Comet - Meteor Associations: D' Criterion Assessment of the Meteor Orbits' Databases of the DMS

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Summary

The photographic and video meteor orbit databases of the Dutch Meteor Society have been cross checked against a list of cometary orbits using the Drummond D' Criterion (Drummond 1979). The results are compared to a non-statistical analysis undertaken in an earlier paper, and some new results noted.

Introduction

In an earlier paper (Greaves 1999) the meteor orbits of the photographic and video databases or the Dutch Meteor Society (DMS) were cross correlated against a list of comet orbits* using a relational database management package to test when the inclination, *i*, ascending node, *W*, and argument of perihelion, ω, were all within a small range. Candidate meteor shower comet associations were then predicted on the basis of the results. This approach was non-statistical.

In this paper a statistical approach is followed primarily utilising the D' Criterion of Drummond (1979). The statistical significance threshold, D_0, below which a derived value of D' can be said to be significant is usually taken as 0.105 for sufficiently large samples (eg Arter & Williams 1997, and further references therein), and the combined DMS photographic and video orbit databases now number around 1480 orbits with the recent update of the photographic dataset (Betlem 1999).

However, it should be noted that although significance thresholds for statistical tests are dependent on the sample size and often tend towards a limit as this sample size increases, it is most likely that the number of meteors from within the sample that are identified as *members* of any *particular* shower also has an affect on the threshold value. Again, where the number of members associated with any particular shower is relatively large in comparison to the full dataset, the threshold will tend to the limit.

Yet the case is not so clear cut for the situation where only two, three, four and five or so members per shower have been identified from the same data sample: it is likely that different threshold values are appropriate to each of these situations (see for example Jopek *et al* 1999). Notwithstanding this, threshold values of 0.105 and 0.15 are often quoted as universal for the Drummond D' and Southworth and Hawkins (1963) D criteria respectively.

In practice such considerations are beyond the remit of this paper, and the author has nonetheless utilised a D' threshold value of 0.100 as the cutoff point between meaningful and non-meaningful comet meteor orbit associations. The reader is encouraged to bear the above caveat in mind, however, when considering results where only a handful of meteors having relatively high D' values are shown to be similar in orbital characteristics to a particular comet. The above considerations are not entirely alien: after all, most people would consider it a matter of common sense *not* to give much weight to a situation where only one meteor has been associated with a particular comet, and even less so if the D' value was near 0.1.

The full results are presented in Appendix Table 1, where the DMS meteor identity, associated comet, D' value and DMS stream identification for that meteor are given. Meteors prefixed with P are from the DMS photographic database (www.dmsweb.org), and those prefixed with a V from the video database (*op cit*). Those beginning with the number 19 are from the recent update (1/11/1999) of the photographic database (*op cit*): although these data were not available for the first paper (Greaves 1999), they do no affect matters greatly when it comes to the identification of "new" associations, as the vast majority of them are either Leonids or Perseids.

Ecliptic meteors can give good D' values for more than one short period comet, thus the table is given in meteor order, such that these problematic occurrences appear together in the table. This means that it is not too easy for the reader to find the cases where a comet is associated with only a handful of meteors: however providing a second table sorted on comet name

would be prohibitive on space. This should present no real problem as all the cases of interest are covered in the body of the article.
The rest of the article includes details of associations in the same order as the first paper (Greaves 1999), to allow intercomparison of results, and is followed by some results particular to the current analysis.

DISCOVERIES

Leo Minorids

The first paper noted a strong similarity between five meteors identified as Leo Minorids in the DMS databases and the comet C/1739, and went on to note that this association, though little known today, was actually mentioned in the discovery paper for the shower itself (McCrosky and Posen 1959)! Indeed, the shower is little known and not always referred to in works.
The same five meteors *all* passed the D' criterion quite well in comparison to C/1739. Four of them have D' values between 0.031 and 0.052, and the fifth having a value of 0.074: all quite good values considering that different apparition orbits of the comet 86P/Halley can have D' values as high as 0.04 when compared to each other!
The meteors are P92021, P95103, V95414, V95465 and V95476, and as far as these DMS orbits are concerned there is little doubt left that C/1739 is the parent body of the Leo Minorids.

kappa Cygnids

In the first paper an association was suggested between the comet C/1345 O1 and the kappa Cygnids. The orbital inclination of the comet was 15 to 20 degrees too small in comparison to the meteor orbits, but otherwise all other elements were quite close, and it was noted that the comet's orbit was only approximately known anyway.
On D' criterion testing, however, the photographic D' values are of the order of 0.3 to 0.4, and the video D' values around 0.2, that is quite a bit above the D_0 threshold value of 0.10! This is not entirely unexpected, as the D' criterion is dependent upon a strong similarity of inclinations in the third term of the equation.
One sole photographic meteor identified as a kappa Cygnid in the DMS databases *does* pass the threshold: P94006 has a D' value of 0.087 in relation to C/1345 O1. The strange thing about this meteor is that it occurred a week or two before the main kappa Cygnid activity *and* has a radiant near *b* Lyræ, quite distant from the normal kappa Cygnid radiant position, which is not too distant from the eponymous *k* Cygni. The author had coincidentally noted during a separate investigation (*work in progress*) that around a dozen radar meteors were well associated via D' with C/1345, and that they too had radiants nearer to *b* Lyræ, radiants in common with P94006. Jopek *et al* 1999 also note that Lindblad actually managed to split this group into two separate subsets by using a Southworth & Hawkins (1963) D criterion threshold D_0 value of 0.10, instead of the usually applied 0.15.
Given the uncertainty in the comet's orbit; the strangely broad nature of this non-ecliptic shower as shown by Jenniskens (1994); the 0.04 AU closest approach distance of the comet; and a set of radar meteors of the right date, infinite velocities and a relatively close radiant that can be shown to be associated with C/1345 O1 via D'; this possible association of C/1345 O1 with the kappa Cygnid meteor shower still deserves further investigation.

Northern Piscids

The first paper suggested that some DMS and MSSWG meteors could well be Northern Piscids, which was probably the same shower as Lindblad's shower number 91 according to Kronk, that these meteors were associated with comet C/1702 H1, and that by implication C/1702 H1 was the parent body of the Northern Piscids.
In the event, the meteors predominantly had D' values of 0.2 to 0.25 in comparison to Lindblad's shower 91, and similarly Lindblad's shower 91 had a D' value of around 0.2 in comparison to C/1702 H1: all above the D_0 threshold value of 0.10 being used here. Yet, all the meteors in question have qualifying D' values when compared to C/1702 H1 directly, and themselves! [As the ascending node of most of these meteors were rotated by 180 degrees in the first paper to bring them in line with their solar longitudes, and as similarly the arguments of perihelion were also so rotated, the results for these objects are not included in Table 1, which solely includes results based on unaltered DMS data].

Other data sources show no evidence for an October shower related to C/1702 H1 (*work in progress*), though it seems likely that a later shower may be so connected. Therefore, the conclusion is that an association of the meteors called Northern Piscids in paper one with C/1702 H1 *may* exist, but that these meteors are *not* Northern Piscids, though coming from a radiant close by in time and space. Consequently, C/1702 H1 is *not* shown as connected with the Northern Piscids by the D' criterion.

Summary

Of the discoveries mentioned in the first paper, the association of the Leo Minorids with C/1739 is doubly confirmed, that of the kappa Cygnids with C/1345 O1 remains enigmatically neither confirmed nor discounted, and that of the Northern Piscids with C/1702 H1 refuted: although there are probably meteors associated with that comet, they just aren't Northern Piscids!

Table 1 : Can be obtained by anonymous ftp download at :
Strw.leidenUniv.nl/ftp1/pub/betlem
/orbits/dmsDtab.xls

ECLIPTIC SHOWERS

alpha Capricornids

The first paper suggested 101P/Chernykh as a possible parent to this shower, and the author is not even remotely surprised to find that the D' criterion in no way confirms this! This is because that comet has a perihelion distance of 2.5 AU, ie it comes nowhere near the orbit of the Earth! Tests like Drummond's D' criteria are very dependent on the perihelion distance, *q*, and the not unrelated eccentricity, *e*, and it was therefore unlikely that any such association should be highlighted by it!

In the first paper the large number of alpha Capricornid meteors with aphelia near to the orbit of Jupiter was noted, and indeed 101P/Chernykh's perihelion is within Jupiter's orbit. The author feels that the difficulties arising with the identification of ecliptic showers with parent bodies may well be a consequence of this over insistence on similar *q*. An ecliptic shower's orbit is liable to be altered greatly by Jupiter's influence, and some of these broad ecliptic streams of large radiant drift could well be consequent on many differing orbits that have been so perturbed into Earth crossing paths. Simple projection of 101P/Chernykh's orbit back in time suggests that it has had a changeable orbit, mostly due to Jupiter, but also occasionally due to Saturn.

On the other hand, Drummond's D' criterion did identify five DMS meteors with the classical alpha Capricornid parent body candidate comet 45P/Honda-Mrkos-Pajdusakova, with D' values ranging from 0.068 to 0.099. Three of these, P90005, P93181 and 1997202 are identified in the DMS databases as Capricornids, but the remaining two, P72008 and V93181 are listed as sporadics.

The video database (at least) had meteor identifications generated via Southworth and Hawkins' (1963) original D criterion (de Lignie 1998), so although at first this looks like a confirmation of a classical viewpoint, two sporadics that have already been shown *not* to be Capricornids are shown associated with 45P, whilst only three out of the total thirteen Capricornids from the databases are shown to be associated with 45P. No asteroidal associations where found.

North iota Aquariids

In the first paper it was noted that only two such meteors were identified as part of this shower in the DMS databases, and that their elements were reasonably similar to C/1907 IV Daniel. As far as the D' criterion is concerned these bodies are not connected, with values of 0.21 and 0.35. It is noted here that the orbital elements for DMS North iota Aquariid V93165 only differs by one degree in each of the inclination and ascending node of Comet Daniel 1907, and by only three degrees for the argument of perihelion. Perihelion distance differs by only 0.13 AU, but eccentricity by 0.25, and as Jopek (1993) notes, D' is somewhat overly dependent on eccentricity.

Summary

No predictions in paper one for ecliptic streams are confirmed. For the alpha Capricornids an association at first appears to be suggested with the comet 45P/Honda-Mrkos-Pajdusakov, however most Capricornids are not shown to be so associated, and two of the meteors that are shown to be so associated have already been identified as *non*-alpha Capricornids. For the North iota Aquariids it can be seen that one meteor only fails to be associated with C/1907 IV Daniel just because of the near parabolic eccentricity of the latter.

This again goes to show a probable over dependence on *q* and *e* in traditional tests when it comes to ecliptic streams: it is not hard to imagine the slight rounding of the orbit of a meteor derived from an eccentric orbit comet that lies near the ecliptic plane via perturbation effects, along with a concomitant slight variation in perihelion distance for such a stream.

CONFIRMED ASSOCIATIONS

As for the already well documented meteor shower-comet associations, Table 1 shows that the Leonids, Orionids and Perseids are again well confirmed by sub-D_0 values as being connected with 55P/Tempel-Tuttle, 1P/Halley and 109P/Swift-Tuttle respectively, often with very low values for D' indeed.

Of the other well known showers in the DMS databases, all the meteors identified as Lyrids and all the meteors identified as Monocerotids therein also show low to very low sub-D_0 values in comparison to P/1861I Thatcher and P/1917 F1 Mellish respectively, associations also confirmed in the first paper.

The sole Ursid candidate from the first paper, DMS meteor V95030, *just* misses being associated with 8P/Tuttle by having a D' prime value of 0.116.

As can be seen from Table 1, C/1491 Y1 and the Boötids (=Quadrantids), do *not* show any association, though "confirmed" in the first paper, with typical values of D' lying in the range of 0.20 to 0.25 and more. Interestingly, C/1939I Kozik-Peltier also shows these sorts of values in comparison to the Boötids, so the case for this shower and comet is still as open as ever.

One surprise was the connection of 2P/Encke with nine DMS meteors that are identified as South Taurids! No such connection was found in the first paper, and furthermore no such connection was found via an independent testing of the DMS meteor databases against comet orbits using the D criterion of Southworth and Hawkins (1963). Jopek (1993) notes that the D criterion compares longitudes or perihelia in its fourth term, whilst the D' criterion compares Laplacian Vectors,

and that in this respect the two criteria differ. It is certainly the authors experience that D' finds more shower-comet associations than D, although this does not necessarily mean that any such are in anyway inherently more valid than those found by D!

The Geminids were tested against 3200 Phæthon using Jopek's (1993) modification of Southworth and Hawkin's (1963) D criterion (where the weighting due to perihelion distance is reduced via a modification in the second term), D_0 here was taken as 0.15, and 324 of the 331 DMS meteors identified as Geminids in the databases surpassed this threshold value, sometimes very convincingly indeed.

Summary

The "big three" shower-comet associations were confirmed, as were the Geminids and 3200 Phæthon, and as were those for the Lyrids and Monocerotids. The Boötids and C/1491 Y1 were *not* confirmed, although some may feel D' of 0.20 to 0.25 is not necessarily too distant from D_0 (values for truly unassociated objects can approach 1, but can start at 0.4 to 0.5). The sole Ursid of the first paper was *nearly* confirmed, but the caveat re threshold level for small numbers of candidates mentioned in the introduction should be remembered.

ESOTERICA

Beta Cygnids

DMS meteor P88035 was *just* confirmed as associated with 103P/ Hartley 2 with a D' value of 0.091 (again the caveat in the introduction re small numbers of candidates and D_0 should be noted). Interestingly, this value is for the *current* orbit of this comet, and *not* the 1985 and 1991 ones, where D' just exceeds D_0, lying at 0.110 and 0.109 respectively. So, P88035 may still be the sole beta Cygnid in the DMS database, and then again it may not, and there may be no such shower!

ASSOCIATIONS FOUND AS A RESULT OF THE CURRENT ANALYSIS

Known Associations

2P/Encke and the South Taurids, and, 45P/Honda-Mrkos-Pajdusakova and the alpha Capricornids have already been noted. Other possible associations are predominantly for meteors that have been identified as "sporadic" in the DMS databases.

DMS meteors V95533, V95539 and V95650 have D' values of 0.053, 0.042 and 0.058 respectively when compared to 3D/Biela, which makes them strong candidates as Andromedid meteors.

DMS meteor V95402 has a D' value of 0.077 in comparison with 21P/Giacobini-Zinner, which could make it a Draconid (also known as Giacobinids), but it is the sole example.

DMS meteors P90006 and P92001 have D' values of 0.052 and 0.095 respectively when compared to 7P/Pons-Winnecke, which would make them June Bootids, but also have D' values of 0.082 and 0.098 respectively in comparison with 73P/Schwassman-Wachmann 3, which would make them tau Herculids! It is interesting to note that Kronk suggests a possible connection between these comets and showers. Some apparitions of these two comets can themselves achieve D' values as small as 0.05 when compared against each other.

Two other DMS meteors uniquely associated with 73P/Schwassman-Wachmann 3 are P85002 and P88001 with D' values of 0.071 and 0.098 respectively.

The sole epsilon Geminid identified in the DMS databases, V93268, along with two sporadic meteors, P95068 and V95472, have D' values of 0.082, 0.065 and 0.074 when compared to C/1964VIII Ikeya, which Drummond (1981) suggested as the parent body for this stream. Olsson-Steel (1987) suggested that the (then) newly discovered comet C/1987III NishikawaTakamizawa-Tago was a more likely candidate, and it giveS D' values of 0.082, 0.069 and 0.069 when compared to the same three meteors! It can be seen that there is not much to choose between the two comets according to D' (and that ironically the meteors identified as sporadic are better candidates then the meteor identified as an epsilon Geminid). Olsson-Steel went on to predict enhanced activity from this shower following the passage of 1987III, but a web search for literature confirming any such occurrence revealed no results.

Unknown Associations

Virtually the only remaining comet-meteor associations that can be found in Table 1 that have more than one meteor candidate per comet are those for 15P/Finlay and 72P/DenningFujikawa. Unfortunately three of them, P92012, P94002 and V93114, are common to both, with D' values of 0.072, 0.098 and 0.086 for 15P and D' values of 0.090, 0.079 and 0.080 for 72P respectively. A fourth meteor, V93141 only shows association with 15P/Finlay, having a D' value of 0.088. Experience has shown the author that these two comets are very promiscuous when it comes to orbital comparisons, and will often pair up with any summer ecliptic meteors, and/or other comets.

A further half a dozen or so singleton associations of meteors with comets appears in the table, but only one is of quite low D' value (P91008 and C/1939III Jurlof-Achmarof-Hassel at 0.56): although these pairings are unique and many other sporadic meteors in the databases remain unpaired, little weight should be giving to such lone occurrences, unless future candidates are found.

One final association, however, is interesting, and that is the one between C/1961 T1 Seki and the DMS meteors V95649, V95730 and V95746 of D' values 0.094, 1.000 and 0.060 respectively. This grouping suggests a new

shower which will be called the Sekiids for the moment (all nearby stars have already been used for shower names) and the full details of which will be elucidated in a separate short paper outlining their properties and their possible relationship with the new DMS stream the b-Leonids (de Lignie 1998), with which they only differ in any particular by a matter of some twenty degrees in argument of perihelion.

Asteroidal Associations

All known asteroids with perihelion distance of less than 1.5 AU were derived from a six month old copy of the ASTORB database, as generated by Lowell Observatory (Bowell) and tested using the D criterion of Southworth and Hawkins (1963) in its modified form (Jopek 1993), which removes the artificial weighting perihelion distance has in the original. The threshold value, D_0, in this case was taken as 0.15, the same canonical value usually utilised with the original D criterion.

As already noted, all but 7 of the 331 DMS database meteors identified as Geminids were confirmed as being associated with 3200 Phaethon in this way, with (incidentally) no nonGeminid and/or sporadic meteors being so confirmed. Few other unique meteor

and those that did exist predominately consisted of only one meteor candidate per asteroid. Except in the instance of asteroid 1990 HA (IAUC 4998), which had a minimal geocentric distance of 0.03 AU on 6th April 1990 (*op cit*).

The new DMS shower of the North delta Arietids (de Lignie 1998) consists of DMS meteors V95514, V95518, V95701, and V95716 with D values of 0.122, 0.095, 0.077 and 0.132 respectively when tested against 1990 HA, and only those four meteors do so. Also, no North delta Arietid was found to be associated with any comet orbit. This object is an Apollo asteroid and a member of the Minor Planet Centre's Potentially Hazardous Asteroid list.

However, complicating the matter, the first three meteors were unfortunately also associated with one other asteroid with D values of 0.995, 0.128 and 0.124 respectively, as was the South Taurid identified DMS meteor V95512 and the sporadic DMS meteor V95691, with D values of 0.147 and 0.131 respectively. This asteroid was 5025-PL, an object only known from three observations made over a four day period ostensibly found retrospectively on photographic plates exposed in 1960, and therefore of very uncertain orbit. It should also be noted, however, that the circumstance of the North delta Arietids are not too dissimilar from the predictions of Hasegawa (1992) for a November shower connected with this asteoid, especially if the DMS observations do not represent the exact time of peak activity (though the geocentric velocity is out by ≈ 10 kms^{-1}).

Although the DMS North delta Arietids appear to be quite faint (m_{vid} around 4), a point of added interest is that the m_{pan} 6.3 fireball MORP 516 (Halliday *et al* 1996), which occurred on 22/11/1979, appears to be a North delta Arietid with a Jopek modified D value of 0.080 in comparison to the averaged elements of the four DMS North delta Arietids (with D values ranging from 0.043 to 0.136 for the individual meteors: ie all below the 0.15 threshold. Similarly, D' values for MORP 516 range from 0.017 to 0.071 in comparison to these meteors). Fireballs are usually considered to be either fresh dust from recent cometary outburst (as with the 1998 Leonid event), or bits knocked off asteroids (grading up to actual meteorites for the brightest objects). These things are of interest in relation to the "defunct comet" and "knocked out of the asteroid belt" debates concerning Near Earth Objects.

Summary

New results based on the current analysis of the DMS database reveal no great surprises nor particularly novel associations, except in two instances.

There appears to be a new shower within the dataset which the author has called the Sekiids, and which may have some connection with the new DMS shower the b-Leonids: details are to be given elsewhere.

The new DMS shower the North delta Arietids have one good candidate as a possible parent body. Another candidate parent body for this stream suffers from a very uncertain orbit, but has been previously cited in the literature as having a possible meteor stream of suitable properties associated with it.

SUMMARY and CONCLUSION

The DMS meteor databases were analysed using D criteria, and their results compared with a previous analysis merely based on concerted filtering of certain orbital criteria with a relational database management package, as presented in an earlier paper.

Previously well known associations of comets and meteors were confirmed via both methods, but curiously the Boötids were only confirmed as associated with C/1491 Y1 via the earlier, non-statistical method. The South Taurids were connected with 2P/Encke here, which was not the case in the earlier paper.

Of the "discovery" predictions made in the earlier paper, one was again confirmed (C/1739 and Leo Minorids), one remains tentative (C/1345 O1 and kappa Cygnids), and one is disproved (although there is a comet meteor association likely for C/1702 H1, it is not with the Northern Piscids).

The ecliptic identifications were not confirmed, but were not adequately disproved either, and the possible association of the alpha Capricornids with 45P/Honda-Mrkos-Pajdusakova

showed some weak but not clinching evidence. Current D criterion methods still seem inappropriate for ecliptic comets and meteor streams due to the weightings they give to perihelion distance and eccentricity. On the other hand, two many associations can be found between ecliptic objects if these elements are ignored altogether, leading to a confusing situation.

Identifications not found in the earlier paper but shown to be possible in this one are for 73P/Schwassman-Wachman 3 (and possibly 6P/Pons-Winnecke) and 3D/Biela, but only for a few meteors. The D' criterion was not sufficient to distinguish between two possible parent bodies for the epsilon Geminids.

A likely "new" stream dubbed the Sekiids by the author (due to its connection with C/1961 T1 Seki whilst all nearby stars and constellations have already been pressed into service for shower names) was found, but the full analysis is beyond the remit of this article and will be presented separately. They may be connected with the new DMS meteor stream, the b-Leonids.

Very little evidence for asteroidal parent bodies was found beyond the well established case of 3200 Phaethon and the Geminids, save in one instance. Although this instance was itself a little complicated with the possibility of a choice of parent bodies (1990 HA and 5025 P-L), either object leads to a Near Earth Asteroid as the parent body of the new DMS shower the North delta Arietids.

* The comet orbital elements were sourced in electronic form via a database on the Guide 7.0 CD-ROM based planetarium program for DOS based IBM PC compatibles from Project Pluto, USA [www.projectpluto.com], plus updated elements from the Central Bureaux of Astronomical Telegrams at cfa-www.harvard.edu.

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