Are There Meteors Originated from Near Earth Asteroid (25143) Itokawa?

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Abstract. As a result of a survey of Itokawid meteors (i.e., meteors originated from Near Earth Asteroid (25143) Itokawa = 1998 SF₃₆), from among the multi-station optical meteor orbit data of ~15000 orbits, and applying the D-criteria, we could find five Itokawid meteor candidates. We also analyzed corresponding mineral materials of the Itokawid candidates through their trajectory and atmospheric data. We conclude, on the basis of our investigation, that the fireball, MORP172, is the strongest Itokawid candidate.

1. Introduction

The problem as to whether meteor showers associated with Near Earth Asteroids (NEAs) exist or not has been discussed by many authors (e.g., Olsson-Steel 1988; Hasegawa et al. 1992; Babadzhanov 1994). The most prominent case is the association between NEA (3200) Phaethon and the Geminid stream complex. However, it should be an exceptional case since Phaethon is considered to be a dormant or extinct cometary nucleus; hence the Geminid stream complex meteoroids were presumably released from Phaethon in its active cometary phase (Gustafson 1989). Meanwhile, meteoroids of asteroidal origin certainly exist and they are usually observed and recognized as meteorites, meteoritic fireballs, or high bulk-density meteors. They are probably produced as impact ejecta by asteroidal collisions. Although there is no asteroid–meteor association as strong as the Phaethon–Geminid complex yet, most likely the asteroidal meteor (or meteorite) streams indeed exist (e.g., Halliday 1987; Terentjeva & Barabanov 2002; Spurný et al. 2003).

The HAYABUSA (MUSES-C) sample return mission target, NEA (25143) Itokawa = 1998 SF₃₆, is one of the Apollo-type NEAs, whose orbital parameters at present epoch are perihelion distance ~ 0.95 AU and small eccentricity ~ 0.28 along with an inclination near the ecliptic plane at ~ 1°.7. The taxonomic class of Itokawa is less the cometary nature than a typical S(IV)-type with rather high albedo (e.g., Binzel et al. 2001; Sekiguchi et al. 2003; Ishiguro et al. 2003). A meteoritic analog would correspond to a LL chondrite (Binzel et al. 2001). Since Itokawa is a small asteroid of ~ 400 m in mean axis, the escape speed
from Itokawa will be only $\sim 25$ cm s$^{-1}$ (Ostro et al. 2004). Consequently, impact ejecta should easily escape from Itokawa toward interplanetary space and some may become meteoroids. The Earth approaches Itokawa’s orbit to within 0.05 AU from late March to early July, over a span of three months, in which we would be able to observe some meteors originated from Itokawa (hereafter, we designate such a meteor as “Itokawid”) every year. If we can obtain the orbital and physical data of the Itokawid meteors, they must give us very important information when compared with the forthcoming analytical results of the HAYABUSA onboard scientific instruments and the sample of Itokawa.

On the basis of the above assumption, we surveyed whether there are Itokawid meteors or not from among the optical meteor orbit database, considering orbital similarity with Itokawa. As a result, we could locate Itokawid meteor candidates. We also analyzed the corresponding mineral materials of the Itokawid candidates through their trajectory and atmospheric data.

2. Survey

We called Japanese visual-meteor observers to watch the Itokawid meteor activity through the observing campaign from the 2001 season. However, no detection has been reported so far. This is supported by the negative results of the Japanese fireball network (JN) monitoring, a total of $\sim 500$ hr, during the 2000–2004 seasons. One of the reasons is that a predicted geocentric velocity for the Itokawids is very slow at only $\sim 6$ km s$^{-1}$, which should scatter their apparent radiant in a large celestial area around Leonis. This makes it difficult for visual meteor observers to distinguish a member of the Itokawids or not. Another reason is that the activity of asteroidal meteors is substantially weak. Indeed, we could not find any past Itokawid records in the several visual meteor catalogues. Thus, the Itokawid activity has never been reported by single-station visual meteor observers.

Unlike the visual meteor observations, we might trace Itokawid activity by retrieving data from the meteor orbit database recorded by multiple-station observations. Considering the orbital similarity with Itokawa, we surveyed whether there are Itokawid meteors among the multi-station optical (photographic and TV) meteor orbit data of $\sim 15000$ orbits. Our database includes: i) the IAU MDC optical meteor orbit data of $\sim 6000$ orbits as of August, 2001 (Lindblad 2001; Lindblad et al. 2001), based upon many astronomical papers that have been published (Steel 1996); ii) 6500 more optical meteor orbits from released catalogues on the internet websites (e.g. DMS additional photo and TV; MSS-WG TV; Ondrejov TV; etc.) and unpublished TMN photographic and JN fireball reductions; and iii) Super-Schmidt graphical reductions (McCrosky & Posen 1961) of $\sim 2500$ orbits, although they were not included in the IAU MDC photographic meteor data (Lindblad 2001) by reason of their lower precision than other photographic reductions; they are comparable in quality to the TV reductions and hence they deserve to be retrieved here.

In investigating the orbital similarity between meteors or a comet/asteroid and meteors, we often use the $D$-criteria, e.g. $D_{SH}$ (Southworth & Hawkins 1963); $D'$ (Drummond 1979); $D_N$ and $D_R$ (Valsecchi et al. 1999). We applied
these D-criteria as a retrieving engine, mainly taking account of discrimination $D_{\text{SH}} \leq 0.15$. The traditional $D_{\text{SH}}$ is defined by a distance of two points of two objects ($A$ and $B$) in the five-dimensional coordinate space systemized by the orbital elements, $e$: eccentricity, $q$: perihelion distance, $\omega$: argument of perihelion, $\Omega$: longitude of the ascending node, and $i$: inclination, as follows (Southworth & Hawkins 1963):

$$[D_{\text{SH}}(A, B)]^2 = (e_A - e_B)^2 + (q_A - q_B)^2 + [2 \sin (I_{AB}/2)]^2 + [(e_A + e_B)/2][2 \sin (\Pi_{AB}/2)]^2$$

where $I_{AB}$ is the angle between both orbital planes and $\Pi_{AB}$ is the difference between the longitudes of perihelion measured from the intersection of the orbits. Therefore, you can easily comprehend that the smaller $D_{\text{SH}}$ is, the stronger the association between Itokawa and meteor will be.

3. Results

We found five Itokawid meteor candidates, as listed in Table 1, where the column heads from left to right are as follows: object name, observed date of the meteors in UT, $e$, $q$ in AU, $a$: semimajor axis in AU, the angular elements, $\omega$, $\Omega$, and $i$ in degree in J2000, $\alpha$ and $\delta$: right ascension and declination of the geocentric radiant in degree in J2000, and $V_G$: geocentric velocity in km s$^{-1}$. The orbital parameters of Itokawa at epoch 2004 July 14.0 TT (= JDT 2453200.5) taken from the NASA-JPL NEO Program website are also presented in Table 1, when mean anomaly was 35$^\circ.690$. The equinox of angular data, except for those of the meteor 00504004, was transformed from B1950 to J2000.

The results of the $D$-criteria are also given in Table 2, where the column heads are the following: object name, $D_{\text{SH}}$ between Itokawa and each meteor, $\lambda$ and $\beta$: longitude and latitude of the perihelion in degree in J2000 (main terms of $D'$), and $U$ and $\cos \theta$: unperturbed geocentric encounter velocity to the Earth and cosine of the angle between $U$ and the direction of Earth’s heliocentric motion (main terms of $D_N$ and $D_R$). $U$ equals $\sqrt{3-T_J}$, where $T_J$ is the Tisserand’s invariant of each object with respect to Jupiter.

The meteors, H7220 and H10330, were picked out from the Super-Schmidt graphical reductions (McCrosky & Posen 1961). $D_{\text{SH}}$ between Itokawa–H7220 is 0.05, the smallest among all the Itokawa–meteor pairs and comparable to the confirmed comet–meteor associations (e.g., 55P–Leonids, 103P–Perseids, Phaethon–Geminids; and others); thus both objects are probably associated with one another. Although outside the predicted months mentioned above, the meteor, HA10000, came from the Super-Schmidt automatic reductions (McCrosky & Shao 1967).

The fireball, MORP172, was multiply photographed by the Canadian fireball network, Meteorite Observation and Recovery Project (MORP), on April 11, 1975 (Halliday et al. 1996); $D_{\text{SH}}$ of 0.09 between Itokawa–MORP172 is somewhat larger than that of Itokawa–H7220. However it is still within a probable association range. It is also notable that the secular near-invariants of MORP172 in the $U$-$\cos \theta$ coordinates match well with those of Itokawa. This suggests that both objects are dynamically in strong relationship to each other (Valsecchi et al. 1999).
Table 1. Itokawid meteor candidates

| Object   | date       | $e$  | $q$  | $a$  | $\omega$ | $\Omega$ | $i$ | $\alpha$ | $\delta$ | $V_G$ |
|----------|------------|------|------|------|----------|----------|----|----------|----------|------|
| H7220    | 1953 Apr   | 0.32 | 0.96 | 1.42 | 214.1    | 21.6     | 2  | 170.7    | +13.7    | 6.5  |
| H10330   | 1954 Mar   | 0.15 | 0.96 | 1.13 | 224.0    | 352.0    | 2  | 155.7    | +25.7    | 3.8  |
| HA10000  | 1957 Feb   | 0.208| 0.904| 1.142| 240.3    | 337.12   | 3.6| 153.8    | +31.5    | 6.1  |
| MORP172  | 1975 Apr   | 0.236| 0.970| 1.27 | 213.5    | 21.05    | 5.1| 182.2    | +33.0    | 5.6  |
| 00504004 | 2000 May   | 0.163| 1.007| 1.203| 8.0      | 224.837  | 3.1| 147.2    | −22.7    | 3.1  |
| Itokawa  |            | 0.280| 0.953| 1.324| 162.683  | 69.153   |    | 1.623    |          | 6.   |

Table 2. Results of $D$-criteria

| Object   | $D_{SH}$ | $\lambda$ | $\beta$ | $U$ | $\cos \theta$ |
|----------|----------|------------|---------|-----|----------------|
| H7220    | 0.05     | 235.7      | −1.1    | 0.20| 0.65           |
| H10330   | 0.15     | 216.0      | −1.4    | 0.12| 0.42           |
| HA10000  | 0.13     | 217.4      | −1.3    | 0.19| 0.22           |
| MORP172  | 0.09     | 234.4      | −2.8    | 0.18| 0.52           |
| 00504004 | 0.15     | 232.8      | +0.4    | 0.10| 0.79           |
| Itokawa  |          | 231.8      | +0.5    | 0.19| 0.55           |
The TV meteor, 00504004, was recorded by the Ondrejov observatory team (Koten et al. 2003) on May 4, 2000; the $D_{SH}$-criterion with Itokawa is just outside the 0.15-limit, but its $\lambda$ and $\beta$ are very close to those of Itokawa and hence in a possible association range.

True anomaly of these meteors, at observed epoch, equals $180^\circ - \omega$ for the Super-Schmidt meteors and MORP172 and $-\omega$ for the meteor, 00504004.

4. Physical approach

Furthermore, we approached the above subject in a physical analysis, in order to ascertain the association between Itokawa and the Itokawid candidates. Unfortunately, most of the physical information (e.g., bulk density, ablation coefficient, spectral data, etc.), are not given in the published data, except for the mass data. However, we could analyze corresponding mineral matters of the Itokawid candidates through their trajectory and atmospheric data instead, i.e., atmospheric density at meteor’s luminous height, velocity, entry angle to Earth’ atmosphere, and mass, using Ceplecha’s (1988) classification. The Itokawid candidates are classified on the basis of evaluating the coefficients $K_B$ only for optical (Super-Schmidt and TV) meteors and $P_E$ and $A_L$ only for fireballs. In these evaluations, we adopted the atmospheric data from CIRA1965.

The results of classification are summarized in Table 3, where the column heads from left to right are as follows: object name, $V_\infty$: initial velocity in km s$^{-1}$, $\cos Z_R$: cosine of zenith distance of the apparent radiant, $H_B$ and $H_E$: beginning and end height of meteor in km, $m_\infty$: initial (photometric) mass in gram, $K_B$, $P_E$ and $A_L$, classified group, and classified mineral matter. It should be also noted that the $K_B$ coefficient for the TV meteors is adjusted adding 0.15 and the logarithm of the total luminosity of MORP172 for $A_L$ is 3.31 (in 0 mag sec).

These evaluations indicate all the Itokawid candidates evidently belong to asteroidal meteors, as shown in Table 3: all the Super-Schmidt and TV meteors are classified in the range of group A as carbonaceous chondrite ($7.30 \leq K_B < 8.00$), while the fireball MORP172 is in group I as ordinary chondrite by $P_E$ classification, $-4.60 < P_E$, but in group II as carbonaceous chondrite by $A_L$ classification, $4.13 \leq A_L < 5.36$. Hence, the classified mineral matter of MORP172 shows more similarity to Itokawa’s surface composition of a LL chondrite analogue suggested by Binzel et al. (2001) than the four other meteors. Interestingly, according to Halliday et al (1989), MORP172 was observed as a likely meteorite dropping fireball with an estimated terminal mass of $\sim 1$ kg; this meteorite might have fallen, and still remains, somewhere near Edam, Canada.

5. Conclusion

As a result of a survey of the Itokawid meteors from among our multi-station optical meteor orbit data of $\sim 15000$ orbits, and applying the orbital similarity criteria, $D$-criteria, we could find five Itokawid meteor candidates. Two out of them, the meteor H7220 and the fireball MORP172, are probably associated with Itokawa, judging from their $D_{SH}$ values. It is also notable that the secular near-invariants of MORP172 in the $U$-$\cos \theta$ coordinates match well with those
| Object      | $V_\infty$ | $\cos Z_R$ | $H_B$ | $H_E$ | $m_\infty$ | $K_B$ | $P_E$ | $A_L$  | group          | mineral matter |
|-------------|------------|------------|-------|-------|------------|-------|-------|-------|----------------|----------------|
| H7220       | 12.8       | 0.97       | 78.8  | 0.085 | 7.62       |       |       |       | A              | carbonaceous chondrite |
| H10330      | 11.4       | 0.82       | 77.6  | 0.027 | 7.61       |       |       |       | A              | carbonaceous chondrite |
| HA10000     | 12.54      | 0.932      | 79.1  | 67.6  | 7.59       |       |       |       | A              | carbonaceous chondrite |
| MORP172     | 12.5       | 0.967      | 66.5  | 31.2  | 2200       | −4.57 | 5.13  | I or II | ordinary-carbonaceous |
| 00504004    | 11.26      | 0.341      | 83.1  | 0.045 | 7.53       |       |       |       | A              | carbonaceous chondrite |
of Itokawa: this suggests both objects have a strong dynamical relationship to each other.

The $K_B$, $P_E$ and $A_L$ evaluations indicate all the Itokawid candidates evidently belong to asteroidal meteors. MORP172 is the only one classified at ordinary/carbonaceous chondrite, the others being in carbonaceous chondrites. Hence, the classified mineral matter of MORP172 shows more similarity to Itokawa’s surface composition of a LL chondrite analogue than the other candidates.

We conclude, on the basis of the investigations above, that the fireball, MORP172, is the strongest Itokawid candidate. However, if you ask whether there are Itokawid meteors or not, we will answer, “Possible”, since only a small sample like this is available so far. Therefore, more optical detections and analyses for the Itokawid meteors are desirable in the future work.

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References

Babadzhanov, P. B. 1994, in Seventy-five years of Hirayama asteroid families: The role of collisions in the solar system history, Y. Kozai, R. P. Binzel, & T. Hirayama (eds), ASP conf. Ser. 63, 168

Binzel, R. P., Rivkin, A. S., Bus, S. J., Sunshine, J. M., & Burbine, T. H. 2001, M&PS, 36, 1167

Ceplecha, Z. 1988, Bull. Astron. Inst. Czsl., 39, 221

Drummond, J. D. 1979, Proc. Southwest Reg. Conf. Astron. Astrophys., 5, 83

Gustafson, B. A. S. 1989, A&A, 225, 533

Halliday, I. 1987, Icarus, 69, 550

Halliday, I., Blackwell, A. T., & Griffin, A. A. 1989, JRASC, 83, 49

Halliday, I., Griffin, A. A., & Blackwell, A. T. 1996, M&PS, 31, 185

Hasegawa, I., Ueyama, Y., & Ohtsuka, K. 1992, PASJ, 44, 45

Ishiguro, M., Abe, M., Ohba, Y., Fujiwara, A., Fuse, T., Terada, H., Goto, M., Kobayashi, N., Tokunaga, A. T., & Hasegawa, S. 2003, PASJ, 55, 691

Koten, P., Spurný, P., Borovicka, J., & Stork, R. 2003, Pub. Astron. Inst. Acad. Sci. Czech Rep., 91, 1

Lindblad, B. A. 2001, in Proceedings of the Meteoroids 2001 Conference, B. Warmbeins (ed), ESA SP-495, 71

Lindblad, B. A., Neslusan, L., Svoren, J., & Porubcan, V. 2001, in Proceedings of the Meteoroids 2001 Conference, B. Warmbeins (ed), ESA SP-495, 73

McCrosky, R. E. & Posen, A. 1961, Smithsonian Contr. Astrophys., 4, 15

McCrosky, R. E. & Shao, C. -Y. 1967, Harvard Meteor Res. Prog., Semiannual Tech. Rep. no. 3

Olsson-Steel, D. 1988, Icarus, 75, 64

Ostro, S. J., Benner, L. A. M., Magri, C., Giorgini, J. D., Rose, R., Jurgens, R. F., Yeomans, D. K., Hine, A. A., Nolan, M. C., Scheeres, D. J., Kausalainen, M., Vokrouhlický, D., Chesley, S. R., & Margot, J. L. 2004, in the 1st HAYABUSA Symposium
Sekiguchi, T., Abe, M., Boehnhardt, H., Dermawan, B., Hainaut, O. R., & Hasegawa, S. 2003, A&A, 397, 325
Spurný, P., Oberst, J., & Heinlein, D. 2003, Nature, 423, 151
Steel, D. 1996, Space Sci. Rev., 78, 507
Southworth, R. B. & Hawkins, G. 1963, Smithson. Contr. Astrophys., 7, 261
Terentjeva, A. K. & Barabanov, S. I. 2002, Sol. Sys. Res., 36, 431
Valsecchi, G. B., Jopek, T. J., & Froeschle, Cl. 1999, MNRAS, 304, 743