Ongoing Meteor Work

The Disintegrating Comet 73P/Schwassmann-Wachmann 3 and Its Meteors

Hartwig Lüthen, Rainer Arlt, and Michael Jäger

We report on the disintegration of Comet 73P/Schwassmann-Wachmann 3 (SW3) and its production of meteoroid trails. The evolution of dust trails of the Comet is studied for ejection years back to the 1890 perihelion passage. Close approaches were found for the 1908 dust trail in 1936 and the 1995 dust trail in 2022 with farther approaches in 1984, 2001, 2011, and 2017. Scrutinization of visual observing records reveals that no outburst of SW3 meteor activity has been reported until now, but distinct annual background activity is found with ZHRs between 1 and 3. The alleged SW3 meteor outburst in 1930 is severely questioned. Prospects for the 2001 encounter of the 1941 dust trail are given. The maximum would be on May 30.41, with a radiant position at $\alpha = 212°$, $\delta = +28°$.

1. Introduction

The disintegration of Comet 2D/Biela last century has always been cited as a classical textbook example for the origin of meteoroids. A similar case of fragmentation has recently been observed in 73P/Schwassmann-Wachmann 3. Discovered at Hamburg-Bergedorf observatory in 1930 [1,2] this typical Jupiter group comet has an orbital period of about 5.3 years and a perihelion distance q close to 1 AU, making it a potential source for meteors. In fact there is a report of a meteor outburst observed on June 9-10, 1930 which may be related to this Comet.

During the 1995 return, the Comet underwent a massive outburst of about 5 magnitudes in amplitude, bringing that Comet to the edge of visibility for the naked eye. Within the distinctly elongated coma (Figure 1b) Boehnhardt and Käufl (see [3,4,5] for full history) discovered four fragments in the nucleus [6]. During the return of the Comet in late 2000, two of these fragments were recovered by Galad and Koleny (Fragment B) and Kadota (Fragment C). A fragment not observed in 1995, but obviously also released at the 1995 return, was discovered by Jäger (Fragment E). The fragments had separated by more than $30'$ and appeared as individual small comets following the main object. ([7] and Figure 1c).

This study follows three objectives: (i) to reanalyze the historical material claiming a meteor outburst in 1930; (ii) to use a dust-trail model to pinpoint the times at which we passed through dust trails in the recent past, in order to allow a reanalysis of still existing observations, and (iii) to alert observers for possible future meteor showers due to debris ejected from 73P/Schwassmann-Wachmann 3.

2. Methods

Comet Photography

Comets were photographed by one of us (MJ) by means of a Schmidt camera ($f = 300$ mm, $f/1.5$; Celestron) or a "Deltagraph" ($f = 990$ mm, $f/3.3$, basically a parabolic mirror with a highly sophisticated coma corrector, Astrooptik Keller), on hyper-sensitized technical pan film (tp2415 or 6415).

Dust trail computations

The orbit of P/Schwassmann-Wachmann 3 was integrated back to 1890, using the orbit from the JPL database, allowing for the gravitational effects of all nine planets and for the non-gravitational terms $A1$ and $A2$. Extending the computation further backwards was not attempted. Slight variation of the initial orbit resulted in massive changes in the times of perihelion passage when integrated to back to the pre-1890 years, indicating that the accuracy of the initial orbit does not warrant such an attempt. Then orbits of test particles having the orbital elements of the comet at perihelion, but different semimajor axis were generated, and integrated to the present time (using the gravitational effects of the major planets except Pluto). This approach is similar to that of McNaught & Asher for the Leonids [8].

Another approach would be to leave the semimajor axis unchanged and to vary the radiation pressure parameter β as done by Lyytinen and van Flandern [9]. However the results of both techniques are very similar as checked for the Leonids and for the Ursids (Lyytinen, *pers. comm.*).

For the integrations the orbit integrator K11, Version 3.0 by Christian Glowinski was used at an accuracy factor of 50 (for the comet integration) or 25 (for the trail computation). This is basically a Runge-Kutta integrator working with a dynamical adjustment of the integration interval. The main advantage is its possibility to process batch jobs, since computation times were quite lengthy on a 366-MHz Celeron PC. Software for generating the input batch files and for analyzing the output files were written by one of us. The resulting $r_{\mathrm{D}} - r_{\mathrm{E}}$ values were plotted as a function of perihelion time; this type of plot giving a rapid overview of even the most chaotic trails. Radiant positions were predicted using software published elsewhere [10]. Star maps were plotted using the package GUIDE 7.0.

3. Assessment of observational records

Reported 1930 meteors

Significant or even strong meteor activity observed from Japan in 1930 is often cited in connection with the discovery of Comet 73P/Schwassmann-Wachmann 3 in the same year. However, the term of a rich meteor display connected with that Comet needs caution.

When we look into the original Kyoto Bulletins of 1930, we find an interesting note in Bulletin 172 about enhanced meteor activity. T. Miyasawa observed faint meteors on May 21, 1930, from a radiant at $\alpha = 219\overset{\circ}{.}75$, $\delta = +29\overset{\circ}{.}67$ [11]. The estimated orbit seemed close to SW3's.

In Bulletin 173, we find details: Miyasawa observed 14 meteors in 1.13 hours (particular period: 11 in 0.42 hours), and his colleague K. Nakamura, 100+ in 0.42 hours [12]. They claim it was "impossible to record all of them." They noted "rapidly declining activity on later days" drawing the conclusion that the meteors are of "other origin than the above mentioned cometary orbit" (SW3, whose orbit was passed on June 9).

The predicted radiant according to Kyoto Bulletin 171 is $\alpha = 234\overset{\circ}{.}5$, $\delta = +44°$ (typo corrected in Kyoto Bulletin 173, [13,14]); if we use their parabolic orbit (Bulletin 171) for a modern radiant prediction by the program of Neslusan et al. [10], we get $\alpha = 219°$, $\delta = +45°$. If we use the orbit given by Kronk [2], we get $\alpha = 220°$, $\delta = +44\overset{\circ}{.}5$, with a minimum distance between the orbits of Comet and Earth of 0.005 AU. As the peak time was predicted for about June 9, a report by K. Nakamura emerges:

On June 9, 1930, he reports 59 in 1.00 hours; on June 10 he reports 36 in 0.50 hours. These rates of 60–70 meteors per hour are generally cited. However, the observations by K. Nakamura should be carefully scrutinized. A similar report for the June Bootids (Pons-Winneckids) in 1921 came from him which turns out to be most questionable. He always claims all meteors were very faint. Consider the comments about the SW3-meteors: "all of those meteors were very faint, and only few of them were as bright as 4th magnitude." There was a full Moon on June 9-10. He further writes about "June 9 and June 10 when bright lunar haloes were high above the southern horizon" [15]. Even observers with very high perception will hardly be able to spot a considerable number of +5 and +6 meteors under such poor conditions (moon and cirrus).

Another item makes us extremely cautious. Checking the original plots of Nakamura for the June Bootids we found that what he calls high activity consists of very many meteors which start *within* the radiant and move out of it for about 10° [16]. Every present-day meteor observer knows that this is nonsense. His companion observer, I. Yamamoto, provides much more consistent plots, though an activity around 10 at best for the 1921 June Bootids.

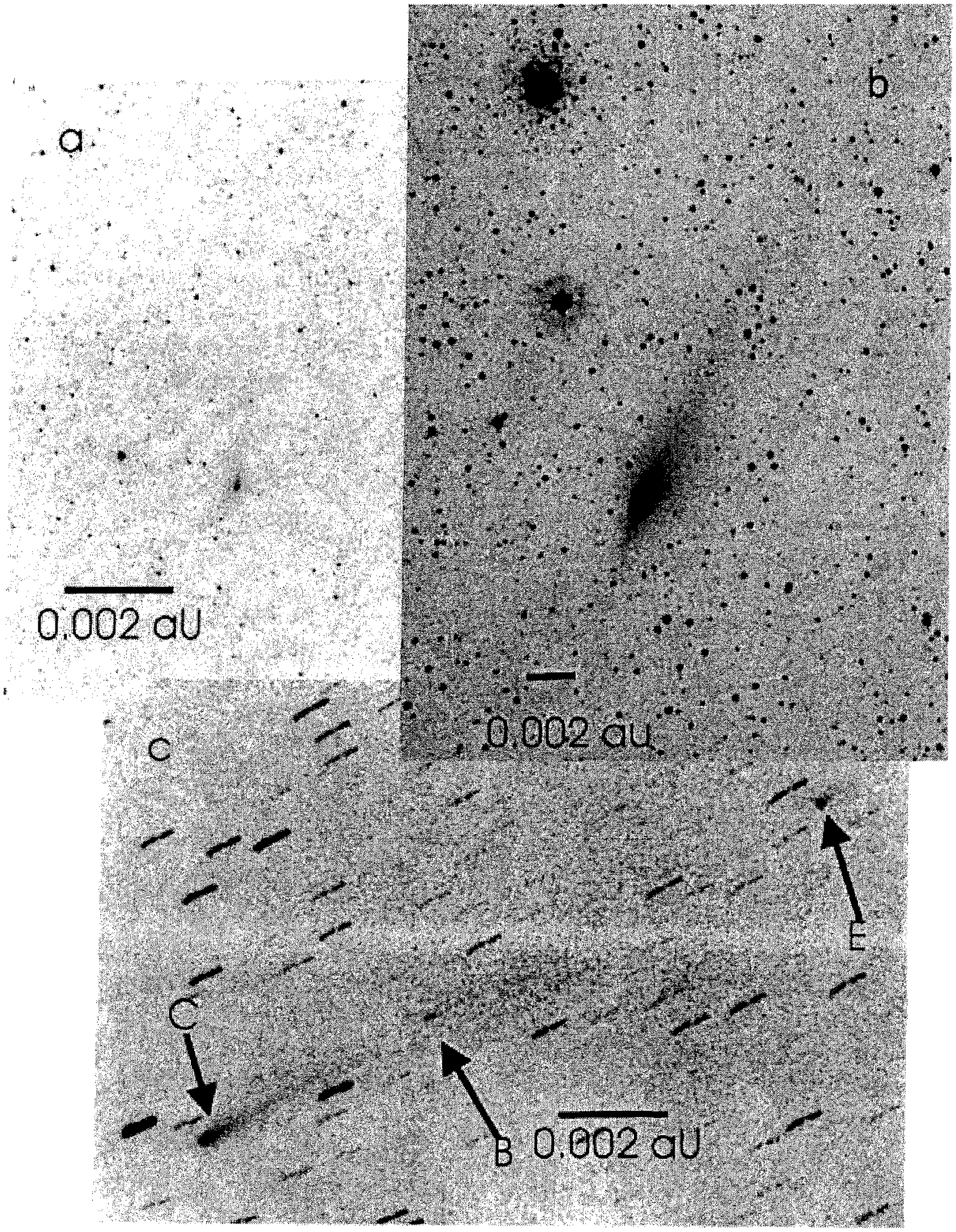

Figure 1 – Development of Comet 73P/Schwassmann-Wachmann 3 as shown by photographs of co-author MJ. a) April 3, 1990, 2^h36^m–2^h40^m UT, taken with the Schmidt camera. Although very close to the Earth ($\Delta = 0.41$ AU), the Comet is quite small and faint (magnitude +10.5). The scale of 0.002 AU is also shown. Note the small coma; the central condensation is surrounded by a faint (gaseous?) halo. b) Composite image of the Comet taken with the same camera on December 15, 1995, 17^h13^m–17^h18^m and 17^h22^m–17^h26^m UT. Although the Comet is very far away from the Earth ($\Delta = 1.79$ AU), it was about 2 magnitudes brighter than in 1990, and the coma was larger in size (compare the 0.002 AU scale). The bright globular cluster in the field is M30; c) the Comet during the somewhat unfavorable 2000 apparition, image taken with the Deltagraph on December 5, 2000. The image is a composite of two images guided indirectly on the Comet (4^h30^m–4^h44^m and 4^h50^m–5^h01^m UT). Three fragments are shown: The main object (Fragment C), the tiny Fragment B and the brighter Fragment E which was discovered by co-author MJ during the 2000 perihelion approach. All three fragments display tails.

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Other old sources

We tried to reveal other observations or at least hints on activity from a possible shower of the Comet. Very old reports in Chinese chronicles were compiled by Tian-shan [17]. He found a few descriptions of showers in May; one prominent example is that of 245 B.C. on April 12. This date would fall on May 13 for the epoch 1900. The striking fact is that Tian-shan infers a radiation from ζ Herculis ($\alpha = 250°$, $\delta = +32$) from the chronicle report.

Other sources of meteors in May are not reliably locatable and must be neglected. Only the report of 1539 is interesting as it has an exact date of May 30, corresponding to June 4 for the epoch 1900.

Without exact date but annotated with some additional information is the report from May 1910 describing that the meteors "glided as though weaving." We may interpret the word "weaving" as a non-linear motion, an impression which is much stronger for very slow meteors. The possible link to the η-Aquarids would thus not be suitable, but as the expression is also used for definite Leonid records (very high velocity), we cannot use the description for the distinction between η-Aquarids and Schwassmann-Wachmann-3 meteors.

The first comprehensive radiant catalog by Denning of 1899 gives quite a few suitably located radiants of which we list the most probable ones formed by considerable meteor numbers [18]. It is worth noting that Denning did not give any interesting radiant in his more recent list of 1923 [19]. The probability that the shower was active is thus somewhat higher for the last century then for the time 1900–1923; the only significant meteor sources are found from Italian 1872 data when a comprehensive meteor project was carried out by the Associazione Meteorica Italiana. The convergence position of 18 meteors at $\alpha = 210°$, $\delta = +48°$, for May 3–15, 1872, is found to be closest to the expected radiant area, though the date is early. Other convergence areas are made of 17 meteors from $\alpha = 215°$, $\delta = +55°$, for May 26–June 11, 1872, and 12 meteors from $\alpha = 214°$, $\delta = +16°$, for May 26–June 13, 1872.

The radiant list of Malzev reporting on meteors from 1929 does not contain any reasonable position [20]; the same holds for lists in the same journal of other years in the 1920s which we are not going to cite here explicitly. It is at least interesting that there was probably no notable activity in the year before the dubious outburst of 1930.

The analysis of 19 689 radar meteors by Sekanina [21] which were observed from 1966 to 1969 reveals no radiant clearly linked to Comet 73P/Schwassmann-Wachmann 3. Sekanina mentions a shower called α-Draconids at $\alpha = 207°$, $\delta = 64°$ for June 22 as the closest candidate, but it is obviously too far from the source we search for.

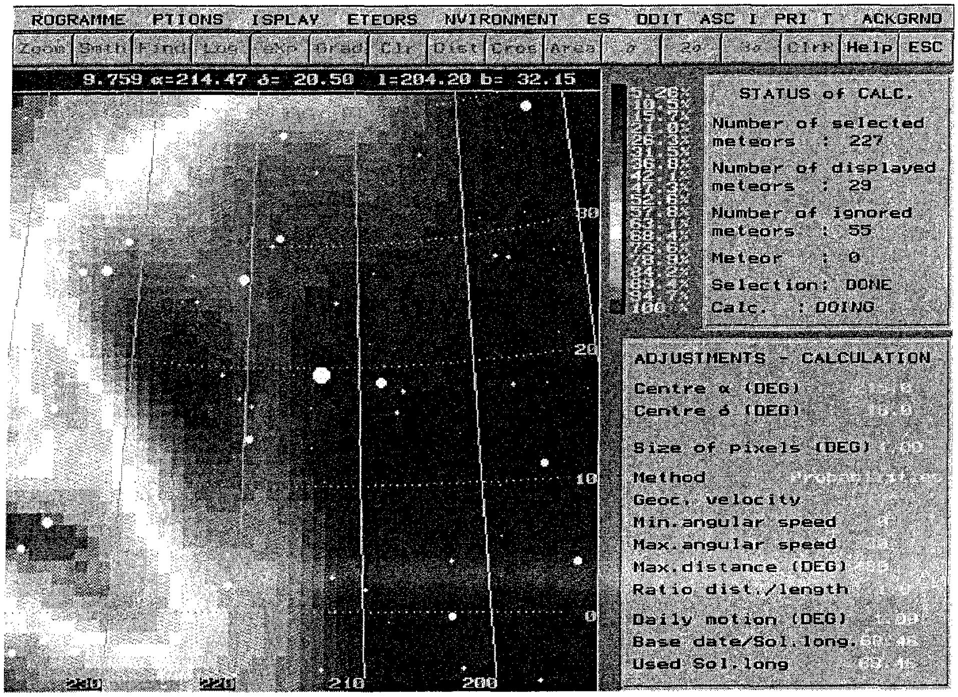
T. Hashimoto from the *Nippon Meteor Society* kindly searched the Society's Journal, the *Astronomical Circular*, for radiant determinations of the so-called May α-Bootids [22]. The five occurrences given in Table 1 may indicate weak annual activity, but the meteor numbers are small, and no real assessment of the data is possible without the original details. As the observers apparently searched for listed positions instead of unknown radiants, we cannot evaluate the prominence of these convergence points above the background noise level.

Table 1 – A search through the *Astronomical Circular*, the journal of the *NMS* (in Japanese), by Takema Hashimoto [22].

Date	α	δ	N	Observer
1969 May 17-18	215°	+25°	5	Y. Takeuchi
21-22	215°	+20°5	6	A. Kawagoe
1970 May 30-31	212°	+23°	4	Ogasawara
30-31	214°	+19°	7	Ogasawara
1971 May 30-31	215°	+20°	5	K. Oikawa

Recent observations

The full set of meteors recorded by intensified video within the network of the Arbeitskreis Meteore and by other camera operators contains more than 24 000 meteors [23]. We checked the period May 20–June 10 of 1999 and 2000 for a possible convergence of meteors near the theoretical position in Bootes. The methods of radiant determination with the Radiant program are described in [24]. We used the most elaborate probability mode and considered zenithal attraction and diurnal aberration. None of the radiant distributions shows an indication for meteors from Schwassmann-Wachmann 3 in 1999–2000 as covered by the video data. An example of such a radiant distribution is shown in Figure 2



STATUS of CALC.
Number of selected meteors : 227
Number of displayed meteors : 29
Number of ignored meteors : 55
Meteor : 0
Selection: DONE
Calc. : DOING

ADJUSTMENTS - CALCULATION
Centre α (DEG) [illegible]
Centre δ (DEG) [illegible]
Size of pixels (DEG) [illegible]
Method [illegible]
Geoc. velocity [illegible]
Min.angular speed [illegible]
Max.angular speed [illegible]
Max.distance (DEG) [illegible]
Ratio dist./length [illegible]
Daily motion (DEG) [illegible]
Base date/Sol.long. [illegible]
Used Sol.long [illegible]

Figure 2 – Radiant analysis of the SW3-ids from video meteor monitoring in 1999 and 2000.

This is at odds with the weak but possibly distinct activity from the source of the so-called May α-Bootids as reported by the Nippon Meteor Society [25]. We use the data reported therein to obtain a rough ZHR profile. Quite a few observers among the contributors have very high corrected sporadic hourly rates. Since the numbers of sporadic meteors are larger than those of the shower, we obtain perception corrections from the sporadic rates assuming a standard value of HR=15 (which is certainly an upper limit). These corrections are: Seishi Akagi (AKASE), $c_{\mathrm{p}} = 0.9$, Takema Hashimoto (HASTA), $c_{\mathrm{p}} = 2.3$ Hiroyuki Kodama (KODHI), $c_{\mathrm{p}} = 0.8$, Kazuhiro Osada (OSAKA), $c_{\mathrm{p}} = 3.5$, Mitsue Sakaguchi (SAKMI), $c_{\mathrm{p}} = 1.3$, Koetsu Sato (SATKO), $c_{\mathrm{p}} = 1.3$, and Kazuhiro Sumie (SUMKA), $c_{\mathrm{p}} = 2.5$, Satomi Yokochi (YOSKA), $c_{\mathrm{p}} = 1.2$, for Mikiya Sato (SATMI) we assumed $c_{\mathrm{p}} = 1.0$ because of lack of data. The average ZHR is thus calculated by

$$\overline{\mathrm{ZHR}} = \left(1 + \sum_i n_i\right) \bigg/ \sum_i \frac{T_{\mathrm{eff},i}}{C_i}$$

as was described in [26]. The values of C_i include the also the perception correction c_{p} here. We have to emphasize that the the c_{p}-values for some of the observers are extremely large, and the straight-forward calibration with c_{p} might not be applicable.

Figure 3 shows the resulting activity profile; significant ZHRs are found in the beginning of the period. Rates drop below the typical detection limit for a minor shower (ZHR ≈ 1) at $\lambda_\odot = 70°$ (June 1). The average limiting magnitude is given in the upper part of Figure 3 and shows that there is no trend because of the the waning Moon. Systematic effects of decreasing lunar interference during the investigated period (last quarter at $\lambda_\odot = 65\overset{\circ}{.}6$) are thus unlikely. It is regrettable that the ascending branch of the profile is not available. The entry-velocity of the Schwassmann-Wachmann-3 meteoroids is near 17 km/s, and all meteors will appear extremely slow. As the observers of the "May α-Bootids" in Japan report meteors up to medium velocity, we suppose that a few additional sporadics might contaminate the rates given in Figure 3. Weak activity was also reported in 1998 from the same source [27]. More observational facts will be given in the sections about the dust-trail encounters.

Since several radiant lists and reports note activity from a radiant close to the theoretical position at Schwassmann-Wachmann debris, we conclude that a weak annual source of this stream exists.

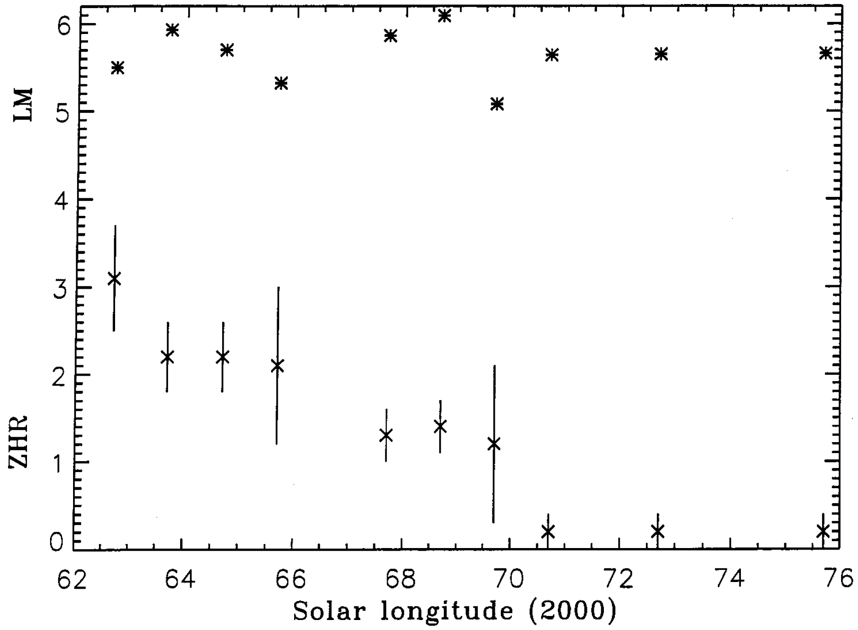


Figure 3 – ZHR-profile for the 2000 SW3-ids reported by Japanese observers. The upper dots give the average limiting magnitude of the same bins.

4. Dust trail encounters in the 20th century

The dust trail situation in 1930

Dust trail computations do not show any direct evidence for enhanced activity. In the $r_D - r_E$ versus T plot (Figure 4) particles within the 1892 dust trail do cross the Earth orbit in May, but the encounter geometry with this trail is quite unfavorable. When the Earth is close to the node, particles were more than 0.01 AU from the Earth. Uncertainty of the comet orbit may shift the trail's position somewhat. However, the nodal longitudes of these particles are at $77\overset{\circ}{.}75$, corresponding to June 8.30 UT, 1930. This is more than 1 day from the time when Nakamura reported his outburst. Other trails do not approach closer than 0.01 AU. The nodal longitudes of their closest particles ($\lambda_\odot = 77\overset{\circ}{.}71$ to $77\overset{\circ}{.}90$) do not match Nakamura's observing time either. A radiant computed with the 1892 trail orbit gives $\alpha = 219°$, $\delta = +45°$, far away from the listed radiant of Nakamura.

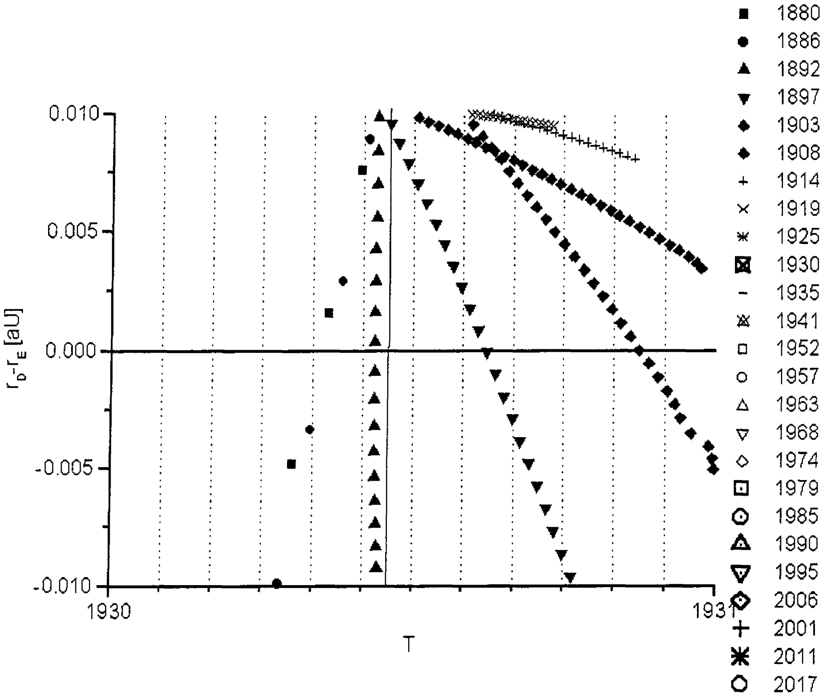


Figure 4 – Distance of the particle at the node from the orbit of the Earth ($r_\mathrm{D} - r_\mathrm{E}$) as a function of Perihelion time T. The particles reaching the node at the same time as the Earth are marked with the vertical line. Dust trails approaching Earth during 1930 are shown. Earth is not at the intersection with the 1892 trail at the proper time.

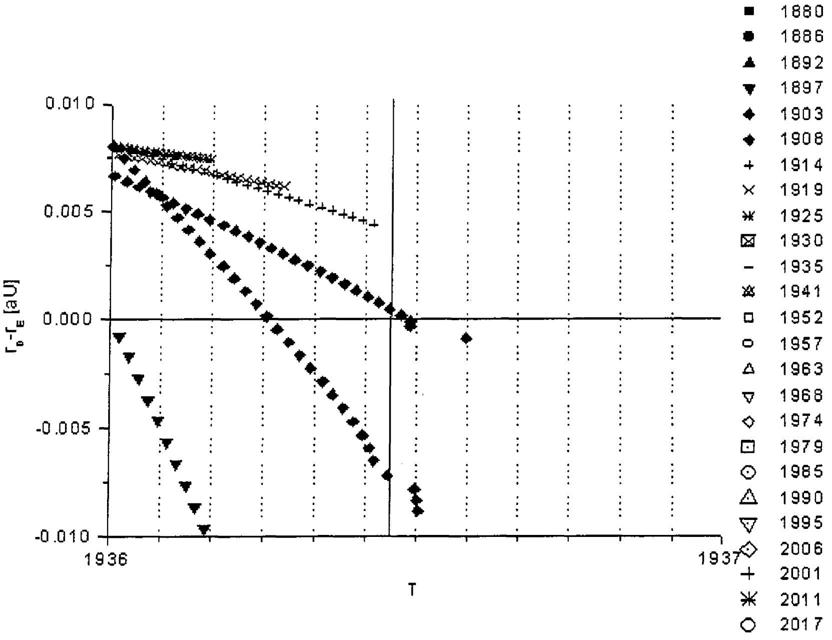


Figure 5 – Distance of the particle at the node from the orbit of the Earth ($r_\mathrm{D} - r_\mathrm{E}$) as a function of Perihelion time T. The particles reaching the node at the same time as the Earth are marked with the vertical line. Dust trails of particles that reach perihelion in the year 1936 are shown. Note the close encounter with the 1908 trail that should have generated a significant meteor activity on June 7, around $18^\mathrm{h}43^\mathrm{m}$ UT.

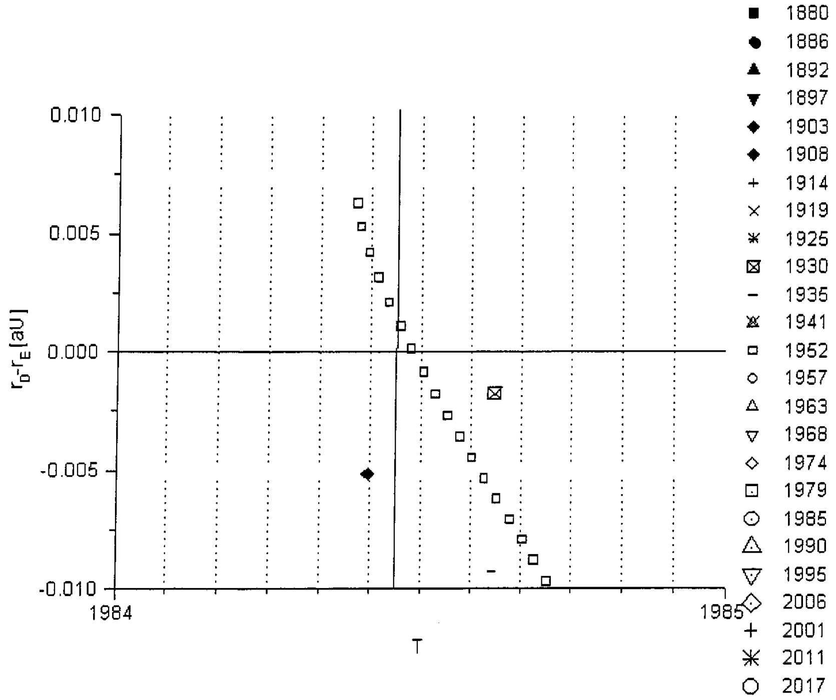


Figure 6 – Fig. 6: Dust trail situation in 1984. Although the miss distance was higher than in 1936, there might have been some activity at June 3, around 11^h17^m UT.

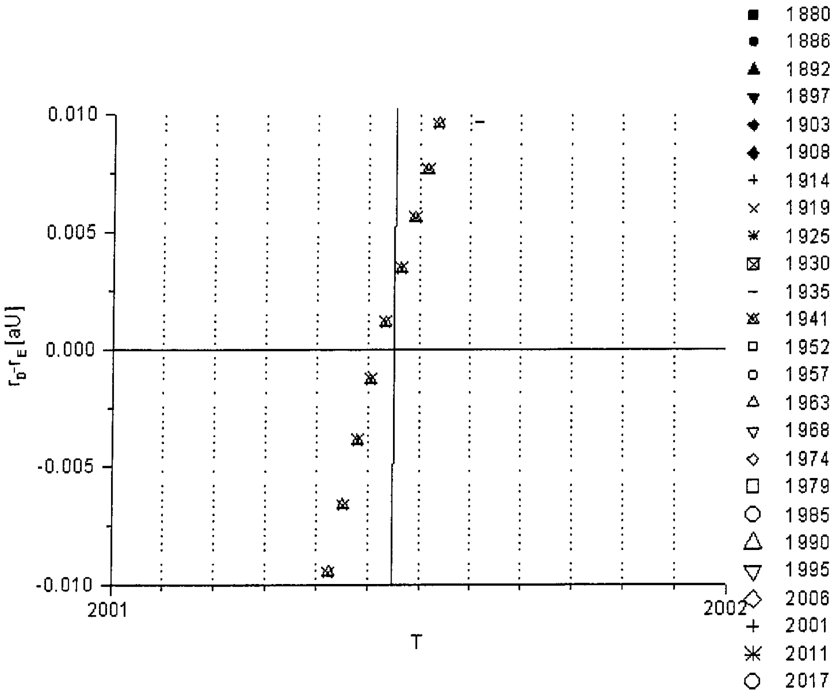


Figure 7 – Dust trail situation in 2001. We pass the 1941 dust trail at a somewhat large miss distance of 0.023 AU on May 30, 9^h50^m UT

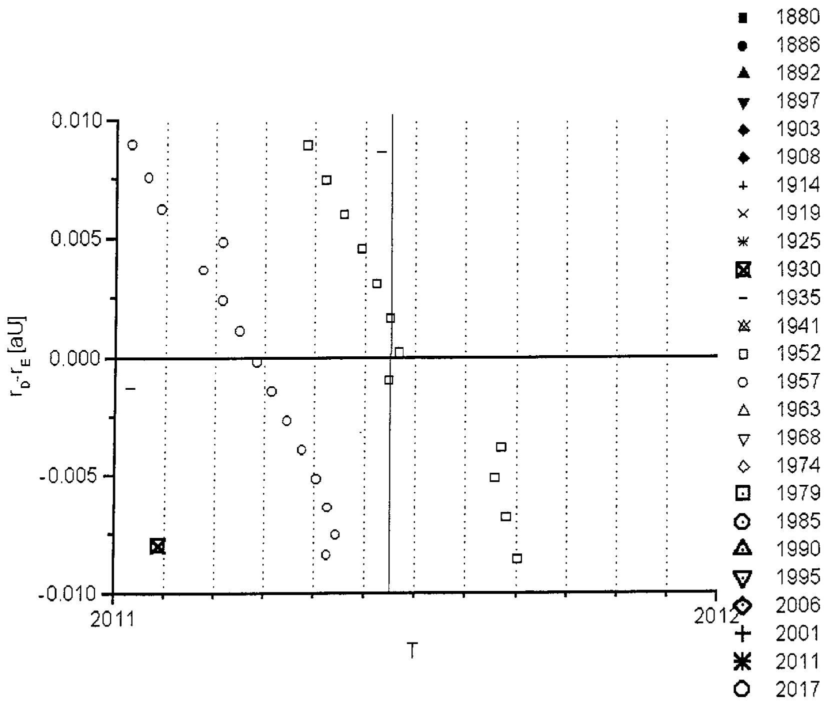


Figure 8 – Dust trail situation in 2011. We will pass the 1952 dust trail at a distance of about 0.0011 AU.

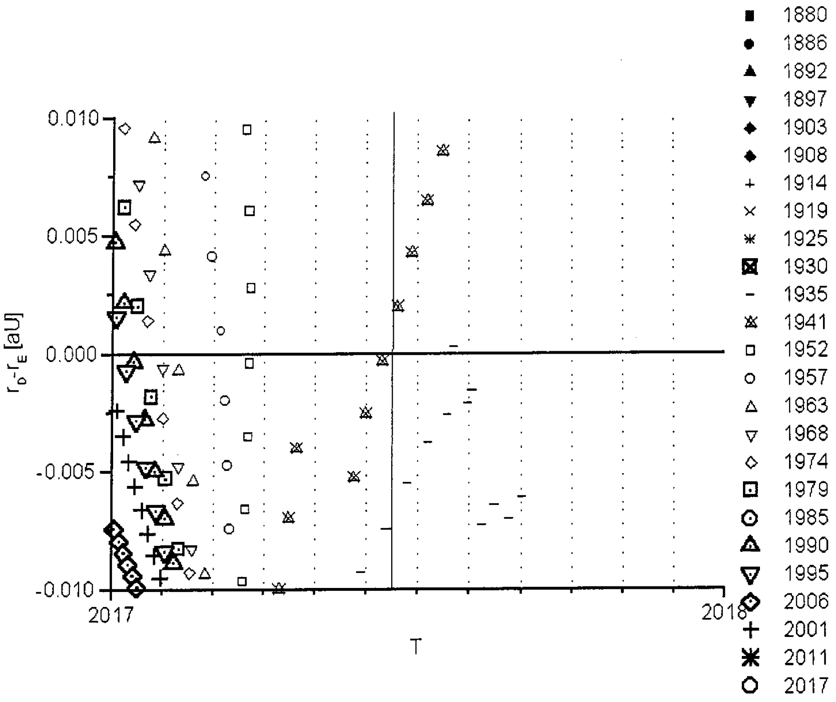


Figure 9 – The 2017 dust trail situation. We will pass the 1941 dust trail at a smaller distance than in 2001. ($r_D - r_E = 0.0013$ AU).

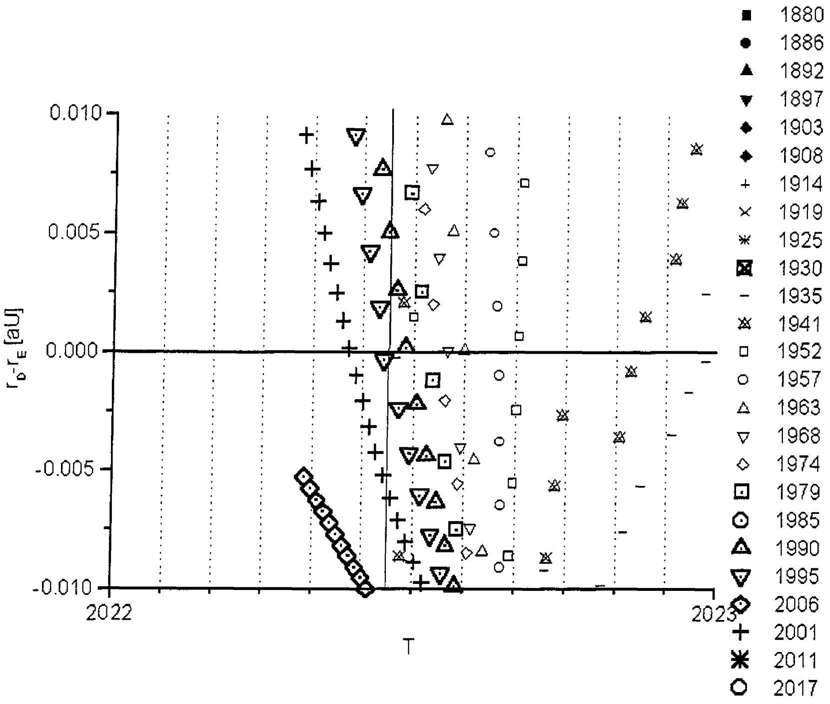


Figure 10 –Probably the best chance to see an SW3-id display will come in 2022, when we pass the 1995 trail at about only 0.0004 AU distance. The display is especially promising: the disintegration of P/SW3 in 1995 should have introduced a lot of dust particles into the trail.

This result does not exclude the possibility that Nakamura observed an outburst from a trail older than those studied here. Since they report activity not only during the reported outburst, but during the week before, their report may reflect a broad background activity rather than a true outburst. Since the orbit in the pre-1890 years appears to be ill defined, we did not check these possibilities by integrating very old trails. Taking all factors together it appears that, apart from the activity enhancement in May 1930, there was *no activity* from Schwassmann-Wachmann 3 on June 9-10. This is supported by Yamamoto's comment that Nakamura "was practically the sole observer of this rich display."

1936 meteors

Figure 5 shows the dust trails in 1936.There is a very close encounter with particles ejected in 1908 ($r_D - r_E = 0.0003$ AU). Of all past encounters found in this study this appears to be the most promising, especially as the particles have a positive value of Δa_0. Particles can reach this position in the trail not only by the ejection process itself, but because radiation pressure will tend to move particles towards positive Δa_0 values. A scan in old archives may be worthwhile, but perhaps the display remained unobserved. Viewing geometry would have favored the Middle East. The radiant will have been a bit low in China and even lower in Japan, and there was a 19-day-old moon in the sky. In Europe it turned dark hours later, but perhaps the descending slope of the peak may have been observed, especially in eastern Europe.

1984 meteors

The next promising-looking encounter is the passage of the Earth near the 1952 trail in the year 1984 (Figure 6). The miss distance (0.0023 AU) was much larger than in 1936. However, uncovering old observations may be easier for 1984. The encounter should have taken place on June 3 around $11^{\mathrm{h}}17^{\mathrm{m}}$ UT. The 4-day-old moon was surely not a problem. At the US west coast evening twilight was just ending at the time of the maximum, whereas in Japan it fell into the morning twilight. Hawaii would have been an ideal place to see that maximum. In any case, plotting data from the hours before and after the expected outburst would be interesting to check for activity from the radiant in the head of Bootes. Katz observed from Canada a maximum hourly rate of six SW3-ids. "This marked some of the highest rates in recent years" [28]. Before being taken as confirmation of the dust trail prediction, the original observations from 1984 should be carefully reanalyzed, since most observers in the past assumed a wrong radiant position (see below). Unfortunately, the observations are not included in the *IMO* database which is comprehensive starting with 1988 only.

5. Comet 73P/Schwassmann-Wachmann 3 1990–2000—the decade of breakup

In 1990, the Comet was no brighter than magnitude +9, despite a close approach to Earth. Figure 1a shows the feeble Comet at a distance of only 0.41 AU ($r = 1.15$ AU, pre-perihelion). A faint outer gaseous coma is visible. The post-perihelion photographs of 1995 (Figure 1b) do not show this outer coma. Photographs using the blue-sensitive emulsion Ectagraphic HC (not shown), which records gas tail and coma structures much better than the red-sensitive tp2415, did not reveal traces of any outer gas coma in 1995. Nevertheless the coma was much larger and brighter than in 1990, considering the larger image scale at the much larger geocentric distance. A (dust) anti-tail is visible in Figure 1b. These images give the impression that during the 1995 outburst/breakup event much more dust was released than during typical perihelion passages of the Comet.

The fragments that were originally discovered in 1995 separated drastically during the following revolution of the Comet. In 2000, the observational conditions were quite inferior to both 1990 and 1995. Comet 73P/Schwassmann-Wachmann 3 was visible before perihelion, with the Comet at a very large geocentric distance of about 2 AU. Nevertheless, the Comet still displayed an increased brightness compared to 1990 and no faint gaseous outer coma. Figure 1c shows, besides the main object (termed Fragment C), the faint fragment of B which was already observed in 1995 and separated from the Comet ($\Delta T = 0.3$ days). The brighter Fragment E, obviously also ejected in 1995 but not observed at that perihelion passage, was first discovered in 2000 by co-author MJ.

6. Future meteor events

After the 1995 disintegration of the Comet, massive amounts of dust appear to have been ejected, and it may be promising to look for SW3-id activity in the coming years. Especially in the years 2017 and 2022 we will be closer to the Comet orbit than in the years before. Therefore we extend this study to these upcoming encounters. It appears that in the years 2011, 2017 and 2022 we may expect meteor activity from the Bootes radiant. The 2022 encounter seems to be especially promising since we pass very close to the possibly richly populated 1995 trail.

Possible 2001 meteors

This encounter does not seem to be especially favorable, with a miss distance even larger than in 1984 (Figure 7). However, since the encounter occurs this year we feel obliged to warn the meteor community of the possible display, although rates may be low. The passage near the 1941 trail occurs at May 30 at $9^{\mathrm{h}}50^{\mathrm{m}}$ UT. Conditions will be fine in the western parts of the US, where the radiant will be 40° high with the Sun 25° below the horizon. The first quarter moon will just have set.

Possible 2011 and 2017 meteors

The next encounters with dust trails will be in 2011 (1952 dust trail, Figure 8) and in 2017 (1941 dust trail, Figure 9). The miss distance will be still fairly large (0.0013 and 0.0011 AU, respectively), but in any case half as far as in 1984 and 2001. On June 2nd, 2011, the maximum will happen at 5:46 UT, favoring observers throughout the USA. The moon is new. In 2017 the eastern and central parts of the USA will have the radiant directly overhead. Even in westernmost Europe the maximum will occur in bright twilight, only the Canary Islands will see it in a dark sky, but with the radiant at about 30 degrees altitude. Again, the waxing moon (5 days old) won't interfere too much.

Possible 2022 meteors

The probably best chance for some activity will be in 2022, when we very narrowly pass the possibly richly populated 1995 dust trail (Figure 10), at a miss distance no more than 0.0004 AU. This maximum will occur at $4^{\mathrm{h}}55^{\mathrm{m}}$ UT on May 31, again favoring the USA. On the Canary islands, twilight will just have begun, and the radiant will be about 11° high. However in the US, the radiant will again be directly overhead.

7. Conclusions

Overview of past and future trail encounters

Table 2 shows a compilation of the Earth's passages close to SW-3 dust trails found in this study. The rates of all these displays are hard to predict, since there is no reliable previous observation helping to establish any idea of the particle distribution as a function of Δa_0. Since all the displays occur at negative Δa_0, on orbits which radiation pressure cannot assist particles to achieve, we feel that the rates would not be too high. This is especially true for the 2001, 2011 and 2017 events. However it appears possible that careful observation may establish some activity at the times of the predicted maxima. We are a bit more hopeful for the 2022 event, since the miss distance $r_{\mathrm{D}} - r_{\mathrm{E}}$ is much smaller, and the chance is that the trail is more populated due to the massive expulsion of dust observed in 1995.

Table 2 – Overview of six close encounters with dust trails ejected from Comet 73P/Schwassmann-Wachmann 3. The geocentric velocity V_{g} (given in km/s) needs to be increased by the about 4 km/s for observing purposes due to the gravity of the Earth.

Date of encounter	Trail	Δa_0	$r_{\mathrm{D}} - r_{\mathrm{E}}$	Node (J2000.0)	α	δ	V_{g}
1936 June 7.78	1908	+0.051	0.0003	77°.69	221°.5	+44°.7	13.9
1984 June 3.47	1952	−0.052	0.0023	77°.28	219°.3	+36°.8	13.2
2001 May 30.41	1941	−0.027	0.0026	69°.04	212°.2	+28°.4	12.5
2011 June 2.24	1952	−0.022	0.0011	71°.22	214°.2	+33°.5	12.9
2017 May 31.136	1941	−0.012	0.0013	69°.64	212°.6	+29°.7	12.4
2022 May 31.205	1995	−0.022	0.0004	69°.44	205°.4	+29°.2	12.1

Predicted radiants

Table 2 also shows the radiant positions, which were computed from the particle orbits that were passing the Earth at the closest possible distance. We plotted these radiant position with Guide 7.0 (Figure 11). It should be noted that the radiant commonly listed for the SW3-ids ($\alpha = 236°$, $\delta = +41°$) is based on observations (or better: a radiant prediction of a preliminary orbit of the parent Comet) of 1930. The designation of these meteors as τ-Herculids is extremely confusing and should be avoided, since the meteors in fact should come from an area between Bootes and Coma. Correct radiant positions should be considered when the shower is observed in 2001, and when old plots from the interesting years are reanalyzed.

The enormous spread in the predicted radiant positions (Figure 11) is also important for the detection of a possible annual activity. It is due to two factors: the orbit of the particles is strongly affected by frequent passages close to Jupiter, and the radiant is very close to the antapex. Due to the vectorial addition with the movement of the Earth slight changes in the orbits of the particles translate to large variations in the radiants. A similar case is the June Bootids which also display quite an extended radiant [29]. Thus it has to be considered that SW3-id meteors do not come from a distinct radiant, but emerge from quite a large area in the sky.

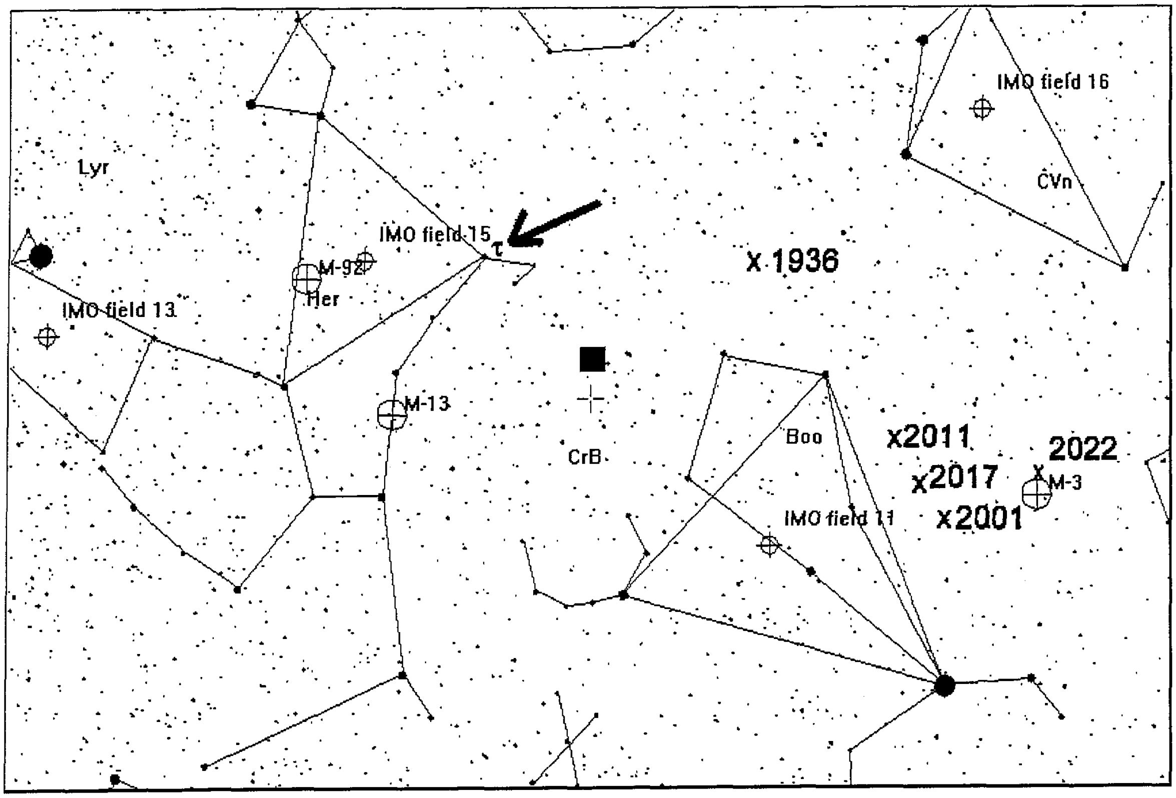


Figure 11 –Localization of the predicted radiants for the SW3-ids dust trail encounters plotted with GUIDE 7.0 (crosses). The gray square marks the frequently cited radiant position of $\alpha = 236°$, $\delta = +41°$. An arrow indicates the star τ Her.

References

[1] S.K. Vsekhsvyatskii, "Physical Characteristics of Comets. (Fizicheskie kharakteristiki komet)", Israel Program for Scientific Translations, Jerusalem, 1964.

[2] G. Kronk, "Comets—a Descriptive Catalog", Enslow Publ., 1984.

[3] C.S. Morris, G.W. Kronk, G. Garradd, J.G.de S. Aguiar, T. Lovejoy, A. Hale, R. Keen, "Comet 73P/Schwassmann-Wachmann 3", *IAUC*, 6246.

[4] H. Bohnhardt, H.U. Kaufl, R. Keen, P. Camilleri, J. Carvajal, A. Hale, "Comet 73P/Schwassmann-Wachmann 3", *IAUC*, 6274.

[5] J.V. Scotti, A. Galad, H. Bohnhardt, H.U. Kaufl, J. Chen, D. Jewitt, K. Reinsch, J. Storm, Z. Sekanina, "Comet 73P/Schwassmann-Wachmann 3", *IAUC*, 6301.

[6] J. Crosevier, D. Bocklée-Morvan, E. Geraud, H. Rauer, N. Biver, P. Colom, L. Jorda, "What happened to comet 73P/Schwassmann-Wachmann 3?", *Astron. Astrophys.* 310, 1996, pp. L17–L20.

[7] K. Kadota, M. Jaeger, A. Galad, P. Koleny, A. Hale, S. Yoshida, "Comet 73P/Schwassmann-Wachmann 3", *IAUC*, 7534.

[8] R.H. McNaught, D.J. Asher, "Leonid dust trails and meteor storms", *WGN* 27, 1999, pp. 85–102.

[9] E. Lyytinen, T. van Flandern, *Meta Res. Bull.* 8, 1999, pp. 33–40.

[10] L. Neslušan, J. Svoreň, V. Porubčan, "A computer program for calculation of a theoretical meteor stream radiant", *Astron. Astrophys.* 331, 1998, pp. 411–413.

[11] "Detection of the new meteoric shower probably connected with the Comet 1930d", *Kyoto Bull.* 172, 1930, p. 2.

[12] "On the Epsilon Bootid Meteors of last May", *Kyoto Bull.* 173, 1930, p. 1.

[13] "New Comet Schwassmann, 1930d", *Kyoto Bull.* 171, 1930, pp. 1–2.

[14] "A Correction", *Kyoto Bull.* 173, 1930, p. 1.

[15] "Observations of the Expected Meteors from the Orbit of Comet Schwassman-Wachmann, 1930d", *Kyoto Bull.* 174, 1930, p. 1.

[16] I. Yamamoto, K. Nakamura, *Mem. College Sci., Kyoto Imperial Univ.* 5,1922, p. 277.

[17] Z. Tian-shan, "Ancient Chinese Records of Meteor Showers", *Acta Astr. Sinica* 14, 1966, pp. 37–58.

[18] W.F. Denning, "General Catalogue of the Radiant Points of Meteoric Showers and of Fireballs and Shooting Stars at more than one Station", *Mem. R. Astron. Soc.* 53, 1899, pp. 203–293.

[19] W.F. Denning, "Radiant Points of Shooting Stars observed at Bristol chiefly from 1912 to 1922 inclusive", *Mon. Not. R. Astron. Soc.* 84, 1923, pp. 43–56.

[20] V.A. Malzev, *Bull. Tashkent Astron. Obs.* No. 1, 1933, pp. 17–23.

[21] Z. Sekanina, "Statistical Model of Meteor Streams. IV. A Study of Radio Streams from the Synoptic Year", *Icarus* 27, 1976, pp. 265–321.

[22] *T. Hashimoto.*message on `meteorobs` mailing-list, June 2000

[23] M. Nitschke, "The German Video Network: an All-Year Automated Meteor Patrol", *Proc. IMC Pucioasa 2000*, Potsdam, 2001, p. 68.

[24] R. Arlt, "The Software Radiant", *WGN* 20, 1992, pp. 62–69.

[25] T. Hashimoto, "May alpha-Bootids appeared again on May 23, 2000", *meteorobs mailing-list and* , `http://www.din.or.jp/~thashi/Inf2000_05_MAB_E.htm`.

[26] R. Arlt, "The Analysis of a Weak Meteor Shower: The June Bootids in 2000", *WGN* 28, 2000, pp. 98–108.

[27] T. Hashimoto, "May alpha-Bootids appeared on May 23, 1998", `http://www.din.or.jp/` ~thashi/Inf2000_05_MAB_E.htm.

[28] G. Kronk, "Meteor showers—a Descriptive Catalogue: Tau Herculids", Web site chapter at `http://www.comets.amsmeteors.org/meteors/showers/tau_herculids.html`, also book published by Enslow Publ., 1988.

[29] J. Rendtel, R. Arlt, V. Velkov, "Surprising Activity of the 1998 June Bootids", *WGN* 26, 1998, pp. 165–172.

Authors' addresses:

Hartwig Lüthen, Behnstr. 13, D-22767 Hamburg, Germany,
`h.luthen@botanik.uni-hamburg.de`,

Rainer Arlt, Friedenstr. 5, D-14109 Berlin, Germany, `arlt@compuserve.com`,

Michael Jäger, Seiberer Str. 225, A-3610 Weissenkirchen, Austria.