The Quadrantids & December alpha Draconids 2012–2019: Multi-year meteor videography

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NEMETODE, a network of low-light video cameras in and around the British Isles operated in conjunction with the BAA Meteor Section and other groups, monitors the activity of meteors, enabling precise measurement of radiant positions as well as the altitudes, geocentric velocities and solar system orbits of meteoroids. The results from observations of the Quadrantid and December alpha Draconid meteor showers during 2012–2019 are presented and discussed.

Equipment & methods

The NEMETODE team employed the equipment and methods described in previous papers,[1,2] and on their website,[3] including Genwac, KPF and Watec video cameras equipped with fixed- and variable-focal-length lenses ranging from 2.6mm semi-fisheye models to 12mm narrow-field systems.

The Quadrantid & December alpha Draconid meteor streams

The Quadrantids (IAU Meteor Data Centre code 010 QUA) are medium-speed meteors with geocentric velocities (Vg) of 41km/s, active from late December to mid-January and appearing from a radiant in northern Boötes (the now defunct constellation Quadrans Muralis: the Mural Quadrant).

Their radiant is circumpolar from the British Isles, although it is low in the northern skies until after local midnight, climbing to an altitude of about 75° at the onset of morning twilight.

The QUAs produce low rates except for a ZHR (Zenithal Hourly Rate) of ~120 at maximum with solar longitude ($\lambda_\odot$) 283.16° (2019 Jan 4, 02:20 UT) according to the International Meteor Organisation (IMO),[4] during a brief full width half maximum (FWHM) period of about 14 hours.[5] Their parent body has been identified as the Amor near-Earth object (196256) 2003 EH_1, although comet 96P/Machholz 1 has also been proposed as their progenitor.[6,7]

The December alpha Draconids (334 DAD) were discovered 10 years ago by the Japanese video meteor network, SonotaCo. They described this meteor shower as being active from late November to the end of December, with a maximum at $\lambda_\odot$= 256.5° (2018 Dec 8) and having a Vg very similar to that of the QUAs.[8] Professional radar studies have shown that both streams are members of a northern toroidal group, a source of meteoroids that is highly inclined to the ecliptic.[9]

In late December the daily motion of the QUA and DAD shower radiants brings them into close proximity with each other, and having similar Vg increases the likelihood of single-station meteors being assigned to the wrong stream. Triangulation from two or more stations was used in this paper to identify candidates from the QUA and DAD radiants.

First results

The first probable single-station DAD and QUA meteors in the NEMETODE data set were recorded on 2010 Nov 16 & Dec 19,[10] respectively, but it was 2012 December before the team obtained multi-station DADs and 2014 January for the QUAs. The latter were reported in the 2015 June *Journal*.[2] At the 2017 Jan 21 Ordinary Meeting of the Association the author presented an update on multi-year Quadrantid results, including a discussion of their close similarity with the December alpha Draconids.[11] This paper summarises the results from QUA meteors recorded in 2014–2019 January and DAD in 2012–2018 December.

Meteor stream catalogues

UFO Analyser and *UFO Orbit* utilise a meteor stream catalogue of each shower's start, maximum and end dates, radiant drift and geocentric velocity. *UFO Analyser* assigns a stream category to each single-station meteor and by default it extends the search window by 10 days before and after the normal shower date limits. To reduce the chance of a meteor being incorrectly assigned to the wrong stream, such as in this case with the overlapping activity timelines of the DADs and QUAs, the extension period was set to 0 days and this parameter setting was also adopted in *UFO Orbit* when identifying multi-station QUA and DAD meteors.

The most comprehensive catalogue distributed with SonotaCo's *UFO* software suite is *ULE_J6* (known as *J6*). EDMONd,[12] the European viDeo MeteOr Network, has produced a *J8* catalogue which includes many of the established minor streams missing from *J6*. The *J8* catalogue is undergoing more frequent revision and version *J8_02* (2019 August) was considered when analysing DAD and QUA meteors, with the following caveats.

It extends the QUA start and end limits by eight days more than *J6*, further increasing the overlap with the DAD shower in December. If the software also added 10 days to these limits this would give an exceedingly lengthy window of Dec 9 to Jan 29, for a shower with such a narrow FWHM around Jan 3–4. The QUAs would be deeply entangled with the DADs and some meteors would be incorrectly classified.

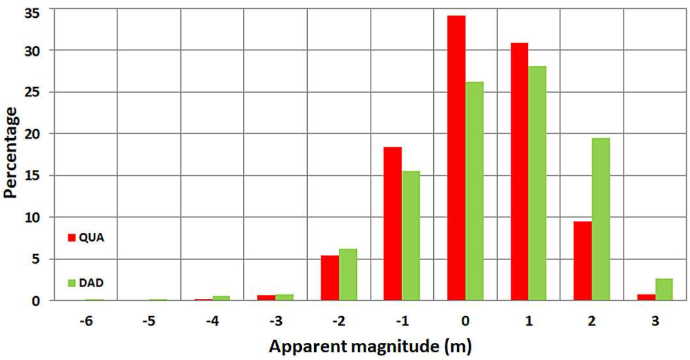

Figure 1. Magnitude distributions of the QUA and DAD meteors, 2012–2019.

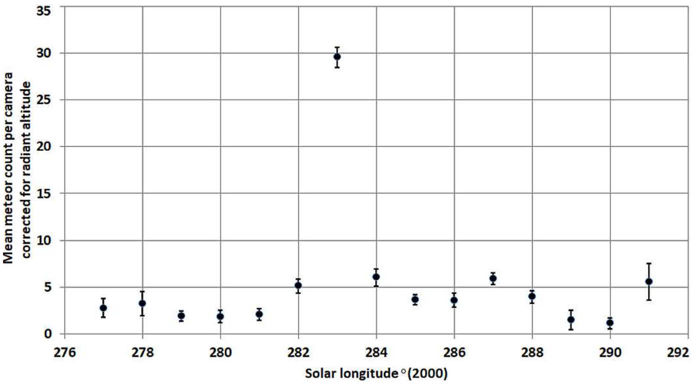

Figure 2. Quadrantids 2014–2019 activity profile.

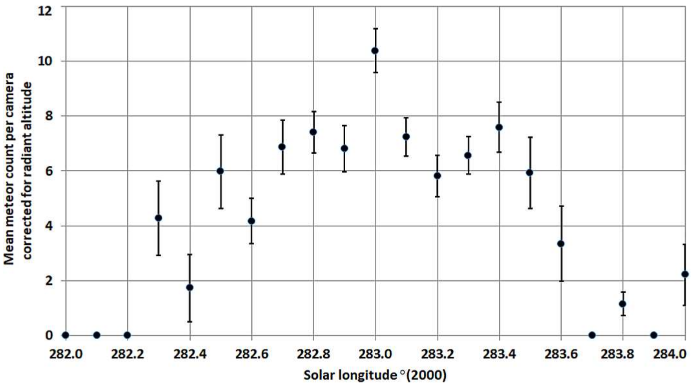

Figure 3. Quadrantids 2014–2019 peak activity profile.

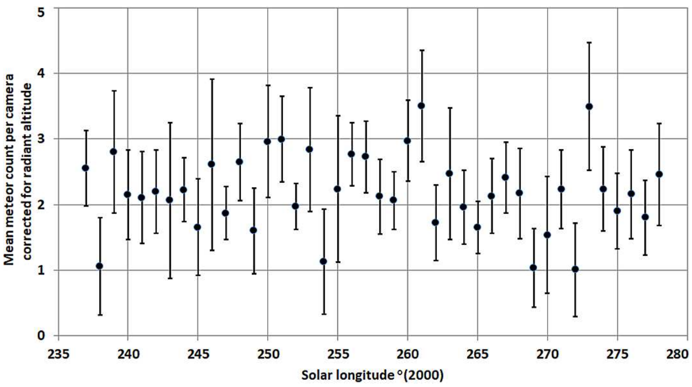

Figure 4. December alpha Draconids 2012–2018 activity profile.

J6 and *J8_02* use the same parameters for the DADs, except that *J8_02* adopts a standard radiant circle of 5° radius, instead of the large radius of 9° used by SonotaCo in *J6*. Hence, using *J8_02* rejects some DADs that are found by *J6*, so it cannot provide a good comparison with SonotaCo's results; the Japanese group had to cast a wide net to discover and monitor this shower.

In the stream catalogues the values of radiant drift in right ascension and declination (dRA° and dDec°, in degrees per degree of solar longitude) play an important role in assigning a meteor to a stream category. The software uses the drift rates to compute the positions of the radiants that are active at the time of a meteor and checks if its trail passes within (or close to) the radiant circles. Any significant error in dRA° and/or dDec° could cause a meteor to be incorrectly classified. In *J6*, SonotaCo gives a dDec° value of +0.17 for the QUAs, but the IAU MDC lists it as –0.25 and in *J8_02* it is –0.2.

For these reasons, this paper uses the *J6* catalogue but with QUA values of +0.5 and –0.25 for dRA° and dDec°, respectively.

Multi-station meteors

UFO Analyser creates an output file of each observer's single-station meteors. These files are collated into annual datasets and processed by *UFO Orbit* to identify and tabulate all simultaneous meteor events (within 3s timing tolerance) recorded by two or more video stations. It is also used to create radiant maps, ground tracks and solar system orbits.

UFO Orbit supports three built-in quality assurance criteria sets:

Q1 – minimum criteria for radiant computation
Q2 – standard criteria for radiant and velocity computation
Q3 – criteria for high precision-computation

A search of the NEMETODE data set for Q1-quality multi-station events found 486 QUAs and 243 DADs from the alignments of 1,086 and 533 single-station meteors, respectively. Only meteors that were components of a multi-station QUA or DAD were used in the analyses in this paper. Table 1 lists the observers who contributed video meteor data.

UFO Analyser estimates the apparent magnitude (*m*) of each meteor. The magnitude distributions of the QUA and DAD meteors are given in Figure 1.

The mean apparent magnitudes of the QUA and DAD meteors are 0.2 and 0.4 respectively, suggesting that the DADs could be slightly richer in faint meteors. The mean QUA magnitude is half a magnitude brighter than that given in ref. 2. This is because multi-station Q-criteria can eliminate some fainter meteors that are otherwise included in single-station analyses.

Quadrantid maximum

The short-duration Quadrantid maximum occurs in early January with the advantage of long dark nights, but the disadvantage that inclement weather can thwart attempts at recording their peak activity. Also, if maximum occurs when the radiant is at low altitude or during daytime, the observer will experience lower rates. Depending on the clarity of the sky, video cameras can record meteors in bright moonlight, even at full Moon. The IAU MDC gives a solar longitude of 283.0° for the Quadrantid maximum.[13] In recent years this equates to the dates, times (UT) and ages of the Moon given in Table 2.[14] For video observers in the British Isles, these years offered different views of the peak activity of the Quadrantids during various lunar phases.

To build a multi-year profile, the 1,086 QUAs were corrected for radiant altitude and the average meteor counts per camera were grouped into bands of 1° solar longitude (~24 hours), as shown in Figure 2.

A sharp and distinctive peak at $\lambda_\odot$= 283° emerged from the inherent variability of the meteor shower and the effects of variable sky conditions on our data. To display the peak in more detail, the QUAs were grouped into bands of 0.1° solar longitude (~2.4 hours), shown in Figure 3.

This suggests that Quadrantid maximum occurred at $\lambda_\odot$= 283.0° with a FWHM duration of about one day, from around $\lambda_\odot$= 282.5° to $\lambda_\odot$= 283.5°. This interval is likely to be broader than that observed in any single year, due to this profile being derived from combining several years' data.

Table 1. Observers who contributed video meteor data

Observer	*Location*
David Anderson	Low Craighead, Scotland Dunure, Scotland
Steve & Peta Bosley	Clanfield, England
Denis Buczynski	Tarbatness, Scotland
Peter Carson	Leigh-on-Sea, England
Allan Carter	Basingstoke, England
Crayford Manor House	Dartford, England
David Dunn	Livarot, France
Dunsink Observatory	Dunsink, Ireland
Mike Foylan	Rathmolyon, Ireland
Nick James	Chelmsford, England
Frank Johns	Newquay, England
Steve Johnston	Warrington, England
Jon Jones	Huntington, England
Charlie McCormack	Galway, Ireland
Andy McCrea	Bangor, Northern Ireland
Michael Morris	Worcester, England
Michael O'Connell	Monasterevin, Ireland
Alex Pratt	Leeds, England
Nick Quinn	Steyning, England
Gordon Reineke	Newbridge, Ireland
Graham Roche	Dublin, Ireland
Jim Rowe	East Barnet, England
Nick Rowell	Gargunnock, Scotland
Jeremy Shears	Bunbury, England
Fred Stevenson	Amersham, England
Peter Stewart	Derriaghy, Northern Ireland
William Stewart	Ravensmoor, England
Ray Taylor	Skirlaugh, England

December alpha Draconid activity profile

The 533 DAD meteors were corrected for radiant altitude and the average meteor counts per camera were grouped into bands of 1° solar longitude (Figure 4).

There is no indication of a significant peak in DAD activity and no evidence in this data set of a maximum near $\lambda_\odot$= 256° as listed by the IAU MDC.[15] However, there is a small rise at $\lambda_\odot$= 261° and a similar increase at $\lambda_\odot$= 273° is caused by a few meteors at low altitudes with large correction factors. Otherwise, the DADs appear to produce consistently low rates throughout the month of December.

Radiant drift

Because of our changing viewpoint of a meteor stream from the Earth as we orbit the Sun, a meteor shower's radiant slowly moves against the background of stars. *UFO Orbit* was used to derive the radiant point for each Q1 multi-station DAD and QUA meteor (corrected for zenith attraction) and they are plotted in Figures 5 & 6.

There is some overlap of the QUA and DAD radiants at around $\lambda_\odot$= 277° (2018 Dec 28–29). Figure 7 features multi-year data to illustrate the close proximity of their radiants. Note the diffuse spread of DADs compared with the more compact QUAs.

Interestingly, the radiant plots display a cluster of QUA activity between $\lambda_\odot$= 286° and $\lambda_\odot$= 288° (Jan 6–8) when we would expect rates to be in decline. This can also be seen in Figure 2.

The data for Figures 5 & 6 were used to estimate the daily drift in right ascension and declination (per degree of solar longitude) of the QUA and DAD shower radiants. The method of least squares gave the following linear fits:

$$\text{QUA}\qquad \text{RA} = (0.462\lambda_\odot) + 98.741$$
$$\text{Dec} = (-0.213\lambda_\odot) + 110.15$$

$$\text{DAD}\qquad \text{RA} = (0.459\lambda_\odot) + 89.865$$
$$\text{Dec} = (-0.225\lambda_\odot) + 117.51$$

Table 2. Times of Quadrantid maxima & the effect of moonlight

Date & time (UT), QUA maximum	*Moon age (days)*	*Moon percent illum.*	*Radiant distance (°)*
2014 Jan 3 15:52	2	7+	96
2015 Jan 3 22:04	13	98+	104
2016 Jan 4 04:11	24	32–	62
2017 Jan 3 10:15	5	25+	112
2018 Jan 3 16:25	17	96–	84
2019 Jan 3 22:35	28	4–	74

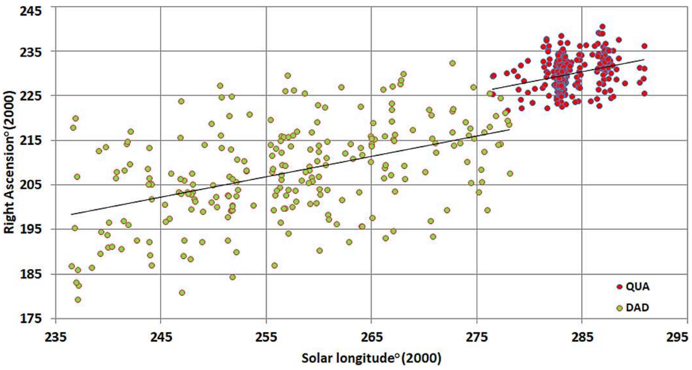

Figure 5. QUA and DAD radiant drift in right ascension, 2012–2019.

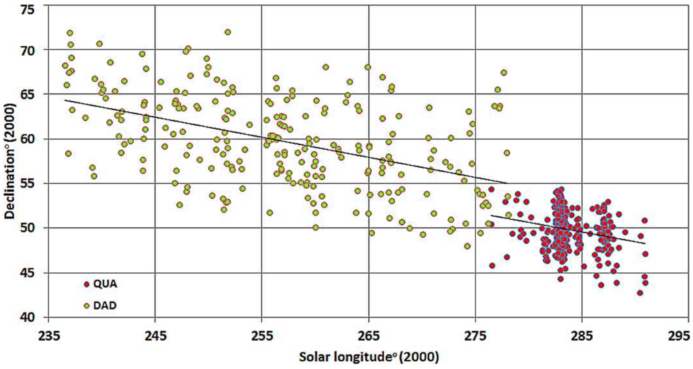

Figure 6. QUA and DAD radiant drift in declination, 2012–2019.

The radiant drift rates of both showers are almost identical.

If we assume that Quadrantid maximum occurred at $\lambda_\odot$= 283.0°, the radiant is then estimated to be located at RA 229.5° (15^h 18^m) and declination 49.9°. The estimated drift of the radiant per degree of solar longitude (~ per calendar day) is +0.46° in RA and –0.21° in declination. These are presented in Table 3 in comparison with other sources.

Detection & extinction altitudes

UFO Orbit computed the start and end altitudes of the Q1-quality multi-station QUA and DAD meteors and estimated their apparent magnitudes (*m*), from which it derived their absolute magnitudes (*M*) (Figures 8 & 9). Absolute magnitude is the brightness the meteor would have if it was observed at the zenith, 100km above the observer.

The method of least squares gives the linear fits:

QUA Detection altitude = $(0.081M) + 97.764$
Extinction altitude = $(2.938M) + 88.082$

DAD Detection altitude = $(–0.019M) + 98.221$
Extinction altitude = $(2.521M) + 87.73$

where altitudes are given in km. The altitude profiles of the QUA and DAD meteors are almost identical.

Geocentric velocities

UFO Orbit computed the *Vg* of 159 QUA and 79 DAD Q2-quality multi-station meteors, which gave the following:

QUA Mean = 40.4 (±0.2)km/s

DAD Mean = 41.7 (±0.5)km/s

These are compared with other sources in Table 4.

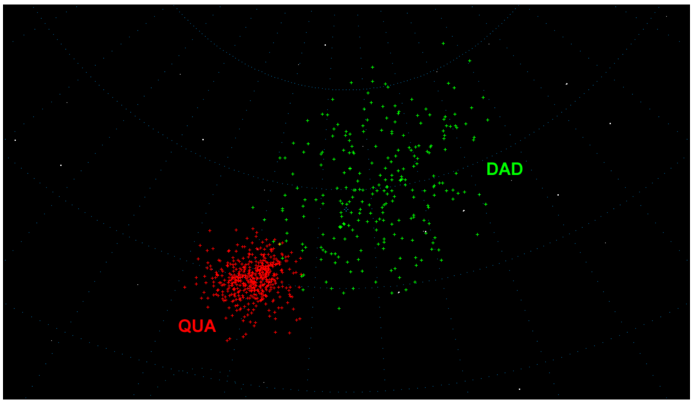

Figure 7. QUA and DAD radiants.

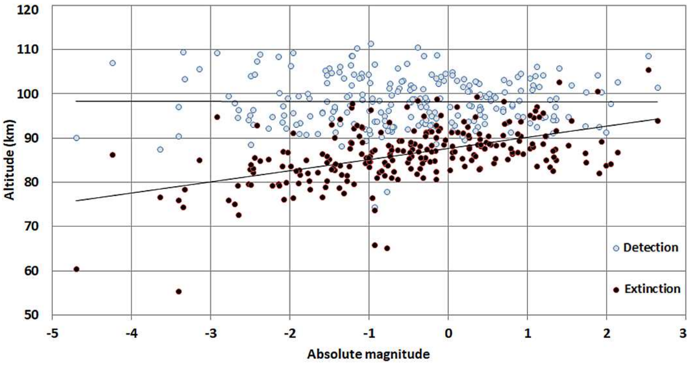

Figure 9. Detection and extinction altitudes of DAD meteors, 2012–2018.

Table 3. The position of the Quadrantid radiant at maximum, its daily motion & DAD data

	Solar long. $\lambda_\odot$ *(°)*	*RA (°)*	*RA (h, min)*	*dRA (°)*	*Dec (°)*	*dDec (°)*
(010 QUA)						
IMO[4]	283.16	230	15 20	0.6	49	–0.2
Jenniskens *et al.*[13]	283.0	230.2	15 21	0.56	49.5	–0.25
NEMETODE	283.0	229.5	15 18	0.46	49.9	–0.21
SonotaCo[8]	283.1	230.0	15 20	0.15	49.0	0.17
(334 DAD)						
Jenniskens *et al.*[15]	256.0	210.8	14 03	0.58	58.6	–0.34
NEMETODE				0.46		–0.23
SonotaCo[8]	256.5	207.9	13 52	0.40	60.6	–0.14

Notes: All positions are for epoch 2000.0.

Orbits

UFO Orbit also computed the orbital elements of 74 QUA and 32 DAD Q3-quality meteors. (Three QUA and 10 DAD meteors with large discrepancies in their semi-major axes were excluded.) A summary of the values for each stream, compared with other sources, is given in Table 5. Tisserand's parameter T_J is computed from a body's orbital elements and in this case it is used to compare its orbit with that of Jupiter (a value of $2 > T_J > 3$ is characteristic of Jupiter-family comets).

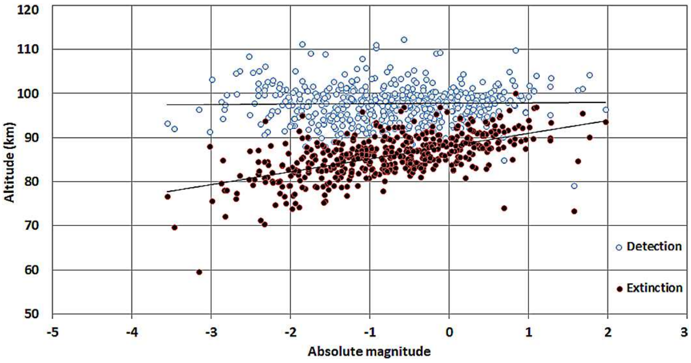

Figure 8. Detection and extinction altitudes of QUA meteors, 2014–2019.

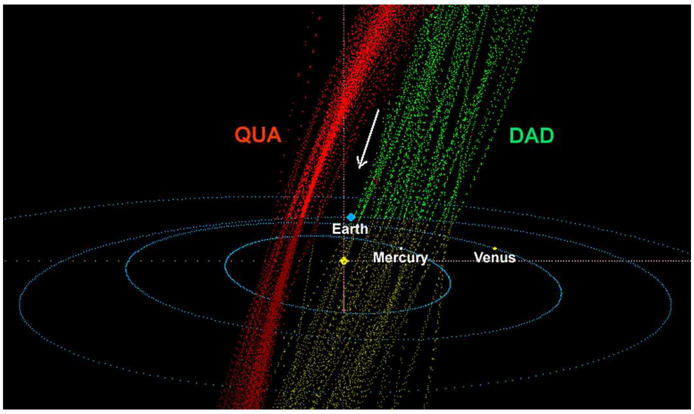

Figure 10. Solar system orbits of Q3-quality QUA and DAD meteors.

The QUA and DAD orbits are very similar, apart from their times of perihelion and their descending nodes when they cross the ecliptic.

Figure 10 is a solar system diagram of the Q3-quality orbits, showing how the Earth encounters first the DAD and then the QUA meteor streams. Both are highly inclined to the ecliptic, so that their meteoroids dive down to the Earth and the meteors appear from high-declination radiants.

Table 4. Geocentric velocities (*Vg*) of QUA & DAD meteors

	Vg (km/s)		*n*	
(010 QUA)				
		±		
Brown *et al.*[13]	41.7		6614	radar
Jenniskens *et al.*[13]	40.7		1029	
NEMETODE	40.4	0.2	159	
SonotaCo[9]	40.0		243	
(334 DAD)				
		±		
Jenniskens *et al.*[15]	40.8		47	
NEMETODE	41.7	0.5	79	
SonotaCo[9]	41.6		145	

Discussion

Canadian meteor radar observations classify the QUA stream as a member of a toroidal group which includes the DAD stream and others yet to be confirmed.[9] Koseki (Nippon Meteor Society) discusses in a 2018 paper the importance of correctly identifying shower members and the problems with extending normal shower limits by several days, with specific reference to the QUA and DAD meteors.[17] Koseki calls for cooperative regulation to be applied to the plethora of 'established' minor showers being added to reference catalogues, some of which are derived from alignments of only a few meteors.

Without careful management of the catalogues, since there will be multiple active radiants on any given night – some in close proximity – when back-tracing an observed meteor trail it is likely to align with more than one radiant, increasing the likelihood of incorrect classification by the analysis software. The shower membership of a single-station meteor is thus probabilistic and provisional.

To mitigate the problem of identification of QUA and DAD meteors, this paper used multi-station triangulation of meteors detected between normal shower limits, and an updated value for QUA radiant drift in declination. The analyses showed that the DADs produce consistently low rates throughout December, whereas the QUAs present a strong short-lived peak of activity in early January at $\lambda_\odot = 283.0°$ (2020 Jan 4, 04:45 UT). The DADs are perhaps richer in faint meteors, with slightly higher *Vg*. Otherwise, both streams display the same radiant drift, detection and extinction altitudes, and their orbital characteristics are very similar.

The Quadrantids are the first major shower of the year and it is always a challenge to observe their elusive peak around Jan 3–4. Radio and video studies show they are not an isolated shower; we have a complex story of activity from more than one stream. It will be interesting to see the results from our data set over the next few years.

Acknowledgements

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Table 5. Orbital elements of QUA & DAD meteors

	a (au)		*q (au)*		*e*		*Peri J2000*		*Node J2000*		*Incl J2000*		*n*	*Tisserand's parameter, T_J*
(010 QUA)														
		±		±		±		±		±		±		
Brown *et al.*[13]	3.35		0.9746		0.709		168.14		283.0		72.4		6614	2.18
Jenniskens *et al.*[13]	2.82		0.979		0.657		171.4		283.3		71.2		1029	2.48
NEMETODE	2.740	0.420	0.980	0.001	0.634	0.007	173.266	0.520	283.882	0.229	70.711	0.272	74	2.54
(196256) 2003 EH1[16]	3.124		1.190		0.619		171.35		282.981		70.840			2.36
96P/Machholz 1[16]	3.033		0.124		0.959		14.746		94.351		58.539			2.03
(334 DAD)														
		±		±		±		±		±		±		
Jenniskens *et al.*[15]	2.48		0.983		0.603		177.4		254.8		71.8		47	2.71
NEMETODE	2.729	0.130	0.976	0.002	0.618	0.019	182.685	2.308	254.193	1.866	71.010	1.220	32	2.56