Sekanina (1973)
71	1969	0.085	0.94	25.9	77.6	25	101.4	10.6	Sekanina (1976)
61·6·1	1961	0.05	0.98	20.3	85.3	38.9	101.4	12.6	Nilsson (1964)
61·6·2	1961	0.06	0.96	23.0	85.5	33.4	105.0	12.4	Nilsson (1964)
605	1969	0.08	0.96	28.0	81.7	17.4	108.6	8.1	Gartrell and Elford (1975)
236	1968	0.08	0.93	24.0	78.2	22.3	100.6	8.9	Lebedinets et al. (1972)
239	1968	0.08	0.96	28.2	78.3	20.6	105.0	9.6	Lebedinets et al. (1972)
48	1959	0.10	0.94	30	77.7	19	106.3	9.4	Kashcheyev and Lebedinets (1967)
Mean		0.08	0.95	26.4	80.1	25.1	104.3	10.5	
S.D.		0.02	0.02	3.2	3.1	6.7	2.5	1.7	
Marsden group (12 members)									
C/1998 A2	1998 Jan 03.74	0.0410	1.0	26.31	80.78	27.93	104.38	11.98	MPC 45180
C/1998 A3	1998 Jan 09.30	0.0419	1.0	22.97	80.73	27.35	101.36	10.33	MPC 45180
C/1998 A4	1998 Jan 10.79	0.0431	1.0	21.35	81.03	26.87	100.25	9.47	MPEC 2002-F70
C/1999 J6	1999 May 11.59	0.0492	1.0	22.47	81.69	26.53	102.00	9.83	MPC 39791
C/1999 N5	1999 Jul 11.24	0.0496	1.0	27.20	82.49	27.08	107.08	12.01	MPC 45181
C/1999 P6	1999 Aug 05.11	0.0494	1.0	21.49	82.01	26.57	101.41	9.43	MPC 45181
C/1999 P8	1999 Aug 14.99	0.0494	1.0	21.28	81.85	26.56	101.06	9.34	MPC 45182
C/1999 P9	1999 Aug 15.04	0.0493	1.0	21.51	81.74	26.55	101.16	9.43	MPC 45182
C/1999 U2	1999 Oct 25.23	0.0492	1.0	22.22	82.05	27.05	102.04	9.90	MPC 36654
C/2000 C7	2000 Feb 04.48	0.0481	1.0	22.34	81.06	24.89	101.50	9.21	MPEC 2002-K48
C/2000 C3	2000 Feb 04.59	0.0487	1.0	23.47	81.85	24.97	103.33	9.68	MPC 44860
C/2000 C4	2000 Feb 05.17	0.0487	1.0	23.05	81.95	24.97	103.04	9.51	MPC 44860
Mean		0.0473	1.0	22.97	81.60	26.44	102.38	10.01	
S.D.		0.0031		1.83	0.54	0.95	1.78	0.93	
Kracht group (4 members)									
C/1999 M3	1999 Jun 30.70	0.0441	1.0	68.03	36.33	12.35	103.89	11.44	MPC 45181
C/1999 N6	1999 Jul 12.30	0.0435	1.0	63.97	32.50	12.15	95.95	10.90	MPC 45181
C/2000 O3	2000 Jul 30.94	0.0540	1.0	48.12	53.46	14.58	100.65	10.80	MPC 41159
C/2001 Q7	2001 Aug 21.80	0.0445	1.0	54.77	43.95	13.28	97.98	10.81	MPC 45182
Mean		0.0472	1.0	58.72	41.56	13.09	99.62	10.99	
S.D.		0.0043		7.88	8.01	0.96	2.98	0.26	
96P	2002 Jan 08.6	0.1241	0.9588	14.581	94.608	60.187	101.98	12.62	MPC 44505

Table 2. Future evolutional phases of 96P and associated candidates (J2000.0).

Name	T (TT)	q (AU)	e	ω (°)	Ω (°)	i (°)	L (°)	B	$D_{\min}$
96P (epoch 2319 Jan 25)	2319 Jan 11.8	0.0406	0.9866	27.968	76.064	26.394	101.50	12.03	
Arietids	1951–1969	0.08	0.95	26.4	80.1	25.1	104.3	10.5	0.075
Marsden group	1998–2000	0.0473	1.0	22.97	81.60	26.44	102.38	10.01	0.046
96P (epoch 2255 Oct 07)	2255 Oct 13.3	0.0551	0.9819	20.000	86.087	38.749	101.93	12.36	
61·6·1	1961	0.05	0.98	20.3	85.3	38.9	101.4	12.6	0.011
96P (epoch 2408 Apr 27)	2408 May 11.4	0.0330	0.9891	55.887	46.428	14.431	101.46	11.91	
Kracht group	1999–2001	0.0472	1.0	58.72	41.56	13.09	99.62	10.99	0.049

5. Concluding Remarks

We can hypothesize that a smaller time-lag implies not only an early-stage of the meteor stream in the orbital evolution and, therefore, a rather dense spatial number density in the meteor stream, but also stronger comet–meteor association (Ohtsuka et al. 1997). Now, we may here simply regard ΔT as the time-lag of orbital evolutions. We thus found that the time-lag between 96P and Arietids is ~ 360 yr; especially, that between 96P and Arietids 61·6·1 is only 294 yr, which are intermediate between 220 yr of Apollo-type Asteroid (3200) Phaethon–Geminids (Ohtsuka et al. 1997) and at least 600 yr of Periodic Comet 2P/Encke-β Taurids (Steel, Asher 1996); both are well known as well-established short-period comet–meteor associations, and both meteor showers are strongest among each stream complex: HR of 80 for the Geminids and 25 for the β Taurids, respectively (Kronk 1988). Similarly, since the Arietid meteor shower is a rather strong member among the likely Quadrantid complex, 96P–Arietids should presumably be such another case. The Arietid activity may be greater from now toward the late 23rd–early 24th century, since the time-lag between 96P and Arietids should be smaller as time passes.

If the Marsden group and the Kracht group have nearly the same a^{-1} as 96P, the time-lags between 96P and each comet group should be ~ 320 yr and ~ 410 yr, respectively, ranging around ~ 360 yr for 96P–Arietids association. Hence, the Marsden group and the Kracht group can also possibly be members of 96P–Arietids association. If this is true, they may be fragments, like larger meteoroids, on the order of 10 m as well as minor Kreutz members, separated from 96P in the previous q-minimum phase, ~ 4000 yr ago. Since most of the members within the two comet groups, observed in 1998–2000, likely survive, it is possible that they will return again in 2003–2005, 96P's one revolution (~ 5.2 yr) after the observations.

For the reason mentioned above, we conclude that 96P, Arietids, the Marsden group, and the Kracht group are further possibly associated with each other now. In order to verify our hypothesis, further observations and investigations of these objects are desirable.

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Appendix. Keys and Symbols to the Text and Tables

T: perihelion time, in Terrestrial Time (TT).
Epoch: osculating date in TT.
q: perihelion distance, in astronomical unit (AU).
e: eccentricity.
ω: argument of perihelion, in degree, equinox J2000.0.
Ω: longitude of the ascending node, in degree, equinox J2000.0.
i: inclination, in degree, equinox J2000.0.
L: longitude of perihelion, in degree, equinox J2000.0.
B: latitude of perihelion, in degree, equinox J2000.0.
$D_{\min}$: minimum D(-value) with 96P.

Note added in proof: Ten more Kracht group members, C/2001Q8, 2001R8, 2001R9, 2002N2, 2002Q8, 2002Q10, 2002S4, 2002S5, 2002S7, 2002S11 (SOHO), and one more Marsden group member, C/2002R4 (SOHO), were detected in the SOHO images (see the data collected by M. Meyer[2]). Now, mean orbital data of the Kracht group, unlike those of the Marsden group, changed somewhat to $q = 0.0470$ AU, $\omega = 54\overset{\circ}{.}54$, $\Omega = 47\overset{\circ}{.}03$, $i = 13\overset{\circ}{.}39$, $L = 100\overset{\circ}{.}83$, and $B = 10\overset{\circ}{.}79$. However, ΔT between 96P$-$Kracht group shifted very little. Furthermore, C/2001R1 (SOHO), near-related Marsden group, was also discovered (MPEC 2002-R57), of which the angular elements ($\omega = 33\overset{\circ}{.}67$, $\Omega = 70\overset{\circ}{.}43$, and $i = 22\overset{\circ}{.}19$) are significantly deviated from those of the Marsden group, therefore matching another evolutional phase of 96P at epoch 2355.

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