Ursids (URS#015) major or minor shower, and another outburst in 2020?

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The history of the Ursid meteor stream has been summarized and a case study based on video meteor orbits is presented. New mean orbits based on a large number of Ursid orbits for different thresholds of dispersion were calculated. The Ursids have a large diffuse radiant with a dense core caused mainly by Ursids recorded during or near the maximum activity. The activity profile based on 12 years video data displays an annual maximum at solar longitude 270.45° and a secondary maximum at 270.80° caused by occasional outbursts associated with dust trail encounters. The peak activity is rather sharp, about half a day for the annual maximum and only a couple of hours for the occasional outbursts. The orbital elements display a large spread which is also visible in the velocity distributions. The Ursids appear to be mainly faint meteors although the occasional outbursts produce some brighter meteors. Ursids ablate significantly higher in the atmosphere than the Geminids because of their fragile cometary composition. Lyytinen and Jenniskens (2006) predicted two possible dust trail encounters for 2020 December 22 with a possible high activity level. The parent comet 8P/Tuttle will return at its perihelion in August 2021 which means the 2020 Ursid activity occurs in a similar situation as in 1993 when very good ursid rates were observed.

1 Introduction

Although the Ursids appear in each shortlist of meteor showers as a major shower, it remains one of the poorest known major showers which remained unnoticed during many years. It was assumed that the Ursids escaped attention because of the often-unfavorable weather for most meteor observers in the northern hemisphere this time of the year. Apart from some outbursts the shower does not appear in observing reports or the activity remained below the detectability level, typical for minor showers.

The history of the Ursids has been summarized in this article and a case study has been made based on the publicly available video meteor orbit datasets. The video data can help to understand the structure of the Ursids as a meteor stream and whether this should be regarded as a major shower or rather as a minor shower with periodic outbursts.

2 Ursid history

The oldest mention of an Ursid outburst might have been recorded in Japan on 1795 December 20, the eve of the winter solstice (Imoto and Hasegawa, 1958). No details about the radiant are given but the date is close to that of possible Ursid activity, just five years after Pierre Méchain in Paris, France, had discovered the parent comet on 1790 January 9. Some historic reports about meteor rains from 1433 in Japan and 1532 in China at the solar longitude of Ursid activity may refer to past outbursts, but very little information is available.

First mention of possible meteor activity from the Ursids parent comet 8P/Tuttle were published in 1874 by A.S. Herschel in the British Association Report with a list of cometary radiants with the following data for Méchain-Tuttle's comet:

Méchain (1790 II)	α = 220°, δ = +76°	Dec. 20+
Tuttle (1858 I)	α = 221°, δ = +77°	Dec. 20+

This reference was cited by W.F. Denning (1916) mentioning that he had observed meteors from a radiant near β Ursa Minoris in various years between December 18–25 from a radiant at α = 218°, δ = +76°. The display had shown no special abundance and Denning called for further observations to recover this meteor shower. In 1923 W.F. Denning lists Méchain-Tuttle meteors with their radiant based on as few as 7 meteors plotted during "various" years (Denning, 1923). Probably the poor weather circumstances for this typical northern hemisphere meteor shower hampered observational efforts during the activity period as no distinct activity of Ursids can be found other than typical for any minor shower.

The Ursids didn't catch attention until observers at the Skalnaté Pleso Observatory (Slovakia) witnessed a meteor outburst in the early evening of Saturday 1945 December 22. Dr. Antonin Bečvář reported these observations as the discovery of a new, formerly unknown meteor shower (Bečvář, 1945). Antonin Bečvář (1901–1965) was one of the founders of the Skalnaté Pleso Observatory in the High Tatras mountains. In original publications the Ursids outburst of 1945 was referred to as Bečvář's meteor stream, Tuttleids and later as the Umids instead of Ursids.

Initially the outburst was reported with an activity level of 169 meteors per hour, which was often cited as a ZHR of 169. The number of meteors were a total of meteors counted by 4 visual observers. In 1951 Dr. Zdeněk Ceplecha (1951) analyzed the observations again and obtained a much lower rate of 48 meteors per hour as an average for three observers. Looking at the rates in 10-minute intervals a peak of 108 meteors per hour was found at 18^h UT (mean value for 3 observers). The precise observing conditions aren't clear from literature, but the usual high meteor activity had been noticed right after twilight around 16^h30^m and further observations were hampered by the rising 84% illuminated Moon in Leo after 18^h30^m when also clouds disturbed when the high meteor activity had ceased.

Ceplecha (1951) also obtained photographic plates from Antonin Bečvář which allowed a more precise determination of the radiant position as well as an orbit for the Ursid meteors. It is not explained how the velocity was determined, this may have been assumed parabolic or the orbital period was assumed identical to that of the comet. The Ursid orbit was in perfect agreement with the orbit of comet Tuttle for return in 1939. The 1945 outburst occurred several years after the perihelion passage of 1940.0, when the parent comet was almost at the opposite side at its aphelion.

Alerted by the 1945 Ursids outburst, visual observations were organized at the Ondřejov observatory (Vanýsek, 1947) and the Skalnaté Pleso Observatory (Bochníček and Vanýsek, 1948). The observers concentrated on the determination of the radiant position while the actual hourly rates remained low in 1946. Further visual observations as well as radar observations did not detect any unusual activity for the Ursids. Prentice (1948) attempted visual observations of the Ursids on 1947 Dec. 22 and Dec. 23, first night had excellent conditions but only 1 possible Ursid was seen, the second night allowed only 25 minutes of observing under very unfavorable conditions, four of the eight meteors were possibly Ursids from which the author estimated an hourly rate of 20. The Ursids were also covered by radar observations at Jodrell Bank which confirmed low rates in 1947 (Clegg et al., 1948) and comparable low rates in all following years until 1953. In literature these radar hourly rates were quoted as representative for visual rates. However, because of the limitations of the radio techniques used and the lack of any decent calibration the only possible conclusion from these observations is that only low rates at best were observed in these years. It is important to know that radar monitoring was done during certain time intervals and not continuously, which means any unforeseen outburst could have remained unnoticed.

After 1953 until 1970, the Ursids were completely ignored, despite that this shower got included in the short lists of major meteor showers in most general astronomy books. When visual meteor observations were resumed in 1970 low hourly rates were reported throughout the 1970s. In general, low rates were confirmed by European, American and Japanese meteor observers and this continued during the first half of the 1980's. British radio observers reported enhanced activity on 1973 December 22 (λ_O = 270.83°, eq.2000) lasting for 1 hour, unfortunately the exact source of the information is not known (Jenniskens, 2006).

The Ursids performed a great show in 1986. Radio observer Luc Gobin monitored radio echoes every day between 19^h30^m and 20^h30^m UT and on December 22 the number of echoes was about 2.5 times higher than other nights (Roggemans and Steyaert, 1987). The radio observations by Luc Gobin were soon confirmed by visual observers in the UK under unfavorable circumstances as well as by two Norwegian visual observers under good circumstances. "*On December 22, Kai Gaarder saw 94 Ursids in 4 hours from* 17^h00^m*–*21^h00^m *UT. Lars Trygve Heen saw 54 Ursids in one hour,* 21^h00^m*–*22^h00^m *UT. Several Ursid fireballs were counted*" (Hillestad, 1987). Kai Gaarder commented to the author: "*I was one of the few lucky to observe the great Ursid outburst of 1986. I was expecting to see about 5 Ursids an hour, but was stunned by the activity comparable to a modest Perseid maximum as I remember it.*". The maximum occurred on 1986 December 22, at 21^h30^m (λ_O = 270.93° J2000) with a ZHR = 122 ±17. This is about 0.38° earlier in λ_O than the 1945 outburst (Roggemans, 1987). The 1945 outburst was in progress when observers noticed it in twilight, no information is available of what happened before the 1945 observations could start because of the twilight in Slovakia. Another remarkable fact is that the 41 years between 1945 and 1986 represents almost exactly three times the orbital period of the comet. The 150 years between the possible first mention of Ursids in 1795 and the 1945 outburst is about eleven times the orbital period of the parent comet (Roggemans, 1987). Steyaert (1987) derived a period of 13.64 years. Unfortunately, no observational data seems to exist around the Ursid activity for some interesting years like1836 and 1904 to confirm this periodicity.

Both the 1945 and 1986 outbursts took place when the parent comet was near aphelion. Jenniskens et al. (2002) found that it takes 45 revolutions for the dust released from the comet to lag half an orbit relative to the comet and to get into the Earth's orbit while the comet's orbit is rather far from Earth's orbit.

In 1994 the Ursids displayed an outburst when the parent comet had passed through its perihelion in 1994. Ilkka Yrjölä recorded significantly enhanced radio echo rates around the Ursid time of maximum in both 1993, before the perihelion passage of the parent comet and in 1994 after the passage (Jenniskens, 2006). These outbursts were much broader than the aphelion outbursts of 1945 and 1986. The 1994 Ursids outburst was confirmed by Japanese visual observers (Ohtsuka et al., 1995). Poor weather hampered most Japanese, only H. Shioi could successfully observe visually although the limiting magnitude was poor (5.2) resulting in a maximum ZHR of more than 100 but with large error margins at λ_O = 270.75° (eq. 2000.0), 200 days after the parent comet had passed through the descending node 0.06 AU outside the Earth orbit. The same report mentions that a similar Ursid outburst had been observed by Bob Lunsford on 1993 December 22 at λ_O = 270.81° (eq. 2000.0), 165 prior to the parent comet's passage through the descending node. Bob Lunsford wrote the author about this: "*My best Ursid year was 1993 when I counted 81 during 4.56 hours of observing on December 22nd. The limiting magnitude was excellent that night as it ranged from +7.11 at the start of the session (01:00 Local Time) to +5.70 at 06:00 local time. My best period produced 26 Ursids during 52 minutes of observing with an LM of +6.77. 21 Sporadics were also seen during this period which was twice as many as any other period*."

Ohtsuka et al. (1995) also refers to enhanced Ursid activity with several fireballs observed in Japan on 1981 December 22 at $\lambda_{\odot}$ = 270.82° when the parent comet had passed 394 days earlier through its descending node 0.08 AU outside the Earth orbit during its perihelion passage in 1980. Ohtsuka et al. (1995) concluded from these 1981, 1993 and 1994 observations that the Ursid meteor stream dust had spread at least over a range of $-12° < \Delta M < +28°$ where ΔM is the difference between the mean anomalies of the comet and the Ursid meteor stream. Also, in 1979 enhanced Ursid activity had been reported on December 22 by observers in Sogne, Norway, about 8 months before the perihelion passage in 1980 (Kronk, 1988).

Meteor stream modelers Esko Lyytinen and Peter Jenniskens discovered that the Ursid meteor stream displayed broad filaments with outbursts around the perihelion passage of parent comet 8P/Tuttle with isolated narrow outbursts with the parent comet at its aphelion. They applied the technique used for the Leonids to calculate the 8P/Tuttle dust trail encounters. This study explained the past observed outbursts and also predicted that the 1405 dust trail might be encountered on 2000 December 22 at 7^h59^m UT and as well as perhaps the 1392 trail at 8^h38^m UT (Jenniskens and Lyytinen, 2000).

A dedicated observing campaign was organized in California and observations started at 5^h25^m UT, initially just a single occasional Ursid was seen. After 7^h UT Ursids appeared more often and after 8^h UT it was obvious an outburst was in progress with relatively faint meteors of magnitude +3 and +5. The peak activity reached a ZHR of about 90 at $\lambda_{\odot}$ = 270.78° (J2000). The observed profile had its maximum between the predicted times for the 1405 and 1392 dust trails, indicating that both trails contributed to the activity profile (Jenniskens and Lyytinen, 2001).

More years with possible enhanced Ursid activity were predicted for 2002, 2004, 2006, 2014, 2016 and 2020. The 2002 predicted enhanced activity did not materialize. Visual observations were seriously hampered by an 89% illuminated Moon while radio data showed only weak activity during the 8 hours covering the time of theoretical peak activity (Boschin et al., 2003). These results were confirmed by the Dutch radio observer Peter Bus in Groningen. The 2004 prediction did not get conclusive observational evidence beyond the usual low or non-existence Ursid activity (McBeath, 2005). Also 2006 did not produce any significant activity and certainly nothing like an outburst (Jenniskens, 2006b).

Video and forward scatter observations confirmed the predicted Ursid dust trail that crossed the Earth orbit at $\lambda_{\odot}$ = 270.84° on 2014 December 22–23, but hourly rates weren't comparable to the 1945 or 1986 levels (Moreno-Ibáñez et al., 2017). Also, Peter Brown, Western University, reported that a significant outburst of Ursid meteors was detected by the Canadian Meteor Orbit Radar (CMOR) between Dec. $22^d23^h15^m$ and $23^d00^h45^m$ UT. The apparent activity maximum occurred at Dec. 23^d00^h UT ($\lambda_{\odot}$ = 270.85 ±0.03°, J2000) with a ZHR in excess of 50 (Brown et al., 2015). The 2014 enhanced Ursid activity was also confirmed in Slovakia (Gajdoš et al., 2015).

In 2016 the Ursids showed a high activity around 10^h30^m (UT) on the 22nd December ($\lambda_{\odot}$ = 270°.78°). Although a strong Ursid activity was also observed in 2014, the activity in 2016 was weaker than in 2014 (Ogawa, 2017). E. Lyytinen had calculated an encounter with the A. D. 1076 dust ejecta of 8P/Tuttle at 2016 Dec. $22^d10^h05^m$ UTC, at $\lambda_{\odot}$ = 270.760°. P. Jenniskens reported that the Earth encountered the A. D. 1076 ejected dust of comet 8P/Tuttle on 2016 Dec. $22^d11^h35^m$ UTC, at $\lambda_{\odot}$ = 270.825±0.010° (J2000) (Jenniskens, 2017).

Other years the Ursid activity remained with low annual activity. The coverage with permanent radio and video monitoring makes it unlikely that any enhanced activity or short outburst would occur unnoticed. Visual observers were too few in number in the past across the planet to monitor activity around the clock. Specific about the Ursids, Norman W. McLeod, one of the most active visual observers in modern times commented these were like the Quadrantids in the sense that observers had to be within 12 hours of the maximum to see much (Kronk, 1988). This being said, it is obvious that several, if not many past Ursid outbursts must have passed unnoticed due to poor coverage and often very bad weather around the time of the year.

Table 1 – The median values for the mean Ursid orbit obtained by CAMS (2016) and SonotaCo (Koseki 2021) compared with the orbit of 8P/Tuttle.

	URS (2016)	URS (2021)	8P/Tuttle (2008)
$\lambda_{\odot}$	271.0°	270.5°	–
α_g	219.9°	219.0°	–
δ_g	+75.4°	+75.3°	–
v_g	32.9 km/s	33.0 km/s	–
a	4.87 A.U.	4.92 A.U.	5.70 A.U.
q	0.940 A.U.	0.940 AU	1.027 A.U.
e	0.807	0.809	0.8199
ω	205.6°	205.9°	207.5°
Ω	270.1°	270.5°	270.3°
i	52.6°	52.8°	54.98°
N	62	390	

For many years the number of known orbits for Ursid meteoroids was very low. For instance, a dedicated observing project for the Ursids in California in 1997 by Peter Jenniskens increased the number of available Ursid orbits at once from two to twenty-four orbits. Some major video meteor networks changed the picture a lot in past 12 years. The orbits published in literature are listed in *Table 1*.

3 The Ursids as observed by video camera networks

CAMS, EDMOND and SonotaCo together have 1101923 video meteor orbits publicly available covering the period 2006 to 2019. In this section we will extract all Ursid orbits from these datasets. Each network has its own criteria to identify the shower association but a quick verification proves that several obvious Ursid orbits were not identified as Ursids. In order to consider all the orbits with the same criteria the author applied an iterative procedure starting from some initial reference orbit to identify all orbits that form a concentration of similar orbits which define the meteor shower. This method has been described before (Roggemans et al., 2019).

To calculate a reference orbit for a collection of similar orbits we do not use the median or average values of the orbital elements, but we compute the mean orbit according to the method described by Jopek et al. (2006). To compare orbits on similarity researchers established different discrimination criteria, often abbreviated as D-criteria. The D-criteria that we use are these of Southworth and Hawkins (1963), Drummond (1981) and Jopek (1993) combined. The oldest and most popular D-criterion, the one established by Southworth and Hawkins or D_{SH} proved often too tolerant and unsuitable for short period orbits near the ecliptic. It is not unusual that orbits which are very similar according to D_{SH}, fail for another D-criteria such as that of Drummond or D_D.

In order to distinguish dispersed and compact orbits we define five classes with different threshold levels of similarity, kind of shells with comparable degree of dispersion. These should help to visualize the degree of dispersion and compactness within the meteor stream. The different classes of similarity are defined as follows:

- Low: $D_{SH} < 0.25$ & $D_D < 0.105$ & $D_H < 0.25$;
- Medium low: $D_{SH} < 0.2$ & $D_D < 0.08$ & $D_H < 0.2$;
- Medium high: $D_{SH} < 0.15$ & $D_D < 0.06$ & $D_H < 0.15$;
- High: $D_{SH} < 0.1$ & $D_D < 0.04$ & $D_H < 0.1$;
- Very high: $D_{SH} < 0.05$ & $D_D < 0.02$ & $D_H < 0.05$.

Removing the classes with better similarity for instance allows one to look at the shell with very dispersed orbits alone. To reduce the number of iterations in our procedure, we remove all orbits which are a priori excluded from being related to the Ursids meteor shower. To estimate the activity period, the radiant size and the velocity range, we take a sample reference orbit from literature and make a preliminary run to identify all possible Ursid orbits for this reference. The activity period, radiant size and velocity range are chosen slightly wider than obtained from this preliminary estimation.

- Time interval: $256° < \lambda_O < 283°$;
- Radiant area: $174° < \lambda_g - \lambda_O < 254°$ & $+62° < \beta_g < +83°$;
- Velocity: 25 km/s $< v_g <$ 40 km/s.

158576 orbits are available within the solar longitude interval, 2757 orbits have the ecliptic radiant within the above area and their geocentric velocity within the chosen range. Starting with the mean orbit as reference, the iterative loop converges with a selection of 1986 similar orbits for which a final mean orbit can be computed for the Ursids. Various researchers use different standards and criteria to define similar orbits. Some shower associations are based only on the radiant position and velocity, some consider very dispersed orbits and others select only very similar orbits to compute a mean orbit for a stream. The problem is that it is often not known how orbits were selected and which threshold has been used to compute a mean orbit. Therefore, the author defined the different classes of similarity in order to keep track of the dispersed particles as well as the dense concentration that makes up the core of the meteor stream. For each similarity class a mean orbit has been calculated. The results are listed in *Table 2*.

Table 2 – The mean orbits calculated for each similarity class according to the threshold of the D-criteria for the Ursids based on the shower identification by the author.

	Low	Medium Low	Medium High	High	Very high
λ_O (°)	270.48	270.48	270.49	270.53	270.6
α_g (°)	219.1	219.0	219.0	219.1	219.1
δ_g (°)	+75.8	+75.8	+75.8	+75.7	+75.7
$\Delta\alpha$ (°)	0.86	0.81	1.38	1.48	1.28
$\Delta\delta$ (°)	–0.57	–0.61	–0.57	–0.45	–0.26
H_b (km)	101.7	102.0	102.2	102.4	102.6
H_e (km)	89.4	89.7	89.9	90.1	89.8
v_g (km/s)	32.8	32.9	32.9	33.0	33.0
λ-λ_O (°)	217.5	217.6	217.8	217.9	218.0
β (°)	+71.8	+71.8	+71.9	+72.0	+72.0
a (AU)	4.85	4.92	4.96	4.98	5.04
q (AU)	0.9297	0.9325	0.9354	0.9376	0.9388
e	0.808	0.811	0.811	0.812	0.814
ω (°)	206.5	206.7	206.4	206.2	206.0
Ω (°)	270.0	269.9	270.0	270.3	270.5
i (°)	51.8	51.9	52.3	52.6	52.6
Π (°)	116.5	116.6	116.5	116.5	116.5
Q (AU)	8.8	9.0	9.0	9.0	9.2
T_j	1.78	1.75	1.75	1.74	1.73
P (y)	10.7	11.1	11.1	11.1	11.3
N	1986	1628	1311	952	496

The 1986 low similarity orbits include 358 dispersed orbits with a slightly lower geocentric velocity of v_g = 32.0 km/s, a lower eccentricity and lower inclination. The advantage of this method is that we can remove or isolate dispersed orbits like shells of orbits with different degrees of dispersion. The more towards the core of the shower with very similar orbits, the higher the geocentric velocity, the higher the eccentricity and the inclination becomes.

Table 3 – The mean orbits calculated for each camera network separately for the Ursids that fulfill the high threshold criteria based on the shower identification by the author.

	CAMS	EDMOND	SonotaCo
$\lambda_\odot$ (°)	270.69	270.49	270.49
α_g (°)	219.4	219.1	218.8
δ_g (°)	+75.7	+75.8	+75.6
H_b (km)	103.3	101.3	102.4
H_e (km)	92.8	88.1	89.2
v_g (km/s)	32.9	32.9	33.2
$\lambda-\lambda_\odot$ (°)	217.9	217.7	218.3
β (°)	+72.1	+72.0	+71.9
a (AU)	4.99	4.92	5.05
q (AU)	0.9382	0.9373	0.9376
e	0.812	0.810	0.814
ω (°)	206.1	206.3	206.2
Ω (°)	270.3	270.3	270.2
i (°)	52.4	52.5	52.8
Π (°)	116.4	116.6	116.3
Q (AU)	9.1	8.9	9.2
T_j	1.74	1.75	1.72
P (y)	11.2	10.9	11.3
N	300	334	318

The three main camera networks use different hardware. CAMS uses a standard of small FoV optics (30° × 22°) and has its own trajectory solver. SonotaCo uses the same Watecs as CAMS but mainly with larger fields of view and has its own detection software and trajectory solver. EDMOND uses the same software as SonotaCo but collects data with a large variety of different cameras and various optics. Question is if it is opportune to mix the data of all three networks for a single analysis? To test this, we calculated the mean orbits for the data of each network. To eliminate outliers, we use the high threshold similarity class ($D_D < 0.04$). The results are compared in *Table 3* and all the parameters are in very good agreement, far within the standard deviation of these values (not listed). The results listed in *Table 2* and *Table3* are in good agreement with the values previously published in literature (*Table 1*).

Note that our sample of CAMS is based on 300 Ursids, about 5 times more than used by Jenniskens (2016) on exactly the same dataset. It is not known how the orbits were selected for the result of CAMS in *Table 1*. Several perfect Ursid orbits were listed as sporadics in the CAMS dataset. In EDMOND and SonotaCo this occurs mainly for dispersed Ursids which were not recognized as shower meteors.

Note that the Ursids have about the same velocity as the Geminids (GEM#4), but the beginning heights of the Ursids are significant above that of the Geminids. For instance for the Geminids we obtained $H_b = 97.0 \pm 2.5$ km and $H_e = 85.5 \pm 4.4$ km, roughly 4 to 5 km deeper in the atmosphere. The reason for this is the composition of the Ursid meteoroids which consists of fragile cometary material that interacts differently with the high atmosphere than the more compact Geminid meteoroids (Roggemans, 2017).

4 The Ursids radiant

In most astronomical literature meteor showers are listed with equatorial coordinates for their geocentric radiants. For most inexperienced readers this is confusing as the position in right ascension and declination refers to a point source. When the 1945 Ursid outburst happened, visual observers at Skalnaté Pleso plotted Ursids on star maps in an attempt to define the Ursid radiant. The results led to some controversy as the plotted Ursids failed to fit the assumption to have a point source or at least very narrow radiant position (Ceplecha, 1951). Of course, plotting errors were problematic but in that time visual plottings were the only way to define radiant positions. Moreover, radiants were assumed to be very narrow in size. How big is a meteor shower radiant at the sky? The size depends upon the meteor shower velocity as well as on the nature of the meteor shower. Very slow velocity meteor showers produce meteors from a widely scattered radiant area. Old and dispersed meteor showers display meteors over a long activity range from diffuse radiants. The Ursid meteoroids that manage to encounter our planet needed as long as about 600 years to get far enough inside the Earth orbit and therefore got dispersed by gravitational and other forces.

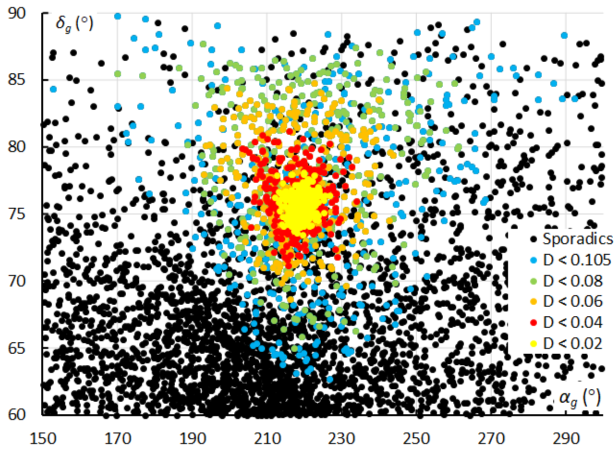

Figure 1 – The geocentric Ursid radiant in equatorial coordinates.

The Ursids may be expected to display a diffuse radiant unless some compact dust trail encounters the Earth. The geocentric radiants in equatorial coordinates for sporadic orbits and for the Ursids are displayed in *Figure 1*. As can be seen, the low threshold radiants are widely dispersed (blue dots). Since the radiant is close to the pole the right ascension covers a wide range. Even the high threshold Ursid radiants span more than 10° in declination. The concentration of black dots below the Ursids is caused by early Quadrantids.

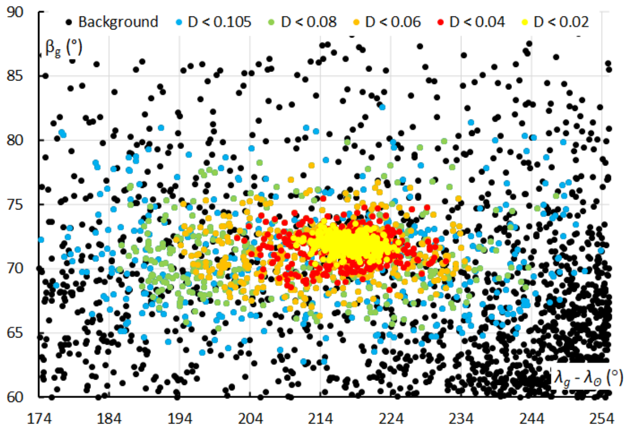

Figure 2 – The geocentric Ursid radiant in Sun-centered ecliptic coordinates.

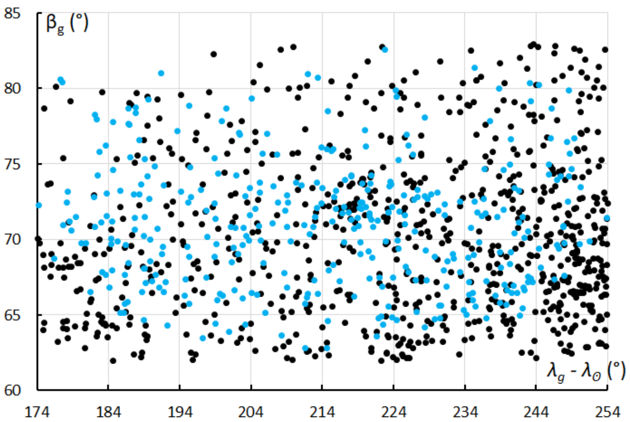

Figure 3 – The backround of Figure 2 with sporadics and dispersed low threshold Ursids which appears hidden by the high and very high threshold Ursid radiants in Figure 2.

Equatorial coordinates are not very suitable to compare meteor shower radiants because of the radiant drift caused by the movement of the Earth around the Sun. The Sun-centered ecliptic coordinates neutralizes this radiant drift by simply subtracting the solar longitude from the ecliptic longitude. *Figure 2* shows this plot. With the ecliptic latitude around 72°, close to the ecliptic pole the radiant appears rather elongated in longitude. Also, in these ecliptic coordinates the Ursids appear as a widely dispersed radiant with a very compact concentration of very similar orbits (red and yellow dots). *Figure 3* displays the same region with only the sporadic radiants and low threshold Ursids. Anyone using only radiant position and velocity to identify Ursids would count all these sporadics as Ursids while their orbits are very different from the Ursid orbit.

5 Ursid activity profiles based on orbits

The number of Ursid orbits collected gives us a glue about the activity level. Poor weather and the variable capture capacity will affect the number of sporadic orbits in the same way as the Ursid orbits. We count the number of sporadic orbits and the number of Ursid orbits in time bins of 0.25° in solar longitude shifted by 0.05 in solar longitude at each step and calculate the percentage of Ursid orbits relative to the number of sporadic orbits. As sporadic orbits we consider all orbits that could not be identified with any known meteor stream. The resulting activity curve is shown in *Figure 4*.

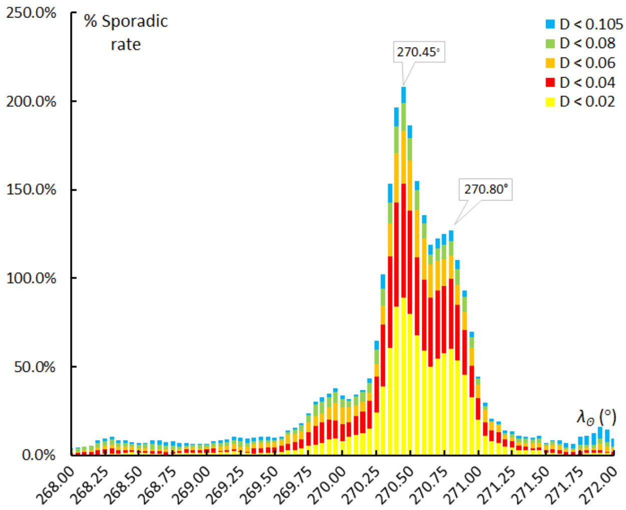

Figure 4 – The number of Ursid orbits in function of the solar longitude expressed as a percentage of the sporadic background counted in bins of 0.25° in solar longitude, shifted by 0.05°.

The most striking aspect is the shape of the profile with a peak that occurs about a little bit earlier than the outbursts observed in the past. The shoulder in the profile 0.35° later may indicate a secondary maximum. The low threshold, very dispersed Ursid orbits (blue and green) have very little effect on the activity profile. The trend is very well visible among the very compact group of Ursid orbits (red and yellow). The Ursids seem to be very variable in strength from year to year. Therefore, we compare the number of Ursid orbits collected year by year, not as percentages but raw numbers of Ursid orbits counted in 0.25° bins in solar longitude, shifted by 0.05° for each step. No calibration was applied. For 2006 and 2007 too few orbits were recorded. In 2019 Ursids were almost absent or perhaps missed. SonotaCo covers the Japanese observing window, EDMOND covers mainly the European observing window while the CAMS network mainly covers the American observing and the European window. Thanks to the long winter nights there is a large overlap between the networks. With a circumpolar radiant active during the longest night of the northern hemisphere the three networks provide global coverage, if lucky with the weather. The number of available orbits by each network is mentioned for the interval 270.0° < $\lambda_\odot$ < 271.5°, to verify if the suspected period with a possible maximum activity has been covered by the networks or not.

2008: SonotaCo had 55 orbits of which 6 Ursids, EDMOND had 90 orbits with 47 Ursids. The highest number of orbits was recorded at $\lambda_\odot$ = 270°.45° by EDMOND. Only the usual annual low Ursids activity was recorded without anything unusual.

2009: SonotaCo had 272 orbits of which 32 Ursids, EDMOND had no orbits at all during the suspect interval. The highest number of orbits was recorded at $\lambda_\odot$ = 270°.60°.

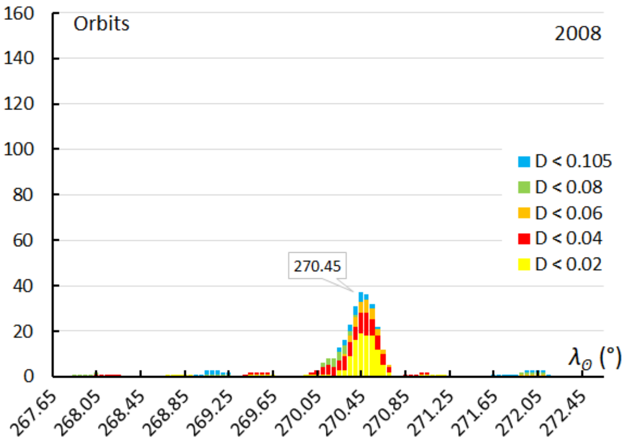

Figure 5 – The number of Ursid orbits counted in 2008 in bins of 0.25° in solar longitude shifted 0.05° at each step.

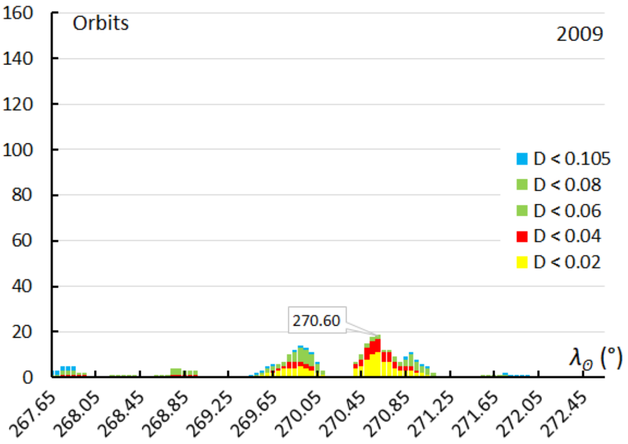

Figure 6 – The number of Ursid orbits counted in 2009 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2010: SonotaCo had 211 orbits of which 50 Ursids, EDMOND had only 3 orbits but no Ursids, CAMS had no orbits in the suspect interval. The highest number of orbits was recorded at $\lambda_{\odot}$ = 270°.50°.

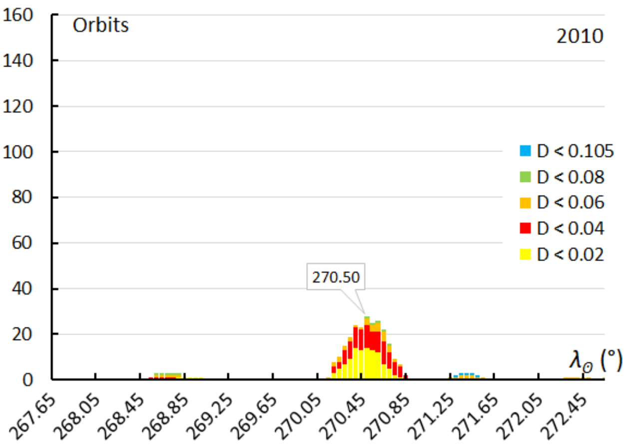

Figure 7 – The number of Ursid orbits counted in 2010 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2011: SonotaCo had 376 orbits of which 89 Ursids, EDMOND had 293 orbits of which 105 Ursids, CAMS had 748 orbits of which 47 Ursids in the suspect interval. The highest number of orbits was recorded at $\lambda_{\odot}$ = 270°.40°.

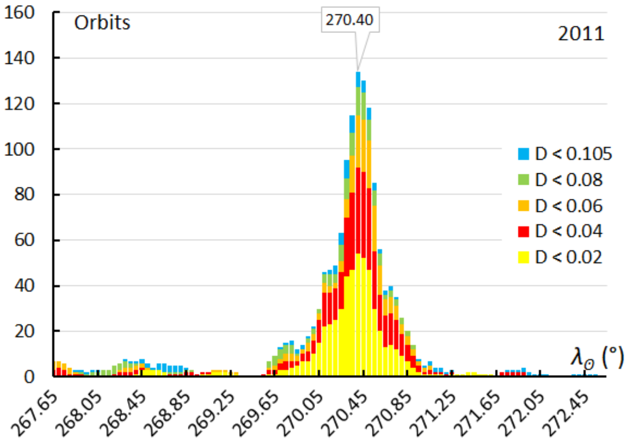

Figure 8 – The number of Ursid orbits counted in 2011 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2012: SonotaCo had 34 orbits of which 3 Ursids, EDMOND had 39 orbits of which 3 Ursids, CAMS had no orbits in the suspect interval. During this year the suspected time interval with the possible Ursid maximum was missed.

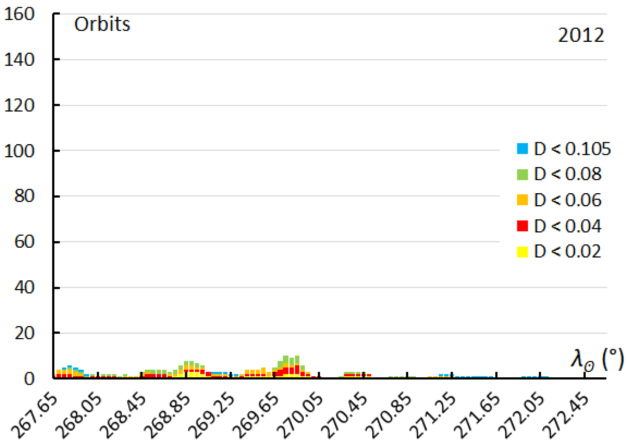

Figure 9 – The number of Ursid orbits counted in 2012 in bins of 0.25° in solar longitude shifted 0.05° at each step.

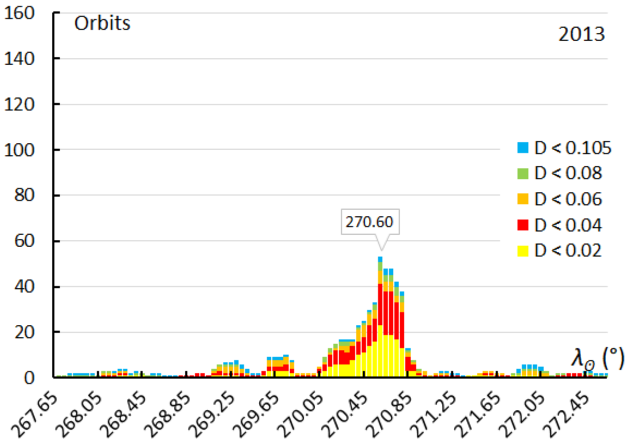

Figure 10 – The number of Ursid orbits counted in 2013 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2013: SonotaCo had 155 orbits of which 17 Ursids, EDMOND had 98 orbits of which 13 Ursids, CAMS had 544 orbits of which 66 Ursids in the suspect interval. The highest number of orbits was recorded at $\lambda_{\odot}$ = 270°.60°. The highest numbers of Ursid orbits recorded seem to be shifted few hours later than at $\lambda_{\odot}$ = 270°.45. Most of these Ursids were recorded by CAMS in the USA. The number of orbits dropped suddenly as the next observing window obviously suffered poor observing conditions.

2014: SonotaCo had 170 orbits of which 23 Ursids, EDMOND had 108 orbits of which 48 Ursids, CAMS had 496 orbits of which 31 Ursids in the suspect interval. The highest number of orbits was recorded at $\lambda_\odot$ = 270°.85°. This year Esko Lyytinen predicted a possible encounter with a dust trail from 1405 at $\lambda_\odot$ = 270°.838° (Jenniskens, 2006). This encounter was also confirmed by CMOR and by other video observing efforts. Although the peak level was rather modest this peak occurred about 0.4° in solar longitude later than the usual annual Ursid maximum.

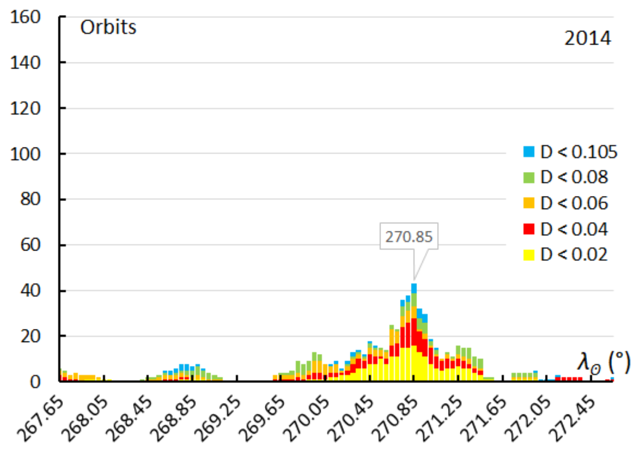

Figure 11 – The number of Ursid orbits counted in 2014 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2015: SonotaCo had 45 orbits of which 3 Ursids, EDMOND had 166 orbits of which 43 Ursids, CAMS had 107 orbits of which 1 Ursid in the suspect interval. The highest number of orbits was recorded at $\lambda_\odot$ = 270°.70°.

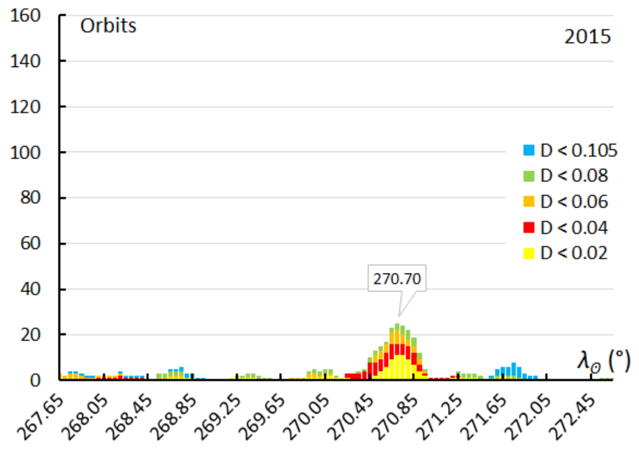

Figure 12 – The number of Ursid orbits counted in 2015 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2016: SonotaCo had 109 orbits of which 12 Ursids, EDMOND had 654 orbits of which 148 Ursids, CAMS had 485 orbits of which 149 Ursid in the suspect interval. The highest number of orbits was recorded at $\lambda_\odot$ = 270°.80°. Also, this year Esko Lyytinen had predicted the possible encounter of a dust trail of 1076 at $\lambda_\odot$ = 270°.76° (Jenniskens, 2006). The profile is interesting as the first maximum which is the annual Ursid peak was unusually strong and mainly covered by EDMOND, while the maximum due to the dust trail of 1076 was mainly covered by CAMS in the USA.

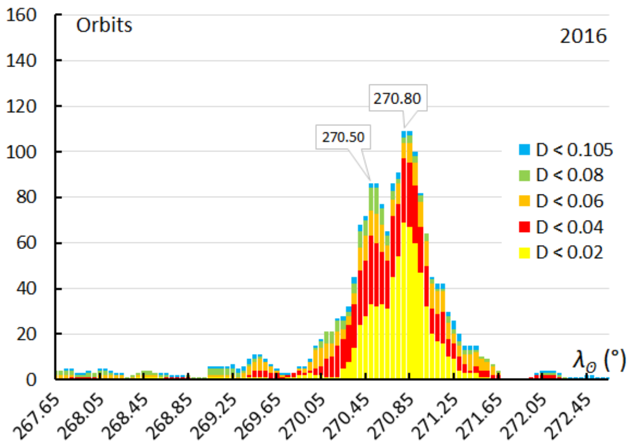

Figure 13 – The number of Ursid orbits counted in 2016 in bins of 0.25° in solar longitude shifted 0.05° at each step.

2017: After 2016 no more EDMOND orbit has been released while CAMS data from 2017 onwards is still kept under embargo. Only SonotaCo data is available and had 313 orbits of which 99 Ursids in the suspect interval. The highest number of orbits was recorded at $\lambda_\odot$ = 270°.75°.

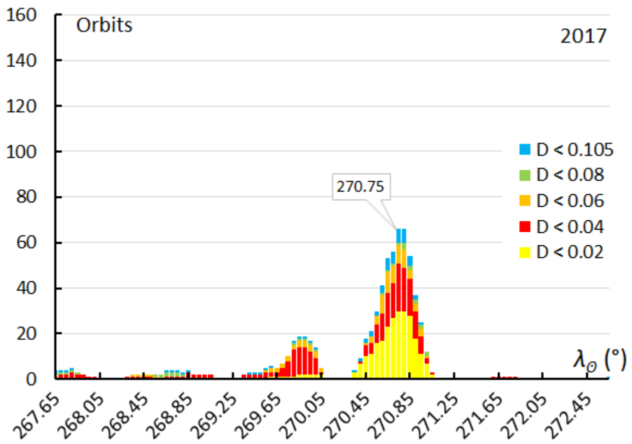

Figure 14 – The number of Ursid orbits counted in 2017 in bins of 0.25° in solar longitude shifted 0.05° at each step.

The activity profile in *Figure 4* shows the annual Ursid maximum at $\lambda_\odot$ = 270°.45° and a shoulder caused by dust trails encountered in some years at about $\lambda_\odot$ = 270°.80°.

6 The Ursid orbital elements

The Ursid parent comet 8P/Tuttle has its node far outside the orbit of the Earth so that dust released from the comet can only encounter the Earth when it gets far enough inside the comet's orbit. Esko Lyytinen and Peter Jenniskens solved this mystery (Jenniskens, 2006). After 45 revolutions the dust lags half an orbit behind the comet and intersects the Earth's orbit. This explains the outbursts when the comet was at its aphelion. Besides these outbursts the Ursids also display annual activity although comparable to typical minor shower activity except for some years when specific dust trails encounter the Earth.

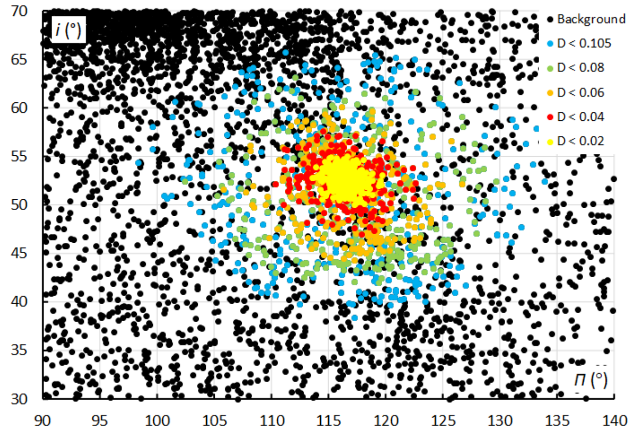

Figure 15 – The distribution of inclination *i* against the length of perihelion *Π* for non-Ursids and the Ursids for the different classes of dispersion.

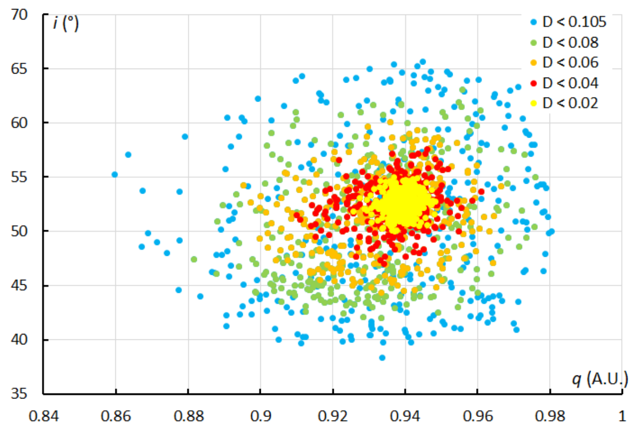

Figure 16 – The distribution of inclination *i* against the perihelion distance *q* for the Ursids for the different classes of dispersion.

Looking at the orbital elements of the Ursids, we see a large spread on the orbits which form a rather diffuse meteor stream with a distinct core of very similar orbits. The spread on Ursid orbits in *Figure 15* is larger than for most other meteor streams. The concentration in the upper left corner is caused by Quadrantid orbit. The distribution of the perihelion distance *q* against the inclination *i* shows a spread of more than 25° in inclination (*Figure 16*).

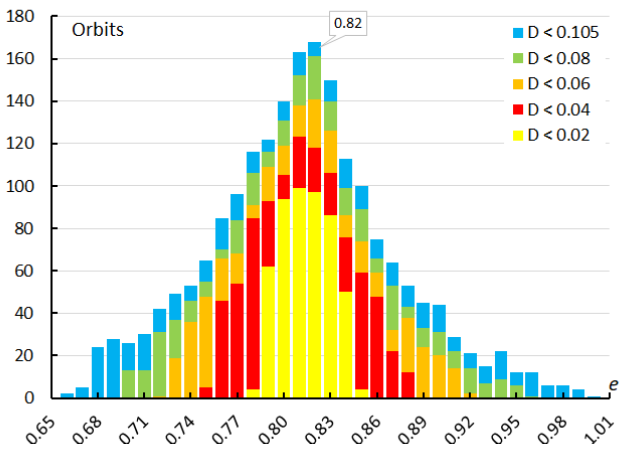

Figure 17 – Histogram with the distribution of the eccentricity *e* for the Ursid orbits with different colors for the shells in function of dispersion, from dispersed (blue, low similarity) to compact (yellow, very high similarity).

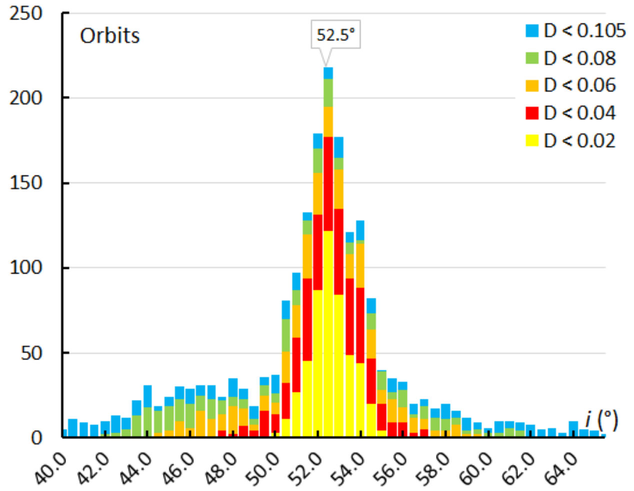

Figure 18 – Histogram with the distribution of the inclination *i* for the Ursid orbits with different colors for the shells in function of dispersion, from dispersed (blue, low similarity) to compact (yellow, very high similarity).

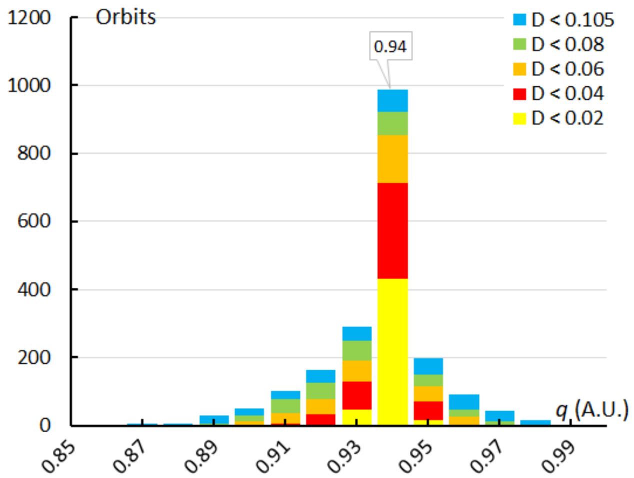

Figure 19 – Histogram with the distribution of the perihelion distance *q* for the Ursid orbits with different colors for the shells in function of dispersion, from dispersed (blue, low similarity) to compact (yellow, very high similarity).

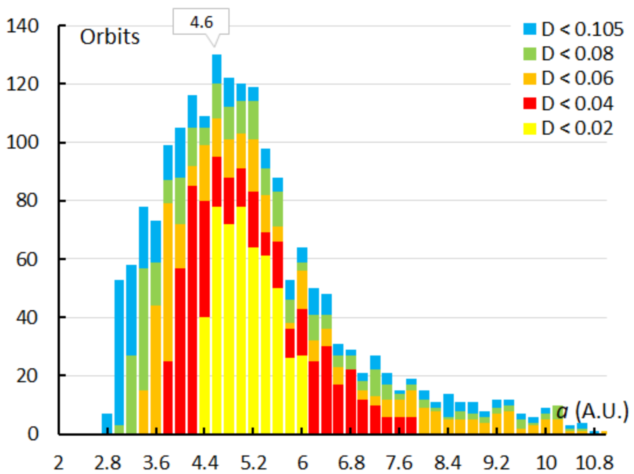

Figure 20 – Histogram with the distribution of the semi major axis *a* for the Ursid orbits with different colors for the shells in function of dispersion, from dispersed (blue, low similarity) to compact (yellow, very high similarity).

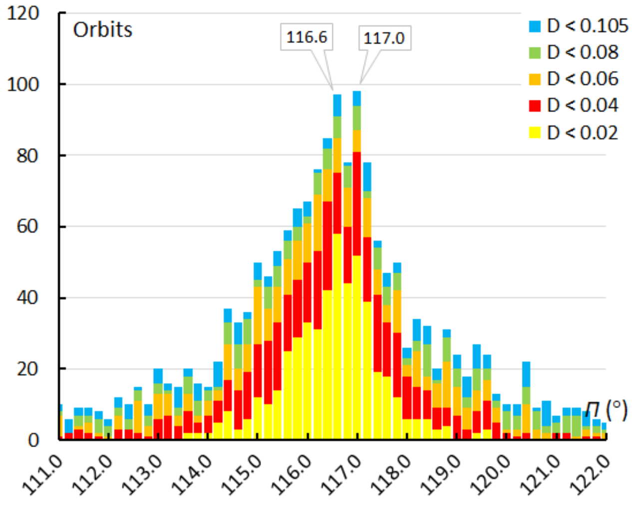

Figure 21 – Histogram with the distribution of the length of perihelion Π for the Ursid orbits with different colors for the shells in function of dispersion, from dispersed (blue, low similarity) to compact (yellow, very high similarity).

The histograms with the distribution of the different orbital elements are typical for a rather diffuse meteor stream (*Figures 17 to 21*). The more compact group of very similar orbits appear mainly during the annual maximum of the Ursids and during the maxima caused by specific dust trails, this is also visible in the activity profiles discussed in *Section 5*. Compact orbits are shown in yellow.

The length of perihelion Π is the only time related orbital element and displays a remarkable dip on the top, with two peaks separated by 0.4° in length of perihelion (*Figure 21*). This corresponds to the annual maximum visible in most activity profiles at $\lambda_{\odot}$ = 270°.45° and the secondary peak at $\lambda_{\odot}$ = 270°.80° to 270.85° caused by specific dust trails in some years like in 2016 (*Figure 13*) and which appears as a shoulder in the general activity profile (*Figure 4*). The difference corresponds to about 9 to 10 hours between the encounter of the Earth with the annual concentration in the Ursid stream and the occasionally present dust trails.

7 Velocity distribution of the Ursids

Every meteor shower is mainly defined by its radiant which indicates the direction from where it encounters the Earth and its velocity relative to the Earth which determines together with the radiant direction the orbit relative to the Sun in our solar system. Radiant size and velocity range determine how compact or how dispersed a meteor stream appears at its encounter with our planet. That is the reason why the measured velocities deserve proper attention just like the radiant characteristics.

In *Figure 22* we see the distribution of the measured geocentric velocities. 33 km/s is the most representative velocity for the Ursids, also listed in *Tables 1, 2 and 3*. The distribution appears skew with more slower velocities than faster velocities. When we look at the radiant distribution in Sun-centered ecliptic coordinates we see the fastest Ursids appear in the direction of the apex (bottom right in *Figure 23*) and slower Ursids away from the apex. The higher the inclination, the faster the Ursids. This appears in both the color code plot of the inclination against the perihelion distance (*Figure 24*) and the plot of the inclination against the length of perihelion (*Figure 25*).

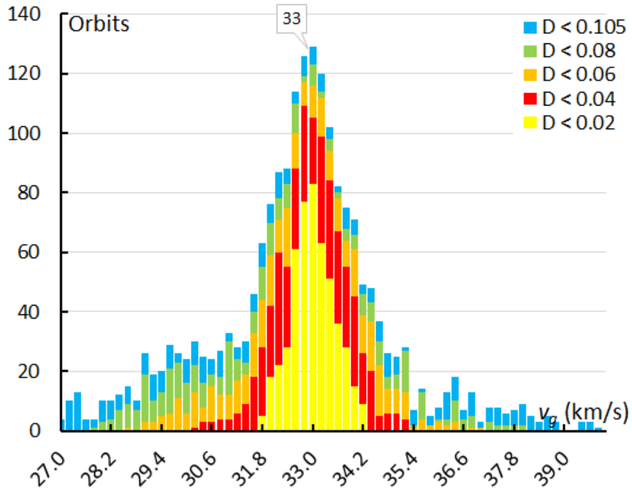

Figure 22 – Histogram with the distribution of the geocentric velocity v_g for the Ursid orbits with different colors for the different shells of dispersion, from dispersed (blue, low similarity) to compact (yellow, very high similarity).

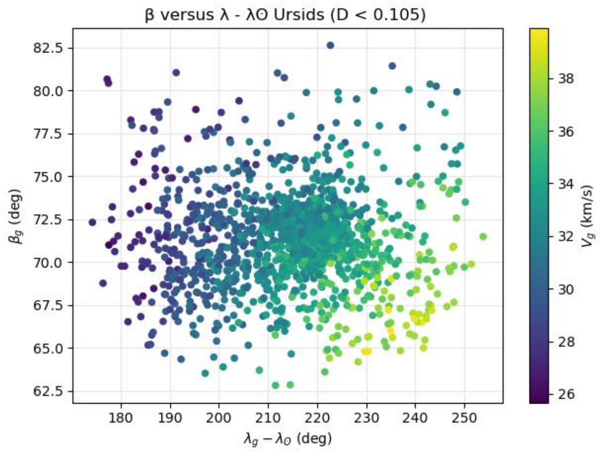

Figure 23 – The Ursid radiant in Sun-centered ecliptic coordinates color coded for the geocentric velocity.

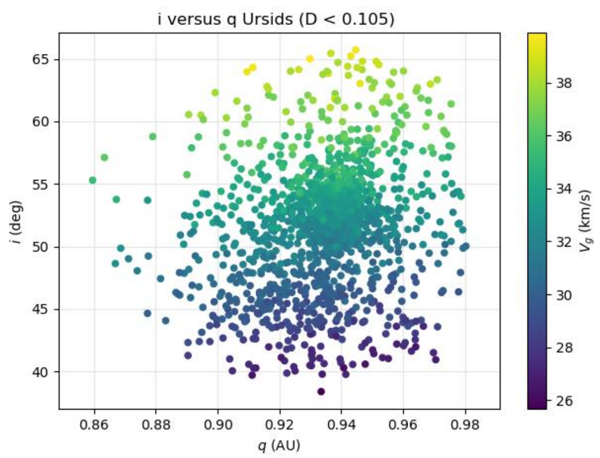

Figure 24 – The orbit distribution with the inclination i against the perihelion distance q color coded for the geocentric velocity.

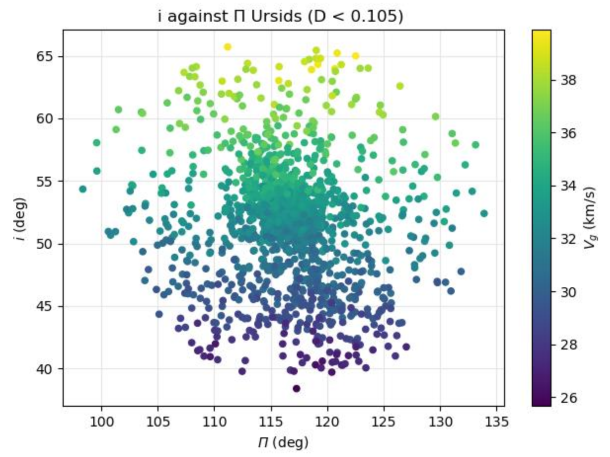

Figure 25 – The orbit distribution with the inclination i against the length of perihelion Π color coded for the geocentric velocity.

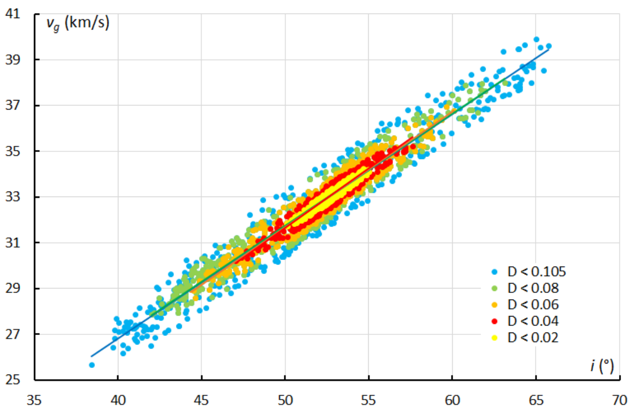

Figure 26 – The geocentric velocity v_g in function of the inclination.

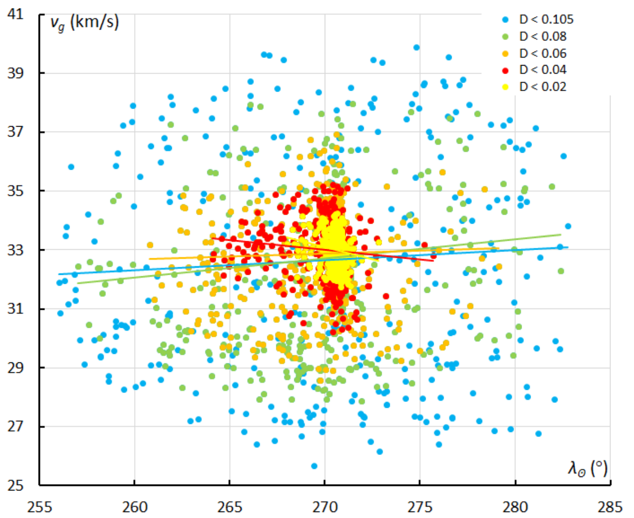

Figure 27 – The geocentric velocity v_g in function of time, solar longitude $\lambda_\odot$.

The relationship between the inclination and the velocity of the Ursids becomes very clear when we plot the velocity against the inclination. All orbits for all similarity classes appear close to the regression line which is the same for all degrees of dispersion (*Figure 26*).

Looking at the variation of the geocentric velocity with time, no trend can be derived throughout the activity period of the Ursid shower. The velocity remains stable during the activity period (*Figure 27*). Note that the Ursid activity consists mainly of very dispersed orbits with a wide spread on the velocities beyond the nights around the maximum activity.

8 The Ursid luminosity

The absolute magnitudes were averaged in time bins of 0.5° in solar longitude shifted in steps of 0.05° (*Figure 28*). The Ursids appear to be fainter than the sporadic meteors! When I saw the graph, I double checked the source data. The sporadics are all meteors for which the orbit could not be identified with any known meteor shower. The strange pattern of the sporadic magnitudes is puzzling. CAMS has more fainter meteors than Edmond and SonotaCo, but the solar longitudes were collected for the three networks combined during 7 years, 2010 until 2016 included. The sporadics seem to get slightly brighter during the considered observing interval, another feature without an explanation.

Some bright ursids have been reported in the past during some outburst but overall, the main activity of the Ursids seems to consist of faint meteors, something rather unusual for shower meteors. It may be interesting to look at the average magnitude per year to check if there are strong differences between years with only annual activity and years with outbursts.

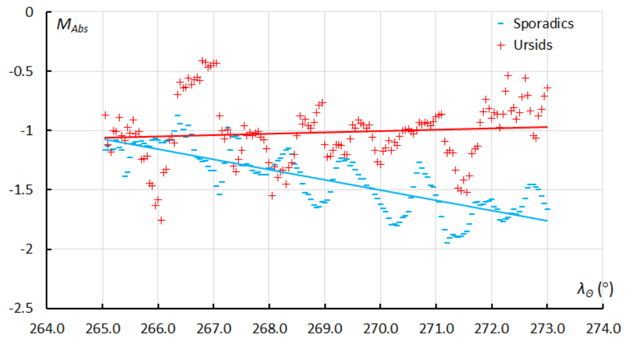

Figure 28 – The average absolute magnitude for the Ursids and for sporadic meteors in function of time.

9 Another outburst in 2020?

The two most recent years, 2014 and 2016, with a prediction by Esko Lyytinen and Peter Jenniskens for enhanced activity caused by a dust trail did materialize. In 2020 Earth may encounter a dust trail of 829 at $\lambda_\odot$ = 270°.57°, which is 2020 December 22 at 6^h10^m UT. There is also a chance to encounter a dust trail of 815 during the interval 270.44° < $\lambda_\odot$ < 270.92° or 2020 December 22 between 3^h and 22^h UT. If one or both dust trails are encountered, each may produce enhanced activity during about one hour. Lyytinen and Jenniskens mention rather high hourly rates as a possibility. However, caution is required with this kind of predictions, nothing can be guaranteed and in the worst case the Ursids will just show their modest annual maximum without any outburst. For the next chance to encounter Ursid dust trails, we must wait until 2028 when the comet will be at its aphelion, a similar situation like with the 1945 and 1986 outbursts.

The last time that the Ursids parent comet 8P/Tuttle passed its perihelion was on 2008 January 27, the next perihelion passage will be 2021 August 27. The 2020 Ursid return is very similar to the 1993 return when very good Ursid rates were observed ahead of the perihelion passage later in 1994.

10 Conclusion

Considering the long-term history of meteor observations, the Ursids remain remarkably absent in 19th and early 20th century. The radiant could barely be detected with a typical minor shower behavior with too few meteors to be recognized as a meteor shower by visual observers. The unexpected outburst in 1945 got plenty of attention in literature and since then, the Ursids ranked on most shortlists as a major meteor shower. Apart from some very weak activity in the years after 1945, the shower remained again unnoticed until 1986 when another outburst was observed. Since then, the Ursids were better monitored but apart from some years with dust trail encounters the Ursid activity remained barely noticeable. The shower should be better qualified as a minor shower with variable activity and potential outbursts.

The Ursids appear to be a very dispersed meteor shower with a sharp annual peak at $\lambda_{\odot} = 270°.45°$ with modest activity. Outbursts related to dust tails produced short lived sharp peaks slightly after the annual maximum.

11 Acknowledgment

The author thanks *Denis Vida* for providing the scripts to plot the velocity distribution with a color gradient and to compute the average orbit according to the method of Jopek et al. (2006). Thanks to the volunteers who maintain the IAU working list of meteor showers (Jopek and Kaňuchová, 2014, 2017; Jopek and Jenniskens, 2011).

We thank the SonotaCo Network members in Japan who have been observing every night for more than 10 years, making it possible to consult their orbits. We thank the camera operators of the CAMS[1] networks[2]. And we thank the contributors to EDMOND[3], including: BOAM (Base des Observateurs Amateurs de Meteores, France), CEMeNt (Central European Meteor Network, cross-border network of Czech and Slovak amateur observers), CMN (Croatian Meteor Network or HrvatskaMeteorskaMreza, Croatia), FMA (Fachgruppe Meteorastronomie, Switzerland), HMN (Hungarian Meteor Network or Magyar Hullocsillagok Egyesulet, Hungary), IMO VMN (IMO Video Meteor Network), MeteorsUA (Ukraine), IMTN (Italian amateur observers in Italian Meteor and TLE Network, Italy), NEMETODE (Network for Meteor Triangulation and Orbit Determination, United Kingdom), PFN (Polish Fireball Network or Pracownia Komet i Meteorow, PkiM, Poland), Stjerneskud (Danish all-sky fireball cameras network, Denmark), SVMN (Slovak Video Meteor Network, Slovakia), UKMON (UK Meteor Observation Network, United Kingdom).

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[1] http://cams.seti.org/
[2] http://cams.seti.org/FDL/
[3] https://fmph.uniba.sk/microsites/daa/daa/veda-a-vyskum/meteory/edmond/

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