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Benefits of an impact mission to 3200 Phaethon: nature of the extinct comet and artificial meteor shower

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ABSTRACT

The asteroid 3200 Phaethon is suggested as a candidate for direct impact research. The object is considered to be an extinct comet and the parent of the Geminid meteor shower. One could say that this provides a possible argument for a space mission. Based on such a mission, this paper proposes to investigate the nature of the extinct comet and the additional interesting possibility of artificially generated meteor showers.

Dust trail theory can calculate the distribution of a bundle of trails and be used to show in which years artificial meteors would be expected. Results indicate that meteor showers will be seen on Earth about 200 yr after the event, on 2022 April 12.

Key words: comets: general – meteors, meteoroids – minor planets, asteroids.

1 INTRODUCTION

The nature of the asteroid 3200 Phaethon as the parent of the Geminid meteor shower is considered an open question (Hsieh & Jewitt 2005). Parents of meteor showers are generally expected to be comets rather than asteroids (Williams 1985). However, unlike a comet, 3200 Phaethon seemed to have a rocky surface, which is characteristic of a B-type asteroid in Bus's taxonomy (Green, Meadows & Davis 1985; Birkett et al. 1987; Bus & Binzel 2002). Coma activity of Phaethon and the dust trail associated with Geminid meteor activity have still not been observed (Williams & Wu 1993; Hsieh & Jewitt 2005). This is a unique case for a parent of a meteor shower. Phaethon's nature is not conclusive as being that of just an asteroid and another possibility is suggested.

Some Apollo-type asteroids, including Phaethon, might be nuclei of former comets deprived of their volatile components. The degassed comets cannot be distinguished from asteroids. So called, they are extinct comets from the dynamical point of view. However, there is no direct physical evidence and thermal history for the cometary nature of Phaethon from the beginning. The investigation of Phaethon will provide the first opportunity to prove this hypothesis.

Meteor spectroscopy is one of the best methods for exploring pristine objects, through meteor phenomena, such as comets and asteroids in the solar system. The physical structure and chemical composition of a Geminids meteor will provide important clues concerning both the origin and the evolution of Phaethon. For example, derived metallic abundances of a 2004 Geminid meteor, especially Na/Mg depletion and excess Ni/Mg, show different features from other meteors whose parents are comets (e.g. Trigo-Rodrìguez et al. 2003; Kasuga et al. 2005a; Kasuga, Watanabe & Ebizuka 2005b). Babadzhanov (2002) reported that the Geminid meteoroids have the largest bulk density relative to that of other major meteor streams of cometary origin. Meteor research is very valid for clarifying the differences in composition between some comets and Phaethon. Research may suggest a lack of volatiles in Phaethon, which may be an asteroidal feature. It is quite essential to determine the mutual evolutionary relationship between comets and asteroids. However, the true nature of Phaethon, whether originally a comet or not, is not conclusive only by observing the Geminid meteors.

For this purpose, we suggest the new type of scientific mission to the asteroid 3200 Phaethon. This is an *in situ* investigation of Phaethon and a first trial for producing artificial Geminid meteor showers as a result of an impact with Phaethon. It was suggested that the on-board measurements of Phaeton will be of particles of material thrown up by the impact along Phaeton's trajectory. The possibility of launching a space probe to Phaethon just before the year 2000 was considered by Padevět, Lála & Bumba (1986). Our new idea is applied to cause artificial meteor showers on Earth using the idea of the Deep Impact mission in 2005 (A'Hearn et al. 2005). After the Deep Impact with 9P/Tempel 1, ejection of dust in great volume was observed from the space probe using a flyby camera and from the ground using telescopes such as Subaru (Sugita et al. 2005). A bundle of dust trails will be formed. In the case of the impact with Phaethon, the same situation is predicted.

An *in situ* probe method is considered by the laboratory simulation of the capture of intact cometary and asteroidal dust particles (Fujiwara, Nakamura & Kadono 1994). This also will be rare and will be the first occasion to improve on data for Geminid meteors, leading to a worldwide campaign that will bring great advances in meteor astronomy, such as the Leonid Multi-Instrument Aircraft Campaign (Leonid MAC; e.g. Jenniskens & Butow 1999) and space-borne ultraviolet spectroscopy of a meteor for the discovery of

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unknown elements related to astrobiology (Jenniskens et al. 2002; Carbary et al. 2003). Increased public awareness, worldwide, is also expected.

In this paper, a simulation of the artificial meteor shower brought by the impact with Phaethon is described with a calculation of the distribution of a bundle of trails. Dust trail theory can be used to show specific years when extra meteor activity will occur and to show that there are other years near the Phaethon nodal intersection epoch. At present, we know that greater natural meteor activity in the Geminid shower could occur every year for several years around the Phaethon nodal intersection epoch. Similarly, we guess that an impact could cause artificial meteors every year for several years around the Phaethon nodal intersection epoch. Dust trail theory was used first to show in which years artificial meteors would be expected.

2 SIMULATION OF THE ARTIFICIAL METEOR SHOWER

In this section we simulate the activity of the artificial Geminid meteor showers and their trails, which are associated with the 'Phaethon Impact' mission. The most simple approach of dust trail theory (e.g. McNaught & Asher 2002) was applied (Sato 2003). The effect of the radiation pressure on the meteoroids is not taken into account in our calculation, because meteoroid particles are characterized as large, compact, blackbody-like particles (Kasuga et al. 2006). The applied orbital elements were obtained by the MPC Orbit Database (MPCORB; IAU Minor Planet Center).

First, an evolution of the orbital elements of Phaethon are summarized in Table 1. The long-term orbital motion of Phaethon has already been clarified: for example, a large-amplitude q–i oscillation arises that lasts about 20 000 yr (Babadzhanov & Obrubov 1987, 1992; Ohtsuka et al. 2006). However, in the short term (for about hundreds of years), the orbit of Phaethon is comparatively steady. Because the orbit of Phaethon is not close to Jupiter, it is little affected by the perturbation of planets. With the passage of time, the perihelion, q, increases slightly, although the semimajor axis, a, is stable. On the other hand, the argument of the perihelion, ω, grows. Then, as the descending node leaves the perihelion, the heliocentric distance R of the descending node tends to increase gradually with the effect of the evolution of the perihelion. The node will reach the orbit of the Earth around 2222.

Secondly, we calculated the distribution of a bundle of dust trails formed at the epoch of the Phaethon Impact. To determine the day of impact with Phaethon, we followed the 'Deep Impact Mission design' (Blume 2005). In order to deliver a substantial science payload, the day that provided the best opportunity to impact 9P/Tempel 1 arose when the orbit of the comet was near its descending node, which was very close to the perihelion, considering all the best mission parameters. In the case of Phaethon, it is also important to impact near the ecliptic plane on the Earth side to carry the flyby and impactor. We have suggested in Table 2 'Phaethon impact days' from 2017 onwards, which are limited chances, when Phaethon passes the ecliptic plane on the Earth side. Hereafter, we have focused on the impact day of 2022 April 12, because other mission programmes are already projected until 2020 in Japan (see http://www.jaxa.jp/press/2005/04/20050406_sac_vision_j.pdf, in Japanese, for a road map for exploration of the Solar system, from the Institute of Space and Astronautical Science, ISAS, the Japan Aerospace Exploration Agency, JAXA).

Table 2. The dates that Phaethon passes the ecliptic plane.

2017 December 23	2025 February 22
2019 May 31	2026 July 31
2020 November 5	2028 January 5
2022 April 12	2029 June 12
2023 September 18	

We show one of the results of a bundle of the trails caused by our Phaethon Impact on 2022 April 12. Because of differential planetary perturbations, the heliocentric distance R of the descending node is a function of the time when particles reach the node. Fig. 1 shows the distributed trail formed due to the Phaethon Impact mission. In 2222, the descending node of Phaethon passes from the inside of the orbit of the Earth to the outside. The trail is calculated using test meteoroids ejected in the direction of the motion of Phaethon (which we define as positive ejection velocities) and in the opposite direction (negative ejection velocities).

The overall orbital evolution is rather slow because the orbit of Phaethon is a long way from Jupiter. Although the orbital evolution of all the test meteoroids is slow for the same reason, the orbital evolution of the dust that is ejected in the direction of the motion of Phaethon is less slow because the orbits are slightly less far from Jupiter. As a result, the descending node reaches the the orbit of the Earth in the early phase in 2222. The negative ejected dust shows the opposite result.

In the case of extreme high-speed dust ejection, for example $+900\,\mathrm{m\,s^{-1}}$, a bundle of dust trails will cross the orbit of the Earth after the epoch of 2160. In contrast, in the event of dust ejection in the negative direction ($-900\,\mathrm{m\,s^{-1}}$), trails will cross the epoch of 2270. As shown by the results of high-speed dust ejection, meteor showers will have been appearing from the period of 2160 to 2270.

However, the ejection velocity of a meteoroid is not high, as revealed by Deep Impact 2005 (A'Hearn et al. 2005). A trail is apt to be formed by much slower ejecta. Fig. 2 shows a period of time when the trail crosses the orbit of the Earth. It is calculated using test

Table 1. An evolution of the orbital elements of Phaethon. R is the heliocentric distance of the descending node (at the current epoch) and the node is seen to reach the orbit of the Earth around 2222. The epoch of ω, Ω and i is J2000.0.

T	q	e	ω	Ω	i	a	R
2022 May 15.18	0.1401	0.8898	322.17	265.22	22.26	1.2714	0.8910
2061 January 28.30	0.1407	0.8894	322.83	264.57	22.54	1.2714	0.9116
2101 March 23.22	0.1411	0.8890	323.35	264.03	22.80	1.2712	0.9284
2141 May 07.63	0.1417	0.8885	323.87	263.52	23.02	1.2705	0.9461
2181 June 17.68	0.1423	0.8880	324.46	262.92	23.30	1.2707	0.9669
2221 July 27.16	0.1427	0.8877	324.97	262.41	23.54	1.2706	0.9843
2260 March 27.06	0.1433	0.8872	325.47	261.89	23.79	1.2709	1.0025
2300 May 09.63	0.1441	0.8866	325.96	261.40	24.04	1.2709	1.0213

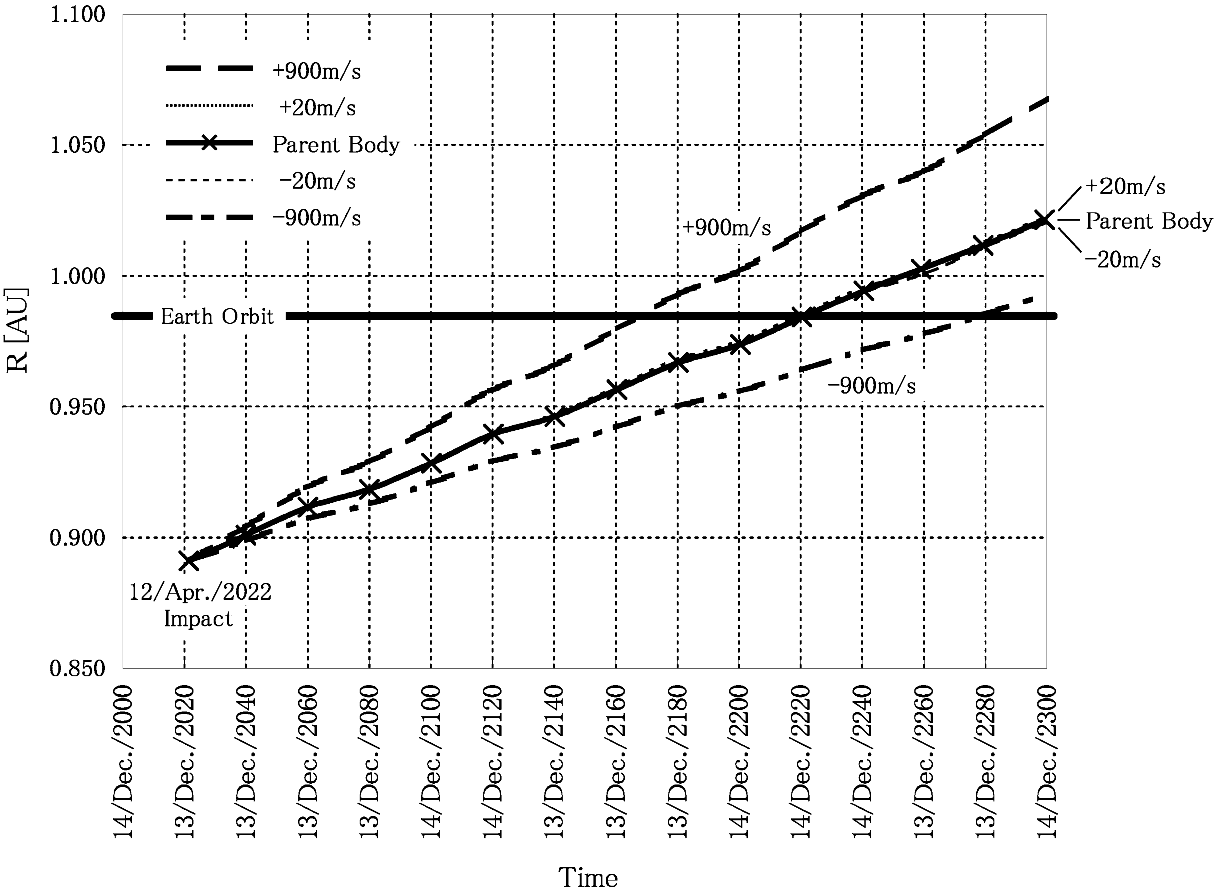

Figure 1. An evolution of the dust of Phaethon every 20 yr. Impact date is assumed to be on 2022 April 12. Ejected dust of ±20 m s^{-1} overlapped the parent body because trails evolve as the parent moves.

meteoroids. The ejection velocity is chosen to be ±20 m s^{-1} because trails evolve as the parent moves. In this case, meteor showers will occur within around 10 yr.

Until 2214, the distance of trails whose ejection velocity of ±20 m s^{-1} is more than 0.002 au from the orbit of the Earth, which is too far to produce meteor showers. On the other hand, the bundle of trails between 2215 and 2225 are within 0.002 au, which is close enough to produce meteor showers. Especially in 2218, 2219, 2222 and 2223, trails approach within 0.001 au, which results in a great activity of meteor showers. The main situations when the trails approach the Earth are summarized in Table 3. After 2224, meteor activity will decrease as the trails occur more than 0.002 au outside the orbit of the Earth.

Meteor showers on Earth are predicted with the Phaethon Impact. In such a situation, meteoroids that are relatively large in size and high in velocity may cause tremendous damage to spacecrafts by their impact, as seen in the 1993 Perseid meteor shower–Olympus satellite anomaly (McDonnell 1993). For a reference, Yano et al. (2003) derived a data set for satellite risk assessments with the relation of each zenith hourly rate (ZHR) in the 1998–2001 Leonid meteor storms. Consequently, Leonid storms in 1999 and 2001 seemed to exceed the risk caused by sporadic meteors at 1 au by factors of ∼2 to ∼4. In the future, meteoroid size, mass, population index and cumulative flux should be considered in order to estimate the significant levels of impact risk to Earth and spacecrafts. Vaubaillon, Colas & Jorda (2006) derived the environment of the meteoroid size distribution, particle density and number of expected collisions for the *in situ* flyby from the Deep Impact. These factors can be applied to the preparation phase of any space mission to a comet. To prevent the impact hazard on Earth and spacecrafts related to the Phaethon Impact mission, we must consider the environment of ejected meteoroids and estimate the hazard precisely as a serious future piece of work.

3 CONCLUSIONS

We suggested the scientific mission to Phaethon, together with the great activity of meteor showers on the basis of dust trail theory. The Phaethon Impact on 2022 April 12 will show a great activity of meteor showers in 2218, 2219, 2222 and 2223. This will be rare and first occasion to improve on data for Geminid meteors leading to a worldwide campaign that will bring great advance in meteor astronomy, such as the Leonid MAC. The true nature of Phaethon, whether originally a comet or not, will be revealed by our scientific mission.

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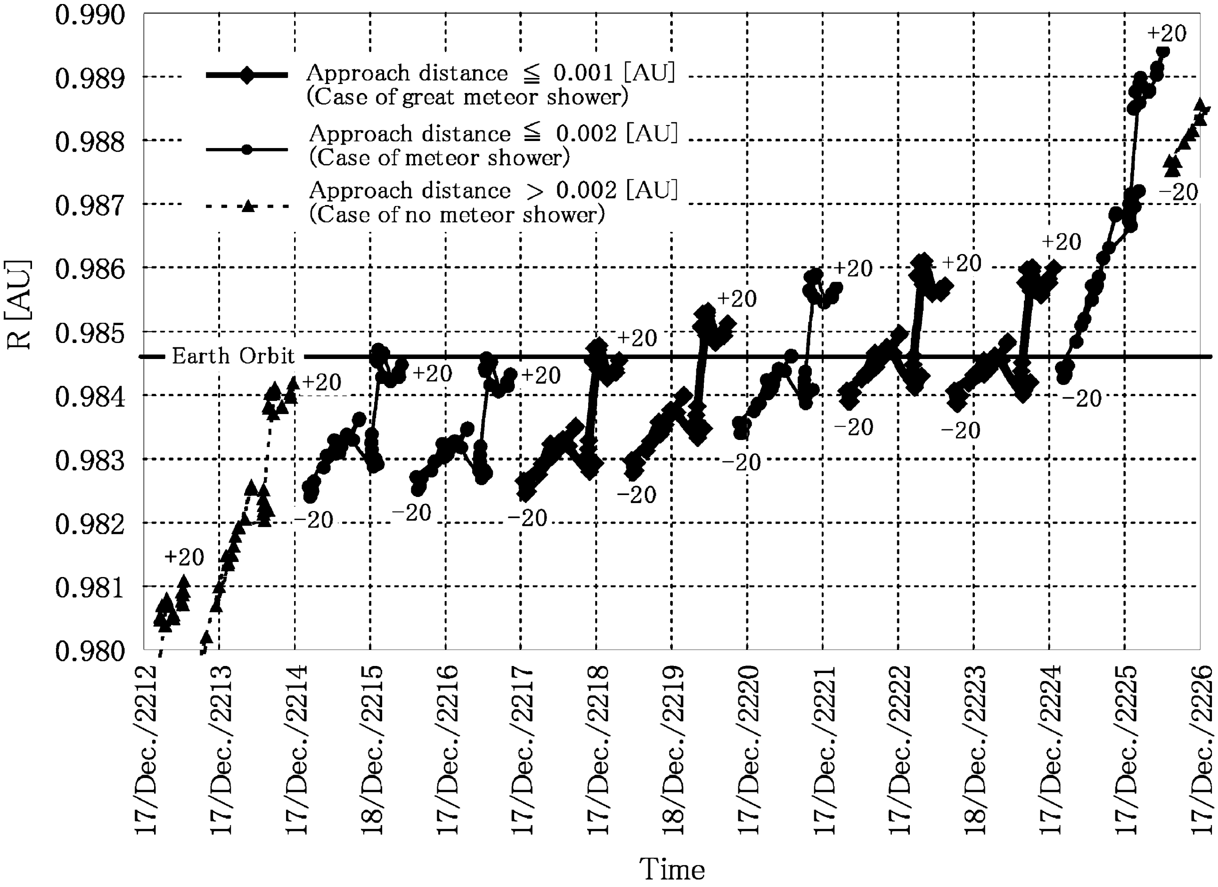

Figure 2. Distribution of a bundle of dust trails after the impact event on 2022 April 12. '+20' (or '−20') is the ejection velocity (m s^{-1}) at impact. Note that the same particles return to the node at a time-spacing corresponding to their orbital period, with the nodal distance R being slightly shifted on each revolution because of planetary perturbations. Meteor showers would be seen between 2215 and 2225 (approach distance $\leqslant$0.002 au). In 2218, 2219, 2222 and 2223, great activity is predicted (approach distance $\leqslant$0.001 au).

Table 3. Main situations when the trails approach the Earth (within 0.001 au).

Year	Time (UT)	ΔR (au)	Ejection velocity (m s^{-1})
2218	December 18 02:00	+0.000 13	+10.8
		+0.000 04	+13.2
		+0.000 07	+15.9
		−0.000 19	+17.4
2219	December 18 08:00	−0.000 65	−4.1
		−0.000 69	−3.9
		−0.000 86	−0.7
2222	December 18 03:00	+0.000 57	−3.4
		+0.000 46	−1.8
		+0.000 37	+0.6
2223	December 18 09:00	−0.000 29	−15.3

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