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The τ Herculid meteor shower and Comet 73P/Schwassmann–Wachmann 3

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ABSTRACT

The τ Herculid meteor shower has not shown any appreciable activity since 1930. However, it is associated with Comet 73P/Schwassmann–Wachmann 3, a Jupiter-family comet that split in 1995. The fragments will pass near the Earth on 2006 May 13, and could produce an outburst of the τ Herculid shower. However, by considering both meteoroids released during the splitting event and on previous perihelion passages back to 1801, we find no evidence for enhanced activity from this shower in 2006. This is a result partly of the dynamics of the parent comet, which suffers frequent close encounters with Jupiter, and partly of the location and timing of the splitting event, which produces a distribution of meteoroids that does not approach the Earth particularly closely. In fact, we show that the 1930 observations date from one of the few expected appearances of the τ Herculid shower and predict that detectable activity will be produced in 2022 and 2049.

Key words: comets: individual: 73P/Schwassmann–Wachmann 3 – meteors, meteoroids.

1 INTRODUCTION

The τ Herculid shower has been linked, based on orbital similarity (Southworth & Hawkins 1963), with Comet 73P/Schwassmann–Wachmann 3 (SW3), a small (∼1.5 km radius; Sanzovo et al. 2001) Jupiter-family comet discovered in 1930 May. The comet was faint (apparent visual magnitude of 6–7) despite passing only 0.0616 au from the Earth. There was a single unconfirmed report of a double nucleus during its discovery apparition (Schuller & Struve 1930), which stimulated the first observations of the τ Herculid shower (Nakamura 1930). Intrinsically faint and suffering occasional close encounters with Jupiter, SW3 was not observed on its subsequent perihelion passage in 1935–36 and was not recovered until 1979. Comet 73P/Schwassmann–Wachmann 3 was again missed on its return in 1985–86 but was seen in 1990, a ‘good’ apparition with the comet reaching 9th magnitude as it passed 0.36 au from the Earth (Kronk 1984).

The 1995–96 apparition was expected to be a poor one owing to a large Earth–comet distance. However, radio observations of SW3 taken just after the comet’s minimum solar elongation and approximately 2 weeks before its perihelion date (1995 September 22; Marsden & Williams 2003) showed a dramatic increase in OH production (Crovisier et al. 1995). Initially undetectable with an upper limit of a few times 10^{28} molecules per second, it peaked a few days later at $2.22 \pm 0.22 \times 10^{29}$ molecules per second (Crovisier et al. 1996), only a factor of 10 below the peak production rates observed for the much larger 1P/Halley during its 1986 apparition (Weaver et al. 1986). Visual observations also showed a sharp increase from $V = +12.8$ a month before perihelion to $V = +5.5$ one month after, despite its large (1.3–1.6 au) distance from the Earth during this period. In 1995 December, sub-nuclei were discovered within the coma, indicating that the comet had split (Bohnhardt et al. 1995). Three to five fragments were reported by different observers. An analysis of the motion of the fragments by Sekanina et al. (1996) (see also Scotti et al. 1996) indicated that the splitting of the nucleus occurred a month or more after the start of the cometary outburst, a conclusion that our own study supports (see details in Section 3.1). On their next return, three fragments (B, C and E) were seen, with the brightest (C) presumed to be the main remnant of the original comet.

On 2006 June 9, the comet will again pass perihelion (Marsden & Williams 2003). On 2006 May 13, as fragment C approaches the Sun, it is expected to pass 0.0735 au from the Earth, with fragments B and E passing even closer (0.0515 and 0.0505 au, respectively). Fragment A will pass at a much larger distance, though uncertainties in its orbit are sufficient to allow for an equally close encounter in the same time frame. We note that these values are sensitive to the non-gravitational parameters assumed, and even closer approaches are possible. Thus a swarm of comet fragments of various sizes, ranging from kilometre sized on down, will pass near the Earth in 2006, and the possibility exists that the τ Herculid shower, typically unimpressive, could be dramatically stronger than usual. Section 2 provides an overview of the methods used to study SW3 and the τ Herculid shower, Section 3 describes the results, and our conclusions are presented in Section 4.

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2 THE MODELS

Numerical simulations were used to determine the time of fragmentation of SW3, as well as to examine both meteoroids ejected during the 1995 cometary outburst and those released by SW3 at earlier perihelion passages. The two sets of meteoroids were handled slightly differently for purely practical reasons. Two separate numerical codes, each well tested and tailored to slightly different strengths, were used, one for each set.

The meteoroids released during the cometary outburst were integrated with a Wisdom–Holman (Wisdom & Holman 1991) type code modified to handle close approaches symplectically by the hybrid method (Chambers 1999). The simulated meteoroids were released from SW3 (as determined from the pre-fragmentation orbit) as well as from each of the four individual fragments deemed to have sufficiently accurate orbits (A, B, C and E). The meteoroids were released in sets of 100 with ejection velocities of 1, 10 and 100 m s^{-1} (typical cometary ejection velocities; e.g. Whipple 1951; Jones 1995) and a radiation pressure parameter β of 0 or 0.001, chosen to span the values expected for large (centimetre sized or larger) particles down to those of a few hundred microns across. Other secondary simulations released meteoroids at 1000 m s^{-1} to provide a look at the extreme outer envelope of the meteoroid complex. A total of 64 000 hypothetical meteoroids were examined. The simulations were run on multiple Itanium 2 processors at the Shared Hierarchical Academic Research Computing Network (SHARCNET) in London, Canada.

A plot of the original orbit of SW3 is shown in Fig. 1. The orbital elements used for SW3 and its fragments are those of Rocher (1996a, 1996b, 2001, 2002a,b), available on the IMCCE website (http://portail.imcce.fr), and listed in Tables 1 and 2.

The release times were chosen at 10-d intervals over a span of 130 d from 1995 August 19 (JD 244 9948.5), the earliest time the cometary outburst could have started, to 1995 December 27 (JD 245 0078.5), well after the last splitting event could have occurred both by our own analysis and by that of Sekanina et al. (1996). This time range includes the peak of OH production observed on September 11–13, is centred roughly on the observed peak in visual brightness in mid-October and stretches through the heightened activity seen for the rest of the year (Crovisier et al. 1996). These meteoroids were then integrated forward to 2006 and their distance

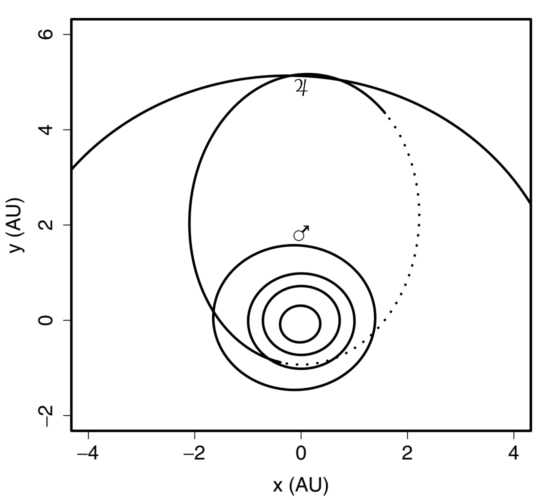

Figure 1. The original orbit of Comet 73P/Schwassmann–Wachmann 3 in 1995. The orbits of Mars and Jupiter are labelled. The dotted portion of the orbit is below the ecliptic.

Table 1. The orbital elements (J2000) of Comet 73P/Schwassmann–Wachmann 3 from Rocher (1996a). M is our derived mean anomaly at the epoch in question. The Style II non-gravitational parameters A_1, A_2 and A_3 are in units of 10^{-8} au d^{-2}. The number of observations and the mean residual σ of the orbital fit are also listed.

	73P/SW3
a (au)	3.0566720 ± 0.0000211
e	0.6948404 ± 0.0000019
i	11°.4237836 ± 0°.0000354
Ω	69°.9474738 ± 0°.0002096
ω	198°.7704871 ± 0°.0001933
M	3°.155407395 ± 0°.00003585
A_1	0.58788
A_2	0.04913
A_3	−0.16827
Epoch (JD)	245 0000.5
observations	202
σ (arcsec)	0.87

from the Earth monitored to determine whether increased activity of the τ Herculid shower was to be expected as a result of the splitting event.

Meteoroids released from SW3 during previous perihelion passages were modelled in essentially the same manner as done by Vaubaillon, Colas & Jorda (2005). A simple physical model of the comet nucleus is used to simulate the ejection of meteoroids, which are then integrated with the RADAU15 (Everhart 1985) algorithm. Table 3 provides the physical parameters used.

The ejection model used here is taken from Crifo & Rodionov (1997). The typical ejection velocity for a 1-mm-size meteoroid ranges from 0 to 40 m s^{-1}. Ejection takes place only at heliocentric distances of less than 3 au and at ejection angles z to the sub-solar point in the range [$0° \leqslant z < 90°$] (i.e. in the sunward hemisphere).

From this model, numerical simulations were performed to examine whether the Earth did or will encounter the resulting stream. The simulated meteoroids were assigned to five size bins: [0.1;0.5], [0.5;1], [1;5], [5;10] and [10;100] mm. This covers the range of meteoroid sizes responsible for visual meteors. Meteoroid ejections from 38 perihelion returns of the comet were considered, from 1801 to 2006, since spreading of the meteoroids over time means that the most recent apparitions are typically the most important contributors to a shower. The comet itself was integrated back in time as needed. This integration takes into account the non-gravitational forces determined by P. Rocher (IMCCE, see also Table 1). Ten thousand (10^4) particles per size bin were simulated for each return of the comet for a total of 1.9×10^6 particles. The program was run on 10–16 parallel processors of an IBM SP4, located at CINES (Montpellier, France). During the simulation, the nodes of the meteoroids that pass closest to the Earth and that do so within ±1 week of the Earth's passage were recorded. These are then used for the prediction of the strength of the τ Herculids from year to year.

3 RESULTS

3.1 Fragmentation

The fragmentation of SW3 was studied with great care by Sekanina et al. (1996) and reported in IAU circular 6301 (Scotti et al. 1996). Our own analysis will be much less rigorous, but is presented here

Table 2. The orbital elements of the fragments of SW3 from Rocher (1996b, 2001, 2002a,b). See Table 1 for details.

	SW3-A	SW3-B	SW3-C	SW3-E
a (AU)	3.0729540 ± 0.0114323	3.0632760 ± 0.0001635	3.0615149 ± 0.0000205	3.0624107 ± 0.0000446
e	0.6960401 ± 0.0010370	0.6940044 ± 0.0000158	0.6938180 ± 0.0000019	0.6938890 ± 0.0000041
i	11°.4231439 ± 0°.0158850	11°.4061700 ± 0°.0001536	11°.4063347 ± 0°.0000226	11°.4064774 ± 0°.0000577
Ω	69°.9380366 ± 0°.0981010	69°.9209155 ± 0°.0006710	69°.9208709 ± 0°.0001273	69°.9196707 ± 0°.0002863
ω	198°.8903634 ± 0°.0898908	198°.7708554 ± 0°.0005432	198°.7770380 ± 0°.0000943	198°.7729333 ± 0°.0003220
M	3°.121030958 ± 0°.01858	−0°.17957968 ± 0°.0000145	−3°.0756142 ± 0°.0000311	−3°.21028943 ± 0°.0000768
A_1	–	−1.17778	0.83701	1.34387
A_2	–	1.04319	0.17893	0.58122
A_3	–	–	−0.19596	−0.31685
Epoch (JD)	245 0000.5	245 1936.5	245 1920.5	245 1920.5
observations	62	80	425	196
σ (arcsec)	0.81	0.54	0.83	1.10

Table 3. Physical parameters of Comet 73P/Schwassmann–Wachmann 3. $[Af\rho]$ (A'Hearn et al. 1984) and r_n are taken from Fink & Hicks (1996) and Sanzovo et al. (2001). The absolute magnitude H_0 is computed by converting the molecular production rate of water Q_{H_2O} provided by Sanzovo et al. (2001) using the equation of Jorda, Crovisier & Green (1992). The parameters f and A are assumed.

Symbol	Parameter	Value
q	Perihelion distance	0.933 au
$[Af\rho](1.44)$	$Af\rho$ at 1.44 au	9.7×10^{-2} m
r_n	Nuclear radius before breakup	1.5 km
H_0	Cometary absolute magnitude	10.7
f	Fractional active area	0.20
A	Visual albedo	0.04

as it generally confirms the previous authors' more detailed work. Suites of 100 clones of each fragment were integrated backwards to the time of splitting. The clones were chosen with orbital elements distributed around the nominal value in a Gaussian distribution with a sigma value equal to the uncertainties in each element (Tables 1 and 2), and integrated with the Wisdom–Holman style code. The mean offset of clones from each other and from the pre-fragmentation position of SW3 near the cometary outburst allows an assessment of the times of splitting to be made.

The backwards integration of the fragments does not return them to exactly zero distance from the primary owing to uncertainties in the elements, accumulating errors in the integration and likely time variability in the non-gravitational parameters. None the less the minimum distance seen in the backwards integration is 10^4 km ($\sim10^{-4}$ au) or less, the exception being fragment A for which the fewest observations are available and no non-gravitational parameters are known, and which only reaches a minimum of 125 000 km.

Based on these simulations, it seems most likely that the fragments split rather late in the cometary outburst. The minima are quite broad making a precise determination impossible, but we estimate that fragments A and B split from the main nucleus between JD 245 0026.5 (Nov 5) and JD 245 0042.5 (Nov 21), and E split from B between JD 244 9998.5 (Oct 8) and JD 245 0039.5 (Nov 18). These late splittings essentially coincide with the timings found by Sekanina et al. (1996), scattered from October 24 to November 23 in 1995. In all cases, the relative velocities seen in the simulations during the splitting are between 1 and 5 m s^{-1}, implying the breakup velocities of the fragments were of this order, again in line with the values of Sekanina et al. (1996).

3.2 Meteoroids from the cometary outburst of 1995

The closest approaches of the comet fragments to the Earth in 2006 are shown in Fig. 2. Note that the time of closest approach is not as the fragments pass their nodes (indicated by the vertical line) but some days prior. This is because the inclination and orientation of the orbit of SW3 are such that the fragments pass above the Earth's Northern hemisphere as they proceed towards their descending node.

The orbit of SW3-A is relatively poorly known with no non-gravitational parameters computed. The dotted line in Fig. 2 shows the closest distance recorded for any of its clones. The nominal orbit and the vast majority of SW3-A's clones pass much further away off the graph, but its orbit is uncertain enough to be consistent with a much closer pass. We recommend that the fragment, if it still exists, be observed telescopically to refine its orbit. We also note

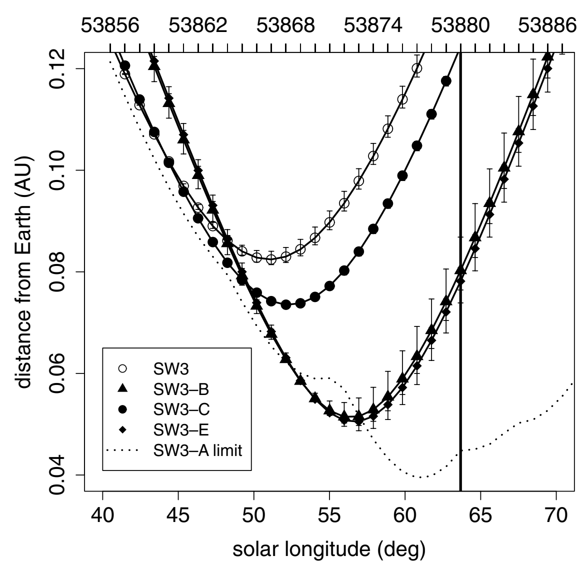

Figure 2. The closest approaches of the fragments of Comet Schwassmann–Wachmann 3 to the Earth in 2006. The error bars indicate the spread in the 100 clones (see text for details). The dotted line indicates the minimum value seen for the clones of SW3-A; however, the fragment itself is off the graph and its clones follow a variety of curves above the dotted line. The top axis is the modified Julian date. The vertical line indicates when fragment C is at its node. The other fragments pass their node within ± 2 d of this time, except A that does so 2 weeks later.

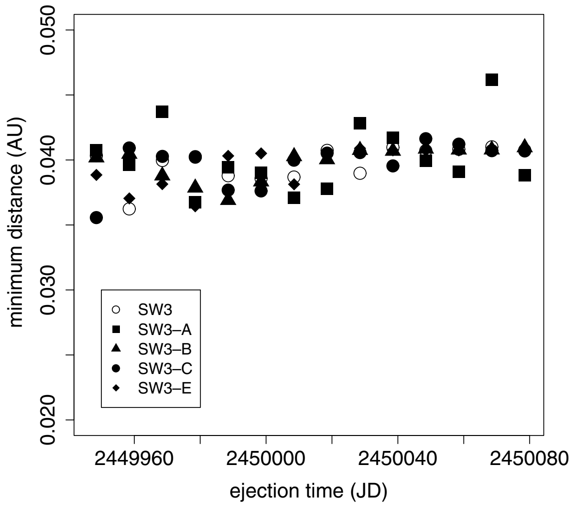

Figure 3. The minimum distance of the meteoroids from the Earth, plotted as a function of ejection time. These meteoroids have ejection velocities of 1, 10 or 100 m s^{-1}.

that the close approach distances of all the fragments are sensitive to the values of the non-gravitational parameters used, changing by a factor of roughly 2 as they are varied from their nominal values to 0. Thus the details of the fragments' close approaches may be changed significantly by plausible alterations in their outgassing patterns or ongoing fragmentation. We encourage observers to recover these objects at the earliest opportunity.

The meteoroids released during the cometary outburst approach the Earth more closely than the fragments themselves but only slightly. Fig. 3 plots the closest approach by any simulated meteoroid as a function of its time of ejection. The closest is 0.036 au, or 14 lunar distances. This meteoroid swarm is thus unlikely to produce any strong meteor activity at the Earth since this usually requires an approach distance of 0.01 au or less (Asher, Bailey & Emel'Yanenko 1999). The closest approach is insensitive to the parent fragment from which the meteoroids were released. This is expected because all the fragments were nearly coincident around the time of splitting. The time of ejection also has little effect on the minimum distance. This is because the ejection velocities considered are small relative to the orbital velocity, and so the meteoroid orbits do not differ greatly from those of the fragments themselves. The meteoroids do spread out along the orbit, and the close approach distance is set rather by the minimum intersection distance between the Earth and the orbit of the stream than anything else, and this minimum distance does not depend strongly on the time of meteoroid release.

There are a number of reasons for the lack of shower activity predicted for 2006 despite the close passages of the fragments and the likely abundance of meteoroids.

One is the location at which the cometary outburst occurred. Fragment C will pass 0.0735 au from the Earth at its closest approach on May 13. At this point it will be 3 weeks pre-perihelion, very close to the point at which SW3 was in its orbit (2 weeks pre-perihelion) when the 1995 cometary outburst started. Since the meteoroids are travelling on (nearly) closed orbits, they will re-converge on the point from which they were ejected, regardless of their ejection velocity or direction. This results in a much reduced spread of the meteoroids in real space as they pass the Earth than would be expected at other points in the swarm's orbit.

In addition, the meteoroids have avoided close encounters with Jupiter during the 11-yr interval since the splitting, and Poynting–Robertson drag has had little time to act, so there have been no significant perturbations to scatter their orbits. We did find that meteoroids ejected at 1000 m s^{-1} during the cometary outburst could intersect the Earth's orbit in 2006. However, they do so only in small numbers, and such high ejection velocities are not expected either from the splitting itself (a few metres per second) or from cometary processes (a few tens of metres per second; e.g. Whipple 1951; Jones 1995). Finally, the τ Herculids have a low encounter velocity with the Earth ($\sim$15 km s^{-1}), which will tend to reduce their detectability should any outliers to the main swarm reach the Earth. Given these factors we predict, based on our model, no unusual activity of the 2006 τ Herculid shower as a consequence of the splitting event of 1995.

3.3 Meteoroids from previous perihelion passages

Historically, the existence of many minor meteor showers has rested on the similarity of a small number of photographic or radar-recorded meteoroid orbits (Lindblad & Southworth 1971; Sekanina 1976). Cook (1973) compiled a working list of meteor showers consisting of many of these minor showers, whose existence was based on both orbital similarity criteria and visual activity. Among the minor streams listed is the τ Herculid shower. According to Cook, the τ Herculids extend from May 19 to June 14 with their peak centred on June 3. The existence of this shower rests on a set of only two photographic orbits identified by Southworth & Hawkins (1963) as forming a 'stream', along with an additional 14 possible photographic orbits associated with the stream according to Lindblad & Southworth (1971). Remarkably, no activity from the shower was recorded by the Harvard Radio Meteor Project (HRMP) that operated during the interval 1961–65 and again in 1968–69, despite the claim that 275 minor meteor streams were detected (Sekanina 1976). More recently, Jopek, Valsecchi & Froeschlé (1999) have examined the same photographic data base as originally used by Southworth & Hawkins (1963) and Lindblad & Southworth (1971) and, by applying a new shower association criterion, found no evidence for the stream. No reliable data on hourly activity have been published, though Southworth & Hawkins (1963) suggest that it is below one meteor per hour.

Detectable visual activity from this shower has been clearly documented on only one occasion, on 1930 June 9/10, when recorded rates approached one per minute (Nakamura 1930). Earlier potential records of visual activity from the shower (Kronk 1988) date from 1916 to 1918 and are weak and generally unconvincing amongst the long list of minor streams 'detected' by visual observers of this era (Denning 1899). Modern activity from this stream is essentially non-existent. The International Meteor Organization does not list the τ Herculids among the possible showers detectable visually on an annual basis (Rendtel, Arlt & McBeath 1995). A search for activity at this time of the year in the records of the Canadian Meteor Orbit Radar (Jones et al. 2005) shows no radiant active near the location given by Cook (1973) in any of the years 2000–2004.

From our simulations, the reason for the paucity of observations of the τ Herculids is quite clear: rarely does the stream associated with SW3 actually intersect the Earth. Considering meteoroids ejected on perihelion passages dating back to 1801, appreciable past τ Herculid activity was only to be expected in 1914, 1930, 1941, 1946 and 1952, though we have been unable to find any records of visual activity during these years with the exception of 1930. Of these modelled

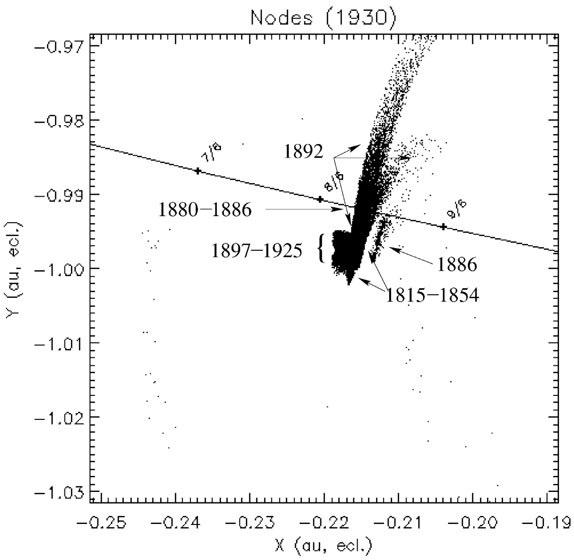

Figure 4. The nodal crossing points of meteoroids ejected from SW3 at all perihelion passages back to 1801, plotted relative to the Earth's orbit for the year 1930. Only meteoroids whose descending node occurred within 1 week either before or after the Earth's passage are shown. Arrows indicate the meteoroids' time of release.

returns, that of 1930 also appears, based on our simulations, to have been the strongest.

The activity recorded in 1930 was a direct consequence of dedicated observations carried out worldwide shortly after the discovery of Comet SW3. It was realized that this comet's orbit passed close to the Earth, thus making a shower possible near the end of May or in early June. As reported by Nakamura (1930), the visual observation of enhanced shower activity was done from the Kyoto Observatory on the nights of 1930 June 9 and 10. During the night of June 9, from 09:51 to 10:51 pm, a total of 59 meteors were plotted radiating from a point near $\alpha = 236^\circ$ and $\delta = +42^\circ$. The next night (June 10), in an interval of 30 min, some 36 additional meteors were noted from roughly the same radiant area.

The location of the nodal crossings of the simulated τ Herculid meteoroids in relation to the Earth in 1930 is presented in Fig. 4. Only those particles passing the node within 1 week of (before or after) the Earth's passage are plotted, selecting those meteoroids that pass closest to the Earth. From this figure, it is clear that substantial material from Schwassmann–Wachmann 3 intersected the Earth's orbit. However, the model predictions have most of this material crossing the Earth's orbit near solar longitude 77°.9 (J2000), whereas a direct interpretation of the timing (assuming local time) given in the report of Nakamura puts this observation almost exactly one degree later, near 78°.9. It is true that some individual test particles come moderately close to the Earth up to a solar longitude of 80° (J2000), and it is possible that the Nakamura (1930) observation refers to these outliers. This would also be consistent with the activity he reports 1 day later. If this is the case, it is probable that the activity was much stronger 24 h earlier, but was not recorded. Another possibility is that the timing of the report is erroneus, perhaps due to the date convention used (i.e. June 9 was really June 8 UT); this would then put the centre of the observation exactly where our model predicts most meteoroids should have been encountered.

As an independent check on the observations, we have computed the theoretical radiant from the modelled test particles closest to the Earth in order to compare with Nakamura's observation. Using the technique described in Neslusan, Svoren & Porubcan (1998), we find that our theoretical geocentric radiant for model particles from all perihelion returns (with a spread of less than one degree between radiant locations from different perihelion passages) is expected at $\alpha = 220^\circ$ and $\delta = +46^\circ$. This is a difference of approximately 10° from Nakamura, which is not unreasonable given the visual plotting accuracy involved. In particular, Nakamura's measurement of the radiant would have been complicated by the fact that it was nearly overhead at the time of observation. We also note that, though we have computed the geocentric radiant and Nakamura plotted the apparent one, these should not differ appreciably as the radiant's altitude was 80° at the time of observation, and thus the 10° difference cannot be explained that way. Although some uncertainty in the observation timing and the radiant position relative to the model remains, given that the only significant visual activity reported from the stream occurred at almost precisely the same time as our model predictions estimate the strongest activity of the shower should have been visible (over the more than 1 century time span examined), we suggest that the visual data largely corroborate the model within the expected uncertainties of both.

The meteors observed by Nakamura (1930) were not those produced by the SW3 apparition of that year. Rather, we find that the τ Herculids seen that year were an unusual confluence of meteoroids produced during several pre-discovery perihelion passages of the comet. In fact, for most years little or no activity is expected, so this stream is not a true annual stream. We note that none of the expected model years corresponds to periods covered by the HRMP (1961–65 and 1968–69) while the two stream members identified by Southworth & Hawkins (1963) occurred in 1953 and 1954, respectively. Although the model activity predicted for 1952 centred about 1952 June 7 does occur within the time frame of operation of the Harvard Super-Schmidt survey, the examination of Super-Schmidt orbits listed in the IAU Meteor Data Centre (Lindblad 1995) shows no records within 1 week of the expected outburst time in 1952.

The variability of the τ Herculid shower is tied to the frequency with which SW3 and its stream have close encounters with Jupiter. Comet Schwassmann–Wachmann 3 is dynamically 'hot', having passed near (within 5 Hill radii) Jupiter five times in the 100 yr preceding the 1995 splitting. As a result, the distance between the stream and the Earth's orbit is variable on a time-scale of decades, and it is not surprising that so is the activity of the τ Herculids.

Looking at the future, no significant number of meteoroids released during pre-splitting perihelion passages is expected to encounter the Earth in 2006. Owing to the pattern of planetary perturbations, again primarily due to Jupiter, meteoroids released from SW3 will not venture into the vicinity of the Earth that year (Fig. 5). Thus neither the meteoroids released during the cometary outburst nor those from recent perihelion passages are expected to intercept the Earth during 2006, despite the recent splitting and the close approach of the fragments to the Earth. The next year for which substantial activity is predicted is 2022 (Fig. 6). Meteoroids released during the 1892 and 1897 apparitions are expected to reach the Earth at the end of May that year. The 2049 τ Herculids are also expected to be stronger than usual (Fig. 7). Assuming that the cometary parameters do not change over time, that the meteoroids have a population index of 2.5 and that in 1930 the ZHR was roughly 100, we find a maximum ZHR of 10 for 2022 and of 5 for 2049. Though there are more trails intersecting the path of the Earth in 2049, the meteoroids are more spread out in interplanetary space (compare the scales of Figs 6 and 7). As a result, the ZHR value of the 2049 τ Herculids should be lower than that of 2022, but the integrated flux of meteors is expected to be somewhat higher.

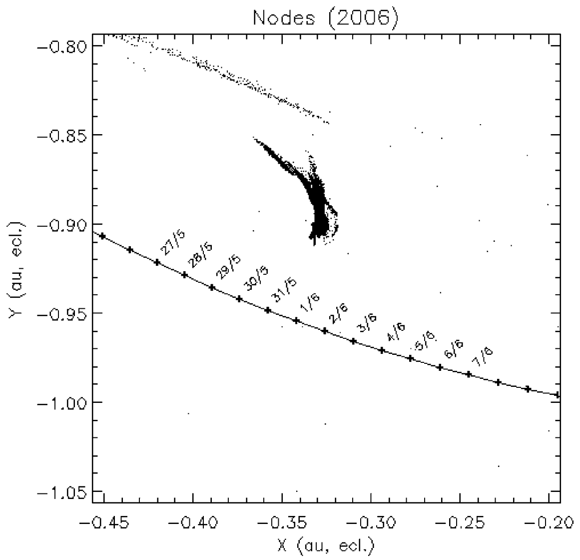

Figure 5. The nodal crossing points of meteoroids ejected from SW3 at all perihelion passages back to 1801, plotted relative to the Earth's orbit for the year 2006.

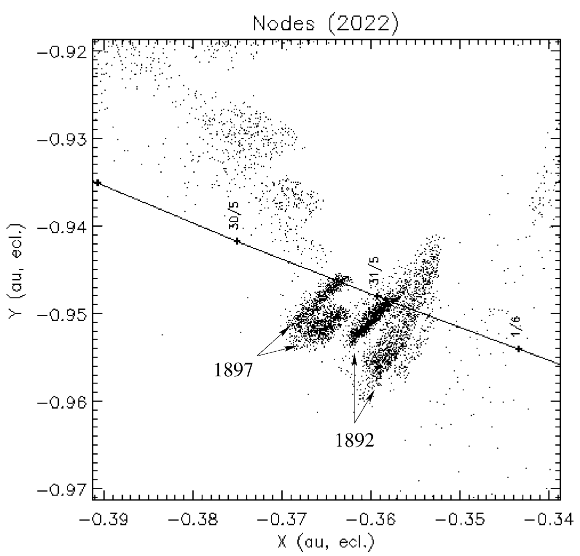

Figure 6. The nodal crossing points of meteoroids ejected from SW3 at all perihelion passages back to 1801, plotted relative to the Earth's orbit for the year 2022.

Note that the time during the year (or equivalently, the solar longitude) at which the stream is observed varies substantially from year to year. This again is due to the effects of close encounters with Jupiter perturbing both the comet and the stream. The 2049 stream (Fig. 7) illustrates this with a long distorted cross-section. The largest number of meteoroids is contributed by apparitions late in the 20th century with some weaker trails produced by earlier perihelion passages. Here the stream's inclination has been reduced from 11° to 6° by a close approach with Jupiter. The sensitivity of the location of the node to the inclination means the footprint of the stream becomes quite elongated, lengthening and diluting the observed shower.

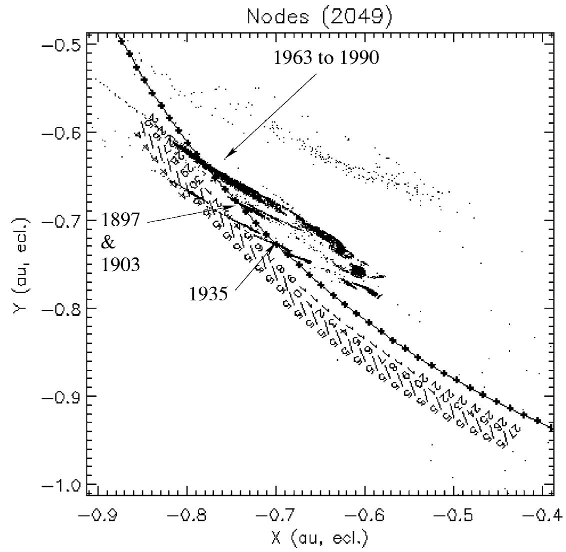

Figure 7. The nodal crossing points of meteoroids ejected from SW3 at all perihelion passages back to 1801, plotted relative to the Earth's orbit for the year 2049.

4 CONCLUSIONS

The τ Herculids are a highly erratic meteor shower, reaching appreciable levels only at intervals separated by decades. During the 20th and early 21st centuries, only the years 1930, 1941, 1946, 1952, 2022 and 2049 are expected to see appreciable activity, and only in 1930 has any strong activity in fact been observed. This variability is a direct result of the dynamics of its parent body, which suffers close encounters with Jupiter roughly a few times in a century. No increase in τ Herculid activity is expected in 2006, despite the recent breakup of the parent comet and the close passage of its fragments to the Earth at that time. The proximity of the positions of the 1995 cometary outburst and the 2006 close approach along the orbit of Comet Schwassmann–Wachmann 3 strongly reduces the spread of the meteoroids released and they are not expected to intercept the Earth in significant numbers. We do note that the close approach distances of the fragments themselves to the Earth are sensitive to outgassing patterns and further splitting, and we recommend that they be recovered telescopically at the first opportunity.

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